International TechneGroup

Challenges in CAE Geometry

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Introduction

- ITI – International TechneGroup Inc.
  - Focussed on critical role of geometry in engineering
  - Offices in Cincinnati, Tel Aviv, Cambridge
- ITI Cambridge, UK
  - Suppliers of CADfix: a tool for translation, repair, and transformation of CAD models for CAE
  - Nearly 40 years of developing CAE tools
  - 25+ years of research into 3D medial object

ITI International TechneGroup CADfix

What is CAE Geometry?

- The representation of the material domains to be simulated
  - Usually volumes
- The interface between design (CAD) and simulation (CAE)

What is CAE Geometry?

Design geometry → CAE geometry → Analysis

What is CAE Geometry?

Design geometry

CAE geometry

Analysis

What is CAE Geometry?

Design geometry ⇄ Analysis

What is CAE Geometry?

- An obstacle!
- Challenge: to make CAE geometry invisible

Examples

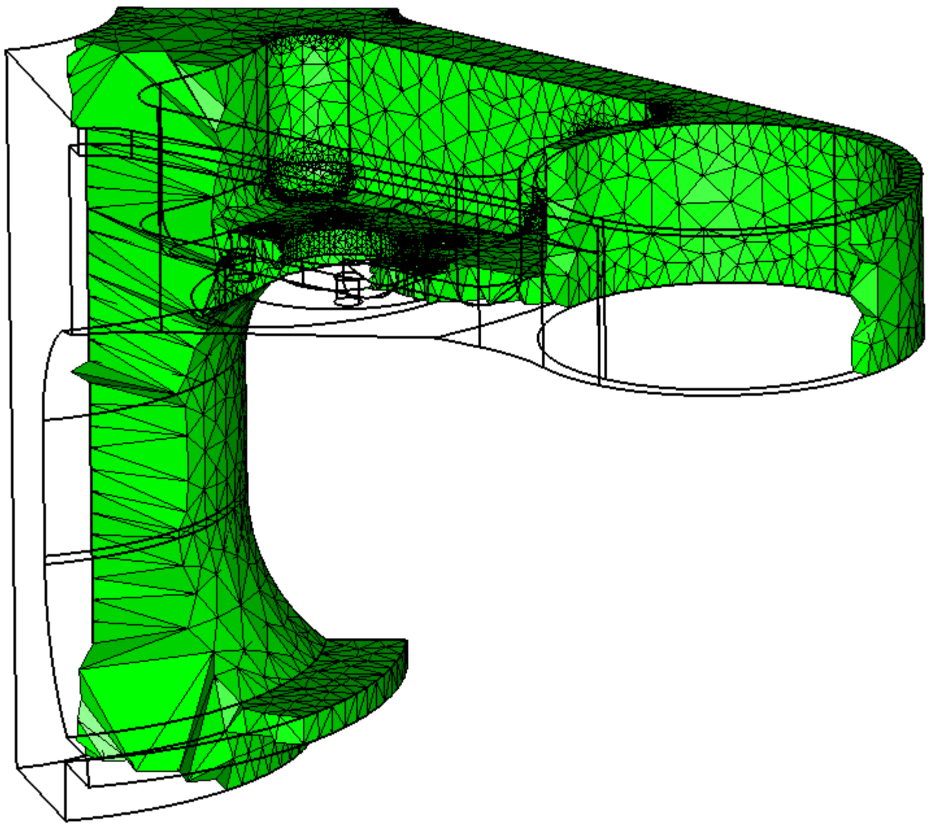
Example: Reasoning about domain

- Boundary representations offer little help in traversing volume
  - Local thickness
  - Local aspect ratio
  - Opposite position
  - Interpolation

- Require some further “scaffolding” to reason about shape of domain

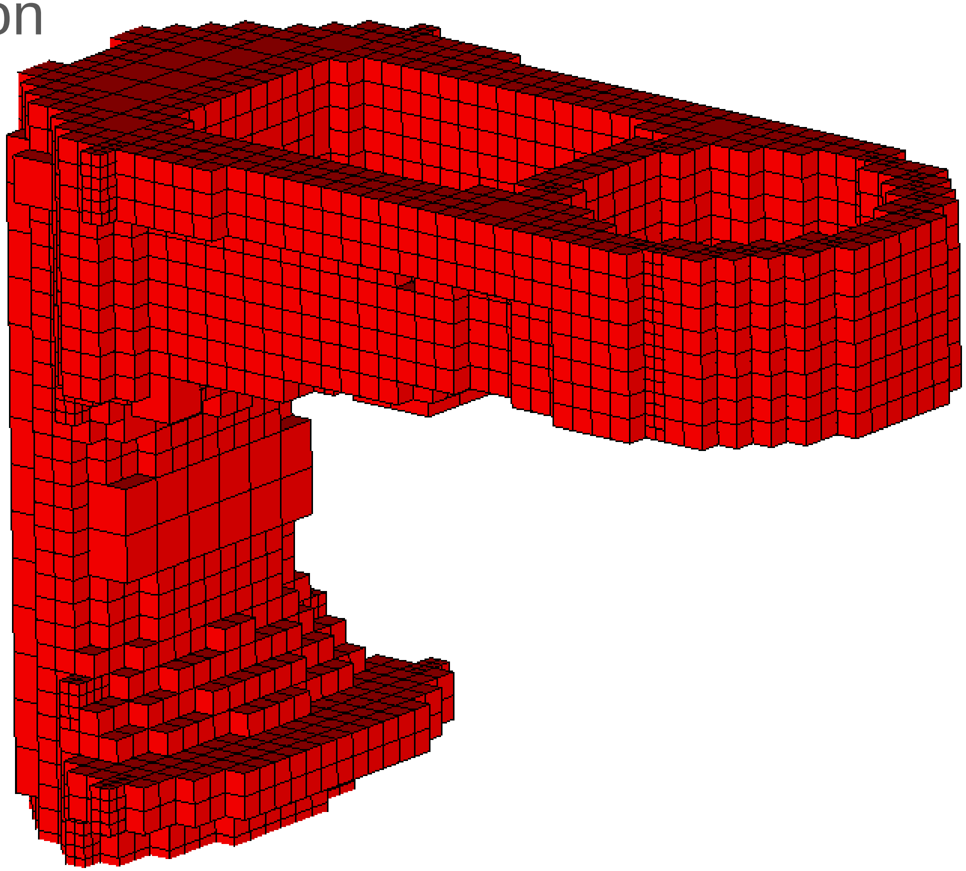
Example: Reasoning about domain

- Approach: tetrahedral mesh
  - Largely robust automatic tetrahedral meshing exists
  - Common scaffold for geometry reasoning
    - Estimates of thickness and aspect ratio
    - Interpolating field over volume
    - Solving PDEs



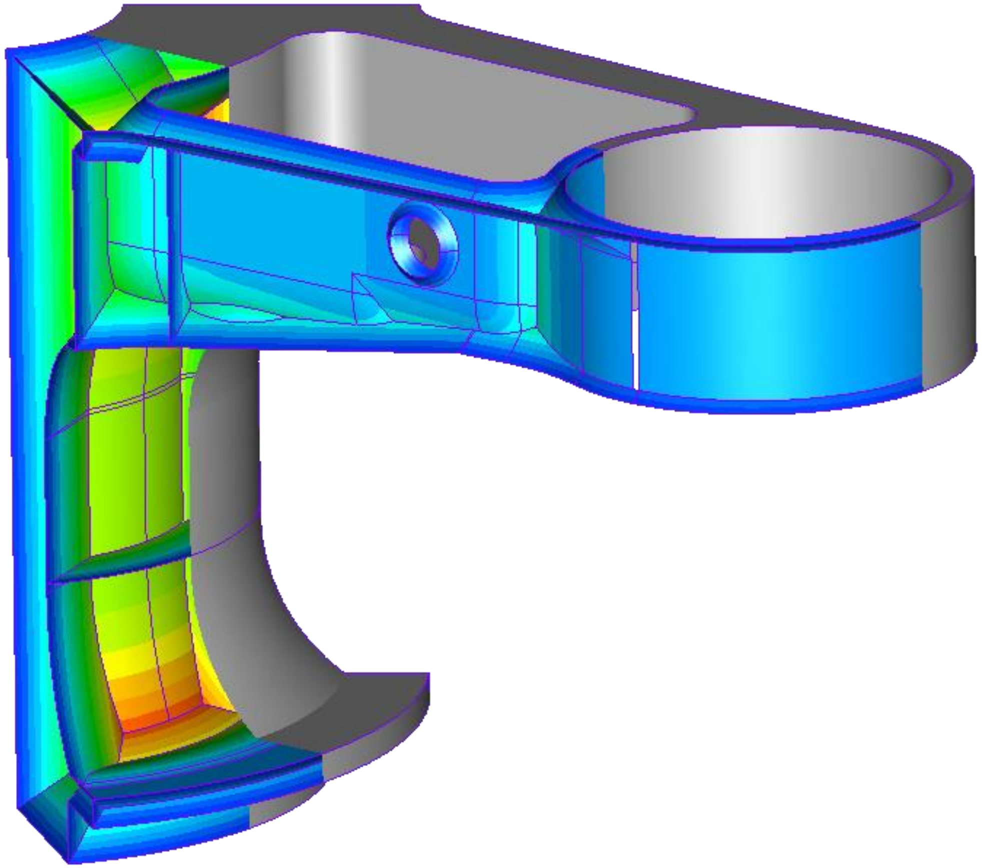
Example: Reasoning about domain

- Approach: octree
  - Robust octree generation straightforward
  - Common scaffold for mesh generation
    - Interpolating field over volume
    - Establishing topology for shrinkwrap style meshing



