



DEVELOPMENT OF A TOOLSET FOR AUTOMATIC STRUCTURED OVERSET MESH GENERATION

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Computational Aerosciences Branch

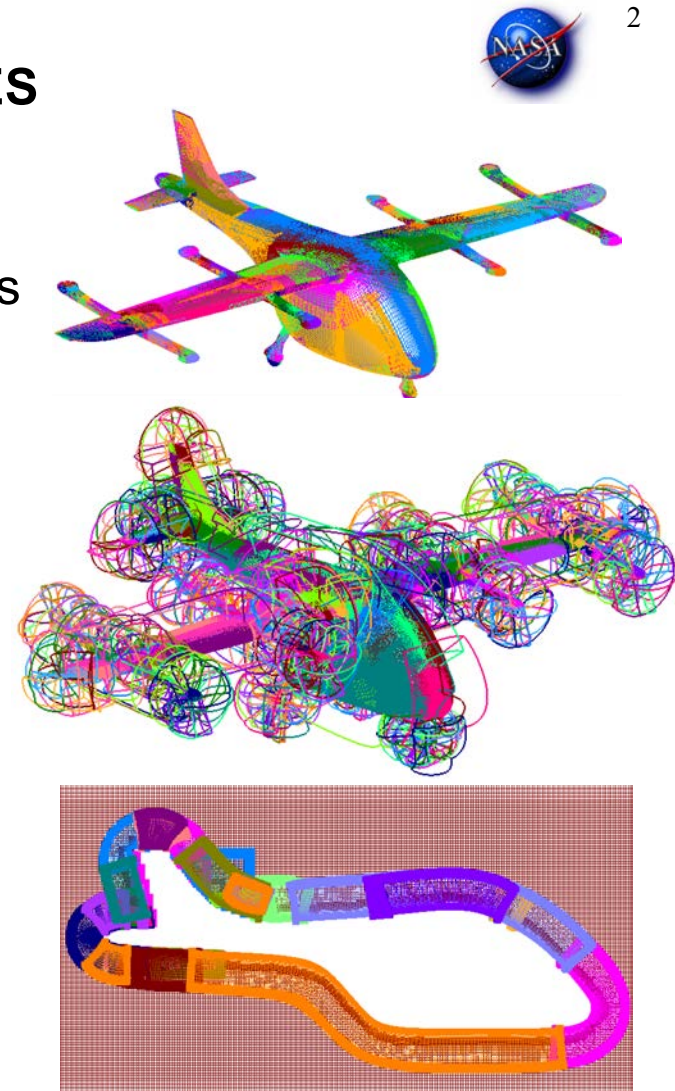
NASA Ames Research Center

16th Symposium on Overset Composite Grids and Solution Technology, Dayton, Ohio, Oct 7-10, 2024

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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)
- Goal: Develop tools to minimize human effort needed
- Demonstrate significant savings with current process:
automation tools + small manual repairs/adjustments



OUTLINE

- Motivation & objectives
- Automation tools overview
- Automation scheme overview
- Test cases
 - Geometry -> Flow solution (AIAA Paper 2024-4305)
 - Surface + volume grids only (prelim. DPW8)
- Concluding remarks

AUTOMATION SOFTWARE FLOW CHART

Clean BRep Solid
Geometry (.stp/.igs/.egads)

Geometric components
specification file

EGADS2SRF

POGS (Pre-processor for
Overset Grid Simulations)

EPOGS

Right_LandGear
1,23:27

Left_Tail
17:19

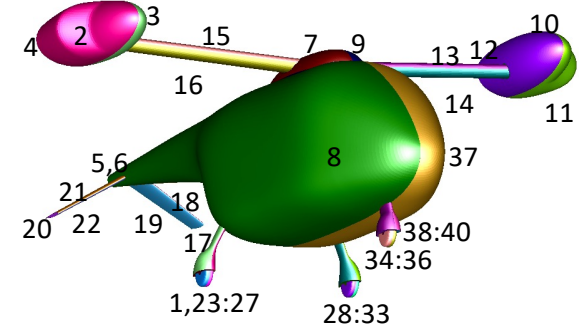
...

Surface grids

Volume grids

Domain Connectivity data

Input files for flow solver & component aeroloads computation



Manual repairs if needed
- Negative Jacobians
- Mesh overlap

Global Control Parameters

Max grid spacing	maxe	Wall normal spacing	Δs_{wall}
Max dihedral angle	maxa	Distance to far field	dfar
Max stretching ratio	sr_{max}	# Fringe layers	N_f
# Pts on shortest edge	npmin	Min donor stencil quality	sqmin

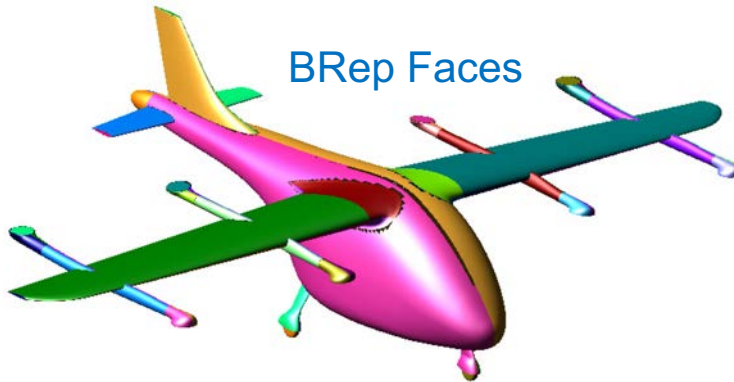
Mesh Automation Metrics

% grids free of negative cell areas/Jacobians
% fringe pts with acceptable donor stencils

