RECENT DEVELOPMENTS IN AUTOMATION OF OVERSET STRUCTURED MESH GENERATION

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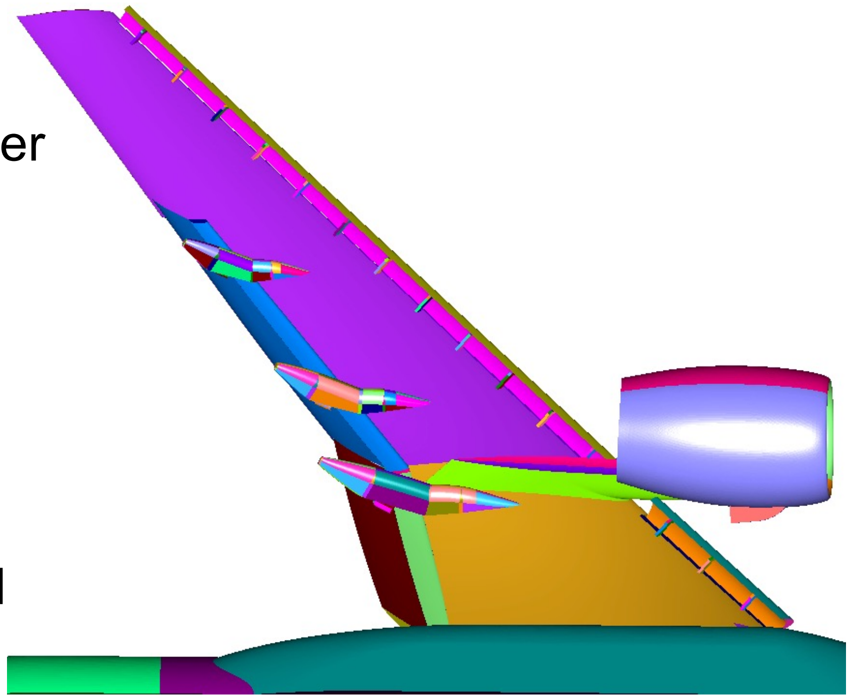
Suffolk, Virginia, November 1-3, 2022

OUTLINE

- Motivation, objectives, challenges
- Automation procedure
- Test cases
- Concluding remarks

MOTIVATION AND OBJECTIVES



- Structured overset viscous flow solvers – highly accurate and efficient compared to other methods
- High-fidelity overset mesh generation – significant user expertise, effort, time (weeks/months, surface grids ~80% time)
- Develop tools to reduce human effort needed
- Goal: 100% automation
- Hybrid: 90+ % automation + manual repairs => significant savings

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CHALLENGES

1. Surface domain decomposition *

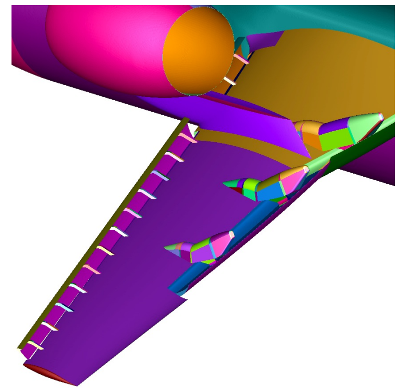
2. Grid point distribution *

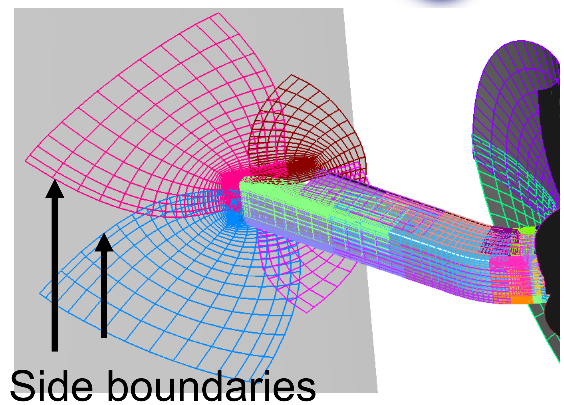
3. Surface meshing scheme *
   - Method selection (hyperbolic/algebraic)
   - Distance estimate

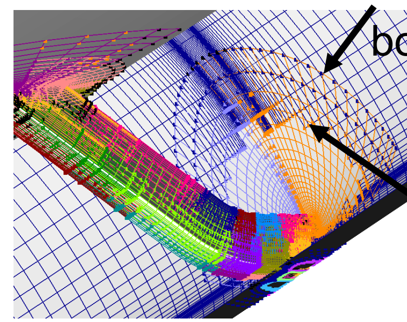
4. Mesh overlap
   - Side *
   - Outer & hole boundaries **

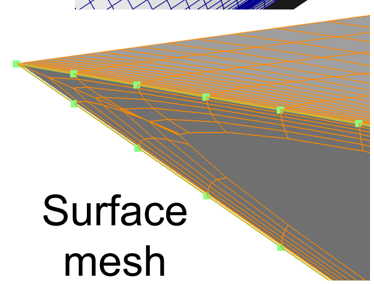
5. Hyperbolic mesh smoothing iterations in concave regions **

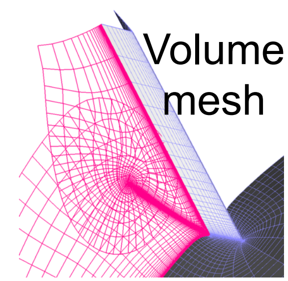
*** To be addressed in future work*











* Chan, W. M., Pandya, S. A., Chuen, A. M., Automation of Overset Structured Mesh Generation on Boundary Representation Geometries, AIAA Paper 2022-3607, Aviation Forum, 2022.

* Chan, W. M., Pandya, S. A., Haimes, R., Automation of Overset Structured Surface Mesh Generation on Complex Geometries, AIAA Paper 2019-3671, 2019.

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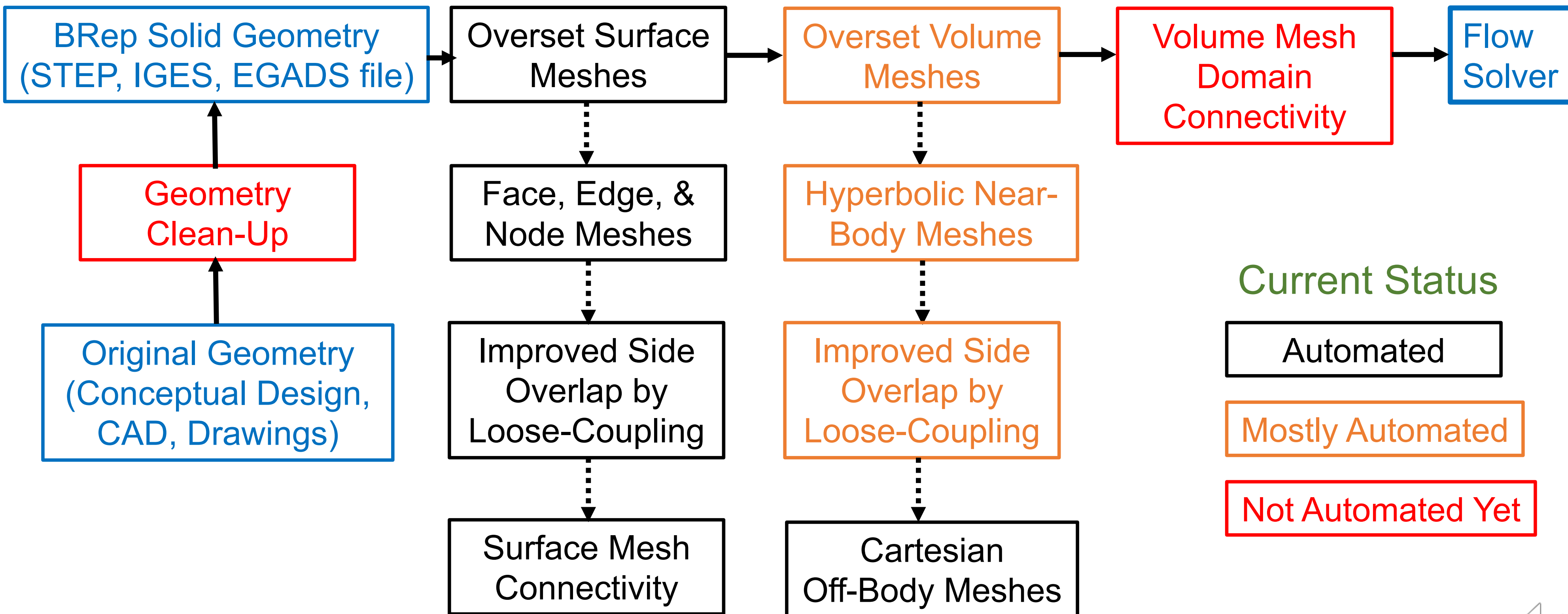
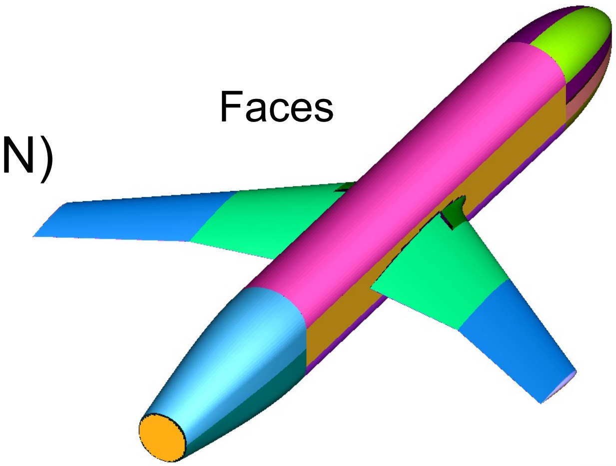
OVERSET MESH GENERATION AUTOMATION FLOW CHART



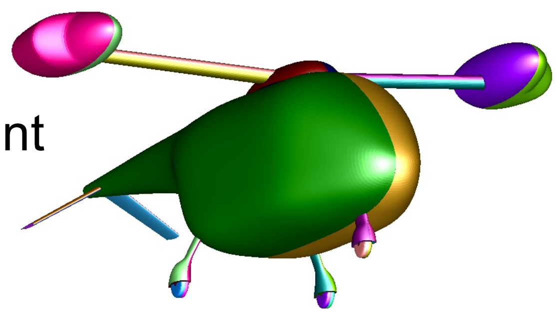
SURFACE DOMAIN DECOMPOSITION

- Input: Boundary Representation (BRep) solid
- Topological relationship: Faces (F), Edges (E), Nodes (N)
- Construct meshes based on F, E, N
- Total <= (# F + # E + # N)



