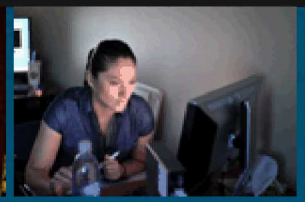
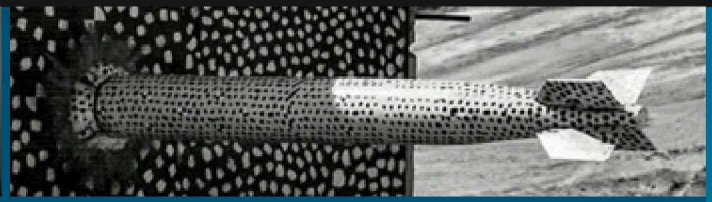
SAND2020-1359PE

# Albany and Plato Engine: Multi-objective optimization using MPMD

CONTRIBUTORS

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PRESENTED BY

Joshua Robbins

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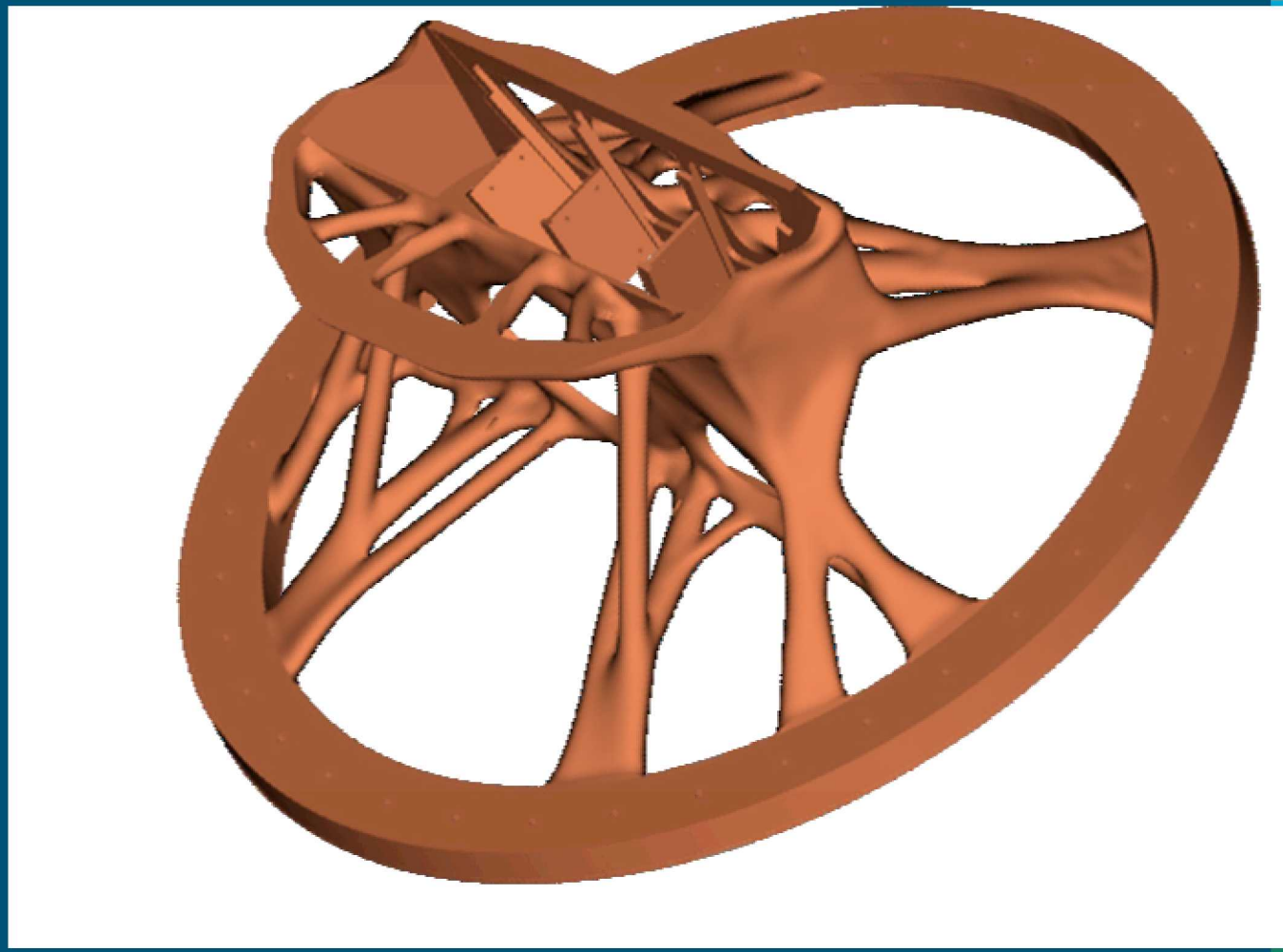
# Outline

