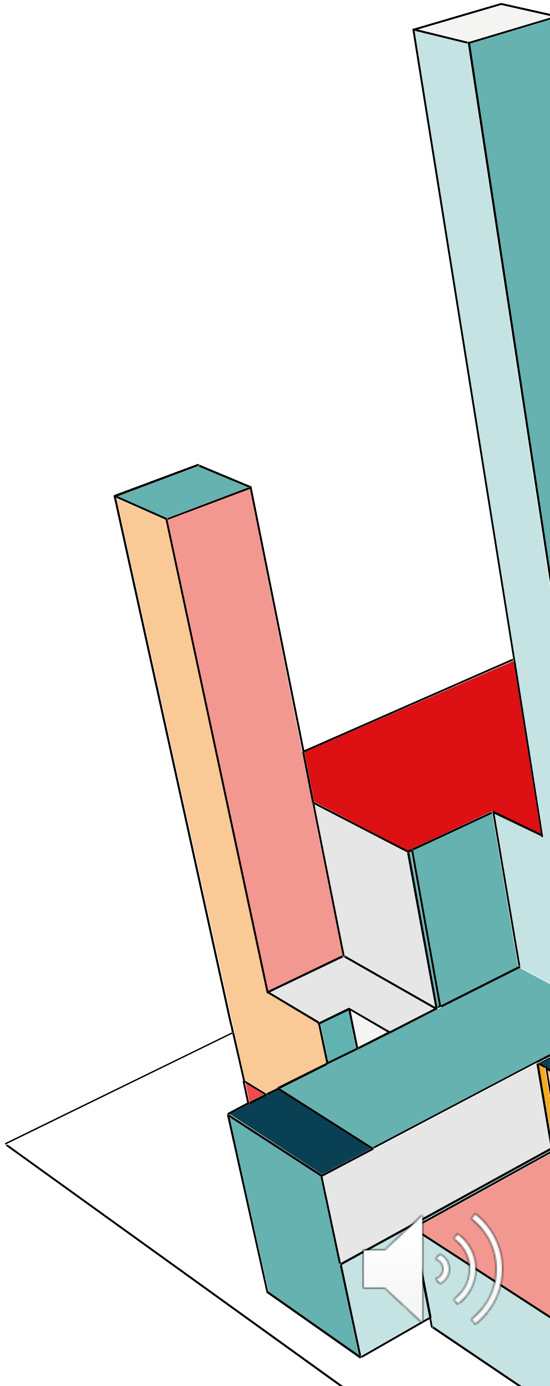
SIMULATION-DRIVEN DESIGN AND MANUFACTURING

AGENDA

- Introduction to manufacturing
- Types of manufacturing
- Why it matters
- Additive manufacturing



INTRODUCTION TO MANUFACTURING

- Subtractive Manufacturing
- Additive Manufacturing
- Hybrid Manufacturing

WHAT IS ADDITIVE MANUFACTURING AND GENERATIVE DESIGN?

- Generative design is an advanced engineering approach in which algorithms independently generate many possible design solutions according to parameters defined by the user.
- Compared to traditional design techniques where engineers iteratively create and analyze just one solution generative design makes it possible to simultaneously explore many optimized outcomes.
- This process depends on a designer defining the constraints, goals, and materials, while the software does the generation.

GENERATIVE DESIGN PROCESS: TECHNICAL BREAKDOWN

Input Definition:

- Specify parameters like constraints, objectives (e.g., minimize mass), loads, materials, and manufacturing methods.

Algorithmic Processing:

- Software explores thousands of configurations, optimizing for objectives like weight, stress, or displacement.

Design Iteration:

- Generates viable alternatives, assessed for metrics such as material usage, strength, and performance.

Result Evaluation:

- Designers review data (e.g., stress, displacement) and compare trade-offs using visual tools like scatter plots.

Manufacturing Integration:

- Final designs are prepared for manufacturing, ensuring compatibility with chosen methods.

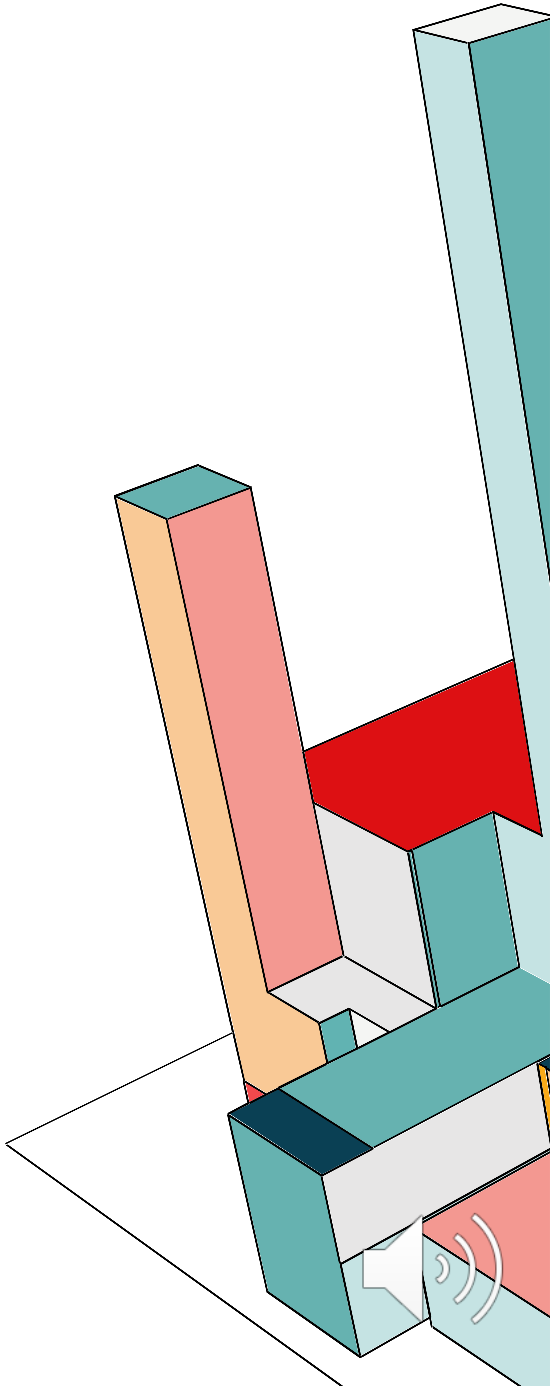
INTRODUCTION TO FUSION 360

Overview of Fusion 360:

- Integration of design, simulation, and manufacture on one platform
- Streamlining of the product development process, from modeling through fabrication.

Key Features:

- **Advanced CAD**: To precisely model
- **Simulation tools**: To analyze performance in the real world.
- **Manufacturing**: CNC machining and 3D printing



USED MODEL

The chosen design for this project is a GE Engine Bracket, a critical component used in jet engines to provide support during handling and maintenance. This bracket must sustain big loads under use without deformation or failure to ensure stability while remaining attached to the engine even in flight. Though primarily active during ground handling, its structural integrity is paramount to general engine safety.

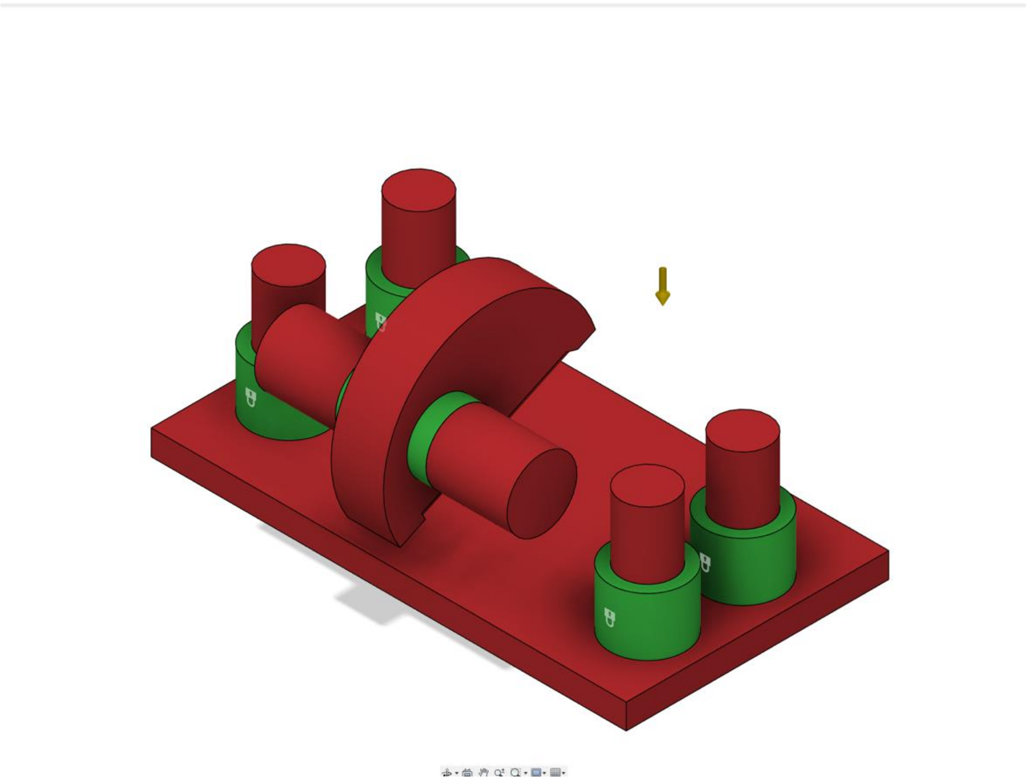
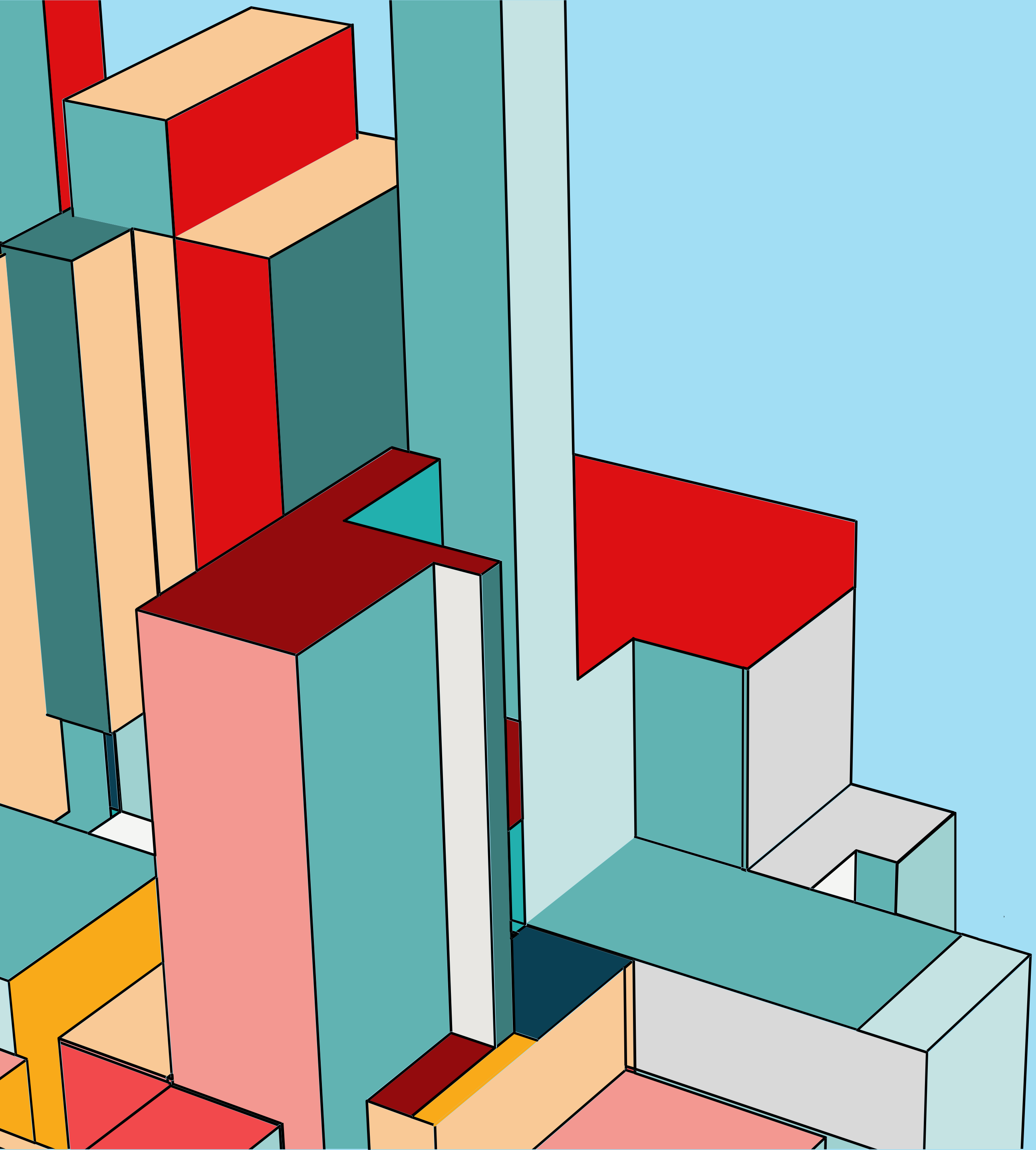
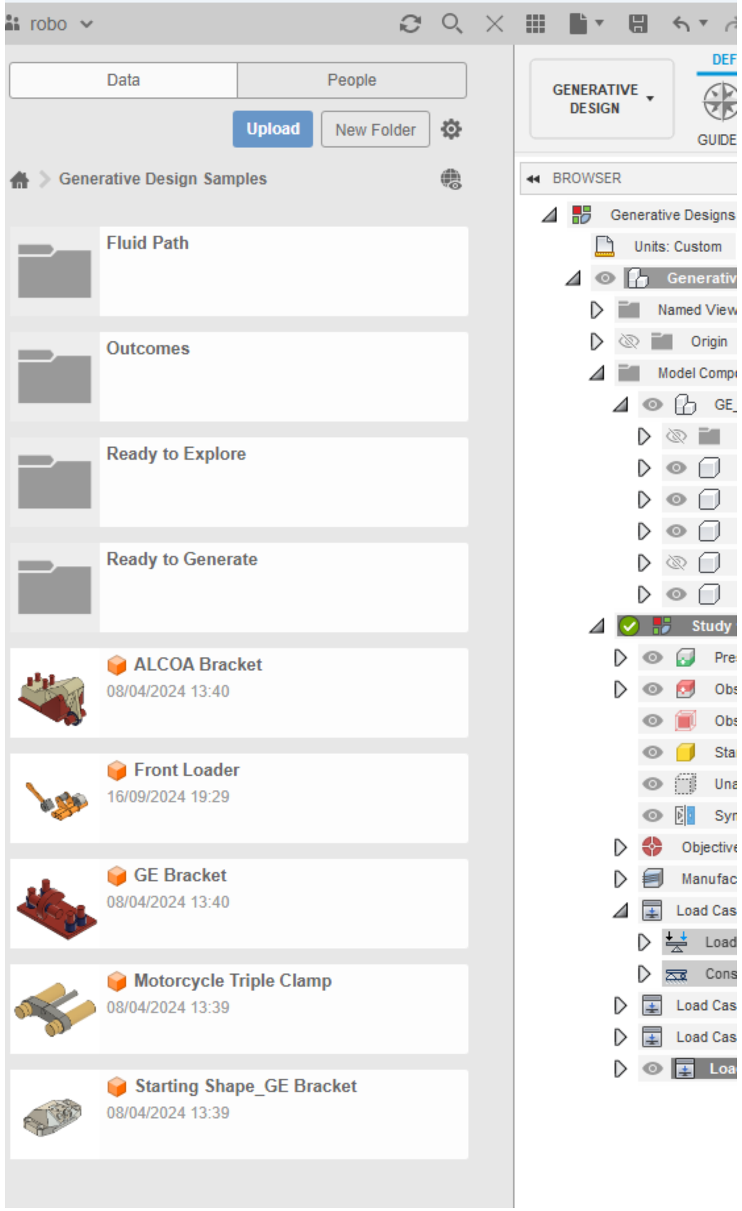


