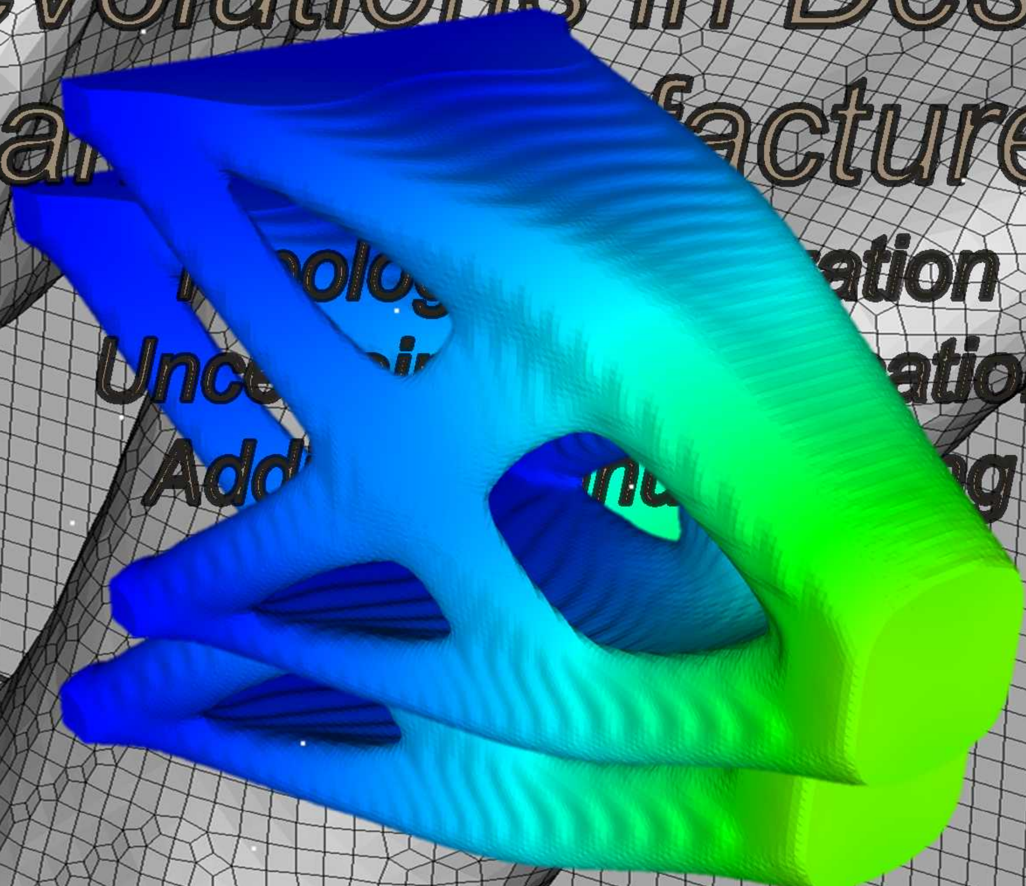
Exceptional service in the national interest

