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OVERSET MESH GENERATION FOR THE HIGH-LIFT COMMON RESEARCH MODEL

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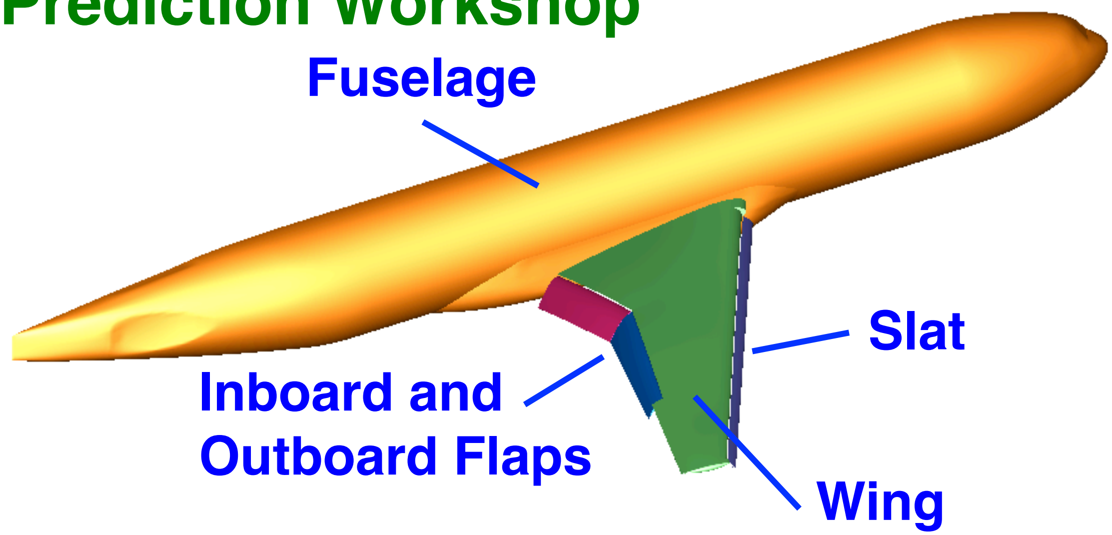
Computational Aerosciences Branch

AMS Seminar Series, March 9, 2017

OVERVIEW

1st AIAA Geometry and Mesh Generation Workshop
3rd AIAA High-Lift Prediction Workshop



- Introduction

- Structured overset meshing methods and best practices using Chimera Grid Tools (CGT): *AIAA Paper 2017-0362*

- Lessons learned
  - Meshing a family of grid systems at different resolutions
  - Grid quality checks

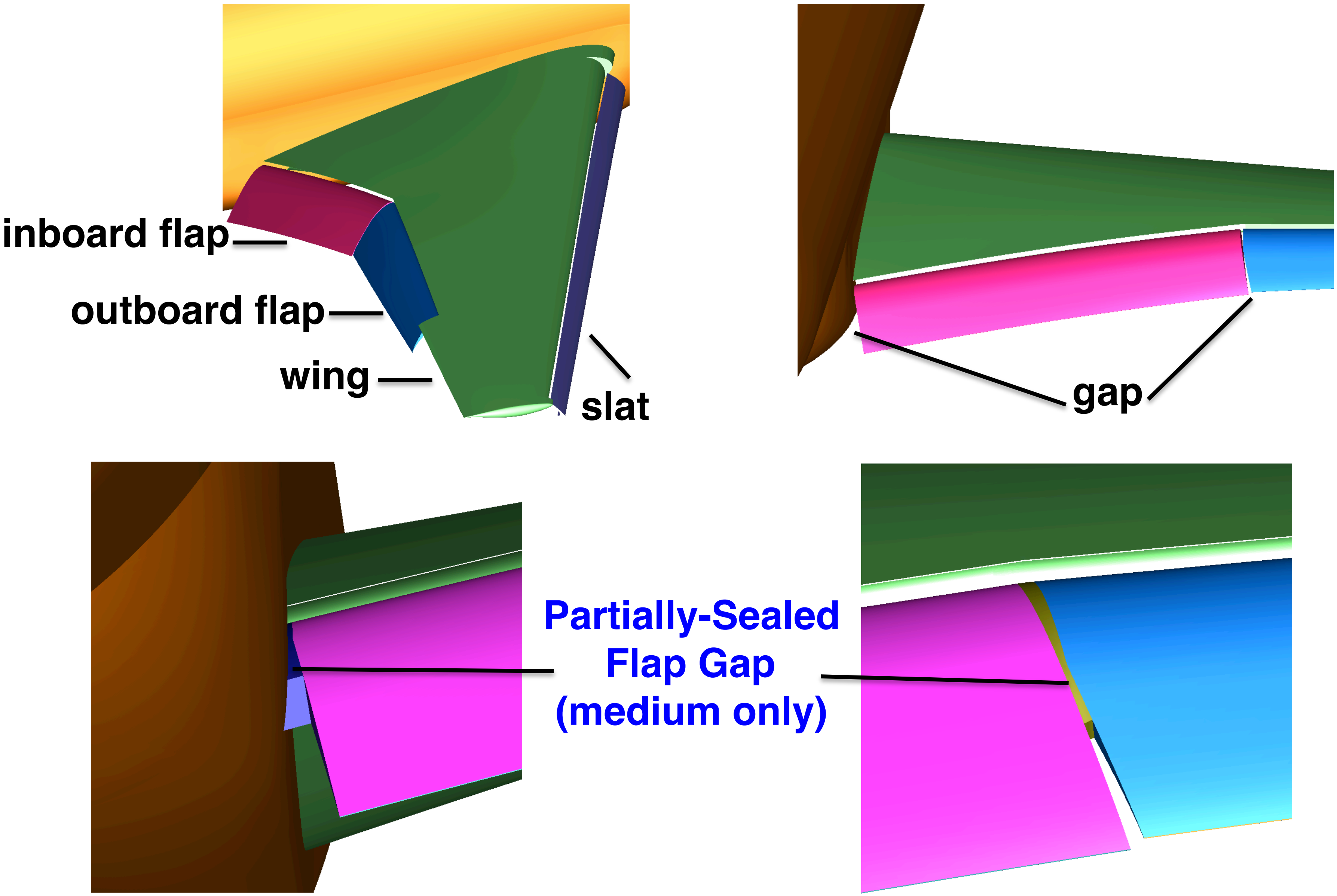
- Summary and conclusions

STRUCTURED OVERSET MESHING USING CGT:

METHODS AND BEST PRACTICES

HIGH-LIFT CRM GEOMETRIC CONFIGURATIONS

Full Flap Gap (coarse, medium, fine, extra fine)



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OVERSET STRUCTURED GRID GENERATION PROCESS AND SCRIPTING FRAMEWORK

Main steps

- Geometry processing
- Surface grid generation: featured-based domain decomposition, grid point distribution, mesh fill
- Volume grid generation: hyperbolic near-body, Cartesian off-body
- Domain connectivity: grid points blanking, donor stencil search
- Input parameters preparation for flow solver: boundary conditions, grid indices for component aerodynamic loads

Develop script that reproduces entire process

- Chimera Grid Tools Script Library (Tcl-based, 200+ macros)
- Component scripts (fuselage, slat, flaps, wing)
- Master script
- Parameterized inputs
  - max stretching ratio (surface and volume)
  - surface grid spacing (max interior, at surface features)
  - volume grid wall normal spacing
  - min number of points on smallest feature

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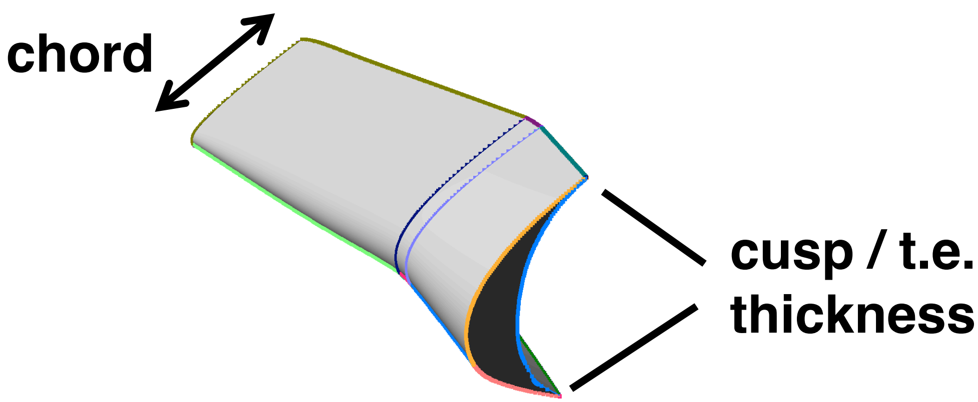
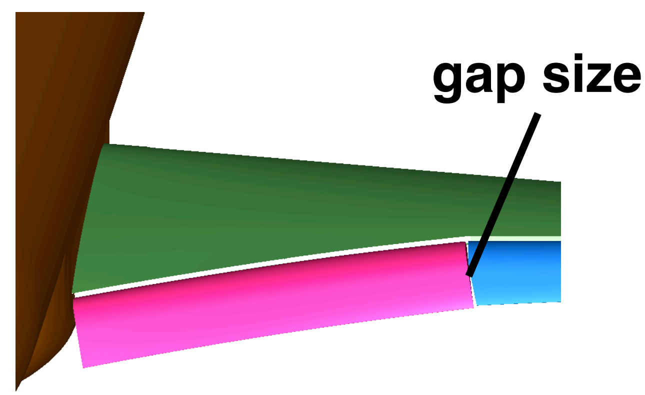
GEOMETRY PROCESSING

- Geometry definition files supplied: native CAD, STEP, IGES
- Create starting point for grid generation script development
  - Unstructured surface triangulation (CART3D format)
    - Generated using ANSA software
    - Sufficient resolution at high curvature regions
  - Surface curves (PLOT3D format)
    - Generated using Chimera Grid Tools from surface triangulation
    - CAD edges including all surface features
- Identify configuration characteristic lengths
  - component length scale
  - smallest feature size
  - gap size between components





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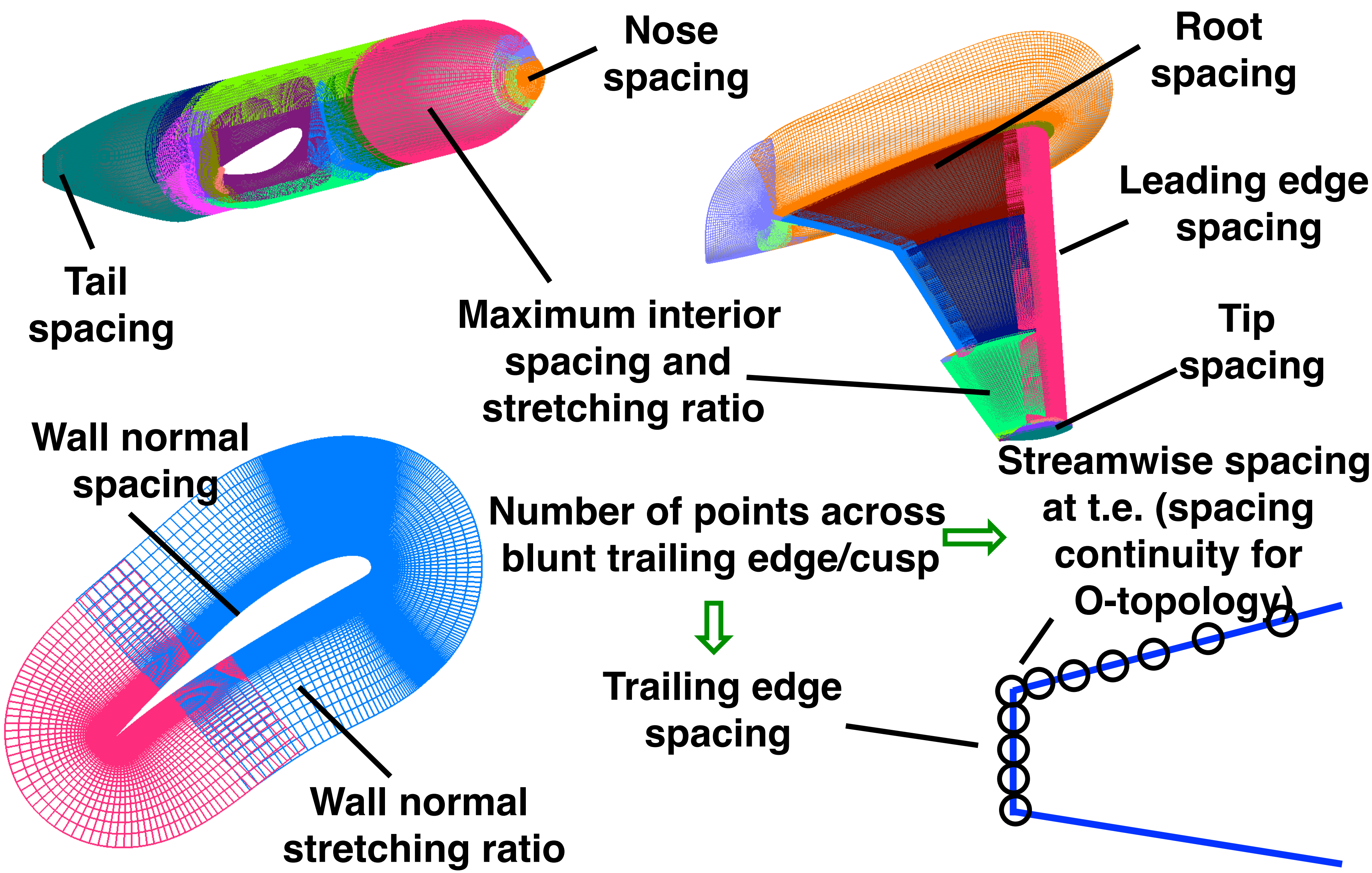
GRID POINT DISTRIBUTION MESHING GUIDELINES

Mostly prescribed by High-Lift Prediction Workshop document



WORKSHOP PRESCRIBED MESHING PARAMETERS

Reference spacing Δs_{ref} = 3% mean aerodynamic chord

Resolution Level	Coarse	Medium	Fine	Extra Fine
# Points on trailing edge	5	9	13	17
Span spacing at flap gap cap grids (x 10^{-2}) *	12.5	8.3	6.25	5.0
Max surface spacing	1.5 Δs_{ref}	Δs_{ref}	Δs_{ref} / 1.5	Δs_{ref} / 1.5^2
Wall normal stretching ratio	1.25	1.16	1.1	1.07
Wall normal spacing (x 10^{-4})	17.5	11.7	7.8	5.2

** Not prescribed by workshop*

GRID QUALITY CHECKS

All volume meshes are automatically checked for
- Positive Jacobians as computed by target flow solver (OVERFLOW)
- Self intersections with surface mesh