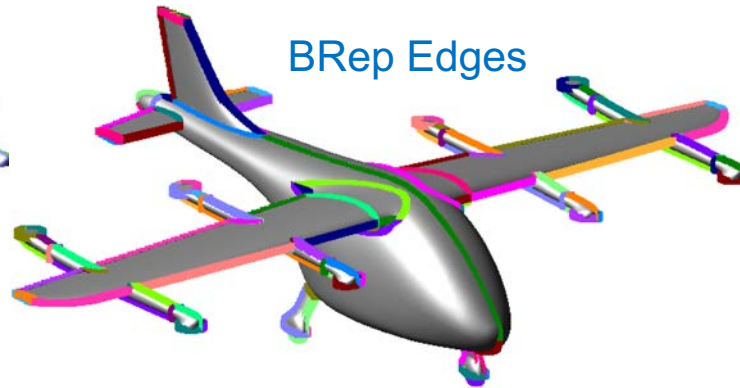
STEP 1: DISCRETIZE BREP FACES AND EDGES

Geometry Input

BRep Faces



BRep Edges

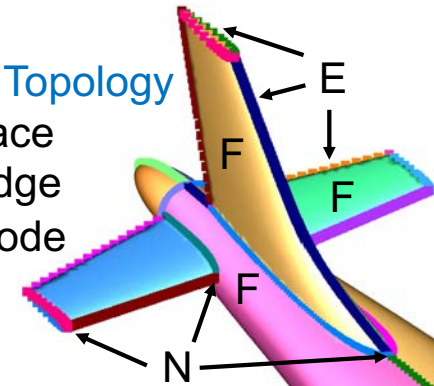


BRep Topology

F = Face

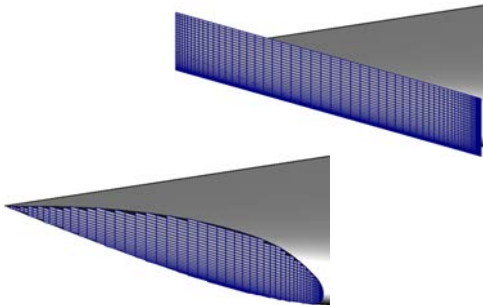
E = Edge

N = Node

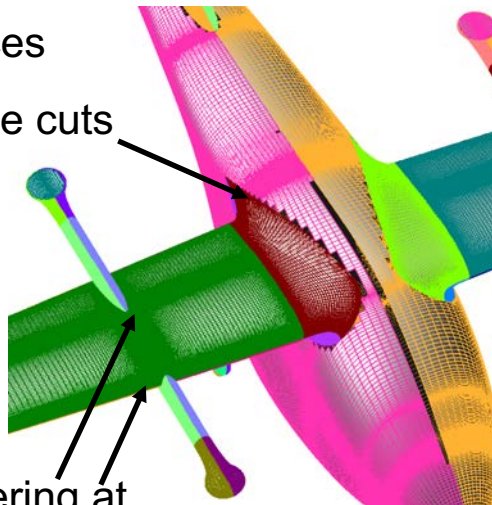


Discretized untrimmed Faces

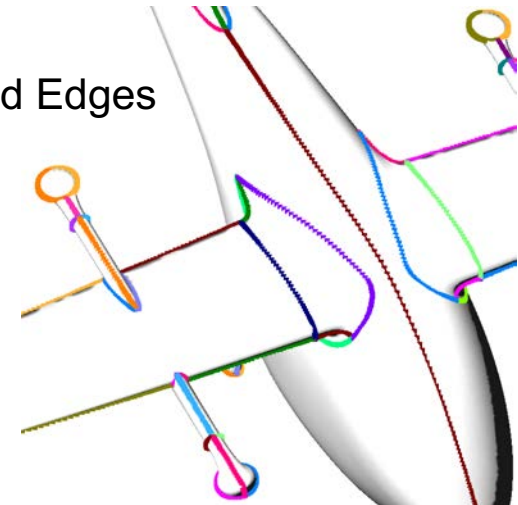
iblocks mark minimum surface hole cuts



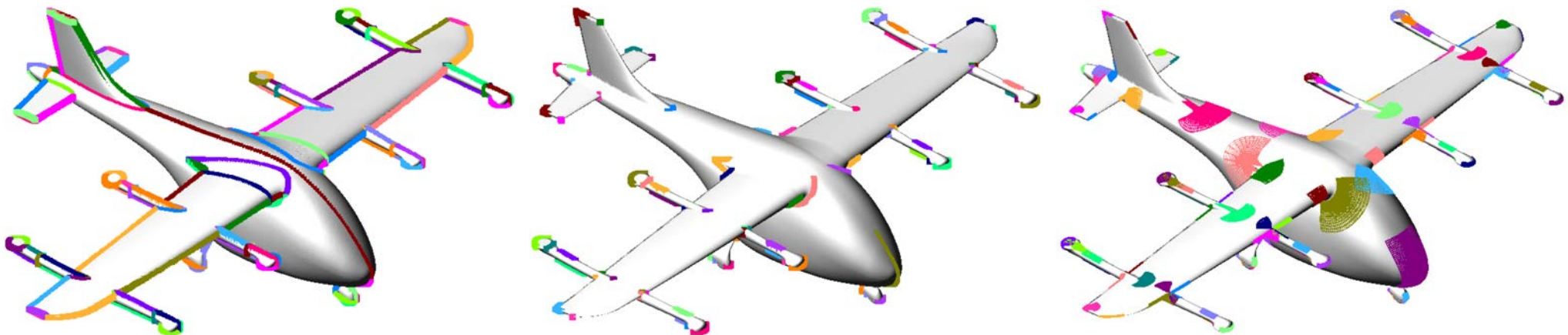
Grid clustering at surface features



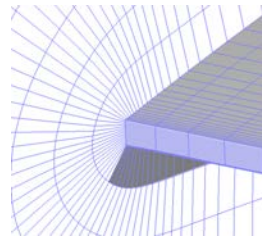
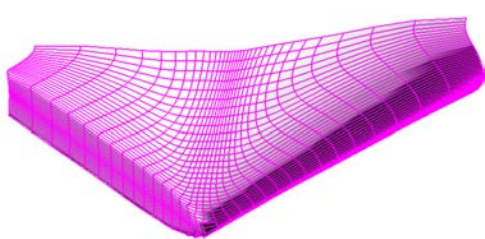
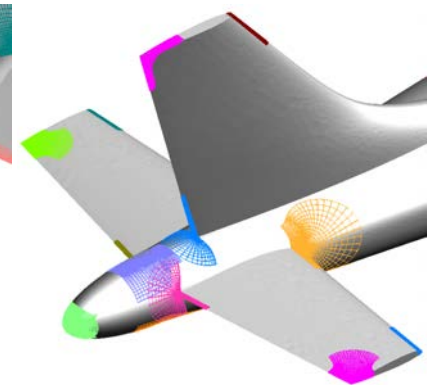
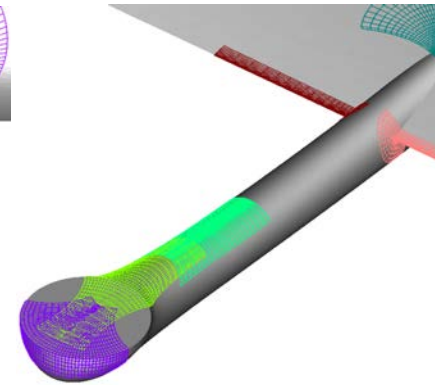
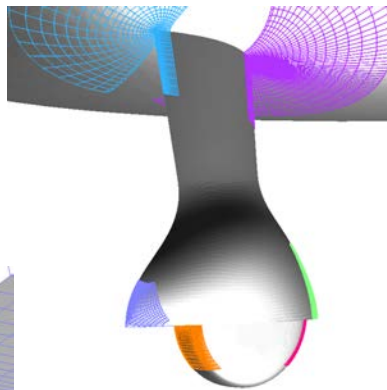
Discretized Edges



STEP 2: NODE MESH CONSTRUCTION

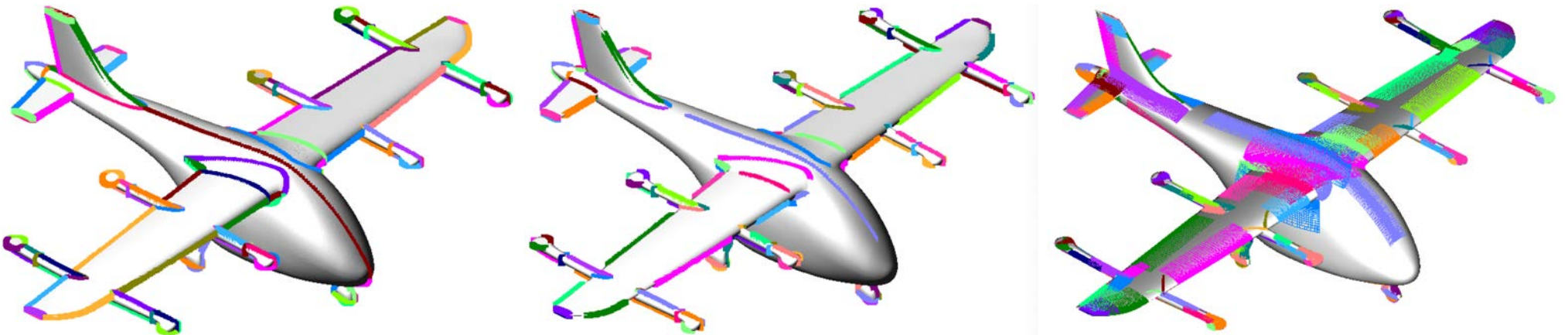


- Select best 2 edges at node to clip and concatenate to form initial curve
- Select hyperbolic or algebraic marching scheme
- Estimate marching distance
- Select initial marching step size



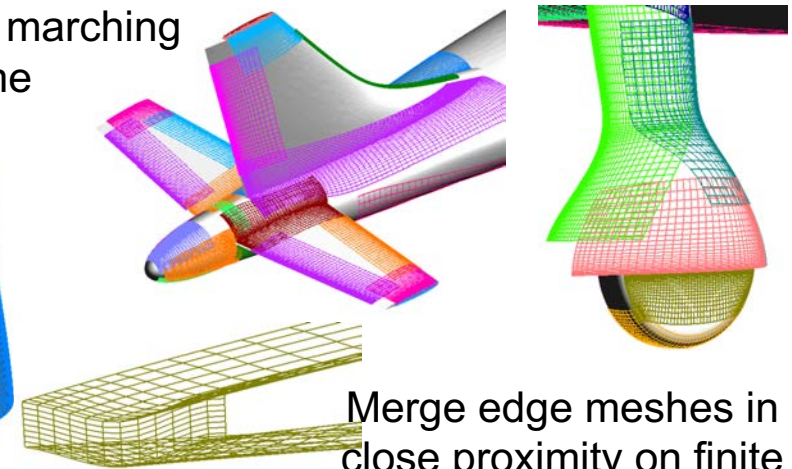
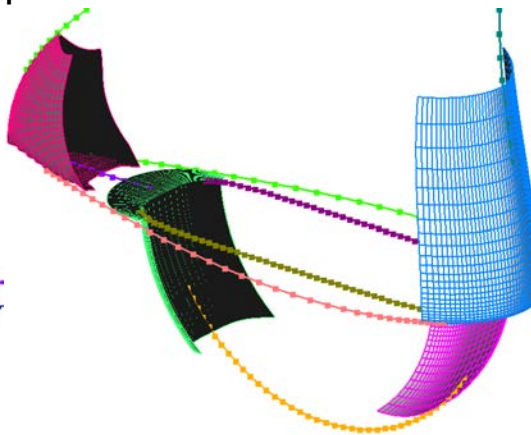
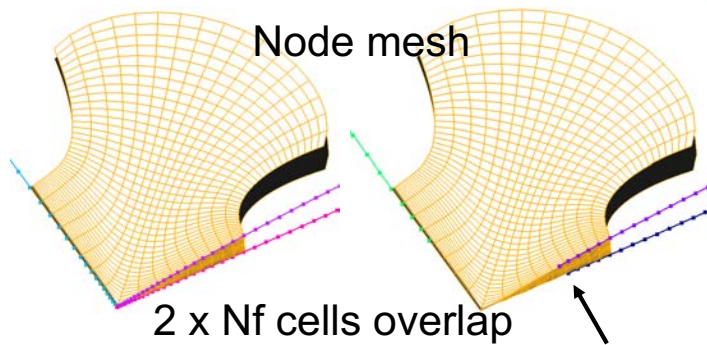
Merge node meshes in close proximity
on finite thickness trailing edges

STEP 3: EDGE MESH CONSTRUCTION



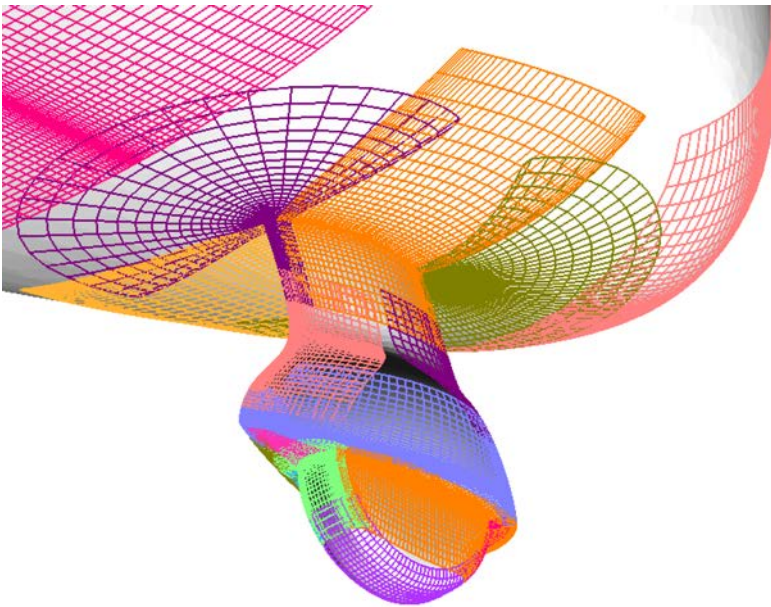
- Construct initial curves by clipping Brep Edges
- Use node meshes to determine clip location to ensure proper overlap

- Same marching scheme

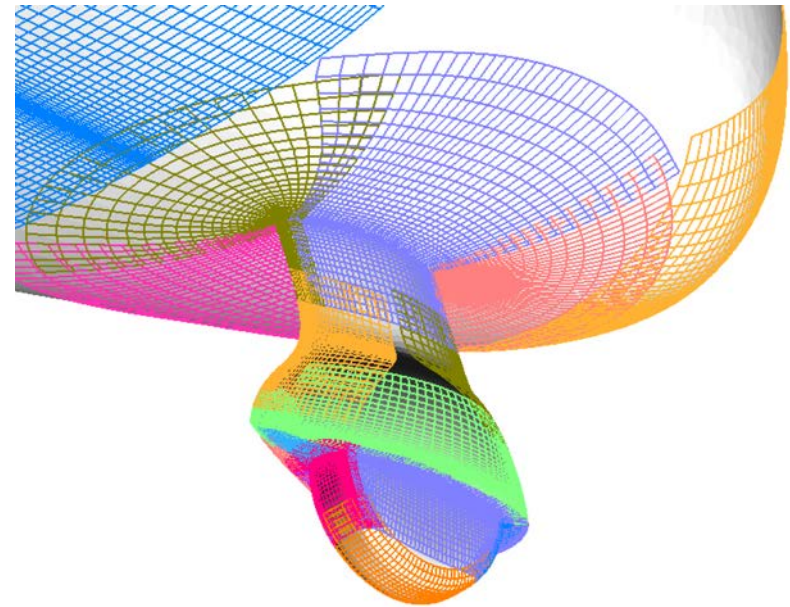


Merge edge meshes in close proximity on finite thickness trailing edges

STEP 4: BOUNDARY COUPLING ITERATIONS BETWEEN NODE & EDGE MESHES



Before boundary coupling iterations

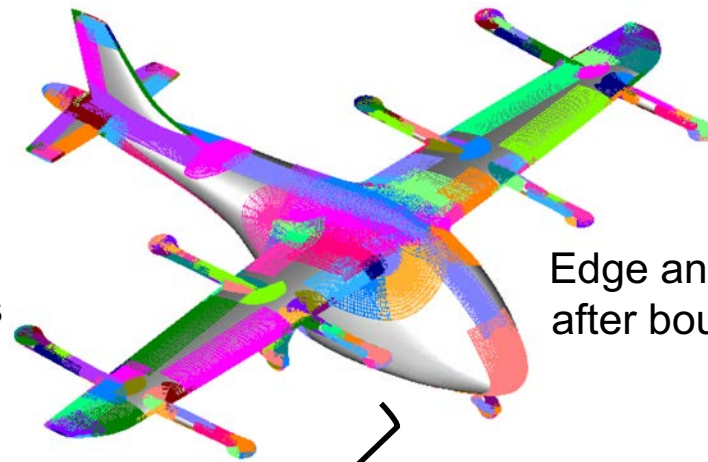


After boundary coupling iterations

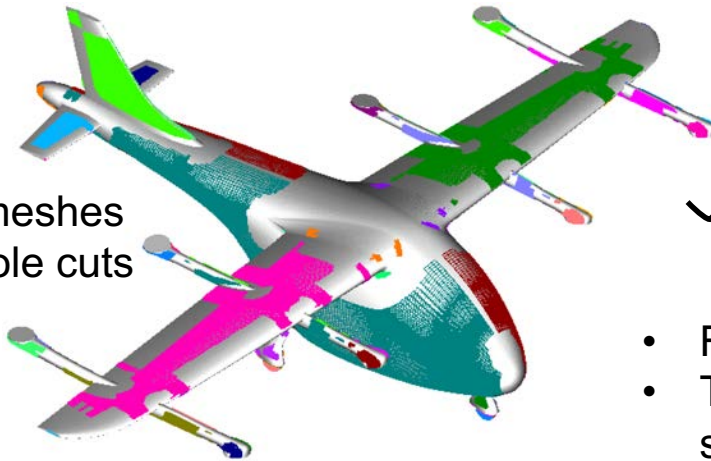
STEP 5: FACE MESH RETRACTION & ELIMINATION