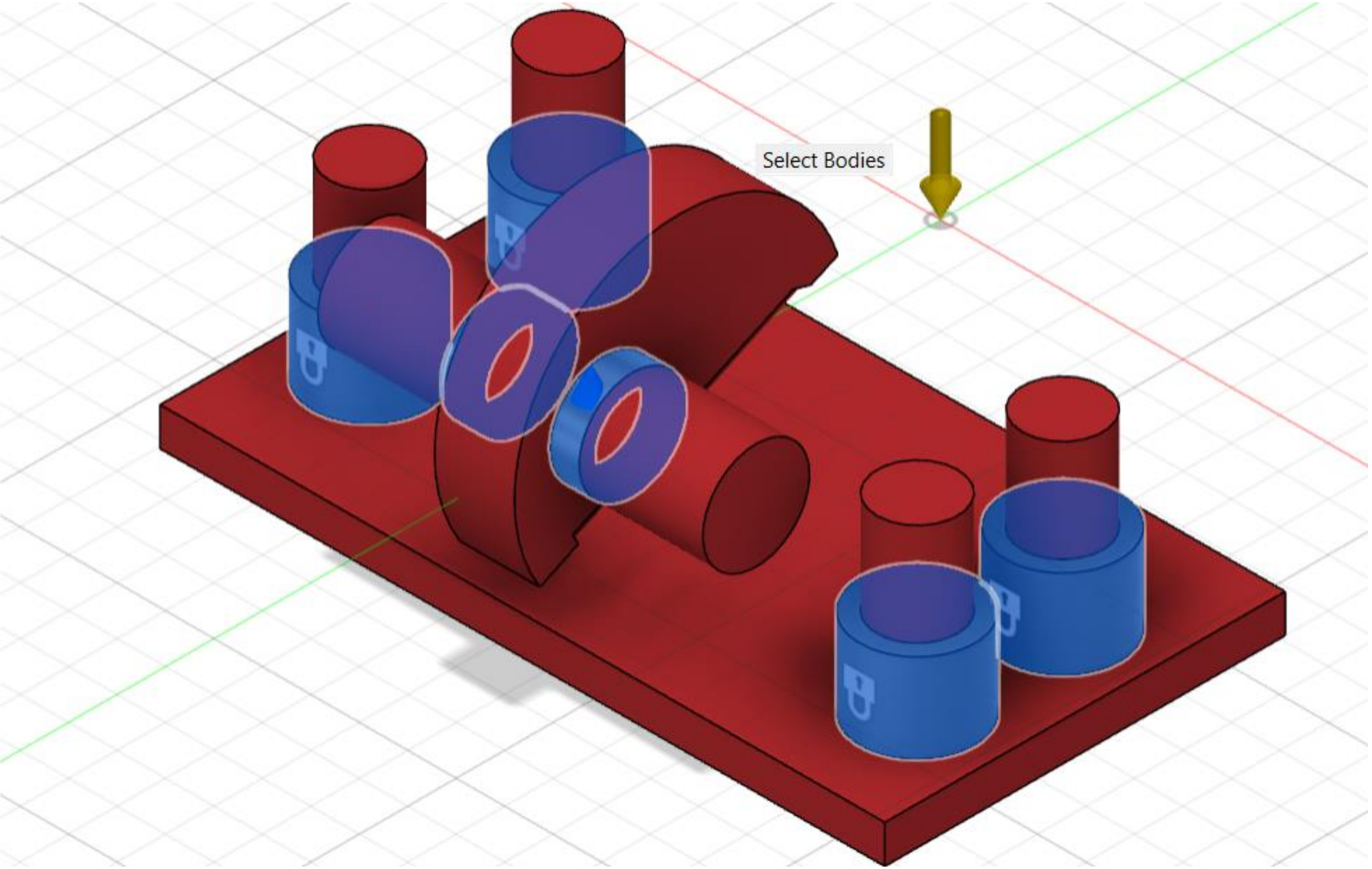
Fig1: GE Bracket



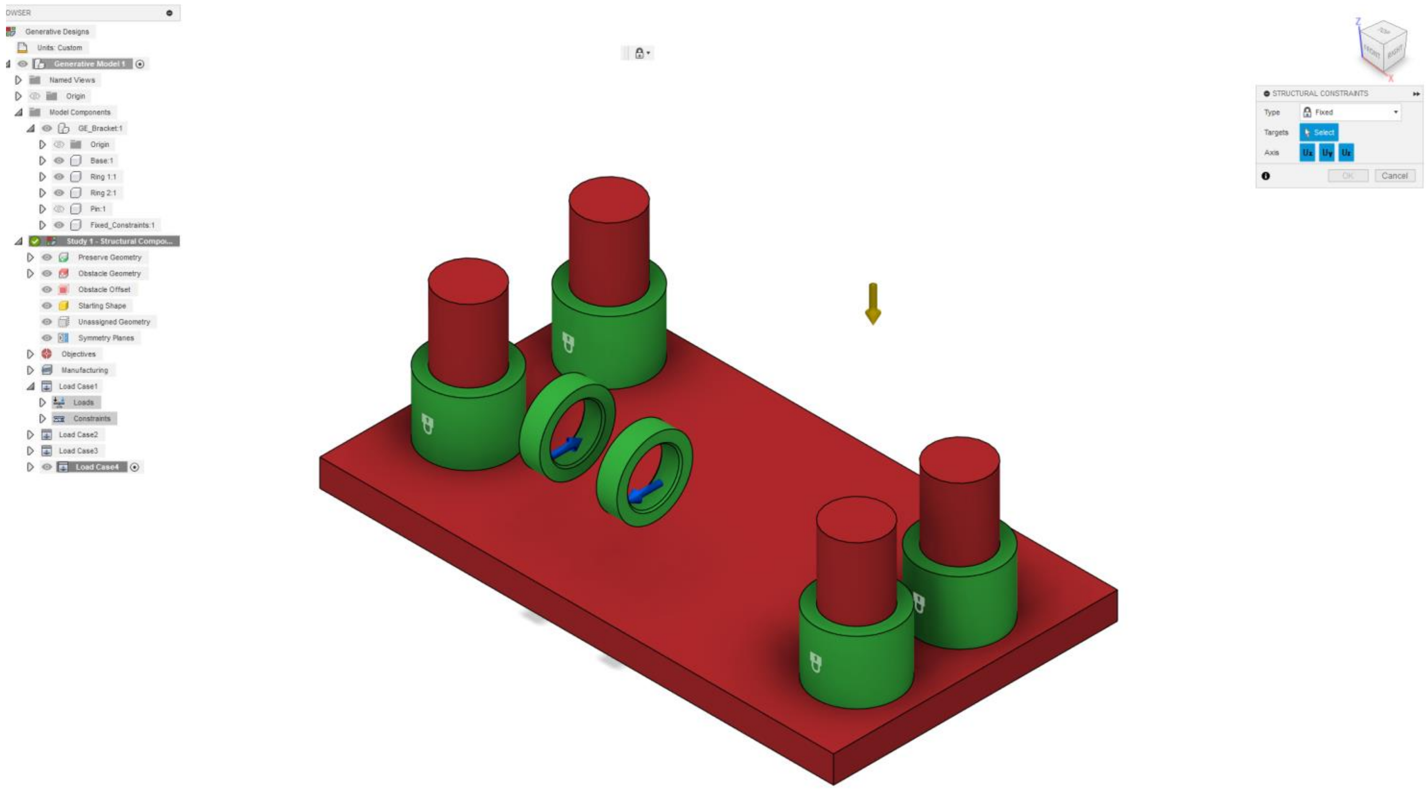
PROCESS



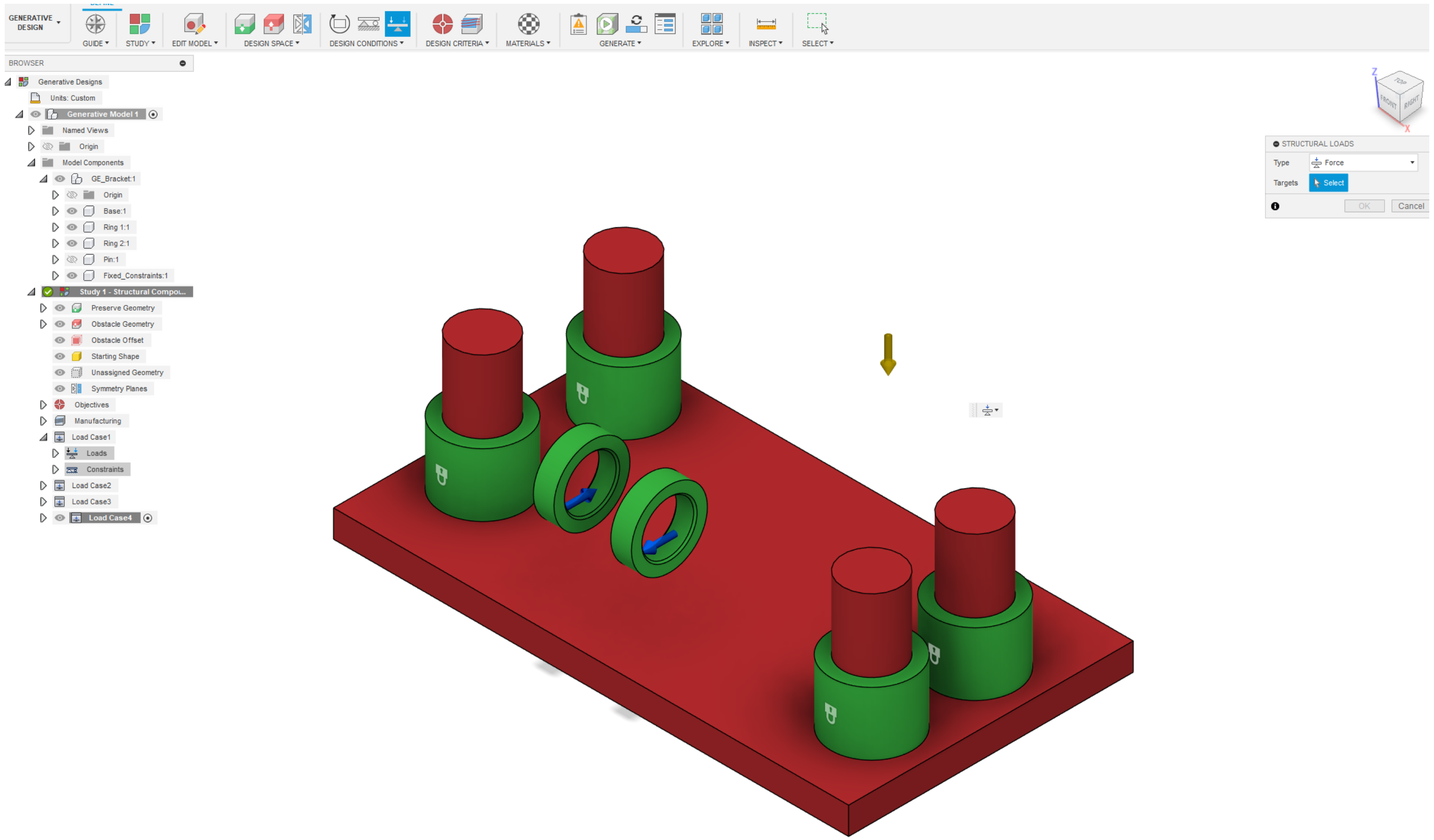
Importing model



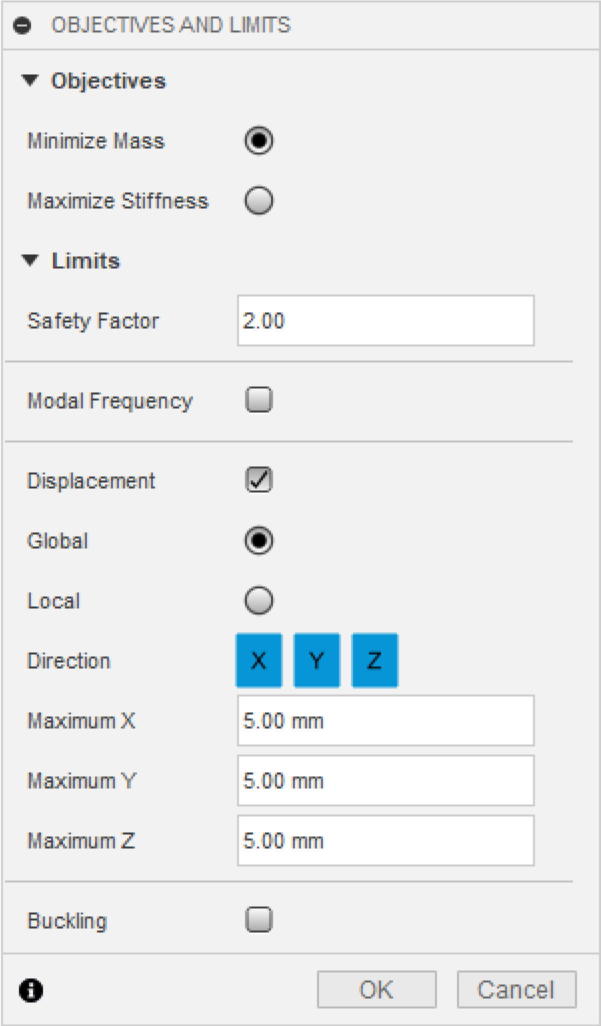
Applying conditions



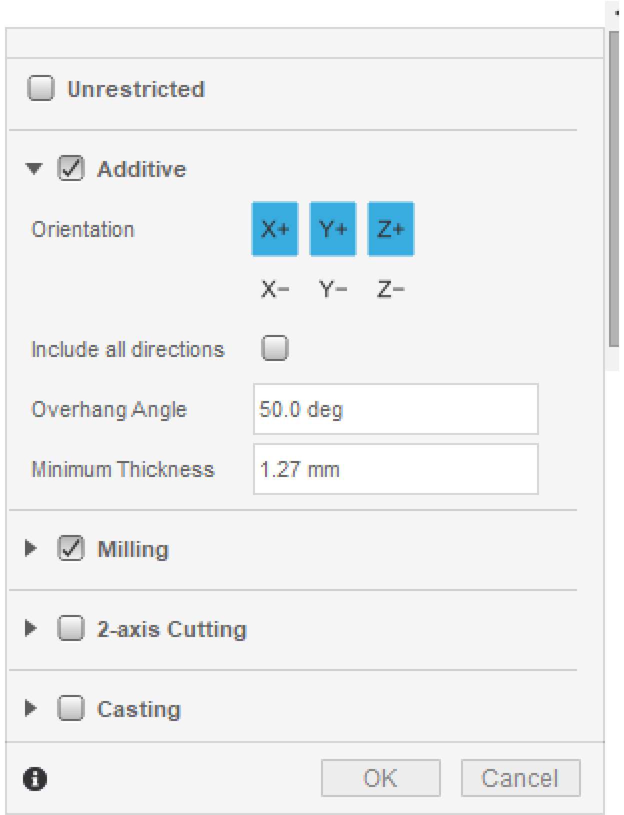
Applying Structural Constraints



Applying Loads(Force)

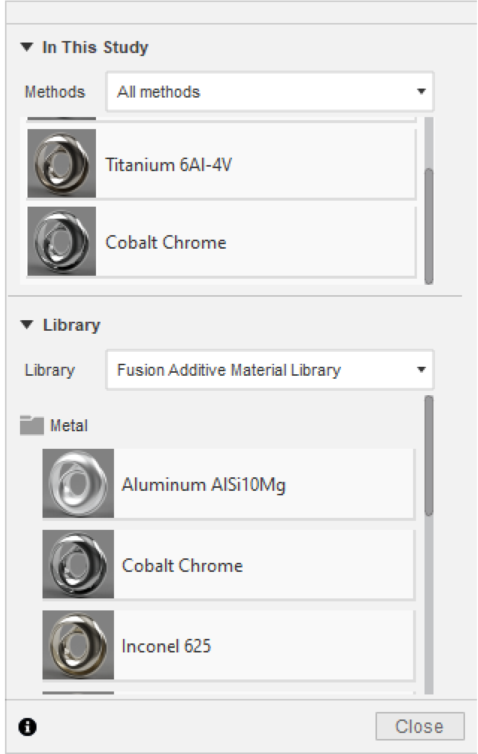


Selecting objective



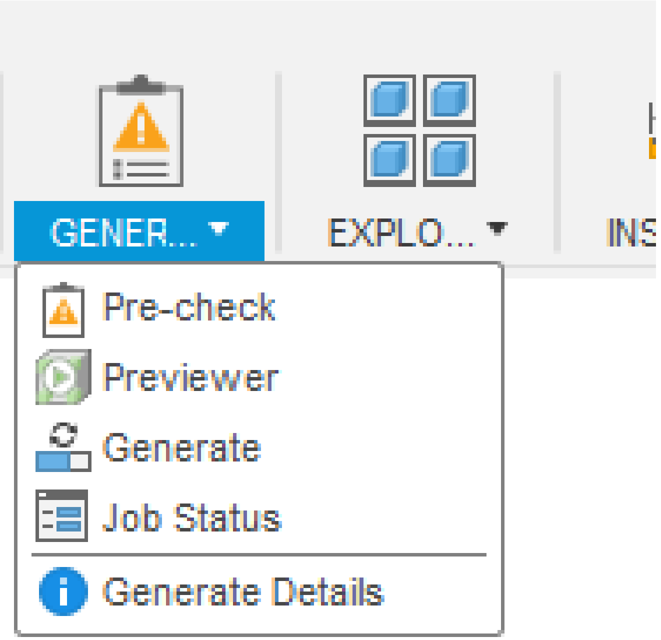
Defining Manufacturing Conditions

MATERIAL SELECTION



The materials used include Titanium (6Al-4V), Aluminum, and Cobalt Chrome, chosen for their varying strength, weight, and durability.

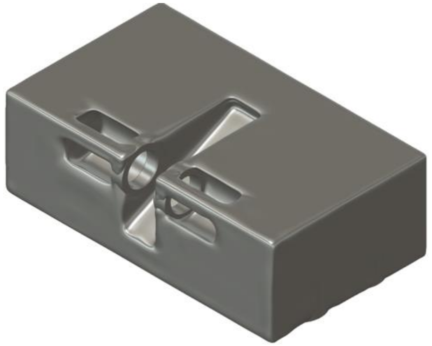
We selected Titanium (6Al-4V), Cobalt Chrome, and Aluminum AlSi10Mg for their distinct properties and potential to meet different performance criteria. Titanium was chosen for its excellent strength-to-weight ratio and corrosion resistance, making it ideal for lightweight yet durable designs. Cobalt Chrome was included for its exceptional durability, wear resistance, and ability to withstand high stresses, making it suitable for heavy-duty applications. Aluminum AlSi10Mg was selected for its lightweight and cost-efficiency, allowing for designs where weight reduction and affordability are priorities. Together, these materials provide a comprehensive evaluation of strength, weight, and manufacturability in the generative design process.



Generate the models

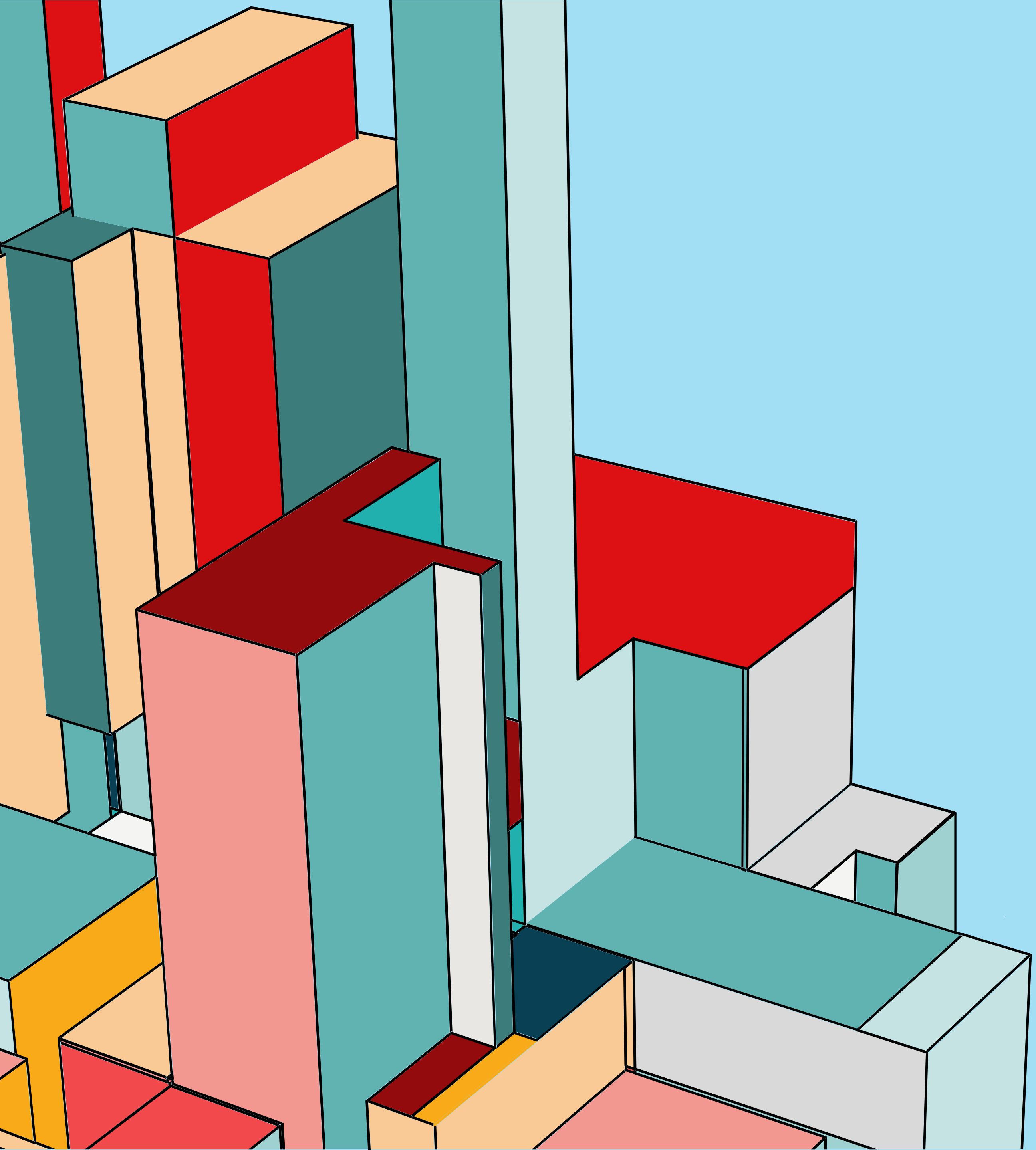
Titanium

Cobalt Chrome



Aluminium AlSi10Mg

These are the Generated models With Generative Design



KEY LEARNINGS

UNDERSTANDING GEOMETRY'S ROLE IN MANUFACTURING COSTS

Overview

- Additive manufacturing (AM) enables the creation of parts with complex geometries, providing flexibility in design.
- Generative and crowdsourced design techniques produce numerous alternatives with similar functions but varied geometrical characteristics.

Challenges

- Differences in geometry can significantly affect costs across manufacturing and post-processing steps.
- Existing tools do not clearly explain how geometry drives costs or support detailed comparisons between design alternatives.

Purpose of the study

- To identify and quantify the impact of factors like part mass, build time, reject rates, and post-processing requirements.

Post-Processing Operations:

- Includes heat treatment, machining, support structure removal, and surface finishing.
- Addresses challenges like high surface roughness and residual stresses common in Powder Bed Fusion (PBF) parts.
- Post-processing can contribute 60–300% of AM costs.

Process-Based Cost Model (PBCM):

- Accounts for geometry-driven variables such as reject rates and scrap rates.
- Incorporates machining for features requiring high dimensional accuracy.

Total Annual Cost (AC):

Summed across materials, labor, energy, equipment, tooling, and other elements:

$$\mathbf{AC_i = AC_{material,i} + AC_{labor,i} + AC_{energy,i} + \ldots}$$

Unit Cost (C): Calculates the cost per part, Where APV is the annual production volume.

$$\mathbf{C = \Sigma(AC_i) / APV}$$

Reject Rates:

Reflect the percentage of parts that fail at e:ach step:

$EPV_i = EPV_{i+1} / (1 - r_i)$

r_i : Reject rate at step i.

- Higher reject rates increase material, labor, and energy costs.

Scrap Rates:

Represent wasted material that does not become part of the final product:

$U_{m,i} = X_{m,i} / \Pi(1 - s_{m,i})$

$s_{m,i}$:Scrap rate for step i.

Geometry's Role:

•Part geometry directly impacts:

- **Reject rates**: Thin or overhanging features can cause failed builds (3%-12%) depending on manufacturing scores.
- **Scrap rates**: More complex geometries often lead to higher material waste (5% - 20%) BY geometry and build orientation.

COST MODEL VALIDATION

Validation Method:

- Compared Process-Based Cost Model (PBCM) predictions to quotes from Materialize Onsite.
- Focused on costs of AM, EDM, and shot peening for an APV of 1000.
- Median absolute error: $89 across 10 designs.
- Strong correlation with Materialize quotes:
- Spearman's $\rho = 0.93$, indicating alignment of key cost drivers.

Findings:

- Post-processing costs accounted for approximately 47% of total production costs.
- Consistent with industry estimates that 40% of AM costs are tied to pre- and post-processing operations.

Cost Analysis:

•For an APV of 2500, part costs ranged from **$2014 to $2289 per bracket**.

Influential factors:

- **Part mass:** Most significant driver of cost.
- **Build time:** Strong positive correlation with cost.

Design Comparisons:

Design D: Heaviest part with 14% higher cost than Design E.

- Higher material usage and AM processing times.