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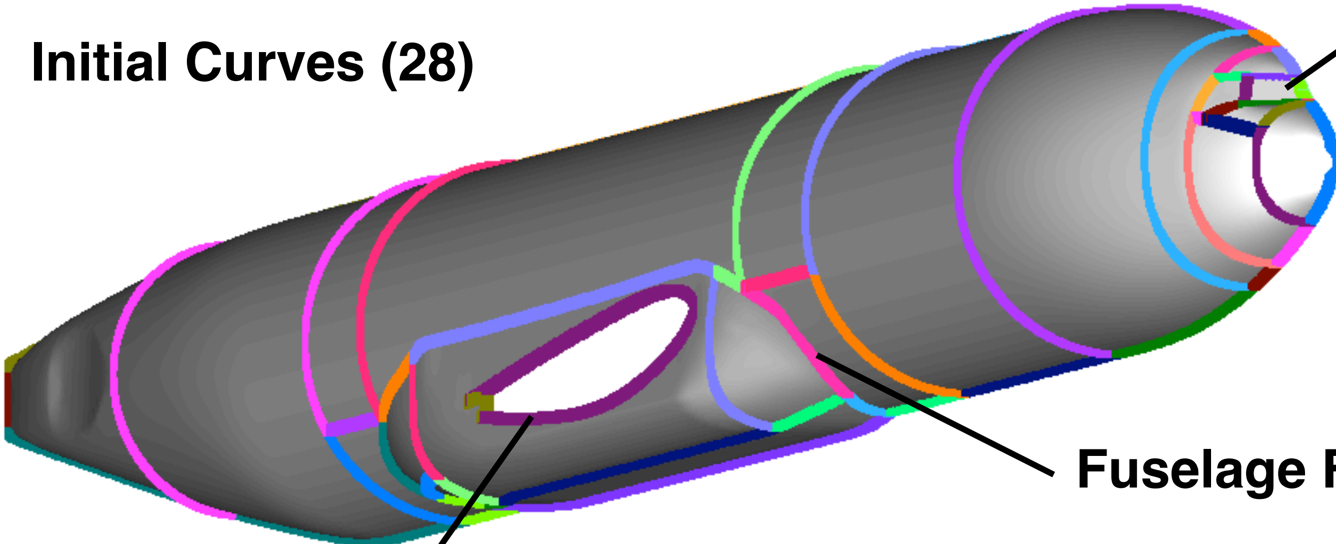
INITIAL CURVES AND SURFACE GRIDS

Fuselage Features: Cockpit Window, Fairing, Wing Intersection

Initial Curves (28)

Cockpit Window

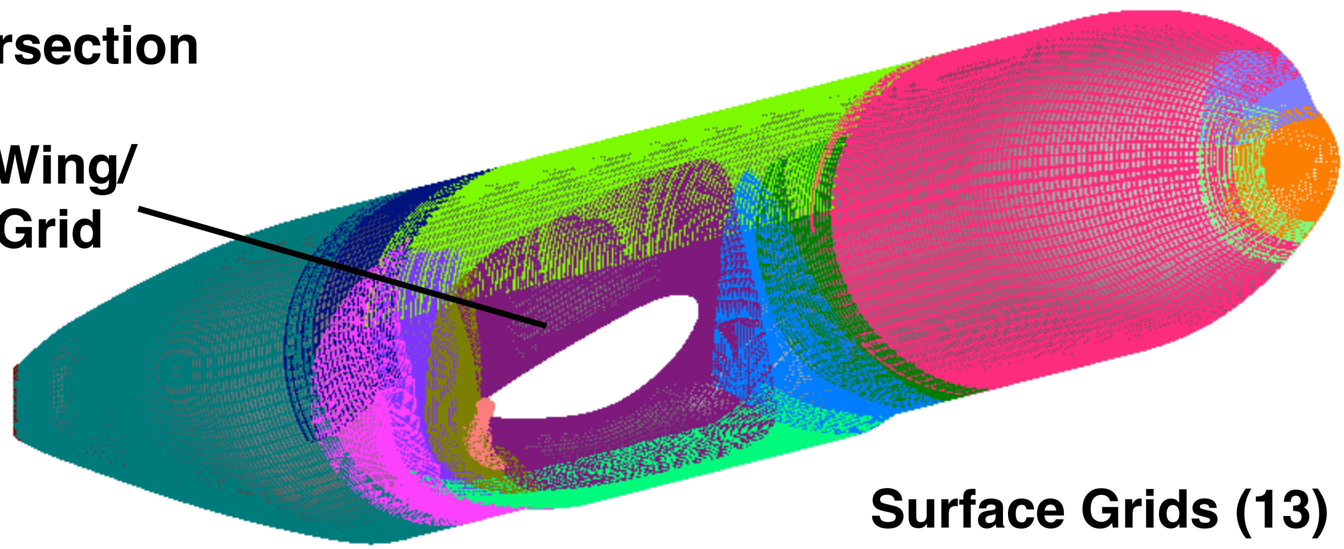


Geometry trimmed by wing intersection curve

Fuselage Fairing

Wing/Fuselage Intersection

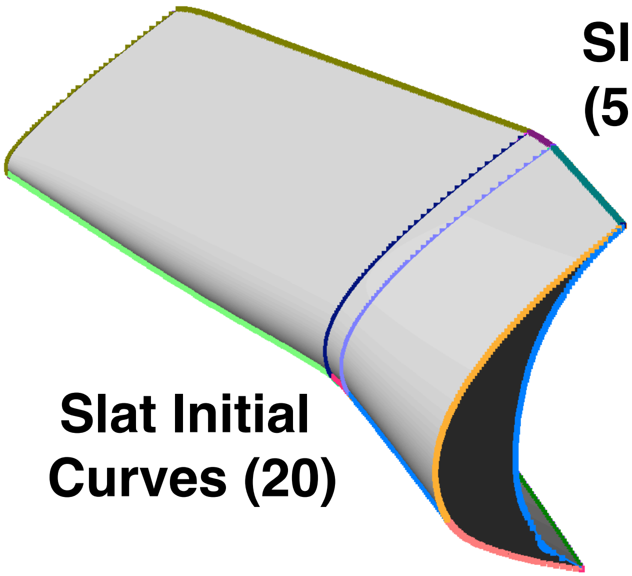
Fuselage Side of Wing/ Fuselage Collar Grid



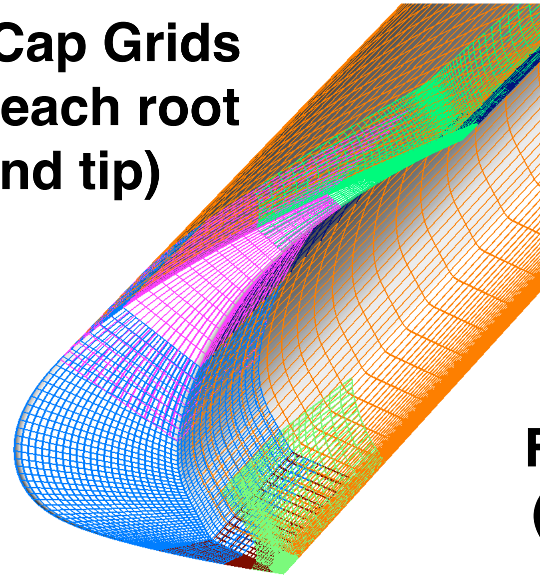
Surface Grids (13)

INITIAL CURVES AND SURFACE GRIDS

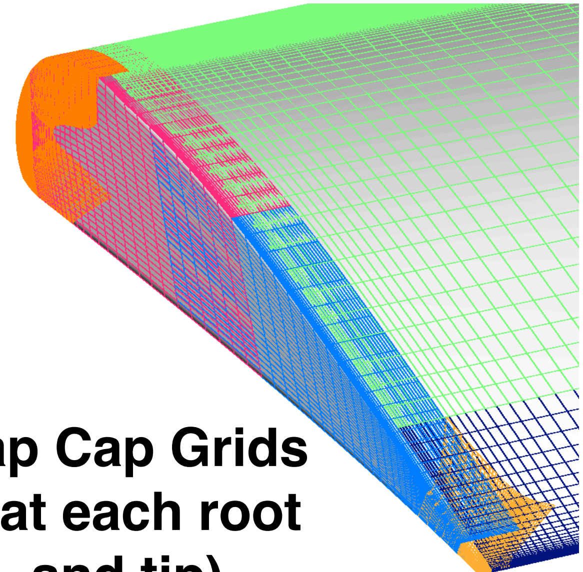
Slat and Flap Features: L.E., T.E., Cusp, Root, Tip



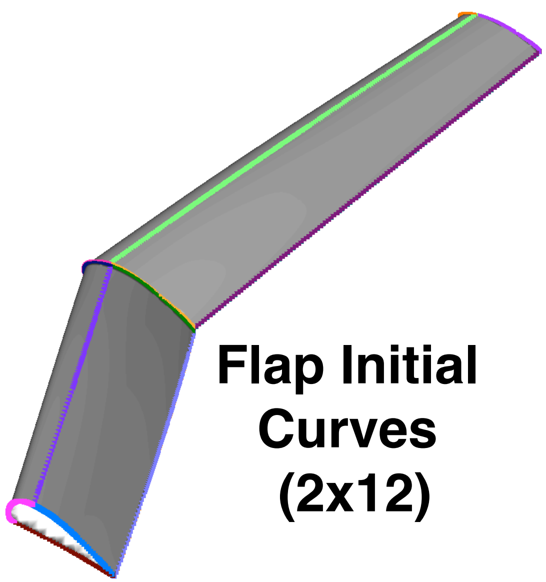
Slat Initial Curves (20)



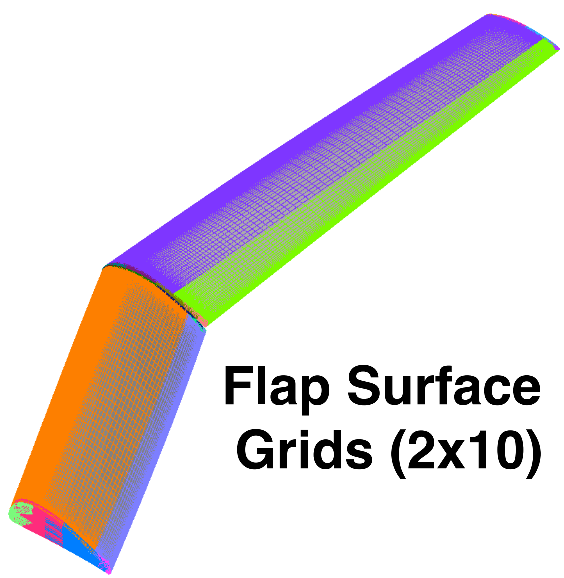
Slat Cap Grids (5 at each root and tip)



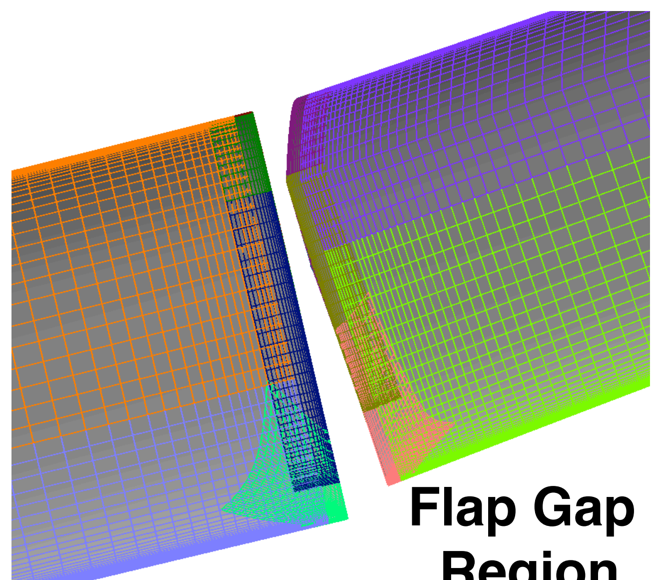
Flap Cap Grids (4 at each root and tip)



Flap Initial Curves (2x12)



Flap Surface Grids (2x10)

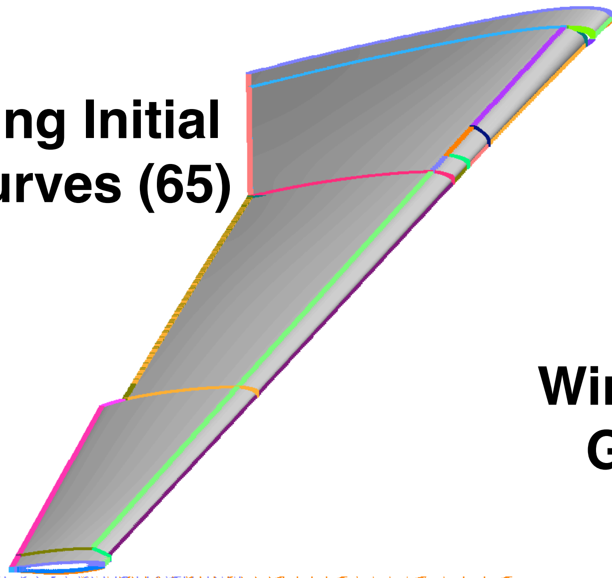


Flap Gap Region

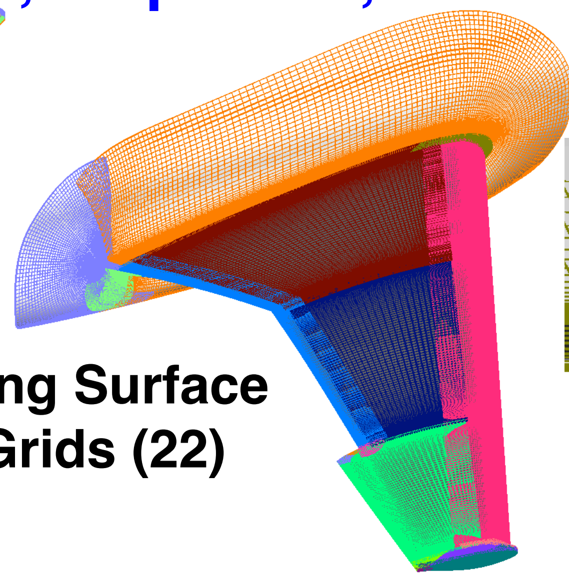
INITIAL CURVES AND SURFACE GRIDS

Wing Features: L.E., T.E., Root Intersection, Tip, Slat Cove, Flap Cove, Cove Side Walls

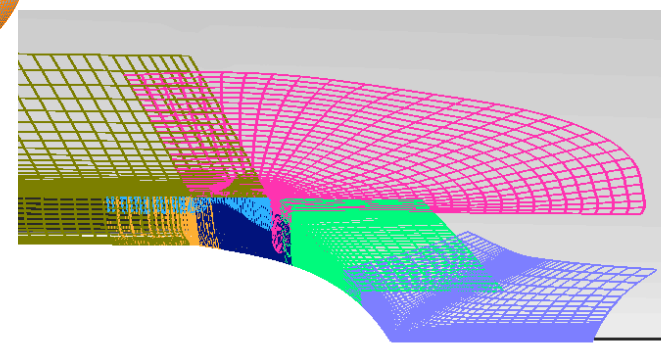
Wing Initial Curves (65)

