Review of Topology Optimization

- What are the two general mathematical approaches to computing optimal topology?
- What are the differences between ESO and BESO methods for doing Topology Optimization?
- Why do topology optimization?
- What is today's main challenge with implementing topology optimization?

Topology Optimization

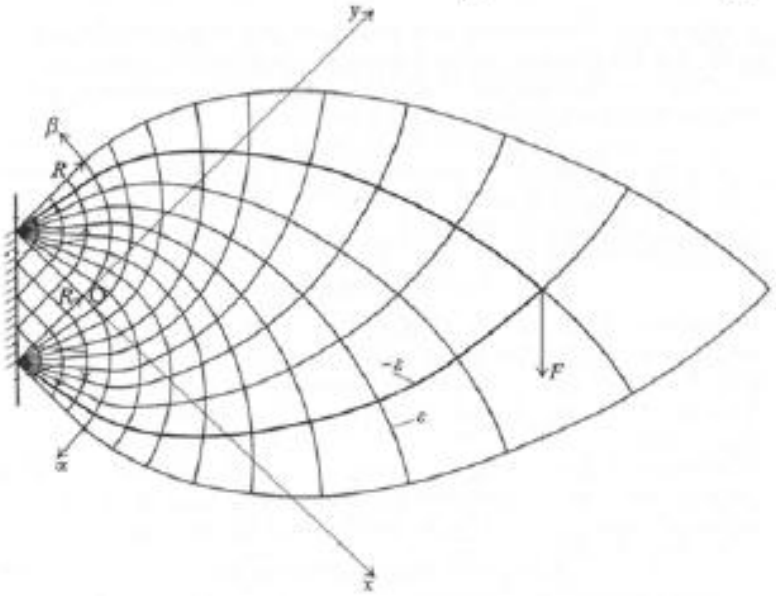
ME 471

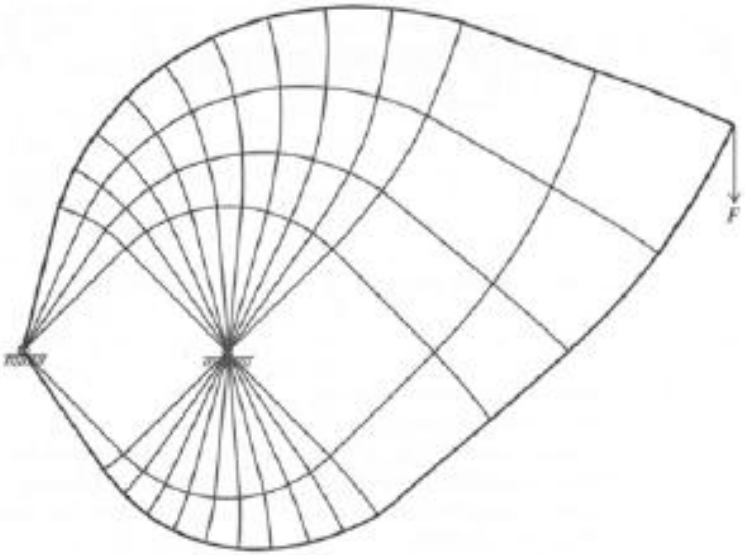
Methods

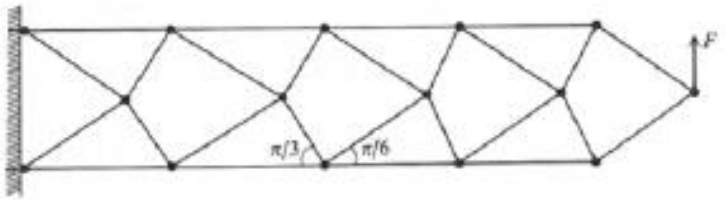
- Continuous Methods
  - SIMP: Solid Isotropic Material with Penalization
  - 3D Density Function
  - Volume of Fluid (VOF) method
- Topological Derivative Sensitivity Methods
  - ESO: Evolutionary Structural Optimization
  - BESO: Bidirectional Evolutionary Structural Optimization
- Truss Methods
- …

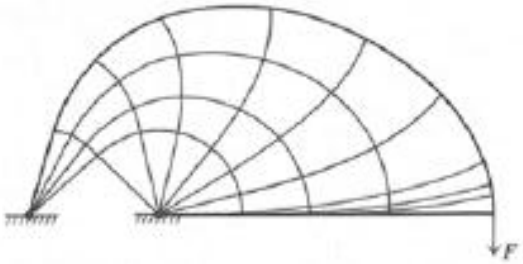
Truss Methods

- ***1904*** Michell – Least weight truss theory



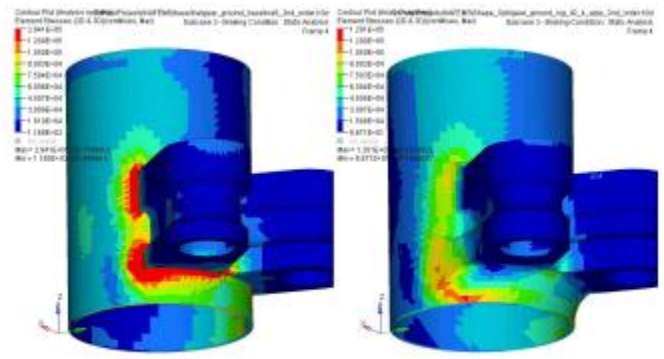


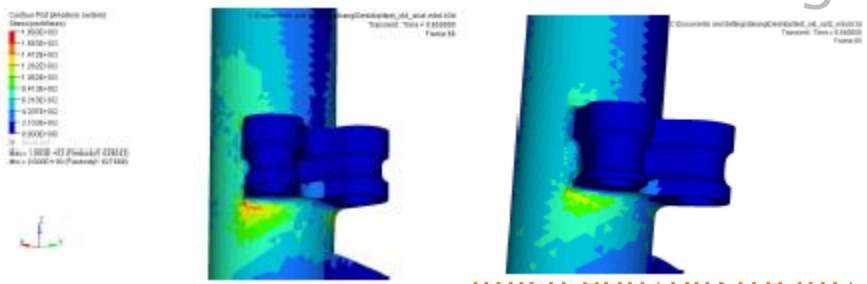


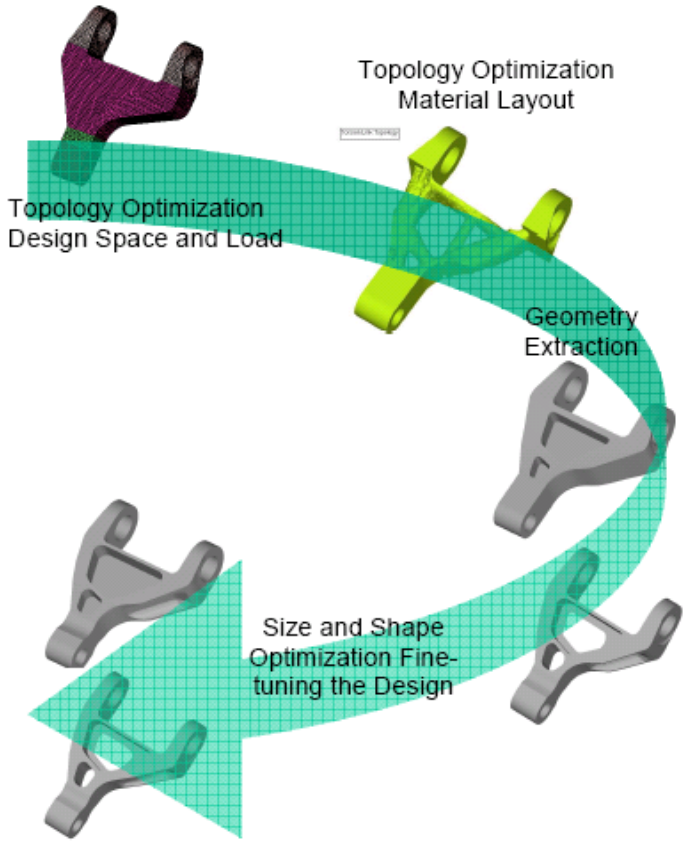


Readings

- Multi-disciplinary design of an aircraft landing gear using concept design and optimization techniques (on TcC)

