# Research Spotlight Forum

1.7.2020 | Advanced Manufacturing

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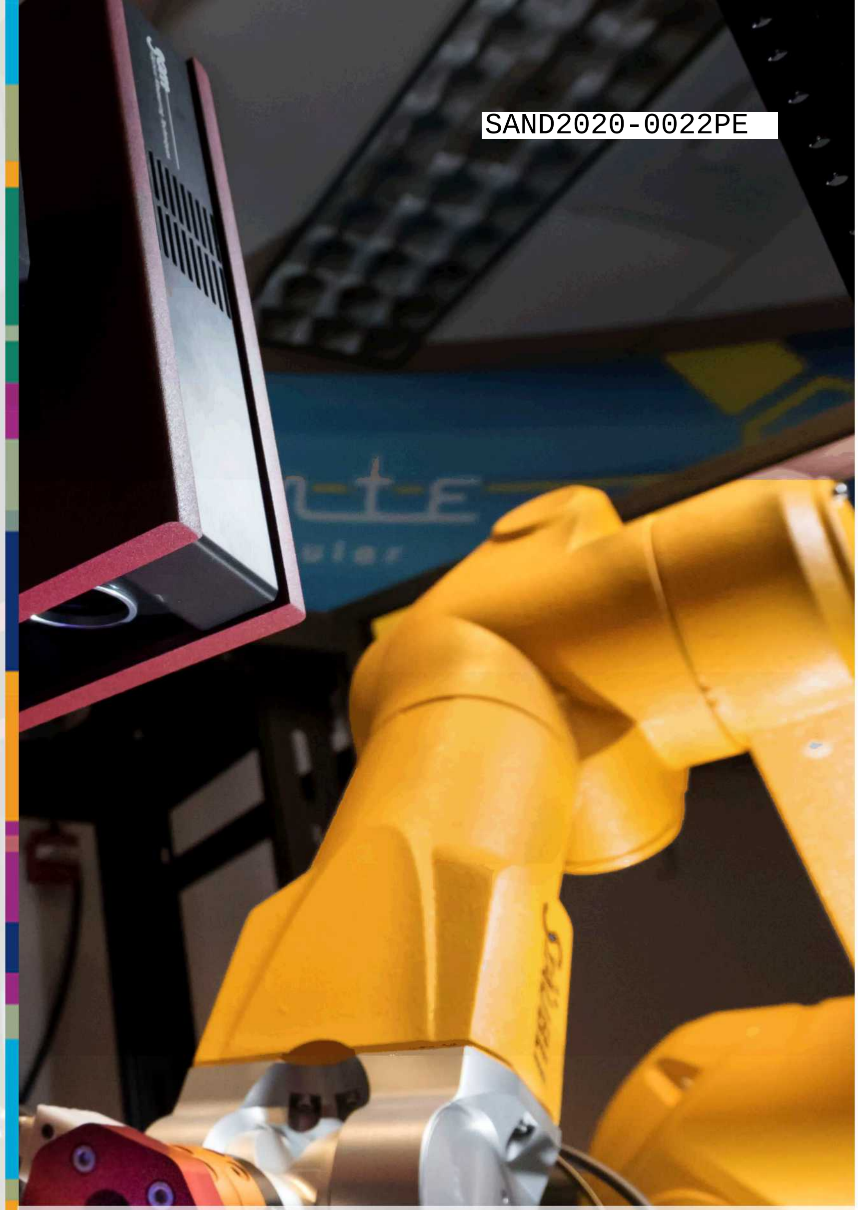

# Optimization-based Design for Manufacturing

Joshua Robbins, Plato Team, Sandia National Labs

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U.S. Department of Energy | NNSA National Nuclear Security Administration