Motivation: Design freedom of AM *

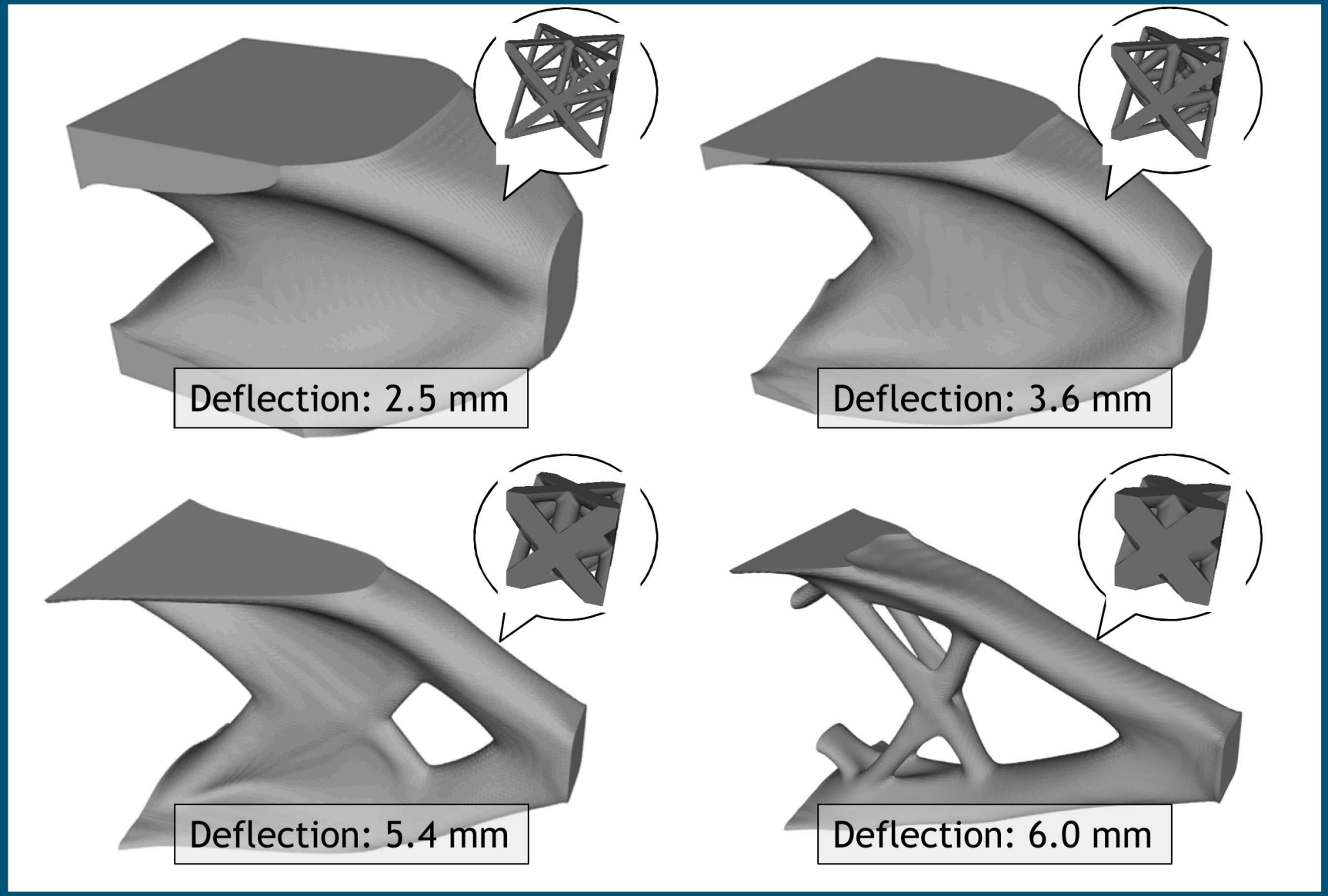
Objective: Design tools to leverage AM

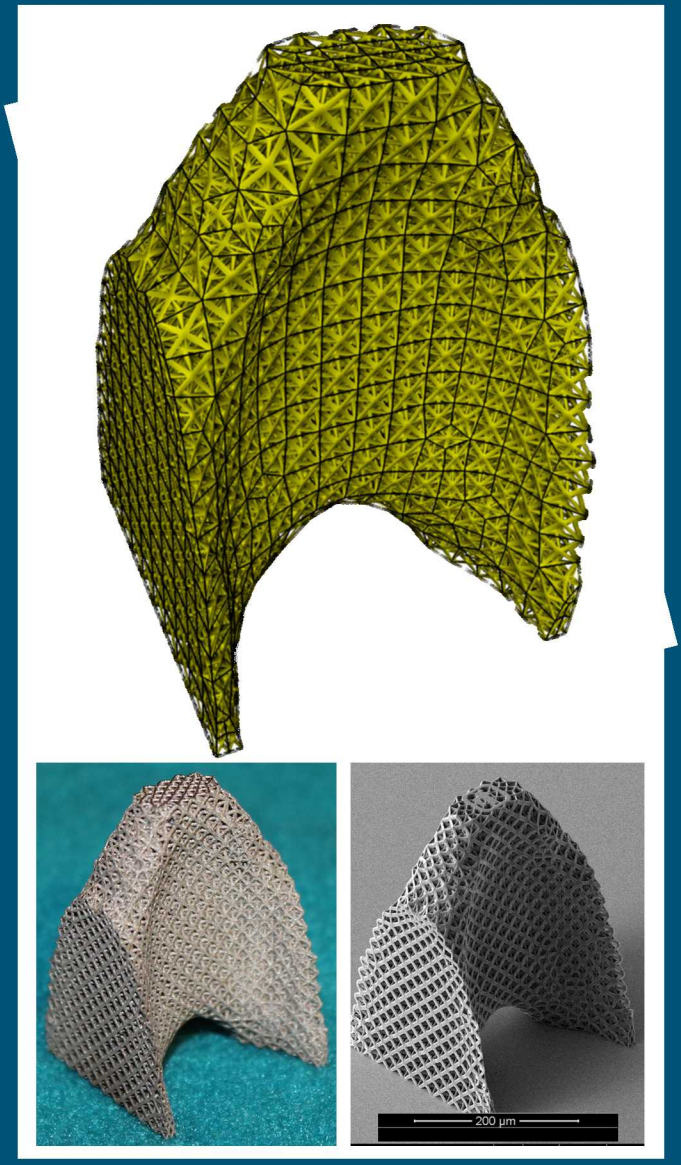
Approach: Task parallelism via MPMD



* B. Jared et al., Additive Manufacturing: Toward holistic design, Scripta Materialia. 135 (2017)

# Design Freedom of Additive Manufacturing



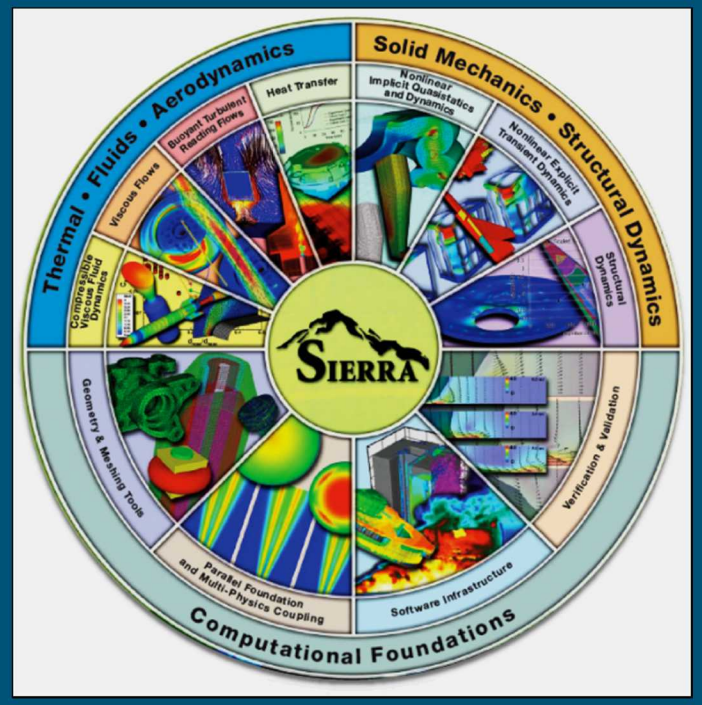




J. Robbins et al., An efficient and scalable approach for generating topologically optimized cellular structures for additive manufacturing, *Additive Manufacturing. 12 B (2016)*

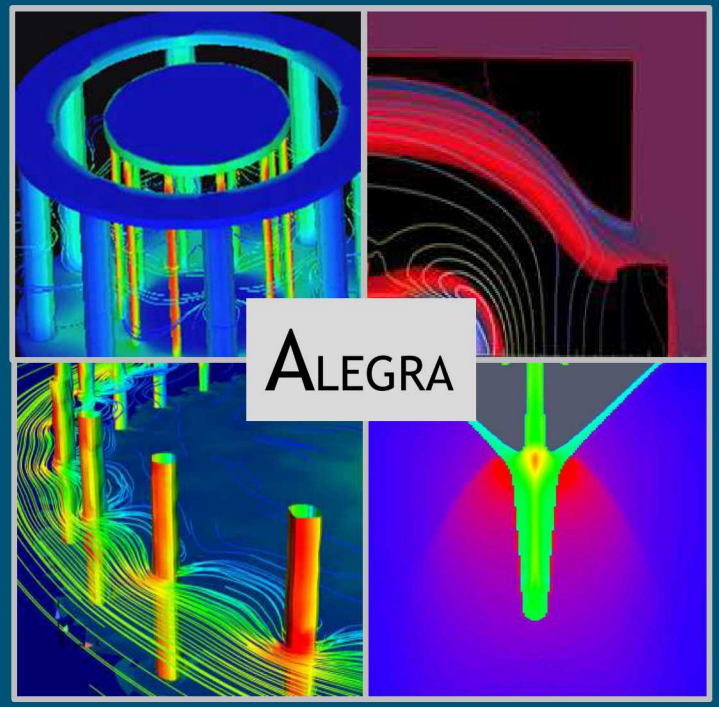
# Design Tools to Leverage AM

Diverse engineering design challenges:

Substantial investment in simulation codes:




Solid Mechanics
Structural Dynamics
Thermal
Fluids
Aero




Hydrodynamics
MHD
Electromechanics
HEDP

# Design Tools to Leverage AM

**Objective:** Provide a design environment that can leverage existing simulation tools and emerging HPC architectures.

**Forward Problem:**


**Inverse Problem:**


**Approach:** Use topology optimization to let performance objectives dictate the design

- Multiple-Program, Multiple-Data (MPMD) for code interaction (new and existing codes)

# Optimization Problem

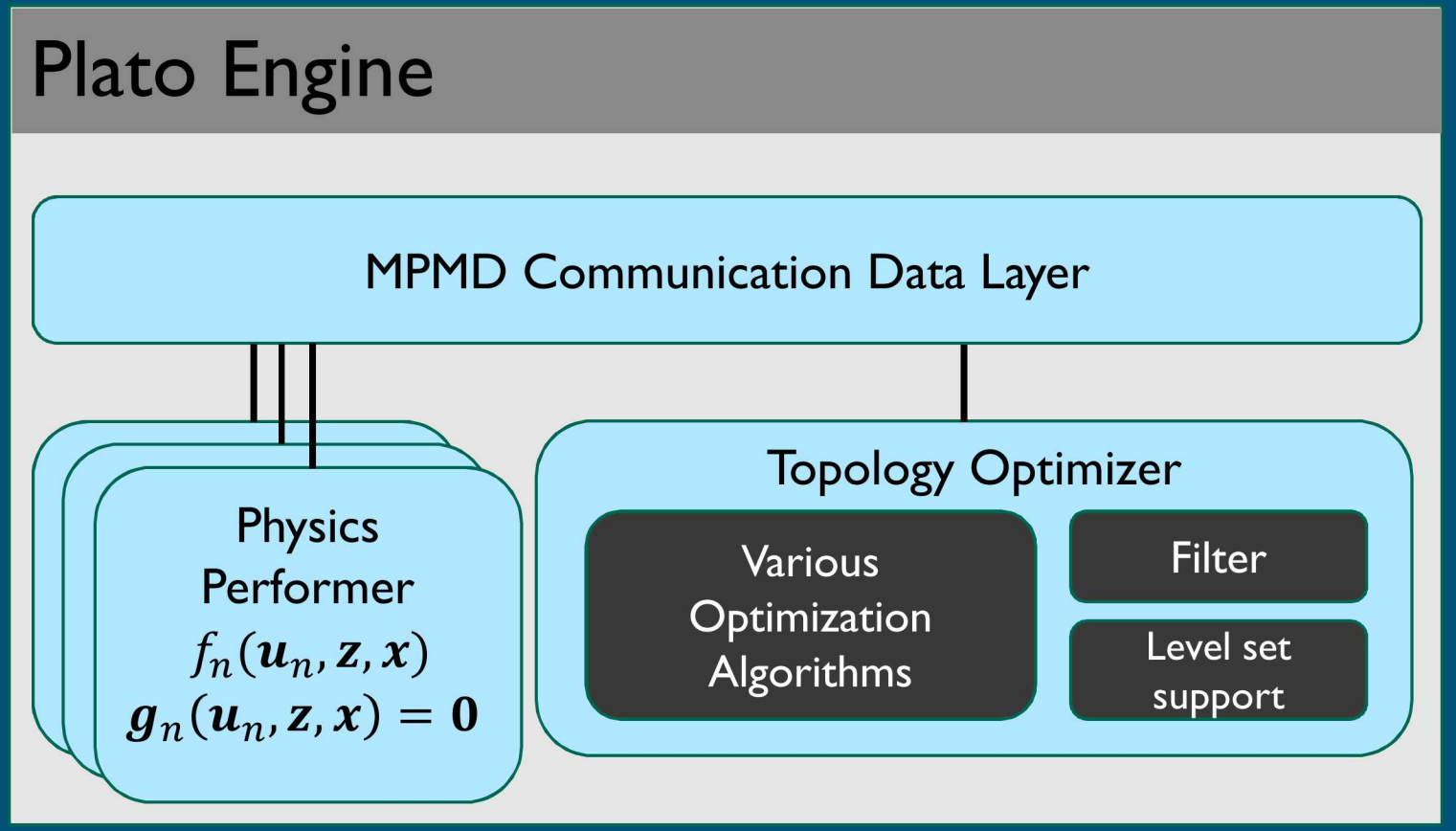
*Objective:* $$\min_{\boldsymbol{z},\boldsymbol{x}} \sum_{\boldsymbol{i}} \alpha_i f_i(\boldsymbol{u}_i, \boldsymbol{z}, \boldsymbol{x})$$

