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# Simulation-Driven Design Optimization

University of Utah  
November 29, 2022

## ***PRESENTED BY***

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[www.morphorm.com](http://www.morphorm.com)





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DRIVING DIGITAL ENGINEERING INNOVATION

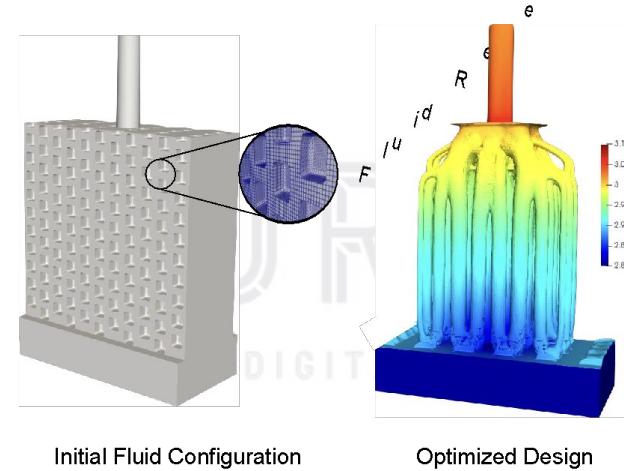
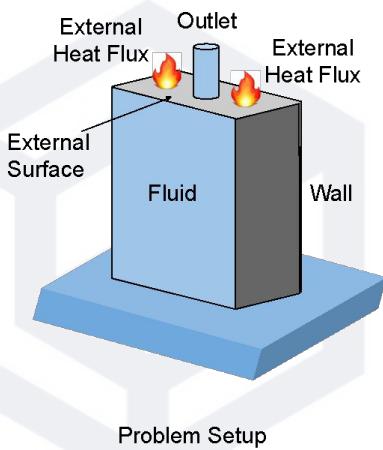
# Motivation

Simulation-Driven Design Optimization

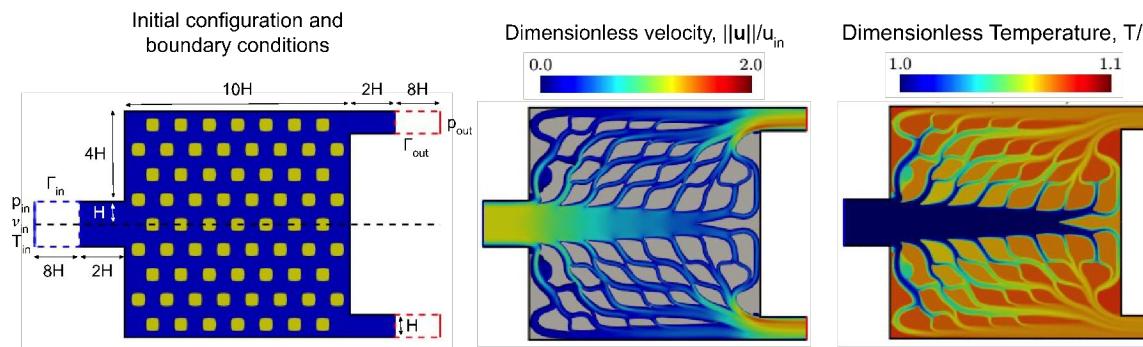




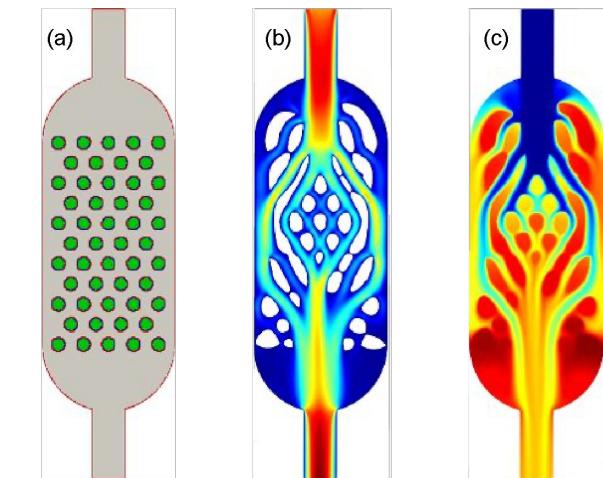
<https://www.boeing.com/defense/f-15/index.page#/gallery>



## Heat Exchanger Design

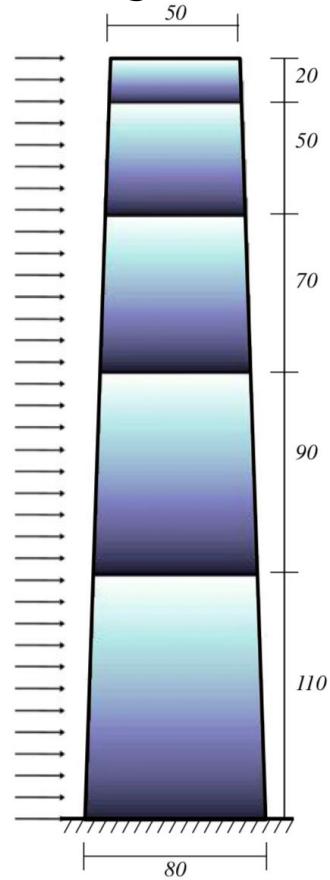


## Heat Exchanger Design



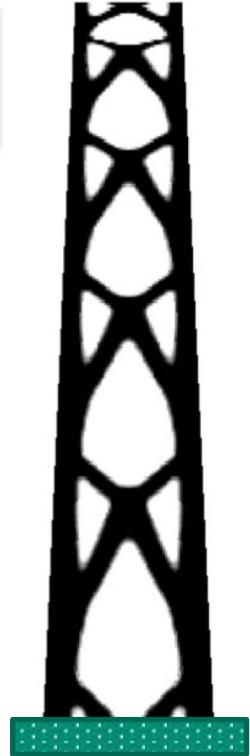
# Structural Engineering

[wikipedia.org](https://en.wikipedia.org)



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ENGINEERING INNOVATION

Could we use  
simulation-driven design  
optimization (SD2O) to  
design a better structure?