# ABOUT YOURSELF

**Biography:**

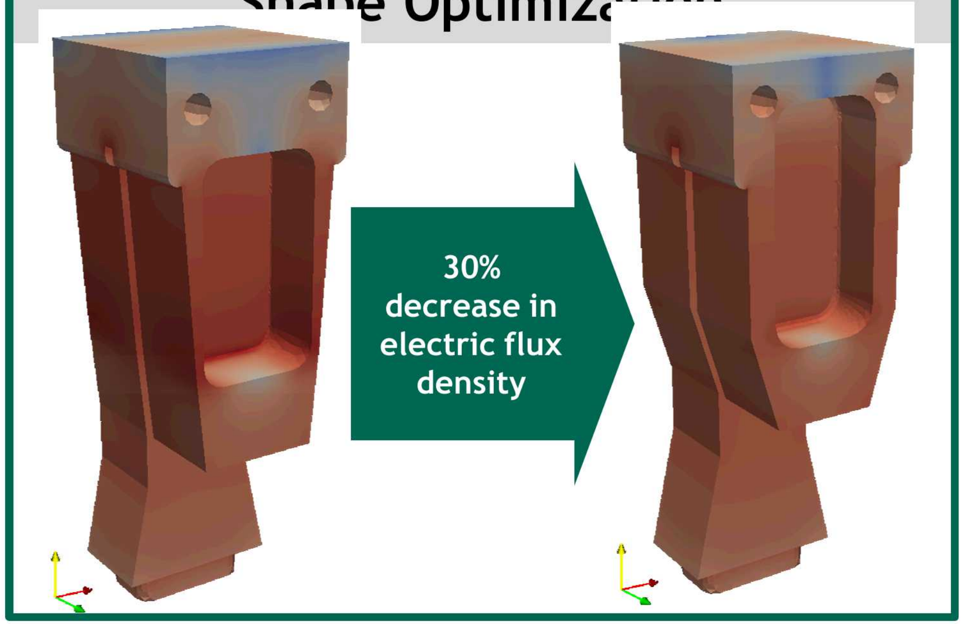
- MS & BS from Washington State University (1997, 1999)
- PhD from UNM (2006) in mechanical engineering
- Sandia Natl Labs in various departments since 1999

**Research areas:**

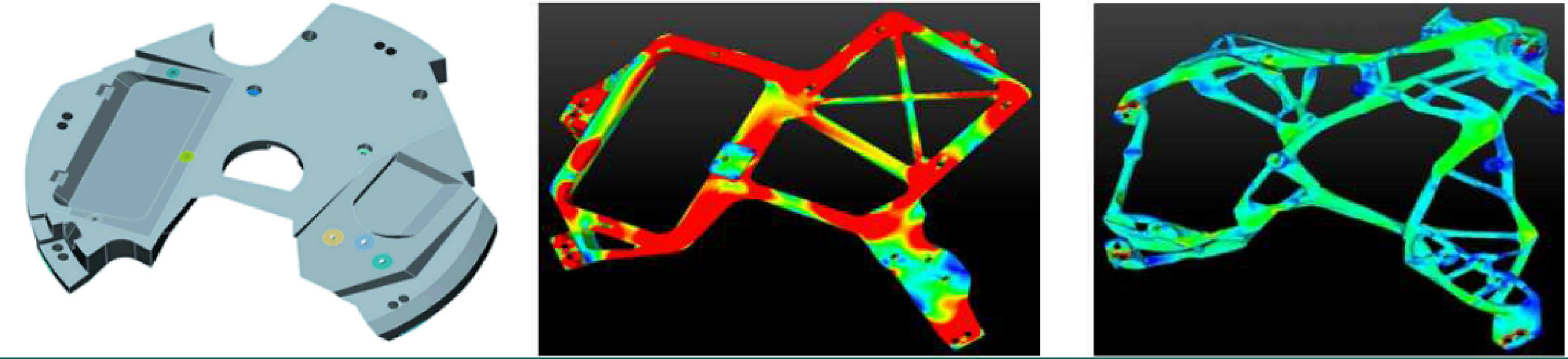
- Optimization-based design tools
- Design for AM

**Research group interests: (Plato Team, four staff, three students)**

## Shape Optimization




## Topology Optimization



# CURRENT WORK: Design for AM

## Goals:

**Incorporate "Manufacturability" objectives:** Integrate manufacturing process awareness into optimization-based design tools to enable manufacturability and performance.

