Simulation-Based Design

PRESENTED FOR

University of Utah
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PRESENTED BY

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Agenda

- About Us
- Motivation
- Traditional Approach
- Simulation-Based Design
- Formulation

Simulation-Based Design

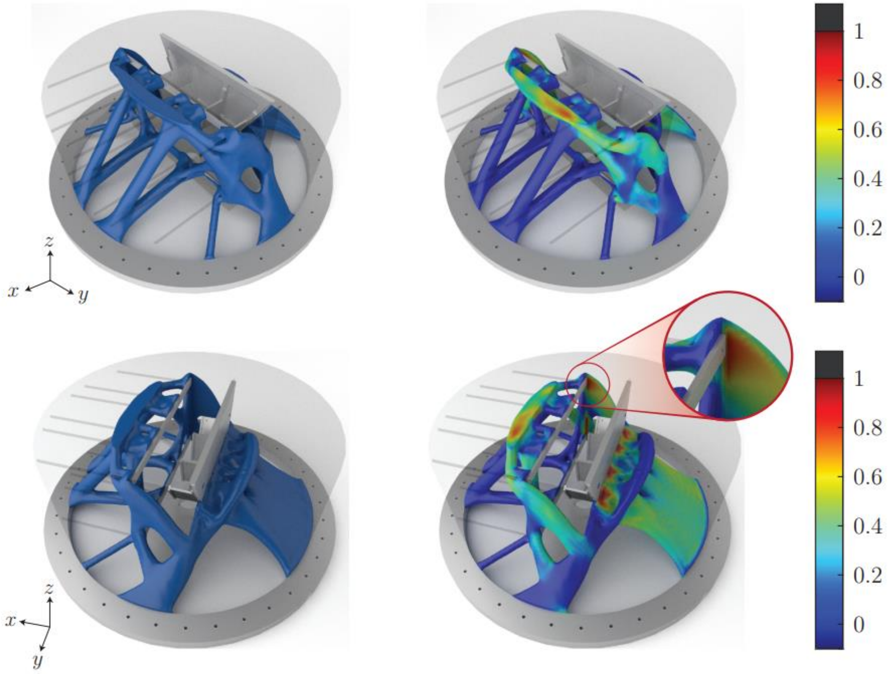
About Us

Profile

About Us: We build optimization and simulation engineering technologies to deliver real-time design solutions, with a strong focus on clean energy and defense sectors

Mission: Empower our clients to achieve engineering breakthroughs with unmatched speed and precision

Vision: Drive transformative advancements in technology through innovation and excellence in digital engineering.



Topology optimized antenna support bracket and the normalized von Mises stress. The von Mises stress is normalized with respect to the stress limit. Results show that the von Mises stress limit is satisfied at every material point.

Computing & Parallelism

- Runs in various computing environments
  - Desktop: Linux, Mac, and Windows (Experimental)
  - HPC: Linux Clusters
  - Cloud Platforms: GCP, AWS
- Exploits concurrency at multiple levels
  - Multiprocessor and multi-GPU simulations
  - Multiple simulations per response
  - Samples in a parameter study
- File management features, including
  - Work directories to partition analysis files

History

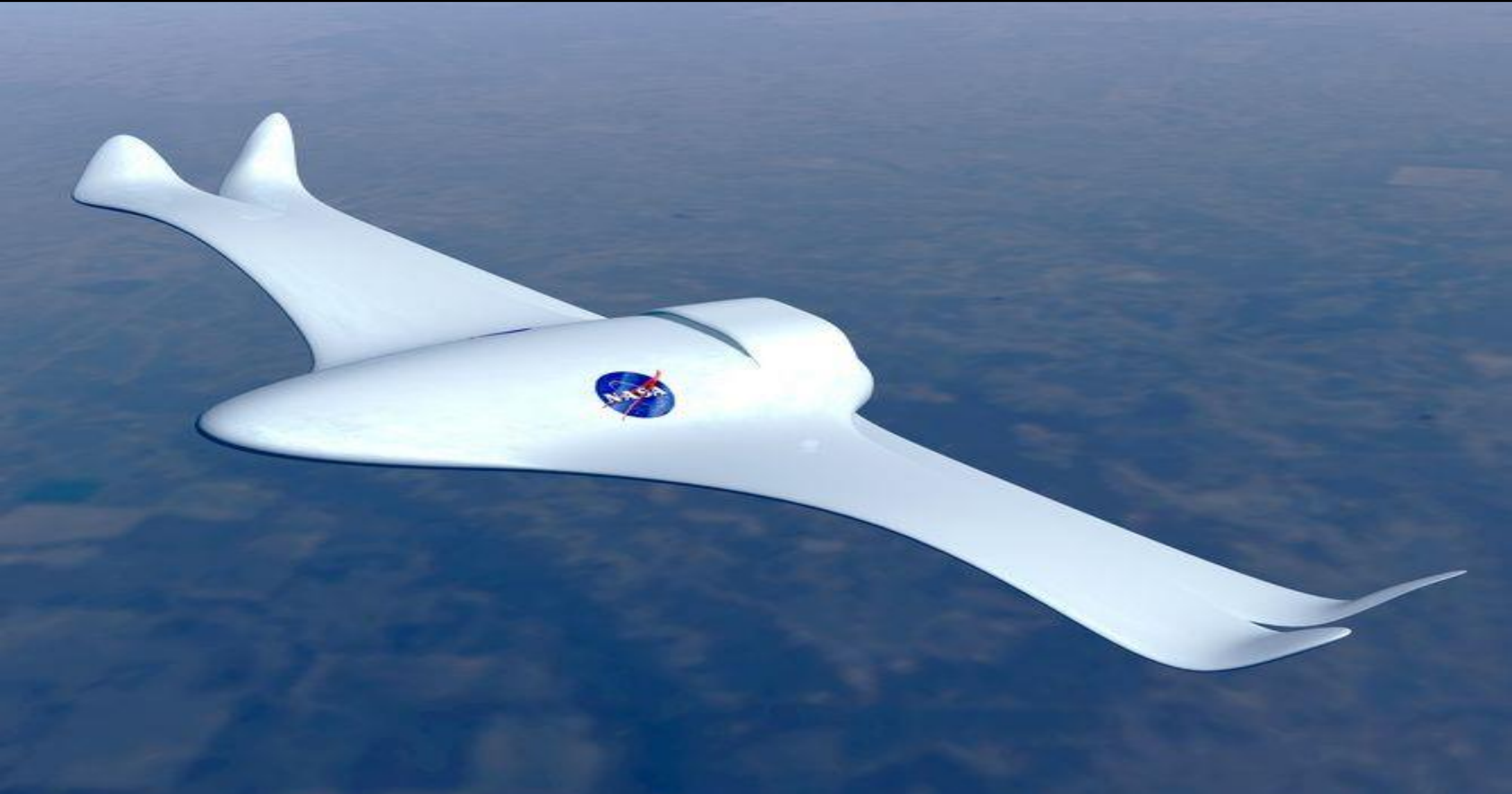
Genesis SNL Plato → DARPA TRADES → SNL DfAM LDRD → SPP SNL-AFRL → SNL NNSA → SNL ASC → Morphorm Spinoff

2015 → 2017 → 2018 → 2019 → 2021 → 2021 → 2022

- Software foundations developed at Sandia National Laboratories (SNL)
- Ongoing partnership with SNL to integrate the latest simulation-based optimization research
- New major release every March 15th and October 15th
  - New minor release every three weeks
- Partners: SNL, DOE, AFRL, JHAPL, Industry

Simulation-Based Design

Motivation



https://www.space.com/25047-morphing-is-one-way-to-make-aircraft-more-efficient-op-ed.html

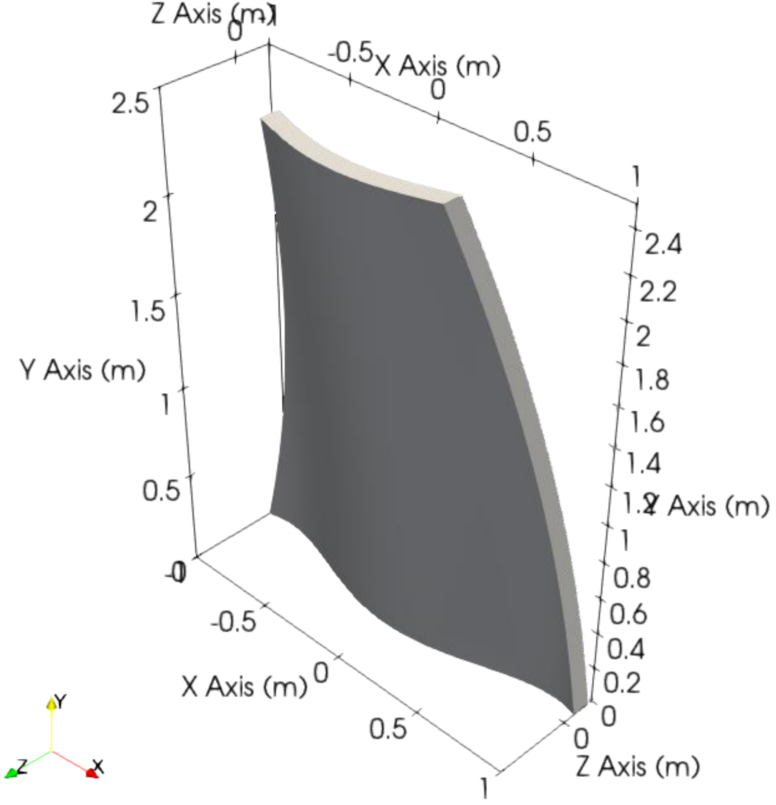
Problem Description

Design Challenge. Find a lightweight structure and actuating forces needed to match a desired deformation profile. The locations of the actuating forces are assumed known.