Sandia National Laboratories

SAND2015-8423PE

Revolutions in Design

a… facture

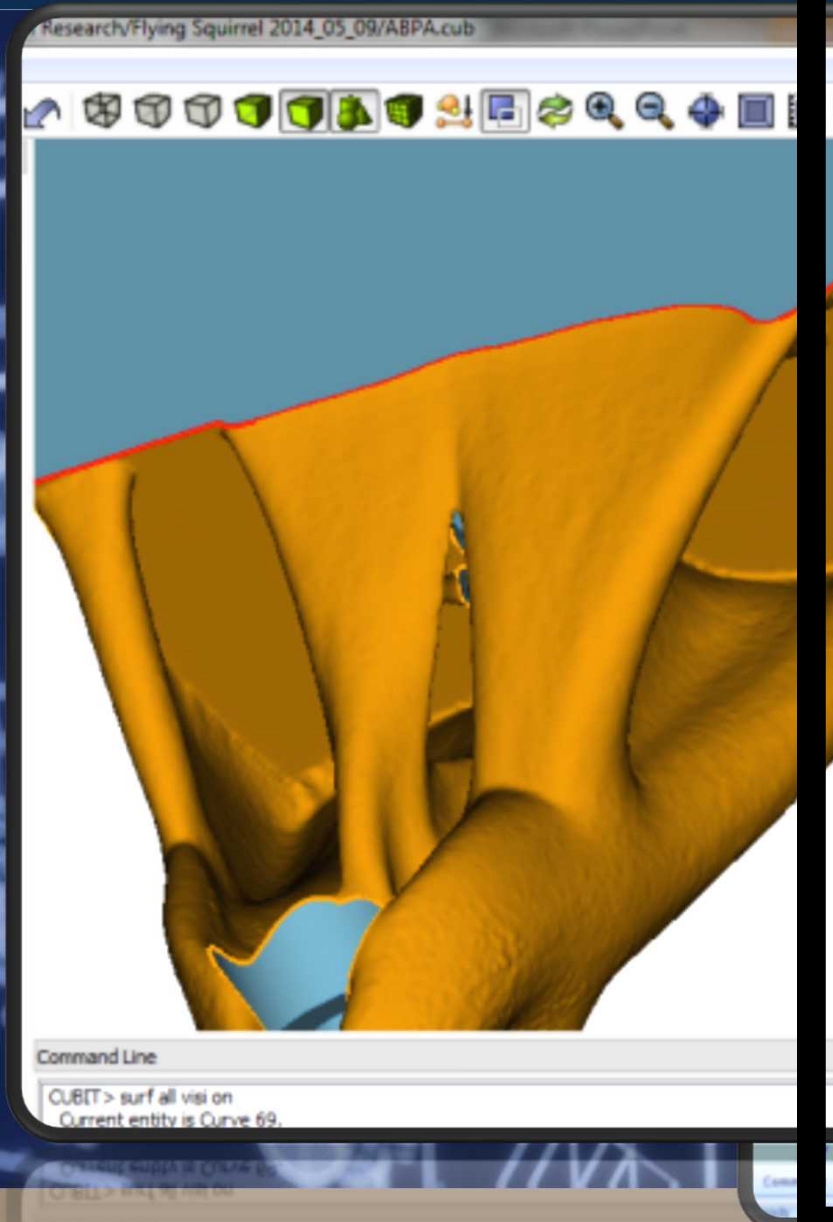


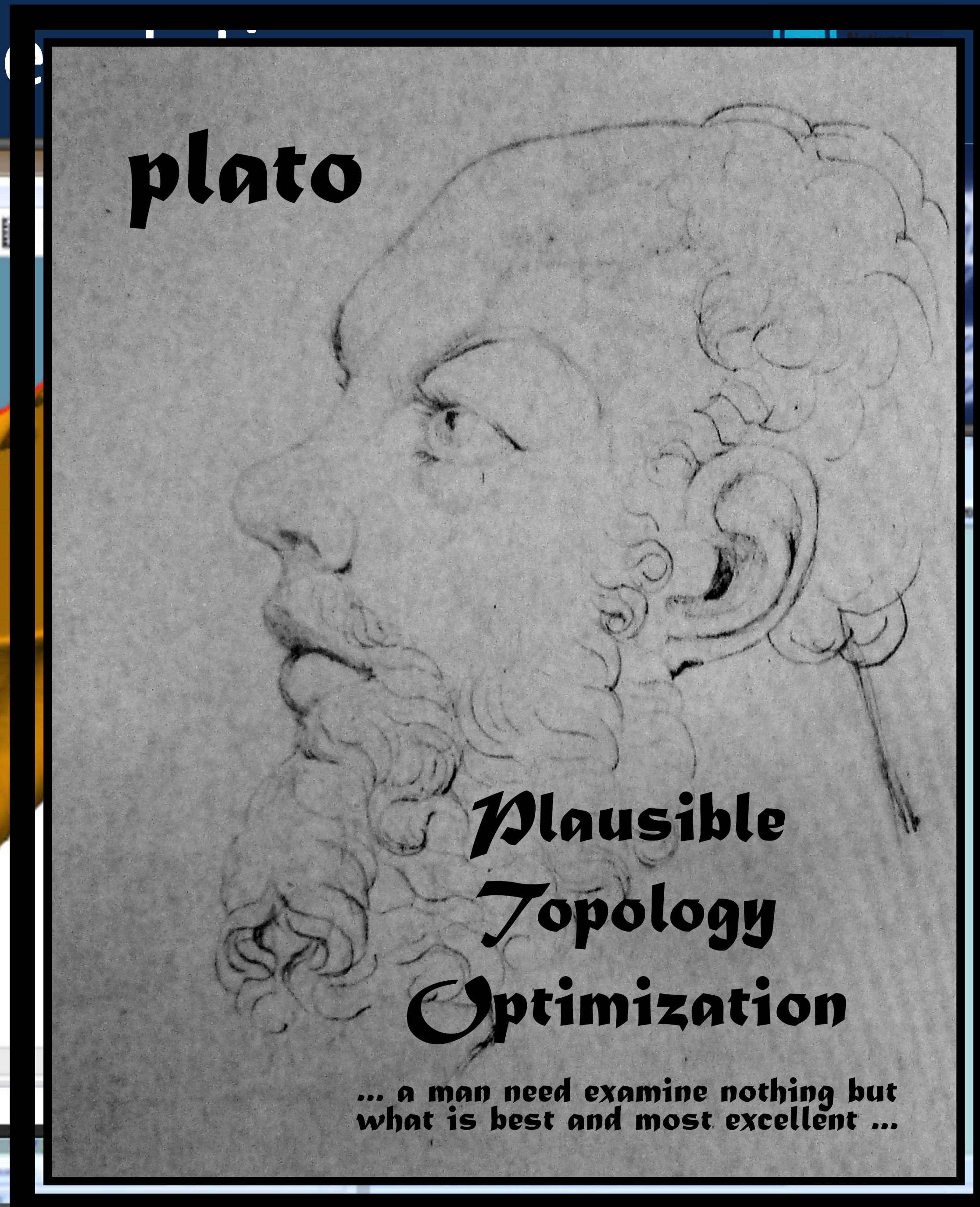
T… olog… ation

Unce… ain… ation

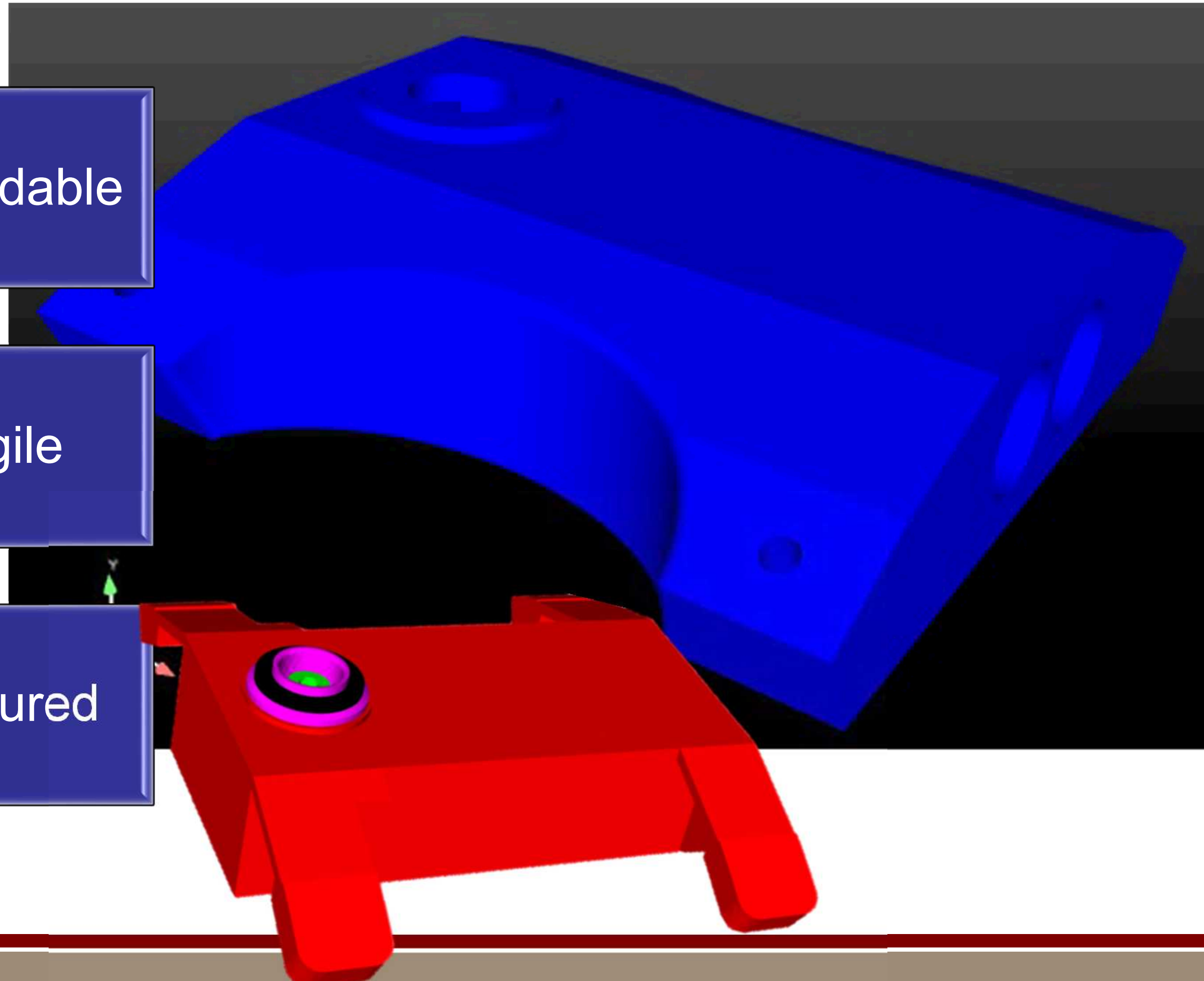
Add… nu… g

Note: This is a Re

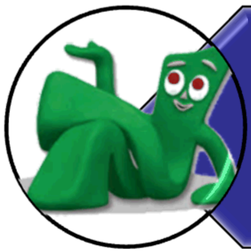




Introduction to This Revolution



Affordable



Agile

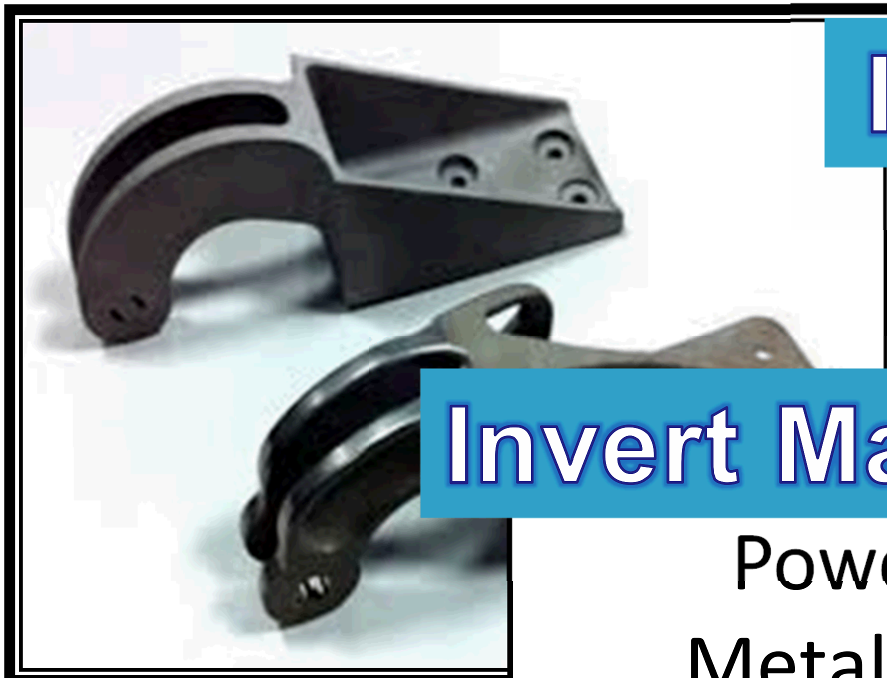
Assured

Additive Manufacturing: Opportunity w/Challenges

Profoundly New
Design Flexibility

In-Situ Material
Qualification

Realizing This Revolution

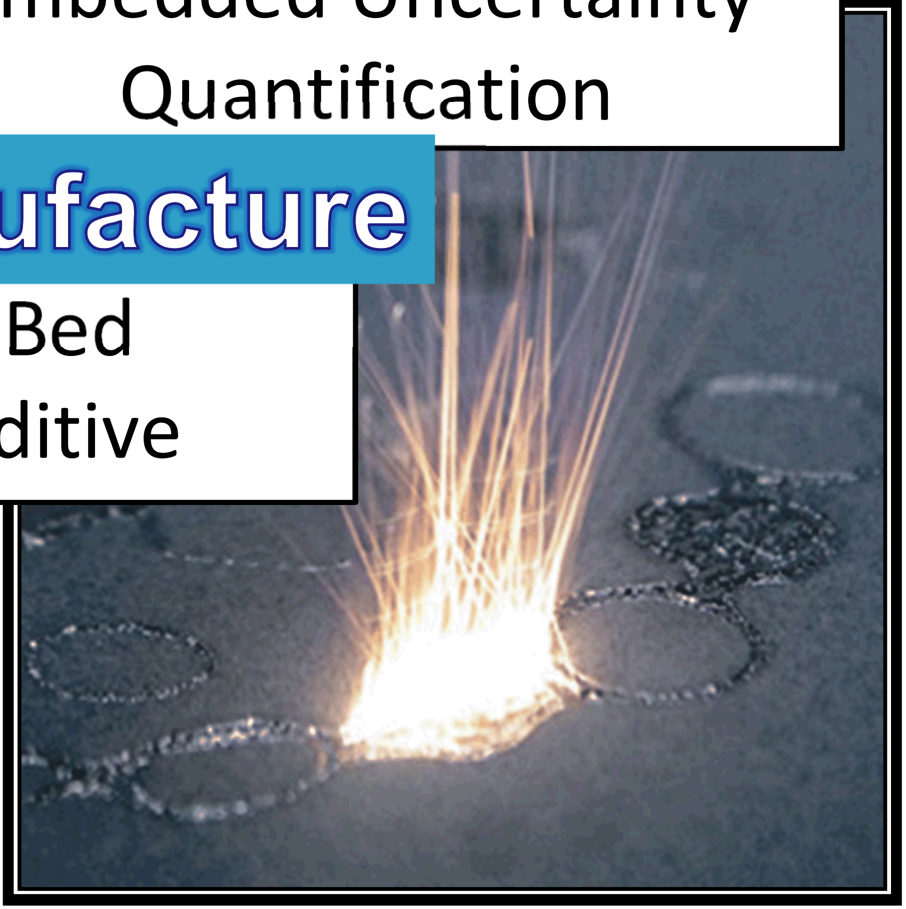


Invert Qualification

Imbedded Uncertainty
Quantification

Invert Manufacture

Powder Bed
Metal Additive



Invert Design

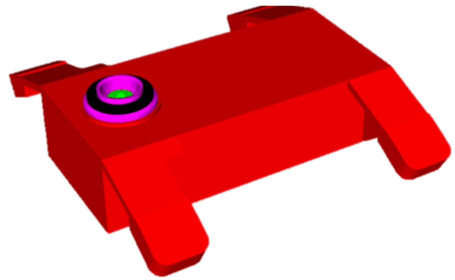
Topology Optimization
with Material Locality

Inversion of Design

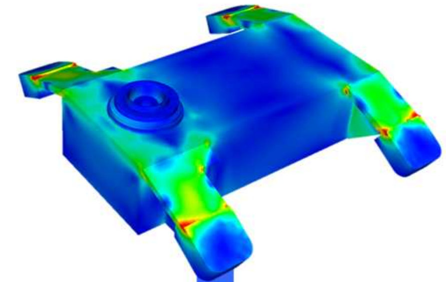
CURRENT

Specify Form

Design



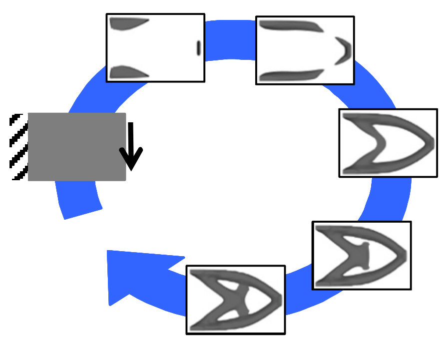
Verify Function Using FEA



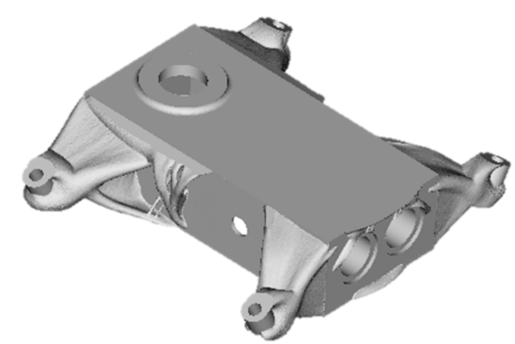
NEW

Specify Design Domain and Function

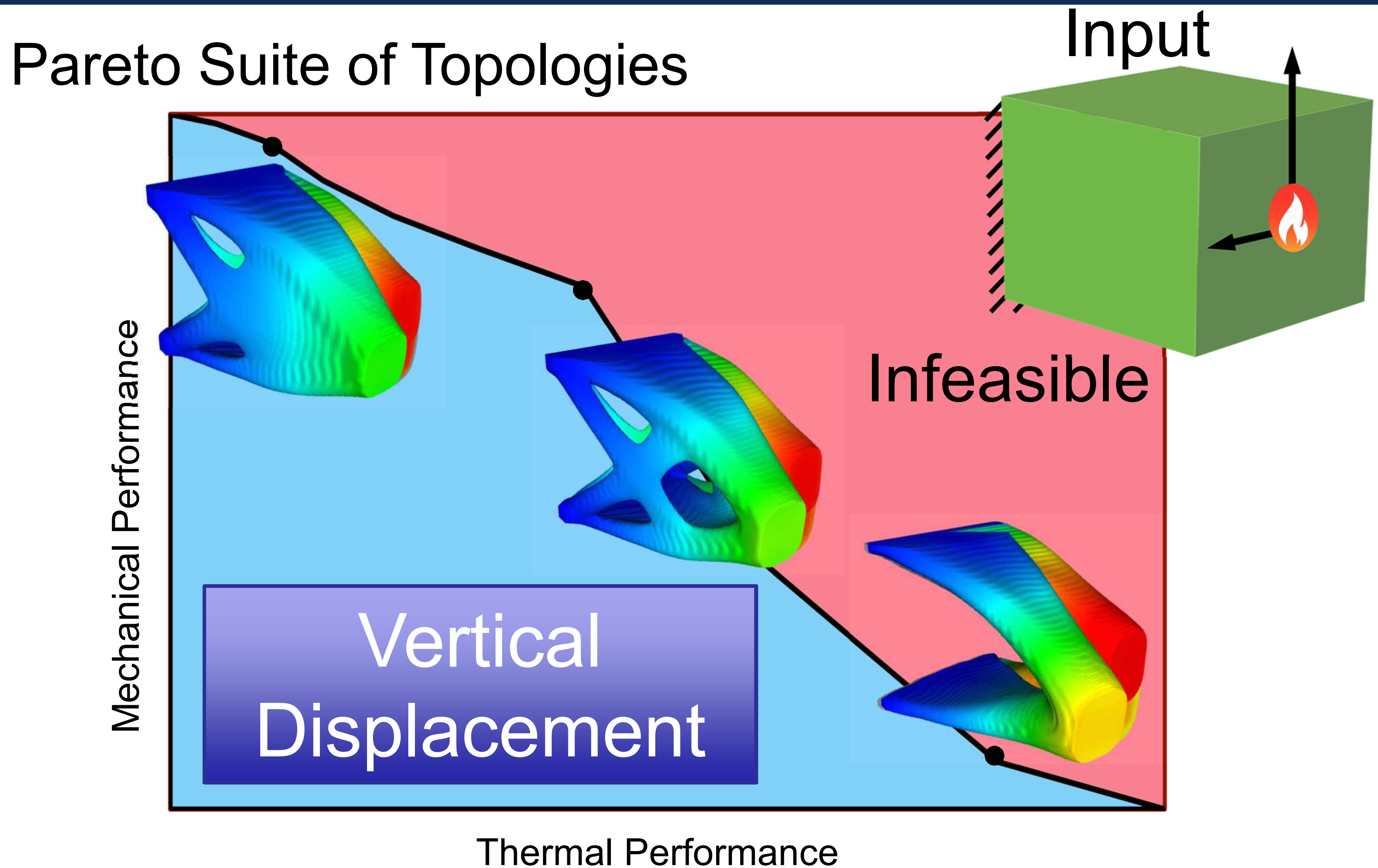
Use Topology Optimization (FEA) to Determine Form that Meets Function



