Exceptional service in the national interest

Sandia National Laboratories

Revolutions in Design and Manufacture: Topology Optimization and Uncertainty Quantification in Additive Manufacturing

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(as told by Corbett Battaile)

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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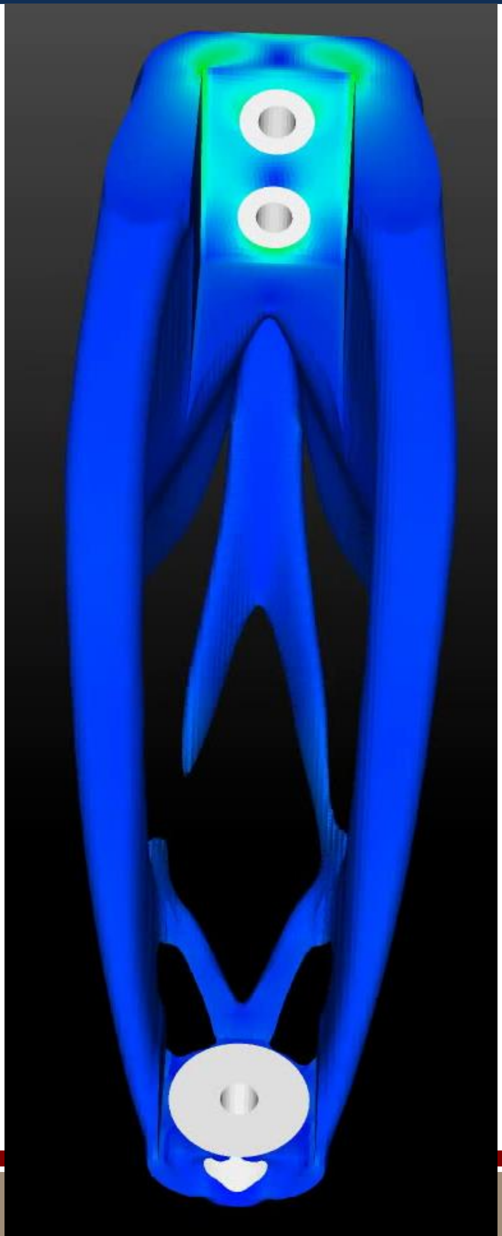
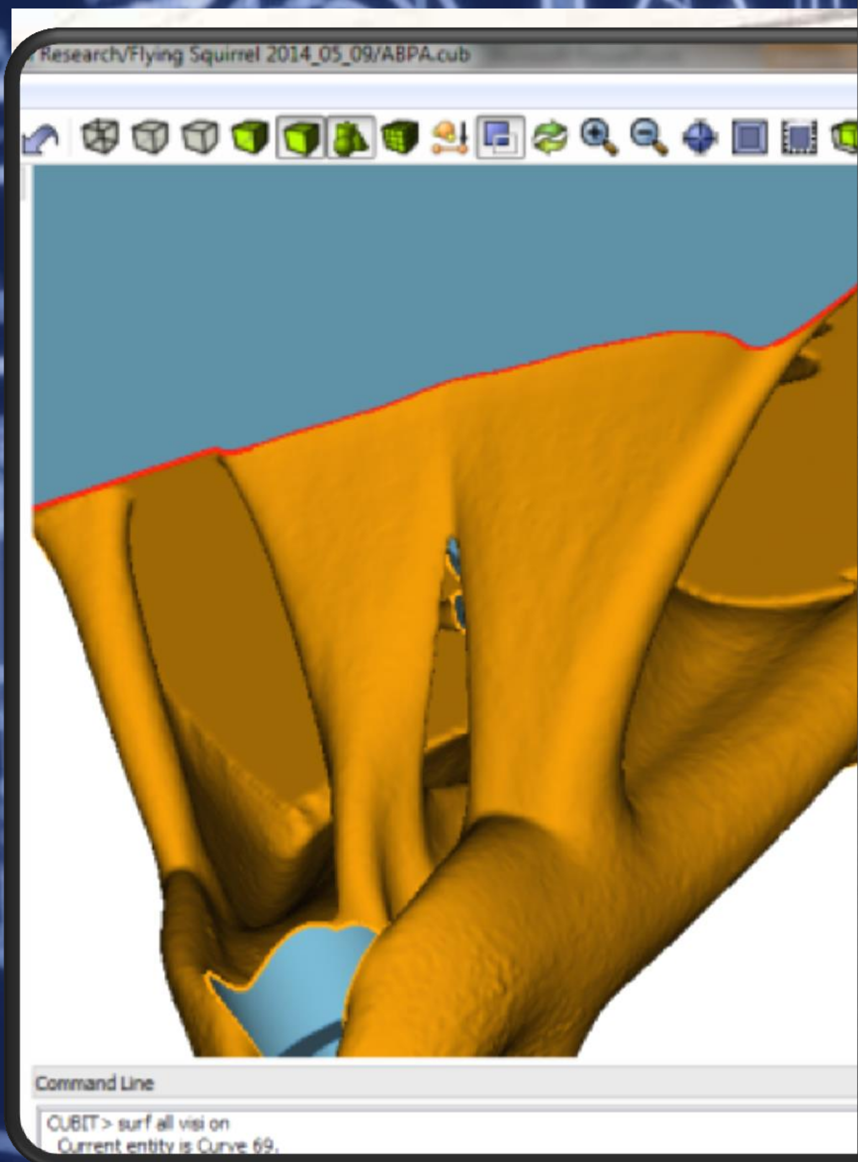
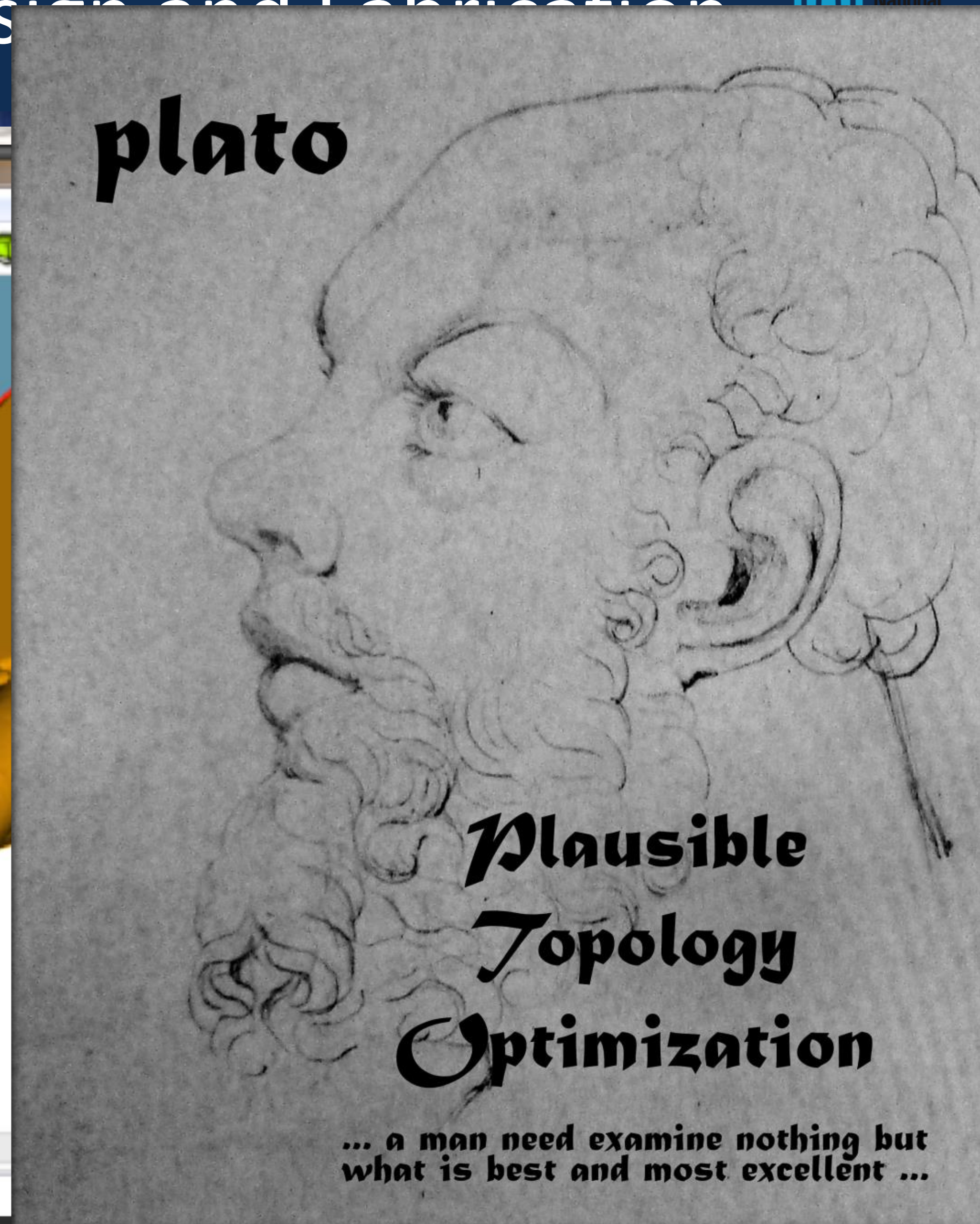
Example: Lantern Bracket



