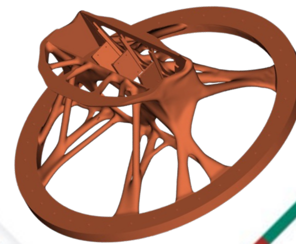
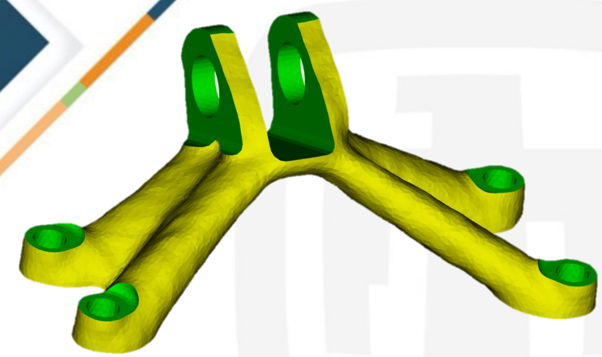
Sandia National Laboratories

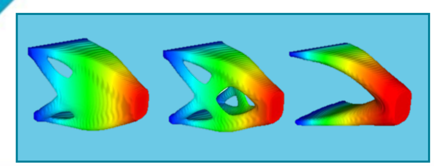
Exceptional service in the national interest



PLATO OPTIMIZATION-BASED DESIGN



Trilinos User Group Meeting



Plato Software Development Team

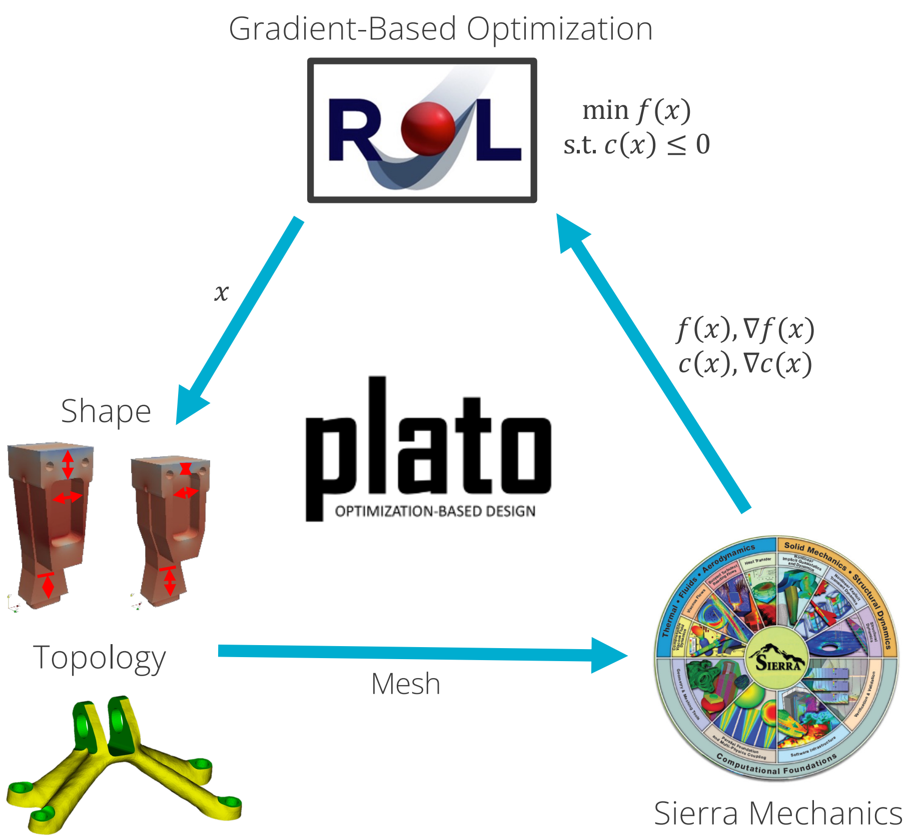
November 1st, 2023

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

U.S. DEPARTMENT OF ENERGY

NNSA

PLATO: OPTIMIZATION-BASED GEOMETRY DESIGN



Strategy for automated design:

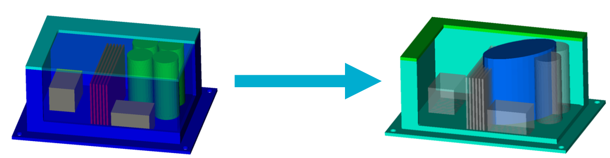
- Quantify quality $f(x)$ of design x via simulation
- Formulate a mathematical optimization problem.

What Plato allows users to do:

- Orchestrate the workflow
- Use gradient-based methods
- Automatically compose function evaluations across software packages for
  - Geometry
  - Meshing
  - Physics Simulation

Plato's purpose at Sandia:

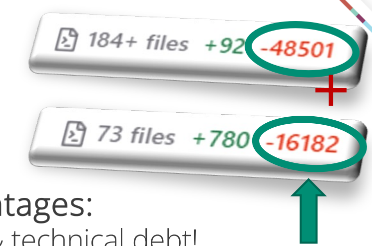
- Platform for shape/topology optimization
- Platform for continued research
- Bread & butter: compliance min., stress-constrained mass min., mass mocks



PLATO: FY23 Q3 NOTEWORTHY ITEMS

- HOW ARE YOU DELIVERING ON 1IC?
  - Production-ready thrust – improved build/test process integrated with Sierra, partnership with analysts
  - Incorporation of ROL's stochastic optimization capabilities via V&V project
  - Ability to work with and connect to Sierra Mechanics
  - Plans to leverage 1540 UX/UI experience/capabilities
- **PERFORMANCE TO PLAN HIGHLIGHTS:**
  - Removal of Plato's legacy optimizers completed. **This offers access to new algorithms and reduces our code maintenance burden through removal of 64k+ lines of code!**
  - Joshua Robbins putting together EDC demonstrator for mass property shape optimization based on SD Modal tool functionality
  - Full continuous integration with merge gating enabled for Plato! Easier to use Sierra with Plato and substantially improves Plato's code credibility moving forward.

Removal of legacy Plato Optimizer and full use of ROL



Over 64K lines of code deleted!

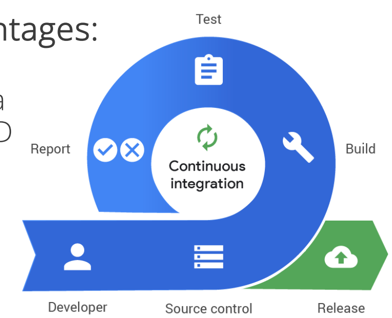
Has resulted in these advantages:

- Removed 64K lines of code & technical debt!
- Reduced maintenance burden
- Increased code sharing
- ROL is only gradient-based optimizer available in Plato

With help of DevOps, Plato is now on SRN under Continuous Integration

Has resulted in these advantages:

- More secure development
- Closer integration with Sierra
- Closer integration with FuSED
- Vastly improve code quality
- Always in a releasable state



HOOK UP TACHO SOLVER

Customer: ASC/Plato

Purpose:

- Epic Goal: Enable Plato Analyze use of ShyLU_Node solver Tacho
- Sprint Goal: Plato interface is completed, Tacho is solving problems

Impact:

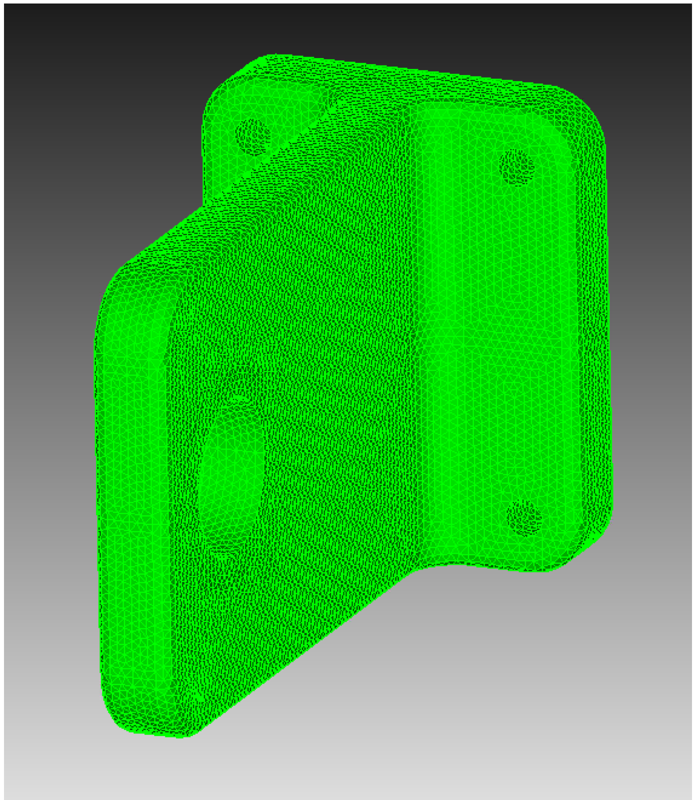
- High-performance cross-platform shared-memory linear solver available in Plato
- More robust testing, CPU-based testing
- Performance improvements?