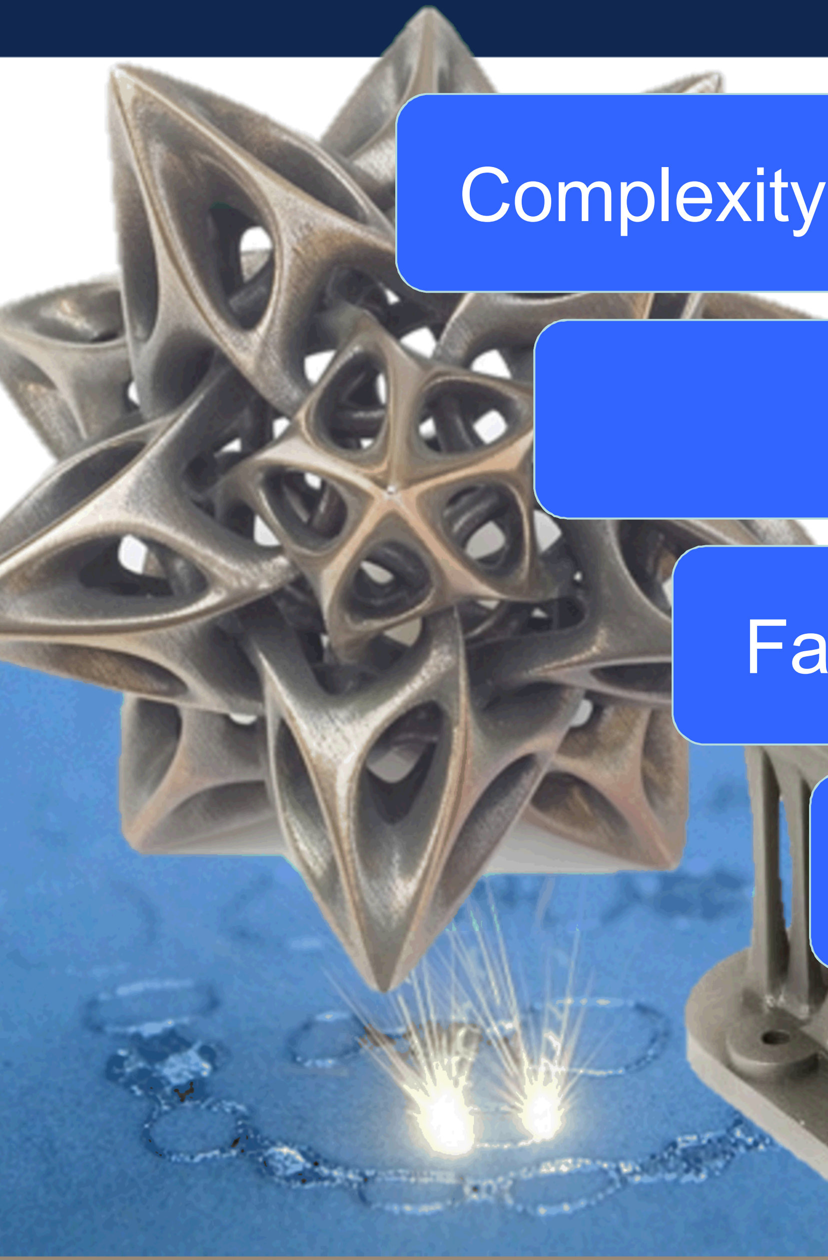
Optimized Design (Form)

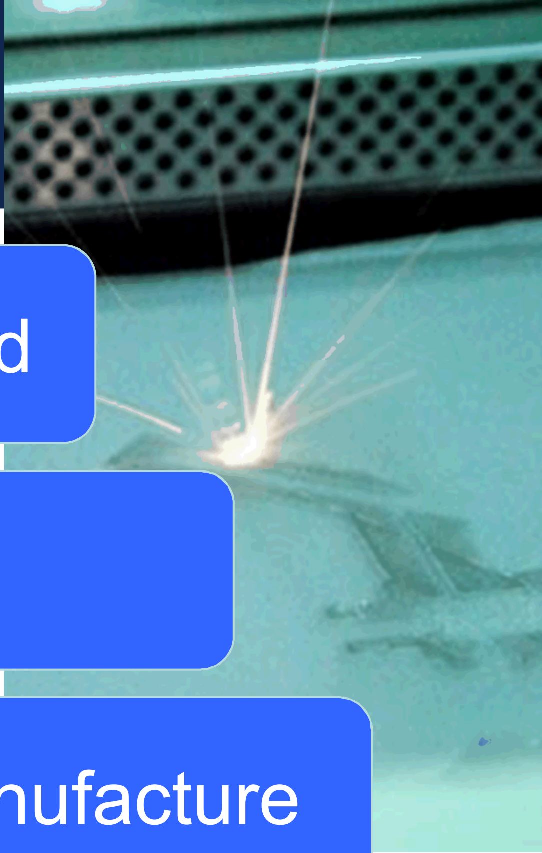


Design as Performance Prioritization



Inversion of Manufacture





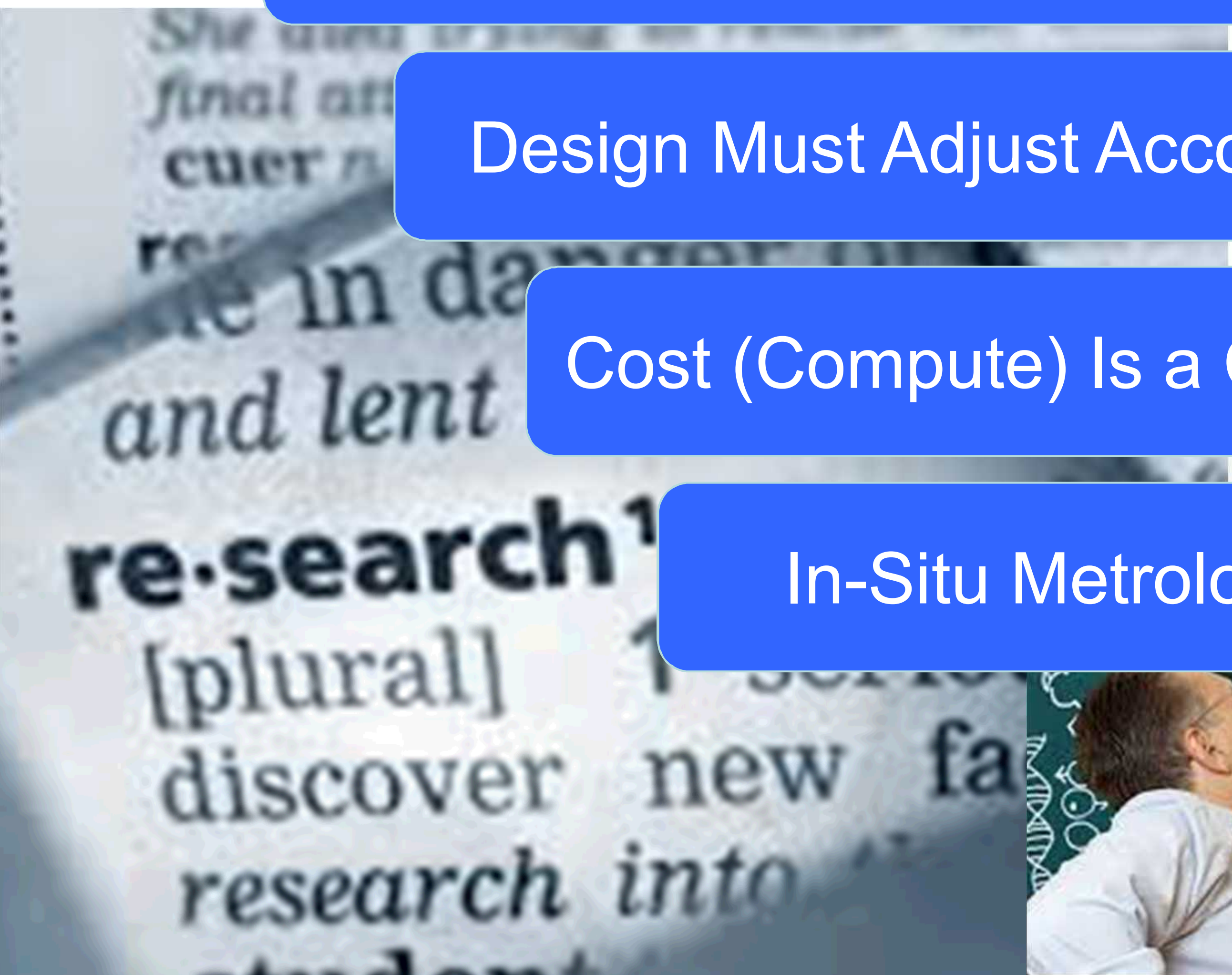
Complexity is ~~Free~~ Preferred

Minimal Waste

Fast Design To Manufacture

Mixed and Graded Materials

Inversion of Qualification



Point-Wise Material Variability

Design Must Adjust Accordingly

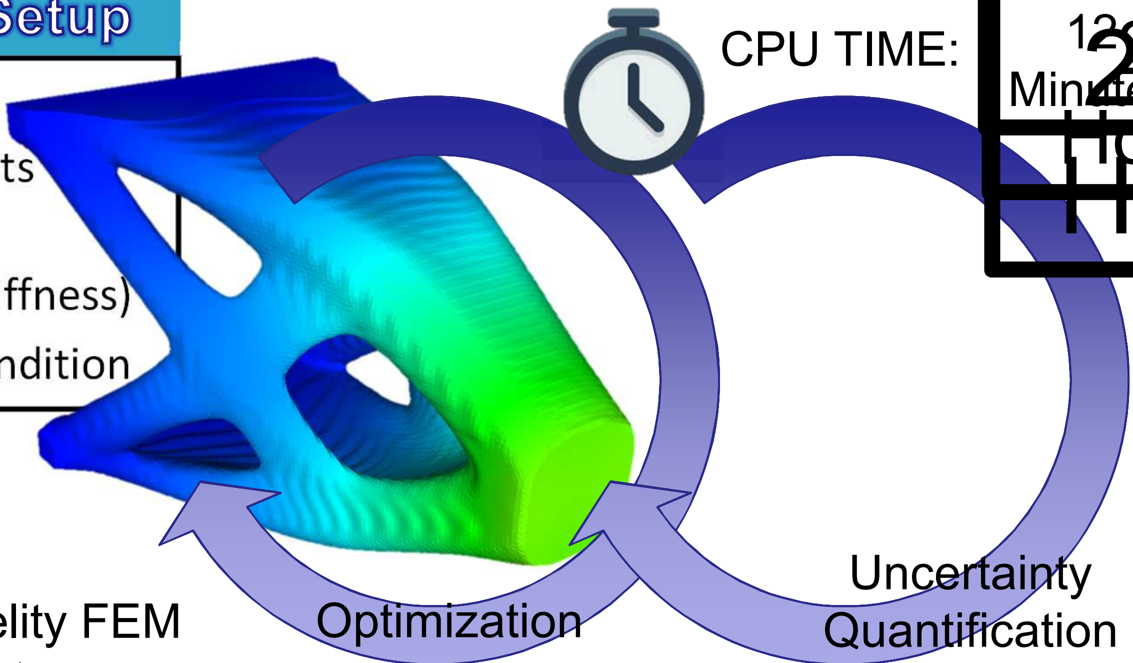
Cost (Compute) Is a Critical Issue

In-Situ Metrology to Validate

The Case For Surrogate-Based Optimization

Problem Setup

- Linear Statics
- 1.5M elements
- 1 Objective (Maximize Stiffness)
- 1 Loading Condition



