A TUTORIAL ON THE AUTOMATIC OVERSET MESHING TOOLSET EPOGS

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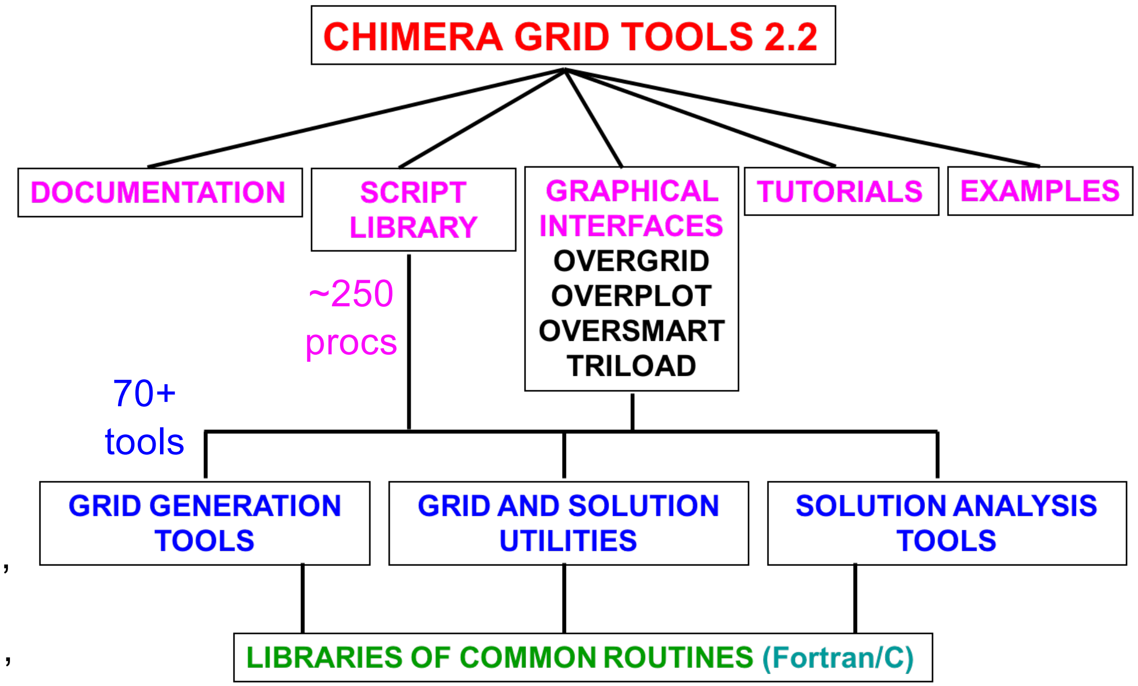
OUTLINE

- Brief overview of Chimera Grid Tools
- Geometry best practices
- Auto-meshing toolset EPOGS

Chimera Grid Tools (CGT) Overview

What is CGT

- A collection of software tools for pre- and post-processing of overset grid CFD computations



Authors

Currently active: William Chan, Andrew Chuen, Shishir Pandya

Previous versions: Stuart Rogers, James Jensen, Henry Lee, David Kao, Pieter Buning, Robert Meakin, David Boger, Steve Nash

Availability

NASA Software Catalog (https://software.nasa.gov/software/ARC-16025-1B)

- U.S. citizens/permanent residents working under U.S. organization in the U.S.
- Fill out and return Software Usage Agreement form
- Version 2.2+ available for use by authors' associated projects

CGT Installation, Documentation, Tutorials

- Software requirements
  - Fortran, C, C++ compilers (gnu, intel) : all
  - OpenGL, X11, Tcl/Tk 8.6 (up to 8.6.15, 9.0.0) : OVERGRID
  - Python, swig, gnuplot : OVERSMART
  - Tcl wish, xmgrace or gnuplot : OVERPLOT

- Installation instructions
  - chimera2.2/doc/{INSTALLATION.html, overgrid.html}

- Operating systems
  - Supported: Linux, Mac
  - Unsupported: Windows (WSL)

- Documentation
  - chimera2.2/doc/man.html -> *.html

- Tutorials
  - chimera2.2/tutorials/* (OVERGRID, Script Library, EPOGS)
  - https://www.nas.nasa.gov/pubs/ams/2014/{05-13-14,05-20-14,05-29-14}.html

CGT Executables

- Run configure script to generate Makefiles

  configure -- help (get list of options)

- Executables
  - single precision set
  - double precision set

- FFIO Library implemented in commonly used CGT tools
  - Files: grid, solution, triangulation, X-rays, domain connectivity data
  - Auto-detect attributes for I/O (big/little endian, single/double precis., …)
  - Subrecord markers for large dataset in single record

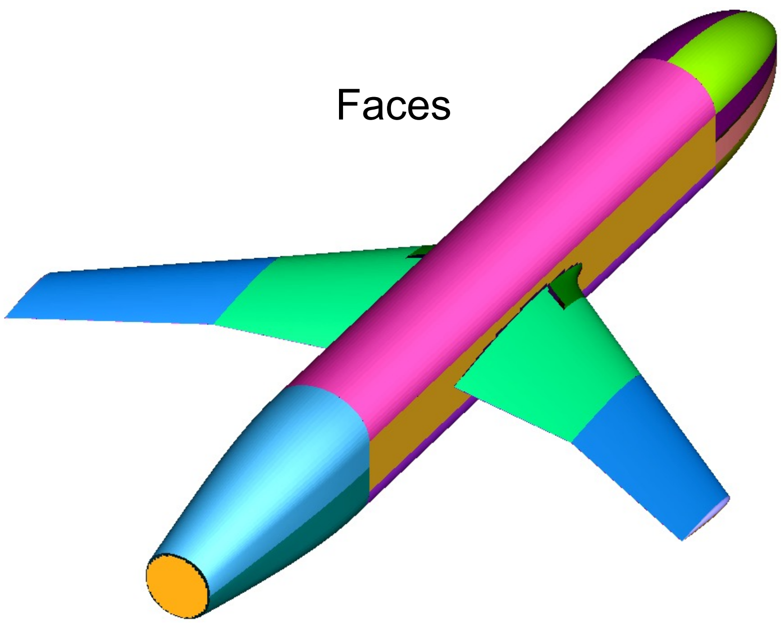
- overConvert used for file conversion and attribute determination

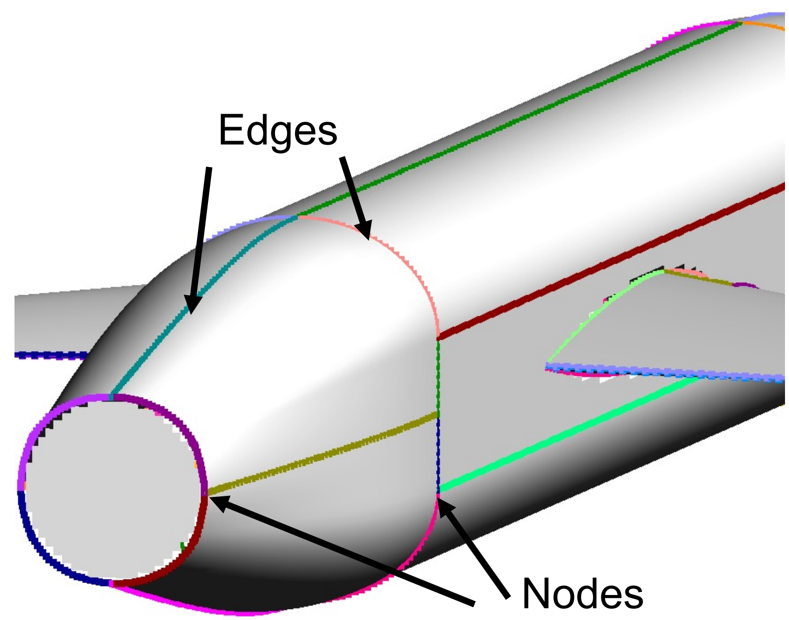
- OVERGRID GUI auto-detects file attributes: single/double precision, big/little endian, iblanks/no-iblanks, …

GEOMETRY BEST PRACTICES

GEOMETRY INPUT

- Boundary Representation (BREP) solid (STEP, IGES, EGADS)
- Topological relationship: Faces (F), Edges (E), Nodes (N)

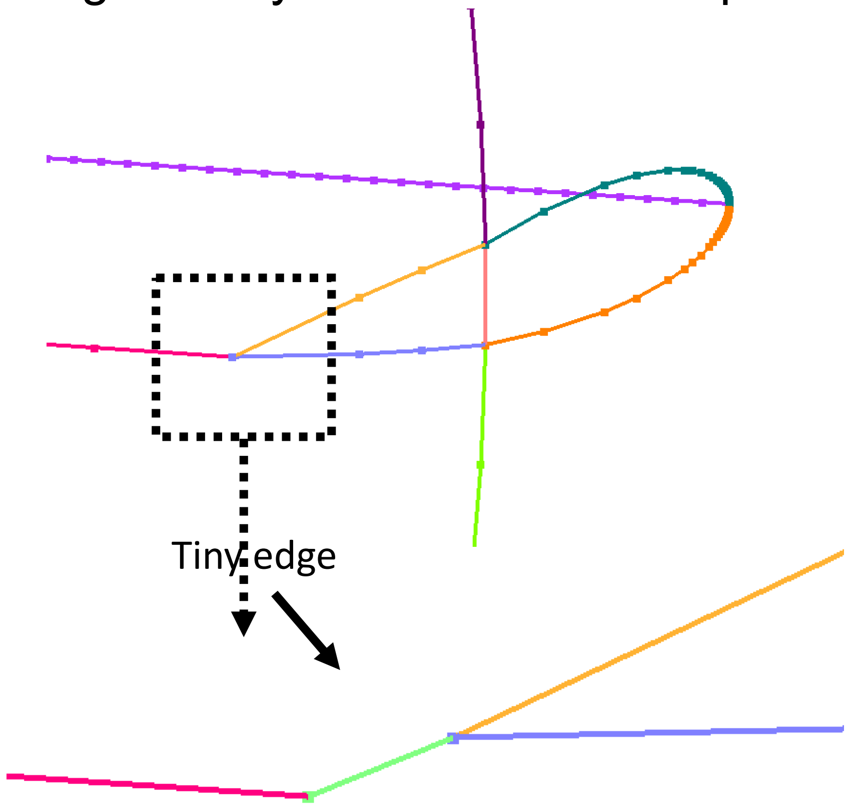


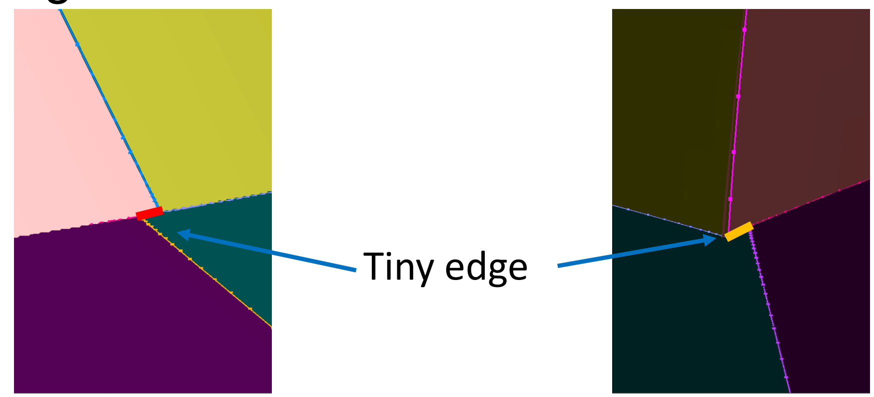


GEOMETRY BEST PRACTICES (1)

