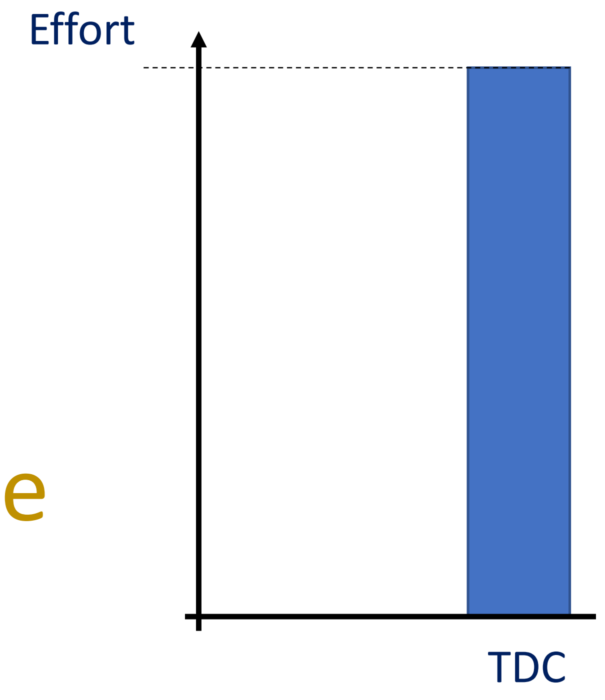
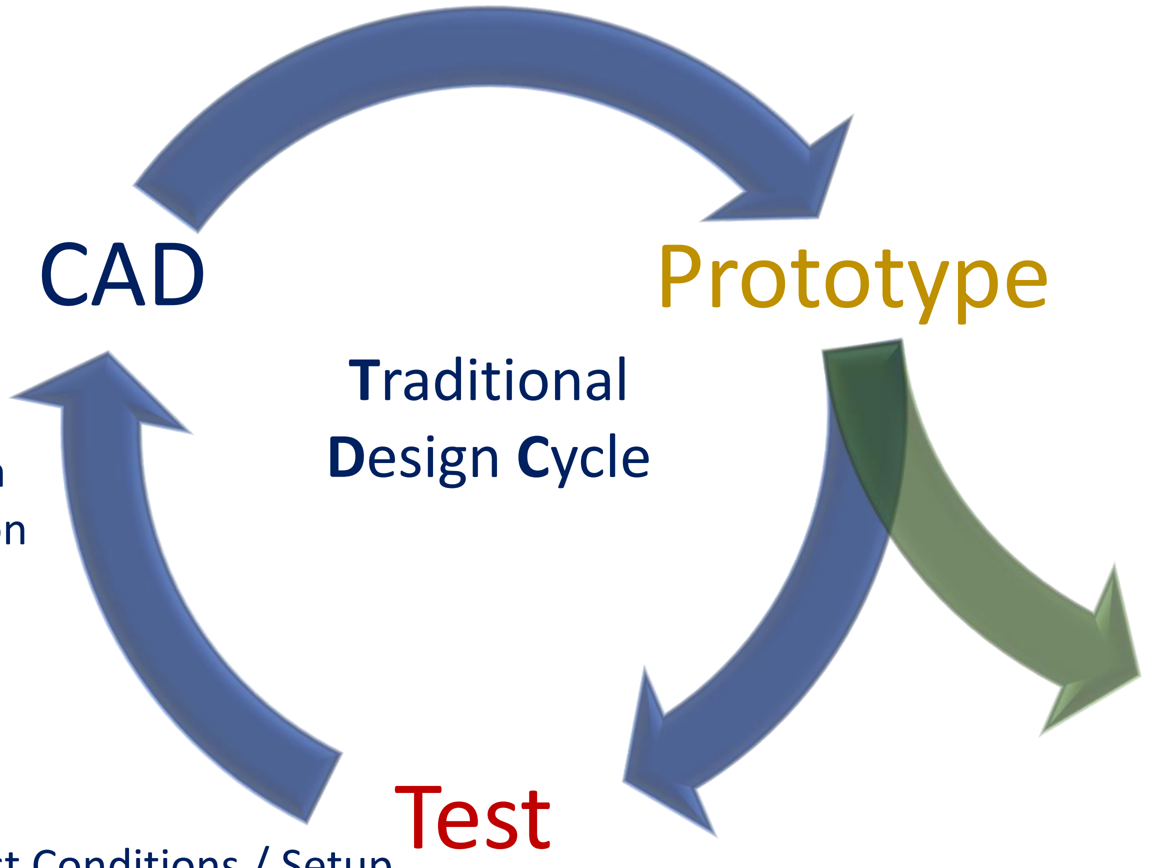
Facing the Challenges of Computational Composite Bike Frame Optimization

Motivation – Reduction of Traditional Design Cycles



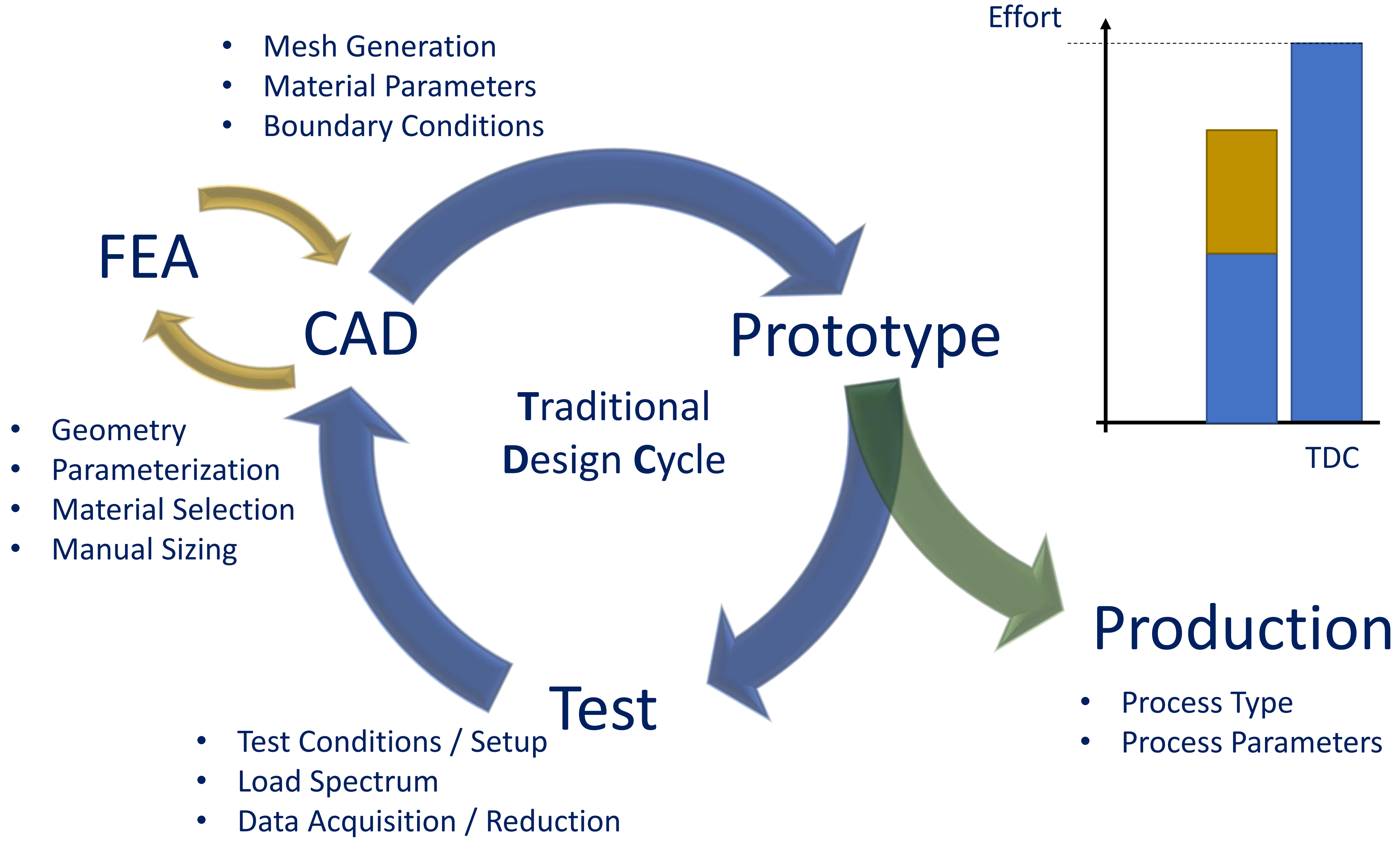
Time consuming and Expensive



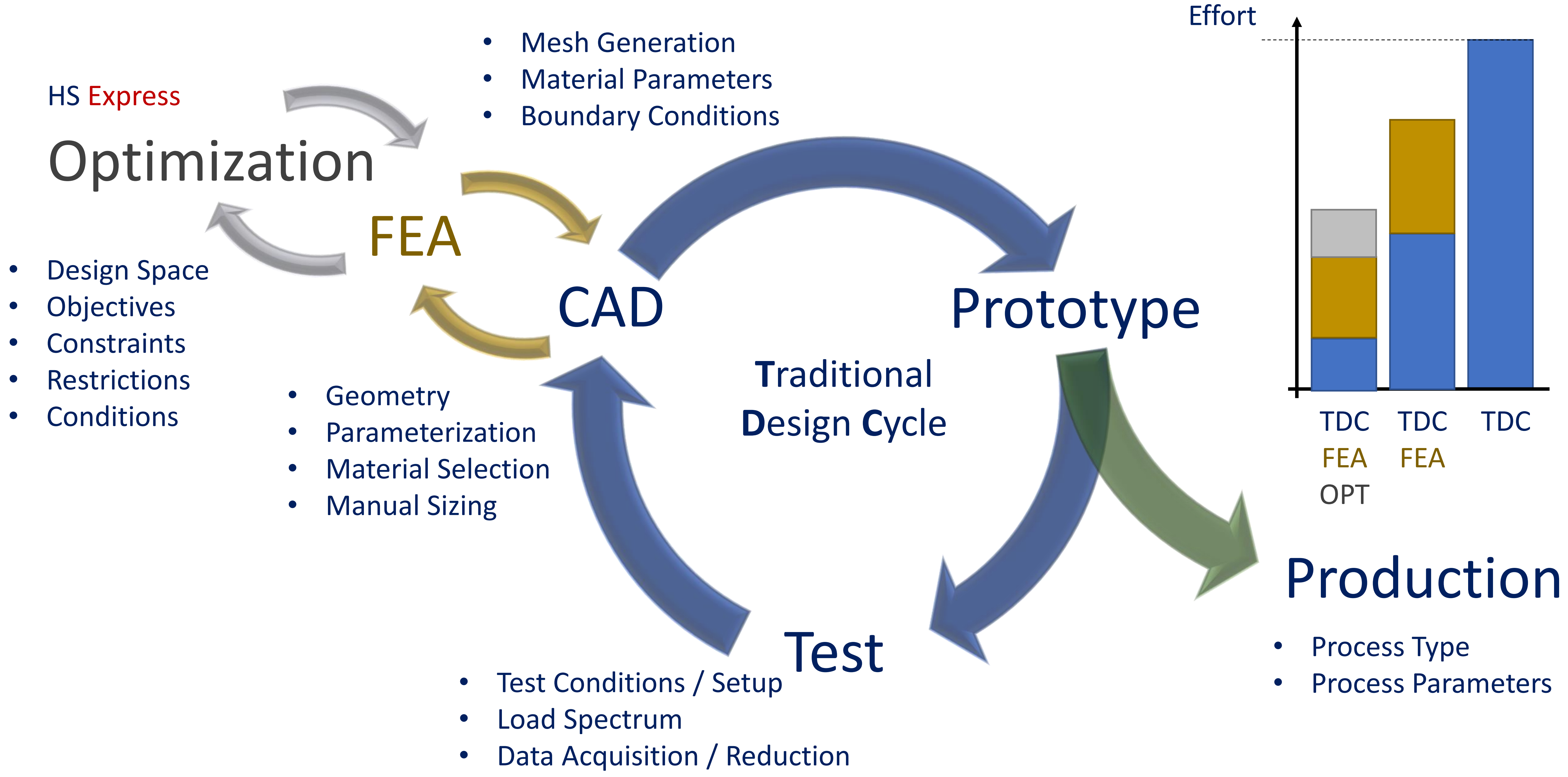
CAD
- Geometry
- Parameterization
- Material Selection
- Manual Sizing

Test
- Test Conditions / Setup
- Load Spectrum
- Data Acquisition / Reduction

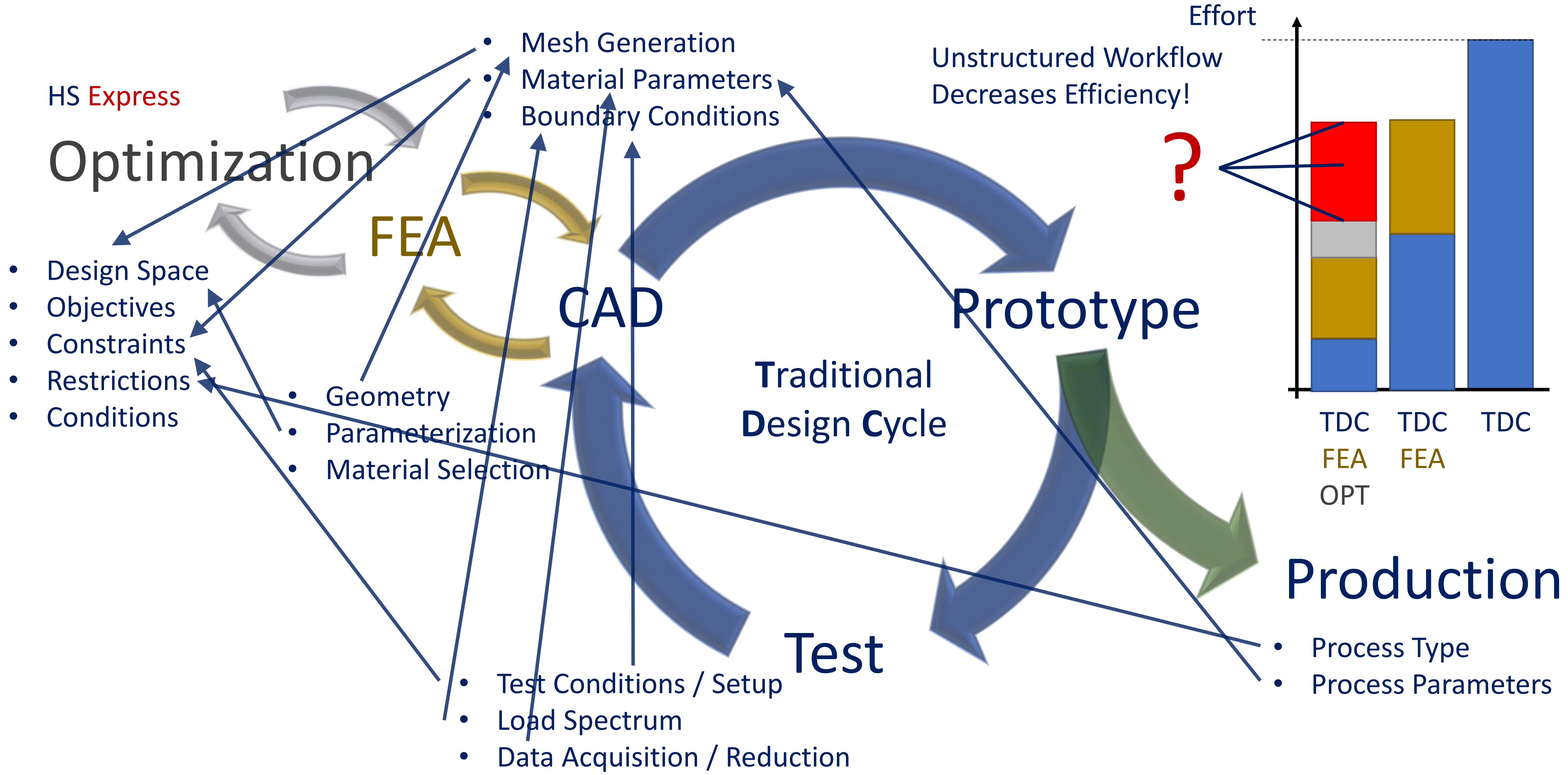
Production
- Process Type
- Process Parameters


Mesh Generation
Material Parameters
Boundary Conditions
FEA
CAD
Prototype
Geometry
Parameterization
Material Selection
Manual Sizing
Traditional Design Cycle
Production
Process Type
Process Parameters
Test
Test Conditions / Setup
Load Spectrum
Data Acquisition / Reduction
Effort
TDC

Motivation – Reduction of Traditional Design Cycles



Motivation – Reduction of Traditional Design Cycles ?

