

MFG225960

## Seamless Generative Design to Manufacturing

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### Learning Objectives

- Discover the steps involved in the generative design process
- Consider how the generative design process could apply to your design and manufacturing process(es)
- Explore the pros and cons of additive manufacturing as it relates to generative design
- Explore the pros and cons of subtractive manufacturing as it relates to generative design

### Description

Design advancements are exciting and offer solutions previously unthought-of to complex problems. But we can't forget the manufacturing processes needed to fabricate and eventually implement that new and optimized design. This class will focus on the emerging Generative Design technology in Fusion 360, and multiple ways to manufacture those designs, capitalizing on additive manufacturing, subtractive manufacturing, and a combination of both. The goal will be to explore design and manufacturing workflows to bring this emerging technology into the fold for potential users with varying levels of manufacturing capability. This class will address the workflow from initial generation to final part, focusing on the best practices found along the way.

### Speakers

Steven Szymeczek received his Bachelor's in Mechanical Engineering from Northern Arizona University. Steven worked in the aerospace industry for several years as

a Design Engineer, while growing his product development skills and interests on the side, eventually starting Penumbra Engineering in 2014 with friend and fellow engineer Dean Pierce. Currently, Steven is Co-Owner of Penumbra Engineering, located in Tucson, AZ. Penumbra focuses on empowering companies to use the advantages of additive manufacturing. He also serves as the Co-Chair of the Additive Manufacturing committee for the Arizona Tech council, whose mission is to make Arizona a national hub for additive manufacturing technologies. Steven is extremely passionate about pushing innovation in AM design and engineering.

Matt Lemay is a part of Autodesk's Fusion Adoption team – focused on ensuring customer success in the adoption of Generative Design & Additive Manufacturing. Before joining Autodesk 3 years ago, Matt was an Applications Engineer in the Aerospace Composites industry and a design engineer for Additively Manufactured surgical implant technology. At Autodesk, Matt has also been involved with the Autodesk Pro Bono program, specifically around projects related to Additive Manufacturing and non-profit medical projects - Granta, low-cost Cranial Implant Manufacturing in Mexico & Nia Technologies, 3D Printed prosthetics in Uganda. Matt's professional passion is helping designers and engineers leverage next generation technology like Generative Design & Additive Manufacturing to create competitive separation.

Marti Deans graduated from University of California, Berkeley where she earned her B.S. Mechanical Engineering and explored manual and CNC manufacturing processes in the Berkeley Student Machine Shop using MasterCAM, HSMWorks, and InventorHSM. Using this experience, she has been working at Autodesk for over 2 years, first developing training and adoption strategies for Fusion 360 users with a focus in manufacturing and now driving awareness for Fusion 360 and its manufacturing capabilities.

## Generative Design Overview

Generative design is an emerging design technology that, at its core, generates multiple outcomes to a design problem based on performance requirements, materials, and manufacturing strategies. You can generate and explore designs that meet your performance and manufacturing requirements while off-loading the computation to the cloud and freeing up your engineers – or yourself – to tackle other challenges.

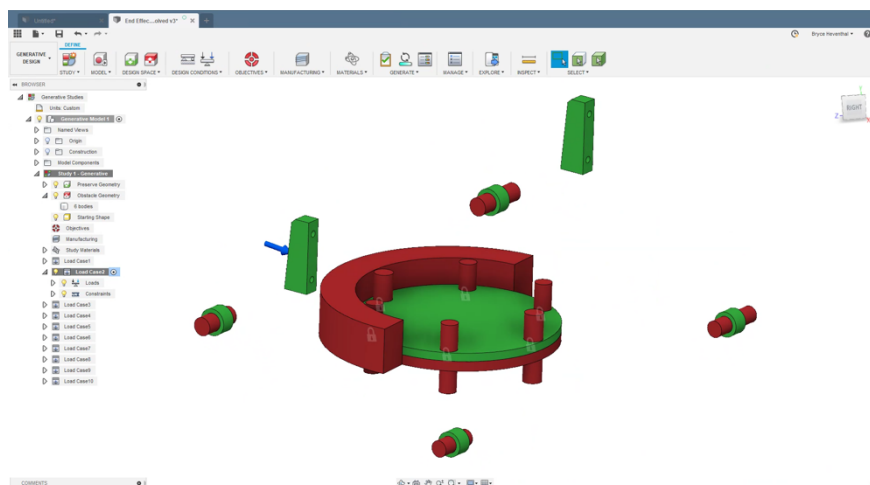
Let's take a closer look at the process and what it really takes to generate a design. Unfortunately, generative design isn't quite magic yet, so there is a bit of front-end work to set up a generative study and start seeing some results.

## Obstacles and Preserves

Obstacle and Preserve regions help define what geometry **must** and **must not** be in the final result. Every part has some kind of interface with another part, like bolt holes, tapped holes, rails, dovetails, etc. Preserve regions define these areas that **must exist** for the part to function properly.

Obstacle regions define areas that need to be **avoided** by the generated outcome. This might include other parts in an assembly, fasteners, tools, and the path of motion of other assembly components.

A Starting Shape is not required to run a generative design study. You may include a starting shape if desired, which will increase the surface area to volume ratio and can help shape the results. Starting Shapes must intersect with all Preserve regions, or the generative study will fail.