*PDE Constraint:* $$\boldsymbol{g}_i(\boldsymbol{u}_i, \boldsymbol{z}, \boldsymbol{x}) = \boldsymbol{0}$$

*Inequality Constraint:* $$h(\boldsymbol{u}, \boldsymbol{z}, \boldsymbol{x}) \leq 0$$

# Overview of Plato Engine (github.com/platoengine)

Plato Engine uses the Multiple Program Multiple Data (MPMD) computing model to coordinate existing simulation tools into a single solution.



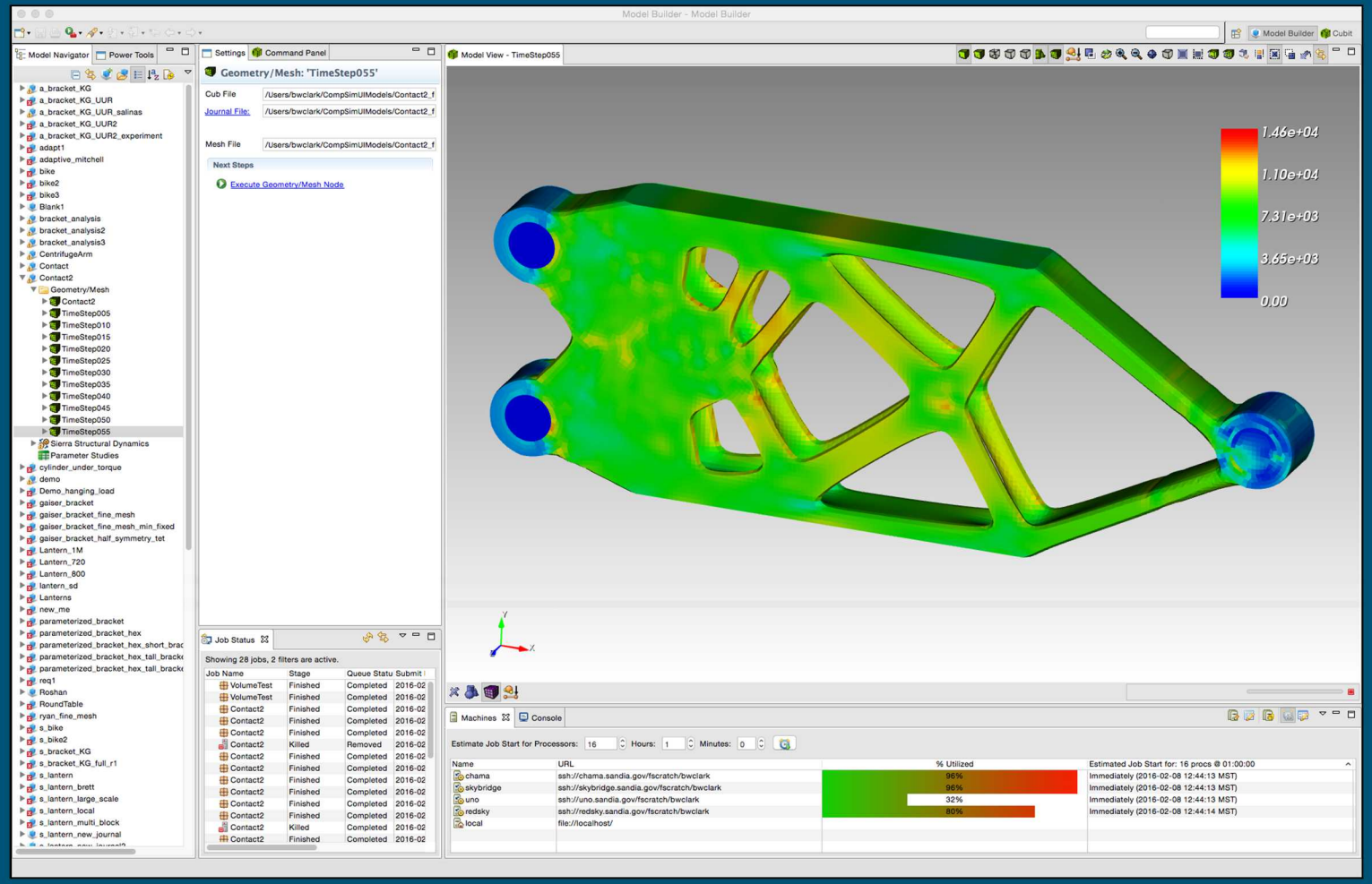
# Overview of Plato Engine

Physics Performers integrate with the Data Layer through the Plato::Application abstract interface.

```
virtual void finalize()=0;

virtual void initialize()=0;

virtual void compute(
   const std::string & aOperationName)=0;

virtual void exportData(
   const std::string & aArgumentName,
   Plato::SharedData & aExportData)=0;

virtual void importData(
   const std::string       & aArgumentName,
   const Plato::SharedData & aImportData)=0;

virtual void exportDataMap(
   const Plato::data::layout_t & aDataLayout,
   std::vector<int>            & aMyOwnedGlobalIDs)=0;
```

# Overview of Plato Engine

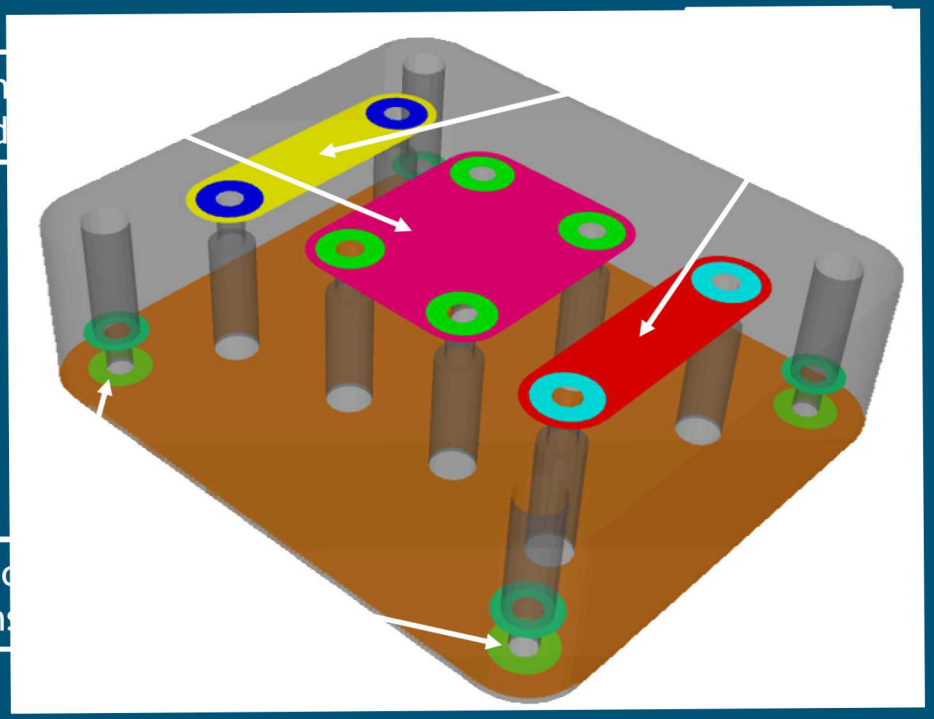
Plato Engine can be used in batch mode (command line) or through the Plato front end.