Material. The structure is made of an elastic material:

- Young's Modulus: 325.0 GPa
- Poisson's Ratio: 0.33

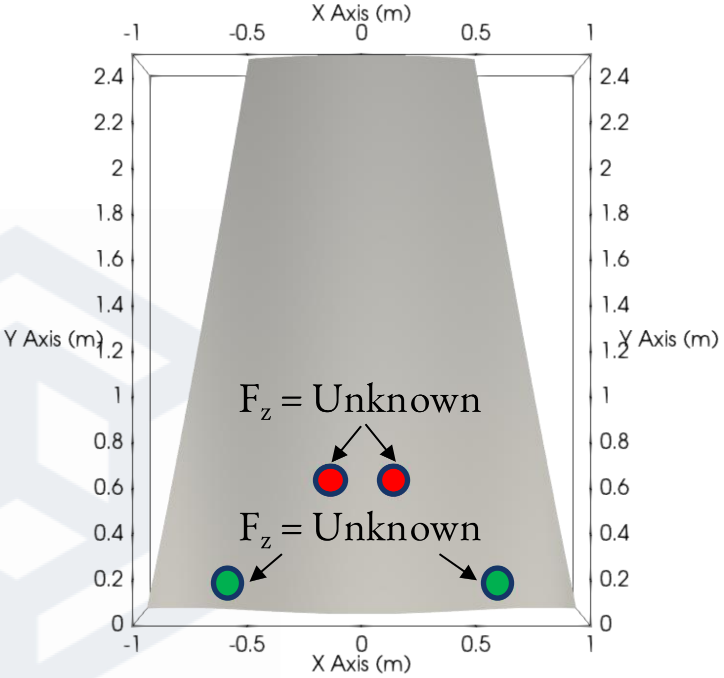
Model. The model is symmetric about the plane at X=0.0, only half of the model is considered for optimization.



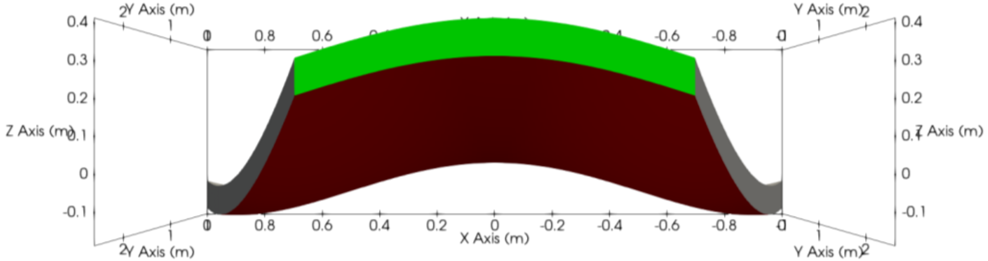
Initial design domain for the topology optimization study.

* See Example 3.2.6 in the Examples Manual for details.

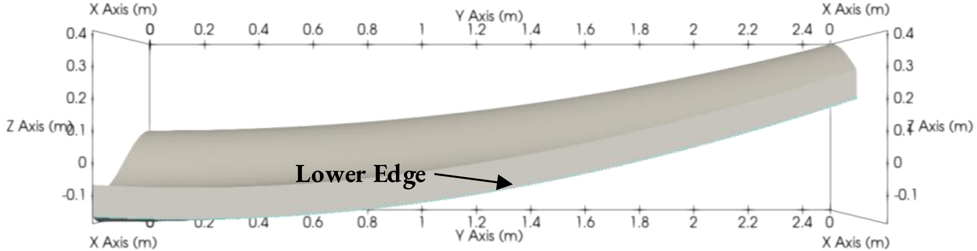
Boundary Conditions



Locations of the actuating forces on the top surface. Regions with matching colors share the same force value. The red and green regions are non-optimizable regions.

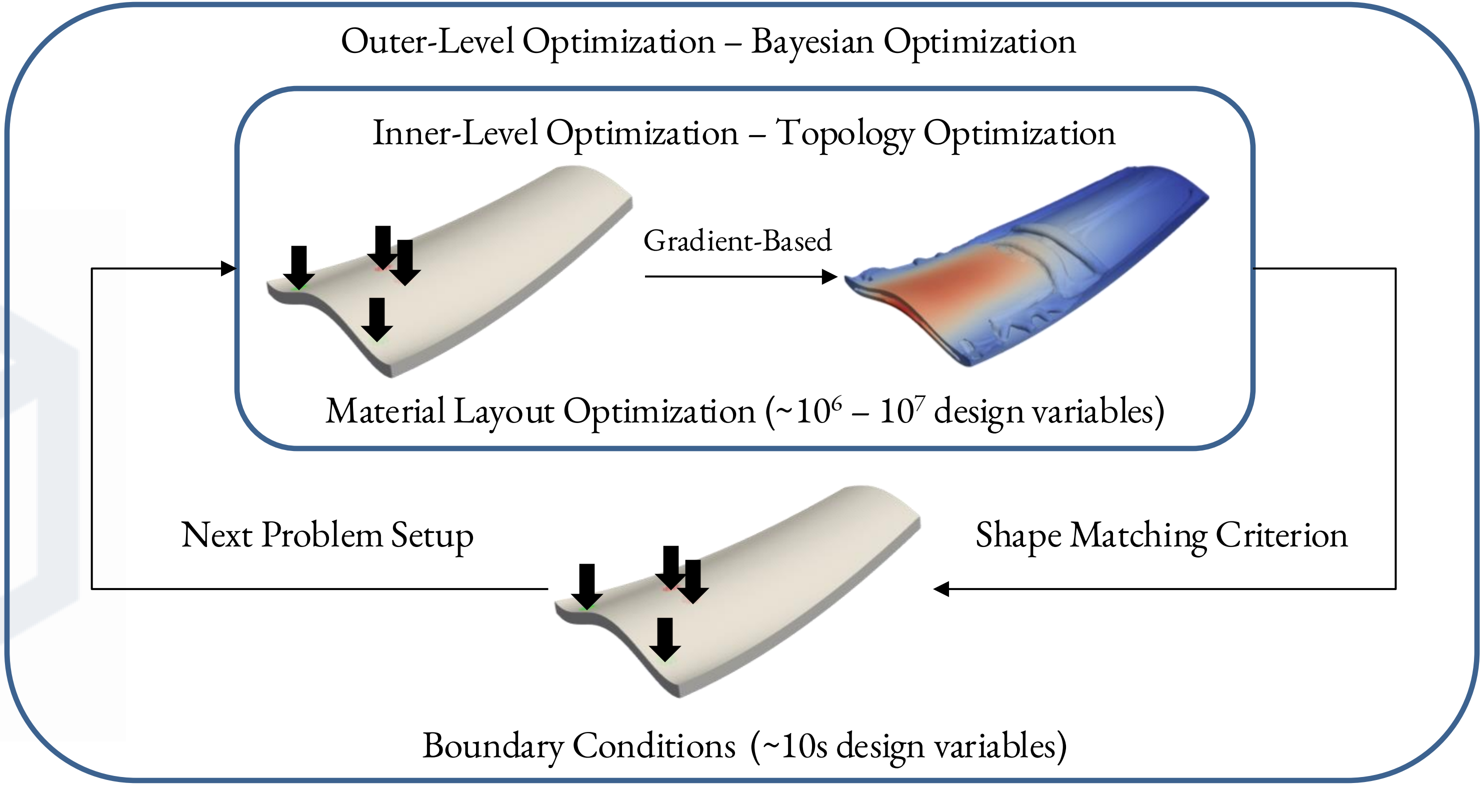


Bottom ***red surface*** *represents the target surface, i.e., deformation profile will be matched at this surface. X, Y, and Z displacements on the* ***green surface*** *are fixed. The* ***red surface*** *is a non-optimizable region.*