Example: Reasoning about domain

- Approach: medial axis
  - Robust 3D medial axis generation is hard but possible
  - Common scaffold for geometry reasoning
    - Thickness
    - Aspect ratio
    - Hex meshing
    - Midsurfacing
    - Feature detection

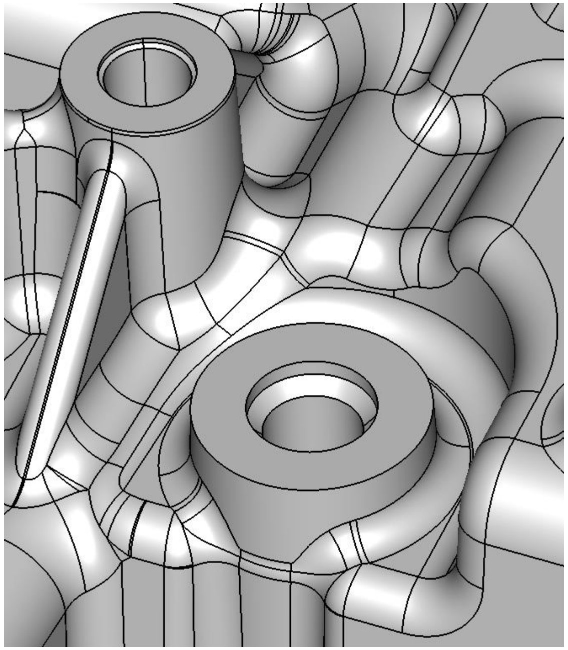


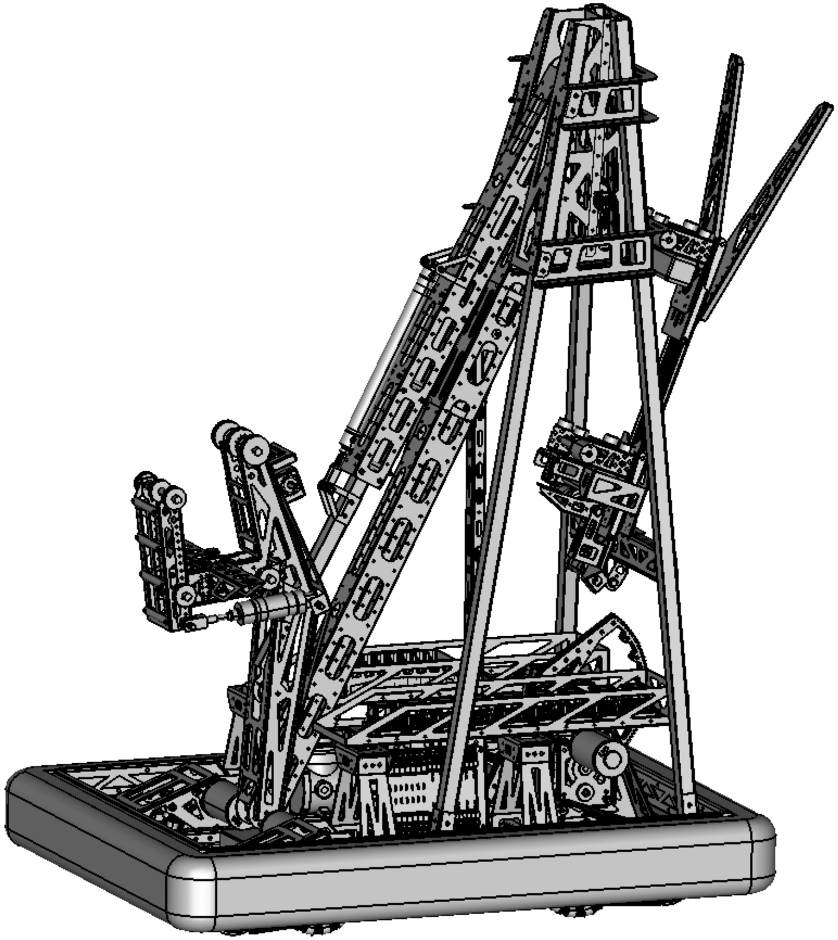
Example: Reasoning about domain

- Challenges:
  - Reasoning about interior of domain given only boundary information
  - Developing a scaffold that accurately answers questions about volume
  - Generating scaffold robustly

Example: Automatic simplification

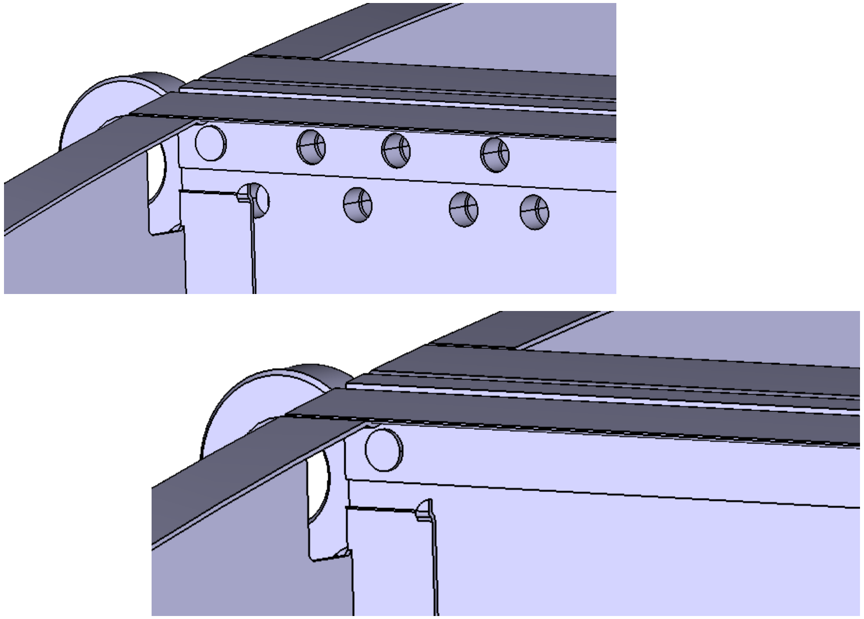
- CAD is typically too complex for efficient simulation
  - Excessive face topology
  - Too much detail