Make sure tolerances << smallest geometric feature size

Tolerances can sometimes get contaminated in geometry format translation process





Edge arc length histogram

	# edges
E <= 1.0E-6 * diag	2
1.0E-6 * diag < E <= 1.0E-5 * diag	0
1.0E-5 * diag < E <= 1.0E-4 * diag	0
1.0E-4 * diag < E <= 1.0E-3 * diag	0
1.0E-3 * diag < E <= 1.0E-2 * diag	14
1.0E-2 * diag < E <= 1.0E-1 * diag	136
1.0E-1 * diag < E <= 1.0 * diag	21
1.0 * diag < E	0

diag = global bounding box diagonal of geometry

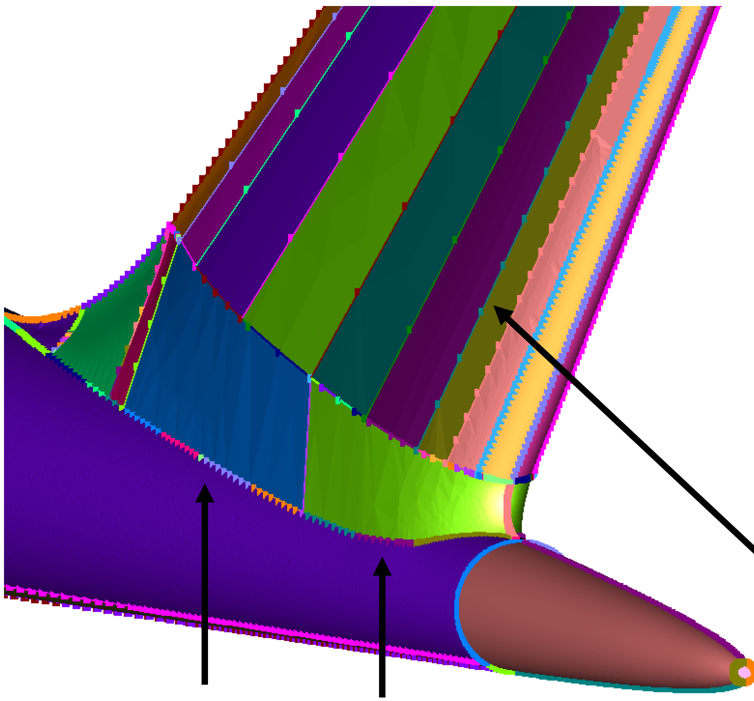
min edge length = 0.00003 at edge 103

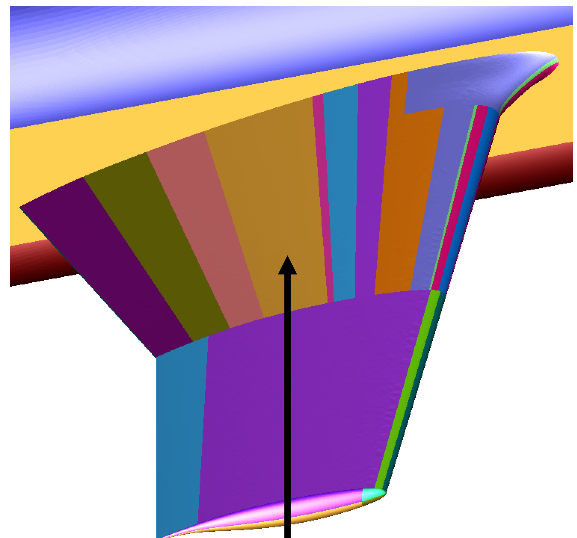
max edge length = 28.08451 at edge 10

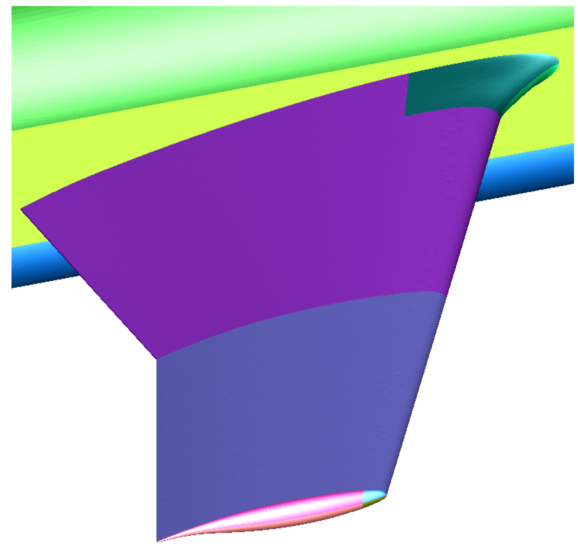
GEOMETRY BEST PRACTICES (2)

Use as few edges and faces as possible to represent the geometry

Use lowest order analytic curves and surfaces possible to describe geometry







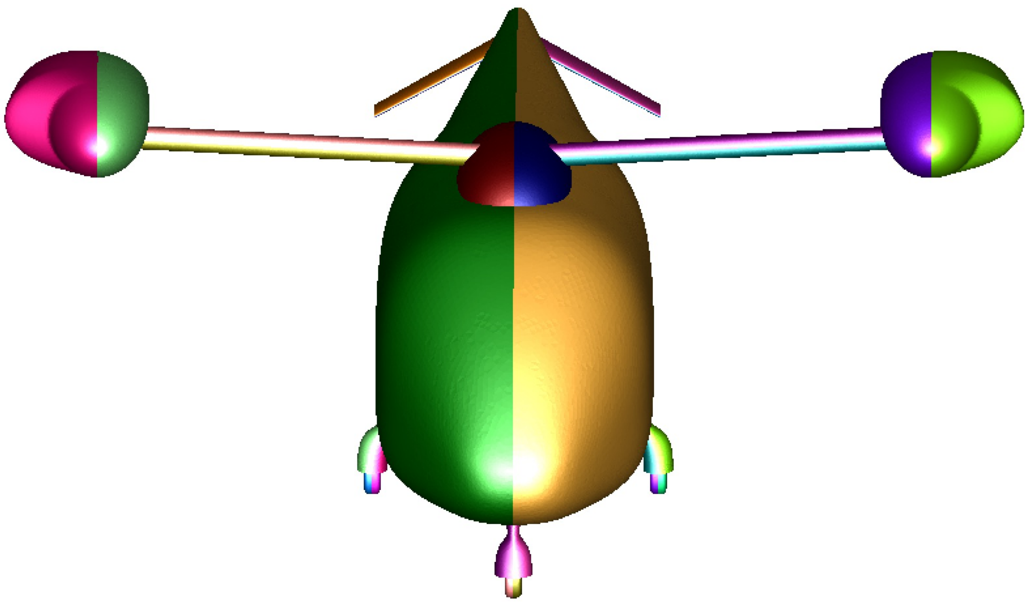
Do this

Use fewer faces

Replace multiple edges with single edge along simple face boundary

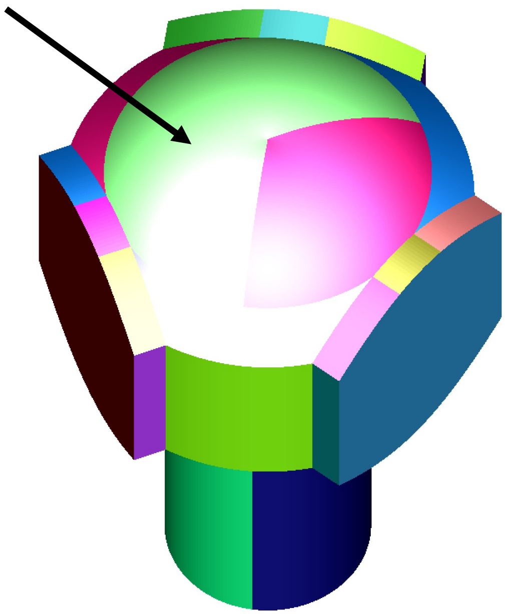
GEOMETRY BEST PRACTICES (3)

Faces, edges and nodes should be symmetric relative to the lines of symmetry



Symmetric vehicle – use same number of faces, edges and nodes on left and right sides

Should be 120 degree wedge



Should have 3-fold symmetry

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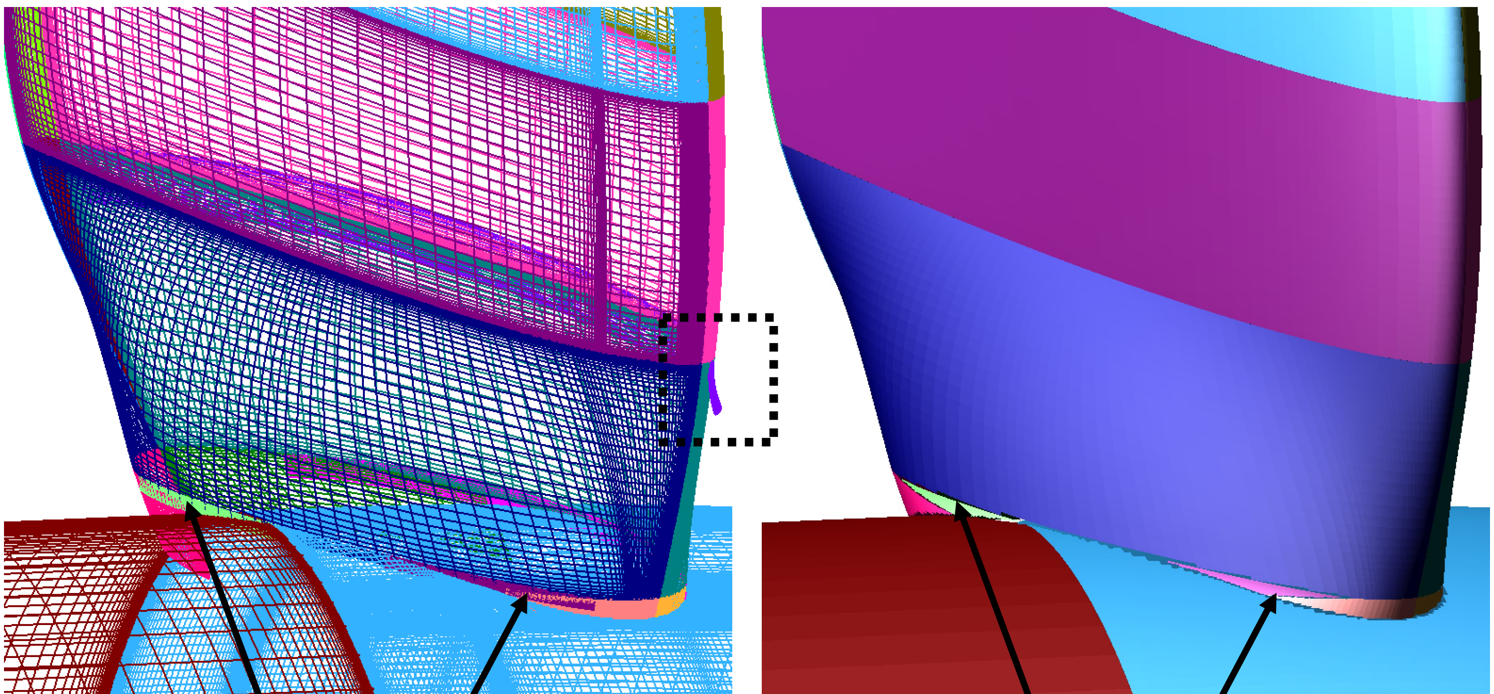
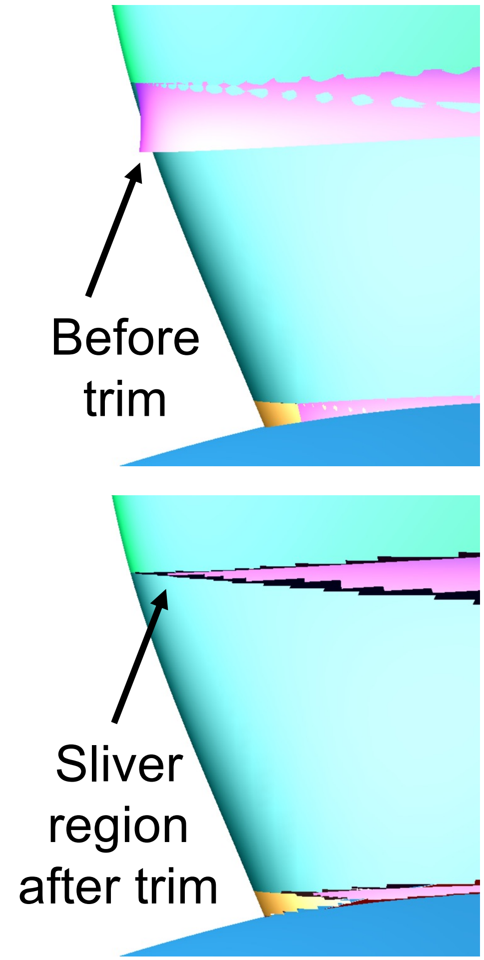
GEOMETRY BEST PRACTICES (4)

