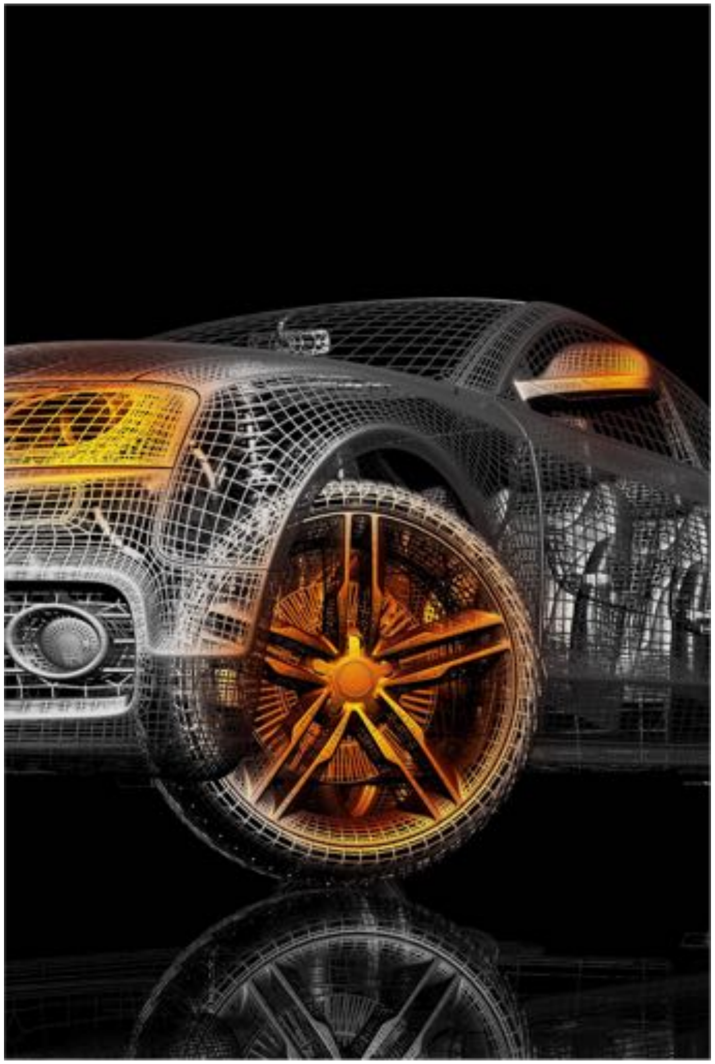

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Isogeometric analysis using the *IGA_INCLUDE_BEZIER keyword in LS-DYNA

Matthew Sederberg, Coreform CEO

Agenda

- Value of *IGA_INCLUDE_BEZIER
  - Isogeometric analysis
  - Unstructured splines
  - Larger explicit time steps
- How to use *IGA_INCLUDE_BEZIER
- Future possibilities

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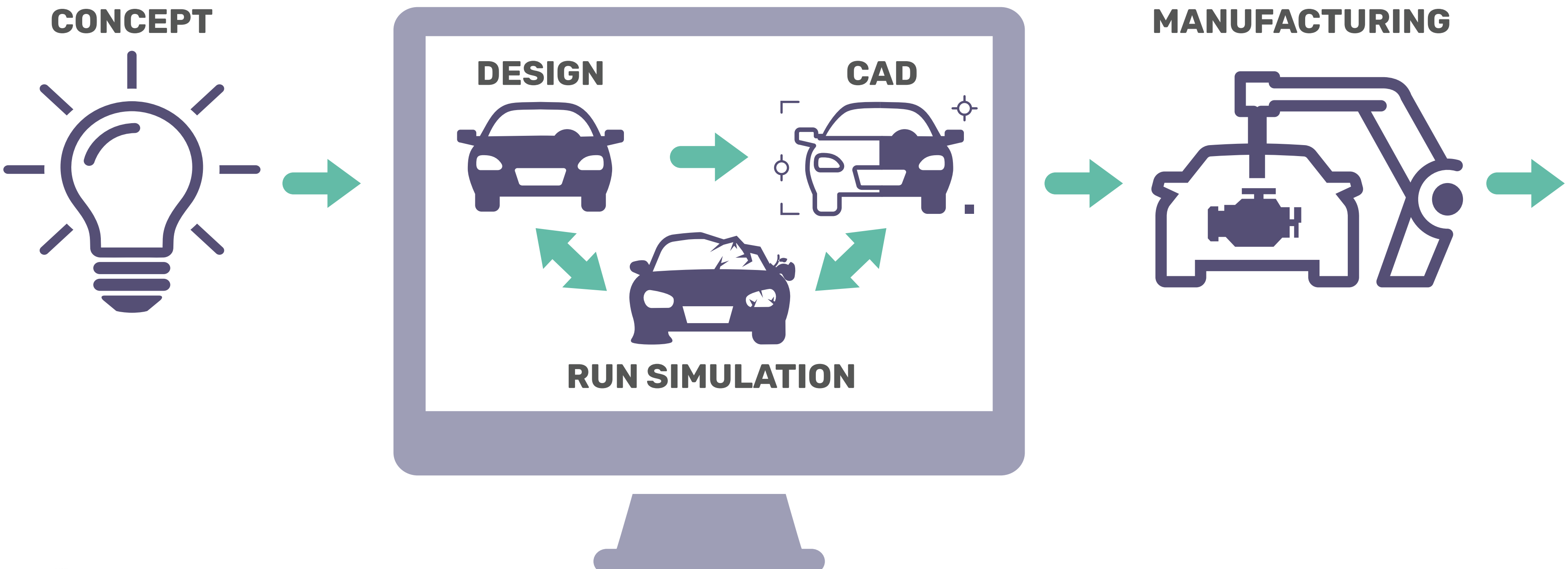
Spline-based simulation papers since 2005
USA • 502
China • 332
Germany • 315
Italy • 265
S Korea • 183
Vietnam • 118
Austria • 105
Iran • 101
Spain • 94
Japan • 87
England • 83
France • 78
Netherlands • 68
Australia • 67
Belgium • 64
Saudi Arabia • 53
India • 52
Norway • 45
Wales • 41
Switzerland • 36
Scotland • 41
Poland • 28
Luxembourg • 27
Singapore • 27
Canada • 26

Vision of isogeometric analysis (IGA):
A single source of truth for design and analysis



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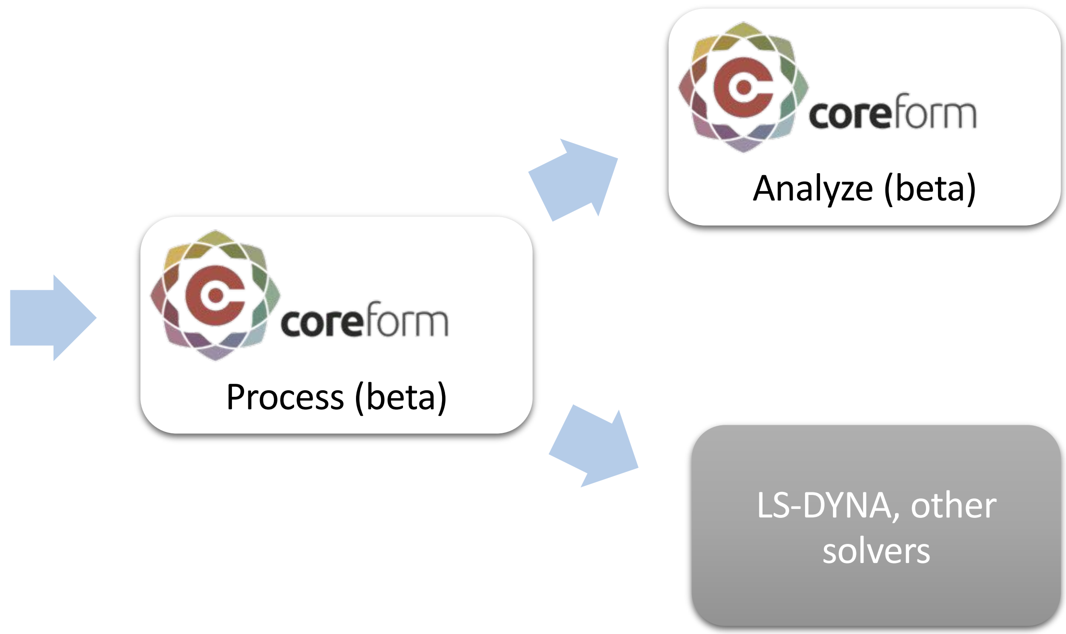
Using highly accurate spline-based FEA

- FEA mesh data

LS Dyna

Nastran

- Next-gen CAD data



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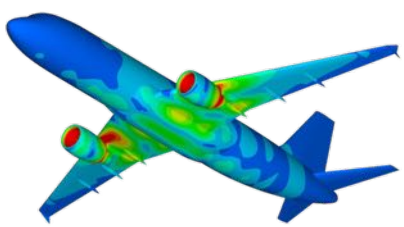
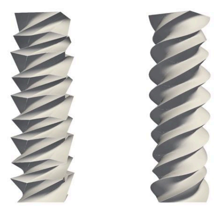
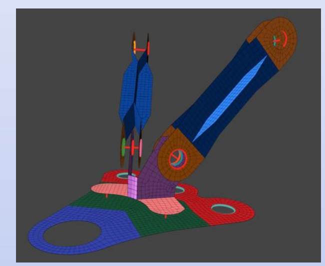
Promise of smooth spline-based FEA

Better simulation through better geometry







Better accuracy in less time

Increased robustness

Lower simulation costs

Minimal change to your workflow

Greatly improved by *IGA_INCLUDE_BEZIER

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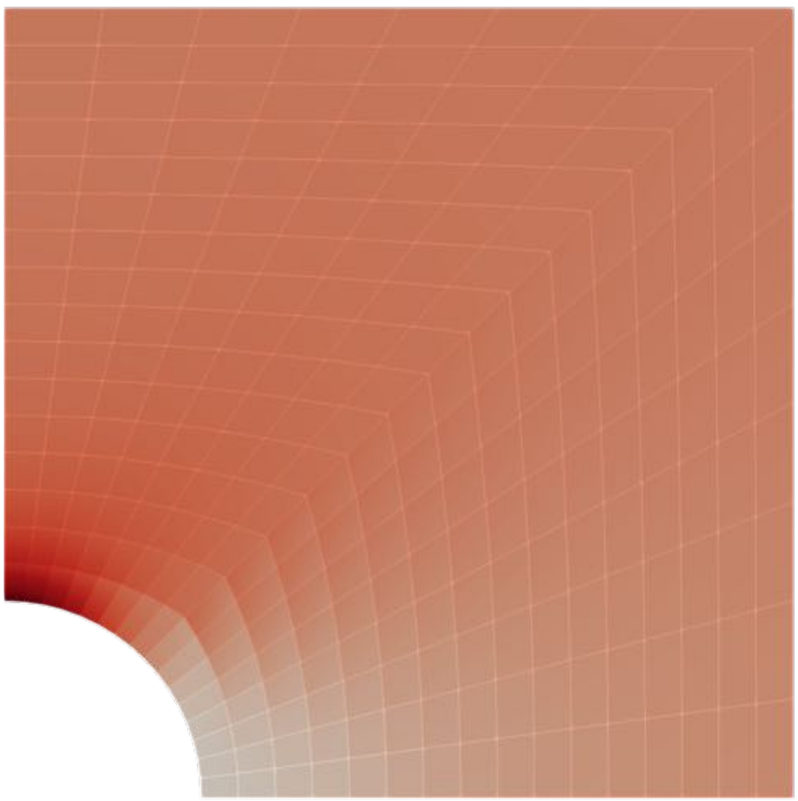
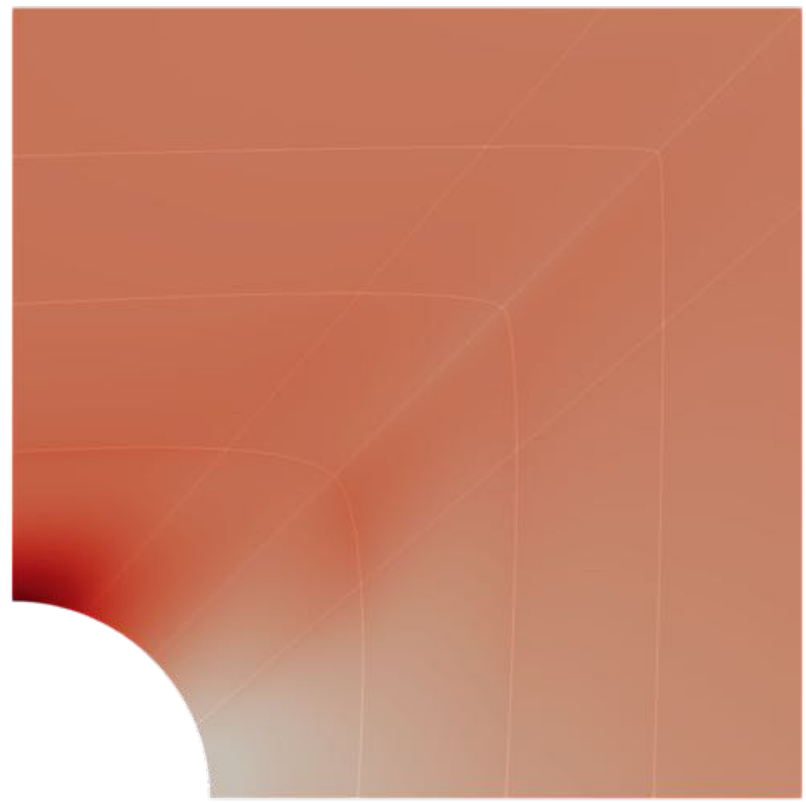
Better stress accuracy: 16x fewer elements for ~1% error



FEA: 256 elements



Splines: 16 elements

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Splines are more robust for large deformations