Design E: Lighter and more complex but:

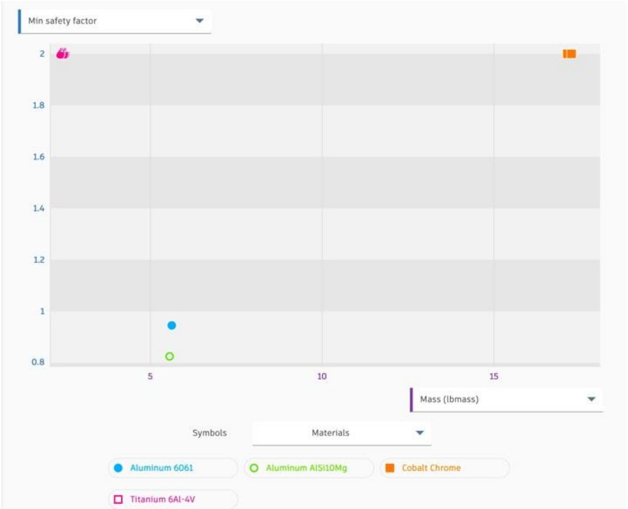
- Higher powder and machining scrap rates.
- Larger batch size reduced costs.

General Observations:

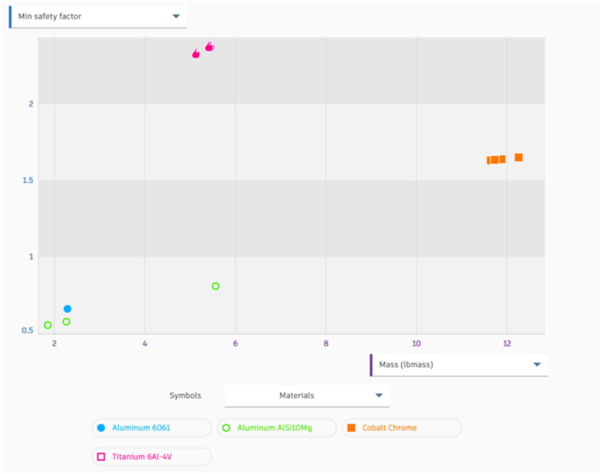
•Mass and print time per part ($\rho = 0.96$, $\rho = 0.70$) had the strongest impact on cost.

•Complex parts tended to be less expensive due to reduced material usage.

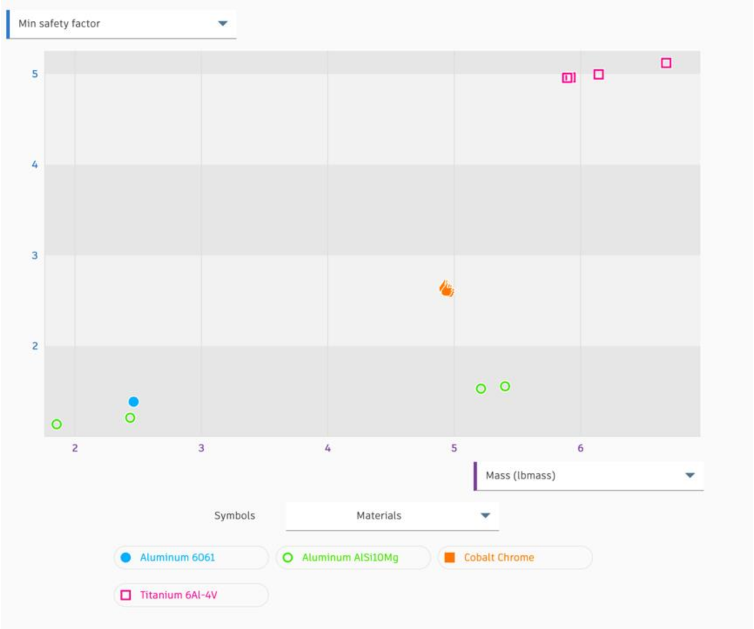
Material Analysis for Different Load Scenarios



Load: 1.5x min



Load: 0.75x max



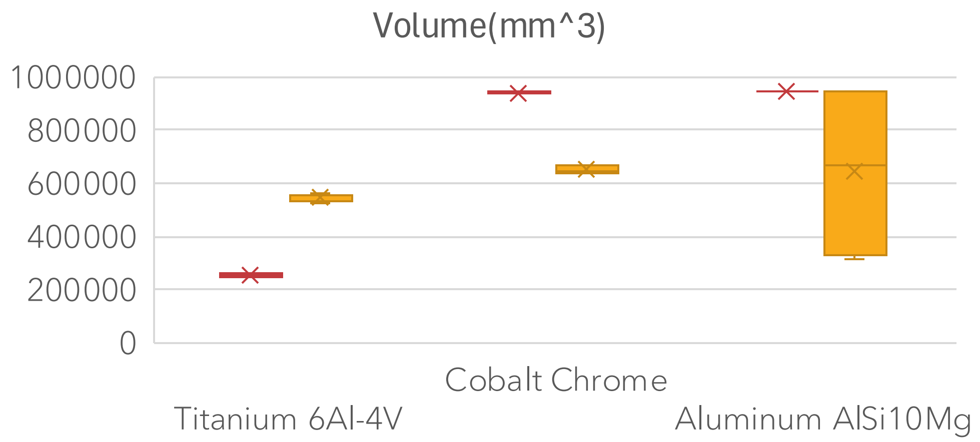
Load: 1.5x max

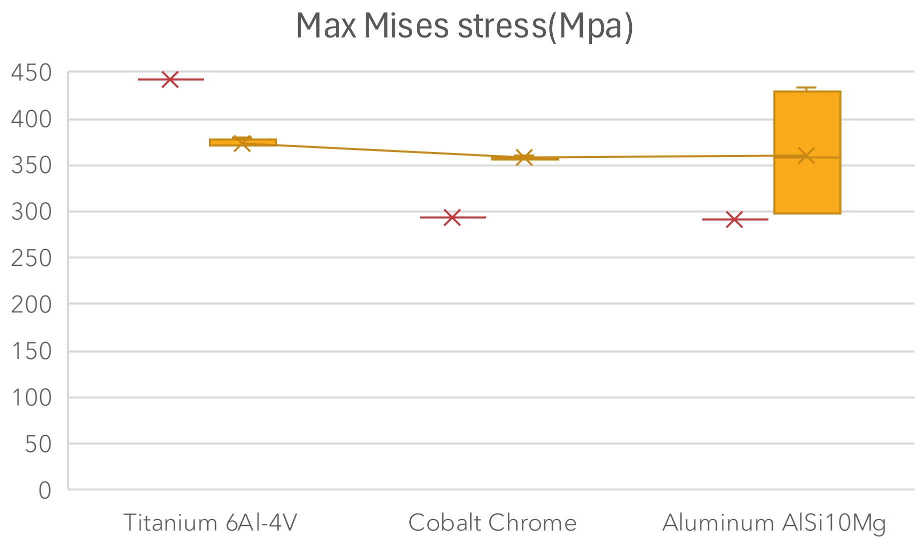
Titanium 6Al-4V: Moderate mass with high safety factors, ideal for high-stress applications requiring structural integrity and weight balance.

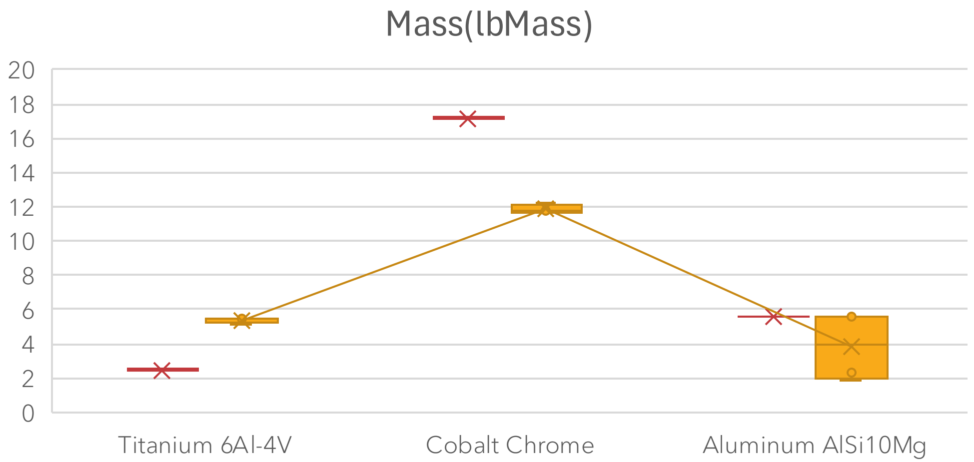
Cobalt Chrome: High mass and moderate safety factors, suited for heavy-duty applications prioritizing strength and durability over lightweight design.

Aluminum AlSi10Mg: Lowest mass with lower safety factors, optimized for lightweight designs in low-stress environments.

1.5 Min and 1.5 max







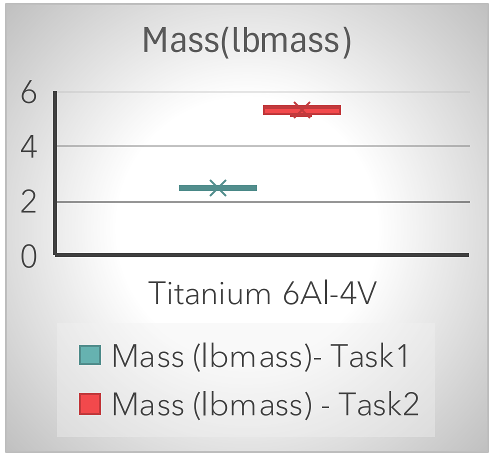
- Titanium: Stable across tasks with slight trade-offs in stress and volume.
- Cobalt Chrome: Noticeable reductions in volume and stress from Task 1 to 2.
- Aluminum: Highly sensitive to criteria, showing significant changes in mass and volume.

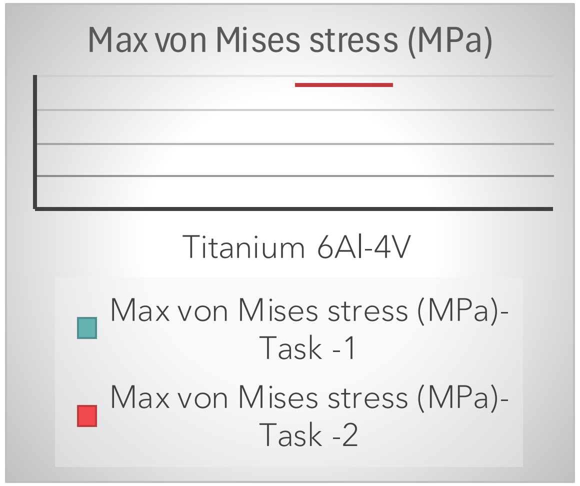
Effect of Material Choice on Metrics (1.5X Loading)

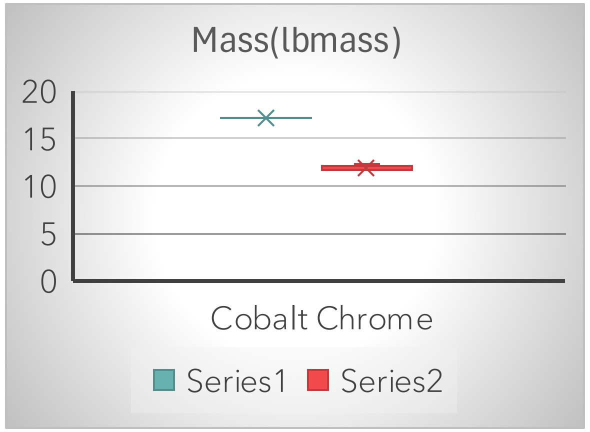
Titanium 6Al-4V:
•Mass: Relatively low and consistent across both criteria.
•Stress: Handles high stresses effectively, with minimal variation across criteria.

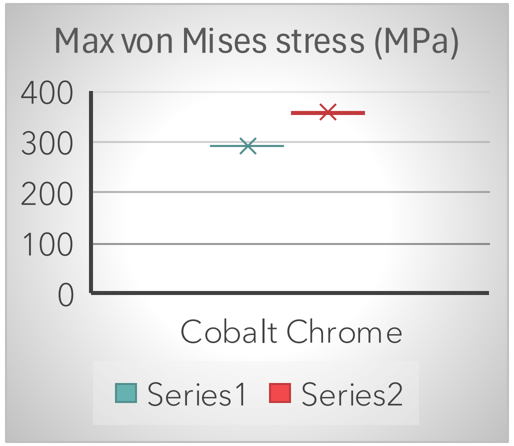
Cobalt Chrome:
•Mass: Significantly higher than Titanium and Aluminum, influenced by material density.
•Stress: Moderate stress tolerance, consistent across criteria but less than Titanium.

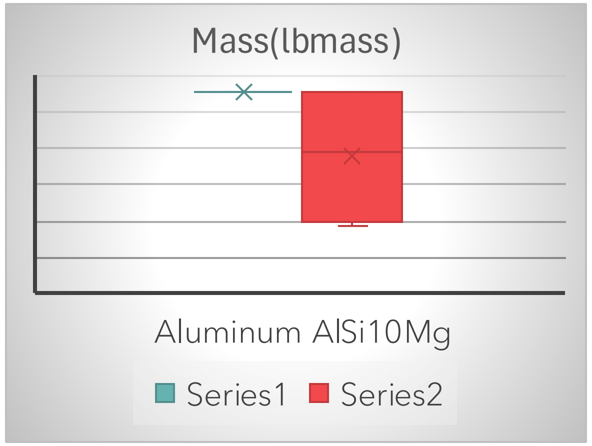
Aluminum AlSi10Mg:
•Mass: Lowest among materials, with significant reduction in Criterion 2.
•Stress: Handles lower stress levels compared to Titanium and Cobalt Chrome, with notable variability.