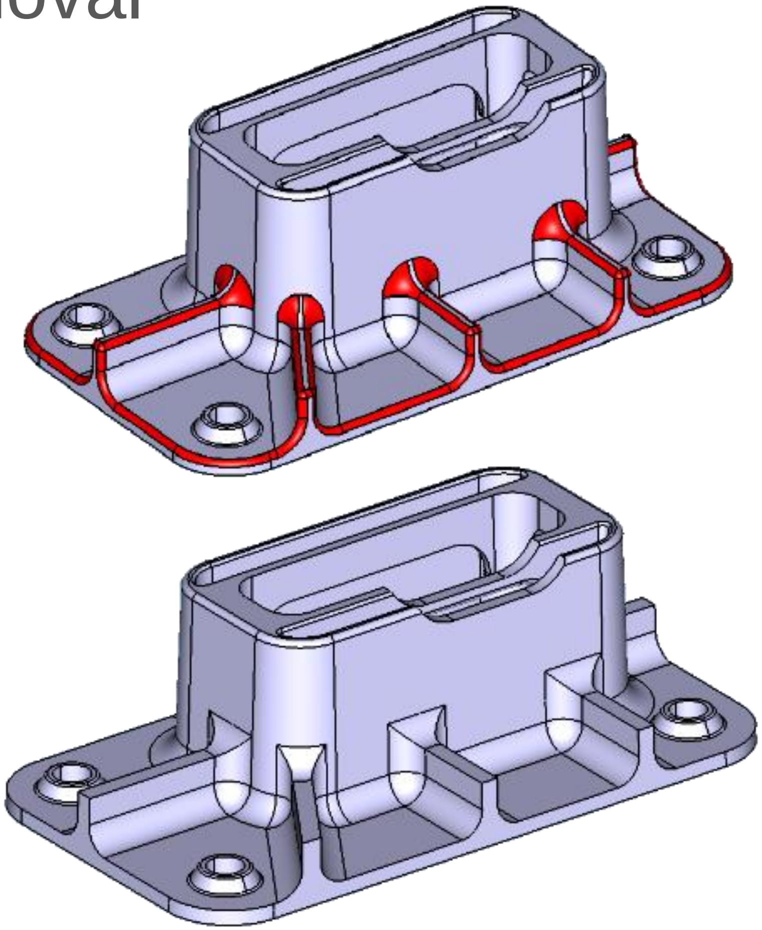




Example: Automatic simplification

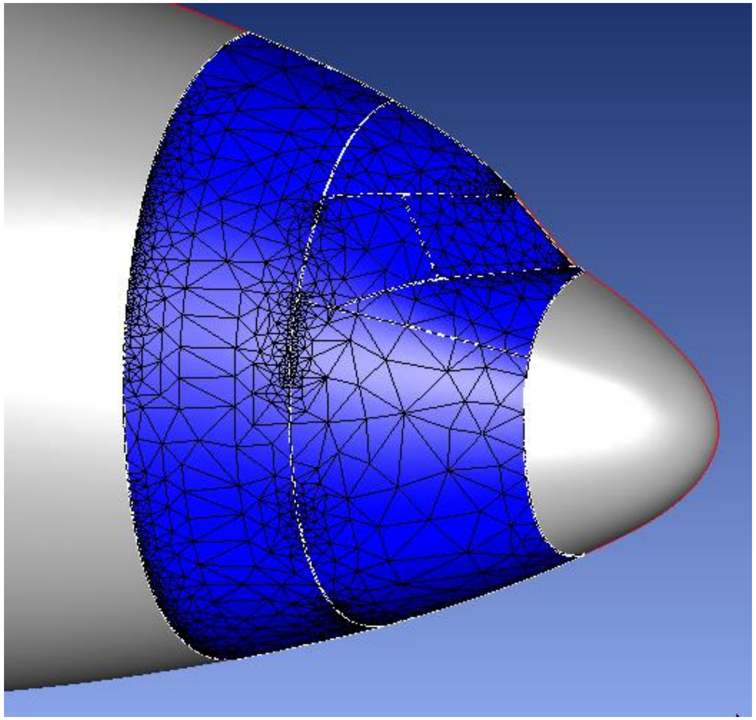
- Approach: B-rep feature removal
  - Holes
  - Protrusions
  - Fillets

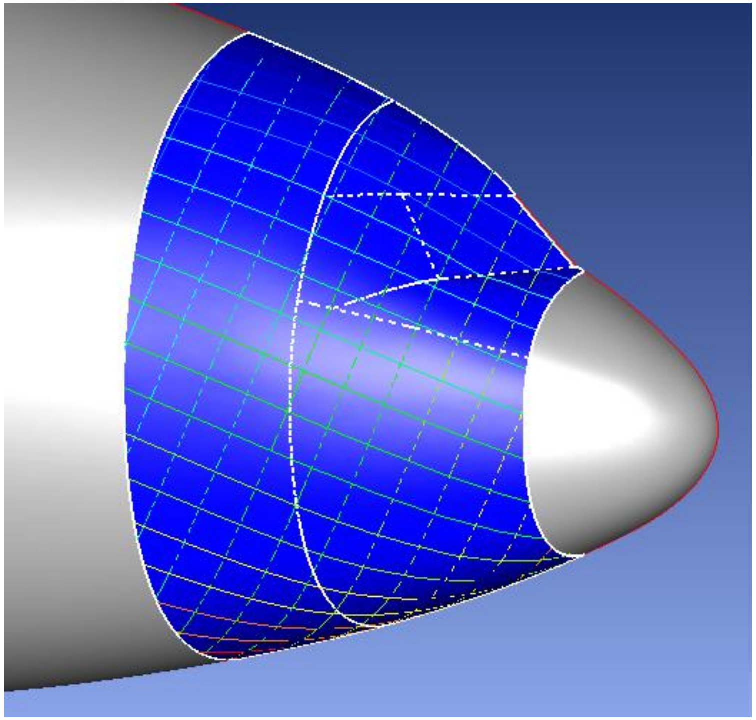




Example: Automatic simplification

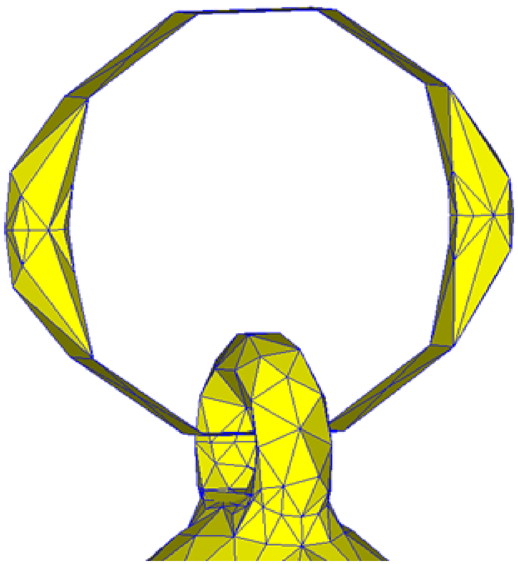
- Approach: virtual topology
  - Treating a carpet of faces as a single face
  - Provide a single parameter space for the whole virtual face

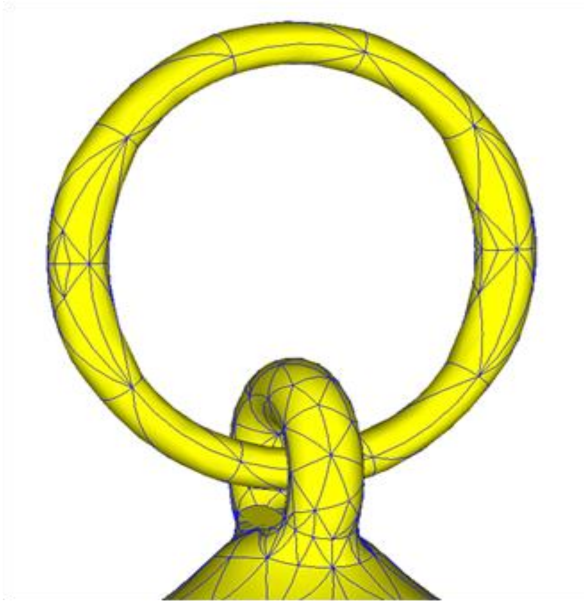




Example: Automatic simplification

- Approach: facets
  - Replace geometry with facetted model
  - Avoids issues with CAD b-rep
  - Curved facets allow more faithful & efficient representation





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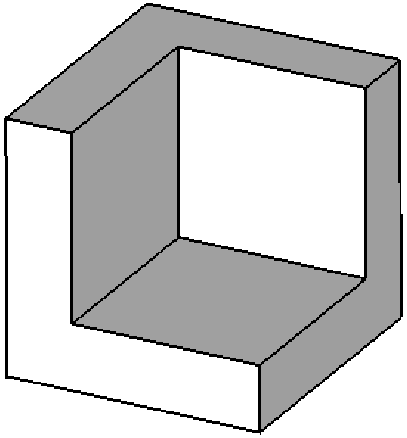
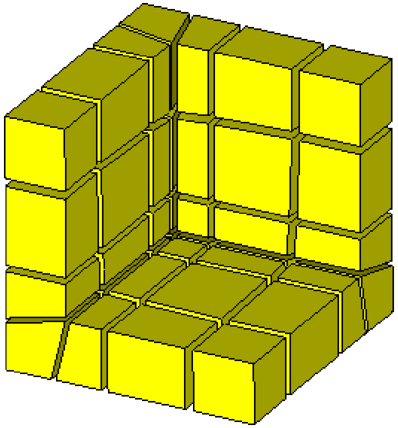
Example: Automatic simplification