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# Trial & Error

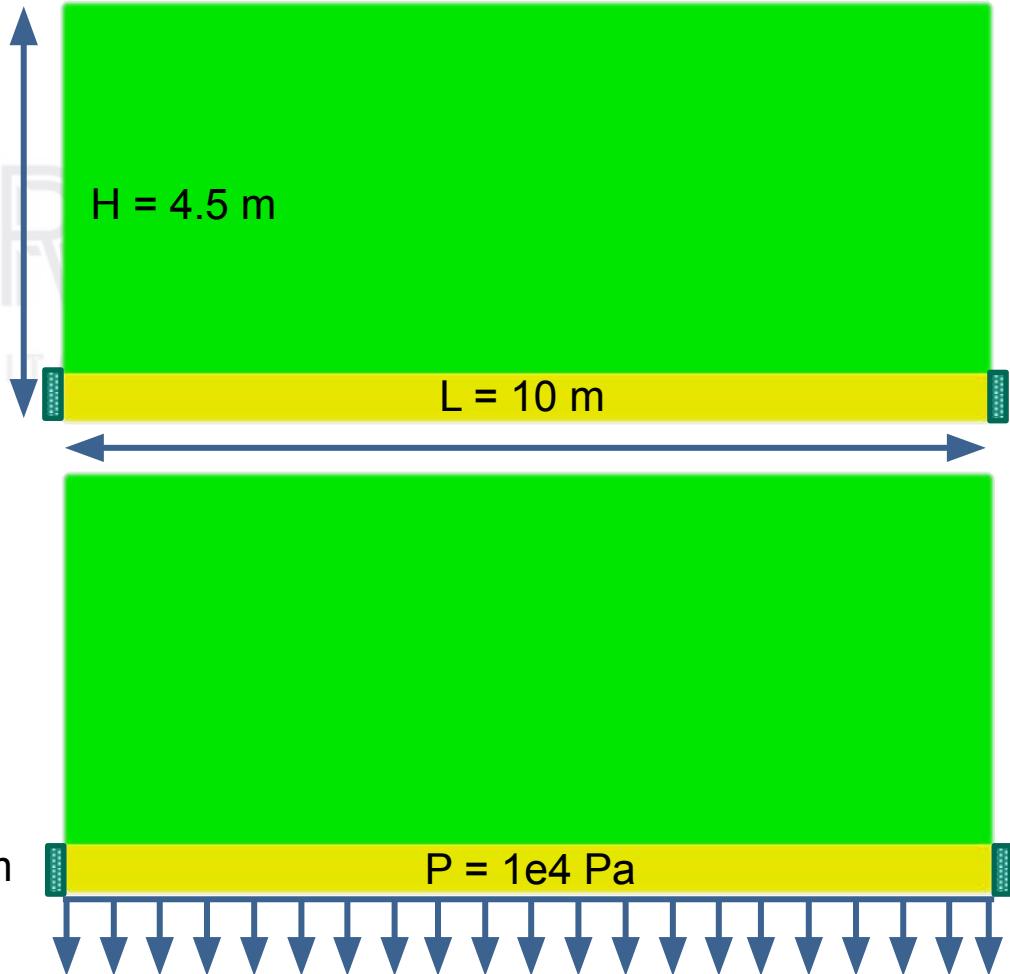
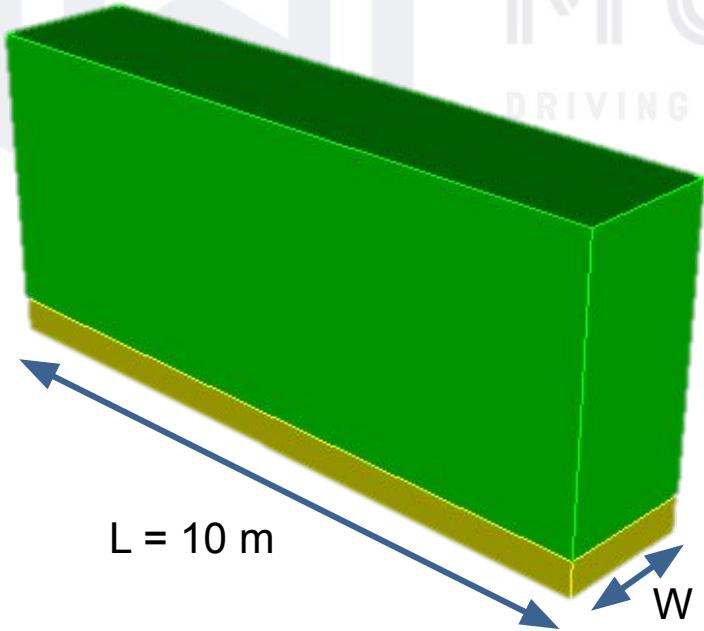
Simulation-Driven Design Optimization



# Structural Design

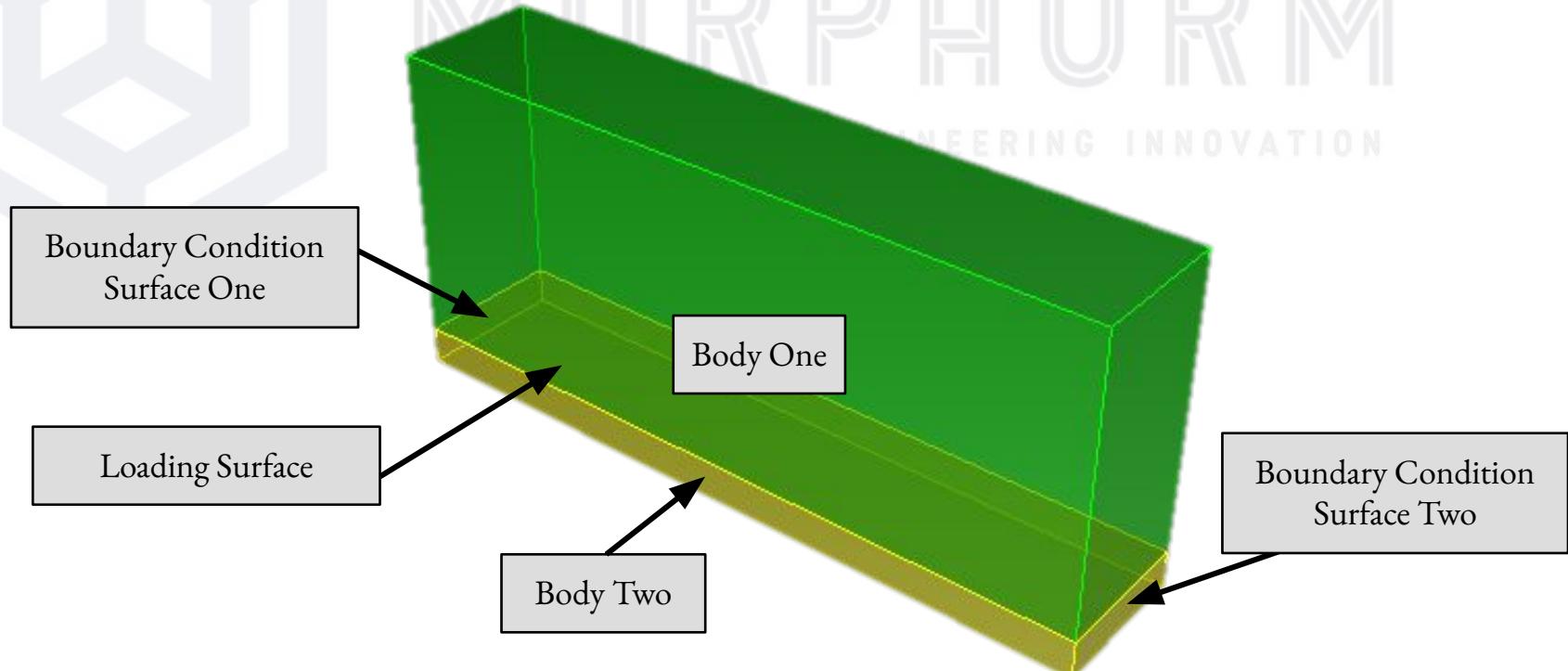
Young's Modulus =  $200\text{e}9 \text{ Pa}$