**Concurrent shape and topology optimization:** Deliver an optimization-based concurrent component and system design tool to reduce design iteration cycle time.

## Progress:

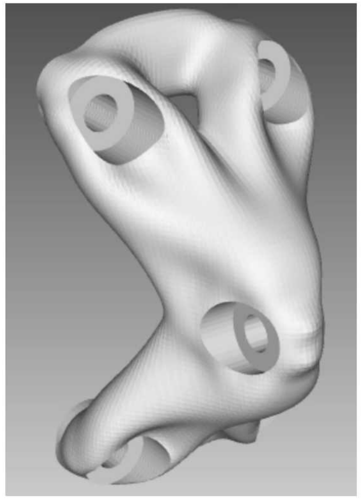
**Completed mid-year demonstrator:** Structural topology optimization with parameterized geometry – Computed the structure that minimizes mass given a stress constraint.

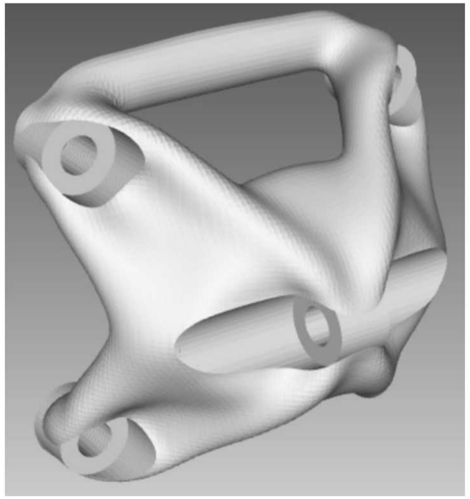
**On target for year-end demonstrator:** Fast process simulation with validation experiments.

## Highlights:

**Plato Tutorial:** Half day tutorial at the USACM Topology Optimization Roundtable introducing the Plato Software Suite.
**Plato Deployment:** Plato VM on Google Compute Platform has ~50 users spanning industry, academia, and government.