# Overview of Plato Engine

Mechan
Load

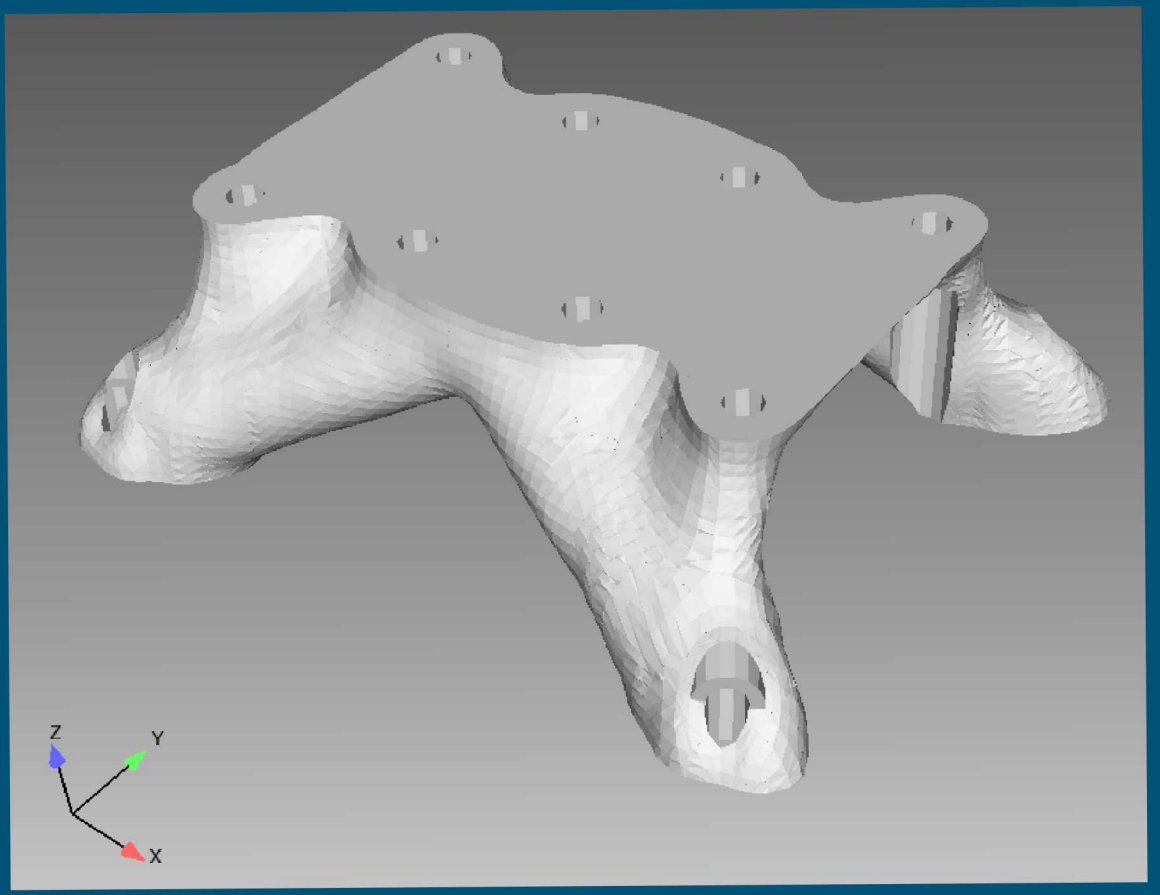
Mechanic
Cons



Sierra
(40 procs)

Plato
(10 procs)

Albany
(30, 35 procs)



- MPMD computing model is used to coordinate multiple Performers into a single optimization.
- Plato::Application wraps Performer code so internal modification isn’t required.
- Optimizers, filters, services, etc., are provided by Plato Engine

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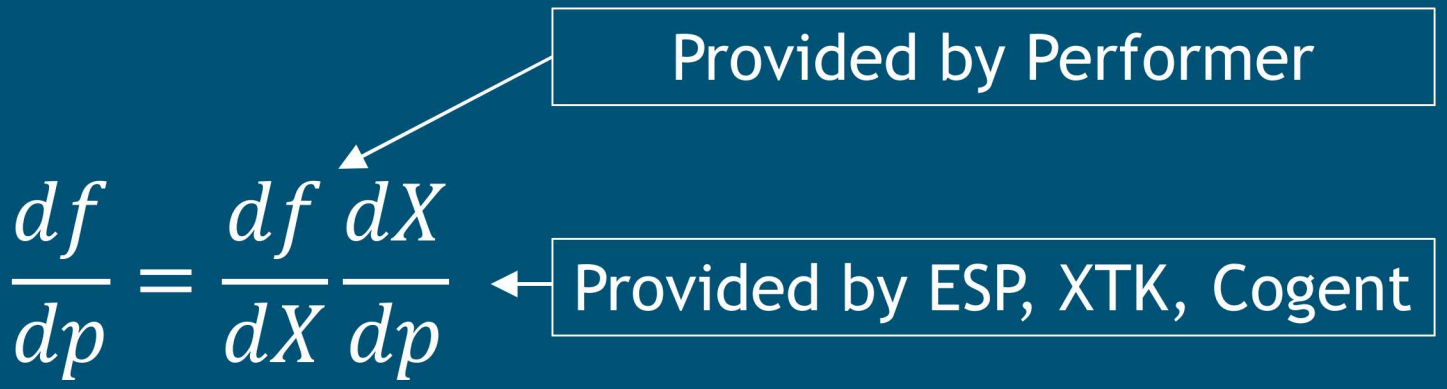
- **Topology** optimization is disruptive, for better and worse.
- **Shape** optimization fits into conventional design process.
  - Engineering Sketch Pad (ESP), MIT
  - XFEM Tool Kit (XTK), CU Boulder
  - Cogent, Sandia
- Shape and topology

# Shape Optimization with ESP, XTK, Cogent

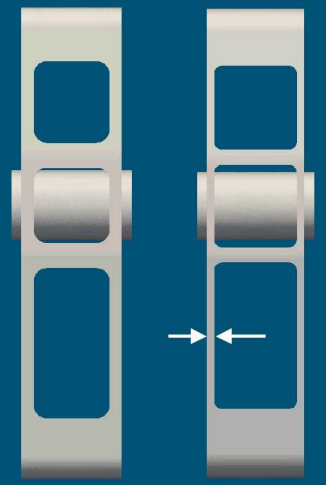
For shape optimization, we need derivatives with respect to the parameters, $p$:



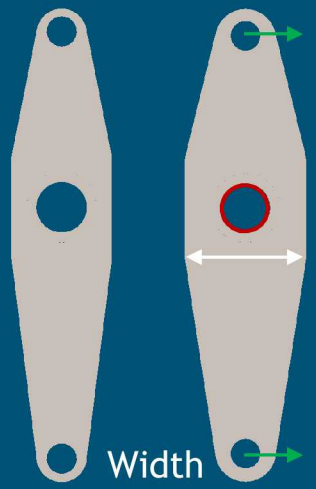

Derivatives with respect to design parameters require parameterized models

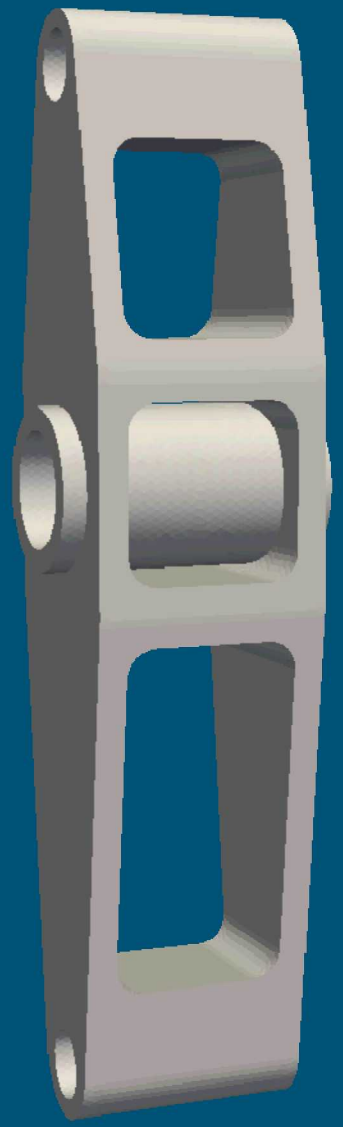
# Compliance Minimization with Volume Constraint