*PRESERVE REGIONS APPEAR GREEN, OBSTACLES APPEAR RED, AND A STARTING SHAPE WILL APPEAR YELLOW.*

## Load Cases

The load cases will determine where material is added to ensure that the design meets the performance requirements. Currently only linear static loads are accepted, but there are plans on the roadmap to add non-linear, dynamic, and thermal cases as well.

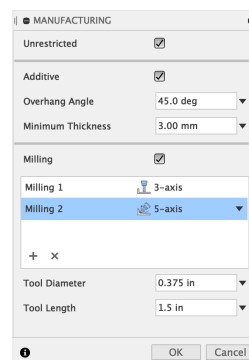
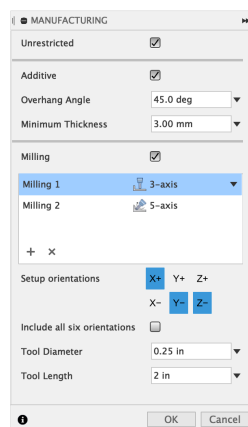
Currently Structural Constraints include Fixed, Pinned, and Frictionless. Fixed constraints can be set to the X, Y, and Z axes (rotation and translation). Pinned constraints can be set to Radial, Axial, and Tangential. Currently Loads include Force, Moment, Pressure, and Bearing Load. Loads can be applied at vertices, edges, and faces as makes sense for the load type.

One important note: loads and constraints can only be applied to Preserves. Obstacles are just there to prevent material from generating in areas that cannot have material.

## Manufacturing Constraints

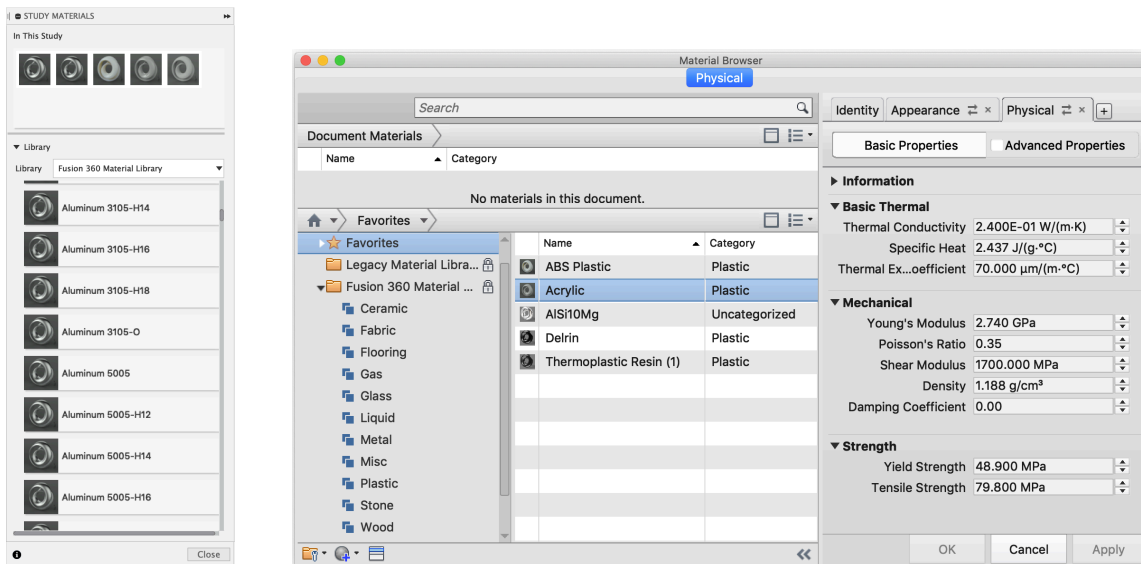
Manufacturing is a consideration that's often considered late in the design process or left as something for the manufacturing specialist to figure out after the fact. Generative design takes manufacturing method into consideration from the start to help ensure the result is something that can be made.

The three manufacturing options are currently Unrestricted, Additive, and Subtractive. Unrestricted doesn't take manufacturing method into account and generates whatever geometry is determined necessary. Additive takes in the Maximum Overhang Angle and Minimum Thickness, adding material to meet the overhang angle. Subtractive can be defined as 3 or 5-axis. Both methods take in the Minimum Tool Diameter and Length, and 3-axis constraints also take in the setup directions.



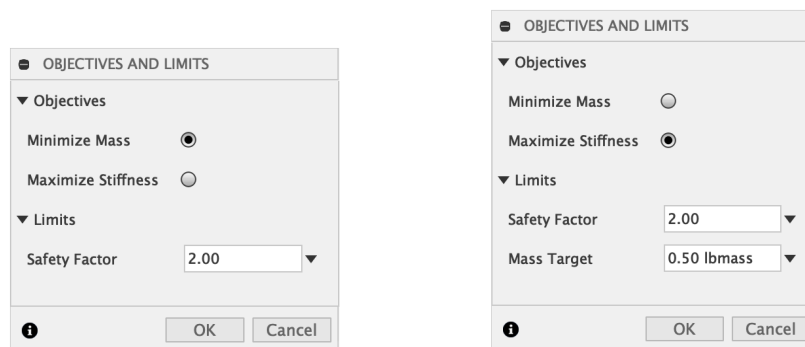
## Material Selection

Any material in the Fusion 360 library can be selected as a study material, as long as that material is linear, so unfortunately materials like wood are out for the time being. You can also define custom materials in the Physical Materials dialog to best simulate custom additive polymers or specific subtractive alloys.