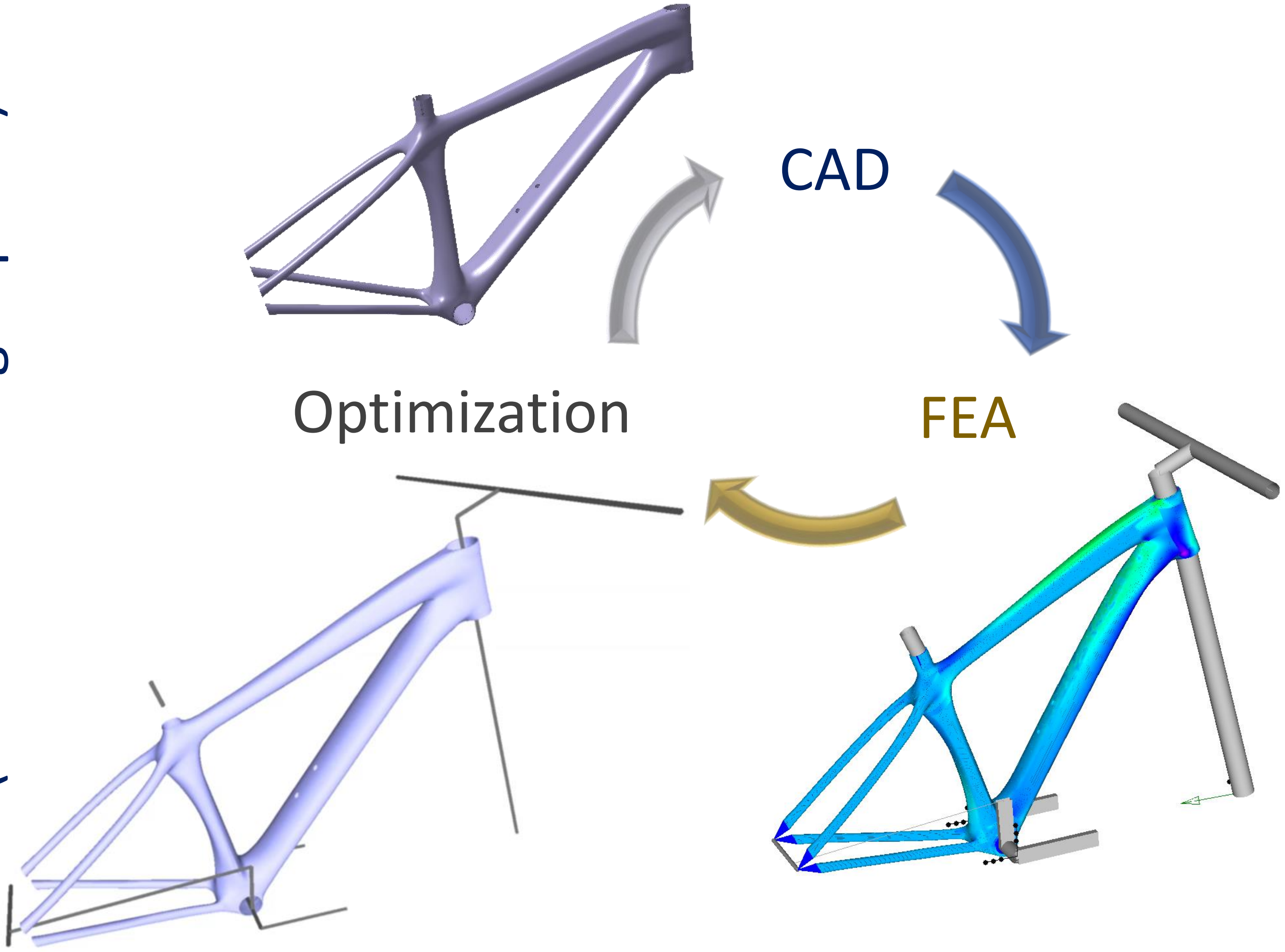


The Importance of Workflow

HyperSizer Express features an Intuitive Setup Wizard to increase efficiency

- **Design Space**
  - Geometry
  - Ply Shapes
  - Ply Number
  - Directions
- **Objectives**
  - Reduction of Weight
- **Constraints**
  - Strength (local)
  - Stiffness (global)
- **Restrictions**
  - Layup Rules
  - Design Rules
  - Ply Extension
- **Conditions**
  - Step Size
  - When Stop Optimizing?

Available Options
(Enormous Design Space!)



Simplicity and Reduction of Design Space: Only Define what is Required

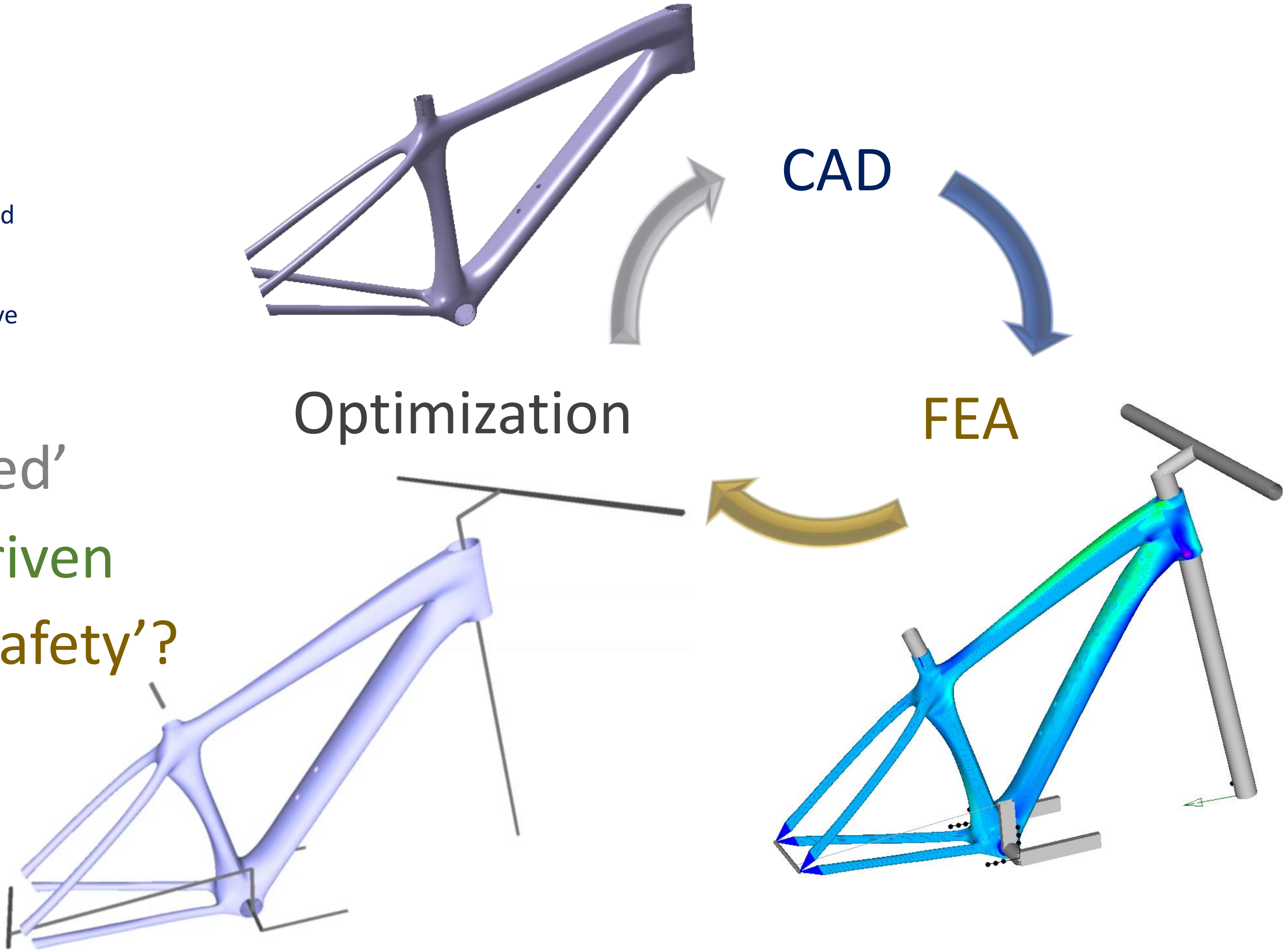
- **Design Space**
  - Geometry — Often given by style and function
  - Ply Shapes — Ply based or laminate based approach
  - Ply Number
  - Directions — Often limited – initial directions needed
- **Objectives**
  - Reduction of Weight — Nearly exclusive objective
- **Constraints**
  - Strength (local)
  - Stiffness (global)
- **Restrictions**
  - Layup Rules
  - Design Rules
  - Ply Extension
- **Conditions**
  - Step Size
  - When Stop Optimizing?

'Casual users' don't want to think about this

'Pre defined'

Process driven

What is 'Safety'?

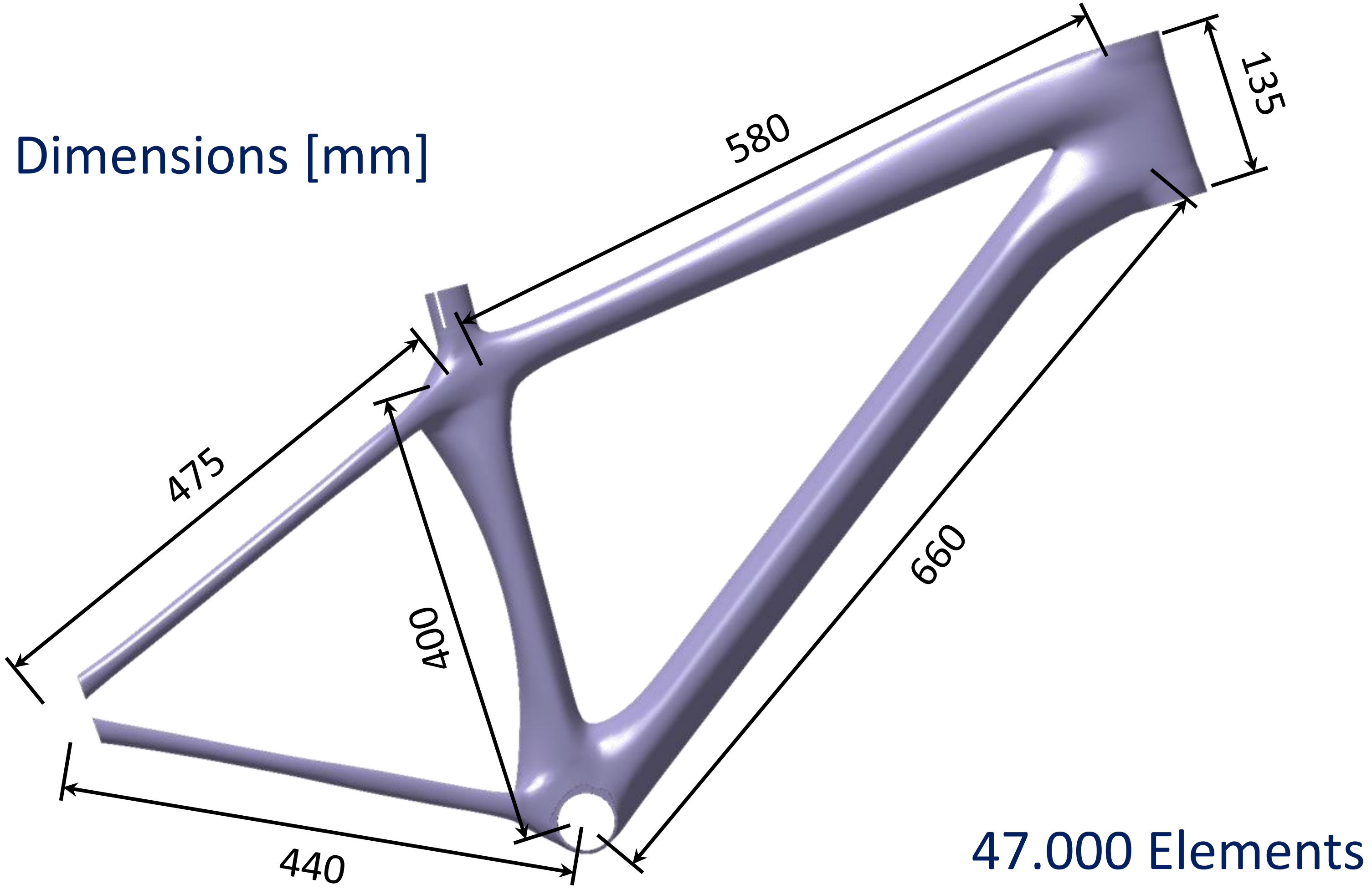


Generic Bike Frame Optimization to Illustrate Challenges

Material
AS4/3502 UD

E_1 = 134.0 Gpa
E_2 = 9.3 GPa
G_{12} = 3.75 GPa
ν_{12} = 0.34

σ_1 = 1400 MPa
σ_2 = 120 MPa
τ_{12} = 92 MPa

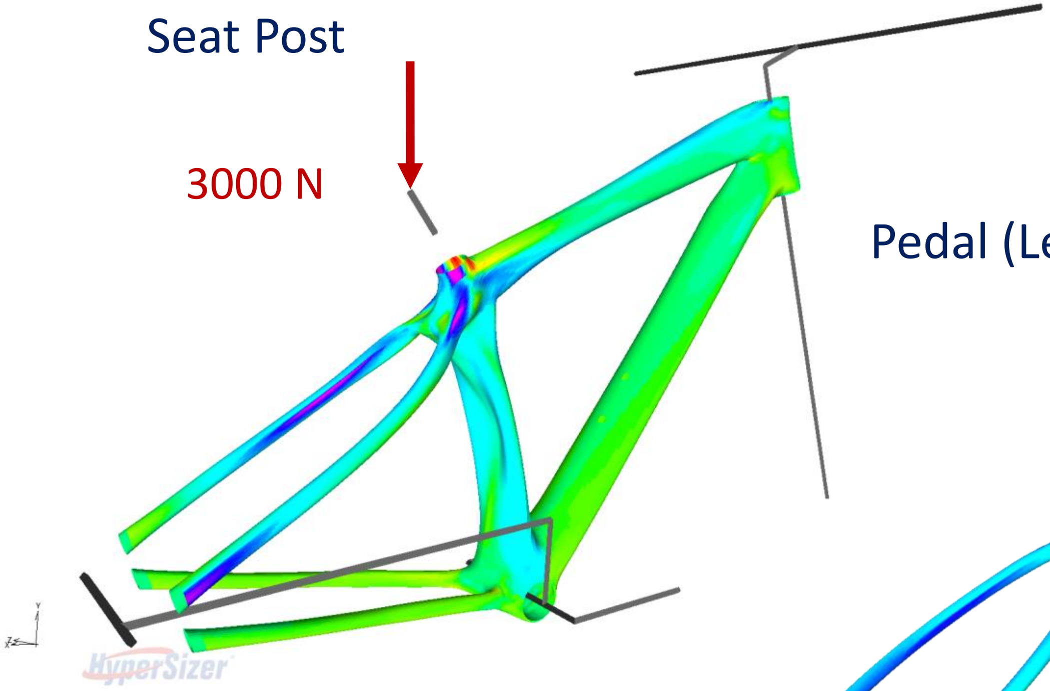


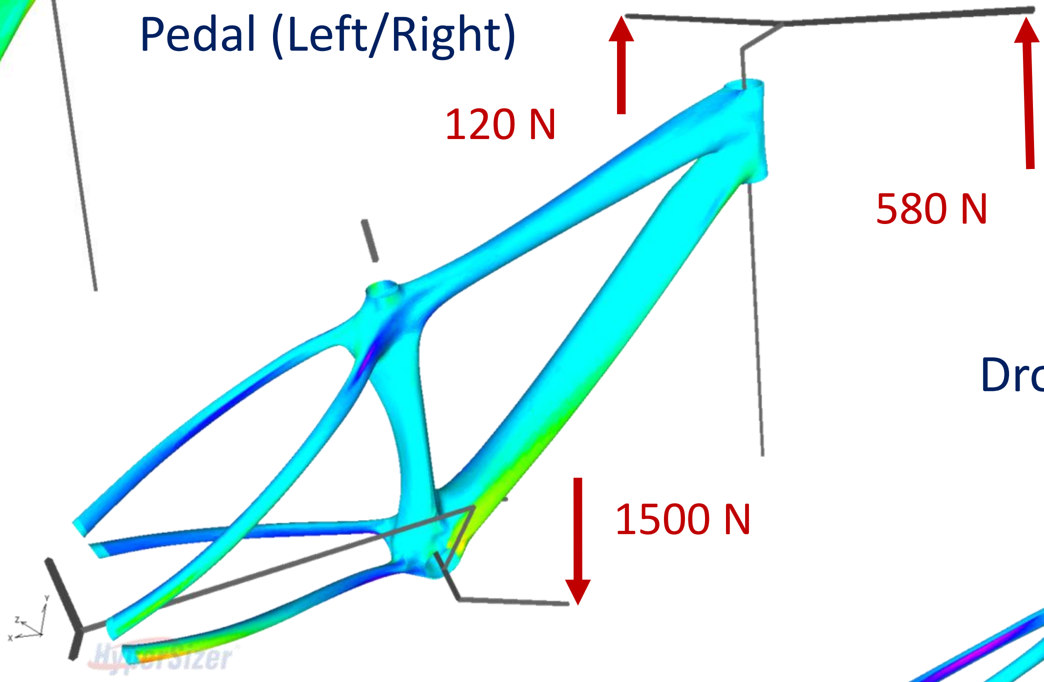
HyperSizer®

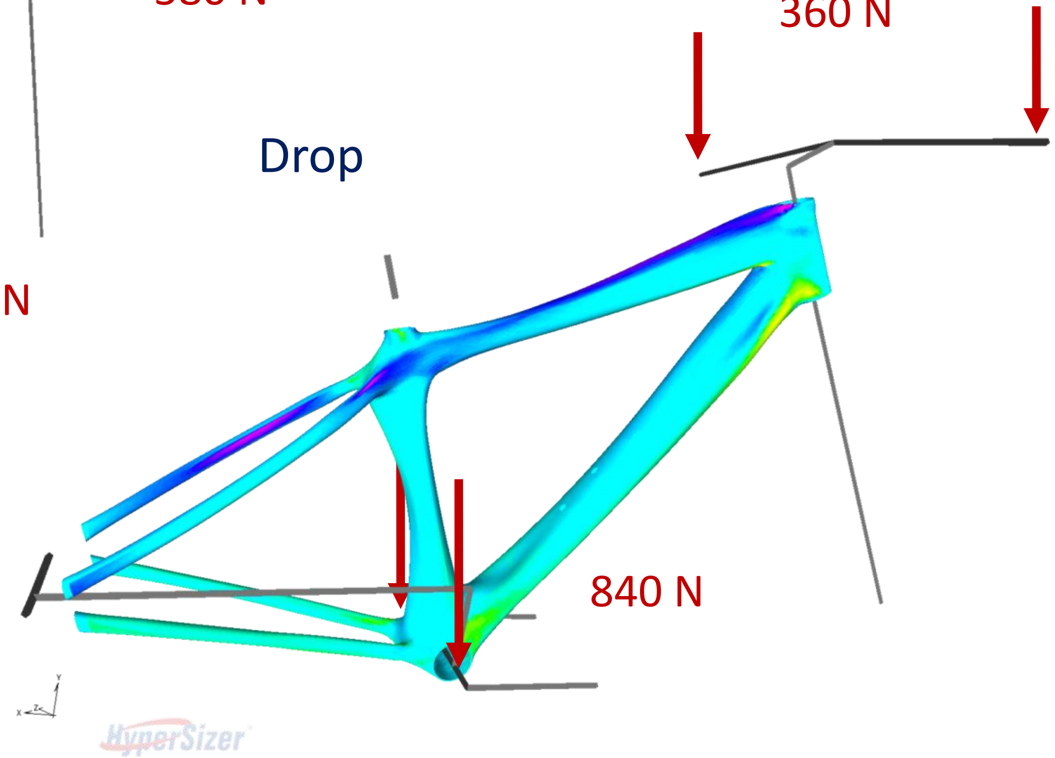
Advanced Composite Failure Criteria

(over 30 Ply and Laminate Based Criteria Available)