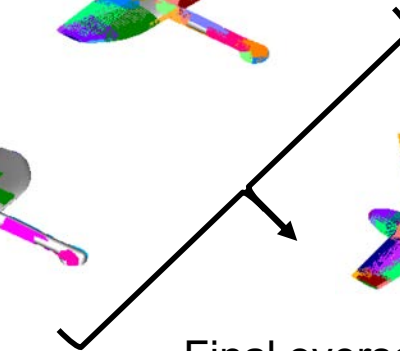
Original face meshes
with minimum hole cuts



Edge and node meshes
after boundary coupling

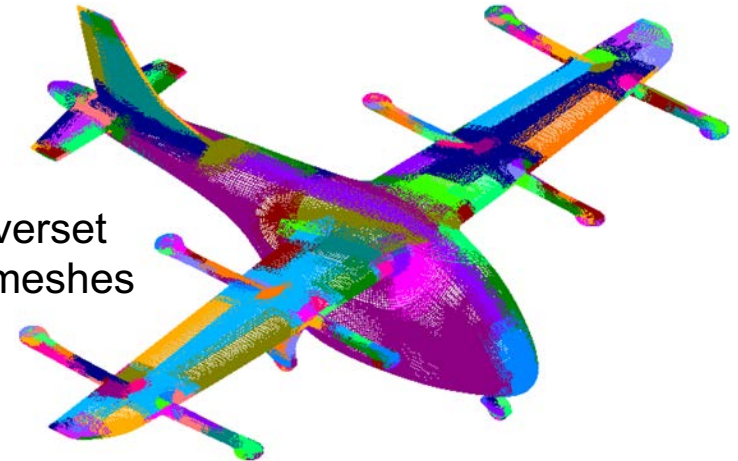


Retracted face meshes
with expanded hole cuts



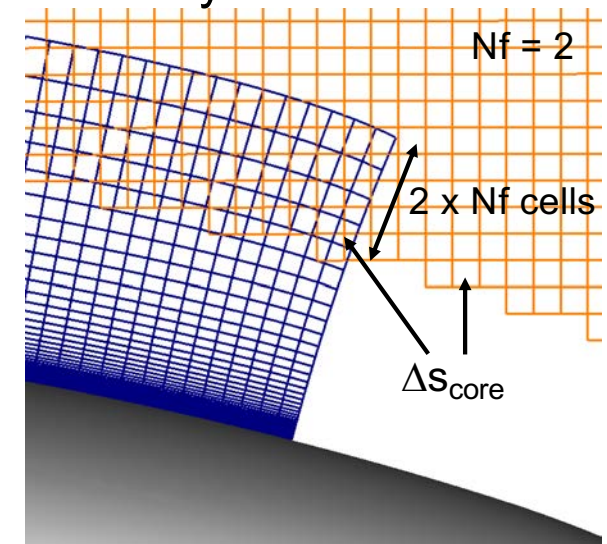
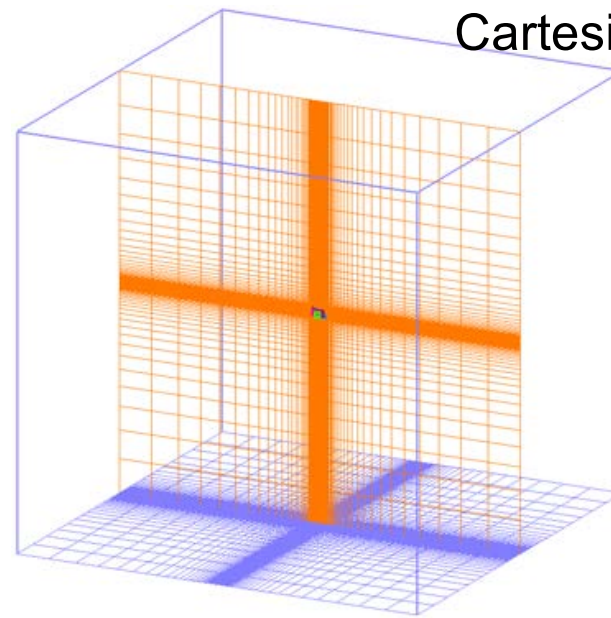
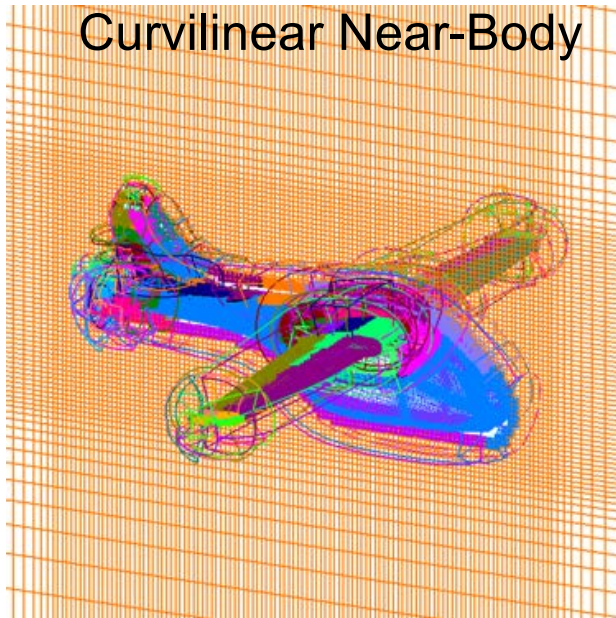
Final overset
surface meshes

- Fractured
- Topologically simple



STEP 6: VOLUME MESH GENERATION

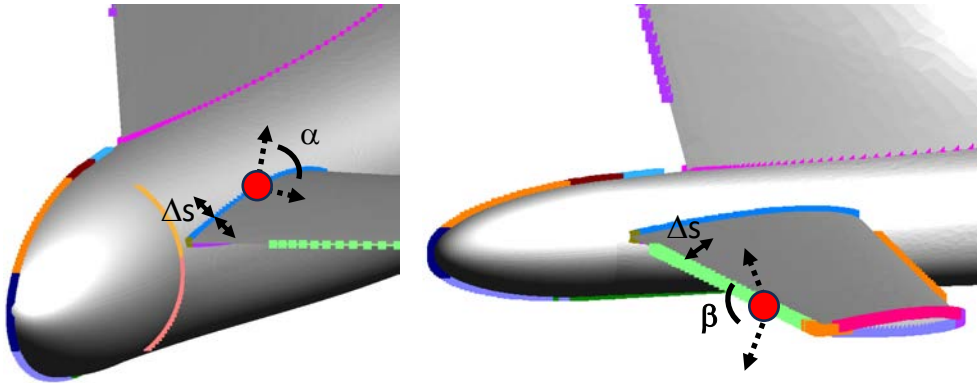
Global parameters: max grid spacing $\Delta s_{\max}$, max stretching ratio $sr_{\max}$



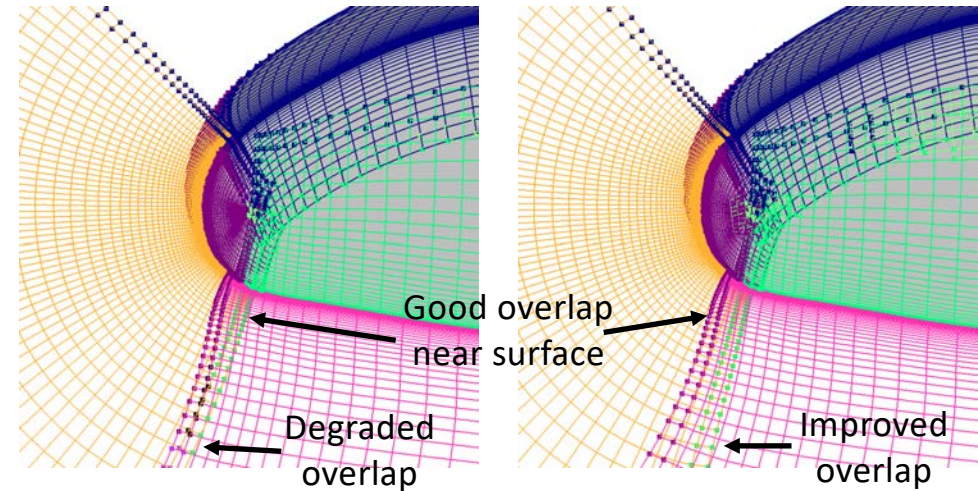
Hyperbolic marching

- Wall normal spacing: user-prescribed (Re # based)
- Marching distance = distance where Δs reaches $\Delta s_{\max}$ using geometric stretching with $sr_{\max}$
- Uniform core Δs_{core}
- Stretched to far field with $sr_{\max}$