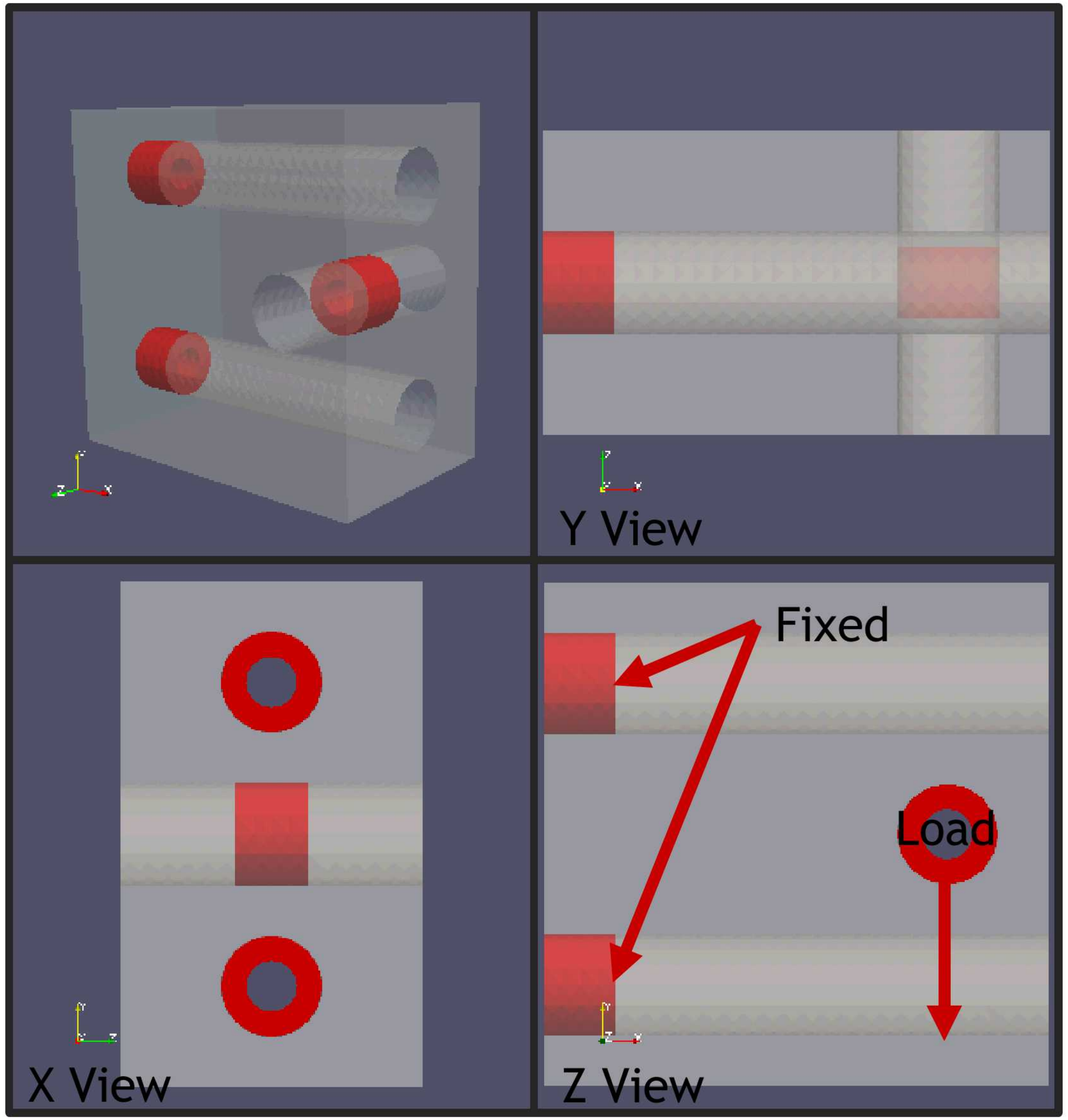
Design courtesy of Clinton Holtey using Plato. Displacement predictions by Kyle Johnson. Red = 0.1 mm.





Concurrently optimize mount locations (shape) and bulk structure (topology)