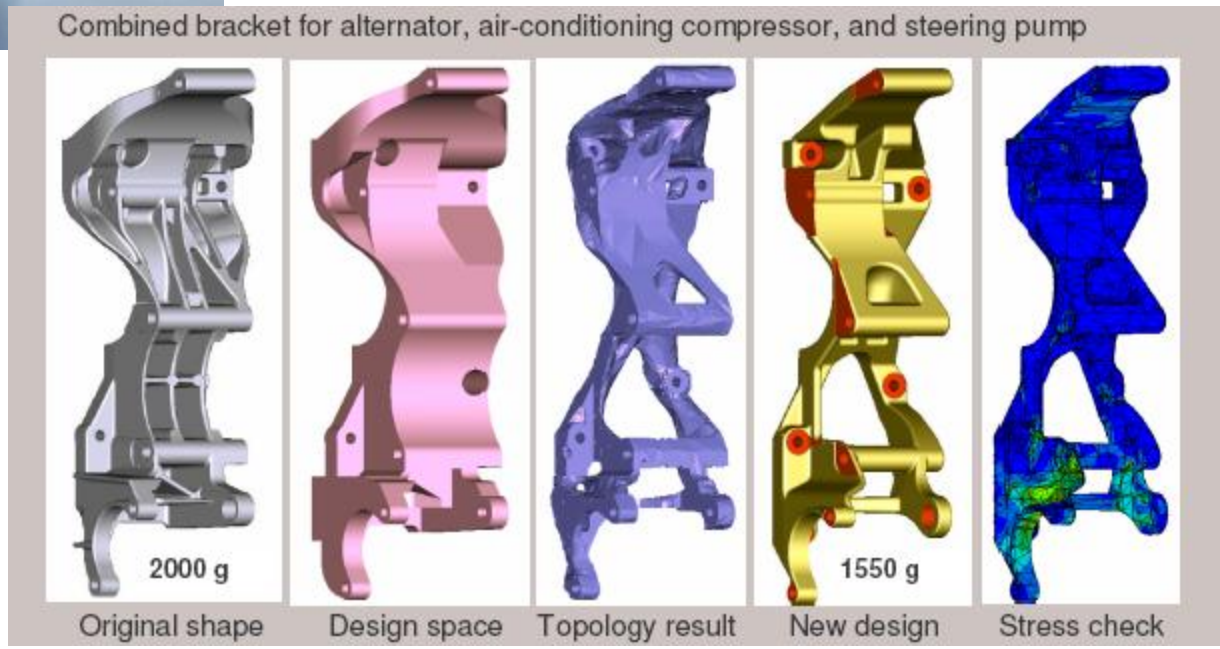






Courtesy of Altair

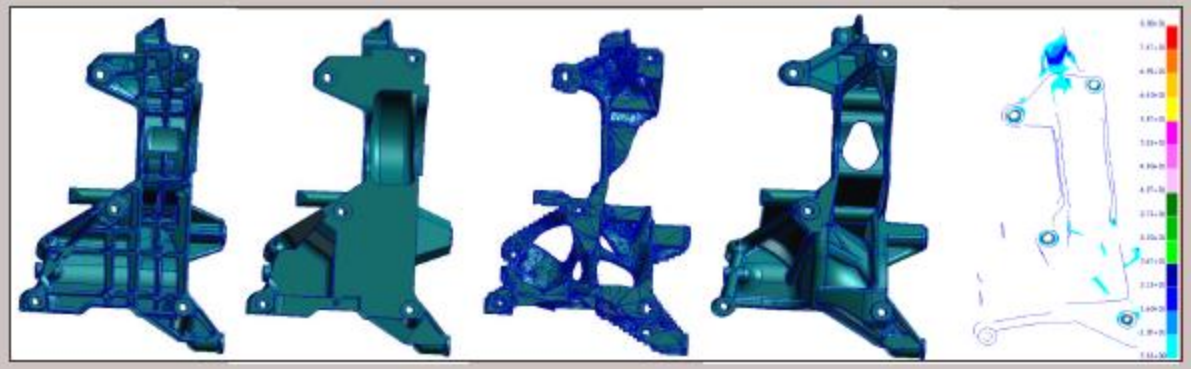
Volkswagen Case Studies



Courtesy of Altair

Volkswagen Case Studies

Combined bracket for alternator and air-conditioning compressor

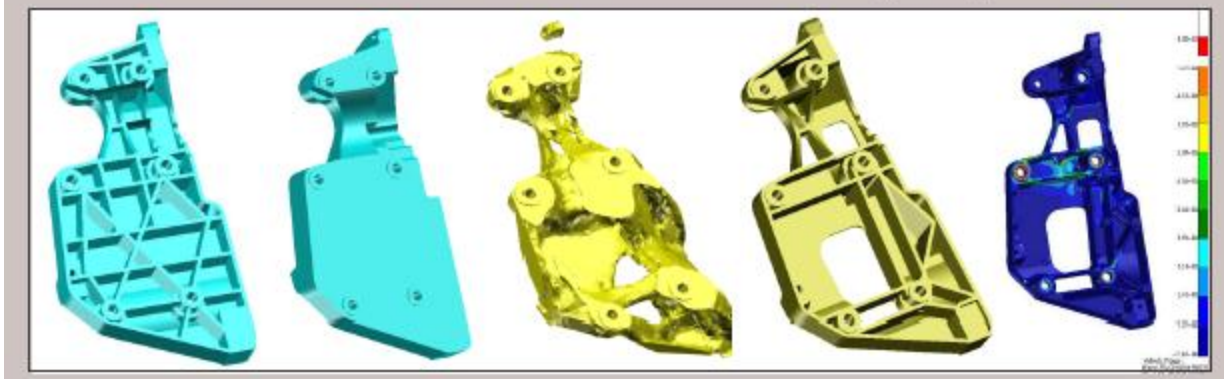


Original shape	Design space	Topology result	New design	Stress check
2018 g		1523 g	1698 g	

Courtesy of Altair

Volkswagen Case Studies

Combined bracket for alternator and air-conditioning compressor

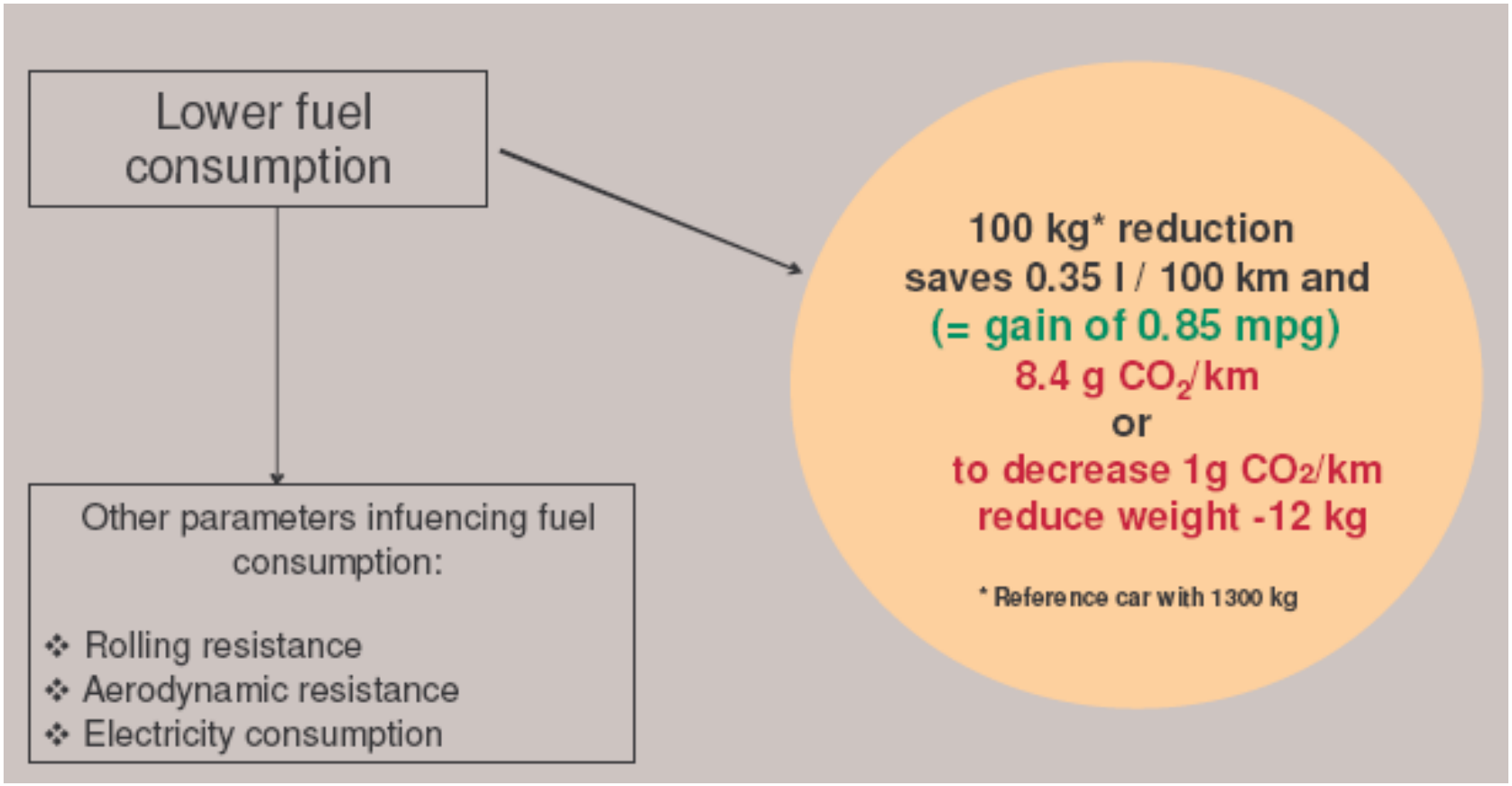


Original shape | Design space | Topology result | New design | Stress check

2058 g | 1676 g

Courtesy of Altair

Volkswagen's Motivation



Courtesy of Altair

Case Studies

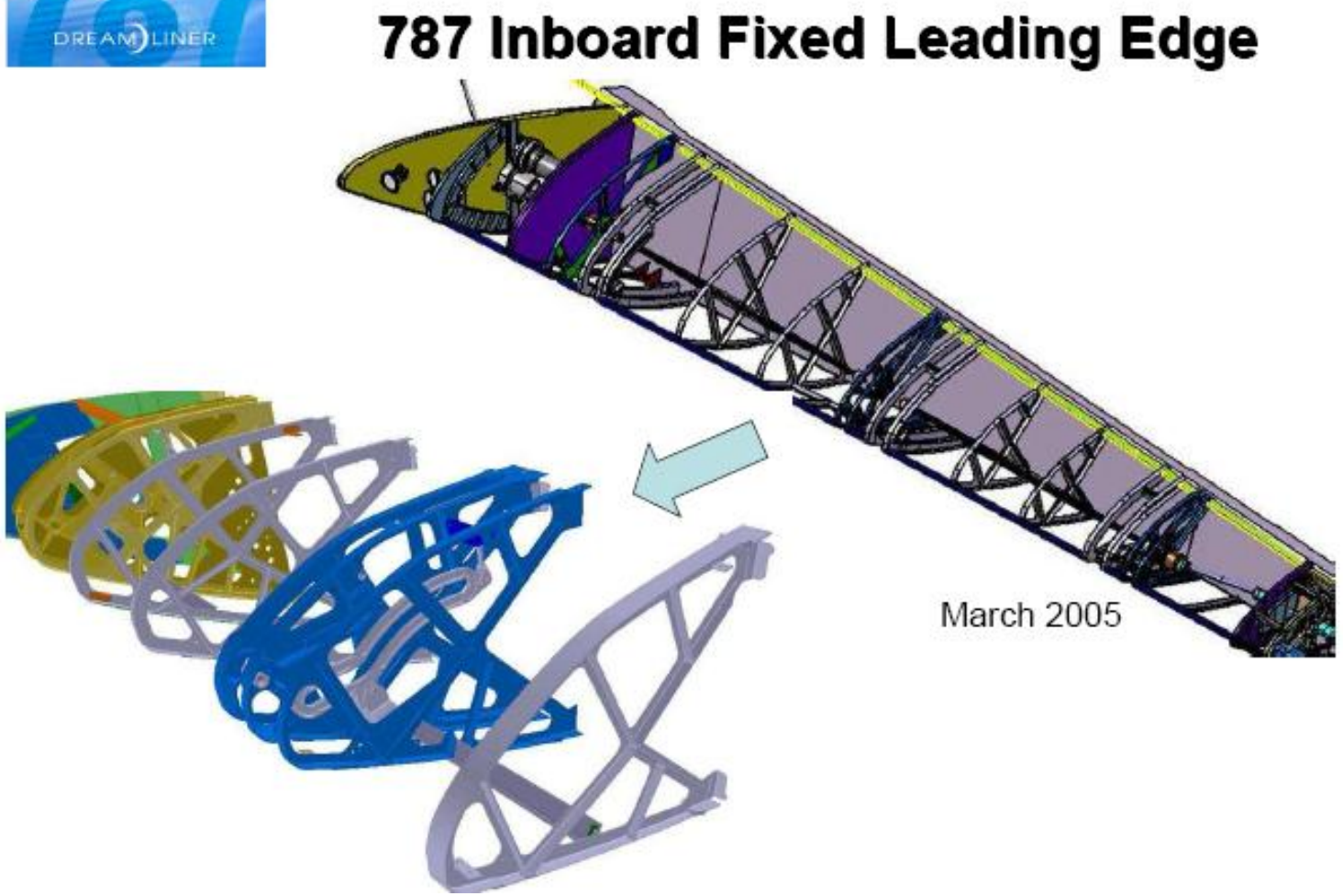
- Boeing
  - What were/are the two overarching design challenges on the 787?

