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PROGRESS IN AUTOMATION OF OVERSET STRUCTURED SURFACE GRID GENERATION

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NASA Ames Research Center

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OVERVIEW

- A brief history of current technology

- Starting point and objectives

- Overview of three main steps

- Algebraic step details

- Future plans for subsequent steps

- Summary and conclusions

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STRUCTURED OVERSET GRID CFD PROCESS

CAD Geometry

Surface Grid Generation

Volume Grid Generation

Domain Connectivity

Flow Solution Computation

Post-processing

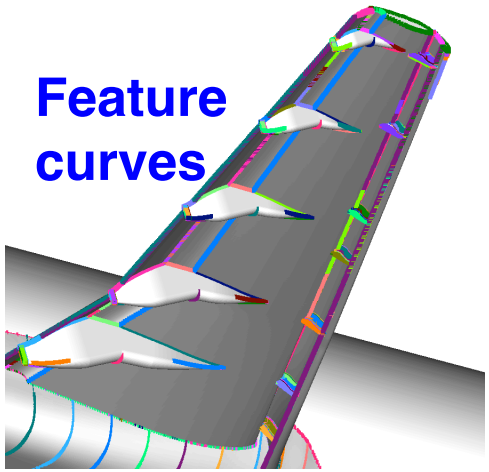
Aerodynamic loads
Flow field features

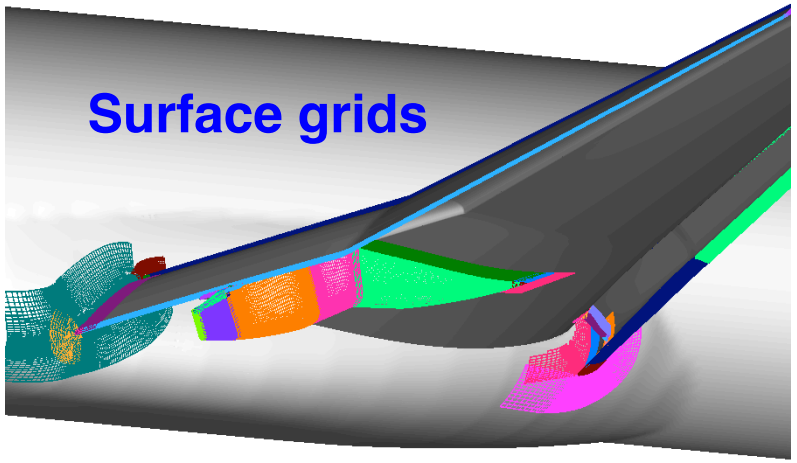
Grid Generation Time

80+% → Surface features identification
Domain decomposition
Grid point distribution
Surface mesh creation
Surface coverage

< 5% → Very simple for good surface grids

5-15% → Depends on algorithm/software





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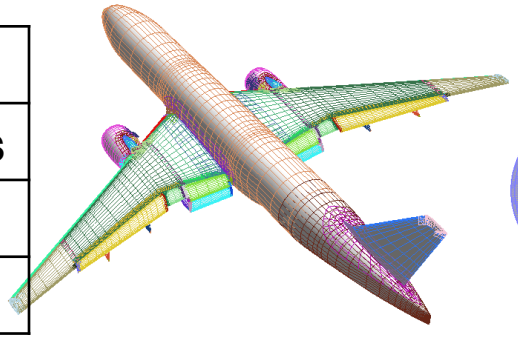
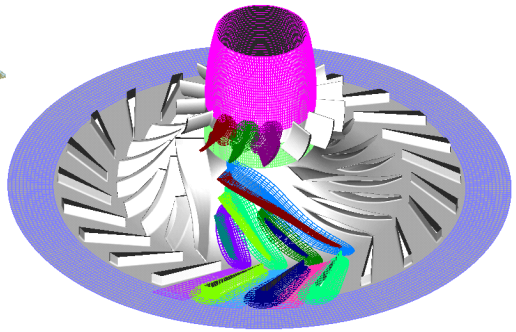
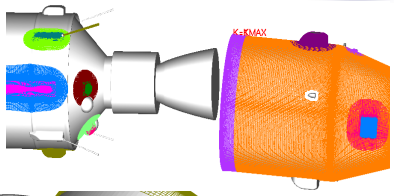
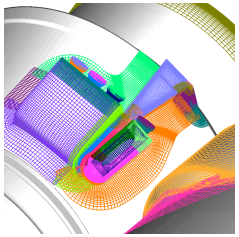
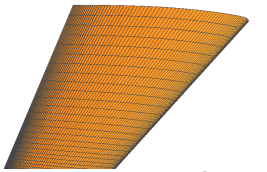
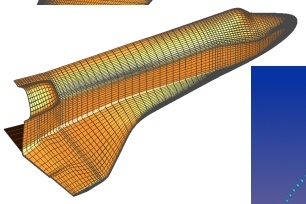
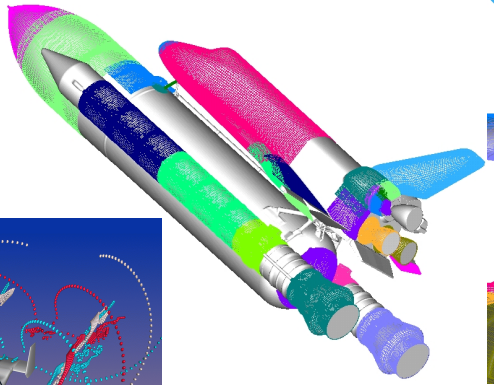
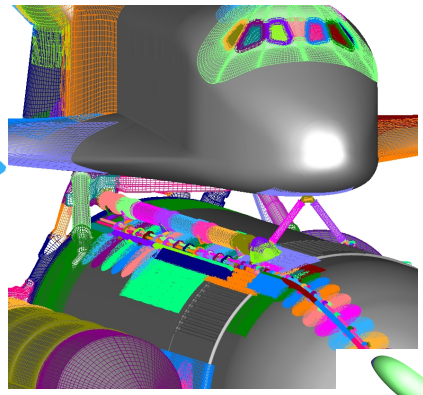
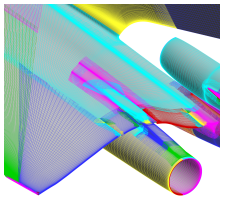
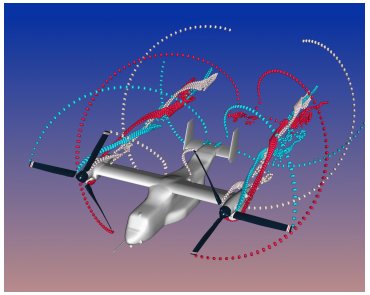
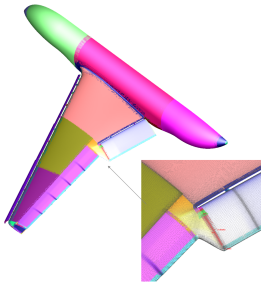
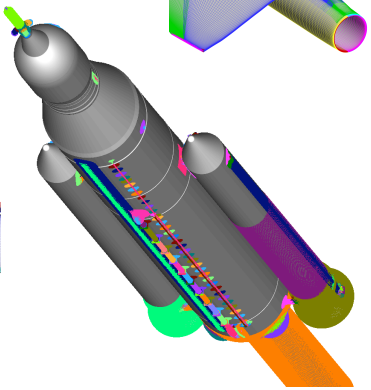
A BRIEF HISTORY

	Number of
C	components
G	grids
P	grid points

1980's
Fortran programs
No tools
No GUIs
C < 10
G < 10
P < 10M

1990's
Chimera Grid Tools, grid-centric scripts, Gridgen, Overture, C ~ 50
G ~100, P ~ 50M

2000's
CGT Script Library, parameterized, component-centric scripts, Glyph,
C ~ 100, G ~ 200,
P ~ 100M

2010's
Parallelized using team of workers,
C ~ 100's, G ~ 1000,
P ~ 100's M

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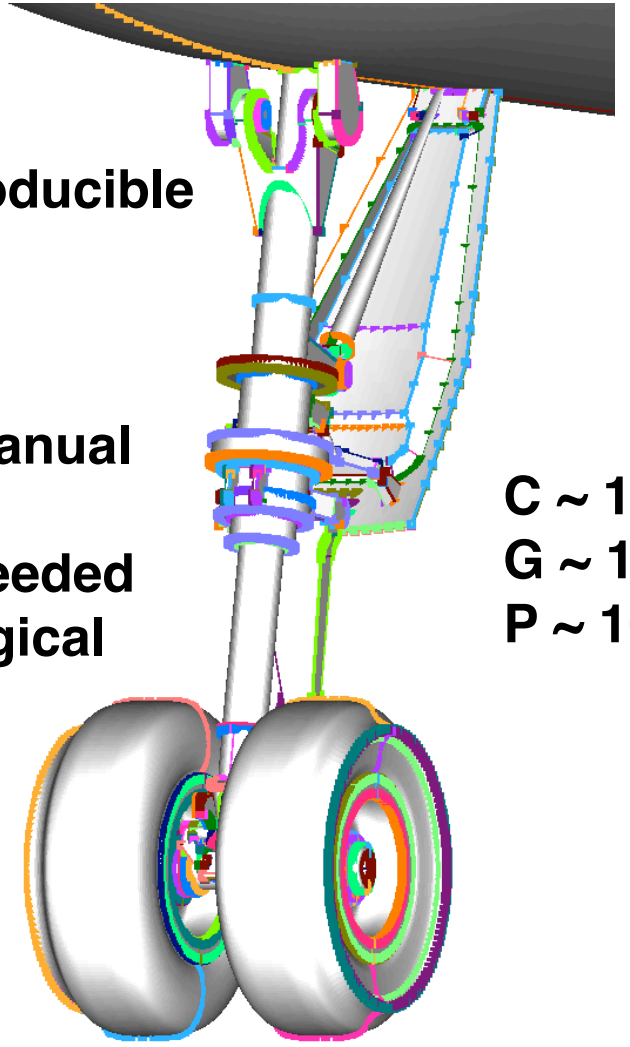
CURRENT TECHNOLOGY LIMITATIONS AND FUTURE COMPUTATIONS