NEAR-BODY VOLUME MESH AUTOMATION



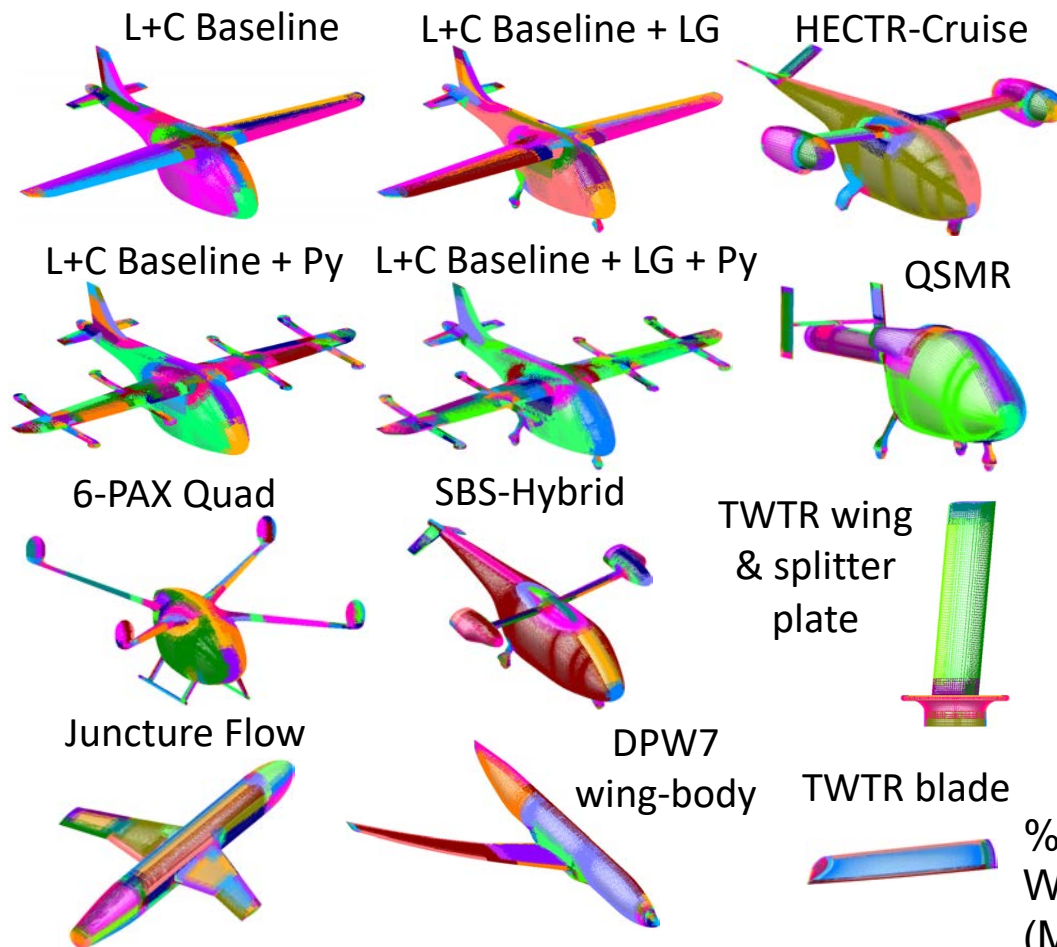
- Automatic surface mesh point distribution based on surface feature angle
 - Concave feature $\Delta s = f(\alpha)$
 - Convex feature $\Delta s = g(\beta)$
- Automatic selection of hyperbolic meshing smoothing parameters
 - 2nd order smoothing coef.
 - # volume smoothing steps
 - # sub-steps



- Automatic splay boundary condition control based on local surface convexity

Auto-adjust if negative Jacobians found

VOLUME MESHING TEST CASES

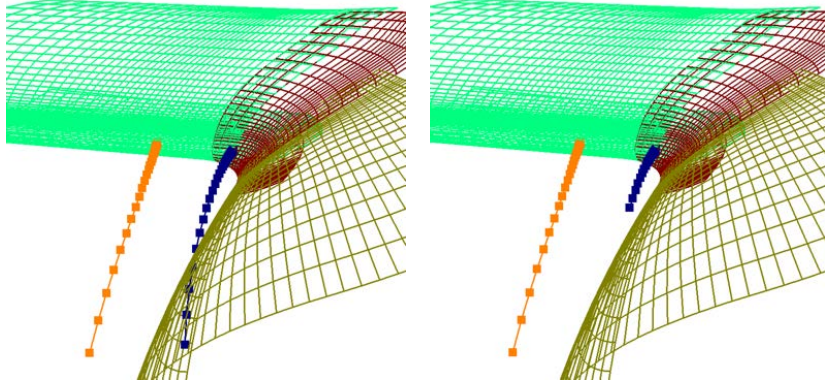


Case	# Mesh	# Vol pts (M)	# Defective Prev/current
L+C Base	96	33.5	16 / 0
L+C Base+LG	164	62.1	26 / 0
L+C Base+PY	265	76.4	29 / 0
L+C Base+LG+PY	332	100.5	39 / 1
HECTR	171	29.5	8 / 3
6 PAX Quad	233	20.5	31 / 3
QSMR	173	15.9	19 / 0
SBS-Hybrid	157	30.0	23 / 3
TWTR wing-splitter	29	24.9	- / 1
TWTR blade	21	3.9	- / 0
Juncture Flow	177	35.6	26 / 0
DPW7 wing-body	69	13.2	- / 1

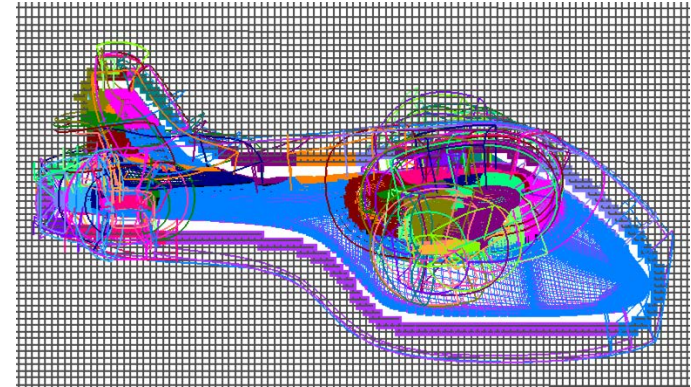
% Acceptable = 97% – 100%

Wall clock time (surface + volume) = 1 min – 12 min
(M2 MacBook Pro)

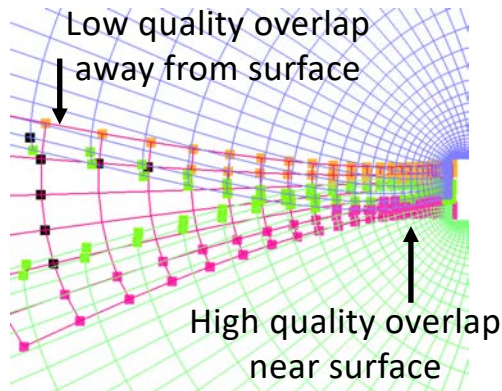
STEP 7: DOMAIN CONNECTIVITY



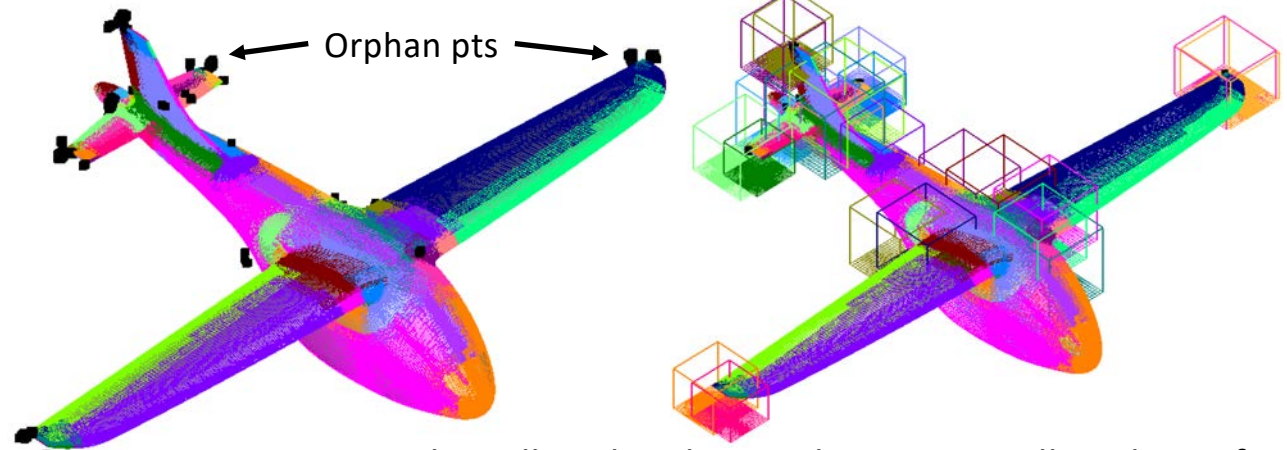
1. Near-body curvilinear volume grids and geometry surface clearance: line segment tests



2. Off-body Cartesian volume grids and geometry surface clearance: X, Y, Z direct ray piercing tests



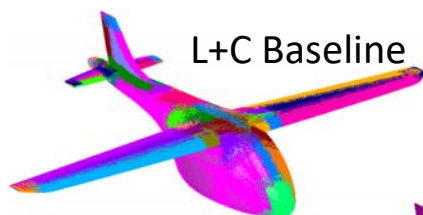
Future work: improve hole-cut quality



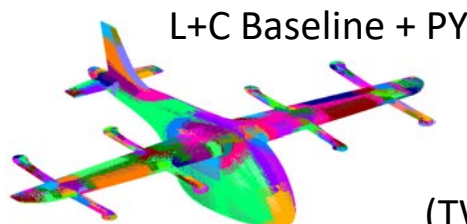
3. Auto-generated small orphan box grids: cover small pockets of off-body orphan points (< ~10% pts overhead)



TEST CASES: GEOMETRY TO SOLUTION

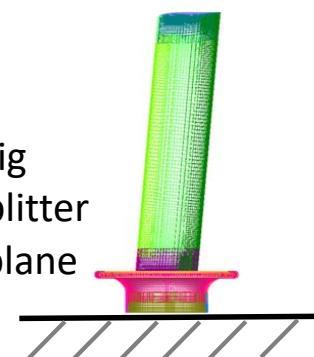


L+C Baseline

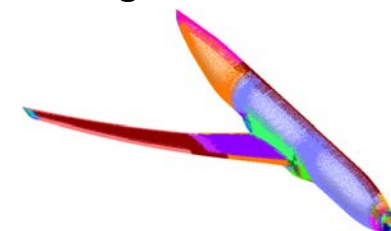


L+C Baseline + PY

Tiltwing Test Rig
(TWTR): wing & splitter
plate on ground plane



AIAA Drag Prediction
Workshop 7 (DPW7):
wing-body at $\alpha=3$ deg.
wing deflection



L+C Baseline + LG

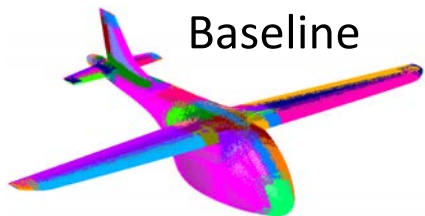


Case	Near-body volume grids		# Defective meshes (% Acceptable)	% Fringe pts with acceptable donor stencils	Total Pre-processing Time	
	# Meshes	# Grid pts			EPOGS+adj	Manual
L+C Baseline	120	60.2 M	0 (100)	99.999	1 d	1 w
L+C Baseline + LG	199	106.1 M	0 (100)	99.978	2 d	2 w
L+C Baseline + PY	347	111.8 M	0 (100)	99.993	2 d	2 w
TWTR	32	22.0 M	1 (97)	99.9996	2 h	2 d
DPW7 (fine)	73	66.1 M	1 (99)	100	2 h	2 d