787 Challenges

- Design 50 light weight/strong ribs for the Wing's Leading Edge.
  - **Why do Topology Optimization?**
    - To determine orientation and quantity of stiffeners for load paths
    - To determine openings for Systems integration or to investigate "what if" configurations
    - To determine best profile of part
  - **Why do Size and Shape Optimization?**
    - To reduce weight
    - To increase stiffness or to understand how much weight a displacement constraint will add
    - To investigate different metal alloys
    - To decrease non-recurring effort (once up the learning curve)
    - For consistent results

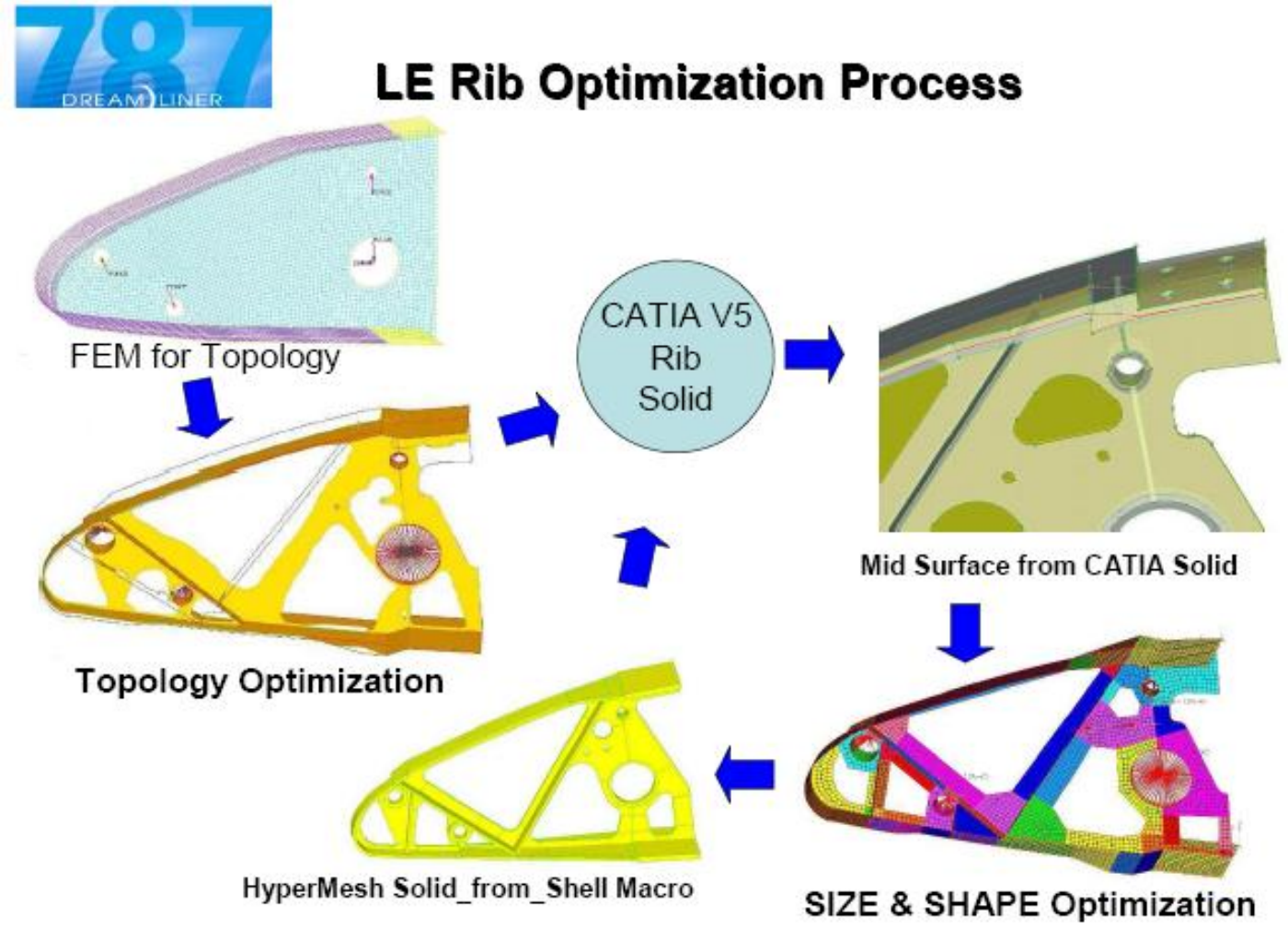
Courtesy of Altair

787 Objective



Courtesy of Altair

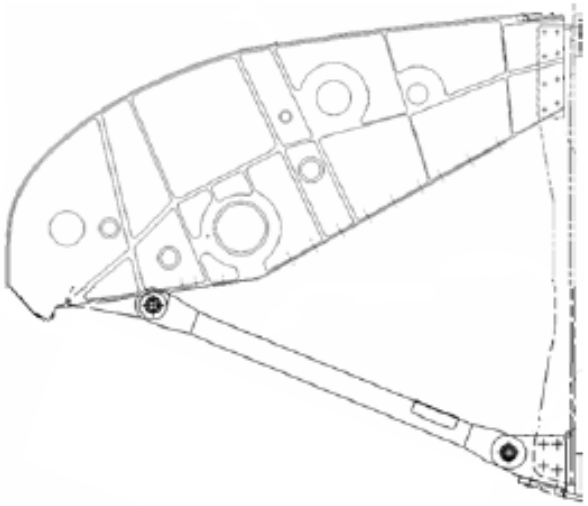
787 Optimization Process



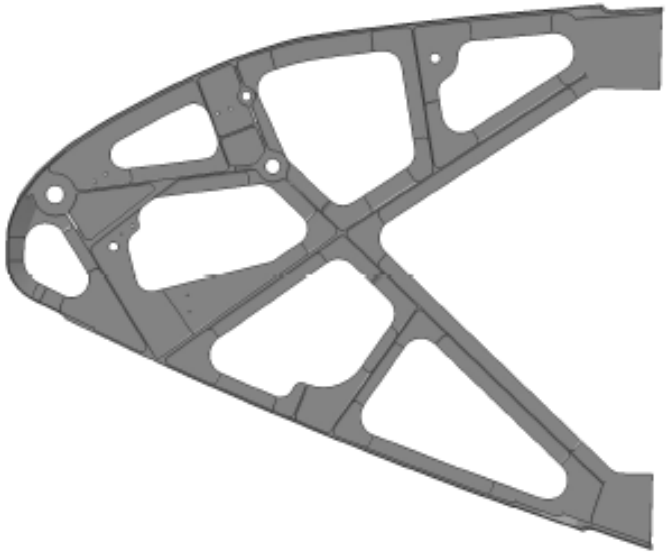
Courtesy of Altair

787 Results

787 Inboard FLE Ribs compared



777 Inboard Main Track Rib

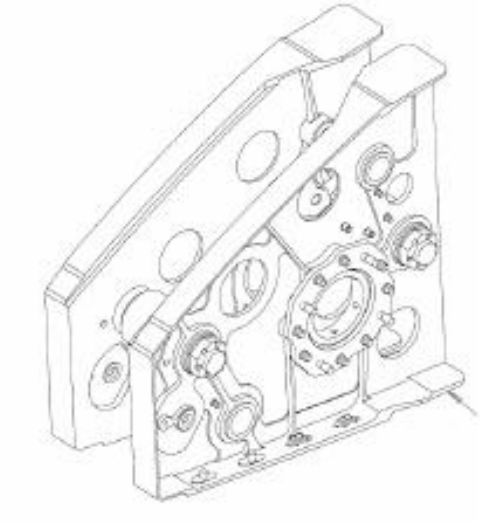


787 Inboard Main Track Rib

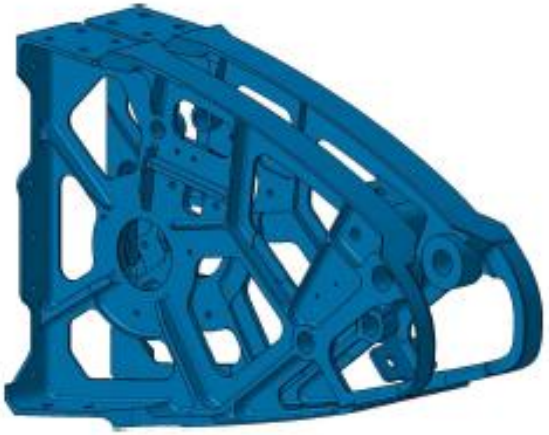
Courtesy of Altair

787 Results

787 Outboard FLE Ribs compared



777 Outboard Main Track Rib

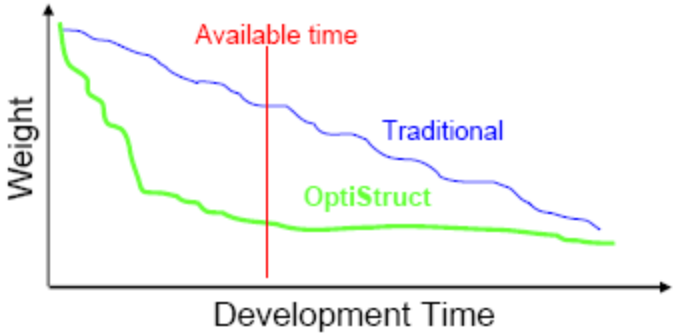


787 Outboard Main Track Rib

Courtesy of Altair

787 Results

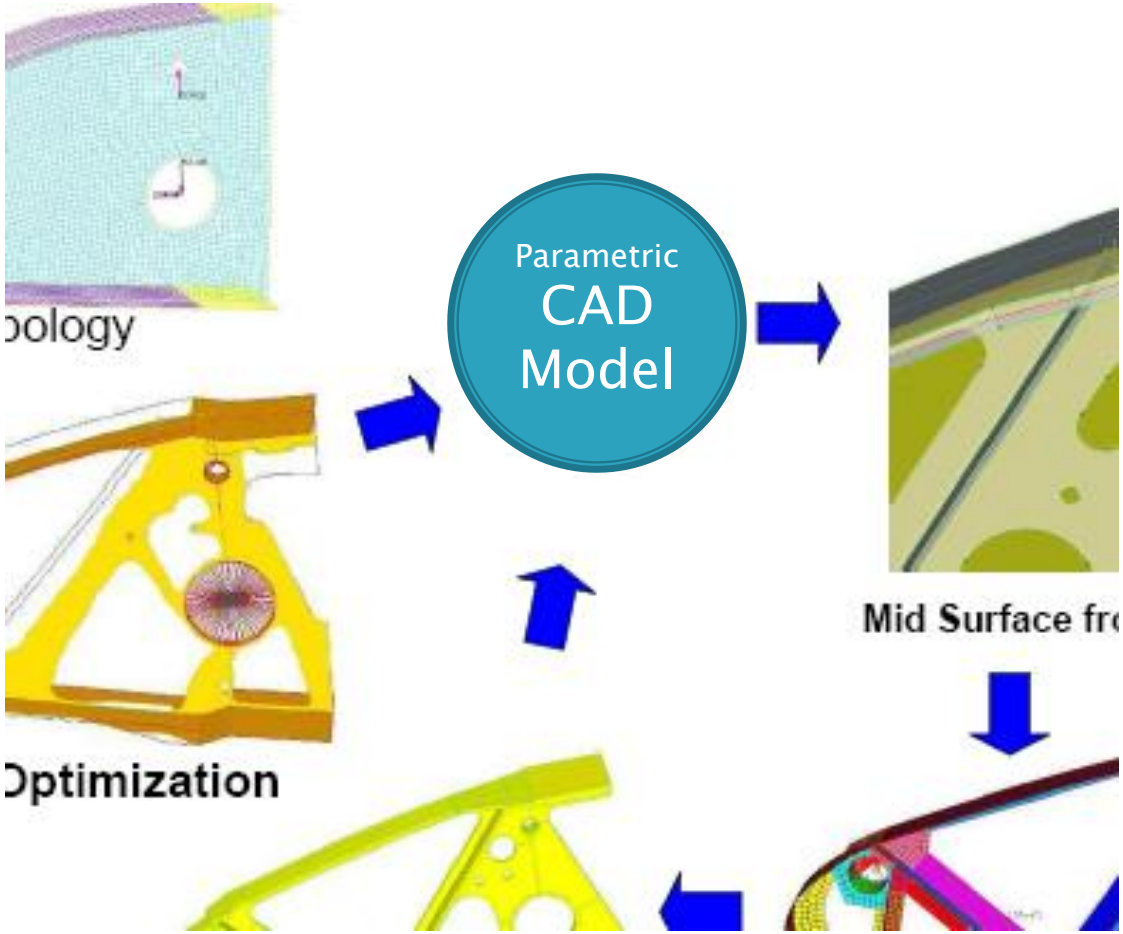
- Met the -12% weight target
- The process got better and quicker
- Following this optimization process made light parts… "Maybe not the lightest, but close"



- Boeing Partners have been (are being) greatly encouraged to embrace optimization technology
- "This is a new technology that will only get better"

Courtesy of Altair

What is today's main challenge with implementing topology optimization?