Poisson's Ratio = 0.3



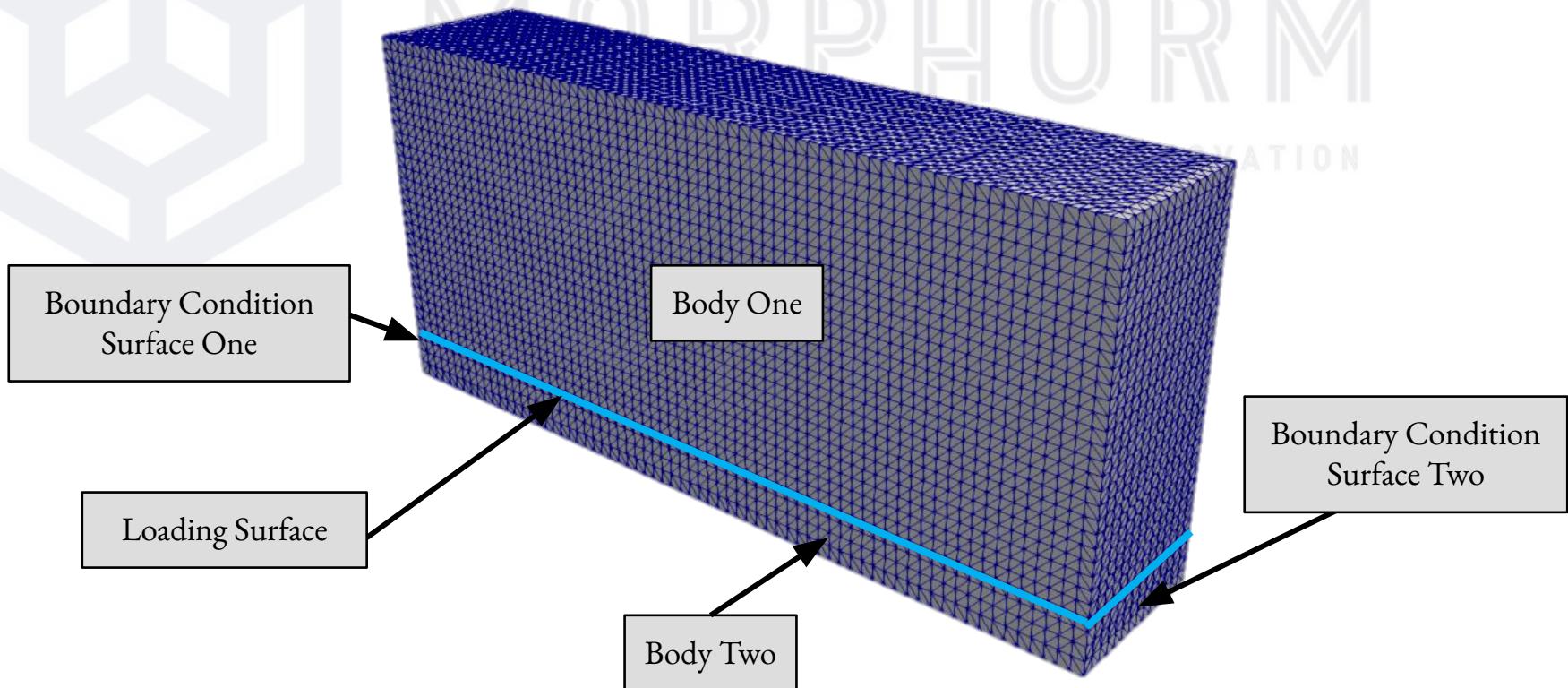
# Approach

## Step 1: Build Attributed Geometry Model



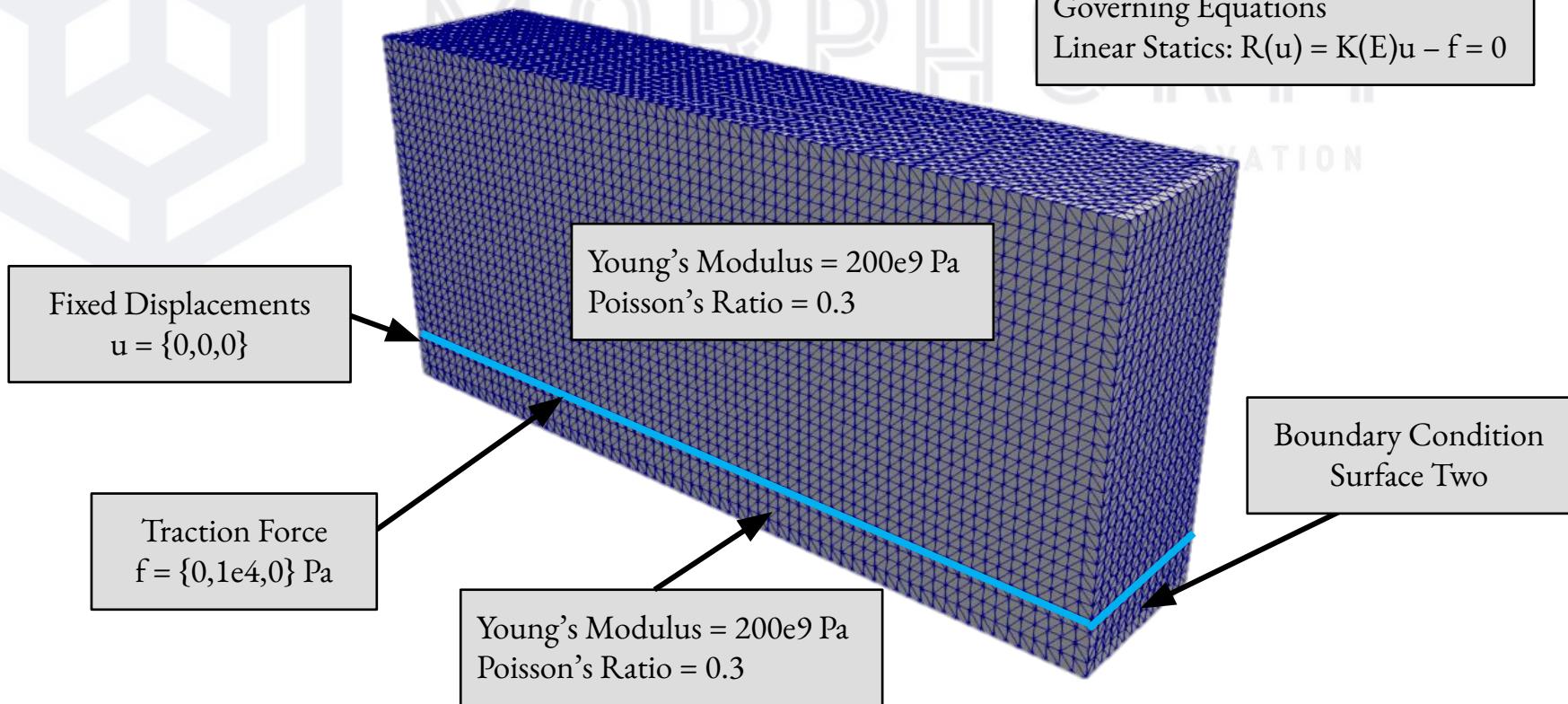
# Approach

## Step 2: Build Attributed Volume Mesh Model



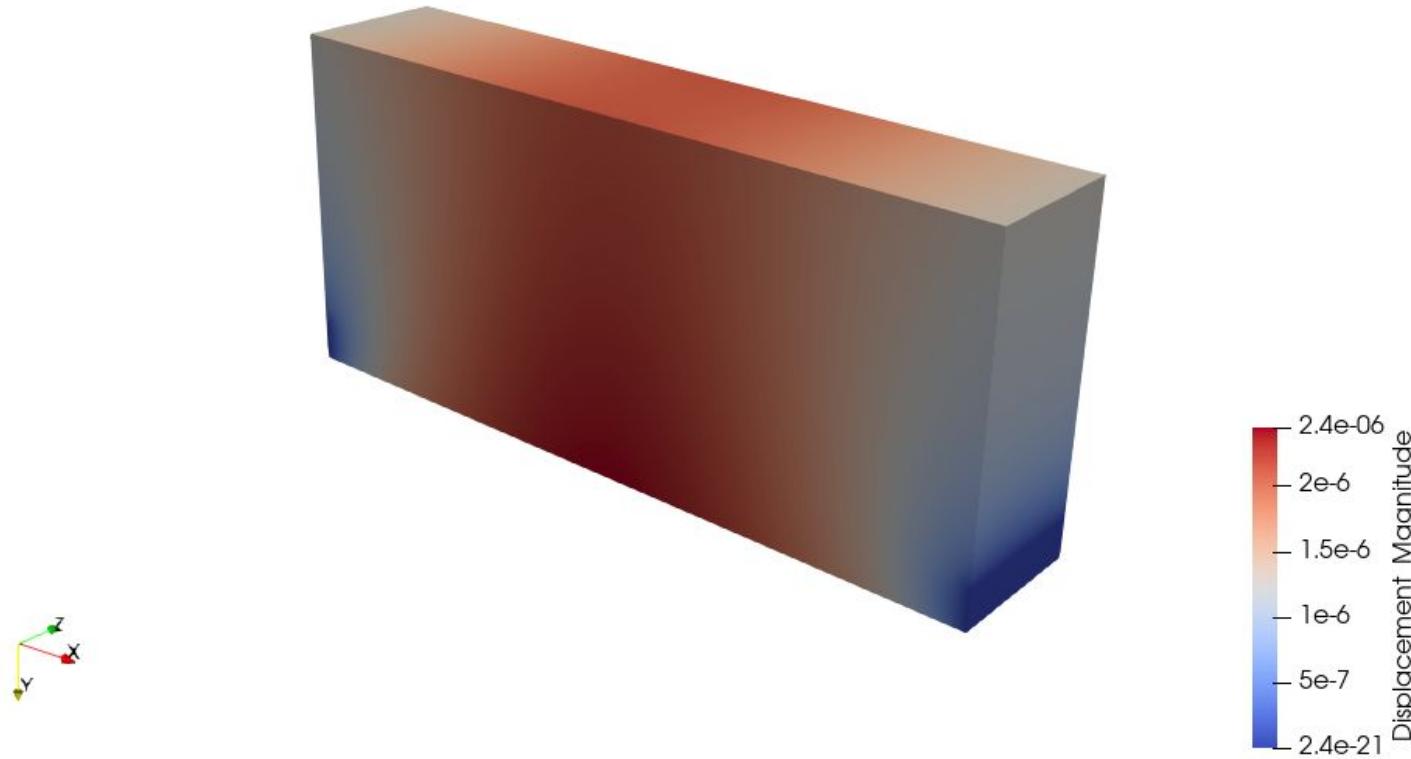
# Approach

## Step 3: Define Physics

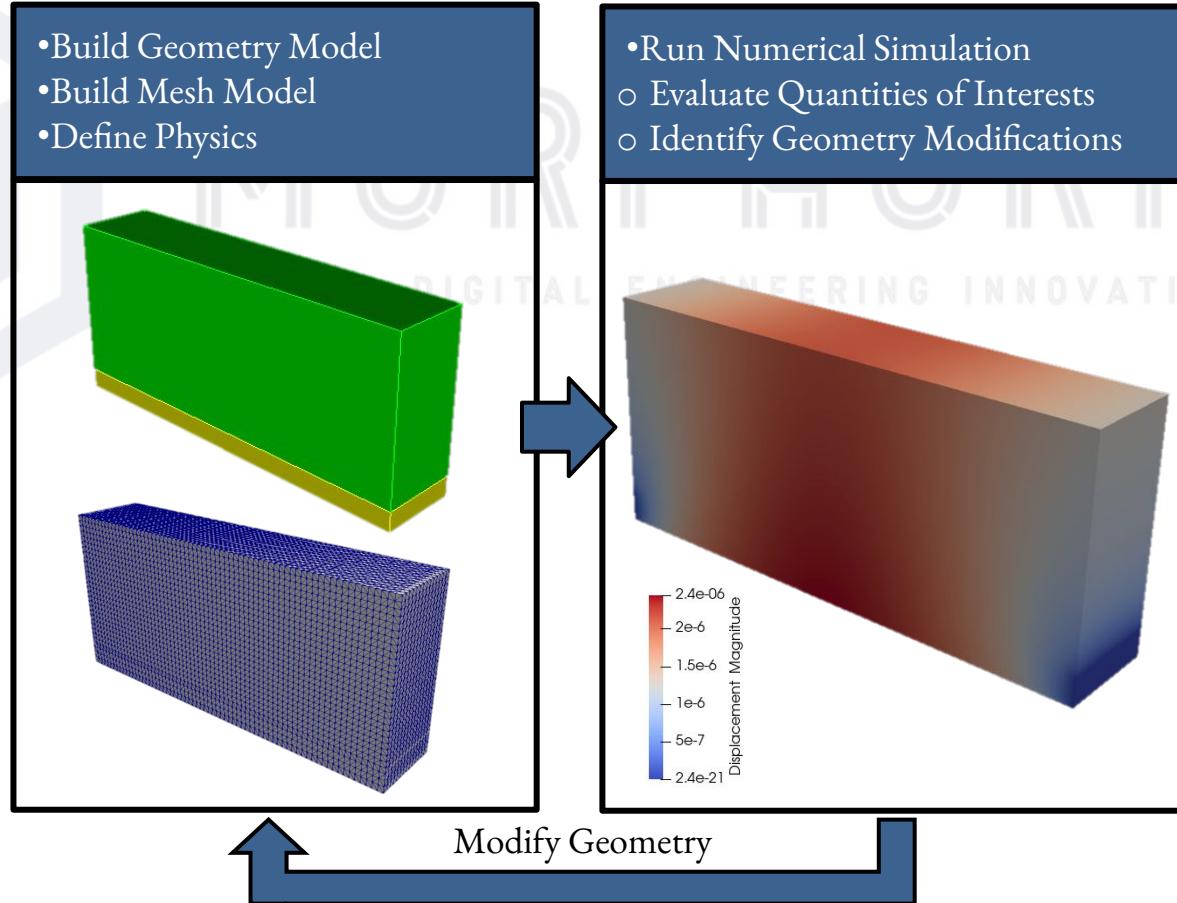