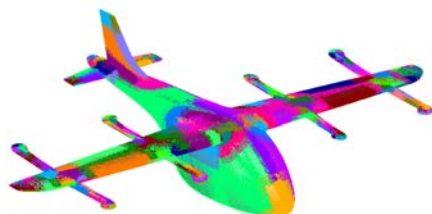
w=week, d=day, h=hour

LIFT+CRUISE (L+C) Surface Grids

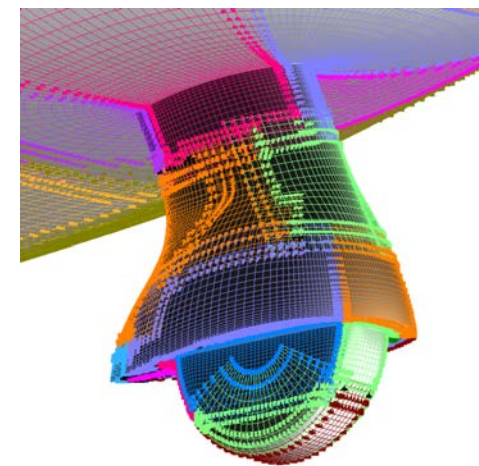
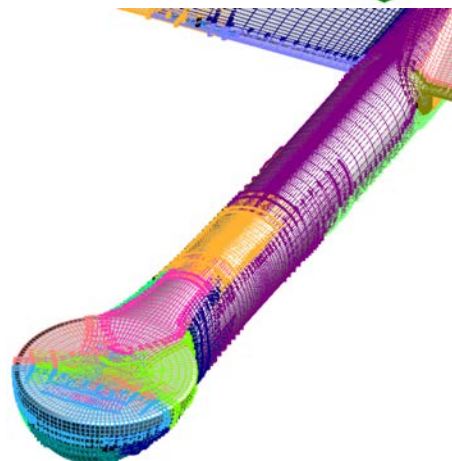
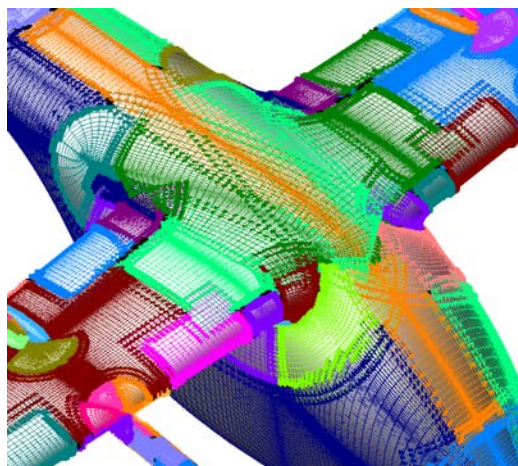
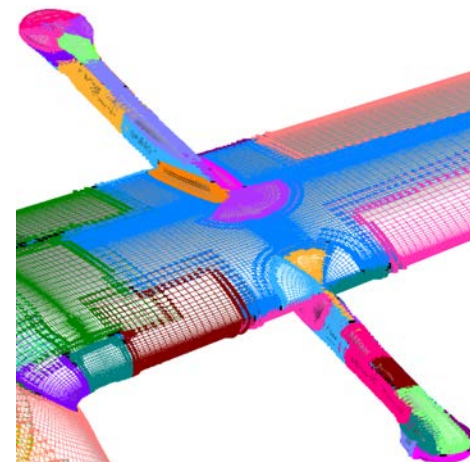
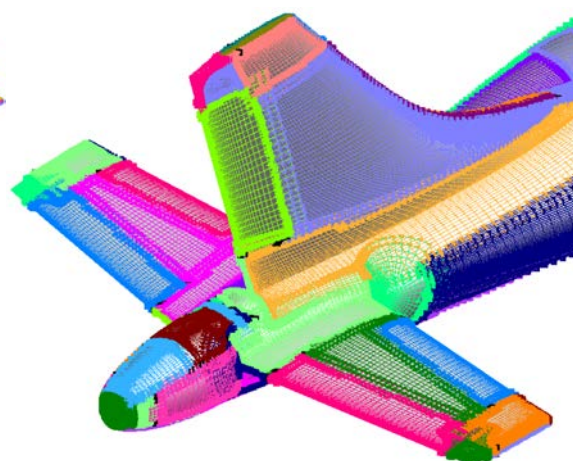
Baseline



Baseline + PY



Baseline + LG

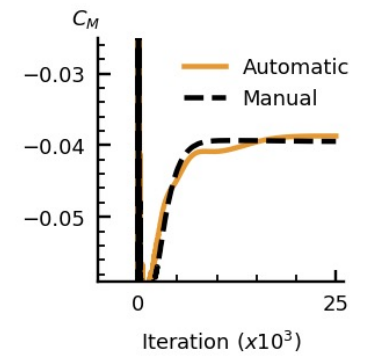
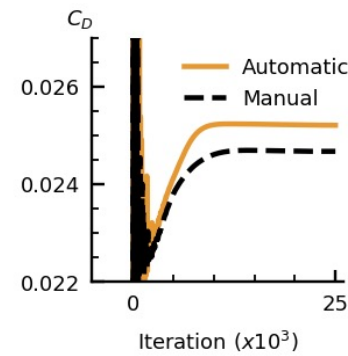
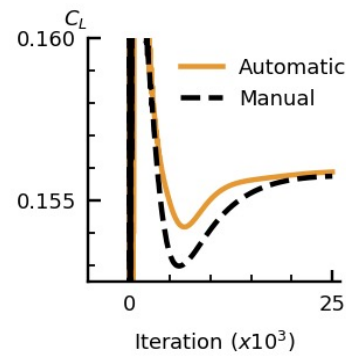
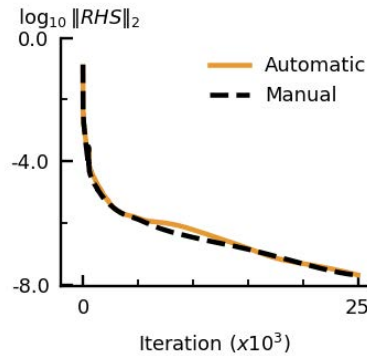


LIFT+CRUISE (L+C)

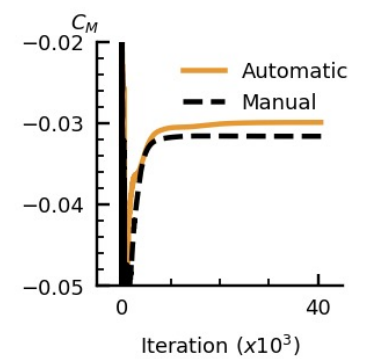
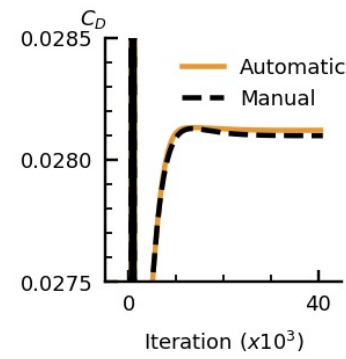
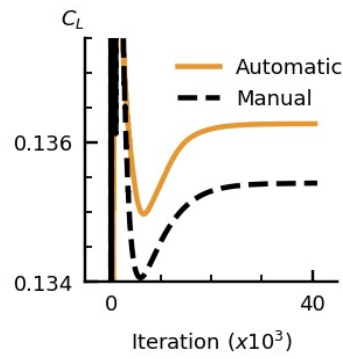
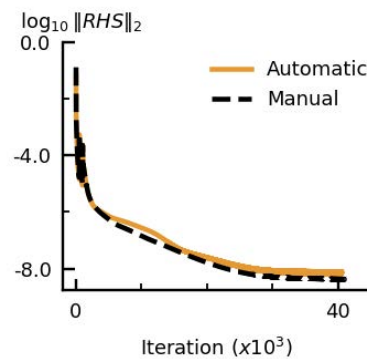
Residuals & Aerodynamic Loads Convergence

- Compare behavior using automatic & manual connectivity

Baseline



Baseline
+ PY

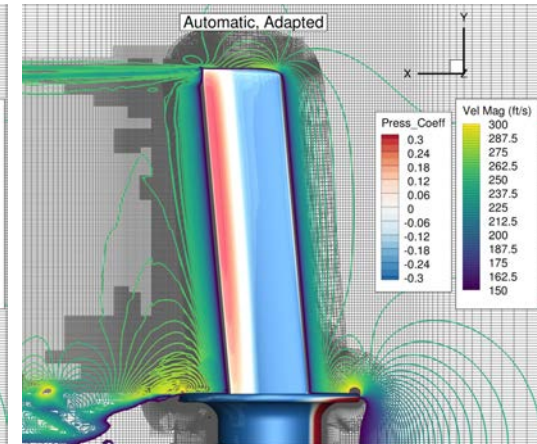
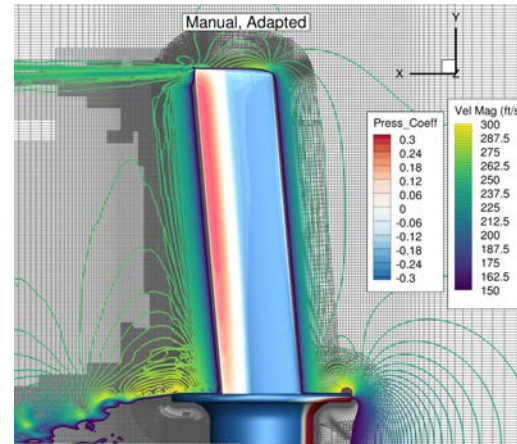
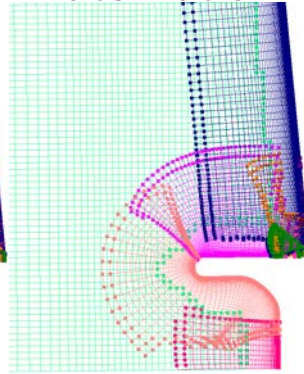
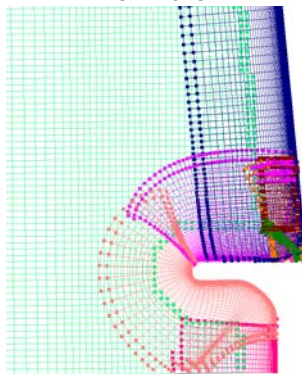
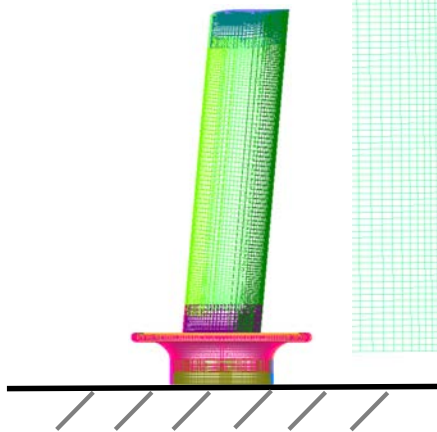


TILTWING TEST RIG (TWTR)