Optimization Variables

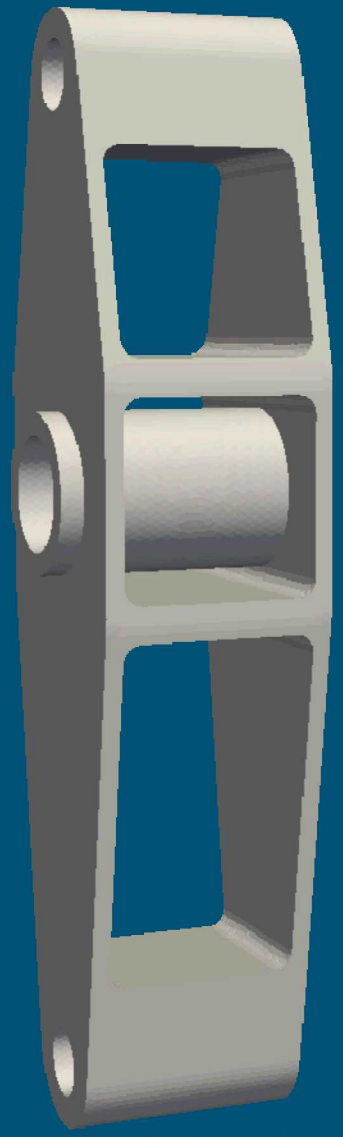


Wall Thickness

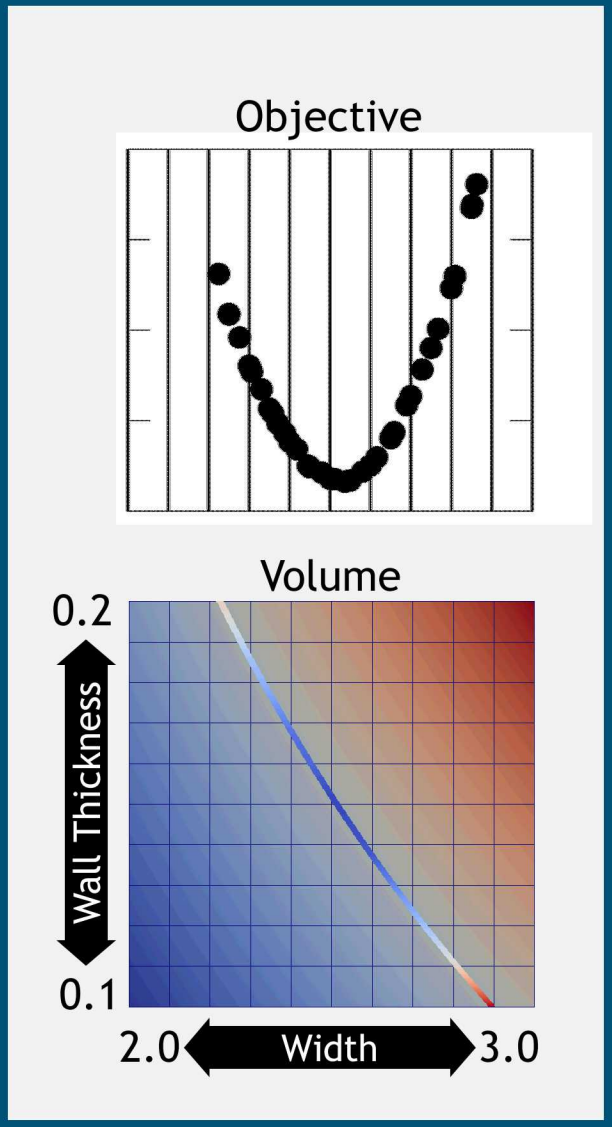


Initial Guess



Optimized



File | Tool | StepThru | Help

Up to date | Undo

H | L | R | B | T | +

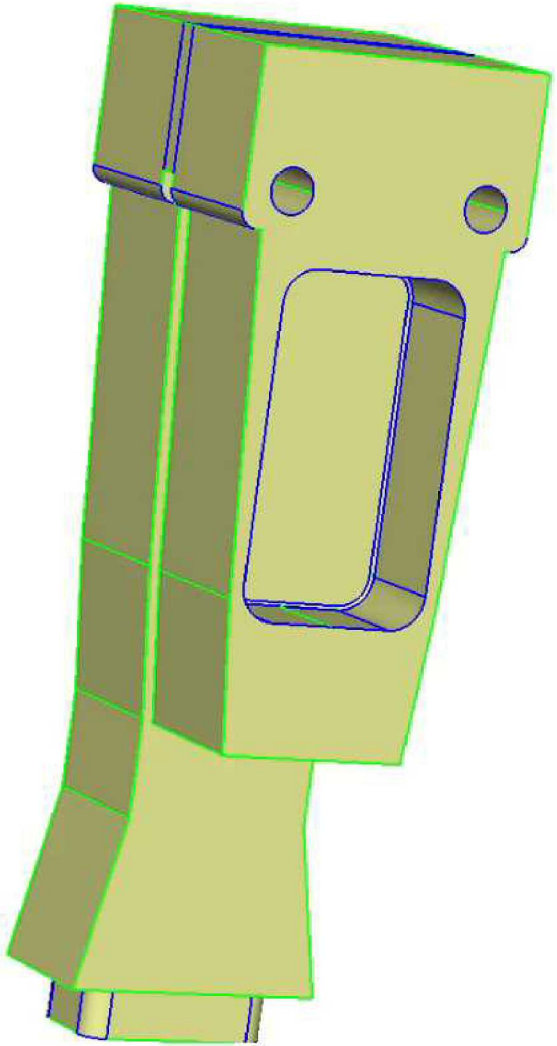
**Design Parameters**

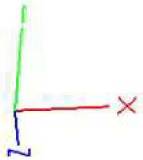
| | |
|---|---|
| TotalHeightA | 1.7 |
| BottomWidthA | 0.4 |
| TopWidthA | 0.5 |
| WaistWidthA | 0.3 |
| SkirtHeightA | 0.3 |
| HeadHeightA | 0.3 |
| WaistHeightA | 0.1 |
| PitWidthA | 0.4 |
| BarrelHeightA | 0.6 |
| TaperHeightA | 0.2 |
| TaperWidthA | 0.4 |
| ThicknessA | 0.2 |
| HeadFilletA | 0.0 |
| CutoutOffsetA | 0.7 |
| CutoutWidthA | 0.3 |
| CutoutHeightA | 0.6 |
| CutoutDepthA | 0.1 |
| CutoutFilletA | 0.0 |
| CutoutBackFilletA | 0.0 |
| TopBoltYOffsetA | 1.4 |
| TopBoltXOffsetA | 0.1 |
| TopBoltHeadRadiusA | 0.0 |
| TopBoltHeadCutoutDepthA | 0.0 |
| TopBoltShaftRadiusA | 0.0 |
| TopBoltDepthA | 0.2 |
| StubWidthA | 0.3 |
| StubDepthA | 0.1 |
| StubHeightA | 0.0 |
| StubFilletA | 0.0 |
| BridgeThickness | 0.0 |
| BridgeHeight | 0.2 |

Local Variables

**Branches**

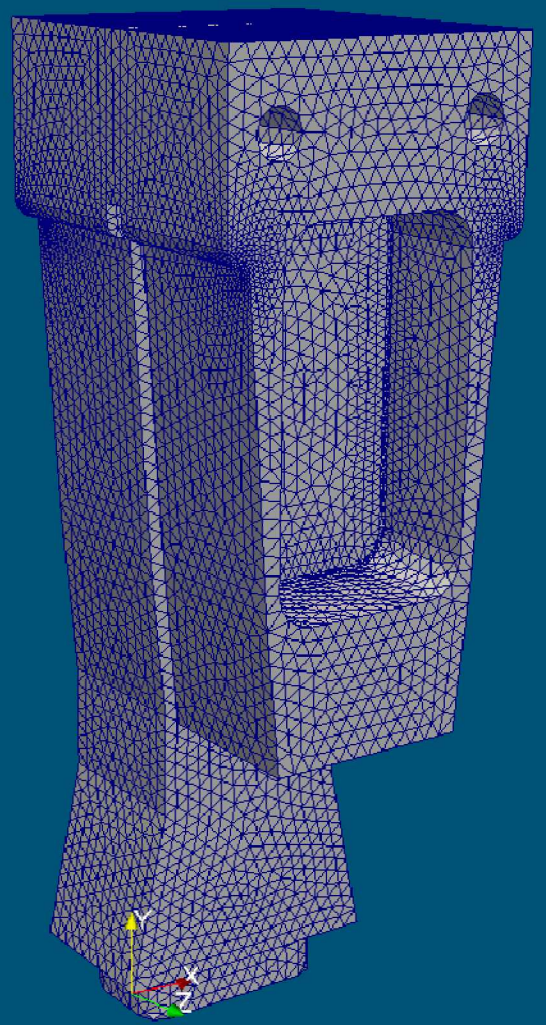
| | |
|---|---|
| Display | Viz |
| solid_body | Viz |
| Axes | Viz |
| DisplayType | |
| DisplayFilter | |