# Approach

Step 4: Run Simulation & Analyze Results



# Workflow





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# Automation

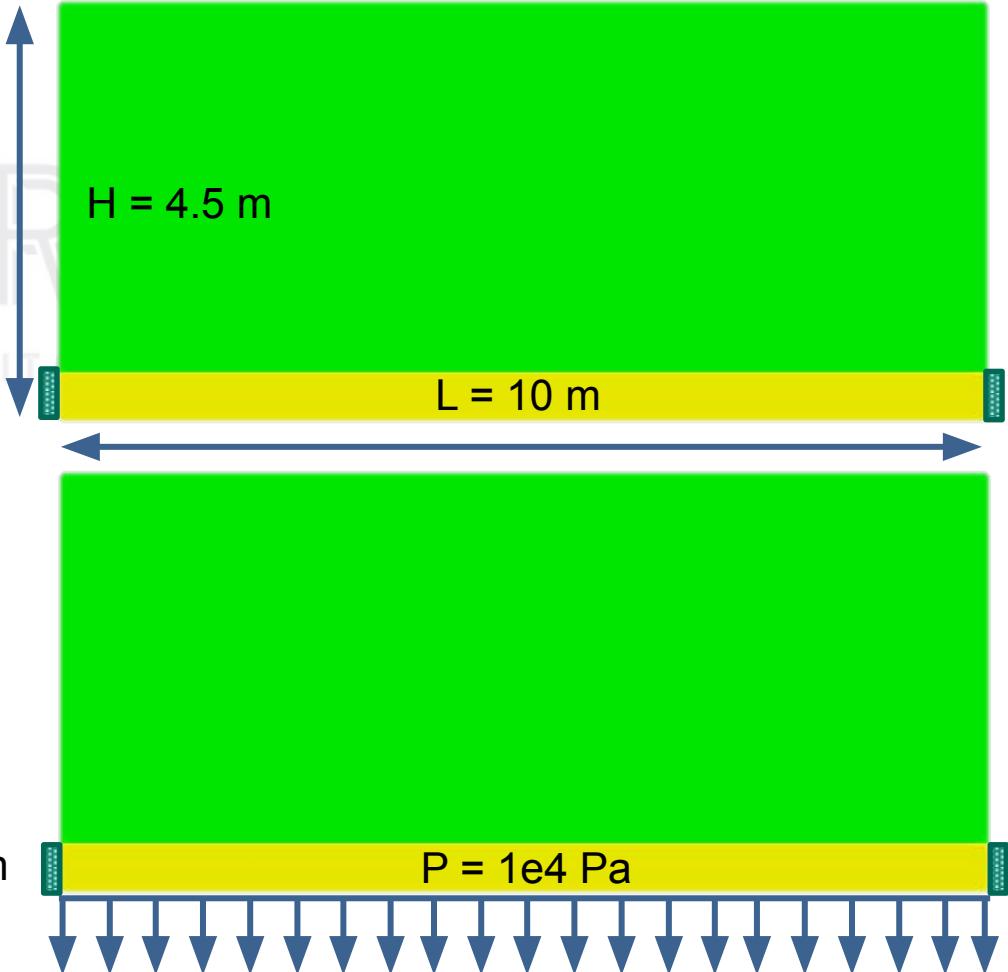
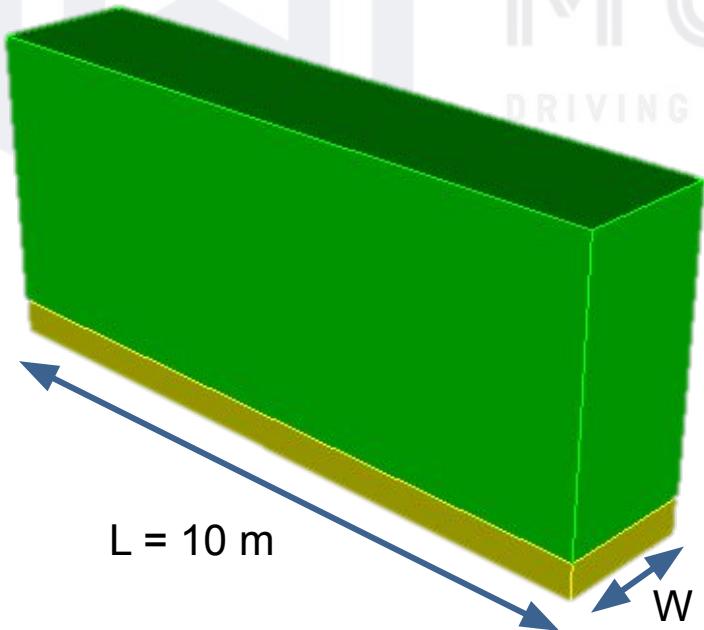
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# Structural Design