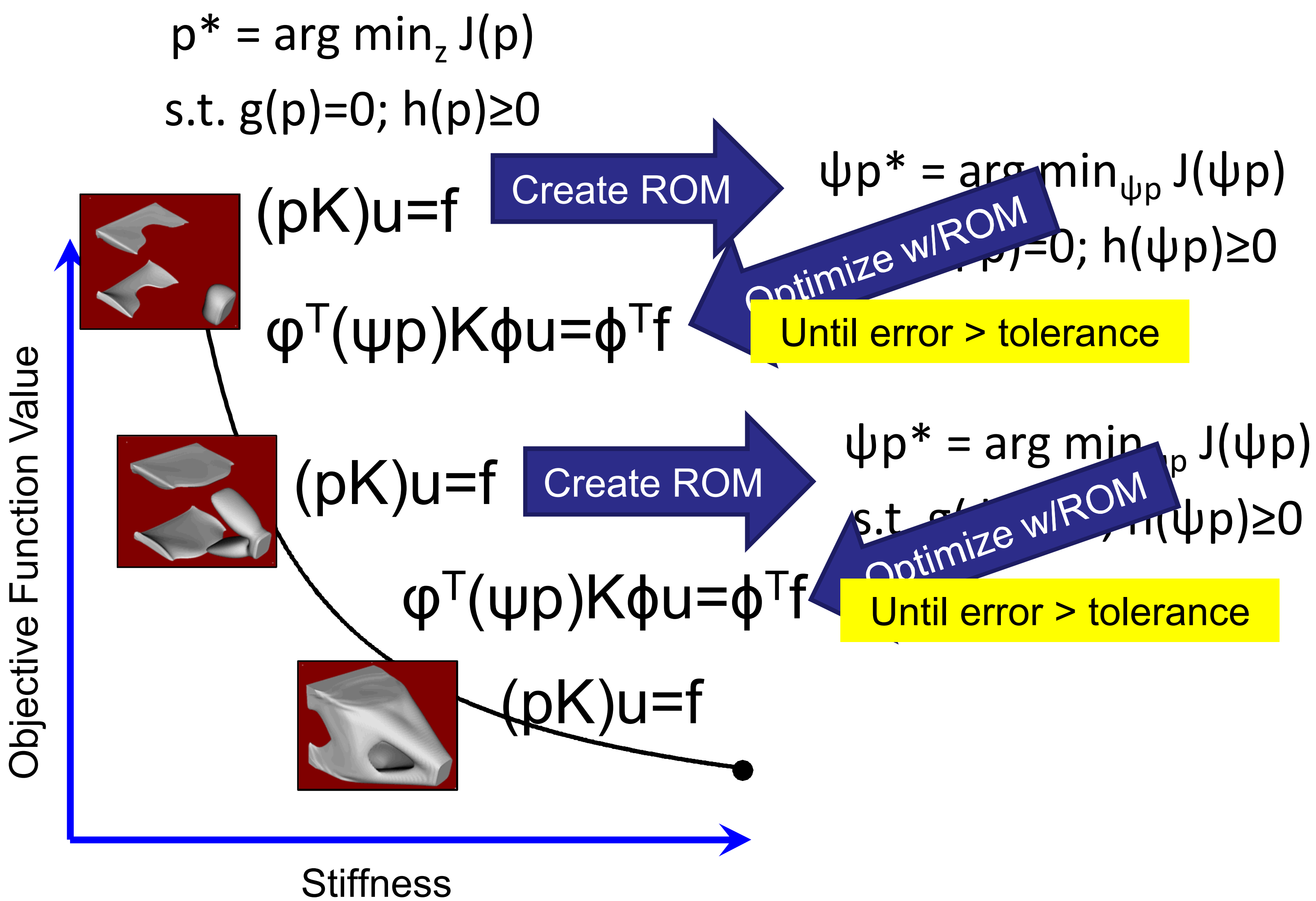
1 High Fidelity FEM ≈ 12 Minutes on 4196 … rs

X 2 Evaluations … er Iteration	X 50 Iterations	X 100 Sample…

Physics- Based Reduced Order Modeling

Smart Sampling Techniques

Physics-Based Reduced Order Modeling



Smart Sampling Techniques

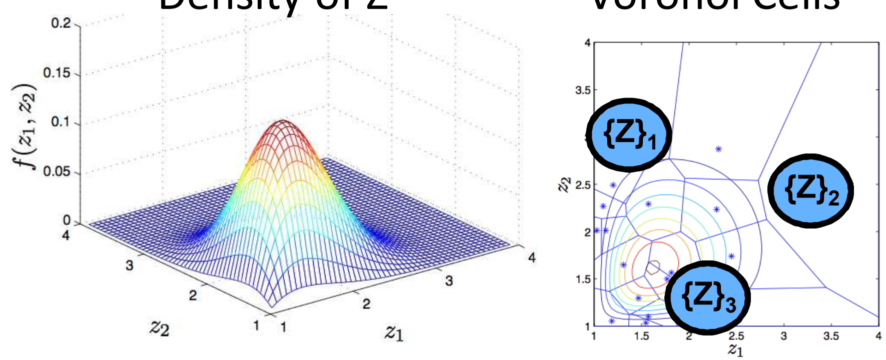
$p^* = \arg\min_p \mathbf{E}[U^T(pK(G,B))U]$

s.t.

$(pK(G,B))U - f = 0; V(p) \le V_0$

Stochastic ROM

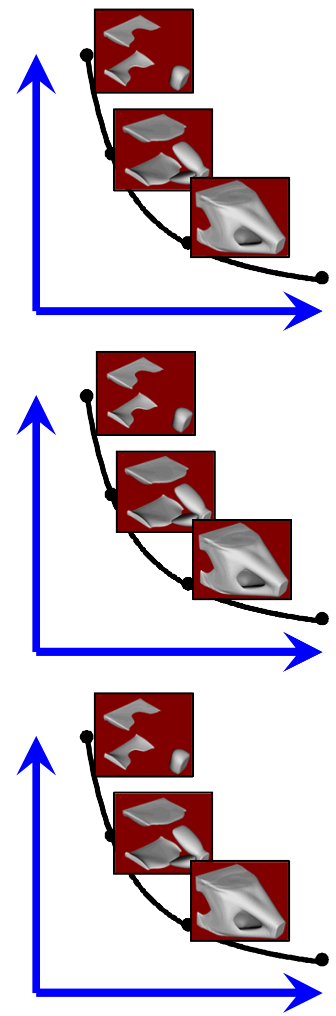
Density of Z | Voronoi Cells



Build SROM Given Available Resources (# FEM Runs That Can Be Performed)

$\{\mathbf{Z}\}_i$ = {Shear Modulus (G), Bulk Modulus (B)}

$1 \le i \le M$, M = #Samples

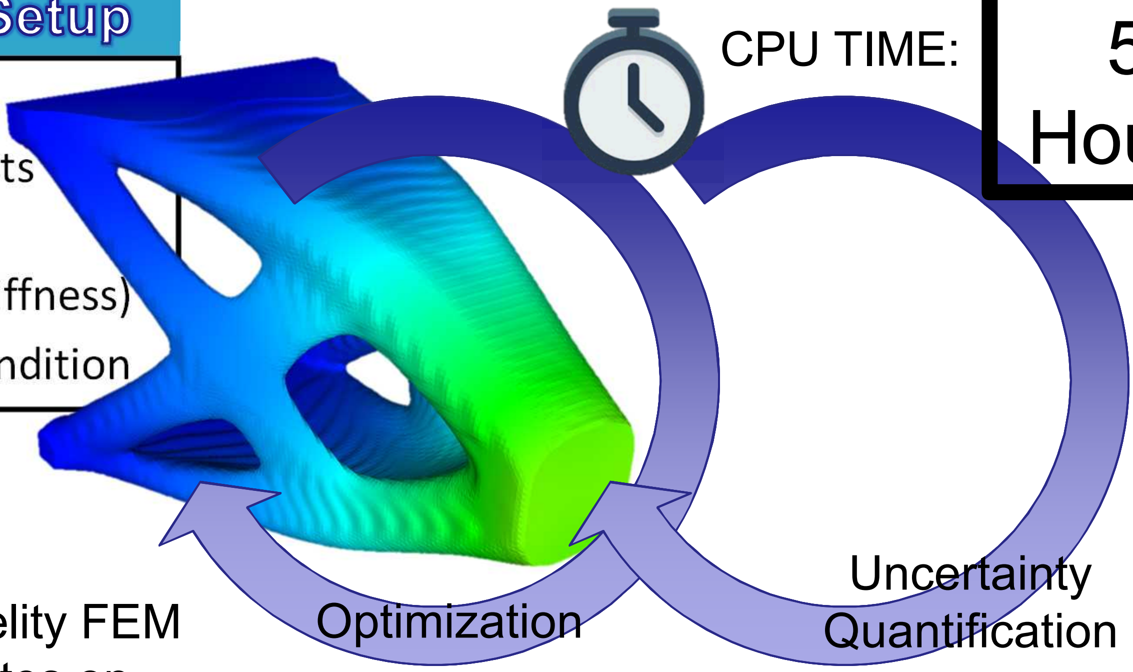


Expected Result of Surrogate-Based Optimization

Problem Setup

- Linear Statics
- 1.5M elements
- 1 Objective (Maximize Stiffness)
- 1 Loading Condition