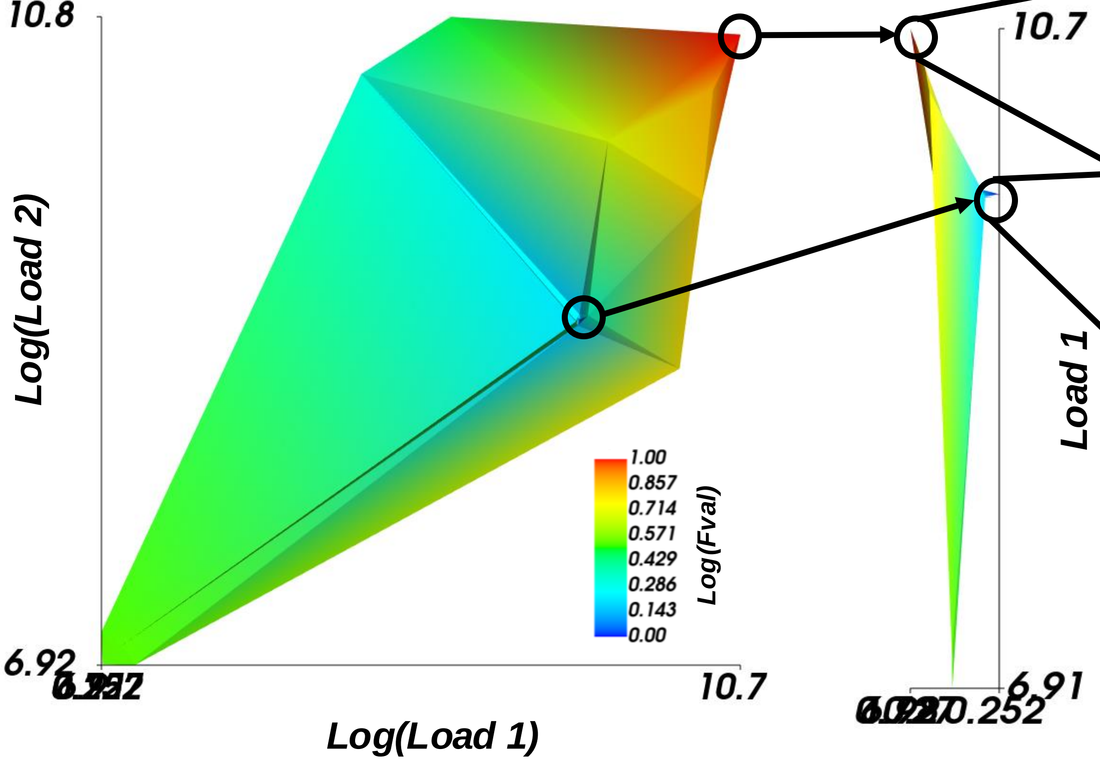


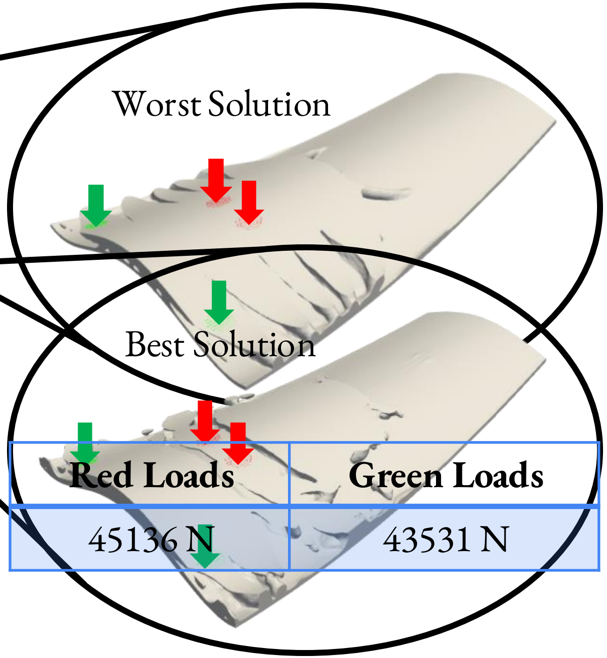
X, Y, and Z displacements along the lower edge are fixed.

Algorithm


Outer-Level Optimization – Bayesian Optimization
Inner-Level Optimization – Topology Optimization
Gradient-Based
Material Layout Optimization (~10^6 – 10^7 design variables)
Next Problem Setup
Shape Matching Criterion
Boundary Conditions (~10s design variables)

Design Surface



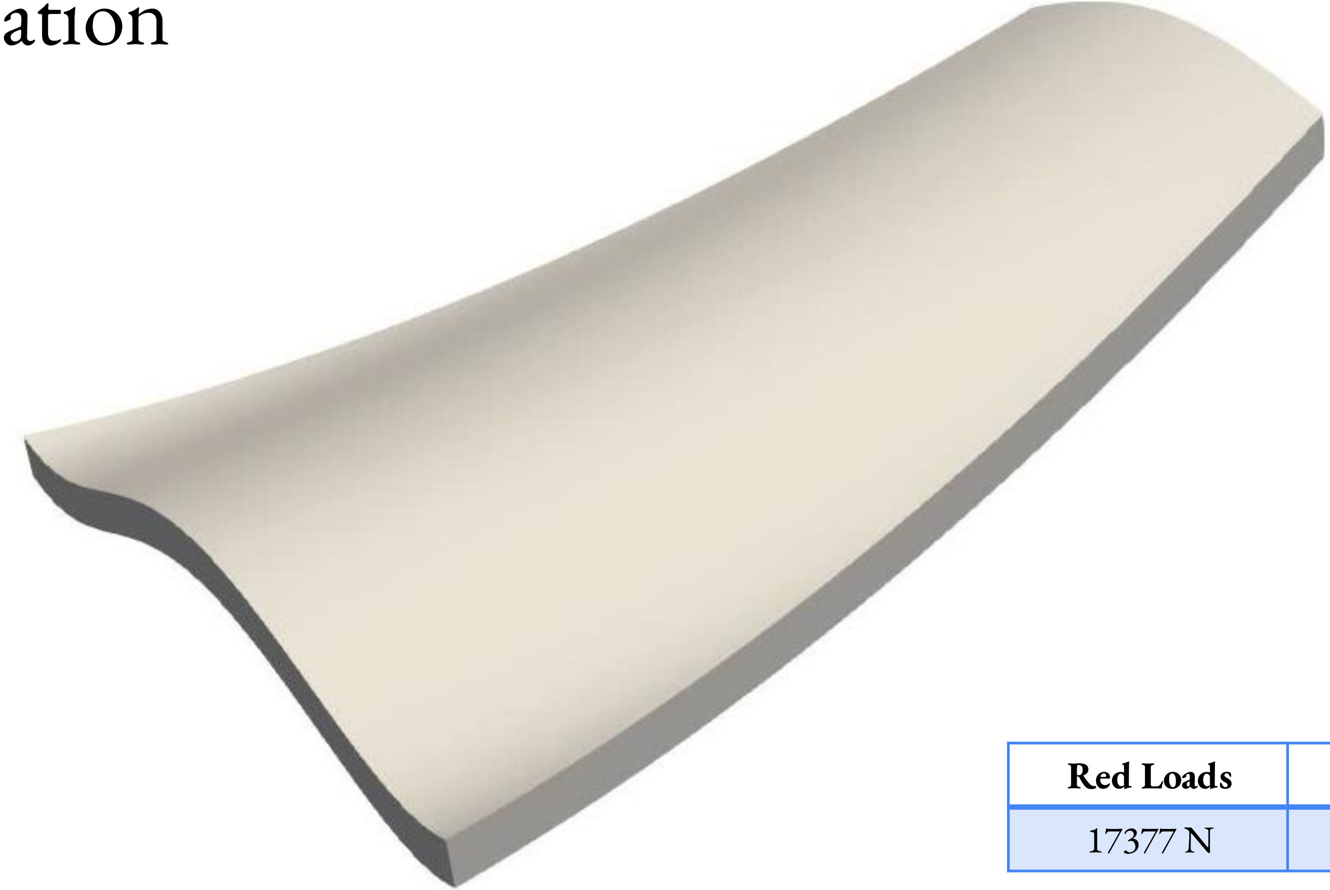


Red Loads	Green Loads
45136 N	43531 N

Red Loads	Green Loads
17377 N	7921 N

Note. The initial optimization study produced 35 design candidates.

Animation



Red Loads	Green Loads
17377 N	7921 N

Simulation-Based Design

Traditional Approach

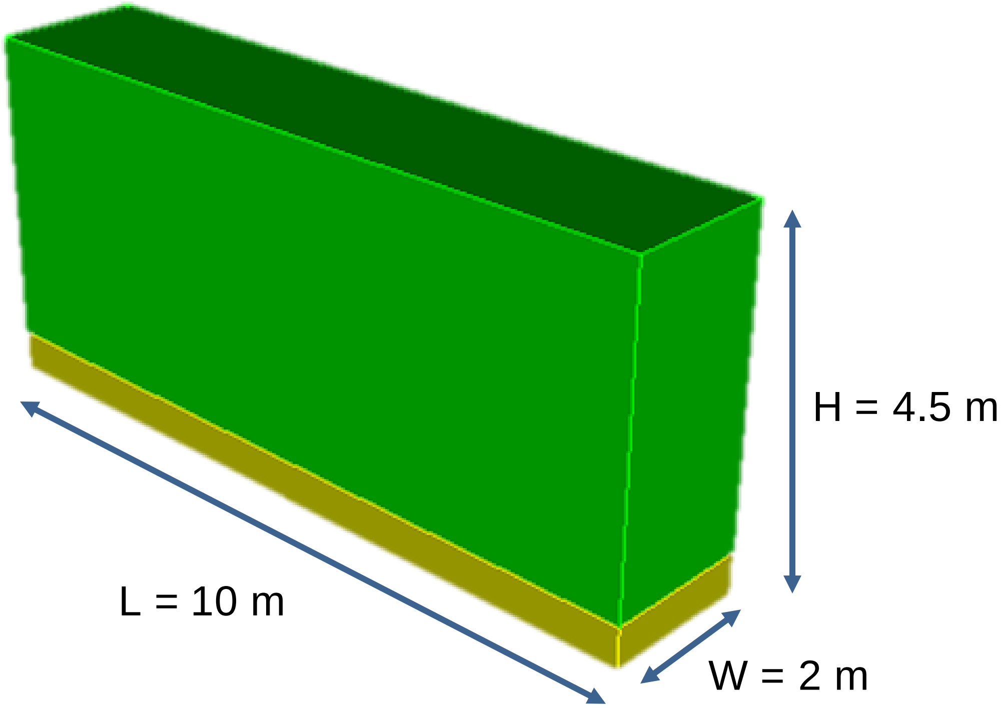
Structural Engineering

Design Challenge. Find a lightweight structure capable of withstanding the expected loading profile.