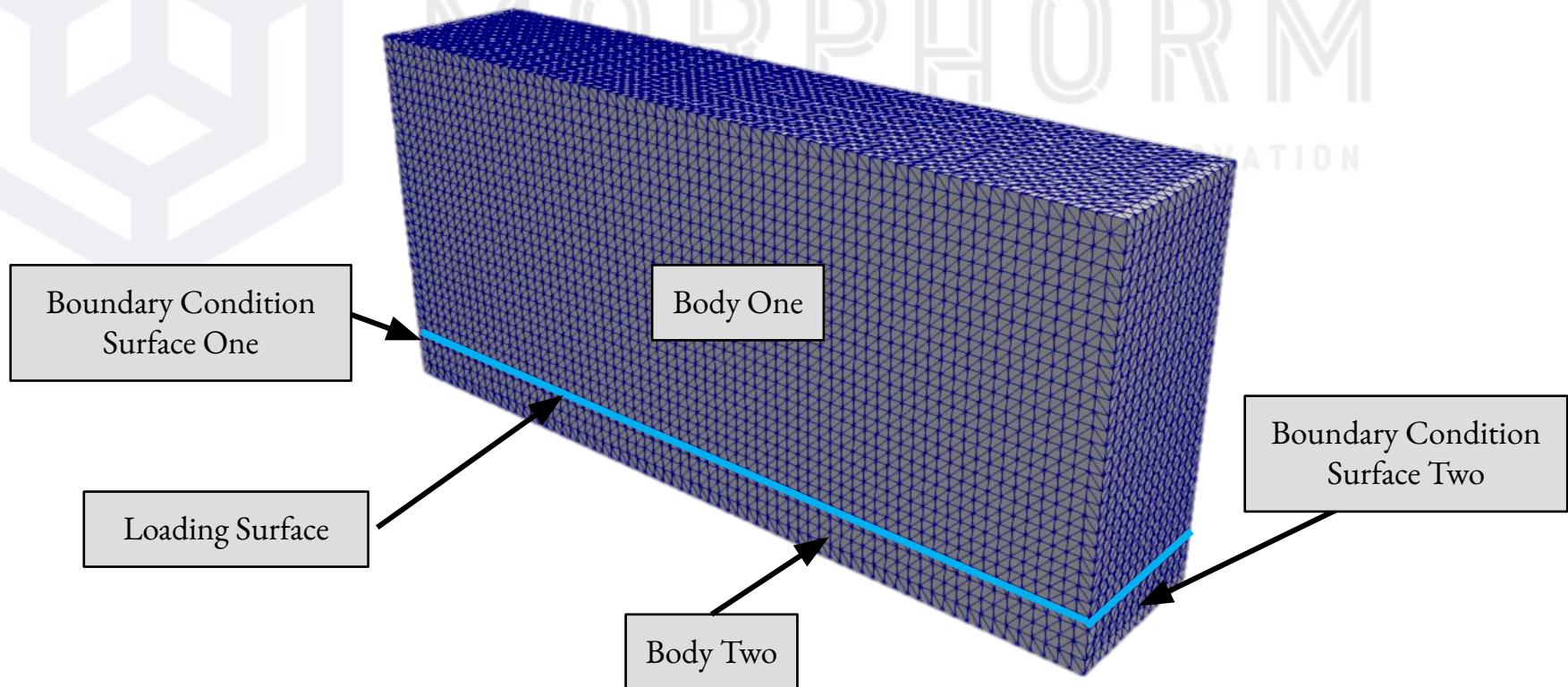
Young's Modulus =  $200\text{e}9 \text{ Pa}$

Poisson's Ratio = 0.3



# Approach

## Step 2: Build Attributed Volume Mesh Model



# Approach

## Step 3: Define Physics & Design Criteria

### Design Criteria

- Minimize Deflections
- Meet Weight Budget

Fixed Displacements  
 $u = \{0,0,0\}$

Traction Force  
 $f = \{0,1e4,0\}$  Pa

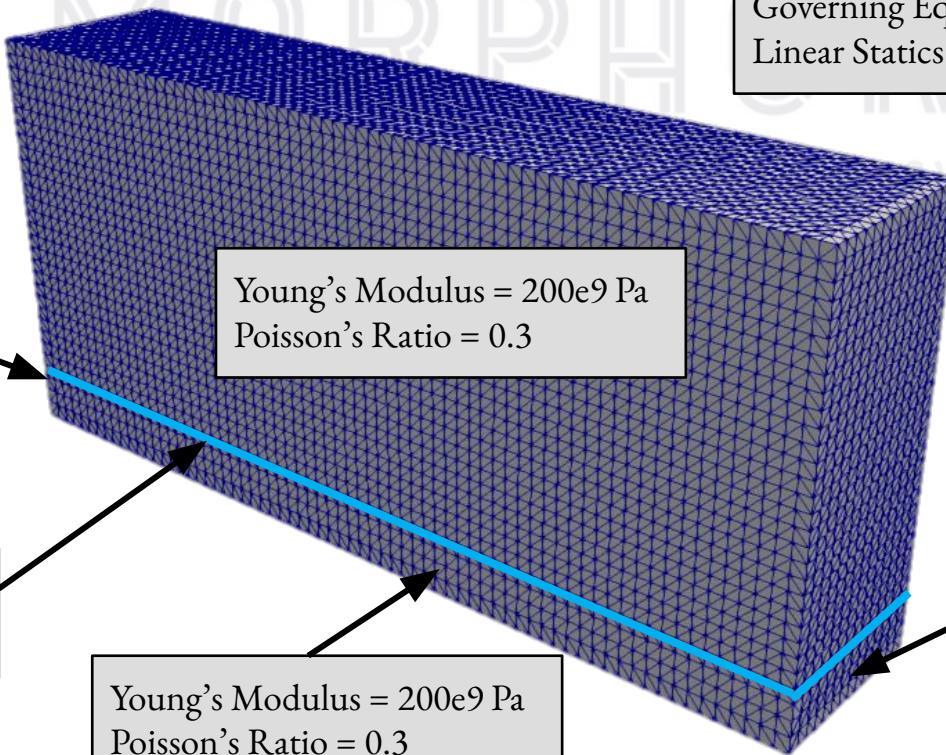
Young's Modulus =  $200e9$  Pa  
Poisson's Ratio = 0.3