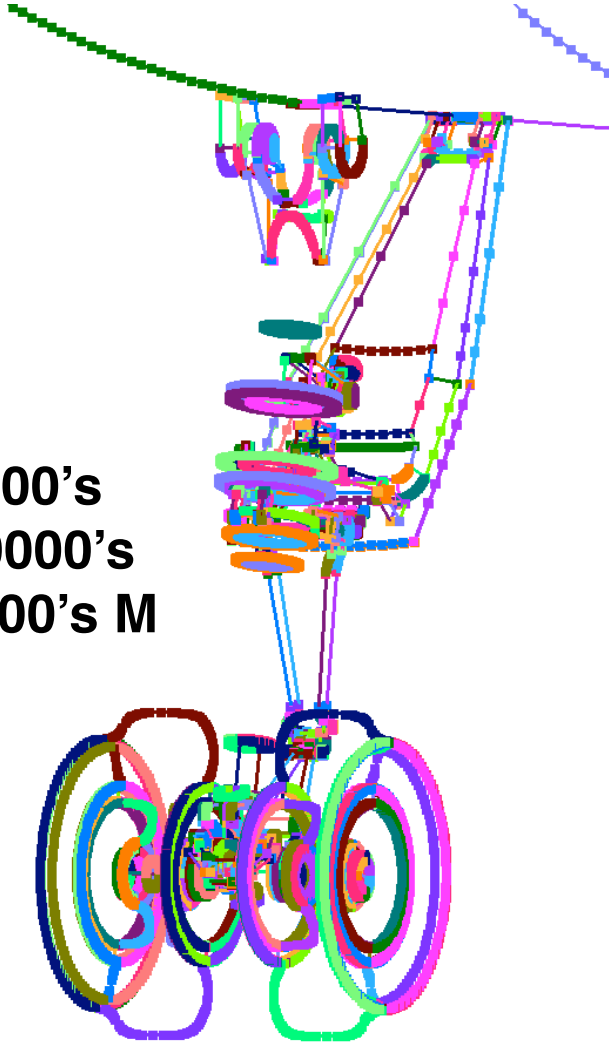
GUI limitations

- Steps not easily reproducible
- Not parameterized

Scripting limitations

- Require significant manual effort to build
- Script modification needed even for small topological changes





C ~ 1000's
G ~ 10000's
P ~ 1000's M

- Manual scripting approach (even with team) is no longer practical
- Difficult to achieve higher level of abstraction beyond component level

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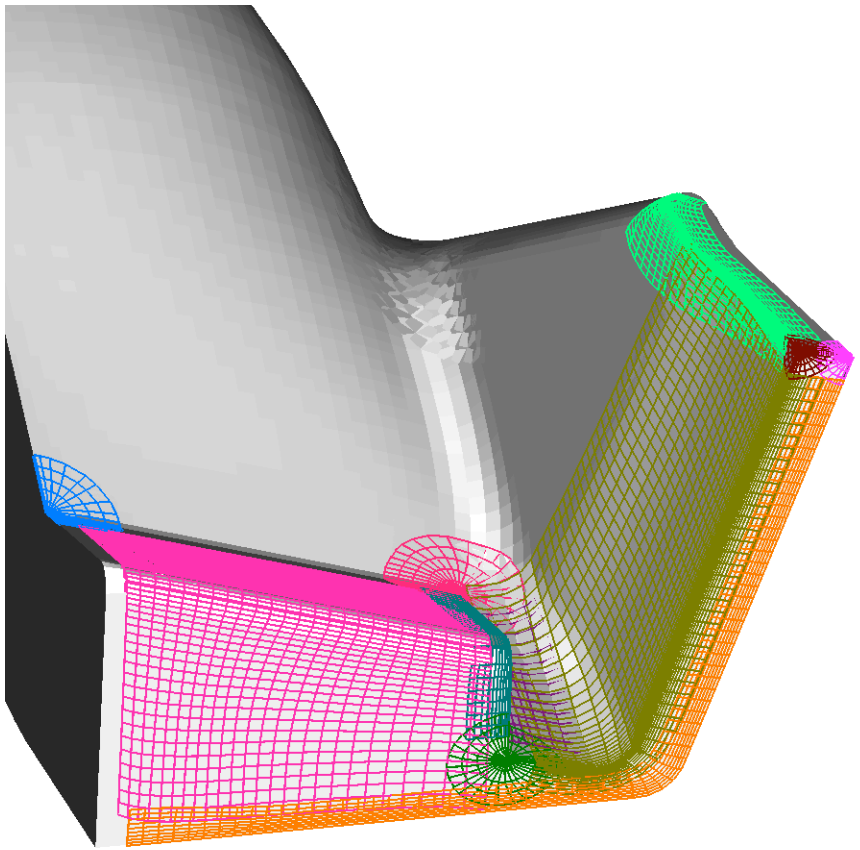
PREVIOUS WORK ON SURFACE GRID GENERATION AUTOMATION

Chan and Gomez
(AIAA Paper 99-3303)
Cover surface features using hyperbolic grids at feature edges and spider web grids at junctions



Dannenhoffer and Haimes
(AIAA Paper 2011-3540)
Use feature trees from CAD solid models to construct grids from basic solid shapes using union and intersection operations

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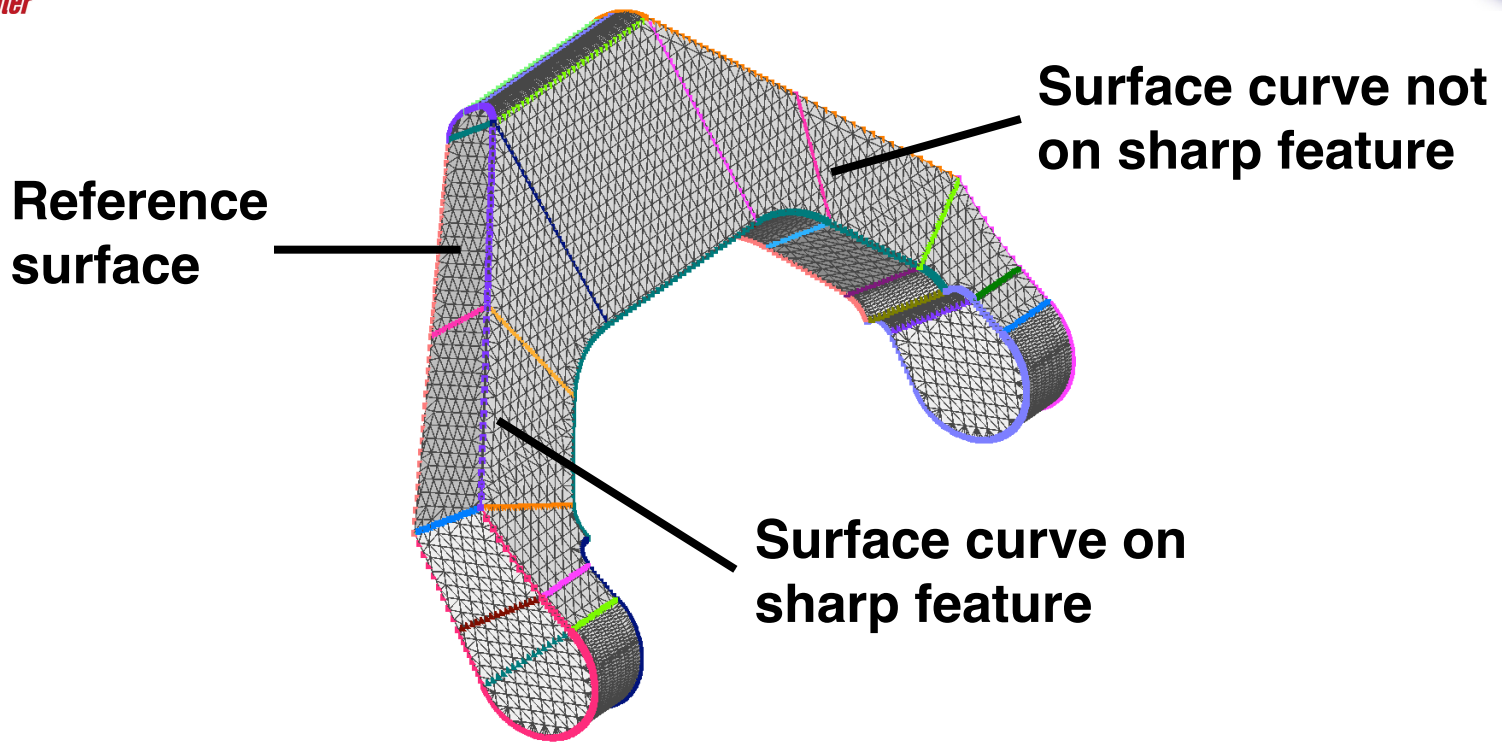
STARTING POINT



- Unstructured surface triangulation geometry representation derived from native CAD, STEP or IGES file with proper resolution of high curvature regions
- Discrete surface curves (subset of triangulation edges)
  - Surface features: sharp edges, max curvature curves (e.g., leading edges), open boundaries
  - CAD patch boundaries
  - Network forms a tesselation of the surface geometry

