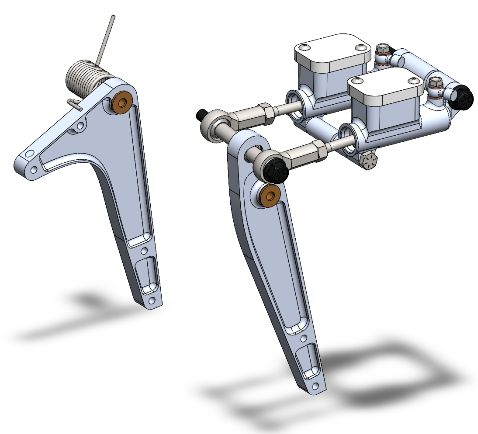
Cornell Baja Racing

Fall 2025

Technical Report



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Projects:
Master Cylinders
Pedals

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1 Master Cylinders

1.1 Abstract

The master cylinders are the front end of the brakes system. They take in the force from the brake pedal and use a piston-cylinder system to convert it to pressure in the brake lines.

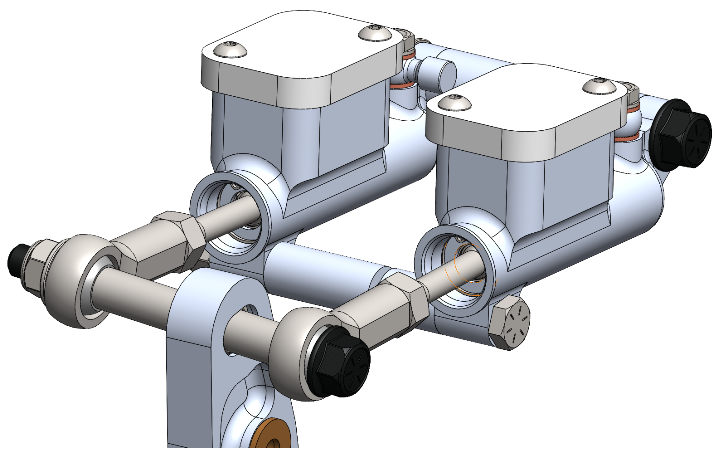

Figure 1: The master cylinders in place, connected to the top of the pedal.

There are two master cylinders. This is because the rules require two entirely separate brake circuits. The way we split the brakes is front and rear: one brake in the front and two in the rear. This also allows for brake bias, which I will talk about later.

1.2 Design Requirements

The brakes as a whole and therefore the master cylinders are largely dictated by rules. The basic idea is that the brakes must be hydraulic and able to lock under any working conditions. There are few specific rules about the master cylinders.

Constraints:

- Two separate hydraulic circuits.

- Rigid link to brake pedal.
- Two separate, rigidly mounted brake fluid reservoirs.
- Must be able to lock all brakes in any conditions.

Objectives:

- Be able to supply enough/not too much pressure to the calipers provided a reasonable input force.
- Smoothly apply pressure into brake lines.
- Minimize friction in order to improve brake feel (more below).
- Allow brake bias to be changed to improve performance and driver preference.
- Let brake bleeding be an easy process that results in a perfect bleed.

In the past, the master cylinders were able to apply so much pressure that the calipers got exploded. That's not ideal, so the geometry of the brake pedal and master cylinders should prevent this. I wanted to also significantly improve the retraction performance of the master cylinders. While brake drag is a very small issue now, there is still potential for it. On TG21, the driver had to pull back on the brake pedal in order to fully release the brakes. The master cylinders should be able to retract themselves without issue.

1.3 Initial Research

1.3.1 Last Year's Car

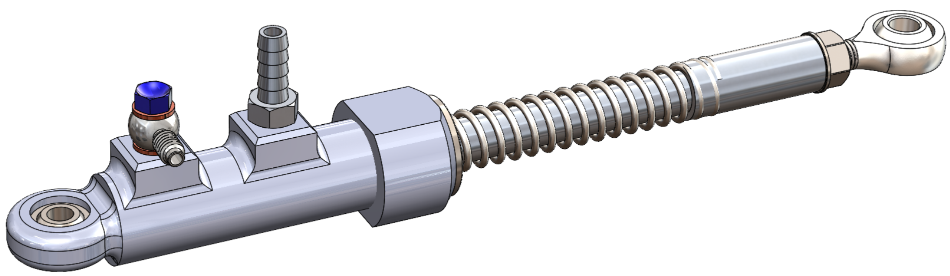

Figure 2: One of TG21's Master Cylinders

The master cylinders suffered zero failures last year! When they were first assembled, there was a small amount of leakage, but that issue was almost immediately resolved. While the master cylinders consistently worked all season, they lacked in some areas. The way the masters were fixed to the car was with two ball joints. This meant they were mounted as a two-force member, which is consistent with many past years. The large difference between TG21 and any other car before was the location of the master cylinders. They are mounted at the top of the pedal bay instead of in front of the brake pedal.

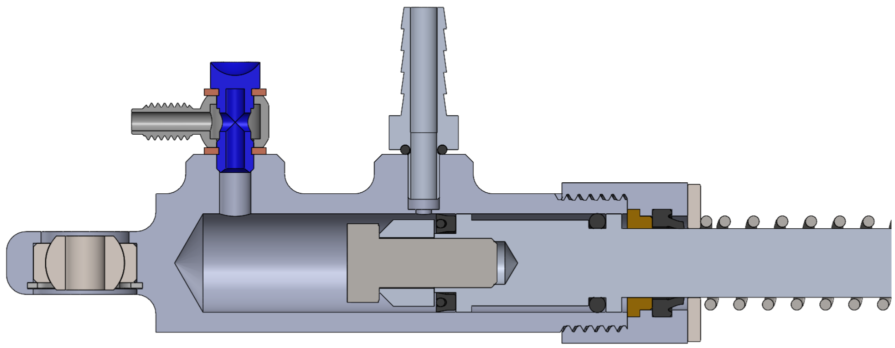

Figure 3: The internals of TG21's Master cylinder

These design choices led a few distinct issues. First, and most serious, was the large amount of friction inside the master cylinders. Friction is, funny enough, the enemy of brakes. It eats away at the pedal feel and driver control of the brakes. Also, large amounts of static friction essentially remove all driver feel from from the brakes. The two-force memberness of the brakes contributed significantly to this. The primary issue is that the masters must react a bending moment (caused by the buckling impulse of the two force member). This is reacted by the bronze bushing at the front of the master and the piston on the inside of the bore. Both of these metal-on-metal contacts provide large amounts of friction.

Another source of friction is the seal at the front of the master cylinder. This seal creates two different issues. First is just the friction that I just talked about. The second, more pressing issue is the break-out force required to retract the piston fully. Like I said before, the piston wasn't retracting fully/correctly, leaving the brake circuit closed when it was meant to be open to the reservoir. The use of a loaded u-cup seal partially explains this issue. The 'loaded' part refers to the fact that there is another o-ring inside of the 'U' of the u-cup seal. This o-ring serves the purpose of pushing the 'U' apart - putting more force on the walls of the cylinder. This helps seal the master cylinders at low pressure but also generates more friction, especially break-out friction.

Figure 4: Deformed piston cap - the upward-facing surface is meant to be flat.

The other way that the seal was generating friction was by being over compressed. The spec on the height of the seal groove is very precise. In TG21's master cylinders, the cap that holds the seal on the piston deformed, essentially squishing the seal more than it was meant to be. This lead to the seal being pressed harder against the walls of the master cylinder.

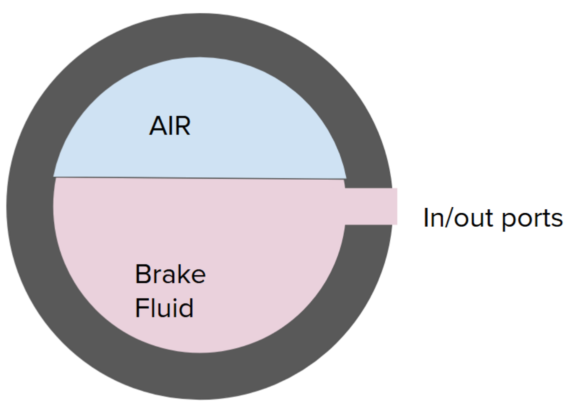

Figure 5: My illustration of the brake bleeding problem.

The issue that arose from the new mounting point of the master cylinders was an unexpected one. The ports (reservoir and brake line out) ended up on the side of the master cylinders - facing horizontally. What this meant is that there was a constant bubble at the top of the master cylinder which was very difficult to get rid of. I will talk more about what I did in the bleeding techniques section.

1.3.2 Online Research

I did a huge amount of random googling for this project. A lot of that was just looking at master cylinder rebuilding videos on YouTube. There are a lot of funny old guys that rebuild master cylinders and film it terribly. I looked into almost every possible type of master cylinder and brake system, including tandem master cylinders, proportioning valves, front-reservoir masters, and more. No single source was particularly helpful, which made the whole process very frustrating.

If you are a future master cylinder designer (hi) I recommend first familiarizing yourself with the system in 90% of all production cars: brake booster, tandem master cylinder, full proportioning valve, and X-shape circuits.