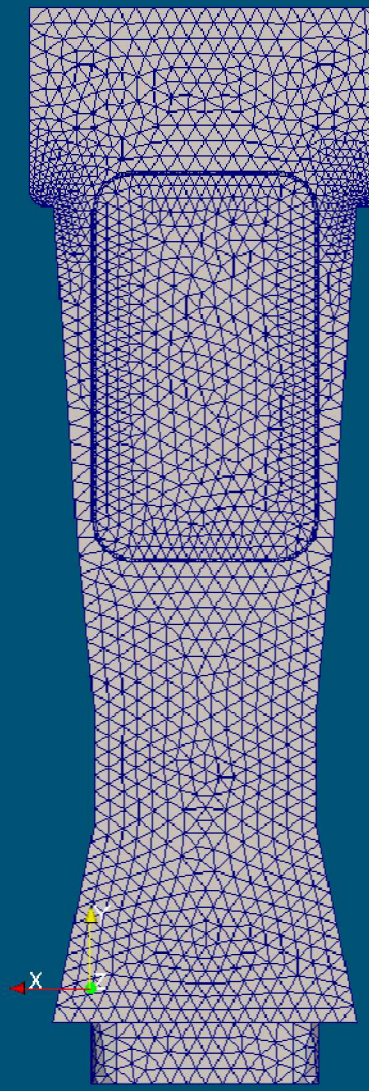


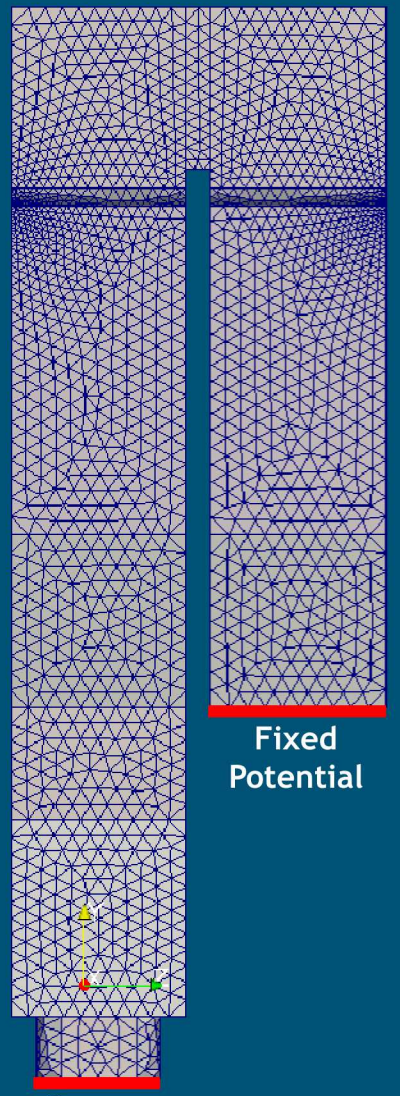


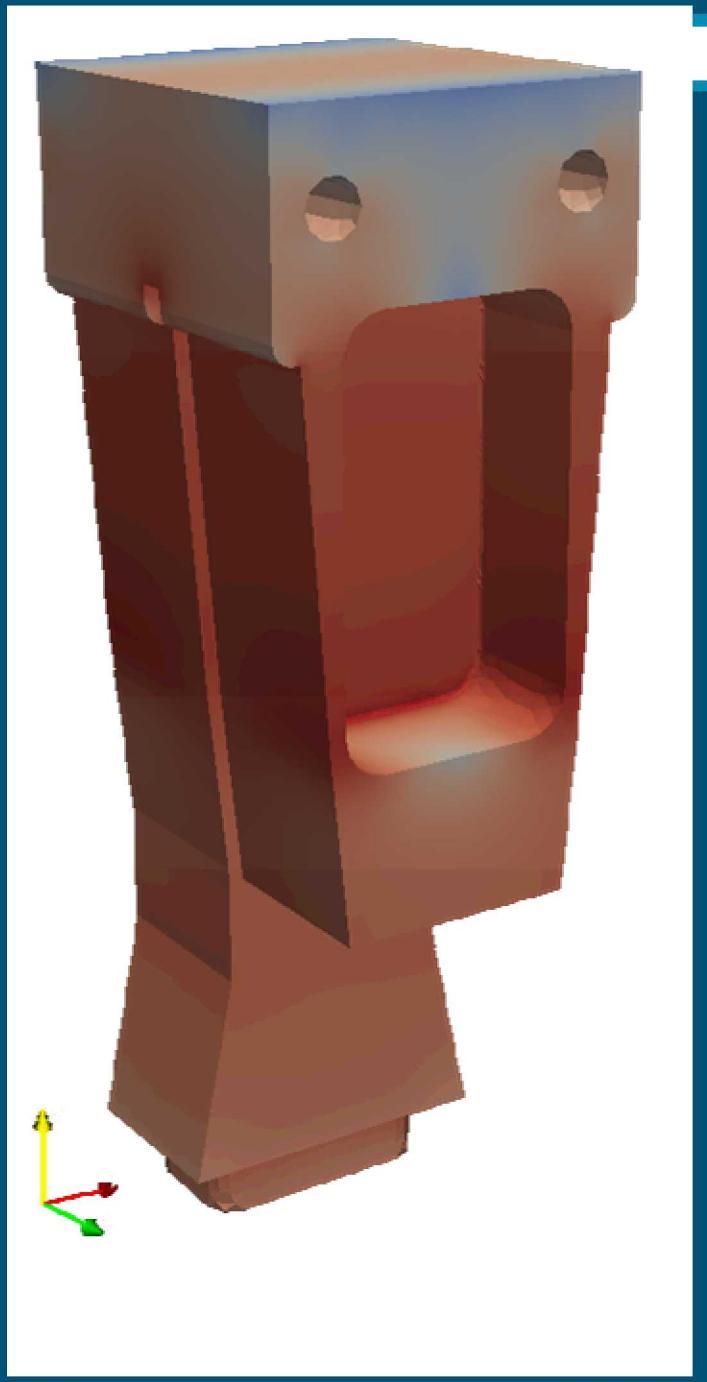
```
Adding: select $body 88
        select $face 71 13 1
            attribute capsGroup $terminal_2
====> Re-build is needed <=====

Entire build complete, which generated 1 Body(s)

Saving model to 'load.csm'

Parameter 'TotalHeightA[1,1]' has been changed to 1.7 ====> Re-build is needed <=====

Entire build complete, which generated 1 Body(s)
```

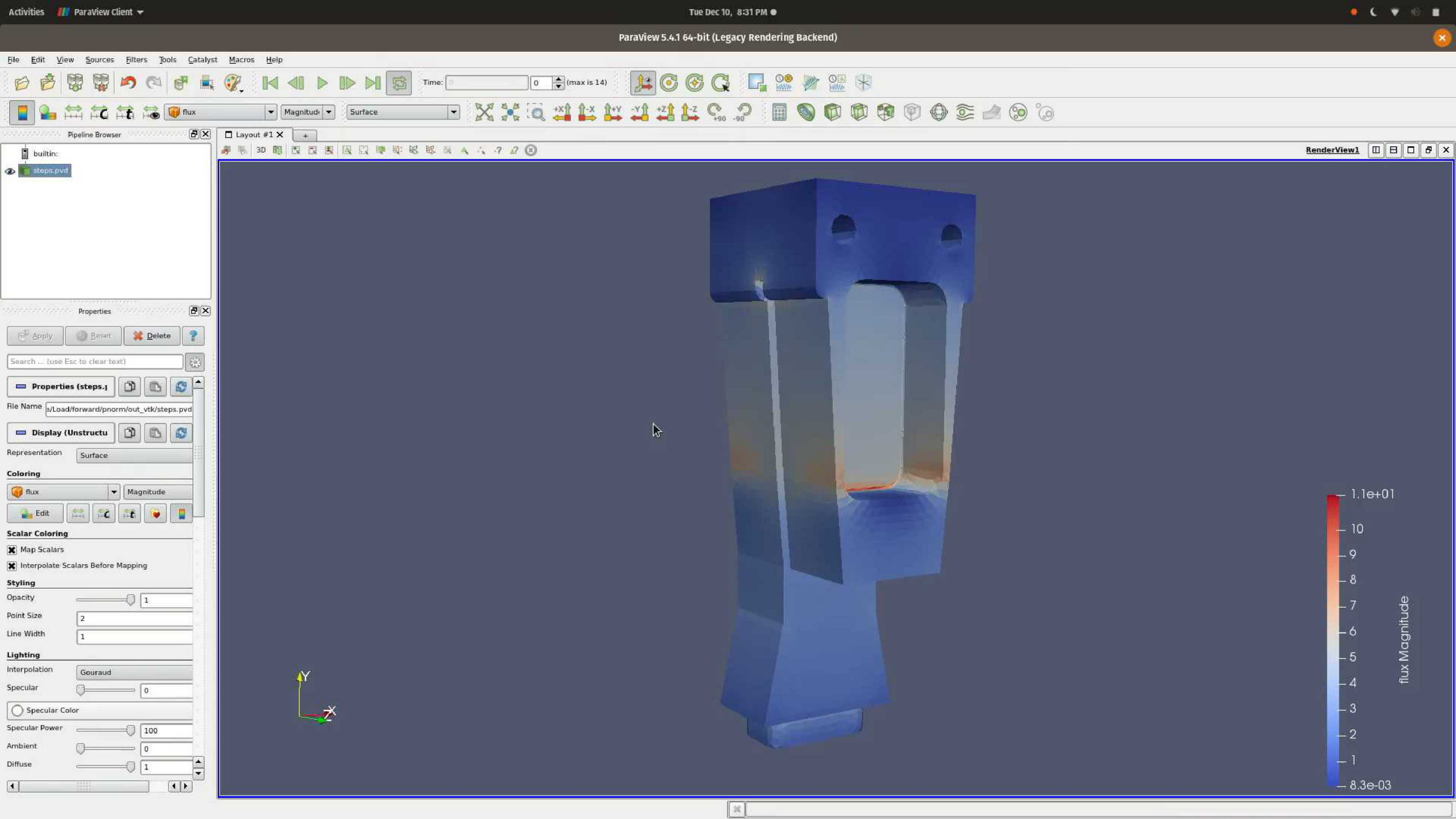
# Electrostatic Load Case





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Time: 0 (max is 14)
flux
Magnitude
Surface
Pipeline Browser
builtin:
steps.pvd
Properties
Apply Reset Delete
Search ... (use Esc to clear text)
Properties (steps.
File Name
e/Load/forward/pnorm/out_vtk/steps.pvd
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Interpolate Scalars Before Mapping
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Specular
Specular Color
Specular Power
Ambient
Diffuse
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3D
RenderView1
1.1e+01
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7
6
5
4
3
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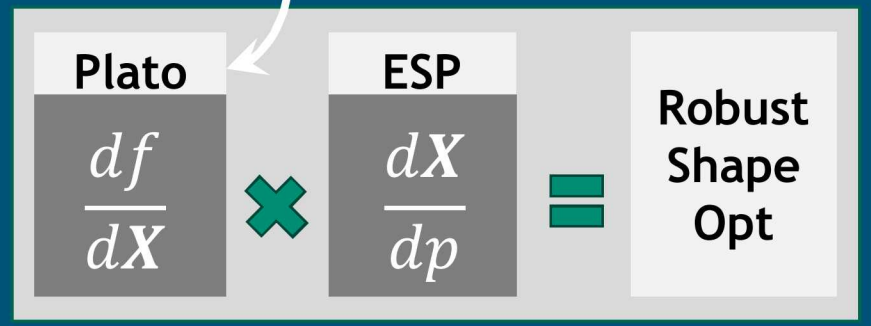
1
8.3e-03
flux Magnitude
Y
X
Z