Avoid sliver and tiny faces



Untrimmed small faces

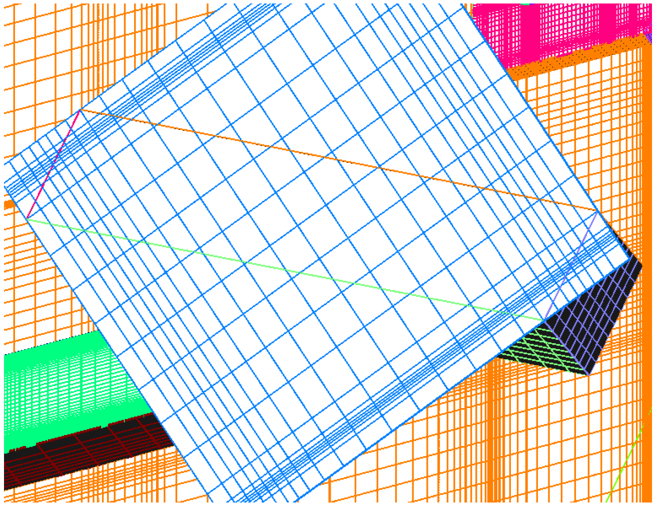
Tiny sliver faces after trim



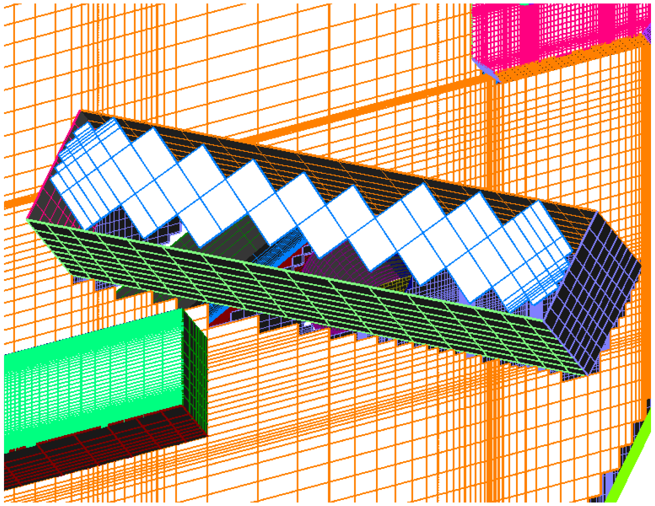
GEOMETRY BEST PRACTICES (5)

Avoid creation of faces with excessive trim

Align isoparameter (u,v) lines with face boundaries

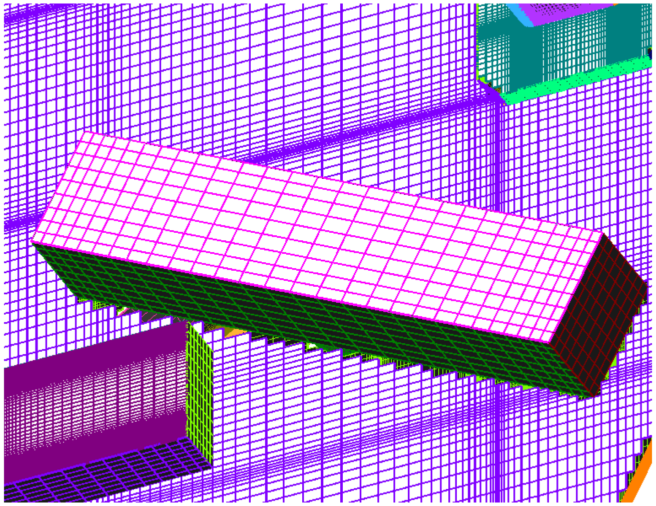


Untrimmed face with misaligned u,v



Trimmed face with misaligned u,v

Avoid this



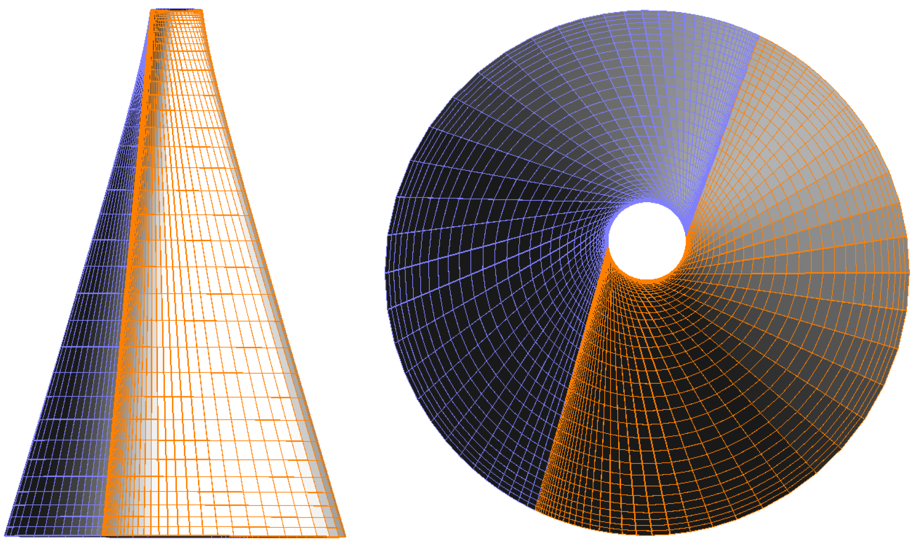
Trimmed face with aligned u,v

Do this

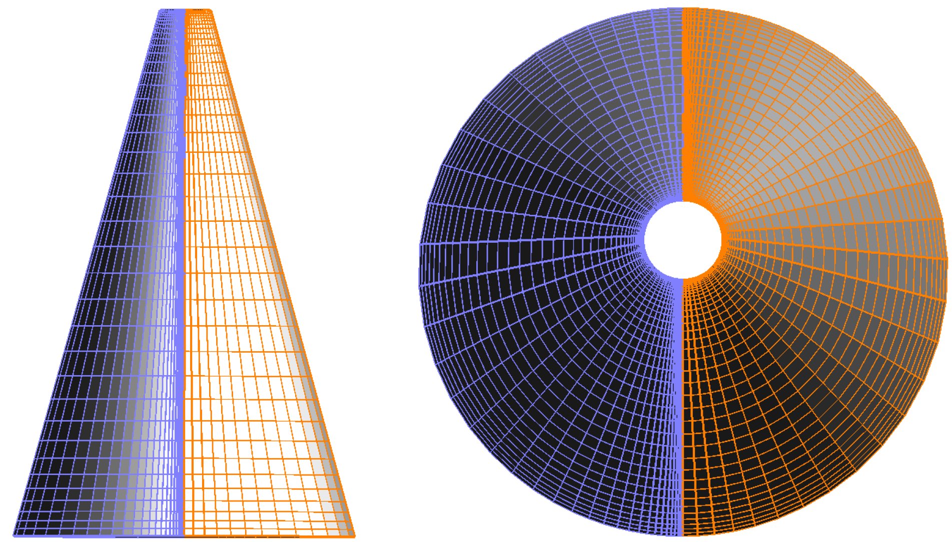
GEOMETRY BEST PRACTICES (6)

Align isoparameter lines of face to surface curvature

Axisymmetric bodies should be created by revolving a profile curve



Isoparameter lines not aligned
with surface curvature



Isoparameter lines aligned
with surface curvature

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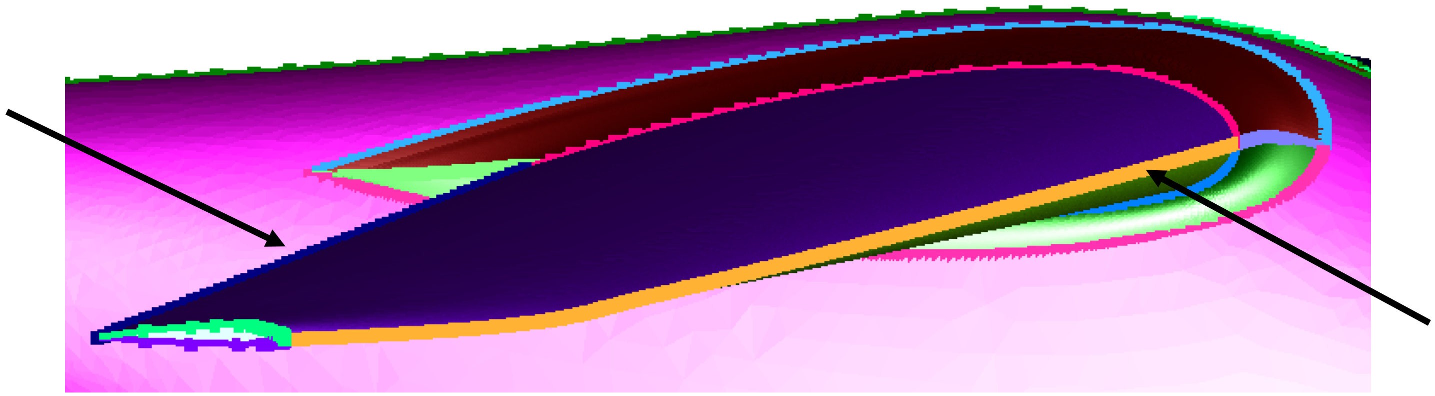
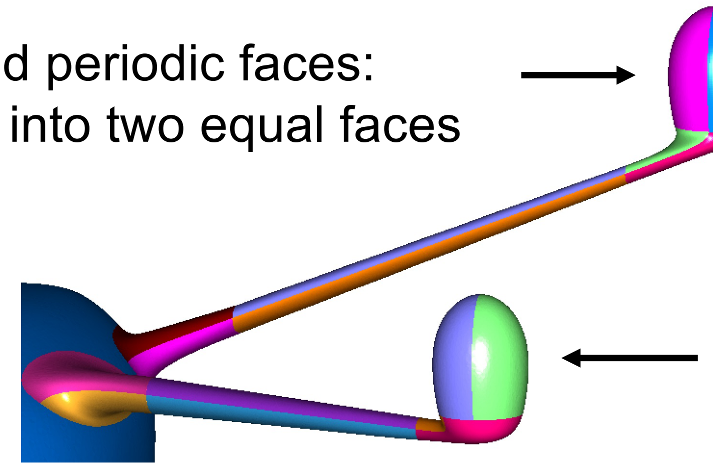
GEOMETRY BEST PRACTICES (7)