## Objectives

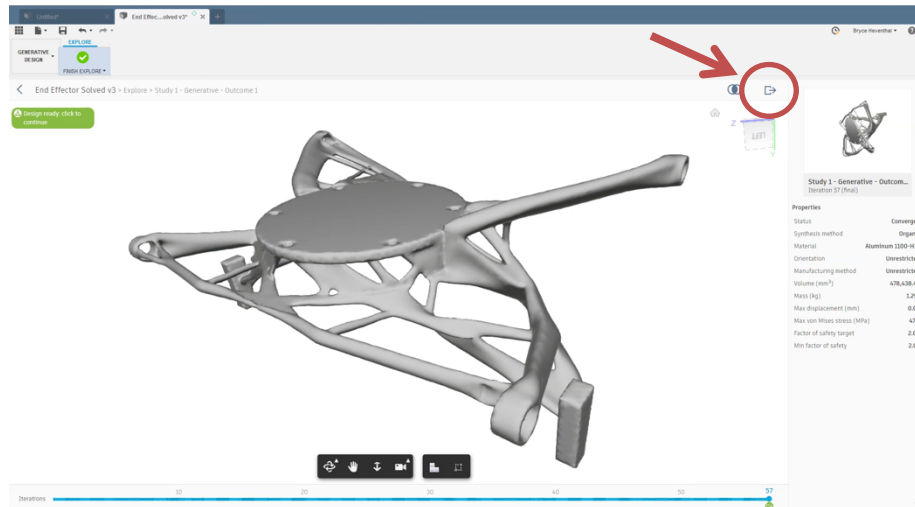
The Objectives are either Minimize Mass or Maximize Stiffness. Minimize Mass takes in a factor of safety target and generates as little material as possible while meeting that requirement. Maximize Stiffness takes in a factor of safety and mass target and tries to reduce deflection for the given mass target.



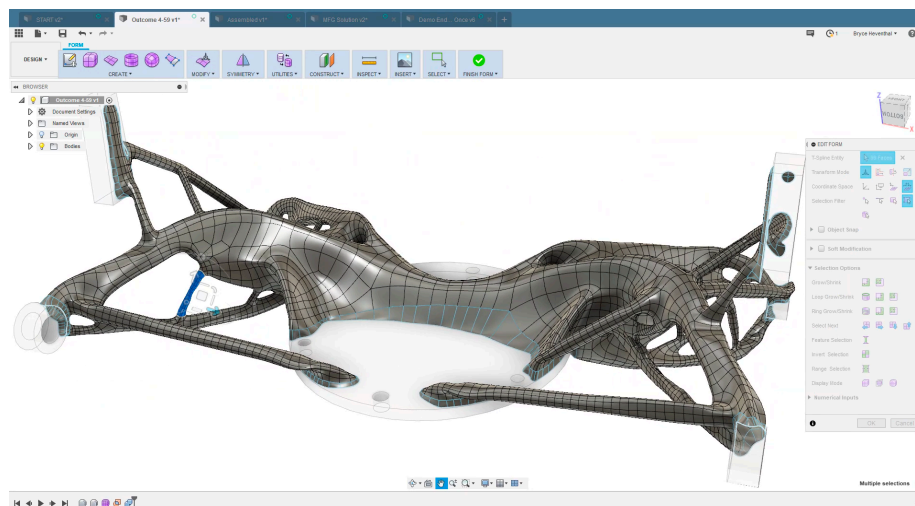


## New Design and T-Splines Editing

Once you find a result that meets your requirements, create a new design using the Export button. This takes the result through a mesh to BRep conversion, creating a new Fusion design with the resulting solid body.



This translation process creates a T-Spline body that represents the organic surfaces created by generative, while maintaining the sharp edges and cylindrical faces from the original preserve geometry. The extremely powerful part of this conversion process is the ability to edit the results using T-Splines. Simply right-click on the T-Spline feature in the timeline and select “Edit” to open Fusion 360’s Sculpt workspace where there are extensive editing tools. If you’re not used to T-Splines, don’t worry, there are plenty of online tutorials [like this one](#).

