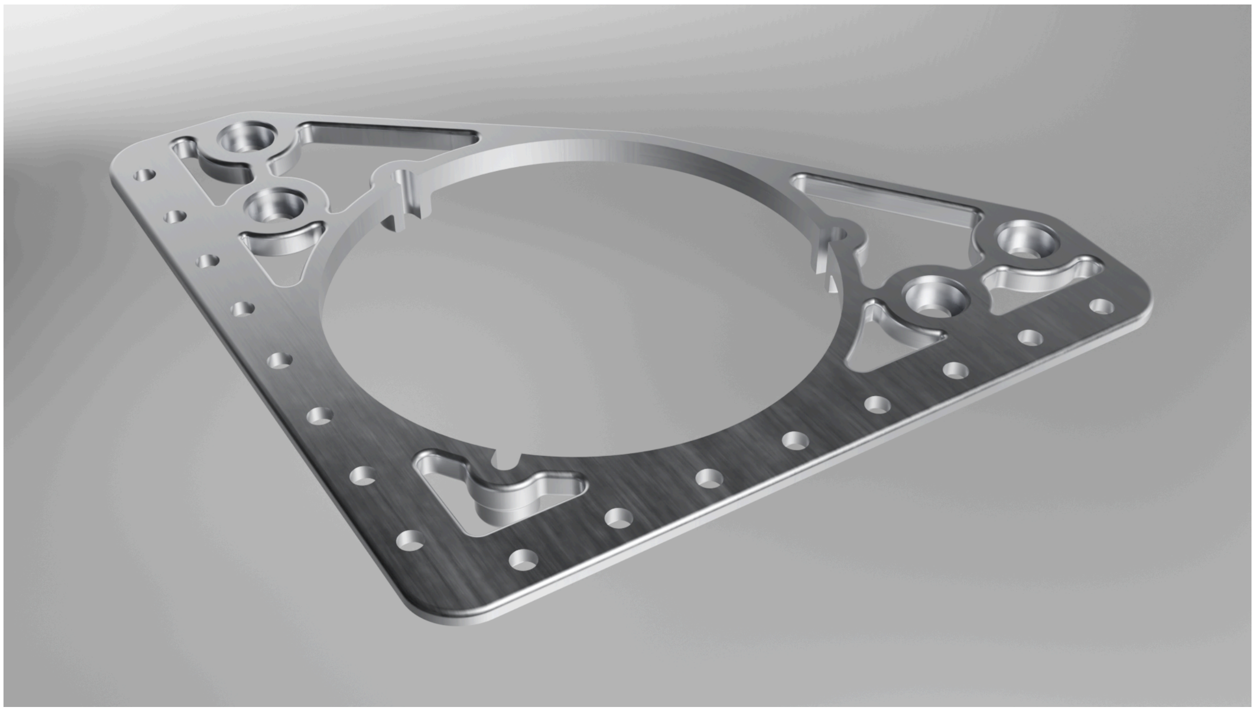
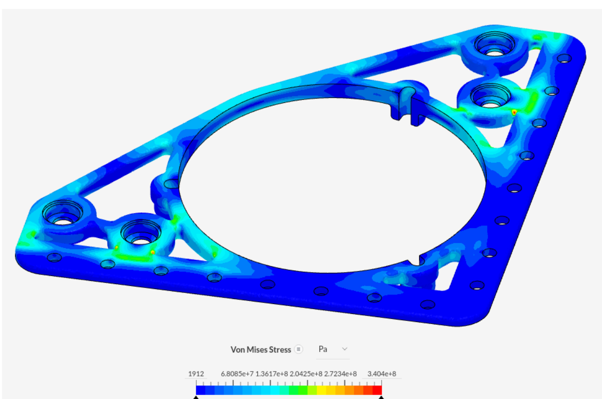
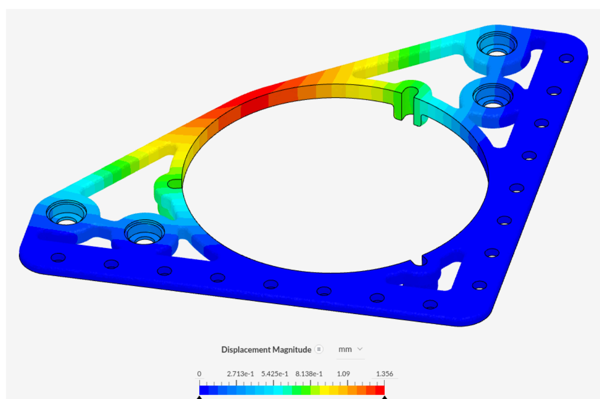
Structural Plate Prototyping for the OSH-1 Drive Base







