Joaquin Jerez Tech Report

BAJA RACING

CORNELL

Brakes Subteam

Abstract

This year I did not work on a specific part, instead I helped provide input across a variety of different aspects within the brakes system. I joined Baja freshman fall, and have been on the brakes team for 7 semesters, which allowed me to contribute to design decisions using knowledge that I’ve gained during my time on the team. I realize that this can be very beneficial, and there is no condensed log of everything we have done in the past years and what we’ve learned. This is incredibly important for a team that cycles through a quarter of its’ members every year.

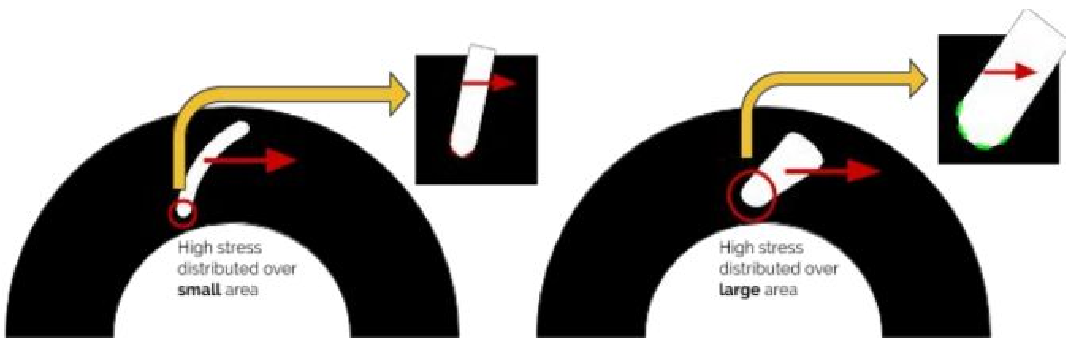
For this reason, I thought it would be beneficial to use this tech report as a quick summary of some of the design choices we’ve made in the past years, their benefits, their drawbacks, and what we learned. Ideally, new brake team members can come to this report and save time making mistakes that we’ve done in the last years, without having to read through multiple tech reports.

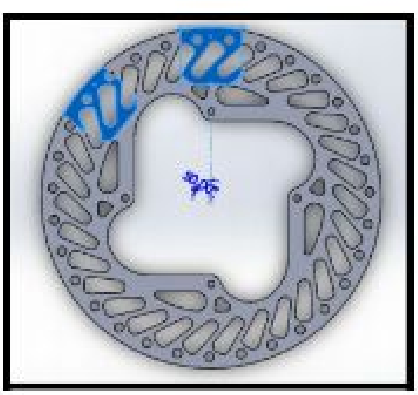
Introduction

First I'll start off with the things that I personally worked on and can provide most insight. Over the years I've worked on the brake rotors, the cutting brakes, the differential unlocker (diff unlocker), and the pedal bay.

Brake Rotors

I have always been pretty involved in the brake rotors as it can be catastrophic if they fail. A broken rotor will not only destroy the hub/rims/ and calipers on the car, but it could also potentially pierce the brake lines causing the driver to lose the ability to brake. The only time that we had a really bad issue with the rotors, is when we first introduced cutting brakes to the car. Cutting brakes allow you to brake on only one wheel, allowing for short hairpin turns. The problem is that the one rotor now has a much greater force. This wasn't accounted for in 2014 (this happened the year before I joined the team). Although we've stopped using cutting brakes, this lesson was valuable this year when designing the rear rotor for out inboard brakes. We had to design a much stronger rear rotor.