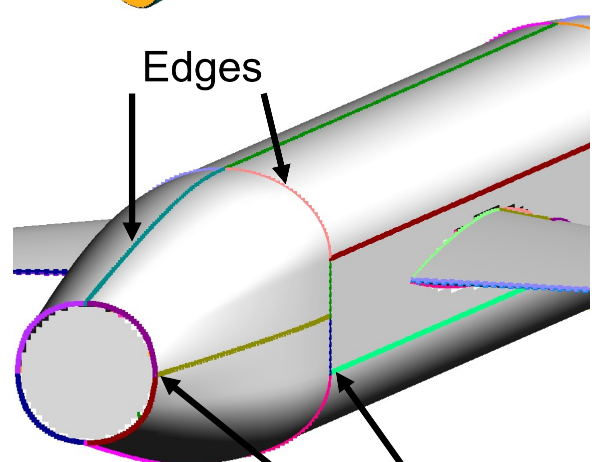
GEOMETRIC COMPONENT SPECIFICATION

- List of faces on each component
- Manually constructed



Enables

- Local component grid spacing scaling
- Creation of input file for component loads integration
- Single component meshing option



OVERSET SURFACE MESH GENERATION PROCEDURE

BRep Solid Geometry (STEP, IGES, EGADS file)

↓

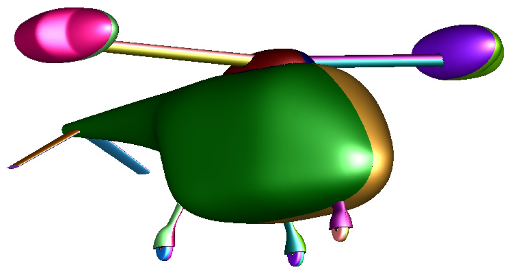
Face, Edge, & Node Meshes

↓

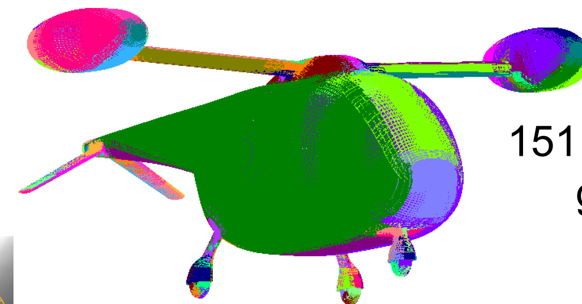
Improved Side Overlap by Loose-Coupling

↓

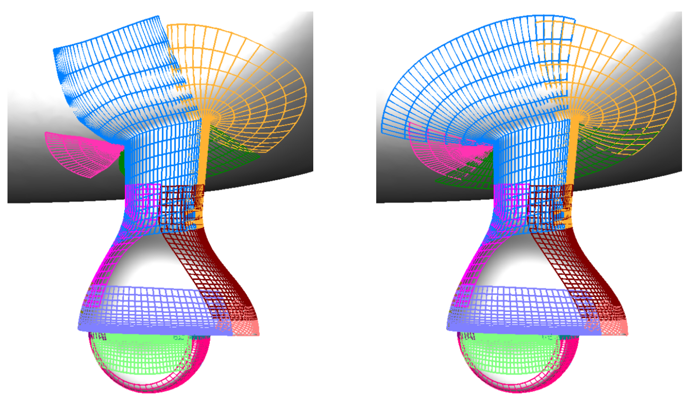
Surface Mesh Connectivity

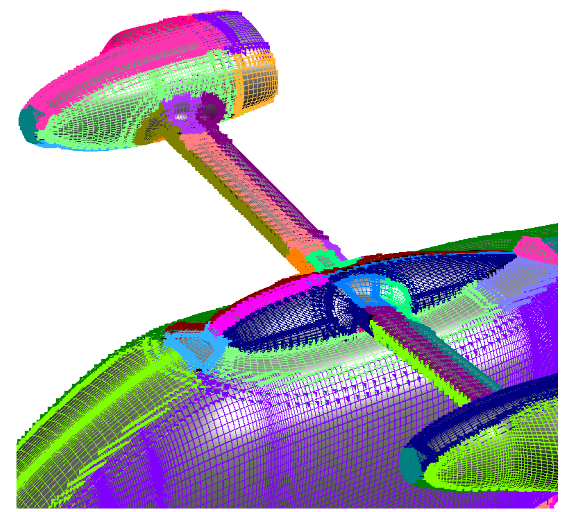


40 Faces, 81 Edges, 45 Nodes



151 Surface grids

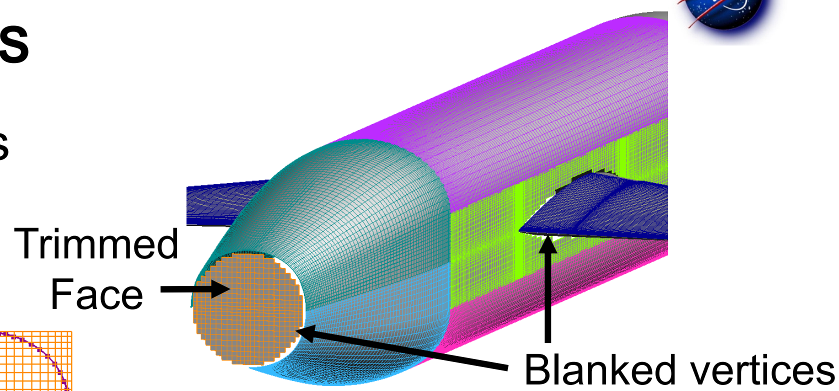


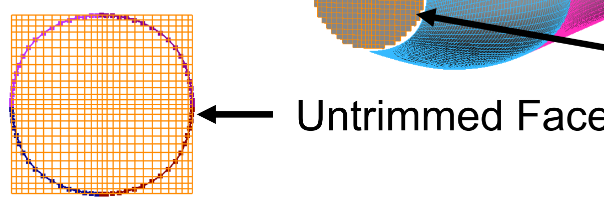


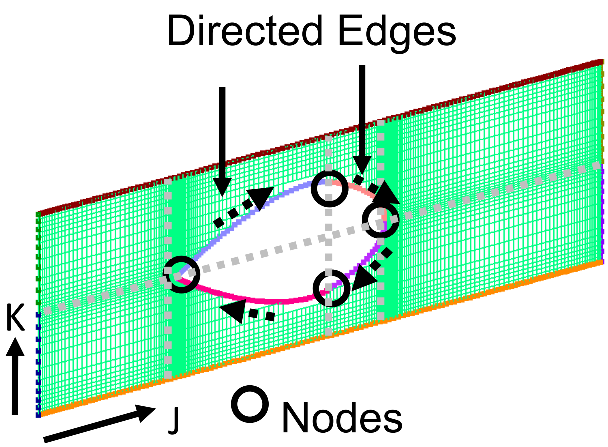
Surface grid hole points & fringe point donor stencils

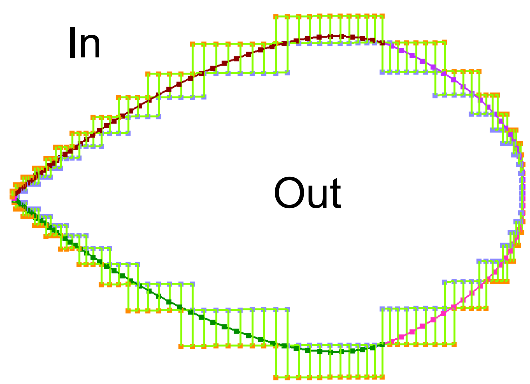
FACE MESHES

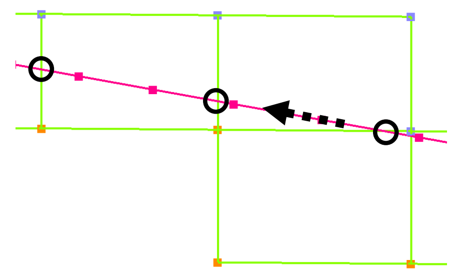
- Nodes divide face into zones in J & K directions
- Construct stretched grid in each zone
- Faces cover entire surface domain
- Trimmed by directed edges





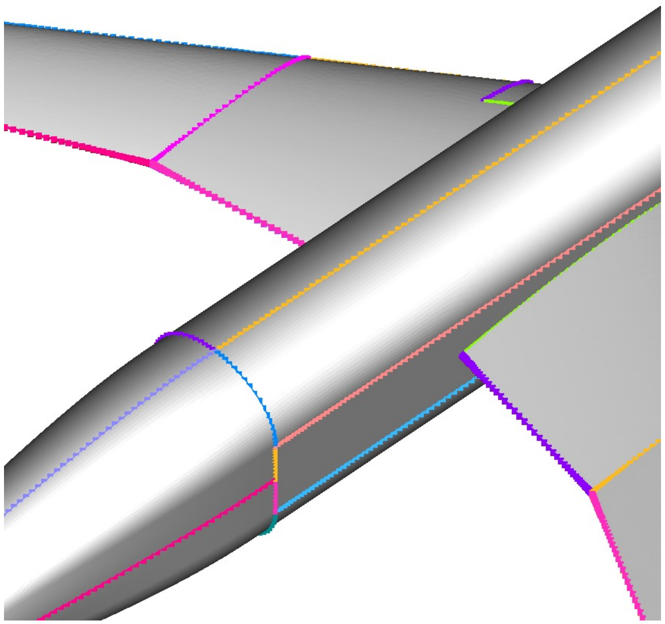




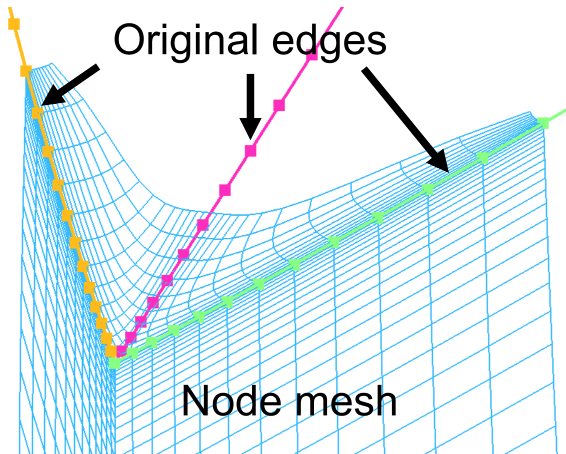


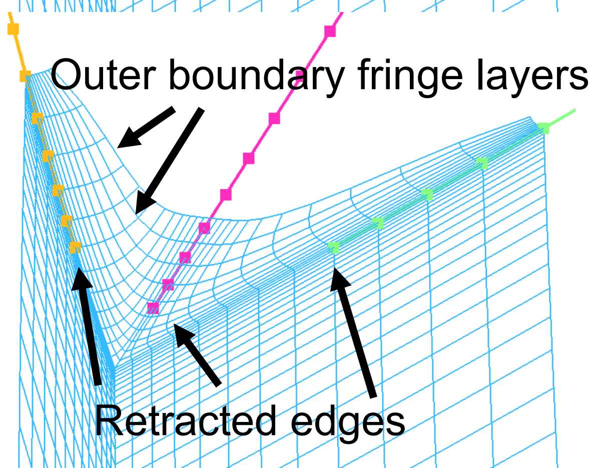
- Use cut-cells to generate iblank array (1/0 = on/outside geometry)
- Minimum hole-cut on face meshes