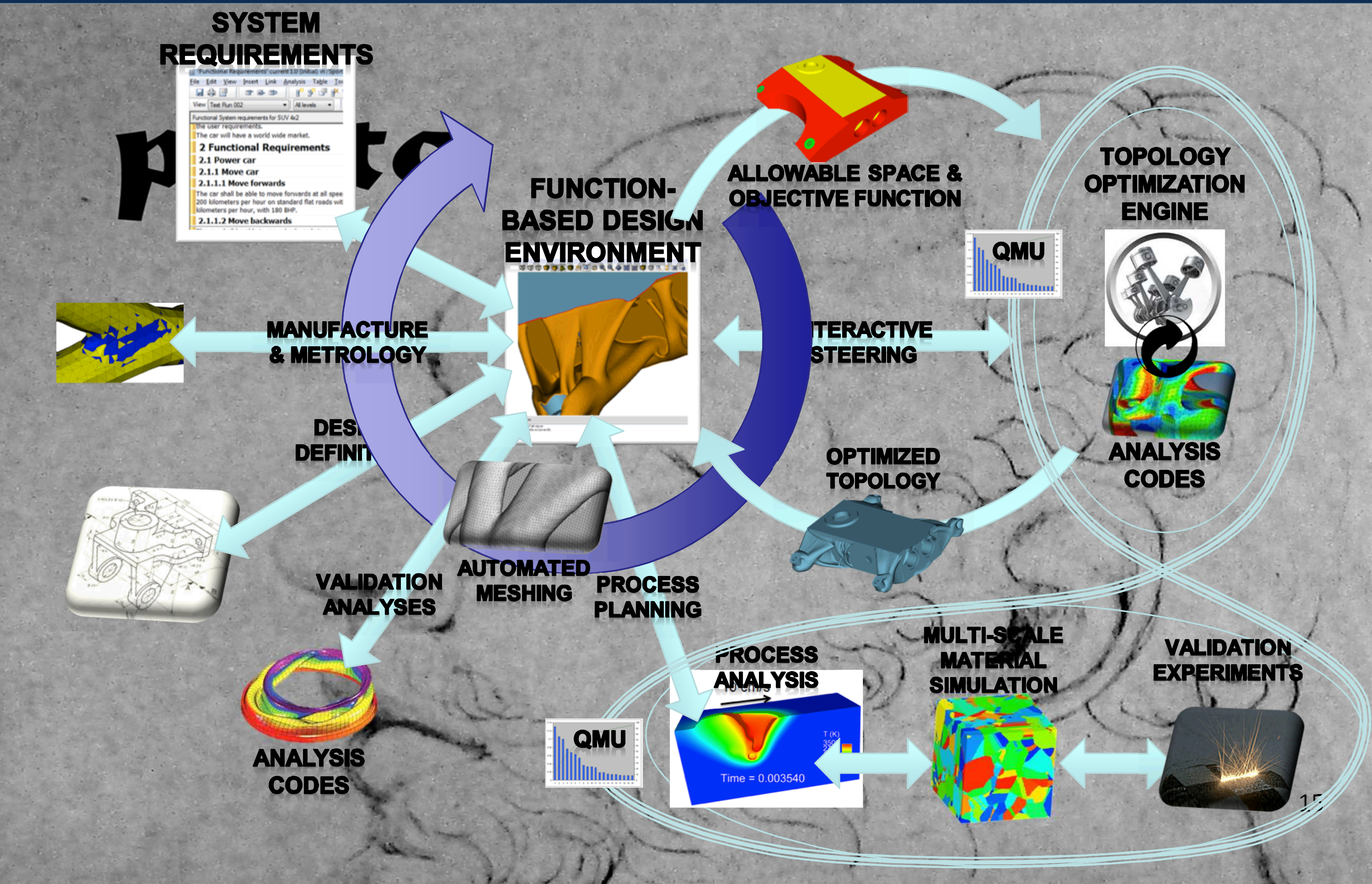
CPU TIME: **5 Hours**



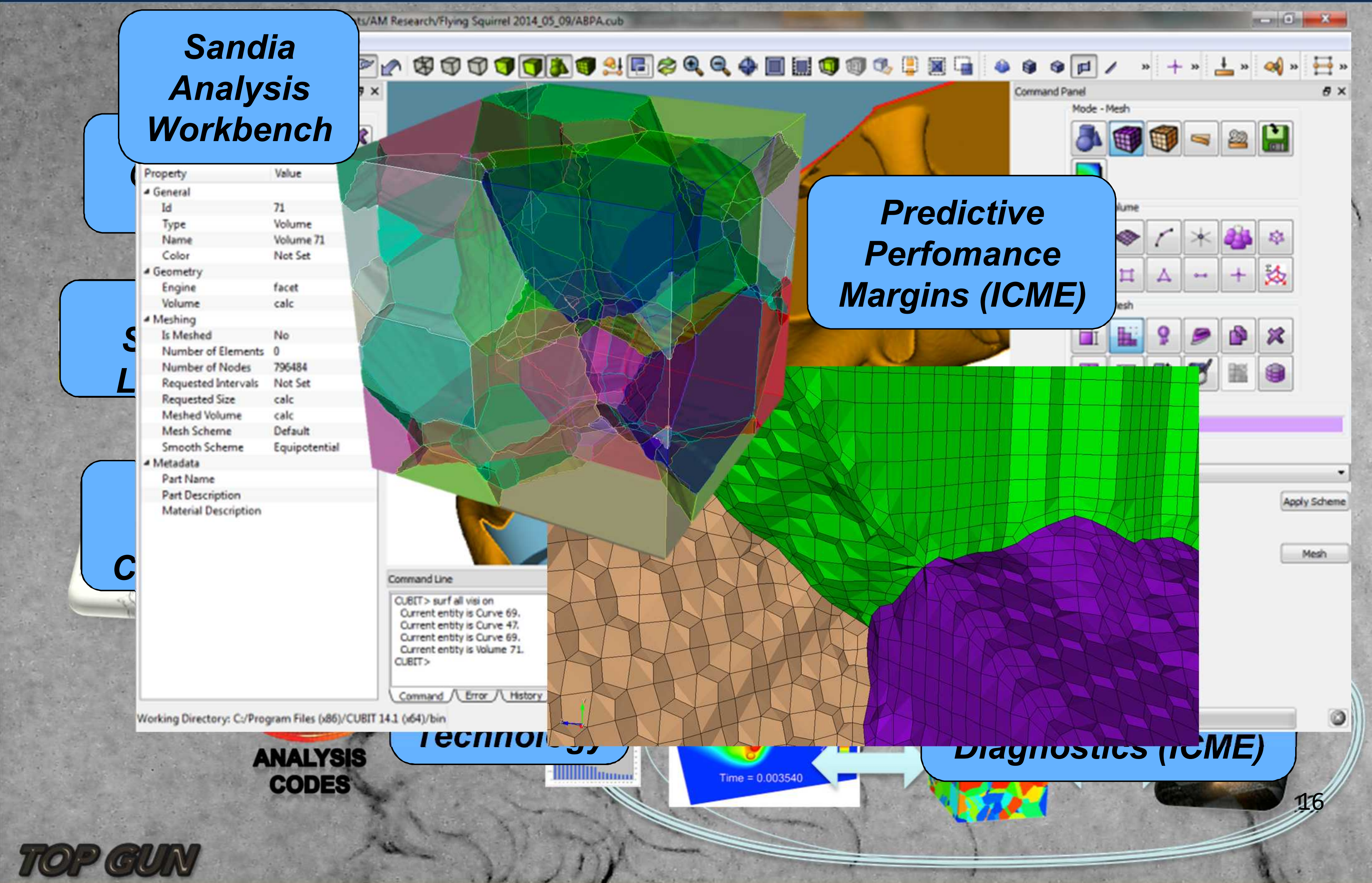
1 High Fidelity FEM ≈ 3 Minutes on 4196 Processors

X 2 Evaluations Per Iteration	X 50 Iterations	X 5 Samples

How Will This Revolution Work?



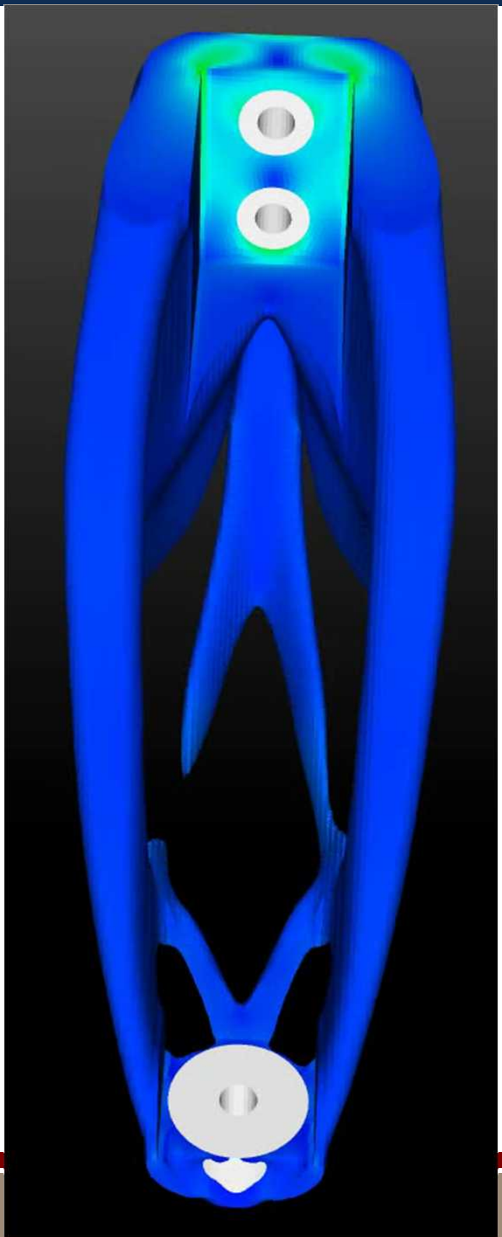
SNL Expertise That Makes This Feasible



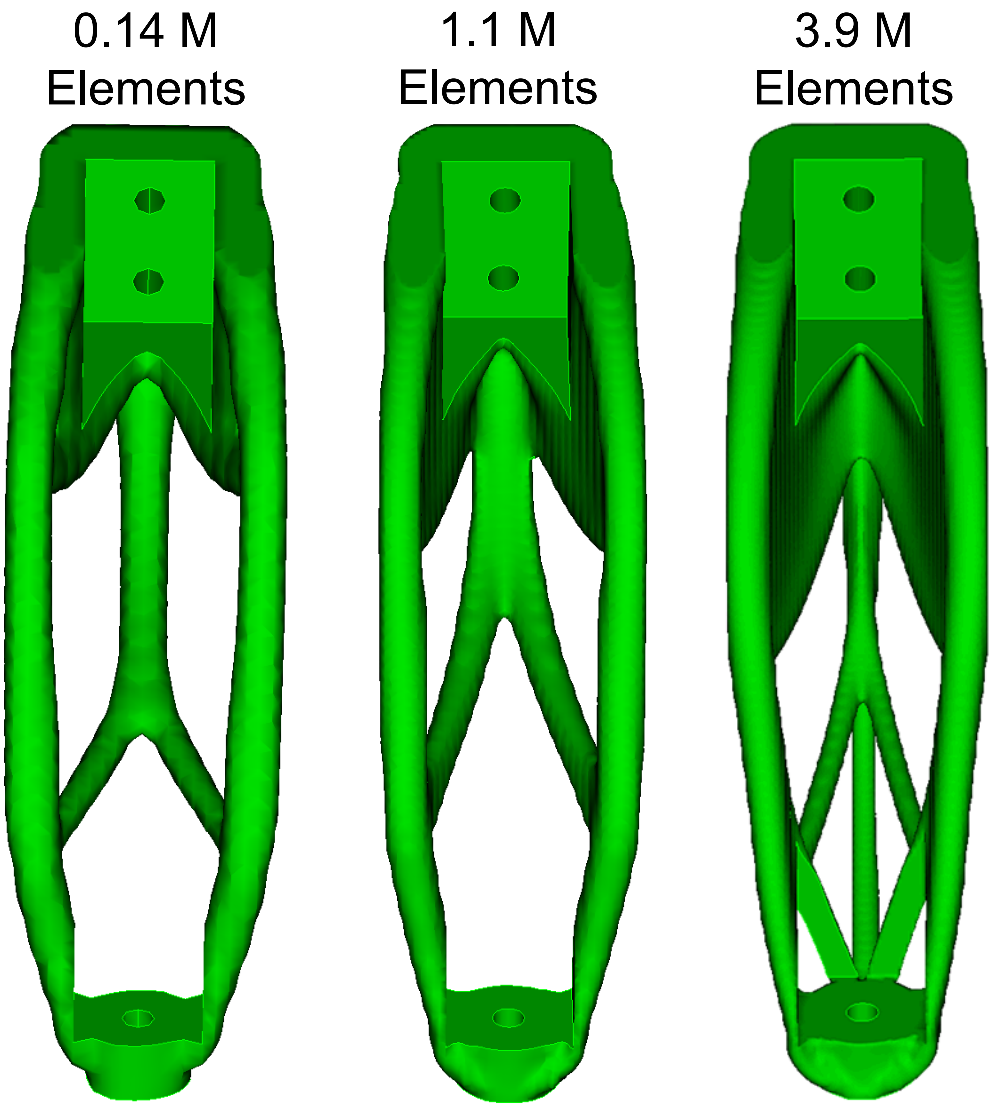
Demonstration: Optimization based design