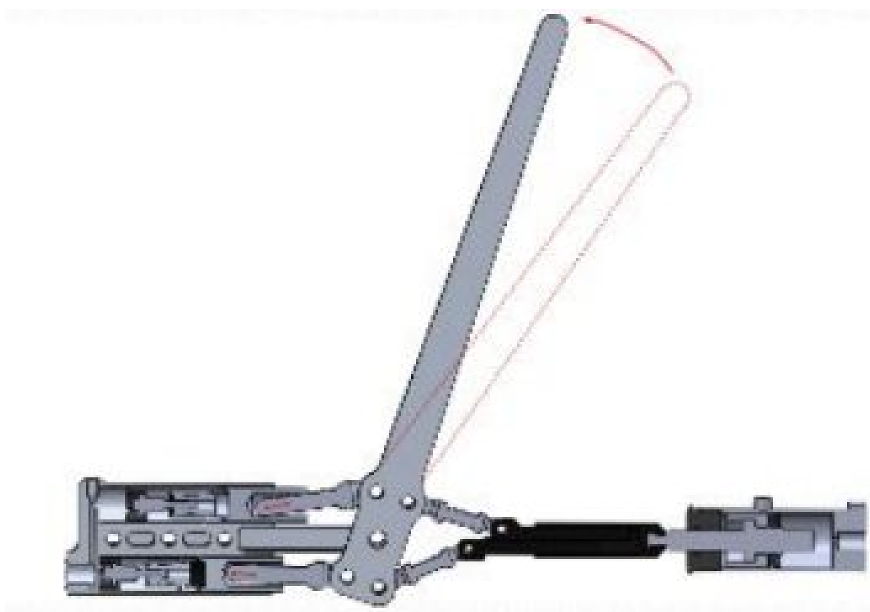


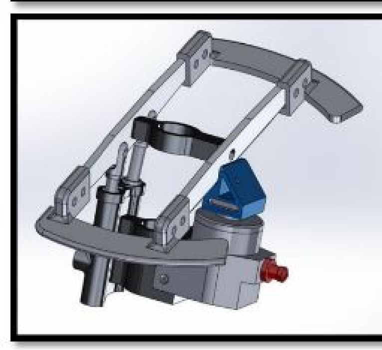


Using ANSYS you can ensure that the rotors won't yield. The figure above shows what I learned when designing the cutout pattern. I noticed that the design on the left (resembles rotors from previous years) had a much higher stress concentrated in the red circle. I looked to mountain bike rotors, which most resemble our rotors, for design inspiration and noticed that a bigger hole actually made the rotor less likely to yield. It's also **very important to consider how the rotor will deform**. If it deforms you want it to contract rather than expand and ruin the calipers. The rotor in the figure is spinning counter clockwise, and the holes are designed to shrink the rotor when yielding.

Cutting Brakes and diff unlocker

As mentioned previously, cutting brakes allow you to brake on only one wheel, allowing for short hairpin turns. This is done by actuating a lever in either direction. The first part of the stroke isolates a single rear brake line, the second part pushes fluid into the isolated brake line, thus locking the wheel. We used them in competition, and they proved to be successful, but ultimately they were not reliable enough to continue using them, and drastically complicated the system. It did win us the design competition every year. These were crucial to our victories in dynamic events, giving us a huge edge compared to other cars which are sometimes forced to have a reverse because they cannot make the tight turns. Ultimately, we replaced this with limiting straps, straps that limit the shock travel, giving us a lower center a gravity and a much tighter turning radius at a much cheaper cost. The problem with limiting straps is that we don't use them during endurance as they only provide benefit in dynamic events.



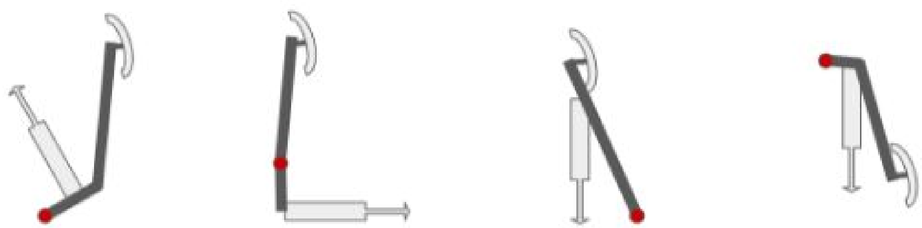


The cutting brakes have gone through multiple iterations going from a lever, to hand paddles, and back to a lever, to not having them at all. Our special design was the hand paddle actuated cutting brakes, but these were never built as we ran out of time before we could prove that they would indeed work.This model can and should be revisited in the future because if successful, it can be very exciting for design, dynamic events, and endurance.

The diff unlocker (to the right in the image with the lever and the blue one in the paddle image) sends fluid to the differential and unlocks it before any braking power is applied to the wheel, to prevent the driveshaft from braking. This is a relatively simple system, but the difficult part was figuring out how to get it to actuate regardless of how the lever was actuated. We tried a cam system and a linkage system, both shown in the images on this page. The cam system wasn't reliable because it could slip out, it also provided a strong moment on the piston which we were worried was going to yield over time. I ended up machining a steel piston to prevent this. The linkage system didn't work well either because it kept binding.