EDGE MESHES

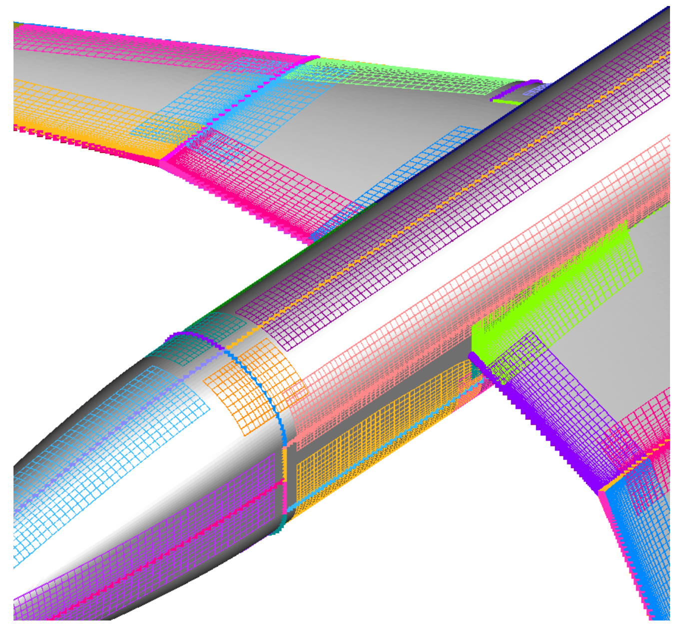


Discretized edges





Variable retraction to achieve optimal overlap with end point Node meshes (created first)



Hyperbolic/algebraic march on each side & concatenate

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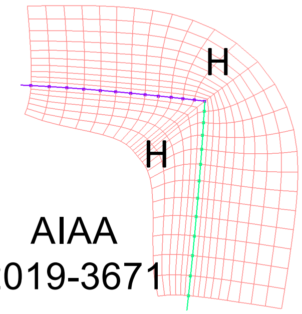
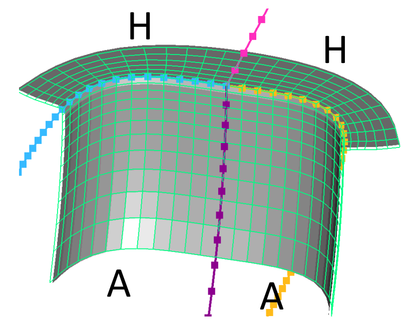
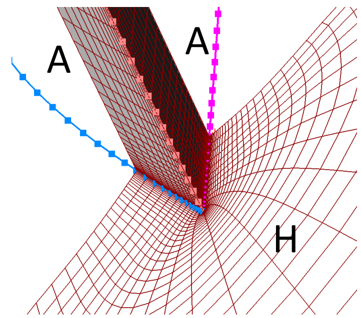
NODE MESHES

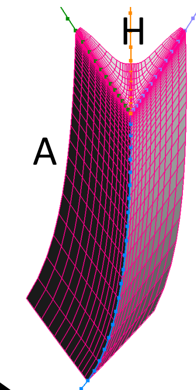
- Construct initial curve to straddle Node by concatenating “best” two Edge segments
- Hyperbolic or algebraic marching: 2, 3, or 4 parts
- Algebraic march switched to TFI if iso-parameter lines of face mesh not aligned with sharp dividing Edge at Node

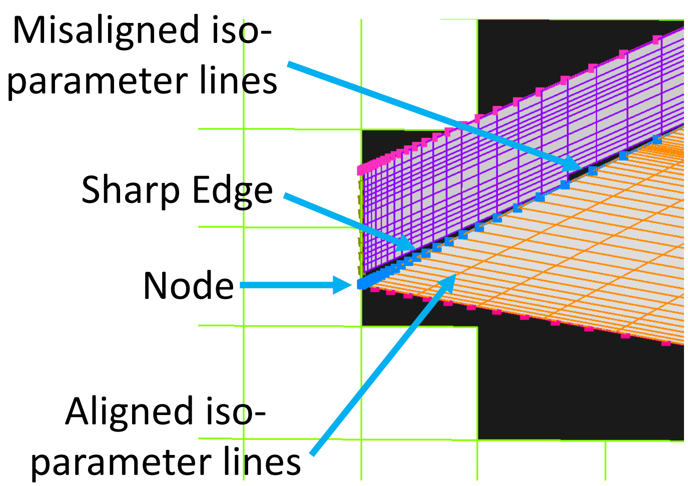


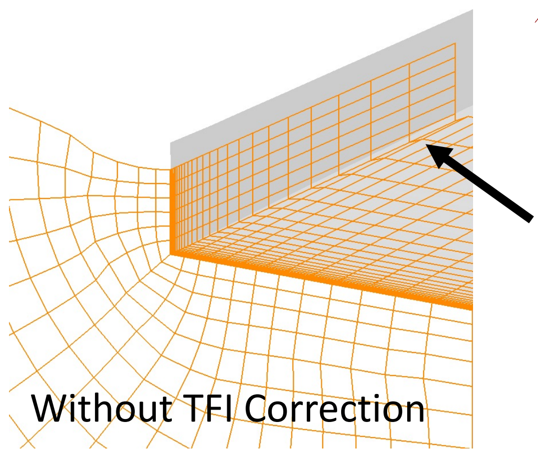
AIAA
2019-3671



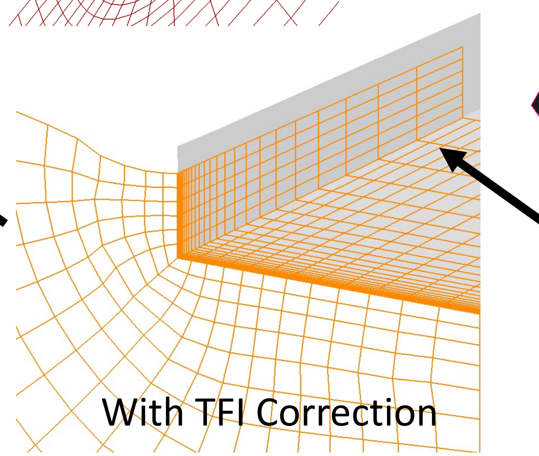








Without TFI Correction



With TFI Correction

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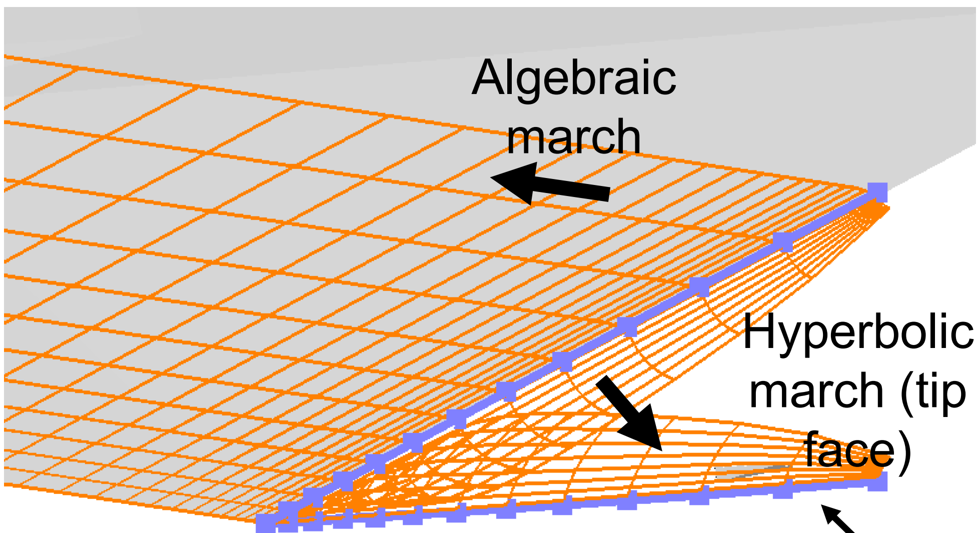
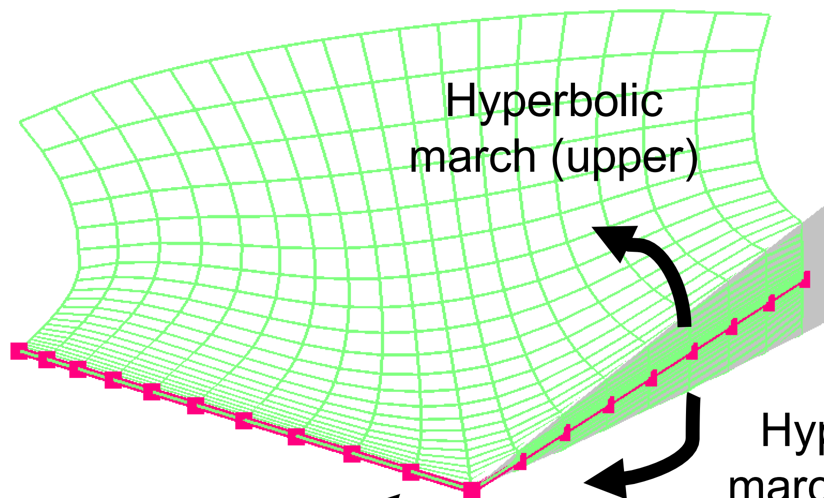
AUTOMATIC CONVERSION TO CAP GRID TOPOLOGY

Node meshes with acute concave corner
Wing/tail tip trailing edge region

No cap: sharp edges preserved at tip

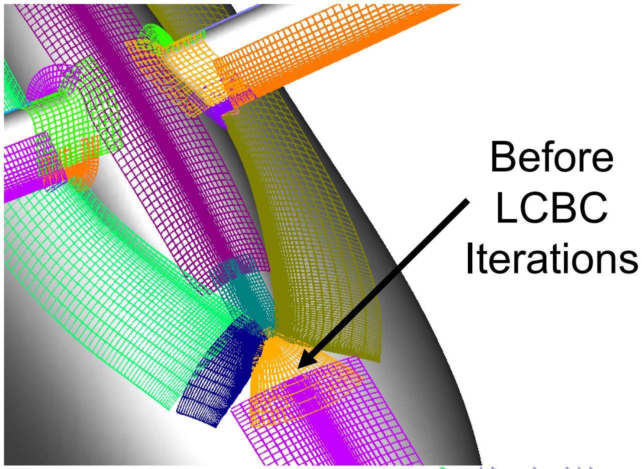
Cap: wrap over sharp edges at tip near t. e.