Recent Example for NSC: Lantern Bracket

Sandia National Laboratories

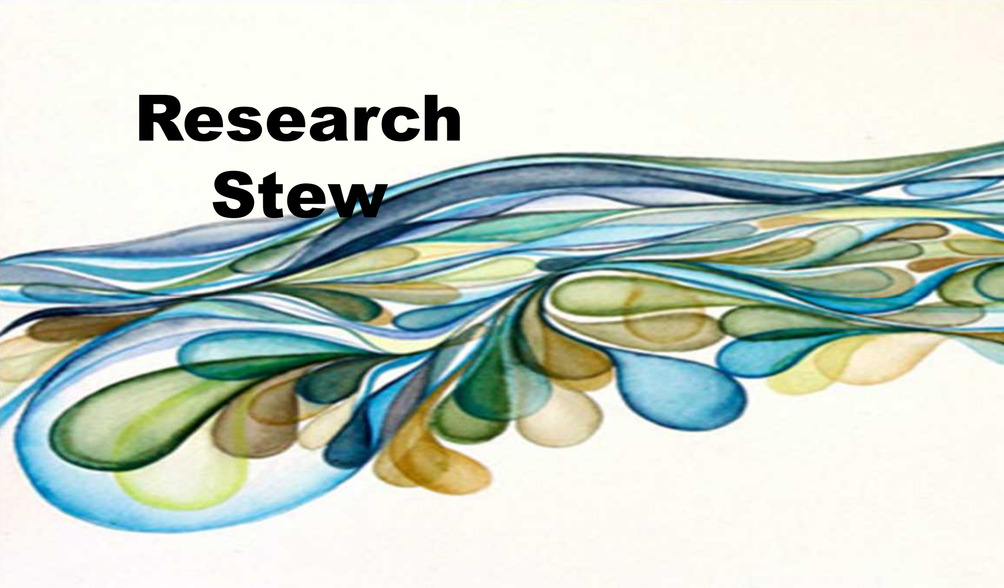


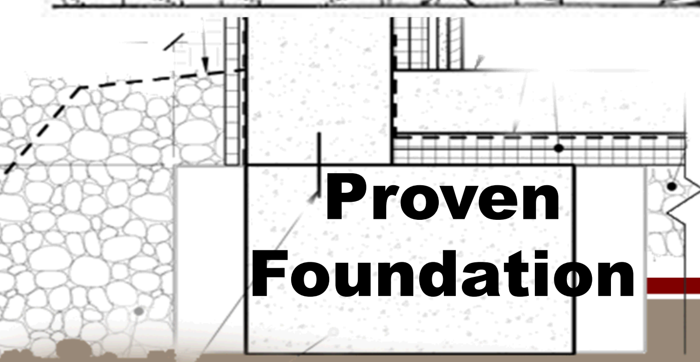
Numerical Sensitivities: Lantern Bracket

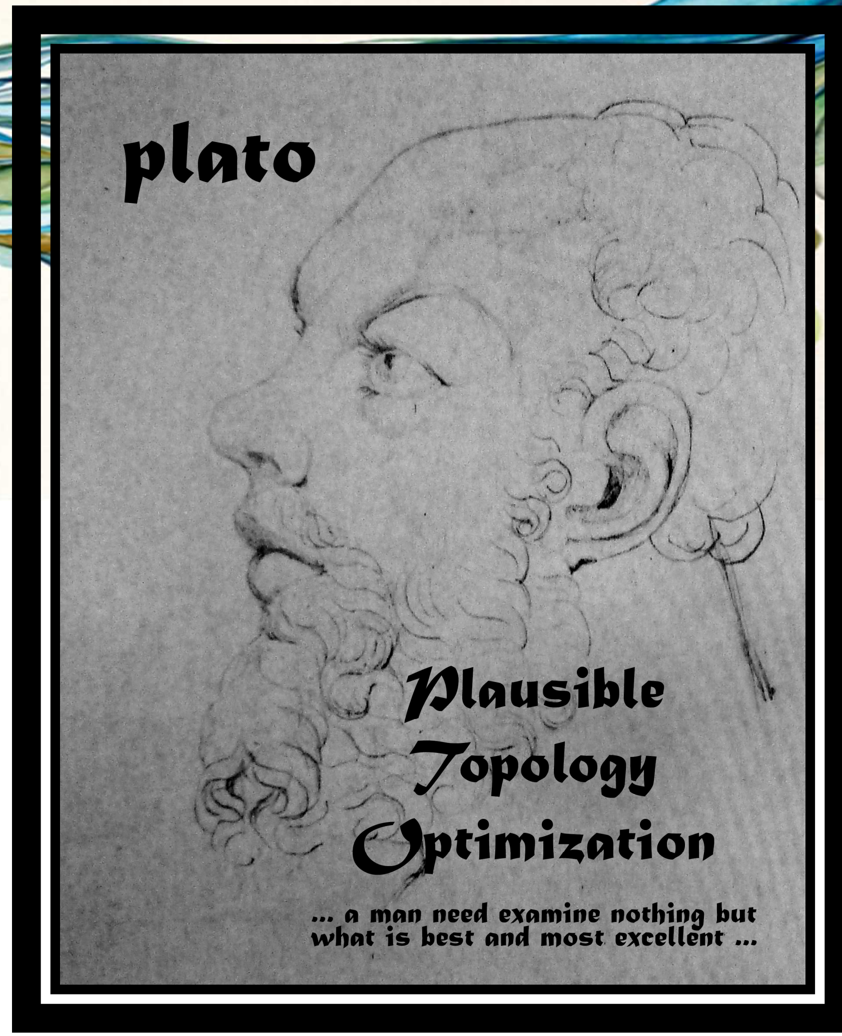


- Obvious dependency on mesh size
- Significant interactions with mesh filter size and mesh size
- Recently discovered sensitivity to mesh regularity and filtering mechanisms

PLATO Technology Plan



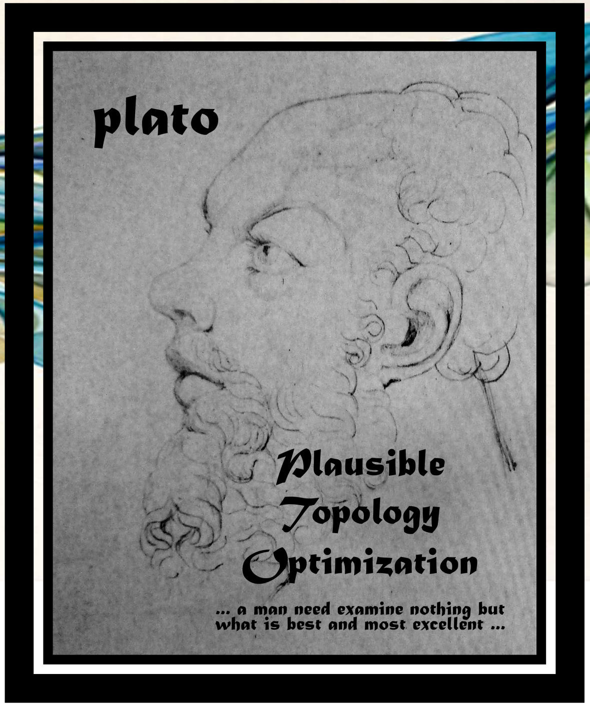




PLATO Technology Plan

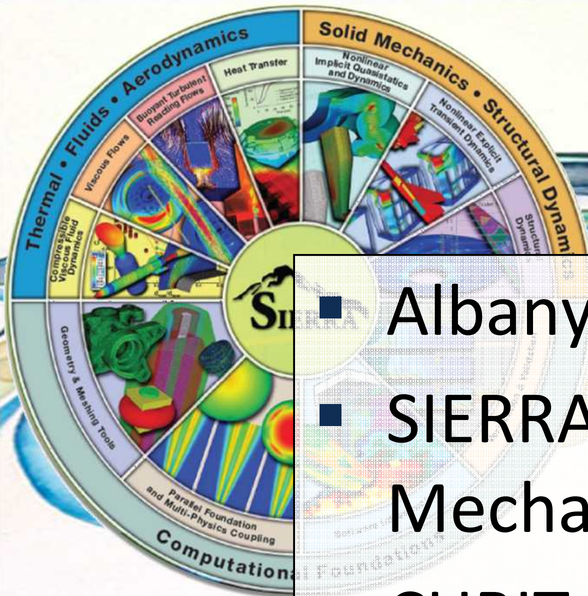
Research Stew

Kurt Maute, U Colorado Boulder
Krishnan Suresh, U Wisconsin
Albert To, U Pittsburg
Alicia Kim, U Cal San Diego

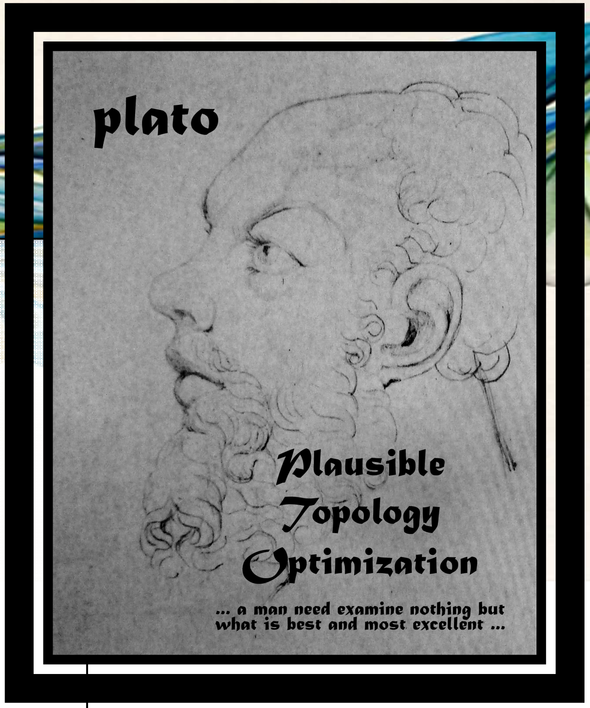


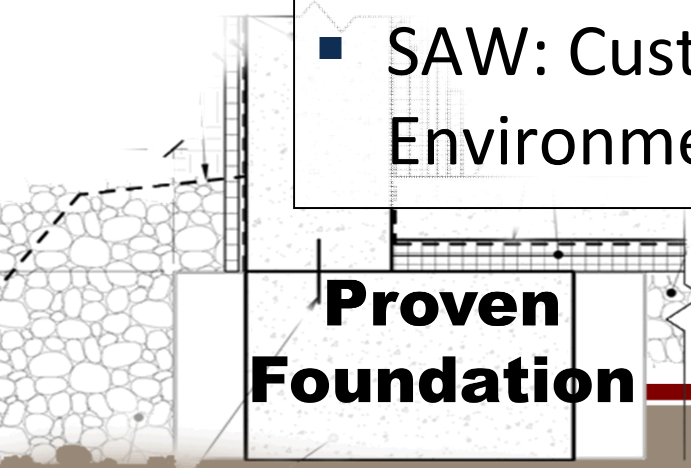
- **X-FEM Explicit Boundaries**
- **Shape Sensitivities**
- Micro to Macro
- Sliding Interfaces
- Compliant Structures
- **Reduced Order Modeling**
- **Adaptive +/- Refinement**
- **Uncertainty Inclusion**