- Tsai- Hill
- Tsai- Wu
- Tsai- Hahn



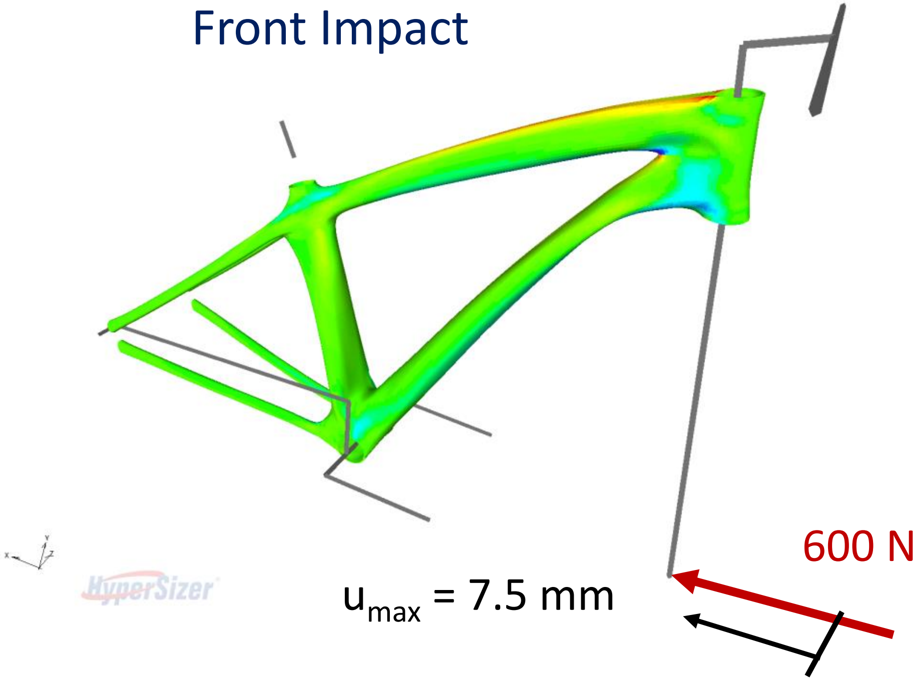




In total, nine load cases considered for strength sizing

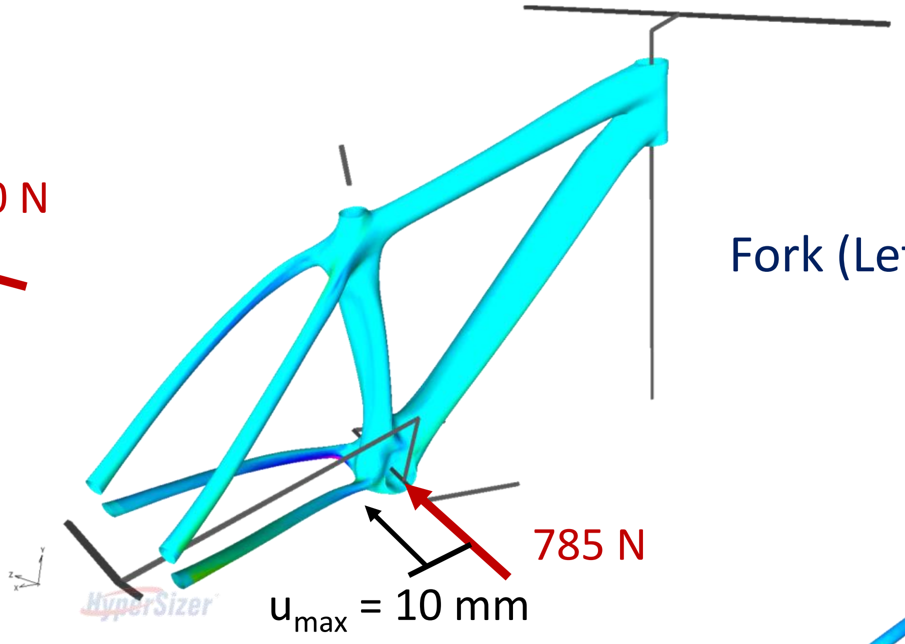
… And Multiple Stiffness Targets

Front Impact

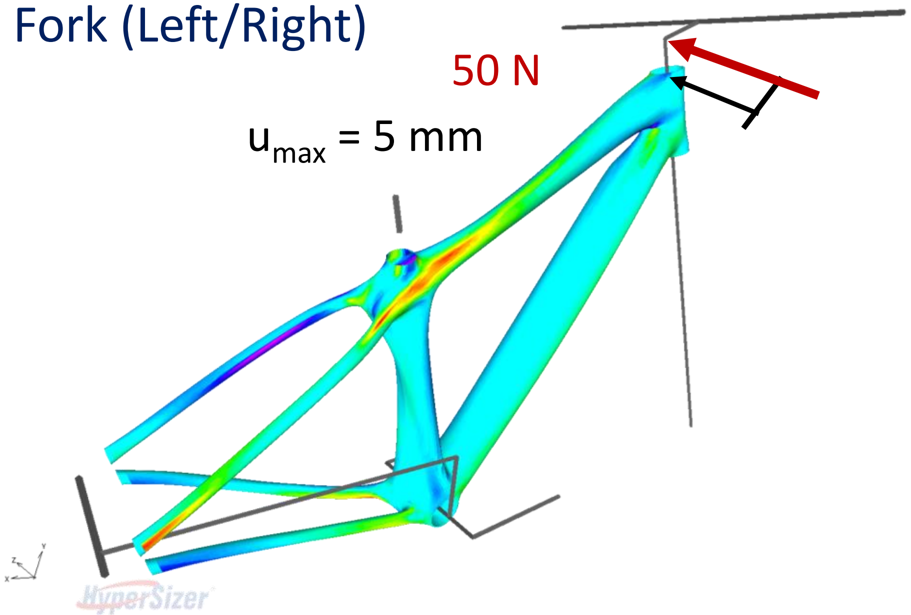


Simultaneously, meet stiffness targets

Bottom Bracket (Left/Right)



Fork (Left/Right)



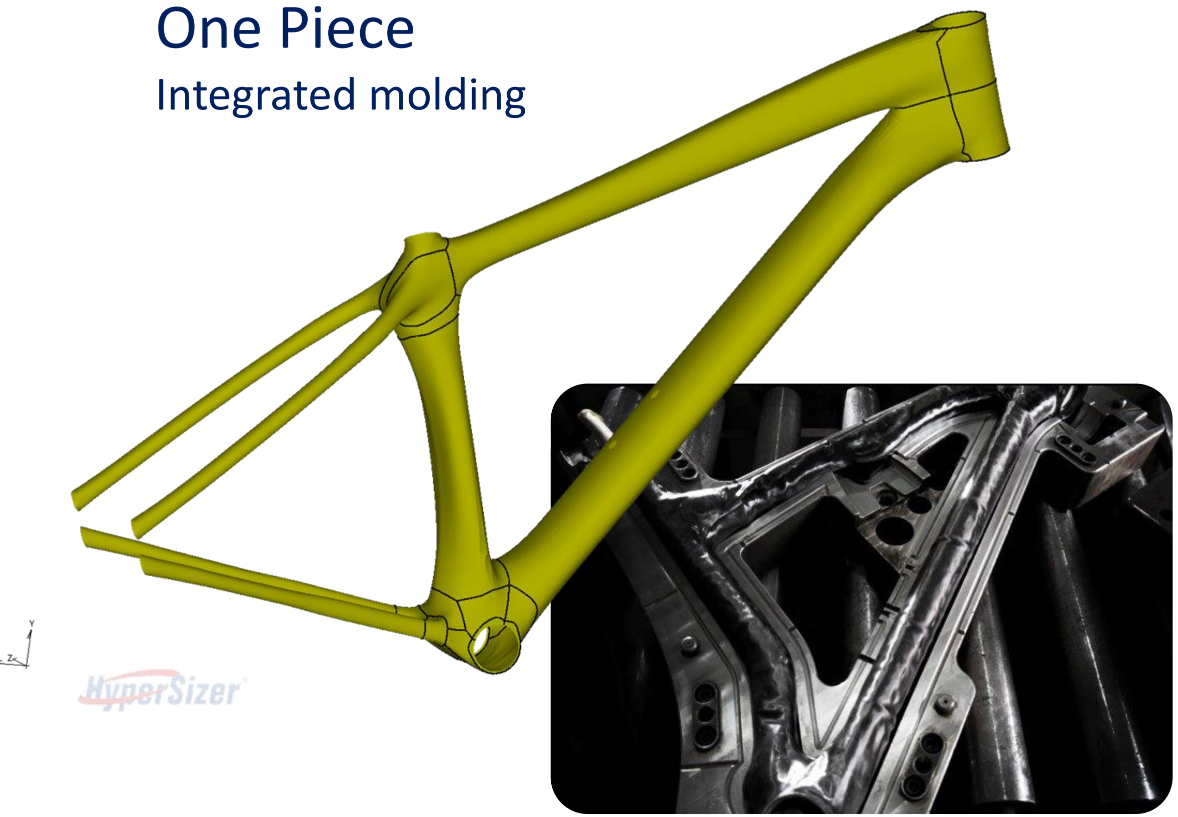
In total, five different structural stiffness targets