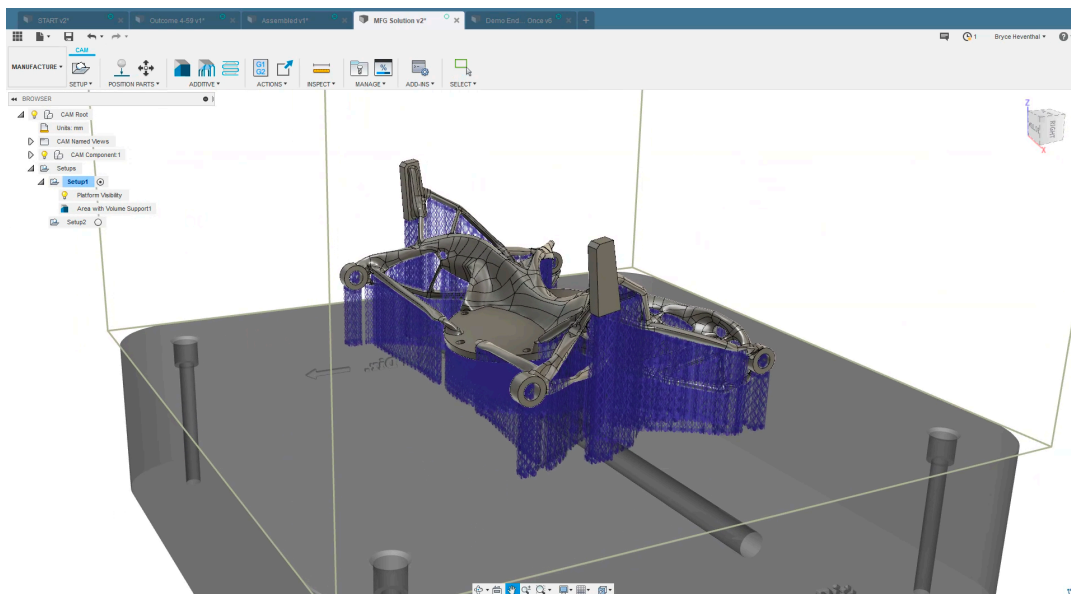


## Simulation

If you've made significant changes to the result with T-Splines editing or if your load cases are better represented with a simulation study more advanced than linear static, you may want to take the edited result through Fusion 360's Simulation Workspace. Fusion 360 uses Nastran solvers and offers advanced simulation study types including Modal Frequencies, Thermal Stress, Structural Buckling, Non-Linear Static Stress, and Event Simulation.

## Manufacturing

Once you have a result that you're ready to manufacture, Fusion 360 offers tools for additive and subtractive manufacturing in the Manufacturing Workspace. The additive tools are currently in preview and are limited to positioning the model on a representation of the build plate and generating support structures including Area with Polyline, Area with Volume, and Area with Bar. These supports are largely targeted at metal sintering but supports for plastic are on the roadmap.



The subtractive manufacturing tools include mature 2 and 3-axis milling, with easy conversion to positional multi-axis – or 3+2 programming – and offer some basic simultaneous multi-axis programming. Turning, mill-turn, and profiling operations are also supported. Manufacturing strategies could easily be their own class, and often are! [This previous AU class](#) goes into some of the details of CAM in Fusion 360, and there is extensive online content to help you get started, like the [Fundamentals of Milling tutorial](#) or the [Learn More page](#).



## Penumbra's Design Challenge

Penumbra Engineering is a product development company empowering the use of additive manufacturing to help hardware companies develop innovative and performance driven products. Penumbra started a project with Perceptive Sensor Technologies (PST), a company supplying sensors with high performance goals for precision, durability, and ease of use. The challenge was to re-design a handheld sensor to meet their high standards while also finding an adaptable solution that can be used across industries and leverage small batch production. The new design needed to be:

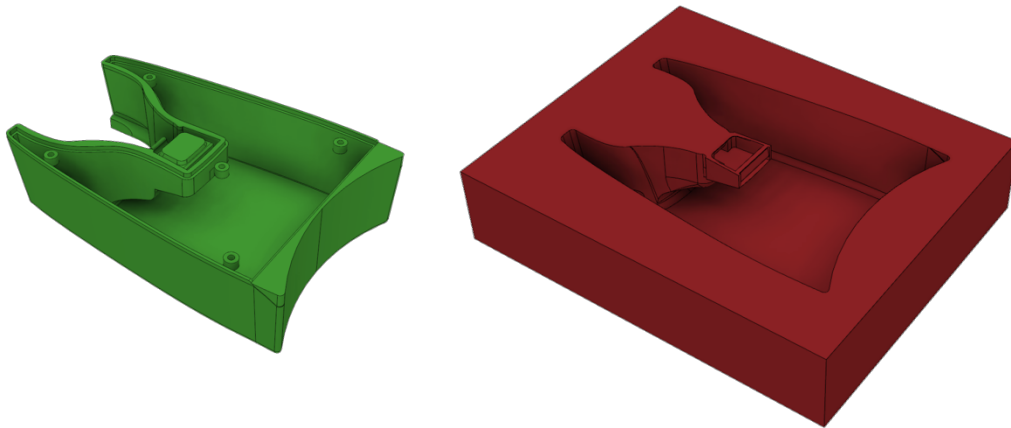
- **durable** enough to withstand extreme environments
- **lightweight** enough to hold for several hours without fatigue
- **well-balanced** to ensure proper stability and ease of use.