Airfoil shapes: define a BRep edge at leading and trailing edges

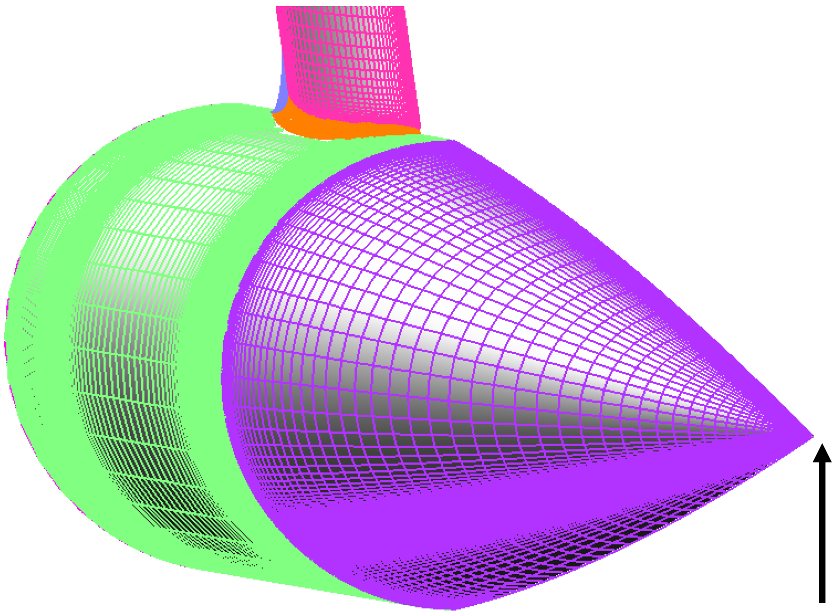


Avoid periodic faces:
split into two equal faces

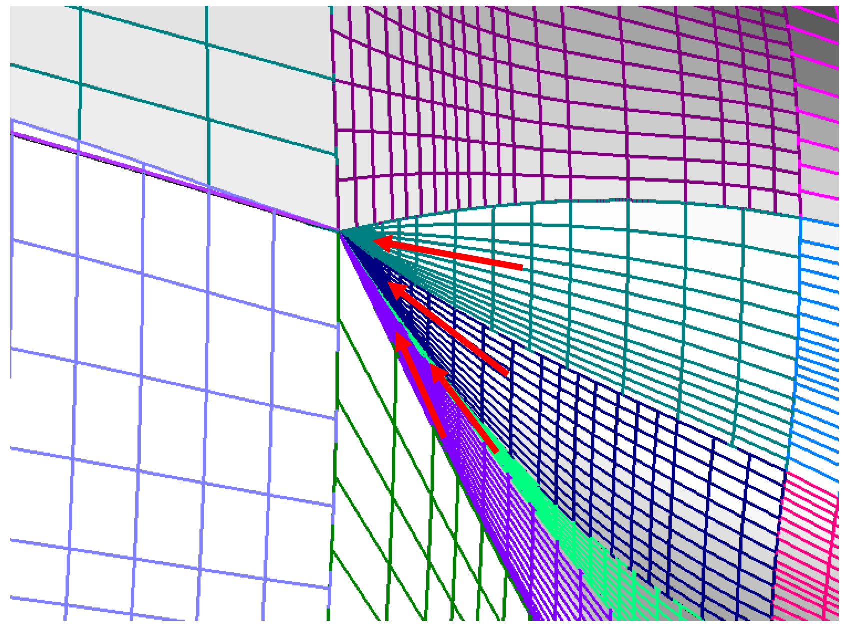


GEOMETRY BEST PRACTICES (8)

Avoid collapsed edges on a face unless dictated by geometry



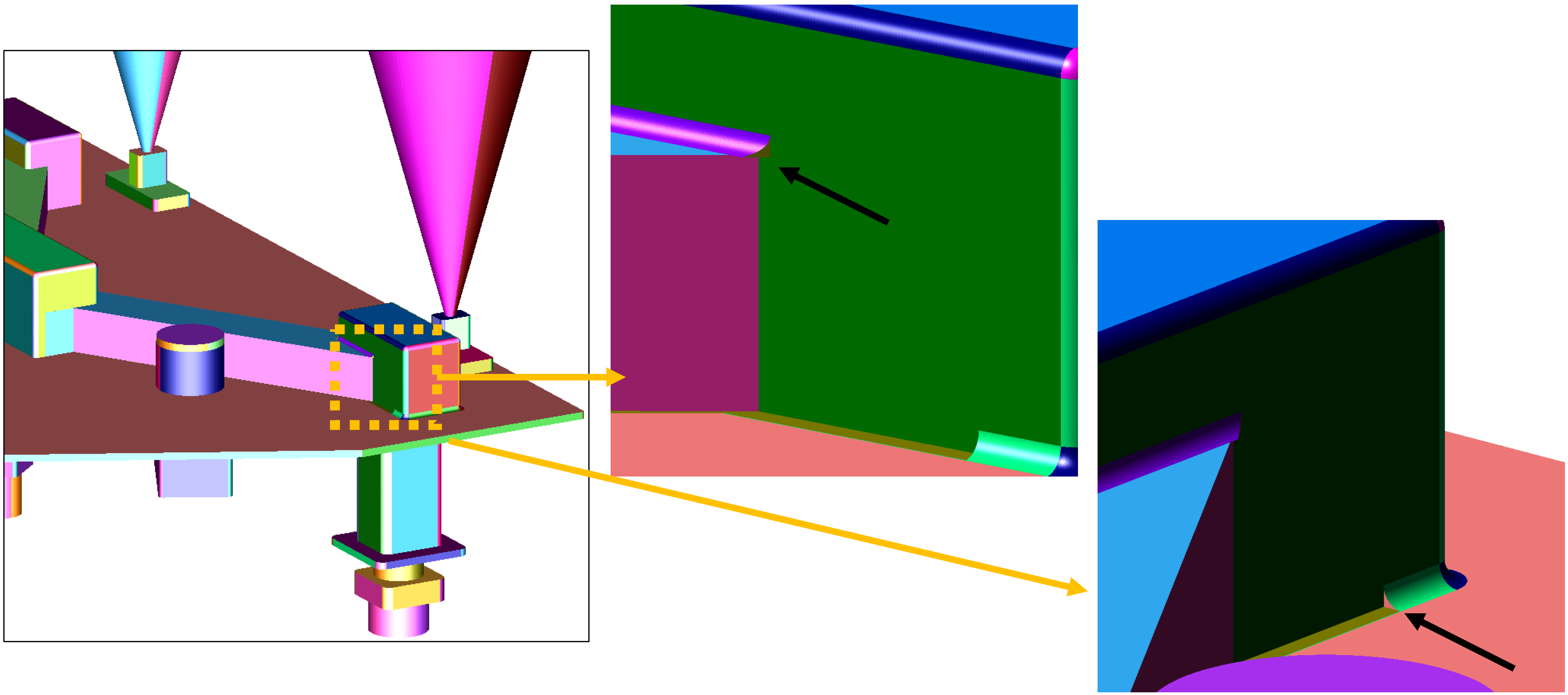
Collapsed edge required at apex of cone



Avoid collapsed edge on smooth surface

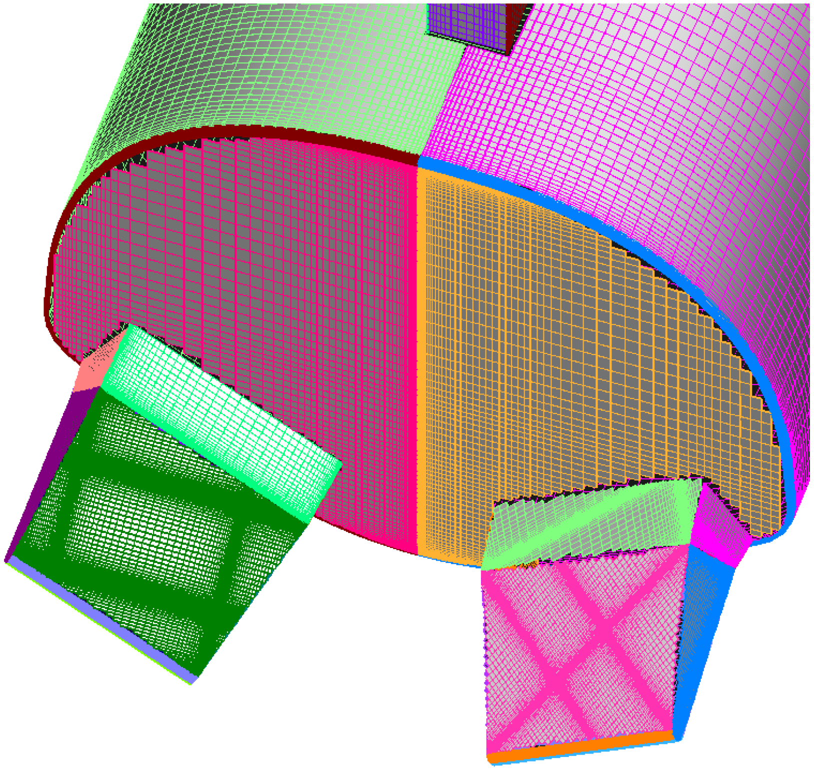
GEOMETRY BEST PRACTICES (9)

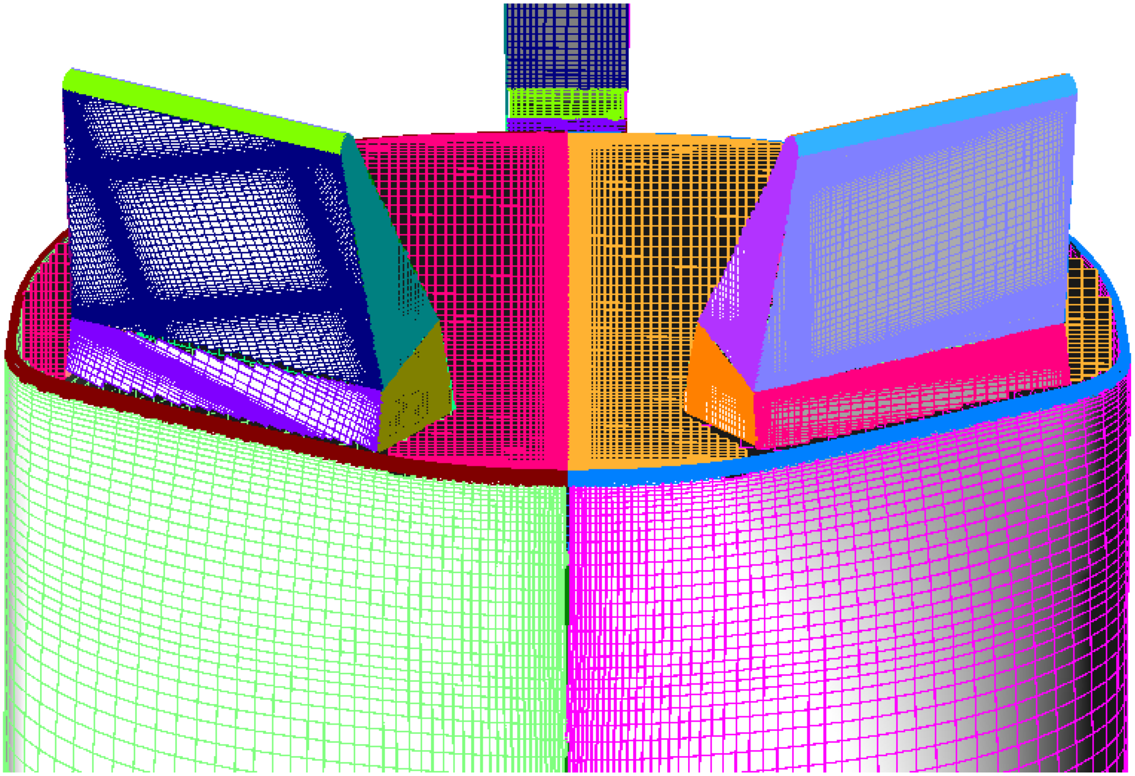
Remove insignificant geometric features for CFD simulations



GEOMETRY BEST PRACTICES

What can be improved here?
Can the output u,v directions be controlled?