PLATO Technology Plan

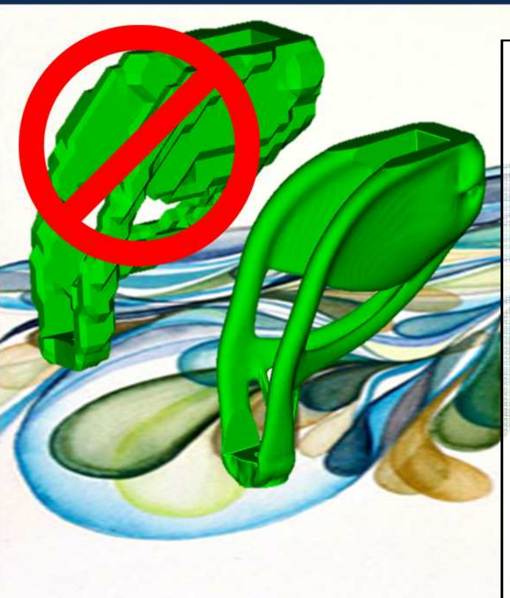


- Albany: Research Platform
- SIERRA: Production Mechanics Codes
- CUBIT: Geometry & Meshing Tools and Expertise
- SAW: Customizable Workflow Environment



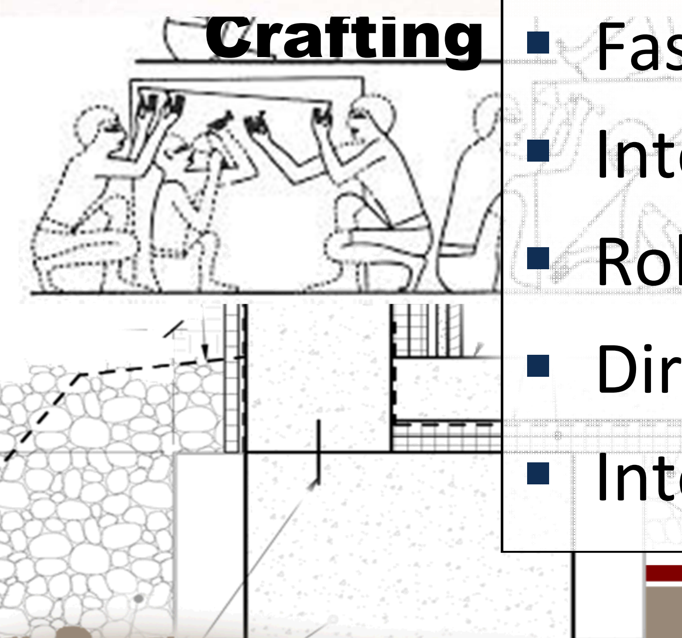


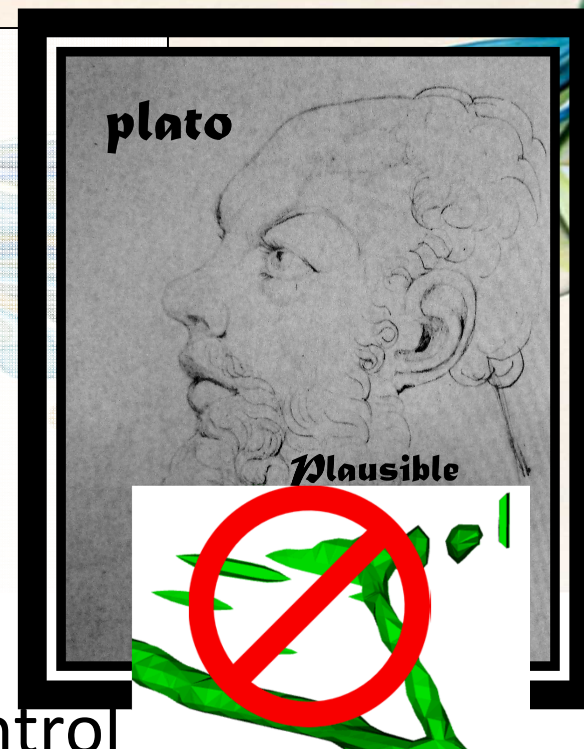
PLATO Technology Plan

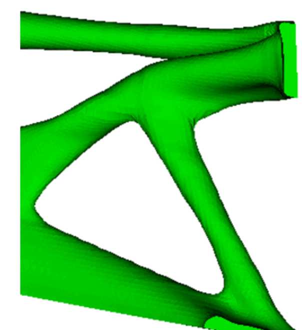


Expected Outcomes:

- Modern Design/ Analysis Environment
- Clean, Smooth, Connected Shapes
- Fast Convergence
- Interactive Speed & Control
- Robust designs
- Directly Printable Output
- Interface to CAD



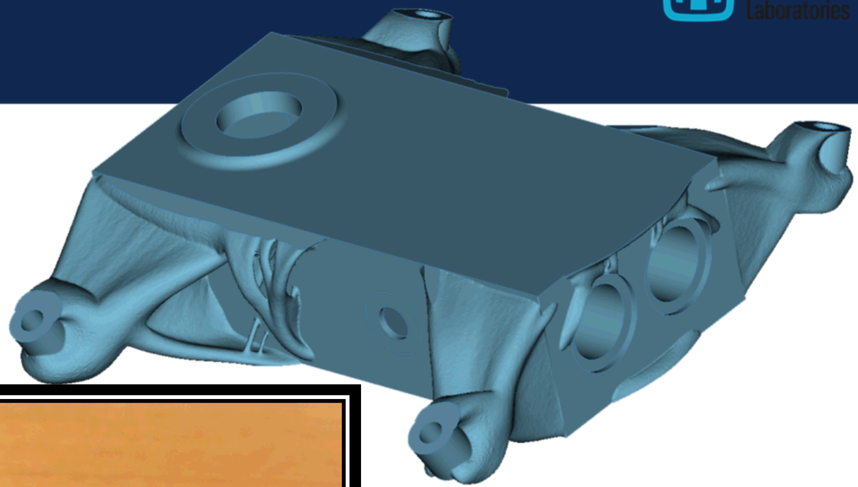


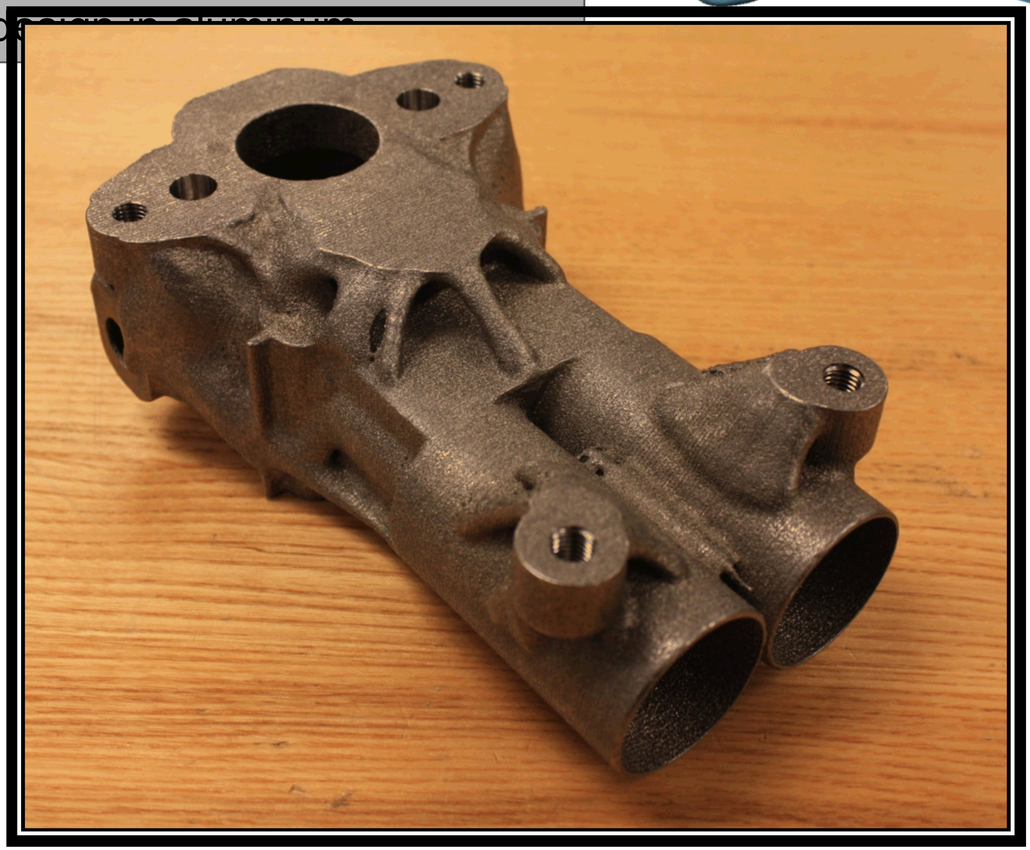


Demonstration Exemplar

Sandia National Laboratories

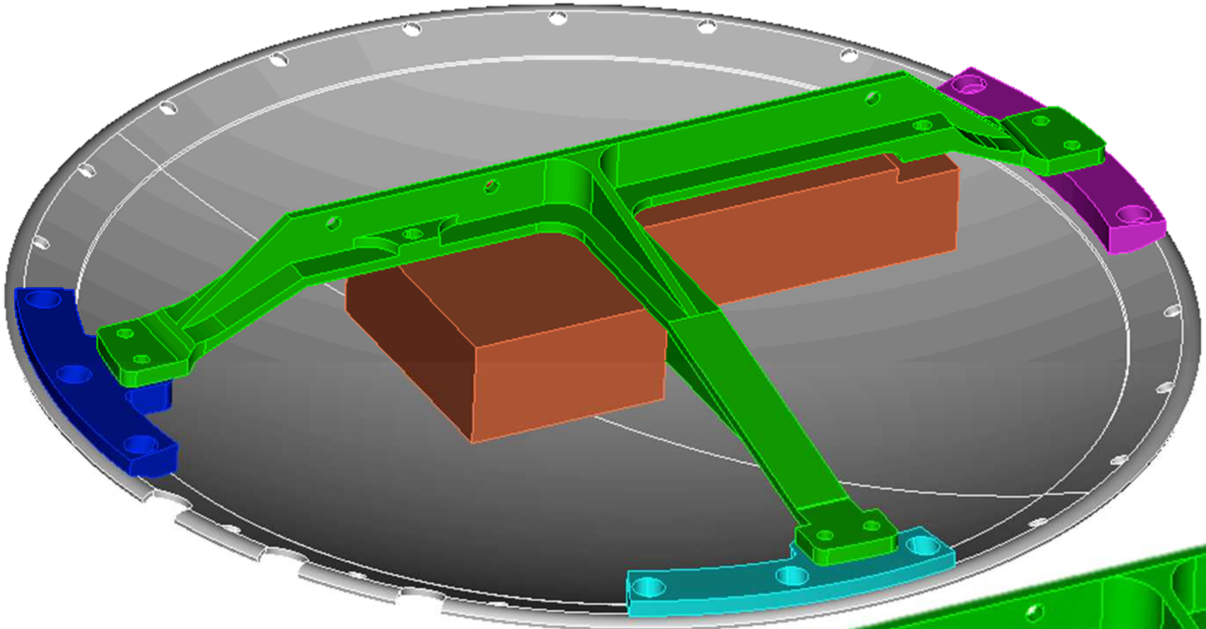
Optimized design (using same mass and material, i.e., carbon phenolic) achieves 39% average increase in modes of interest, compared to 23% increase achieved by printing original d