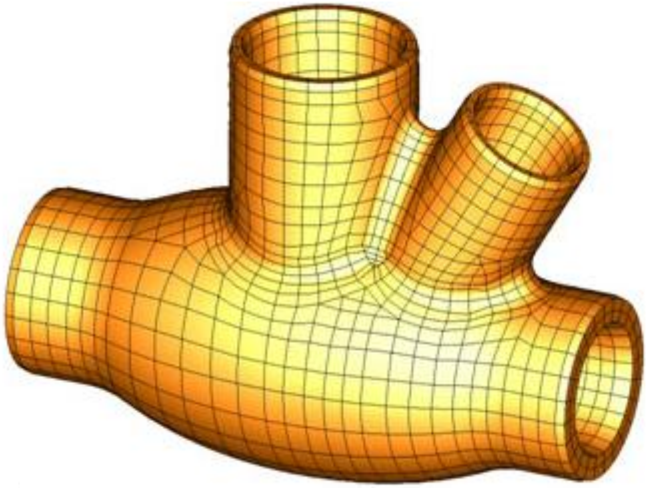
- Challenges
  - Maintaining connection back to CAD model
  - Automation
  - Robustness
  - Detecting & removing emergent features
  - Reporting changes in an understandable way
  - Building trust in process

Example: Partitions for hex meshing

- Solver requires boundary-fitted hex elements
  - For reasons of speed & fidelity
- Domain must be partitioned into topologically hexahedral regions
  - Requires significant expertise to do well
  - Difficult to automate







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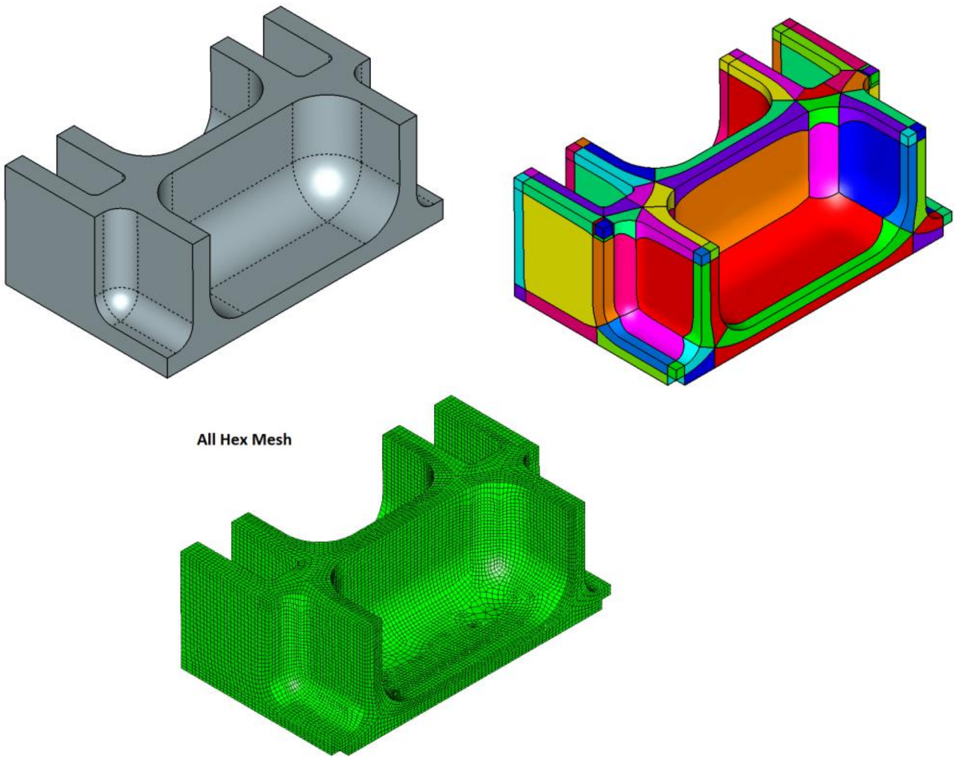
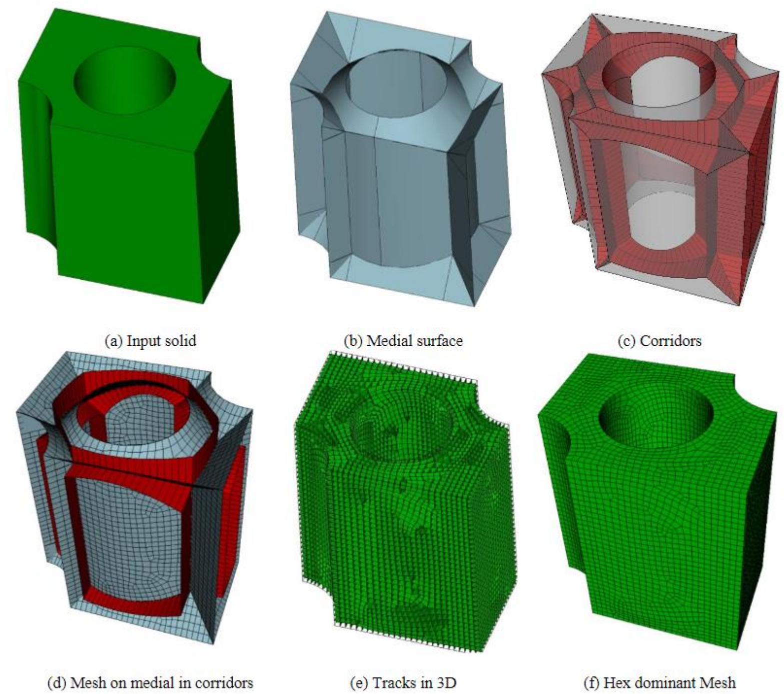
Example: Partitions for hex meshing