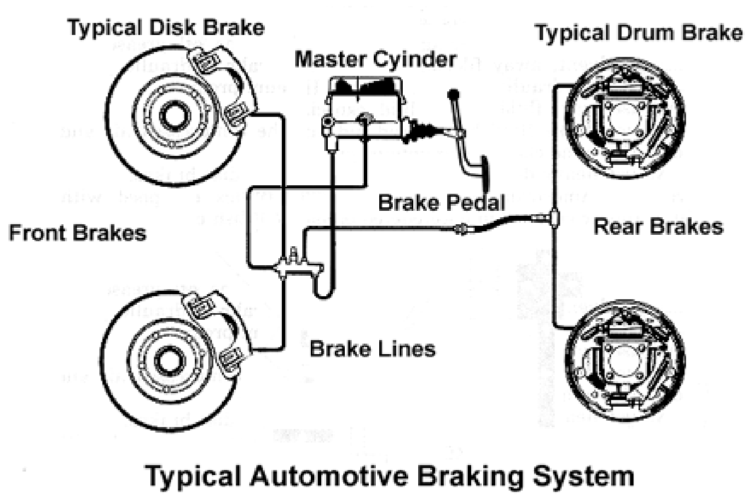

Figure 6: Typical production car brake system

1.4 High Level Description

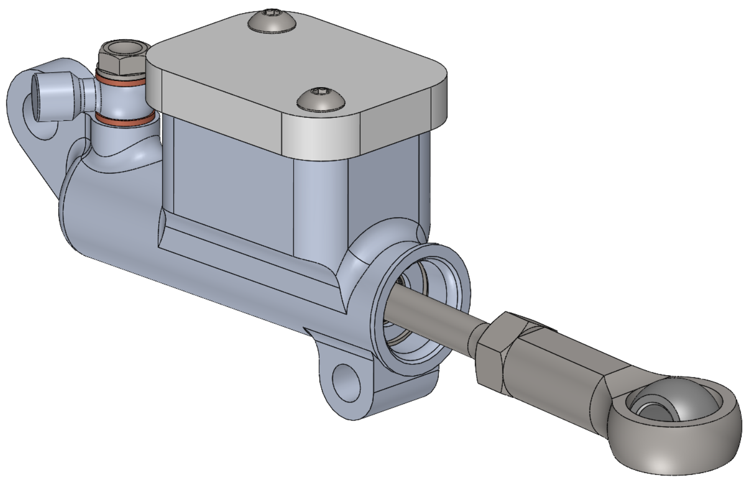

Figure 7: Full master cylinder assembly

The final design for the master cylinder is a rigidly mounted housing, separated piston and pushrod, and integrated reservoir. The overall change in mass is a 0.06lb or 12% reduction per master cylinder.

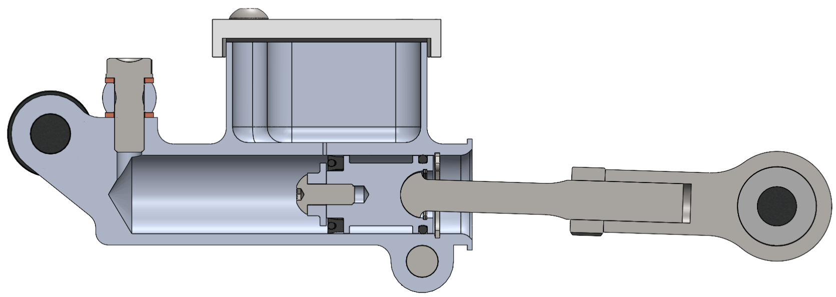

Figure 8: Cross-section view of the entire master cylinder

1.4.1 Rigid Mounting

The switch to rigidly mounting the master cylinders is the largest change I made to the design. It has massive effects on every part of the system.

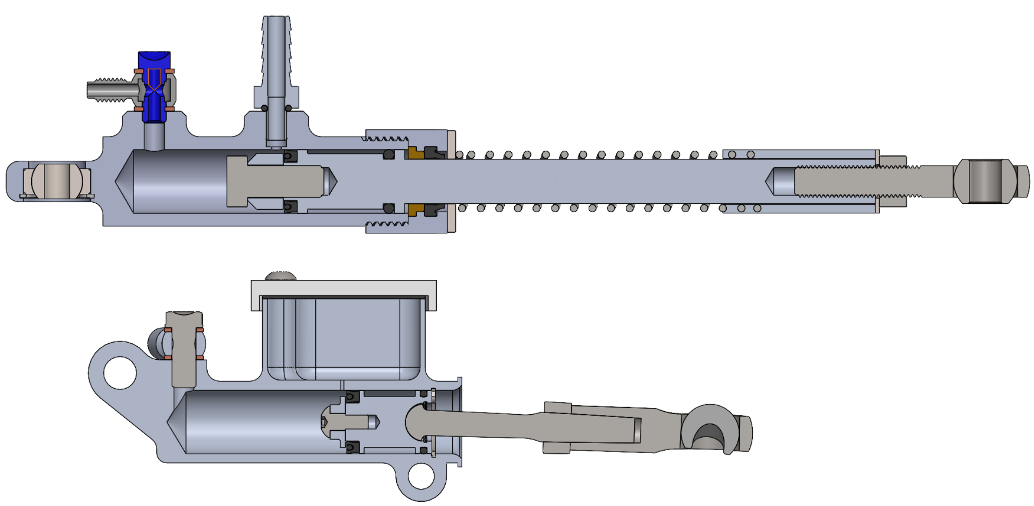

Figure 9: 1:1 Comparison between TG21 and TG22's master cylinders.

The first difference it makes is easy to see: length. The TG21 master cylinders are about 10 inches long in total. This is a result of the geometry at the top of the pedal box. There is no good way to mount them, so they have to extend all the way from the pedal to the shock bracing tube.

The next biggest change is in the design of the piston-pushrod system. In TG21, they are a single aluminum part. For TG22, the piston and pushrod are two separate pieces.

The mounting itself is achieved using two bolts - one 5/16" behind the butt of the master cylinder and one 1/4" just under the mouth. The location of these bolts was constrained by the frame tube that the masters are mounted to (the pedal bracing tube). Ava kindly moved the pedal bracing tube to be exactly behind the pedals for more convenient mounting.

1.4.2 Reservoir

The second most interesting change that I made, and maybe the most noticeable, is the location of the reservoir. The legacy solution was what is called a remote reservoir: The brake fluid reservoir is a separate container connected with a rubber tube to the master cylinder.

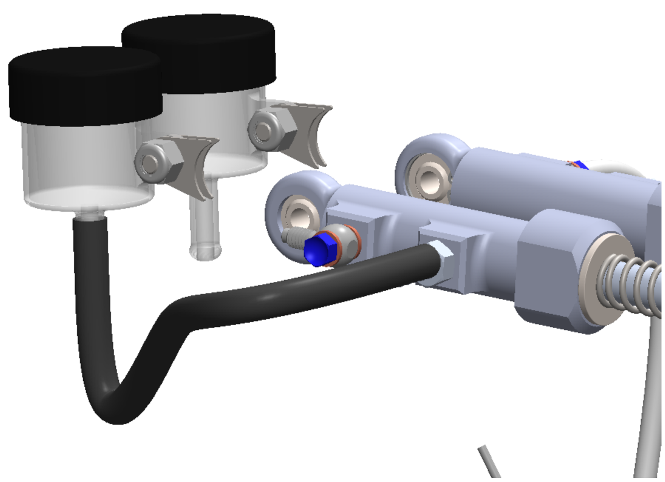

Figure 10: Remote Reservoirs on TG21

The major issue with the remote reservoirs was their mounting location. Contrary to the image, they were both mounted to a single weld nut on the shock bracing tube. This had two problems: First, they were prone to slipping downward and becoming angled, which looked ugly and reduced their usefulness. Second, they were nearly below the master cylinders, meaning any bubbles in the masters would just stay where they are. For correctly placed remote reservoirs, the tube connecting them to the master cylinders should only go down, never turning upward like the ones on TG21 do. This was my mistake as I was tasked with deciding how to mount the reservoirs.

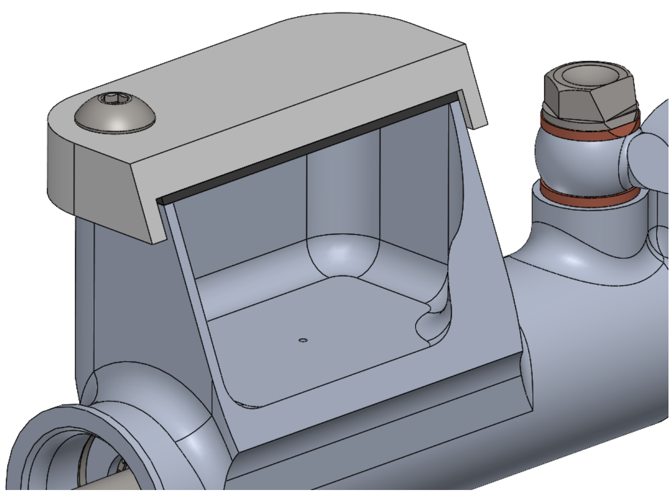

Figure 11: Cross section showing TG22's integrated reservoir.

The solution to this was the make the reservoir an integrated part of the master cylinder. It has a wall thickness of 50 thou and is sealed with a custom 1/32" buna-n gasket. I want to change this gasket to a baffled 3D printed one, but I have not had the time to design it yet.

Another change to the reservoirs that I made was the size of the fill port hole. This hole serves two purposes: to allow new fluid to enter the brake lines when bleeding the brakes, and to allow for expansion and contraction of the fluid and brake components under temperature. The total volume of the brakes system has small fluctuations, and the reservoir port must be able to let fluid into and out of the brake circuits when that happens.

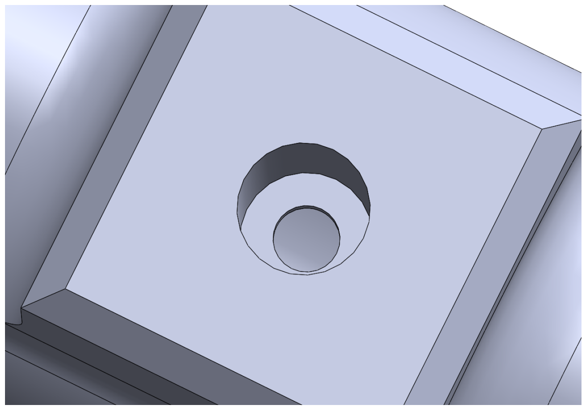

Figure 12: TG21's reservoir fill port.