	FEA	Spline
Degree	1	2
# of nodes	160	160
Timesteps completed	144	209

FEA

Splines

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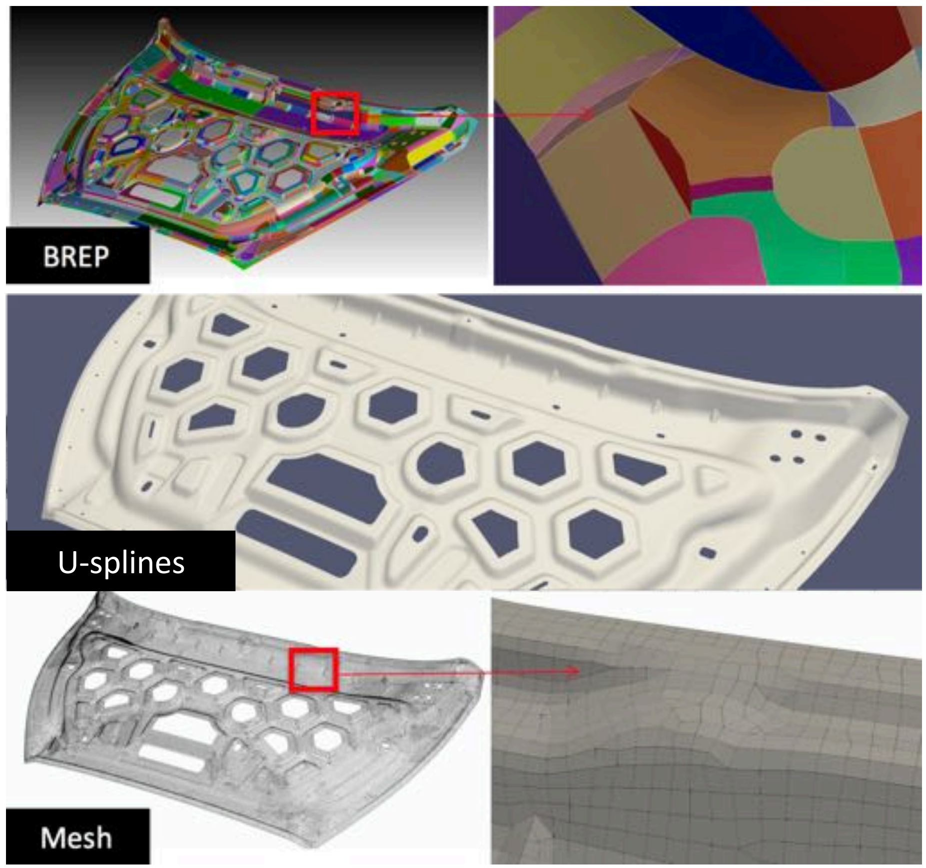
U-splines: next-gen CAE/CAD technology

Traditional engineering design

Next-gen design and analysis

Traditional engineering analysis



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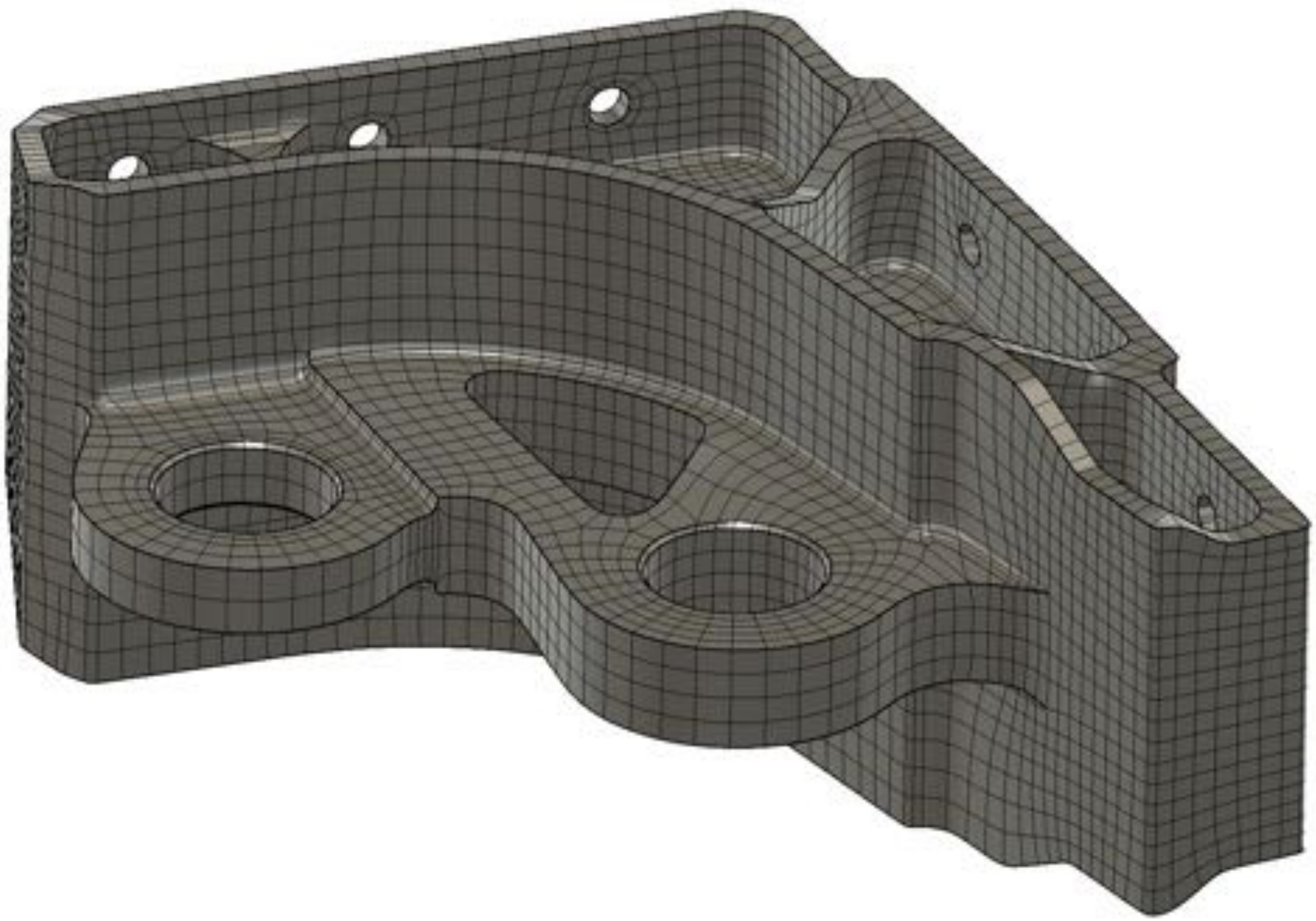
Analysis-suitable geometry



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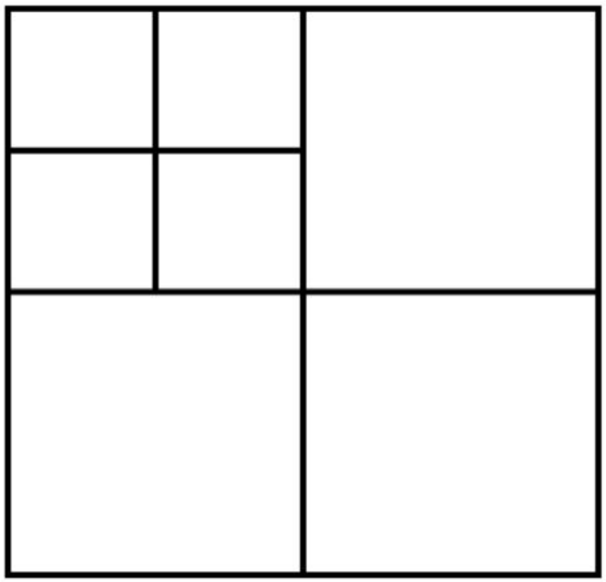
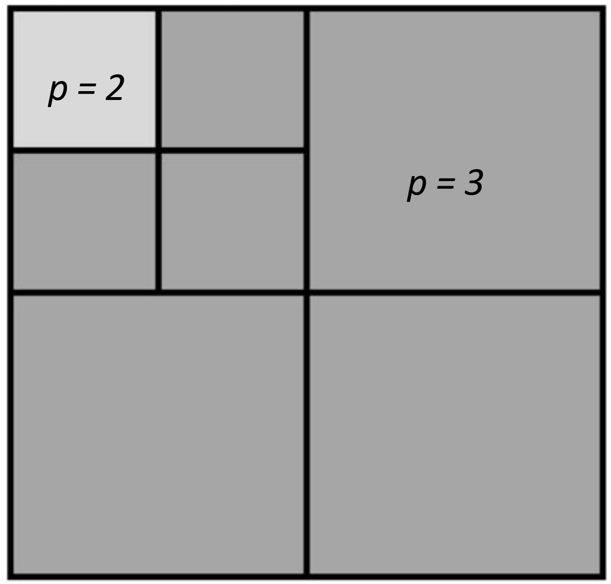
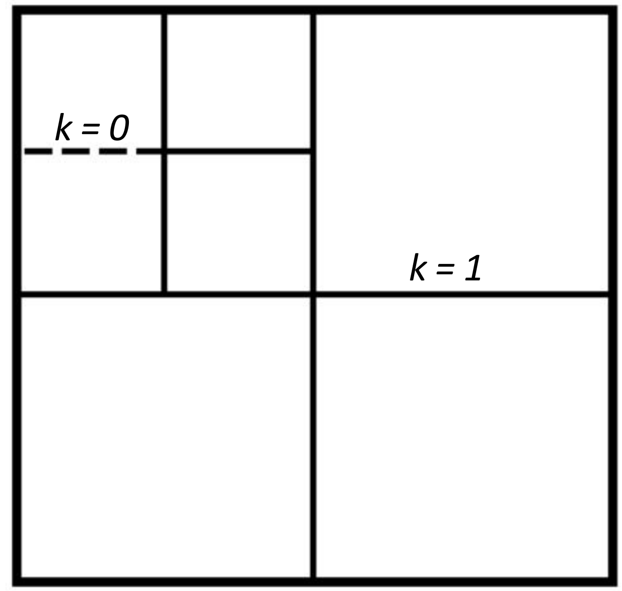
Non-uniform topology



Non-uniform degree



Non-uniform smoothness



- Partition of unity
- Compactly supported
- Positive
- Linearly independent

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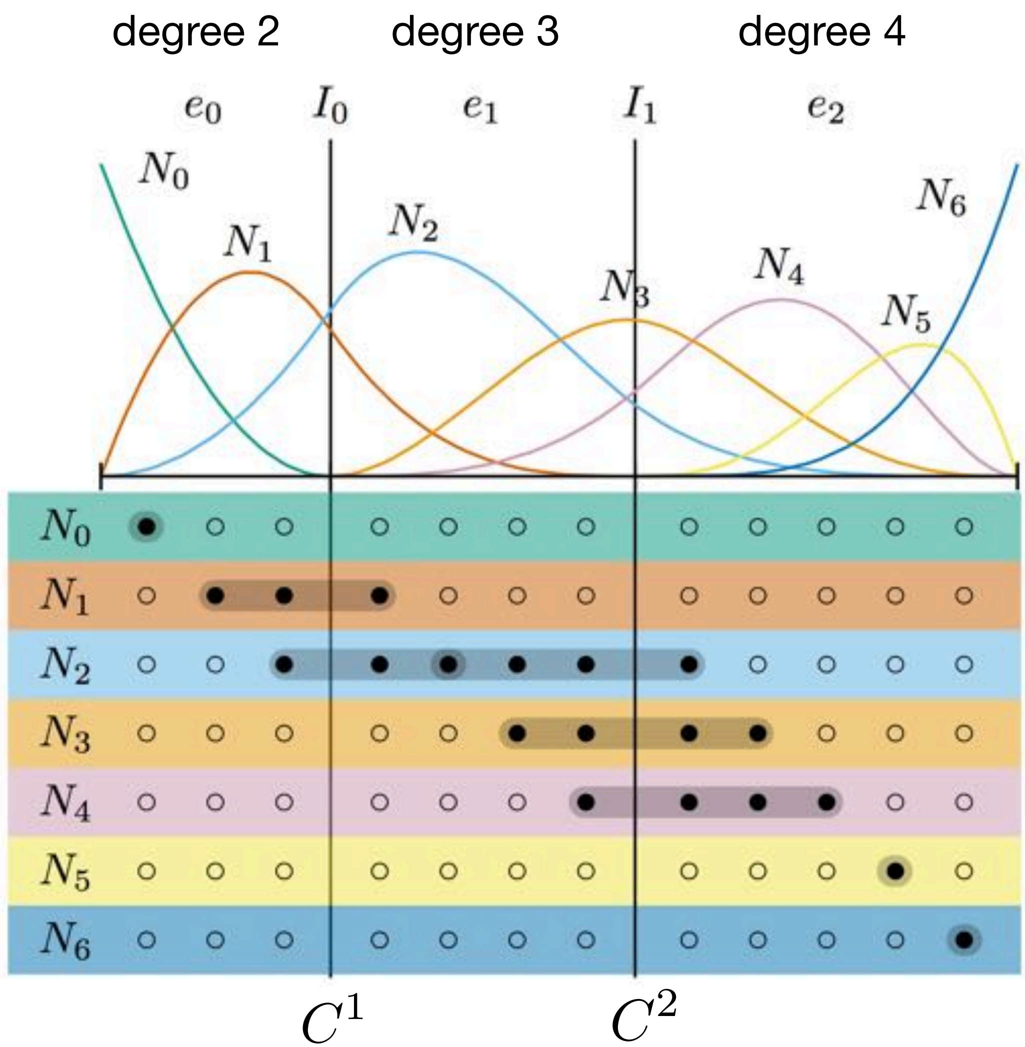