Challenge: Design for Manufacturing

Impose Ply Extension Constraints according to the fabrication technique

One Piece

Integrated molding

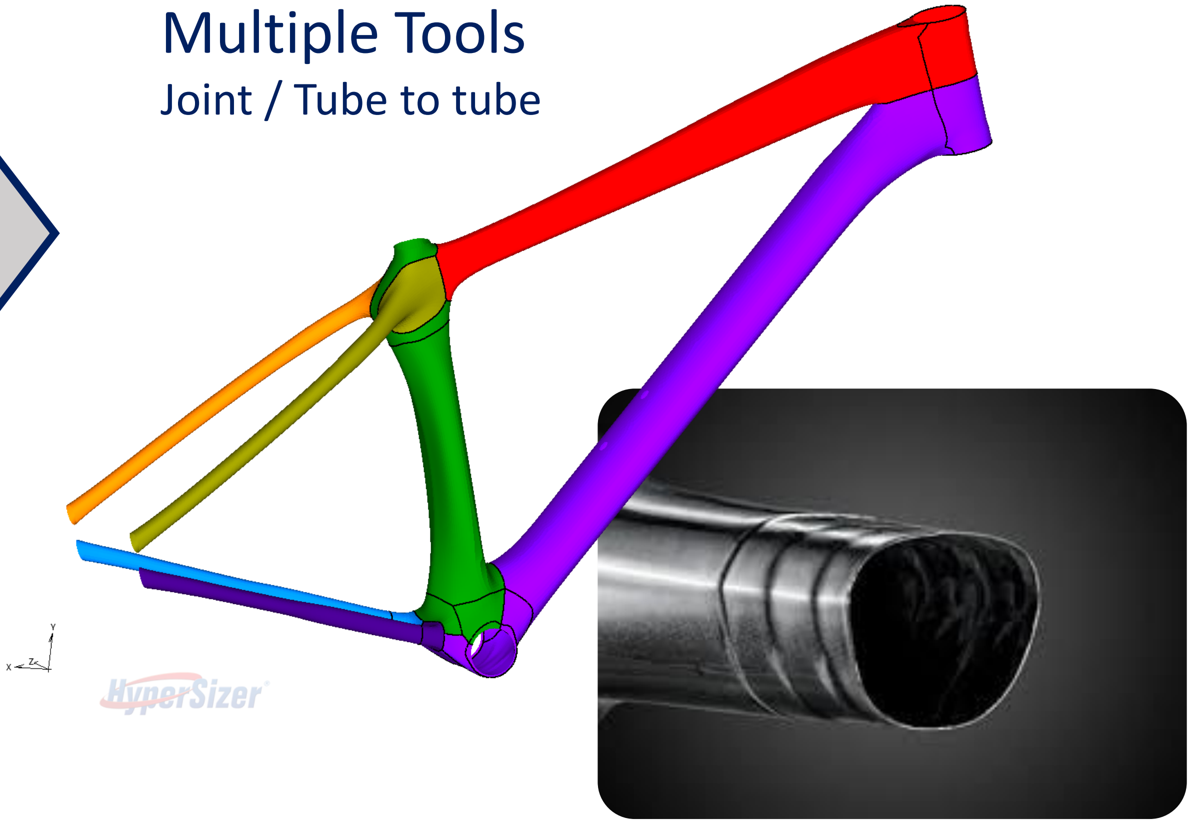


http://www.pinkbike.com/news/

Plies can extend over entire structure

Multiple Tools

Joint / Tube to tube



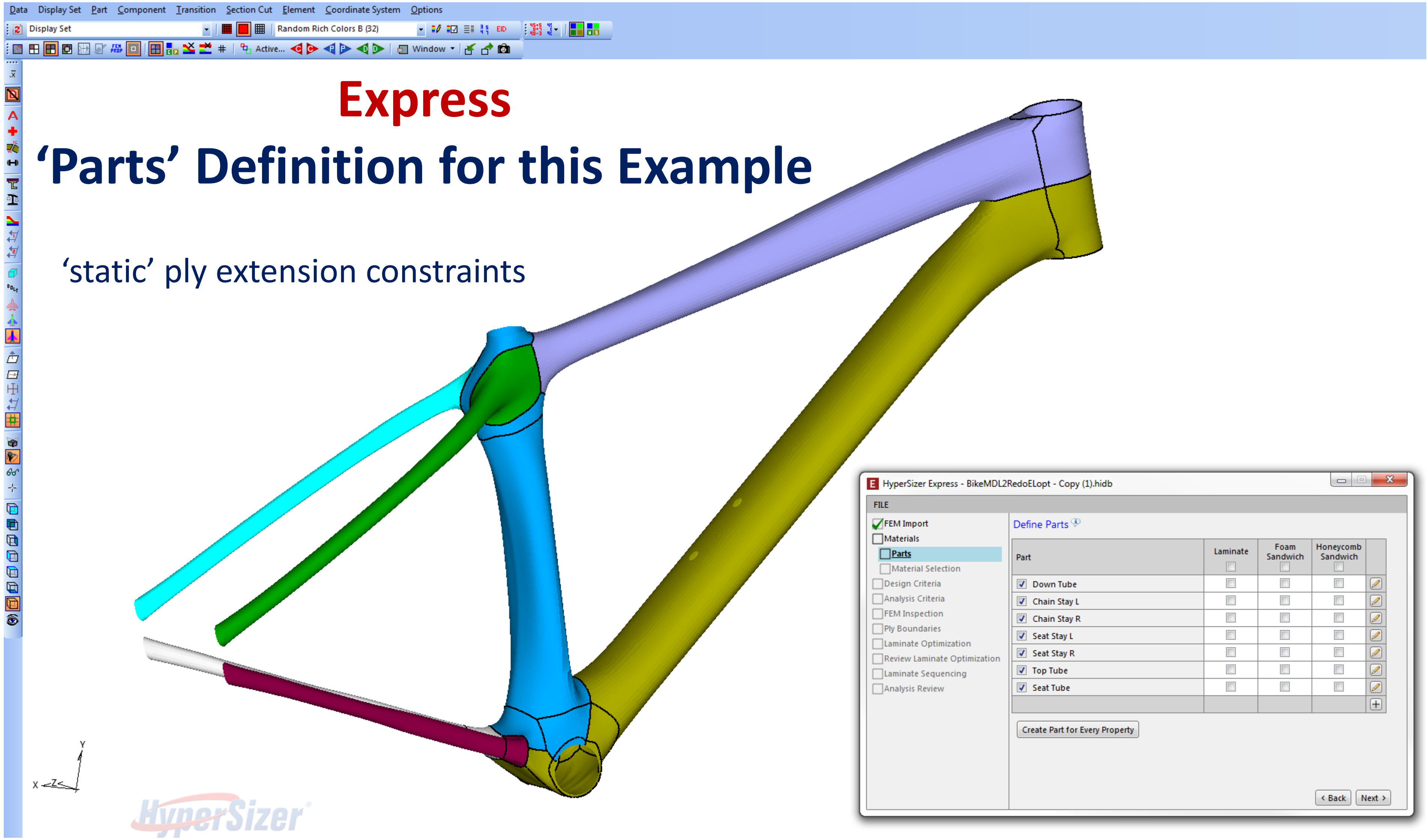
http://blog.schellers.com/

Regions limiting ply extensions

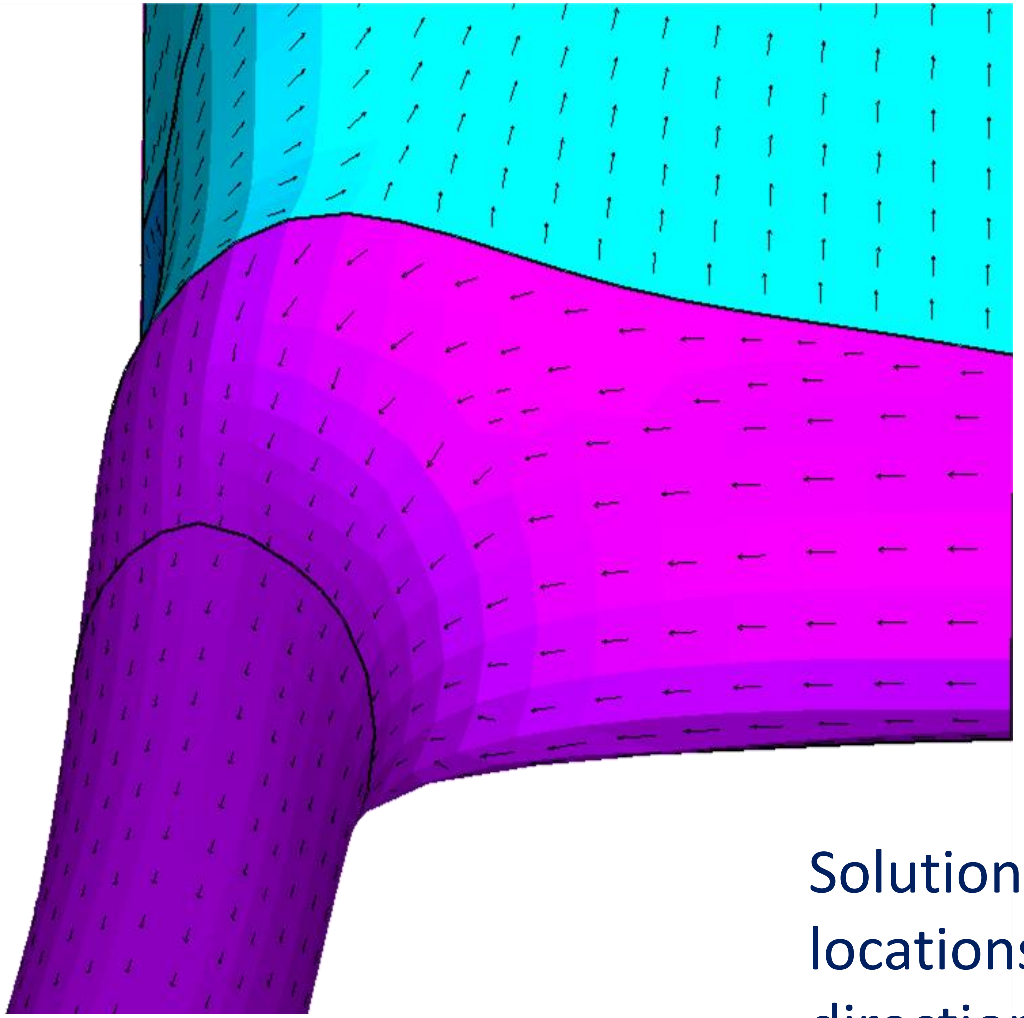
Express

‘Parts’ Definition for this Example

‘static’ ply extension constraints



Ply Extensions due to Discrete Ply Angles based on Material Reference Directions

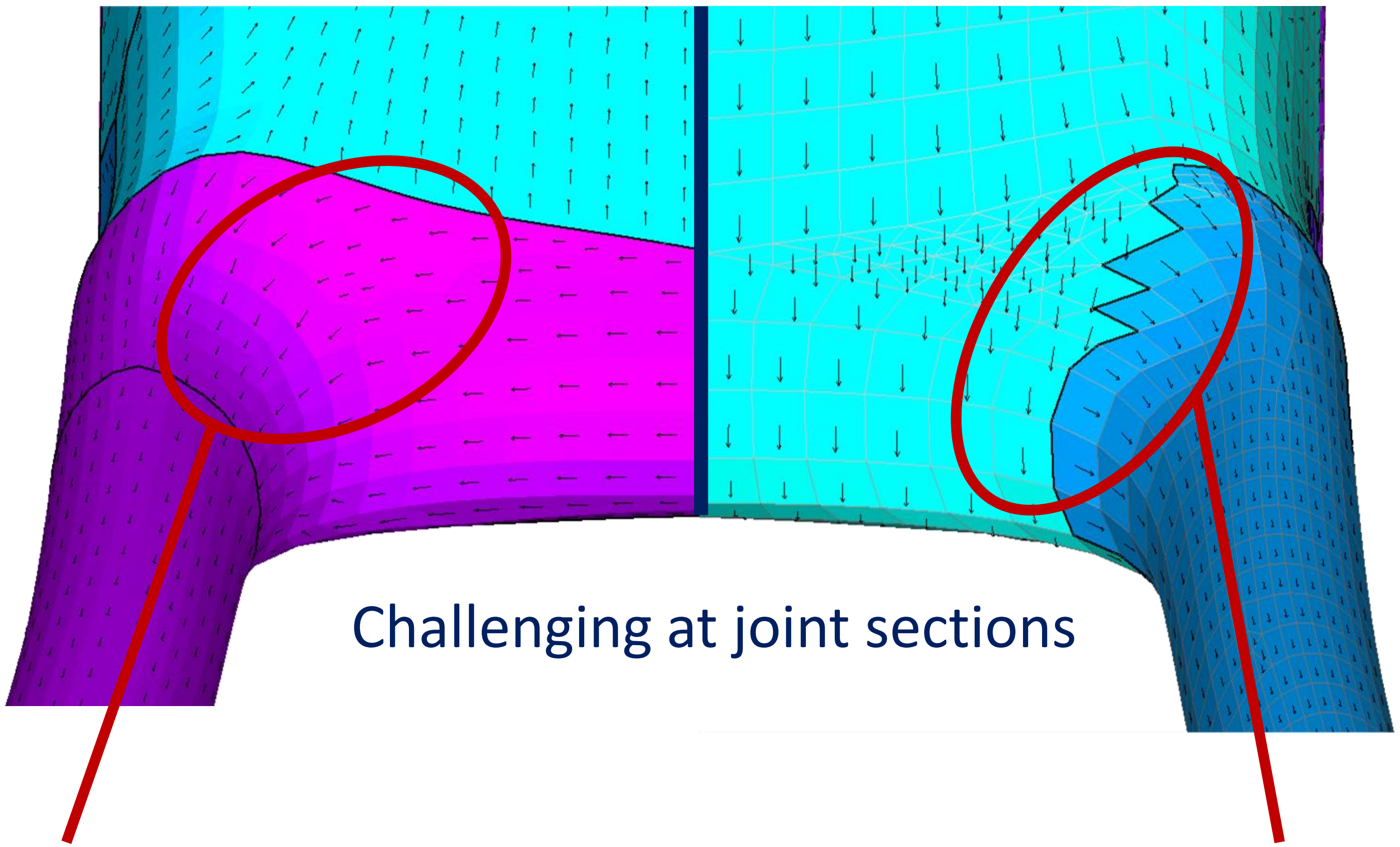


Only very few locations allow for ply continuity across this boundary!

Whenever the fiber angle between element neighbors are identical to one of the discrete allowed ply angles.

Solution: Impose ply extension constraints at locations of discontinuous material reference directions

What is the Best Material Reference Direction?



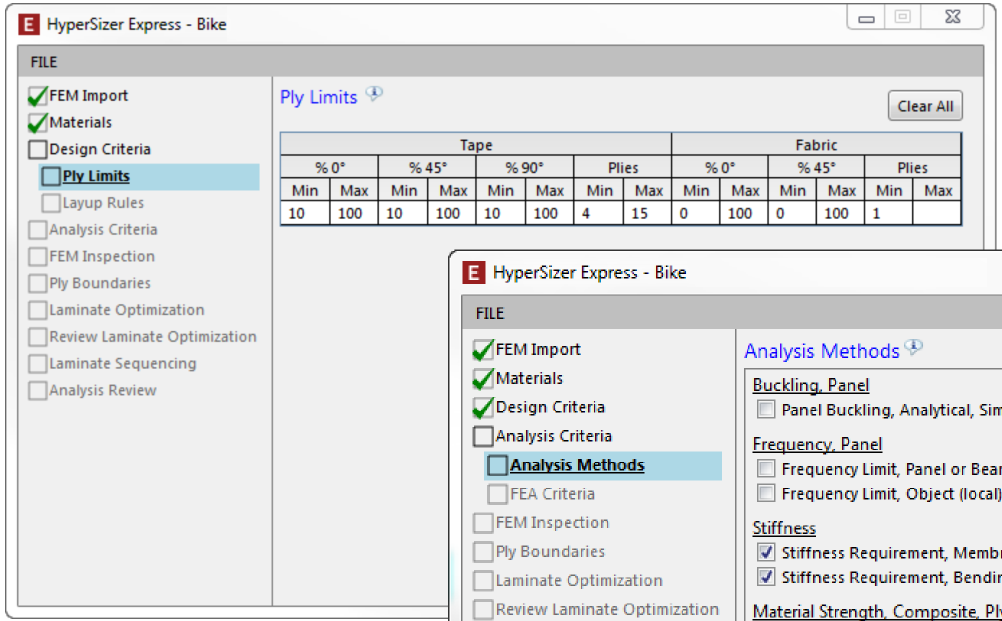
Considerable ply thinning in critical area
Good for load introduction to chain stay

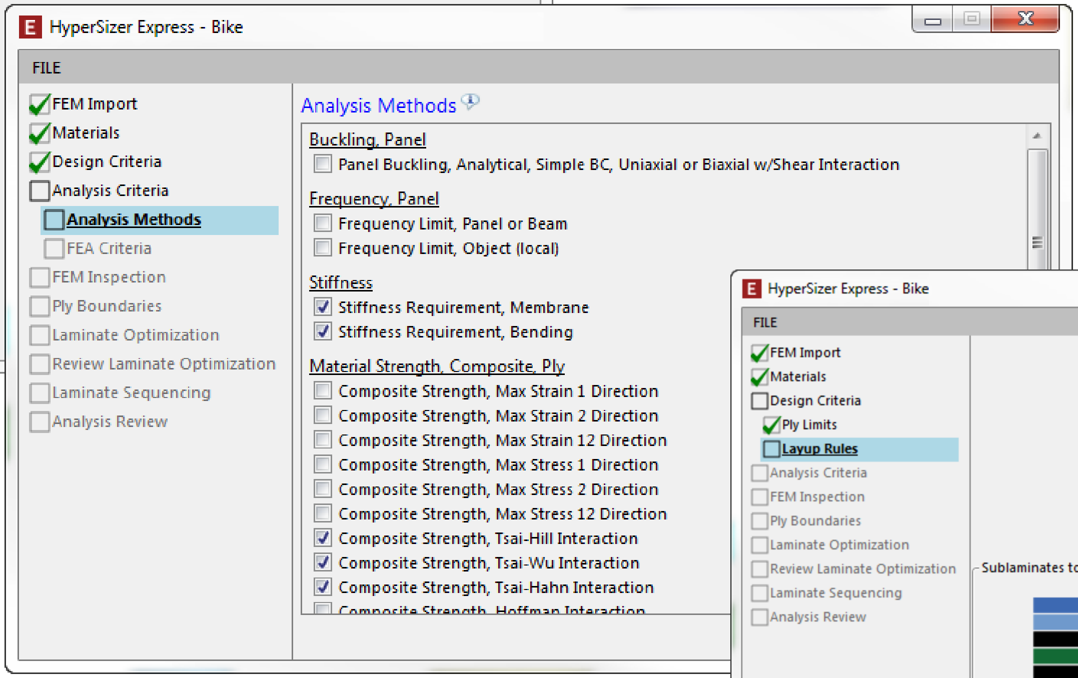
Ply drops and adds in critical area
Consecutive plies in bottom bracket

‘Parts’ (ply extension constraints) are very efficient!	‘Strong’ restriction for ply shapes Generates ‘cracks’ at each part boundary.
• Fabrication technique constraints	This is covered!
• Material reference angle constraints	Only by utilizing a continuous fiber angle optimization, we can ‘truly overcome’ this issue. (Algorithms still inefficient, design space is too wide)
• Avoid impossible flat pattern	Still inefficient to generate a flat patterns (reverse draping) of every ply, and regenerate new extension constraints.

Challenge: Design for Safety

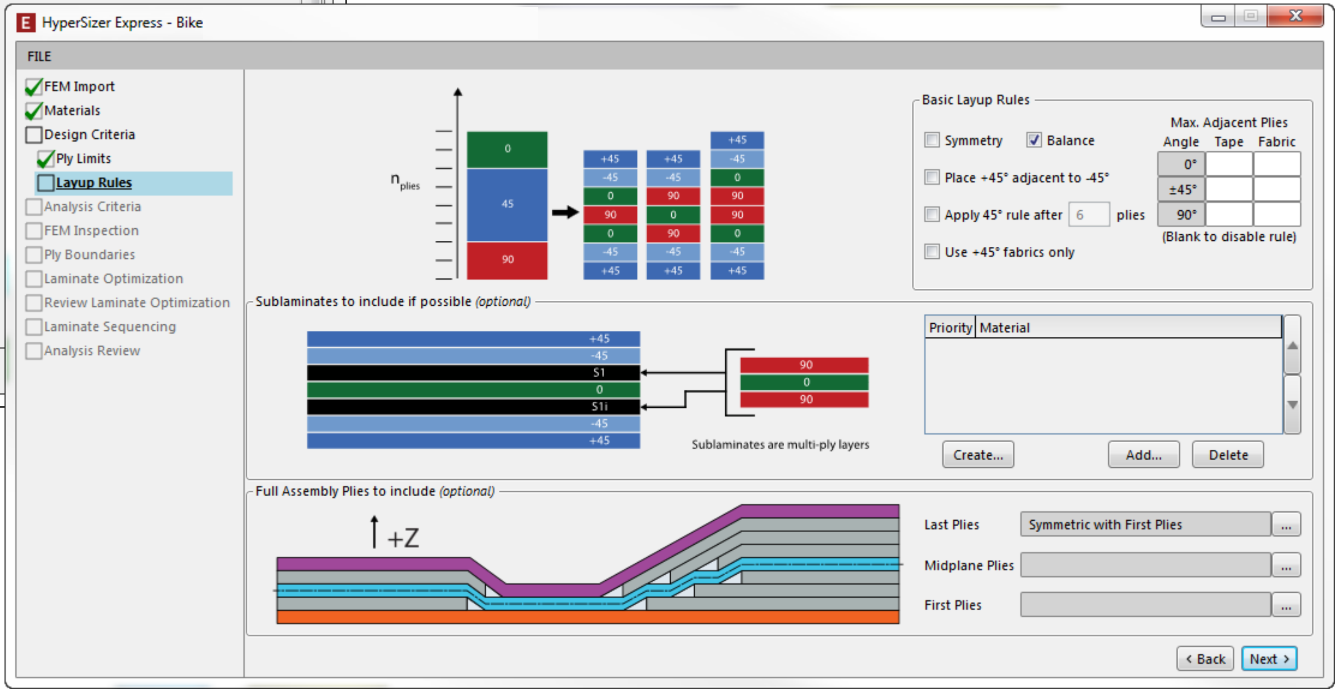
HyperSizer®





What is 'Safety'?

- Damage Tolerant Design?
- Maximum Dissipation of Energy at Fracture?
- Fracture Type (Pseudo-ductile)?
- Design to First Ply Failure at Ultimate Loads?
- Maintain Structural Integrity?
- Early Signs before Catastrophic Failure?



A combination of

- Strength Criteria
- Stiffness Targets
- Ply Limits
- Layup rules
- Design Load Spectrum and Boundary Conditions

Challenge for Bike Community

- **Identification and Unification of Safety Measures.**
- **Transformation to Requirements on Mechanical Properties and Layup Rules**

Stored

Light Riding

Heavy Riding

Accident

What is 'Safety'?