The hole in TG21's master cylinder was 0.1", which shredded the u-cup seal every time it passed under it. I changed the hole size to 1/32", which should significantly reduce seal damage (shown below).

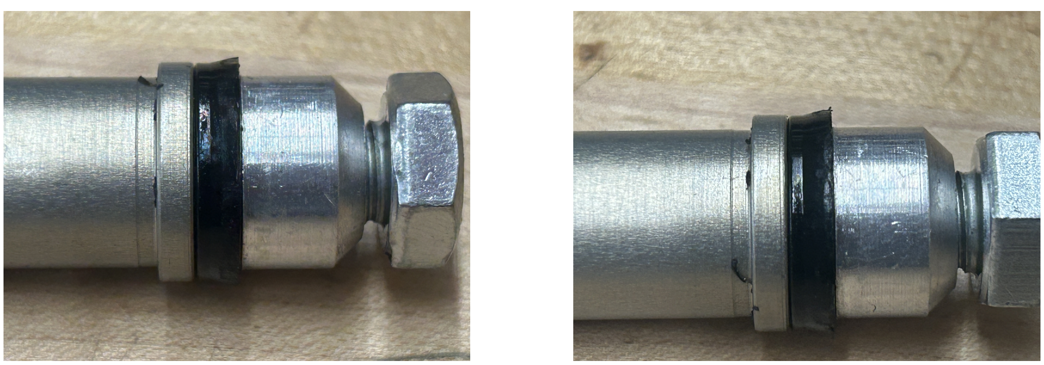

Figure 13: Left: Almost new u-cup. Right: U-cup showing damage after about 30 passes over TG21's fill port.

1.4.3 Piston Assembly

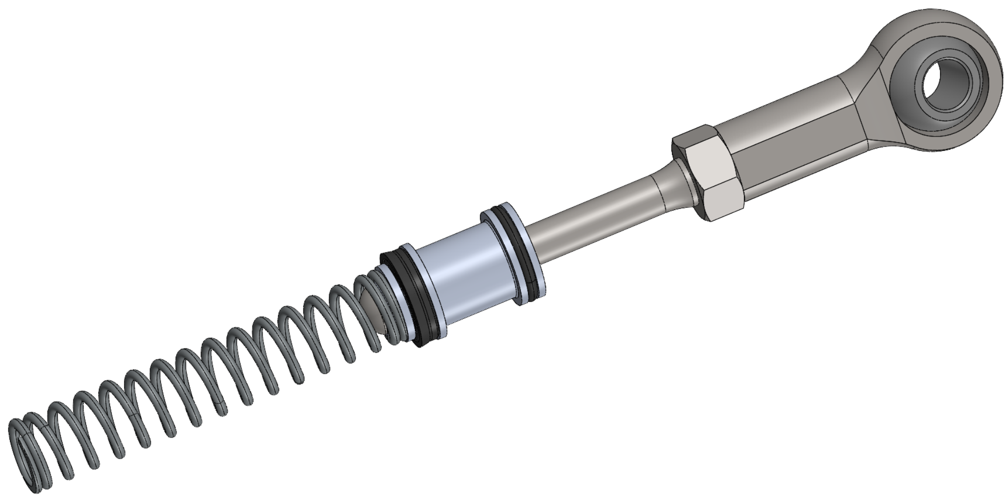

Figure 14: Full piston-pushrod assembly.

Another large change that I made this year was the change from an external spring to an internal spring. The purpose of the spring is to retract the piston when there is no force applied on the pedal. TG21's master cylinders had issues retracting, so I made sure to spec the spring correctly to be able to retract the piston at any location. As a result, the spring is quite heavy: 22lbf/in spring rate. At full depth, it applies 31 lbf.and at full retraction it applies 16. That requirement was determined by retraction force testing that I did (further down). Installation of the piston will require about 20 lbf. before the retaining circlip is in, which may be a challenge.

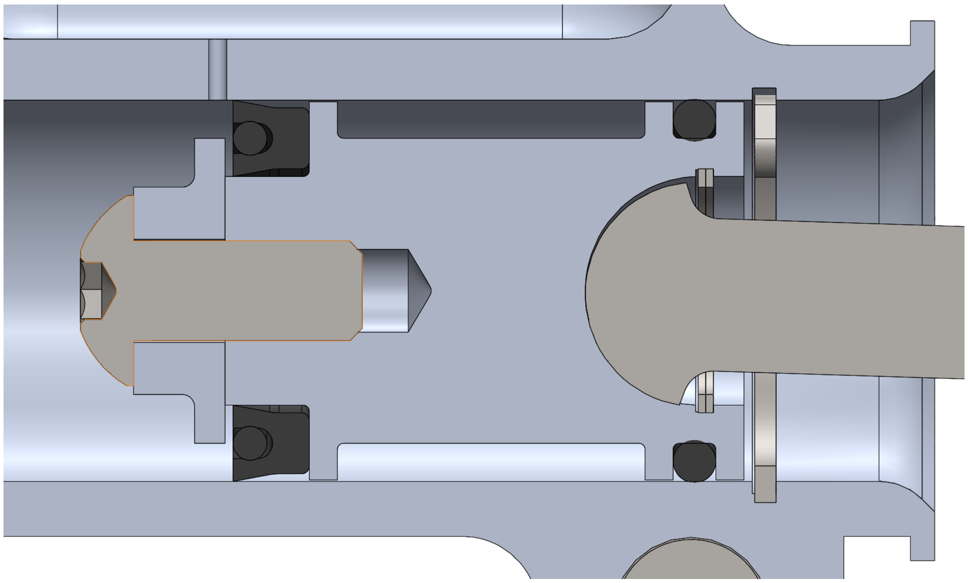

Figure 15: Piston inside the bore of the master cylinder.

Starting from the left side of the piston, the bolt and hat have been changed. The hat now has a flange to hold the spring in place and a much larger surface touching the piston. This ensures the seal groove height is perfectly in tolerance. To accommodate, the bolt has been changed from a 5/16¨-18 to a #8-32 bolt. Given the fact that this bolt sees essentially zero load, I am not worried about it at all. I found a chart for installation torques of noncritical bolts in 6061-T6. Which I plan to use to ensure the piston cap bolt does not begin to loosen. The current design of the piston uses the old loaded u-cup seals, but they are likely to end up using a different u-cup seal that I found in the Allegheny-York catalog.

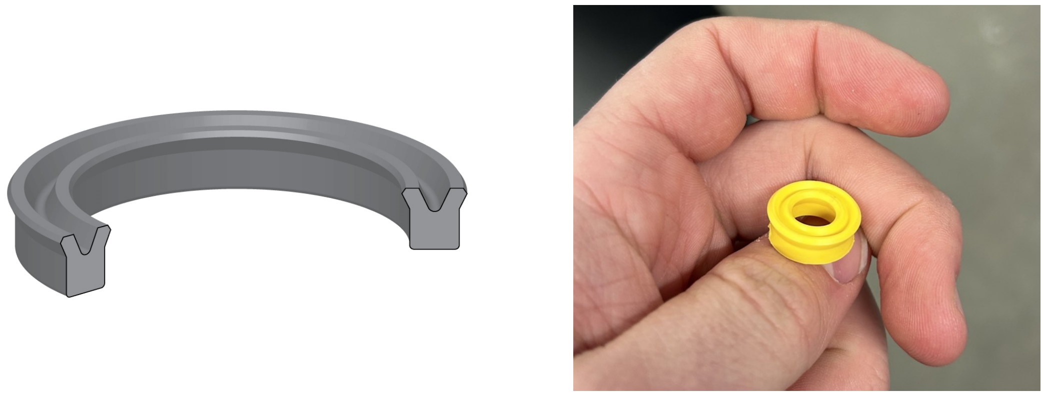

Figure 16: The new u-cup seal from Allegheny York.

This seal is specifically designed to reduce friction. It also has trimmed edges, which should help to minimize the wear from the reservoir port. The yellow color was also a fun surprise.

The final interesting feature of the piston is the fact that the pushrod is retained in it by a circlip. This was to ensure that if the piston got stuck (impossible) it could still be removed. This feature is probably not necessary, but the team leads wanted it and it has no negative effect on performance.

1.5 Hand Calculations

Pedal Geo:	**Value**	**Unit**		**Pressure FOSs**	**Front**	**Rear**	**Unit**	**Pushrod (steel)**	**Front**	**Rear**	**Unit**
Pedal Length	6.000	in		Max Pressure (fl	2.122	1.414	FOS	length:	3.000	3.000	in
Master Length	1.400	in		Pressure to lock	1.887	1.599	FOS	Diameter	0.250	0.250	in
Pedal Stroke (ho	3.000	in		Volume	4.961	9.923	FOS	I	0.000	0.000	
Pedal MA	4.286	in		Real Stroke	0.141	0.071	in	Critical Force	6097.968	6097.968	lbs
Master Stroke	0.700	in		Locking Force	96.999	114.418	lbs	Buclking FOS	5.963	3.976	FOS
Bias to Rear	0.600	%		Explode Force	266.218	399.327	lbs	Crumble FOS	15.220	10.146	FOS
Caliper Require	**Front**	**Rear**	**Unit**	**Statics Calcs**	**Front**	**Rear**	**Unit**	**Spring Spec**	**Value**	**Unit**	
Locking Pressure	542.000	959.000	psi	Hoop stress (psi)	3195.467	4793.201	psi	Est. Break Out	12.000	lbs	
# pistons	8.000	4.000	#	Desired FOS	2.000	2.000	FOS	K	22.000	lbs/in	
piston dia	0.830	0.830	in	required thicknes	0.016	0.024	in	Rest Length	2.500	in	
Piston area	4.328	2.164	in^2					Butt Length	1.050	in	
Piston Retraction	0.010	0.010	in	True Bias	**Front**	**Rear**	**Unit**	Force @ no Com	16.500	lbs	
Caliper Volume (	0.043	0.022	in^3	% Bias	0.541	0.459	%	Force at Max Co	31.900	lbs	
Max Requireme	**Front**	**Rear**	**Unit**	**Master Cylinder**	**Value**	**Unit**					
Horatio Foot For	183.000	183.000	lbs	Bore	0.625	in					
Fluid bolt explosi	2169.340	2169.340	psi	Bore area	0.307	in^2					
Max Force in	313.714	470.571	lbs	Stroke Volume	0.215	in^3					
Max Pressure	1022.550	1533.824	psi	Thickness	0.100	in					

Figure 17: My hand calculations for the master cylinders.