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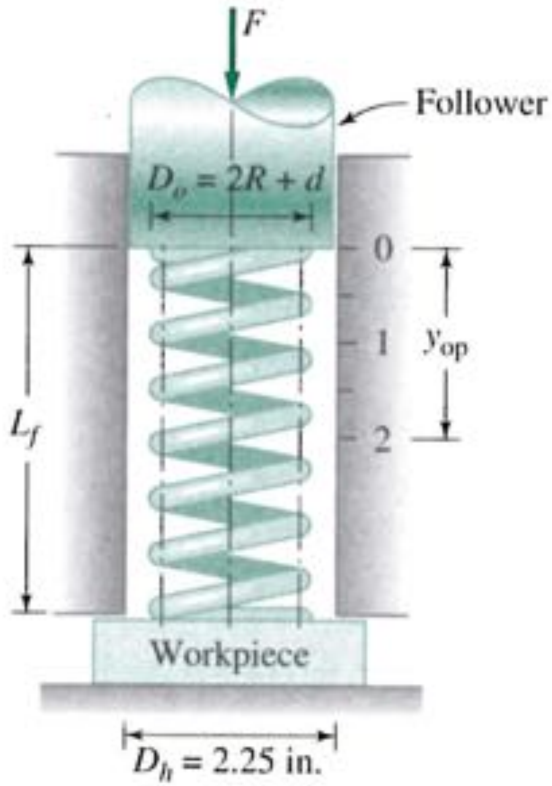
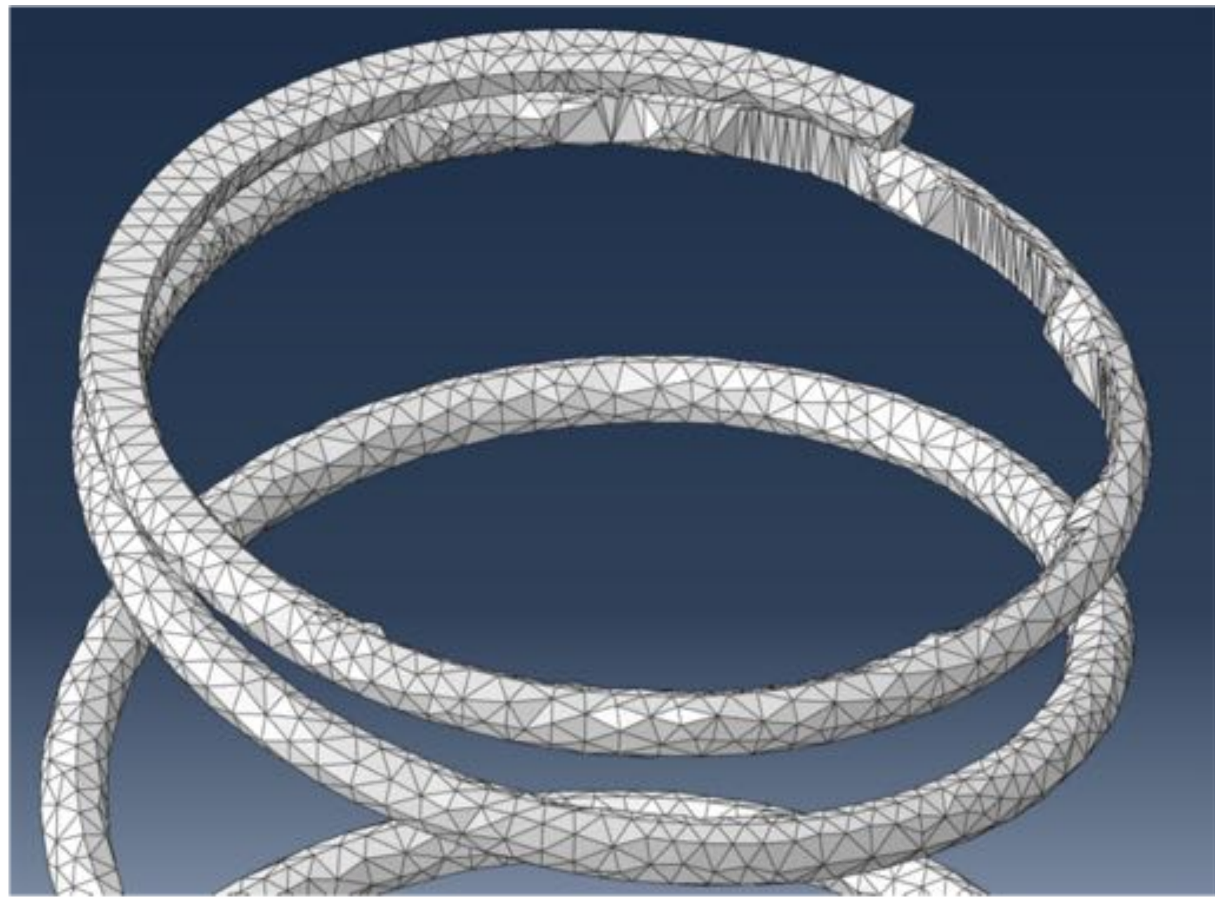
Better accuracy with less time and effort





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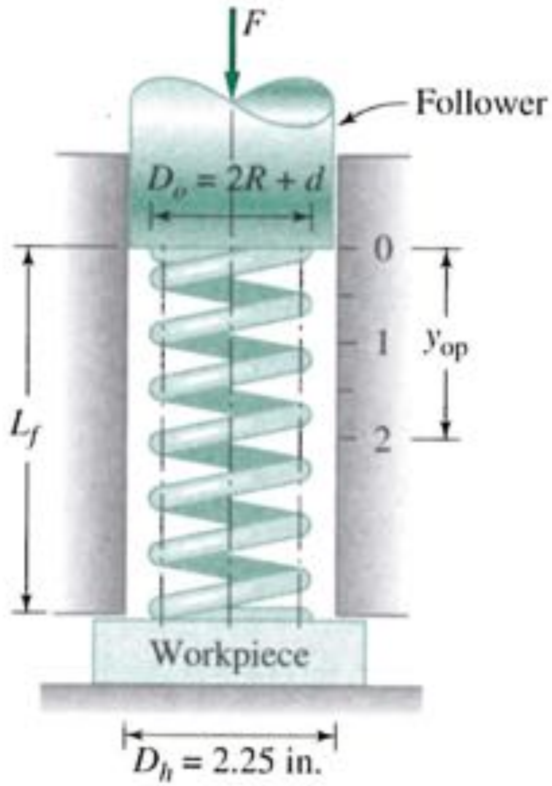
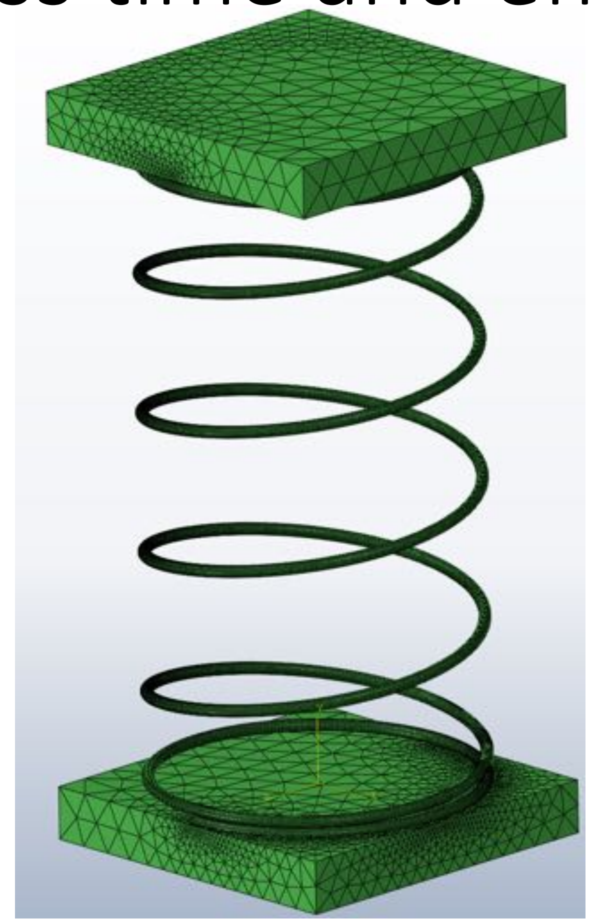
Better accuracy with less time and effort





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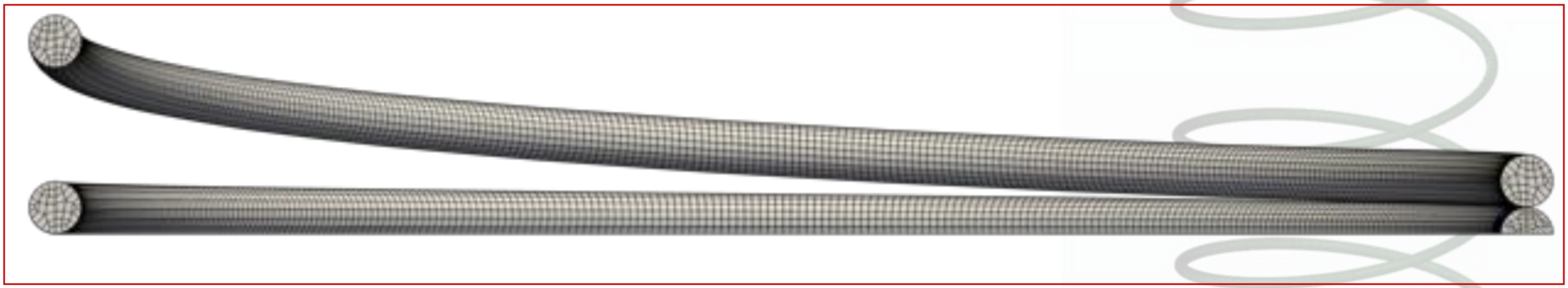
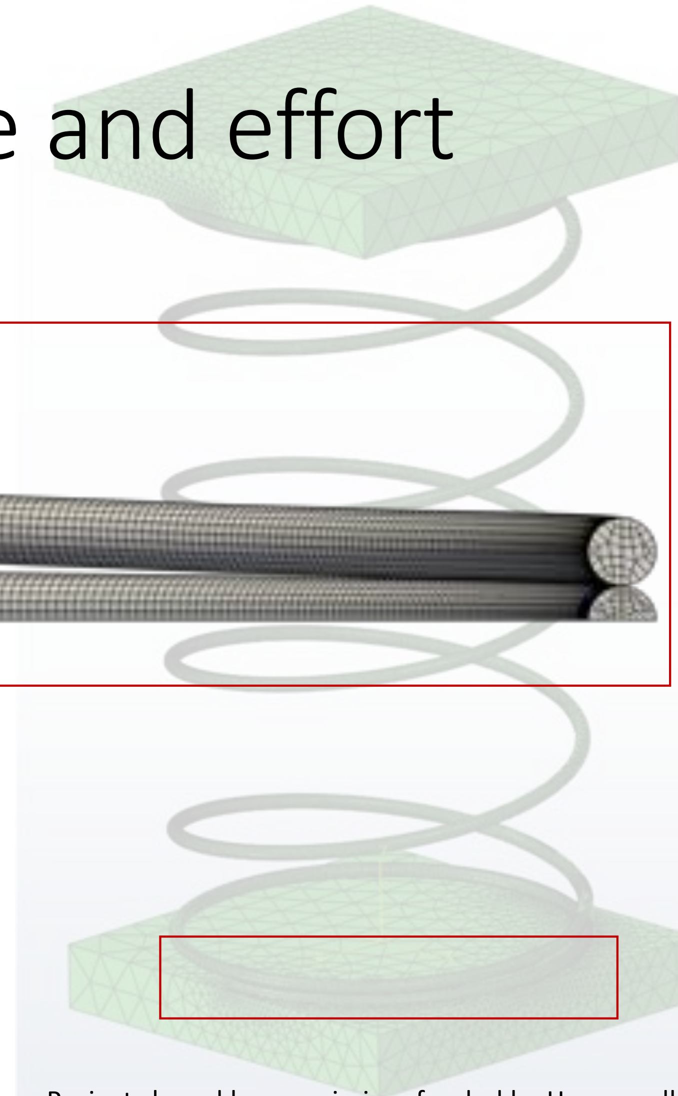
Better accuracy with less time and effort



225,000 small elements required to capture curvature with FEA!



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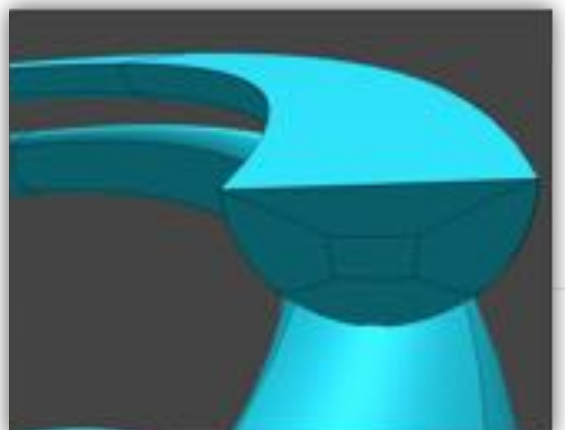
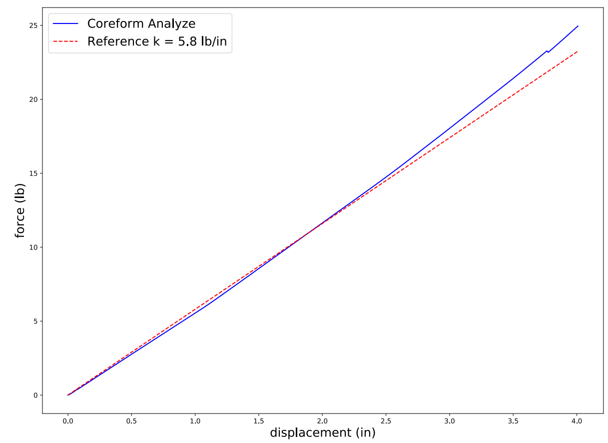
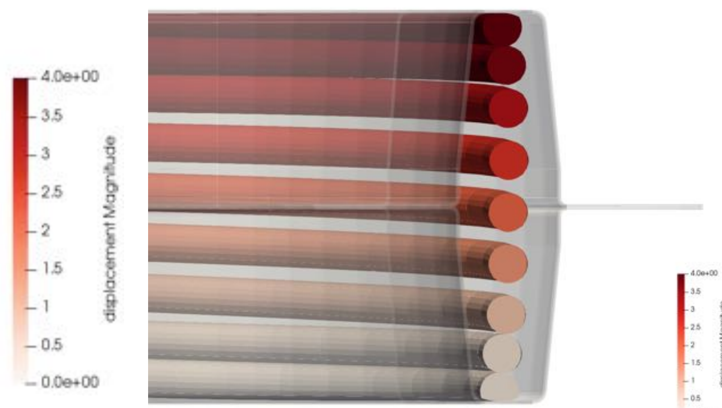
Better accuracy: 50x faster, 500x fewer elements