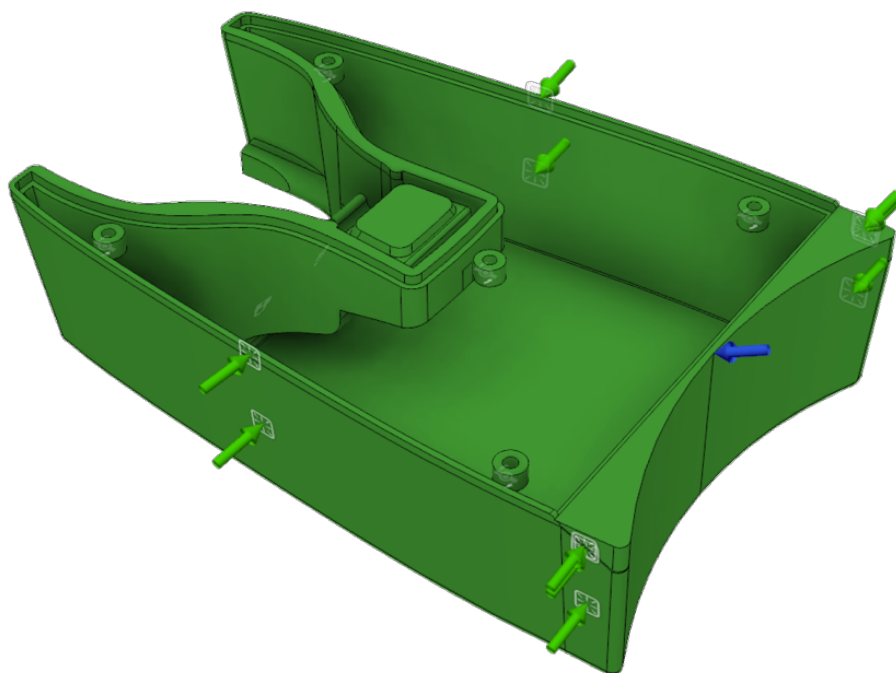
Penumbra looked to generative design to help them create a design that would be lightweight while maximizing stiffness to increase durability, while exploring materials that allowed them to use additive manufacturing methods for the small batch production they wanted. Then, we wanted to explore subtractive manufacturing methods and injection molded materials to see if there was opportunity to leverage generative design for all the same design parameters but moving to large batch production.

### Generative Setup

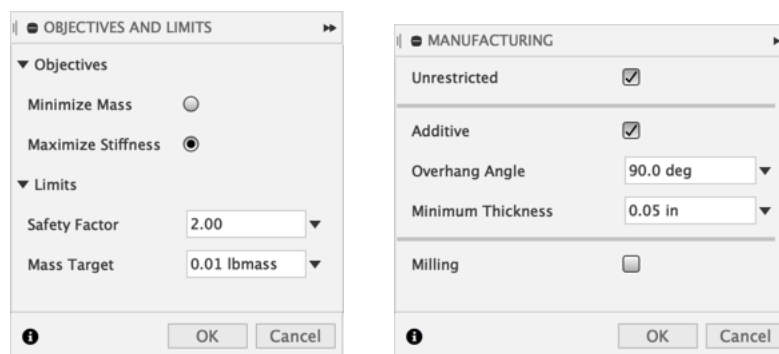
Penumbra started their design with preserves for the outer shell of the design, since they wanted to maintain the features and industrial design work that had gone into the design of the outside. There were also preserves for the holes where screws would attach the base to the rest of the scanner.



Loads were then applied to areas where the scanner would see the most bumps and bangs to increase the durability, as well as internal loads like the moment on the screw holes. Each load was added in a series of Load Cases, where each Load Case represents a real-life loading scenario.



For manufacturing, the initial design had a Maximize Stiffness Objective to increase the stiffness, and therefore durability, while keeping the mass as close as possible to the mass target of 0.01 lbmass. The Factor of Safety was 2, meaning the result should fail at twice the entered loads. The Manufacturing constraints were Additive manufacturing constraints with an Overhang Angle of 90 degrees and a Minimum Feature Size of 0.05 in, and Unrestricted. The material was set as HP Nylon PA12, a polymer used for additive manufacturing with HP Multi-jet Fusion with mechanical properties nearly identical to injection molded plastic.



## Generative Results

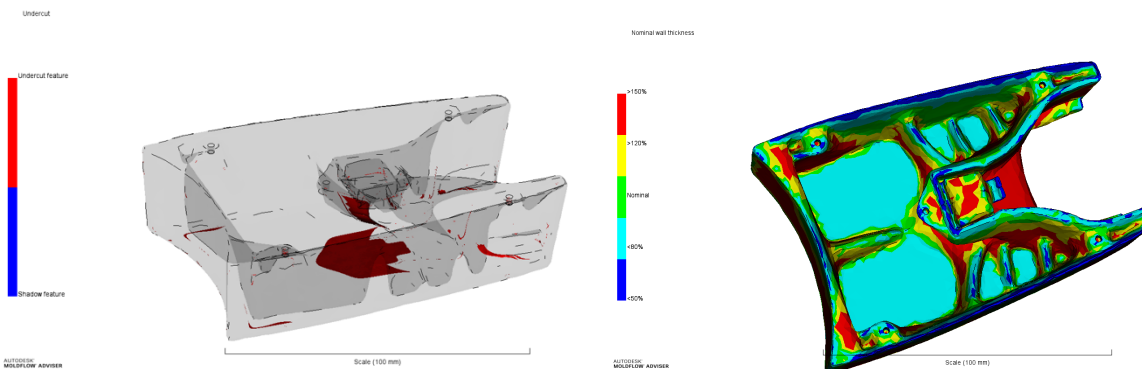
The results were essentially a generatively designed internal ribbing structure that added strength in all the necessary locations without extensive hours of work by a human designer adding ribs, simulation, moving the ribs, simulating, and so on. Even the Unrestricted results were suited for HP's Multi-jet Fusion, since the structures are essentially self-supporting. Penumbra repeated this process for the handle of the sensor, resulting in the final designs below.