- Approach: 3D medial axis

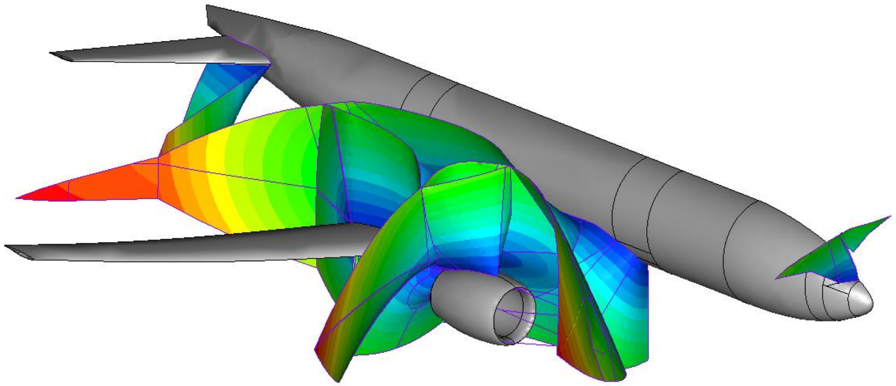


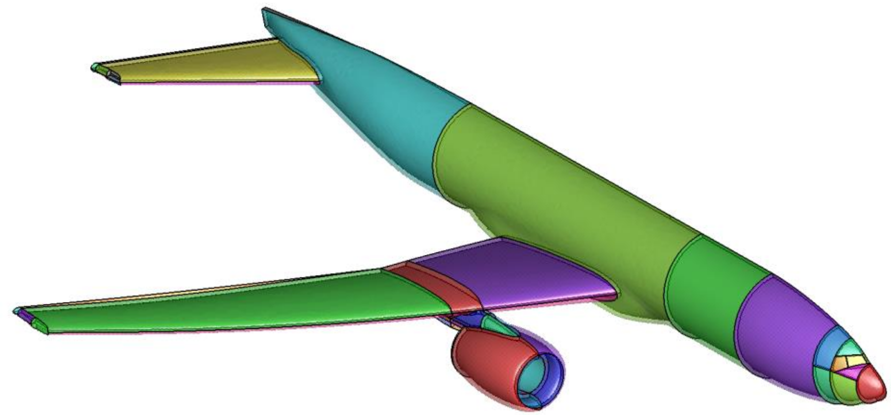


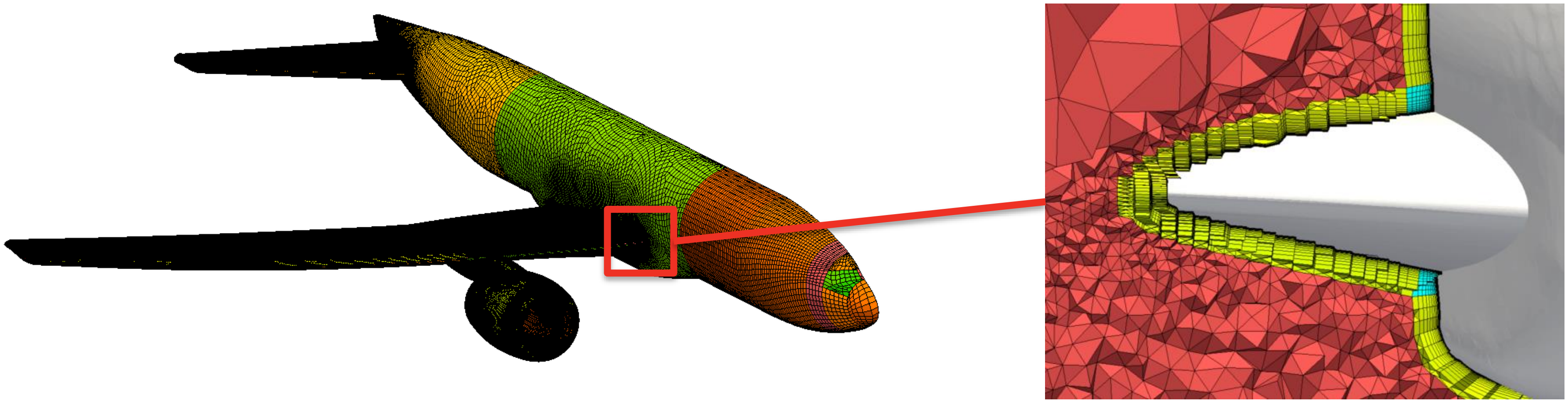
LayTracks3D: a new approach to meshing general solids using medial axis transform, Quadros, 2014.

Example: Partitions for hex meshing

- Approach: 3D medial axis (external)

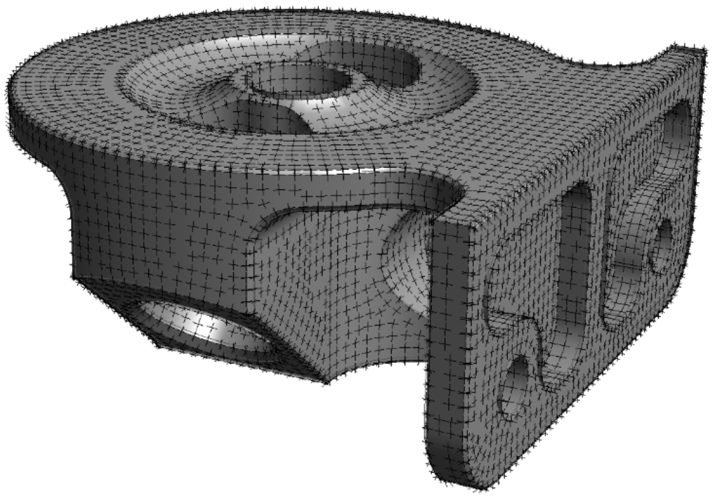


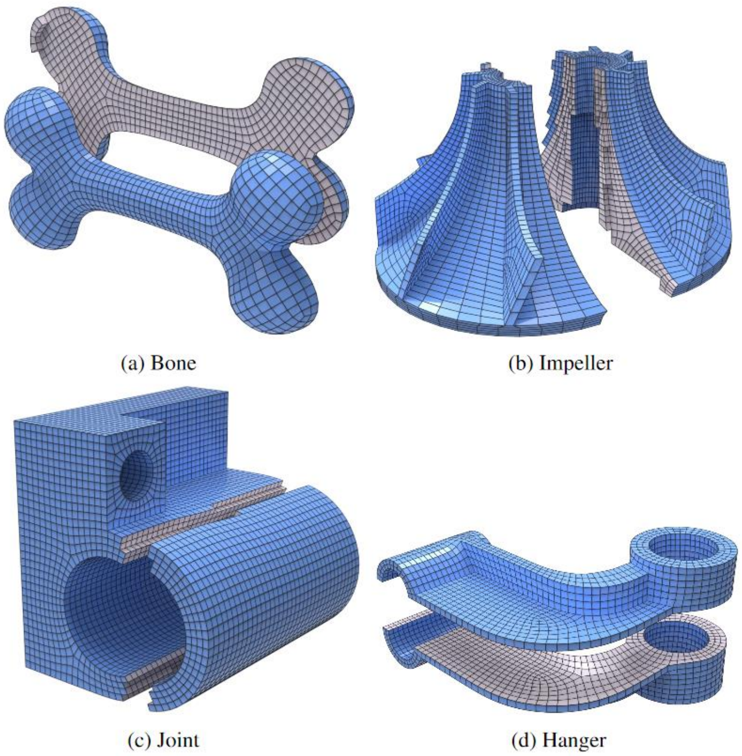




Example: Partitions for hex meshing

- Approach: 3D frame field





Hex-dominant meshing approach based on frame field smoothness, P.-E. Bernard et al, 2014.

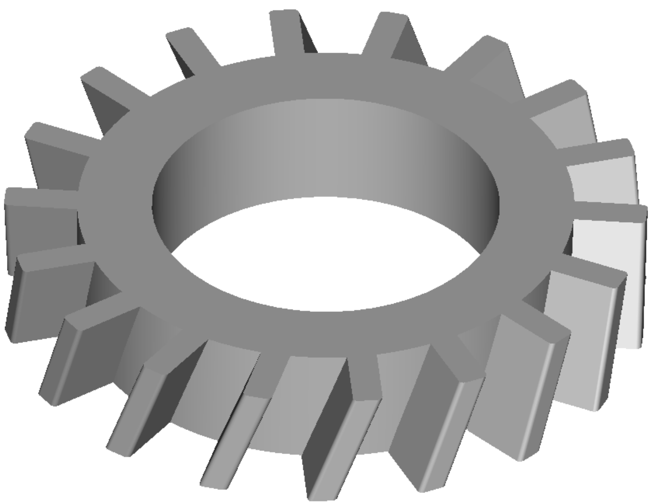
All-Hex Meshing using Singularity-Restricted Field, Yufei Li et al., 2012.

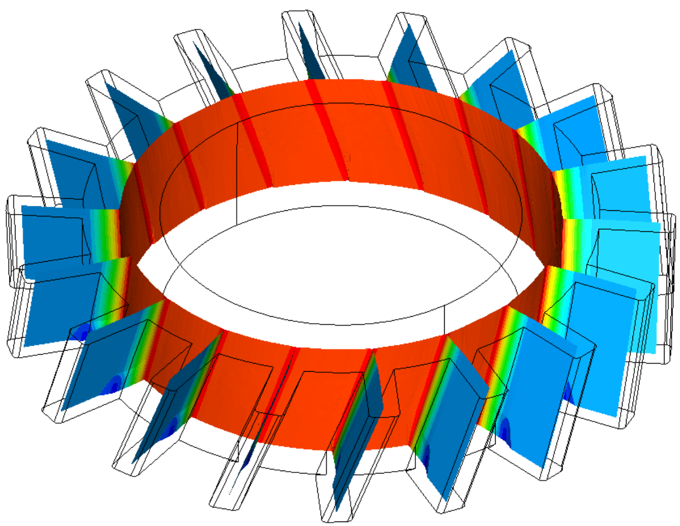
Example: Partitions for hex meshing

- Challenges:
  - Automation
  - Quality
  - Robustness
  - Scale
  - Managing compromises between geometric accuracy and mesh quality