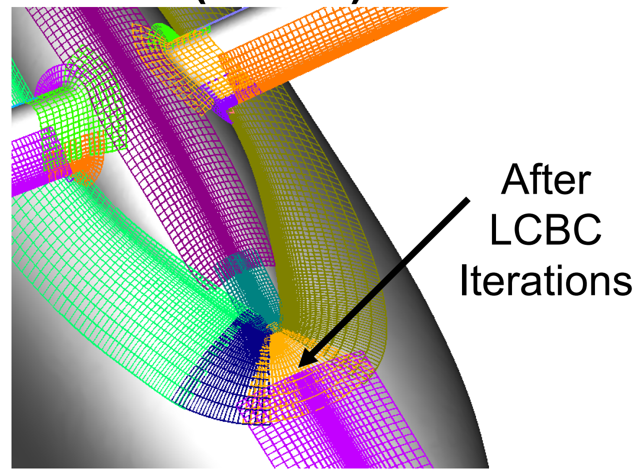


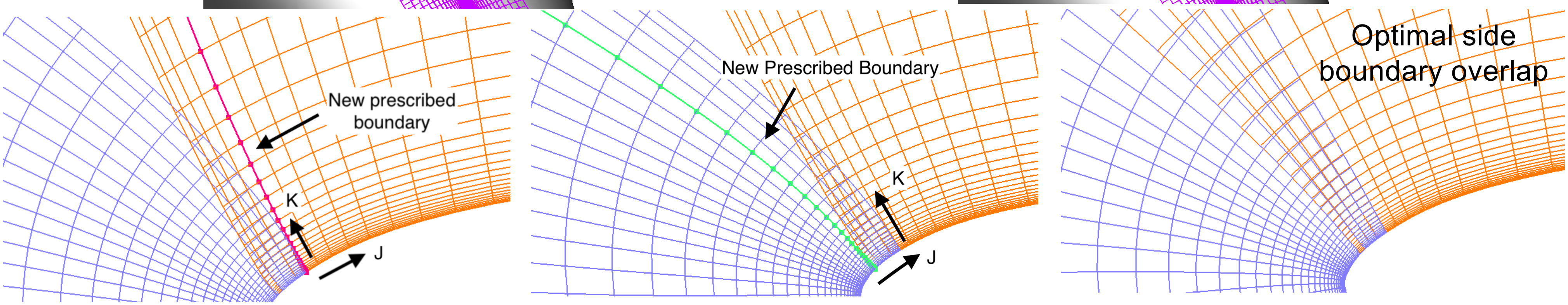


Initial curve for hyperbolic/algebraic march

IMPROVED SURFACE GRID OVERLAP USING LOOSELY-COUPLED BOUNDARY CONDITIONS (LCBC)







Chuen, A. M., Chan, W. M., Overlap Preservation Using Loosely-Coupled Boundary Conditions for Body-Fitted Structured Overset Grids, AIAA Paper 2022-0216, 2022.

OVERSET VOLUME MESH GENERATION PROCEDURE

Overset Surface Meshes

↓

Hyperbolic Near-Body Meshes

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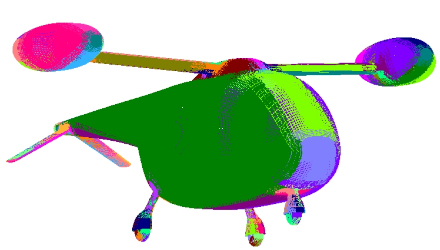
Improved Side Overlap by Loose-Coupling

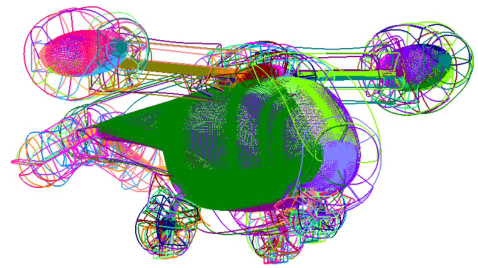
↓

Cartesian Off-Body Meshes

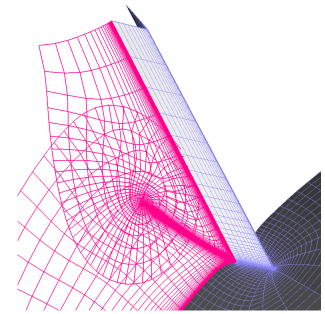
↓

Overset Volume Meshes

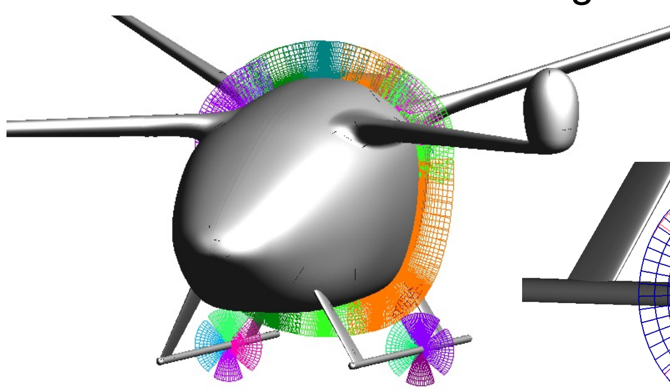


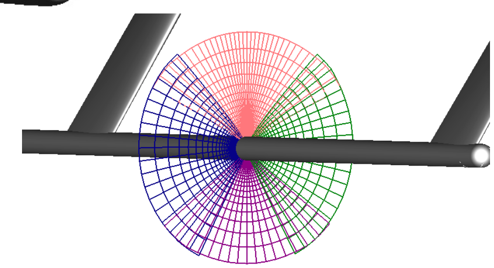


- Same wall spacing, marching distance, stretching ratio
- Auto selection: smoothing parameters, splay boundary conditions with concave region detection

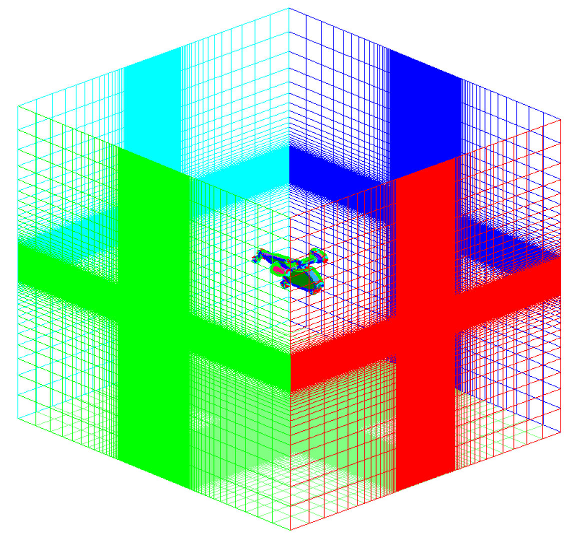


Removal of negative cell volumes (work in progress)



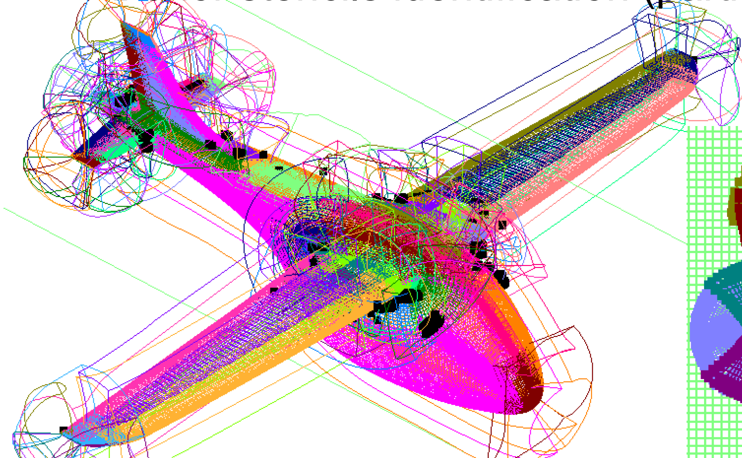


Volume mesh LCBC more complex due to presence of hole boundaries and collar grids

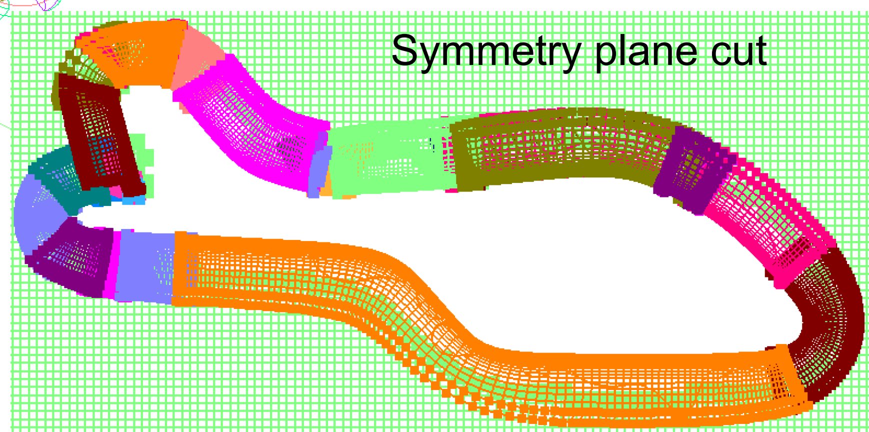


OVERSET VOLUME MESH DOMAIN CONNECTIVITY
(work in progress)

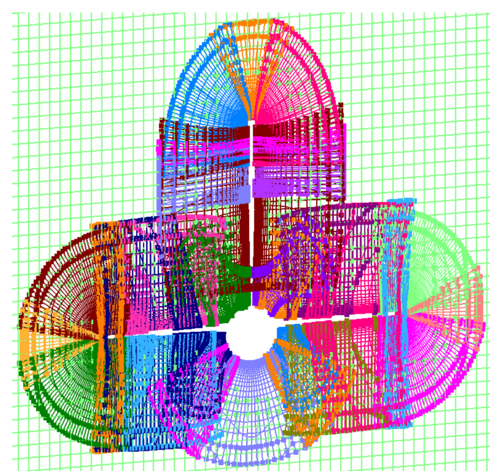
- Inherit surface holes from surface grids
- Near-body grids minimum hole
  - Grid index directions: J, K tangential, L normal
  - Check L line segments intersection with surface grid and blank all points in L after intersection
  - Check for minimum distance clearance from surface grid cells
- Off-body grid minimum hole – X-ray method using z-constant lines on Cartesian mesh
- Minimum hole expansion
- Donor stencils identification (partially completed from volume mesh LCBC)