Courtesy of Altair

Integrating Topology Optimization with CAD

A Methodology for Defining CAD Parametric Geometry via Semi-Automatic Topology Recognition

ParaCAD
Parametric CAx Research Laboratory

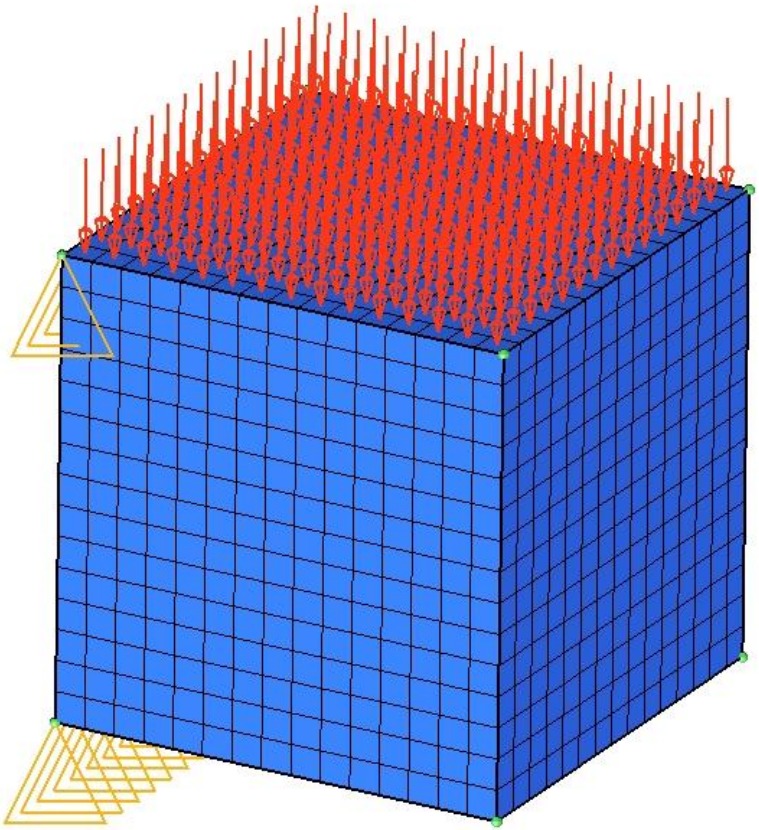
S. Larsen

BRIGHAM YOUNG UNIVERSITY

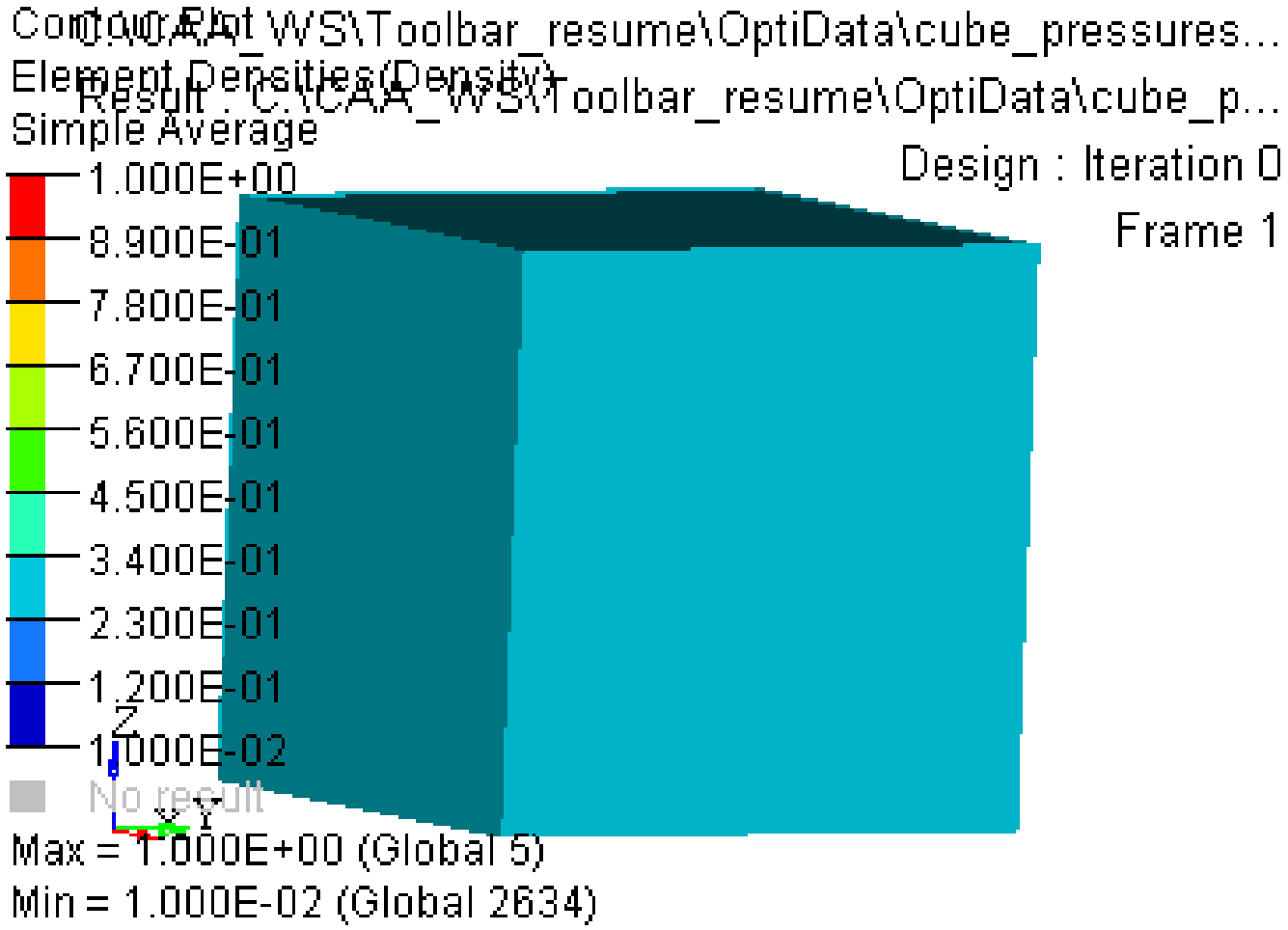
Outline

- Background
- Research Objectives
- Methodology
- Results
- Future Work

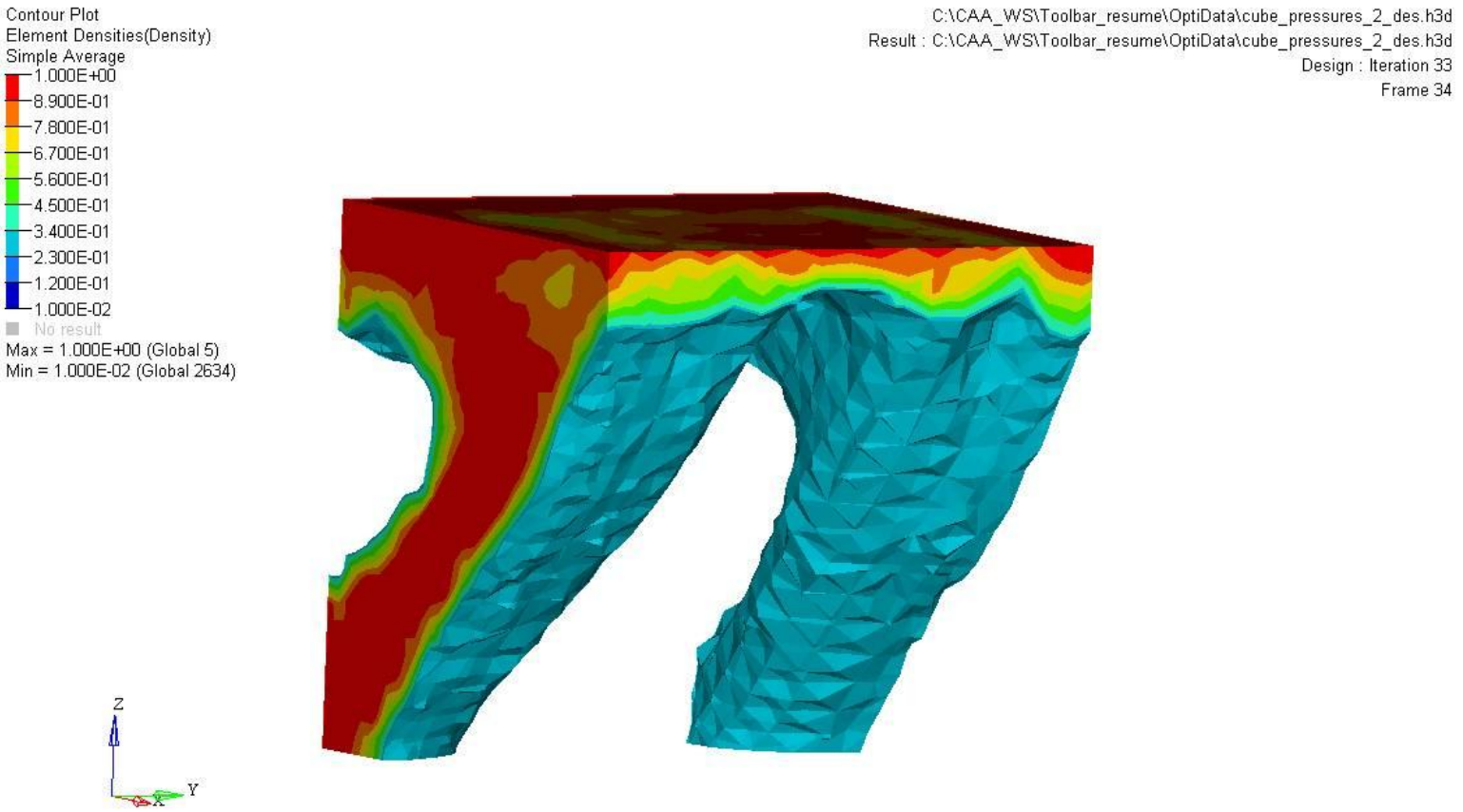
Topology Optimization



Topology Optimization

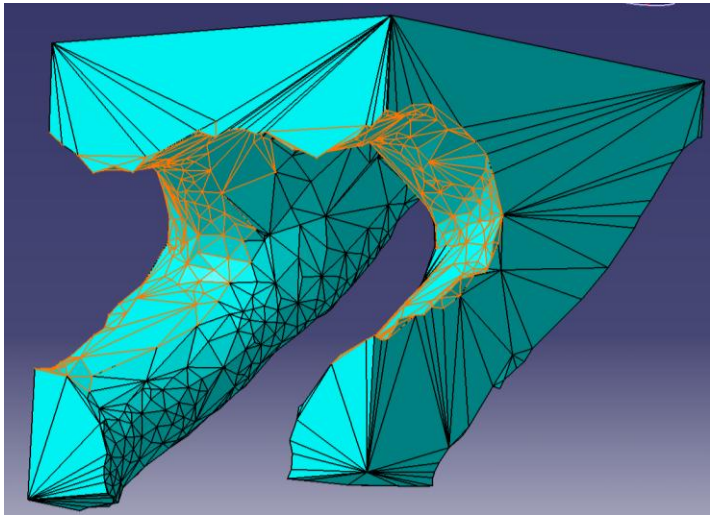


Topology Optimization

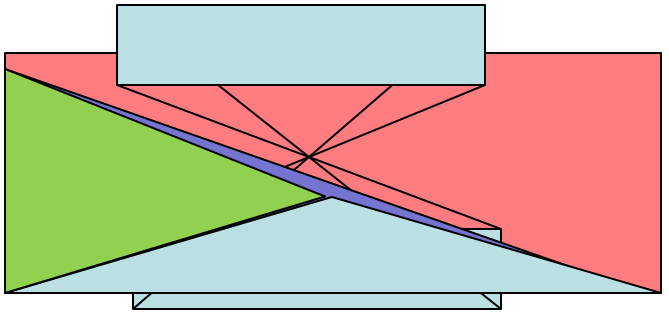


Topology Results

- "Smoothed" faceted surfaces



- Common problems
  - Duplicates
  - Quadrilaterals
  - Non-manifold



Background

S Simple

P Parametric

A Automated

S Standard

M Measured Fitness

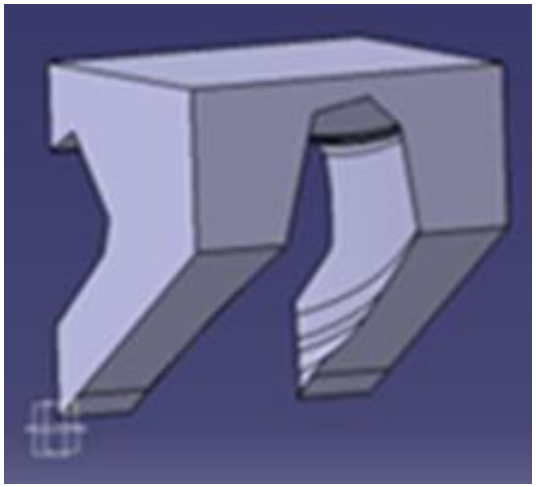
Simple

Parametric

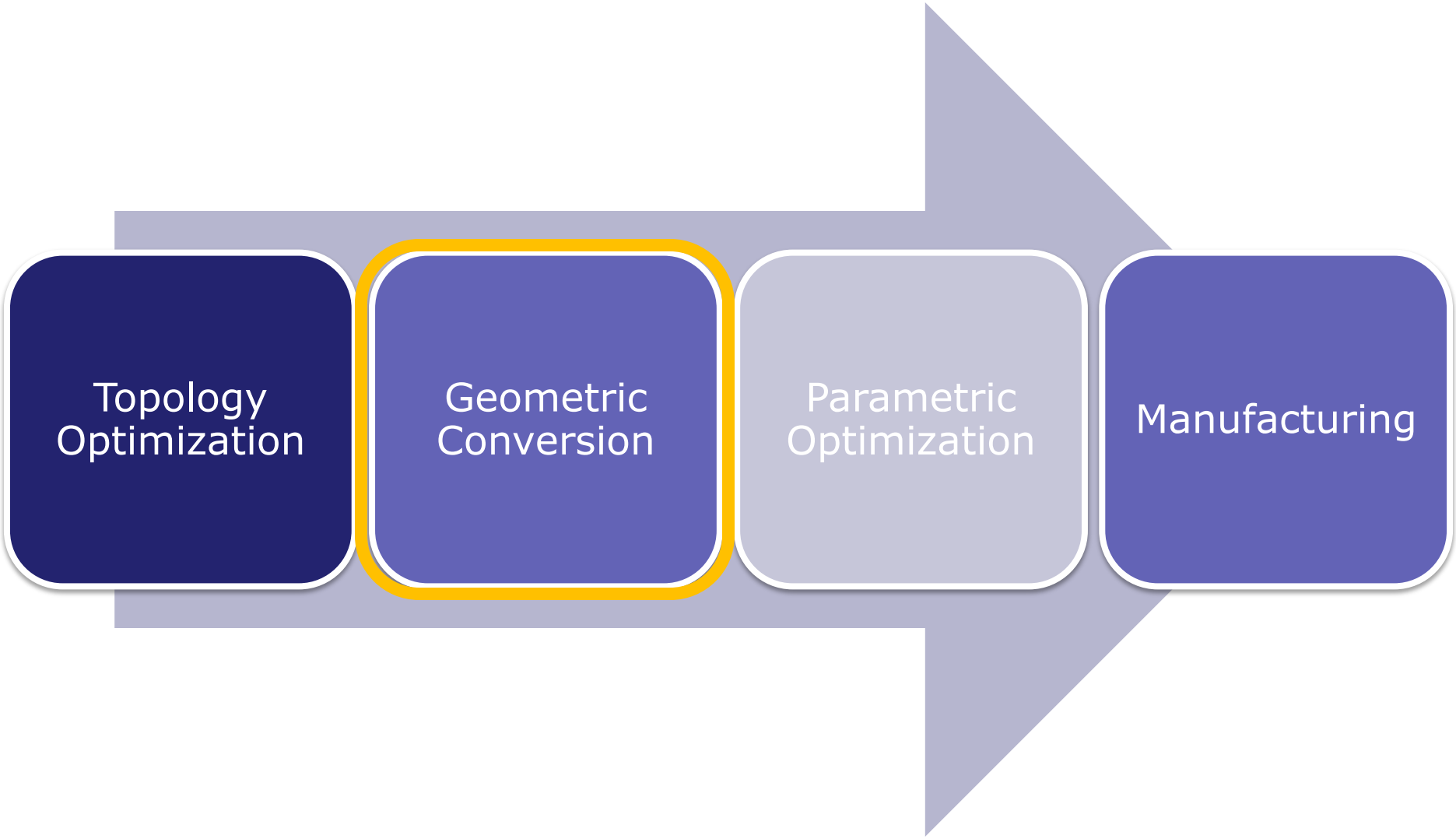
Automated

Standard

Measured Fitness



Standard Approach



Standard Approach

- Manual Post-Processing
  - Model created by hand
  - Model linked by hand into parametric optimization

Pros

- Manufacturable
- Control of complexity
- Parametric results

Cons

- Time intensive
- Topological fitness is not measured
- No automatic link to parametric optimization