A Revolution in Des



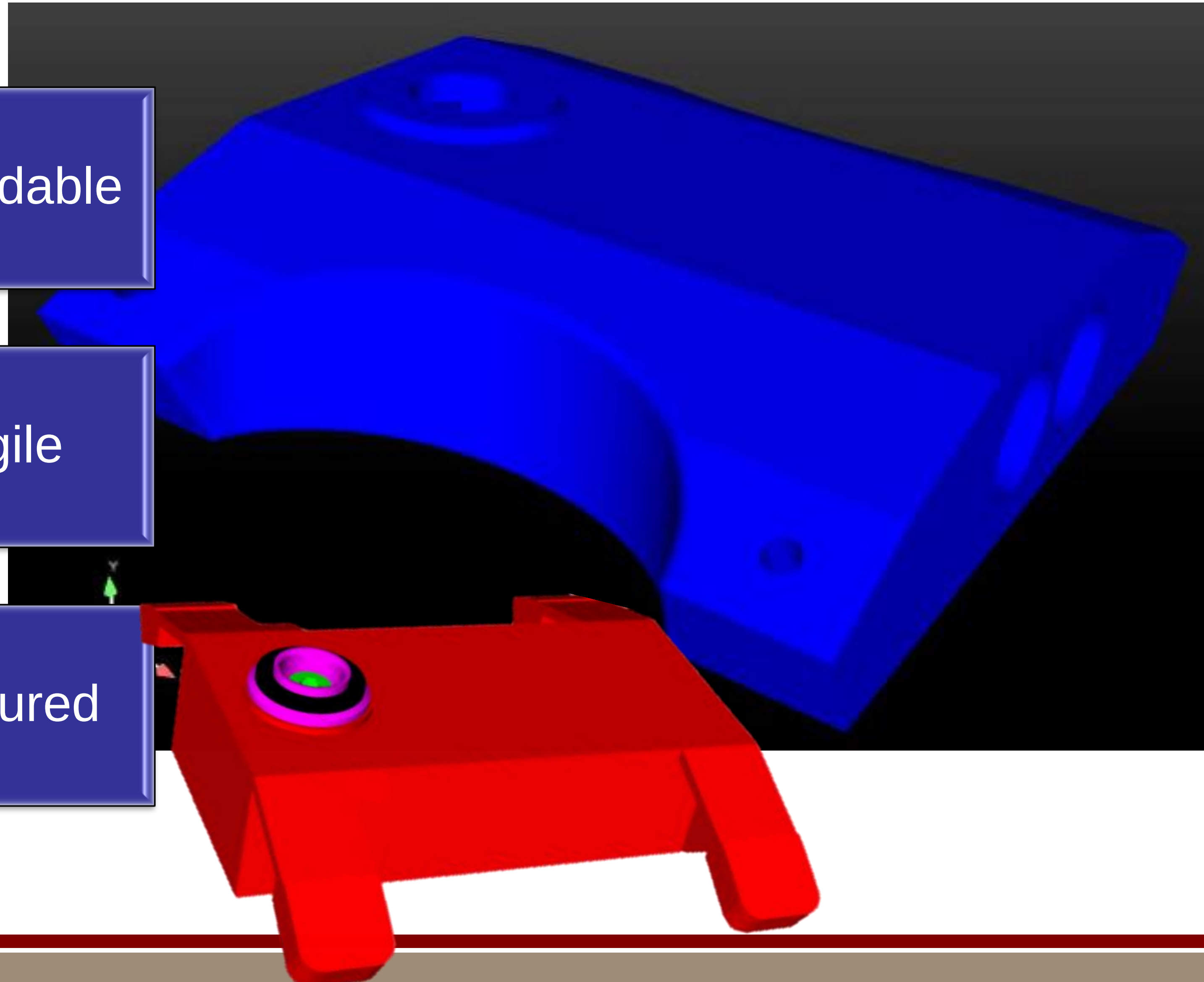


Introduction to This Revolution

- Affordable

- Agile

- Assured



Enormous Opportunity (with Challenges)

Profoundly New Design Flexibility

In-Situ Material Qualification

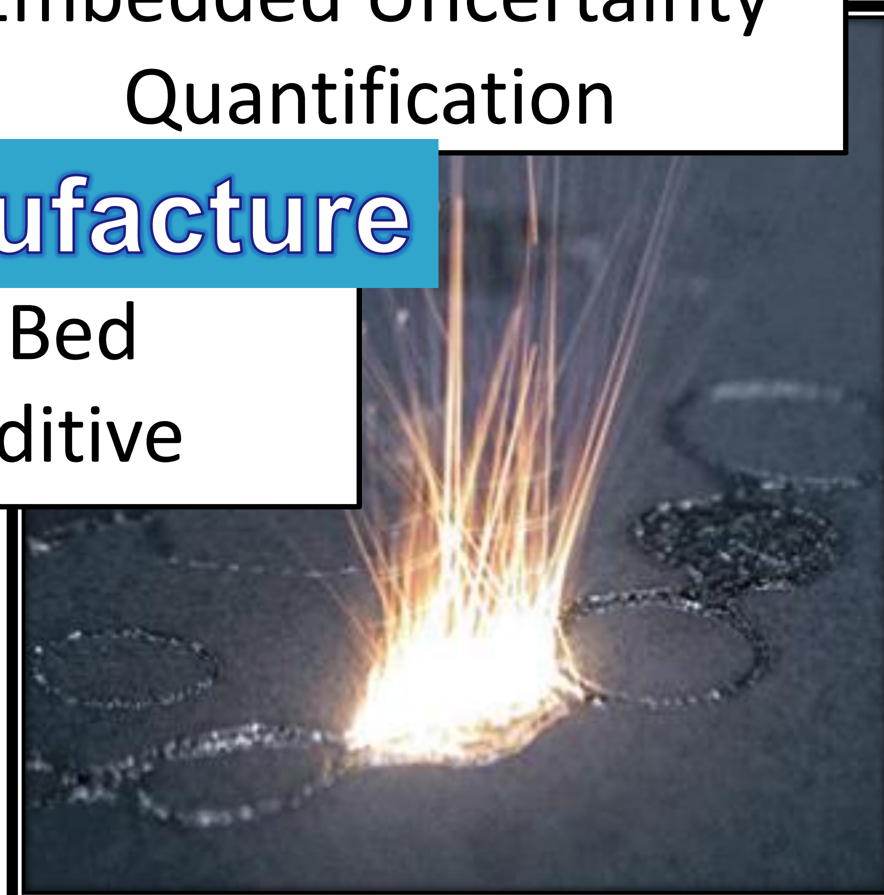
Inverting Conventional Design Paradigms

Invert Qualification

Embedded Uncertainty Quantification

Invert Manufacture

Powder Bed Metal Additive



Invert Design

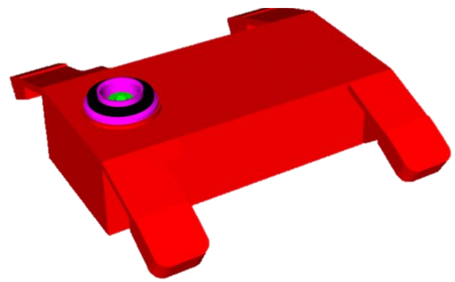
Topology Optimization with Material Locality