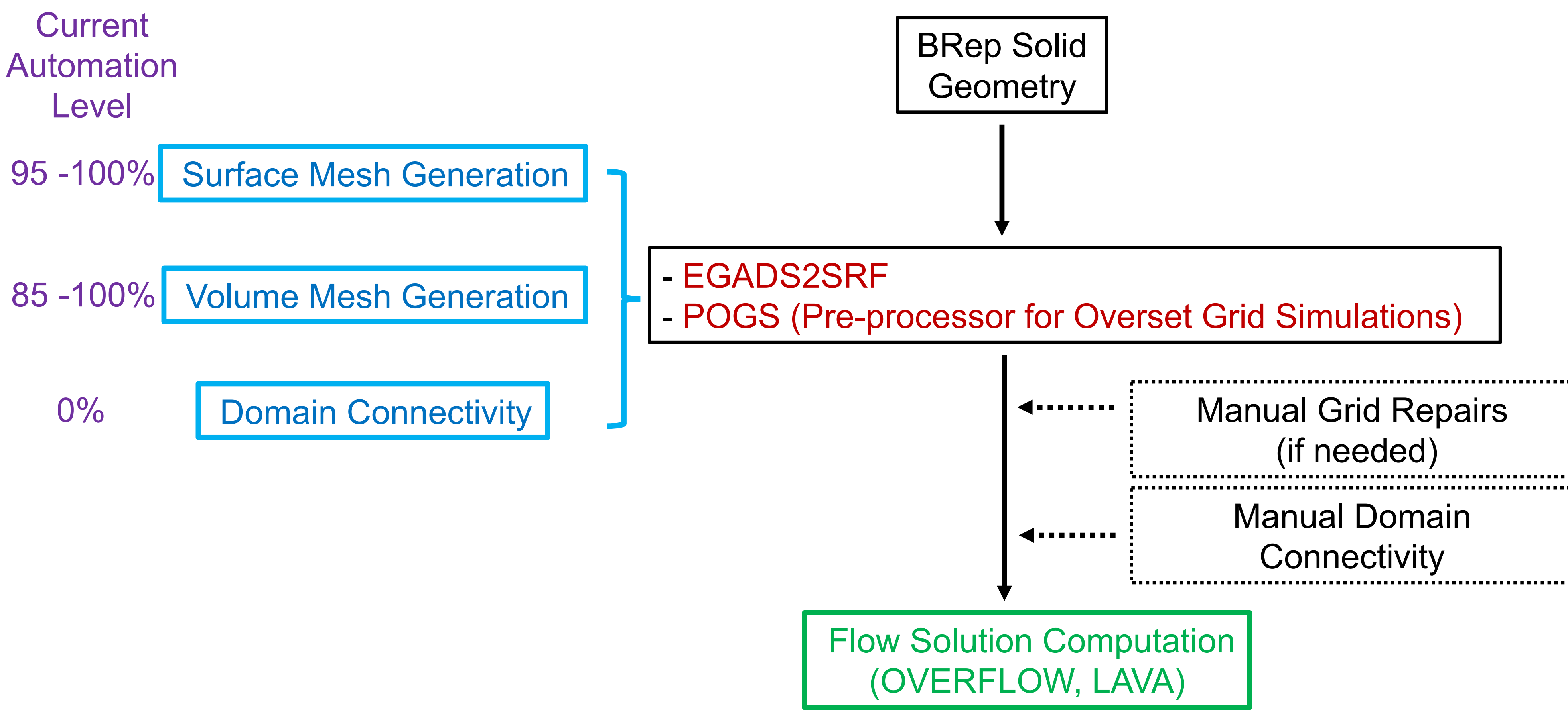
15.8 M volume grid pts
1863 orphan pts



Vertical/horizontal tail cut



OVERSET MESH GENERATION AUTOMATION SOFTWARE



AUTOMATION SOFTWARE FLOW CHART

BRep Solid Geometry
(STEP, IGES, EGADS file)

Engineering
Sketch Pad
(ESP) from MIT

Global parameters
- max turning angle
- max grid spacing
- max stretching ratio
- min # pts on edge

EGADS2SRF

- Face meshes
- Surface triangulation
- Discretized edges
- Edge-face topology
- POGS input file
  - # fringe pt layers
  - volume mesh wall spacing
  - donor stencil quality

POGS – Pre-processor
for Overset Grid
Simulations

- Edge & node surface meshes
- Surface domain connectivity
- Near & off-body volume meshes
- Flow solver input file (OVERFLOW, LAVA b.c.)
- Component aero-loads comp. input file (FOMOCO)

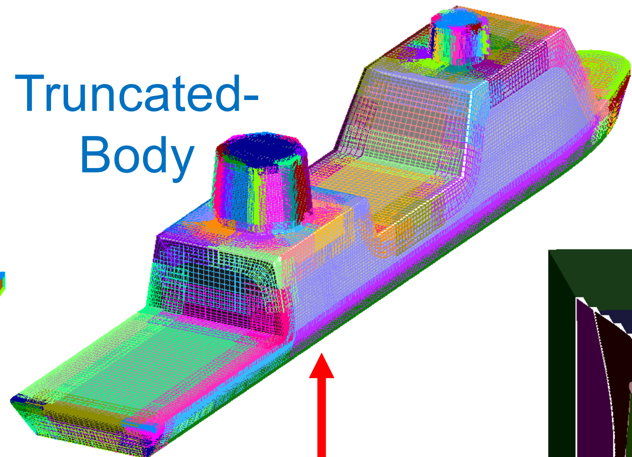
Volume Mesh Domain Connectivity
- Currently manually performed
- Work in progress in POGS

Flow Solver

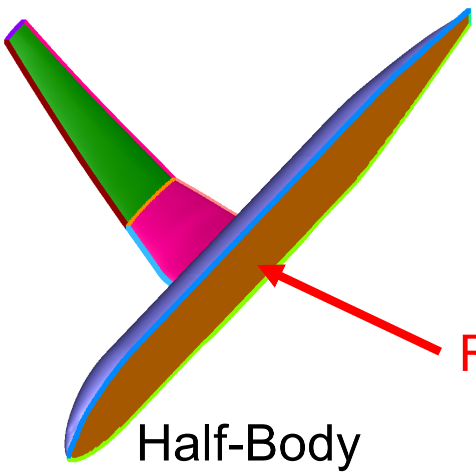
OPEN GEOMETRIES & SINGLE COMPONENT MESHING

Open Geometries

Truncated-Body

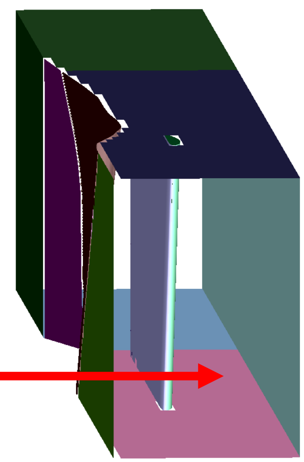


Single Component Meshing

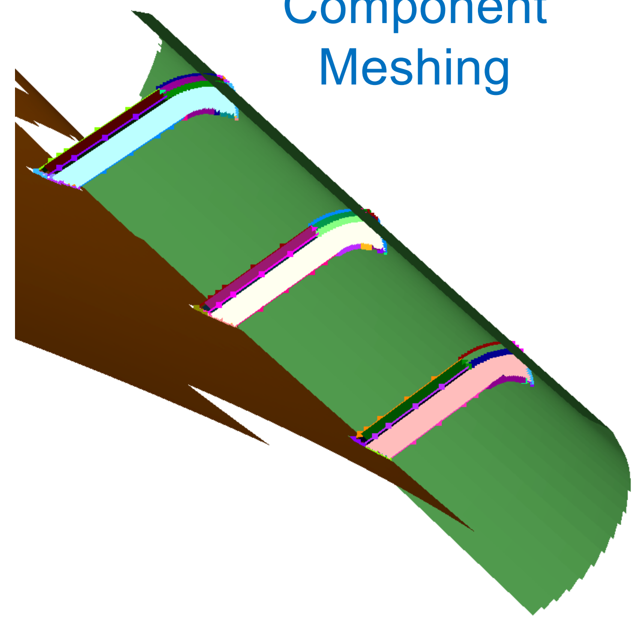


Half-Body

Removed Face(s)



Internal Flow with Entrance & Exit



E.g., mesh one or more slat brackets + connected faces

- User-specified list of faces to remove
- Auto-update of face/edge/node topology

TEST CASES

All cases ran on 2018 Mac BookPro laptop, 2.9 GHz Intel Core i9, 16GB memory

- Surface meshes – mostly single processor
- Volume meshes – 6 OpenMP threads

Mesh quality (% acceptable)

- % surface meshes with no negative cell areas
- % volume meshes with no negative Jacobians or self-intersections

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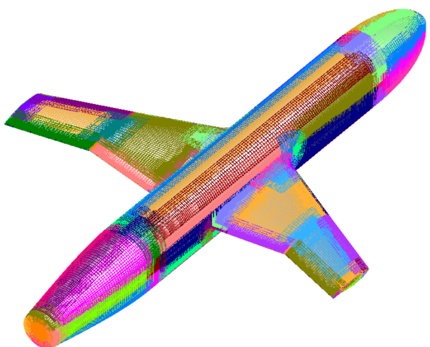
JUNCTURE FLOW EXPERIMENT WING-BODY DLR-F6 and NACA-0015

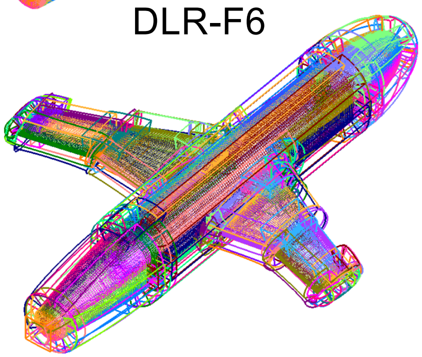
Model	# Meshes	# Volume mesh pts	% Acceptable meshes Surface	Volume	Wall clock time surface+volume
DLR-F6	171	15.8 M	100%	98%	1 min 19 sec
NACA-0015	145	14.1 M	100%	97%	0 min 58 sec

Manual meshing time ~ days

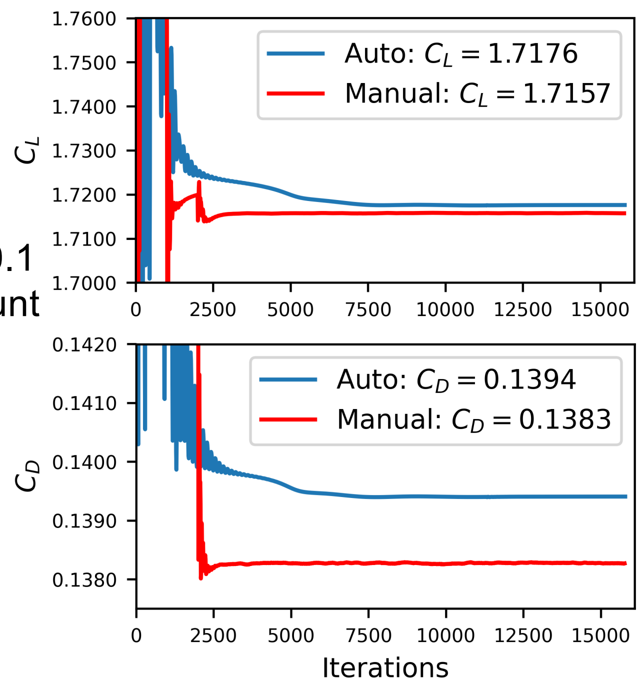
Volume mesh repair + connectivity ~ 2 hrs.