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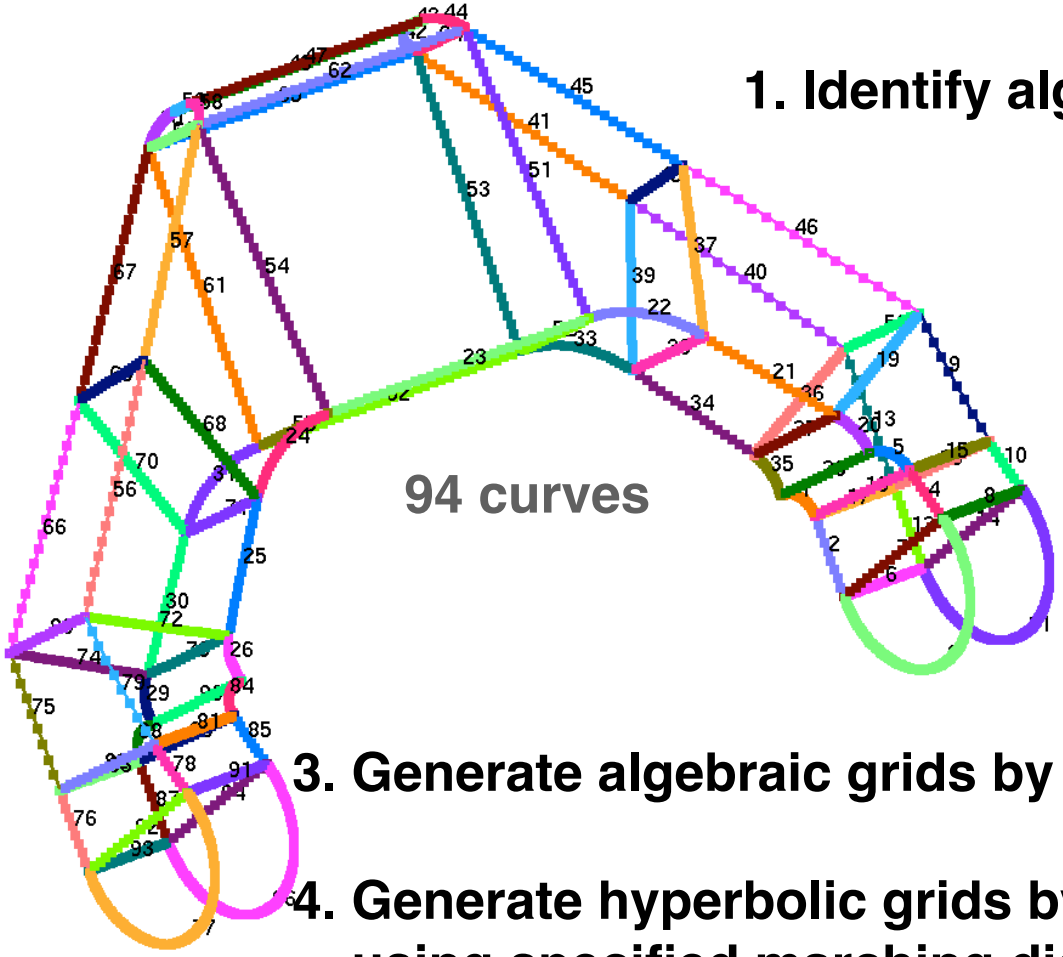
CURRENT MANUAL PROCEDURE



1. Identify algebraic and hyperbolic domains

2. Determine grid point distribution on curves:
   - uniform/stretched
   - end point and max spacing
   - match grid points on opposite boundaries

3. Generate algebraic grids by specifying bounding curves set

4. Generate hyperbolic grids by marching from initial curves using specified marching distance, initial and end spacing, max stretching ratio

5. Concatenate algebraic and hyperbolic grids where appropriate

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OBJECTIVES

Develop algorithm/software for overset structured surface grid generation
- Significant manual effort reduction (near term)
- Full automation (long term)

REQUIREMENTS

- Capture essential surface features so that they lie on grid interior
- Distribute grid points to
  - resolve surface and flow features accurately
  - maintain smooth variation with low stretching ratio (trunc. error)
- Maintain NFRINGE points overlap between neighboring grids where NFRINGE is determined by flow solver differencing stencil

GOOD TO HAVE

- Compatibility of cell attributes in overlap regions
- As few domains as possible, but not critical since flow solver will break grids up for MPI runs

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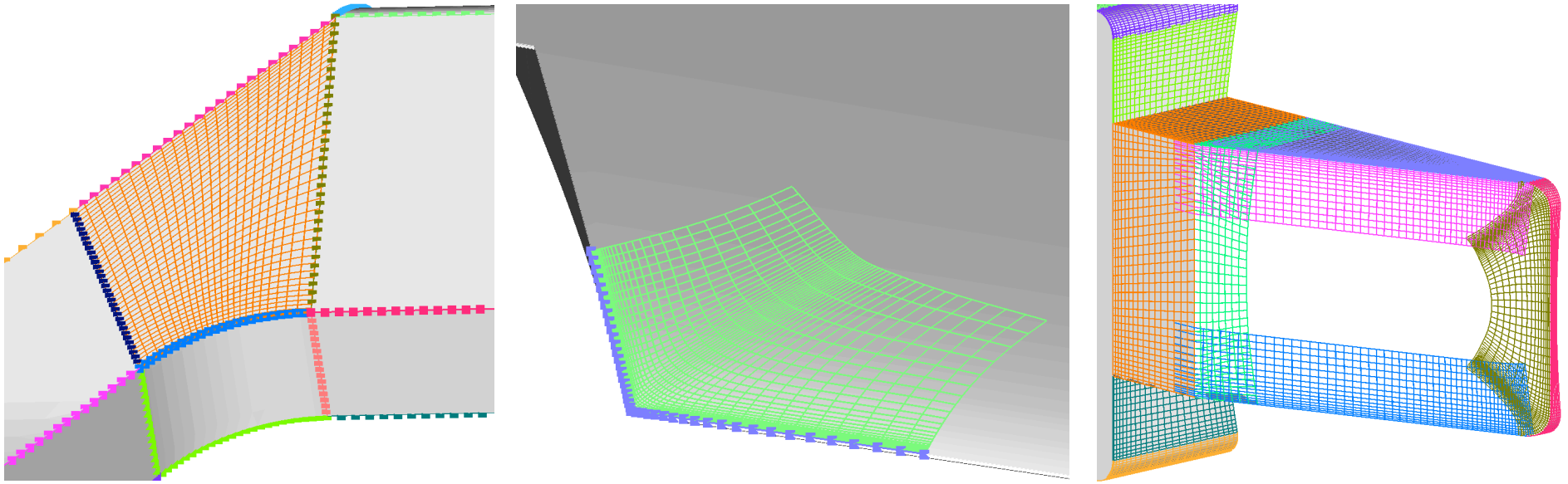
TOP LEVEL DEVELOPMENT PLAN



Build grids around surface features using

1. **Algebraic methods (domains bounded by 4 curves)**
2. **Hyperbolic methods (domains bounded by 1 curve)**

Fill remaining interior gaps on smooth regions of geometry with algebraic or hyperbolic grids

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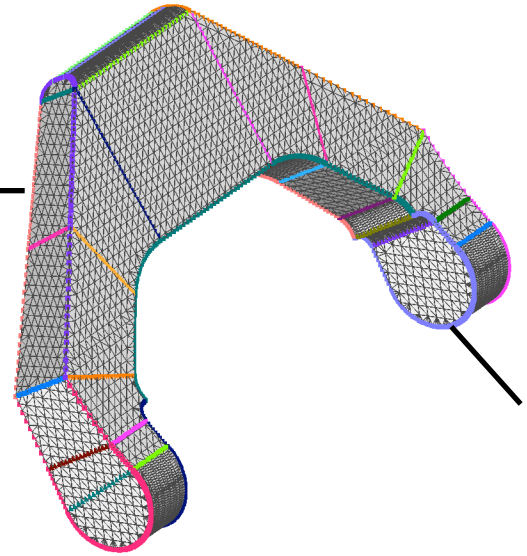
ALGEBRAIC STEP
Control Parameters



Default values in () below

Classification Parameters

θ_{sharp} : curve is a sharp edge curve if it mostly lies on triangulation sharp edges [if angle between neighboring triangles unit normal is larger than θ_{sharp}] (20 deg)

θ_{tot} : curve is turning curve if the total turning angle > θ_{tot} (30 deg)

Grid Point Distribution Parameters

Np_{min} = minimium number of points on a curve (5)

SR_{max} = max stretching ratio (1.2)

Δs_{max} = max interior grid spacing (0.5% of global bounding box diagonal)

θ_{ml} = max local turning angle on turning curves (5 deg)

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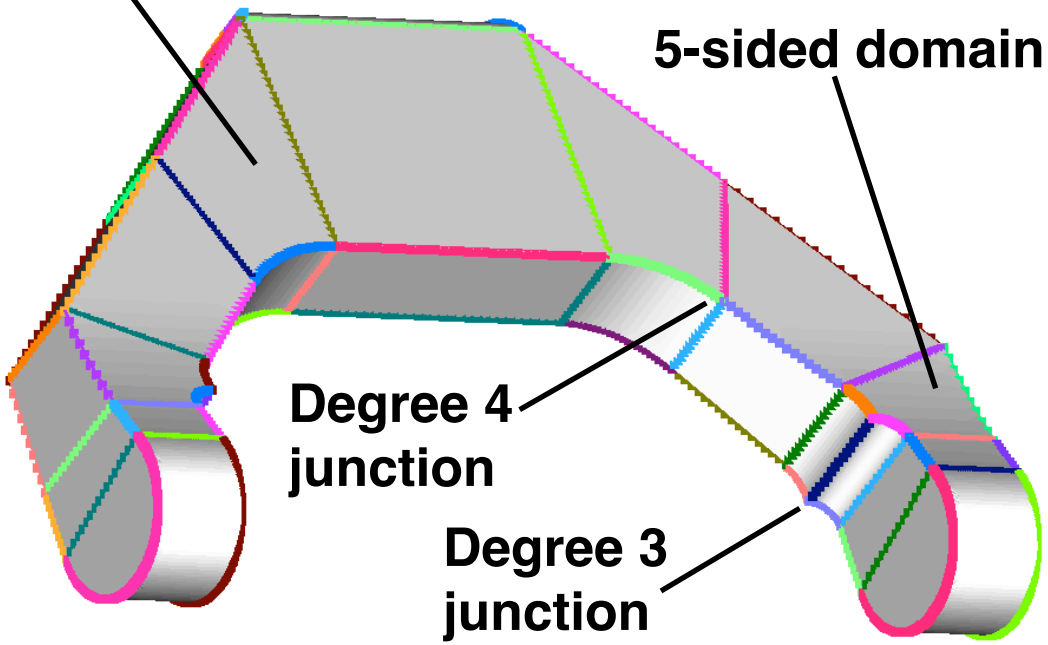
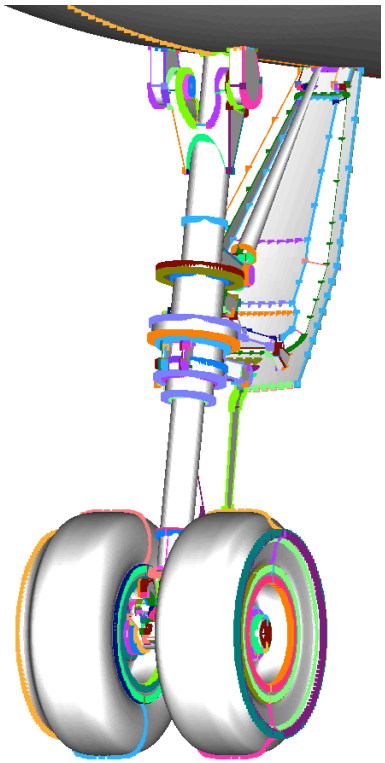
ALGEBRAIC STEP
1. Determine Curves Network Connectivity