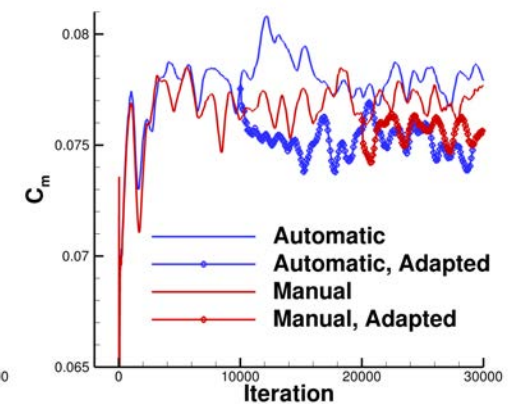
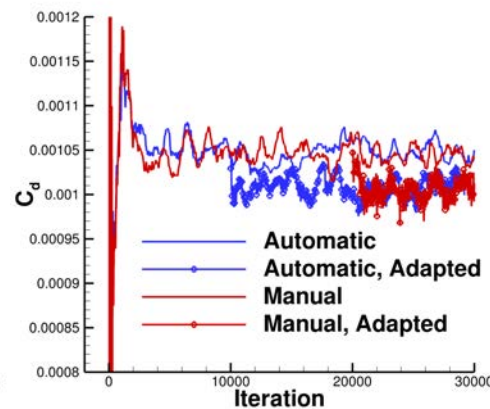
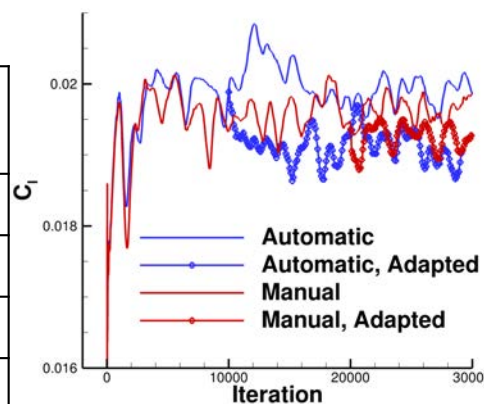
Wing & splitter plate
on ground plane

Manual

Automatic

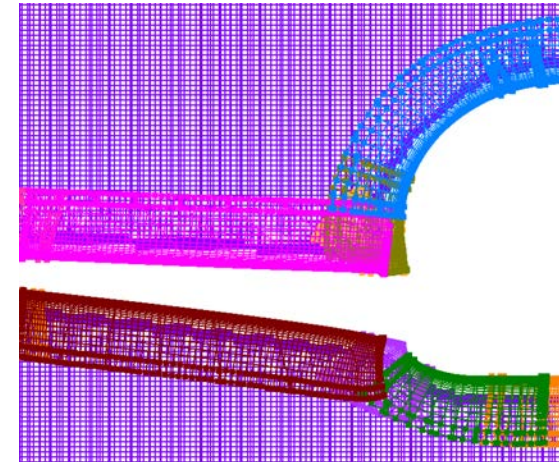
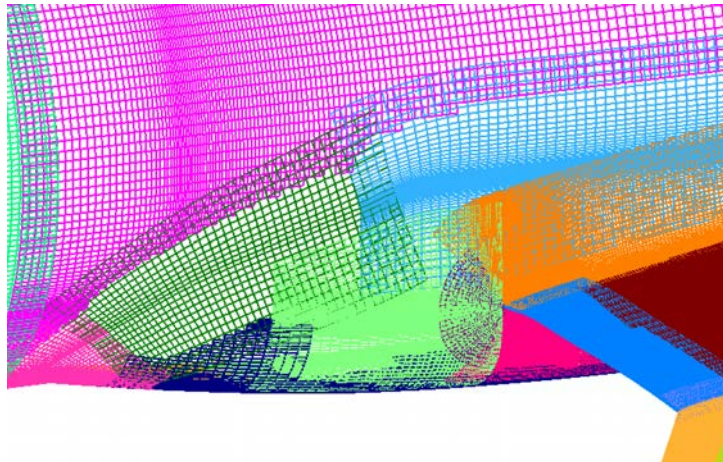
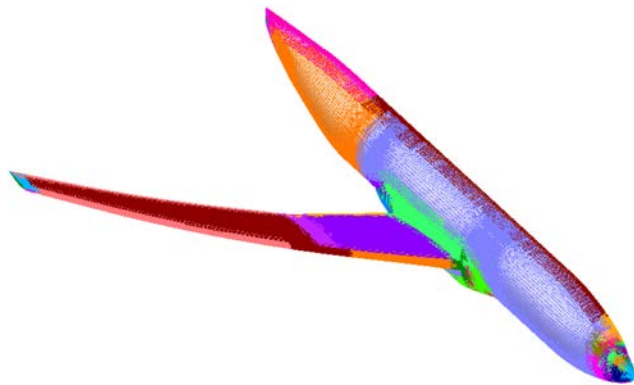


Case	Connect-ivity	Wake Adaption
1	A	Off
2	M	Off
3	A	On
4	M	On

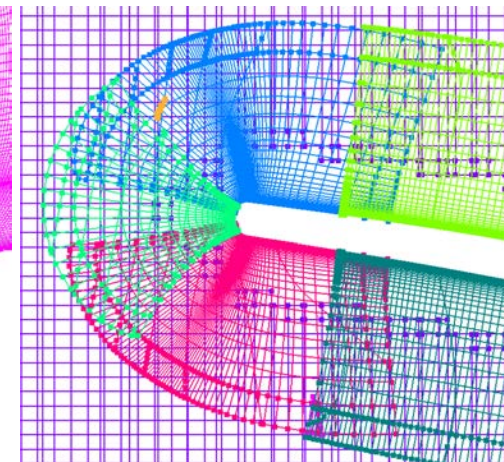
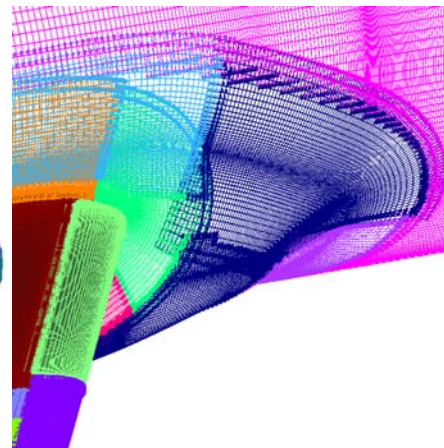
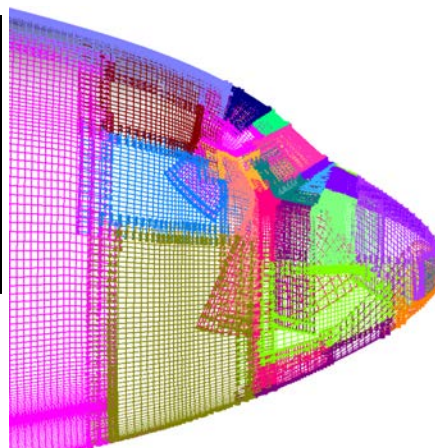


7TH AIAA DRAG PREDICTION WORKSHOP (DPW7)

Wing Deflection at $\alpha = 3.0$ deg., $Re = 5M$



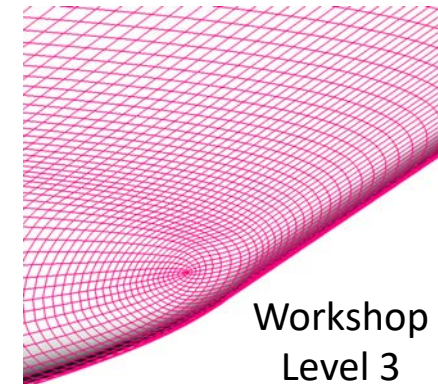
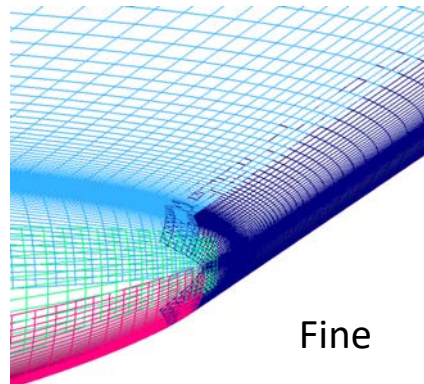
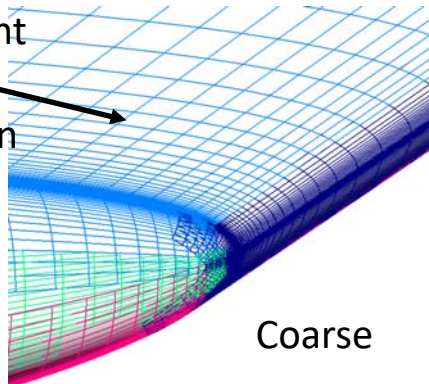
Case	# Surface grid pts	# Near-body volume grid pts
Coarse	0.23 M	13.6 M
Fine	0.64 M	66.1 M



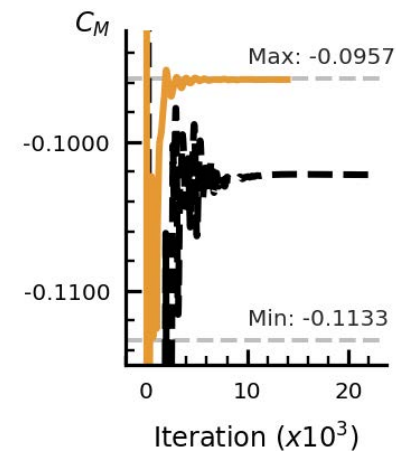
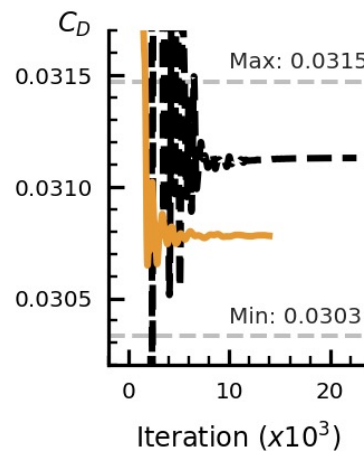
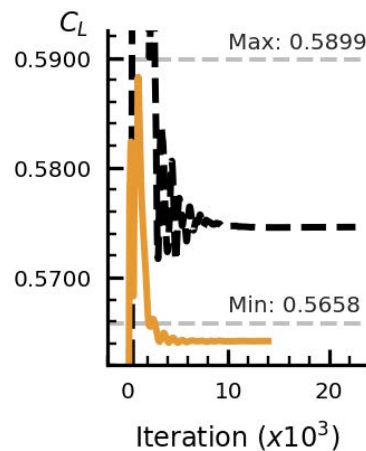
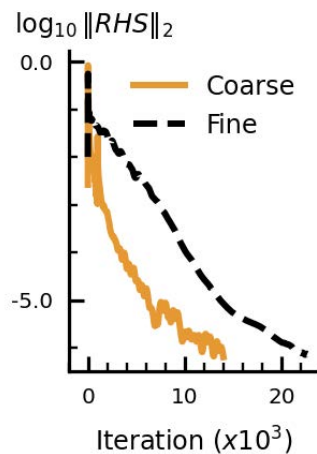
7TH AIAA DRAG PREDICTION WORKSHOP (DPW7)

Residuals & Aerodynamic Loads Convergence

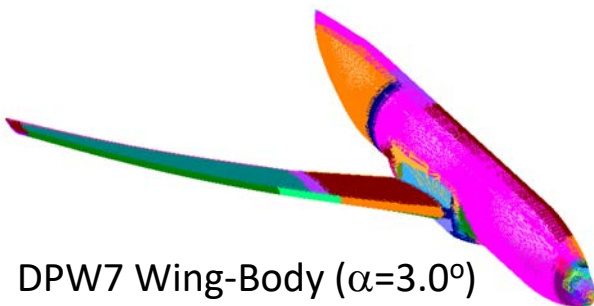
Insufficient
grid
resolution



- Workshop min/max from 8 different solvers/datasets



8TH AIAA DRAG PREDICTION WORKSHOP TEST CASES Level 3 (medium) Resolution



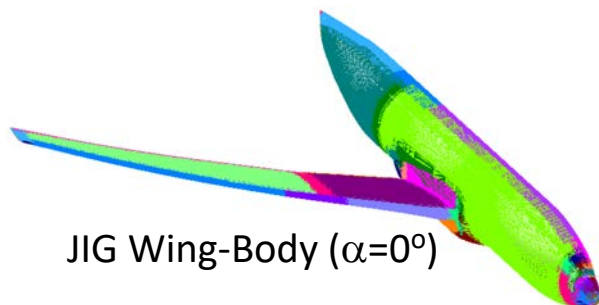
DPW7 Wing-Body ($\alpha=3.0^\circ$)