HOOK UP TACHO SOLVER

Instead of a few days' effort, this turned into a two-sprint odyssey.

Thanks for your help:

- Clark Dohrmann – lending us his interface
- Kyungjoo Kim – helping us compile it
- Christian Trott – helped us update to newer version of Kokkos



HOOK UP TACHO SOLVER

Timing comparison with AmgX (@ 1e-12) on compliance minimization problem

DOFs	Tacho runtime (forward solve)	AmgX runtime (forward solve)	Tacho runtime (optimization)	AmgX runtime (optimization)
10245	14 s	15 s	11 s	18 s
86559	12 s	16 s	29 s	35 s
195357	14 s	16 s	53 s	91 s
626409	36 s	19 s	170 s	136 s
931500	50 s (14 GB mem)	22 s	252 s	191 s
1470714	Out of memory	26 s	Out of memory	300 s
4857837	Out of memory	Out of memory	Out of memory	Out of memory

HOOK UP TACHO SOLVER

- Large startup cost obscures behavior for small problem sizes
- AmgX scales better for large problems, as expected
- GPU build of Tacho limited by 32-bit integer indices (this is a choice), device memory.
- Tacho amortizes symbolic factorization cost significantly: subsequent solves in optimization loop much quicker than the first
- To try:
  - Tacho multi-core CPU builds on larger systems (no device memory limit)
  - Tacho with higher-order elements (AmgX struggles)

HOOK UP TACHO SOLVER

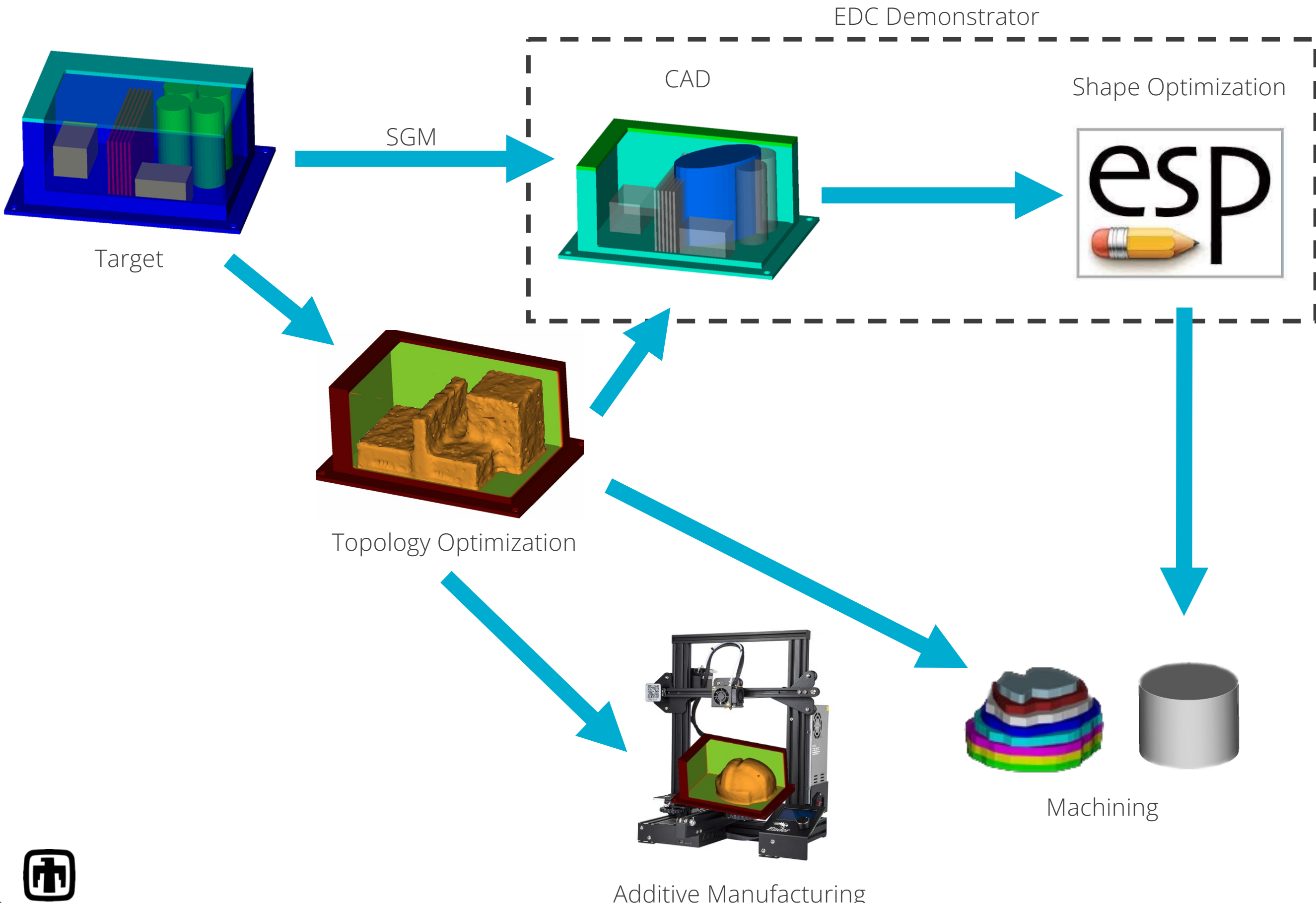
Timing comparison with AmgX (@ 1e-12) on orthotropic compliance minimization problem (poorly conditioned linear system)

DOFs	Tacho runtime (optimization)	AmgX runtime (optimization)
32448	21 s	102 s

Summary

- Tacho is faster for up to a few hundred thousand DOFs
- Tacho is faster and more robust for poorly-conditioned systems
- Tacho works on CPUs and non-nVidia hardware
- We will default to Tacho but keep AmgX
- We will delete our interface to Epetra-based solvers

MASS MOCK DESIGN



Topology Optimization
- Rapid interrogation of target properties
- Material downselect
- Inspiration

Shape Optimization
- Dialing it in

EDC demonstrator
- shape optimization of mass properties
- web-based UI components

plato
OPTIMIZATION-BASED DESIGN

LONG-TERM VISION FOR MATCHING DYNAMICS (FY24+)

User-friendly tools for mass/dynamic mock design and fixture design that drive development of UI/UX components and connection to DEE.

Automatic conversion of CAD to simplified CSG (SGM)
- Mass-properties-aware simplification

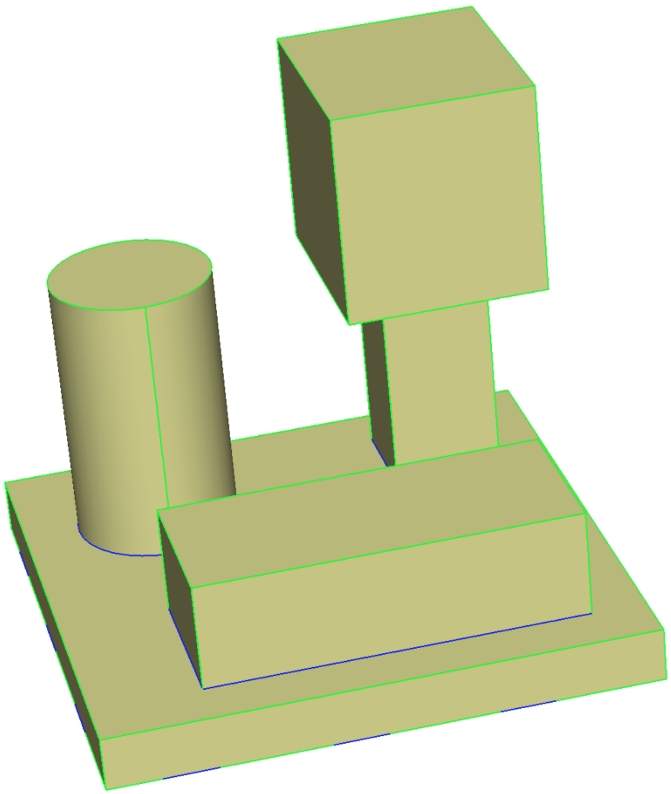
Improved numerical algorithms (Sierra/SD)
- Shape sensitivity for shells and contact; investigate MPE sensitivity
- Great opportunity to refactor and clean up Plato-SD interface

Improved problem formulation (FuSED/ROL)
- Optimal selection of measurement locations
- Generalization measurement operators to account for experimental data.