Feature curves
Unsplit : 688
Split : 1272

Junctions
Deg 3 : 610
Deg 4 : 149
Deg 5 : 8
> Deg 6 : 0

Four-sided domains : 311

- Split curve at interior point if necessary so that all curves only meet at end points
- Identify all junction points (where 3 or more curves meet)
- Store curve ID and end point for all curves meeting at junction

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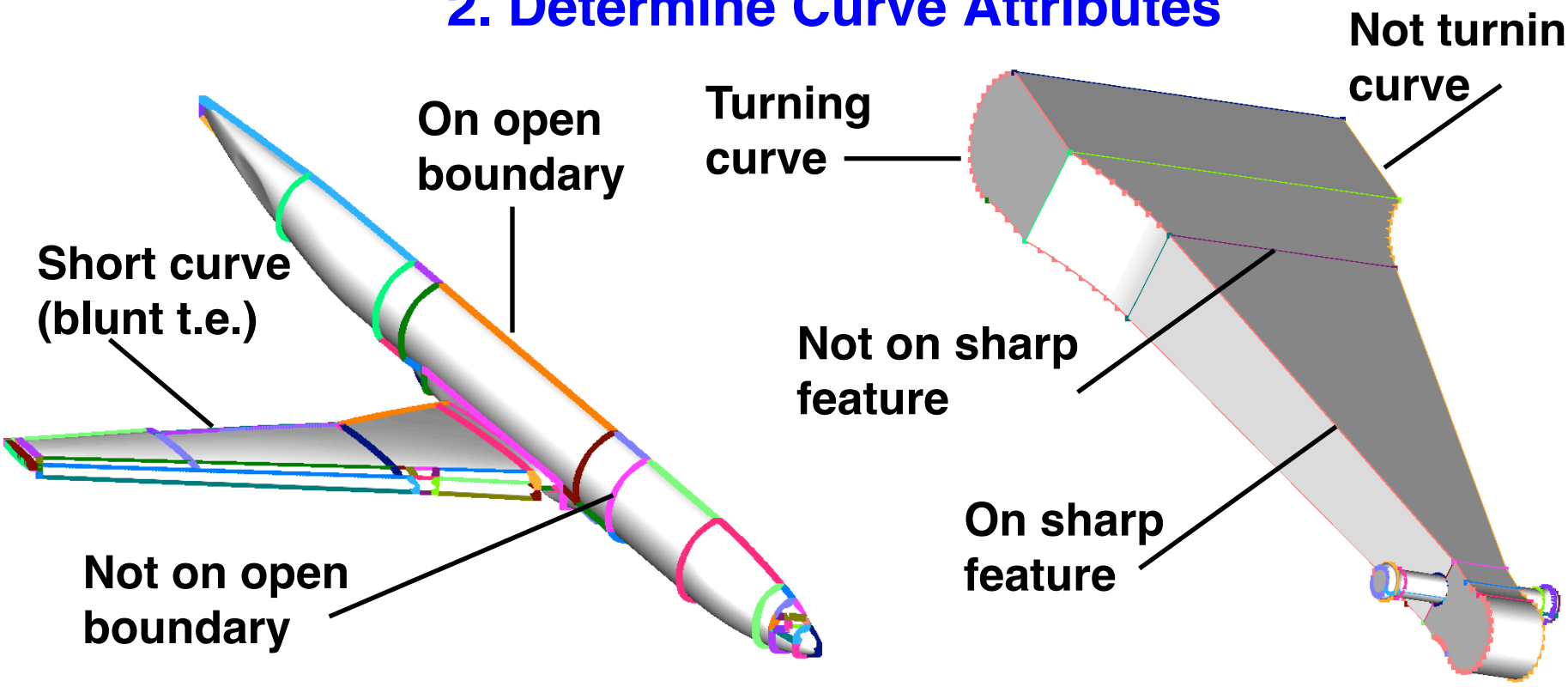
ALGEBRAIC STEP
2. Determine Curve Attributes



- On sharp feature (yes – must preserve, control parameter θ_{sharp})
- On open boundary (yes – can only go one side for grid concatenation)
- Is a "short" curve (total arc length <= $(Np_{min} - 1) * \Delta s_{max}$)
- Is a "turning" curve (total turning angle > θ_{tot})

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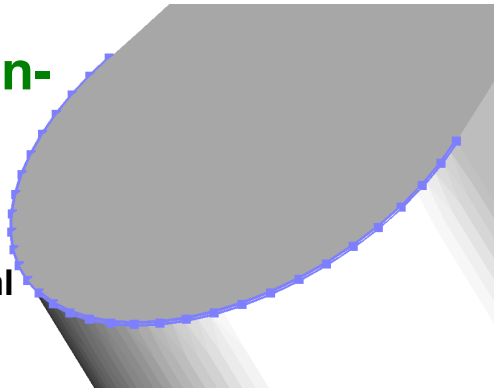
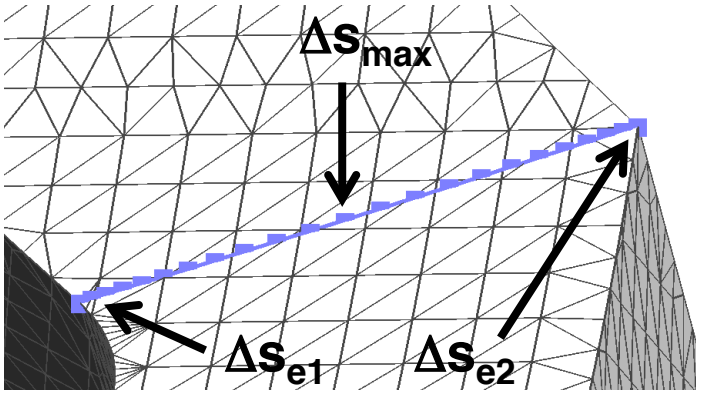
ALGEBRAIC STEP
3. Distribute Grid Points on Curves
3.1. Determine Distribution Type and Spacings

Turning curves or short non-turning curves:

Uniform spacing Δs determined by Np_{min} or θ_{ml}





Long non-turning curves:

Non-uniform spacing hyperbolic tangent distribution with specified

- max stretching ratio SR_{max}
- max interior spacing Δs_{max}
- spacing at end points Δs_{e1} , Δs_{e2}
  - on geometry open boundary $\Delta s_e = 0.5\ \Delta s_{max}$
  - on geometry sharp edge with dihedral angle θ
  - use scale factor $\kappa(\theta)$ such that $\Delta s_e = \kappa(\theta)\ \Delta s_{max}$
    - concave corner ($\kappa > 1$, increases linearly with increasing concavity)
    - convex corner ($\kappa < 1$, decreases negative exponentially with increasing convexity)

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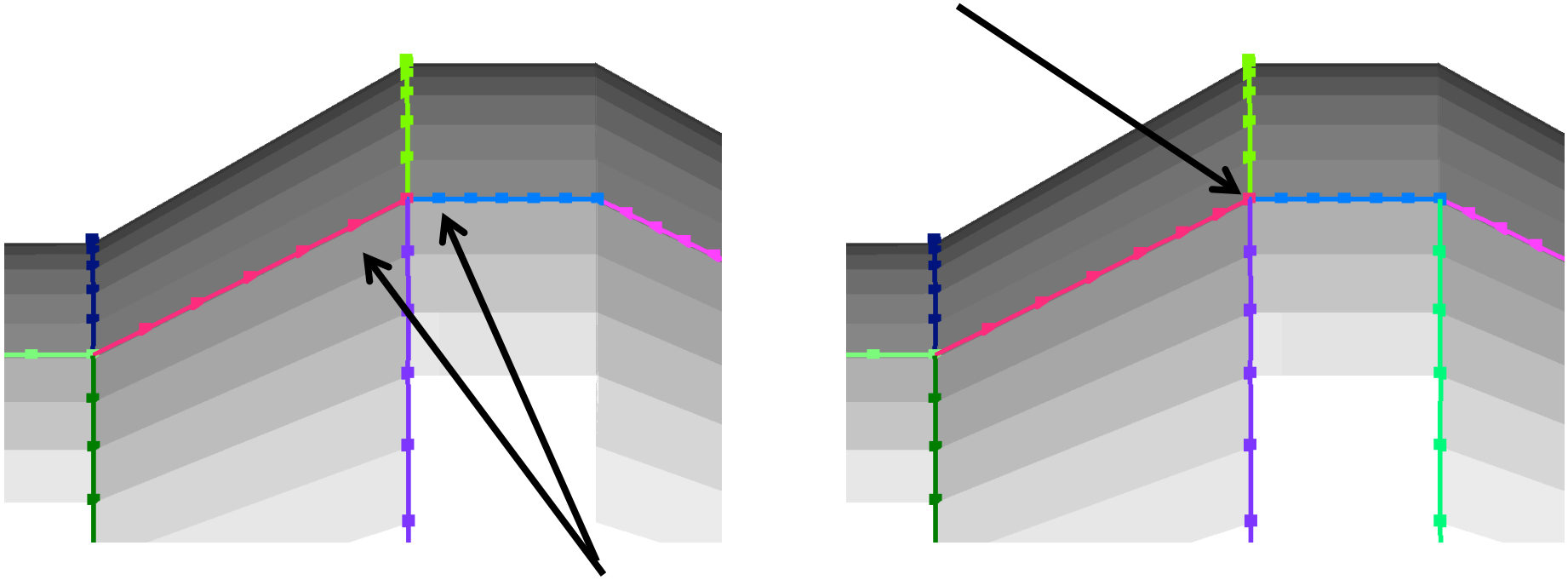
ALGEBRAIC STEP
3. Distribute Grid Points on Curves
3.2. Match Grid Spacing at Junctions

Impose grid spacing continuity for matching curve pairs by taking minimum of predicted grid spacings



Matching pair at junction
(compare curve end point unit vectors at junction)