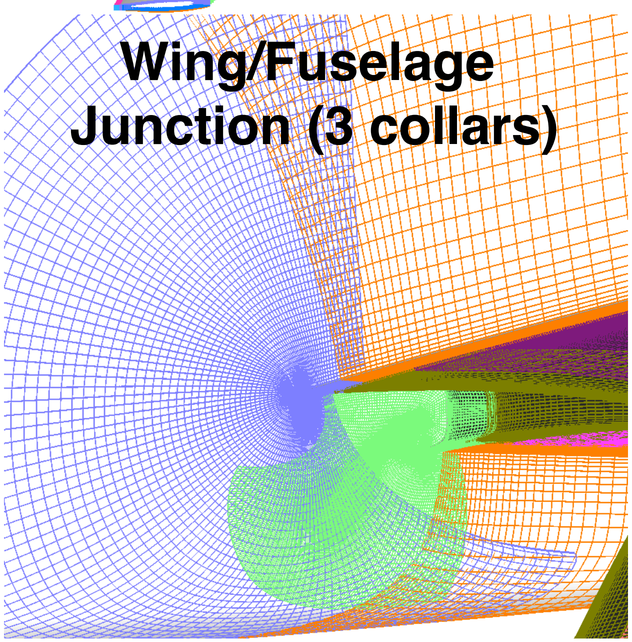


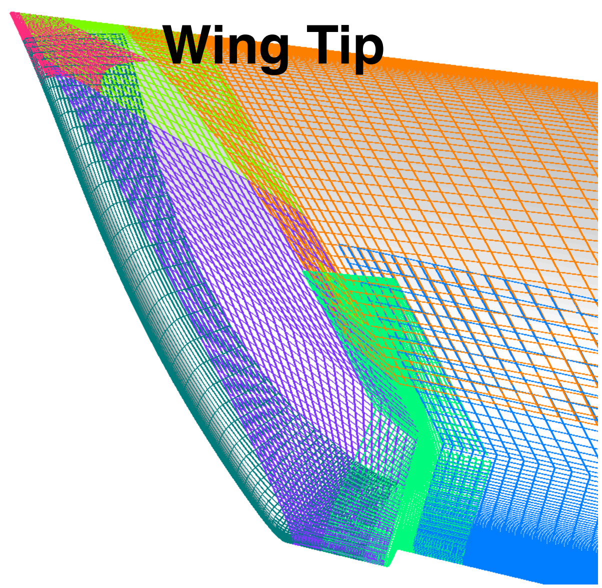
Wing Surface Grids (22)

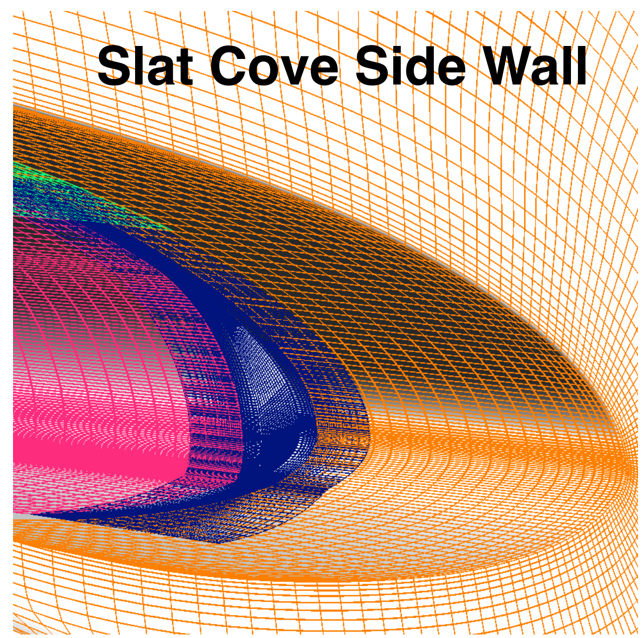


Flap Cove Side Wall





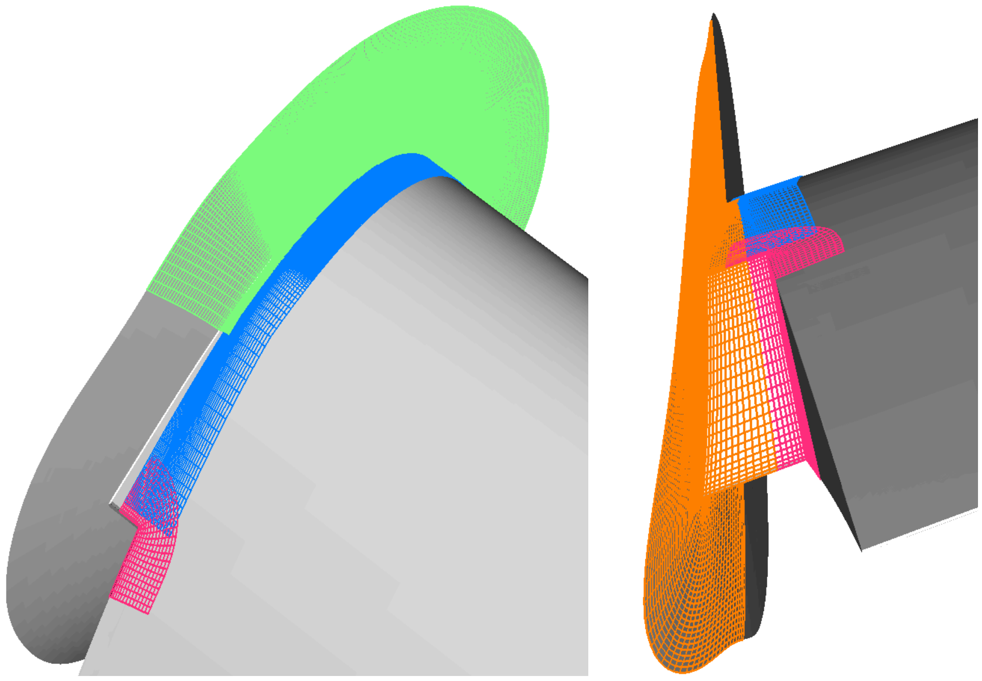




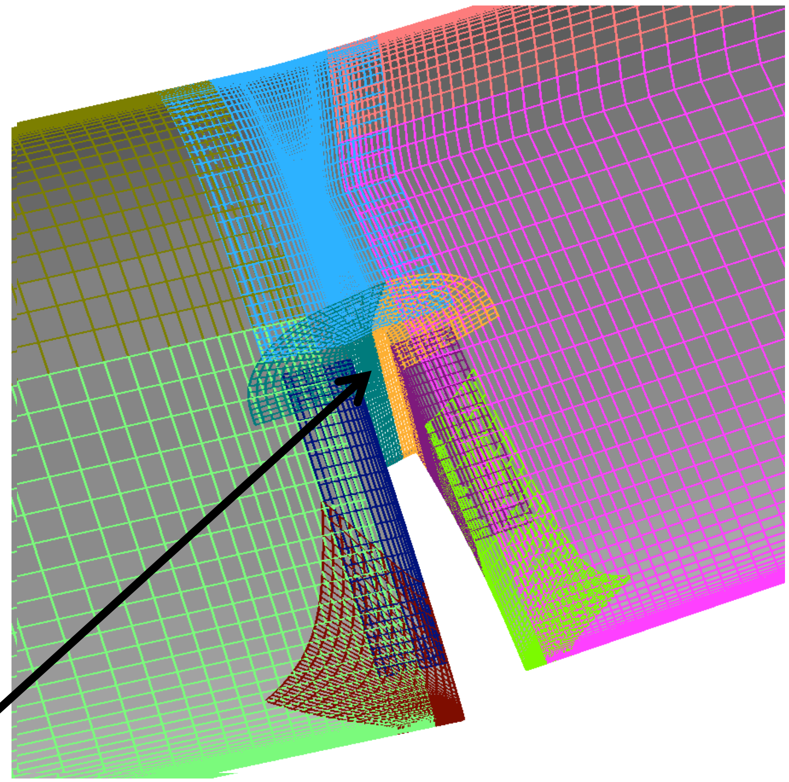
FLAP PARTIAL SEAL SURFACE GRIDS

Re-use grids from full flap gap case for fuselage, slat, wing, and flaps

Partial flap seal against fuselage

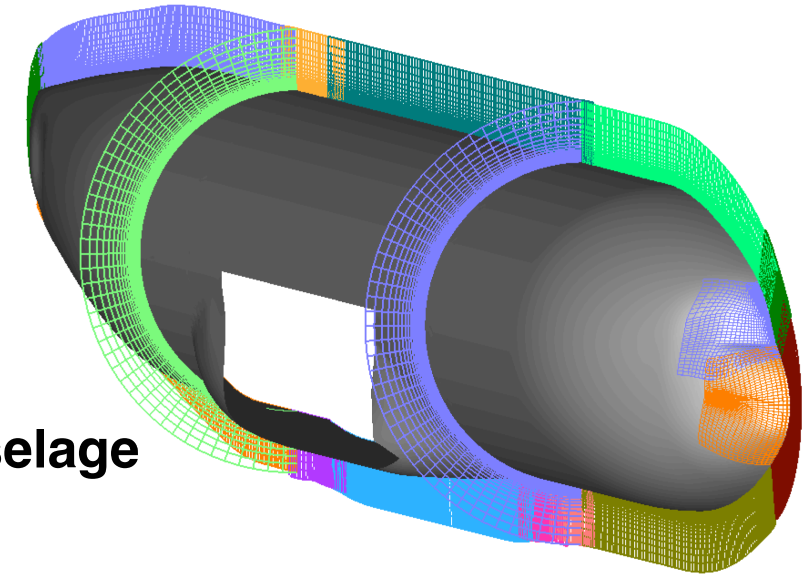


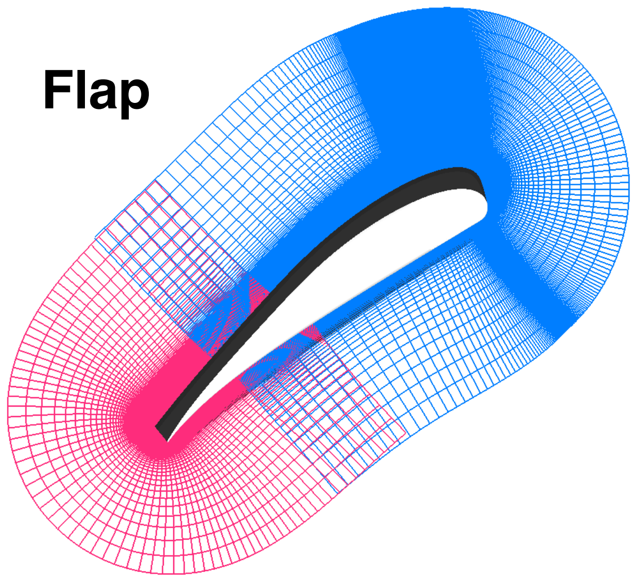
Partial flap seal between inboard and outboard flaps

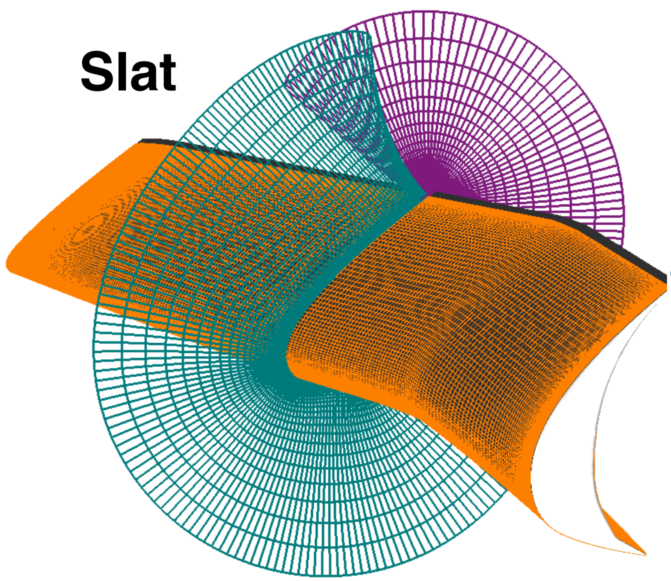


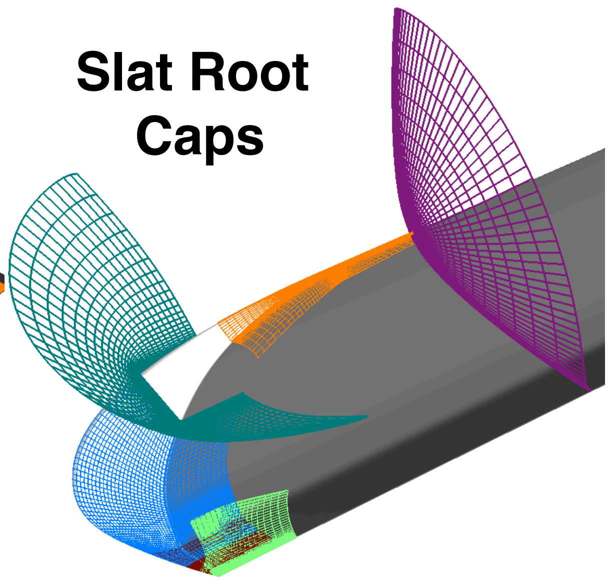
Back and side wall cap split into two grids to avoid double concave corner => easier for hyperbolic volume mesh generation

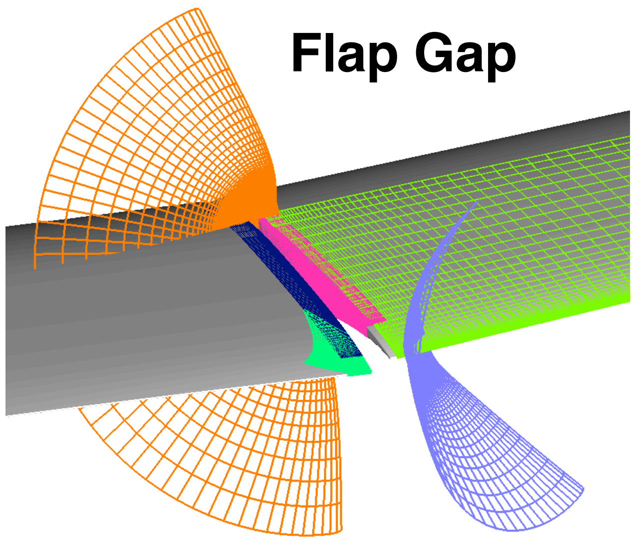
SLICES OF FUSELAGE, SLAT, FLAP VOLUME GRIDS











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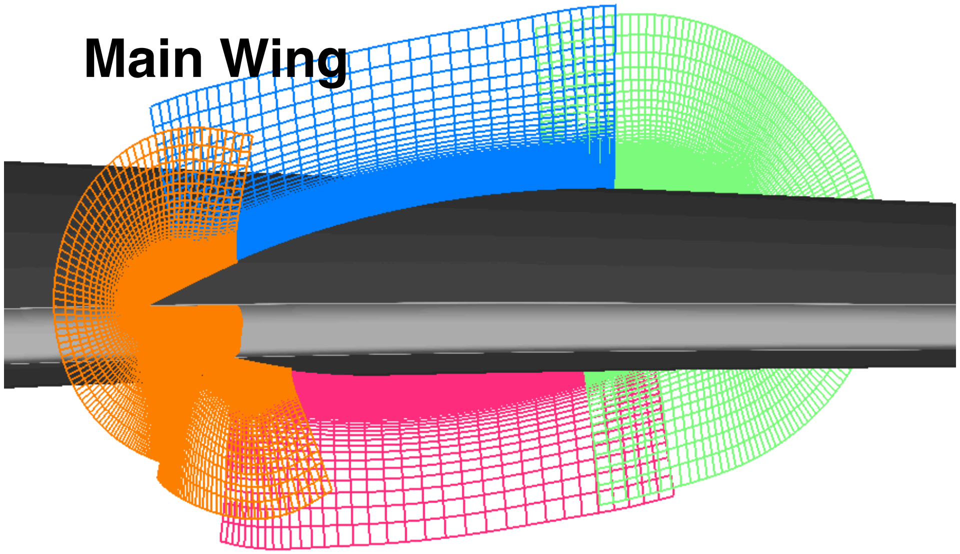
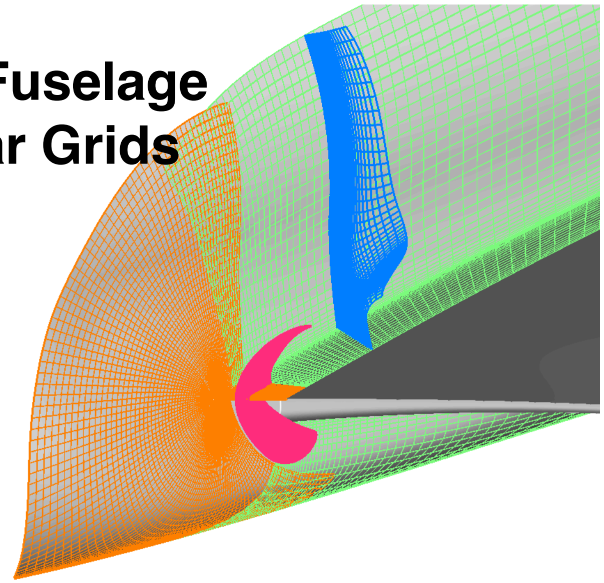
SLICES OF WING VOLUME GRIDS