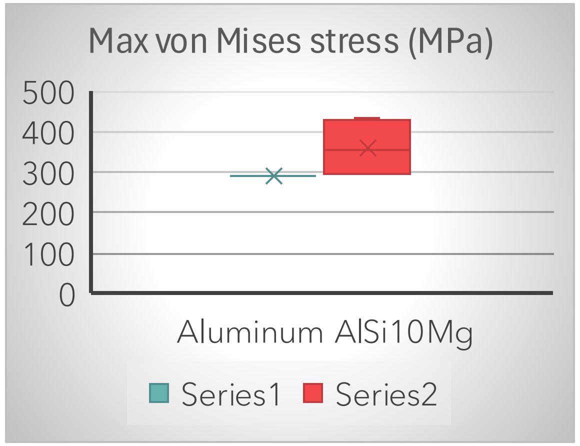

Mass(lbmass)
6
4
2
0
Titanium 6Al-4V
Mass (lbmass)- Task1
Mass (lbmass) - Task2

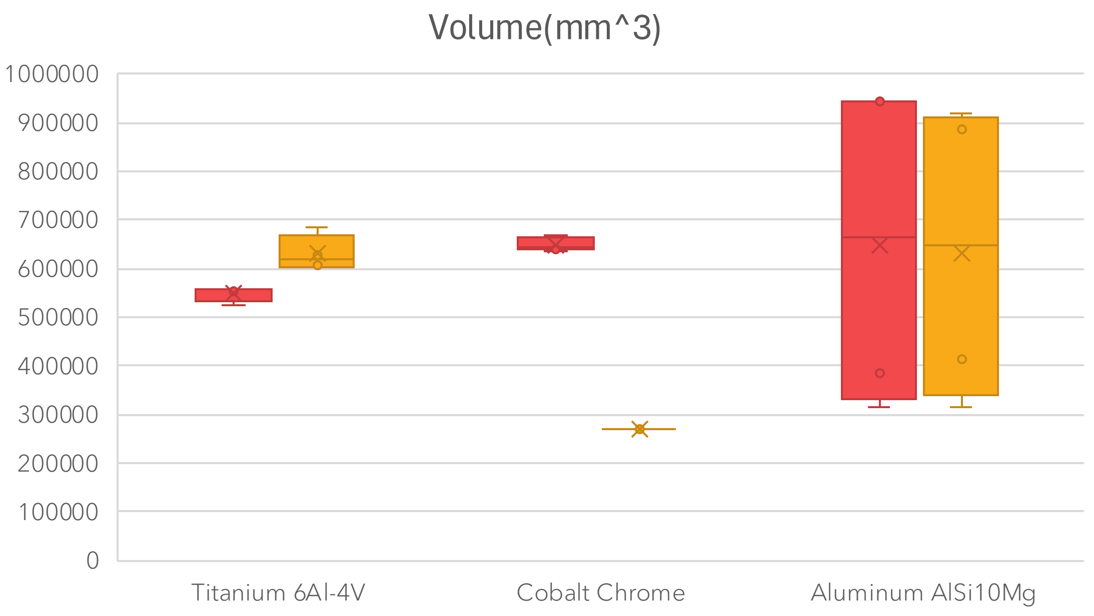

Max von Mises stress (MPa)
Titanium 6Al-4V
Max von Mises stress (MPa)- Task -1
Max von Mises stress (MPa)- Task -2

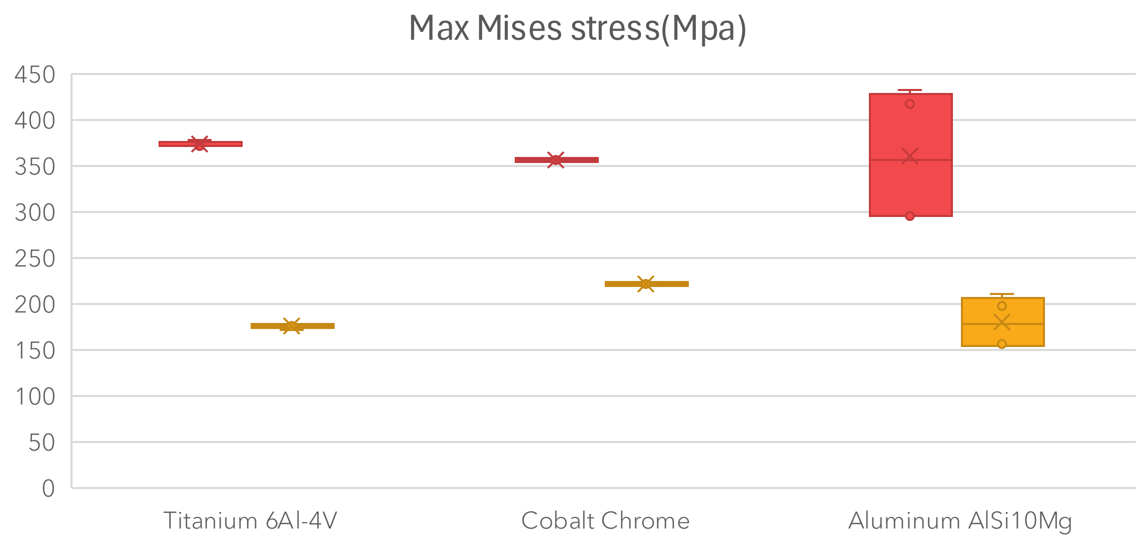

Mass(lbmass)
20
15
10
5
0
Cobalt Chrome
Series1
Series2

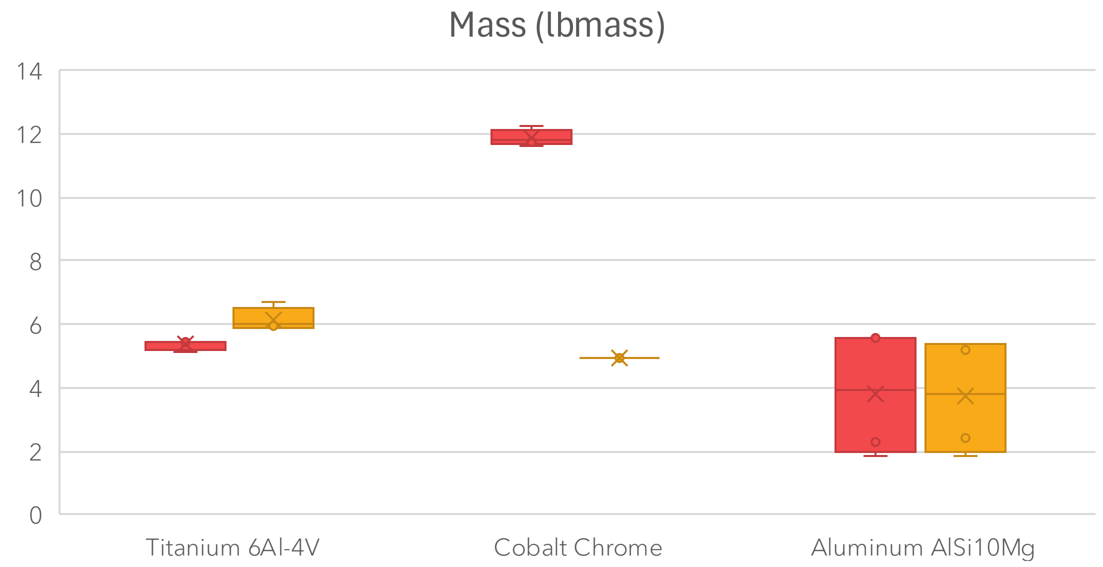

Max von Mises stress (MPa)
400
300
200
100
0
Cobalt Chrome
Series1
Series2


Mass(lbmass)
Aluminum AlSi10Mg
Series1
Series2


Max von Mises stress (MPa)
500
400
300
200
100
0
Aluminum AlSi10Mg
Series1
Series2







- Titanium: Handles increased load with minor adjustments to volume and stress, making it suitable for high-stress applications.
- Cobalt Chrome: Stable across loads, offering moderate stress performance with minimal design changes.
- Aluminum: Sensitive to load increases, with significant stress impact at 1.5X; best for lower-stress scenarios.

task1_1.5_min (v4~recovered)* | task2_1.5_max v5 | task3_0.75_max v2 | Expiring Soon

EXPORT ▾ CREATE ▾ FINISH EXPLORE ▾

Name	Preview Features	Recommendation	Processing status	Generative model	Material	Manufacturing method
Study 1 - Structural ... - Outcome 1		73.403 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 2		73.273 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 3		73.318 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 4		95.556 %	Converged	Generative Model 1	Titanium 6Al-4V	3 axis milling
Study 1 - Structural ... - Outcome 5		0 %	Completed	Generative Model 1	Aluminum 6061	3 axis milling
Study 1 - Structural ... - Outcome 6		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 7		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 8		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 9		21.82 %	Converged	Generative Model 1	Cobalt Chrome	3 axis milling
Study 1 - Structura... - Outcome 10		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 11		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 12		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 13		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	3 axis milling

Load: 1.5x min

Study 1 - Structur... - Outcome 4
Iteration 32 (final)

Properties

Status	Converged
Generative model	Generative Model 1
Material	Titanium 6Al-4V
Orientation	X+, Y+, Z+
Manufacturing method	3 axis milling
Visual similarity	Unique
Volume (mm^3)	258,902.084
Mass (lbmass)	2.529
Max von Mises stress (MPa)	441.264
Safety factor limit	2
Min safety factor	2
Max displacement global (mm)	0.466
Max displacement X (mm)	0.27
Max displacement Y (mm)	0.315
Max displacement Z (mm)	[illegible]

Best Design: Titanium 6Al-4V (Outcome 4)

Reason for Selection(Study 1):
Compared to other Designs we have this model matches our desired specs

Mass: Moderate (5.12 lbmass), balancing strength and weight.

Stress Tolerance: High (441.264 MPa), ideal for high-stress applications.

Volume: Compact (258,092 mm^3), ensuring efficient material usage.

Safety Factor: 2, meeting structural requirements.

EXPORT ▾ CREATE ▾ FINISH EXPLORE ▾

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Study 1 - Structural ... - Outcome 1		73.403 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 2		73.273 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 3		73.318 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ... - Outcome 4		95.556 %	Converged	Generative Model 1	Titanium 6Al-4V	3 axis milling
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Study 1 - Structural ... - Outcome 6		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 7		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 8		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ... - Outcome 9		21.82 %	Converged	Generative Model 1	Cobalt Chrome	3 axis milling
Study 1 - Structura... - Outcome 10		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 11		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 12		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 13		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	3 axis milling

Load: 1.5x max

Study 1 - Structur... - Outcome 4
Iteration 13 (final)

Properties

Status	**Completed**
Generative model	**Generative Model 1**
Material	**Titanium 6Al-4V**
Orientation	**X-, Y-, Z-**
Manufacturing method	**3 axis milling**
Visual similarity	**Unique**
Volume (mm^3)	**524,491.887**
Mass (lbmass)	**5.122**
Max von Mises stress (MPa)	**379.13**
Safety factor limit	**2**
Min safety factor	**2.328**
Max displacement global (mm)	**0.304**
Max displacement X (mm)	**0.129**
Max displacement Y (mm)	**0.232**
Max displacement Z (mm)	**0.187**

This model has the best balance of weight, compact volume, and stress tolerance, making it ideal for high-stress applications. It combines strength and efficiency. outperforming heavier or less durable alternatives.

EXPORT ▾ CREATE ▾ FINISH EXPLORE ▾

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Study 1 - Structural ... - Outcome 1		73.403 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
Study 1 - Structural ...- Outcome 2		73.273 %	Converged	Generative Model 1	Titanium 6Al-4V	Additive
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Study 1 - Structural ...- Outcome 7		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ...- Outcome 8		0 %	Converged	Generative Model 1	Cobalt Chrome	Additive
Study 1 - Structural ...- Outcome 9		21.82 %	Converged	Generative Model 1	Cobalt Chrome	3 axis milling
Study 1 - Structura...- Outcome 10		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 11		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 12		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	Additive
Study 1 - Structura... - Outcome 13		0 %	Completed	Generative Model 1	Aluminum AlSi10Mg	3 axis milling

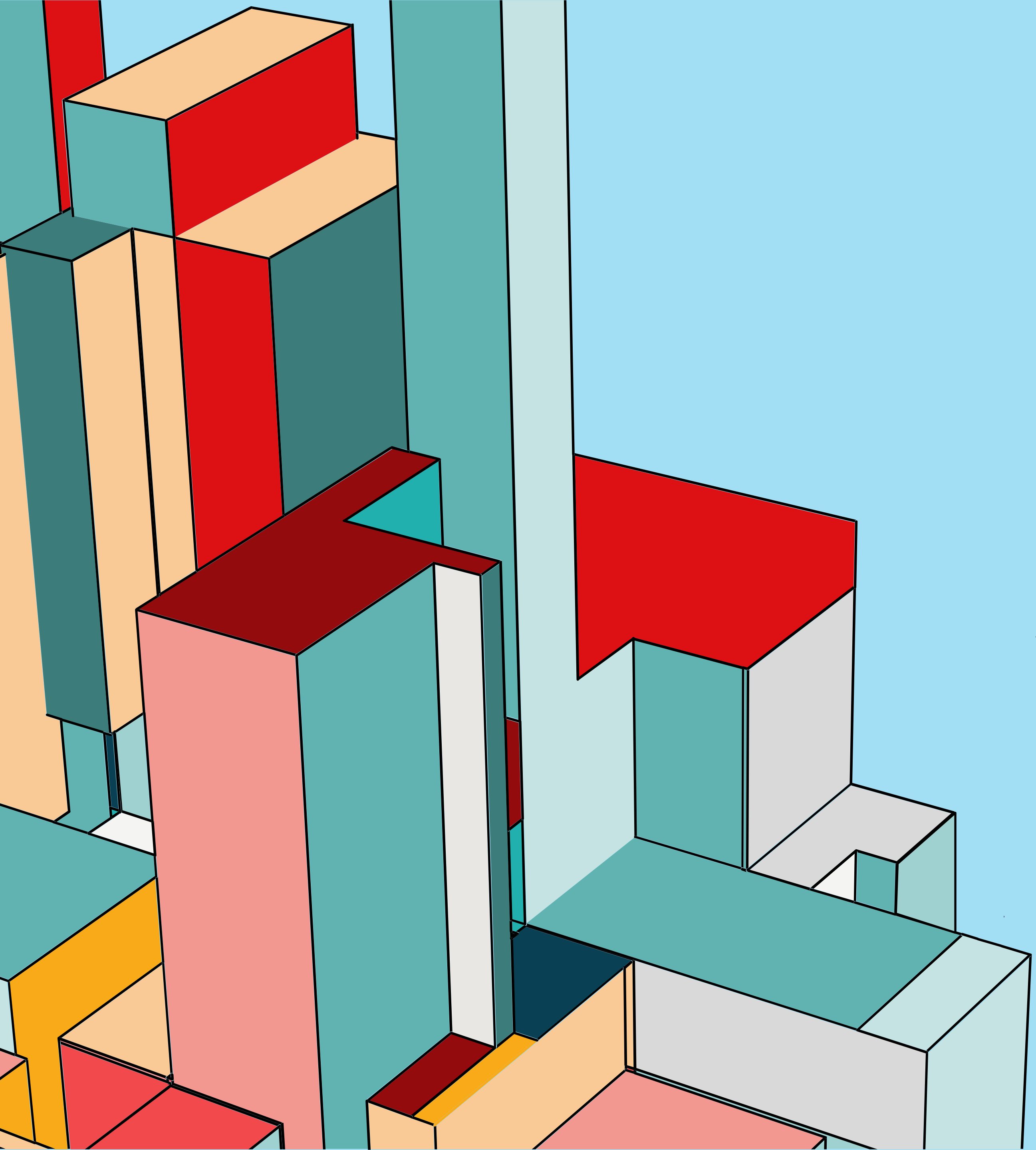
Load: 0.75x max

Study 1 - Structur... - Outcome 9
Iteration 15 (final)