- Damage Tolerant Design?
- Maximum Dissipation of Energy at Fracture?
- Fracture Type (Pseudo-ductile)?
- Design to First Ply Failure at Ultimate Loads?
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A combination of
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Challenge for Bike Community
- **Identification and Unification of Safety Measures.**
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Optimize Performance

Lab Test

Well defined and good for comparisons

https://www.cervelo.com/

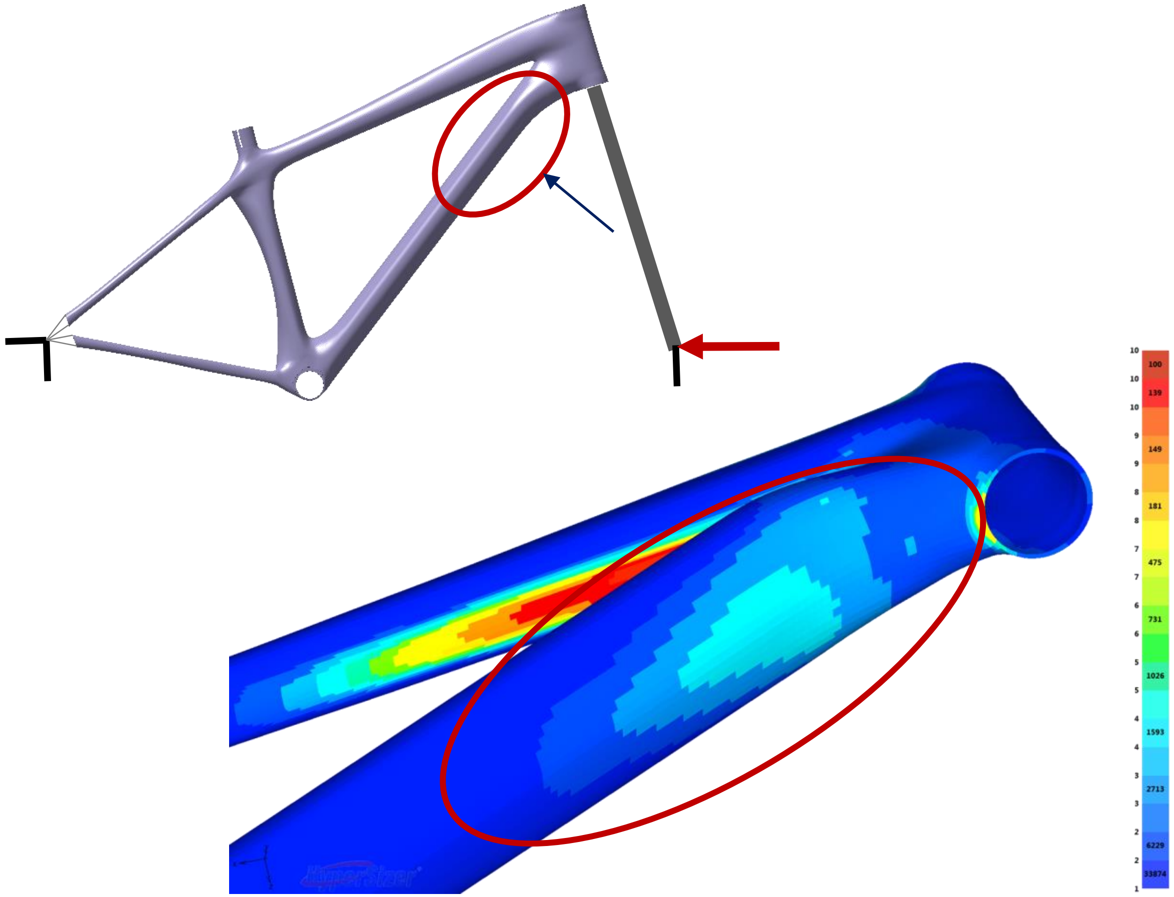
Riding Conditions

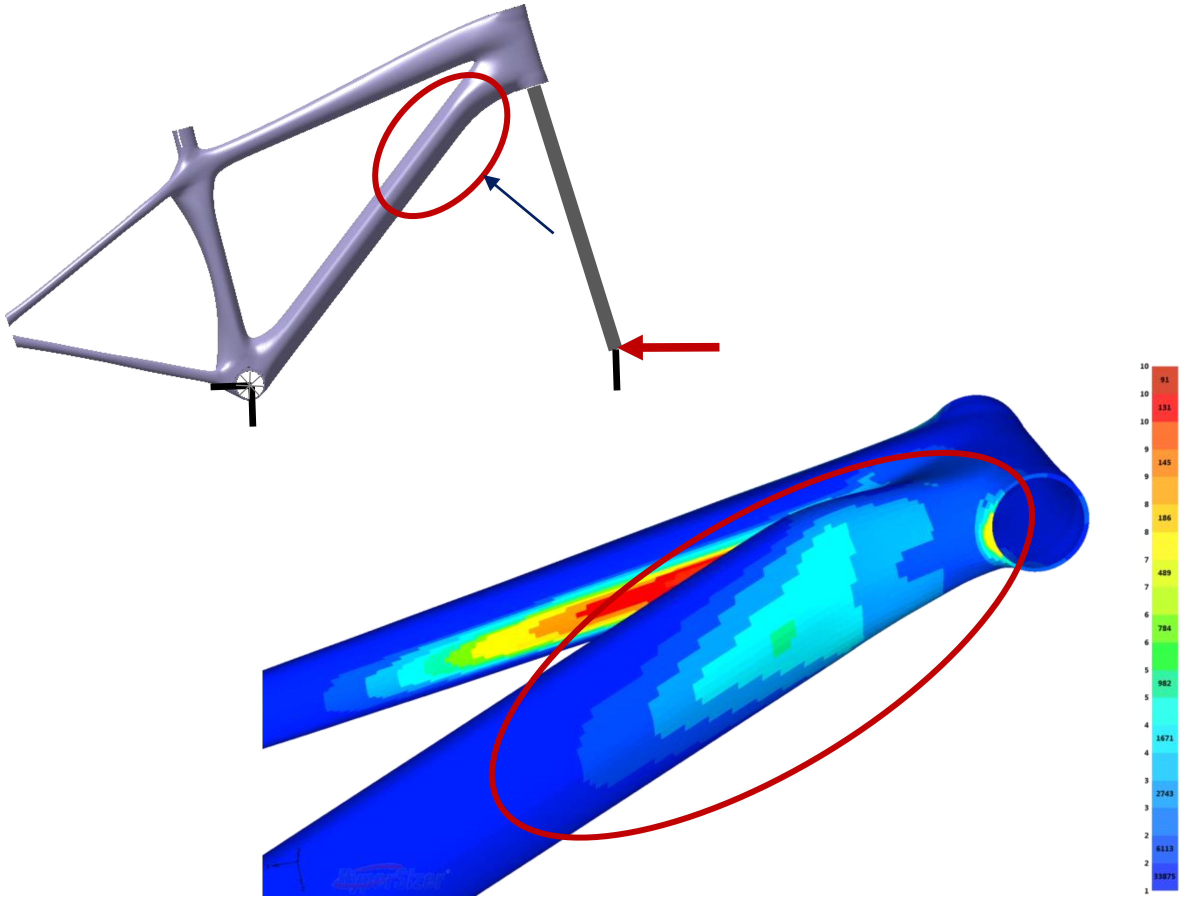
What you really need

http://www.jbcf.jp

Ideally, they are identical… otherwise – optimize for both, simultaneously!

Numerical optimization can **at best** be as meaningful as the boundary conditions and loads

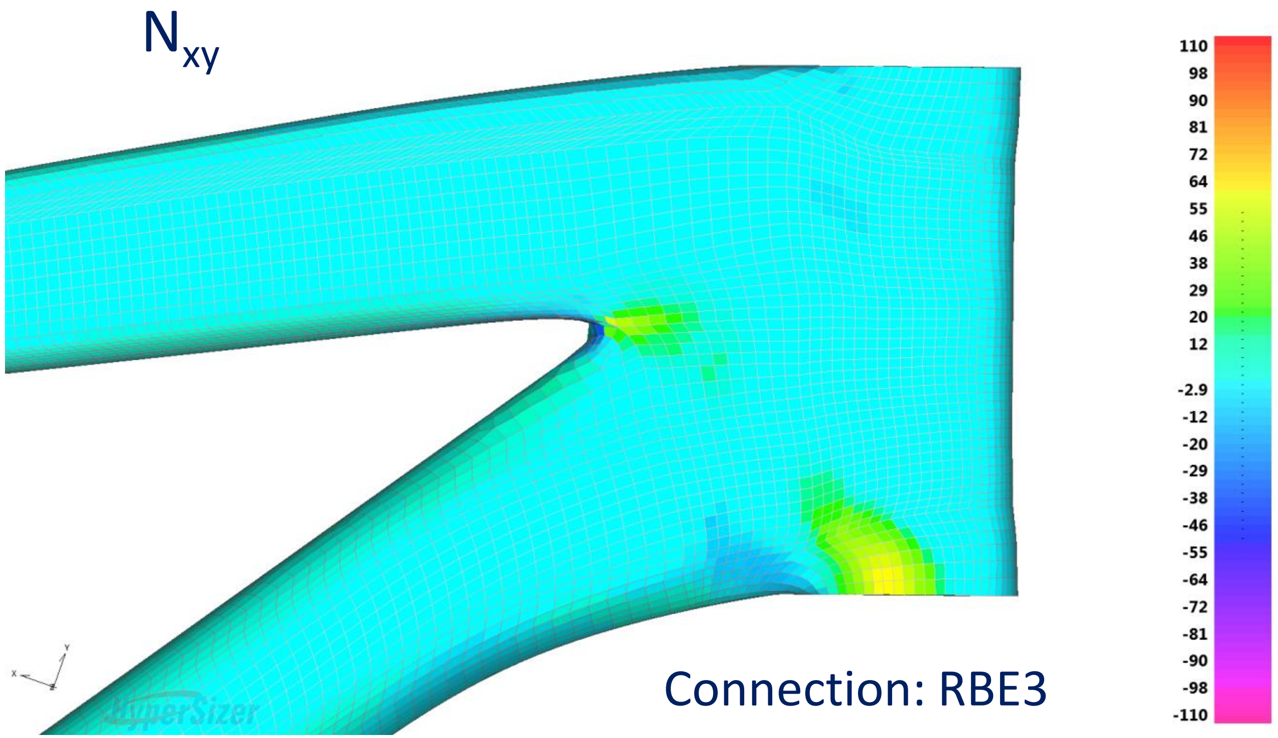


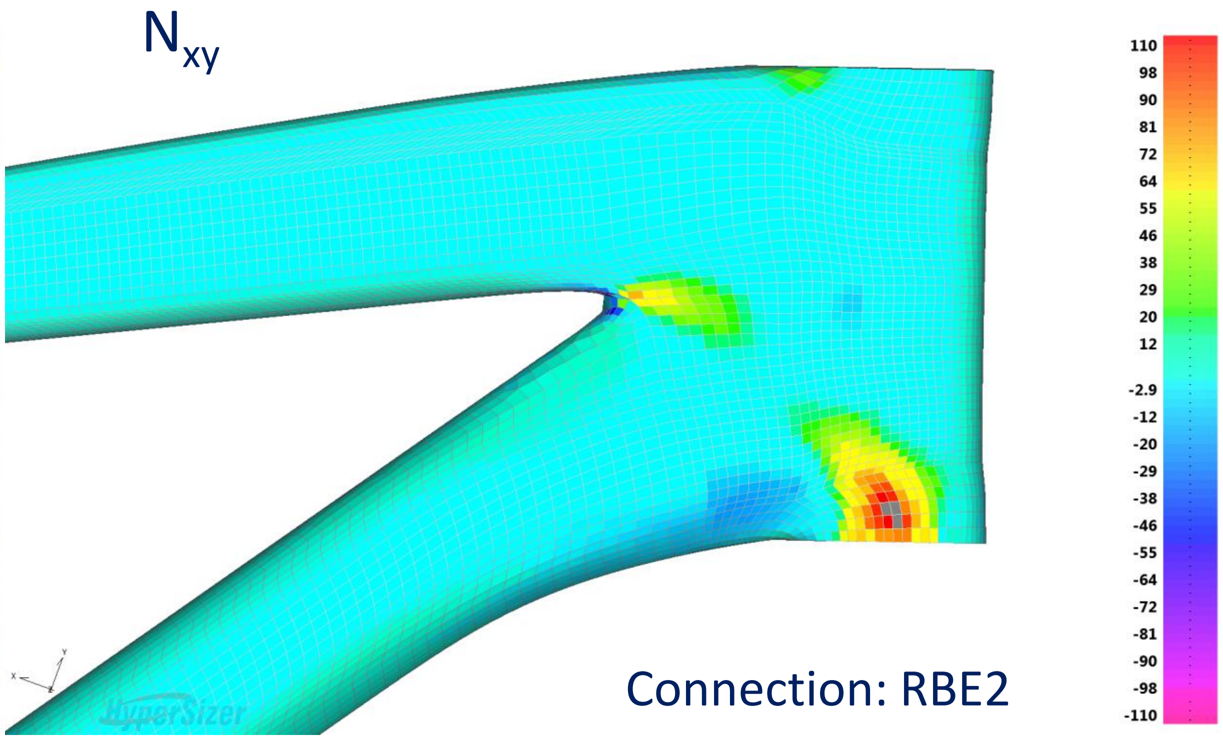


Optimized ply shapes - even far away of the load introductions and boundary conditions - can be affected by your choice of boundary conditions, loads and constraints.

It is important **which** and **how** loads are introduced!

Example: Load introduction through different formulations of rigid body elements attached to shells representing the bearing cups (filtered out) at head tube



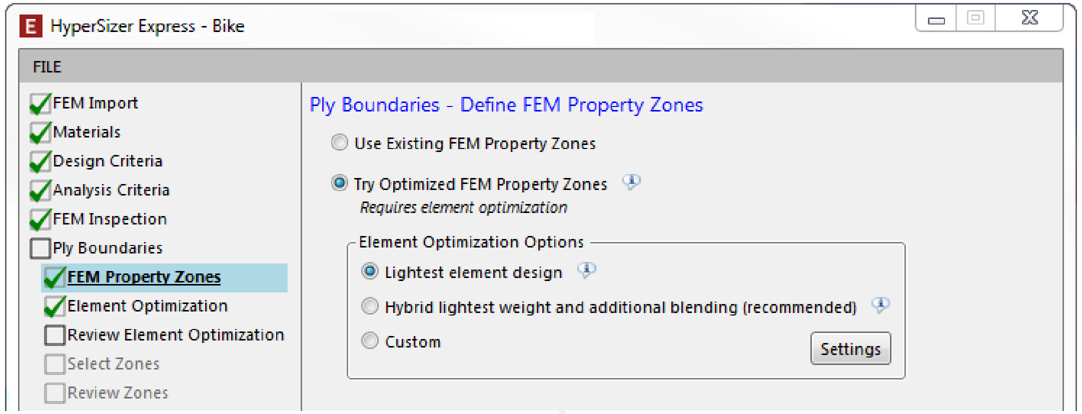


Arbitrary load concentrations cause increase of ply counts

Challenge: How to distinguish between real load concentrations and artificial load concentrations?

Challenge: Weight vs. Manufacturability

Lightest Design



Hybrid Design

Stiffener – like structures

Mass: 0.45 kg

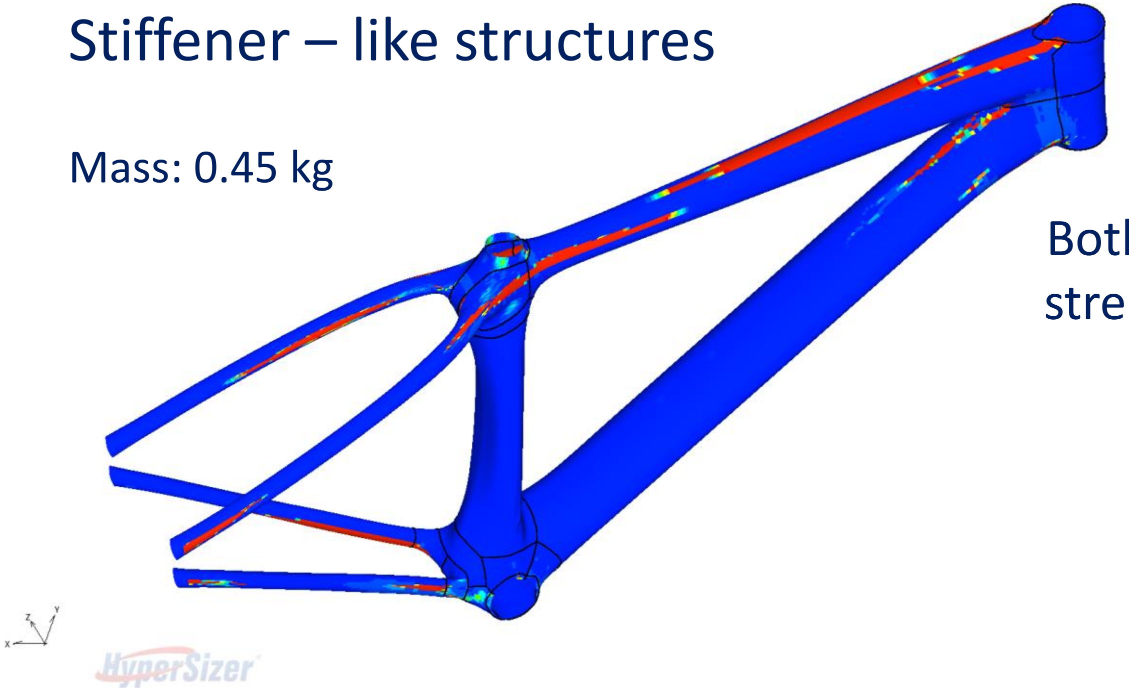
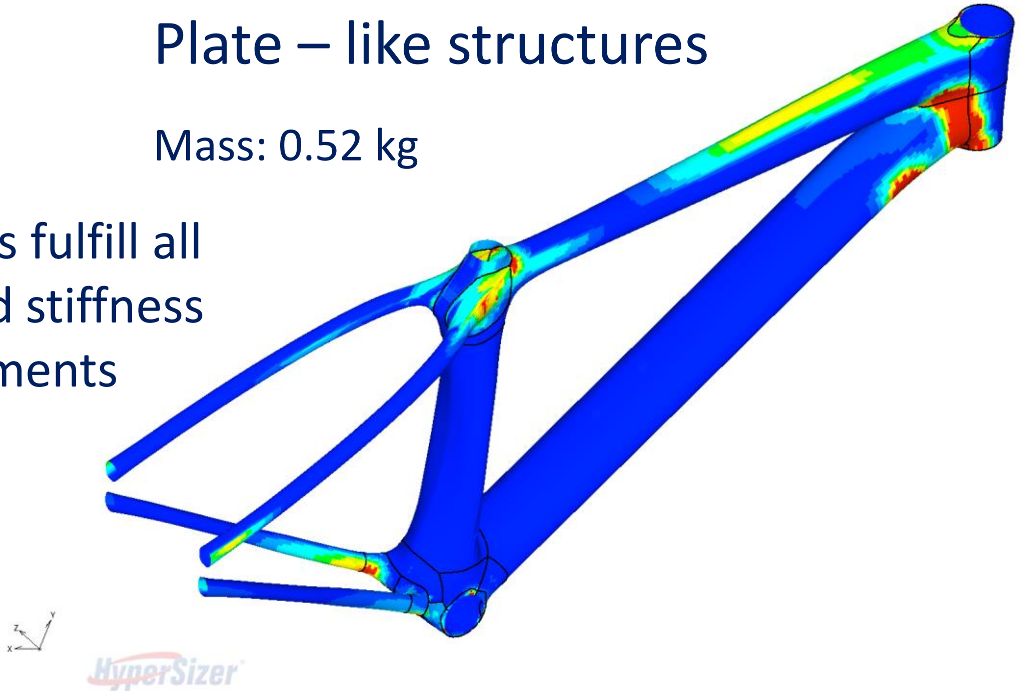