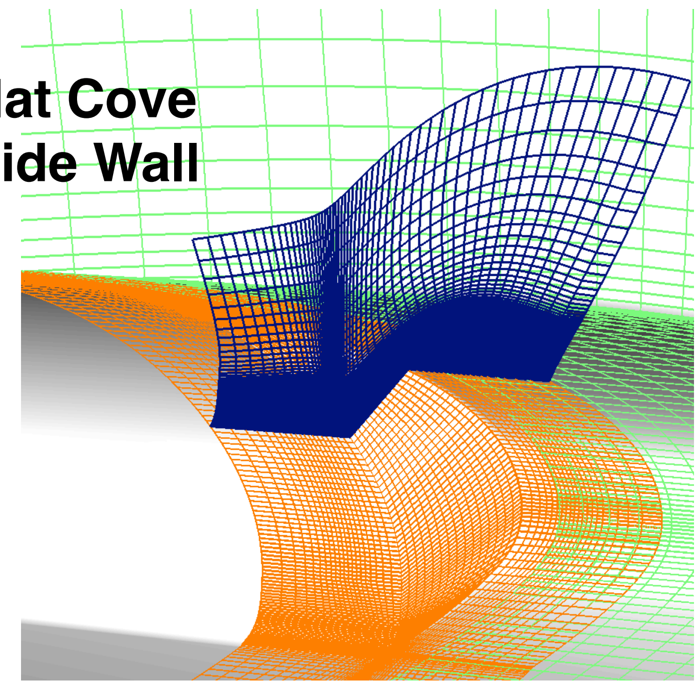
Main Wing



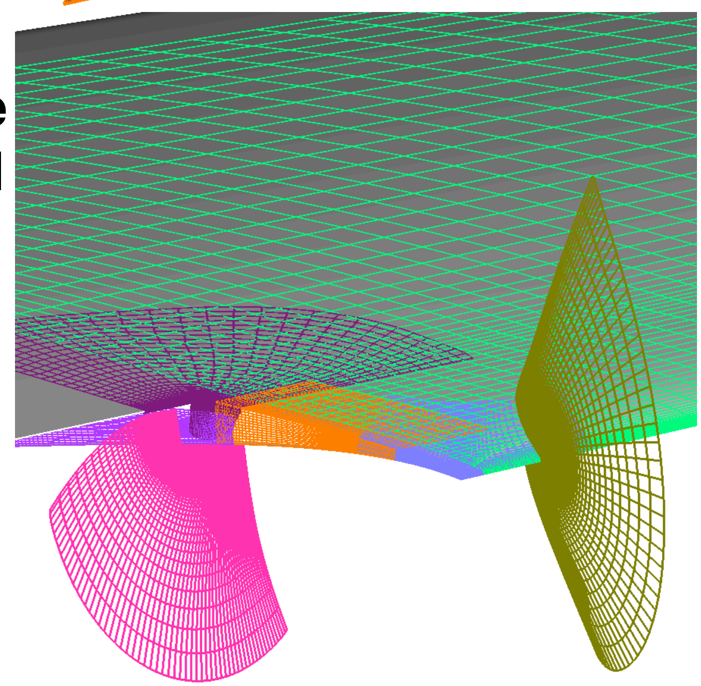
Wing/Fuselage Collar Grids



Slat Cove Side Wall



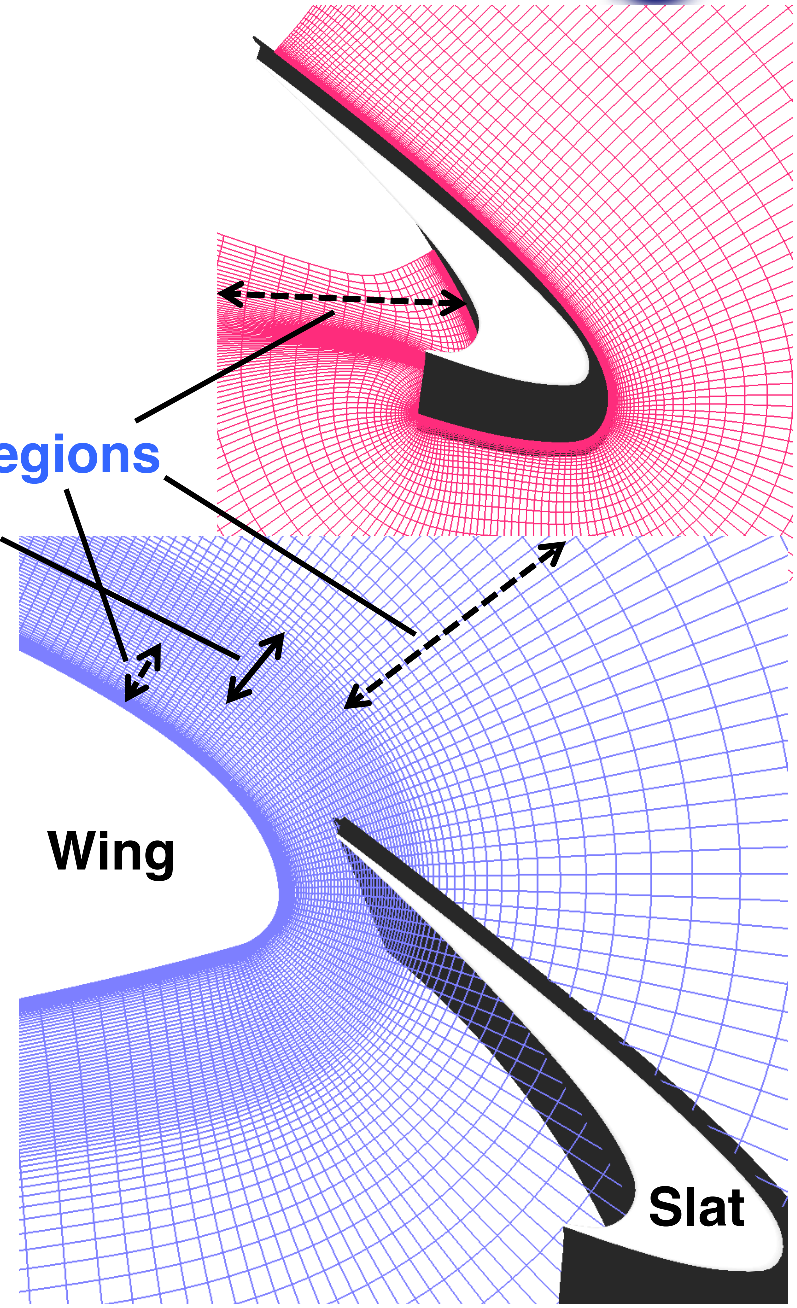
Flap Cove Side Wall



WALL-NORMAL GRID POINT DISTRIBUTION

Fuselage and Slat

1. Uniform spacing first two cells (Δs_{wall})
2. Stretched region to outer boundary



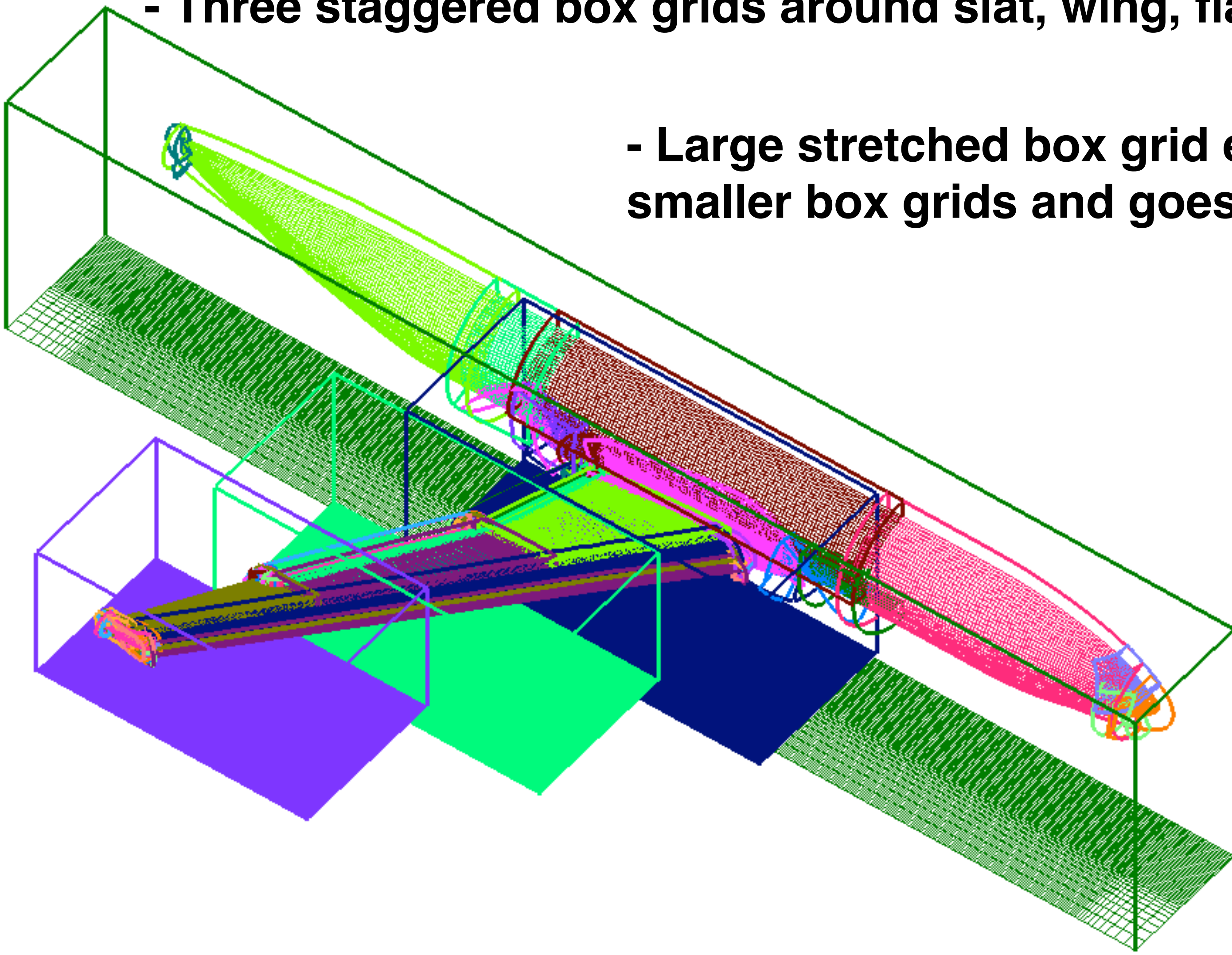
Wing and Flaps

Need to resolve shear layer from preceding component for accurate drag prediction

1. Uniform spacing first two cells (Δs_{wall})
2. Stretched region
3. Shear layer region
   - Uniform spacing = 100 x Δs_{wall}
   - Thickness = 3 in.
   - Distance from wall = 1.5 in.
4. Stretched region to outer boundary

OFF-BODY STRETCHED CARTESIAN VOLUME GRIDS

- Cartesian box grid with uniform core and stretched outer layers
- One box grid around fuselage volume grids
- Three staggered box grids around slat, wing, flaps



- Large stretched box grid encloses all smaller box grids and goes to far field

DOMAIN CONNECTIVITY
Comparison of Two Approaches

Chimera Components Connectivity Program (C3P)

- Inputs: boundary conditions for each mesh, and component ID for each solid wall (low manual effort needed)

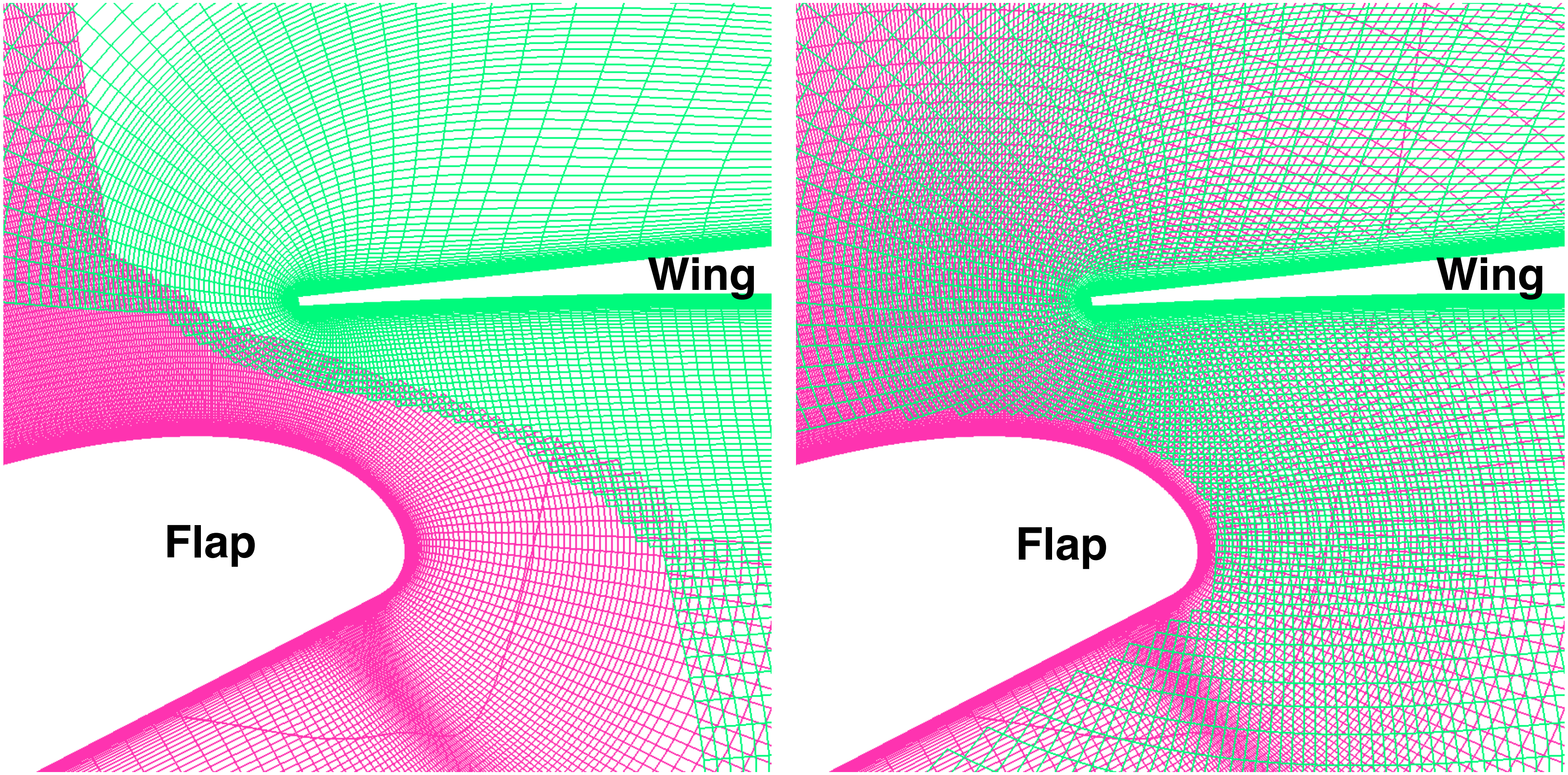
- External process performed prior to running OVERFLOW flow solver