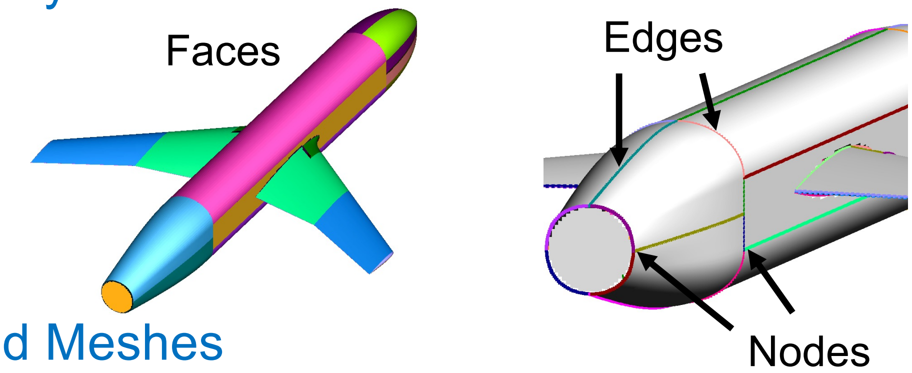


EPOGS AUTO-MESHING TOOL

BOUNDARY REPRESENTATION (BREP) GEOMETRY & MESHES

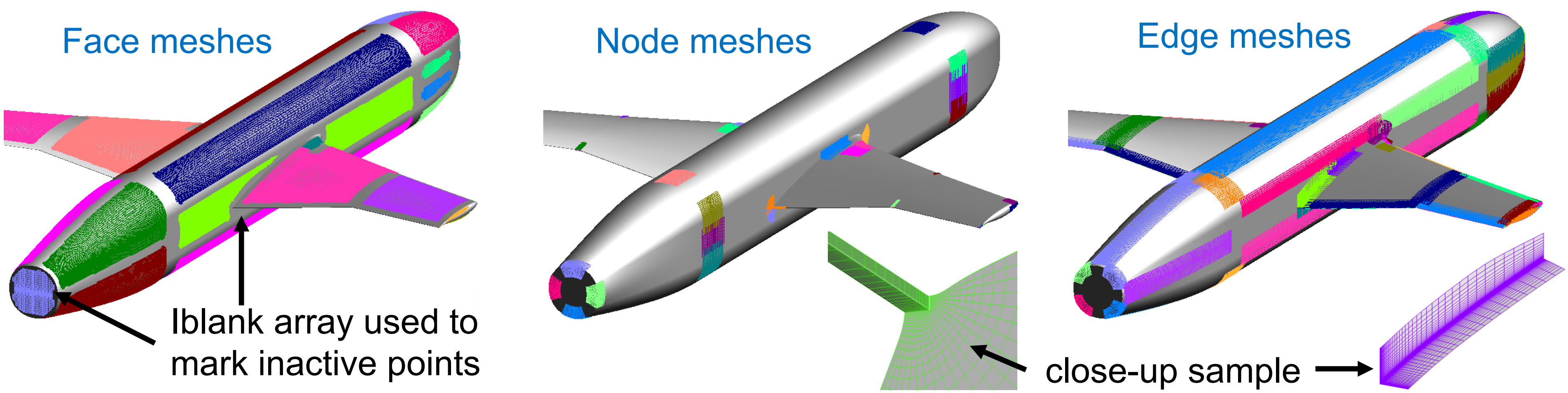
Input Geometry

- Boundary Representation (BRep) solid
- Interface: Engineering Sketch Pad (ESP) from MIT

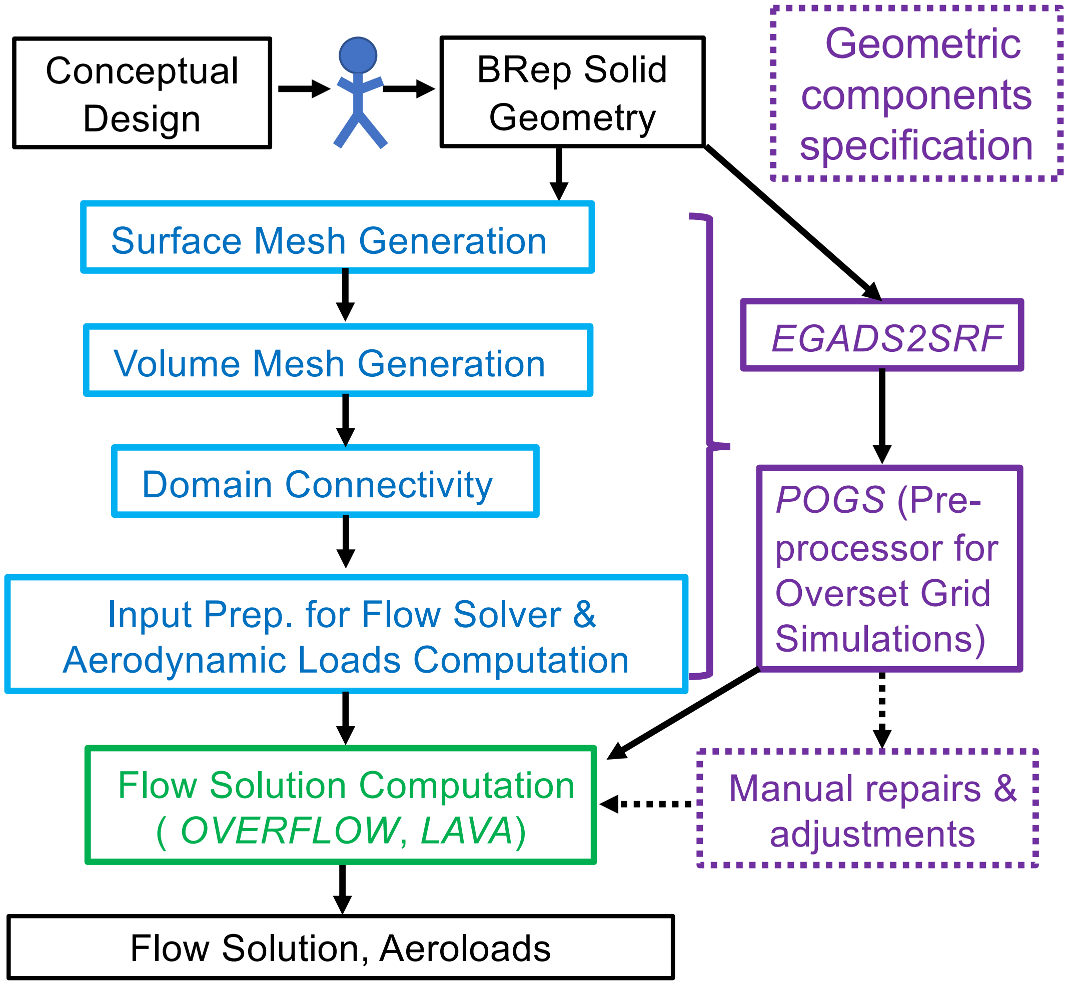


Auto-Generated Meshes

- More fractured than manually created meshes (Total # <= F + E + N)
- Does not appear to affect RANS flow solution aeroloads, convergence, cost (AIAA Paper 2023-3602)



STRUCTURED OVERSET MESH GENERATION AUTOMATION



Files needed to run OVERFLOW

Grid: grid.in

Domain Connectivity Data
- External: XINTOUT (fringe pts & donor stencils)
- Internal X-rays hole cut: xrays.in

Component forces/moments convergence history
- Aeroload components <= geometric components
- Output files from running CGT/mixsur < fomoco.i

Flow solver inputs: over.namelist
- Numerical scheme
- Hole cut instructions if using X-rays
- Boundary conditions

Prescribed relative motion dynamics:
- Config.xml, Scenario.xml
- Dynamics components <= aeroload components

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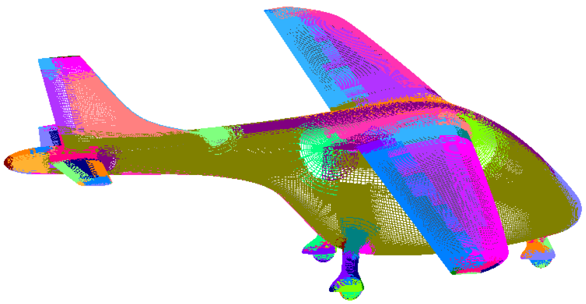
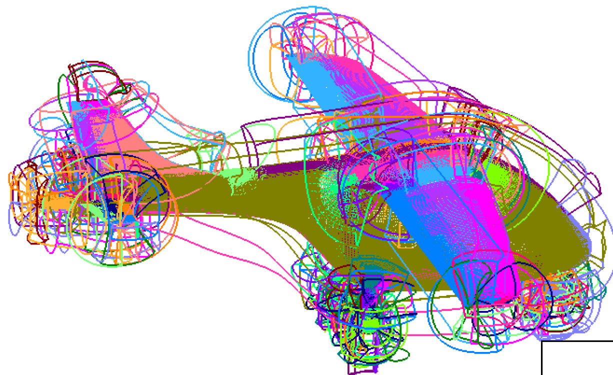
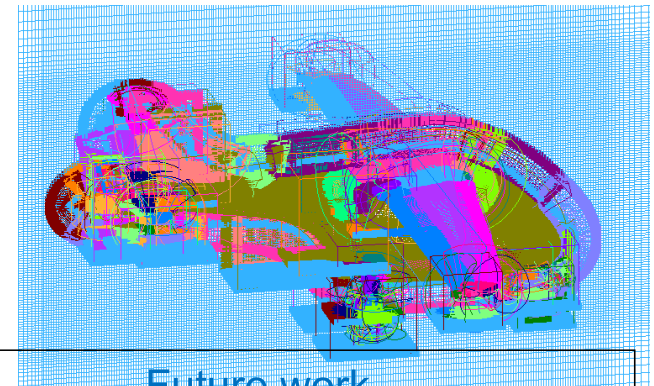
AUTOMATION TOOLS CURRENT STATUS







Future work

- Componentized volume meshes
- Mesh overlap
- Hole-cut
- Efficiency

Mesh automation metrics

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

	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

OVERVIEW OF AUTO-MESHING PROCEDURE

- CGT should be compiled with “--enable-omp” in the “configure” command to activate OpenMP
- Set environment variable OMP_NUM_THREADS (number of processors to be used)

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

EGADS2SRF — Engineering Sketch Pad (ESP)

POGS (Pre-processor for Overset Grid Simulations) — Manual repairs & adjustments if needed

Files needed to run flow solver

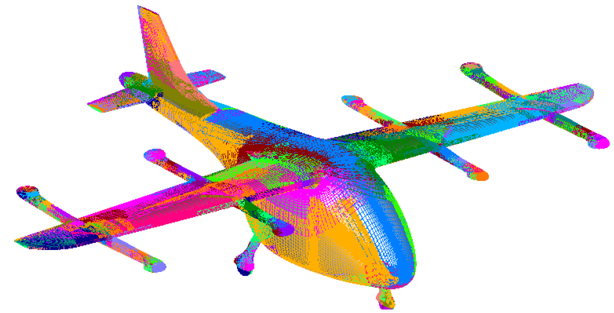
GLOBAL MESH CONTROL PARAMETERS

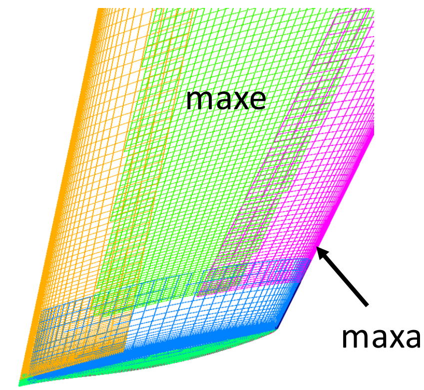
EGADS2SRF

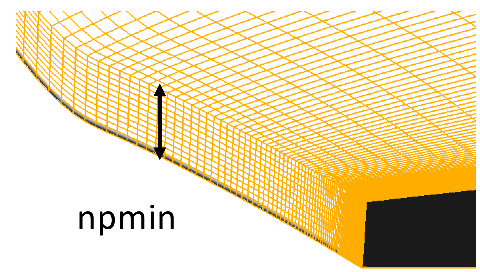
isym	Symmetry 0 = no symmetry 1/2/3 = half-body in +x/+y/+z 11/12/13 = full-body symmetric about x=0/y=0/z=0
maxe	Max cell-size / grid spacing (grid unit)
maxa	Max dihedral angle (degrees)
maxc	Max chordal deviation
maxsr	Max stretching ratio
npmin	Min # points on shortest edge (finite thickness t.e.)
dswall	Wall normal spacing in volume grids (grid unit)

POGS

nfringe	Number of fringe points layers at outer and hole boundaries
stenqual	Min acceptable stencil quality for orphan pts flagging
dobnd	Distance to far field boundary (grid unit or rel. near-body bbox)