## Creative Use of Subtractive Constraints

The above method and workflow are serving Penumbra very well. They're able to manufacture small batches of the scanner as needed, making customized designs without hours and hours of design work. But what if their needs changed, and suddenly they wanted or needed to go into large scale production? Additive manufacturing may no longer be the best solution, and they would likely need to turn to a more traditional manufacturing method, likely injection molding for a thin-walled plastic part like the part they've been printing on the HP 3200.

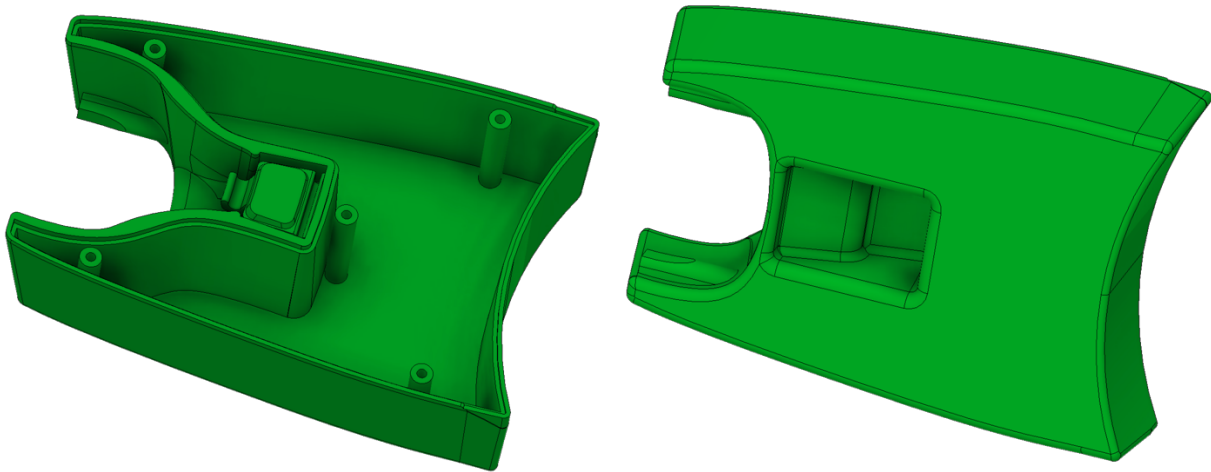
The first step before even starting a generative design solve was determining if the preserve geometry was manufacturable with injection molding. Generative design assumes that all preserves are manufacturable, so we had to start out with a validated set of preserves.



Our initial preserve geometry used in the additive study had some problems. There was a large undercut (highlighted in the image on the left) and there was a lot of variance in the wall thickness (highlighted in the image on the right). Rules of thumb for plastic design include:

- consistent nominal wall thickness
- drafted walls, ideally around 3 degrees
- no overhangs or shadow features

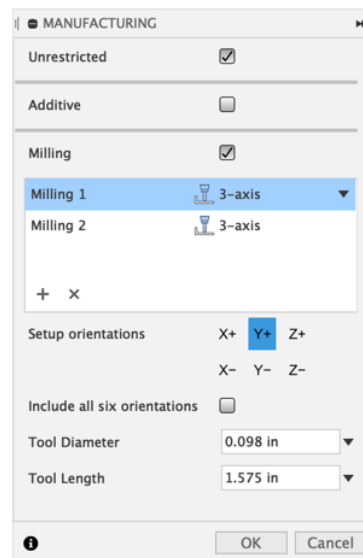
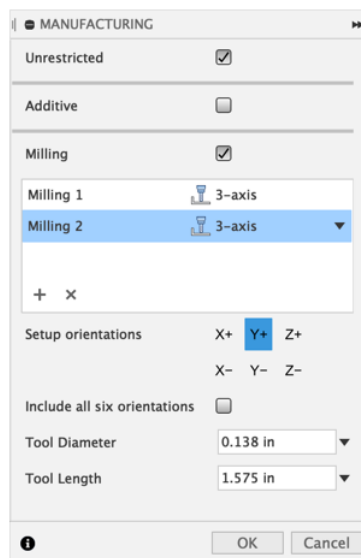
So far, we were breaking nearly all of these with our preserves, so the first step was to adjust the preserve model to better match the injection molding manufacturing method. The updated preserves are shown below and were validated with the same Moldflow analysis as above.