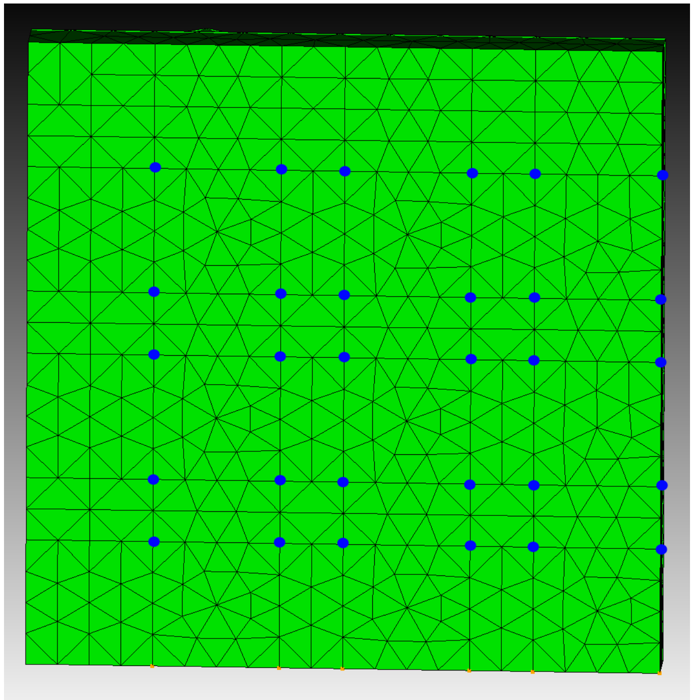
Level-set Methods for Topology Optimization (LDRDs: Alberdi, Dugger)
- Necessary to get good solutions with dynamic physics

plato
OPTIMIZATION-BASED DESIGN

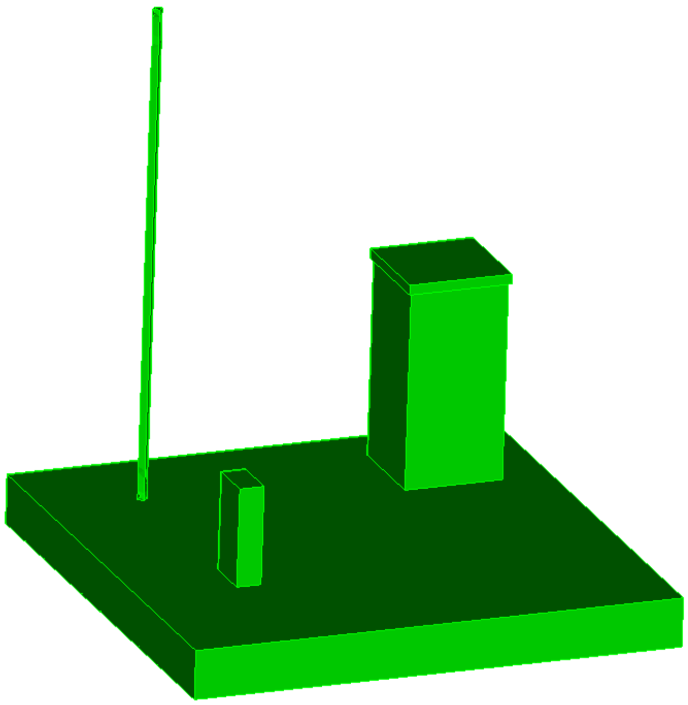
MASS MOCK MODAL MATCHING



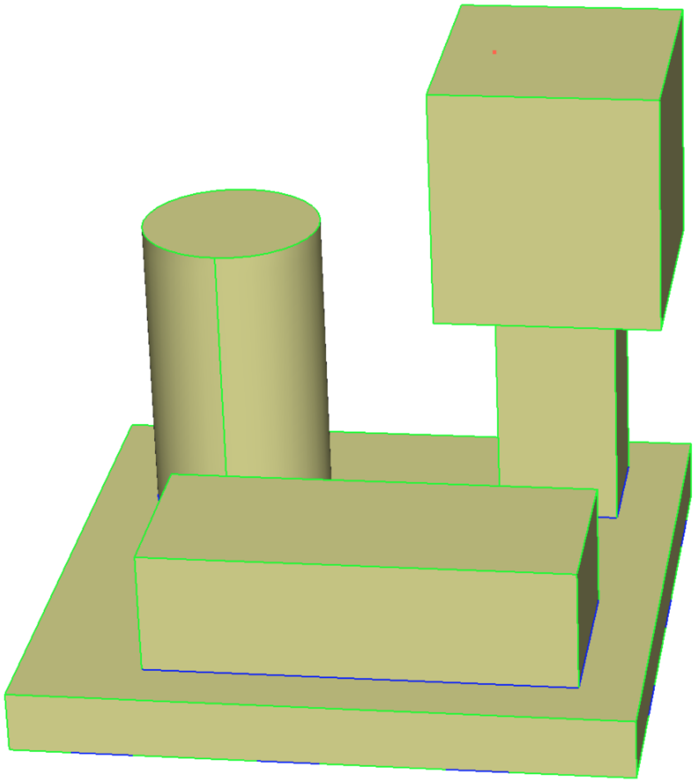
Modes measured at blue dots on the bottom of the geometry