These calculations helped me determine everything from pedal geometry to wall thickness to pushrod diameter. Note the factors of safety highlighted in green. The calculations are also linked at the bottom of this report.

Inputs	**in.**		**Outputs**	**Rear:**	**Front:**
Bias to Rear	0.6		Bias Bar	1.09375	0.59375
Masters C2C	2.5		Front Bolt	1.155	0.655
MC Front Tab Width	0.6		Back Bolt	1.305	0.805
MC Back Tab Width	0.3				
Front Frame Tab Thickness	0.09		**Validation:**	**Difference**	**Total**
Back Frame Tab Thickness	0.09		Bias Bar	TRUE	TRUE
Pushrod Eye Thickness	0.4375		Front Bolt	TRUE	TRUE
Pedal Eye Thickness	0.375		Back Bolt	TRUE	TRUE
Intermediate:	**in.**		**Bolt Lengths:**	**in.**	
Total Front Width	1		Nut Length	0.6	
Total Rear Width	1.5		Bias	3.5375	
Bias Bar Usable Width	1.6875		Front	3.7	
Front Bolt Usable Width	1.81		Back	3.4	
Back Bolt Usable Width	2.11				

Figure 18: The calculator I built to calculate the length of the bias spacers.

There are six total bias spacers in the master cylinder assembly: two on each mounting bolt and two on the bias bolt. Last year, I was frustrated with the lack of control of the bias spacer, so I built a calculator to give the exact required length of each bias spacer.

1.6 Finite Element Analysis

I analyzed the master housing on its own and the piston and pushrod together.

1.6.1 Housing

The load cas on the housing is essentially a 2000psi maximum pressure applied on all of the bore of the master cylinder that will see fluid pressure. It is constrained by compression only supports on the bolt holes and tabs.

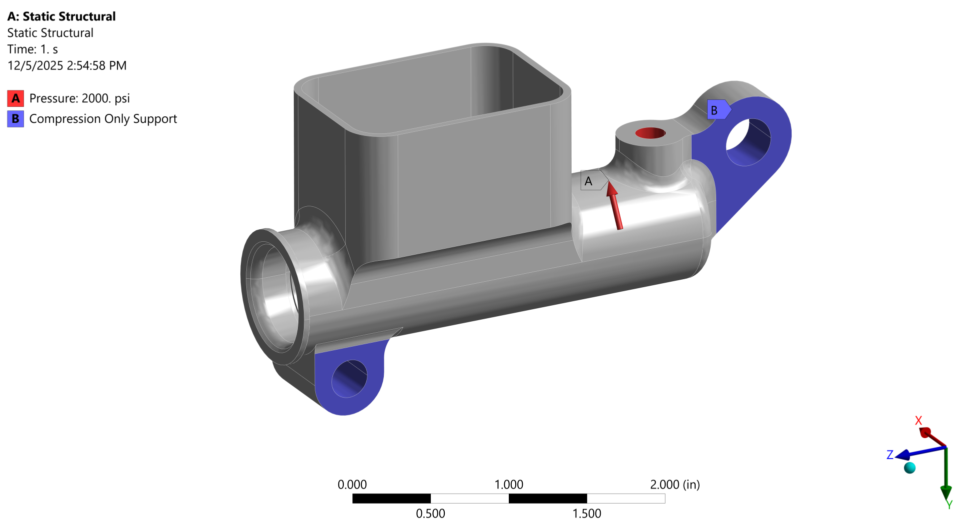

Figure 19: Housing Setup

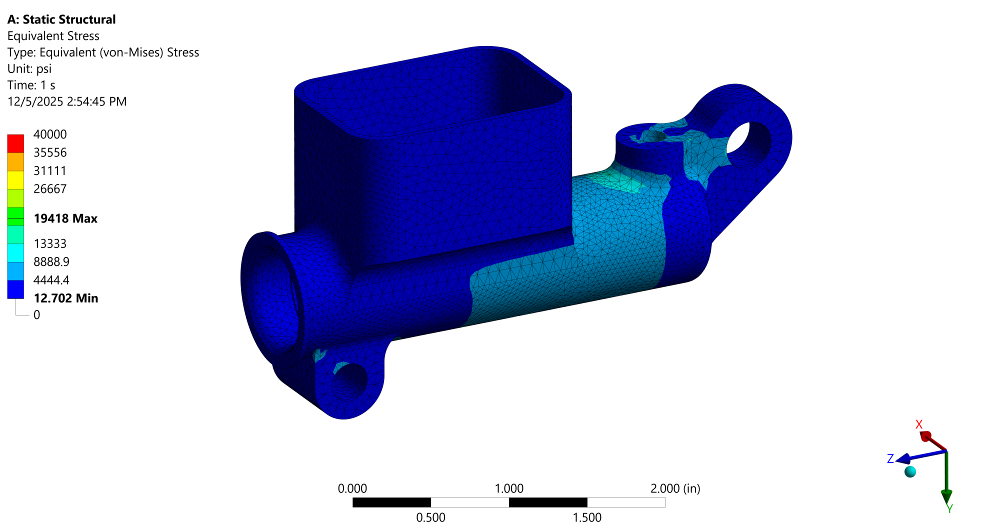

Figure 20: Housing Von-Mises Stress.
FOS = 2.06

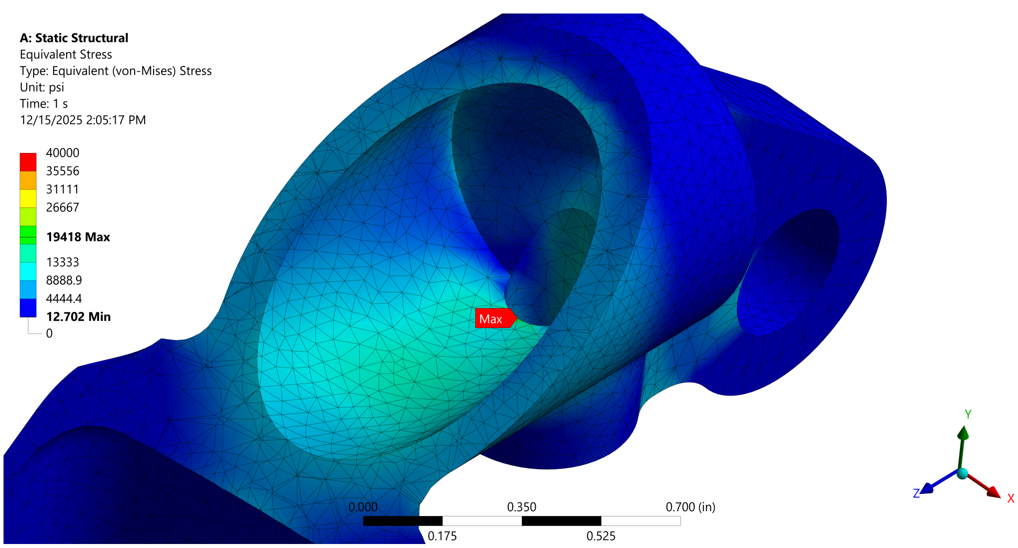

Figure 21: Location of max stress in housing.

The maximum stress is in the corner of the out port hole. I do worry a small amount that a crack could form here, but the max stress is still quite low.

1.6.2 Piston & Pushrod

I used a Frictional Contact and Contact Sizing to model the contact of the two parts as accurately as I could. I am quite happy with how the results turned out.