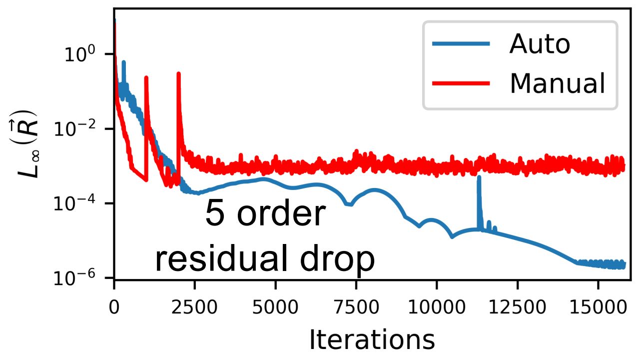


DLR-F6



< 0.1 count

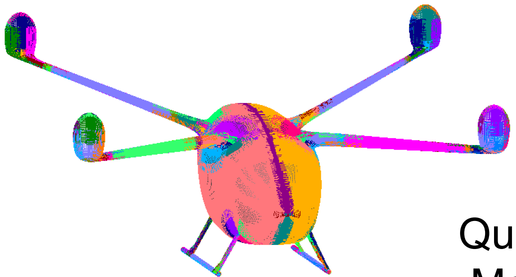




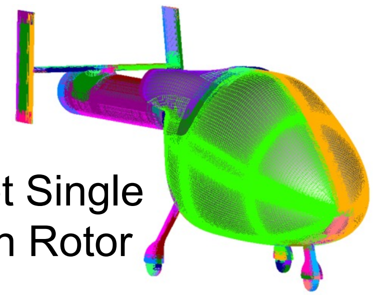
Method	# Pts	C_L	C_D
Manual (OVERFLOW)	50.9 M	1.7157	0.1383
Manual (LAVA)	56.8 M	1.7159	0.1380
Automatic	60.5 M	1.7176	0.1394

ROTORCRAFT CONCEPT VEHICLES

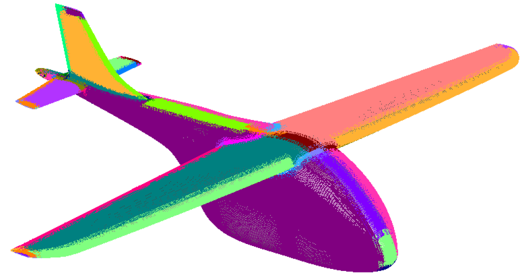
Manual meshing time ~ weeks per vehicle



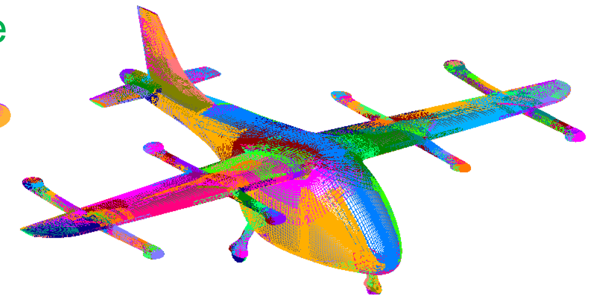
6-Pax Quadrotor



Quiet Single Main Rotor



Lift+Cruise (no pylons, no gears)



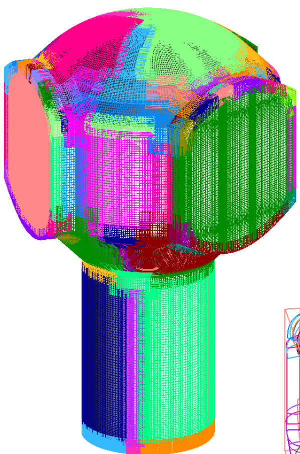
Lift+Cruise (with pylons & gears)

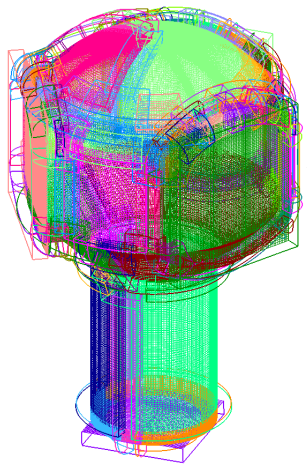
Concept Vehicle	# Meshes	# Volume mesh pts	% Acceptable Surface	% Acceptable Volume	Wall clock time surface+volume
6-Pax Quadrotor	227	21.7 M	100	94	5 min 15 sec
Quiet Single Main Rotor	179	15.2 M	99	97	3 min 1 sec
Side-By-Side	162	14.8 M	100	100	4 min 3 sec
Lift+Cruise (no-pylons, no-gears)	87	35.6 M	100	98	7 min 1 sec
Lift+Cruise (with pylons & gears)	365	43.7 M	99	98	4 min 9 sec
Tiltwing Cruise	307	38.6 M	100	98	4 min 47 sec

Side-By-Side Hybrid

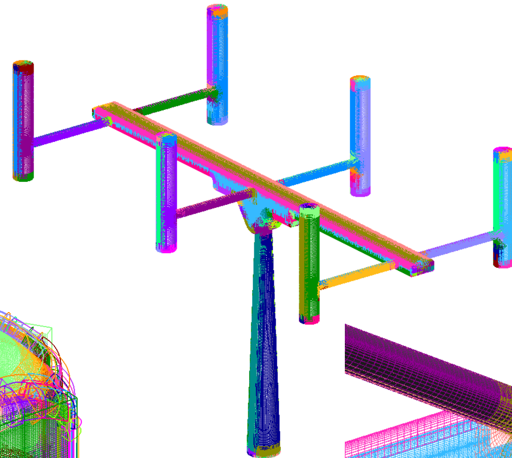
Tiltwing Cruise Mode

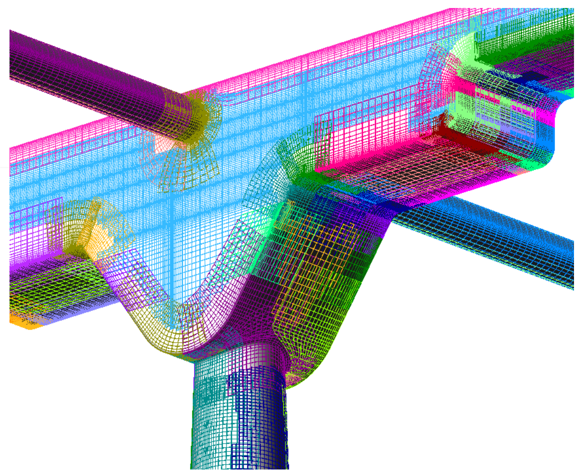
ROTOR HUB AND MULTI-ROTOR TESTBED



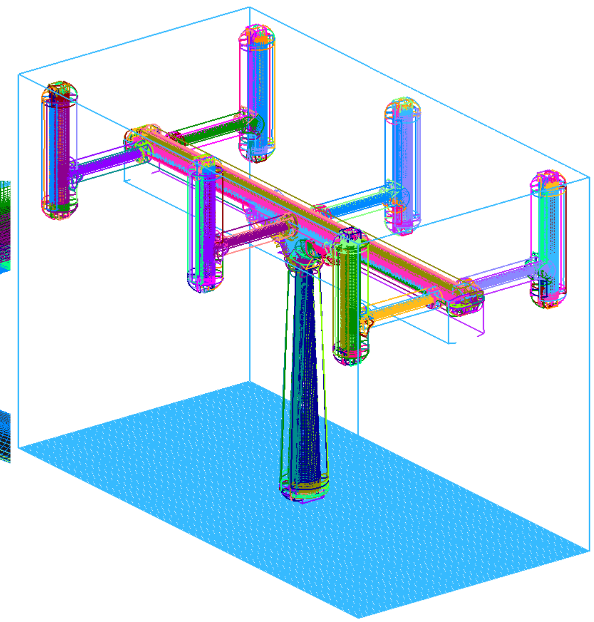


Rotor Hub





Multi-Rotor Testbed



Case	# Meshes	# Volume mesh pts	% Acceptable Surface	% Acceptable Volume	Wall clock time surface+volume
Rotor Hub	142	4.9 M	99	99	0 min 35 sec
Multi-Rotor Testbed	258	35.6 M	100	100	1 min 35 sec

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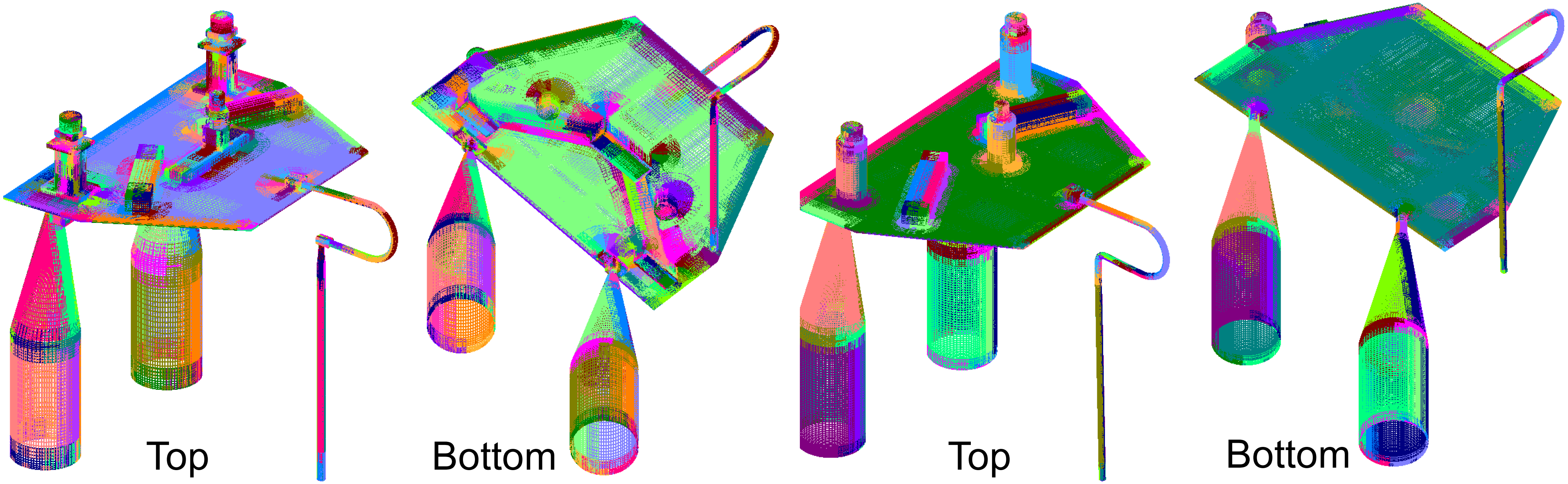
SIDE-BY-SIDE ROTORS WIND TUNNEL HARDWARE