Properties

Status	**Converged**
Generative model	**Generative Model 1**
Material	**Cobalt Chrome**
Orientation	**X+, Y+, Z+**
Manufacturing method	**3 axis milling**
Visual similarity	**Unique**
Volume (mm^3)	**271,199.589**
Mass (lbmass)	**4.957**
Max von Mises stress (MPa)	**224.924**
Safety factor limit	**2**
Min safety factor	**2.605**
Max displacement global (mm)	**0.141**
Max displacement X (mm)	**0.078**
Max displacement Y (mm)	**0.091**
Max displacement Z (mm)	**0.127**

Outcome 9, utilizing Cobalt Chrome, offers a well-balanced solution for medium-stress applications. Its moderate mass (4.957 lbmass) and compact volume (271,199 mm^3) ensure efficient material usage without compromising durability.
With a safety factor of 2.605 and minimal global displacement (0.141 mm), this design provides excellent structural stability and stiffness.
While not as lightweight as Aluminum, it significantly outperforms in stress tolerance (224.92 MPa) and durability, making it a reliable choice for applications requiring strength and compactness.

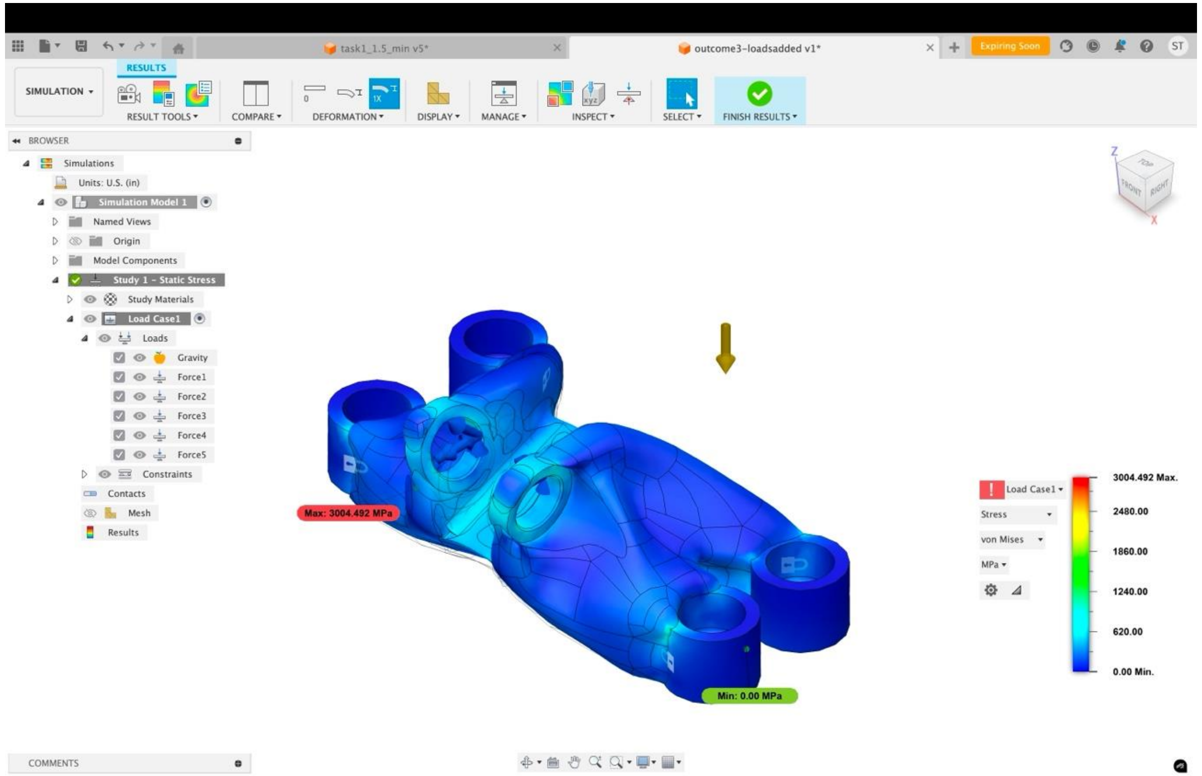


STRESS ANALYSIS

SIMULATION ANALYSIS OF GE BRACKET DESIGN

In this analysis, the 1.5x loading condition is applied to the proposed GE bracket design to investigate its detailed stress distribution, displacement, and structural performance. This analysis is crucial for ensuring the design will meet safety and reliability criteria in smart manufacturing applications.

STRESS DISTRIBUTION RESULTS



•Maximum stress: **3004.492 MPa**.

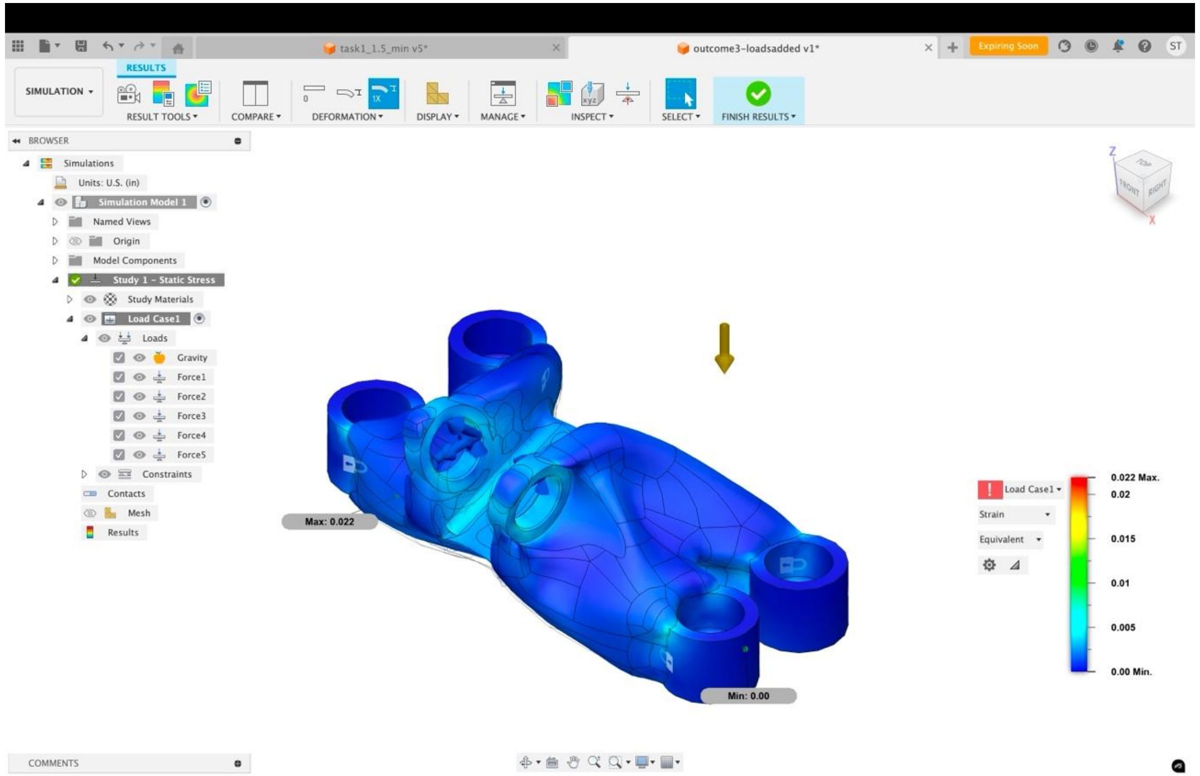
•Stress concentration occurs near sharp edges and mounting points, which are critical for structural stability.

Implications:

•The stress value exceeds typical yield strengths of most materials, indicating potential failure in these regions.

•Revisions in material selection are needed will further work on to resolve this issue.

STRAIN ANALYSIS



Observations:

•Maximum strain: **0.022 (dimensionless)**.

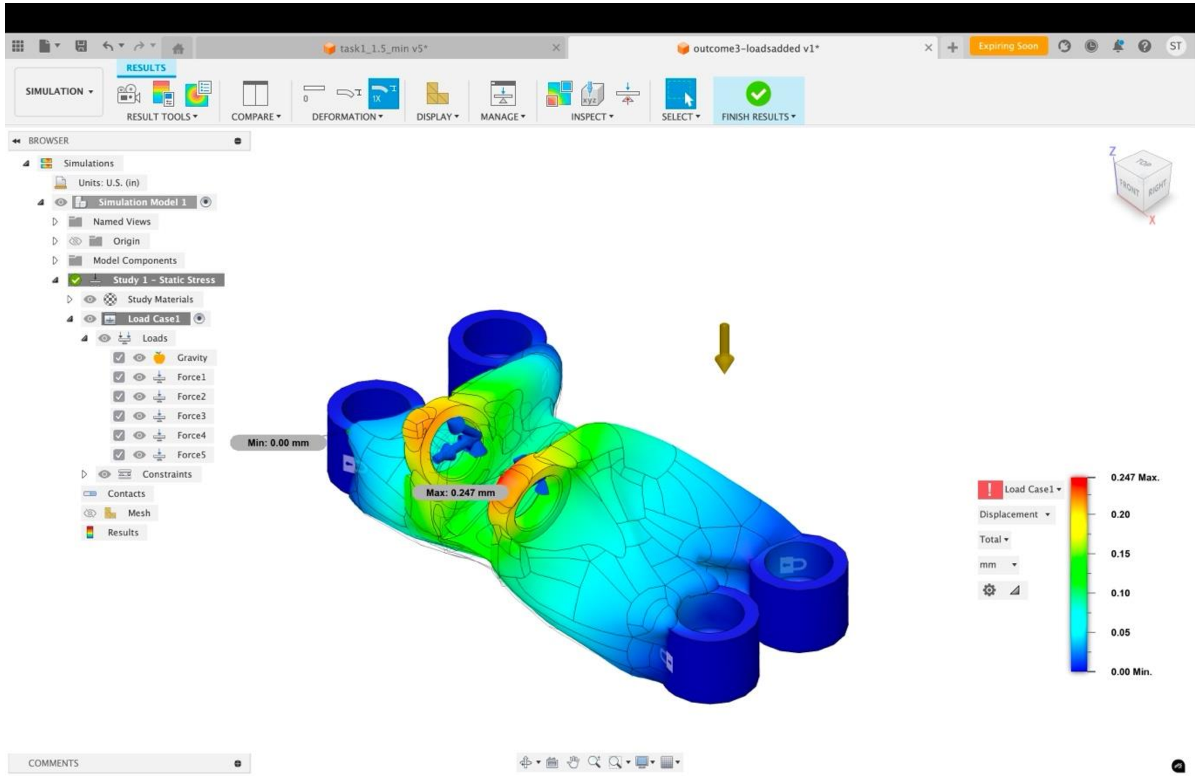
•Strain is localized in regions experiencing high stress, particularly around edges and fillets.

Implications:

•Strain exceeds safe limits for elastic deformation, risking permanent deformation in these areas.

•Structural redesign or improved material properties are necessary to ensure durability under repeated loading.