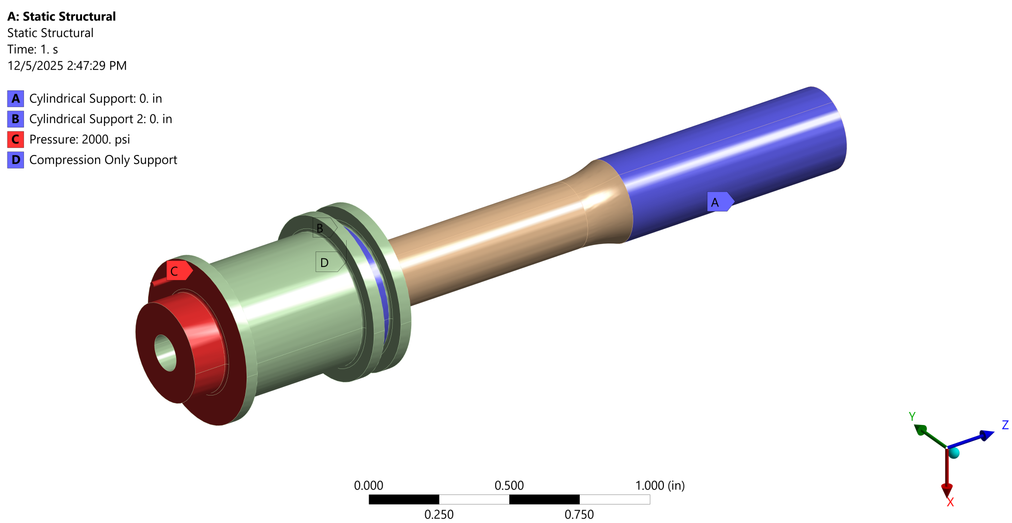

Figure 22: Piston & Pushrod Setup

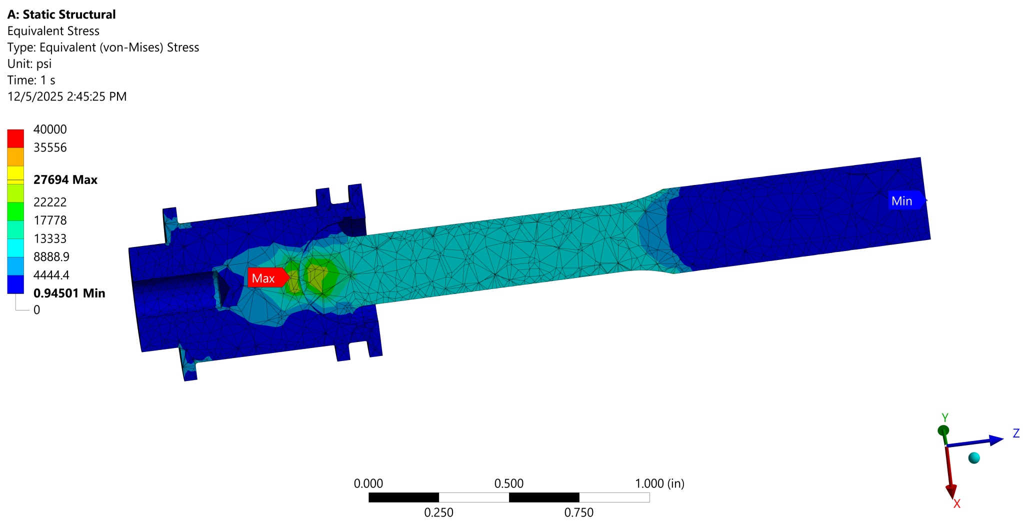

Figure 23: Piston & Pushrod Von-Mises Stress.
FOS = 1.44

1.7 Testing

I performed multiple tests to inform design decisions I made. The tests largely involved the old master cylinders.

1.7.1 Seal Break-Out Friction Force

The purpose of this testing was to determine the spring froce I would need to retract the pistons. For this testing, I attached only the McMaster u-cup seal on a TG21 piston. I then slowly it out of the housing, using a scale to record the max force required. I did ten tests with the seal facing the correct way and ten with it facing backwards to determine the break out force both in retraction and compression.

Figure 24: Testing Setup

The result of this test was that it takes (conservatively) 12 lbf. to retract the seal and 9 lbf. to compress it.

1.7.2 Reservoir Material Testing

I had initially planned to construct the reservoirs out of some sort of plastic. My options were basically to 3D print them at the RPL or to machine them out of acrylic or polycarbonate. This idea was scrapped eventually because it would have been way too tall. The reservoirs would have stuck up out of the hood and nobody wanted that. The integrated reservoir is also significantly less complex to make and has no risk of leaking.

I tried printing both a FDM ABS print and a SLC resin print for the test reservoirs. The resin print was successful in staying sealed while the ABS print leaked almost immediately.

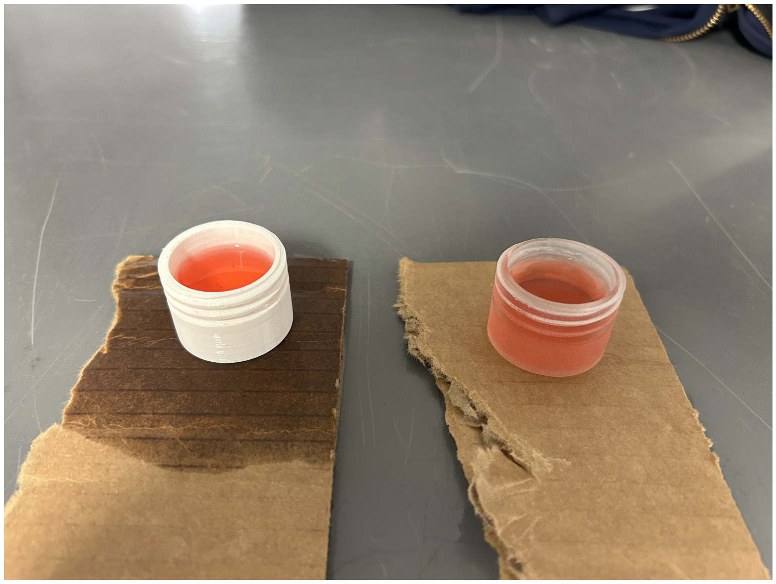

Figure 25: ABS and Resin 3D printed reservoirs filled with mineral oil. The ABS reservoir shows signs of leaking.

Part of me still wishes the reservoirs were plastic in some way. It is quite useful to be able to see through them. Despite that, it is impossible to justify when the integrated reservoir is much more robust.

1.7.3 Pressure Gauge

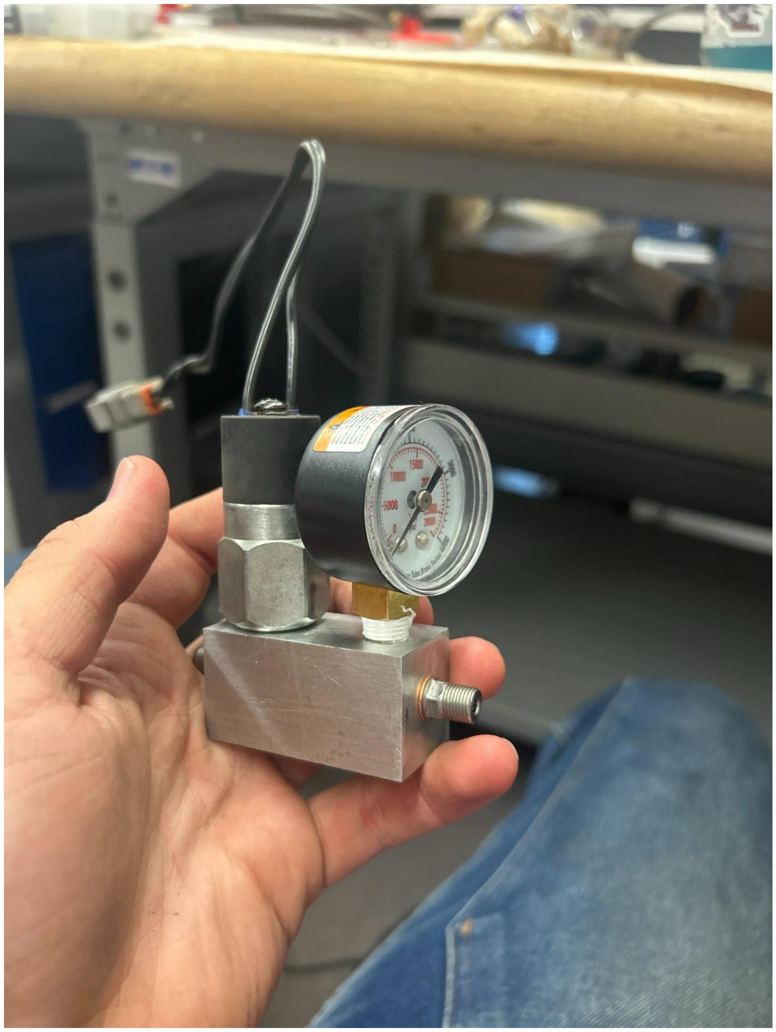

Figure 26: Custom T-block with pressure gauge.

Early in the semester, I created a custom T-block that had a pressure gauge installed in it. The purpose of the gauge was to determine the activation pressure of the brake light switches we have been using.

I didn't get any valuable numerical data from this test. What I did learn is that even what I had considered a good brake bleed was not so. The pressure in the brake lines was inconsistent and much lower than expected.

1.8 Testing I would do if I had a million hours

- **Brake Bias testing:** I would love to get out to the track and iterate from a 20% to a 80% rear bias. I am interested in driver feel (with multiple drivers), locking force, and the actual front/rear locking bias. I think this would be a huge step towards a real understanding of how to use brakes to make a fast car.

- **Pressure transducers:** I would like to see data with a pressure transducer in each brake circuit and a hall effect sensor on each rotor. This would tell us how the brakes are really being used and what our real locking pressures are.

- **Brake Test Rig:** Having a separate brake dyno and full system testing rig would allow for easier brake testing of all sorts. This would include some way of quantifying rotor performance, pressure response, and the real effects of a bias bar.

1.9 Manufacturing

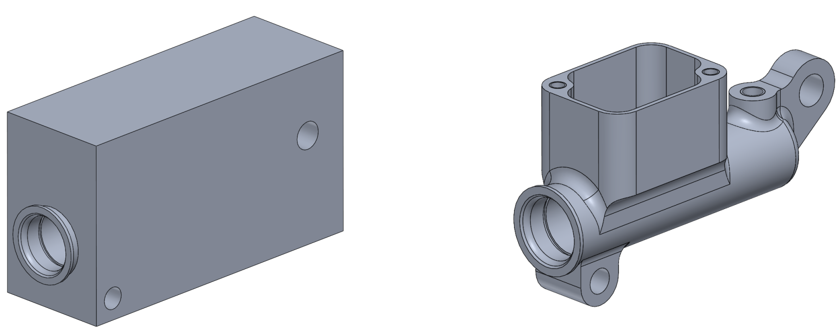

Figure 27: Master cylinder housing premachine and final shape.