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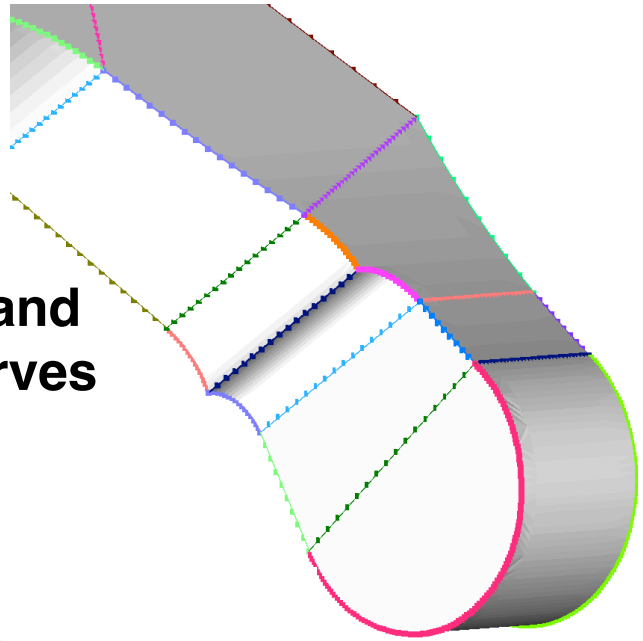
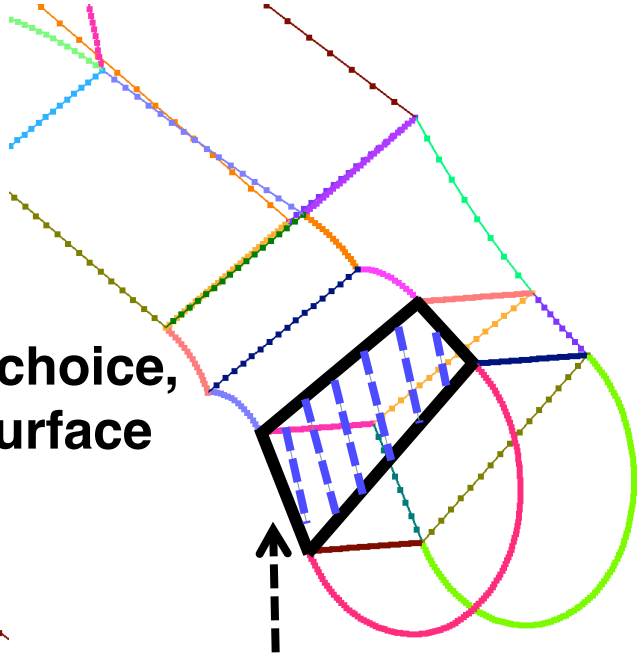
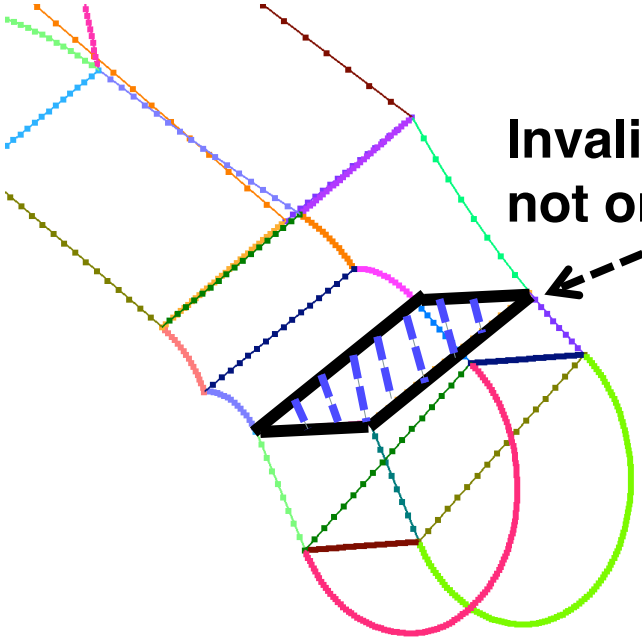
ALGEBRAIC STEP
4. Identify Four-Sided Domains



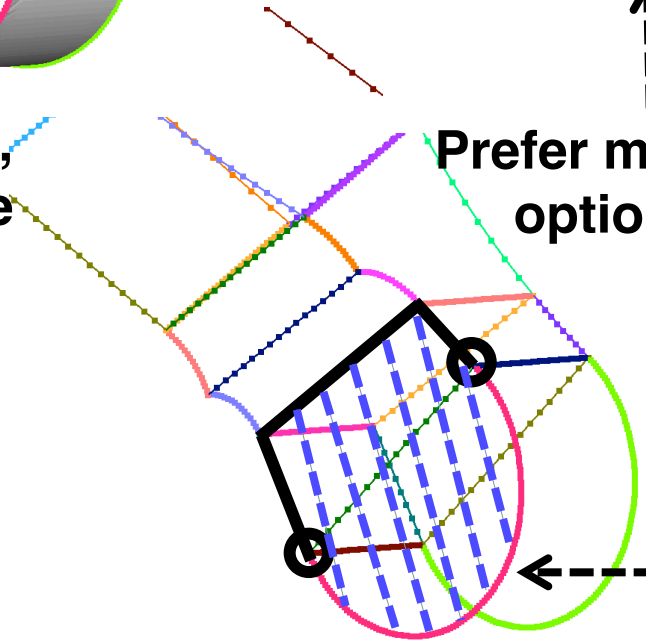
Geometry and surface curves



Valid choice, on surface



Invalid choice, not on surface



Prefer more orthogonal option at corners

Not preferable

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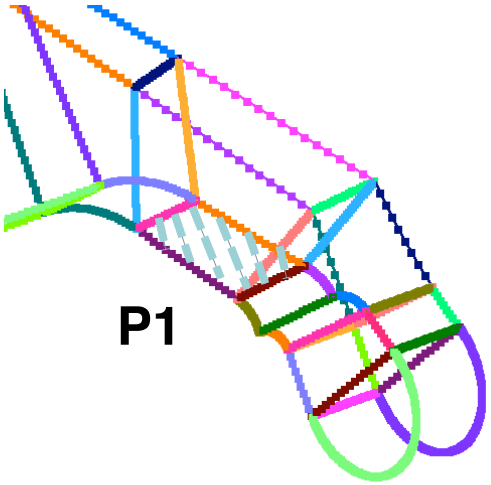
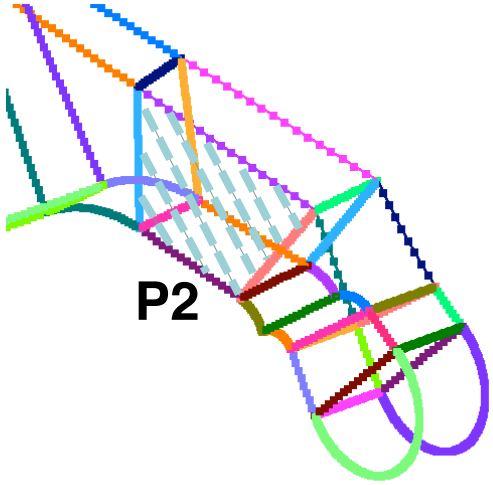
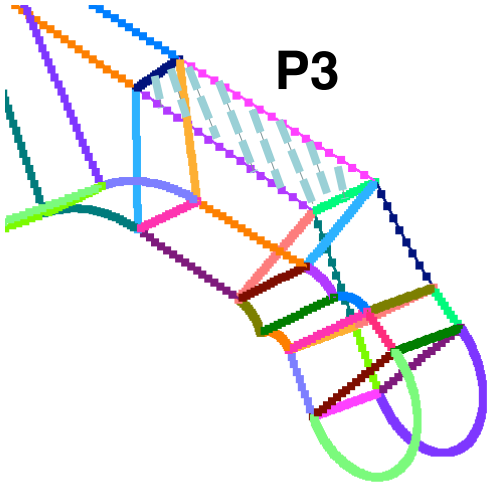
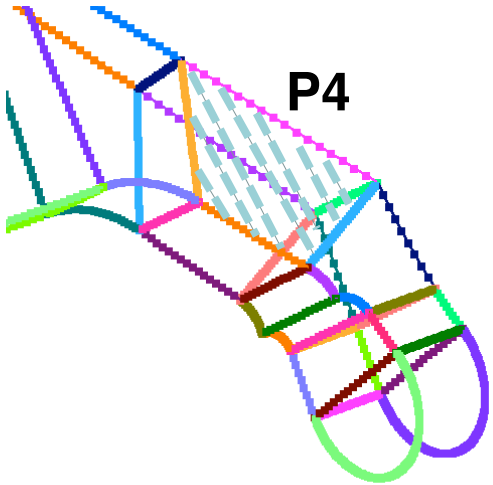
ALGEBRAIC STEP
5. Identify Adjacent Four-Sided Domains for Subsequent Concatenation









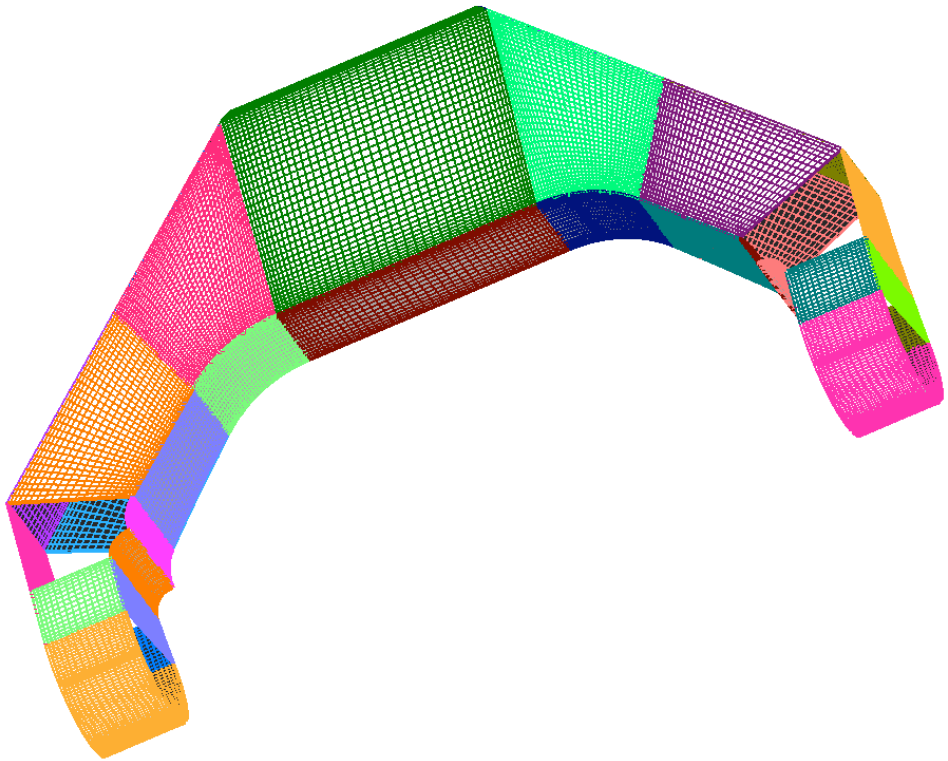
- Start with initial curve on open boundary or sharp edge bounding a four-sided domain