Material. The structure is made of an elastic material:

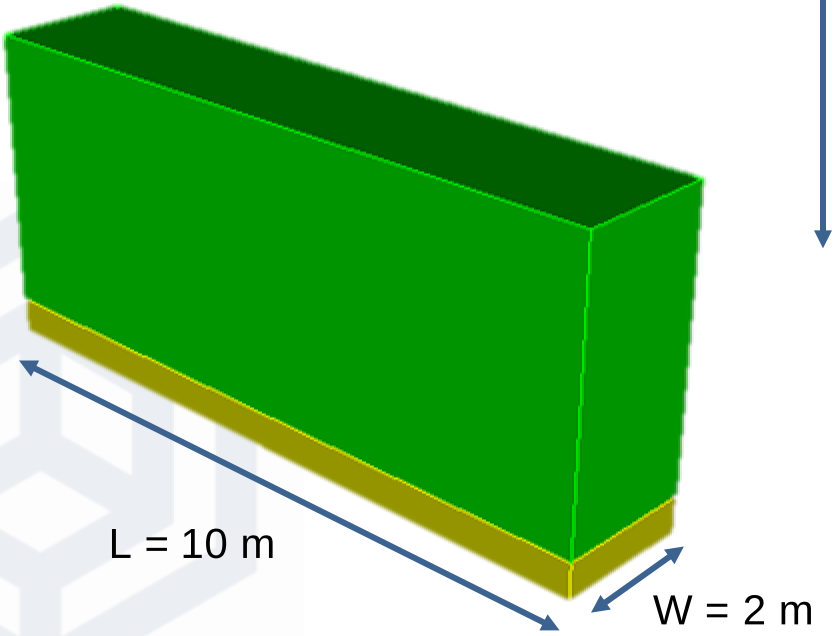
- Young's Modulus: 200.0 GPa
- Poisson's Ratio: 0.3

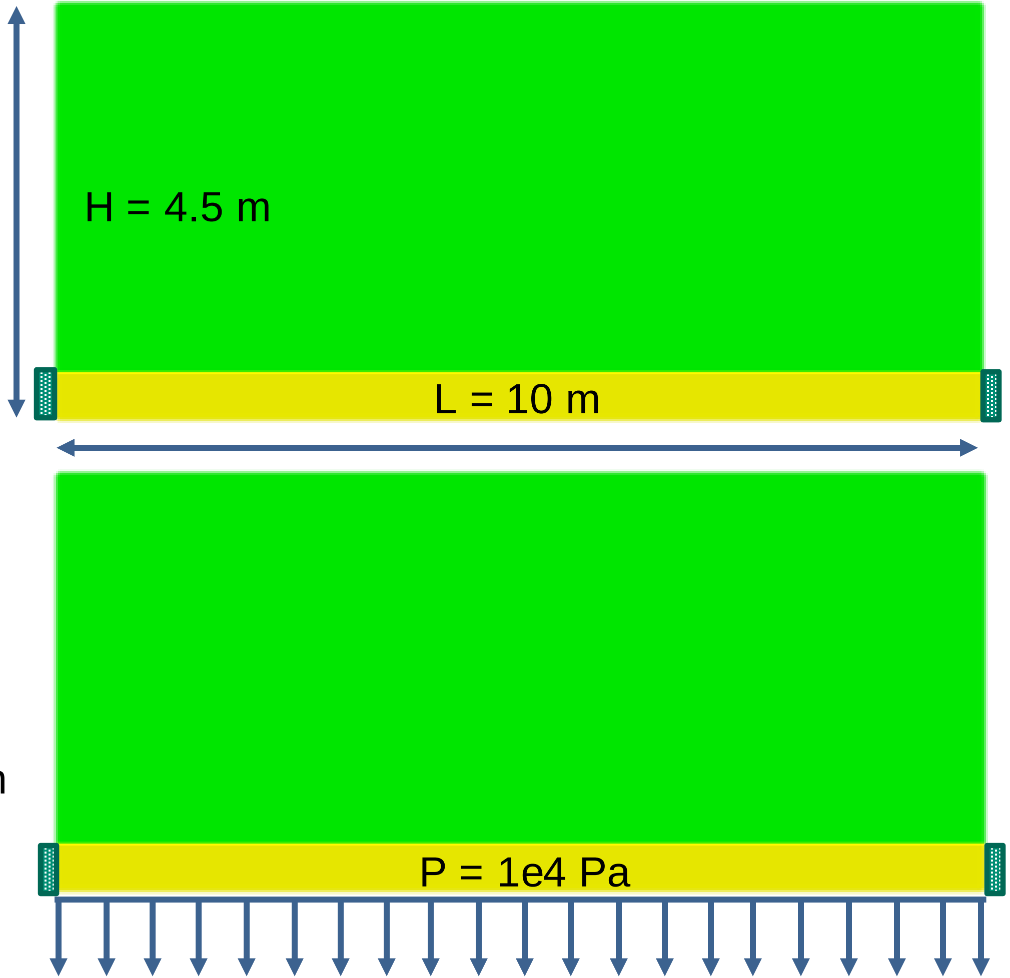
Desired Outcome. Reduce cost



Allowable design space for the topology optimization study.