Part CAD (OnShape)
Simulation Project (Simscale)

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Course: Prototyping for Concept Validation (EDNS 498-A)
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Background

Over the summer of 2025 and into the fall semester, I have been working to develop and build an omnidirectional (holonomic) wheeled drive-base for a robot that will compete in the Rival Robotics competition.

The primary element of this design is the swerve module (pictured to the right), which uses two motors and a series of gears to achieve independent control over the orientation (azimuth angle) and angular velocity of a wheel.

When four of these modules are placed at the corners of a chassis, they can work together to move the robot along complex trajectories.

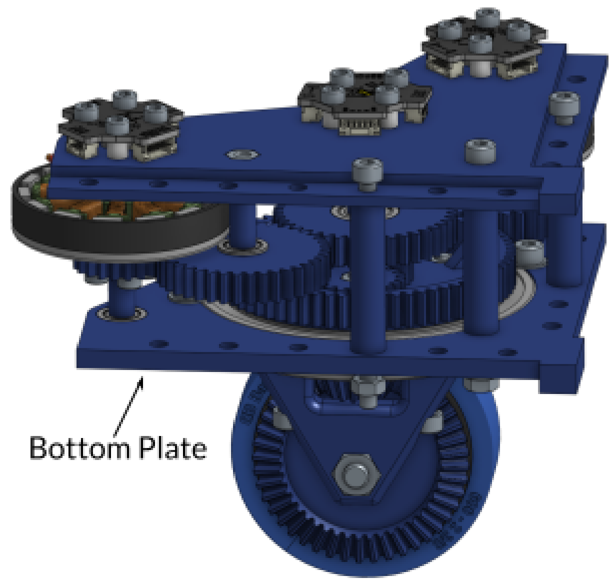


Figure 1: Front View of Initial Swerve Module Design

Throughout this project, it became clear to me that this drive base could be very useful beyond just the competition robot. And so, I decided to start work on version two, which will eventually be released as an open source hardware + software platform under an initiative entitled Open Holonomics.

Project Context

Of particular interest for this project is the main support plate for the swerve module, termed here the "bottom plate". This part absorbs the vast majority of the force from the weight of the robot and from impacts to the wheel assembly. Importantly, version two of this platform will be designed for use with larger, heavier robots–16x16" frame at 50lbs vs 12x12" frame at 20lbs–and so validating that this vital part of the drive base can sustain such forces is imperative for further development.

More specifically, the goal of this project and prototype is to validate that the core design elements will continue to perform reliably when scaled appropriately to this larger platform. With this goal in mind, I used OnShape to design the part.