Young's Modulus =  $200e9$  Pa  
Poisson's Ratio = 0.3

### Governing Equations

$$\text{Linear Statics: } R(u) = K(E)u - f = 0$$

Boundary Condition  
Surface Two



# Approach

Step 4: Solve Simulation-Driven Design Optimization Problem

Front View



Top View



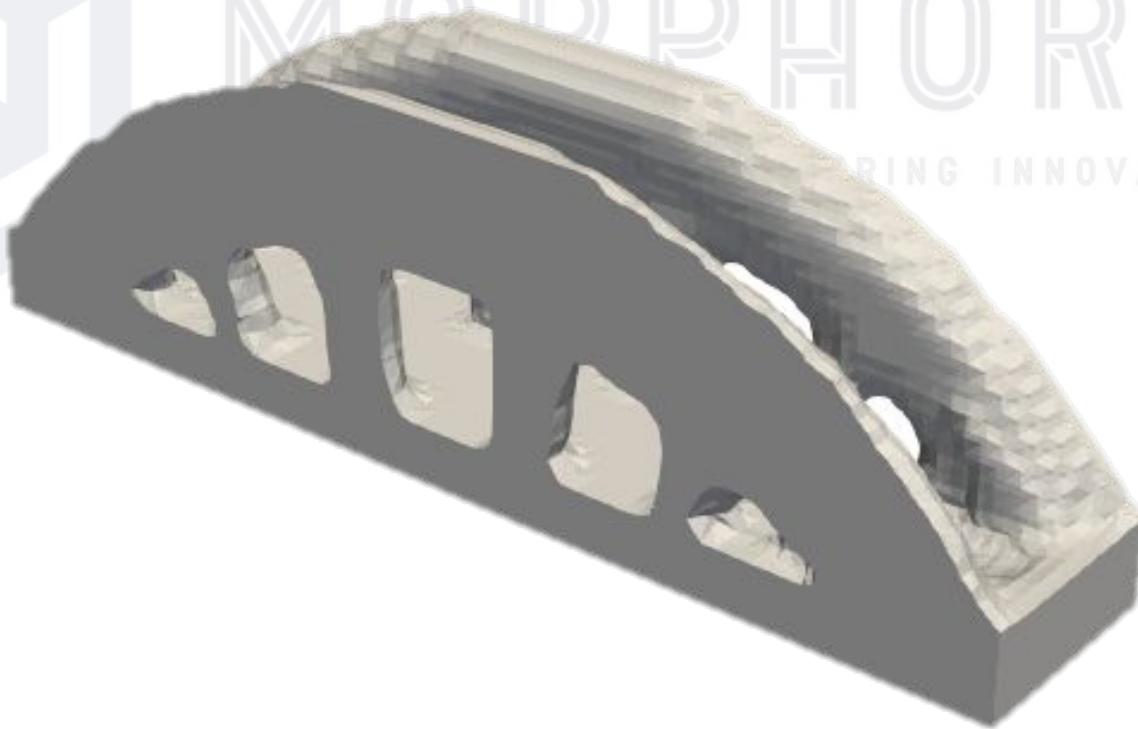
Displacement Magnitude

Side View



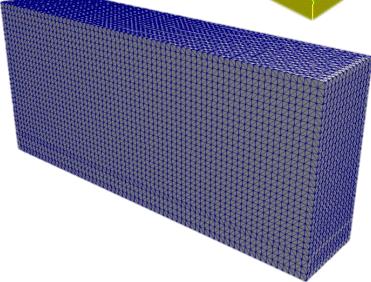
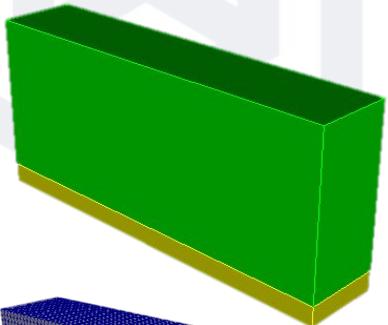
# Approach

Step 5: Build Geometry Model

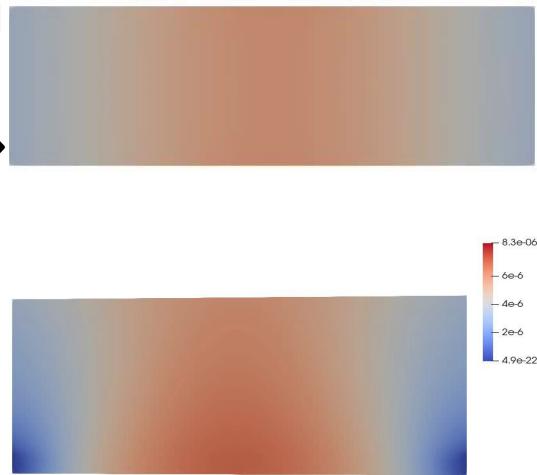


# Workflow

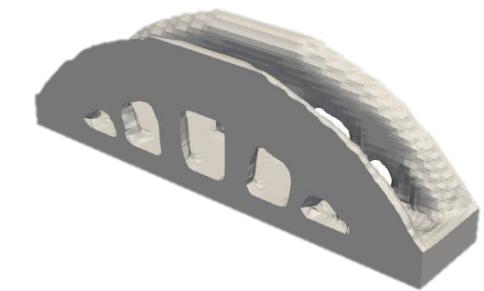
- Build Attributed Geometry
- Build Attributed Mesh Model
- Define Physics



- Solve SD2O Problem
  - Optimization Algorithm
  - Numerical Simulation



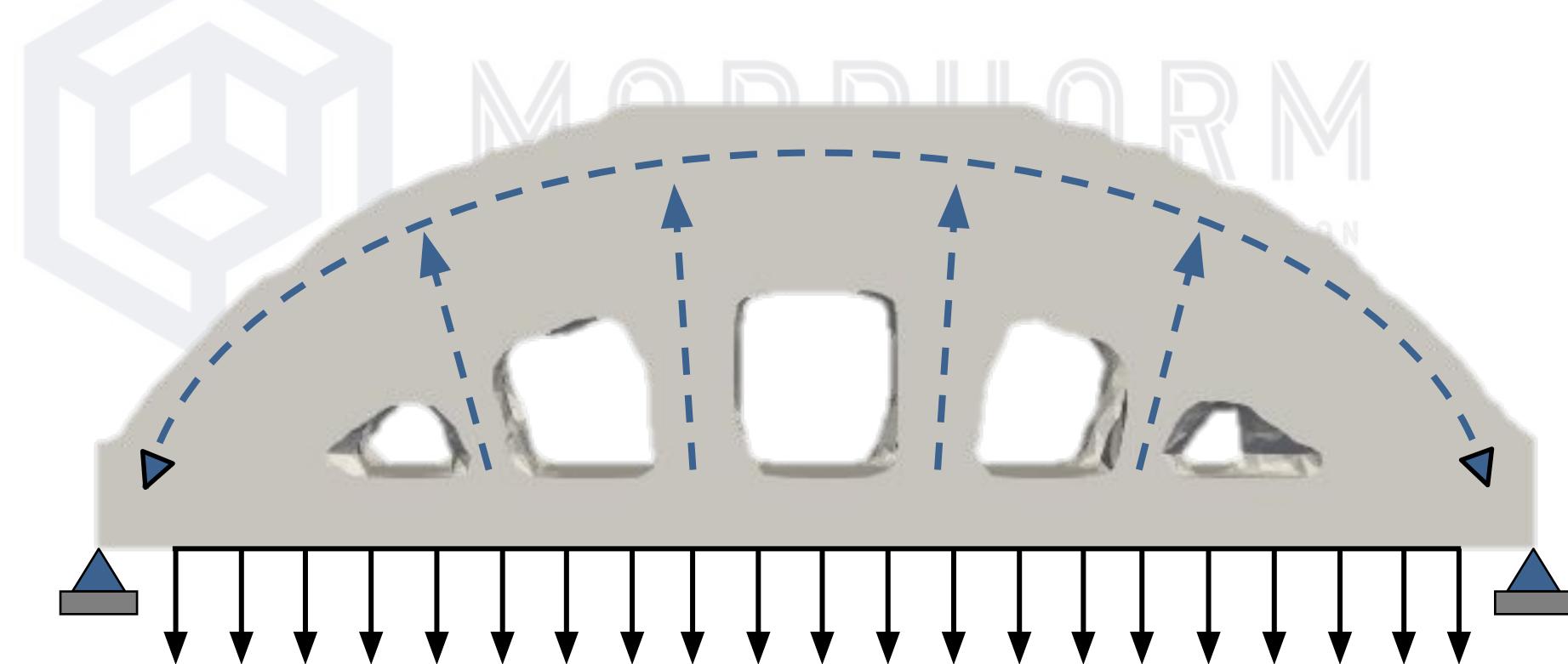
- Rebuild Geometry Model
  - Geometry Documentation
  - Shape Optimization