OVERFLOW-DCF (DCF)

- Inputs: boundary conditions for each mesh, X-ray map for each hole cutter, list of grids to be cut by each X-ray, constant offset distance for each hole cut instruction (significant manual effort needed)

- Built into the OVERFLOW flow solver

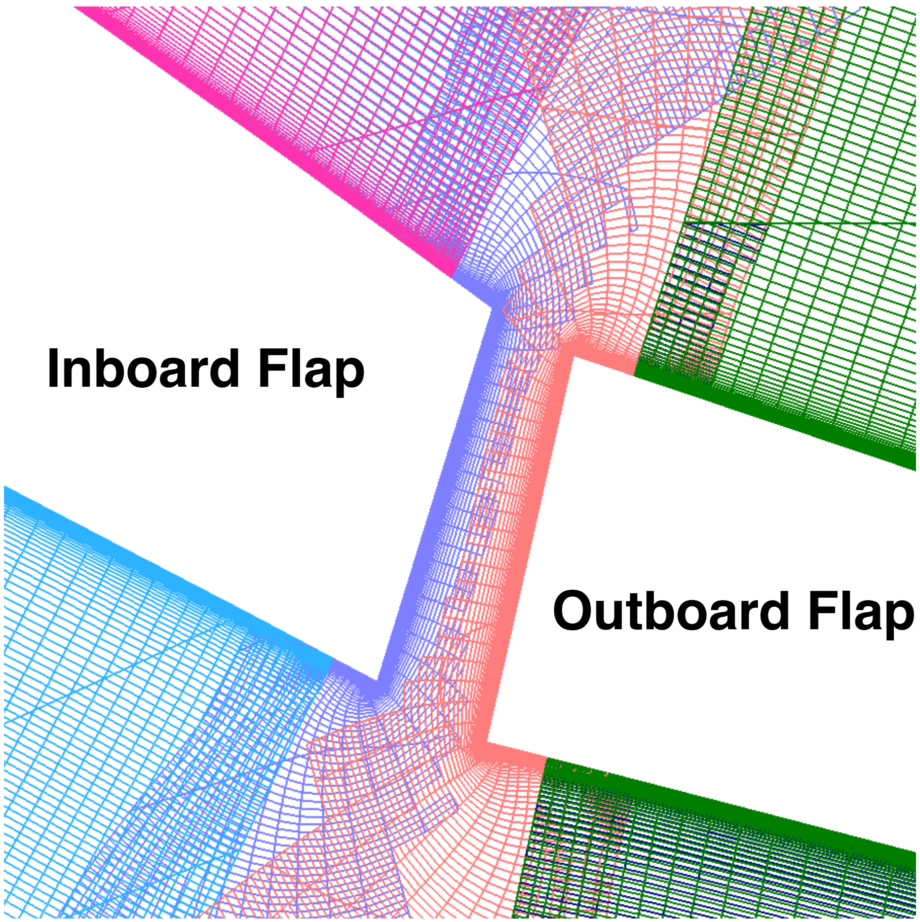
CONSTANT SPAN CUT THROUGH VOLUME MESH (Wing Trailing Edge, Flap Leading Edge Region)



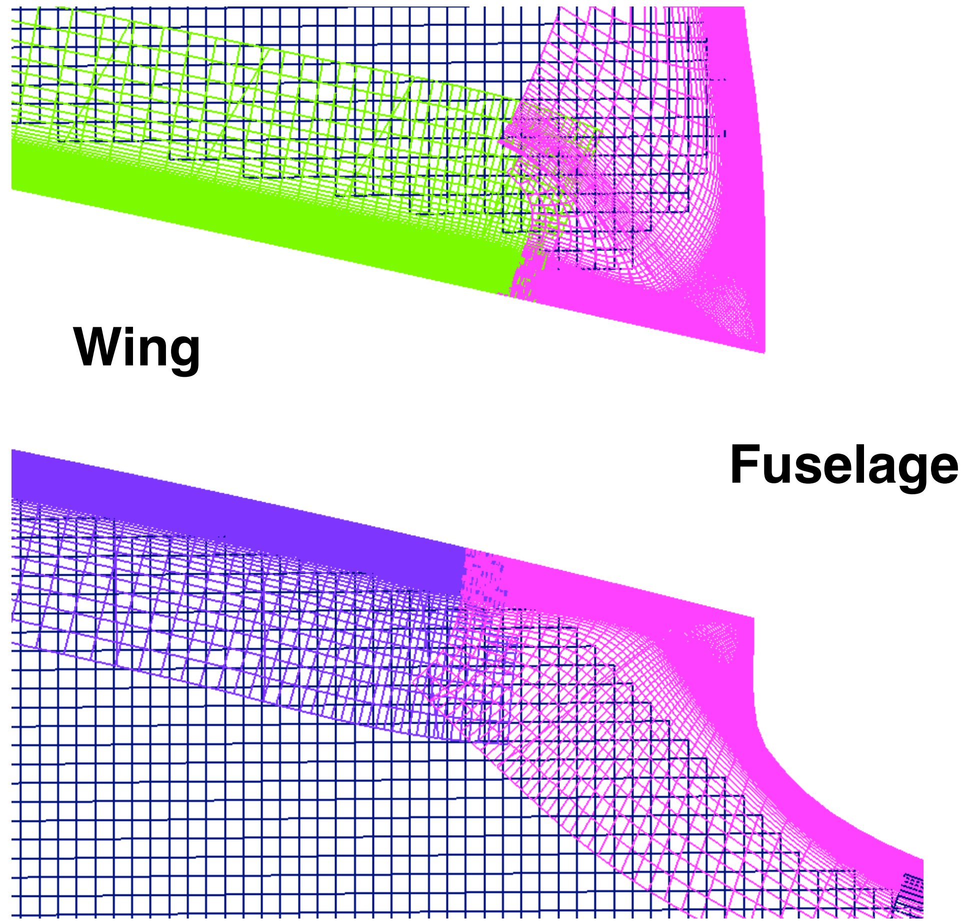
C3P
(spatially variable offset)

DCF
(constant offset)

VARIOUS VOLUME SLICES FROM C3P CONNECTIVITY



Constant-x cut across flap gap



Constant-x cut at wing/ fuselage junction

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GRID SCRIPT DEVELOPMENT TIME (MEDIUM MESH)

Two different domain connectivity methods/software

Task	Time (hr.)	% of Total
Geometry processing	3.75	5.5
Surface grid generation	56.05	81.7
Volume grid generation	4.50	6.6
Domain connectivity (C3P)	1.20	1.7
Input prep. (flow solver b.c., post-processing)	3.1	4.5
Total	68.6	100

Task	Time (hr.)	% of Total
Geometry processing	3.75	4.7
Surface grid generation	56.05	69.9
Volume grid generation	4.50	5.6
Domain connectivity (DCF)	12.8	16.0
Input prep. (flow solver b.c., post-processing)	3.1	3.9
Total	80.2	100.0

GRID SCRIPT DEVELOPMENT FOR DIFFERENT LEVELS OF MESH RESOLUTION AND PARTIALLY-SEAL FLAP GAP

Full flap gap coarse, fine, and extra-fine level grid systems
- Created independently from the medium level system
- Not a redistributed version of medium mesh

Partially-sealed flap gap medium system
- Created by copying fuselage, slat and wing grids, and some flap grids from full gap grid system
- Only need to create grids for partial seals

Flap Gap Geometry	Full Gap				Partial Seal
Resolution Level	Coarse	Medium	Fine	Extra Fine	Medium
Grid script development time (hr.)	10.0 *	68.6	17.75 *	12.5 *	12.0 *

** Additional development time beyond medium mesh script*

GRID SYSTEM STATISTICS

- Entire process performed on Linux Xeon desktop workstation
- All timings include i/o

Flap Gap Geometry	Full Gap				Part Seal
Resolution Level	Coarse	Medium	Fine	Extra Fine	Medium
# Grids	72	72	76	102	73
# Surface grid points (x 10^6)	0.27	0.51	1.02	2.08	0.53
# Volume grid points (x 10^6)	24.1	65.4	189.3	564.7	66.3
Grid script devel. time (hr.)	10.0	68.6	17.75	12.5	12.0
Grid script exec. time (min.)	3.25	5.35	12.63	34.83	1.65
Connectivity (C3P) exec. wall time (min.), mem use (GB) 24 OpenMP threads	1.14 (6)	2.85 (13)	7.25 (31)	28.23 (81)	3.1 (13)
Connectivity (DCF) exec. wall time (min.) 24 MPI ranks	0.50	1.52	n/a	n/a	n/a

n/a = not attempted due to extra manual time needed to create special X-ray cutters

OVERFLOW PRELIMINARY RESULTS

(Tom Pulliam)

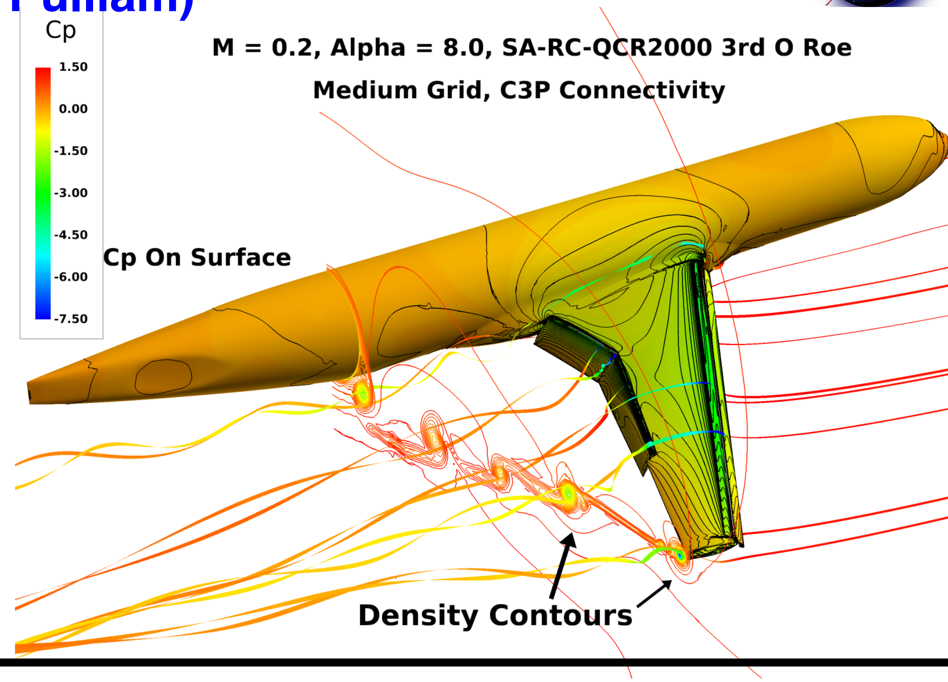
Grid Sizes

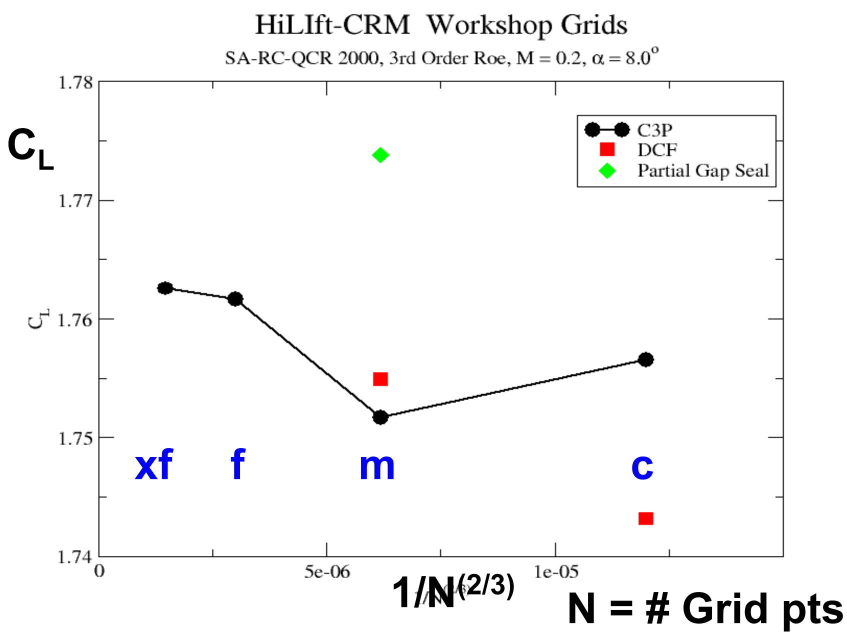
- Coarse: 2.4M
- Medium: 6.5M
- Fine: 189M
- X-Fine: 565M

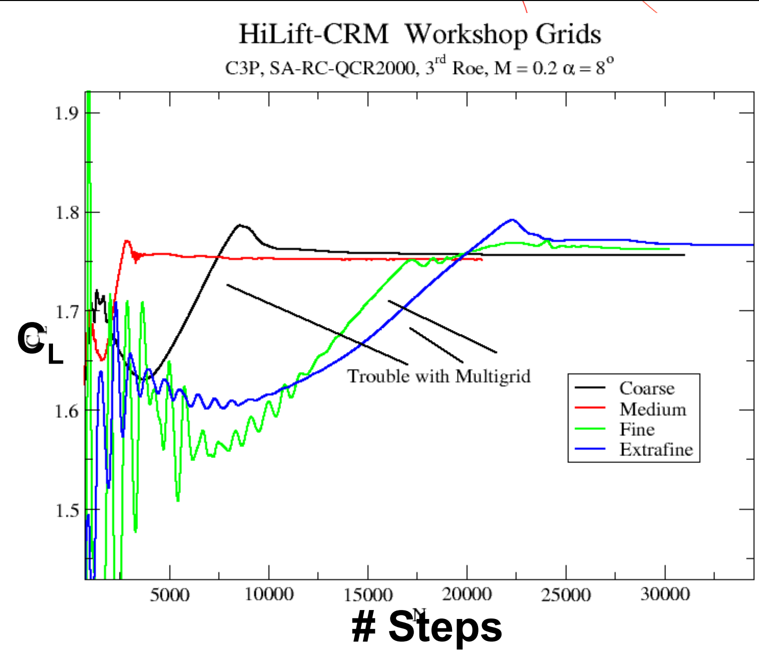
Connectivity: C3P and DCF

Parameters:

- Mach = 0.2, Alpha = 8 deg,
- Re = 3.26M based on MAC
- 3rd order Roe, SA-RC-QCR2000







LESSONS LEARNED FROM MESHING EXERCISE

GENERATION OF FAMILY OF GRID SYSTEMS AT DIFFERENT MESH RESOLUTIONS (COARSE, MEDIUM, FINE, EXTRA-FINE)

- Grid system at each resolution level is generated independently of each other starting from geometry definition