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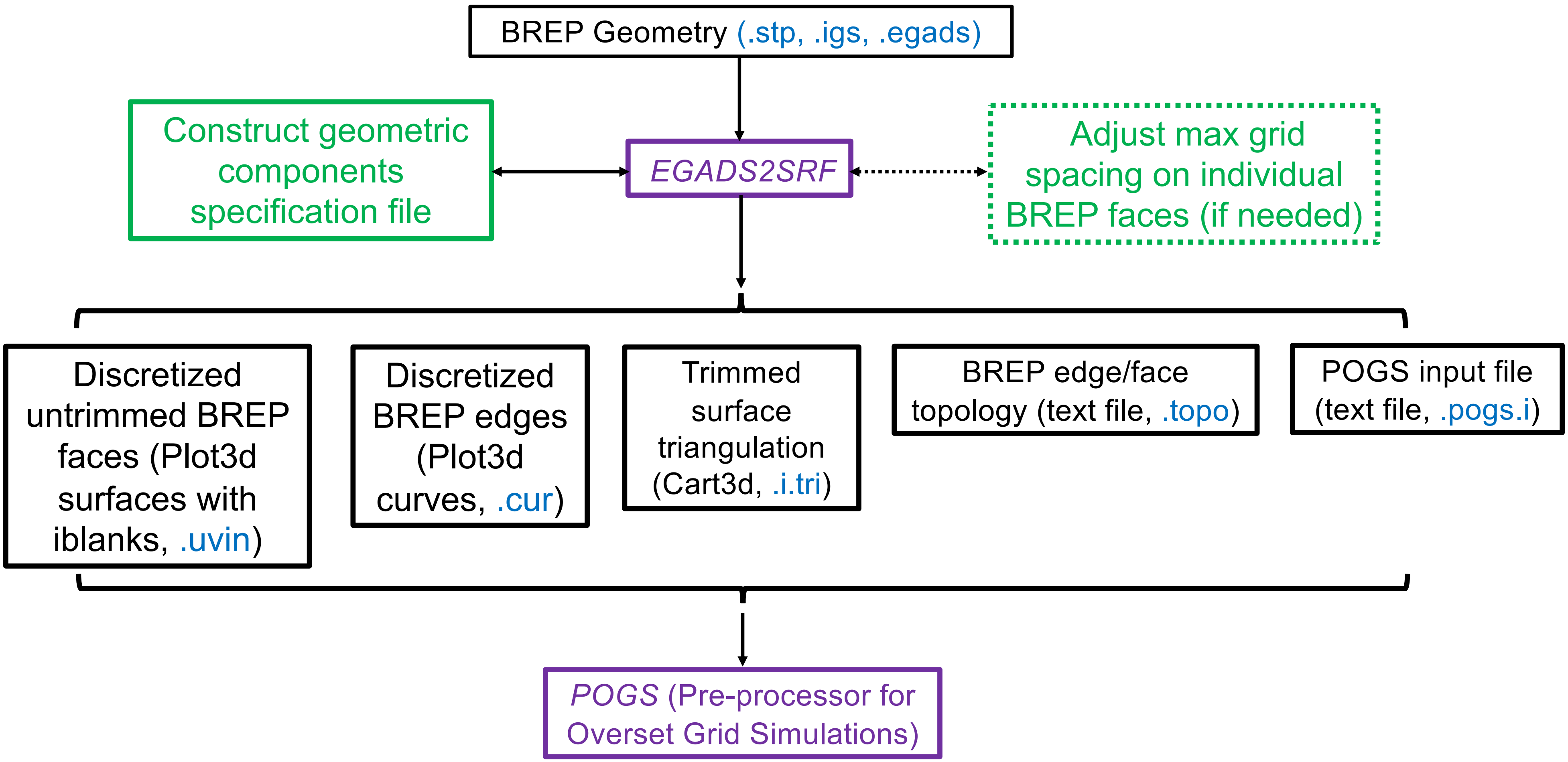
EXPANDED EGADS2SRF WORKFLOW



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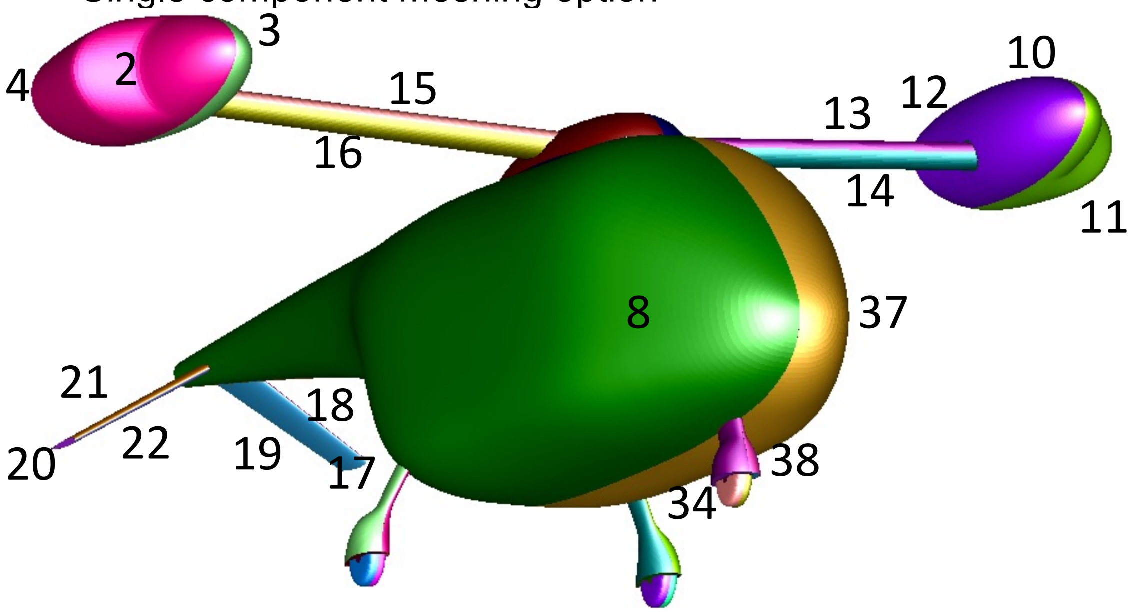
GEOMETRIC COMPONENTS SPECIFICATION

- Text file: component name + list of face numbers
- Information usually not available from geometry file (STEP/IGES)
- Manual construction with OVERGRID + Text Editor
  (< 10 minutes for example below)
- Enables:
  - Local component characteristic length -> local max grid spacing
  - Auto construction of input file for component aero loads computation
  - Single component meshing option



Geometric Components Data File
(*geom*.001.gcomp)

Right_LandGear 1,23:27	Left_Wing 13:14
Rotor_1_Cowling 2:4	Right_Wing 15:16
Main_Fuselage 5:6,8,37	Left_Tail 17:19
Fuselage_Fairing 7,9	Right_Tail 20:22
Rotor_2_Cowling 10:12	Left_LandGear 28:33
	Front_LandGear 34:36,38:40

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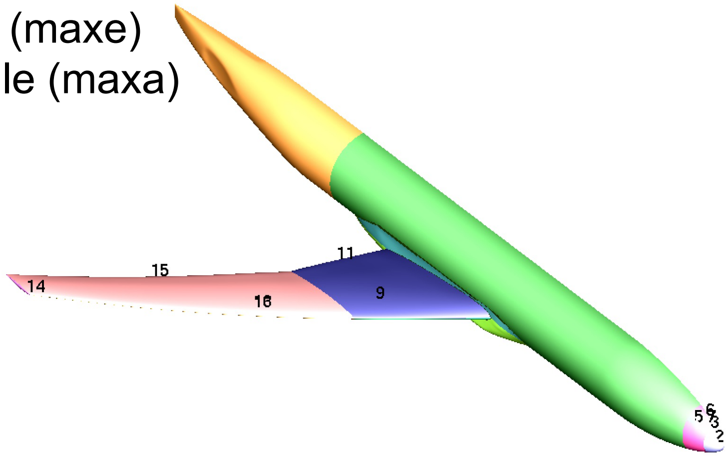
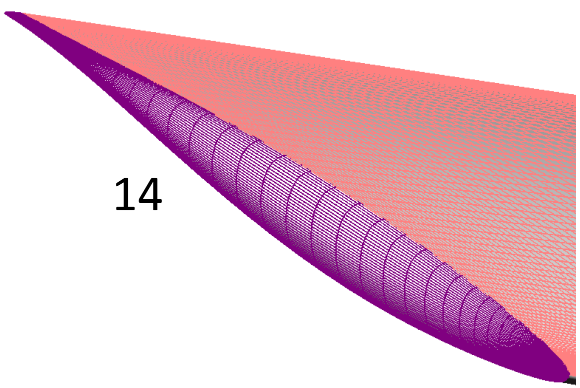
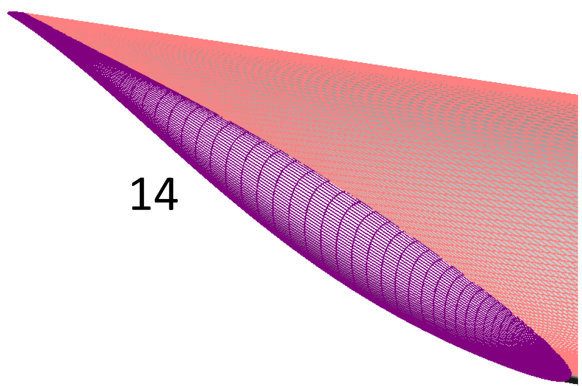
POINT DISTRIBUTION PARAMETERS FOR FACES

Editable text file
- max grid spacing (maxe)
- max dihedral angle (maxa)





maxe = 6.49163



maxe = 3.25

Face Parameters File
(*geom*.001.face)

17	10.00000	4.00000	nface, maxe, maxa
! Face	max spacing	max angle	component
1	10.00000	4.10238	Fuselage
2	10.00000	4.10238	Fuselage
3	10.00000	4.10238	Fuselage
4	10.00000	4.10238	Fuselage
5	10.00000	4.10238	Fuselage
6	10.00000	4.10238	Fuselage
7	10.00000	4.10238	Fuselage
8	10.00000	4.10238	Fuselage
9	6.49163	4.00837	Wing
10	6.49163	4.00837	Wing
11	6.49163	4.00837	Wing
12	10.00000	4.10238	Fuselage
13	10.00000	4.10238	Fuselage
14	~~6.49163~~ 3.25	4.00837	Wing
15	6.49163	4.00837	Wing
16	6.49163	4.00837	Wing
17	6.49163	4.00837	Wing

EGADS2SRF

Command-Line Options (1)

egads2srf -i ifile [-maxa maxang] [-maxe maxedge] [-maxc maxchord] [-isym sym] [-smedge smalledge] [-npmin np] [-maxsr maxsrat] [-epst epstd] [-u units] [-scale scfac] [-dswall dsw] [-b bodygen] [-frm frmstring] [-stop stoploc] [-c] [-r] [-help] **>! e.o**

[ ] = optional inputs

ifile = input file containing geometry (igs, stp, egads)
maxang = max allowed dihedral angle in degrees (10.0)
maxedge = max allowed arc length of triangle edge or structured mesh spacing (-0.025)
> 0 take value as input
< 0 take absolute value times global bounding box diagonal arc length as input
maxchord = max allowed chordal deviation (-0.001)
> 0 take value as input
< 0 take absolute value times global bounding box diagonal arc length as input
sym = symmetry specification (0)
= 0 : no symmetry specified
= 1/2/3 : geometry is a half body on the +x/+y/+z side
= -1/-2/-3 : geometry is a half body on the -x/-y/-z side
= 11/12/13 : geometry is a full body symmetric about x=0/y=0/z=0
smalledge = small edge arc length (0.0). (remove edges smaller than smalledge)
np = minimum number of points in each direction in u, v tessellation (9)
maxsrat = max stretching ratio for surface/volume grids (1.2)

EGADS2SRF

Command-Line Options (2)

egads2srf -i ifile [-maxa maxang] [-maxe maxedge] [-maxc maxchord] [-isym sym] [-smedge smalledge] [-npmin np]
[-maxsr maxsrat] [-epst epstd] [-u units] [-scale scfac] [-dswall dsw] [-b bodygen] [-frm frmstring]
[-stop stoploc] [-c] [-r] [-help] **>! e.o**

[ ] = optional inputs

epst = bounding box expansion arc length (0.01)
(extend uv bounding box of triangles by epst * triangle bounding box diagonal;
increase this parameter slightly to unblank more points on uv structured patches)

units = unit conversion (no conversion)
(convert output grid files to different unit assuming input geometry has been
interpreted in mm; use this option only if egads2srf could not determine units
from input geometry file
= in/ft/m/cm

scfac = scale factor to be applied to output grids in .i.tri, .cur, .uvin (1.0)

dsw = wall normal spacing for volume grids to be used in pogs (1.0e-4)

bodygen = solid body number to make grids on for cases with multiple solid bodies (all)

frmstring = list of faces to remove from meshing domain for open geometry, e.g., 3,8,15:17

stoploc = stop location (contents/faces/ftable)

-c Run in inquiry mode to report contents only (number of solids, faces, edges, nodes)

-r Re-run using parameters stored in egads2srf.log

EXPANDED POGS WORKFLOW

POGS

Surface grids (go.sur)

Near-body volume grids (go.vol)

If needed:
- Repair negative Jacobians
- Improve mesh overlap
- Restart

OVRF = OVERFLOW

Off-body box grids	OVRF	POGS	POGS + OVRF	POGS
Domain Connectivity	OVRF X-rays & DCF	POGS (XINTOUT)	POGS + OVRF Mixed-mode (XINTOUT)	PEGASUS, LAVA, etc.