Inverting Conventional Design Paradigms

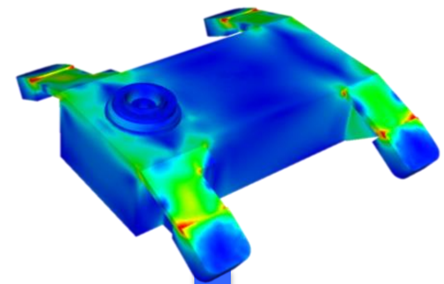
CURRENT

Specify Form

Design



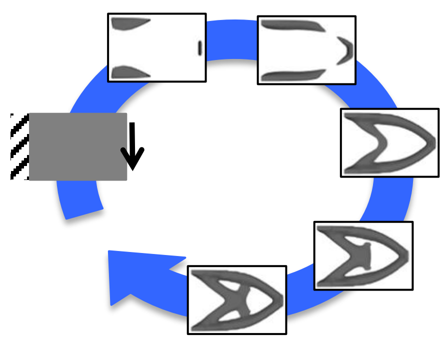
Verify Function Using FEA



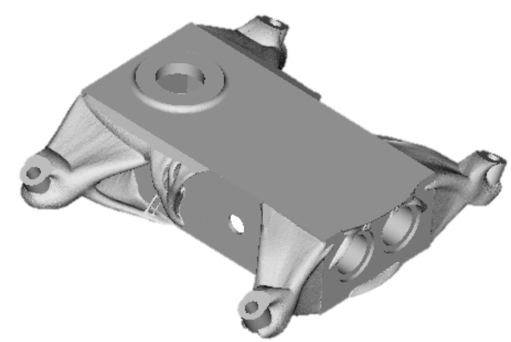
NEW

Specify Design Domain and Function

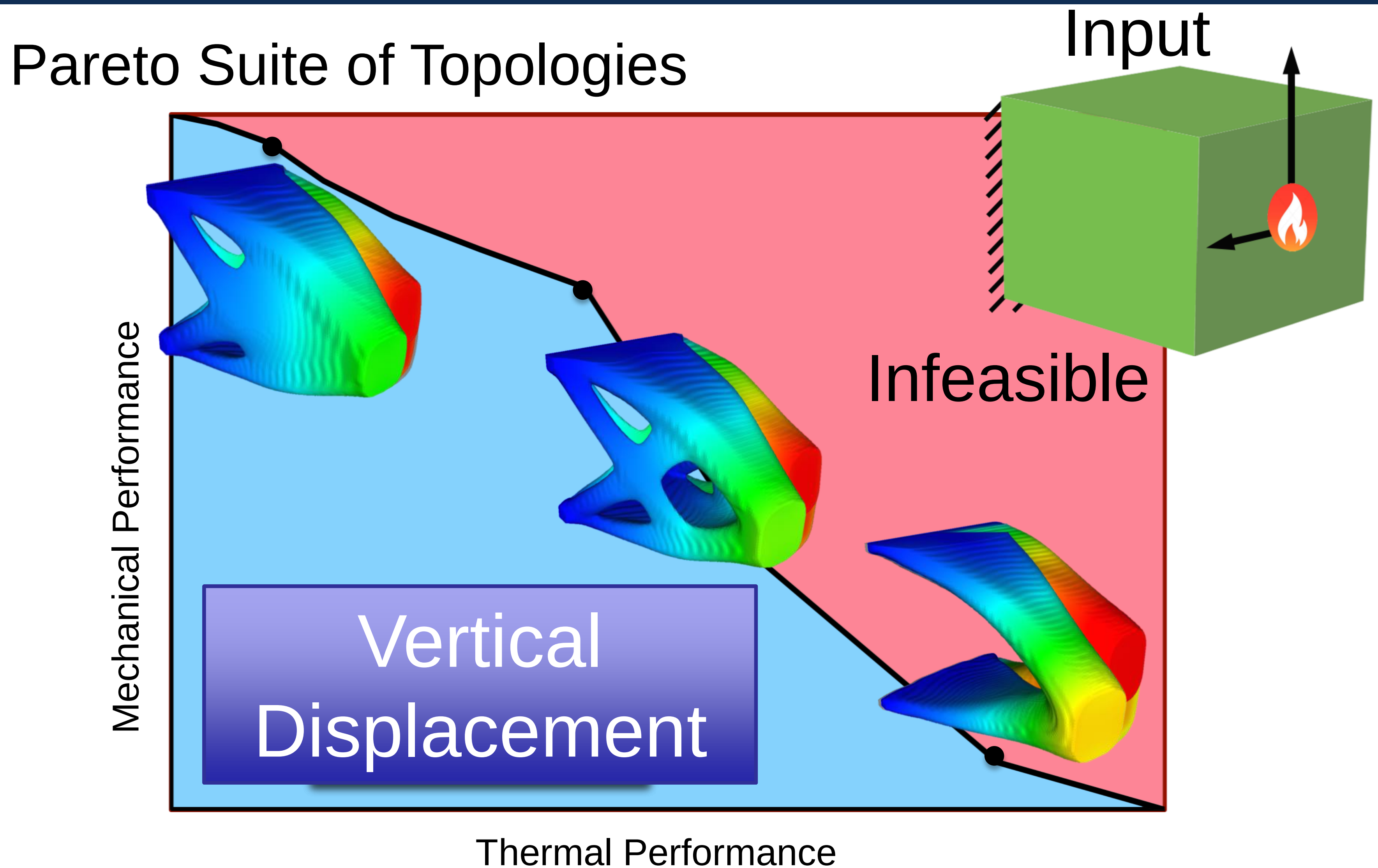
Use Topology Optimization (FEA) to Determine Form that Meets Function



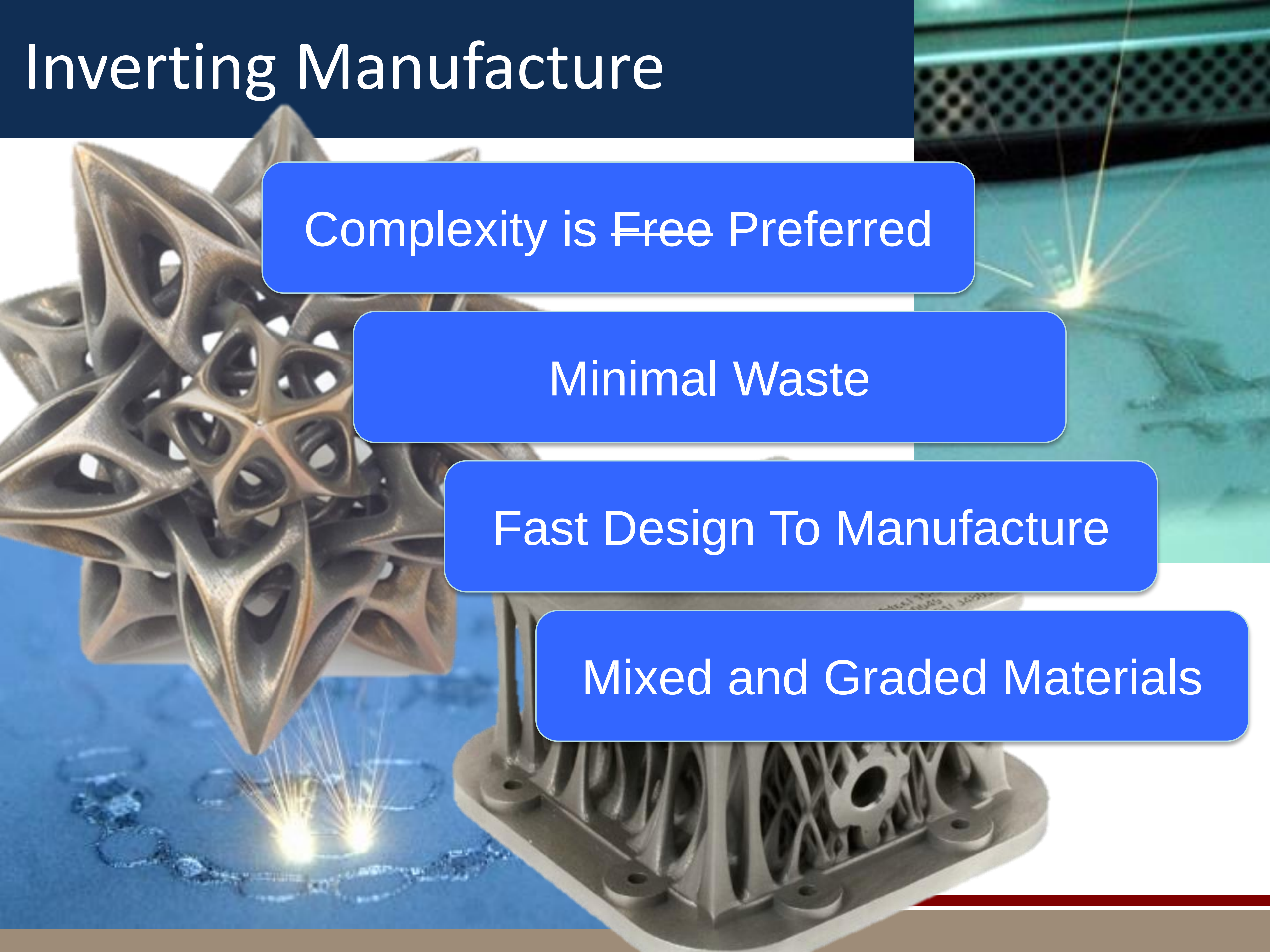
Optimized Design (Form)