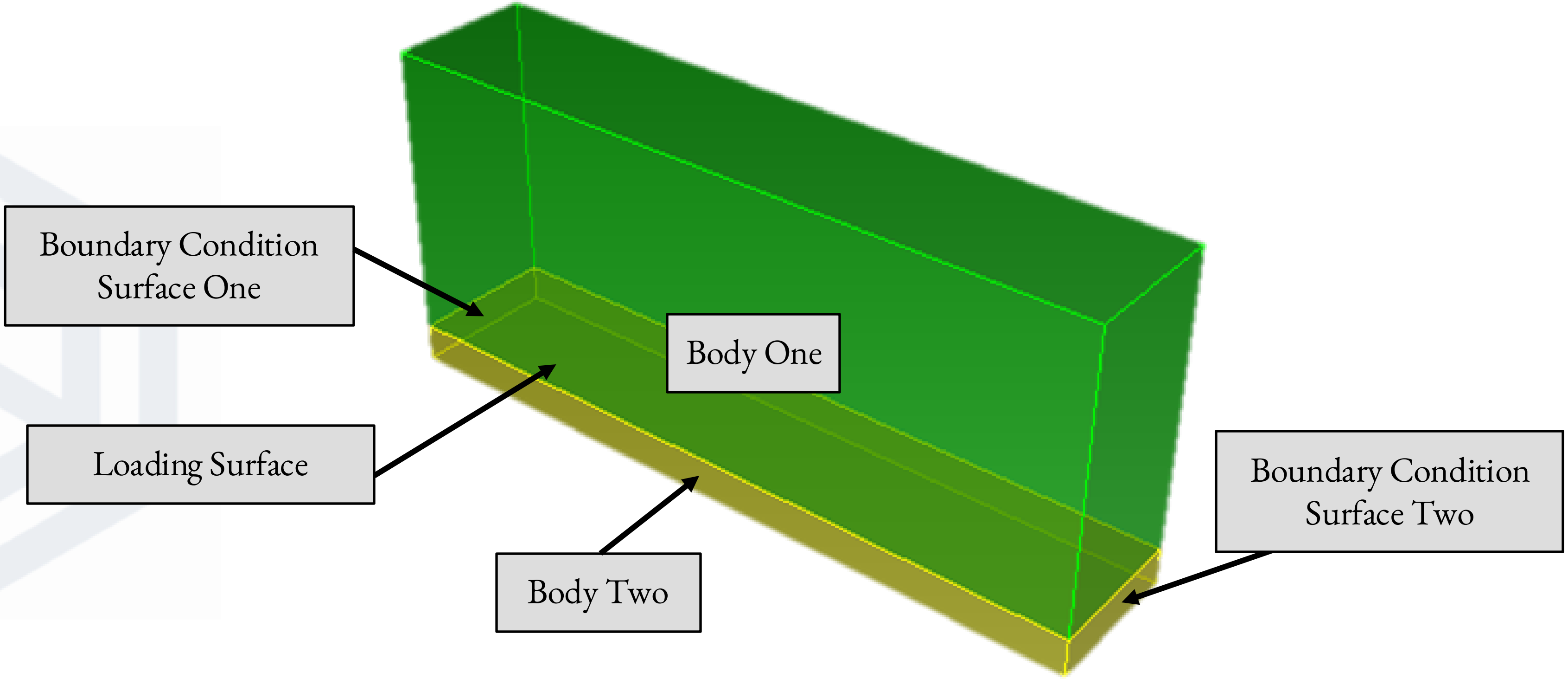
Boundary Conditions





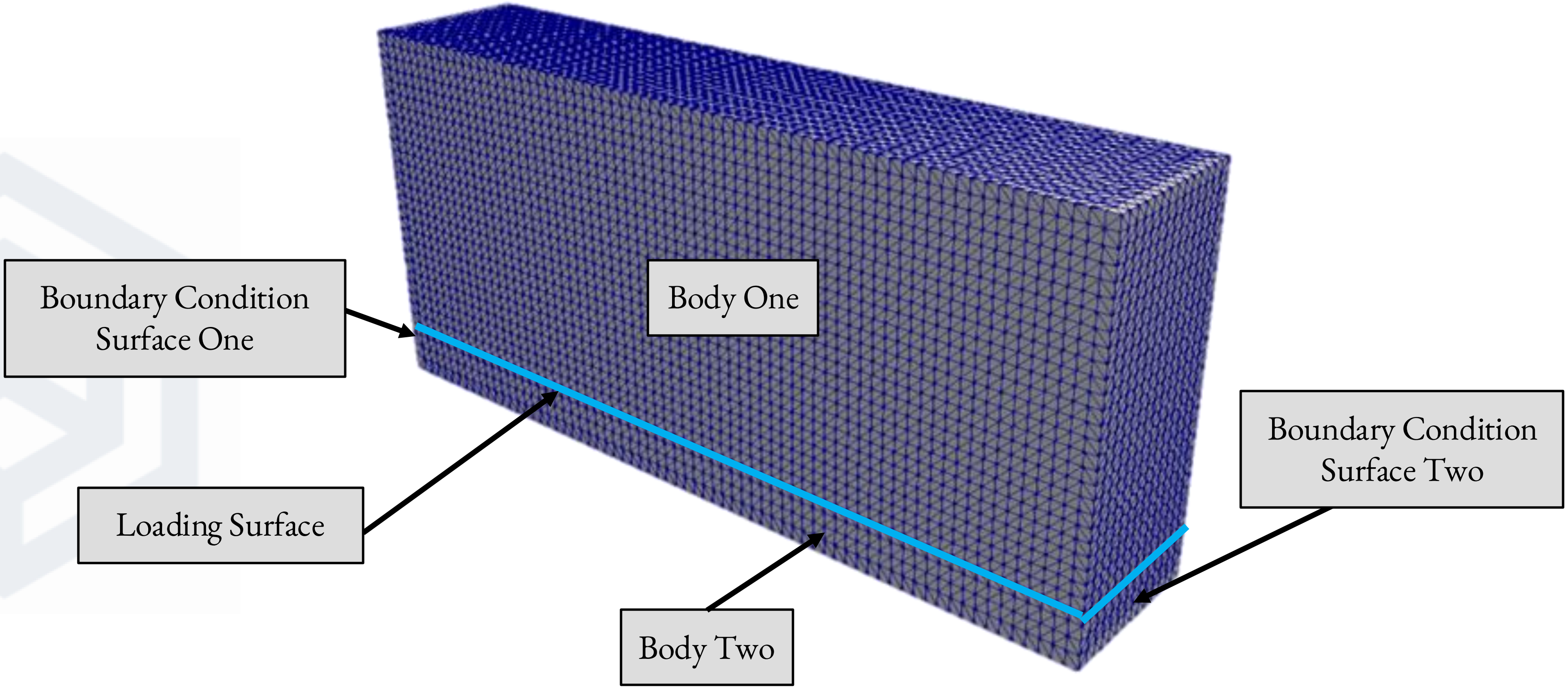
Workflow

Step 1: Build Geometry



Workflow

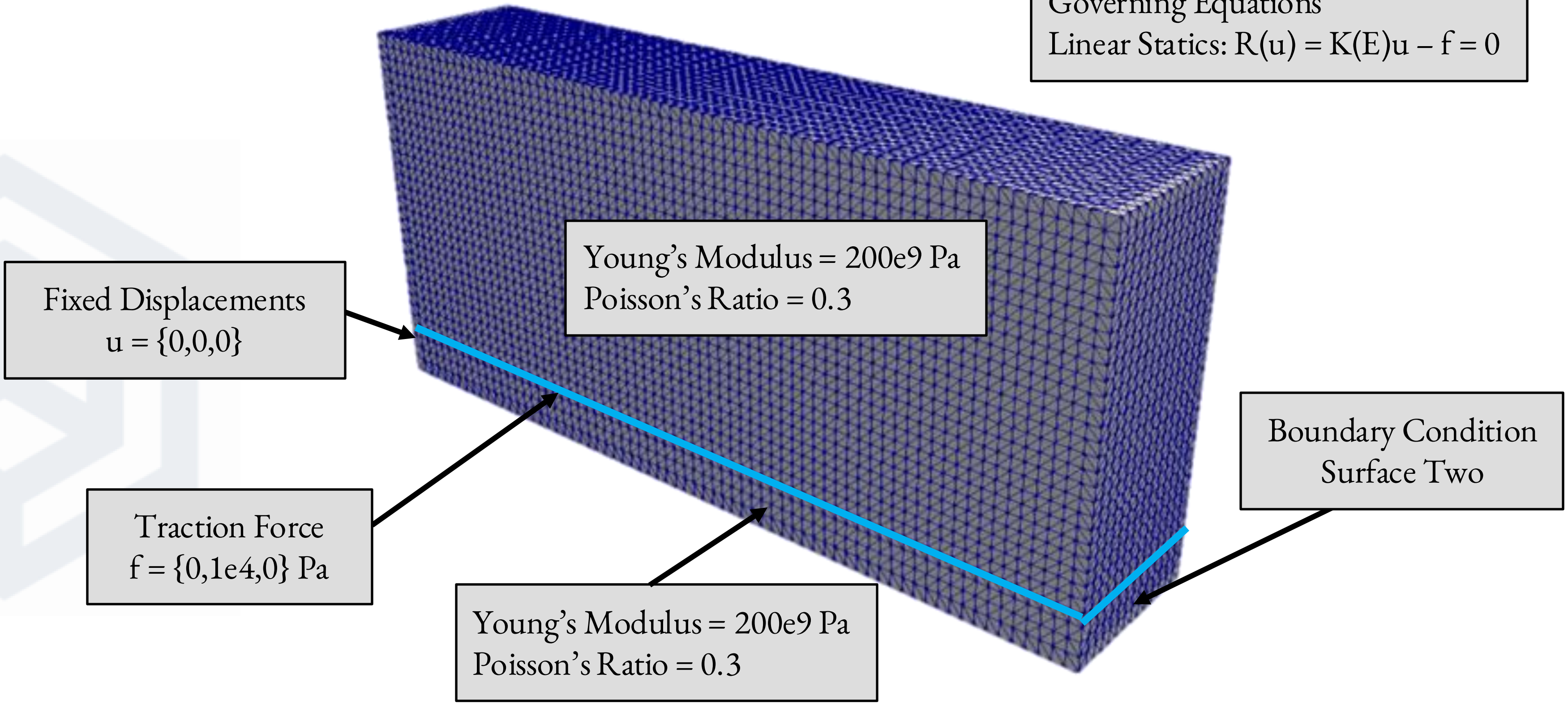
Step 2: Build Mesh



Workflow

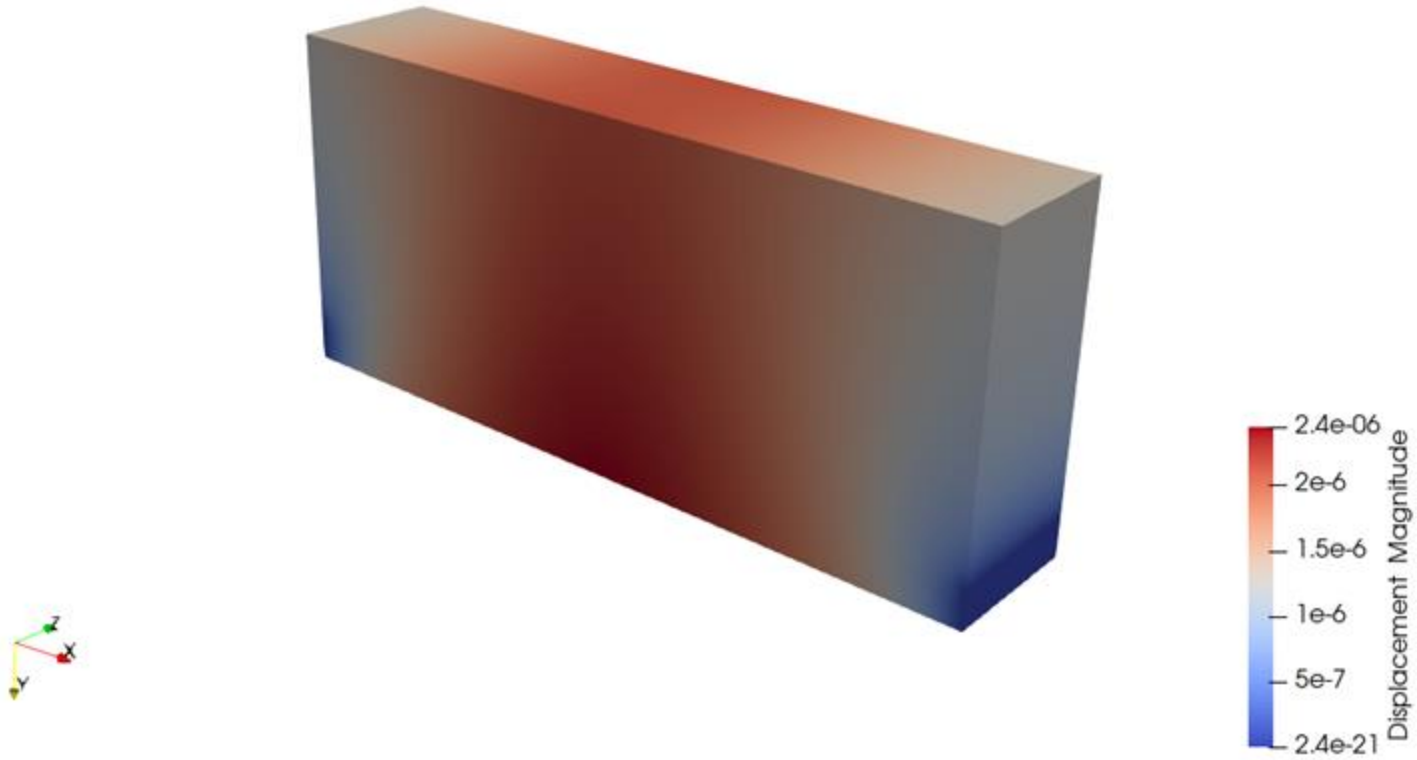
Step 3: Simulation Setup

Governing Equations
Linear Statics: R(u) = K(E)u – f = 0



Workflow

Step 4: Run Simulation