- Hard to repeat

Finite Element Approach

- Mesh Refinement
  - Reduce data points through mesh refinement algorithms
  - Simplify geometry through “smoothing”

Pros

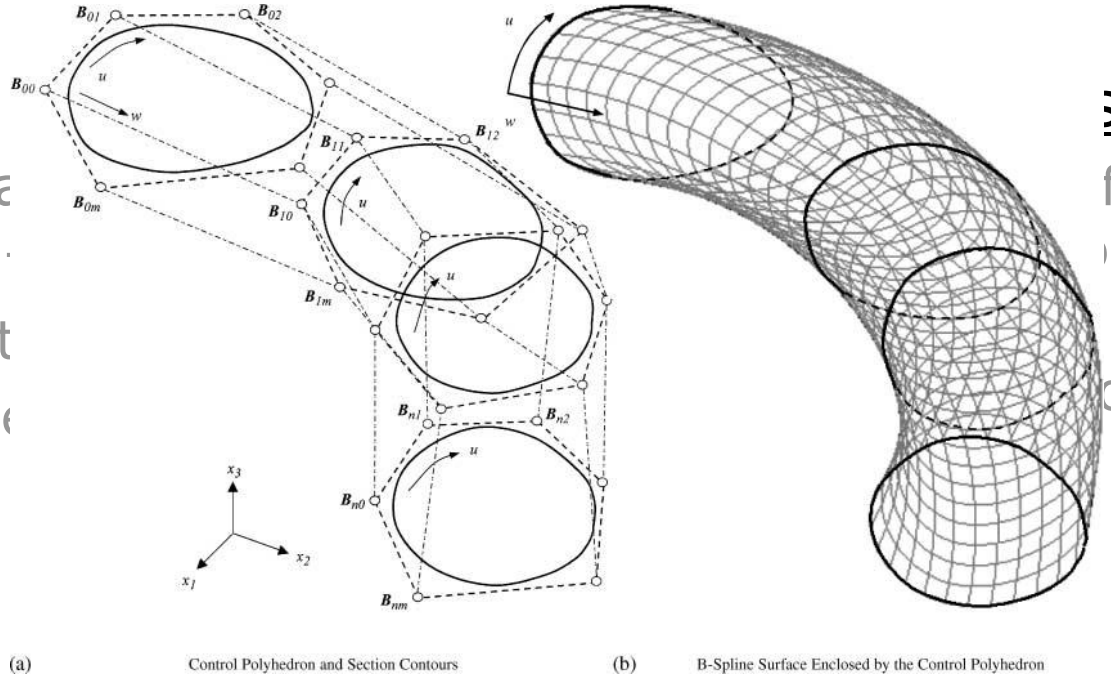
- Little user input required
- Repeatable

Cons

- Non-parametric results
- Difficult to link to parametric optimization
- Non-standard model format

Parametric Approach

- B-Spline solution
  - Cut model into cross sections
  - Image processing of cross sections to create B-splines
  - Link B-Splines to create NURBS



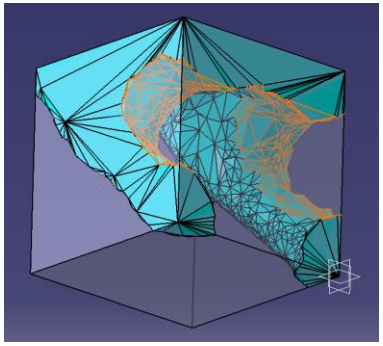
(a) Control Polyhedron and Section Contours (b) B-Spline Surface Enclosed by the Control Polyhedron

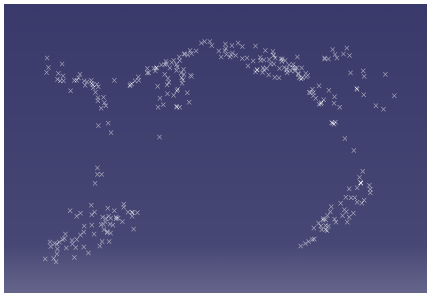
Tang & Chang 2001

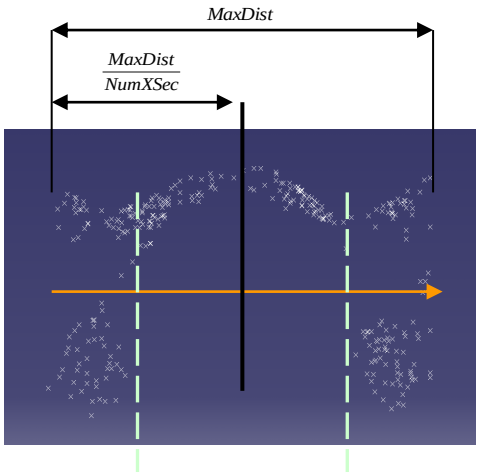
Research Objectives

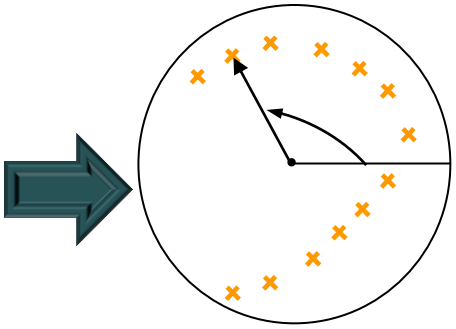
- Simple
  - Manage tradeoff between defining parameters and geometric fitness
- Parametric
  - Model defined by standard CAD features that can be linked to size/shape (parametric) optimization
- Automated
  - Reduce time to post process
- Standard
  - Use simple CAD features familiar to designers
- Measured Fitness
  - Algorithm must utilize fitness measure to determine appropriate topology