*NEW PRESERVE TOP VIEW (LEFT) AND BOTTOM VIEW (RIGHT)*

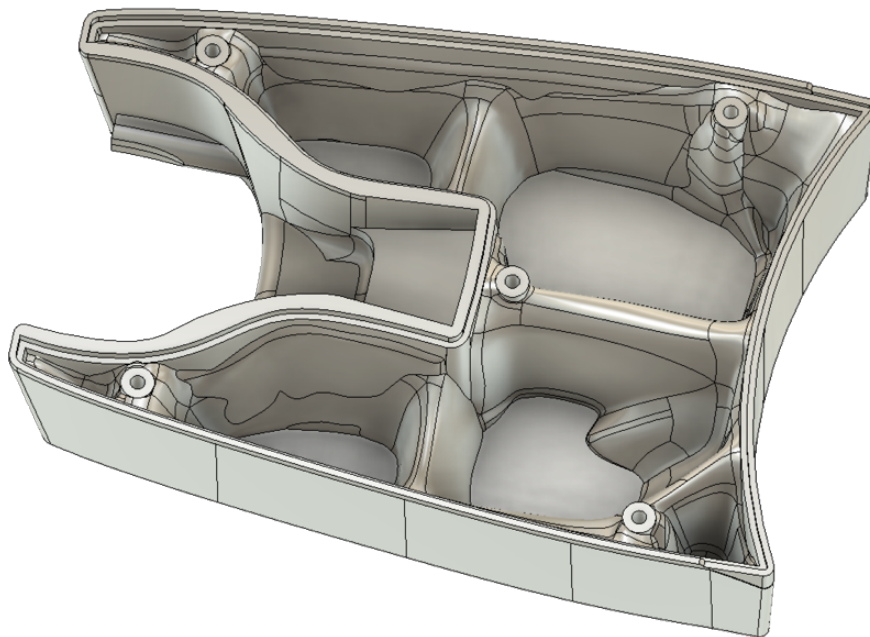
## Subtractive Constraints

The challenge here is that currently, there are no injection molding constraints in generative design. There are, however, Subtractive manufacturing constraints, and we had a hunch that if it was machine-able, it was likely close to injection mold-able. Using all the preserves, obstacles, load cases, and design objectives from the previous section, we re-ran the study with subtractive manufacturing constraint, as well as materials that would match injection moldable plastics.



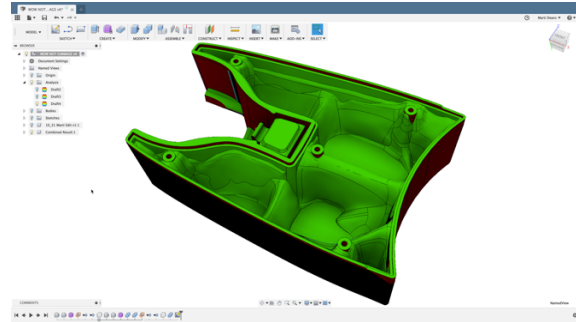
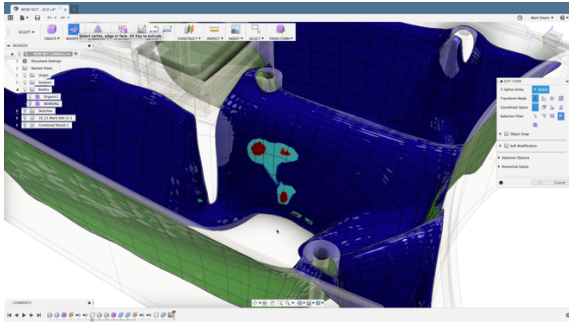
Two setups each with a small tool diameter with a long length was used to try to replicate the manufacturing ability of a mold, since molds can have very small internal and external radii, while also having tall and steep walls.

After exploring the available results, the one selected gave an organic internal rib structure that added support along the centerline, sides, and at angles in the front corners of the part.