MASS MOCK MODAL MATCHING

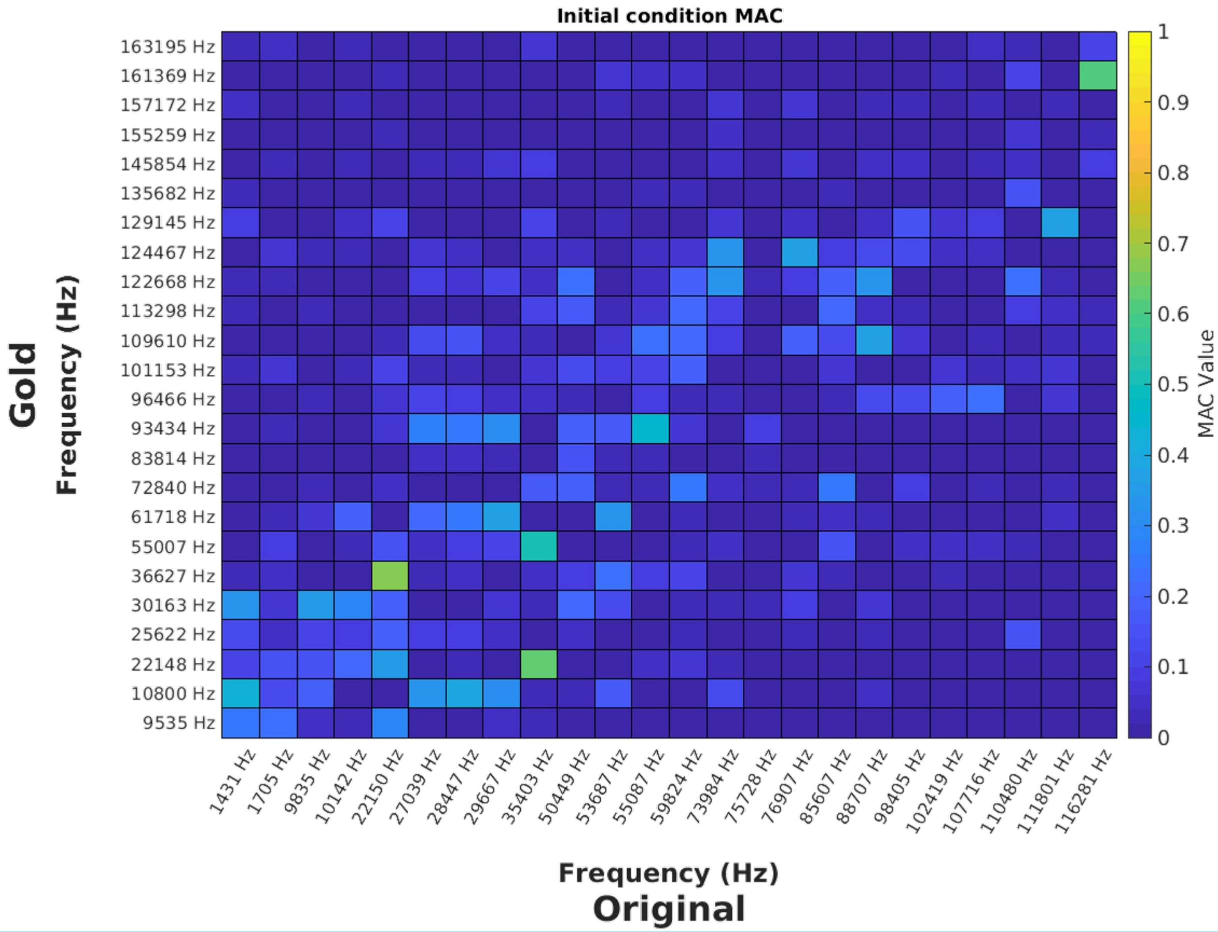


Initial

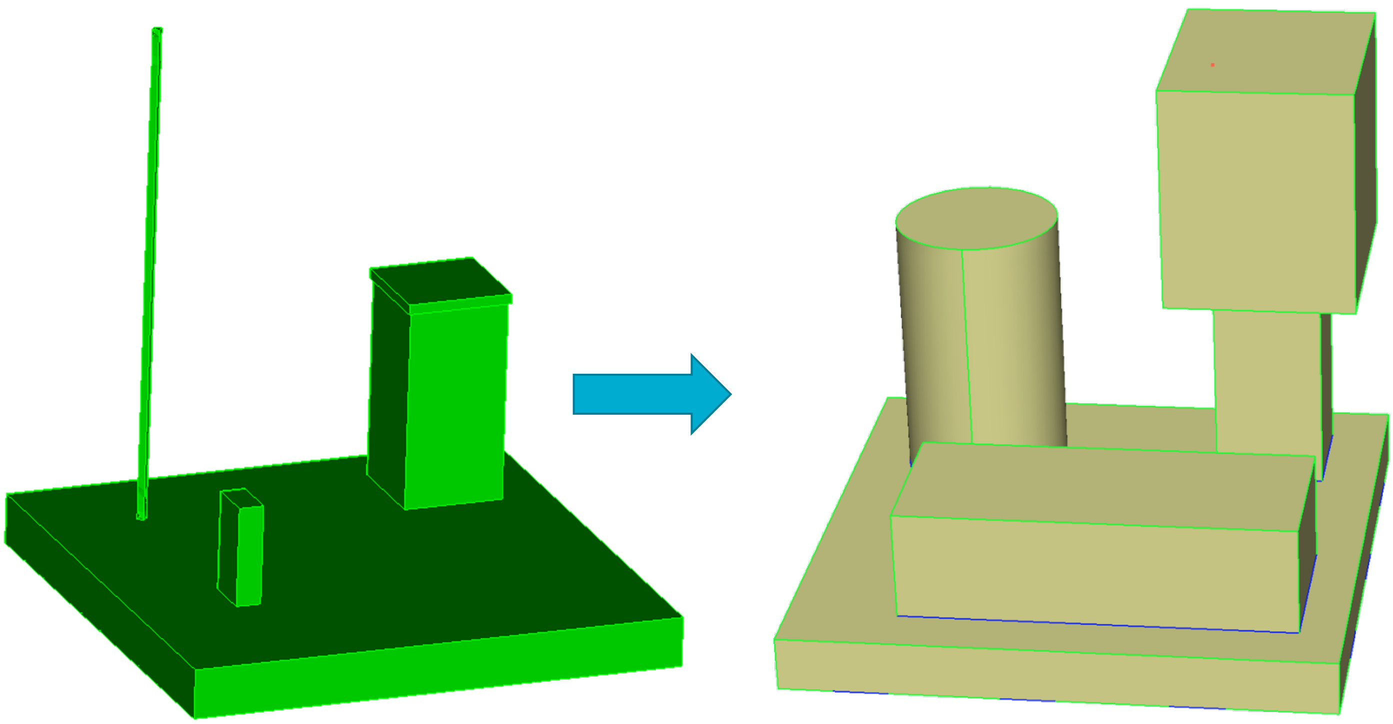


Gold

MODAL ASSURANCE CRITERION (MAC)