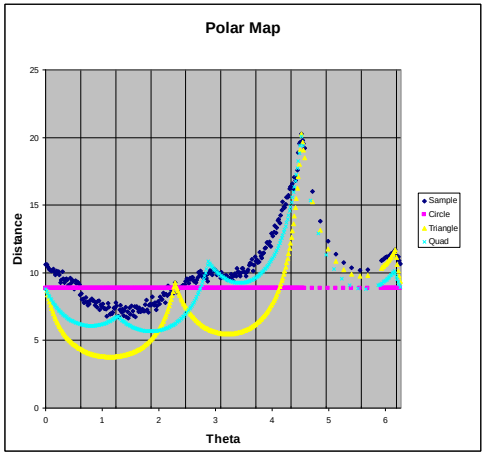
Process Overview

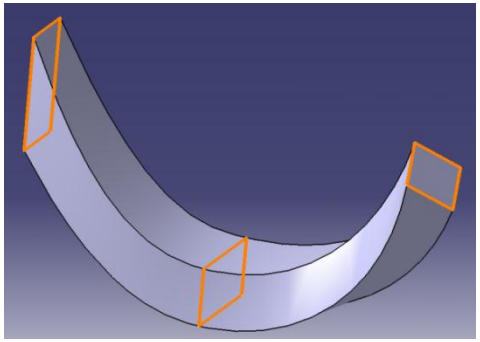






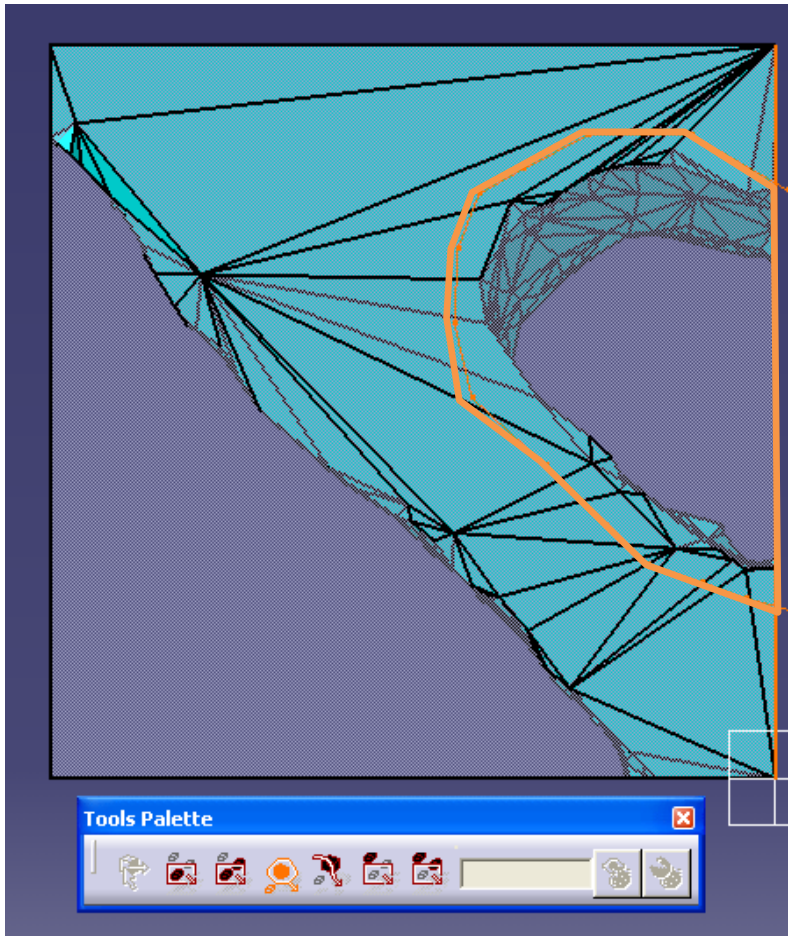






Shape Recognition Algorithm

- **Feature Surface Selection**
- Uniform Point Cloud Generation
- Point Cloud Segmentation
- Cross Section Sampling
- Shape Template Comparisons
- Topological Fitness
- Geometry Creation



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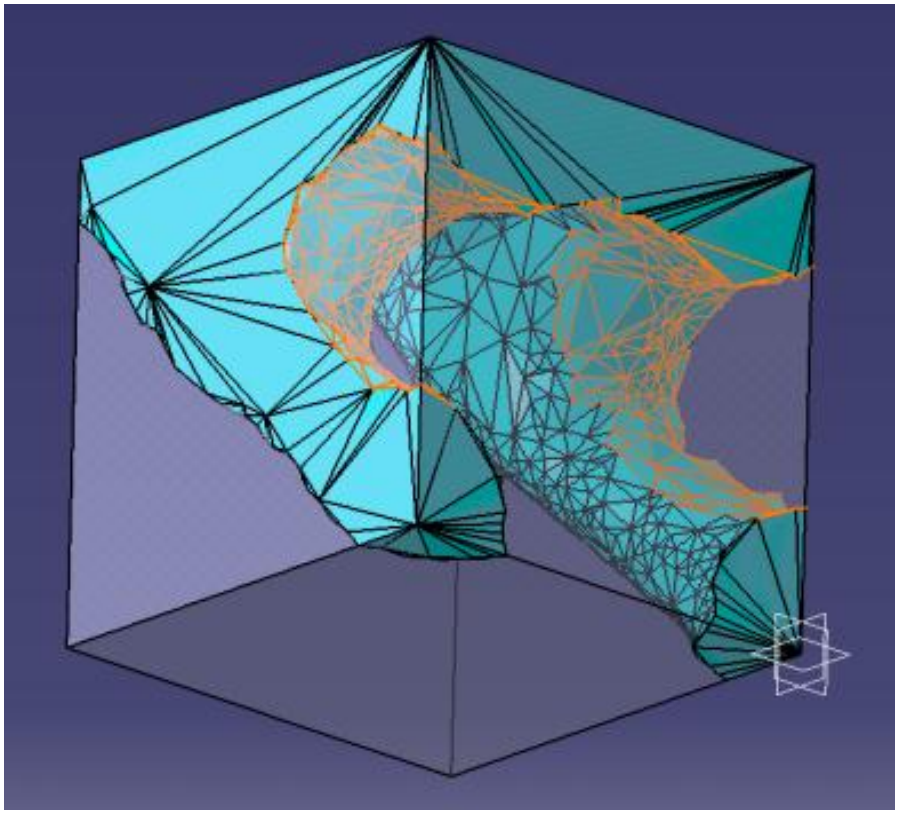

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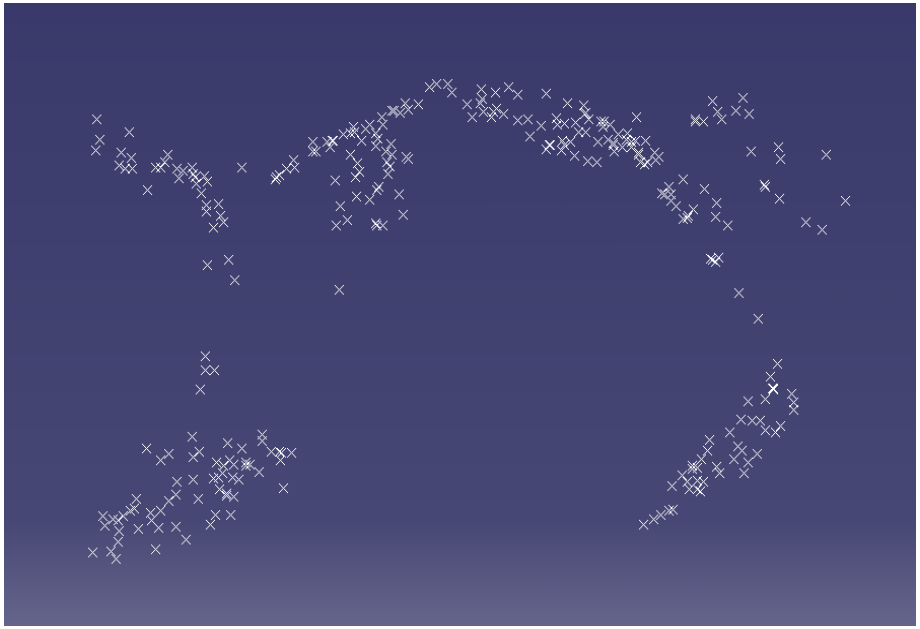

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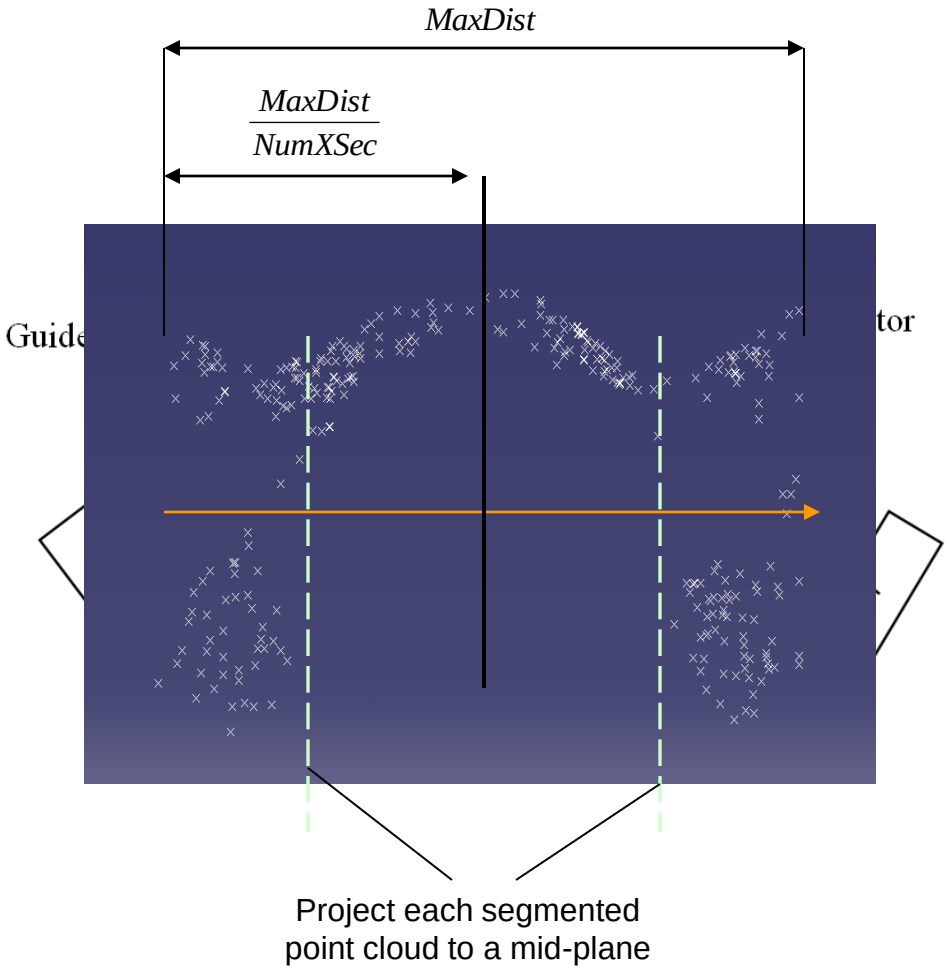