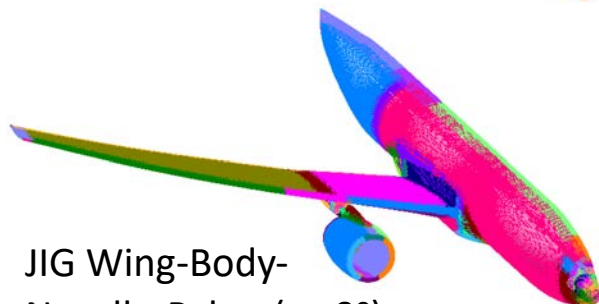
JIG Wing-Body-Tail ($\alpha=0^\circ$)



JAXA Wing-Body-Tail
($\alpha=4.84^\circ$)



JIG Wing-Body ($\alpha=0^\circ$)



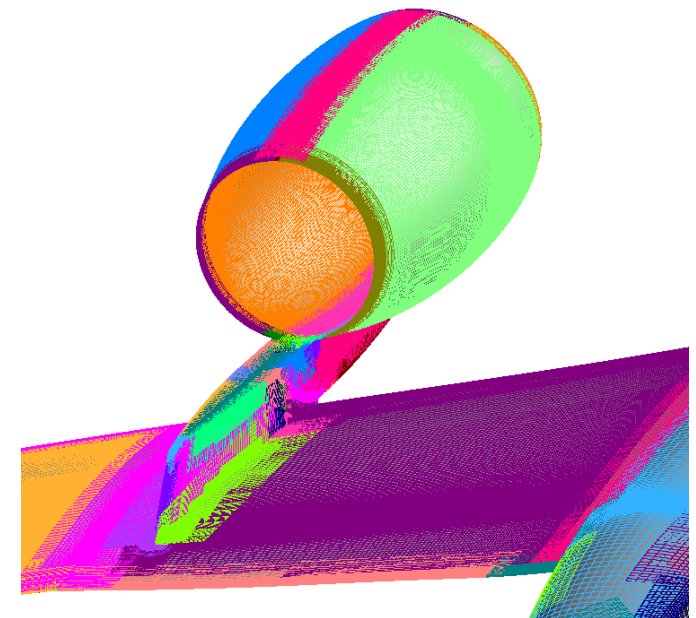
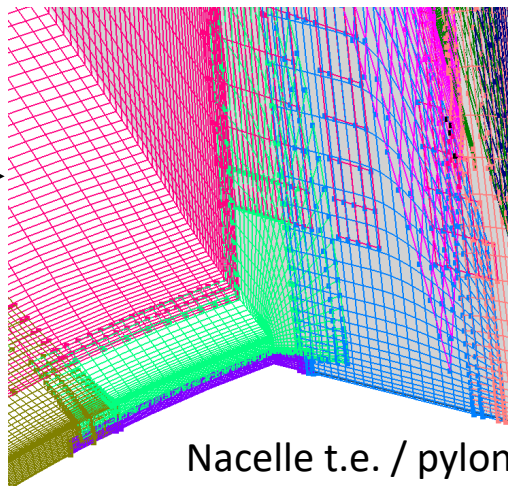
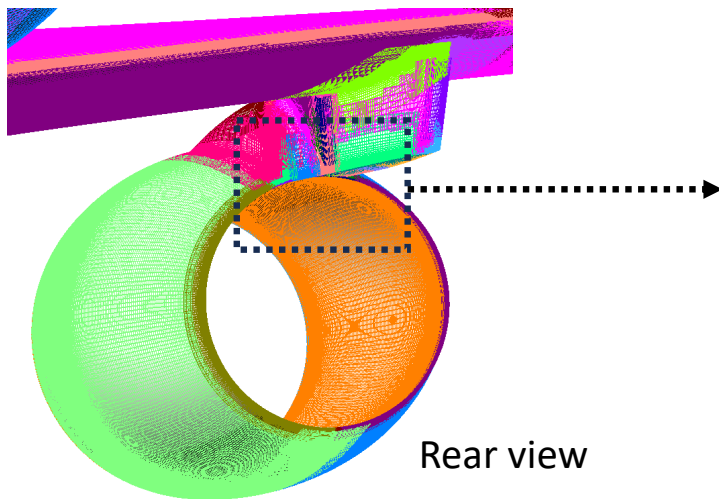
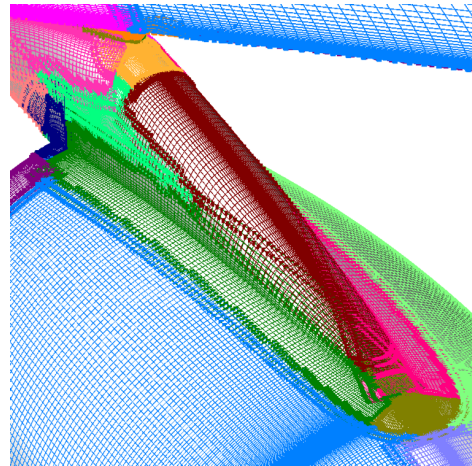
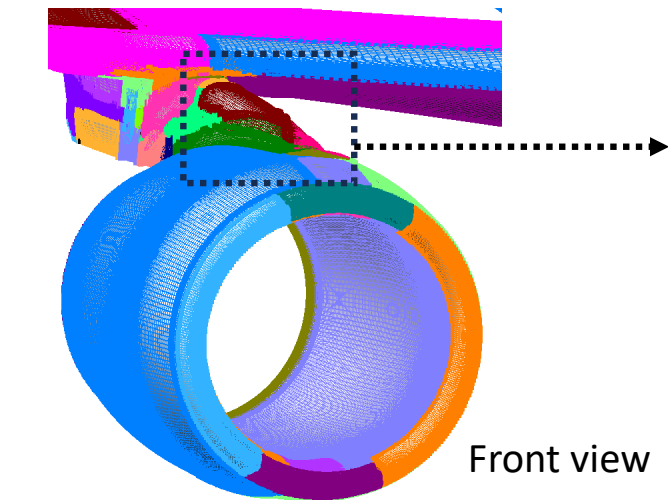
JIG Wing-Body-
Nacelle-Pylon ($\alpha=0^\circ$)

12 OpenMP threads on
MacBook Pro M2

Case	# Grids	# Surf. Pts (M)	# NB Vol. Pts (M)	# Repairs		Wall Time (surf+vol)	
				J	O	egads2srf	pogs
DPW7 WB	72	0.40	30.1	0	1	6m 53s	3m 11s
JAXA WBT	85	0.64	48.5	0	3	8m 43s	3m 55s
JIG WB	72	0.41	31.2	0	1	7m 39s	2m 44s
JIG WBT	86	0.64	48.9	0	3	9m 9s	3m 52s
JIG WBNP	127	0.71	54.2	1	3	15m 45s	3m 47s

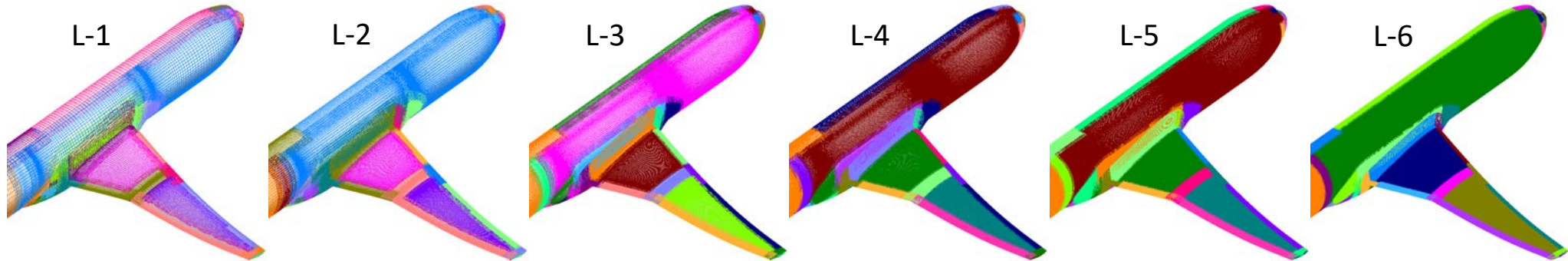
8TH AIAA DRAG PREDICTION WORKSHOP TEST CASES

JIG Wing-Body-Nacelle-Pylon



8TH AIAA DRAG PREDICTION WORKSHOP TEST CASES

Grid Family for Mesh Resolution Study (2.5x factor)



L	maxa (deg)	maxe	npmin	maxsr	Δs wall (x 10 ⁻⁴)	# grid	# Surf. Pt (M)	# Total Vol. Pt (M)	# Repairs		Wall Time (surf+vol) MacBook Pro M2	
									J	O	egads2srf	pogs
1	5.0	15.0	9	1.19	5.423	66	0.12	9.9	0	3	1m 51s	0m 48s
2	4.5	10.0	13	1.135	3.615	67	0.25 (x2.1)	26.3 (x2.7)	0	3	3m 52s	1m 46s
3	4.0	6.667	17	1.10	2.410	73	0.48 (x1.9)	63.1 (x2.4)	0	3	7m 46s	4m 4s
4	3.5	4.444	21	1.07	1.607	73	0.87 (x1.8)	155.3 (x2.5)	1	3	19m 41s	11m 56s
5	3.0	3.0	25	1.05	1.071	75	1.64 (x1.9)	405.3 (x2.6)	1	2	47m 7s	39m 21s
6	2.5	2.0	29	1.04	0.714	77	3.41 (x2.1)	1039.7 (x2.6)	1	4	136m 17s	129m 58s

CURRENT STATUS

	2018	2021	2022	late 2023	Current (test cases)	Parallelization
Surface Mesh	0	80 - 95%	85 - 100%	98 - 100%	99 - 100% (30+)	not yet
Volume Mesh	0	0%	80 - 95%	97 - 100%	98 - 100% (30+)	yes
Domain Connectivity	0	0%	0%	0%	99.978 - 99.999% (5)	partial

FUTURE WORK

- Volume mesh improvements
 - Near-body – component-based normal marching distance
 - Off-body – component-based and multi-layered box grids
- Automatic mesh overlap repairs
- Wall-distance-based variable hole-cuts
- Parallel efficiency improvements

CGT NEXT RELEASE

- In progress
 - Internal testing
 - Public release paperwork
- Anticipated release
 - Beta - end of 2024
 - Public - early 2025