- Different meshing parameters prescribed for each level (e.g., max stretching ratio, max interior surface grid spacing, grid spacing at surface features, number of points on t.e., volume mesh wall normal spacing)

- Current practices do not provide automatic adjustments of marching distances and smoothing parameters

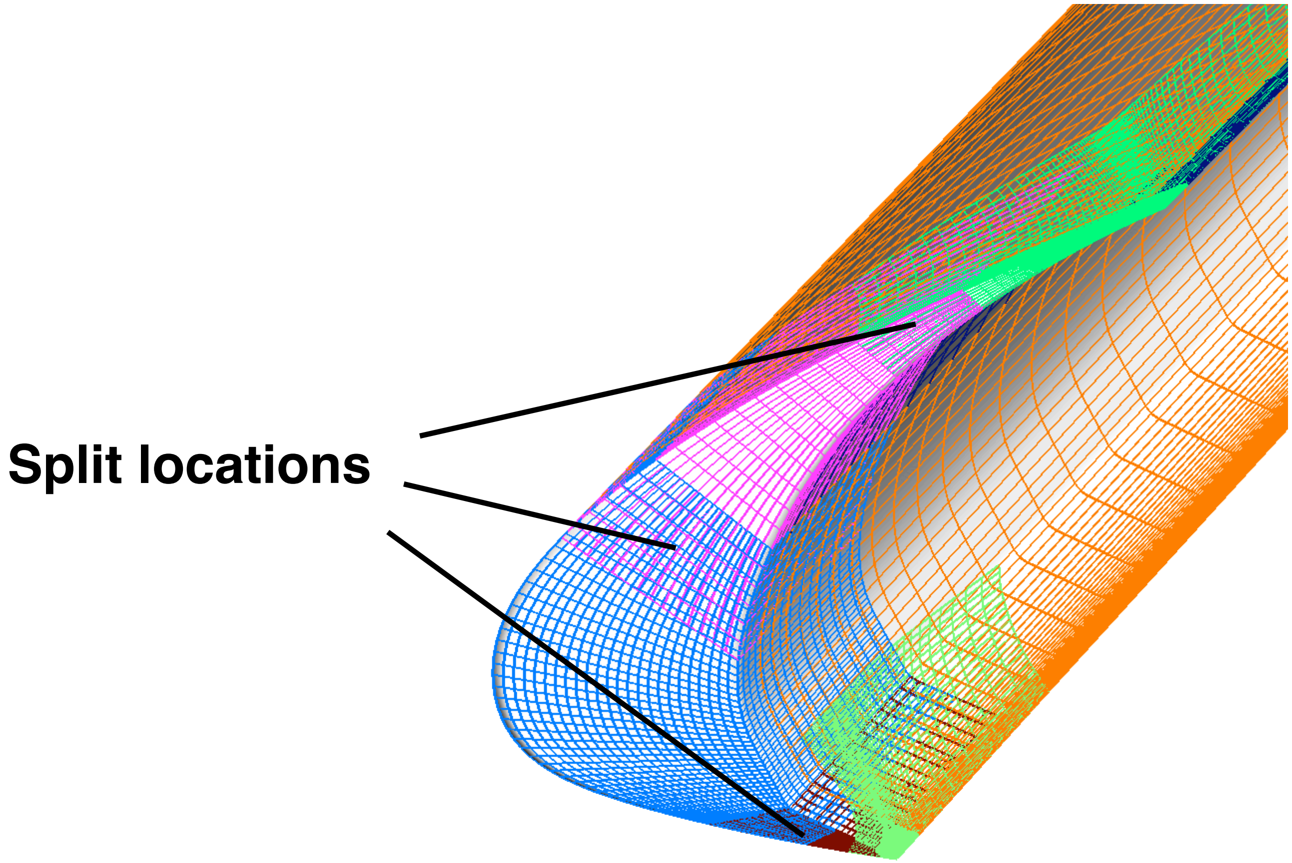
- Significant grid script execution time at extra-fine level (> 0.5 hr)

PARAMETER ADJUSTMENTS AT DIFFERENT LEVELS OF GRID RESOLUTIONS (1)

Hard coded grid indices for medium mesh script

Splitting locations defined by

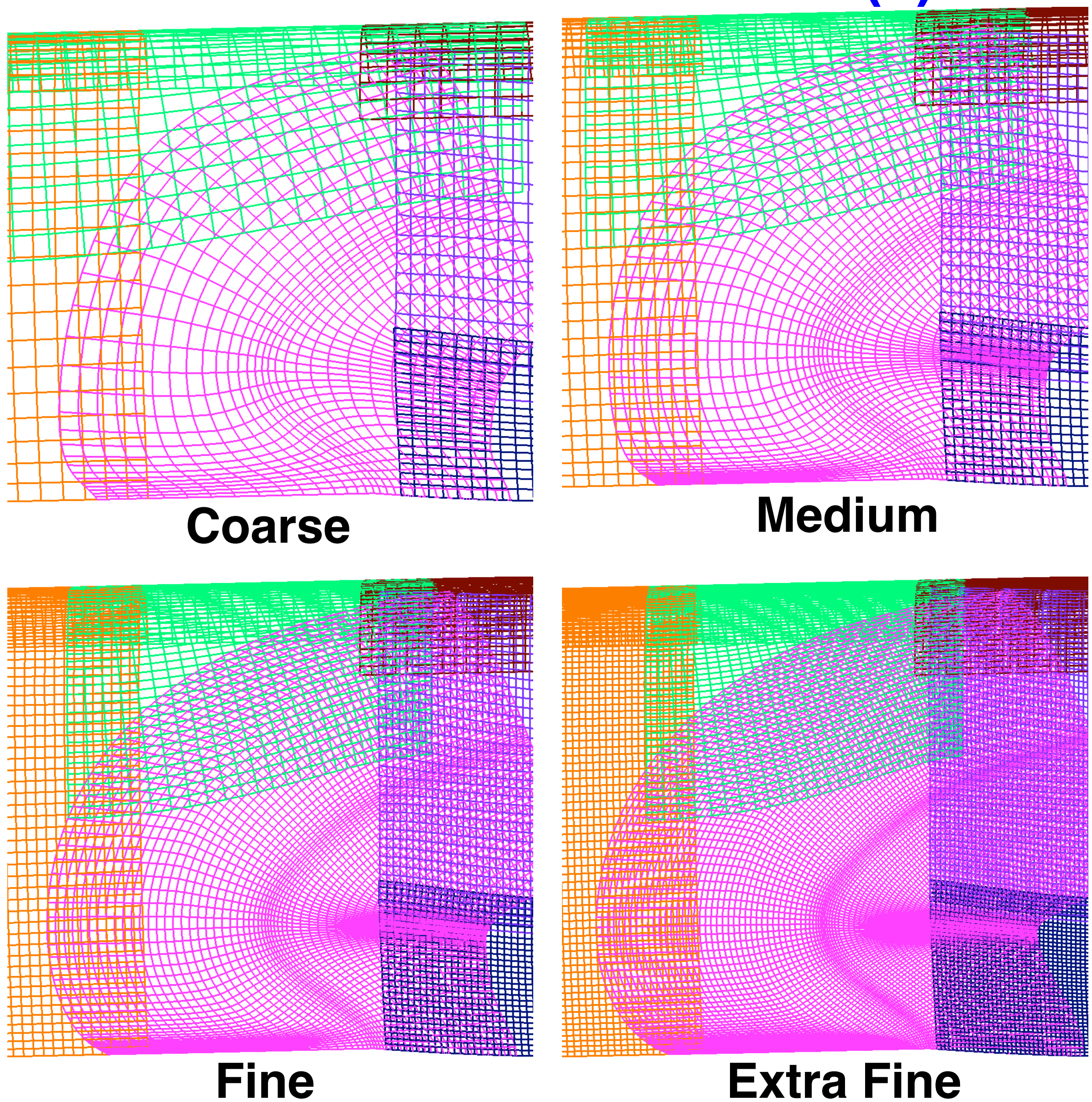
- **Grid indices => faster one level (medium) mesh development**
- **Grid coordinates or distance to reference point => slightly slower one level development but works for all levels**



PARAMETER ADJUSTMENTS AT DIFFERENT LEVELS OF GRID RESOLUTIONS (2)

Hyperbolic grid marching distances chosen to provide optimal overlap at coarse level (e.g., 5-point overlap for 5-point flow solver stencil)

- Too much overlap at fine and extra fine levels



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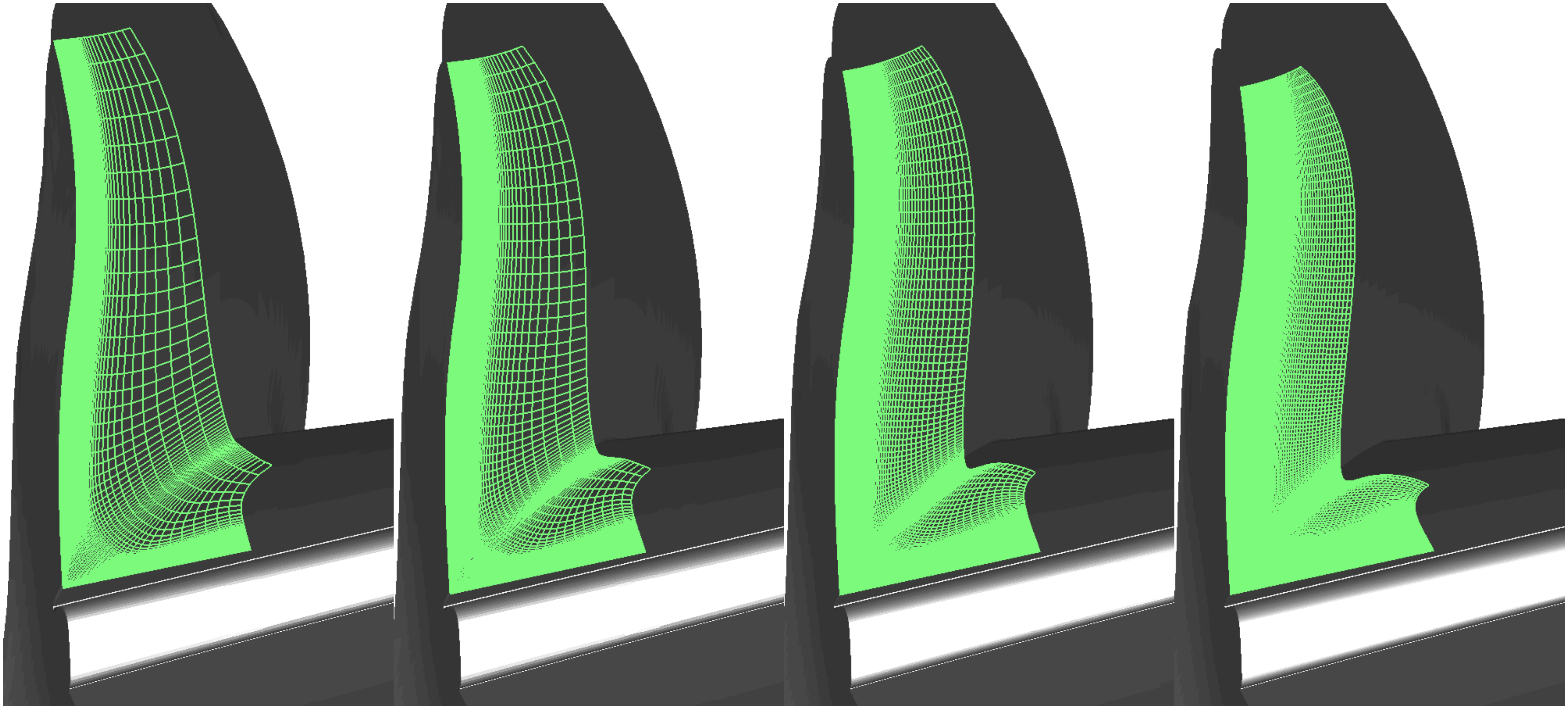
PARAMETER ADJUSTMENTS AT DIFFERENT LEVELS OF GRID RESOLUTIONS (3)

Finer grid spacing in concave corners in finer levels

- Need to adjust smoothing parameters for hyperbolic marching



Coarse **Medium** **Fine** **Extra-fine**

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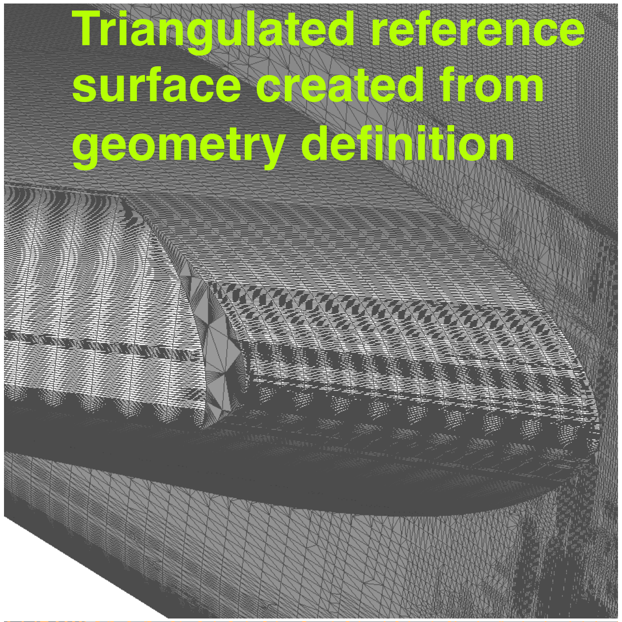
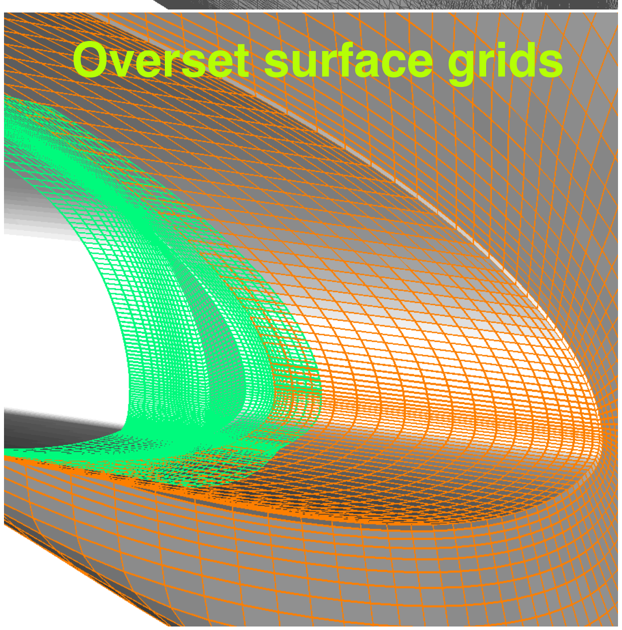
GRID QUALITY CHECK UTILITIES NOT CURRENTLY IN CGT