Flow solver input file (over.namelist)

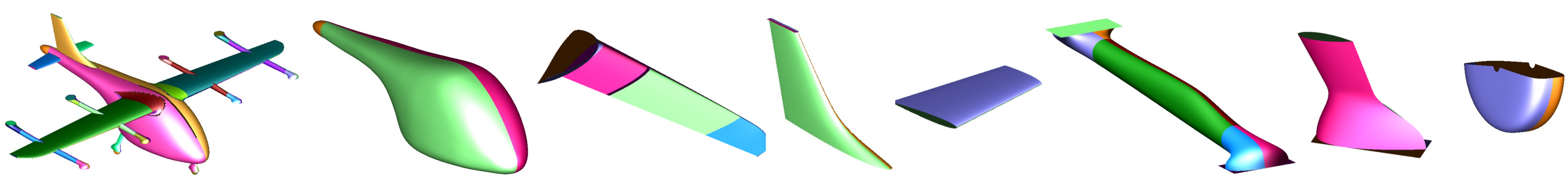
Final volume grid system (grid.in)

Input file for component aerodynamic loads computation (fomoco.i)

Flow Solver

POGS: Off-body Grids and Domain Connectivity Options

Off-body box grids	OVERFLOW	POGS	POGS + OVERFLOW	POGS
Domain Connectivity	OVERFLOW X-rays & DCF	POGS	POGS + OVERFLOW Mixed-mode	PEGASUS, LAVA, …
POGS Output	• Surface grid file containing face meshes for each component to begin X-ray construction (may need more work to close volume) • Hole cut instructions for each component cutter with first estimate of XDELTA offset in $XRINFO blocks in over.namelist	XINTOUT (all grids)	• XINTOUT (near-body grids) • xrays.in (single X-ray for entire geometry) • Single hole-cut instruction in $XRINFO block in over.namelist	



POGS: Input Files for Flow Solver & Force/Moment Computation Tool

Flow Solver

- OVERFLOW (over.namelist)
  - Boundary conditions for all grids
    - Viscous wall for all near-body grids
    - Symmetry plane (half-body cases)
    - Far field for off-body grid
  - Hole-cut instruction estimates (if using DCF)

- LAVA (go.bc)
  - Boundary conditions file

Force/moment computation tool FOMOCO/USURP (fomoco.i)

- Grid index ranges for each geometric component defined in *rootname*.001.gcomp

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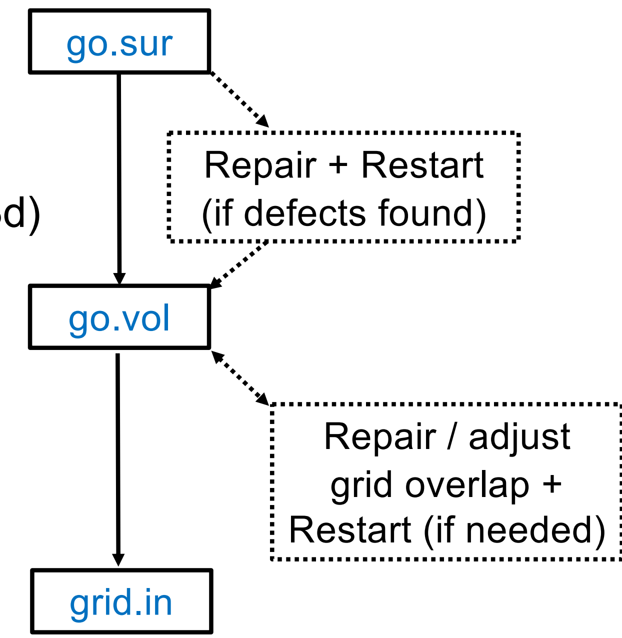
POGS: Input and Output Files

Input

- stp/igs/egads file with at least one solid (e.g., *geom*.stp)
- Geometric components specification file (e.g., *geom*.001.gcomp)
- Output files from egads2srf (.uvin, .cur, .i.tri, .topo, .pogs.i)

Output:

1. Overset surface grids with iblanks: go.sur (Plot3d)
2. Overset volume grids without iblanks: nb.vol, go.vol (Plot3d)
3. Overset volume grids with volume connectivity iblanks: grid.in (Plot3d)
4. Domain connectivity data: XINTOUT/INTOUT
5. Component forces/moments computation input file: fomoco.i (text)
6. Flow solver input files
   - OVERFLOW name list input: over.namelist (text)
   - LAVA boundary conditions input: go.bc (text)



POGS: Command-Line Options

pogs [-nopro] [-noprofpt] [-noscon] [-itermax_sur niter] [-novol] [-nobox]
[-dcf] [-nodcf] [-combinebods nbody] [-start startloc] [-stop stoploc] **< *geom*.001.pogs.i >! pogs.o**

-nopro : do not project surface grid pts onto to BREP geometry
-noprofpt : do not project surface fringe pts onto donor stencils
-noscon : do not compute surface mesh connectivity
-itermax_sur : max iterations for surface LCBC (default is 100)
-novol : do not generate near-body volume grids
-nobox : do not generate off-body Cartesian box grid
-dcf / -nodcf : write / not write DCF blocks in OVERFLOW input file
-combinebods : number of bodies in relative motion (= #BREP solids)

-start startloc : starting location in code indicated by startloc
= volgen (make volume grids, needs go.sur, go.sub)
= boxgen (make off-body box grids after repair, needs go.sur, go.sub, go.vol)
= vdocona (volume connectivity part a, needs go,sur, go.vol, go.sub, SINTOUT)
= vdoconb (volume connectivity part b, needs ga.vol)
-stop : stoploc: stopping location in code indicated by stoploc
= go.sur (surface grids)
= go.vol (volume grids)
= ga.vol (volume connectivity part a)
= splitr.cur, nm.sur, enm.sur, gs.sur (for advanced users)

-dcf : perform domain connectivity using
DCF in OVERFLOW
(need to build xrays.in)
-nodcf : perform domain connectivity
within pogs (write XINTOUT)

TYPICAL COMMAND-LINE WORKFLOW

1. "*egads2srf -i geom.stp -stop faces*" - output file guvo.sur

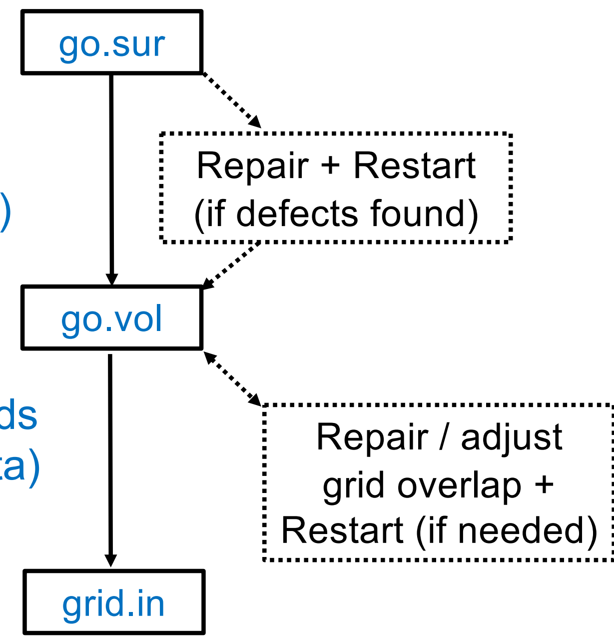
2. Construct geom.001.gcomp

3. "*egads2srf -i geom.stp -maxa 4.0 –maxe 5.0 >! e.o*"

4. *"pogs -stop go.sur* < *geom*.001.pogs.i >! p.1" -> go.sur (surface grids)

5. *"pogs -stop go.vol* < *geom*.001.pogsi >! p.2" -> go.vol (volume grids)

6. *"pogs -start vdocona* < *geom*.001.pogs.i >! p.3" -> grid.in (volume grids with domain connectivity data)



RUNEPOGS

(pronounced ‘run– epogs’)

A script called “runepogs” can be used to run a collection of cases

For each case, it performs the following:

- executes egads2srf followed by pogs

- reports
  - total number of volume grids
  - total number of volume grid points
  - number of defective surface and volume grids
  - wall clock time

FAQ

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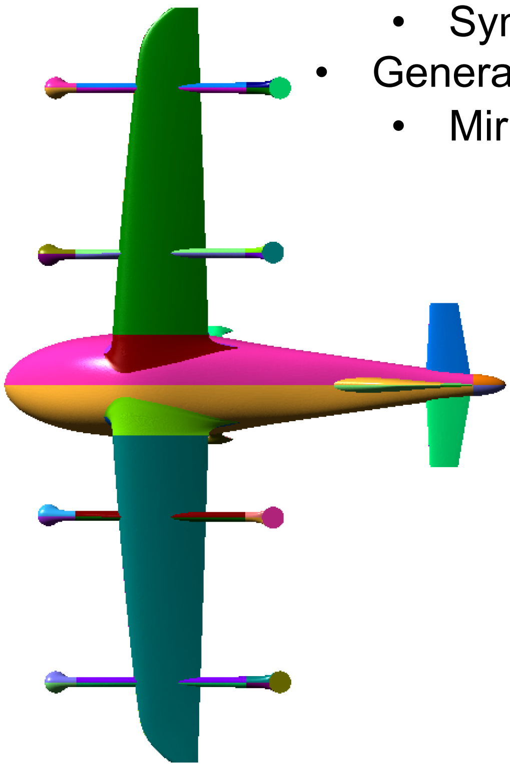
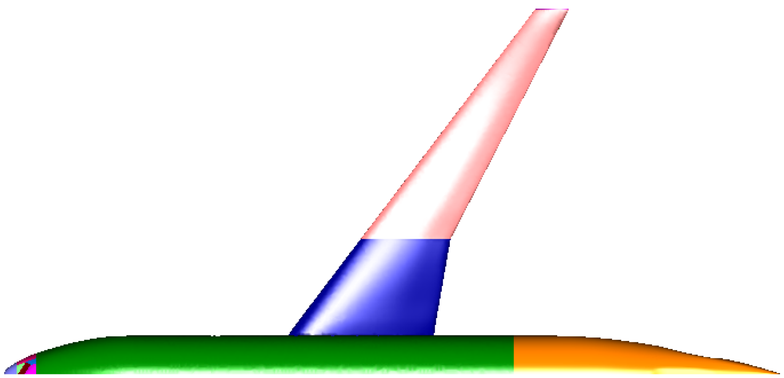
CONFIGURATIONS WITH SYMMETRY OR GROUND PLANE

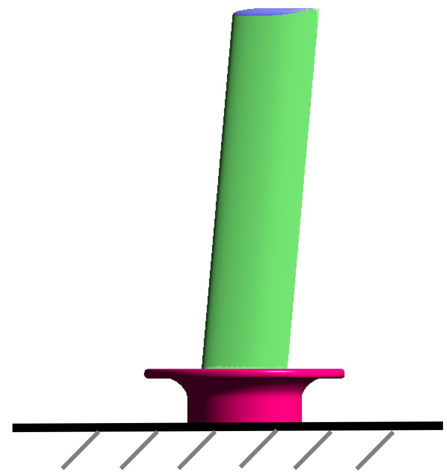
Input geometry: Full-body



- Generate grids on full body (-isym 0)
  - Symmetric grid system not guaranteed
- Generate grids on half-body (-isym 11/12/13 for x/y/z symmetry)
  - Mirror to guarantee symmetric grid system