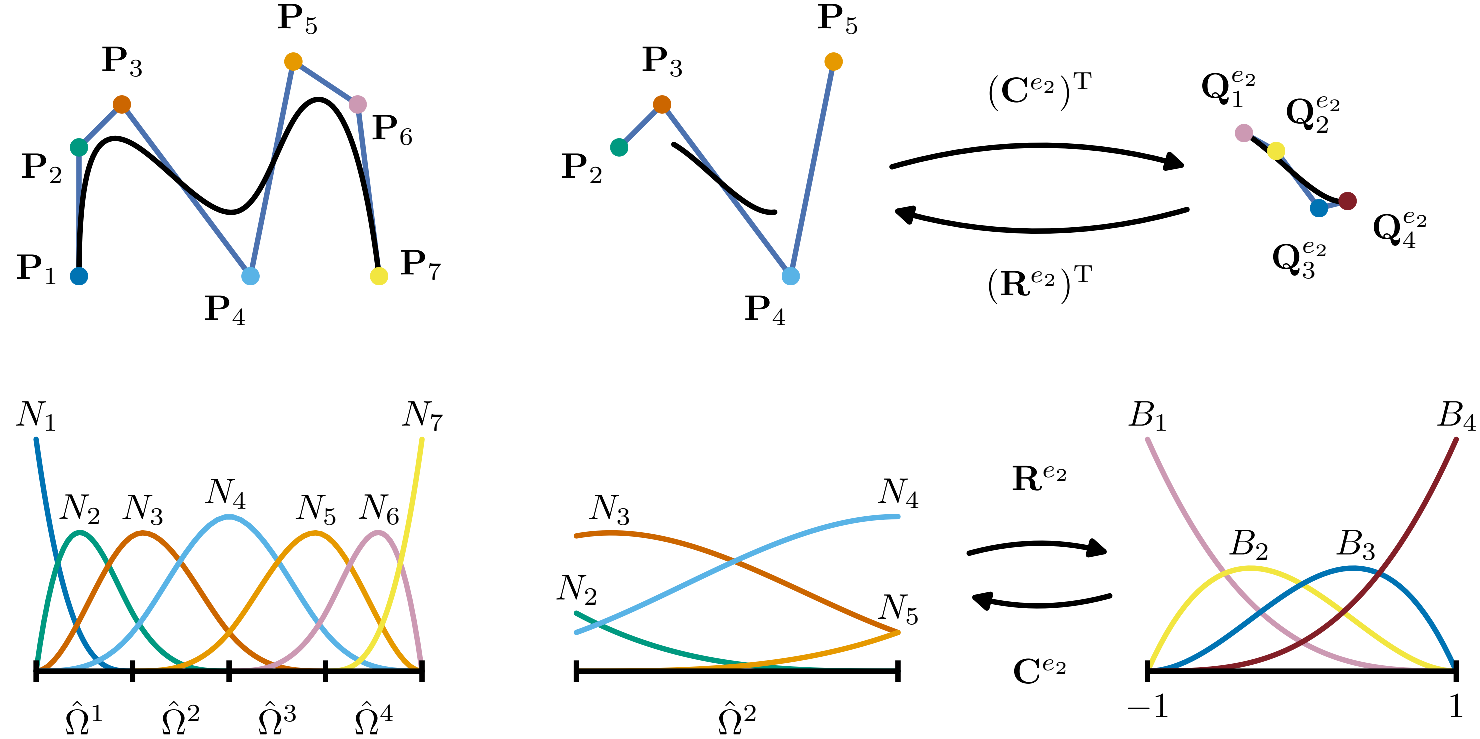
	FEA	U-Splines
Elements	225,000	500
Total compute hours	384	8







Bézier extraction: Equivalence between Bézier and B-spline representations



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*IGA_INCLUDE_BEZIER

Purpose: import complex spline data into LS-DYNA

- Improvement over old Bezier extraction keyword
- Allows for simplex and prism elements
- More efficient data storage

Current status

- Still under active development
- Beta version: scheduled for summer of 2019
- Public availablity: scheduled for Rev 12 of LS-DYNA Keyword Manual

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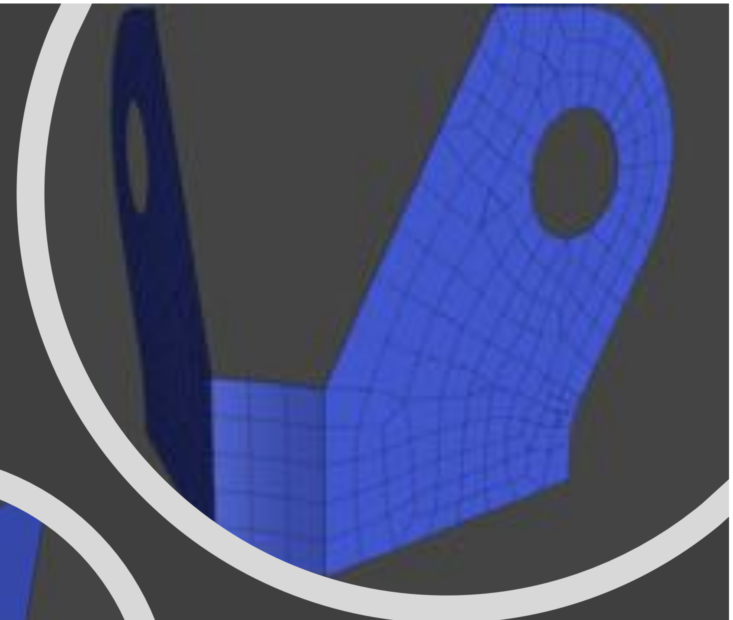
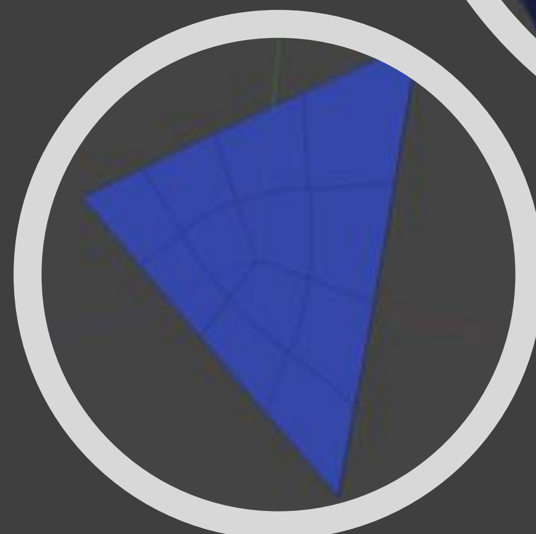
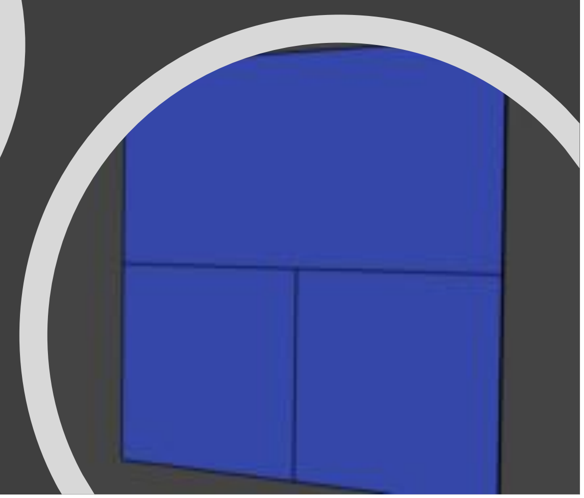
*IGA_INCLUDE_BEZIER format

- **Patch data**
- **Geometry**
- **Elements descriptions**
- **Coefficient vectors**







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*IGA_INCLUDE_BEZIER features:

1. Increased explicit time step size
2. Import of solid spline models
3. Import of T-spline CAD models
4. Smoothing of unstructured FEA meshes via U-splines
5. Future possibility of IGA assembly models in LS-DYNA

1. Increase explicit time step size

The central difference method

Evolution Through Time

$$\mathbf{M}\mathbf{a}_{n+1} = \mathbf{R}_{n+1}(\mathbf{d}_{n+1})$$

$$\mathbf{d}_{n+1} = \mathbf{d}_n + \Delta t \mathbf{v}_n + \frac{\Delta t^2}{2}\mathbf{a}_n$$

$$\mathbf{v}_{n+1} = \mathbf{v}_n + \frac{\Delta t}{2}(\mathbf{a}_n + \mathbf{a}_{n+1})$$

Stability Condition

$$\Delta t \leq \frac{2}{\omega^h_{max}}$$

n = Time step number

Δt = Time step size

$\mathbf{d}$ = Displacement

$\mathbf{v}$ = Velocity

$\mathbf{a}$ = Acceleration

$\mathbf{M}$ = Mass matrix

$\mathbf{R}$ = Residual, note that $\mathbf{R}_{n+1}$ is independent of $\mathbf{a}_{n+1}$

ω^h_{max} = Maximum discrete frequency

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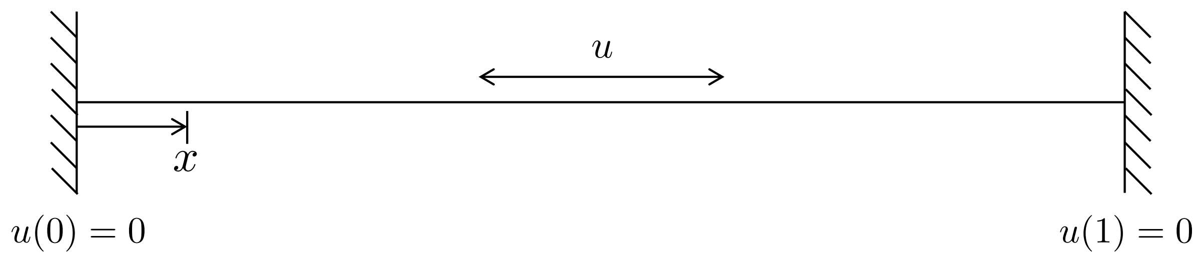
1D vibrating rod

$$L = E = \rho = 1 \qquad \frac{\partial^2 u}{\partial x^2} + \omega^2 u = 0$$



Exact modes:

$$u_n = \sin(n\pi x)$$

$$\omega_n = n\pi$$

$$\text{for } n = 1, 2, 3, 4, \ldots$$

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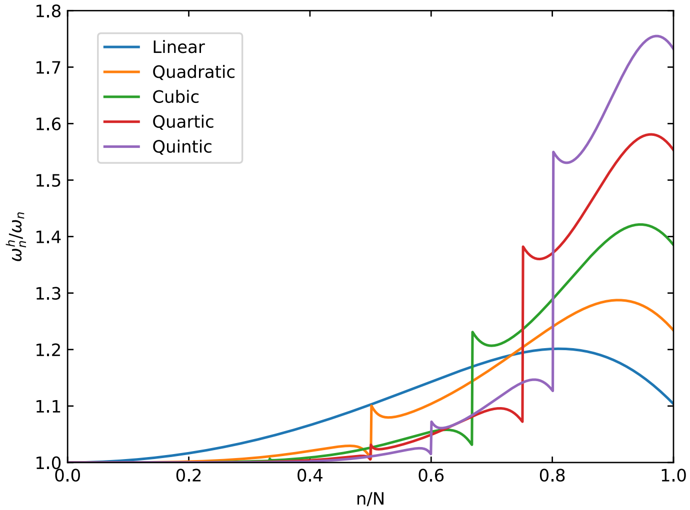
Lagrange



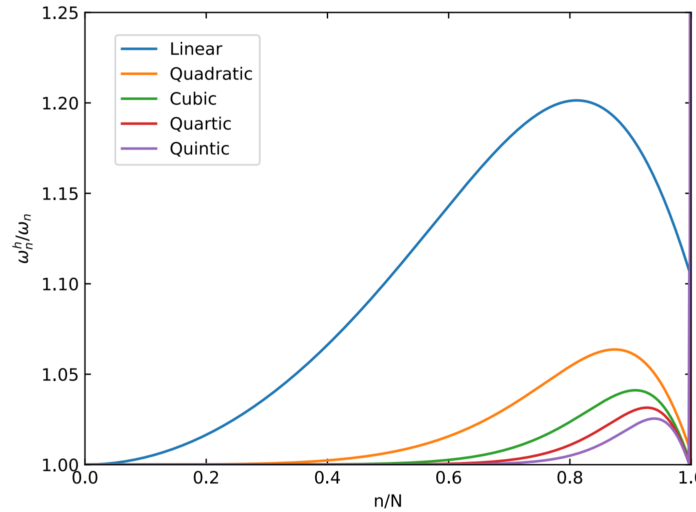
$n =$ Mode number

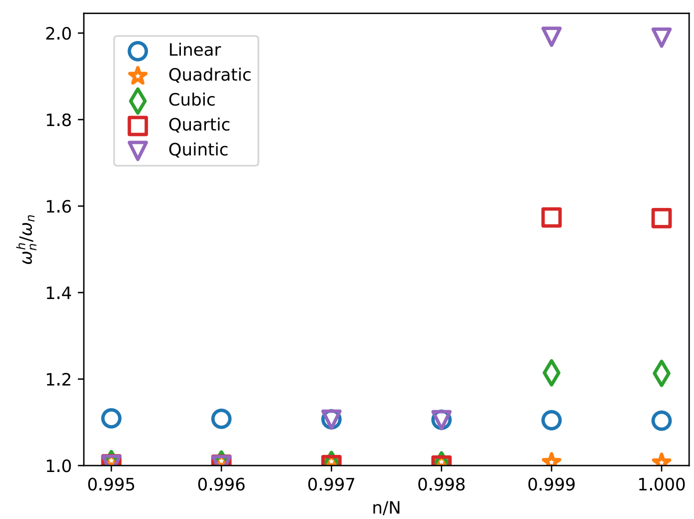
$N =$ Number of DOFs

$\omega_n =$ Exact nth frequency

$\omega_n^h =$ Discrete nth frequency

NURBS





Raising continuity helps most of the spectrum, but not the highest frequency

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The challenge of increasing degree

Increase degree

↓

Decrease time step

- Lagrange
- Multi-patch NURBS
- T-splines
- etc.

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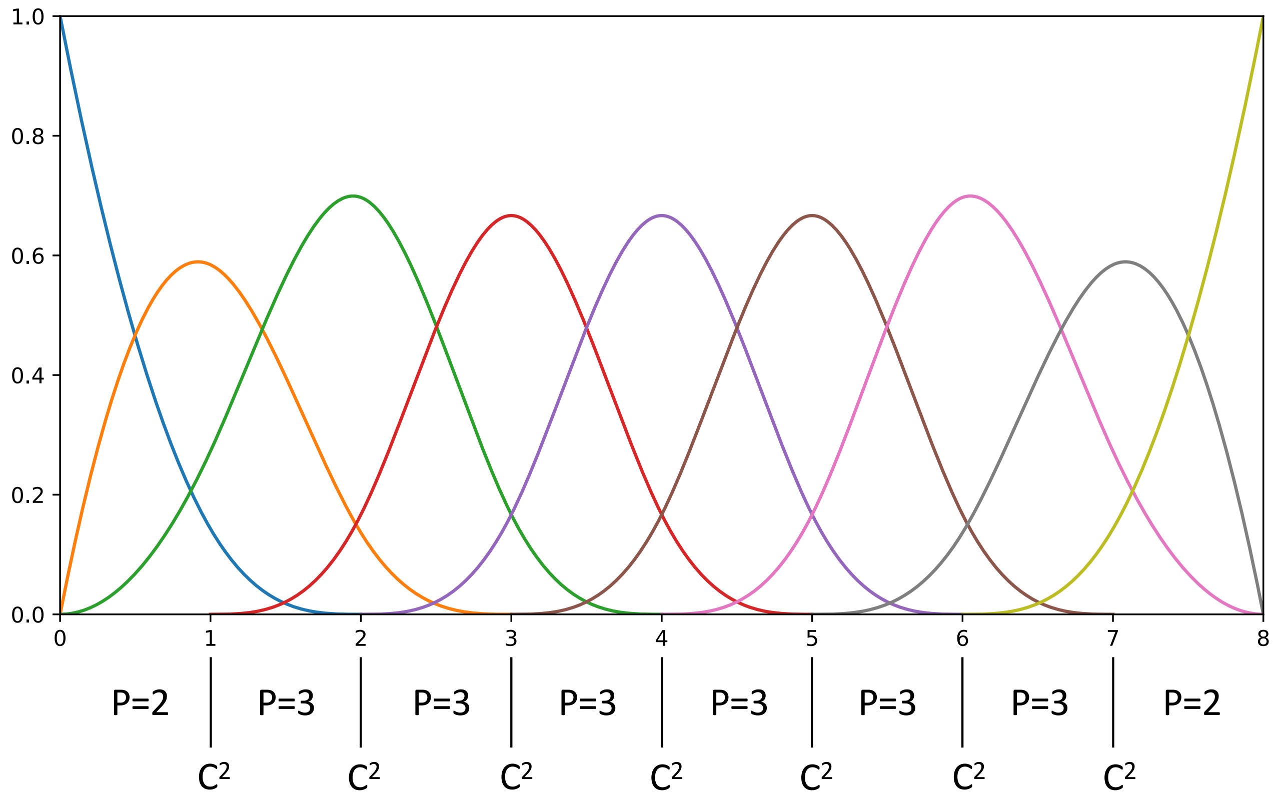
U-splines can uniquely **increase** the time step