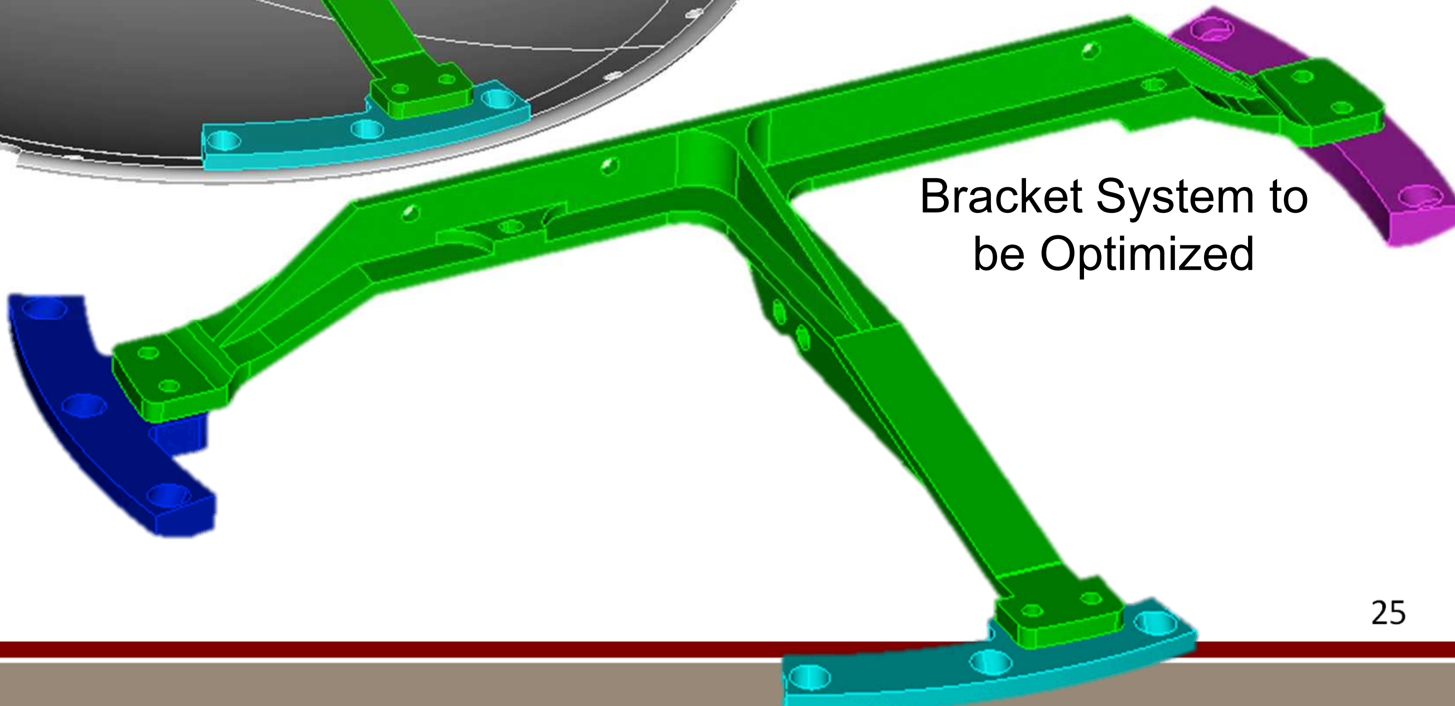




Bracket Design Problem

Entire Bracket-Mass Assembly

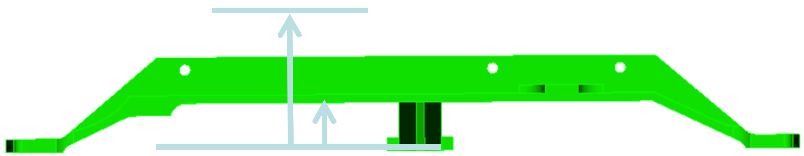


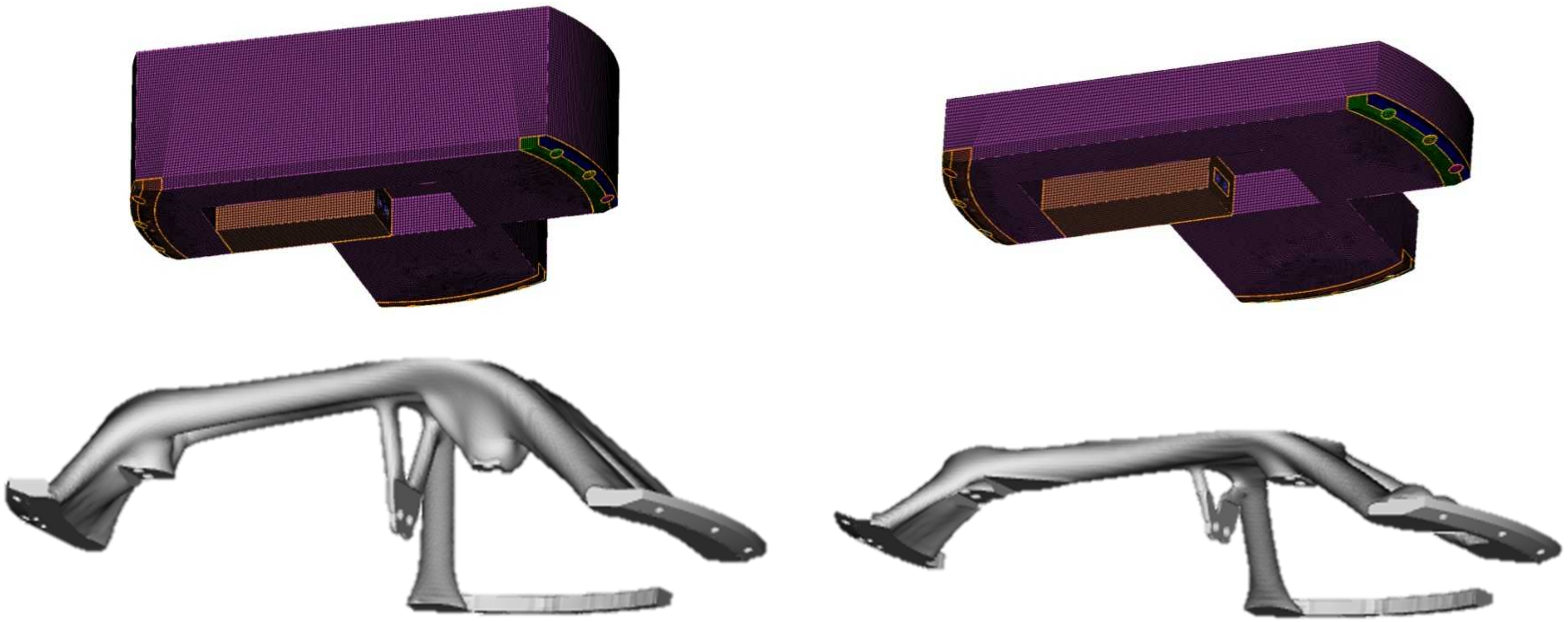


Bracket System to be Optimized

Bracket Design Problem

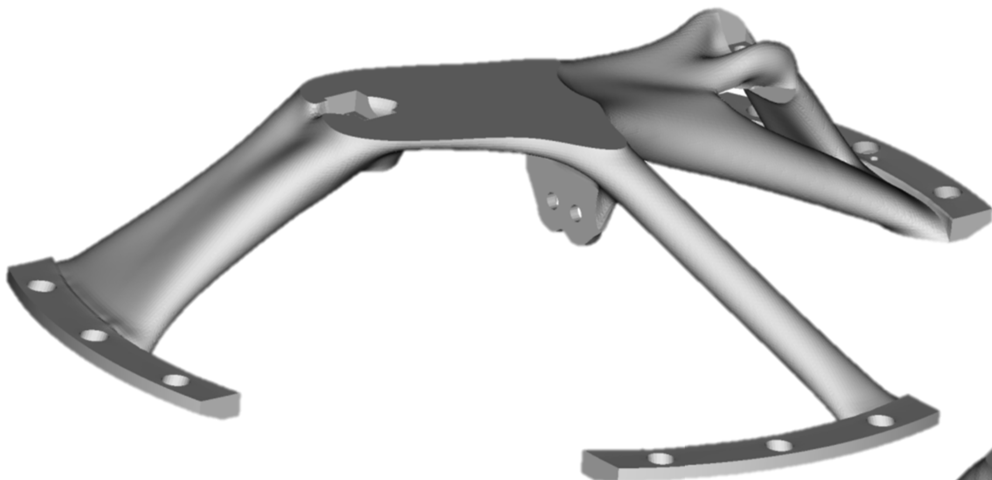
Rapid Design Response to Source Requirement Change

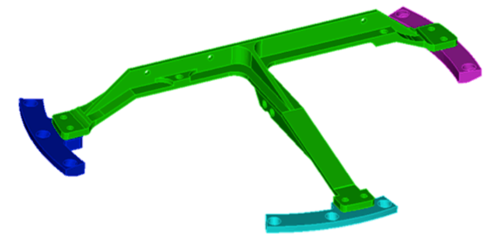




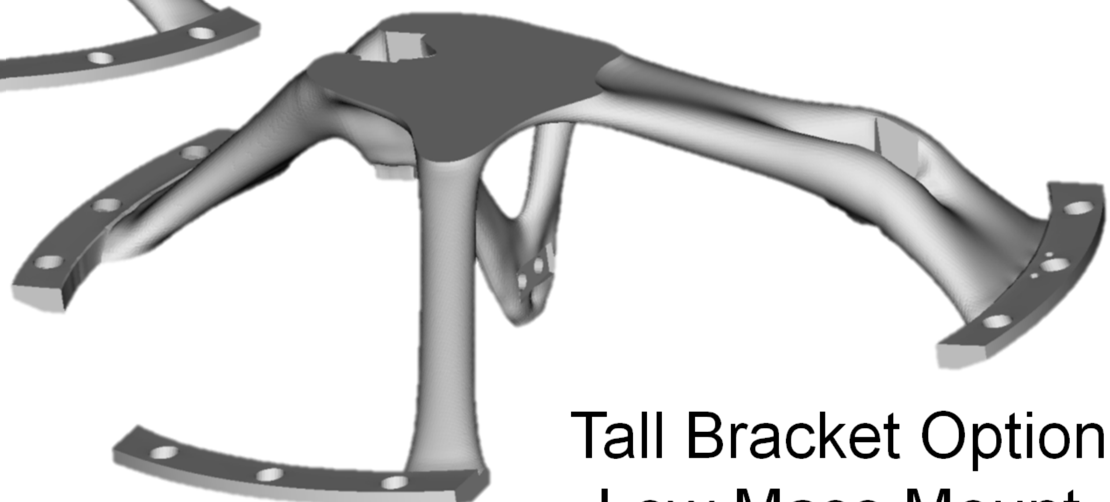
Bracket Design Problem

Refinements on Design with Options on Mass Mounting





Tall Bracket Option
High Mass Mount



Tall Bracket Option
Low Mass Mount

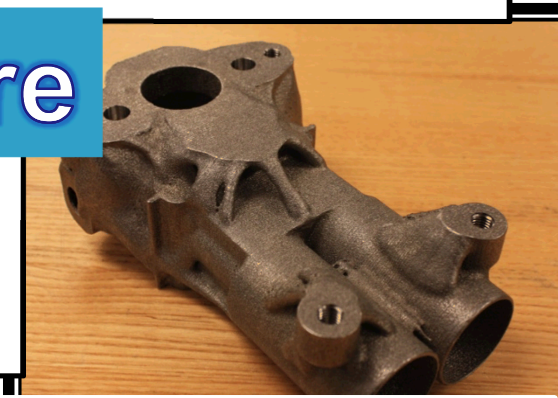
Realizing the Revolution

Invert Qualification

In-Situ Validation of
Materials & Processes

Invert Manufacture

Powder Bed
Metal Additive



Invert Design

Topology Optimization
with Material Locality

- Disruptive Change for NW
- Disruptive Change for SNL
- Disruptive Change for World of Engineering