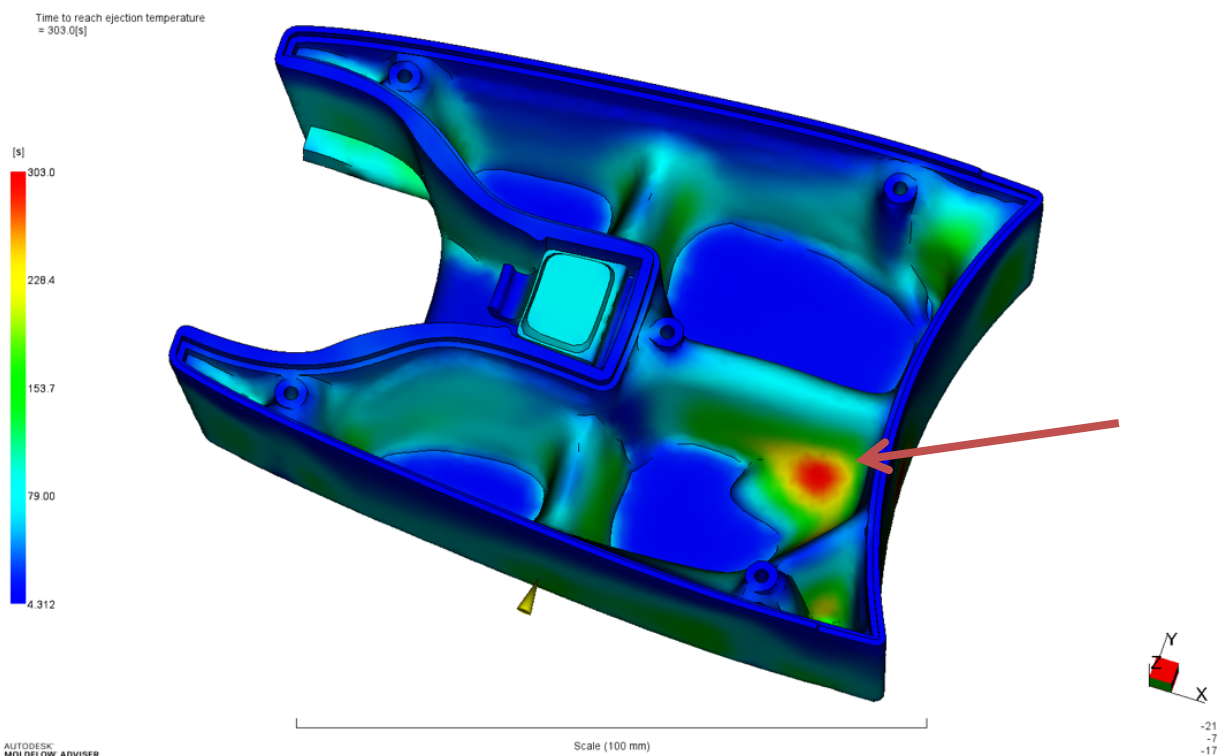


T-splines editing allowed manipulation of the output geometry to smooth potentially problematic areas and make a uniform draft on all the surfaces. The draft analysis tool in Fusion 360 color codes areas on the part to indicate the draft angle, and live updates during T-spline manipulation, making it easy to edit the T-splines with confidence that the result would have an acceptable draft. The draft analysis tool was run on the final result as well.



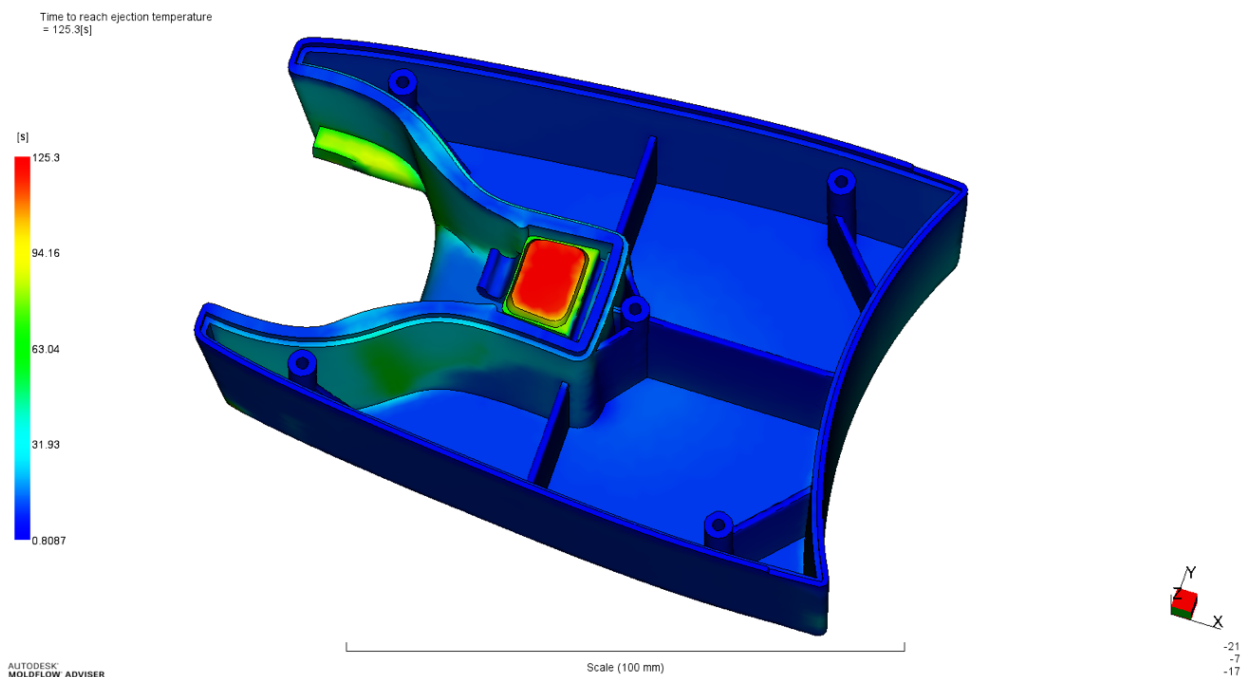


Moldflow Adviser was used analyze this design to see how feasible it was to injection mold. Unfortunately, it turned out there were several problems with the design that made it less than ideal for injection molding. The generated supports were thick compared to the nominal wall thickness of the shell that acted as the preserve, and this caused a lot of issues like extremely long cycle time due to extended cooling, and problems with shrinkage across the part. The original clip design was also suboptimal, as there was only a small channel that allowed it to fill with plastic, which added to the long cycle time.



## Redesign for Injection Molding

Although the generated geometry was not suitable for injection molding right out of the box, it does offer an overlay to design a more optimized rib pattern. We redesigned the ribs using traditional plastics design rules of thumb using the locations and heights of the generated support areas as a guide.



The new design showed significant reduction in mold cycle time in the majority of the part – 305 s vs 83 s (the maximum time to ejection not including the clip). The clip was still a problem area and would need to be redesigned before this part is ready for production; since we were focused on the internal support structure, we felt this was outside the scope of this case study and did not redesign the clip at this time.

## Conclusion

Penumbra was able to leverage generative design and additive manufacturing to create a customizable, balanced, and strong design that met all of their engineering specifications. This design increased strength by 78% while maintaining the top and bottom balance that was so important to reduce user fatigue.



While extensive manufacturing methods are on the generative design roadmap, the use of current manufacturing constraints to generate a design that can be used as a guide for optimized results is applicable to many industries and manufacturing processes, as we discovered using subtractive constraints to guide the design of a part for injection molding.

For access to generative design, download a trial of Fusion 360 at [fusion360.autodesk.com](https://fusion360.autodesk.com) and to get started on the generative design process, there is learning content [here](#).