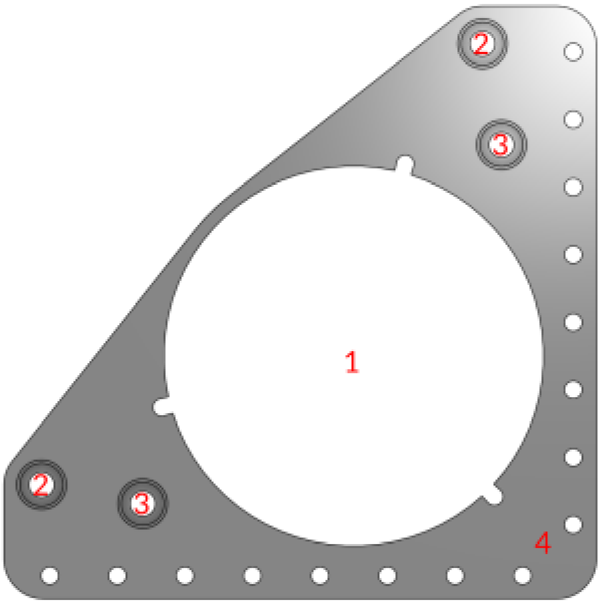


Figure 2: V1 | Minimum Requirements Met

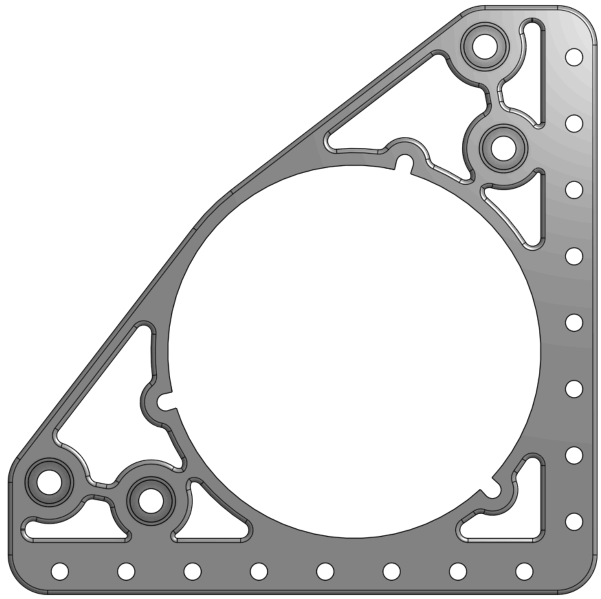


Figure 3: V2 | Optimized for Weight Reduction

Two part versions were designed: V1 was the simplest possible part that still included all necessary features while V2 skeletonized the design and used fillets to optimize for weight reduction and aesthetics. The important design elements are as follows:

1. Azimuth bearing cutout and retaining holes
2. Cutouts for motor support bearings
3. Cutouts for gearing support bearings
4. Chassis mounting features

Additionally, the part material has been changed from printed PETG-CF to 6061 aluminum. With this material, V1 has a mass of 85 grams while V2 saves 20 grams for a mass of 65 grams.

In reality, V1 of the part was designed and simulated, and those results made it clear that there was room for weight reduction given the design requirements. With these results in hand, another round of design and simulations were performed to produce V2.

Simulation and Validation

Simulation Parameter Estimation

The primary question to answer here is, how much force should be applied to the part? Some rough calculations show that each bottom plate would have to endure around 56 Newtons (12.5 lbs) of force when the robot is resting. That is, not a lot, and from intuition alone it's clear that these parts can sustain this force without issue. Simulating this situation would simply be a waste of resources.

This robot will move, however. It will accelerate, it will collide with obstacles, it will go over bumps and off small ledges. It will be subjected to substantially more force than when it is just sitting idle. The benchmark I decided on was a fall from rest at a height of 10cm (approx 4 inches) as that is close to the height of the curb outside my house. I figured that if I were to be driving and using this robot where I live, that this would be about the harshest impact it could potentially experience, at least in terms of force on the drive base.

Estimating impact force from a collision requires knowledge of the distance over which that impact takes place. From my initial, smaller prototypes, I estimated that there was about 5mm of compliance in the wheel assembly. With this estimate, and some kinematics to determine the rough impact duration, I came up with an average sustained force of around 4400 Newtons which comes out to 1100 Newtons on each of the swerve modules. I ended up rounding this down to an even 1kN simply because I thought it was a nicer number.

It's important to note here if the drive base were to drive off of a 10cm curb at reasonable speeds, that it would likely see a much smaller impact force as it would roll off the curb one or two wheels at a time instead of falling straight down. Hence, the 4400 Newton estimate is certainly an upper bound, and that is why I felt comfortable in rounding the simulated force to 1kN.

Simulation Setup

I used Simscale, a cloud based simulation platform, to perform the FEA of these parts. When integrated into the robot chassis, the bottom plate will be supported on either side by aluminum rails and the wheel forces will be transmitted through the azimuth bearing retaining studs (see figure 4). In the simulation, these constraints are represented by a rigid support along the chassis mating face, and a 1kN force distributed across the three azimuth bearing supports (figure 5).