Example: Midsurfacing

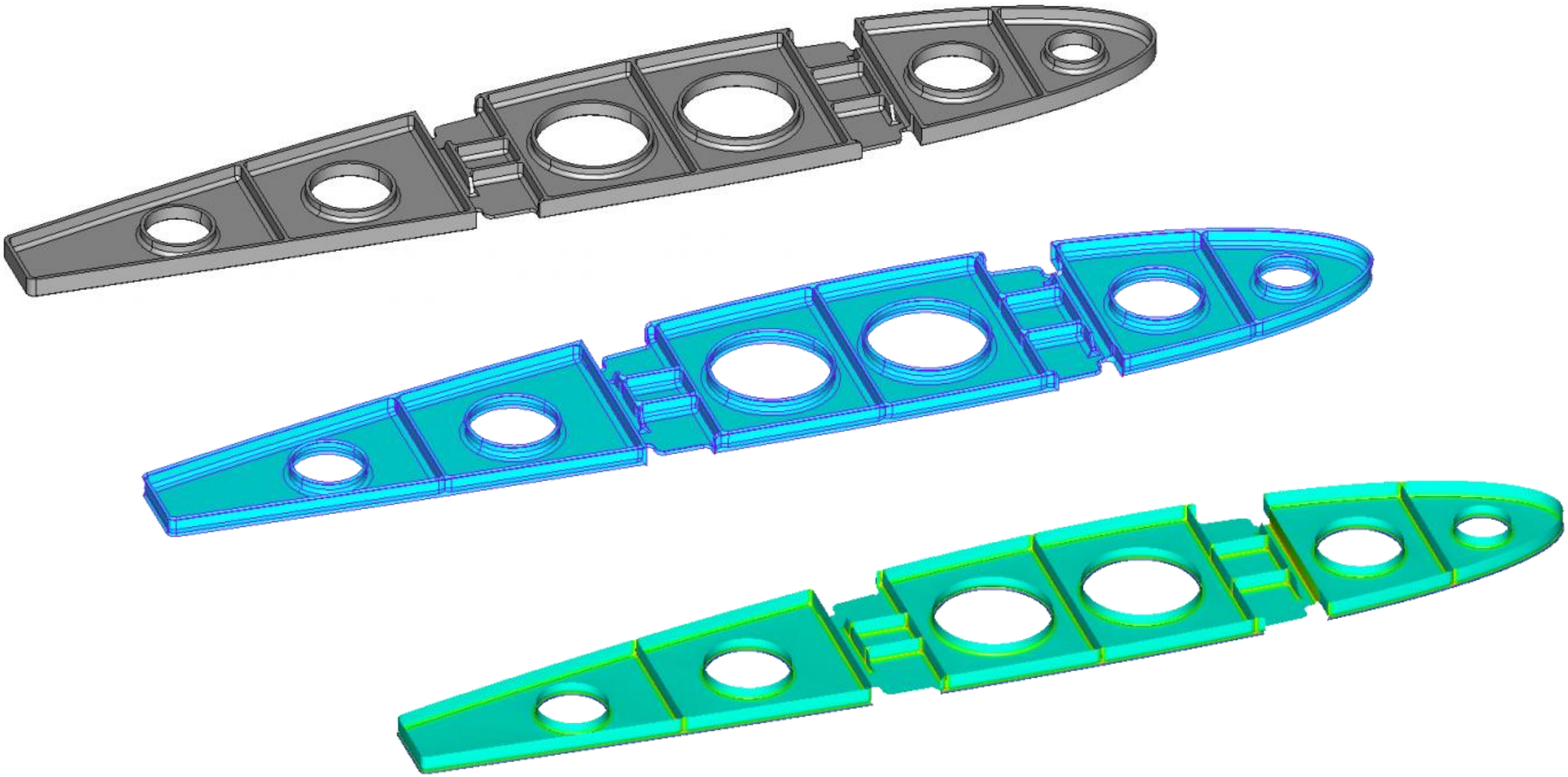
- Simulation of sheet metal parts can be accelerated by simulation with shell elements
  - Improved speed & sometimes fidelity
- Domain must be reduced to midsurface representation
  - Difficult to fully automate





Example: Midsurfacing

- Approach: 3D medial axis



Example: Midsurfacing

- Challenges
  - Connection back to CAD from idealised model
  - Automation
  - Robustness
  - Scaling
  - Junctions
  - Handling areas poorly approximated by midsurface

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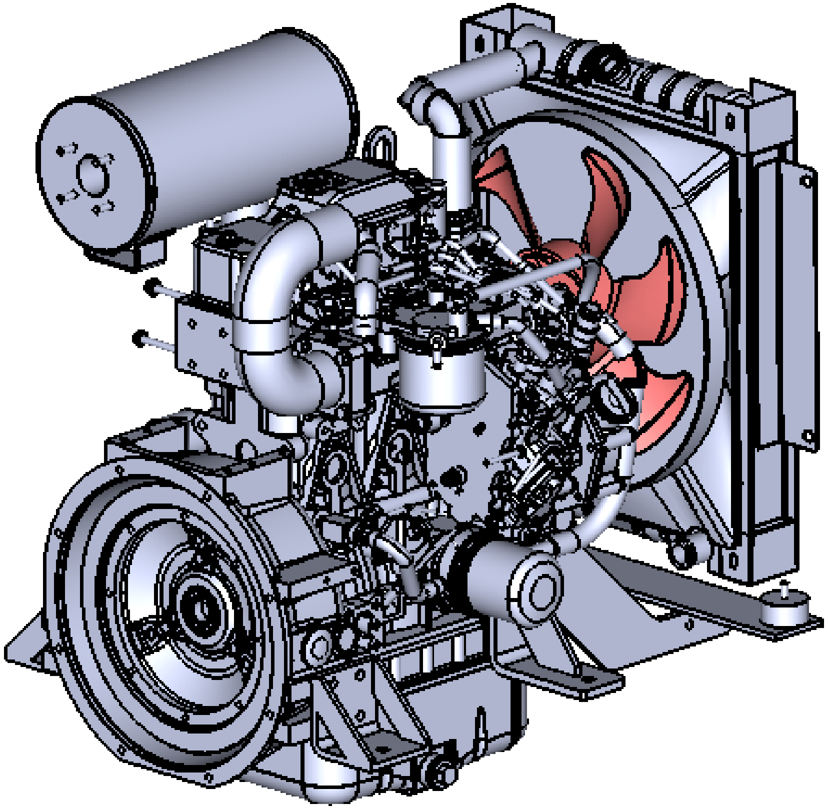
Example: Outer mold line

- Simulation needs wetted skin (OML)
- Design is very complex and "dirty" with gaps & overlaps between parts
  - Not feasible to prepare with manual tools



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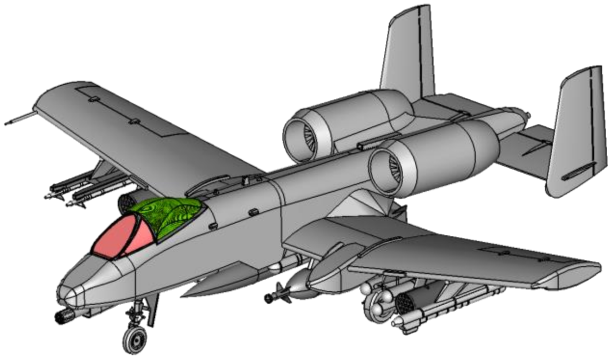
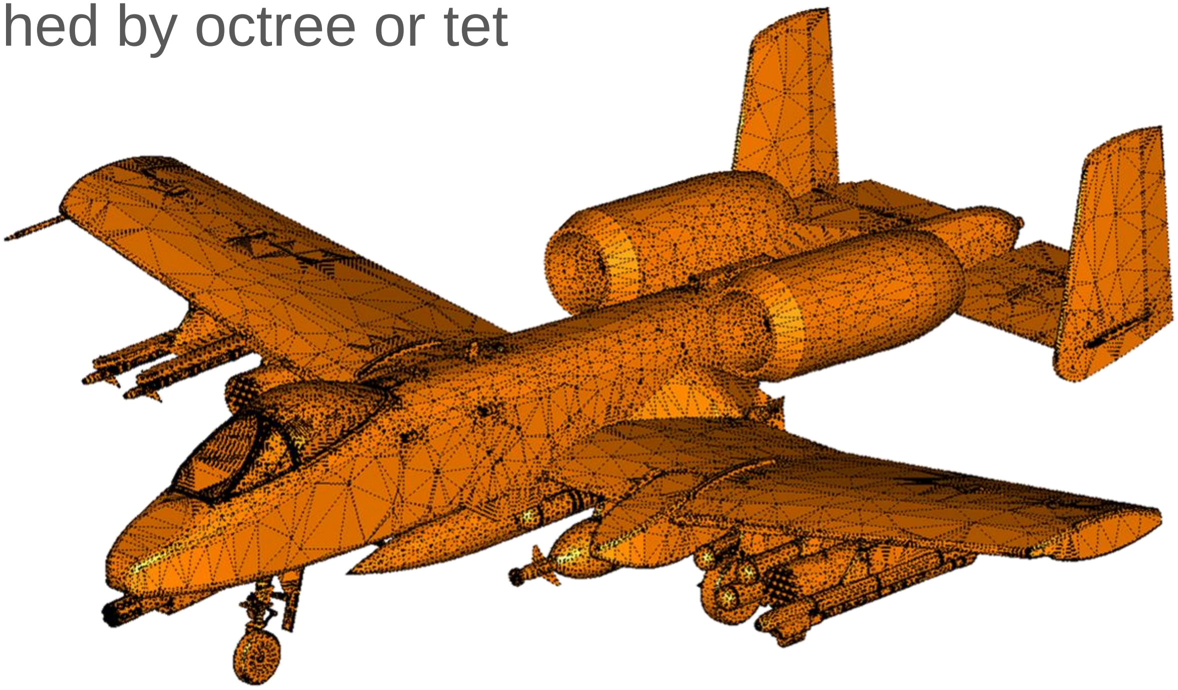
Example: Outer mold line

- Approach: Shrinkwrapping
  - One-click method
  - Discard holes, gaps, features smaller than some ε
  - Topology established by octree or tet mesh





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Example: Outer mold line

- Challenges
  - Building trust in automated process
  - Reporting where geometry was/wasn’t respected
  - Leak detection: spotting when a shrinkwrap fails to suppress a hole & leaks inside
  - Unwanted “webs” between nearby parts
  - Maintaining sharp edges
  - Keeping edges for boundary conditions

Example: Corrosion

- Real parts experience damage & aging
- Point scan data can provide geometry of damaged parts
- How to integrate this data into analysis?