- Look for other four-sided domains that can be concatenated to initial or opposite curve

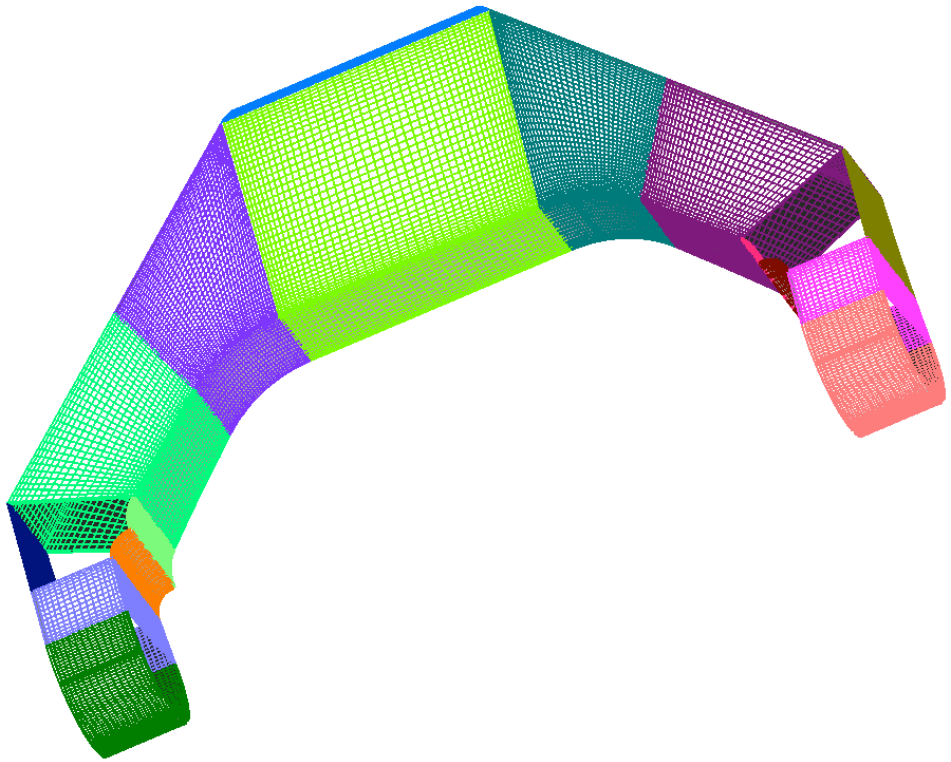
- Single direction sweep only

P1, P2, P3, P4 can be concatenated – impose same number of grid points on curves in concatenation direction

ALGEBRAIC STEP
6. Generate Surface Mesh Using TFI and Concatenate



Before concatenation: 38 patches



After concatenation: 16 patches

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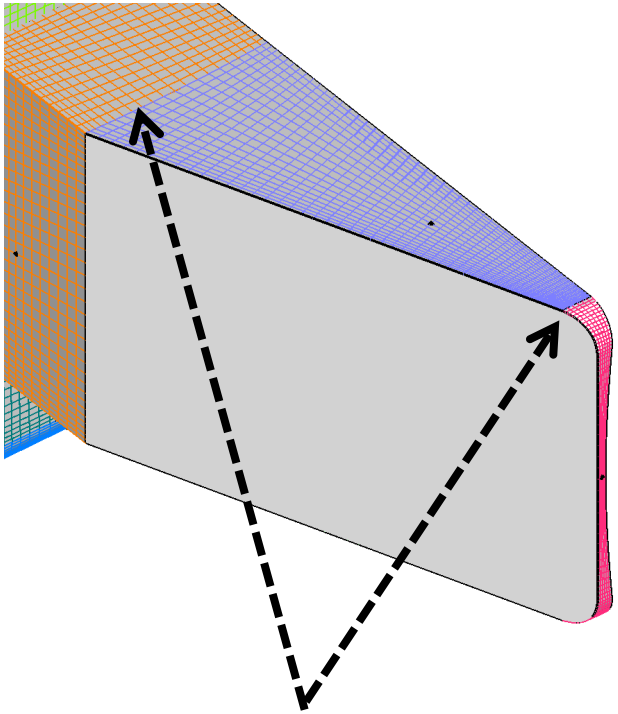
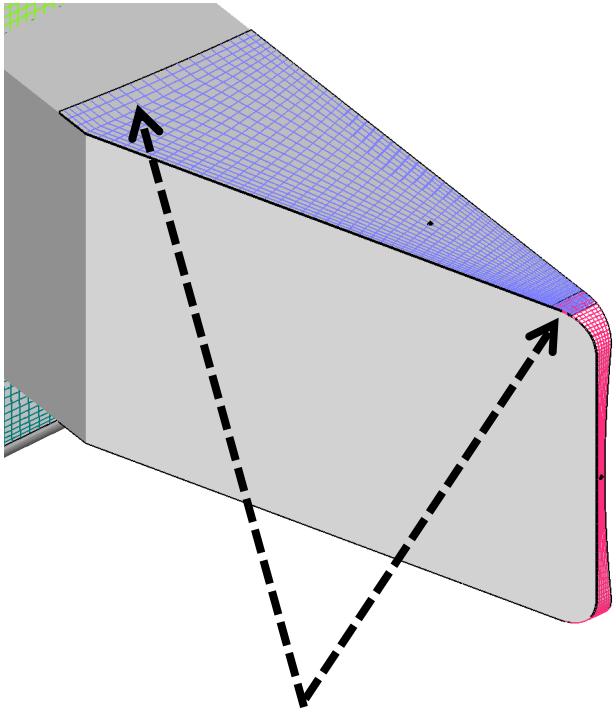
ALGEBRAIC STEP

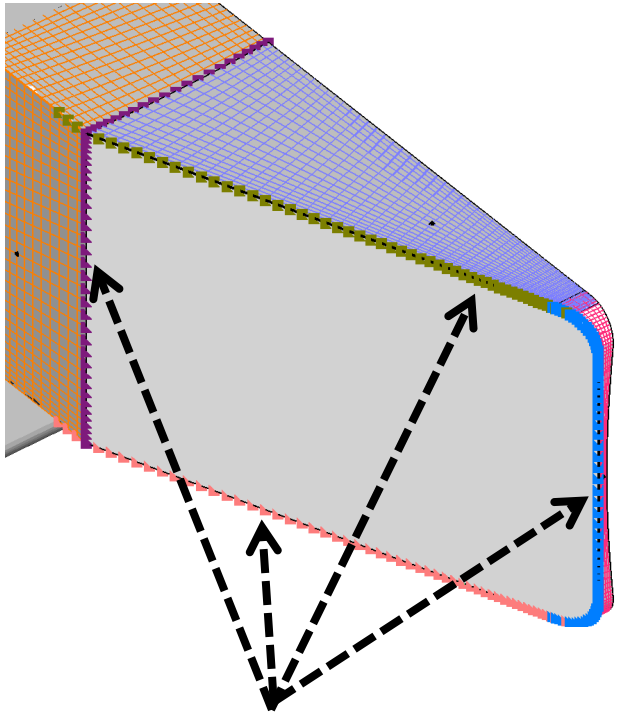
7. Perform TFI Extension at Boundaries and Identify Initial Curves for Hyperbolic Marching (in progress)



Abutting patch boundaries after TFI

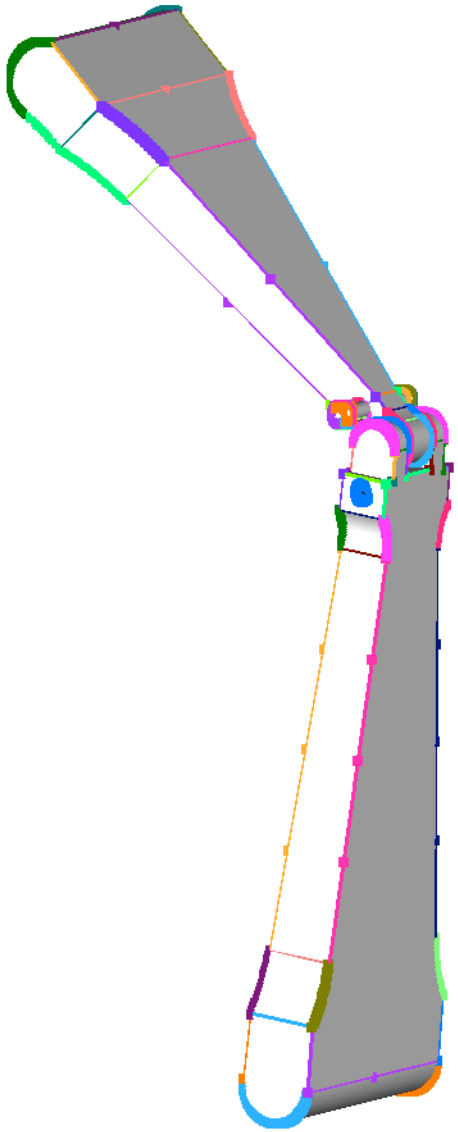


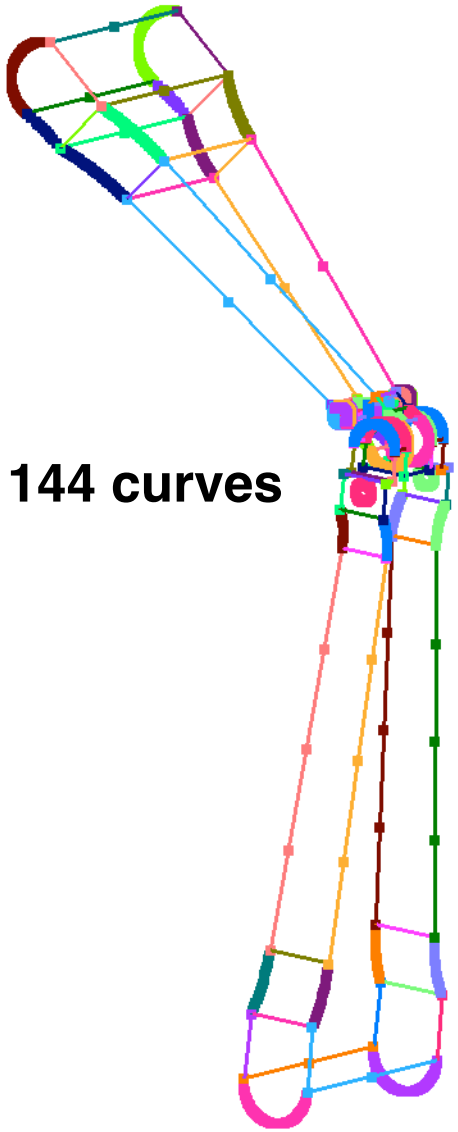
TFI extension at boundaries not on sharp edge