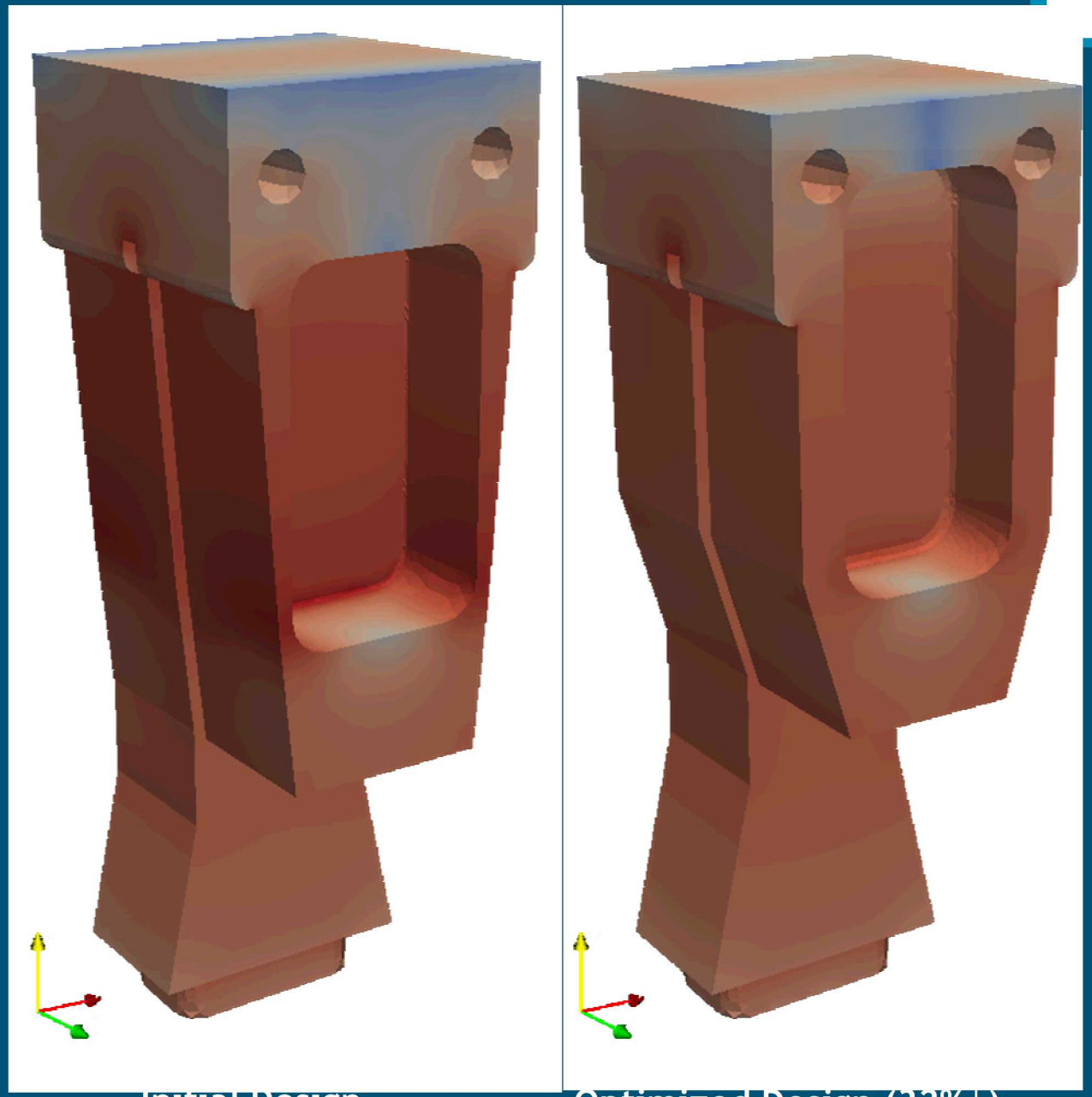
# Shape Optimization with Plato/ESP

**Progress:**
- ESP functionality implemented in Plato Engine
- Beta Plato/ESP capability available for early adopters.

**Next Steps:**
- Testing and hardening of Plato/ESP
- Shape optimization + topology optimization

Your physics and objectives go here



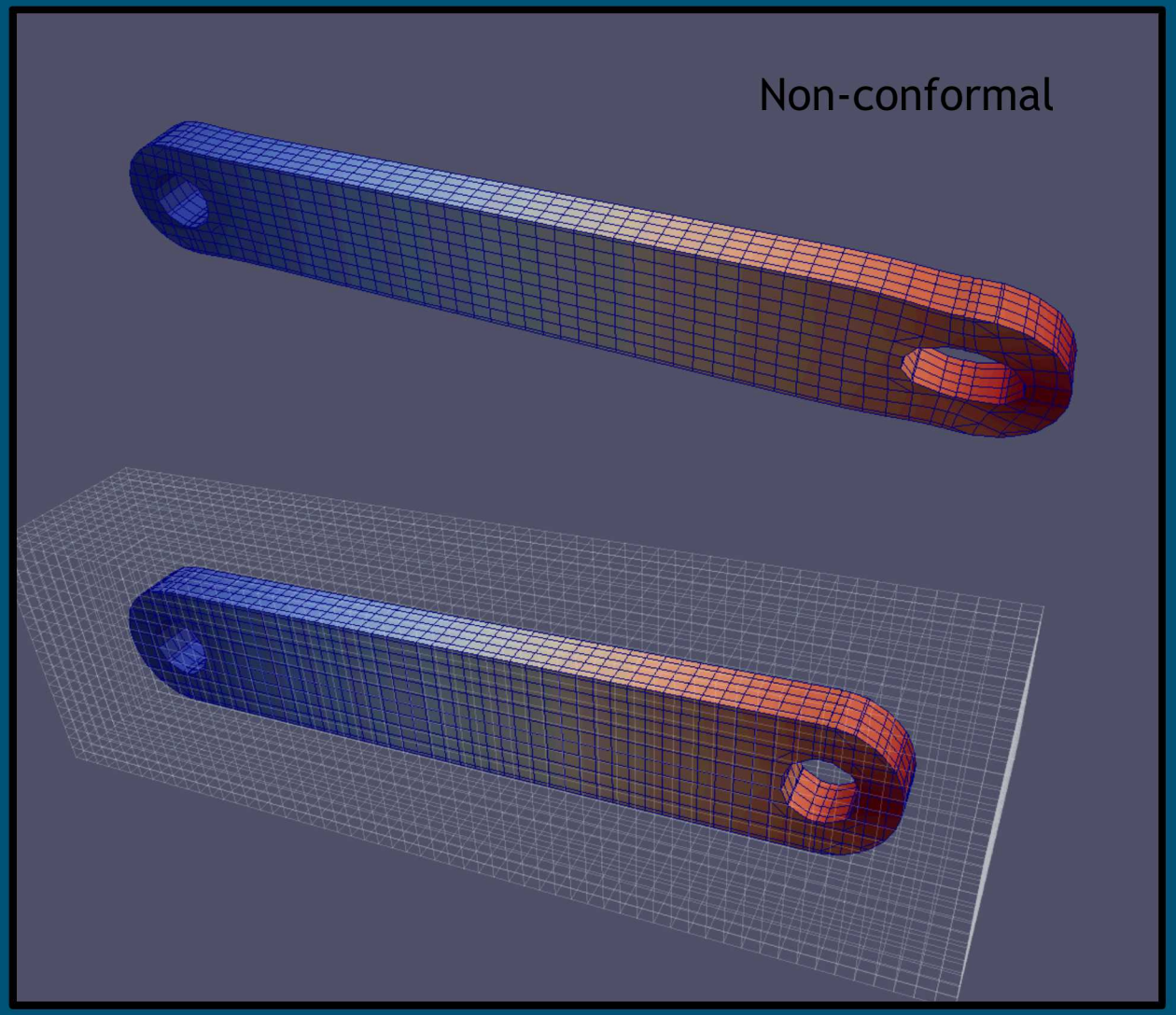



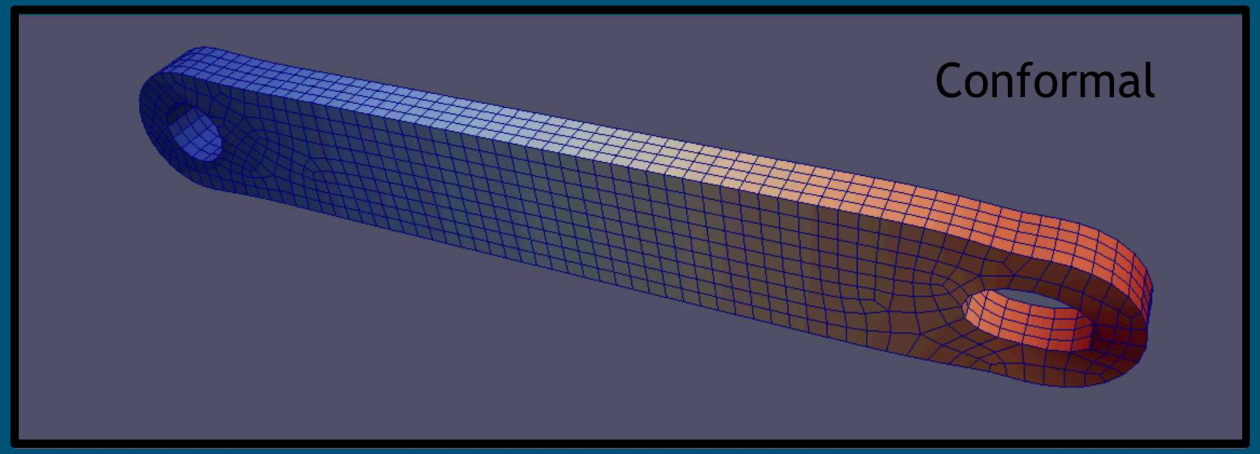
Initial Design

Optimized Design (32%↓)