Plate – like structures

Mass: 0.52 kg

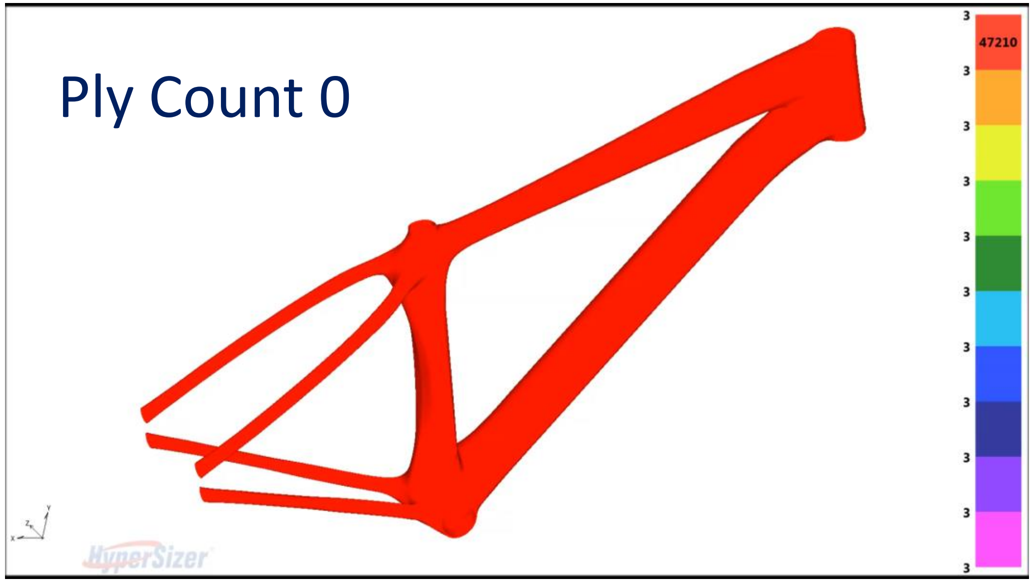


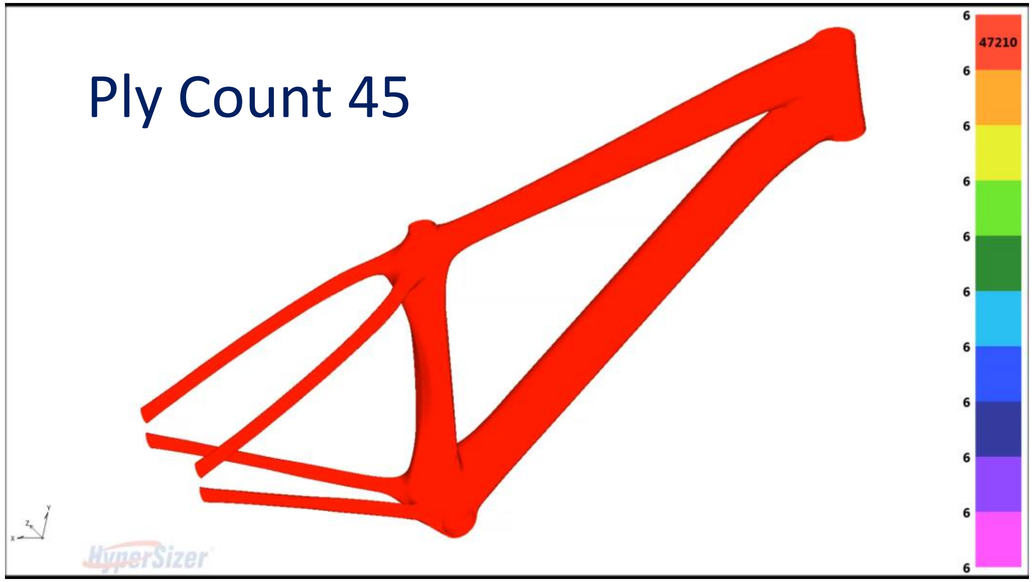
Both designs fulfill all strength and stiffness requirements

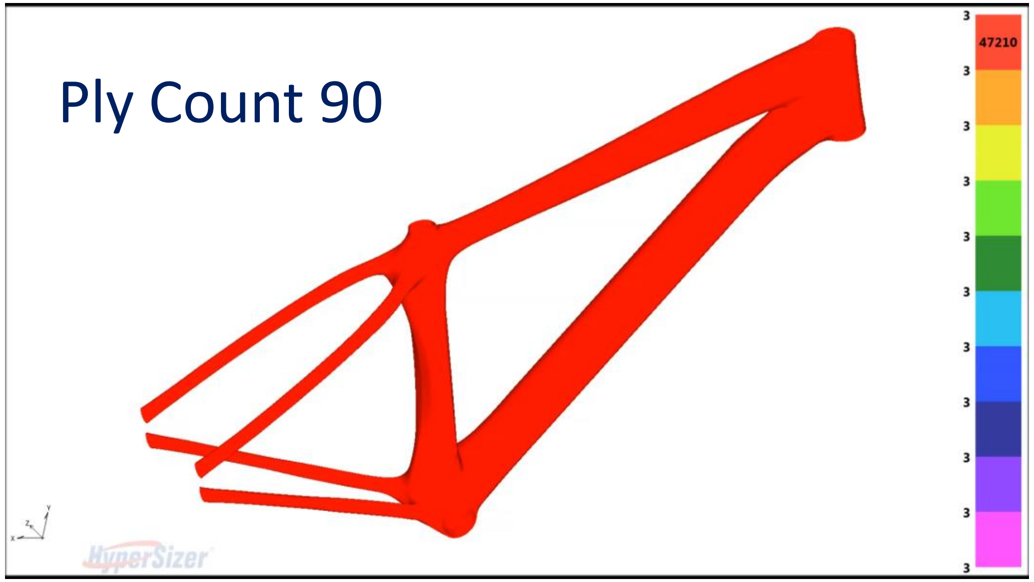
"Base line laminate locally highly reinforced – focuses loads"

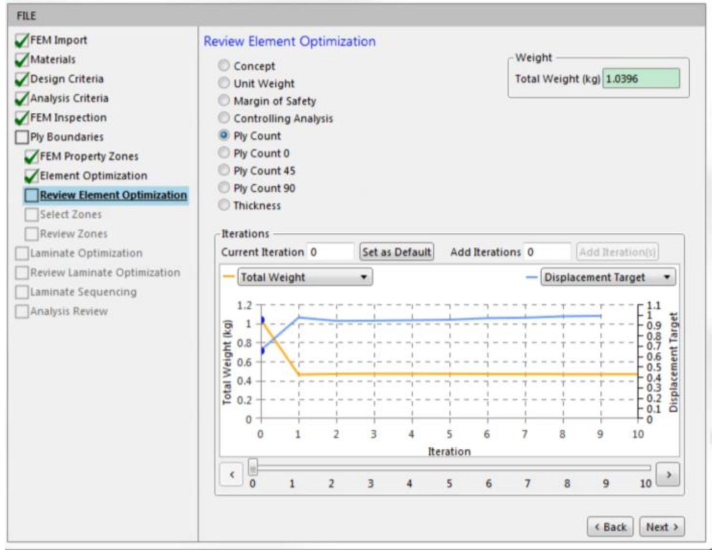
"Thin, spread out laminates inclined to distribute loads"

Design Change



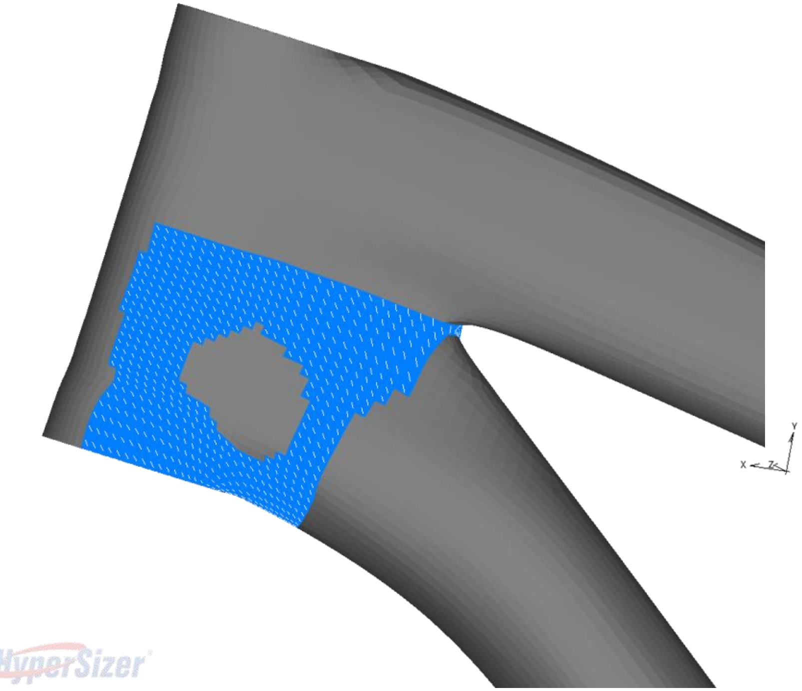




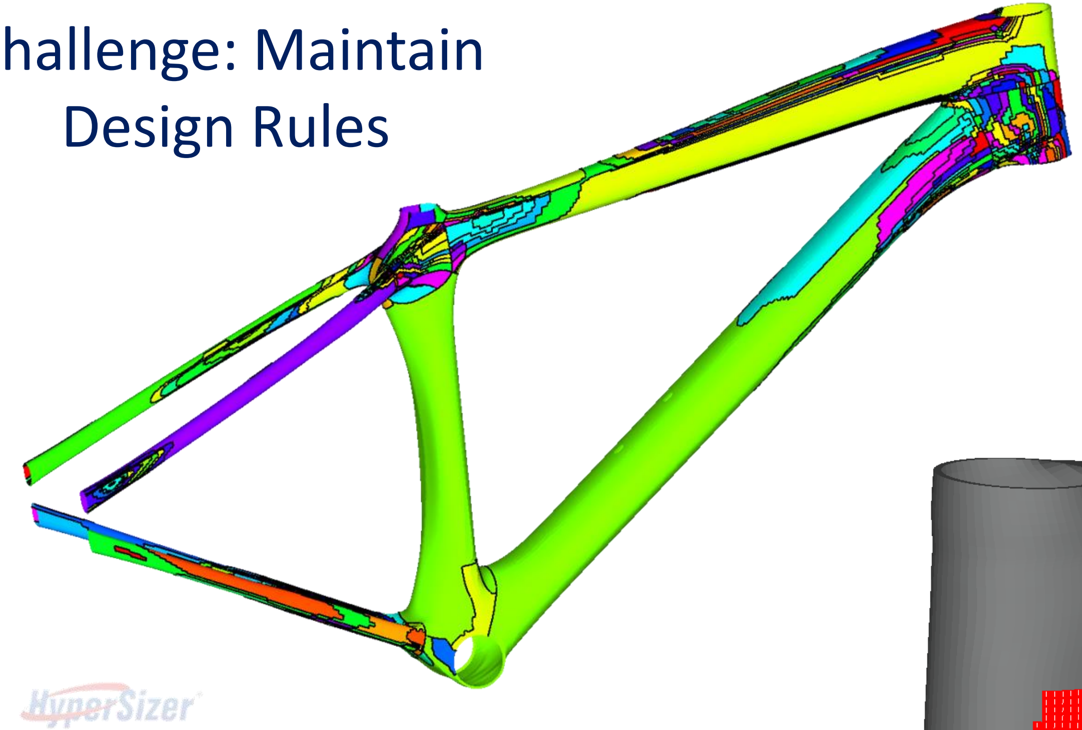


Challenge: Balance between Weight vs. Manufacturability (Ply Based)

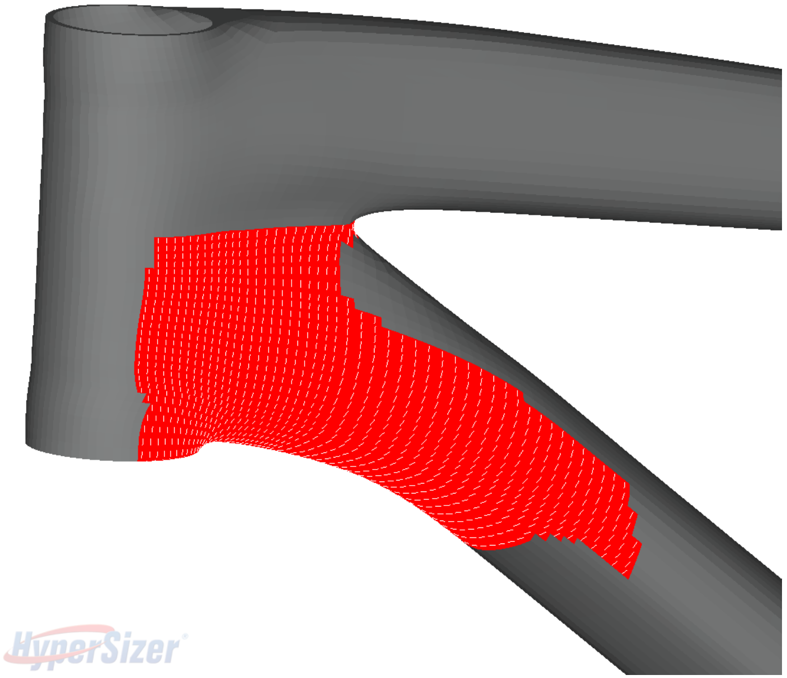
Complex/Small Plies
Low Weight



Challenge: Maintain
Design Rules



Continuous/Big Plies
Increased Weight

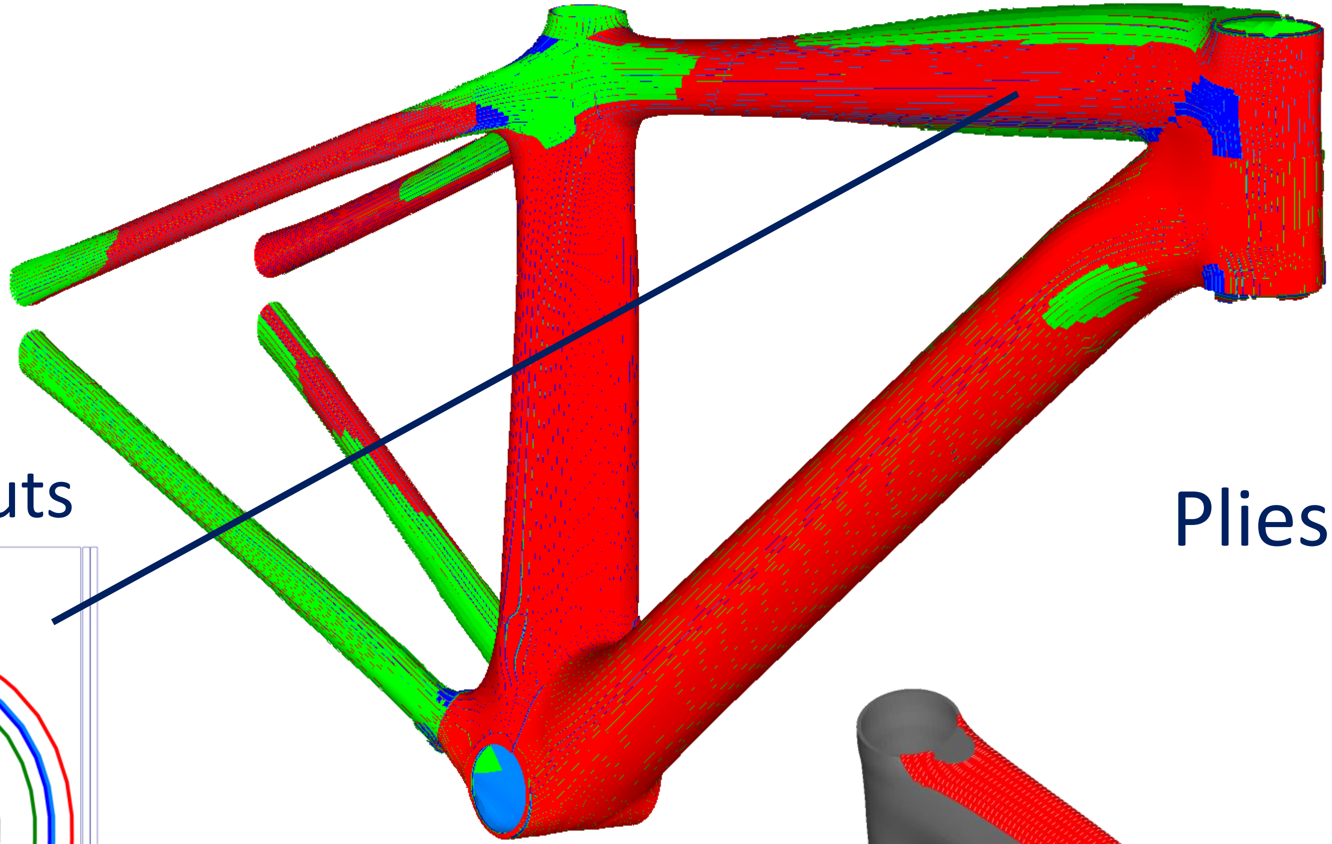


Replace or remove small plies?