Design by Performance Prioritization



Inverting Manufacture



Complexity is ~~Free~~ Preferred

Minimal Waste

Fast Design To Manufacture

Mixed and Graded Materials

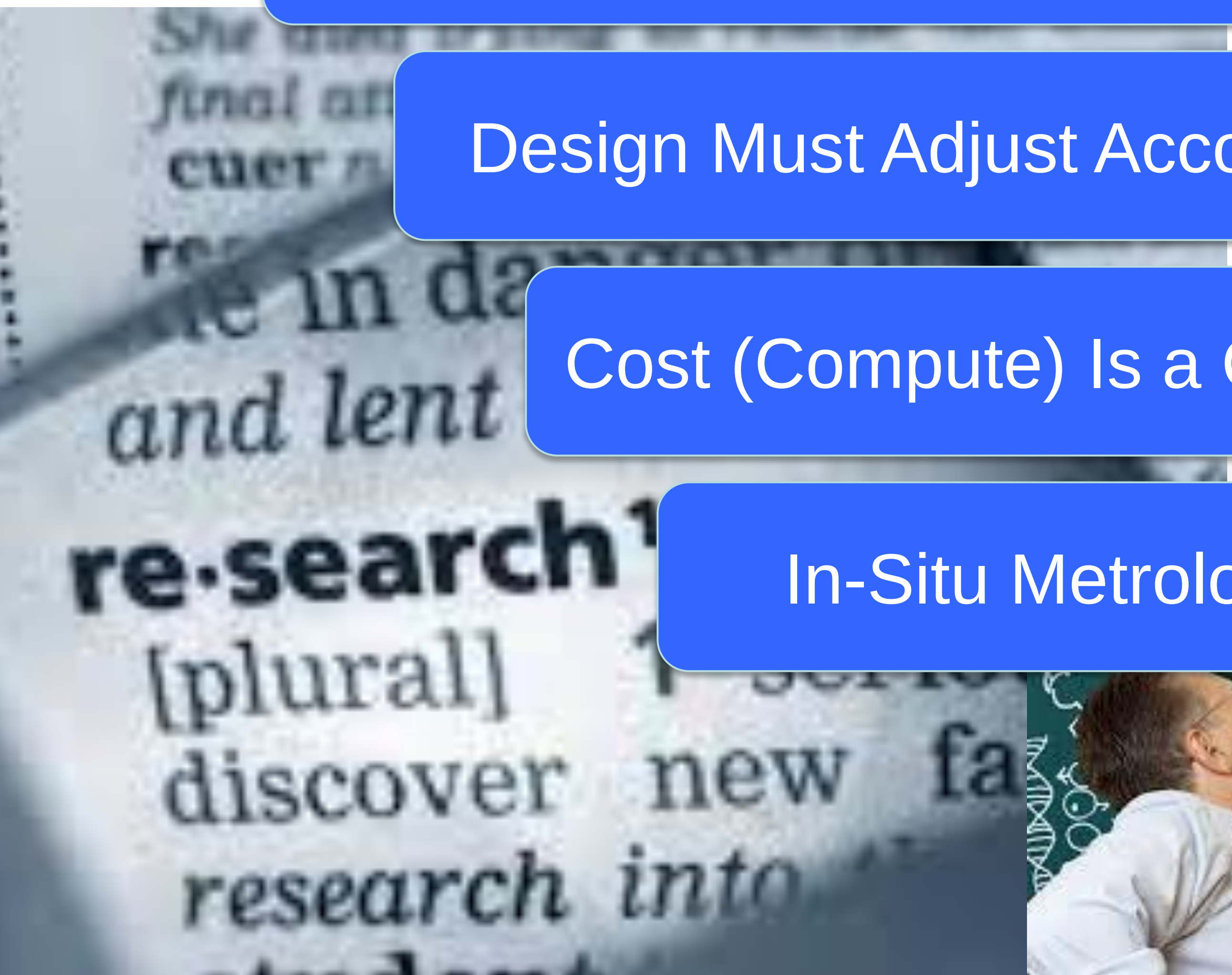
Inverting Qualification

Point-Wise Material Variability

Design Must Adjust Accordingly

Cost (Compute) Is a Critical Issue

In-Situ Metrology to Validate

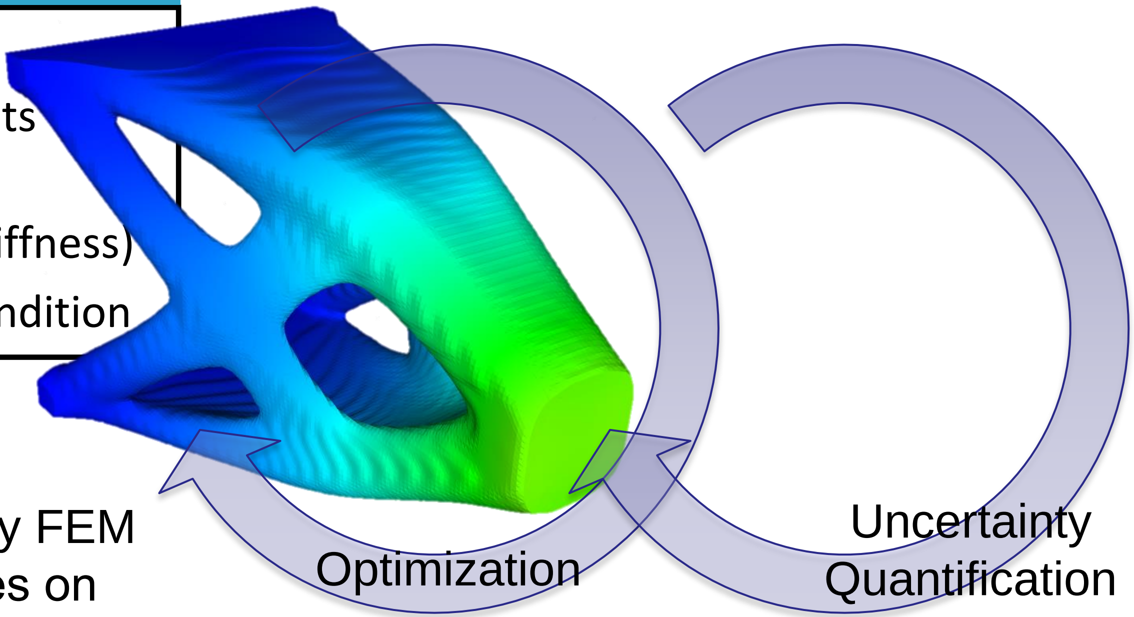


Making Resource Requirements Reasonable

Problem Setup

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

CPU TIME: 1200 Minutes
20 Hours
2000 Weeks!