DISPLACEMENT ANALYSIS



Observations:

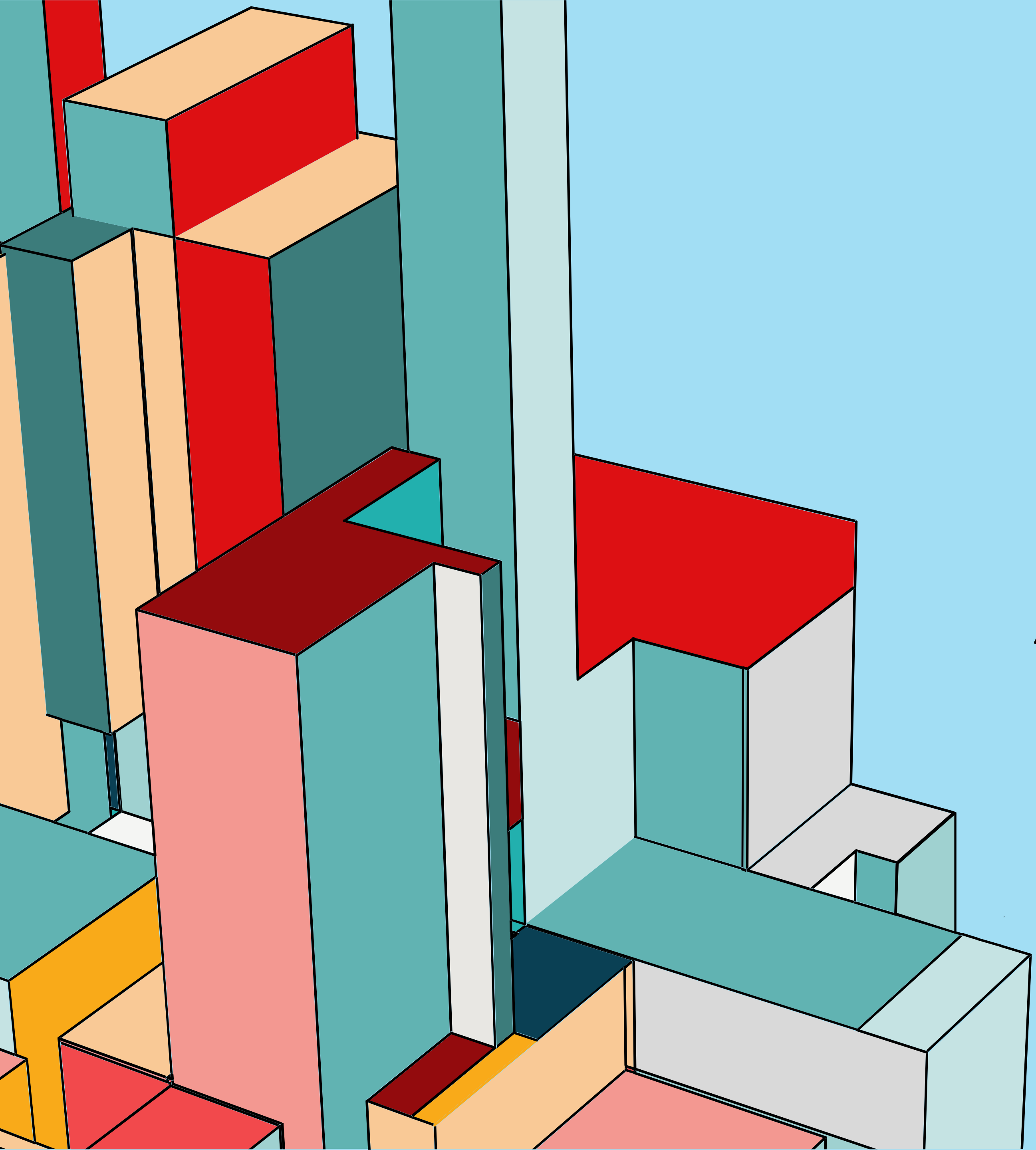
•Maximum displacement: **0.247 mm**.

•Displacement occurs near the central regions but does not significantly affect critical mounting points.

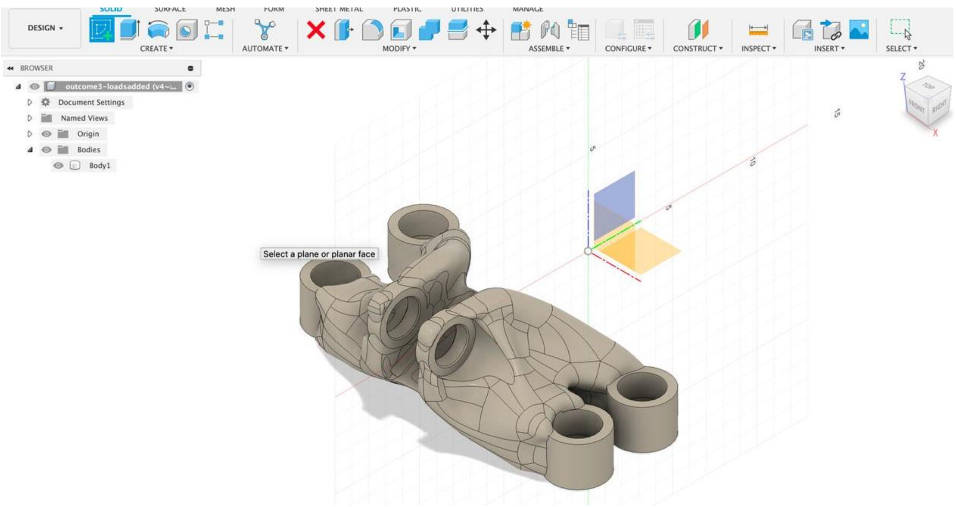
Implications:

•While the displacement is higher than previously observed, it is still within operational tolerances for most precision components.

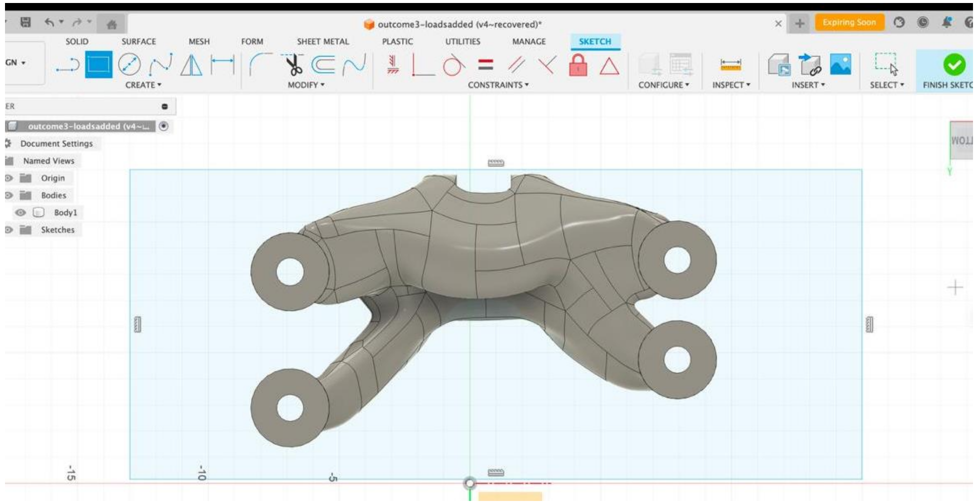
•Reinforcement in displacement-prone areas may help minimize deformation further.