Additional Optimization



# Simulation-Driven Design



# Tied Arch Bridge



<https://www.ib-miebach.de>

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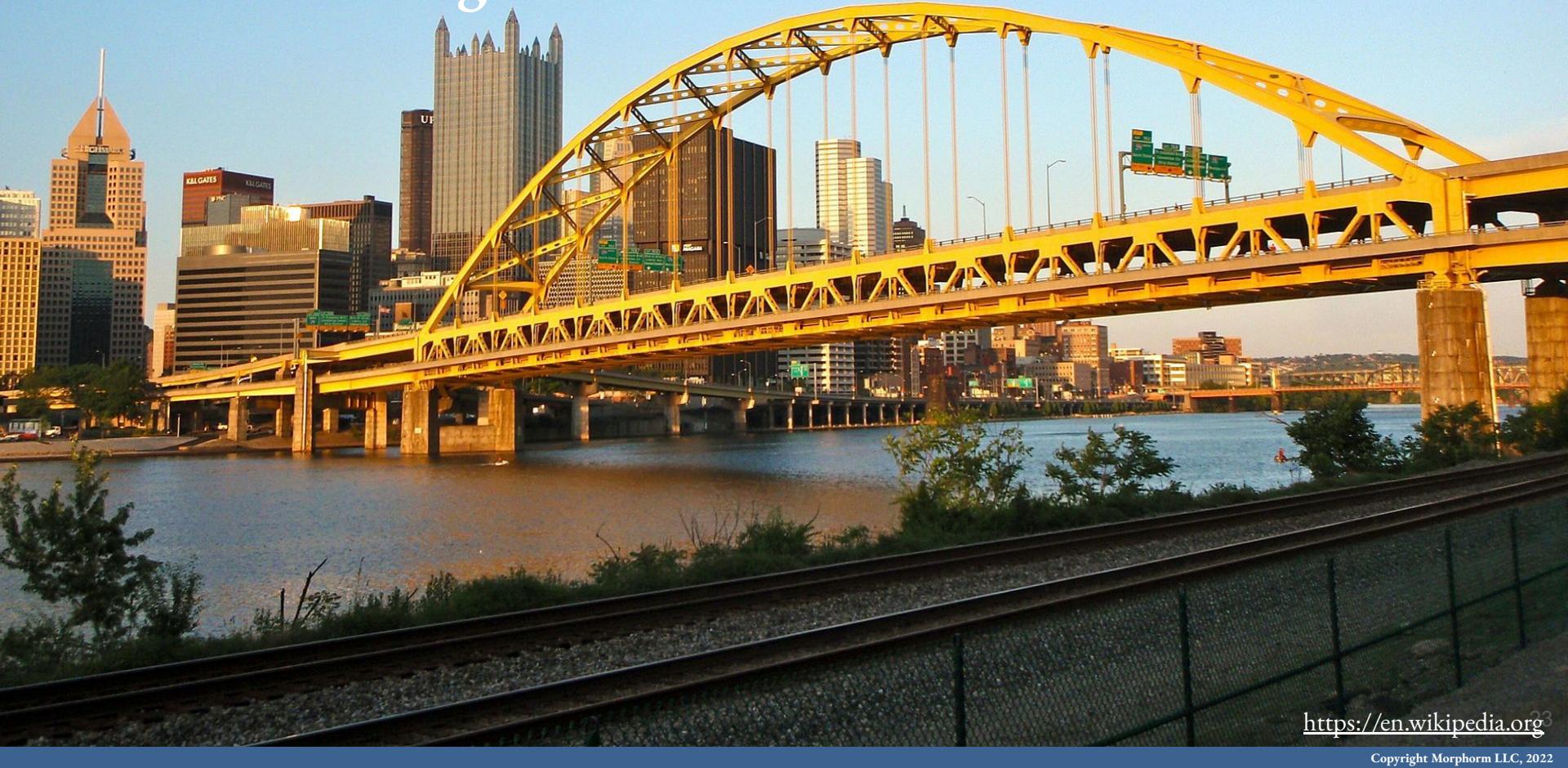
# Tied Arch Bridge



<https://en.wikipedia.org>

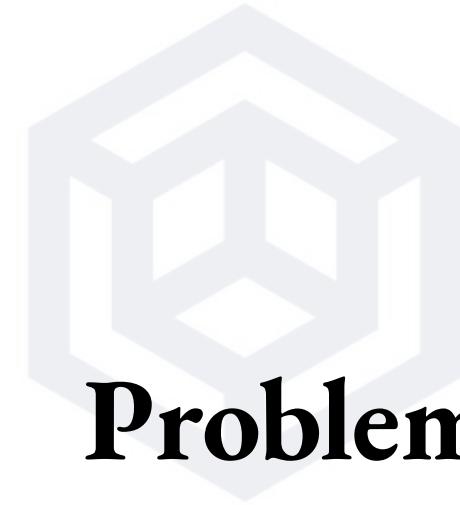
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# Tied Arch Bridge