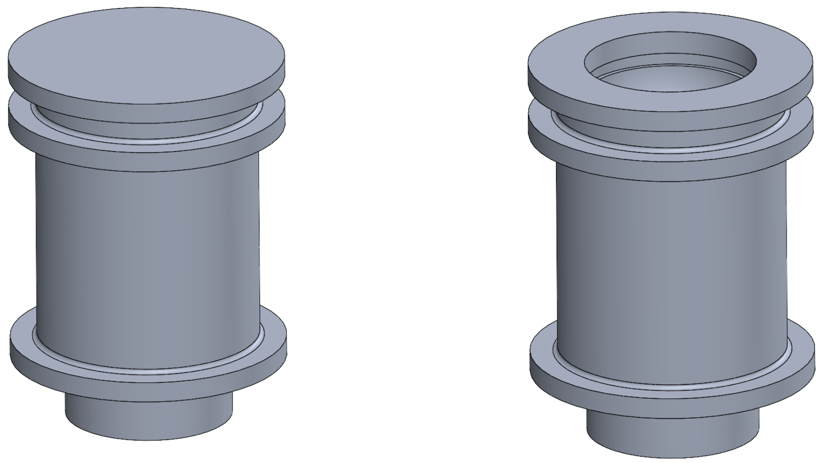

Figure 28: Piston housing premachine and final shape.

Both the housing and piston have premachine configurations. For the housing, the only features finished in the premachine are the bore, piston retaining ring groove, mounting holes, and boot flange. For the piston the only features not finished in the premachine are the pushrod pocket and retaining ring groove.

The master cylinders will be made out of 7075 aluminum, although all of their analysis and design was based around the weaker 6061-T6 aluminum. Both the housing and piston will be anodized for improved surface hardness.

1.10 Current Status

The master cylinder and piston premacines are being completed and hardware is being ordered.

Small Tasks Still Remaining

- Model boot for the front of the cylinder.
- Machine pistons for Allegheny-York seal.
- Finalize frame tube mounting and tab situation.

1.11 Future Improvements

Future improvements will be determined by the function of the master cylinders. The performance of this new design is so unknown that I can't come up with any improvements without knowing its issues first.

2 Pedals

This part of the report is going to be much shorter as the pedals still need a decent amount of work to be complete. Please read my Spring 2026 tech report for a more complete idea of the pedals.

2.1 Abstract

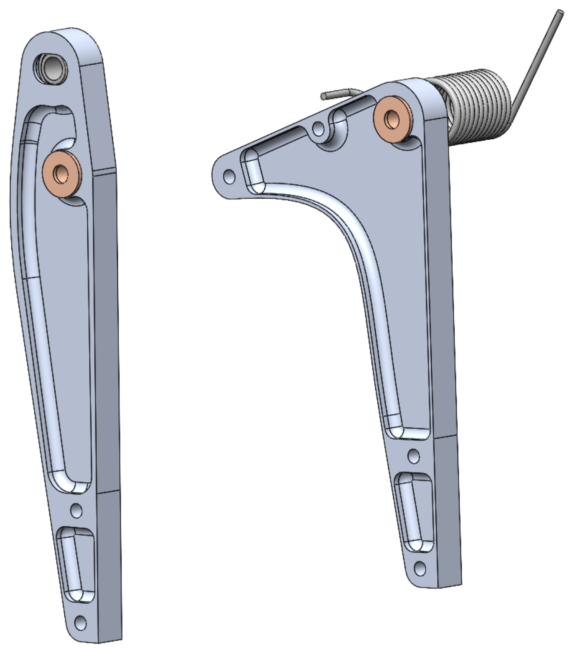

Figure 29: TG22's Brake and Throttle Pedals.

The purpose of the pedals is to actuate the brakes and throttle systems based on driver foot input. The brake pedal largely converts foot force in to brake force out, while the throttle pedal is more focused on foot travel in to throttle travel out.

2.2 Design Requirements

The pedals are majorly constrained by everything around them. The only real flexibility in the pedals is how they look.

Constraints (from rules):

- Brake pedal must be able to fully actuate both master cylinders and withstand 450 lbf.
- Throttle pedal must be structurally sound and able to actuate the throttle from 0% to 100% throttle.
- Throttle pedal must have an adjustable hard stop to prevent it from overextending the throttle mechanism on the engine.

Objectives:

- Brake and throttle pedal must have a sensible and comfortable range of motion.
- Pedals must be able to withstand normal driver input force.
- Pedals should look pretty.

2.3 Initial Research

2.3.1 Last Year's Car

Silas Wilson designed the pedals last year. He did a really nice job of it.

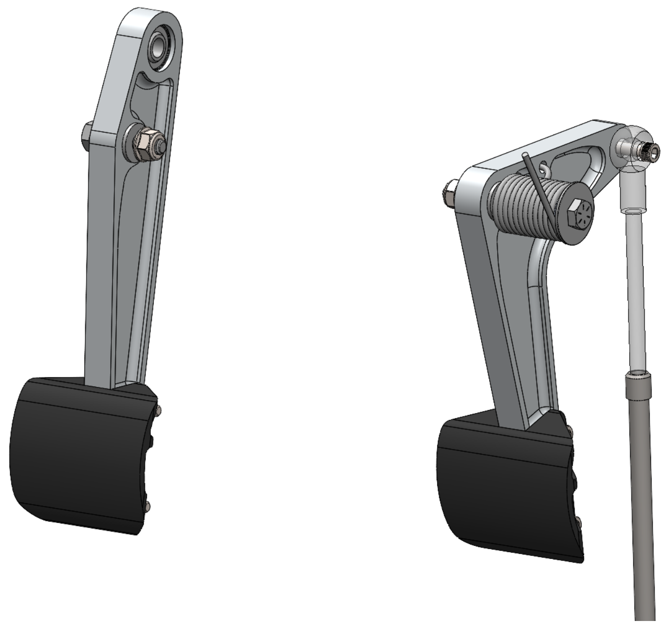

Figure 30: TG21's full pedal assembly

Both pedals have a very simple tapered I-beam design. They are supported by 1/4-20 bolts with bronze sleeve and thrust bushings. The throttle pedal has a torsion spring to help return the throttle to zero.

2.4 High Level Description

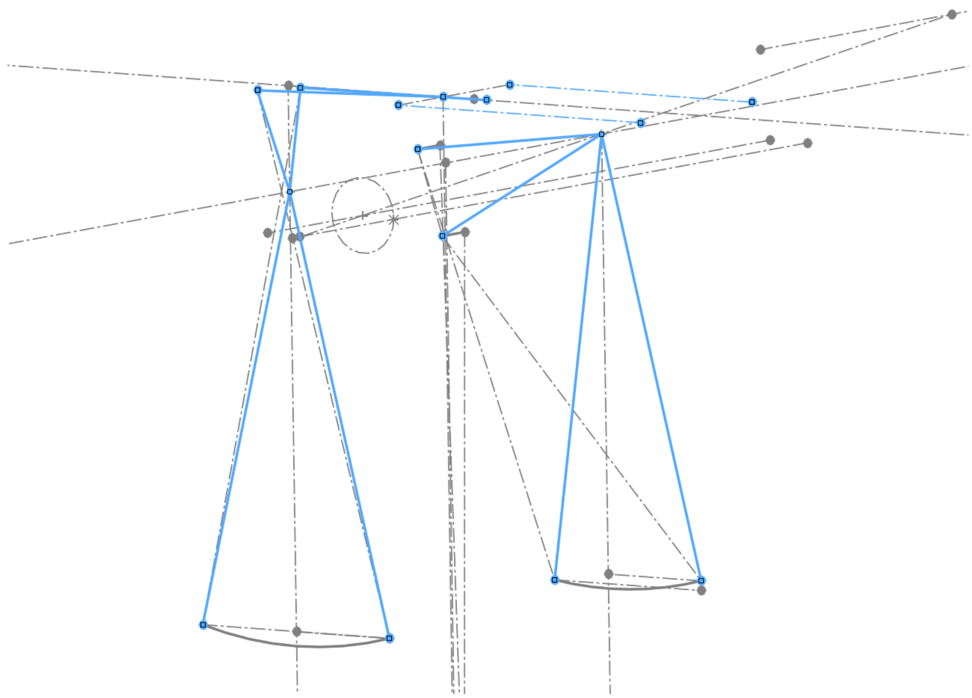

Figure 31: TG22 pedal geometry 3D sketch.
Highlighted: Pedals in 0 and 100% travel, master cylinder location

The final shape of the pedals has not been fully finished, but the geometry and performance changes are final. The overall length of the pedals as increased by 1/4". For the brake pedal, the mechanical advantage has increased from 3.67 to 4.29, a 17% increase. This corresponds to a 14% decrease in force required to lock the brakes (at optimal bias).

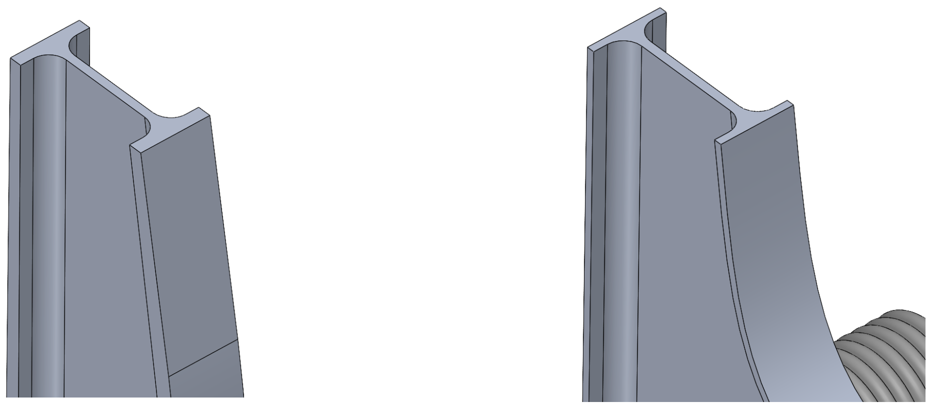

Figure 32: Brake pedal (left) and throttle pedal (right) cross sections

The style of the pedals has remained essentially unchanged. They are still 1/2" thick with a simple I-beam design. The thickness of the web has been essentially halved, from 0.125" to 0.06". This thickness roughly matches the web thickness in the subframes, so it is very machinable.