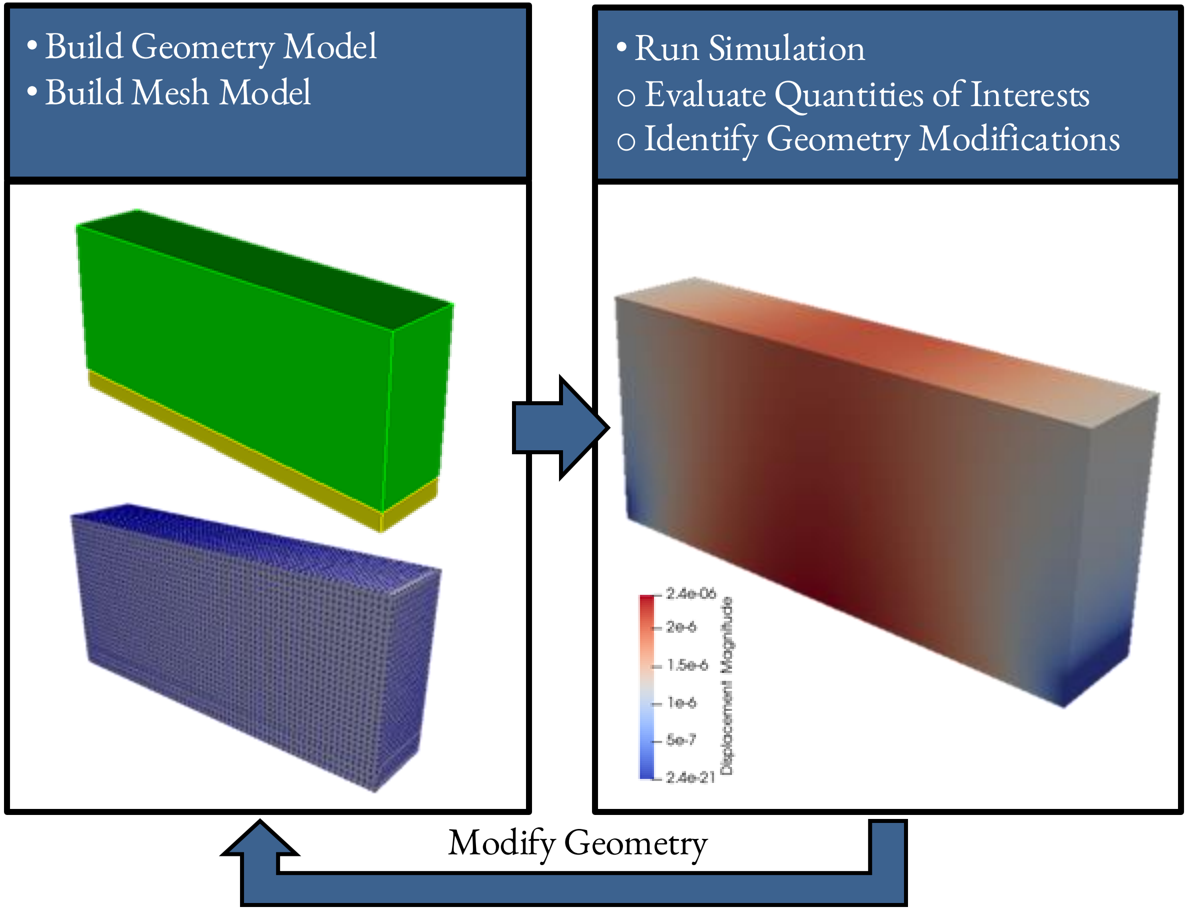
Workflow

Step 5: Iterate

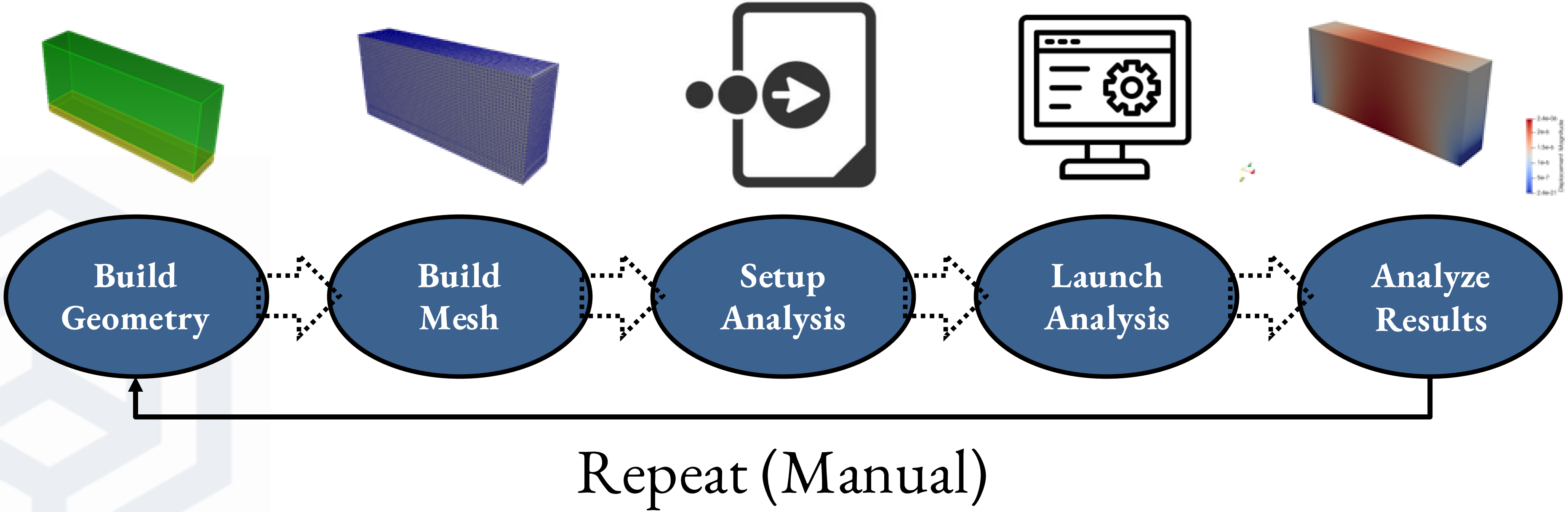
Manually modify the geometry based on the simulation results

Re-generate mesh and re-launch simulation to analyze new geometry

Analyze results and modify geometry if necessary



Summary

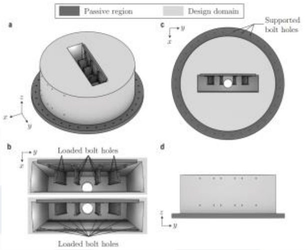


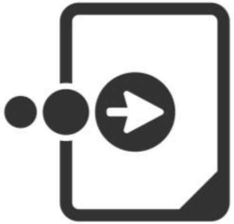
Can we accelerate the design process?