# Topology Optimization with "Process Objectives"




*Objective:*

$$\min_{z}\left(\alpha f_1(u_1,z) + (1-\alpha) f_2(u_2,z)\right)$$

$$f_1(u_1,z) = \left\langle \nabla u_1^T, C\nabla u_1^T \right\rangle$$

$$f_2(u_2,z) = \left\langle \nabla u_2^T, C\nabla u_2^T \right\rangle$$

*PDE Constraints:*

$$\nabla \cdot C\left(\nabla u_1 - \varepsilon^{in}\right) = 0$$

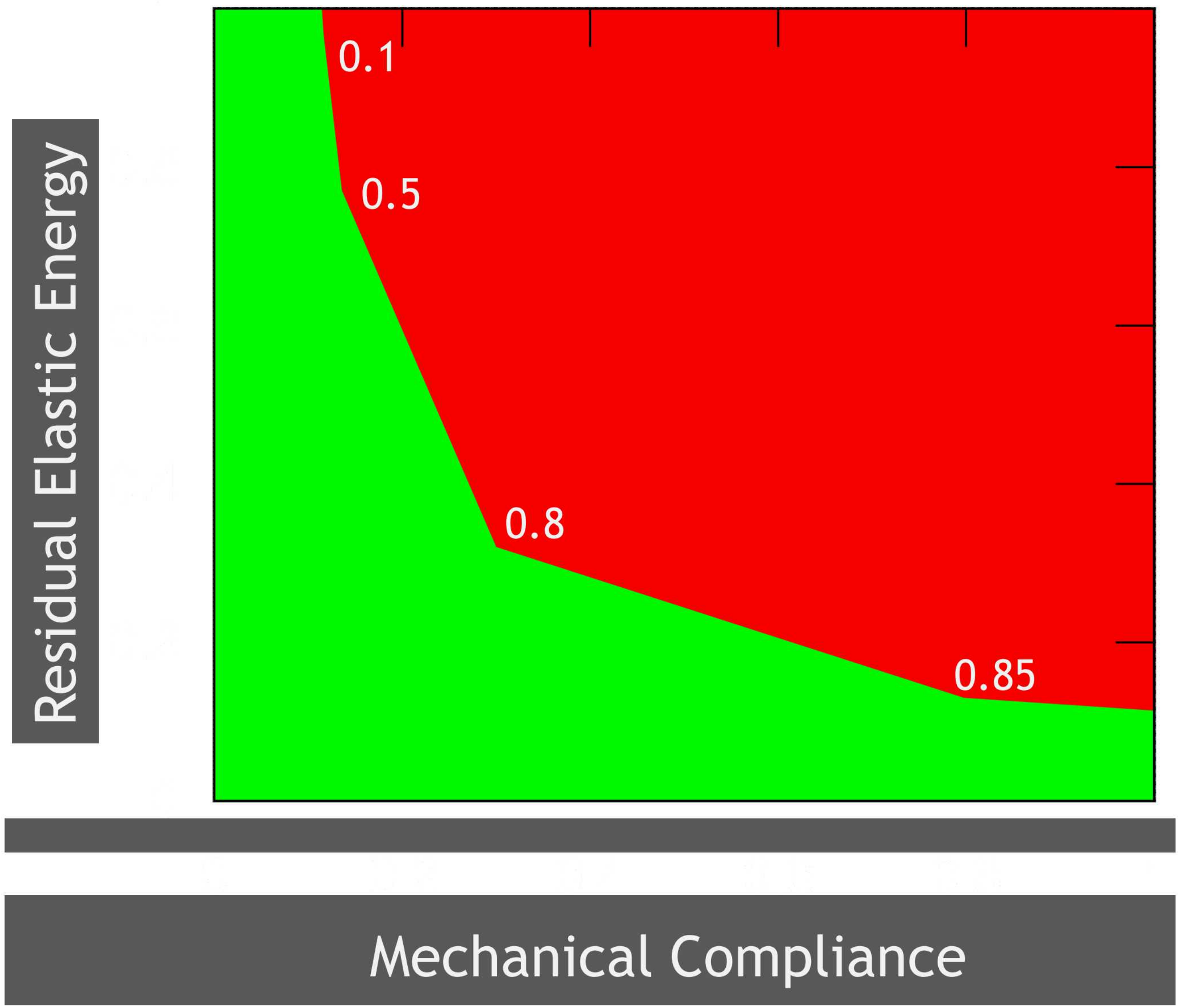
$$\nabla \cdot C\nabla u_2 = 0 \quad C\nabla u_2 \cdot n = \tau_n \ \forall\, x \in \partial\Omega_n$$