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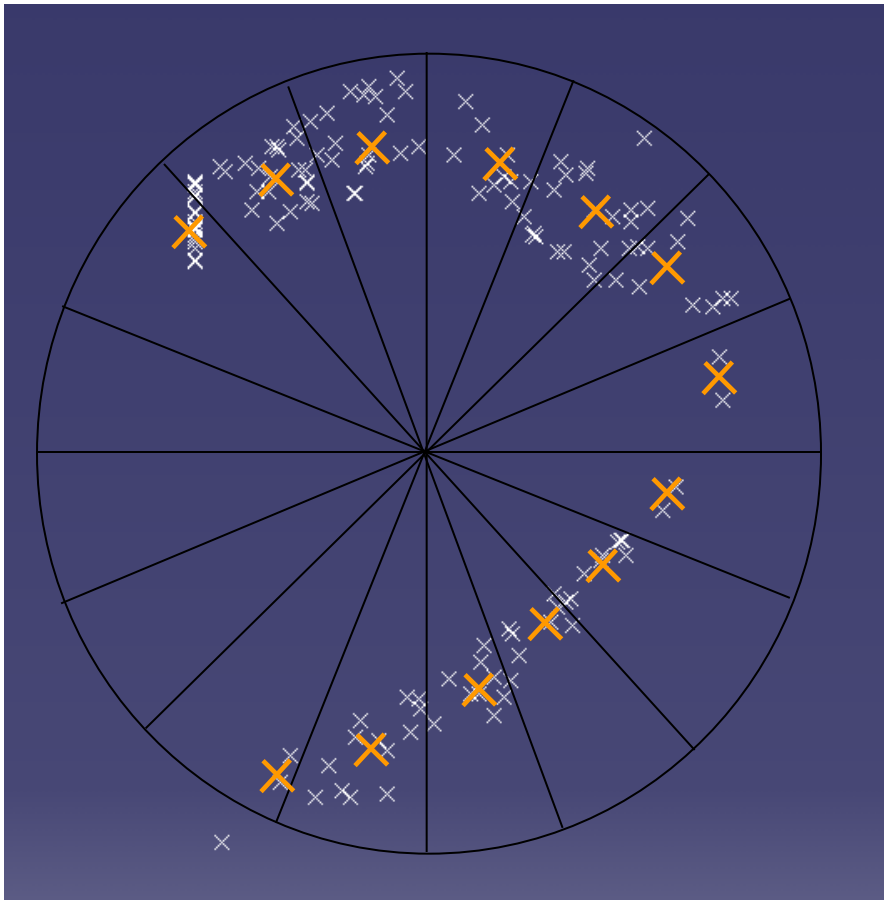

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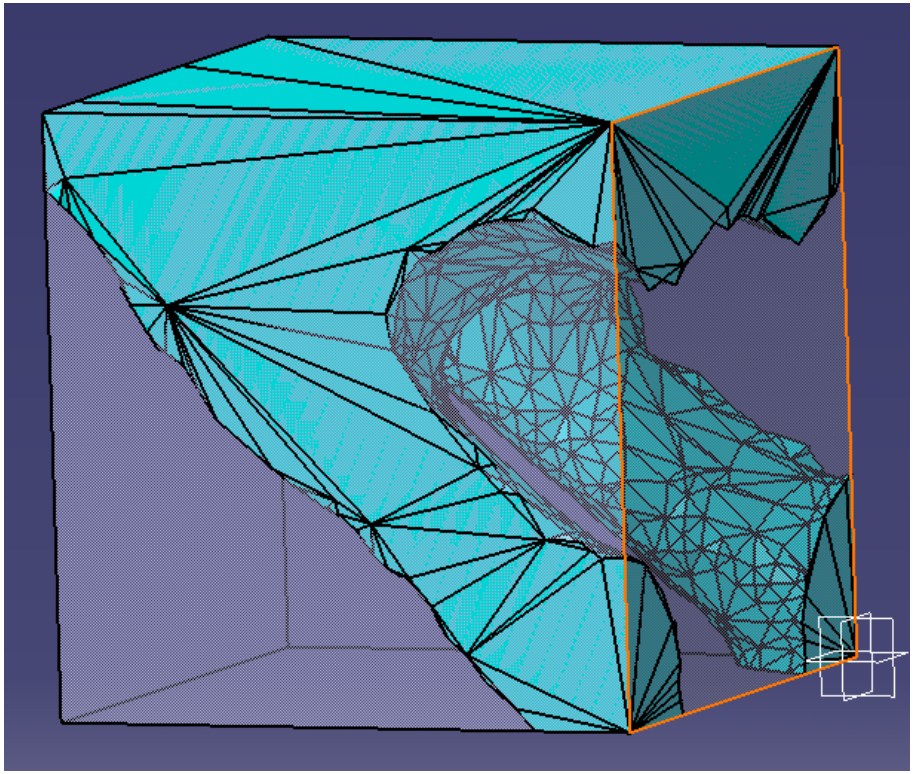

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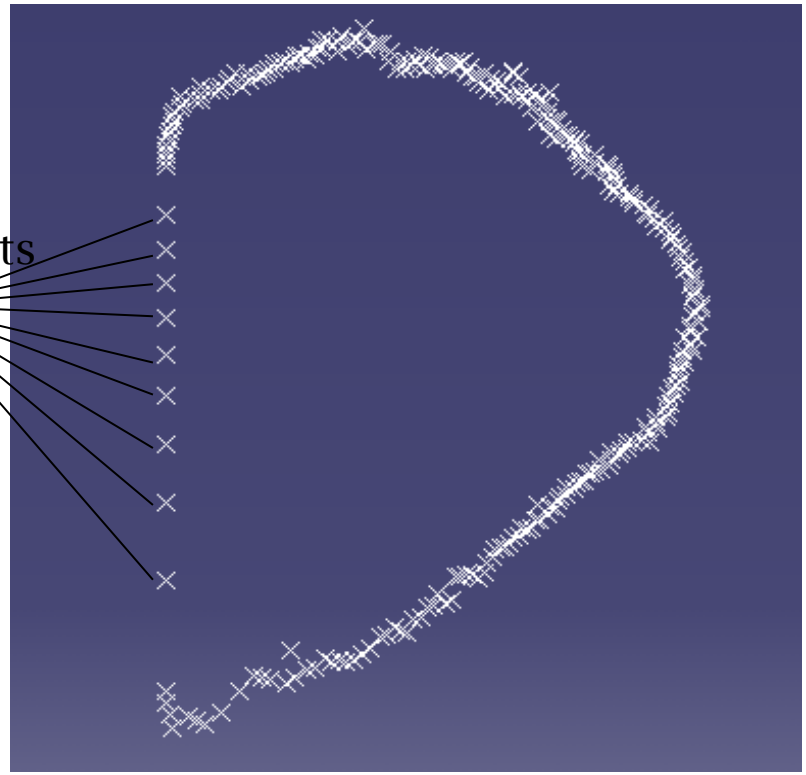

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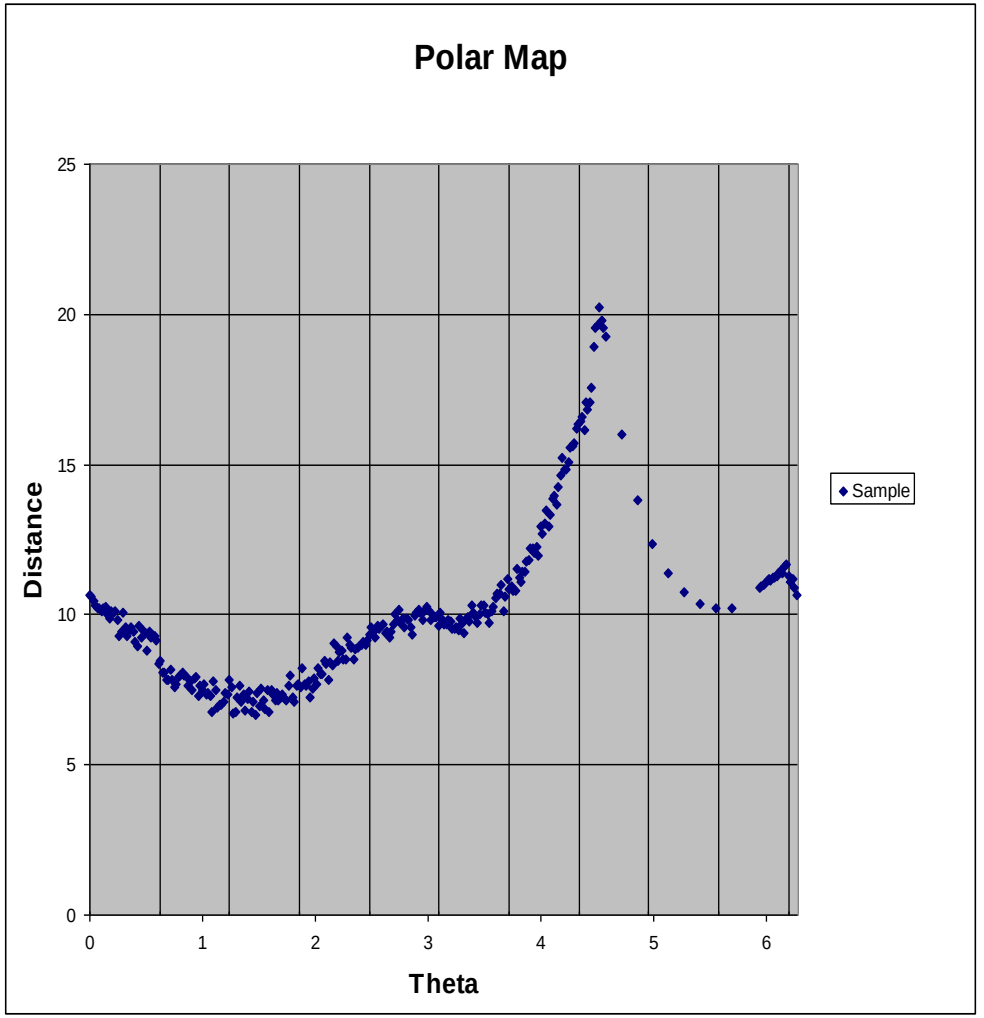

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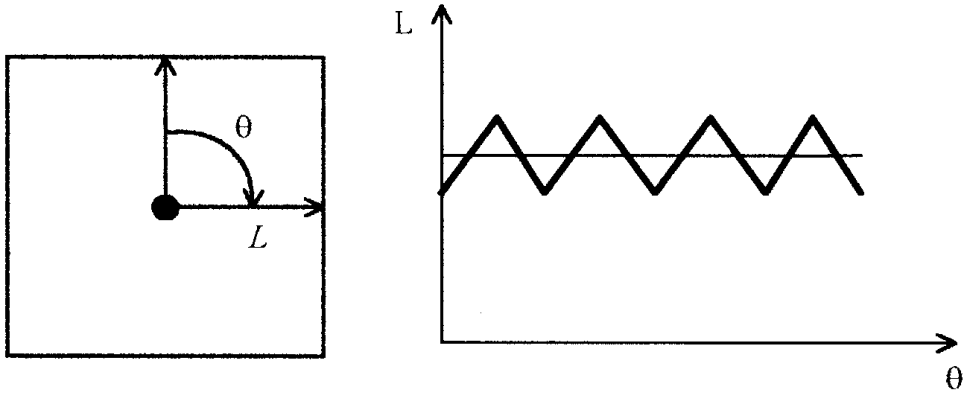