Initial curves on exposed boundaries for hyperbolic marching

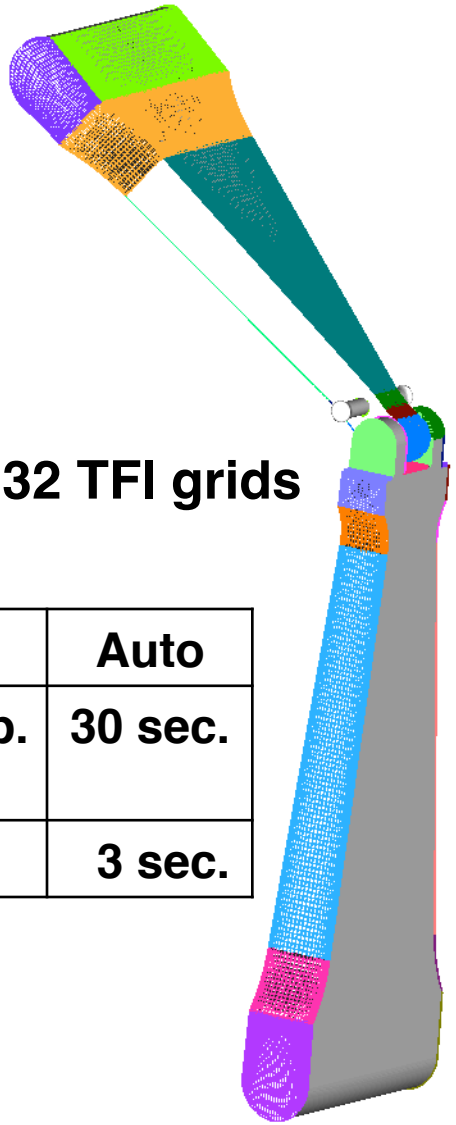
TEST CASES
Landing Gear Strut





144 curves

32 TFI grids



Mode	Auto
Input prep. time	30 sec.
CPU time	3 sec.

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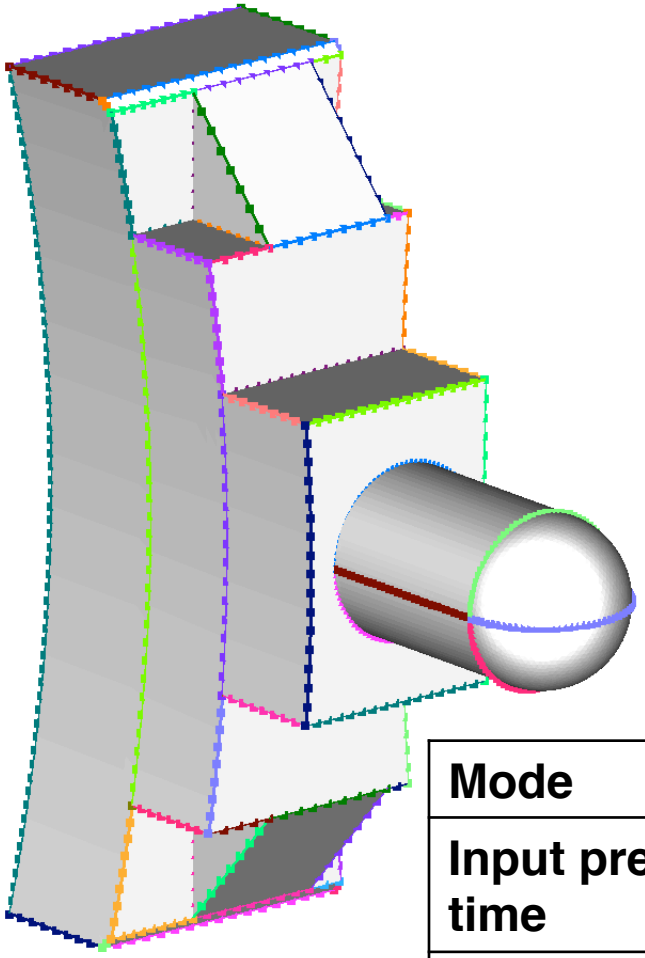
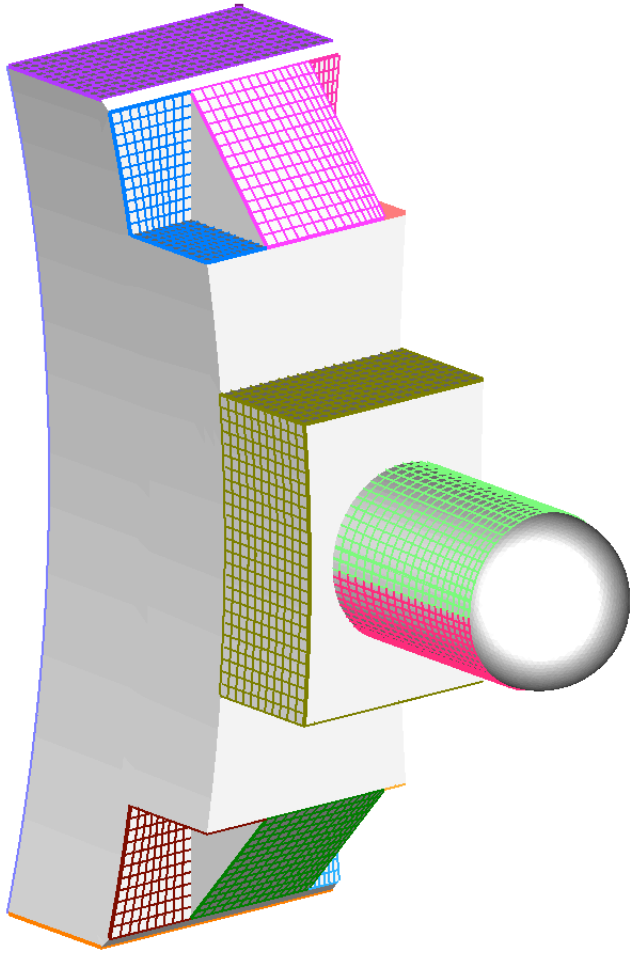
TEST CASES
Attach Hardware



73 curves

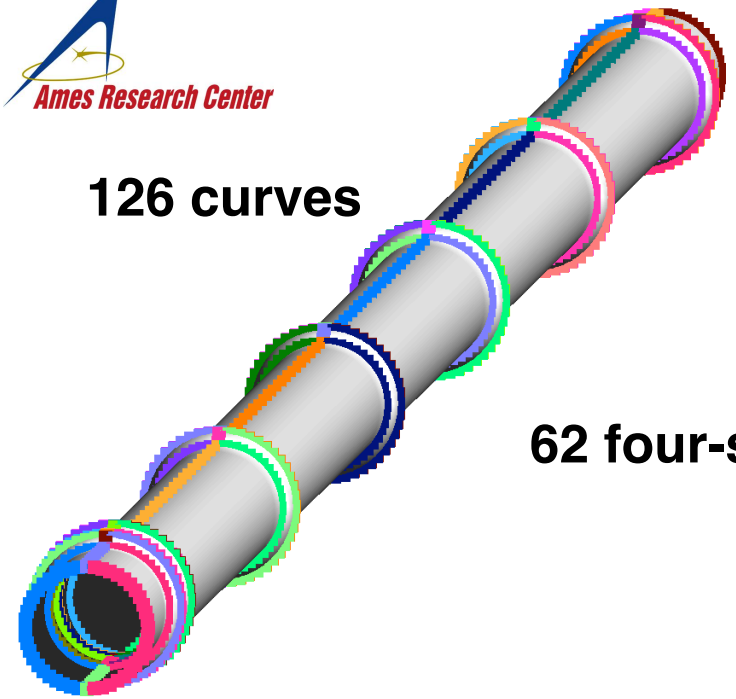
Mode	Auto
Input prep. time	30 sec.
CPU time	2.5 sec.



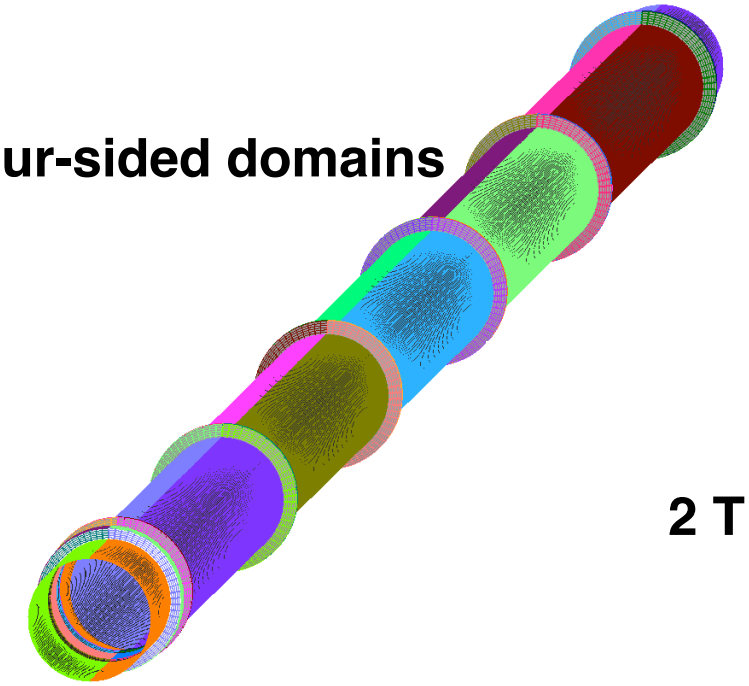
14 TFI grids

TEST CASES
Feedline

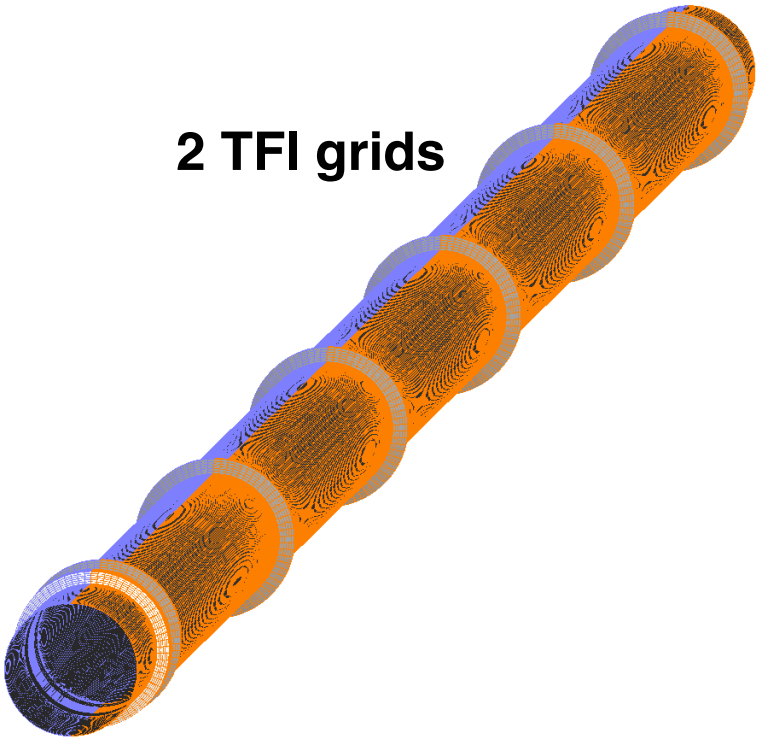
126 curves



62 four-sided domains



2 TFI grids



Mode	Manual	Auto
Input prep. time	30 – 60 min.	30 sec.
CPU time	2 sec.	2.5 sec.