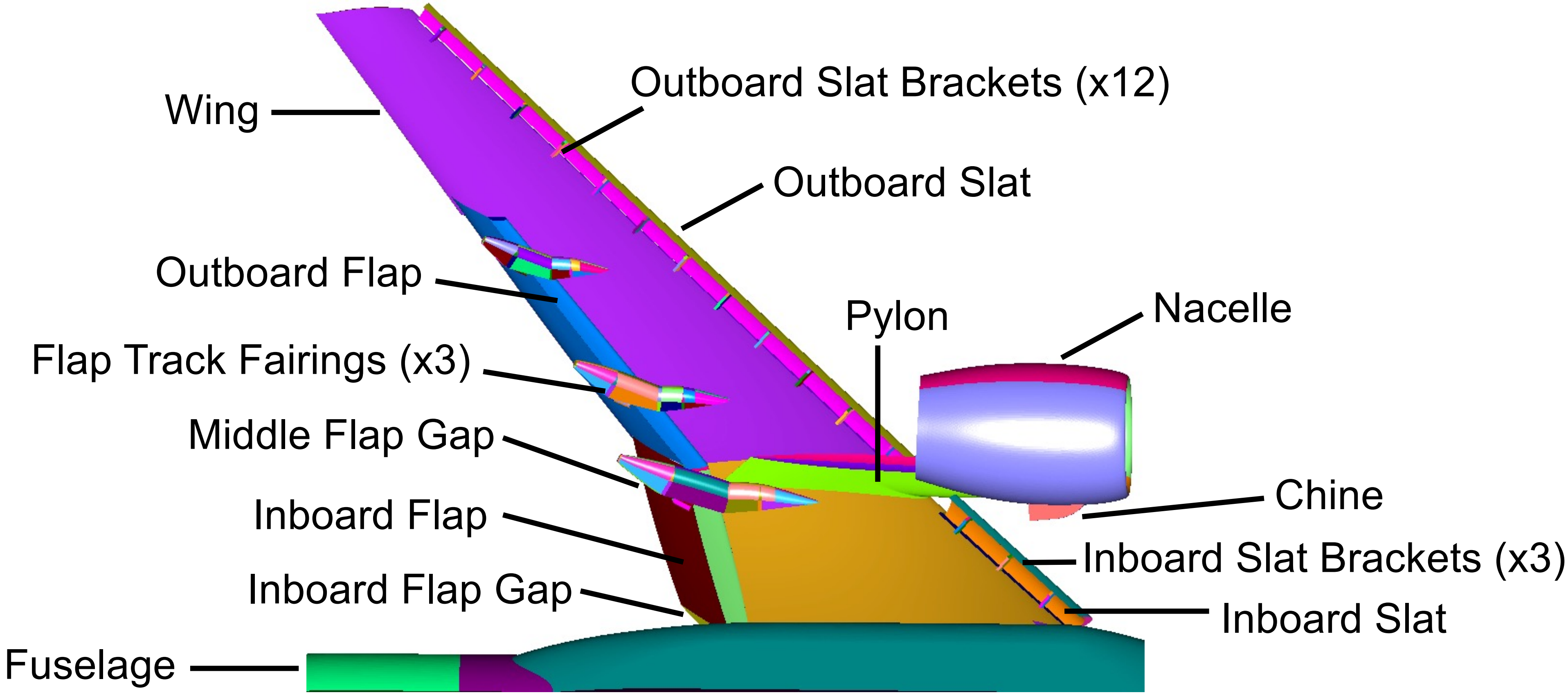
Complex Simplified

Case	# Meshes	# Volume mesh pts	% Acceptable Surface	% Acceptable Volume	Wall clock time surface+volume
Complex	883	41 M	99.8	96	4 min 14 sec
Simplified	251	11 M	100	99	1 min 27 sec

HIGH-LIFT COMMON RESEARCH MODEL (HLCRM)

High-Lift Prediction Workshop 4

Half-body geometry: 414 Faces, 1108 Edges, 698 Nodes



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HLCRM AUTO SURFACE MESH STATISTICS

Single Component Runs

Component	# Meshes	# Mesh pts (x 10^6)	% Acceptable meshes	Wall clock time
Fuselage	123	0.63	99%	25 min 29 sec
Inboard Slat	59	0.18	85%	10 min 13 sec
Outboard Slat	147	0.91	87%	18 min 5 sec
Flaps + gaps	99	0.30	75%	12 min 14 sec
Pylon+Nacelle+Chine	74	0.61	89%	17 min 43 sec
Inboard Slat Bracs (x3)	95	0.17	85%	10 min 49 sec
Outboard Slat Bracs (x12)	426	0.51	84%	16 min 13 sec
Inboard Flap Track Fair.	176	0.25	94%	12 min 35 sec
Middle Flap Track Fair.	182	0.30	93%	12 min 44 sec
Outboard Flap Track Fair.	183	0.33	92%	14 min 26 sec
FTF Connectors (x3)	124	0.30	75%	10 min 6 sec
Wing	451	1.70	85%	59 min 20 sec
Complete HLCRM *	413	2.70	100%	44 min 16 sec

* Face meshes only, Edge + Node meshes in progress

Manual meshing time ~ 4 months

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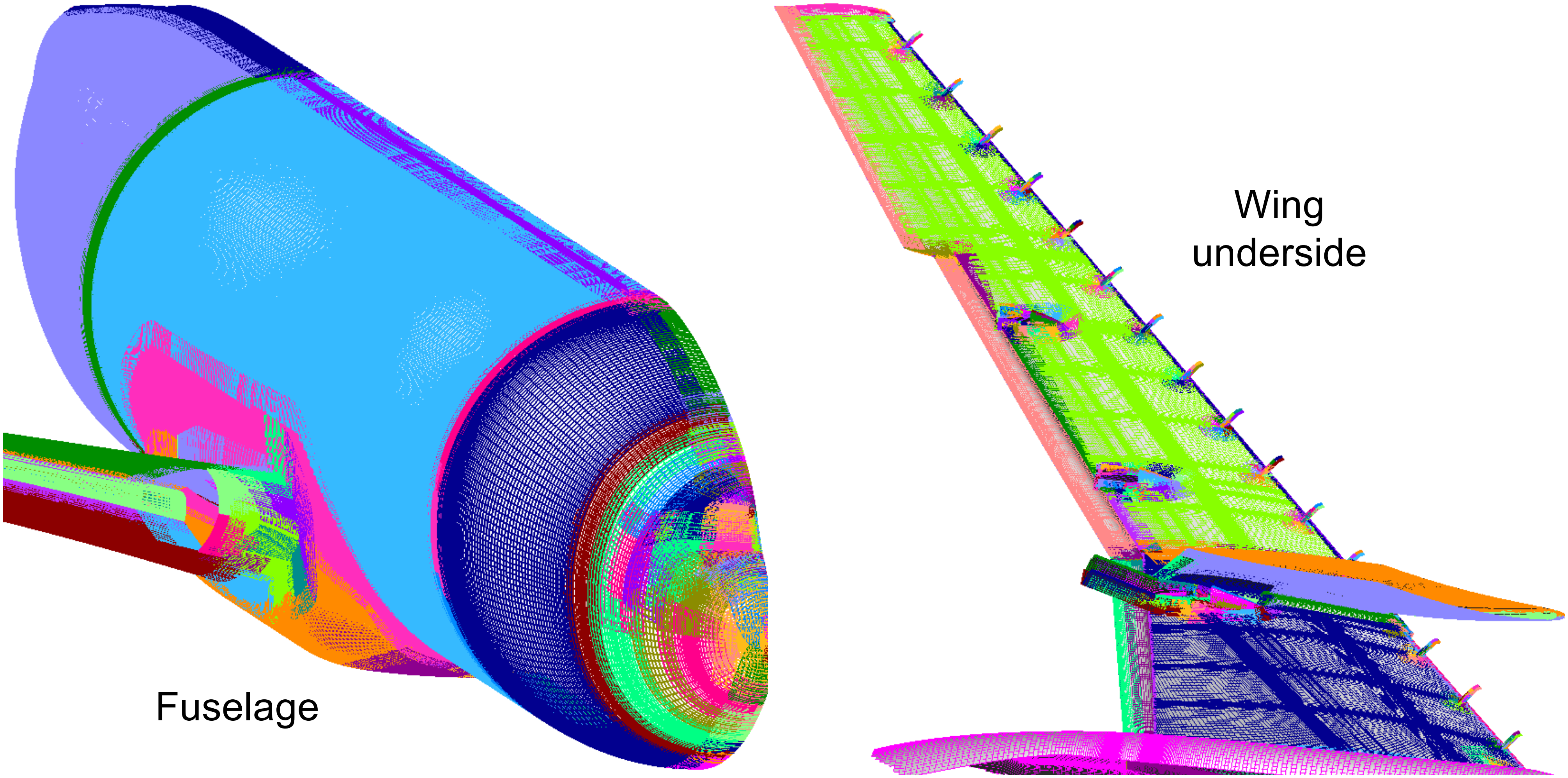
HLCRM: FUSELAGE AND WING