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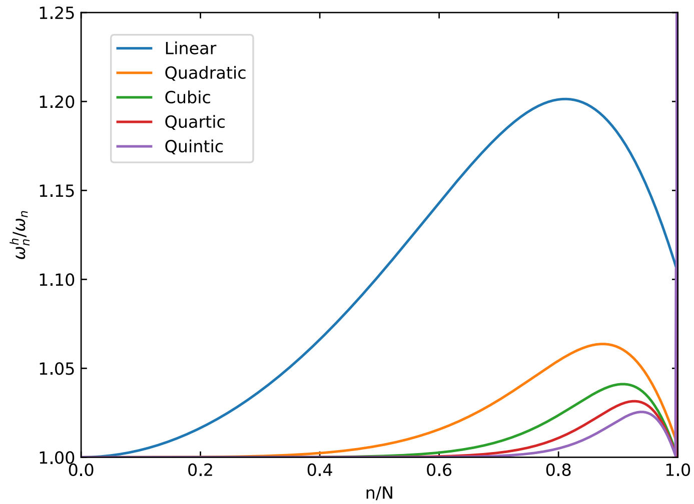
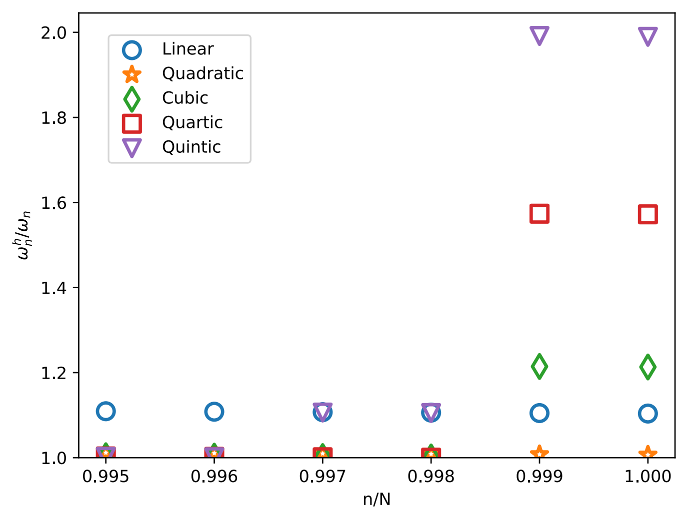
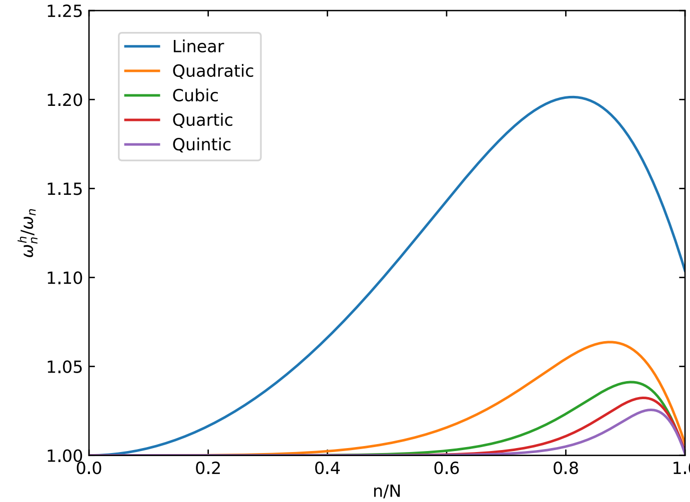
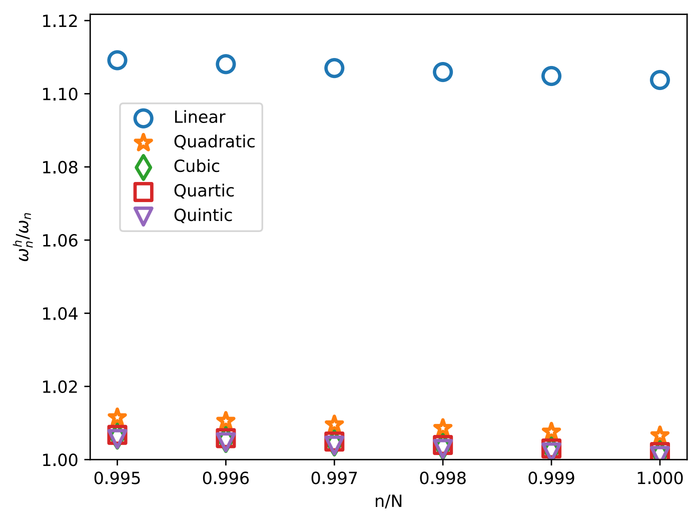
NURBS





U-splines





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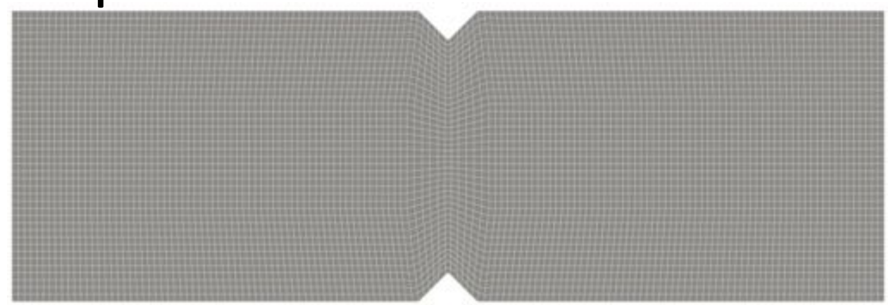
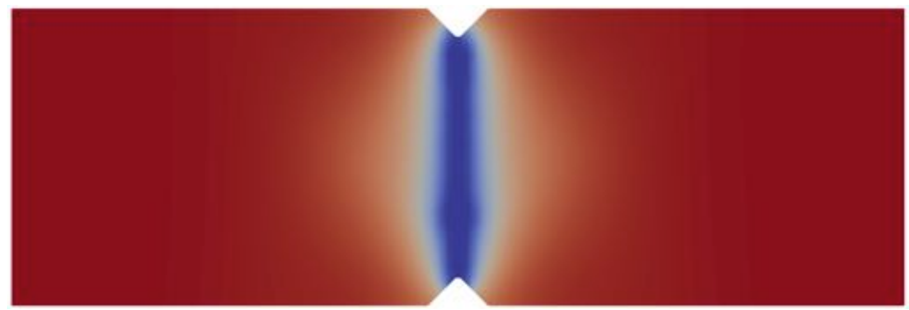
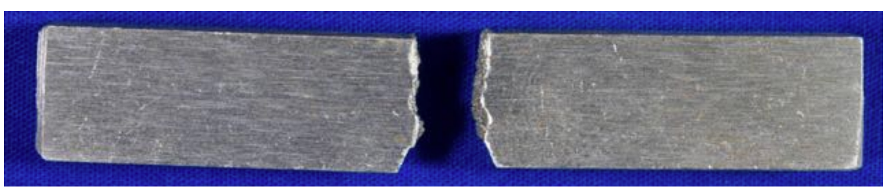
Time step example: v-notch problem



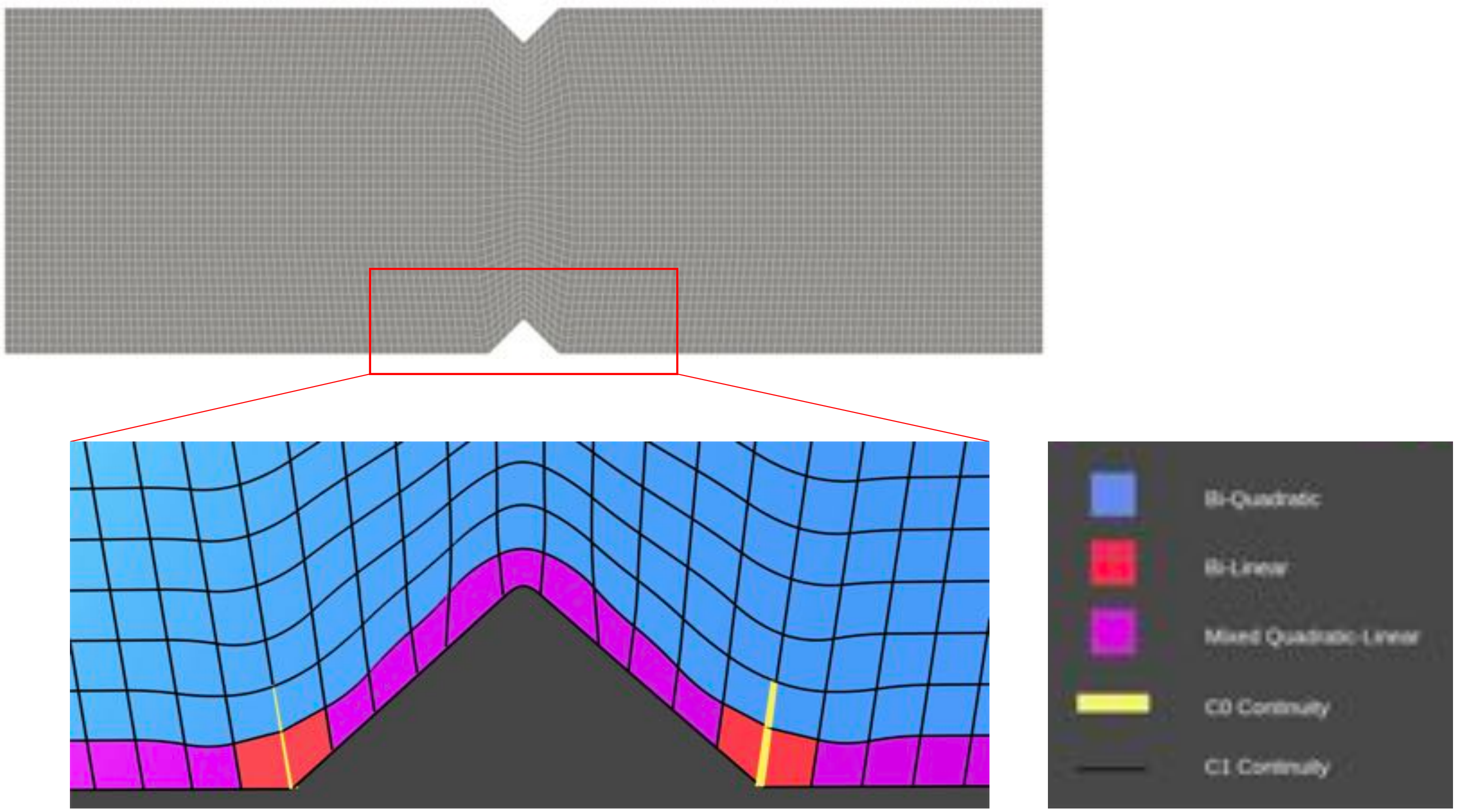
Crack formation





Crack after fracture

Optimized U-Spline basis



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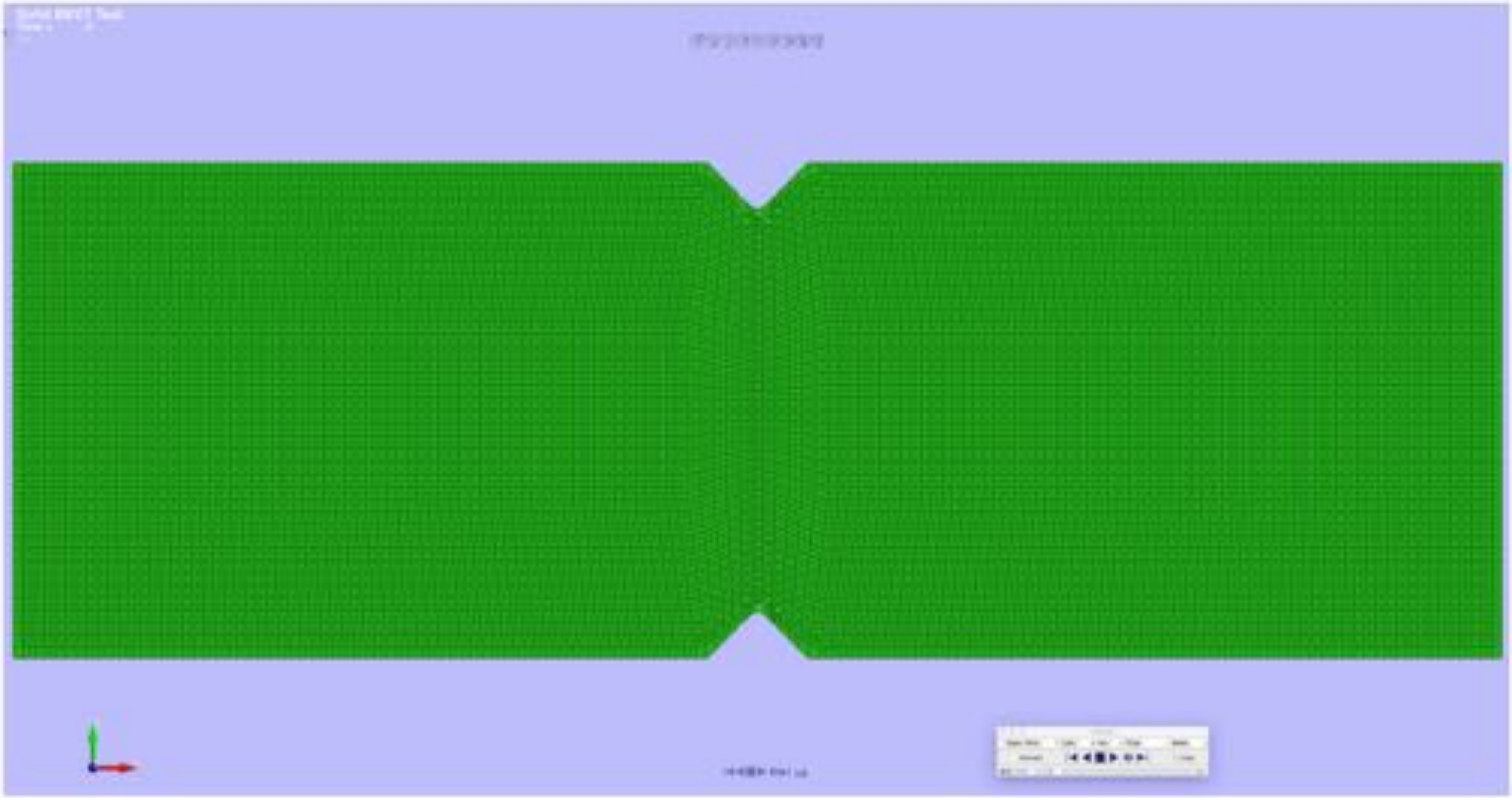
Optimized U-Spline in LS-DYNA via *IGA_INCLUDE_BEZIER