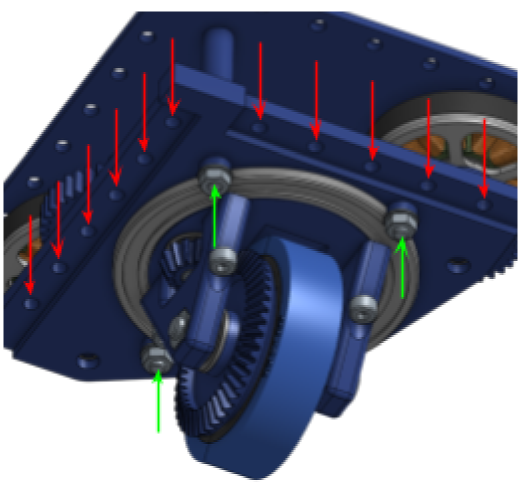


Figure 4: Impact (green) and Support (red) Forces on the Plate

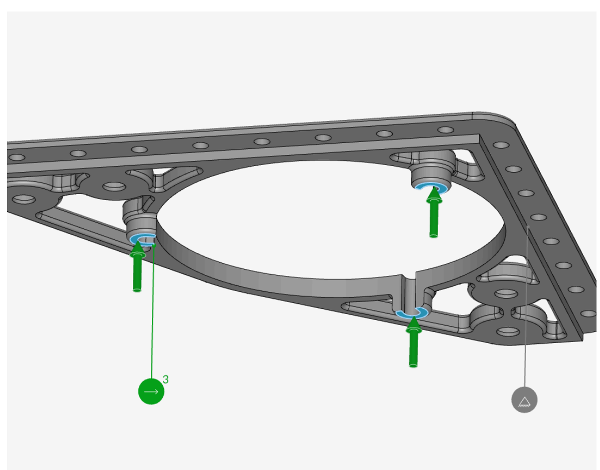


Figure 5: Simulation Boundary Conditions

Results

For detailed images of simulation results refer to the appendix.

According to Matweb, 6061 aluminum has a tensile yield strength of 276 MPa. V1 of the part saw a maximum VonMises stress of approximately 115 MPa and a maximum displacement of 600 micrometers. This result displays a factor of safety with regard to material yield of 2.4. This result, in concert with the knowledge that the 1kN load was an upper bound prompted me to iterate to version 2 to reduce part mass.

V2 used a skeleton thickness of 4mm, and saw a maximum VonMises stress of 340 MPa with a maximum displacement of 1.4mm. This result strongly suggests that the weight reduction measures were too aggressive, and that the part is likely to yield under the specified requirements. It should be noted, however, that these stresses occur in small, localized areas of the part.

Future Development and Iteration

These results suggest that small changes to skeleton thickness and part geometry may be sufficient to mitigate stress concentrations. Another variable that this analysis did not consider is the overall thickness of the part. The part thickness throughout both versions of the prototype was held constant at 5mm as that was the thickness of the plate in the original design. It is likely that increasing part thickness would significantly improve the part strength as the force tends to deflect the part in the vertical direction. Increased vertical thickness will improve cross sectional properties for this type of bending.

Another factor to consider is that other elements of the swerve modules contribute to the impact absorption of the entire drivetrain. Importantly, the bearing that sits in the plate for the azimuth axis is quite substantial. It is 8cm across, 1cm deep, and made of steel. Given that the plate deflects most aggressively around the bearing itself, it is very likely that the addition of the bearing would increase the rigidity of the assembly immensely.

It is clear that a next iteration on this design should include less aggressive weight reduction measures, with a focus towards rigidity and reliability. While the existing designs may work, this part is an integral element of the larger system, and reliability should be prioritized over extreme optimization for this reason.

In conclusion, this prototype and these simulation results validate that these design concepts and features can perform adequately for the required application with further iteration and tweaking to certain parameters.

References and Inspiration

This design was based on my own original work. The initial drivetrain design was inspired by these similar projects:

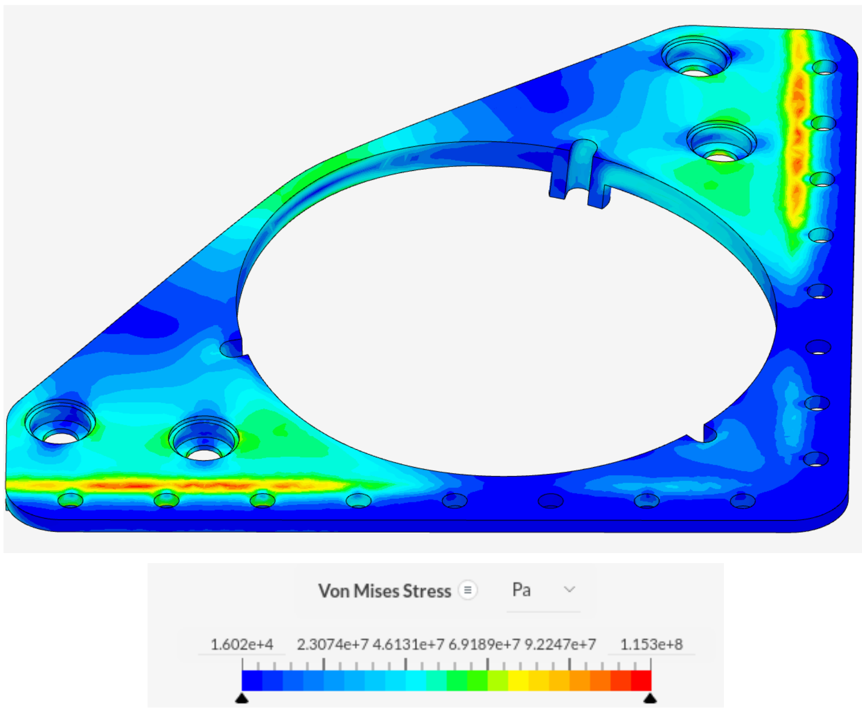
- Swerve V4 from Alex Hattori
- FTC Swerve Drives from TerraVoxel
- MK4i Swerve from Swerve Drive Specialties

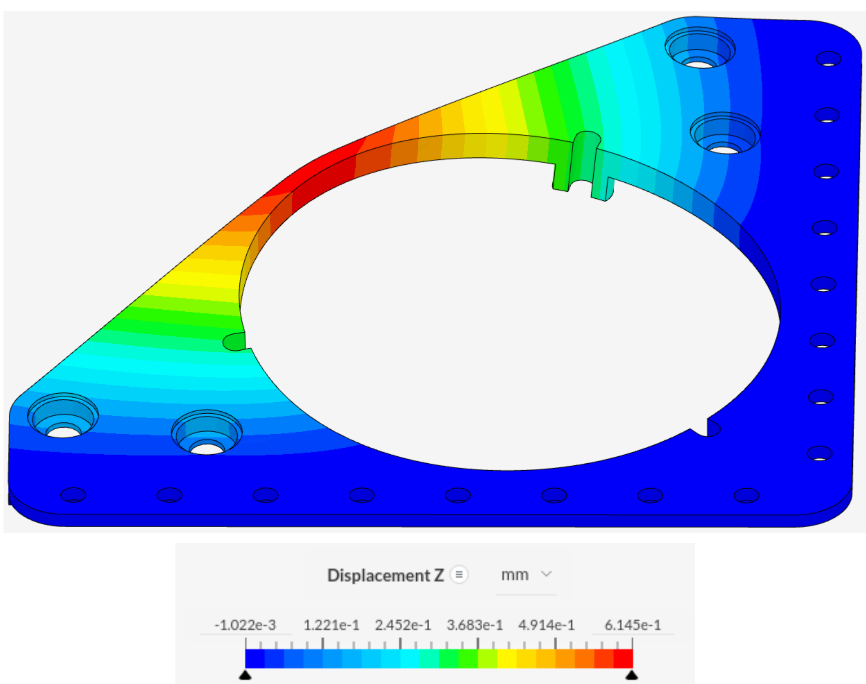
Material properties for 6061 aluminum were found here.