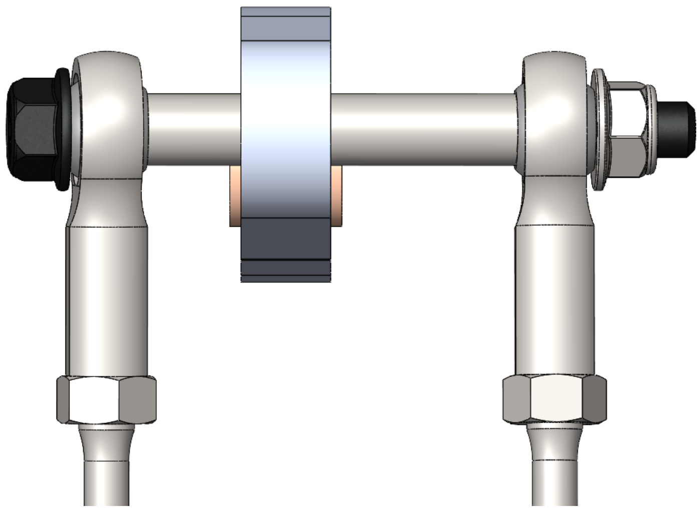

Figure 33: Brake bias bar and pushrods (from above).

The bias bar is designed in the exact same way as TG21's. The bar itself is a grade 8 5/16-18 bolt with spacers on it to maintain the bias ratio. The purpose of the bias bar is to send more force to one master cylinder or another. For TG22, we want to send more force to the master cylinder that controls the rear brake circuit because there is only a single rear caliper, compared to the dual front calipers.

2.5 Finite Element Analysis

Each pedal sees two different load cases that are each analyzed in two different ways. They see a head-on force and a 1/2" offset remote force. Each of those load cases is then put into an eigenvalue buckling study to ensure that the pedals are geometrically stable.

For all non-rules dictated load cases, I used 250 lbf. as my max pedal force. Last year, it was measured that Horatio is capable of applying 183 lbf. on a pedal. The 250 lbf. is therefore a conservative value, especially for the offset force cases.

2.5.1 Brake Pedal

For the brake pedal, the rules specify that it must be able to withstand 450 lbf at the pedal face. I used this value for the head-on load case.

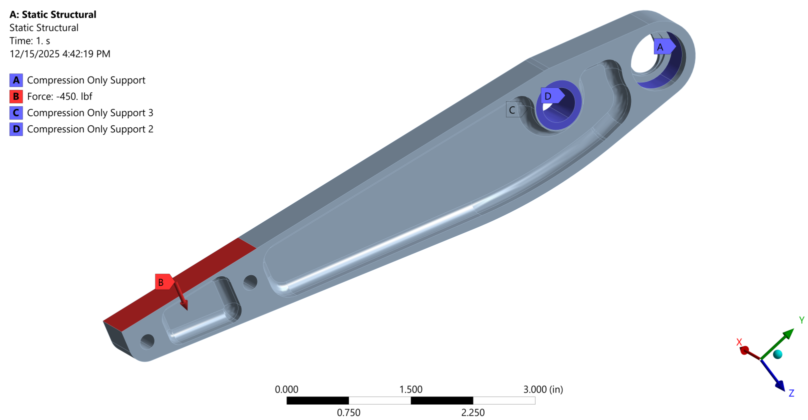

Figure 34: Brake pedal head-on (450 lbf.) setup.

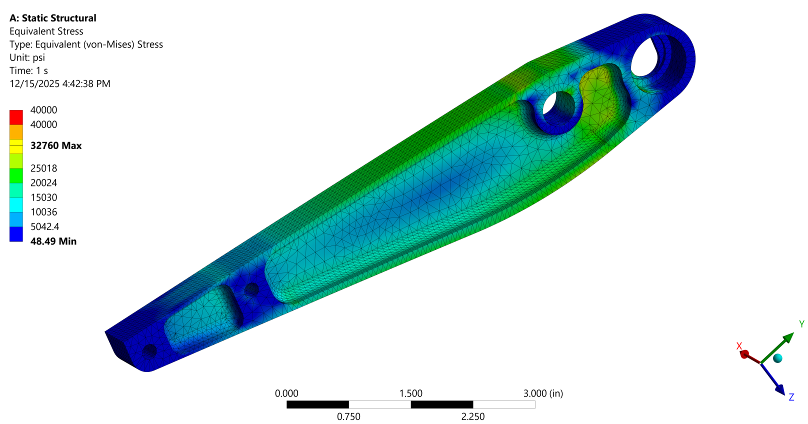

Figure 35: Brake pedal head-on Von-Mises Stress.
FOS = 1.22

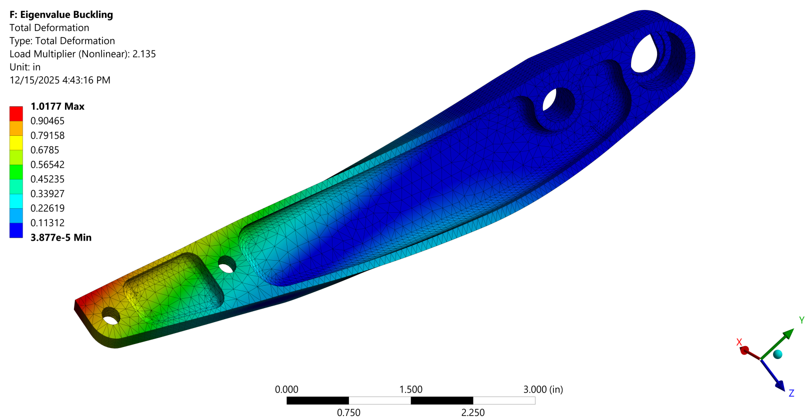

Figure 36: Brake pedal head-on eigenvalue buckling.
FOS = 2.14

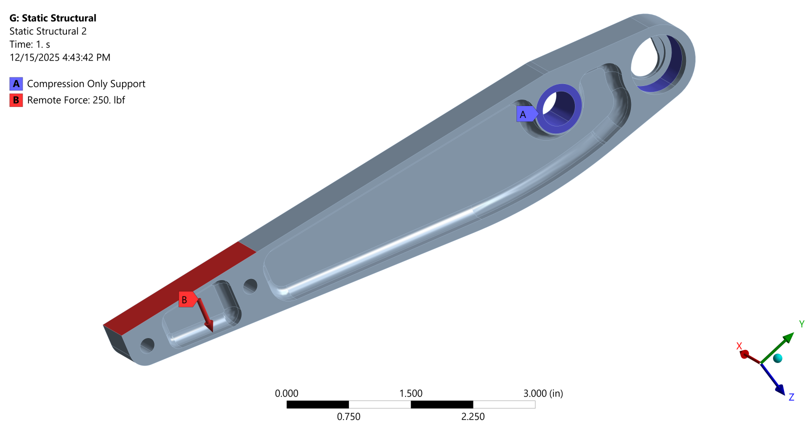

Figure 37: Brake pedal 1/2" offset (250 lbf.) setup.

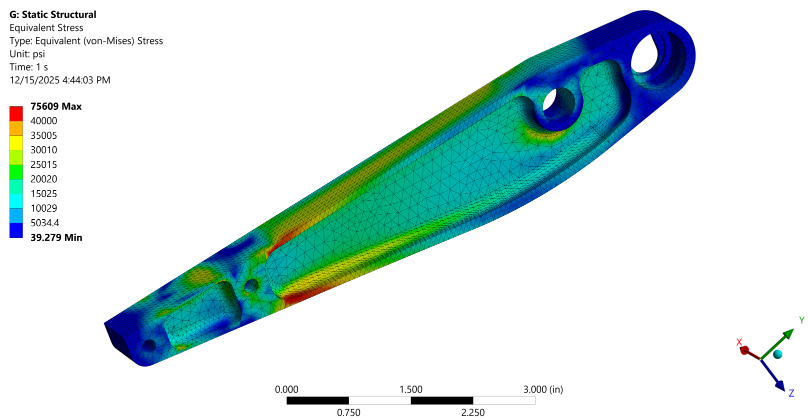

Figure 38: Brake pedal 1/2” offset Von-Mises Stress.
FOS = 0.53

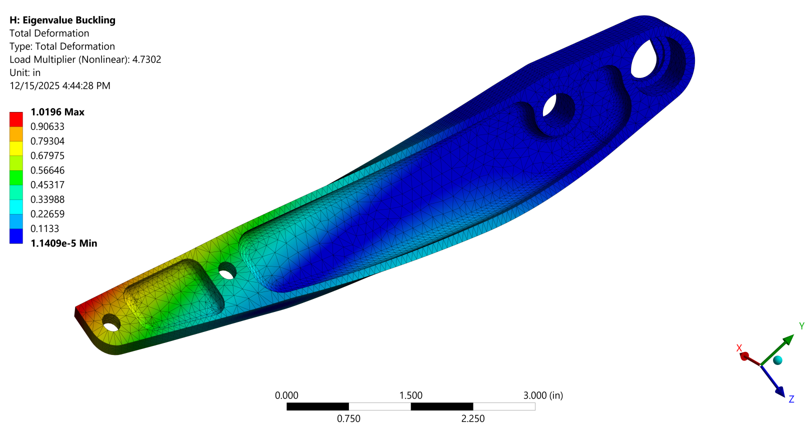

Figure 39: Brake pedal 1/2” offset eigenvalue buckling.
FOS = 4.73

As you can see, the pedal currently miserably fails the offset force load case. It will need material to be added to the weakest points (flange near the bottom end of the pedal). I am also slightly skeptical of the 4.73 buckling FOS in the offset case. I would have expected a much lower value. Because eigenvalue buckling is inherently non-conservative, the 2.14 buckling FOS of the head-on case could be worrying, but when you consider that that corresponds to 961 lbf. applied to the pedal, the FOS for the real max force (250 lbf.) is around 3.84.