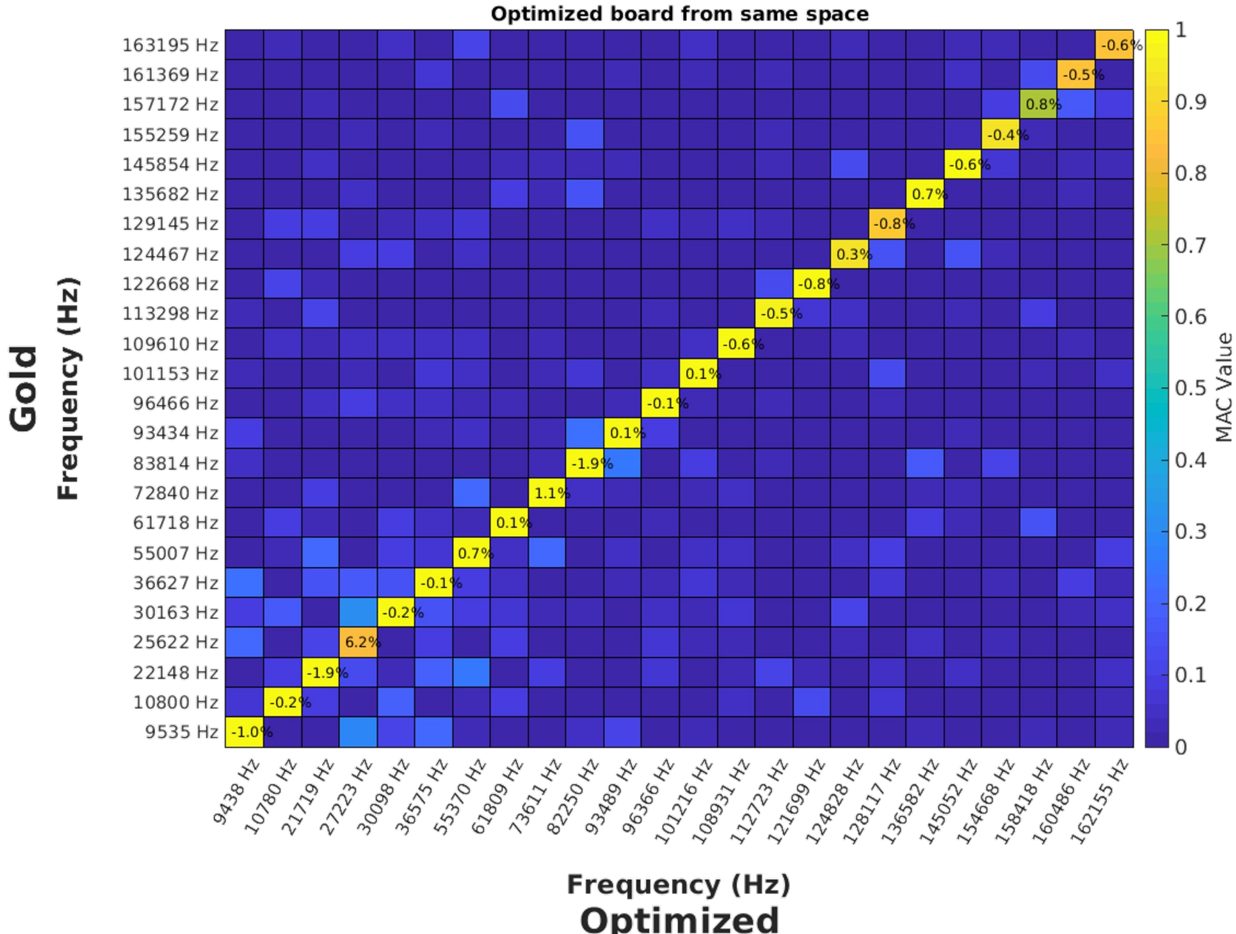


MASS MOCK MODAL MATCHING

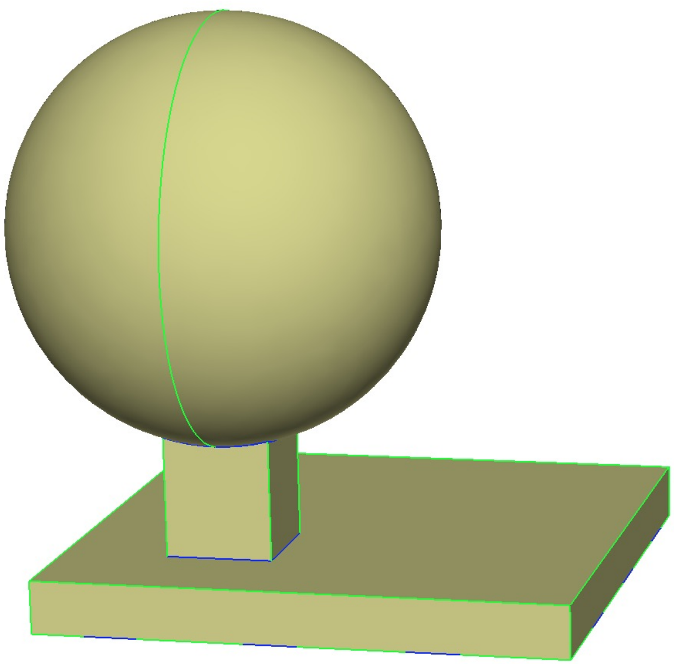


Gold	Optimized
2.5	2.522263
2.5	2.506502
5	4.997805
1.5	1.519576
4.25	4.315312
4	4.255144
3.75	3.547251
3	2.966192
7	7.199514

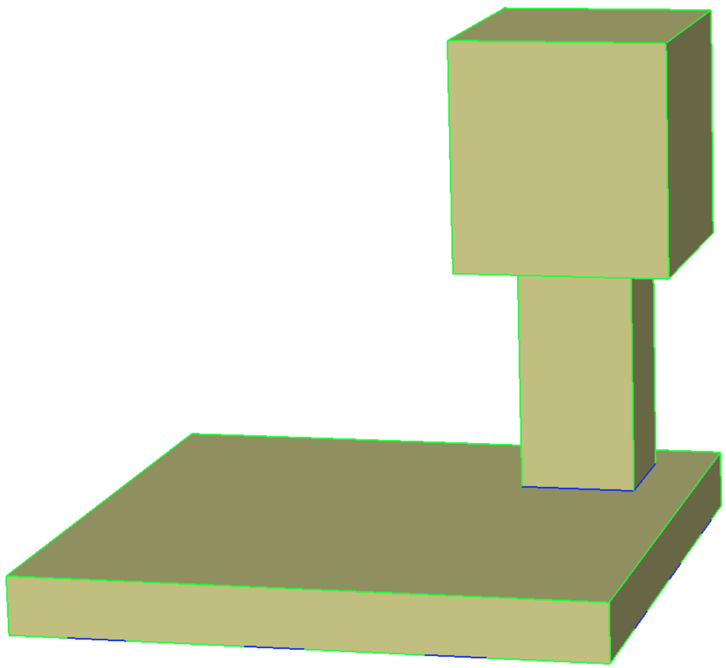
MODAL ASSURANCE CRITERION (MAC)