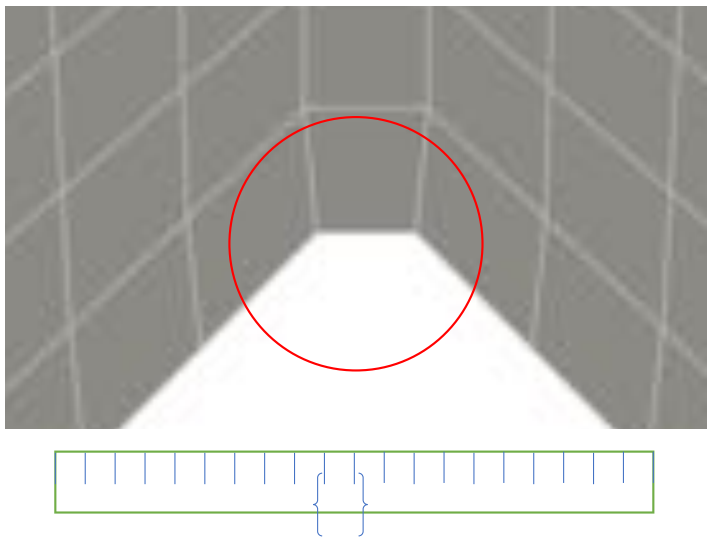


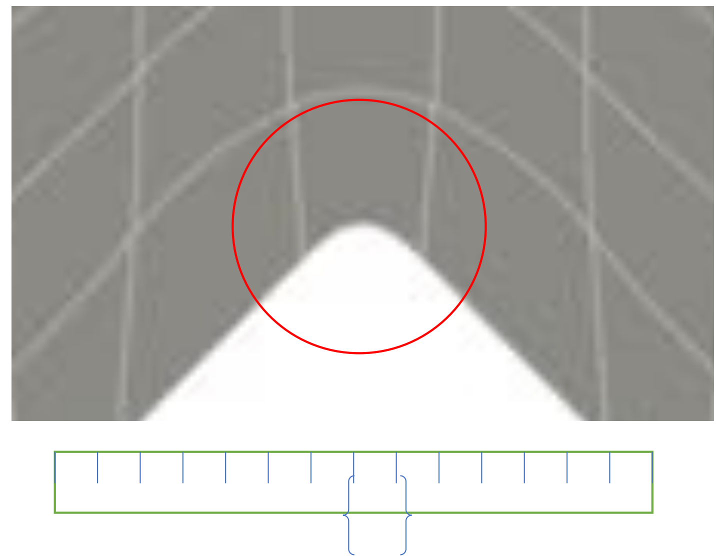
Lower simulation costs

Smooth fillet captured!

FEA

U-splines





Time step: 1.35×10^{-7}

Time step: 2.18×10^{-7}

60% larger time step!

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Superior explicit dynamics

Basis Type	Time Step (LS-DYNA)
Linear	1.35×10^{-7}
Multipatch NURBS	1.25×10^{-7} ← Smaller than linear FEA
U-Spline	**2.18×10^{-7}**

60% larger time step than linear!

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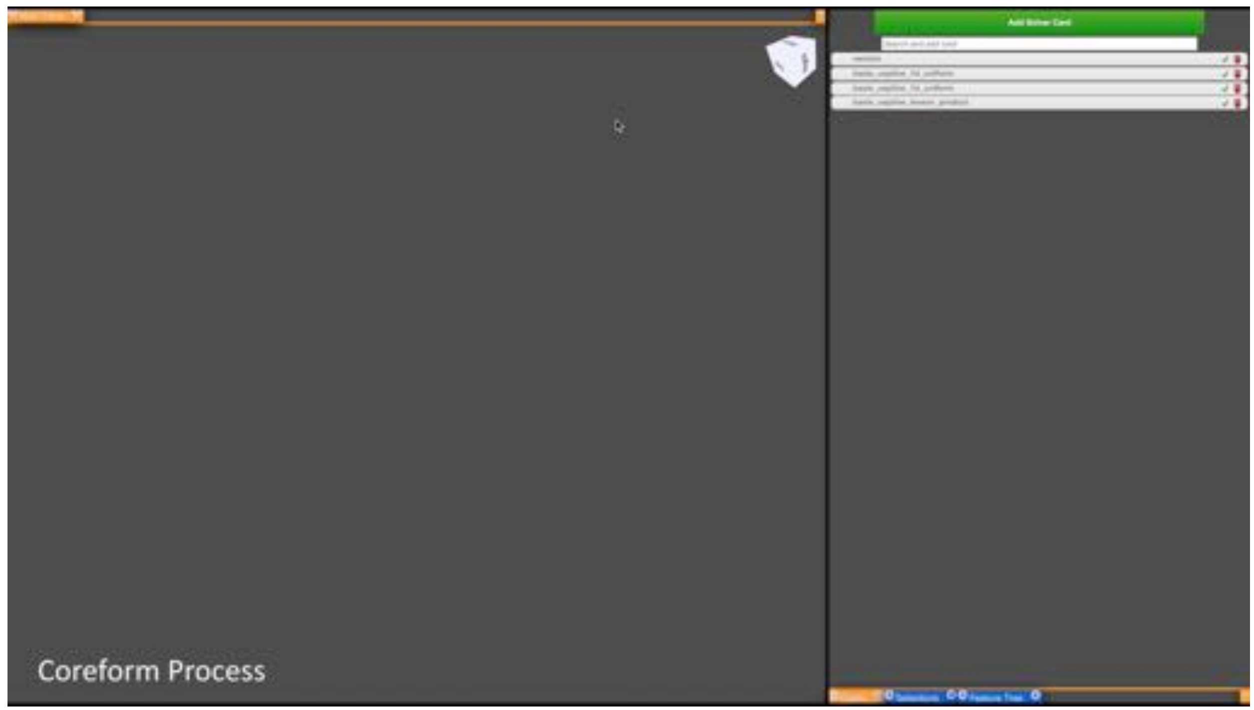
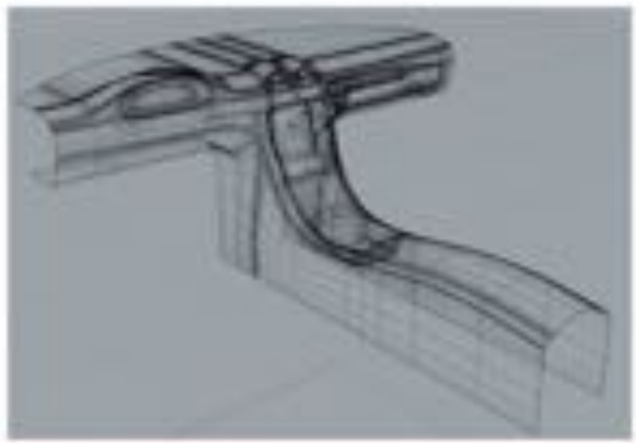
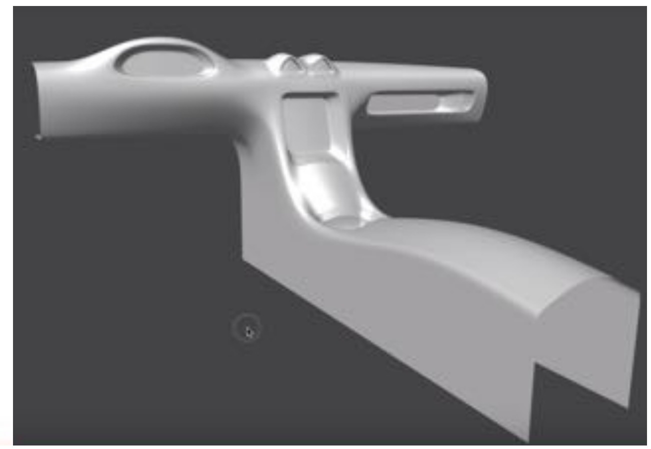
2. Import solid spline models

U-spline solid spring model



3. Import T-spline CAD model

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3. Import T-spline CAD model

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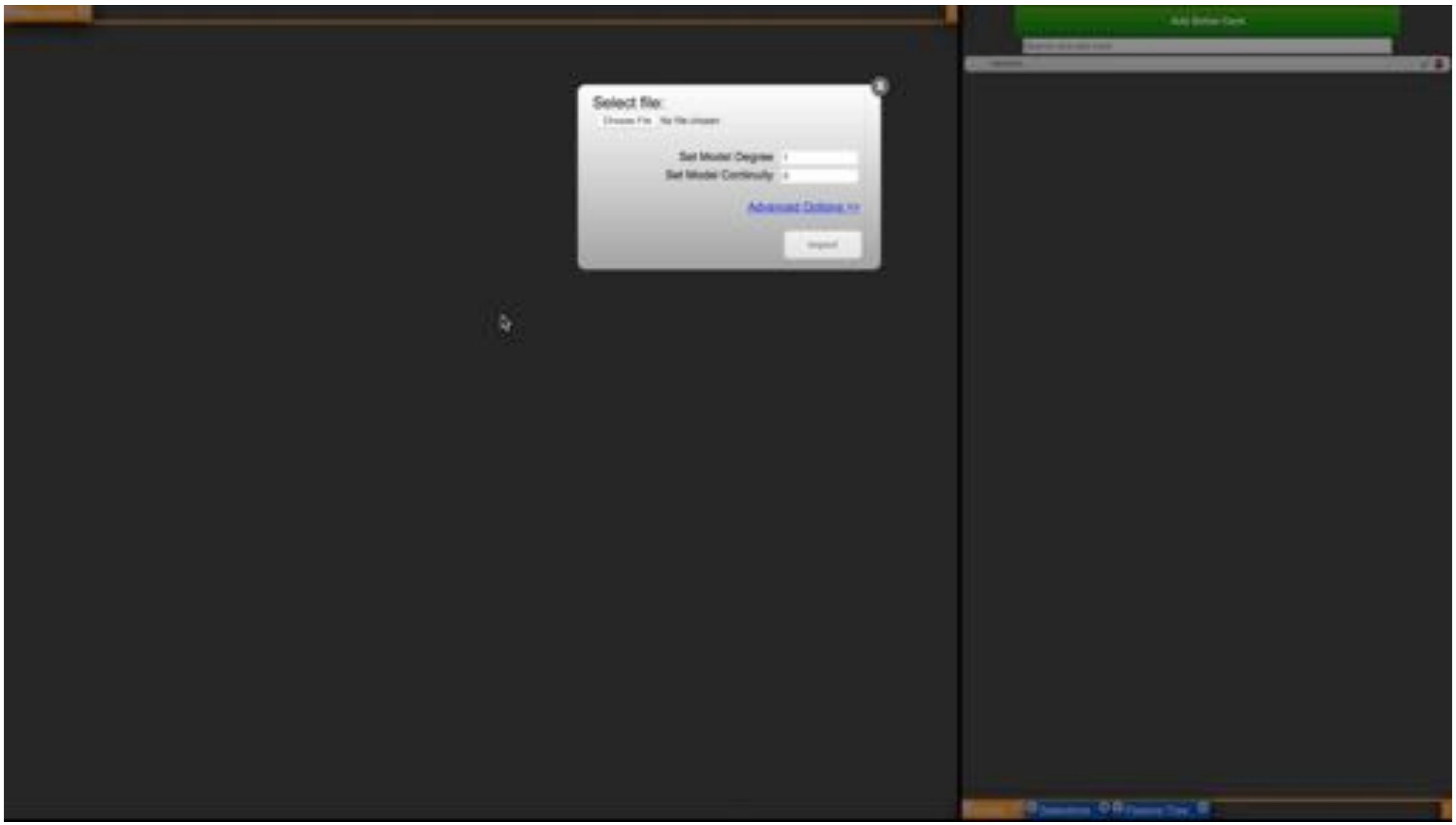
4. Smooth unstructured FEA mesh via U-splines



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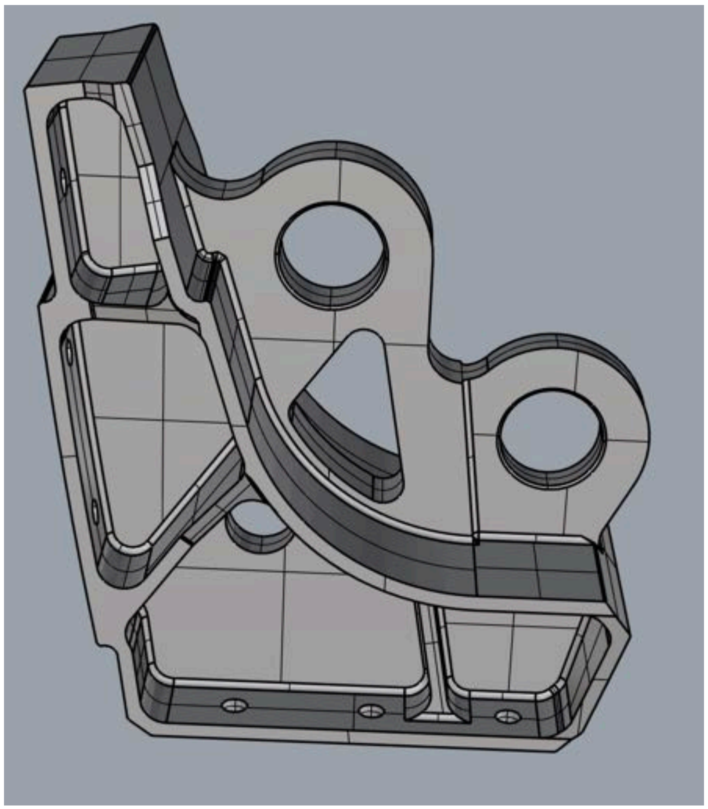
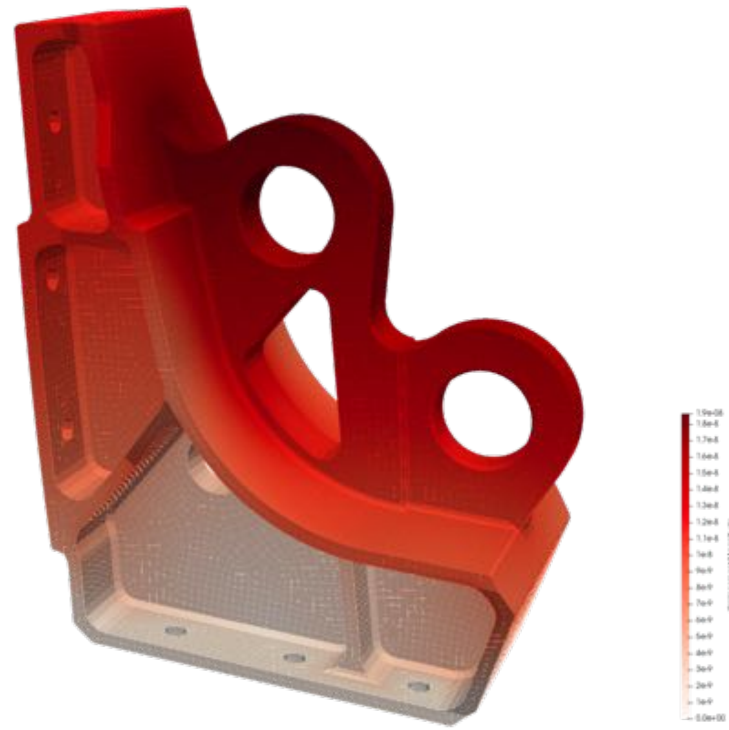
4. Smooth unstructured FEA mesh via U-splines





coreform Automatic conversion of solid BREP to U-spline surface. Retopology by Trellis.