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# Problem Formulation

Simulation-Driven Design Optimization



# 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

Governing Equations Are Satisfied

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

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

subject to

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

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





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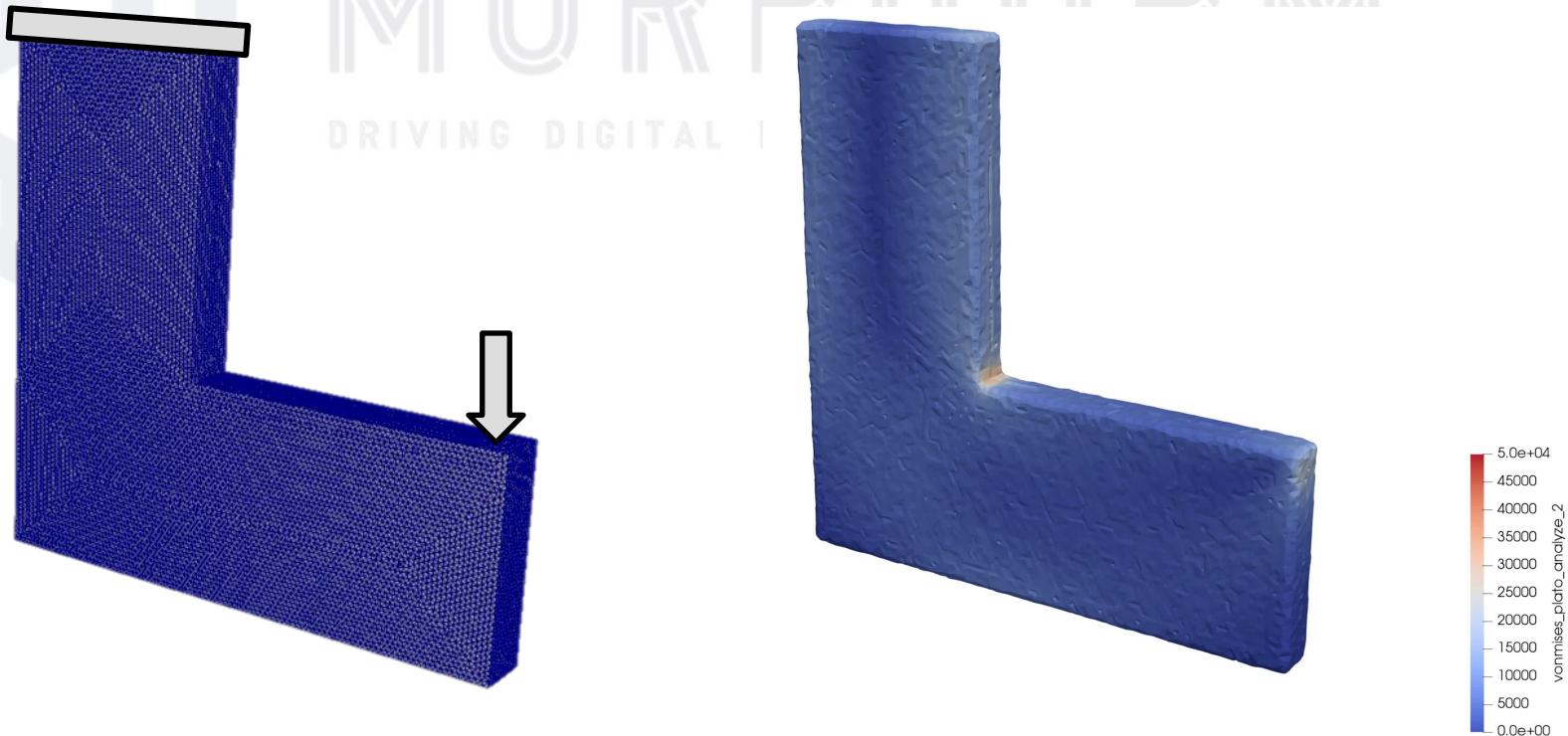
# Design Requirements

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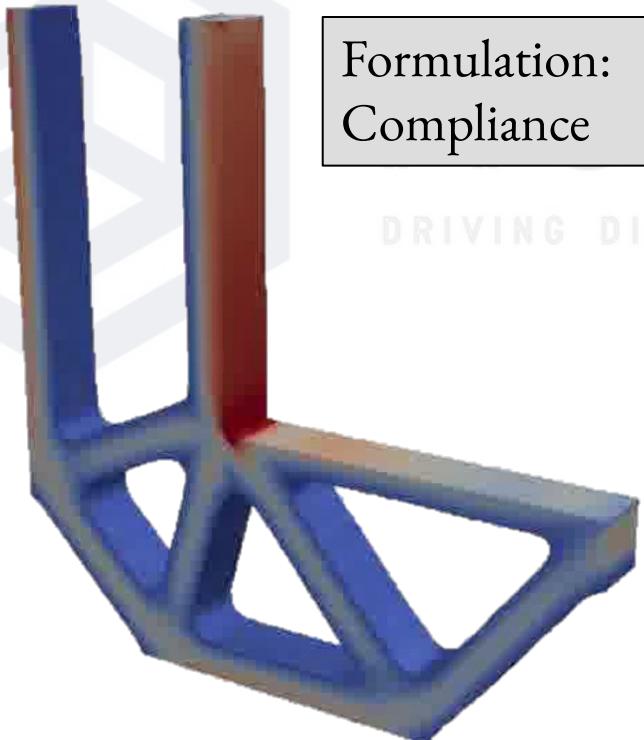


# Enforce Local Design Requirements

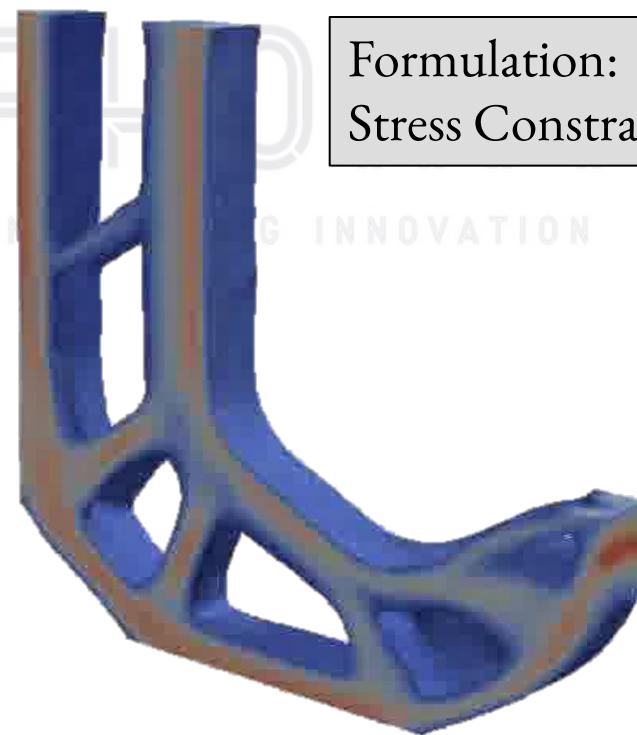
Minimize Mass & Constraint Local Von Mises Stress



# Will the Problem Formulation Impact Results?



Formulation:  
Compliance



Formulation:  
Stress Constrained

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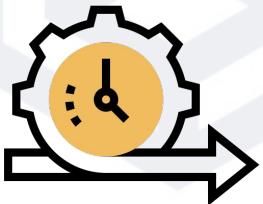
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# Opportunity

Simulation-Driven Design Optimization



# Trends



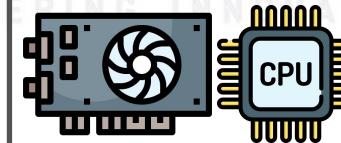
AGILE  
ENTERPRISE



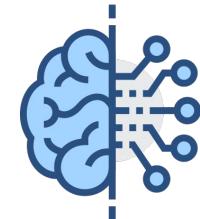
3D PRINTING



CLOUD  
COMPUTING



HETEROGENOUS  
COMPUTING

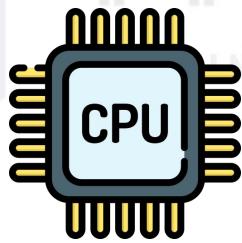


ARTIFICIAL  
INTELLIGENCE

# Opportunity



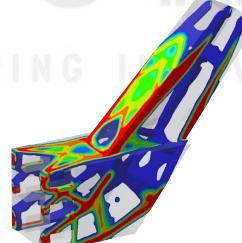
LEGACY  
SOFTWARE



HOMOGENEOUS  
COMPUTING



SLOW  
SOFTWARE

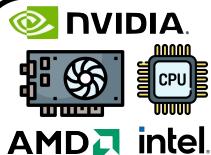


SIMPLE  
SOLUTIONS

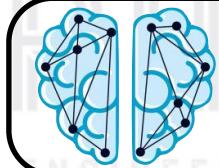


UNRELIABLE  
DESIGNS

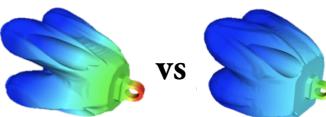
# PROPOSAL



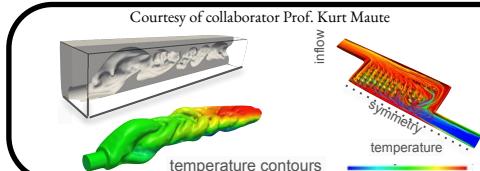
HARDWARE ABSTRACTION



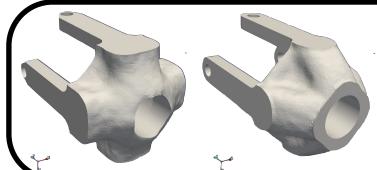
INTELLIGENT DESIGN TOOL



REAL-TIME DISCOVERY



MULTI-PHYSICS  
EXPLORATION



BUILT-IN RELIABILITY





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# Thank You

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