# Optimization-based Design for Manufacturing Project:

- ‘Meshless’ design – concurrent SO/TO
- Process-aware design

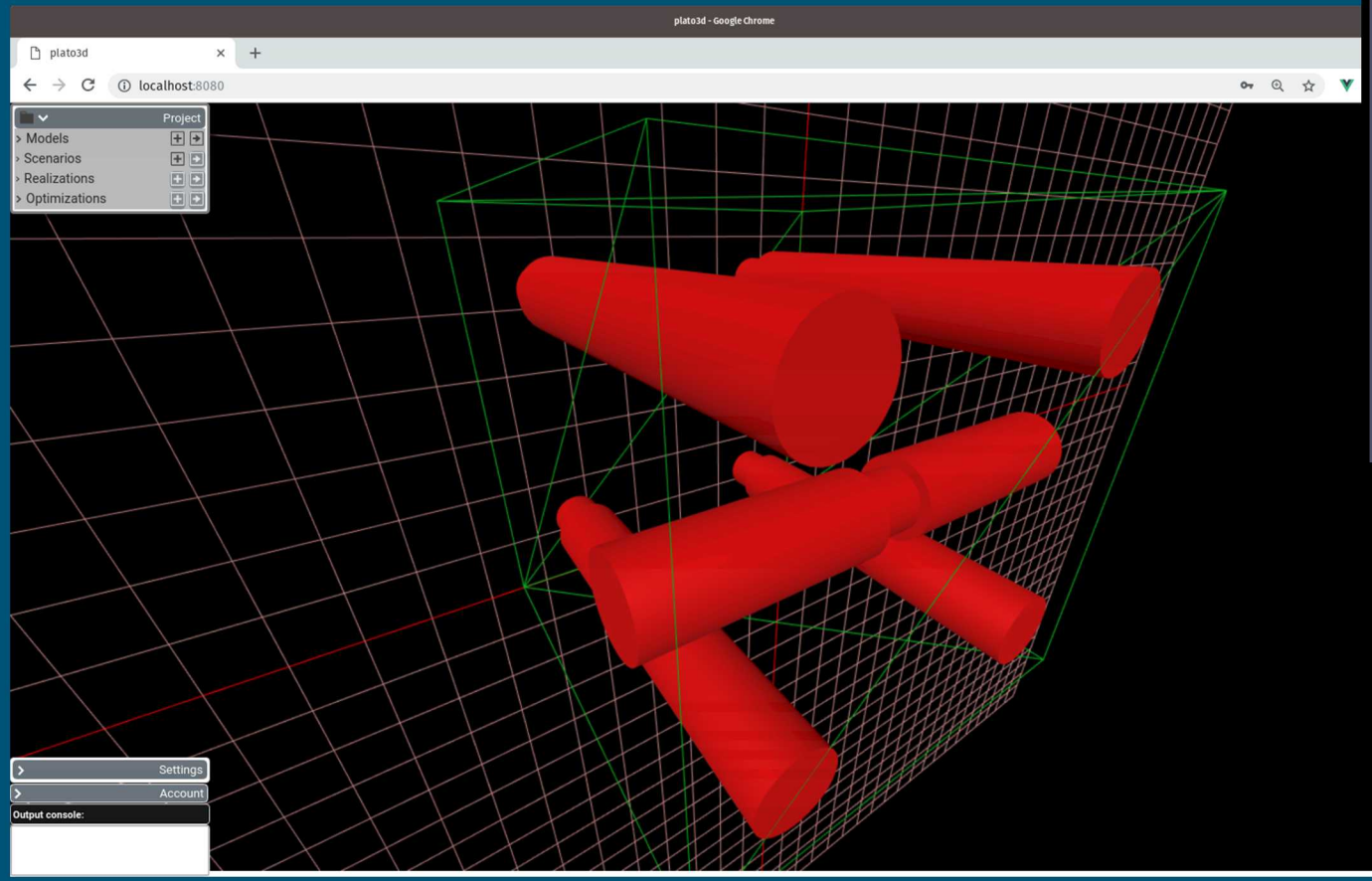


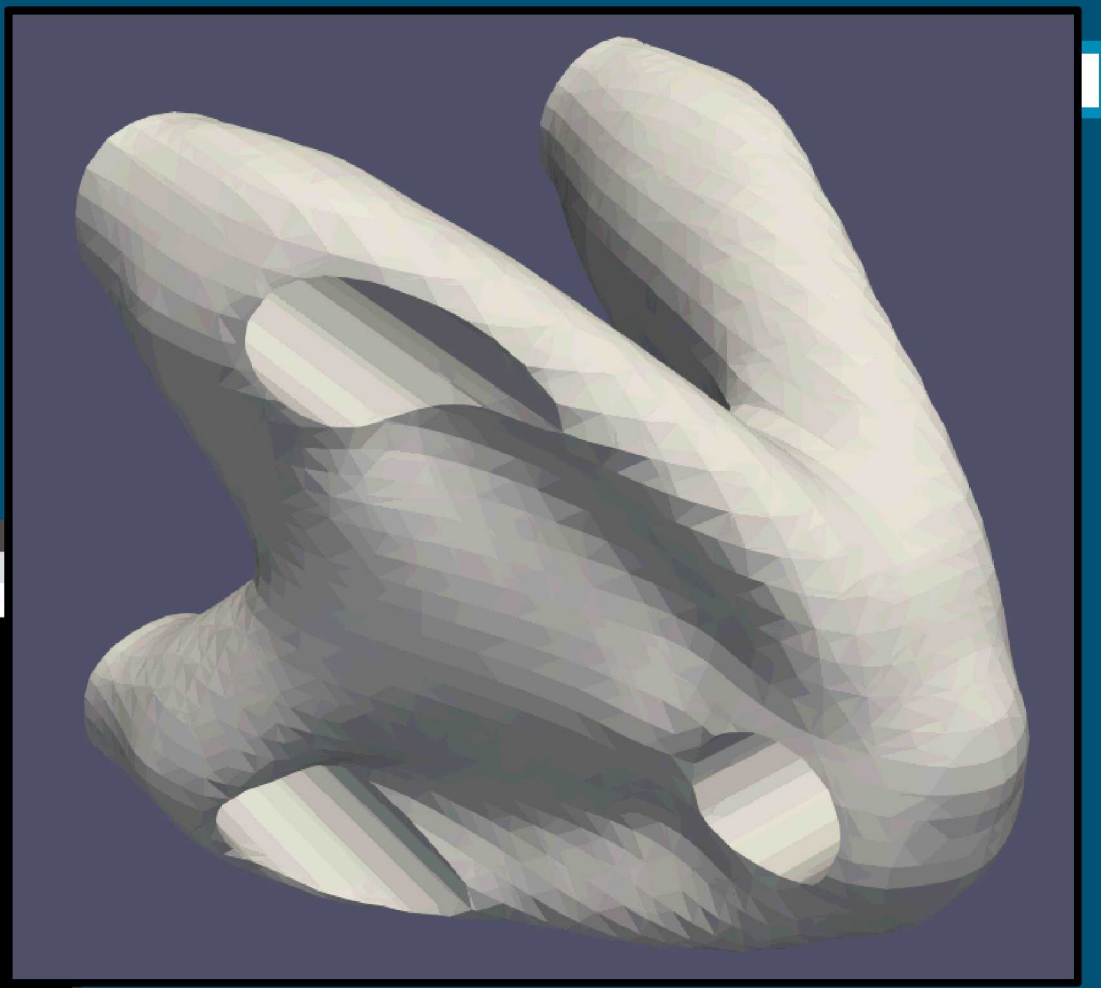



# ‘Meshless’ Design

Capture geometry on a background mesh non-conformally:

- Simplifies geometry construction and meshing
- Permits movement of fixed geometry within a design domain
- Permits optimization of assemblies



- Albany on Google Compute Platform (GCP)
- REST API with Server Sent Events (SSE)
- No mesh, just geometry

- Shape optimization workflow de-emphasizes meshing.
  - Simplifies user experience (user interface)
  - Complicates user experience (parameterized models)
  - Has lower barrier to entry

# Thank you