CONCLUDING REMARKS

- **First time demonstration:** complete overset grid pre-processing automation using EPOGS
 - Creation of surface & volume grids, domain connectivity data, input files for flow solver and component aerodynamic loads computation
 - Mostly automated, may need small manual adjustments
- Five test cases show comparable aerodynamic loads and solution convergence between manual and auto connectivity
- **First time demonstration:** DPW7 case shows converged aerodynamic loads computed from auto-generated fine mesh fall inside workshop range from 8 datasets
- **First time demonstration:** creation of 6-level mesh family for DPW8 grid resolution study
 - 10M - 1B grid points
- Significant reduction in effort and time for pre-processing
 - Weeks -> days, Days -> hours

ACKNOWLEDGEMENTS

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Transformational Tools and Technologies (TTT)

Computational Resources

NASA Advanced Supercomputing (NAS) Facility

Discussions, Data & Geometry Support

Dr. Pieter Buning (LaRC)
Dr. Tom Pulliam (ARC)
Ben Rider (Boeing)
Eduardo Solis (STC)

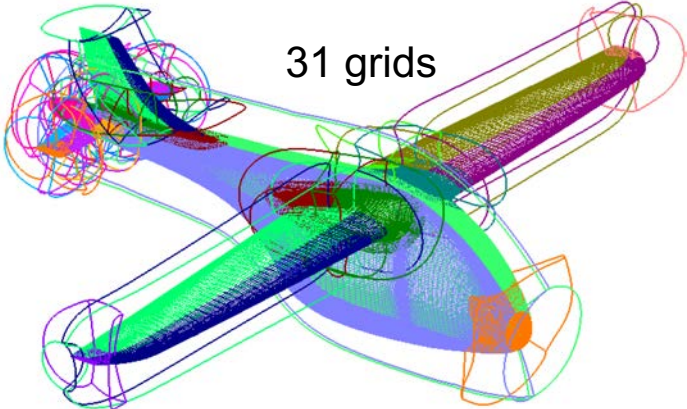
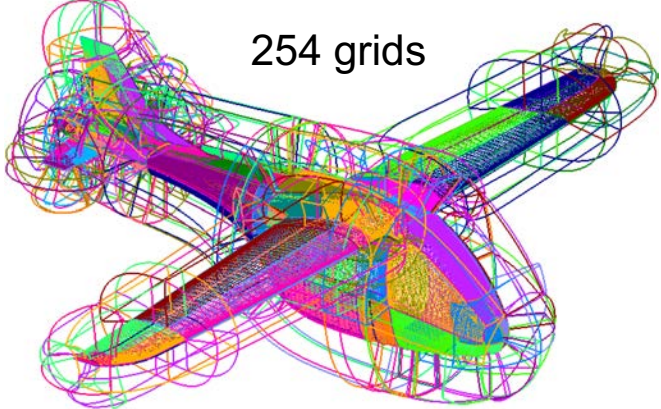
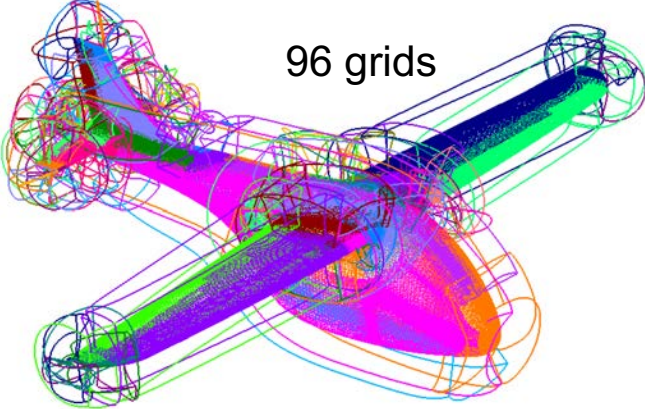
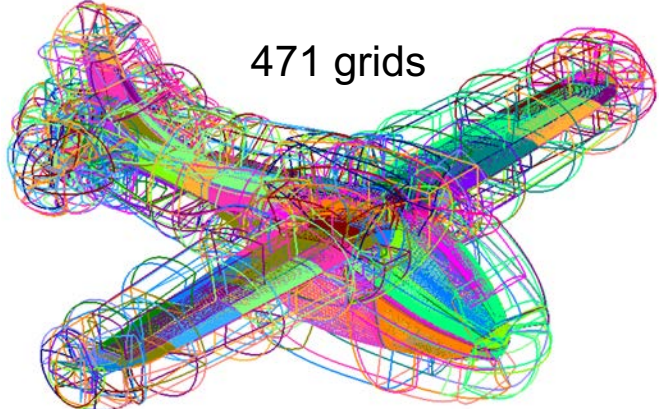


BACKUP

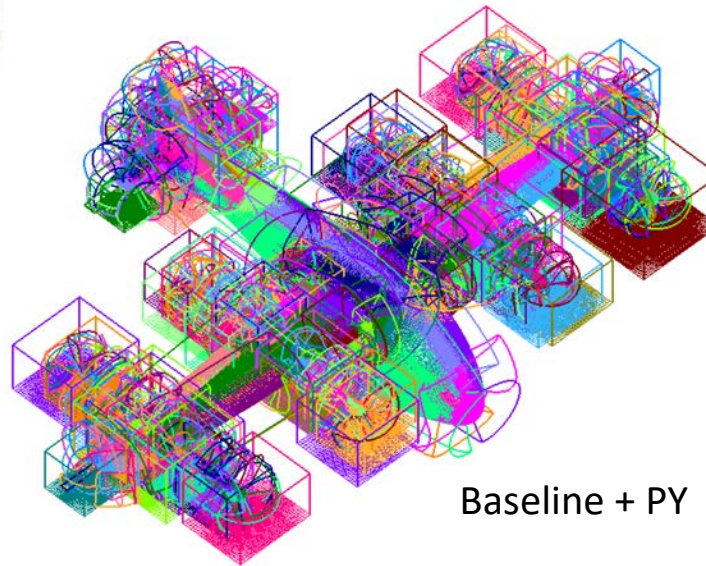
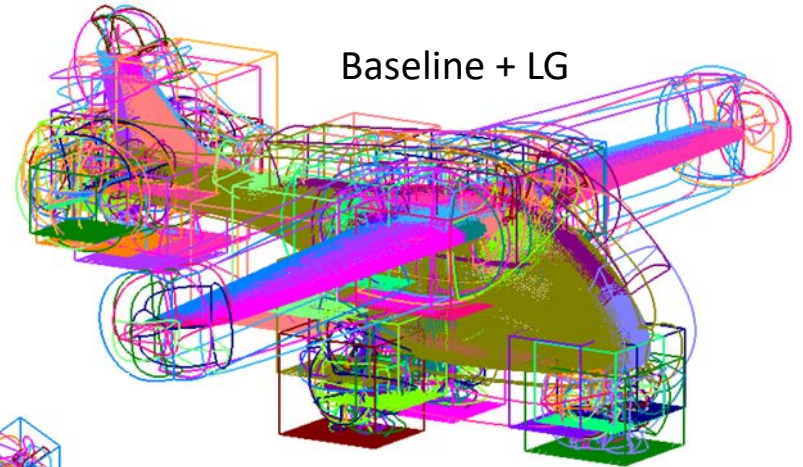
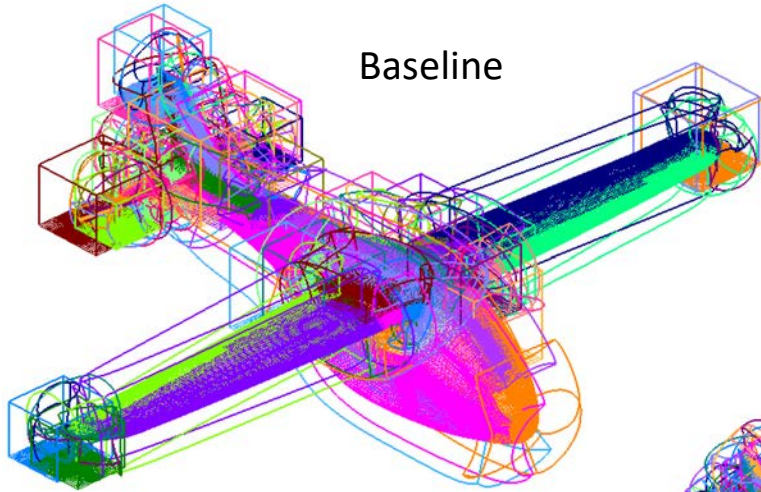
FAQ ON FRACTURED AUTO-GENERATED GRIDS

AIAA Paper 2023-3602

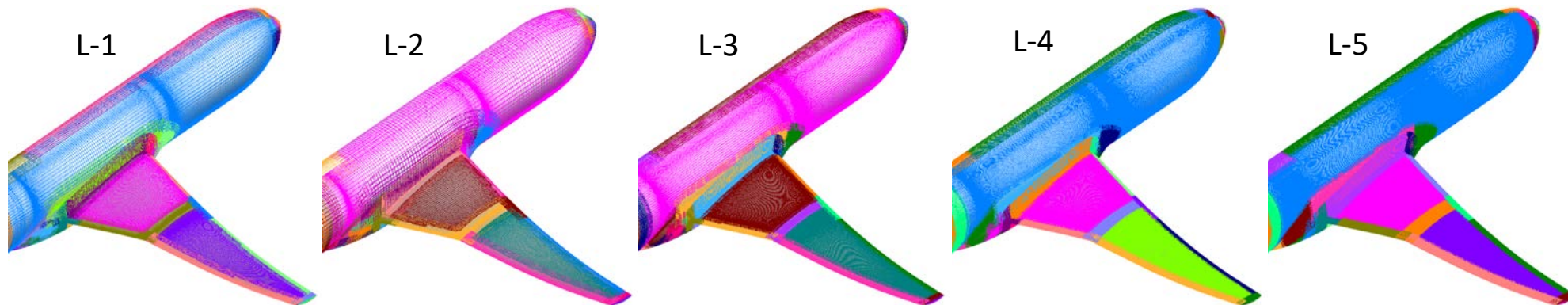


	Before MPI split	After MPI split
Manual meshes (~ days)	 31 grids	 254 grids
Auto meshes (~ hours)	 96 grids	 471 grids

LIFT+CRUISE (L+C) Volume Grids



8TH AIAA DRAG PREDICTION WORKSHOP TEST CASES Grid Family for Mesh Resolution Study (3.0x factor)



L	ang (deg)	edge	npmin	sr	Δs wall (x 10 ⁻⁴)	# grid	# Surf. Pt (M)	# Total Vol. Pt (M)	# Repairs		Wall Time (surf+vol)	
									J	O	e2srf	pogs
1	5.0	15.0	9	1.18	5.423	66	0.12	11.3	1	3	1m 53s	0m 46s
2	4.5	10.0	13	1.12	3.615	66	0.27 (x2.3)	30.4 (x2.7)	0	3	4m 1s	1m 51s
3	4.0	6.667	17	1.075	2.410	71	0.54 (x2.0)	90.0 (x3.0)	0	3	8m 25s	5m 9s
4	3.5	4.444	21	1.046	1.607	76	1.01 (x1.9)	261.9 (x2.9)	0	3	21m 37s	18m 34s
5	3.0	3.0	25	1.04	1.071	-	1.62 (x2.1)	-	1	1	47m 21s	38m 27s
6	2.5	2.0	29	1.03	0.714	-	-	-	-	-	148m 19s	-