4. Smooth unstructured FEA mesh via U-splines

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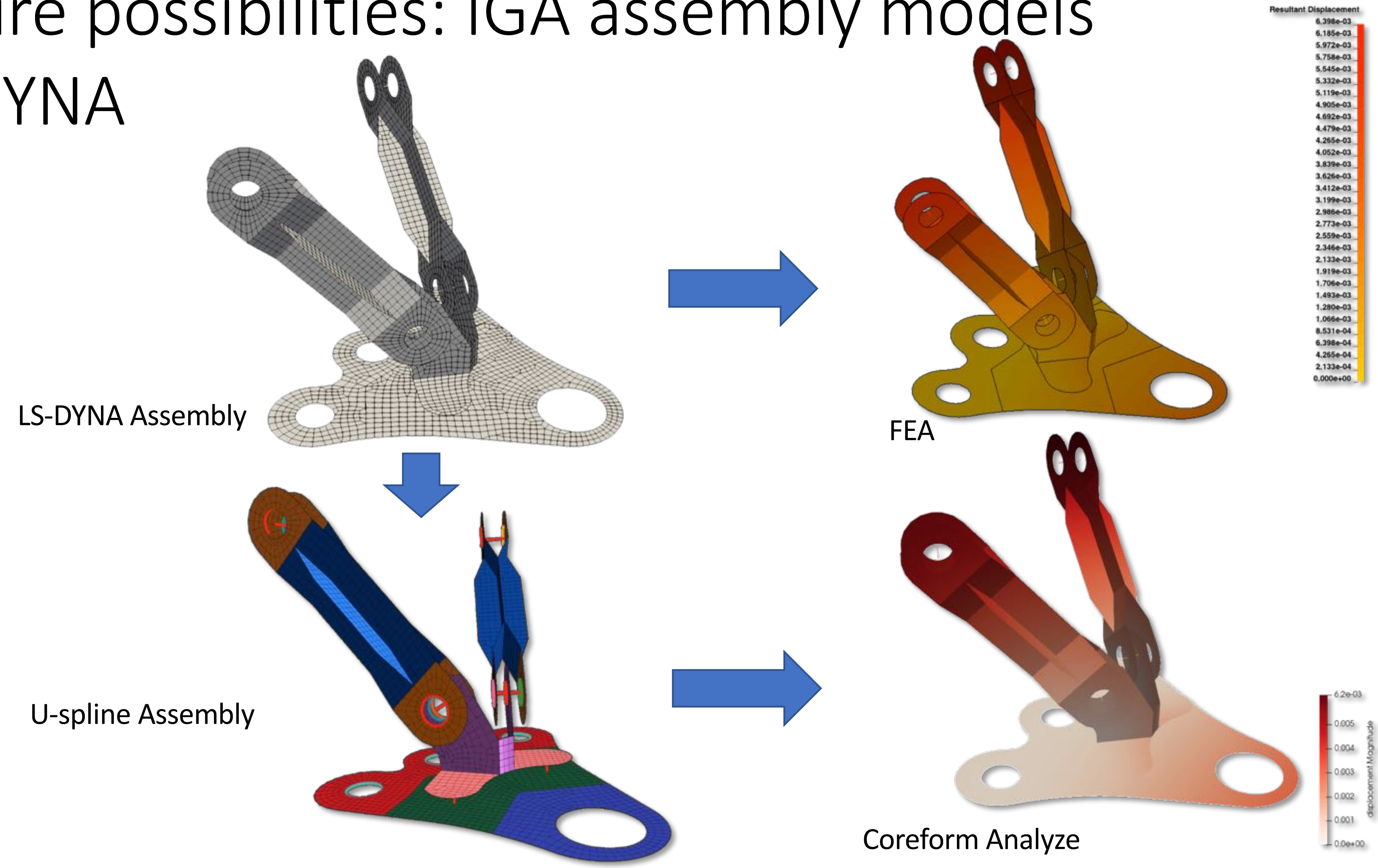
5. Future possibilities: IGA assembly models in LS-DYNA



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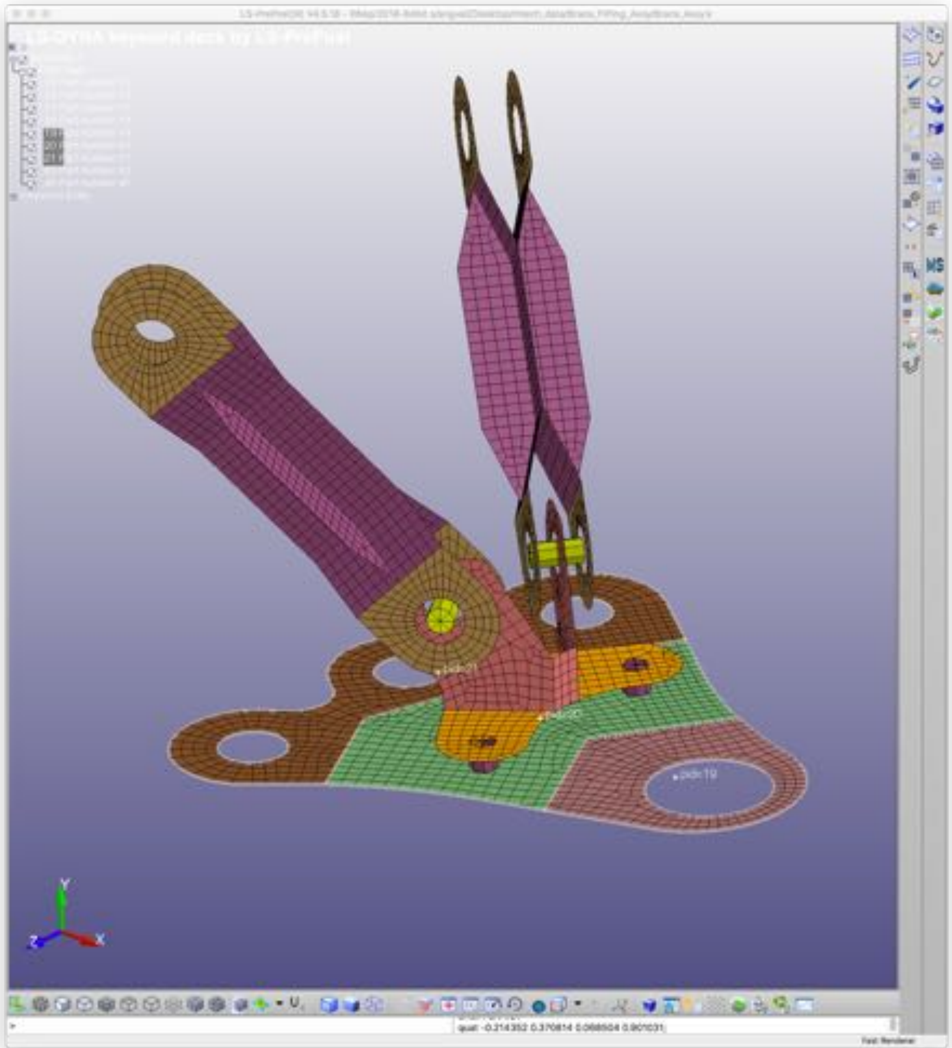
IGA workflow

1. **Import** LS-DYNA assembly
2. **Convert** linear mesh to Degree 2 U-spline, **smooth** element boundaries to be C1 where possible
3. Automatically **translate** material properties, element types, connections
4. **Redefine** applied loads for IGA-suitability
5. **Run** simulation



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IGA workflow

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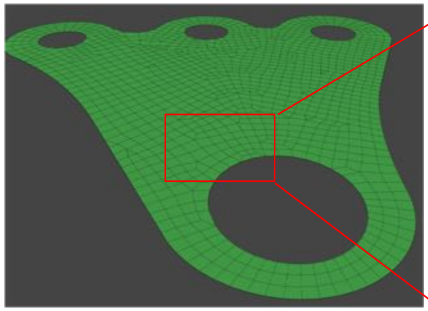
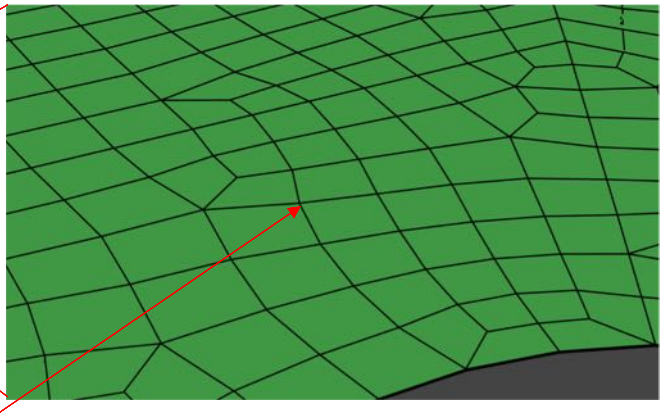
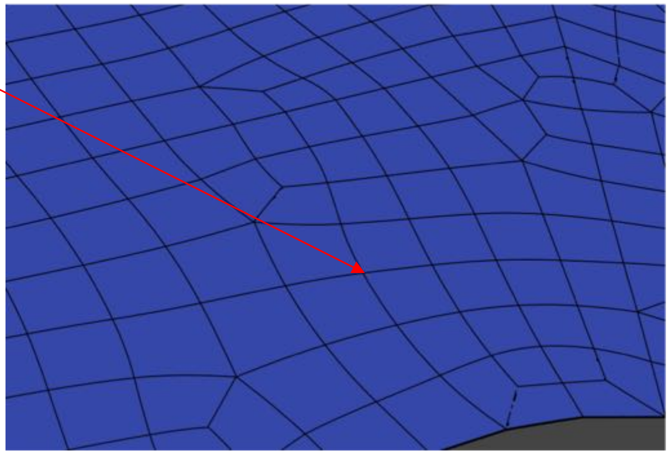


P1, C0 everywhere:



Elements are C0 everywhere.

P2, C1 where possible:



Increased smoothness in quadratic mesh

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IGA workflow

1. **Import** LS-DYNA assembly
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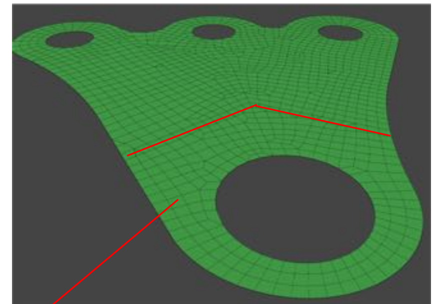
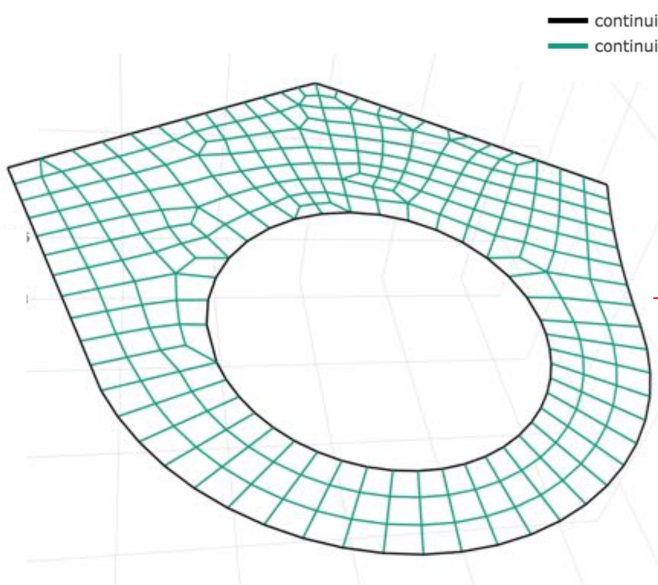
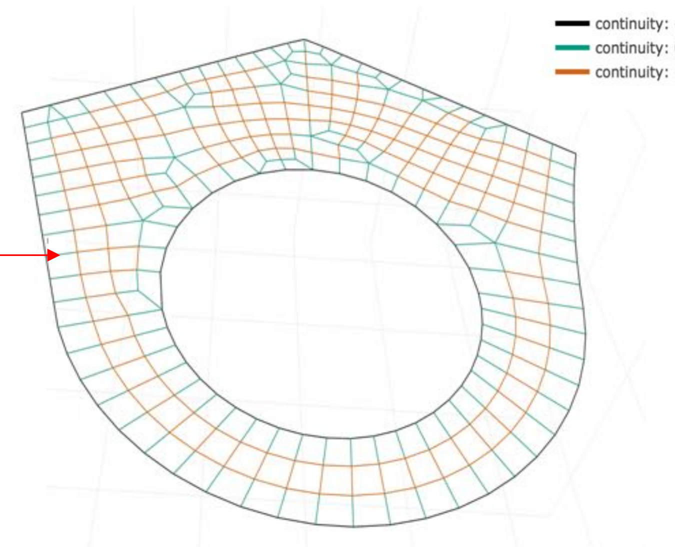
4. **Redefine** applied loads for IGA-suitability
5. **Run** simulation