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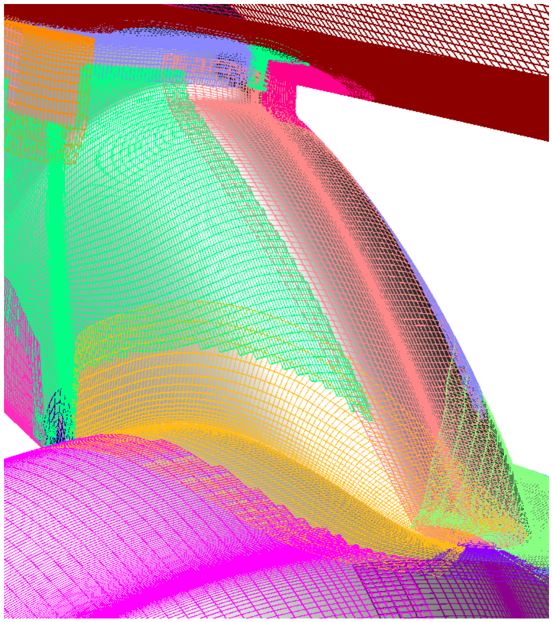
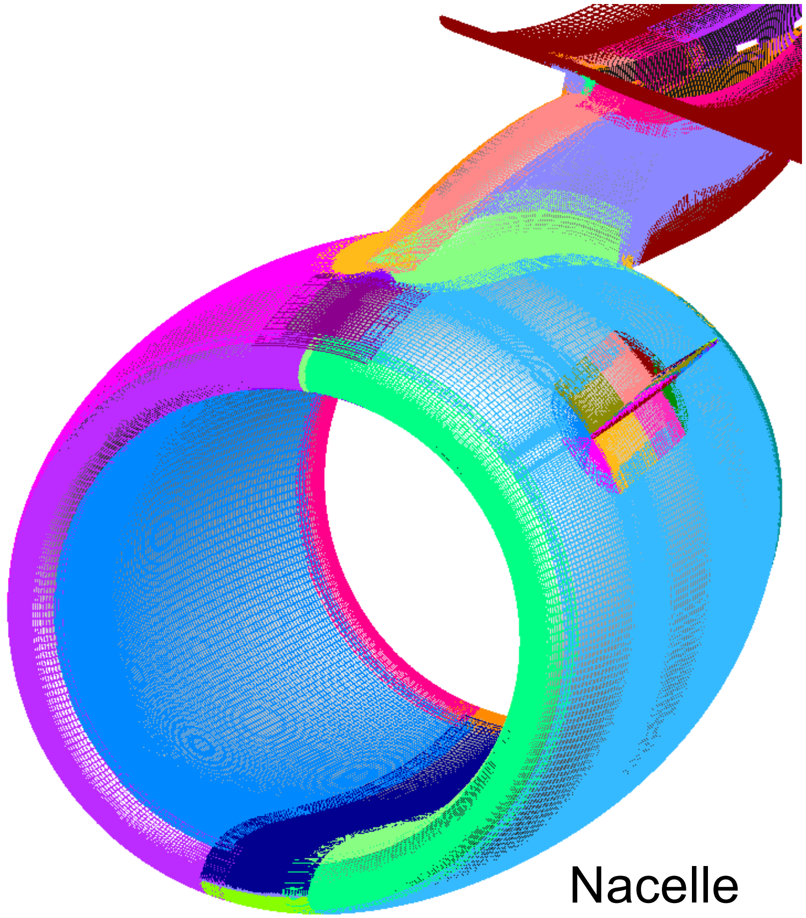
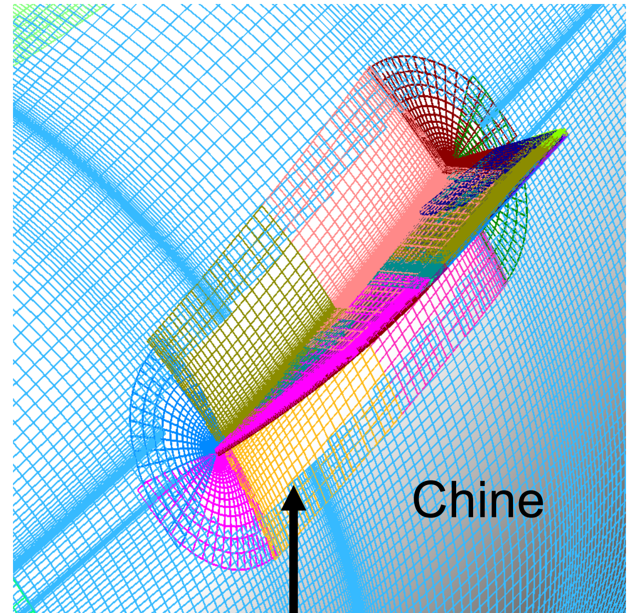
HLCRM: PYLON/NACELLE/CHINE



Pylon

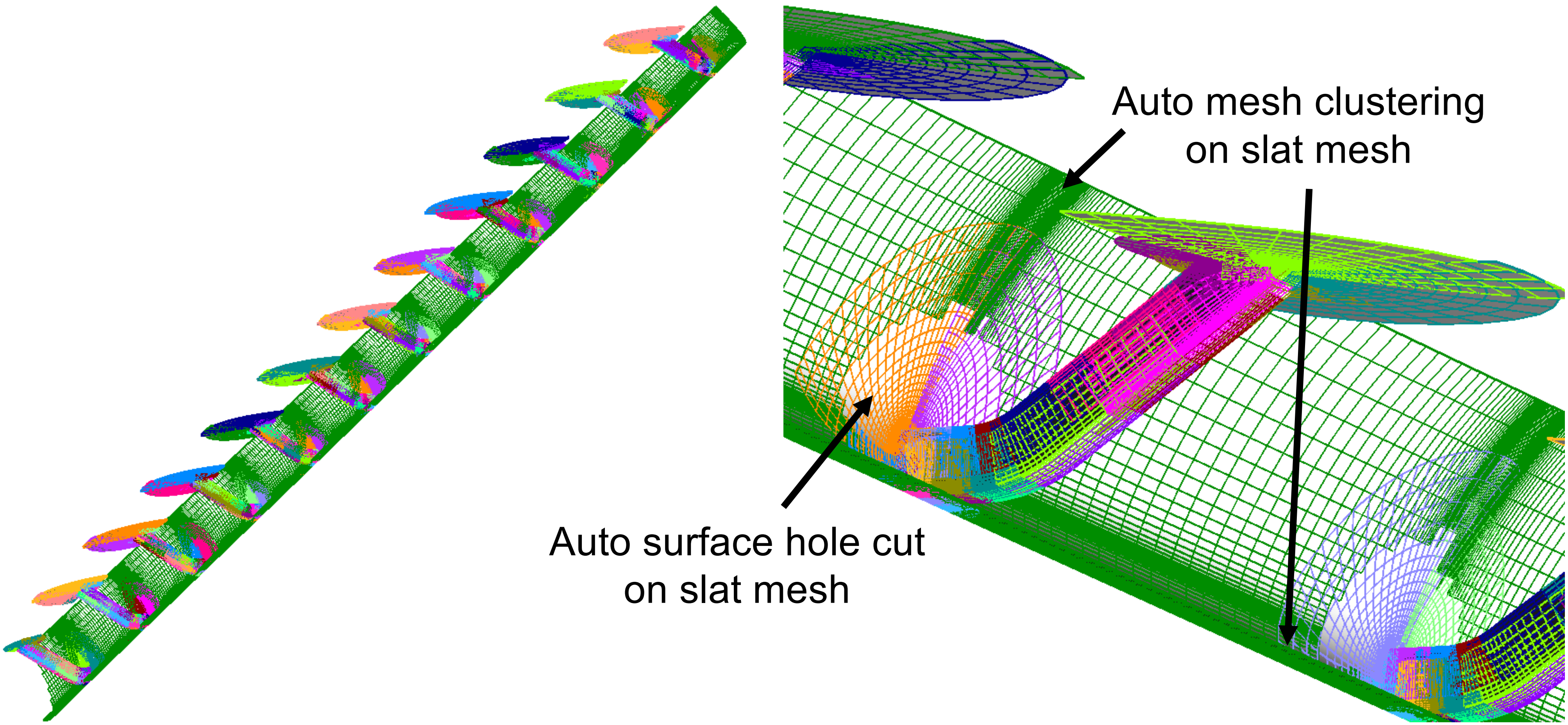


Nacelle

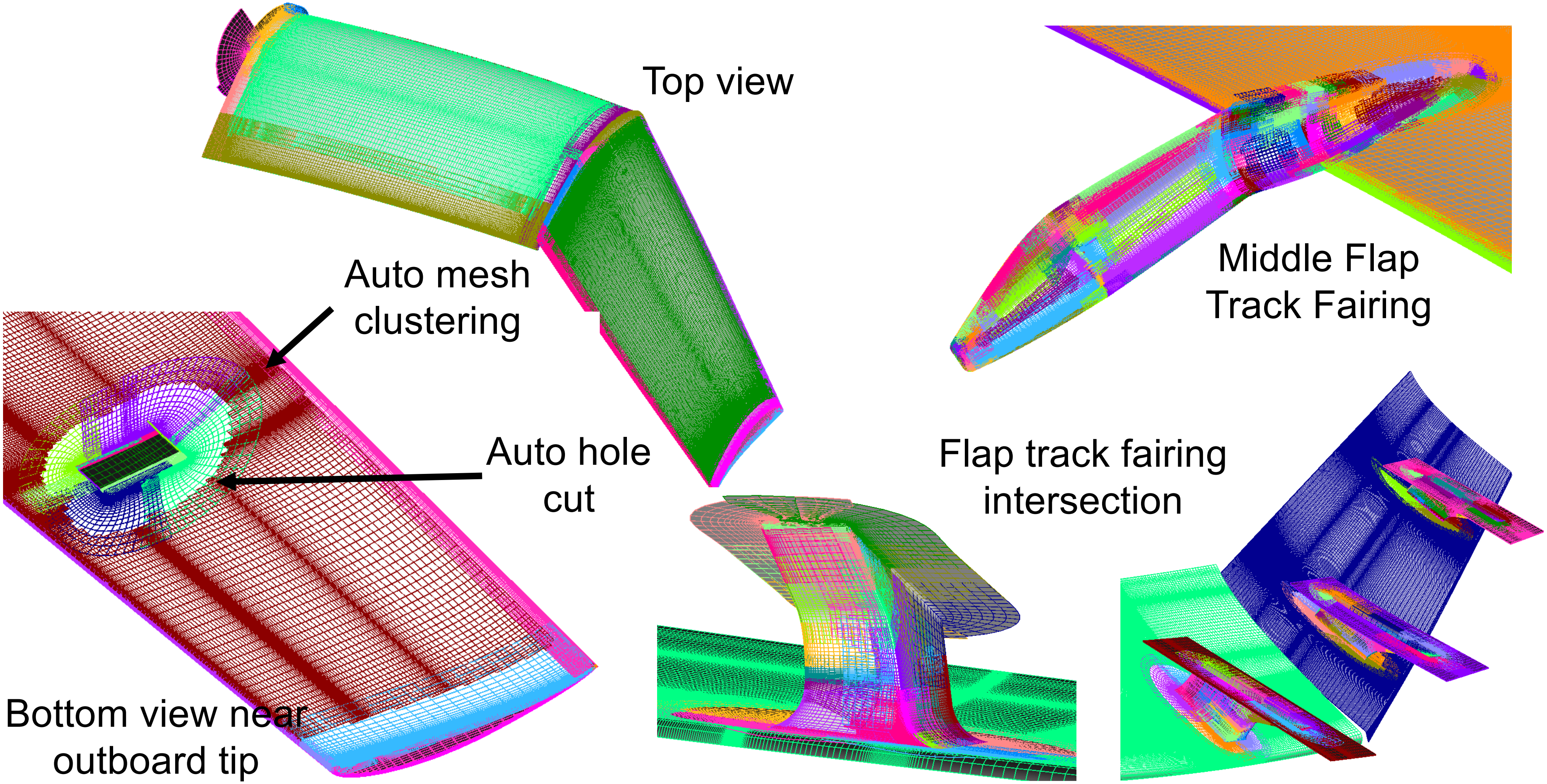


Auto surface hole
cut on nacelle mesh

HLCRM: OUTBOARD SLAT BRACKETS



HLCRM: FLAPS & FLAP TRACK FAIRINGS



CONCLUDING REMARKS

- Automation scheme on BRep solids
  - Surface domain decomposition into face, edge, node meshes
  - Near and off-body volume mesh generation
  - Domain connectivity (surface: automatic, volume: manual)
  - Input files: flow solver, component loads computation
- Low to medium complexity cases (Juncture Flow, RVLT concept vehicles, wind tunnel hardware)
  - 99 - 100% acceptable surface meshes
  - 94 - 100% acceptable volume meshes
- Preliminary flow solutions on Juncture Flow F6 and Lift+Cruise concept vehicle cases show comparable convergence behavior and converged aerodynamic loads as manual meshes
- Significant reduction in effort and time: hybrid auto & manual meshes
  - Weeks/months -> days
  - Days -> hours

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Transformational Tools and Technologies (TTT)
Revolutionary Vertical Lift Technology (RVLT)
Advanced Air Transport Technology (AATT)

Computational Resources

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