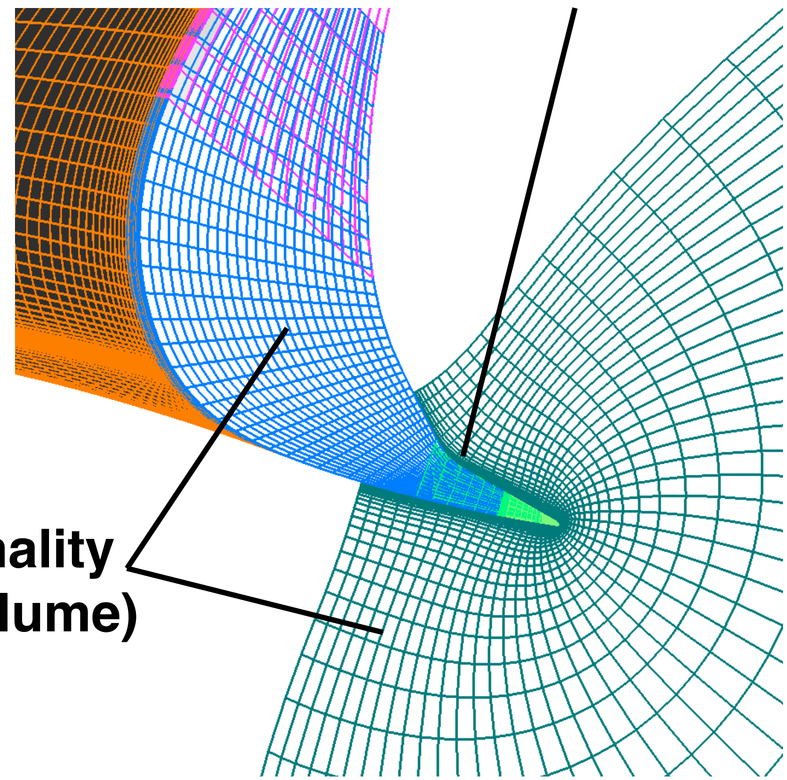




Need min/max and distribution of grid attribute statistics => Histogram and color map display

1. Distance of surface grid points to geometry definition (Native CAD, STEP, IGES)

2. Distance to wall of first grid point normal to viscous wall



3. Cell orthogonality (surface and volume)

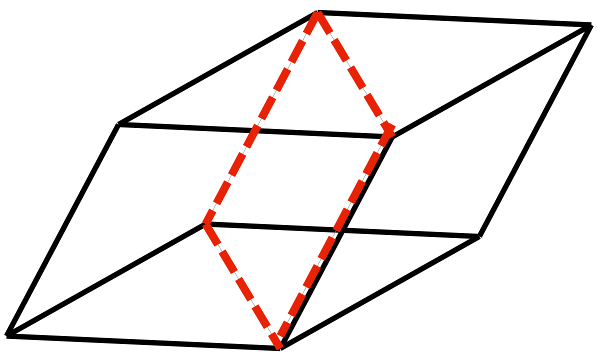
GRID QUALITY CHECK UTILITIES IN CGT (1)
Jacobians and Cell Volumes

Must pass

1. Jacobian computed using same subroutine as in target flow solver OVERFLOW (all > 0)
2. Self-intersection of volume grid points against surface grid (none)

Mostly pass

3. Cell volume using hexahedral decomposition into 6 tetrahedrons
4. Stretching ratio (<= 1.2)



- Cut into 2 prisms
- Cut each prism into 3 tets
- Bad cell if
  1. any tet volume < 0
  2. sum of 6 tet volumes < 0

Cell Volume Check

	Sum 6 tets			One or more tets	
	Negative sum			Negative vol	
Entity	# Cells	(J,K,L)	Min Vol	# Cells	Min Tet Vol
1	0				
2	0				
3	0		2.526e-04	9	-2.719e-06
4	0				
5	0		9.463e-04	186	-2.195e-04
6	0				
7	0		4.672e-04	59	-2.892e-04
8	0		3.594e-05	12	-4.785e-07
9	0		5.191e-04	6	-1.232e-07
10	1	(26,38,28)	-1.567e-03	216	-1.884e-03
11	0				
12	0				

OVERGRID Diagnostic

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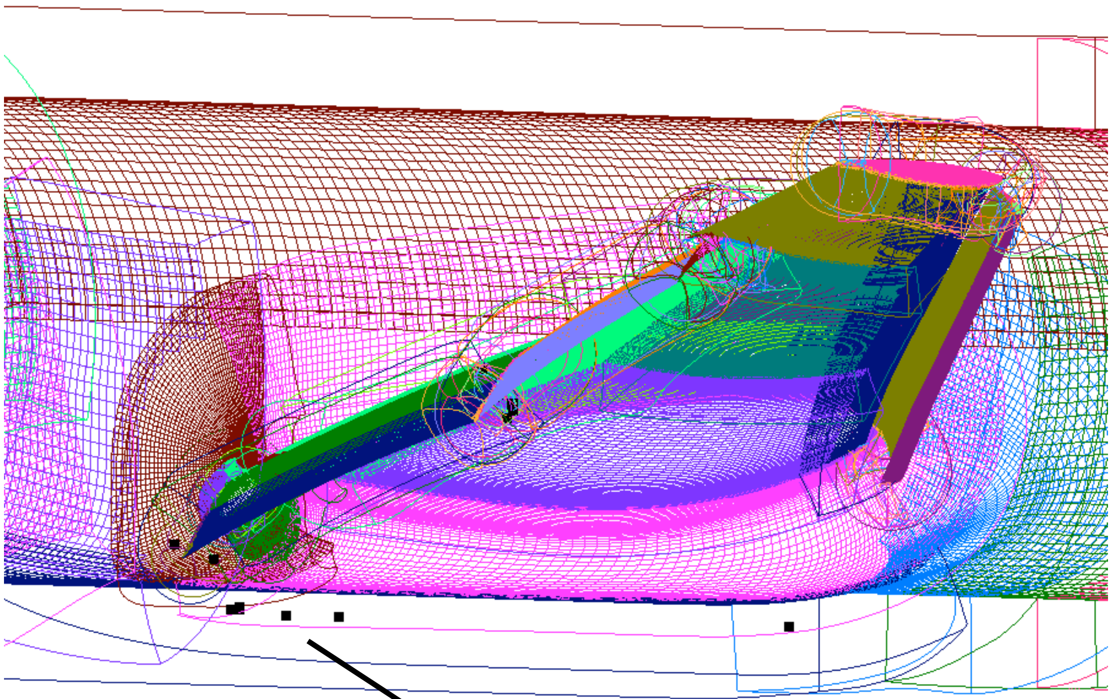
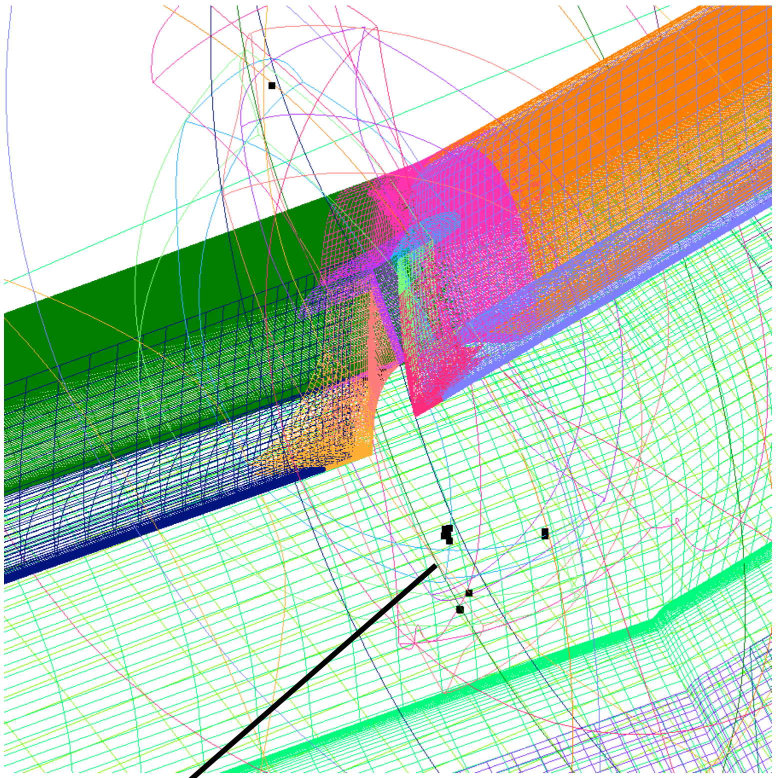
GRID QUALITY CHECK UTILITIES IN CGT (2)
Domain Connectivity: Orphan Points

Number, location and spread (OVERGRID)





Total = 25, sparse points away from surface

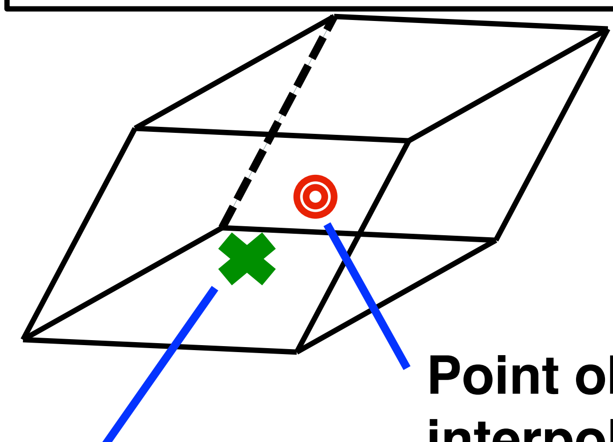
GRID QUALITY CHECK UTILITIES IN CGT (3)

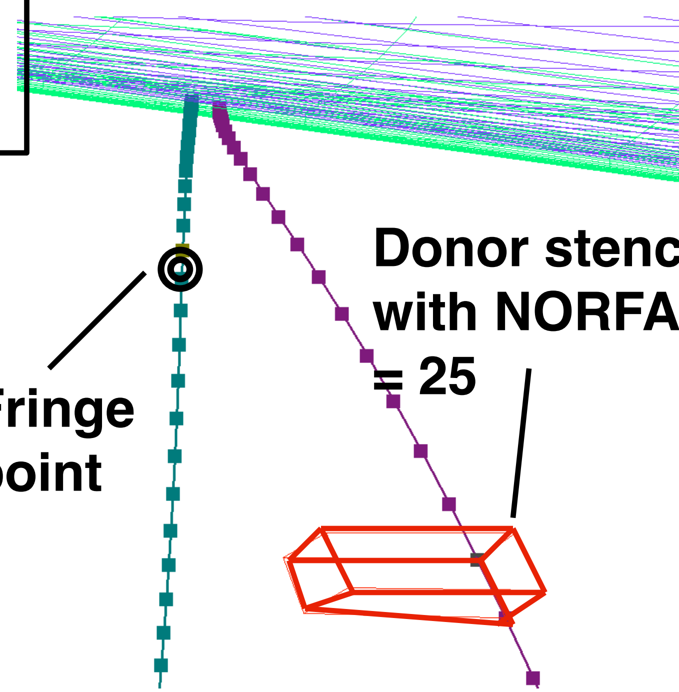
Domain Connectivity: Fringe Point Donor Stencil Accuracy

Histogram of distance between fringe point and vertex obtained by donor stencil interpolation (*intchk* tool in CGT)

Distance	Number of pts	% Total
d < 0.0001,	2592370,	89.207
0.0001 <= d < 0.001,	127886,	4.401
0.001 <= d < 0.01,	128241,	4.413
0.01 <= d < 0.1,	47312,	1.628
0.1 <= d < 1.0,	10167,	0.350
1.0 <= d < 10.0,	49,	1.7E-03
10.0 <= d,	0,	0.0

Set NORFAN carefully in OVERFLOW for viscous stencil repair





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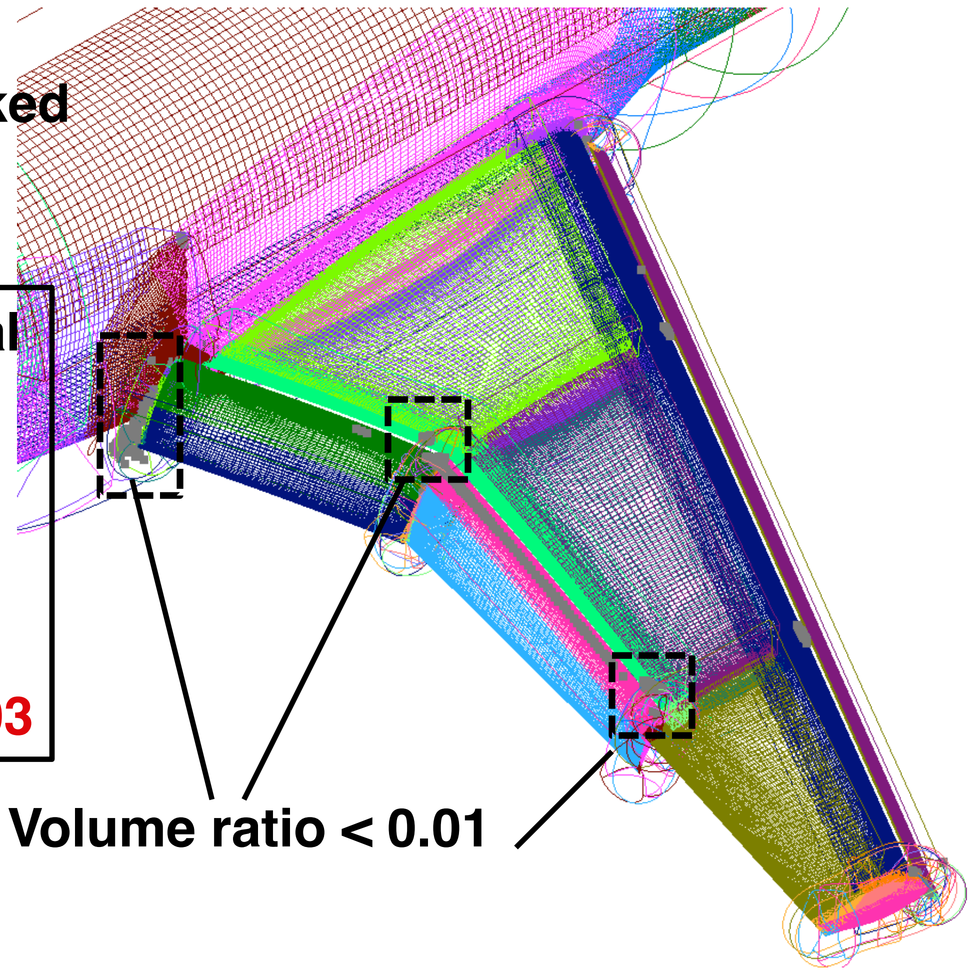
GRID QUALITY CHECK UTILITIES IN CGT (4)
Domain Connectivity: Donor Stencil Attributes Compatibility

Compatibility of cell attributes between fringe point and donor stencil
- Cell volume ratio histogram table (intchk) and location map (OVERGRID)
- Bad ratio => gradients cannot be transferred accurately between grids