Input geometry: Half-body or body on ground plane

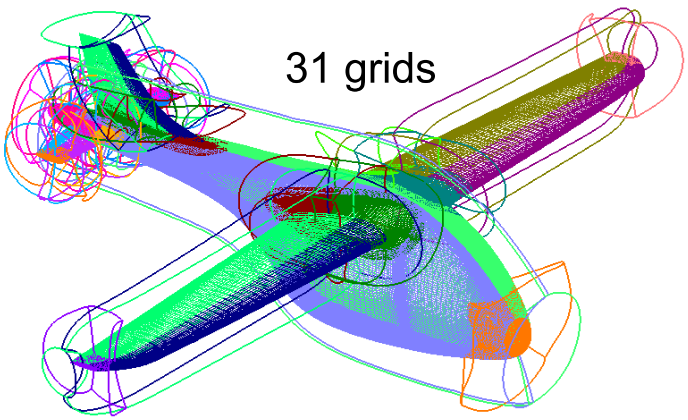
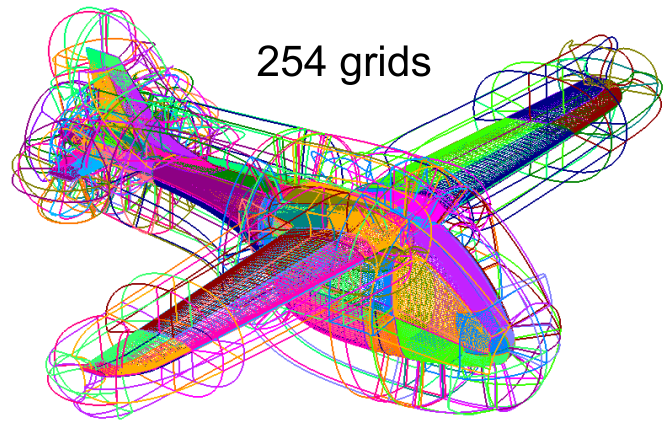
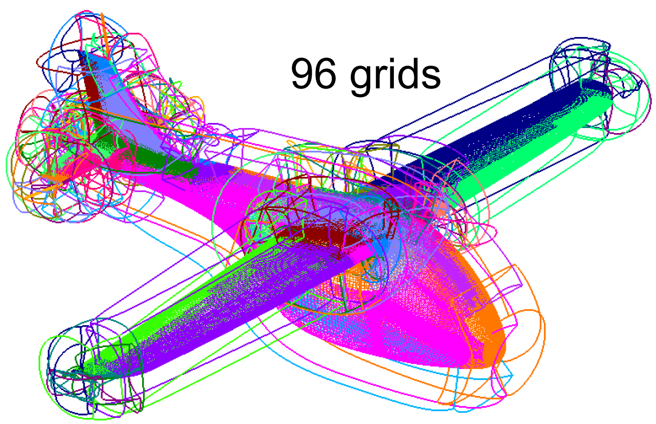
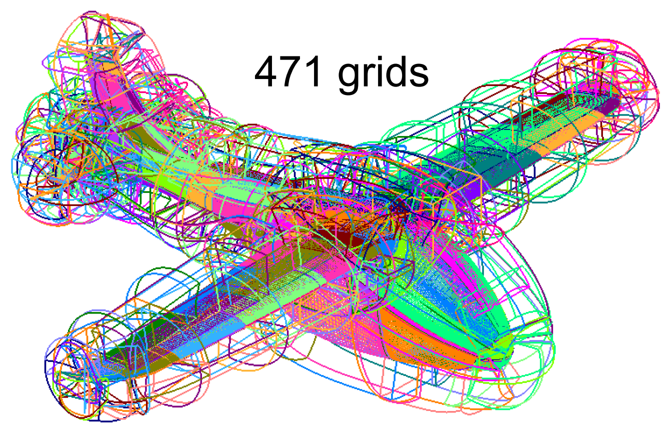




- Constant x/y/z plane on open boundary
  - -isym 1/2/3 for constant x/y/z

COMPUTING SOLUTIONS ON FRACTURED AUTO-GENERATED GRIDS

AIAA Paper 2023-3602

	Before MPI split	After MPI split
Manual meshes (~ days)		
Auto meshes (~ hours)		

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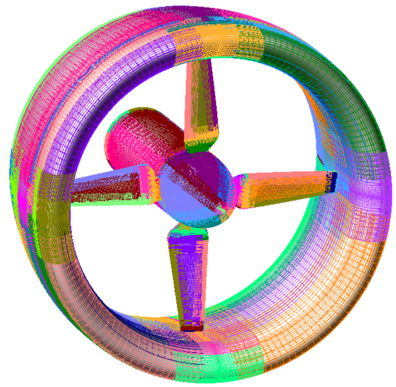
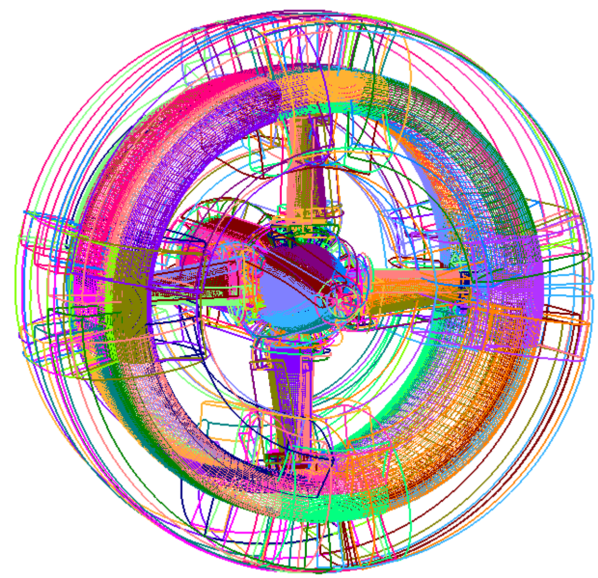
COMPONENT BUILD-UP

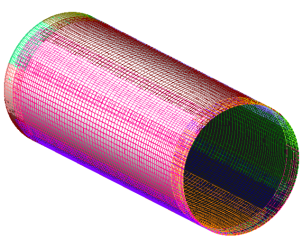
Non-connected components example
- Three solids
- Run with “-b 1”, “-b 2”, “-b 3” to get output files in 3 sub-directories
- Run with ”-combinebods” in top level directory to get combined grid file, over.namelist, fomoco.i



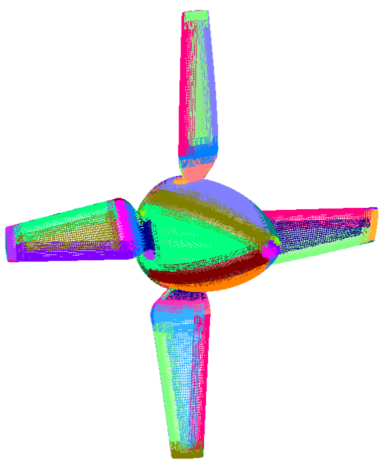
- Connected components - to be implemented

Final system

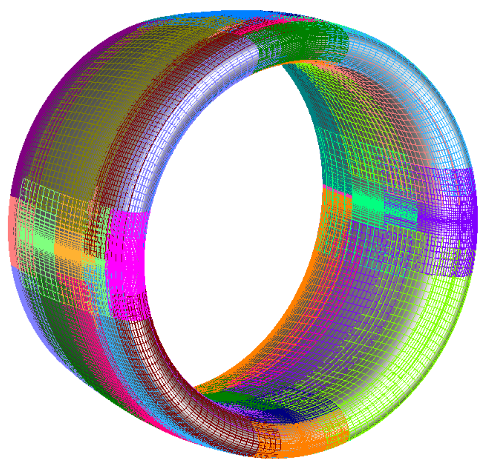




Stationary centerbody



Rotor



Shroud

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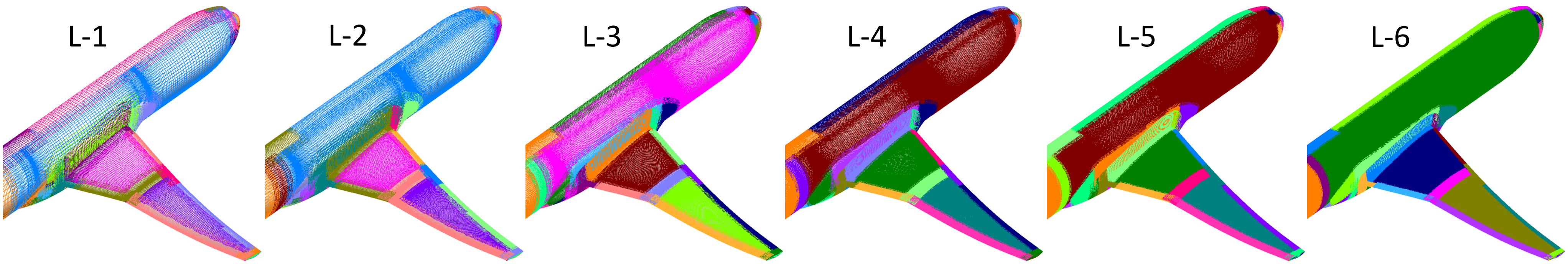
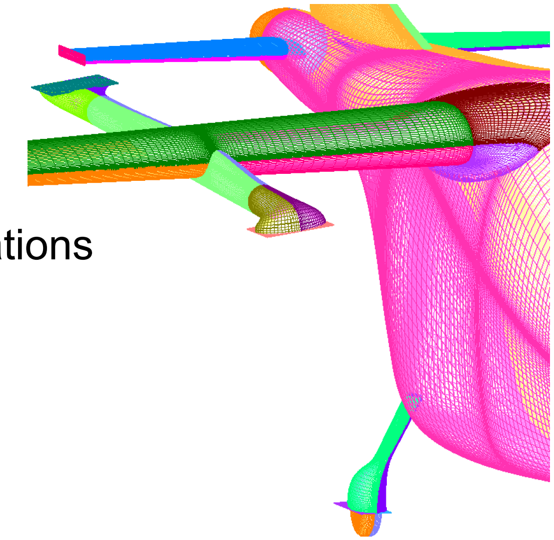
MESH FAMILY GENERATION AT DIFFERENT RESOLUTIONS

- Controlled by global parameters
- Component max grid spacing scaled as fraction of global max grid spacing
- Local grid spacings scaled as fraction of component max grid spacing



Level	maxa (deg)	maxe (in)	maxc	npmin	maxsr	Dswall ($x10^{-4}$)	klayer	# Vol. Pts (M)	Wall Time (surf+vol)
1	5	15.0	0.5	9	1.19	5.423	2	9.9	2m 39s
2	4.5	10.0	0.5	13	1.135	3.615	3	26.3 (x2.7)	5m 38s
3	4.0	6.667	0.5	17	1.10	2.410	4	63.1 (x2.4)	11m 50s
4	3.5	4.444	0.5	21	1.07	1.607	5	155.3 (x2.5)	31m 37s
5	3.0	3.0	0.1	25	1.05	1.071	6	405.3 (x2.6)	86m 28s
6	2.5	2.0	0.1	29	1.04	0.714	7	1039.7 (x2.6)	266m 15s

BREP SOLID GEOMETRY NOT AVAILABLE



Problem

- Geometry exists as a collection of independent surfaces
- Potential problems: gaps, overlaps, inconsistent representations

Options

- Go back to source and ask for BREP solid
- For cases with well-defined surfaces that form a closed body (work in progress)
    - Try SEW utility from ESP
    - Provide discretized surfaces, curves, edge/face topological relationship as created by EGADS2SRF. Then start from POGS.

PUBLICATIONS

Chan, W. M., Chuen, A. M., Advances in Automation of Overset Structured Volume Mesh Generation and Domain Connectivity, AIAA Paper 2024-4305, Las Vegas, NV, Jul 29 - Aug 02, 2024.

Hosseini, S. S., Chuen, A. M., Chan, W. M., Computational Aerodynamic Study of the Lift+Cruise VTOL Concept Vehicle Components, Transformative Vertical Flight 2024, Santa Clara, CA, Feb 2024.

Chuen, A. M., Hosseini, S. S., Jensen, J. C., Chan, W. M., Aerodynamic Simulations for Complex Geometries Using Automatically Generated Structured Overset Meshes, AIAA Paper 2023-3602, AIAA Aviation Forum, San Diego, CA, Jun, 2023.

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

PRESENTATIONS

Chuen, A. M., Hosseini, S. S., Jensen, J. C., Chan, W. M., A Study on Flow Solutions Computed on Automatically and Manually Generated Structured Overset Meshes, *AMS Seminar Series*, Sept., 2023.

Chan, W. M., Chuen, A. M., Recent Developments in Automation of Overset Structured Mesh Generation, *AMS Seminar Series*, Jan., 2022.

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