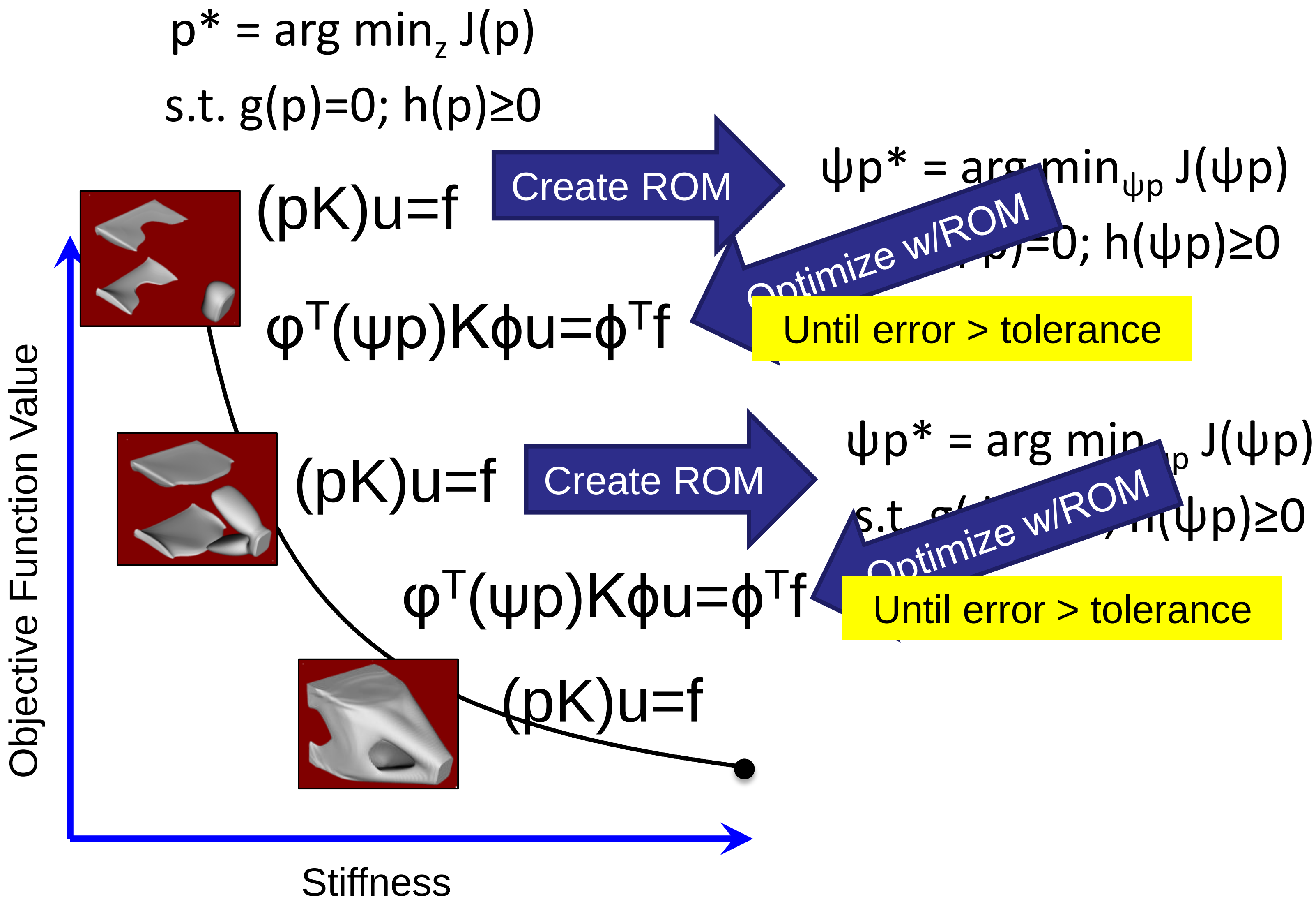
1 High Fidelity FEM ≈ 12 Minutes on 4196 Processors

X 2 Evaluations Per Iteration	X 50 Iterations	X 100 Samples

Physics- Based Reduced Order Modeling

Smart Sampling Techniques

Physics-Based Reduced Order Modeling



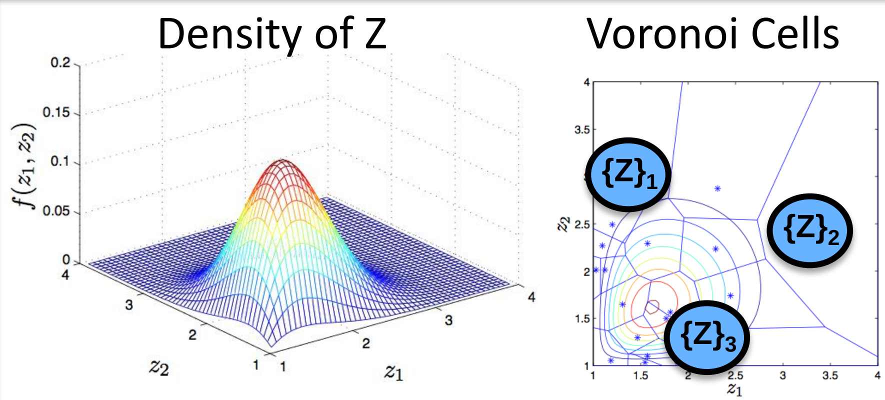
Smart Sampling Techniques

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

s.t.