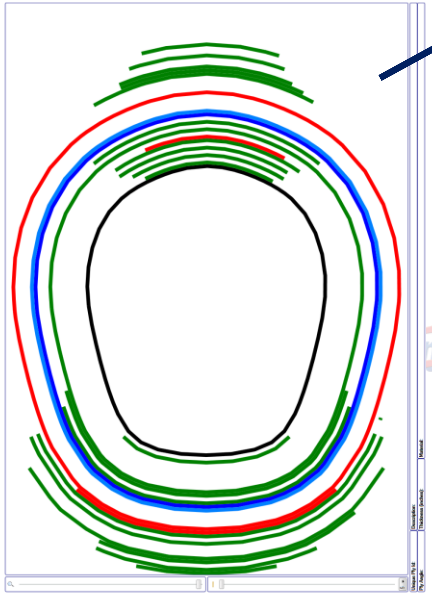
How to replace: Extend other ply?
Grow ply?
Duplicate other ply?
Patch up?

Fill in holes?
Which hole size is allowed?

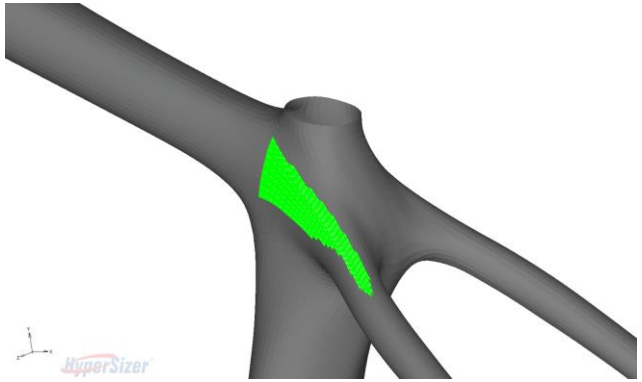
Ply Based Approach - Results

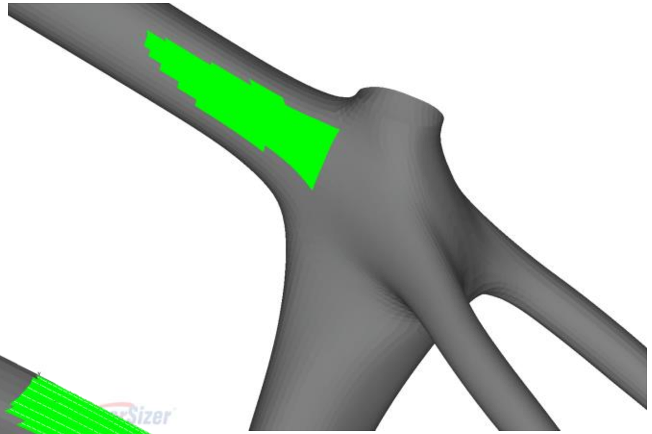


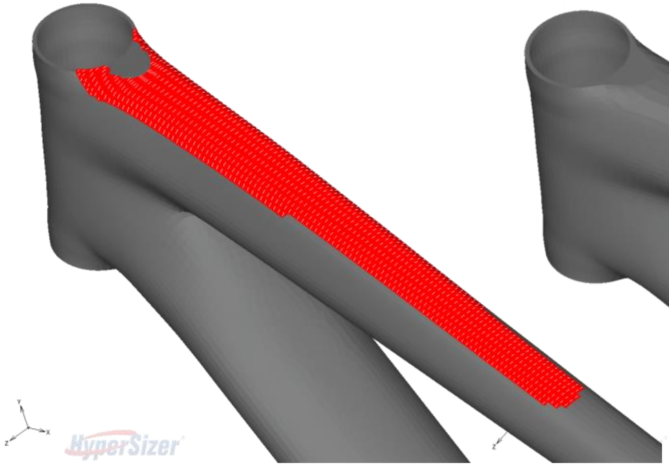
Section Cuts

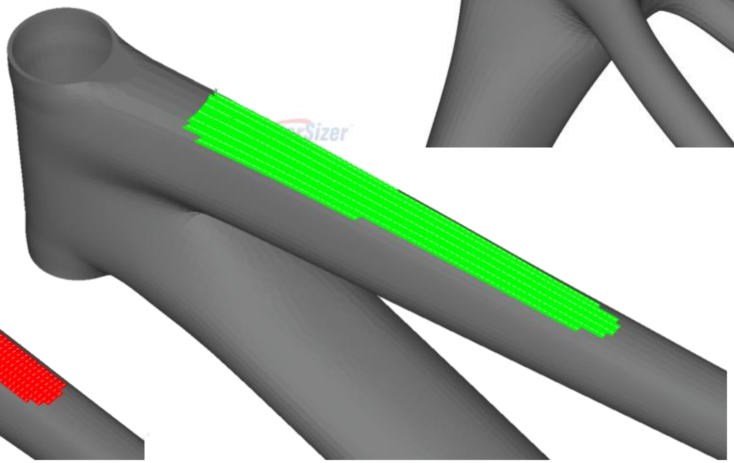


Plies





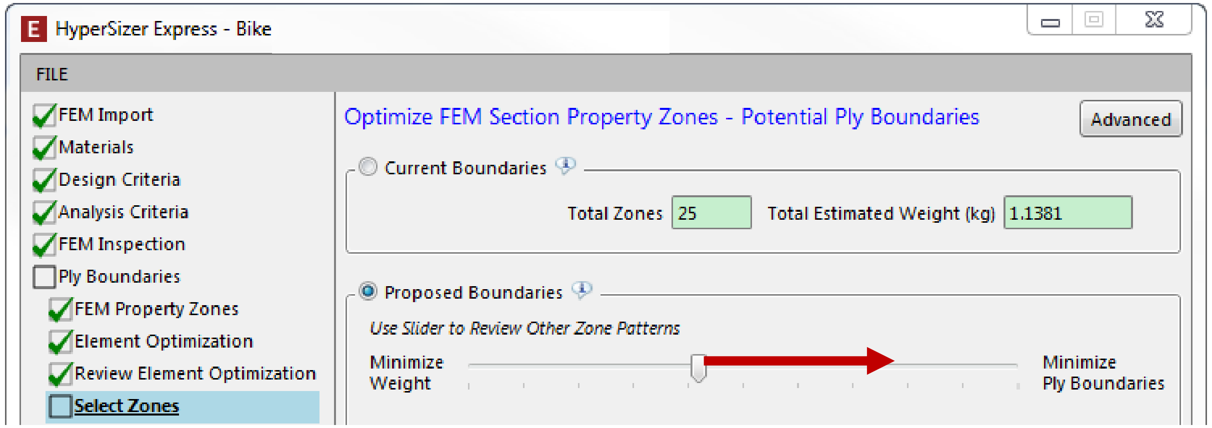




Final Mass: 0.47 kg
Time: 20 min

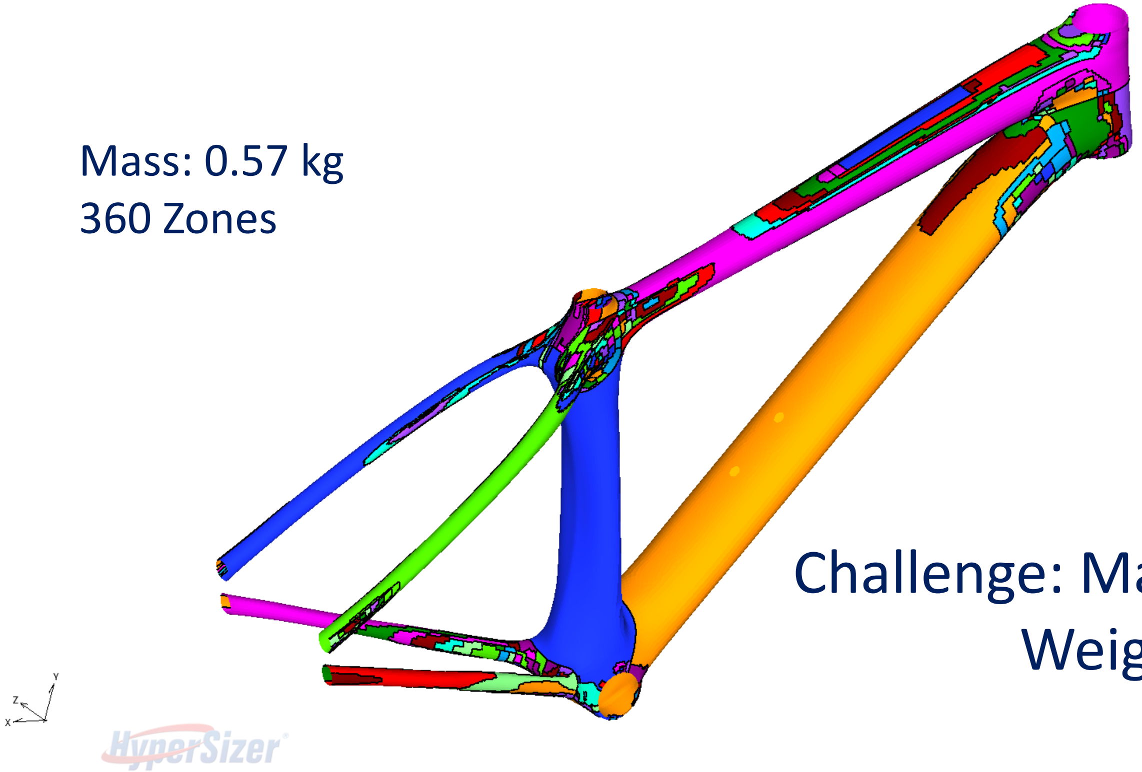
Challenge: Weight vs. Manufacturability Zone (Component) Based