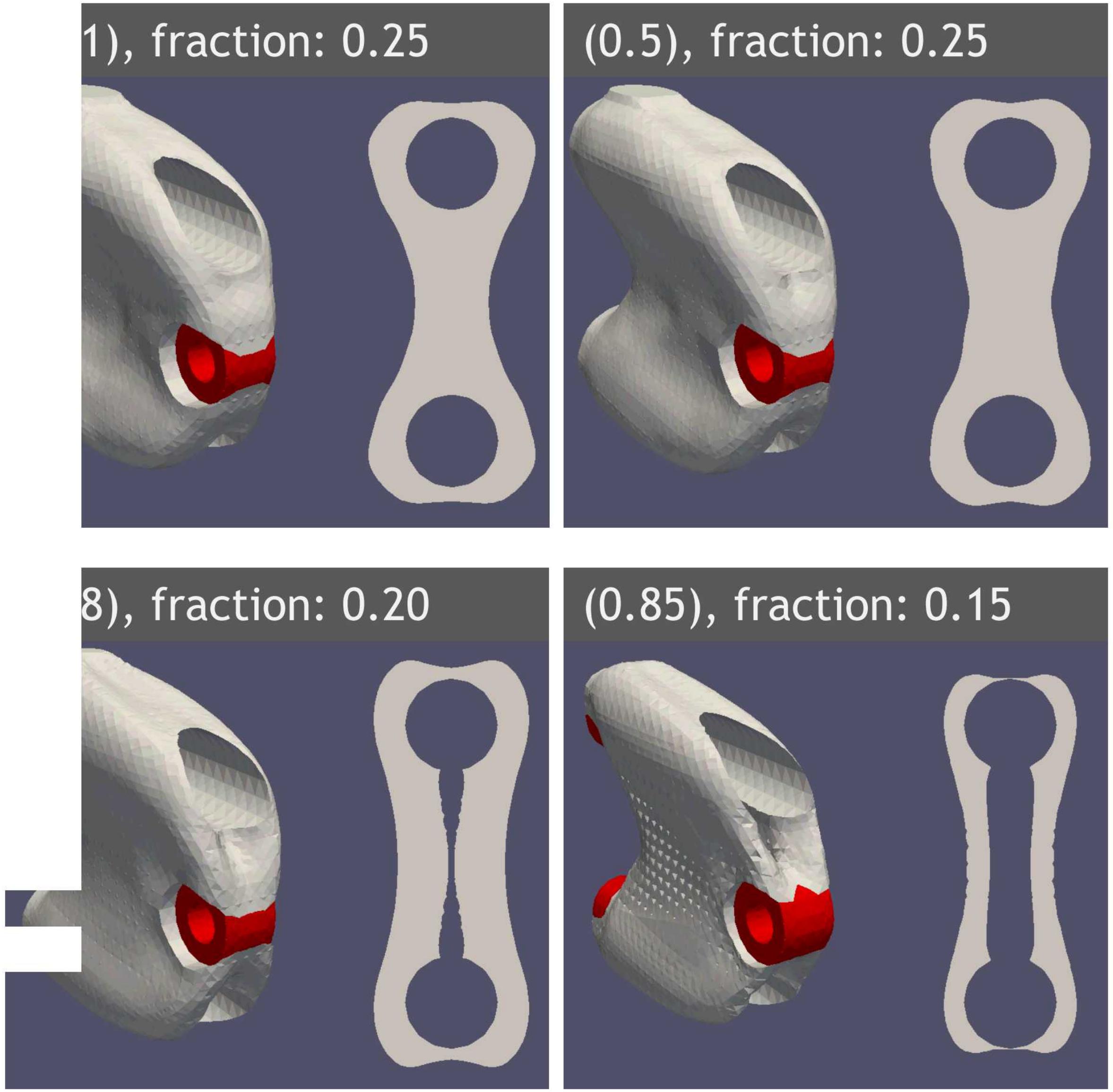
$$u_n \equiv u_n(x,t) \in R^{n_d} \quad u_n = 0 \ \forall\, x \in \partial\Omega_d$$