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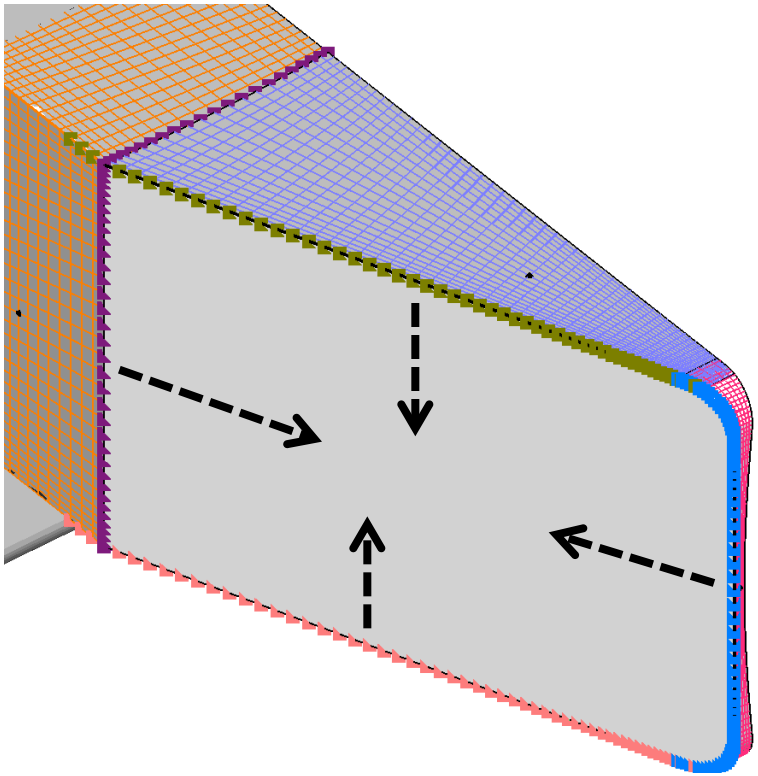
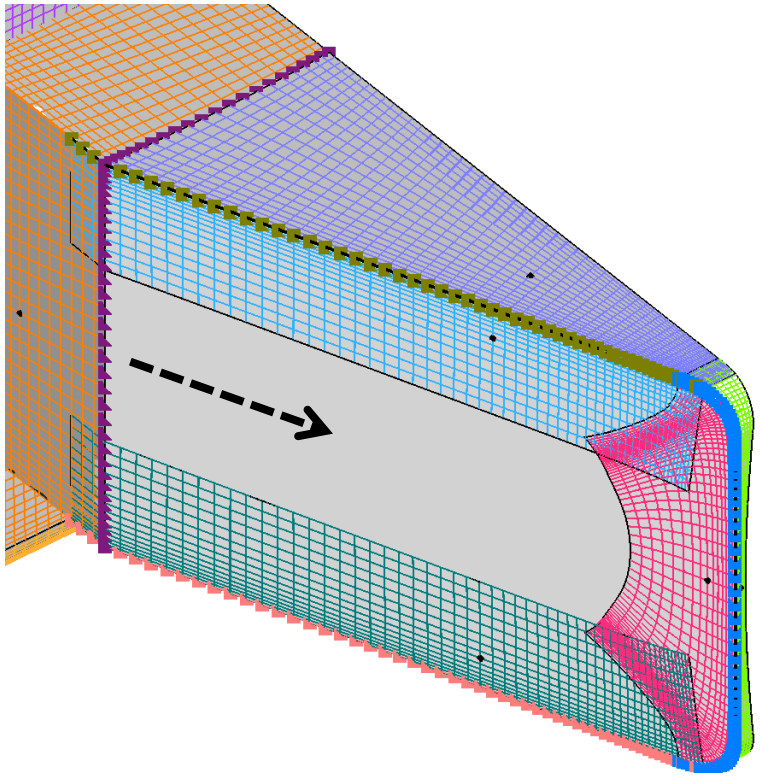
FUTURE PLANS FOR HYPERBOLIC STEP





Auto extract initial curves for hyperbolic marching
- **Exposed boundary curves from algebraic step**
- **Unused original curves after algebraic step**

Auto determine spatially variable marching
- **distance and grid point distribution**
- **direction**

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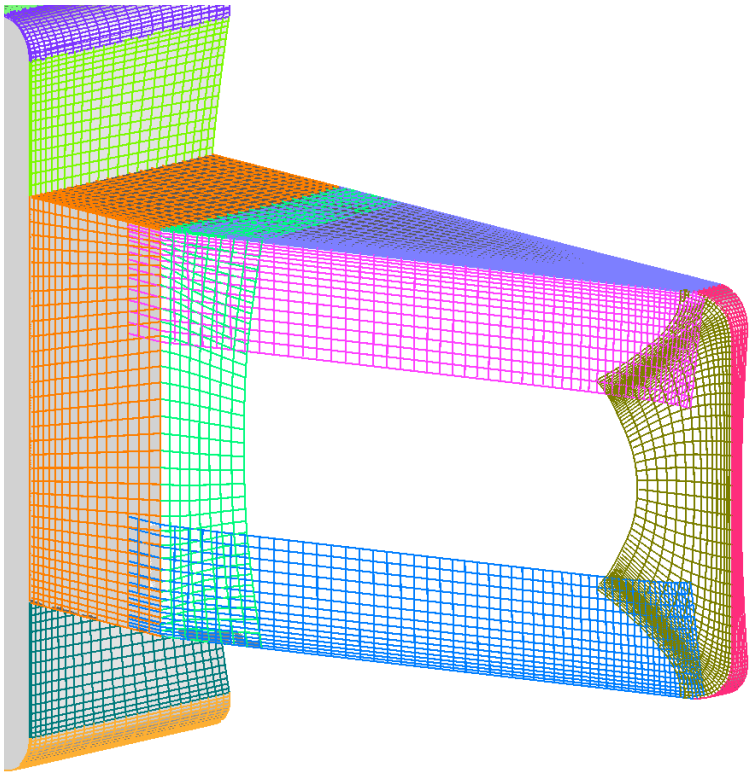
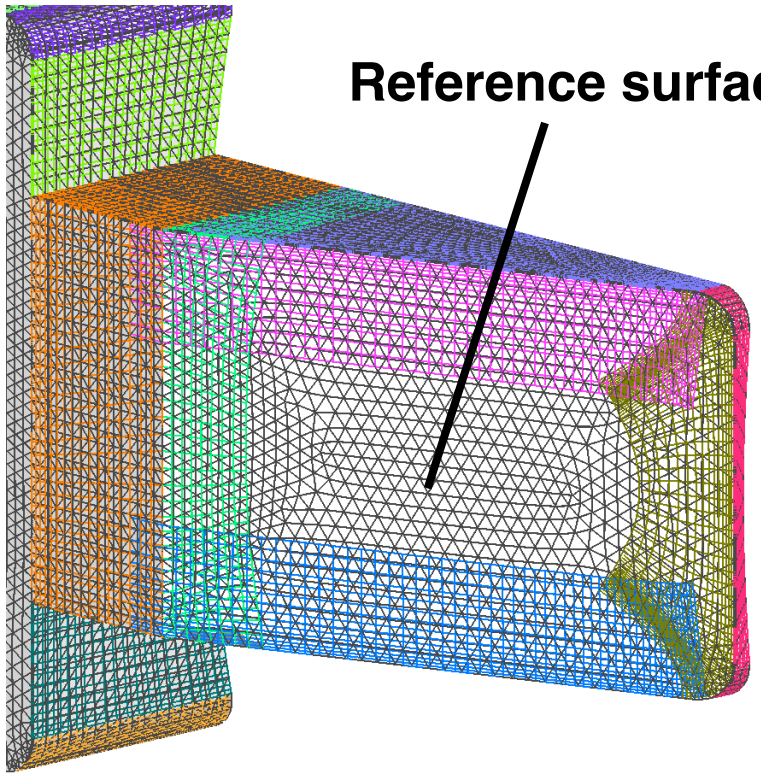
FUTURE PLANS FOR GAP FILLING STEP





- Gap regions (if there are any) are not bounded by surface features
- Project reference surface vertices onto surface grids from algebraic and hyperbolic steps
- Identify vertices that fail to find donor stencil (orphan vertices)
- Identify orphan cells from orphan vertices on reference surface
- Build algebraic/hyperbolic grids over orphan cells

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SUMMARY AND CONCLUSIONS

- A high level procedure has been designed for automation of overset structured surface grid generation

- Geometry starting point
  - Unstructured surface triangulation representation
  - A set of surface feature curves that tesselates surface

- Approach: algebraic, hyperbolic, gap-filling steps

- Algebraic step
  - Auto curves network connectivity
  - Auto grid point distribution
  - Auto grid generation on four-sided domains
  - Auto concatenation sweep
  - Auto boundary extension (work in progress)
  - Significant time saving over current manual practice

- Future plan: automation of hyperbolic and gap filling steps