Many Zones
Low Weight

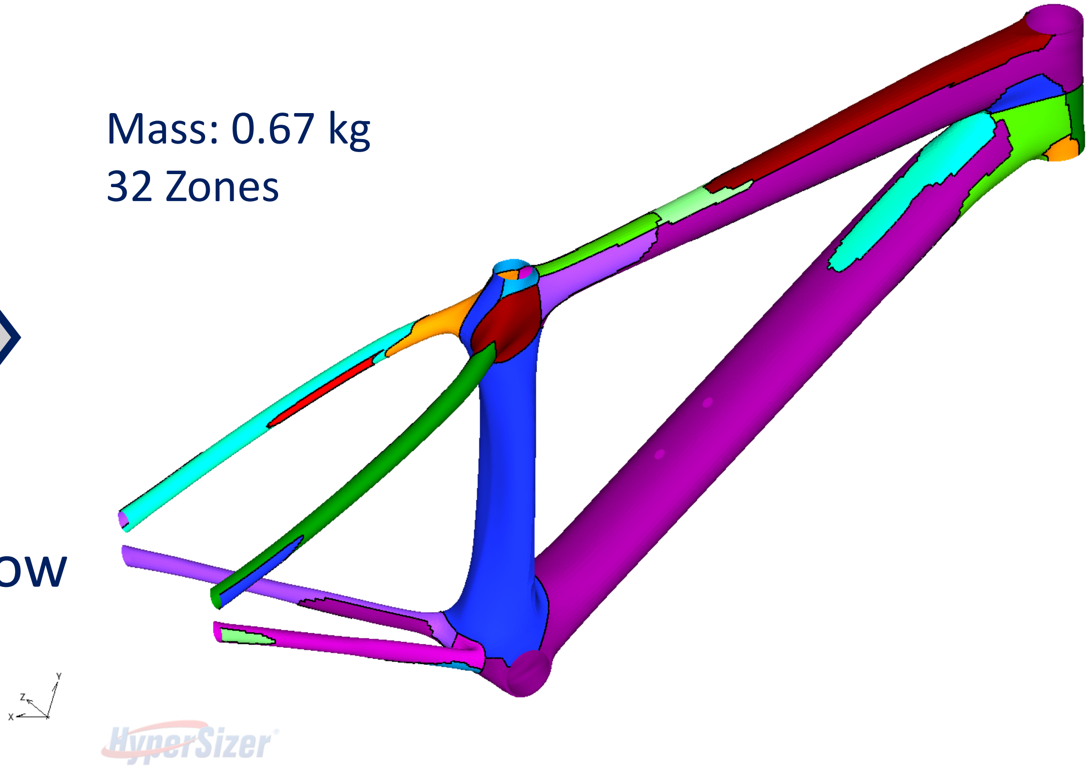


Fewer Zones
Increased Weight

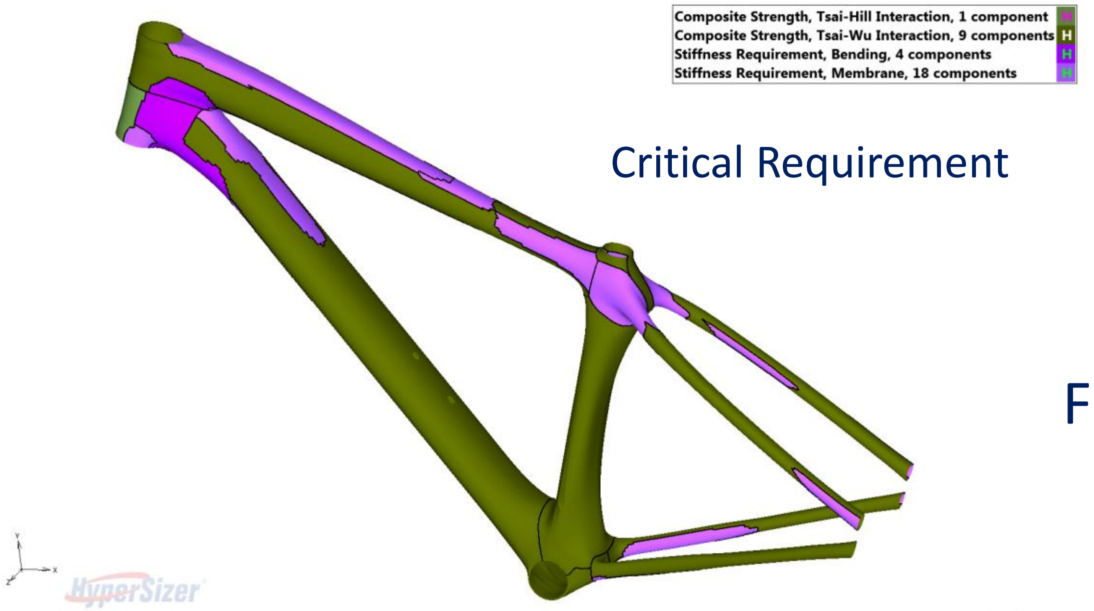
Mass: 0.57 kg
360 Zones

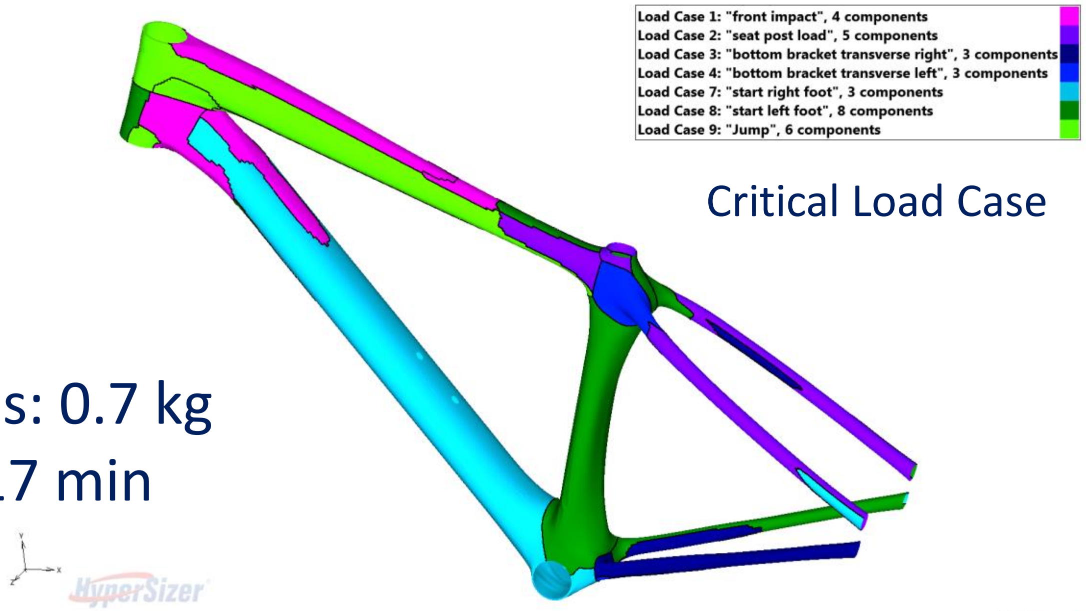


Mass: 0.67 kg
32 Zones

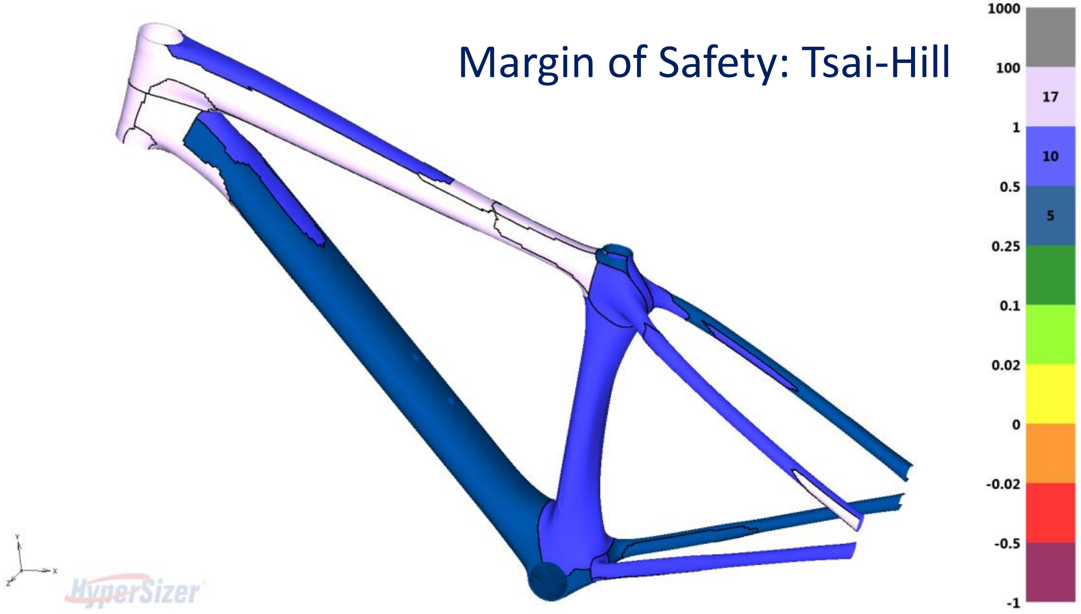


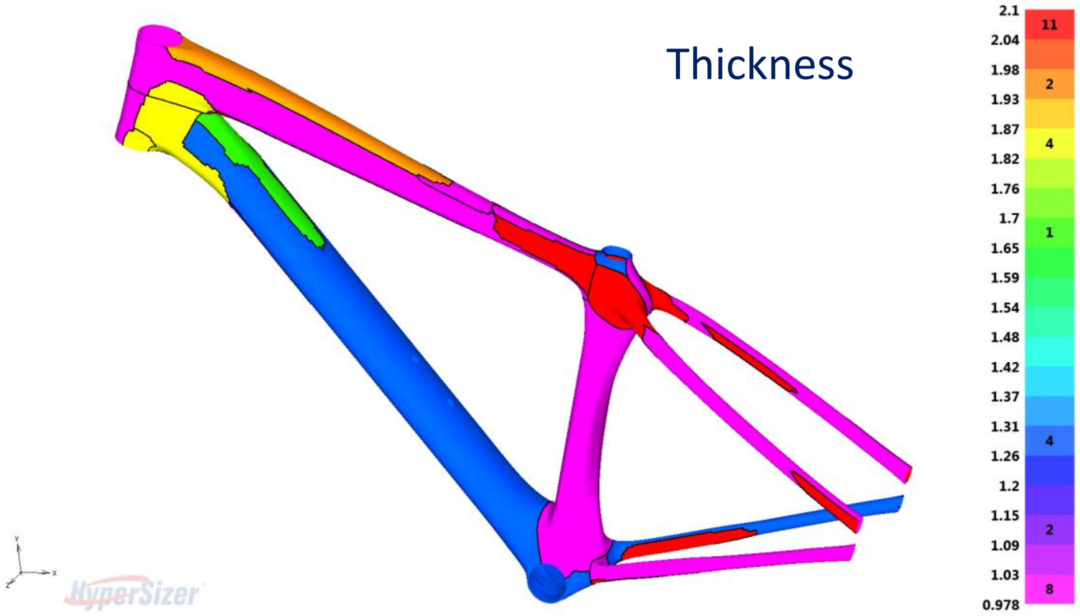
Challenge: Maintain Low Weight



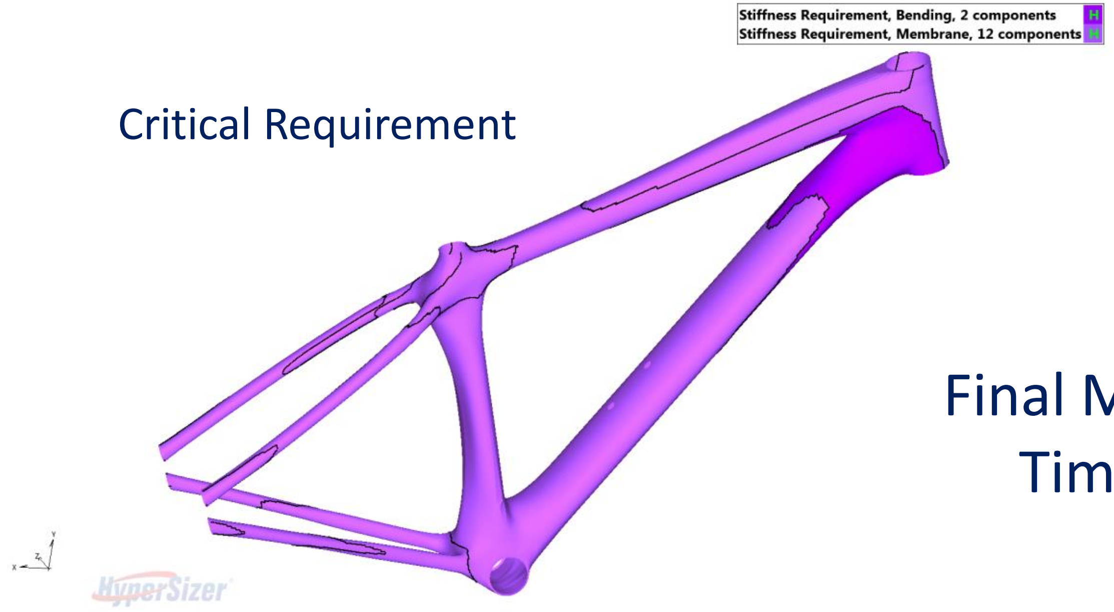


Final Mass: 0.7 kg
Time: 17 min

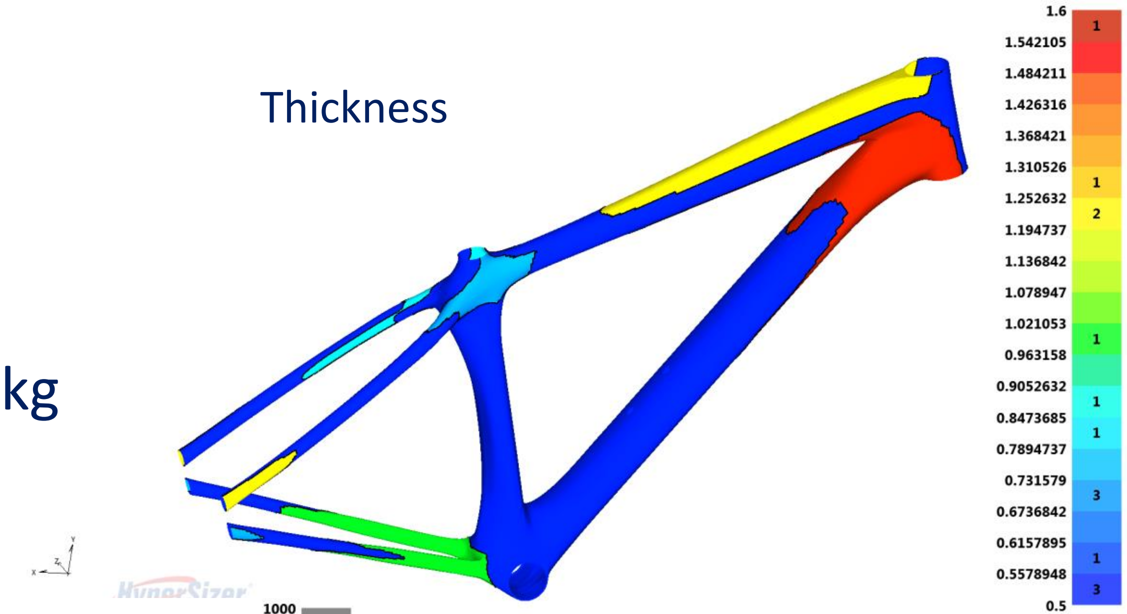




Critical Requirement

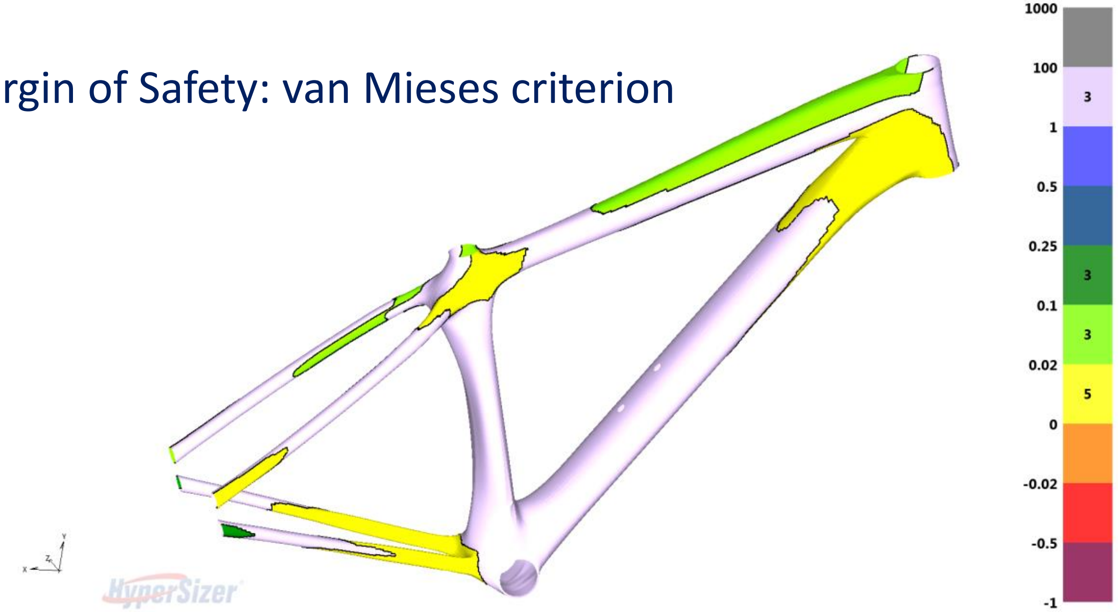


Thickness

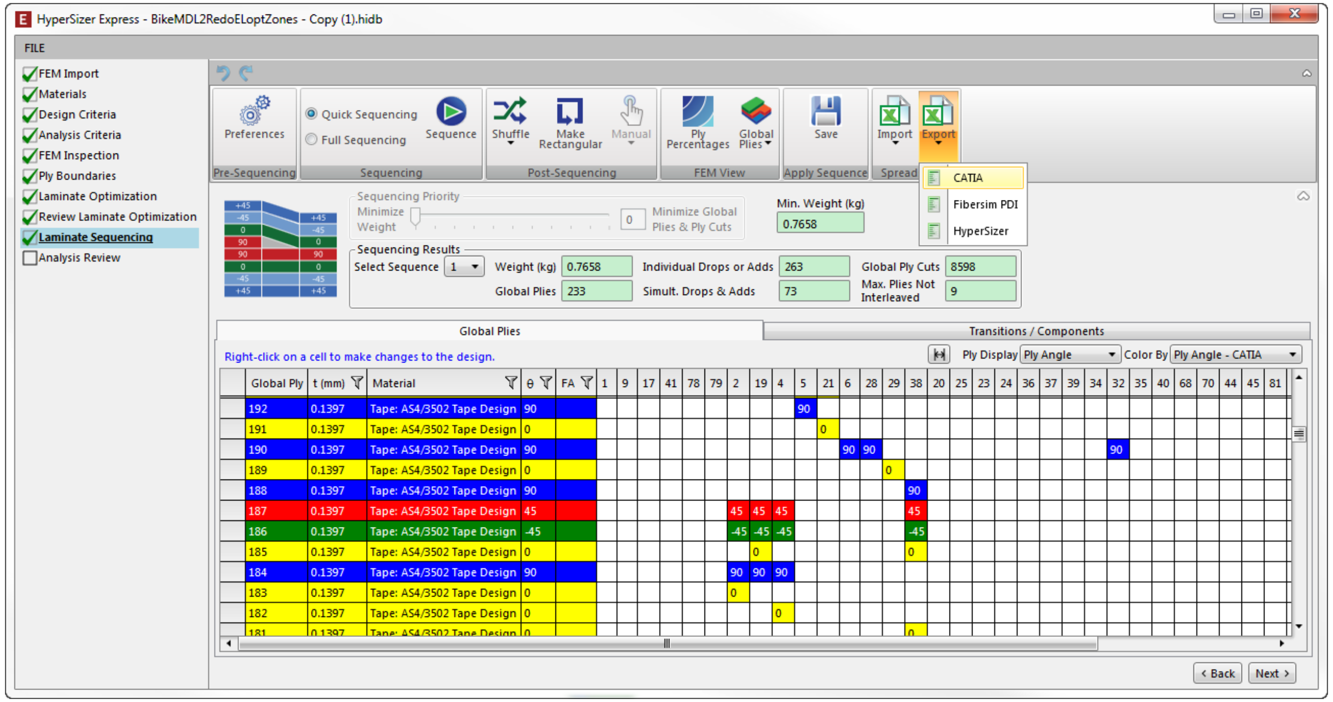


Final Mass: 0.82 kg
Time: 12 min

Margin of Safety: van Mieses criterion



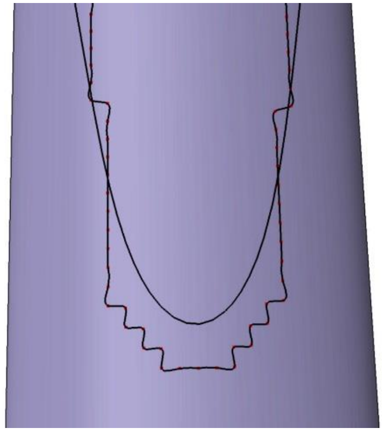
Challenge: Closing the Loop – Making Optimization Results Accessible



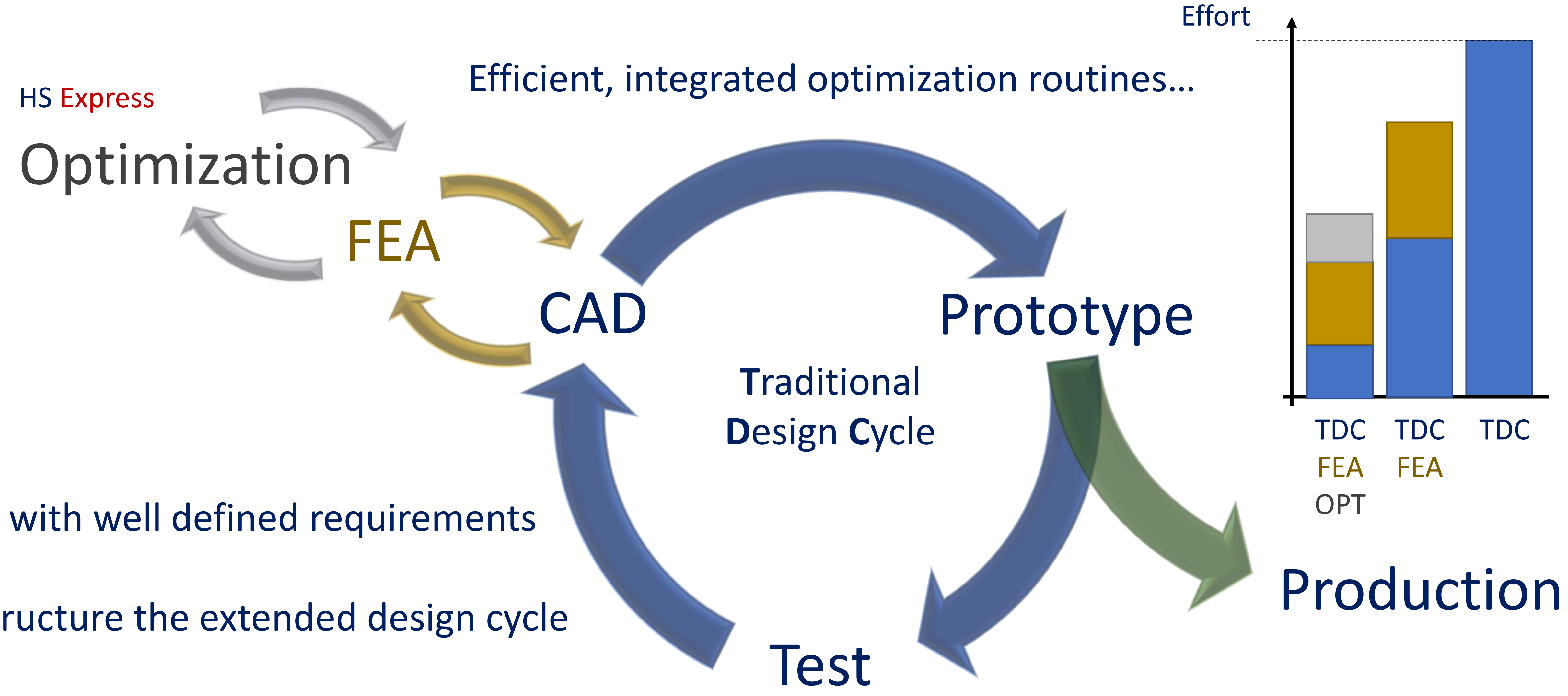
Export of the ply or zone boundaries to CAD.

Export the ply book of your optimized design, and import to CAD software.

What is the proper smoothing that best supports the user?



Efficient, integrated optimization routines…



… with well defined requirements

structure the extended design cycle

and effectively reduce the total effort!