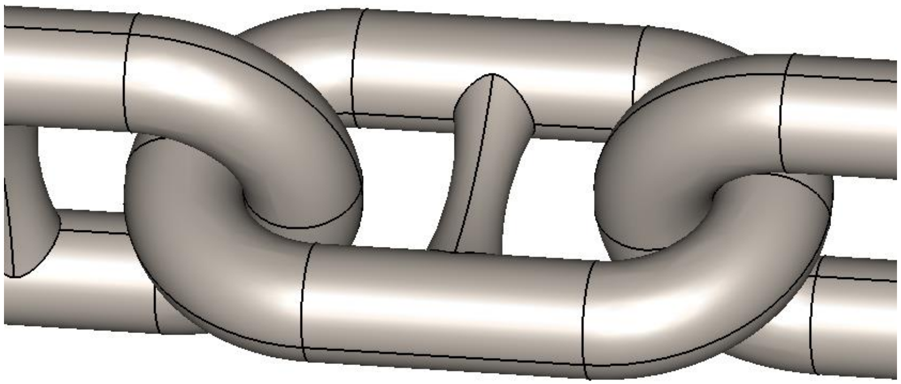
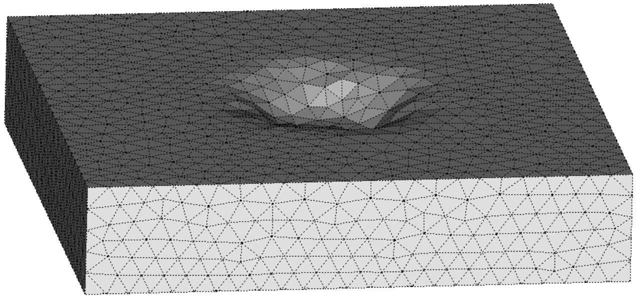
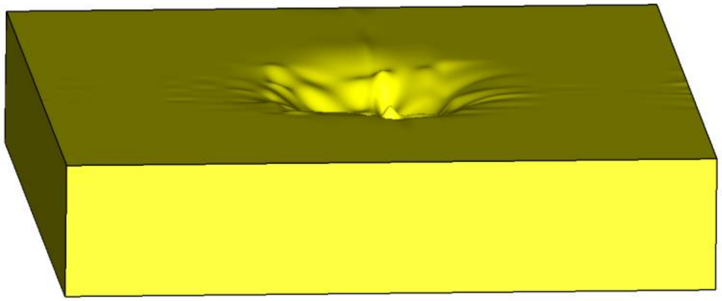


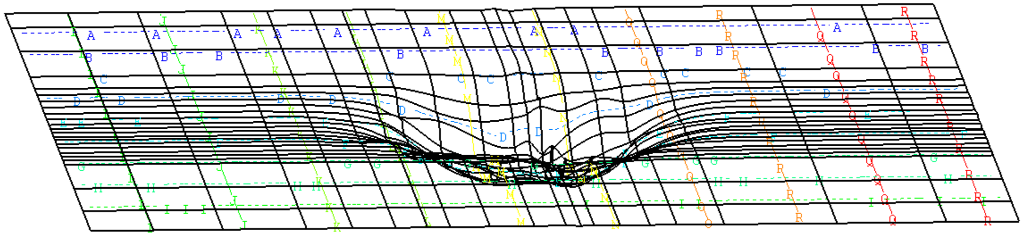
Photo: Doug Letterman

Example: Corrosion

- Approach: NURBS morphing
  - Find offsets between point scan & CAD model
  - Deform CAD model to fit point scan
  - Mesh & analyse deformed CAD model as usual





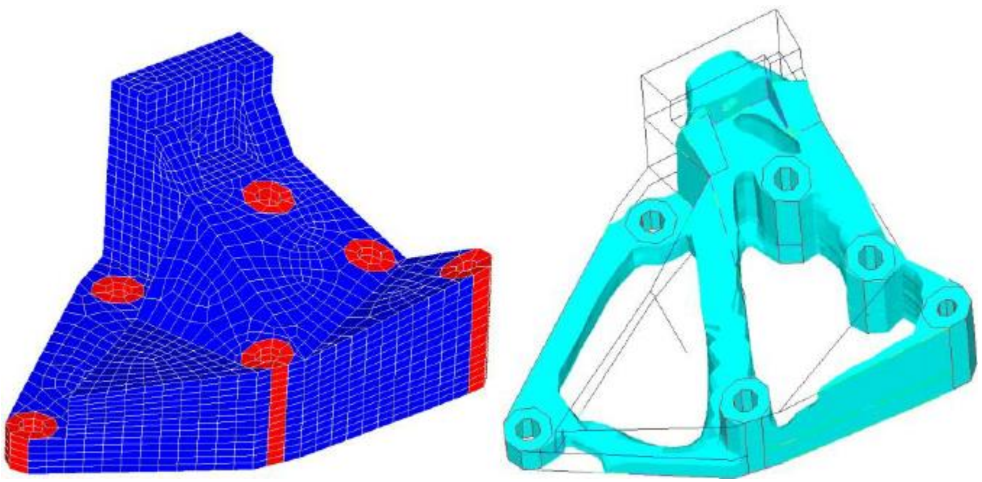


Example: Corrosion

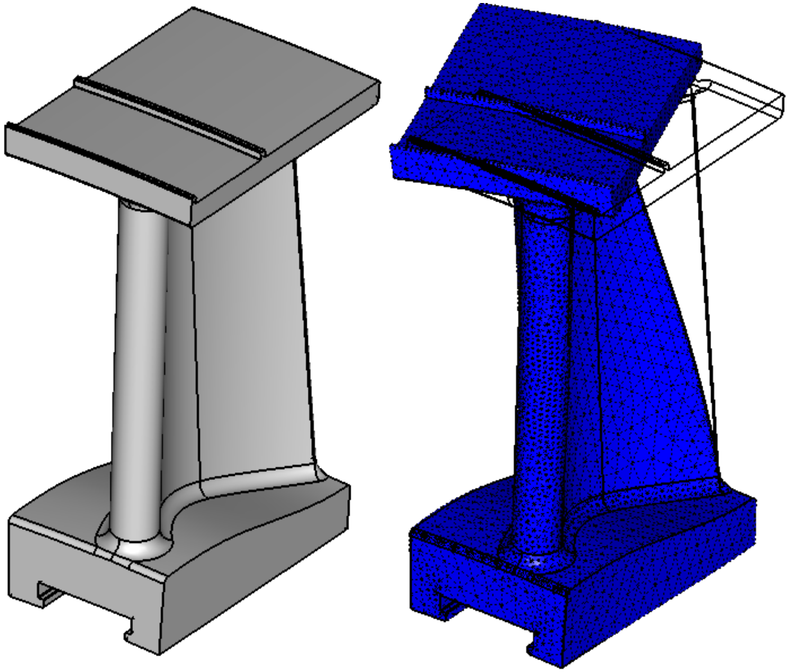
- Challenges
  - Point cloud registration against CAD
  - Noise & artefacts in point cloud data
  - Constructing deformation vectors from point cloud
  - NURBS deformation with variable sample density
  - Changes which alter model topology

Example: Optimised design

- Take an optimised model back to design
  - Optimised design typically consists of a modified mesh
  - Must be taken back to CAD to be useful downstream