*Inequality Constraint:*

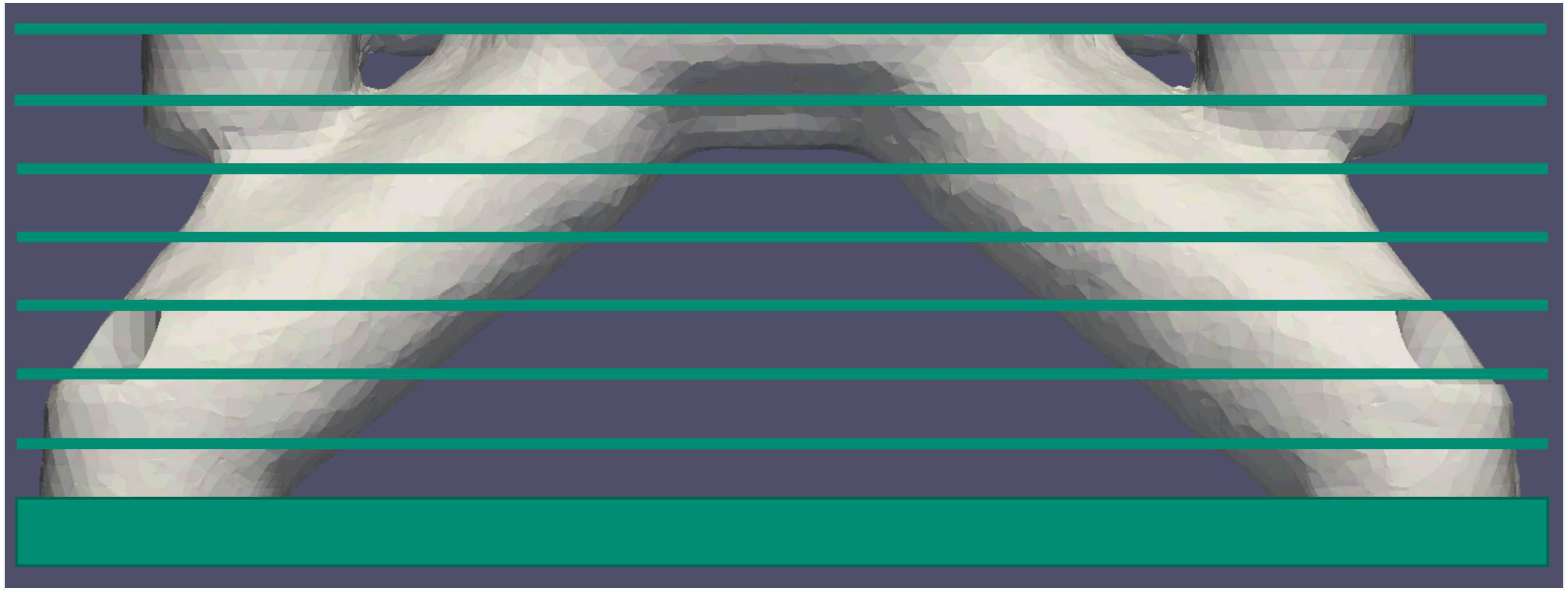
$$h(u,z,x) \leq 0$$

# Topology Optimization with "Process Objectives"



# Approach



## Simulation Process

- For each "super layer"
  - Deposition
  - Time dependent thermomechanical equilibration
- Remove from baseplate
- Compute mechanical equilibrium and process outcomes (metrics)

## Balance Equations

$$\rho C_p \dot{T} - \nabla \cdot q - \dot{q}_v = 0$$
$$\nabla \cdot \sigma + b = 0$$

## Material Response

$$\sigma = C\,\varepsilon^e$$
$$q = k \nabla T$$
$$\varepsilon^e = \nabla_s u - \alpha\left(T - T_{ref}\right) - \varepsilon^p(c)$$

## Solution Variables

$$u \equiv u(x,t) \in R^{n_d}$$
$$T \equiv T(x,t) \in R$$
$$c \equiv c(x,t) \in R^{n_s}$$

# FUNDING SOURCES


- Optimization-based Design for Manufacturing, LDRD (2019-2021)
- Transformative Design, DARPA (2017-2021)
- Topology Optimization, ASC program

# RESEARCH NEEDS

**Process-aware material models:** LDRD project scope was intentionally limited to ideal material response. Can software be developed that provides fast and accurate predictions of 3D printed metal properties from information about the printing process and part geometry?

**Differentiable support structure:** Thermal and mechanical history of the printed part depend on support structure. Fast, differentiable support structure is required for design optimization.

**Applications:** Plato is i) open-source, ii) designed for relatively easy addition of new physics and objectives, iii) GPU-enabled for desktop computing, iv) MPI-enabled for multi-objective optimization, uncertainty quantification, parameter studies, etc., and v) builds conveniently on Google Compute Platform.™