Lin & Chao, 2000

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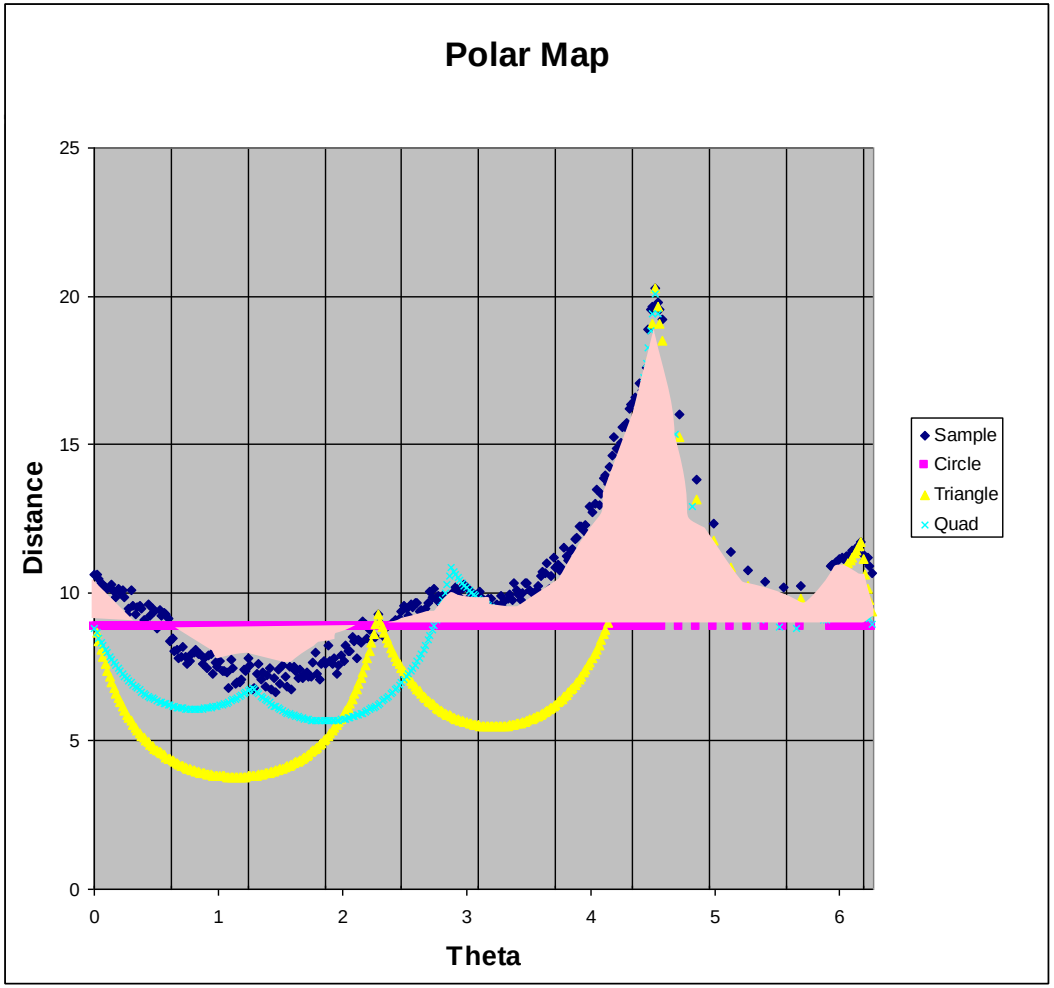

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Template Fitness Residuals

	Circle	Triangle	Quadrilateral
CS 1	1200	4000	600
CS 2	1450	3500	1250
3D Fit	**2650**	**7500**	**1850**

Pair Wise Template Comparison

	Circle	Triangle	Quadrilateral
Circle	0	-183%	30%
Triangle	65%	0	75%
Quadrilateral	-43%	-305%	0
# Params / X- Section	4	12	16

Shape Recognition Algorithm

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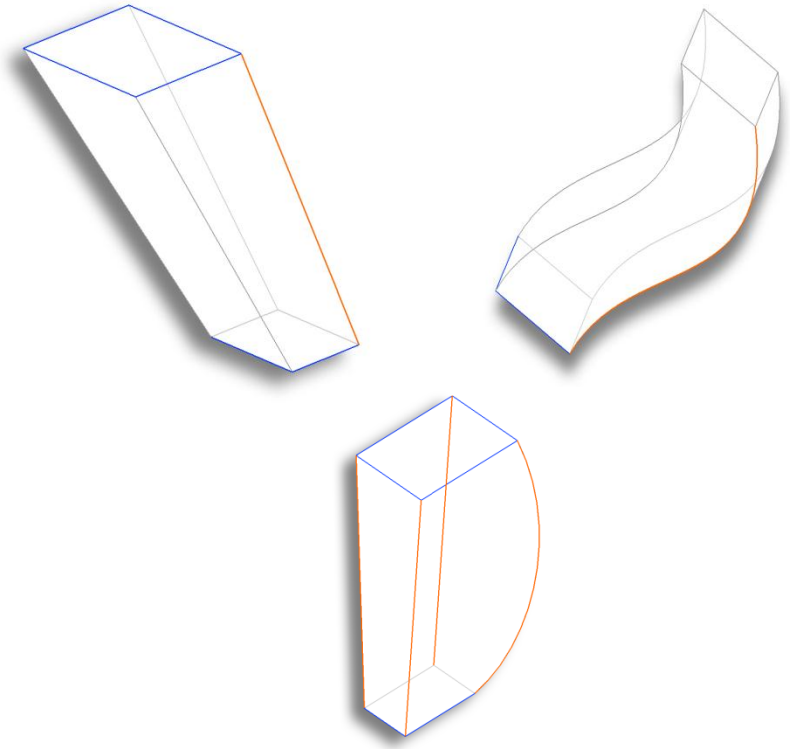
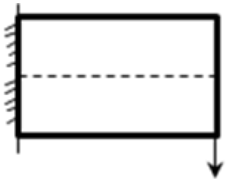
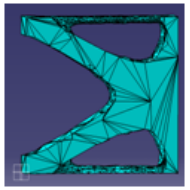
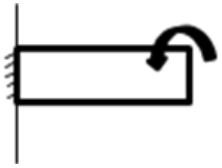
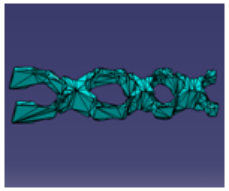
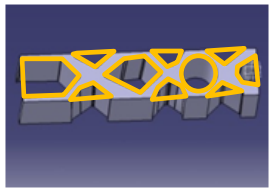
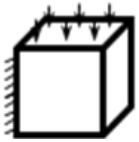
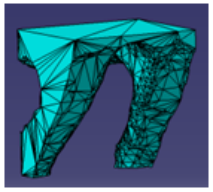
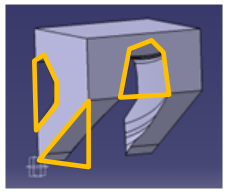
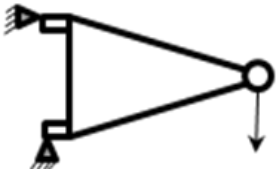
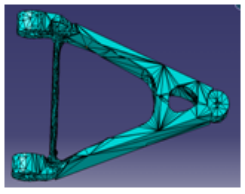
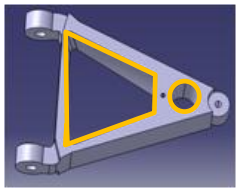
- **Geometry Creation**

Cross Section / Spine Modeling



Results

ParaCAD
Parametric CAx Research Laboratory

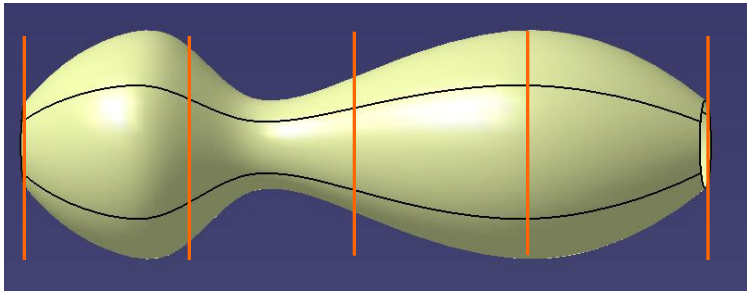
Loading Conditions	TO Results (Optimal Part)	Parametric Model	# Features	% of Optimal Volume
I 			4	133%
II 			10	158%
III 			3	101%
IV 			2	126%

Research Objectives

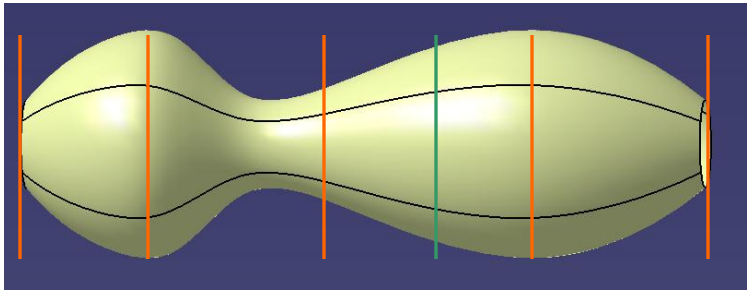
- Simple – **Complete**
  - Manage tradeoff between defining parameters and geometric fitness
- Parametric – **Complete**
  - Model defined by standard CAD features that can be linked to to size/shape (parametric) optimization
- Automated – **Semi-Automatic**
  - Reduce time to post process
- Standard – **Polygonal Cross Sections**
  - Use simple CAD features familiar to designers
- Measured Fitness – **Least Squares and Volume**
  - Algorithm must utilize fitness measure to determine appropriate topology

Future Work

- Cross Section Placement
  - Problem:
    - Cross Sections are not placed in optimal positions

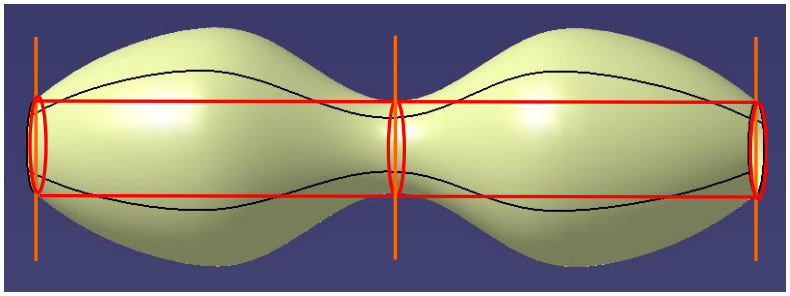


  - Suggested Solution:
    - User defined CS placement option
    - Calculate placement and let the user adjust them



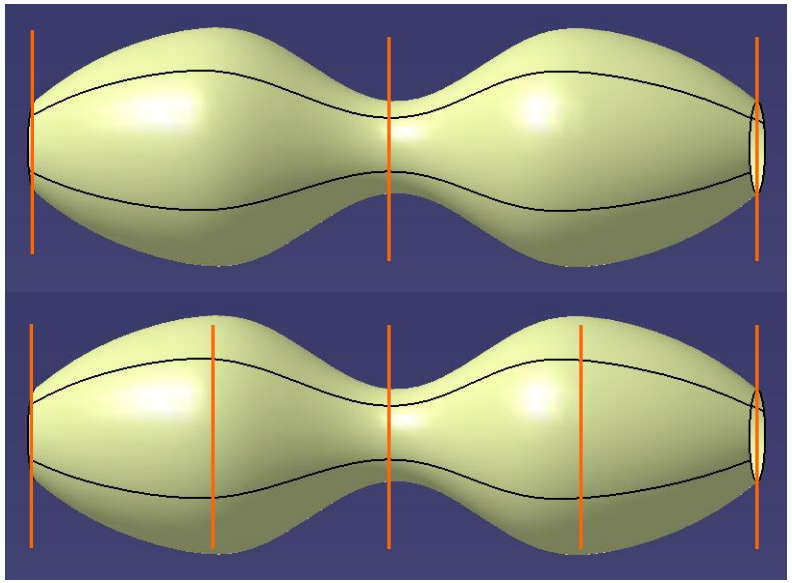
Future Work

- Number of Cross sections
  - Problem:
    - User CS # selection



Poor Fit

  - Suggested Solution:
    - Run the algorithm twice and report to the user the difference.



Future Work

- Non-Convex Shape Templates
  - Problem:
    - Shape Templates don't support non-convex cross sections
  - Suggested Solution:
    - Multi-reference point extension of polar mapping method