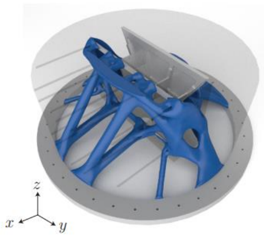
Simulation-Based Design

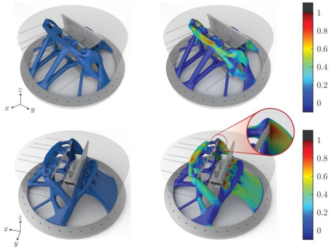
Automation

Workflow







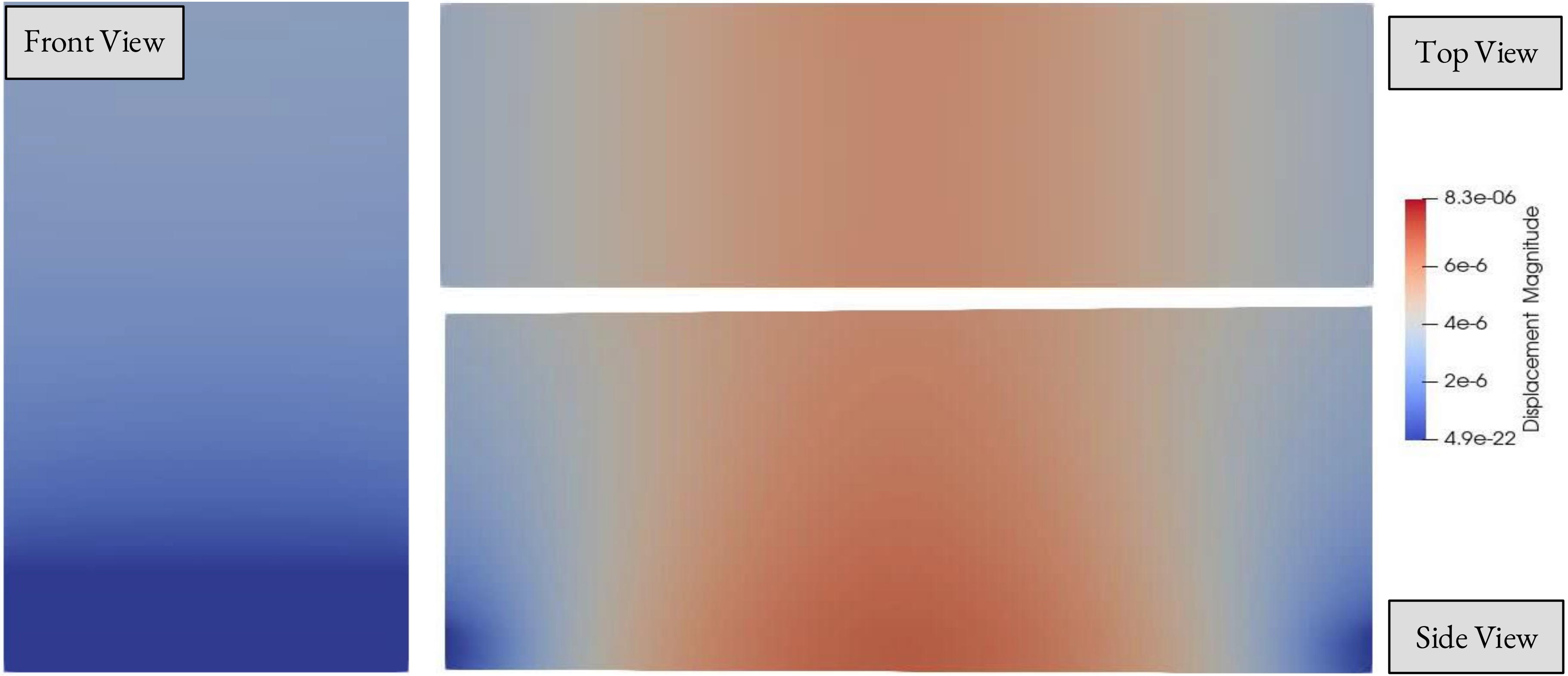


Initial Geometry → **Setup Analysis** → **Launch Analysis** → **Modify Geometry** → **Design Options**

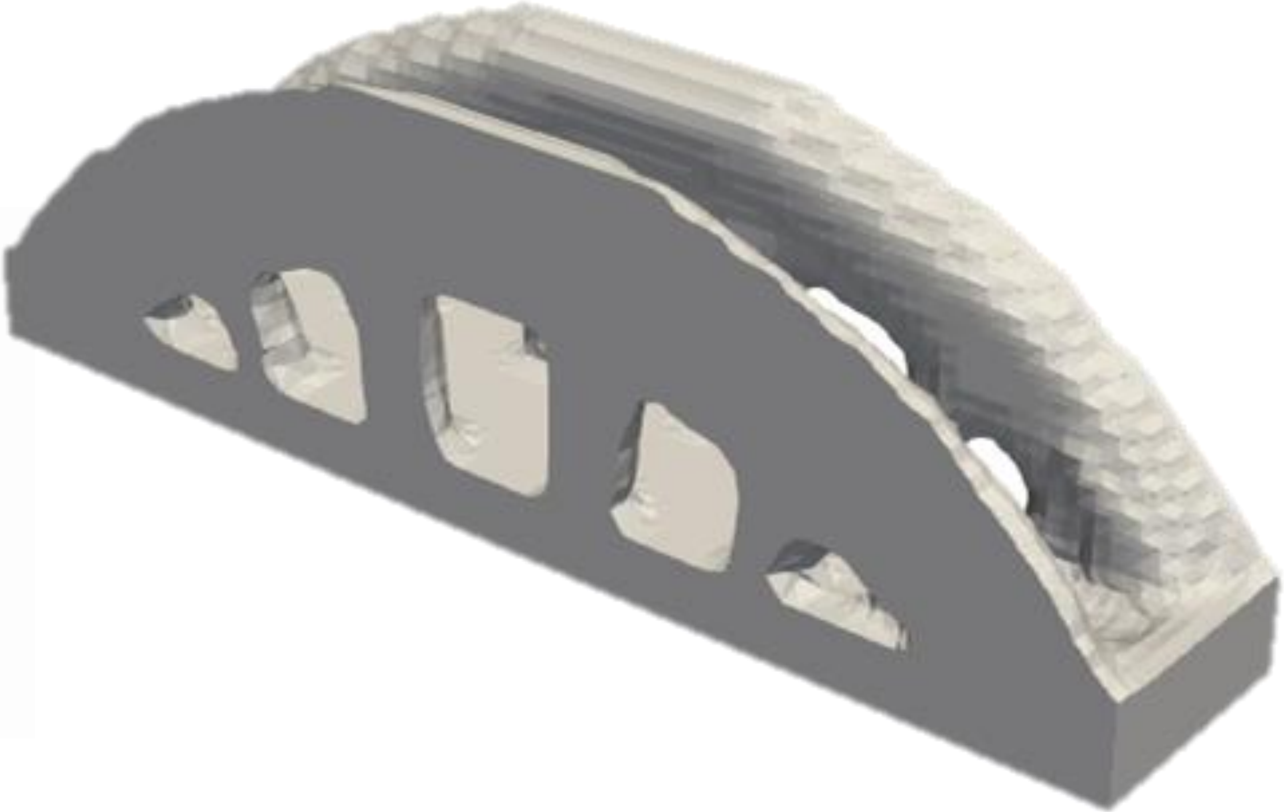
Computer-Driven Engineering

Animation

Computer-Guided Engineering



Optimized Structure



Tied Arch Bridge

https://www.ib-miebach.de

Tied Arch Bridge

https://en.wikipedia.org

Simulation-Based Design

Formulation

Problem Formulation

Find a structural design that *maximizes* structural rigidity and *meets* the mass budget requirement.

Optimization Problem Statement

$$\text{Design}^* = \arg \underset{\text{Design}}{\text{maximize}}\ \text{Structural Stiffness}$$

subject to

$$\text{Governing Equations Are Satisfied}$$

$$\text{Structural Mass - Mass Requirement} \leq 0$$

Problem Formulation

Find a structural design that *maximizes* structural rigidity and *meets* the mass budget requirement.