MASS MOCK MODAL MATCHING

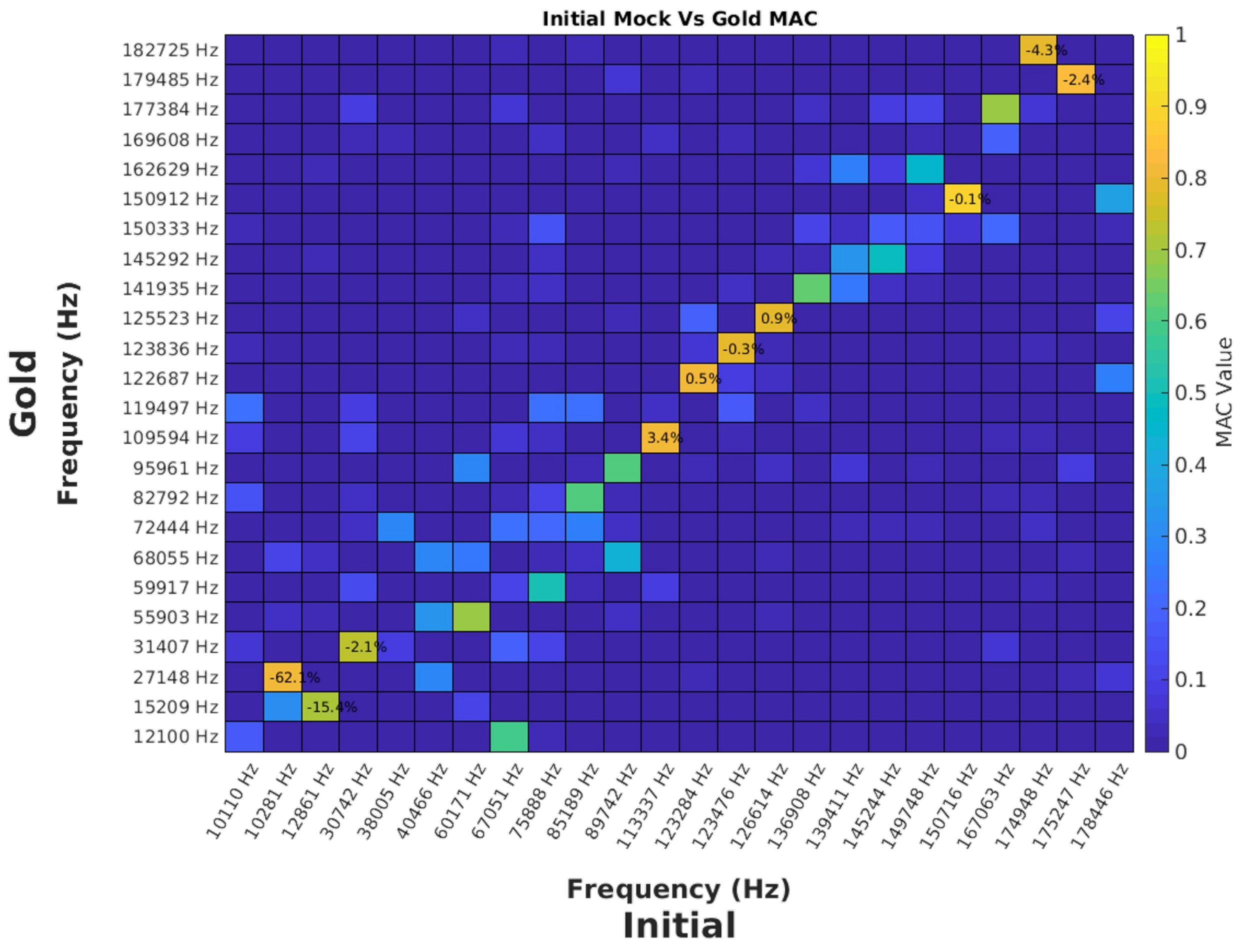


Initial

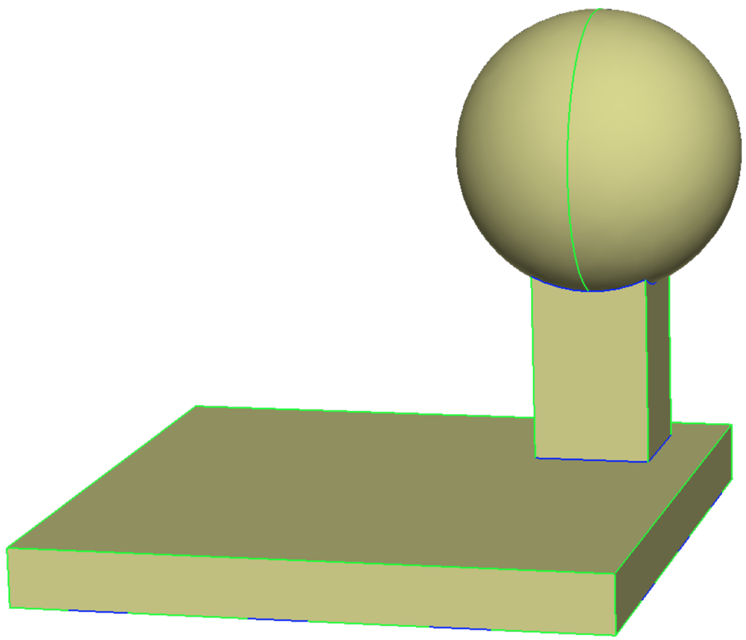


Gold

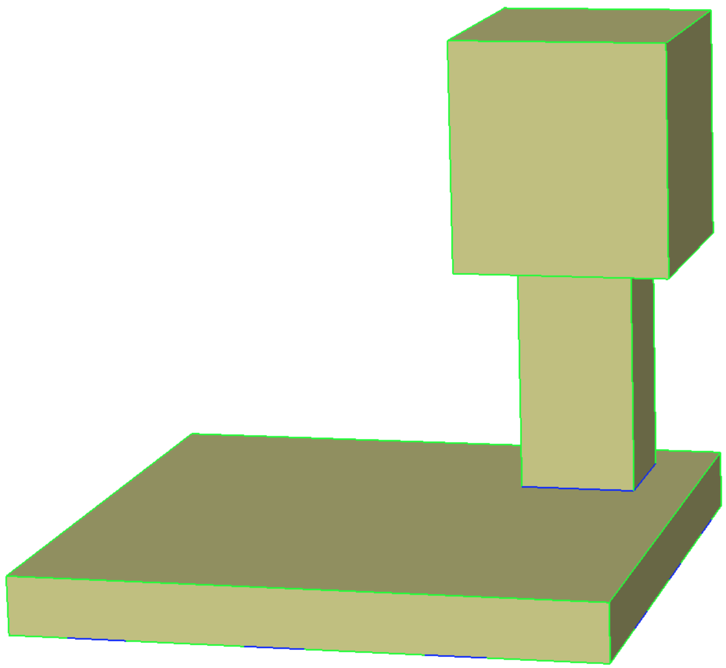
MODAL ASSURANCE CRITERION (MAC)



MASS MOCK MODAL MATCHING

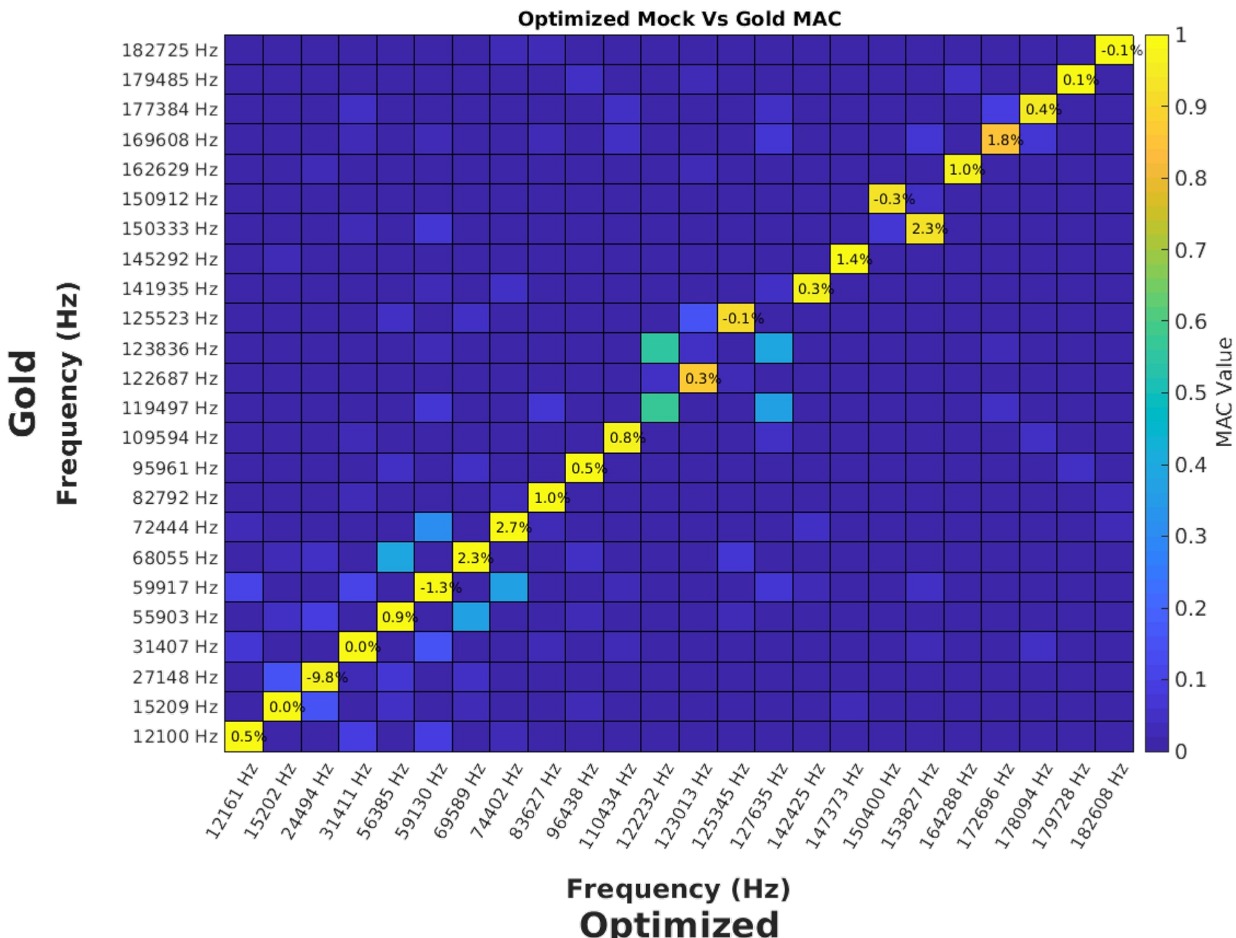


Optimized



Gold

MODAL ASSURANCE CRITERION (MAC)



PARALLELIZATION OF STOCHASTIC ROL

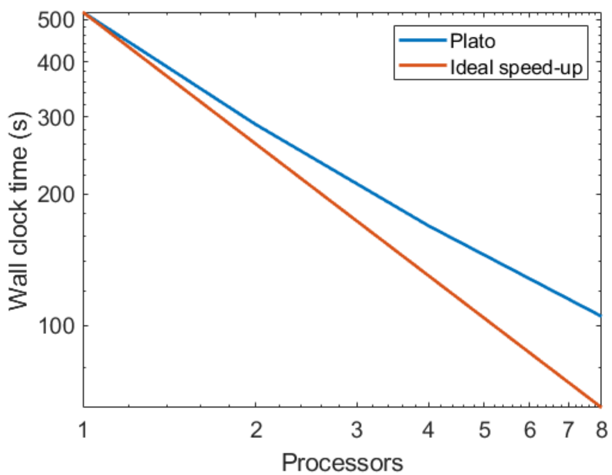
Customer: ASC

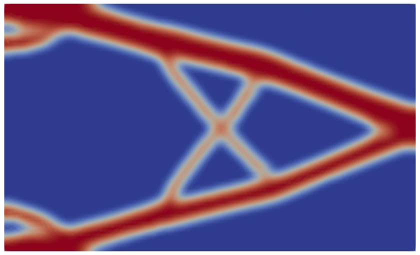
Purpose:

- Epic Goal: Integrate stochastic ROL methods
- Sprint Goal: Implement parallelization
  - Stochastic methods evaluate large numbers of samples
  - Batch compute objectives/gradients over available physics codes
- Future work:
  - Write report

Impact:

- Running stochastic problems is more practical





Gaussian distribution load
32 samples

Customer: ASC

Purpose:

- **Epic Goal**: Integrate stochastic ROL methods
- **Sprint Goal**: Write final V&V report
  - Summarized work completed and implementation details
  - Demonstrated parallel speed-up
  - Provided examples of larger scale problems

Impact:

- Reporting and documentation of stochastic optimization features

Risk neutral

Risk averse

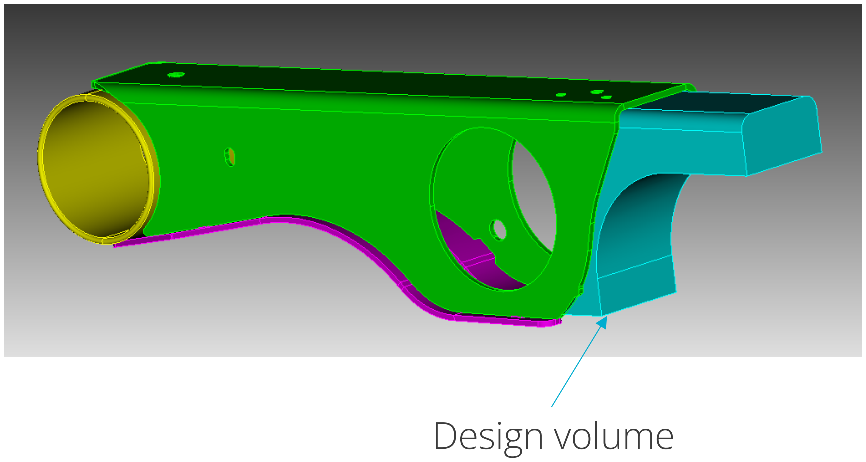
BRACKET OPTIMIZATION

Purpose:

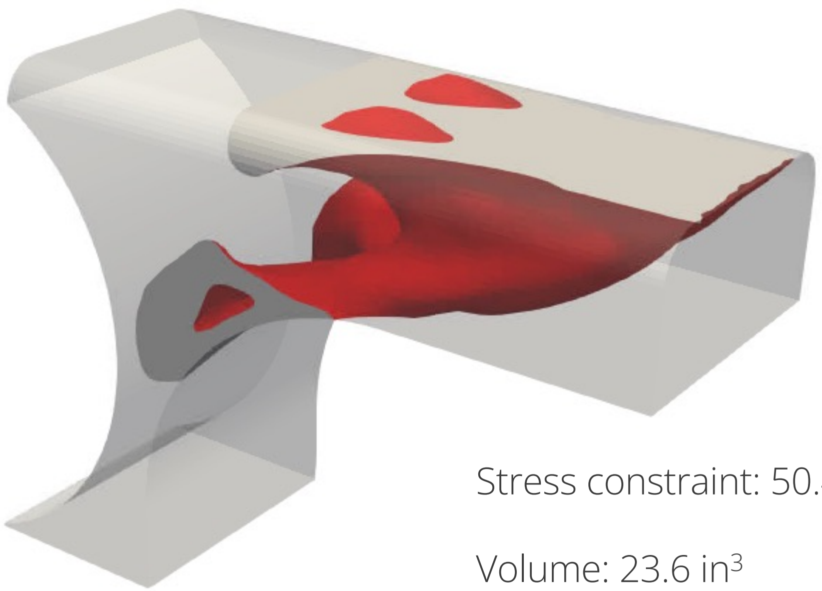
- Sprint Goal:
  - Validate bracket designs
  - Follow-up optimization
  - Stress constrained mass minimization

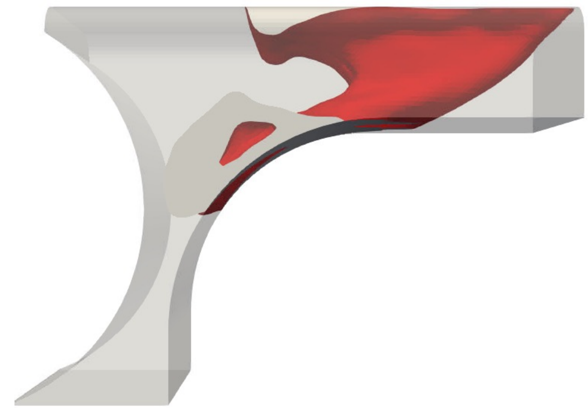
Results:

- Provided several optimized designs for different stress constraints
- Customer to additively manufacture in 316 stainless



316 STAINLESS STEEL

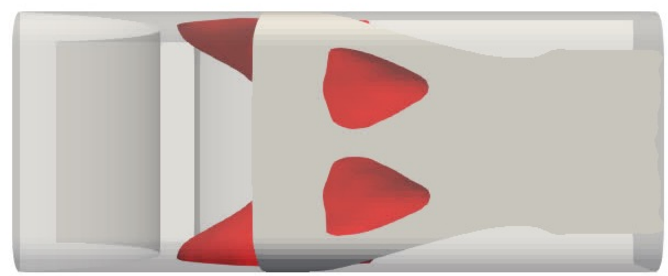




Stress constraint: 50.4 ksi

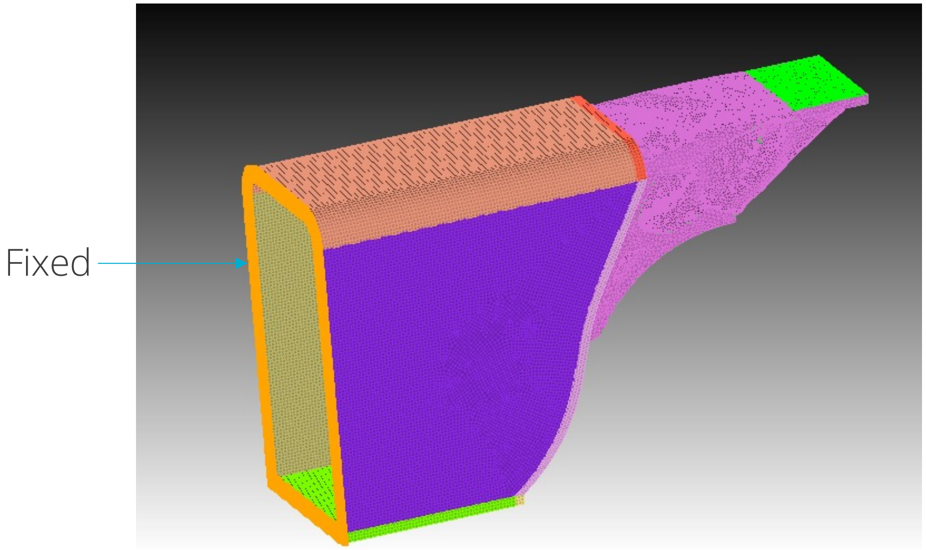
Volume: 23.6 in^3
Mass: 6.7 lbs
Vol frac: 15.2%

Original volume: 155.2 in^3
Original mass: 44.5 lbs

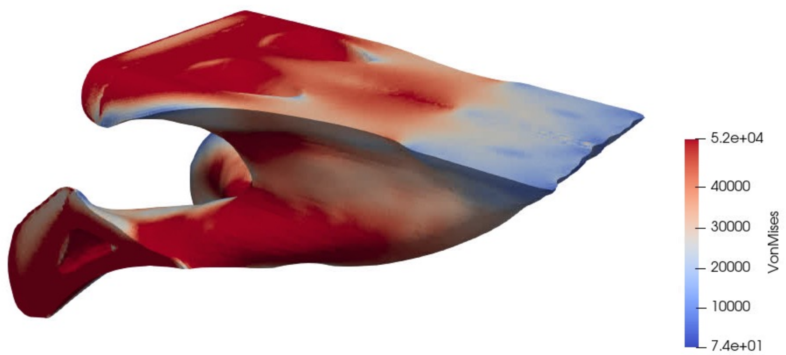


ANALYSIS RESULTS

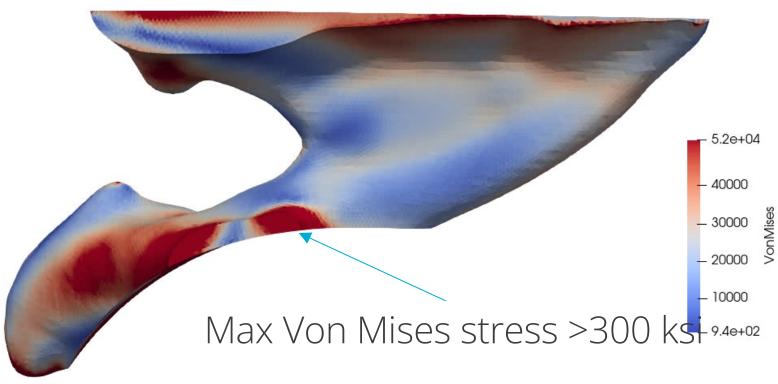
- Extract surfaces from results
- Remesh with tets
- Run in Sierra/SD with a mounting bracket to mimic trailing arm and tet10 elements
- Tied contact BC for weld at interface of the two blocks
- Fixed BCs placed on back of bracket