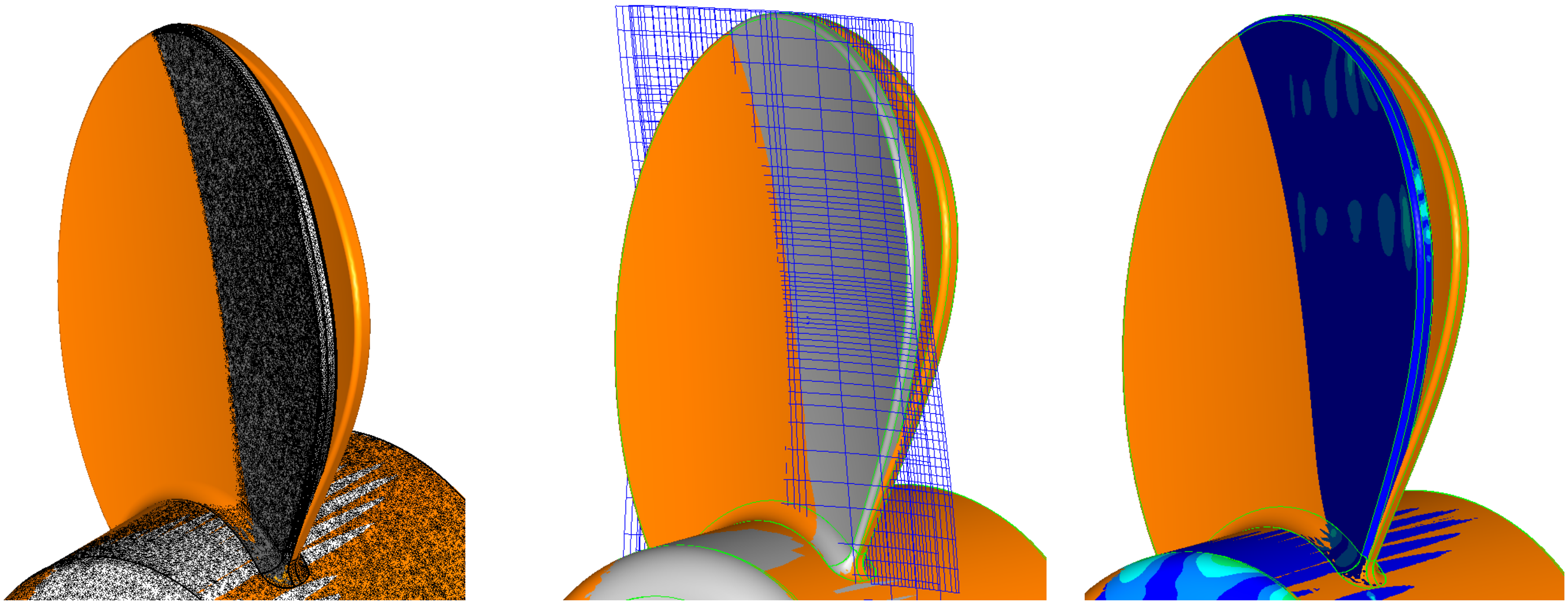


Topology Optimization in Aircraft and Aerospace Structures Design, Jihong Zhu et al.



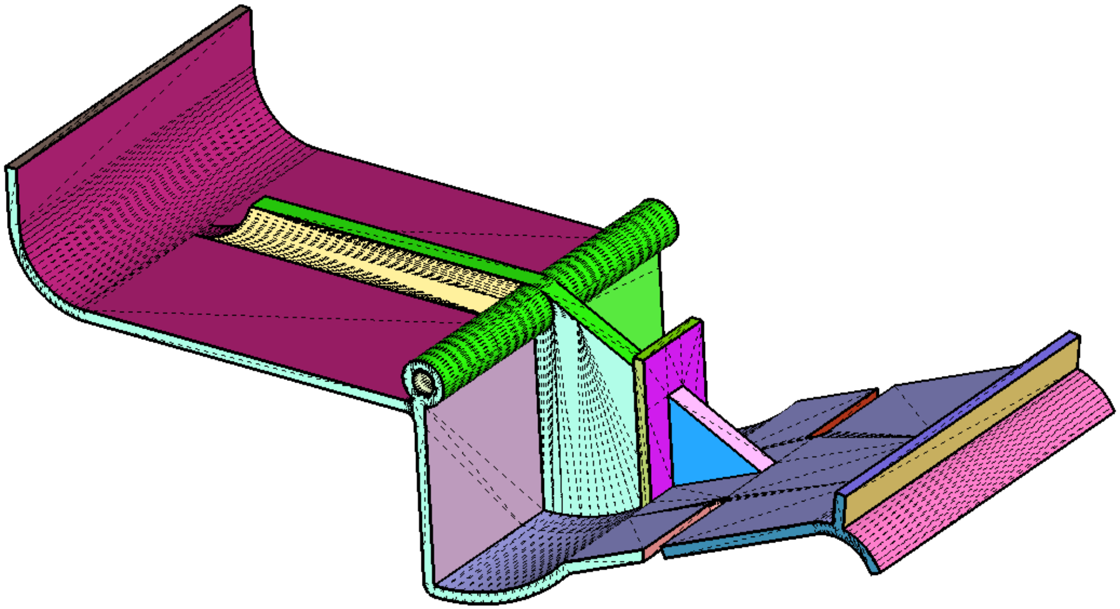
Example: Optimised design

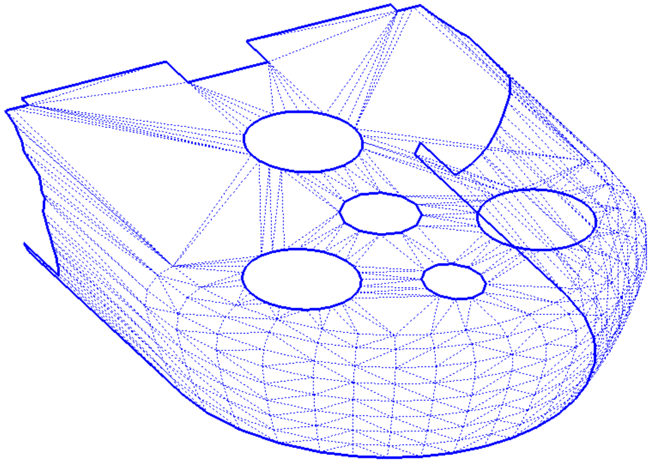
- Approach: morphing
  - Apply mesh deformations to deform CAD model
  - Morph NURBS surfaces to fit deformation results

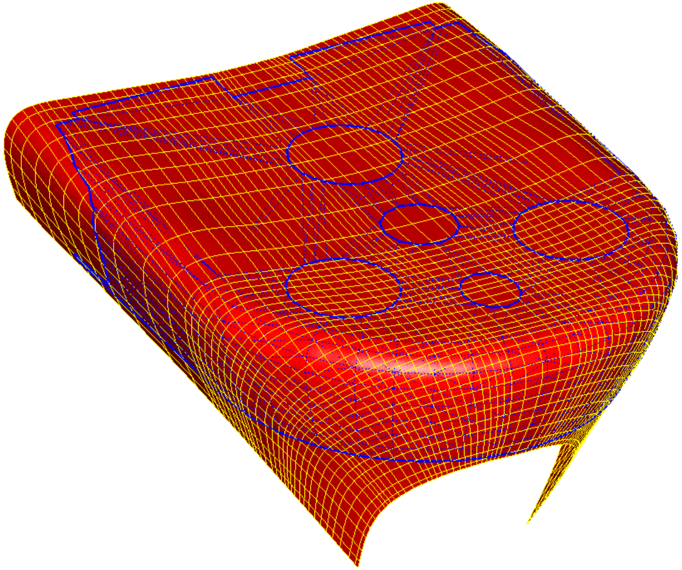


Example: Optimised design

- Approach: back-to-CAD
  - Segment mesh & fit NURBS surfaces







Example: Optimised design

- Challenges:
  - Automation
  - Maintaining connection to starting CAD
  - Taking discrete results to continuous CAD
  - Morphing with data of variable density
  - Segmenting non-smooth data for NURBS fitting
  - Fitting NURBS to non-smooth data

Conclusions

- CAE geometry is necessary
  - CAD is not suitable for simulation
  - CAD is not suitable for optimisation
- Bi-directional connection between CAD and CAE requires better CAE geometry
  - Automatic translations of CAD to CAE
  - Associativity between CAD and CAE geometry
  - Translation of optimal CAE geometry back to CAD
- Technologies already exist to help
  - Lots more work is needed

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Thank you!

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