Appendix - Simulation Results

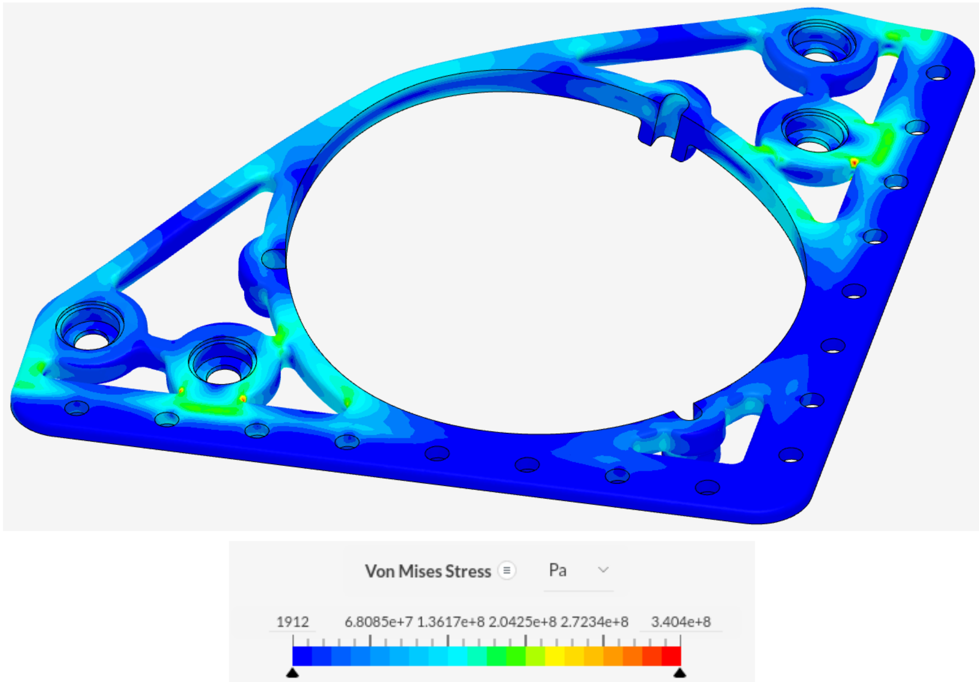
The scaling factor for displacement is 10 across all results.

V1

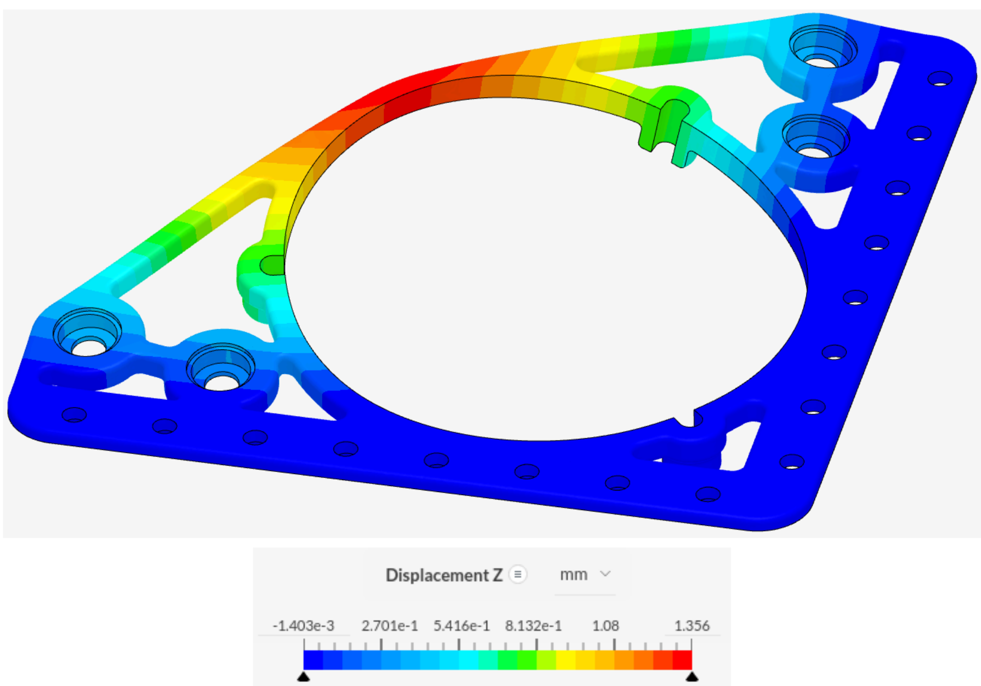




V2



Von Mises Stress
Pa
1912
6.8085e+7
1.3617e+8
2.0425e+8
2.7234e+8
3.404e+8



Displacement Z
mm
-1.403e-3
2.701e-1
5.416e-1
8.132e-1
1.08
1.356