Section of the original linear mesh

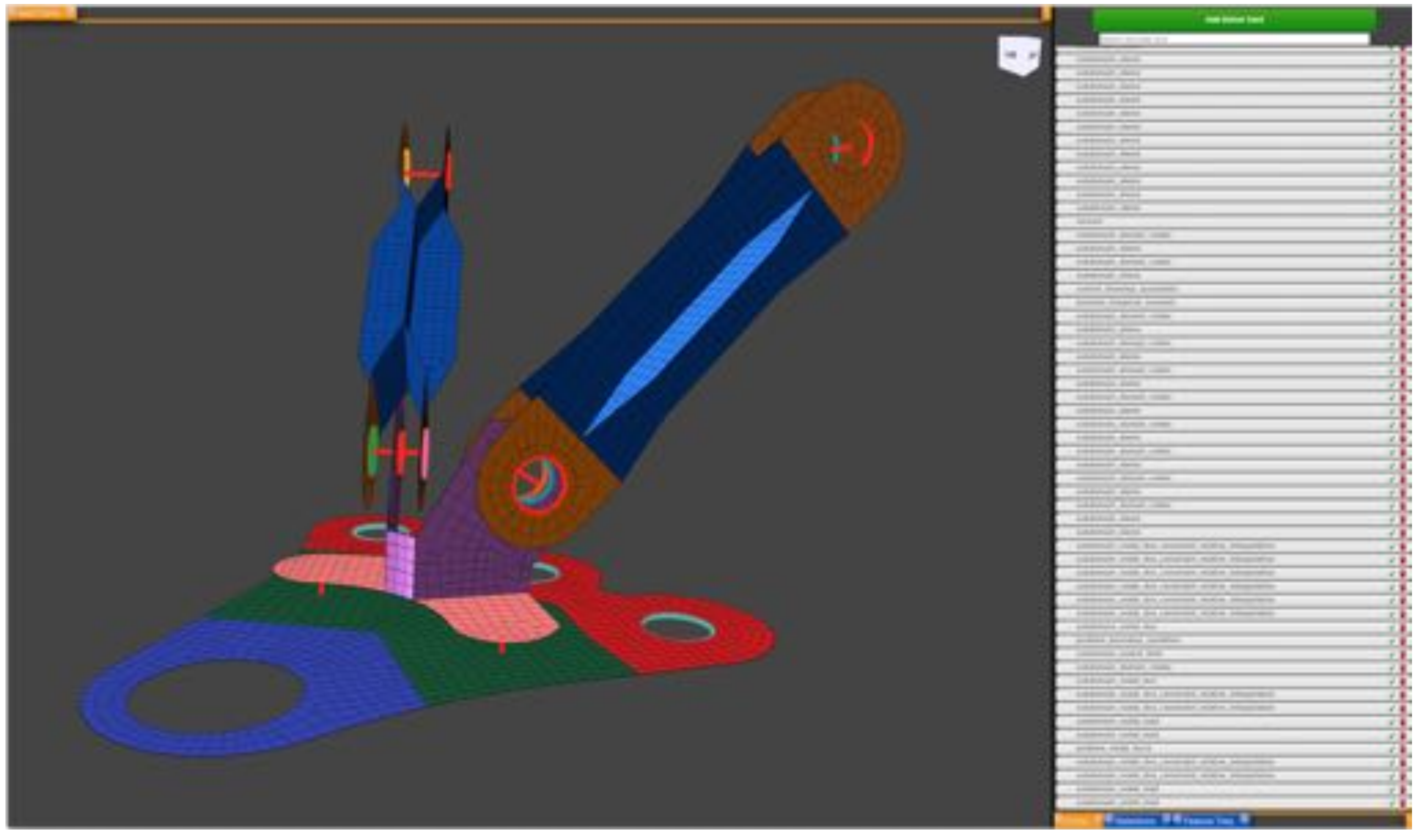


Section of the smoothed U-spline model

Another view of the smoothness (continuity) of the U-spline model

IGA workflow

1. **Import** LS-DYNA assembly
2. **Convert** linear mesh to Degree 2 U-spline, **smooth** element boundaries to be C1 where possible
3. Automatically **translate** material properties, element types, connections
4. **Redefine** applied loads for IGA-suitability
5. **Run** simulation



List of cards in the Coreform IGA assembly

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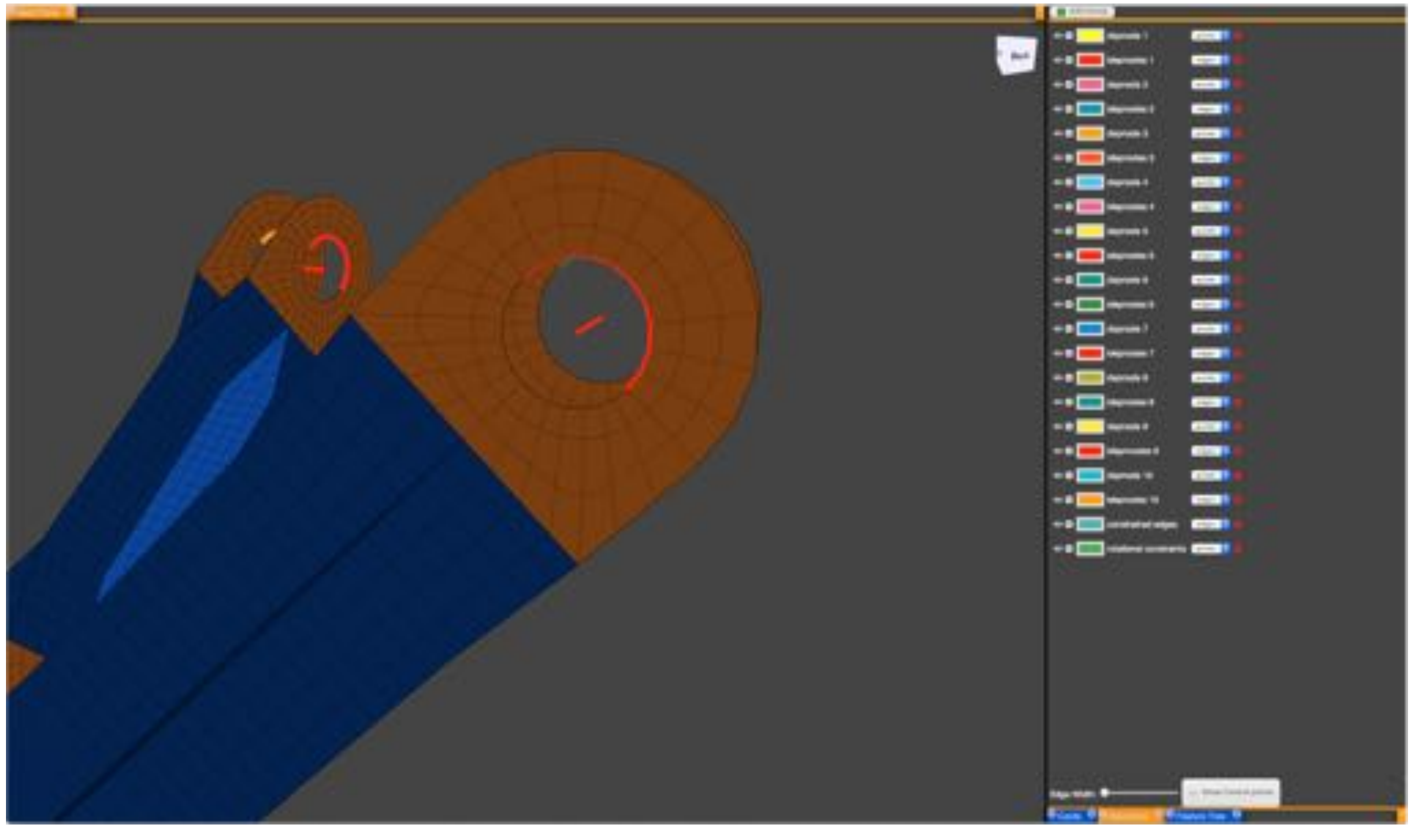
IGA workflow

1. **Import** LS-DYNA assembly
2. **Convert** linear mesh to Degree 2 U-spline, **smooth** element boundaries to be C1 where possible
3. Automatically **translate** material properties, element types, connections
4. **Redefine** applied loads for IGA-suitability
5. **Run** simulation



Loads and boundary conditions were assigned directly to the geometry instead of to nodes for improved accuracy.

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IGA workflow

1. **Import** LS-DYNA assembly
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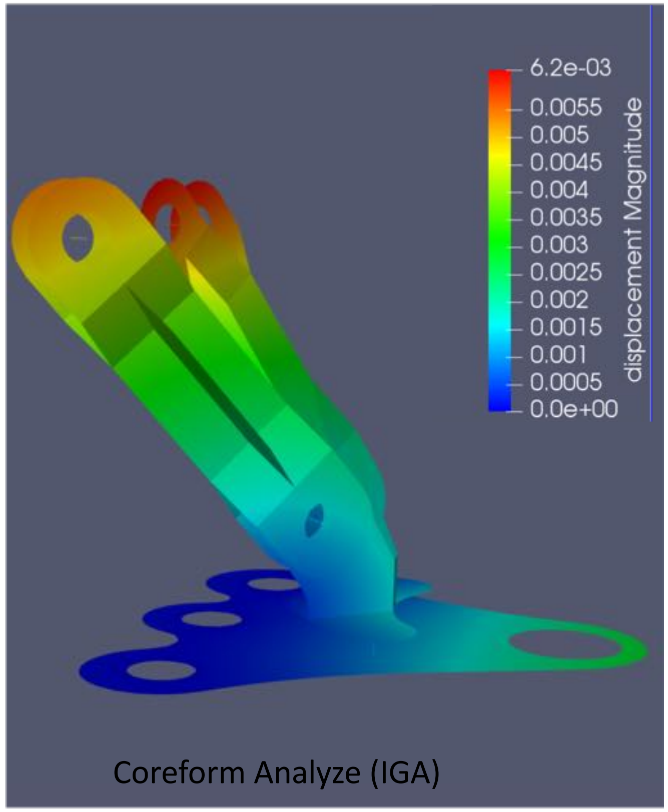
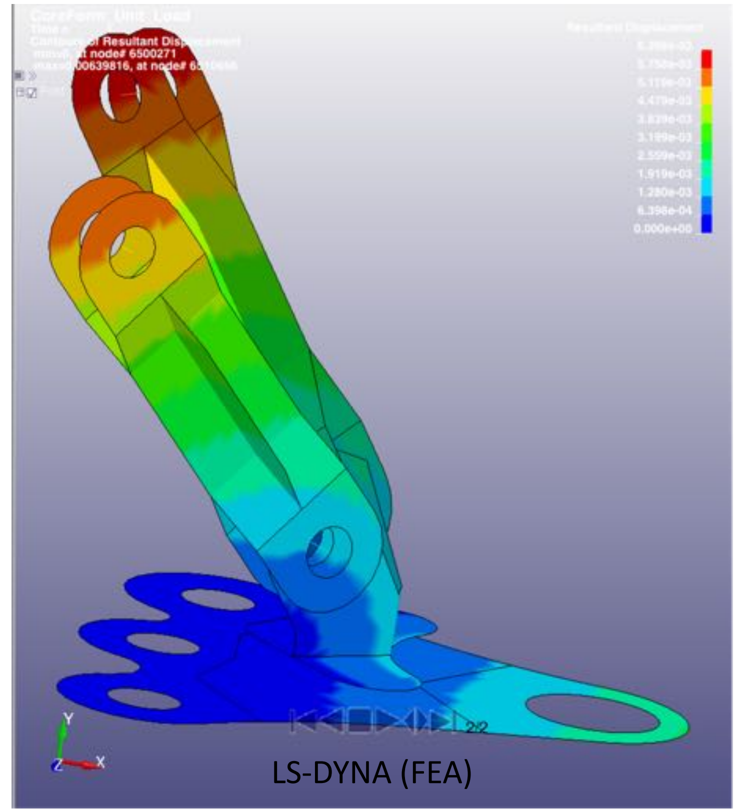


Coreform Analyze (IGA)


LS-DYNA (FEA)

We ran the simulation using both Coreform Analyze (IGA) and LS-DYNA (FEA). While the codes use different bases and formulations, the max displacements were within 3% of each other, a strong validation that the underlying physics are correct.

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Want to learn more?

IGA short course

- Theory and application
- Coreform offices in Utah, USA
- August 21-22, 2019

IGA 2019

- Annual IGA conference
- Munich, Germany
- September 18-20, 2019

Want to use our beta software?

Come talk with me.

Love IGA?

Come be team member #17 at Coreform.

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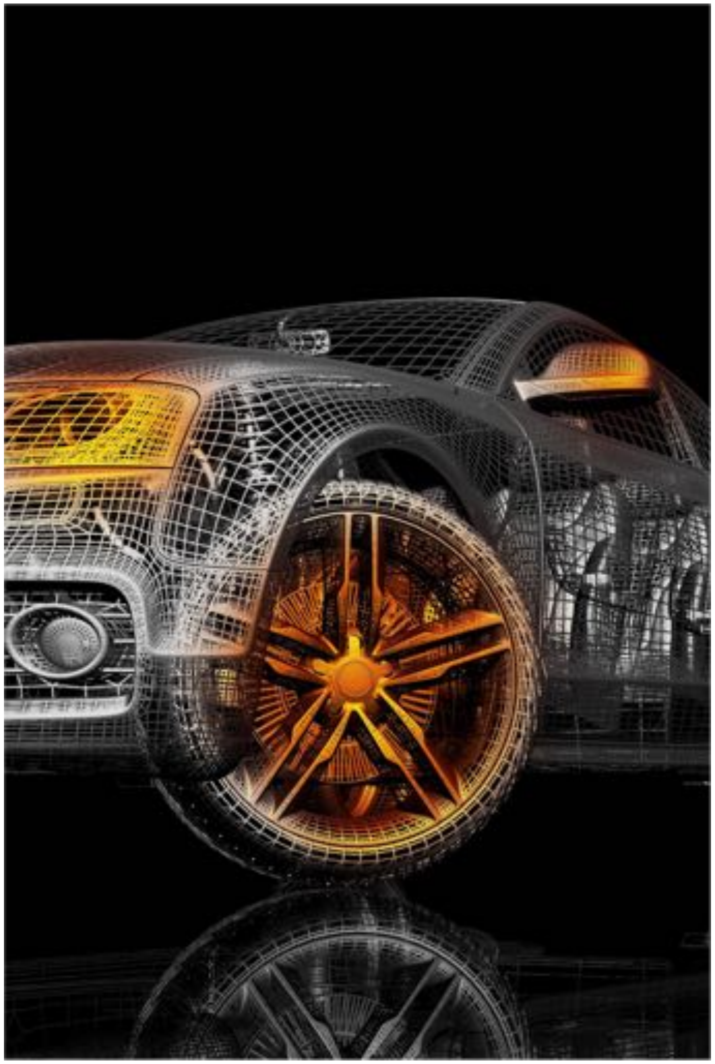

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Thank you!

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