2.5.2 Throttle Pedal

The biggest difference with the throttle pedal's analysis is the use of a zero-displacement support to model the pedal stop. The push-pull cable for the throttle only applies a very small amount of force, so the maximum load is seen at the pedal stop.

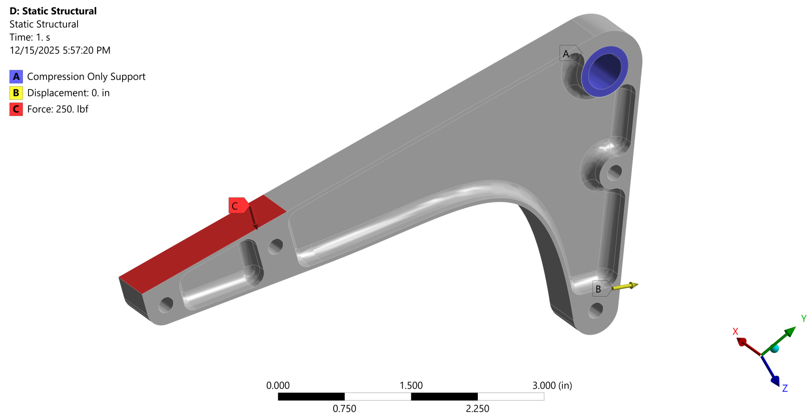

Figure 40: Throttle pedal head-on (250 lbf.) setup.

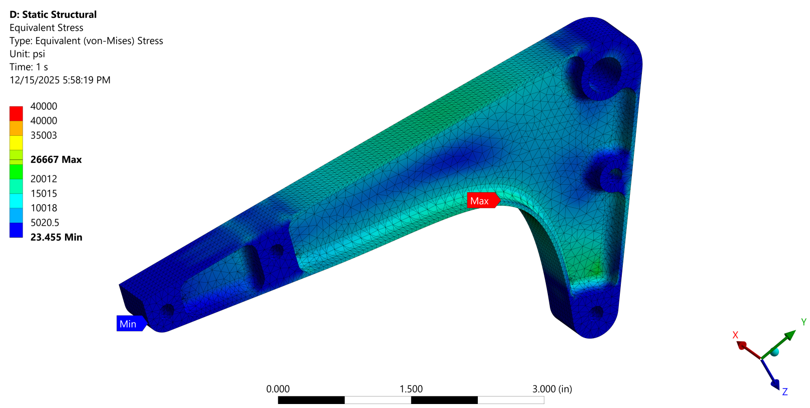

Figure 41: Throttle pedal head-on Von-Mises Stress.
FOS = 1.5

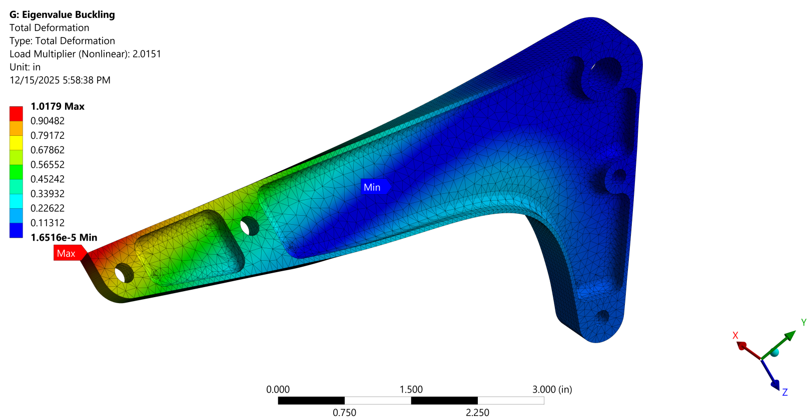

Figure 42: Throttle pedal head-on eigenvalue buckling.
FOS = 2.02

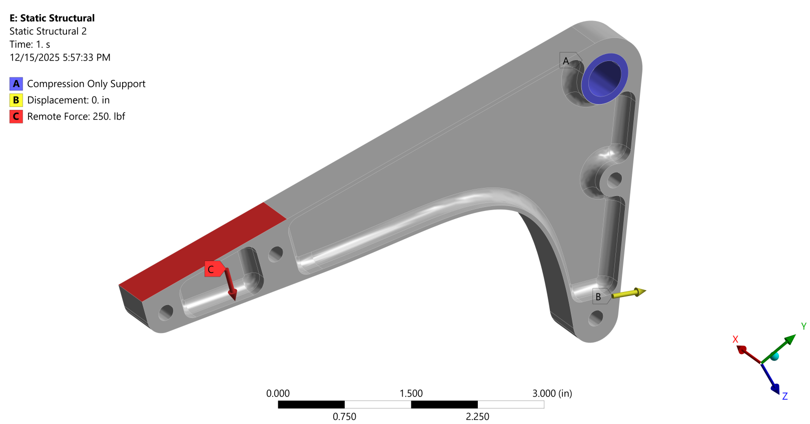

Figure 43: Throttle pedal 1/2” offset (250 lbf.) setup.

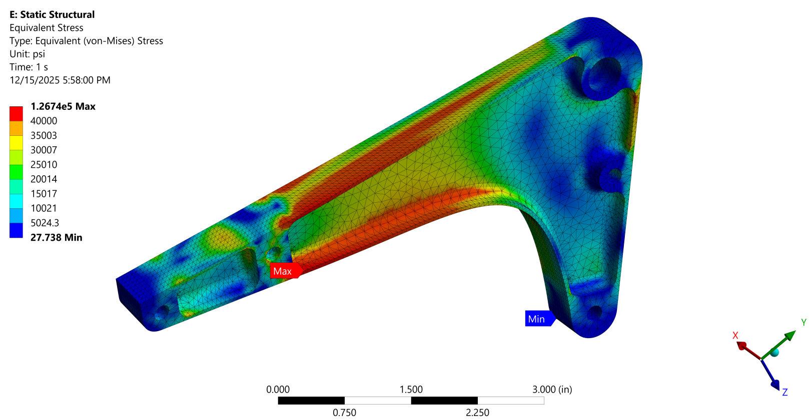

Figure 44: Throttle pedal 1/2" offset Von-Mises Stress.
FOS = 0.32

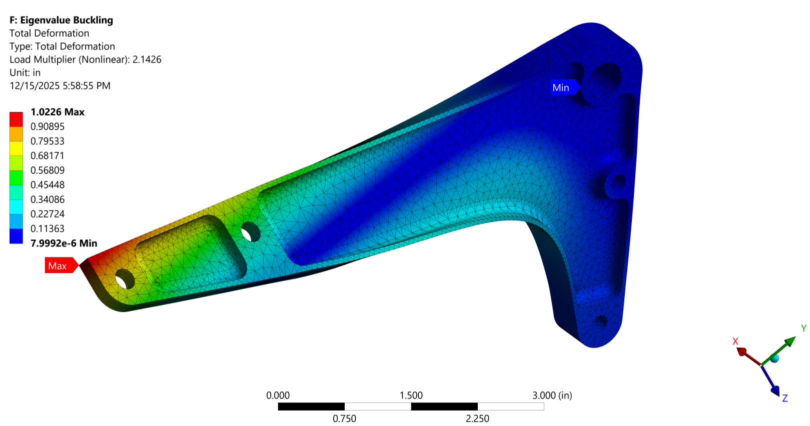

Figure 45: Throttle pedal 1/2" offset eigenvalue buckling.
FOS = 2.14

The throttle pedal is in a similar state to the brake pedal. The offset force load case does come close to passing. The throttle pedal will definitely require more material to be added. For this reason, I am not concerned about the 2 FOS on each buckling case. That number will naturally increase when more stiffness is added to the pedals.

I would like to revisit the offset load case and verify its accuracy. I believe there is a slight discrepancy between the way that a remote force is applied and the way that the pedal is actually loaded.

2.6 Manufacturing

The pedals only consist of three unique manufactured parts. The two pedal bodies will be machined in two ops on the Tormach. They will have a shared fixture plate, just like last year. The pedal faces will be 3D printed by the RPL.

2.7 Current Status

The pedals are currently fully designed but require some material to be added so that they pass the newer load cases. Stock is in so as soon as that happens they can be manufactured.
Additionally, the push pull cable and pedal faces need to be added to my design. They will be very similar to the design that Silas made last year.

2.8 Future Improvements

Looking back at old pedals, I am a little curious to see if a shape different from just a simple I-beam would be more structurally efficient. I didn't have the time to investigate this, especially because the pedals were basically a side project, but I would be very interested in that. Also, I wanted to implement generative design into the pedal creation process. The pedals are one of few parts on the car that have almost perfectly clear load cases. Their working conditions are, for the most part, entirely known, which would make generative/computer optimized design possible.

3 Personal Reflection

I think I bit of a little more than I could chew this semester. I thought that a lighter course load would allow me to take on a relatively heavy Baja workload. Unfortunately, especially because this was my first semester as a TA, this was just not super true. I am incredibly happy with how my design has come out, but I do wish that I had more time to do testing. More real-world validation would have made me a LOT more comfortable with the design.

When the master cylinders started to be manufactured, I suddenly became very stressed. I had a day where all I wanted to do was cry and curl up into a ball because I was so nervous about the design. I just felt like there were a few too many last minute changes that I hadn't given myself time to mull over. Luckily it got better after a couple of days and I am more comfortable now. It really helped me to take a day off from Baja and school to just do my laundry, work out, and play Minecraft.

Massive shoutout to Akshay for helping me get through that stress. ALSO of course thank you very much to everyone who trusted me to make these master cylinders in a completely new way. Seeing my initial vision coming to life has been incredible. Lastly, if you read this far, thank you for taking the time to hear out my silly ideas. Brakes subteam for life.

A Appendix

A.1 References & Links

- All of the brave previous master cylinder designers' tech reports
- Parker O-Ring Handbook
- Installation Torque Tables for Noncritical Applications - NASA
- Allegheny York EZ Seal Selector
- My Hand Calcs