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

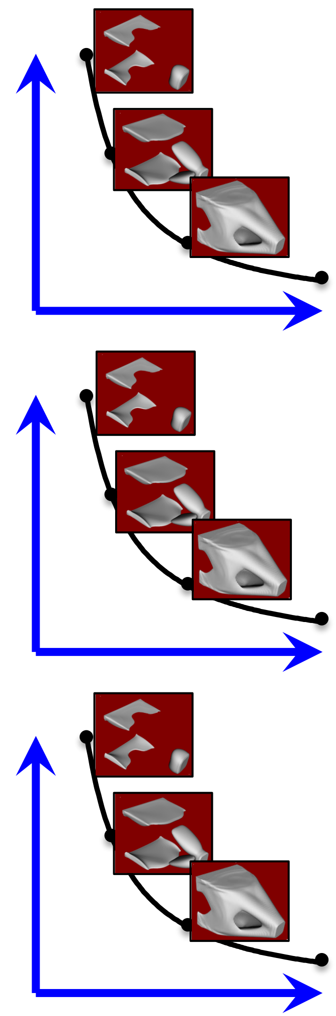
Stochastic ROM



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



Benefits of Surrogate-Based Optimization

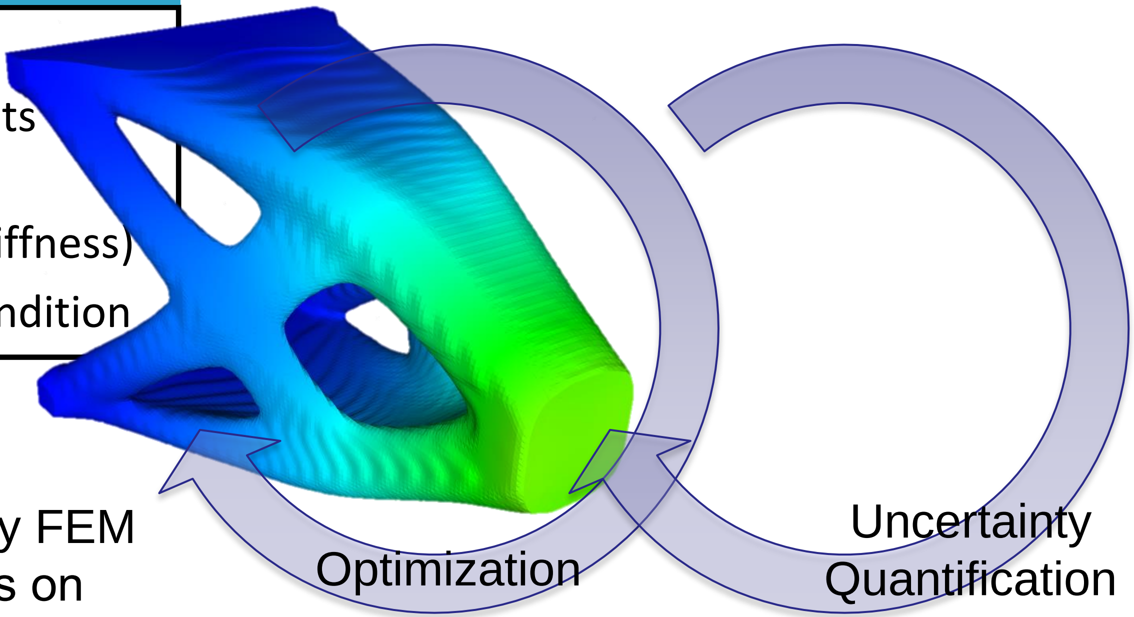
Problem Setup

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

5 Hours

CPU TIME

1 High Fidelity FEM ≈ 3 Minutes on 4196 Processors

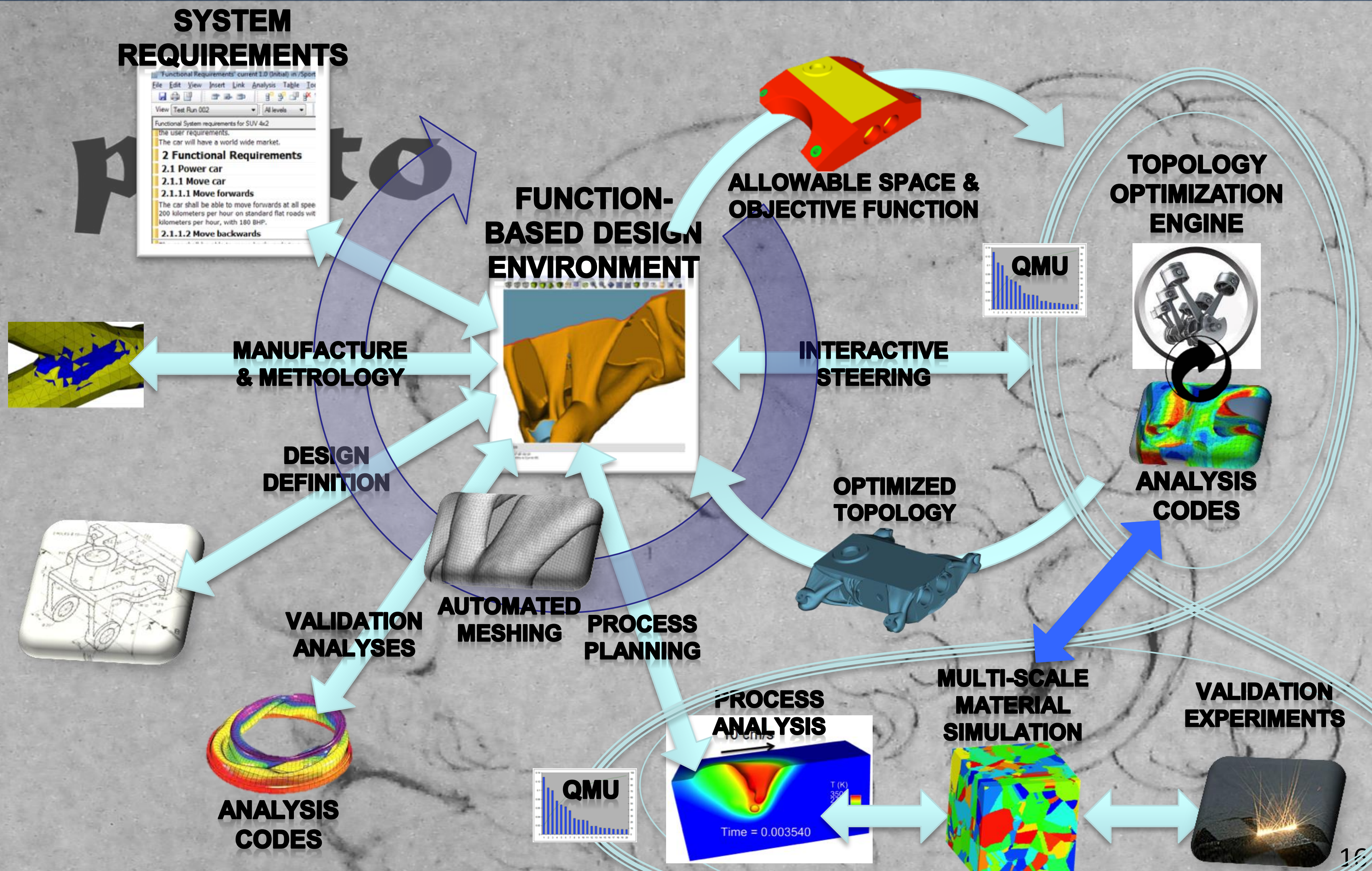


X 2	X 50	X 5
Evaluations Per Iteration	Iterations	Samples

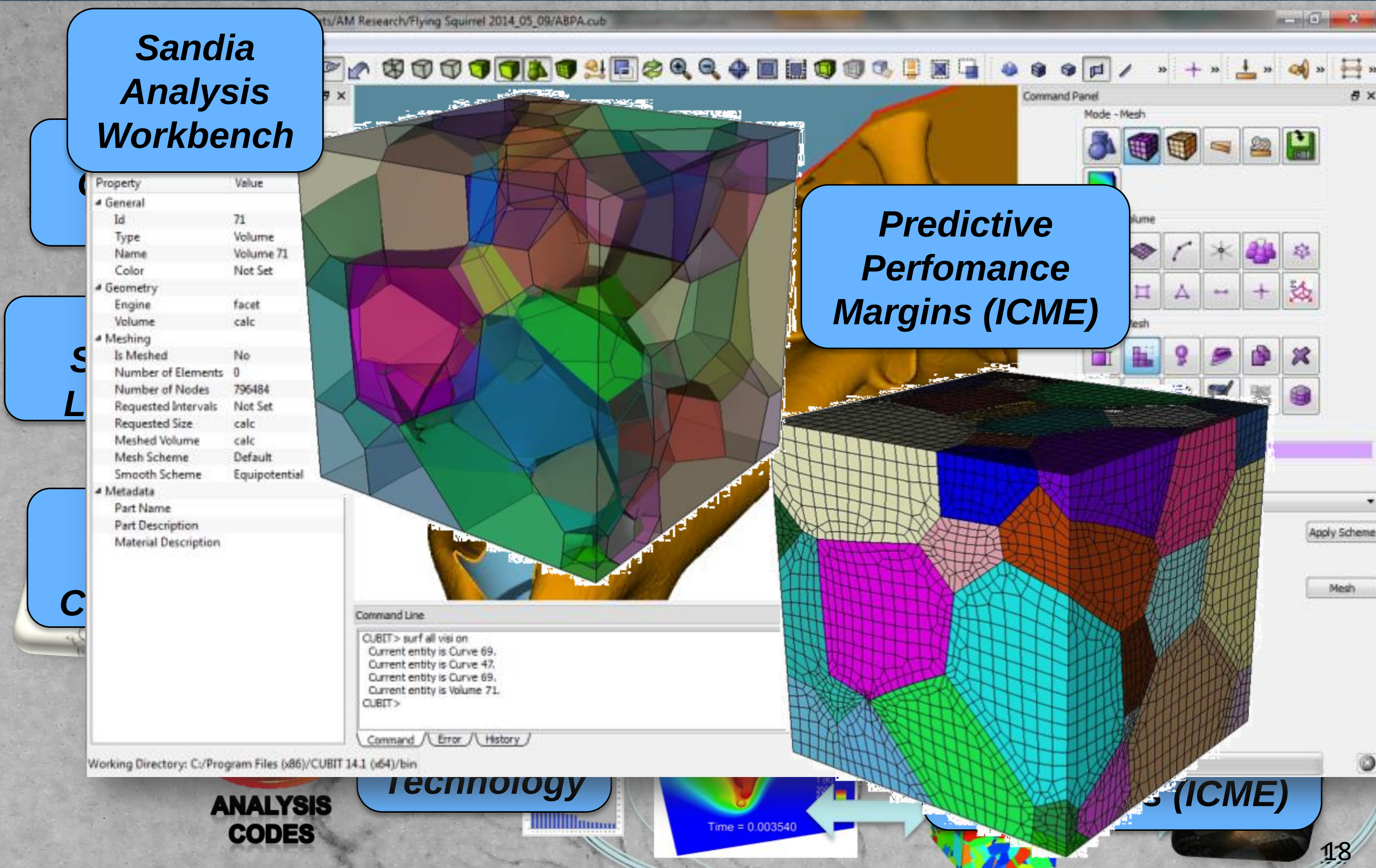
Physics- Based Reduced Order Modeling

Smart Sampling Techniques

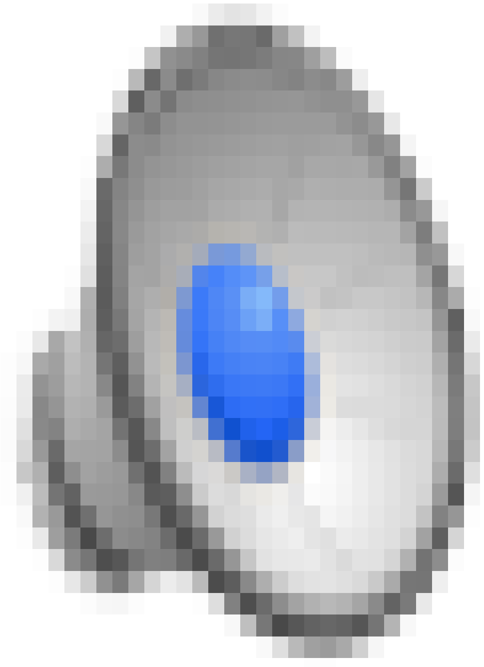
How Does This All Tie Together?