Optimization Problem Statement

$$\text{Design}^* = \arg \underset{\text{Design}}{\text{minimize}} \; \frac{1}{2}\mathbf{u}^{\mathbf{T}}(\text{Design})\mathbf{f}$$

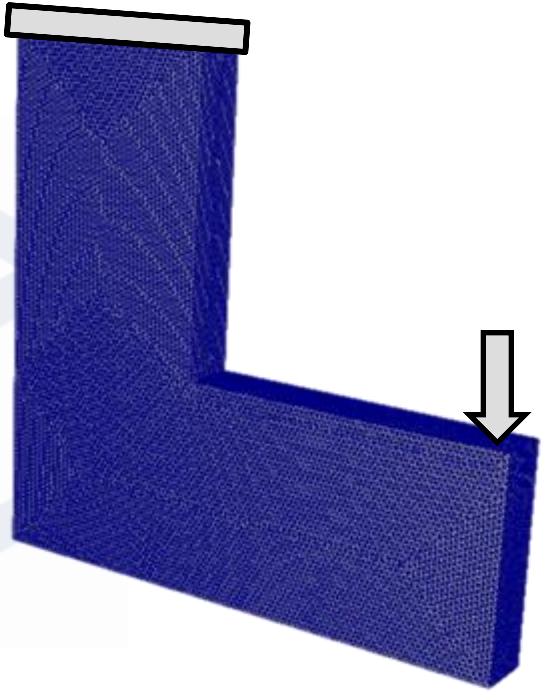
subject to

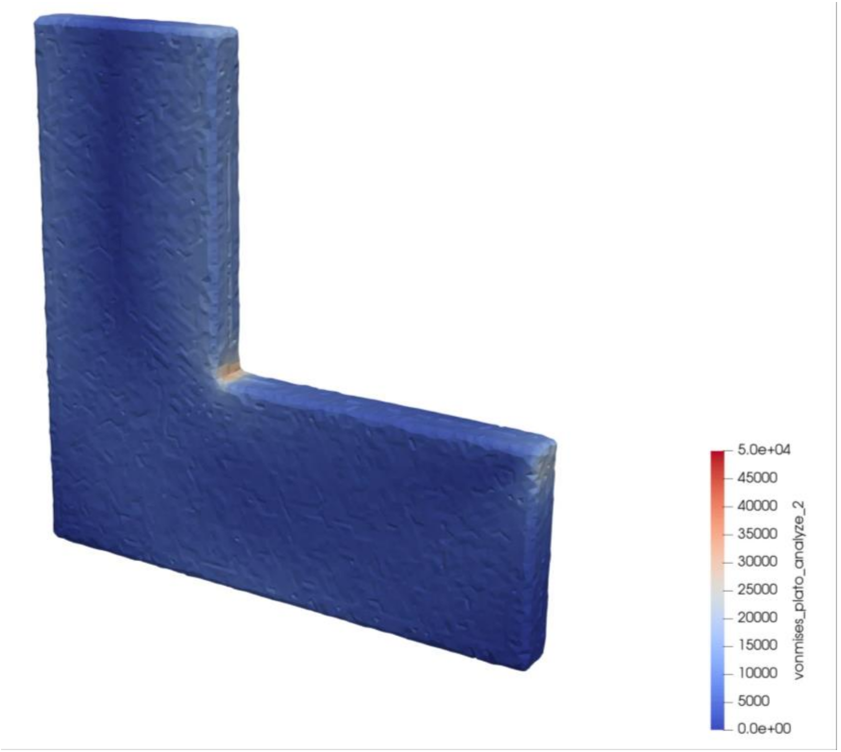
$$\mathbf{R}(\mathbf{u}(\text{Design}), \text{Design}) = \mathbf{K}(\text{Design})\mathbf{u} - \mathbf{f} = \mathbf{0}$$

$$\mathbf{G}(\text{Design}) = \text{Mass}(\text{Design}) \text{ - } \text{Mass Req.} \leq \mathbf{0}$$

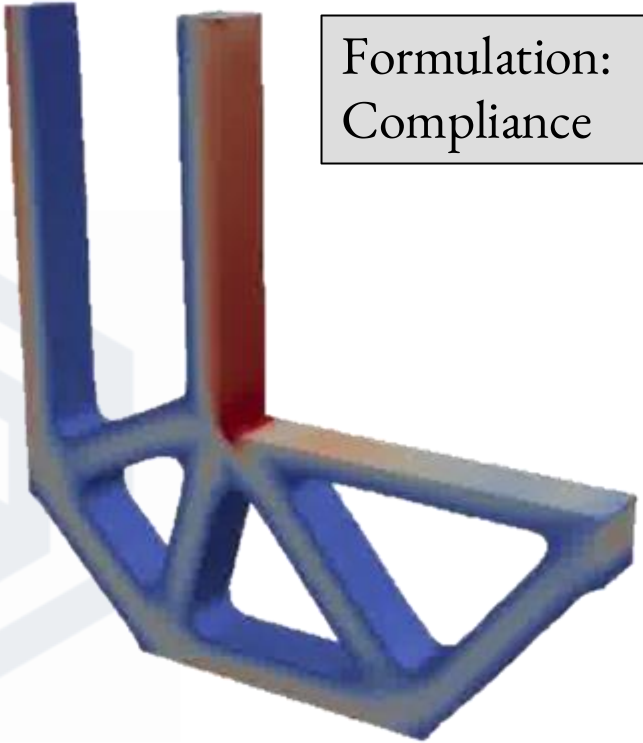
Enforce Local Design Requirements

Minimize Mass & Constraint Local von Mises Stress

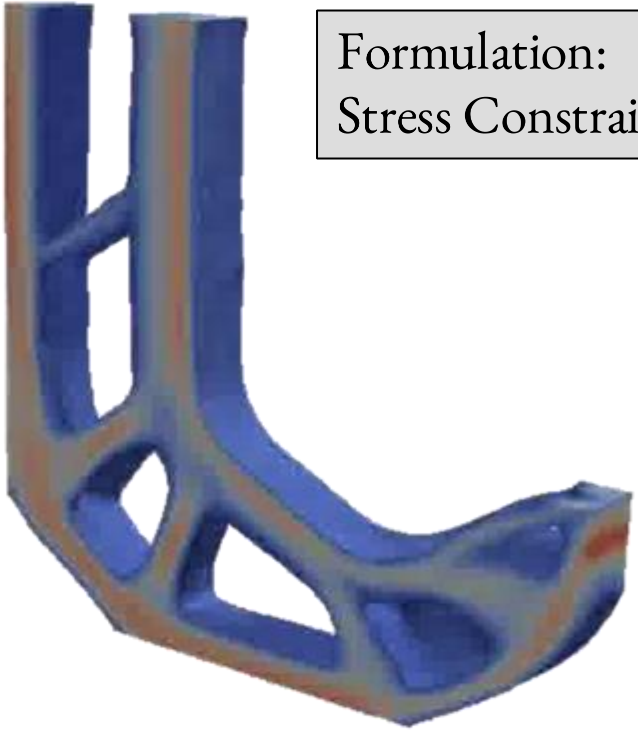




Will the Problem Formulation Impact Results?



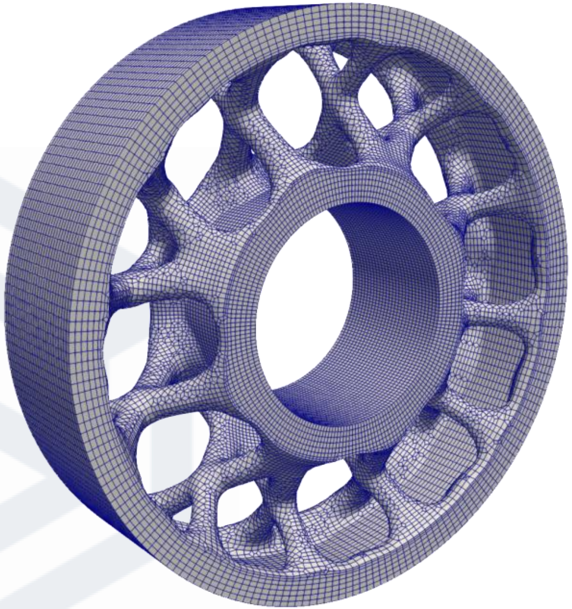
Formulation:
Compliance



Formulation:
Stress Constrained

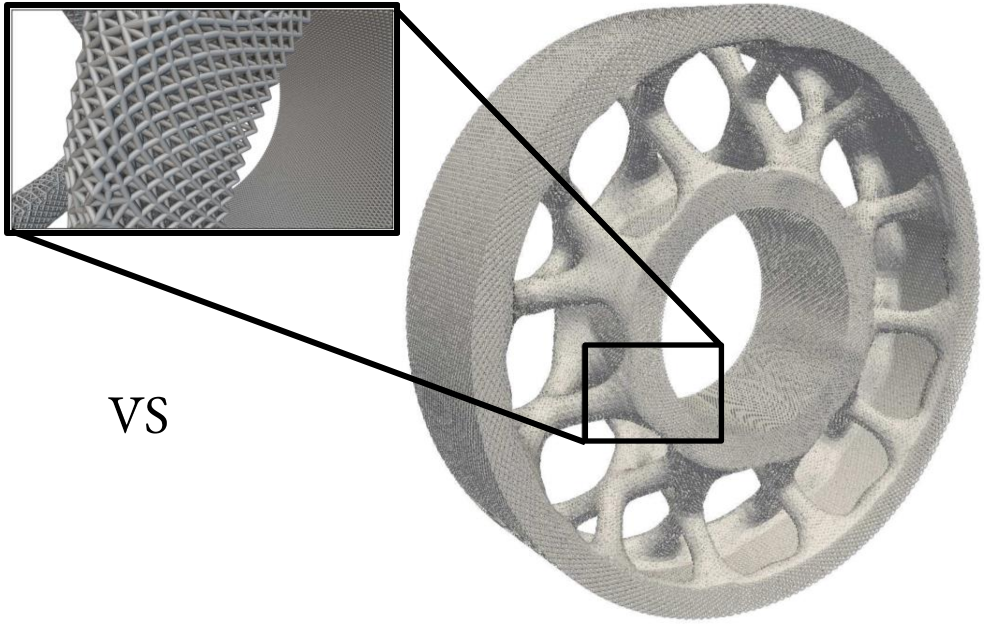
Topology Optimization

Spatially-Varying Lattices



Conformal
Topology Optimization

VS



Lattice-Based
Topology Optimization

Thank you

Simulation-Based Design