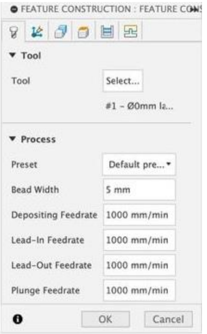
MANUFACTURING AND SIMULATION



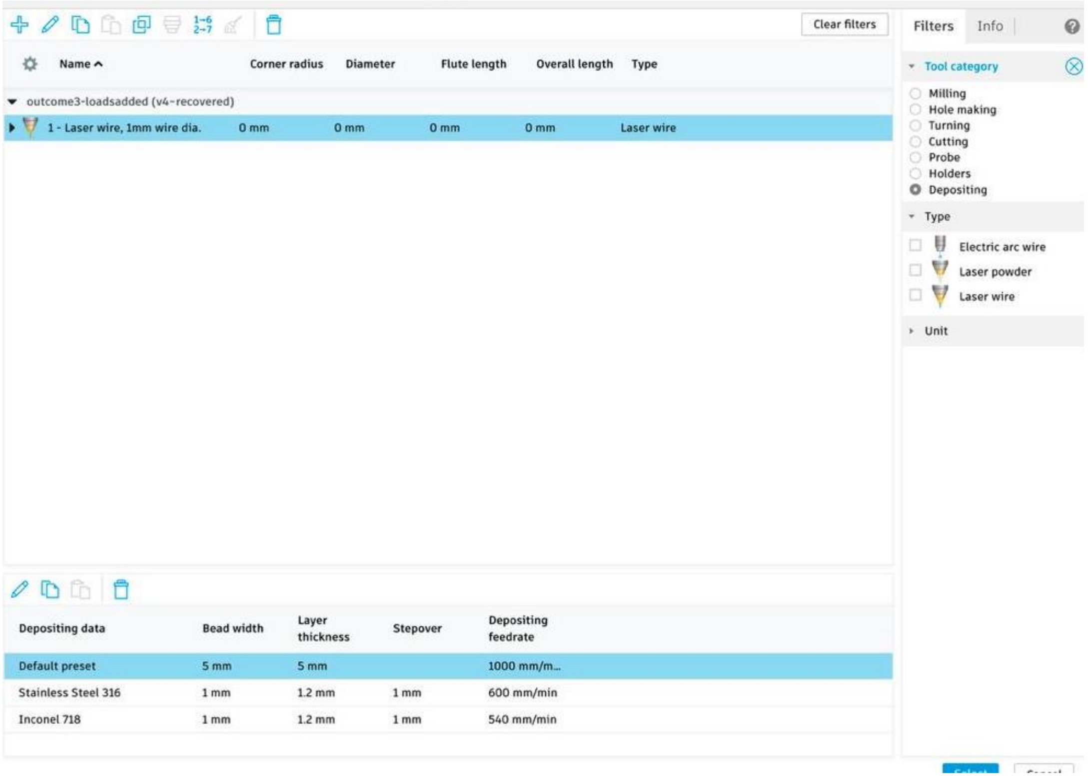
Selecting the plane



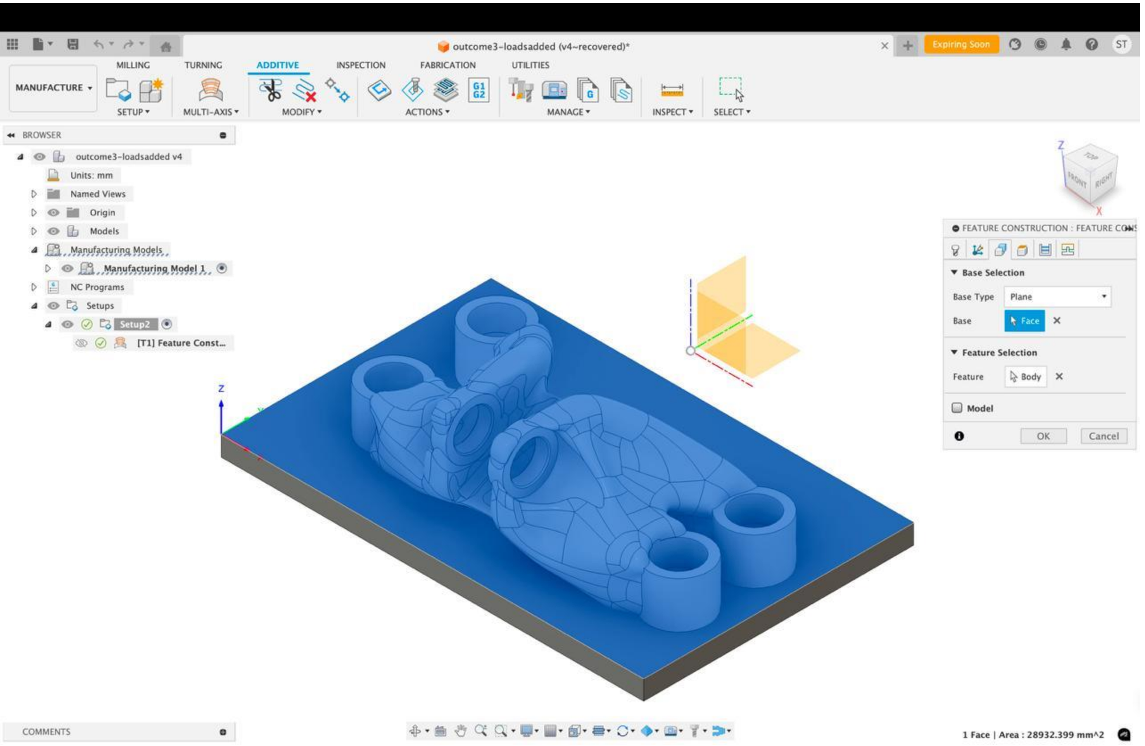
Dimensions for the Base plate

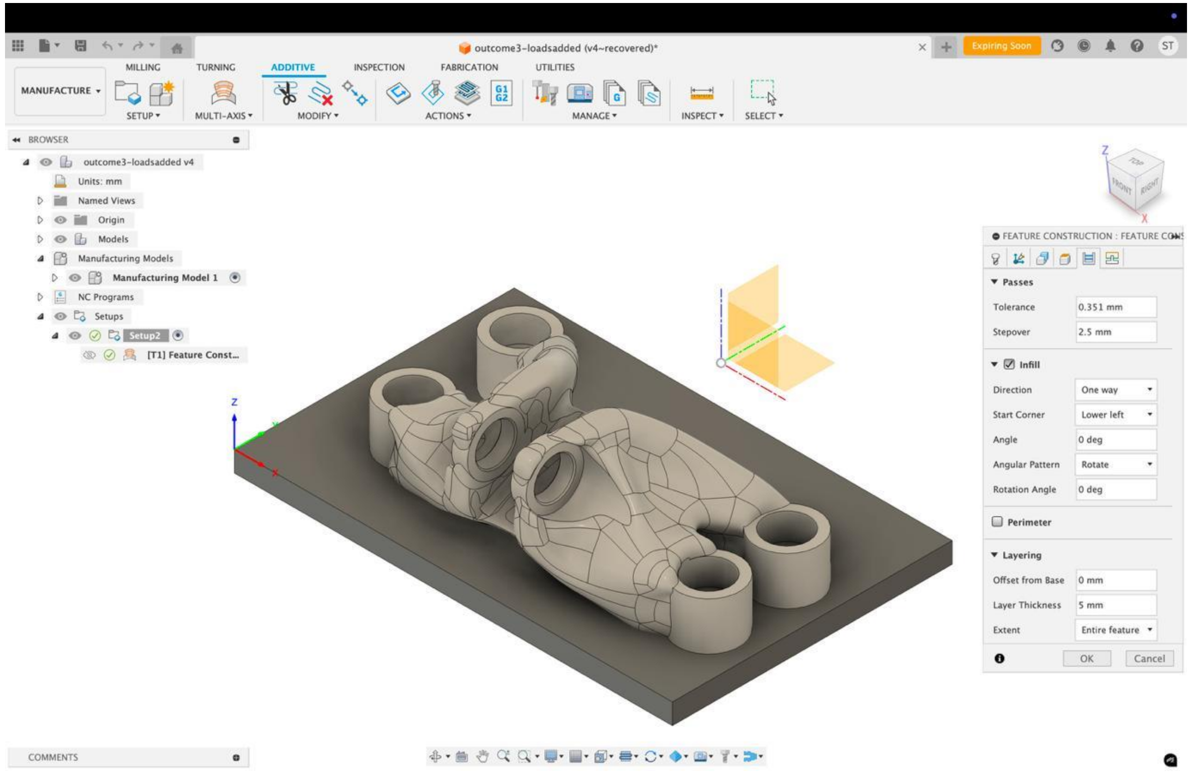


Select Tool



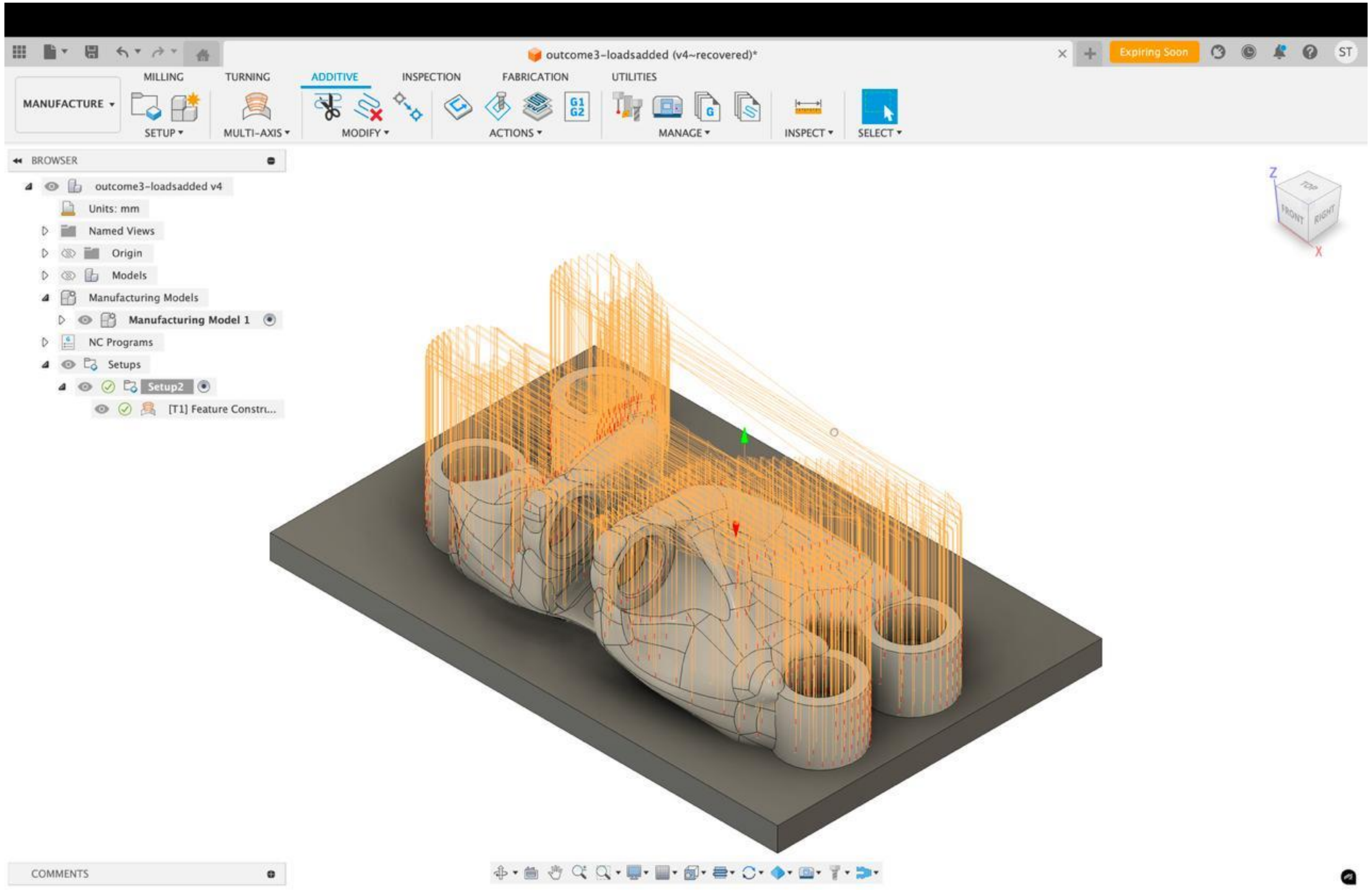
Selecting Laser wire 1mm wire dia



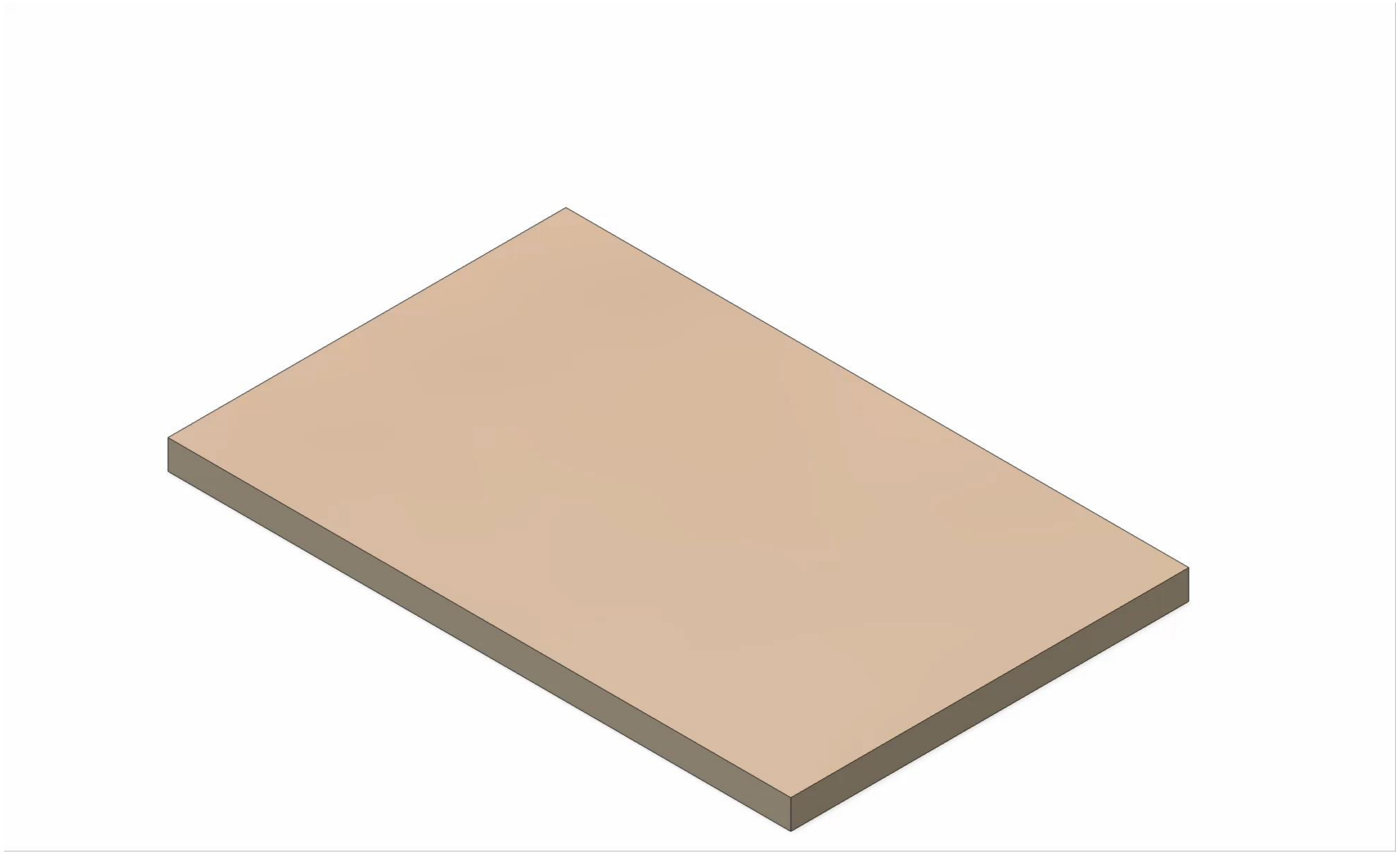


Base plate and face selection for geometry

Tolerance of 0.351 mm selected and passed.

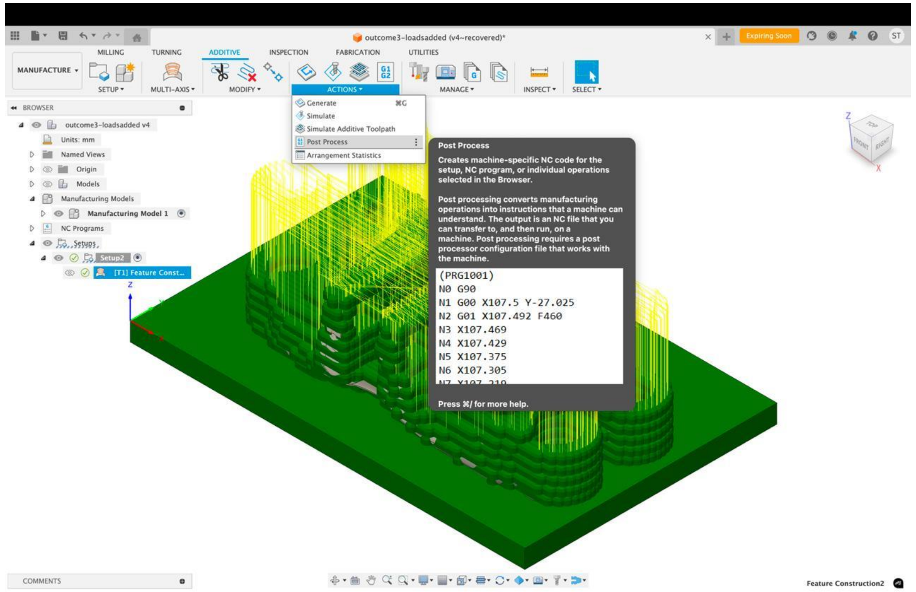


Tool path generated

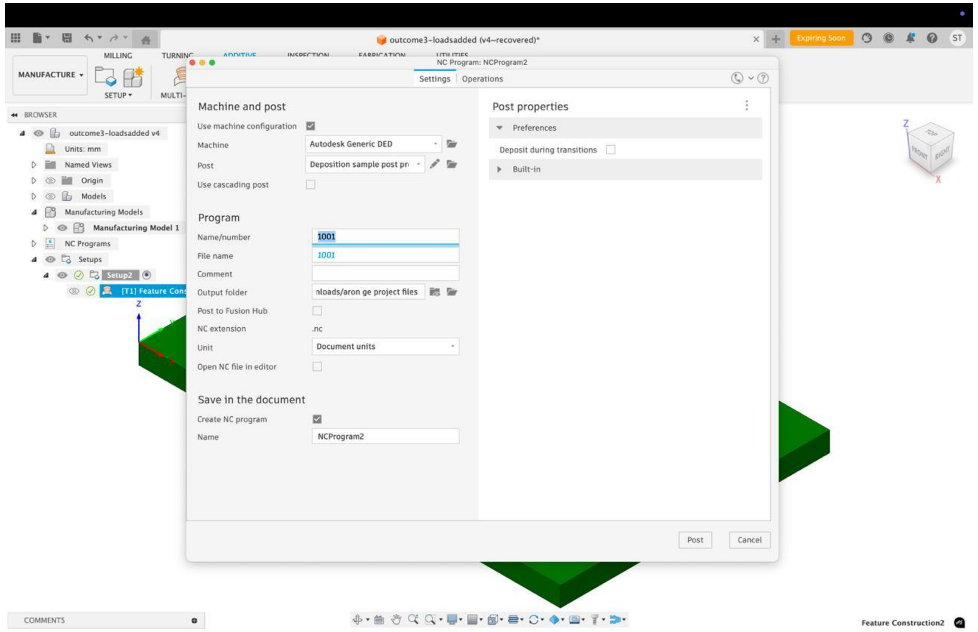


Simulation

POST PROCESSING



Post processing



Generates the G-code

KEY OBSERVATIONS:

- **Process Efficiency:**
- The simulation workflow follows a systematic approach:
    - Plane selection
    - Base plate dimensioning
    - Tool and material selection (Laser wire, 1mm dia)
    - Geometry validation (tolerance 0.351 mm)
    - Tool path generation
- **Potential Challenges:**
- **Tolerance Limitations:** While 0.351 mm is acceptable, deviations could affect final part performance.
- **Material Selection Sensitivity:** Different materials (e.g., Titanium, Aluminum, Cobalt Chrome) react variably under different loading scenarios, impacting stress distribution and displacement.
- **Post-Processing Complexity:** Significant dependency on post-processing steps like machining, support structure removal, and G-code generation adds to overall cost and time.
- **Machine Compatibility:**
- The selected tools and processes align with advanced additive manufacturing technologies.
- Fusion 360's compatibility with CNC machining and wire-laser techniques ensures seamless execution.
- Generated G-code enables reliable transfer to CNC machines, minimizing errors during manufacturing.

RECOMMENDATIONS FOR IMPROVEMENT:

1. **Refinement of Stress Concentration Zones:**
    1. Redesign areas with high stress concentration (e.g., sharp edges and mounting points).
2. **Optimize Geometry for Tolerance:**
    1. Ensure consistent geometry validation to reduce reliance on extensive post-processing.
3. **Material-Specific Adjustments:**
    1. Fine-tune simulation for specific material behavior under varying load conditions.
4. **AI Integration:**
    1. Utilize AI-based simulation tools to predict failure zones and optimize tool paths efficiently.
5. **Explore Hybrid Manufacturing Techniques:**
    1. Combine additive and subtractive methods to balance cost and precision.

LEARNING OUTCOMES

- I gained experience working with tools like generative design, stress analysis, and additive manufacturing workflows.
- This project taught me how to weigh different factors like material, structural integrity, and cost when comparing various design options to make the best decisions.
- I learned how to analyze the impact of materials and loading conditions on a design's performance,
- Using simulation tools, I improved my ability to predict and refine designs for better performance in real-world applications. Which is critical for ensuring both feasibility and reliability.
- I experienced firsthand how generative design can create lightweight, innovative solutions while maintaining strength and functionality.

FUTURE LEARNING OPPORTUNITIES

- Explore the potential of multi-material generative design and hybrid manufacturing processes.
- Study how AI and machine learning can further enhance the generative design process.
- Analyze more case studies to better understand industry-specific applications of generative design and simulation.
- Learn more features in fusion 360 lot to uncover.

THANK YOU