Diverse Tools and Expertise Necessary

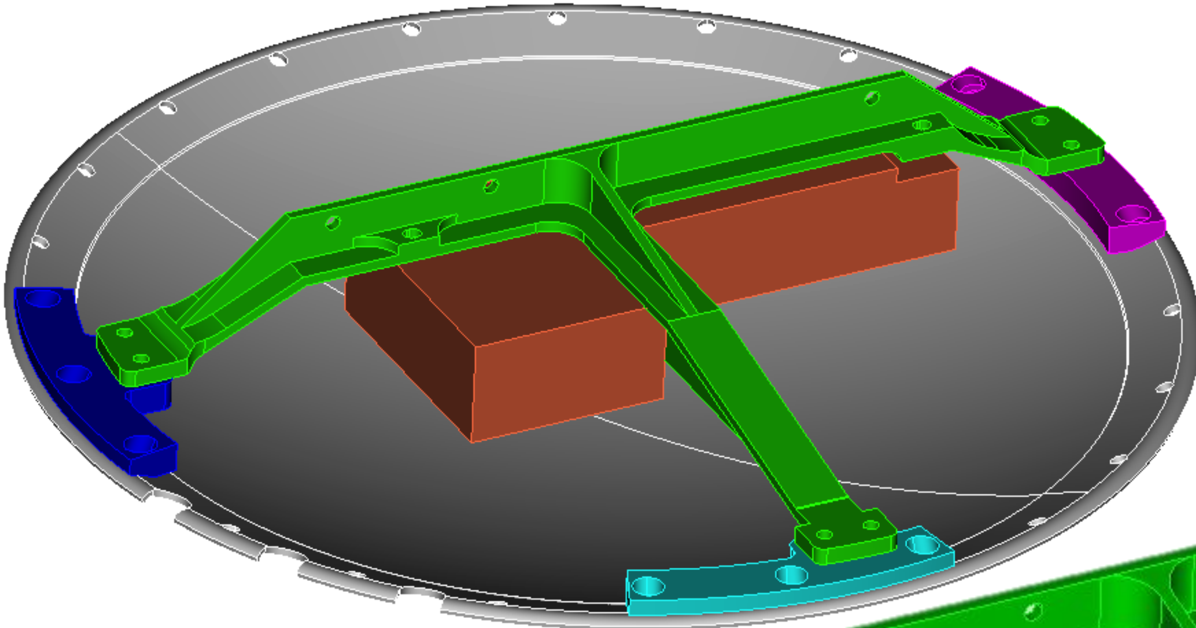


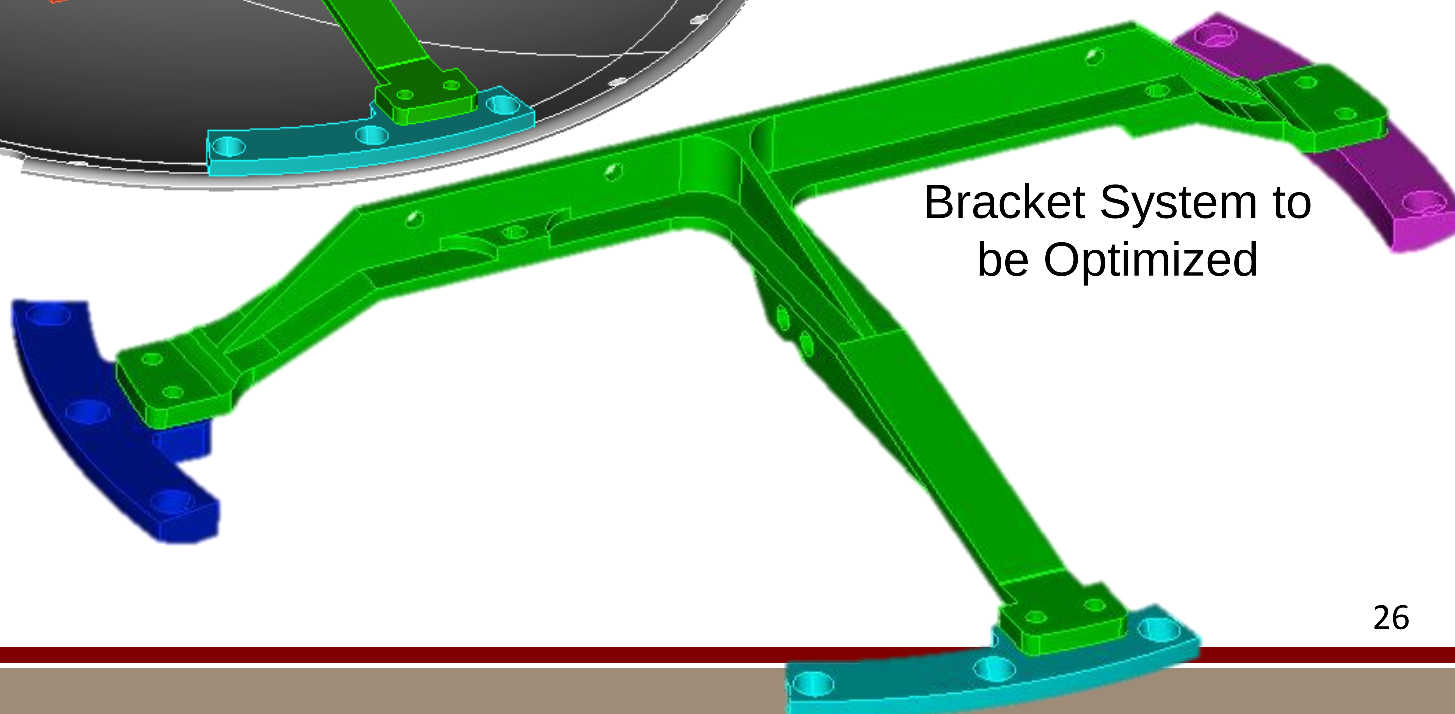
Optimization in Action



Example: Bracket Redesign

Entire Bracket-Mass Assembly

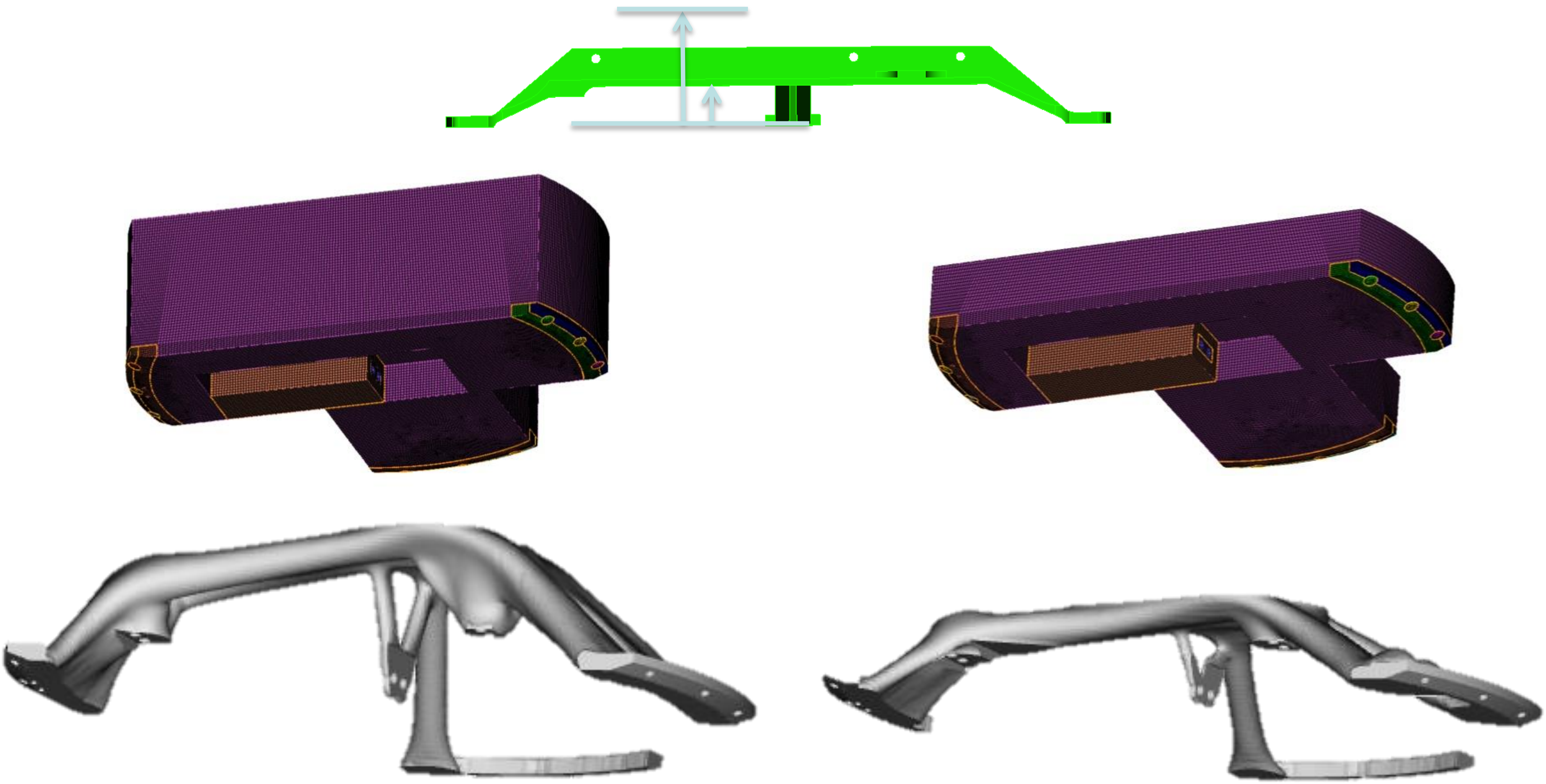




Bracket System to be Optimized

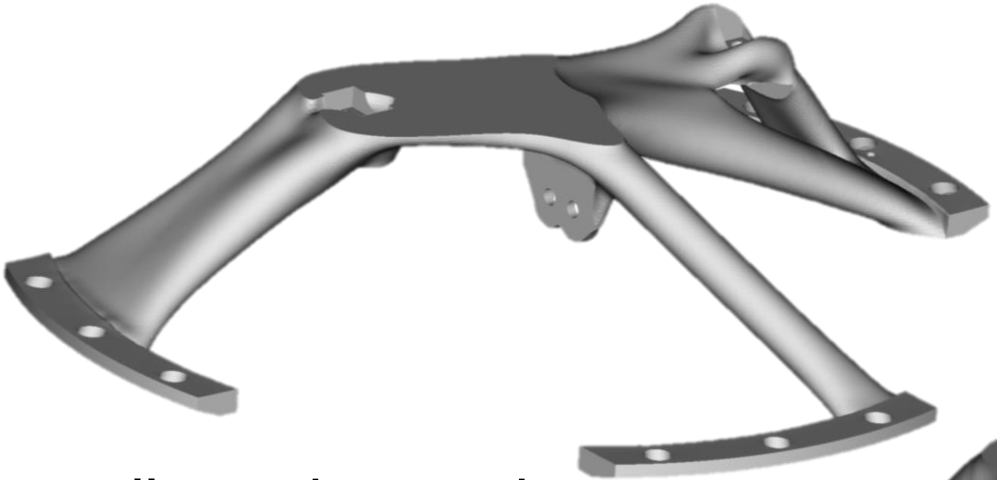
Example: Bracket Redesign

Rapid Design Response to Source Requirement Change

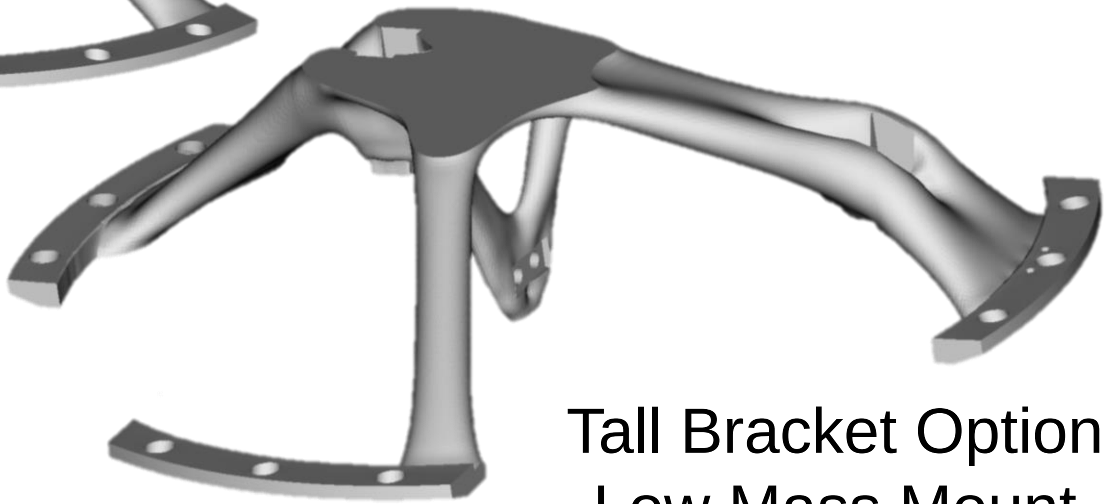


Example: Bracket Redesign

Refinements on Design with Options on Mass Mounting



Tall Bracket Option
High Mass Mount

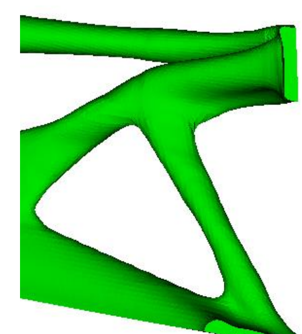


Tall Bracket Option
Low Mass Mount

Moving Forward: 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



Inverting Conventional Design Paradigms

Invert Qualification

In-Situ Validation of
Materials and 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 the World of Engineering