Other attributes that could be checked
- Cell aspect ratio, orientation

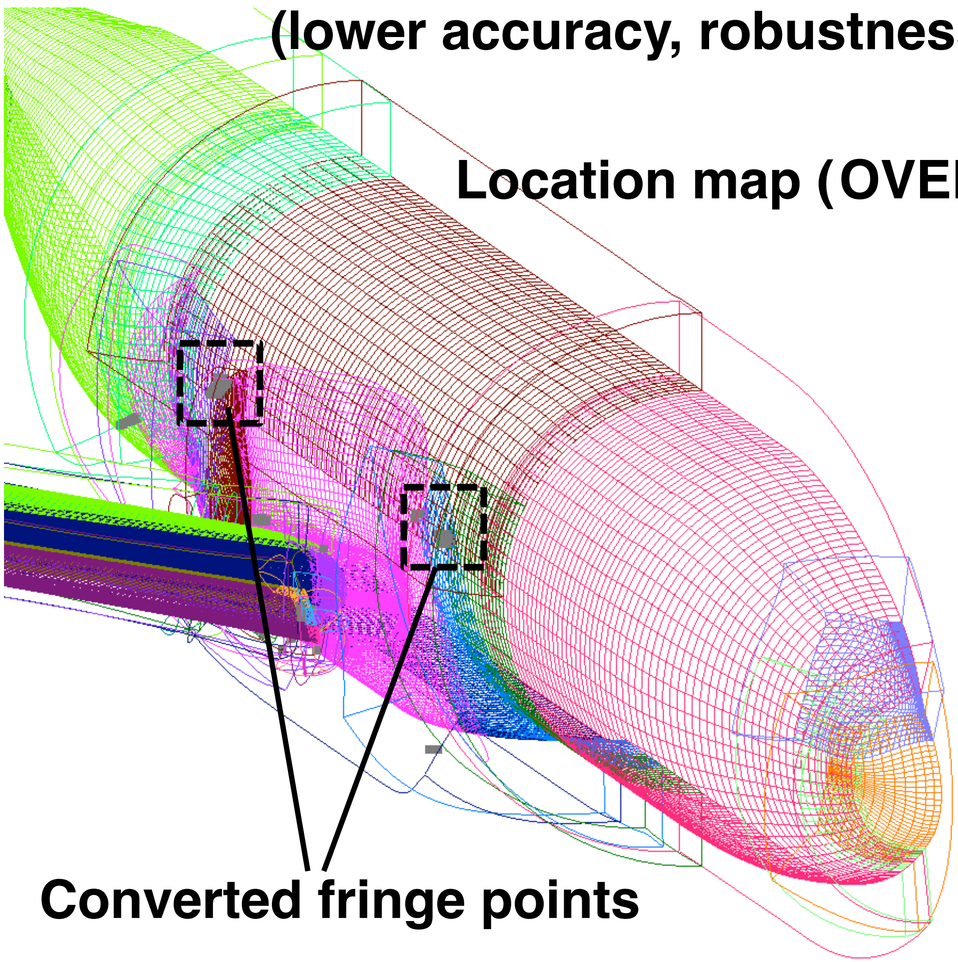
Volume ratio	# Pts.	% Total
0.5 <= C <= 1.0	2714268	48.26
0.2 <= C < 0.5	1705036	30.32
0.1 <= C < 0.2	670232	11.92
0.01 <= C < 0.1	525048	9.34
0.001 <= C < 0.01	9631	0.17
C < 0.001	21	0.37E-03

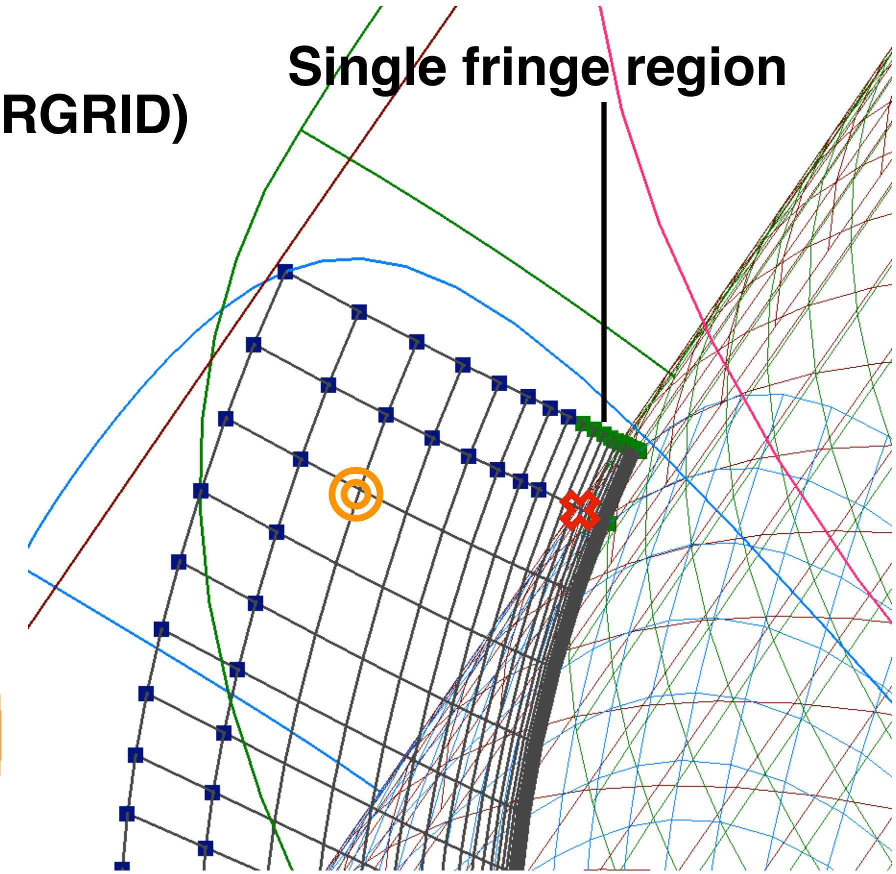


GRID QUALITY CHECK UTILITIES IN CGT (5)

Domain Connectivity: Conversion to Lower Fringe Layers

- Insufficient grid overlap to support double fringe locally
- Option to convert from double fringe to single fringe
  => full 5-point differencing stencil not supported in flow solver (lower accuracy, robustness)





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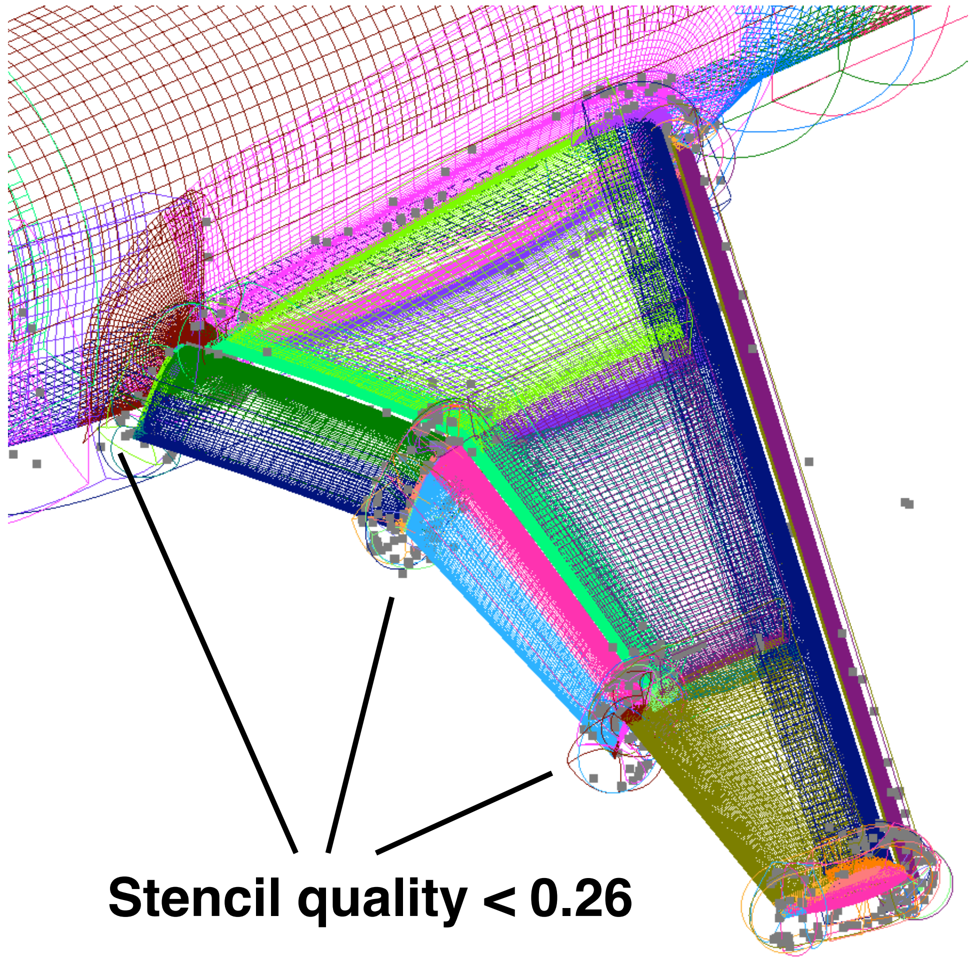
GRID QUALITY CHECK UTILITIES IN CGT (6)
Domain Connectivity: Donor Stencil Quality

Histogram table (intchk) and location map (OVERGRID)

Stencil Quality	Number	% Total
Q = 0.0	0	0.0000
0.0< Q < 0.1	0	0.0000
0.1<= Q < 0.2	0	0.0000
0.2<= Q < 0.3	4858	0.1672
0.3<= Q < 0.4	12120	0.4171
0.4<= Q < 0.5	14660	0.5045
0.5<= Q < 0.6	14054	0.4836
0.6<= Q < 0.7	19504	0.6712
0.7<= Q < 0.8	24788	0.8530
0.8<= Q < 0.9	23280	0.8011
0.9<= Q < 1.0	45317	1.5594
Q = 1.0	2573858	88.5697



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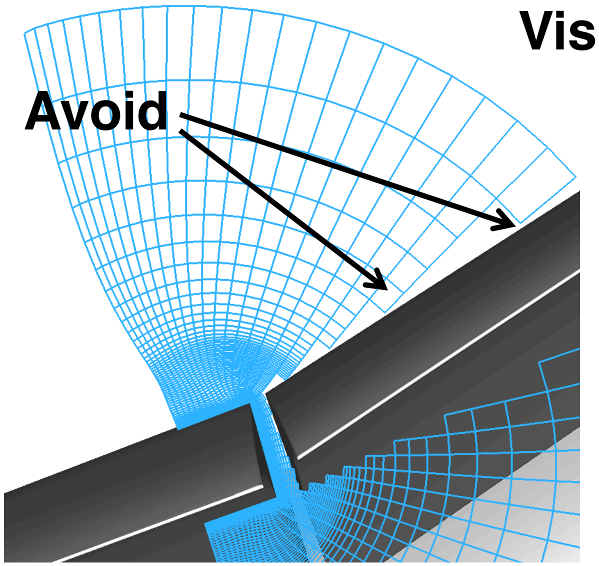
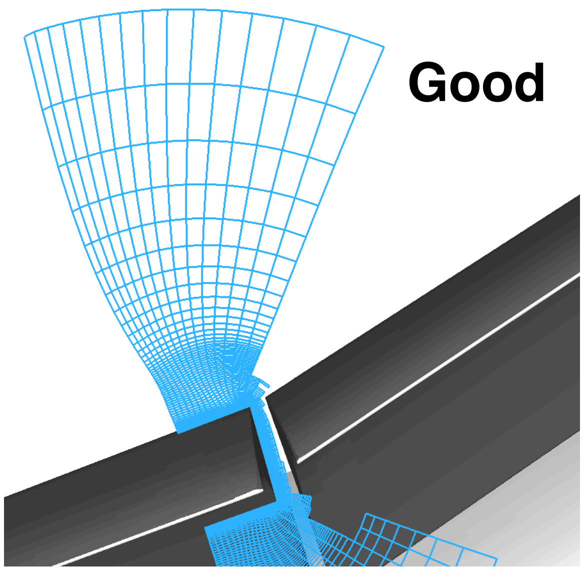
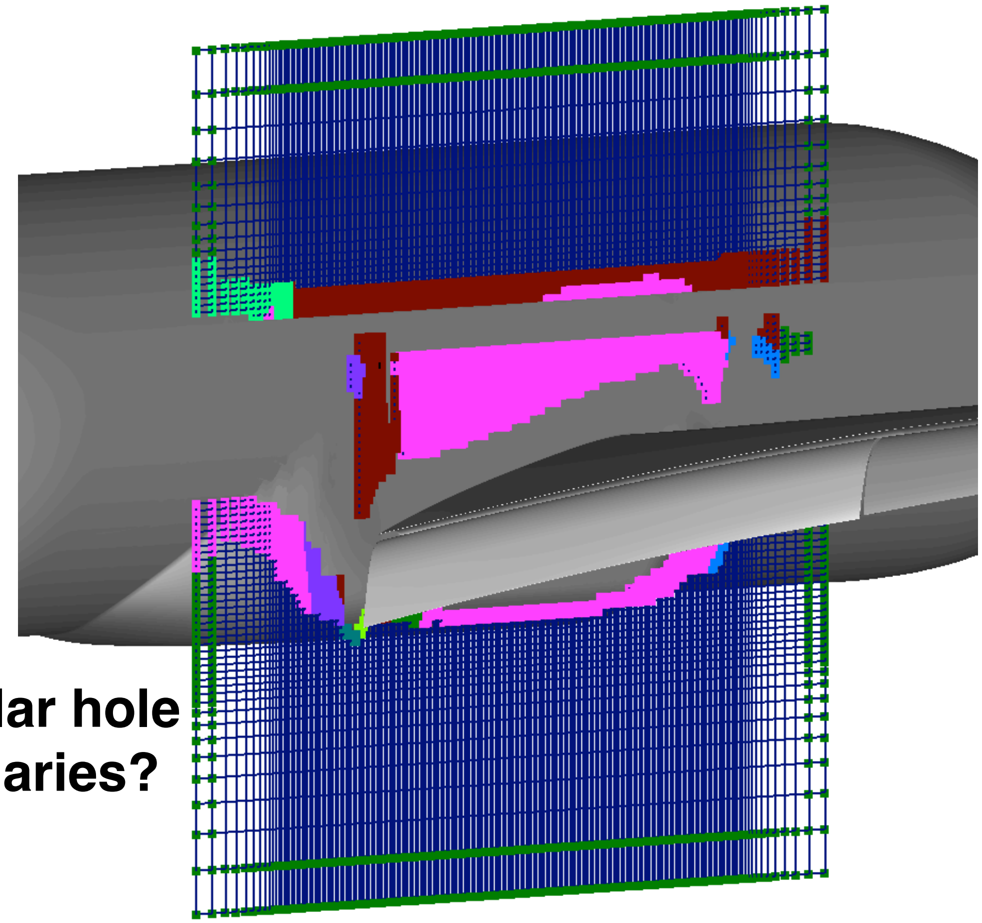
GRID QUALITY CHECK UTILITIES IN CGT (7)

Domain Connectivity: Hole Boundary Location & Smoothness

Visualization in OVERGRID







Irregular hole boundaries?

Chan, Pandya, Rogers, Efficient Creation of Overset Grid Hole Boundaries and Effects of Their Locations on Aerodynamic Loads, AIAA Paper 2013-3074, 2013.

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SUMMARY AND CONCLUSIONS (1)
Workshop Baseline Meshes

- Grid systems generated and scripted using Chimera Grid Tools
  - Full flap gap geometry (coarse, medium, fine, and extra fine levels)
  - Partially-sealed flap gap (medium only)

- Workshop guidelines are mostly consistent with current overset grid generation best practices

- Surface grid generation is the most time consuming step

- Some adjustments needed in developing grid scripts for different levels of grid resolution => ideas for further automation development

- Total development time for all 5 systems ~ 121 man hours

- Grid script execution time ~ a few minutes (coarse, medium, fine), half hr.+ (extra-fine)

- Preliminary solutions have been computed using OVERFLOW for all 5 grid systems

SUMMARY AND CONCLUSIONS (2)
Grid Quality Checks

- Effective evaluation using histograms and location maps

- Wish list
  - Distance to geometry
  - Distance of first volume grid point to wall
  - Cell orthogonality

- Must-pass grid quality checks
  - Jacobians and self-intersection on surface

- Mostly-pass grid quality checks
  - Cell volumes
  - Various domain connectivity statistics
  - Need study on how flow solution is affected
    - Accuracy
    - Convergence
    - Robustness / Stability

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