316 STAINLESS DESIGN



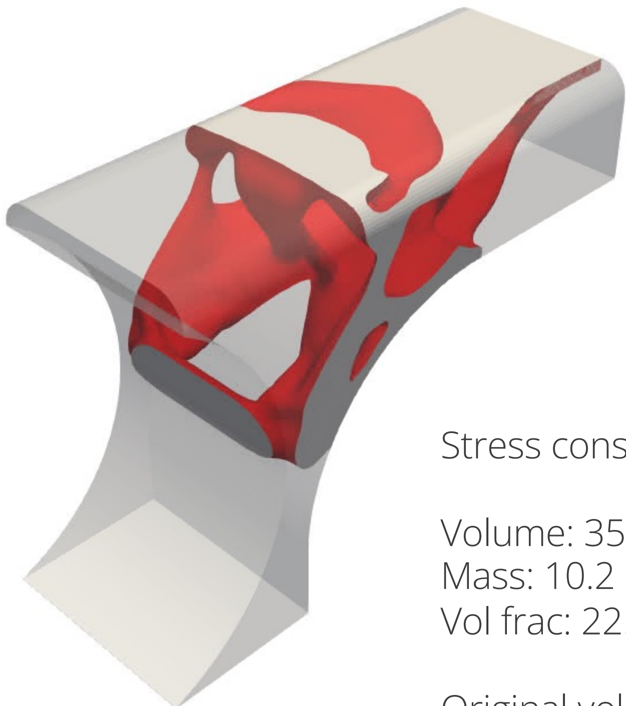
Von Mises stress, capped at 52 ksi
Yield strength 59 ksi



Center cut-through

MODIFIED FIXED BCS

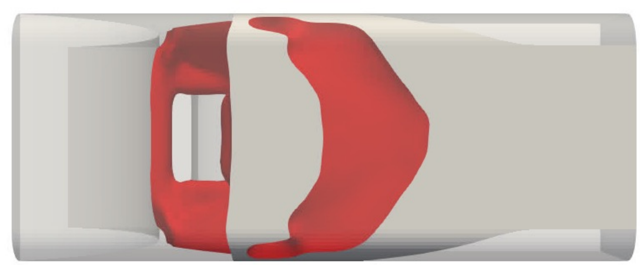
Fixed tangential displacement components
Free normal components



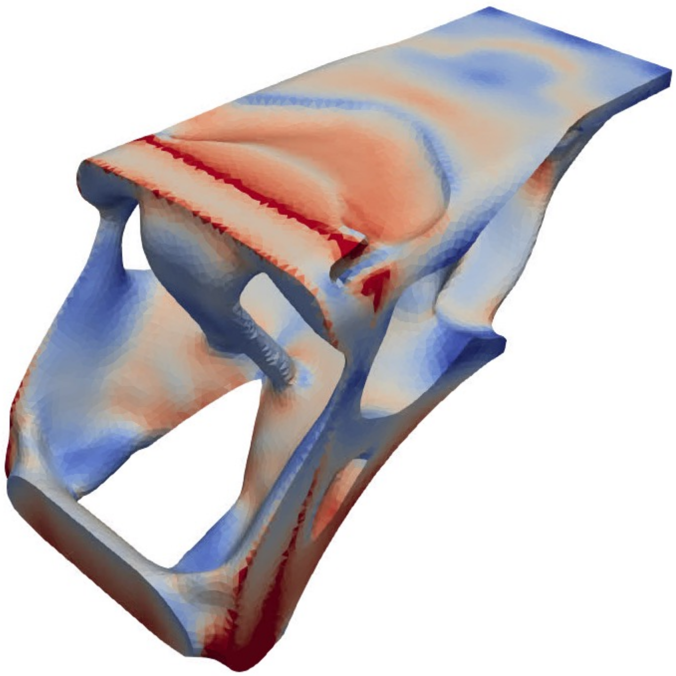
Stress constraint: 50.4 ksi

Volume: 35.5 in^3
Mass: 10.2 lbs
Vol frac: 22.8%

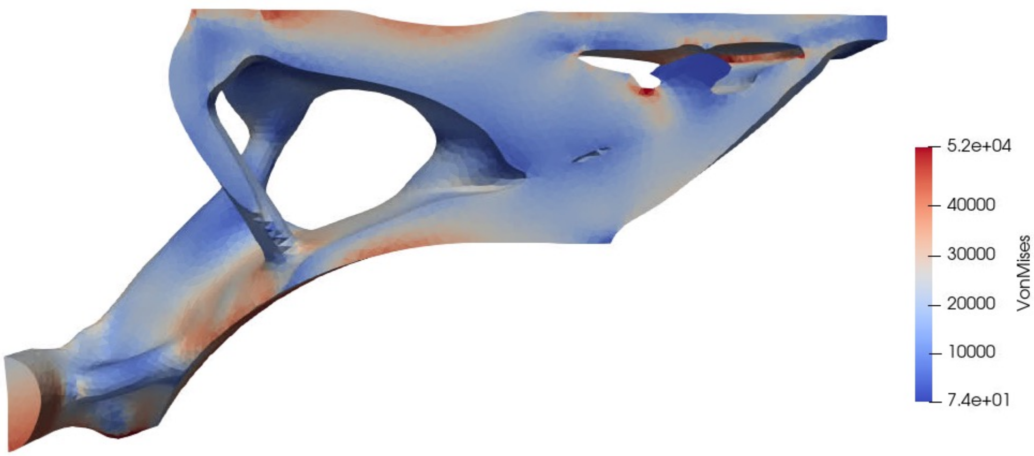
Original volume: 155.2 in^3
Original mass: 44.5 lbs



MODIFIED FIXED BCS

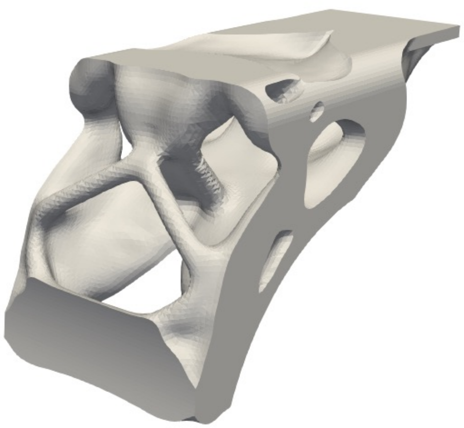


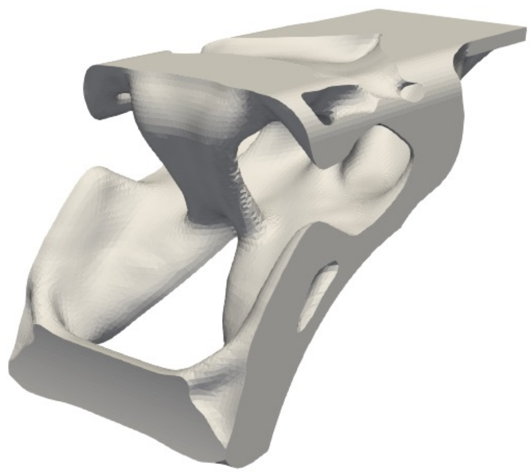
Von Mises stress, capped at 52 ksi

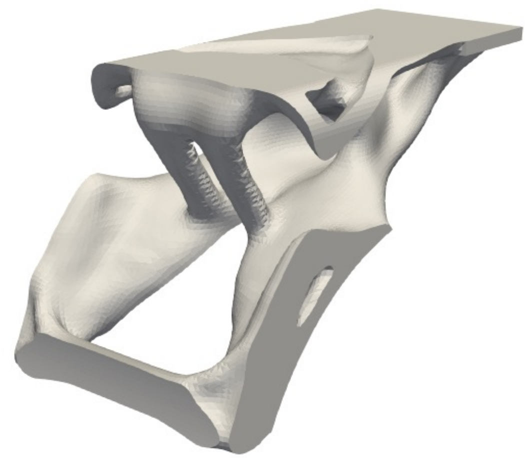


Center cut-through

316 stainless steel







Stress constraint: 60% yield strength (35.6 ksi)

Mass: 12.7 lbs

Stress constraint: 70% yield strength (41.5 ksi)

Mass: 10.3 lbs

Stress constraint: 80% yield strength (47.5 ksi)

Mass: 8.7 lbs

CONCLUSION: DIRECTION OF PLATO

Plato has an entrepreneurial history…

- Focus on research capabilities: proof of concept without maturation
- Development of its own optimizers, physics code
- Success in proving capability, bringing in SPP, LDRD funding

but now is becoming a production code:

- Strengthening Agile practices
- Incorporation of Continuous Integration (CI)
- Switch to ROL, pivot focus to Sierra Mechanics while maintaining AM engagements

Desired relationship with Trilinos:

- Strong collaboration with ROL on research, optimizer development, stochastic problems
- Continued engagement with Kokkos for performance portability
- Development of Tacho: need for performance-portable shared-memory sparse-direct linear solver