Pedal Bay

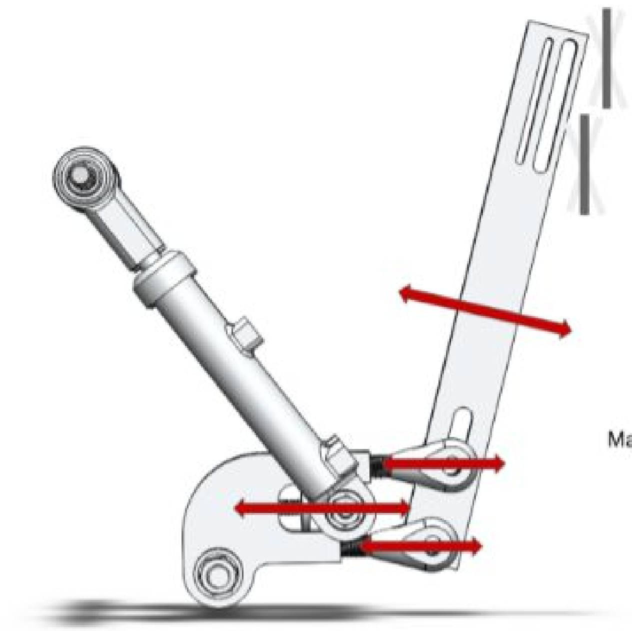
I have really high hopes for this years pedal bay. The pedal bay has always been an issue because there are so many factors at play that it is very hard to optimize. The pedal bay needs to be comfortable for the driver, provide enough mechanical advantage to lock the car even if the system isn't perfectly bled, have enough travel that you can provide a variable brake force, and also must fit within a tiny space in the front of the car. The geometry of the pedal can be optimized using simple statics and matlab, but the mounting points and orientation of the masters relative to the pedal must be chosen first. Here are a couple options that we've considered in the past and are doing now:

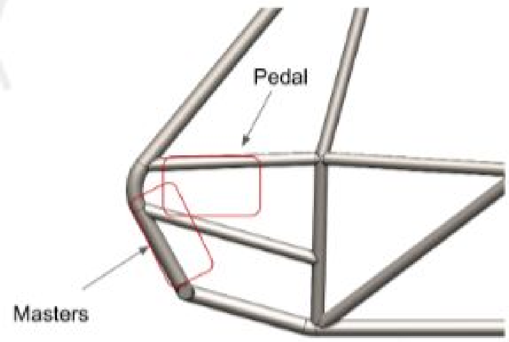


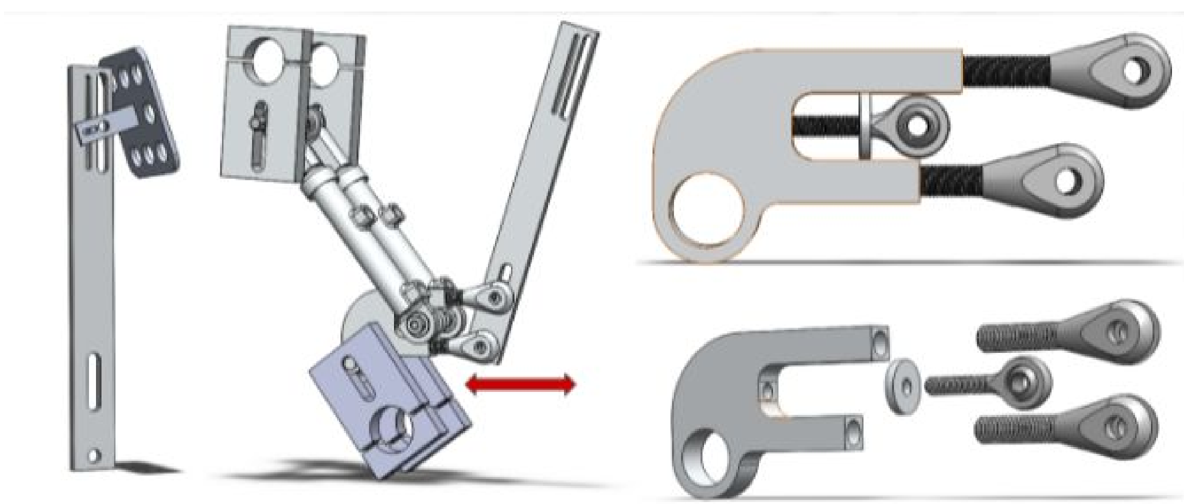
Option 1		Option 2		Option 3		Option 4	
Pros	Cons	Pros	Cons	Pros	Cons	Pros	Cons
+Pedal Placement		+Pedal Placement		+Pedal Placement			+Pedal Placement
+Max MA		+Max MA		+Max MA		+Max MA	
+Adjustability		+Adjustability		+Adjustability		+Adjustability	
+Stroke Optimization		+Stroke Optimization			+Stroke Optimization	+Stroke Optimization	
+Integration			-Integration	+Integration		+Integration	

Above is a table listing the pros and cons of each. Ultimately option 2 is better than option 1 although the table says otherwise. We were able to solve the integration issue this year by moving the steering rack up, leaving room underneath for the masters. The reason why option 2 is so good is because it allows for very easy adjustability. Machining also becomes easier, especially when iterating through pedal stems (which usually happens in order to find a comfortable position for the driver).

Finally, we are using an adjustable pedal bay in order to determine the best placement for the pedal, stem, and masters. This is very helpful during the testing phase, using the actual drivers to determine if the comfort, mechanical advantage, and positioning are all in tune. Below is a few renderings of my adjustable pedal for M14.



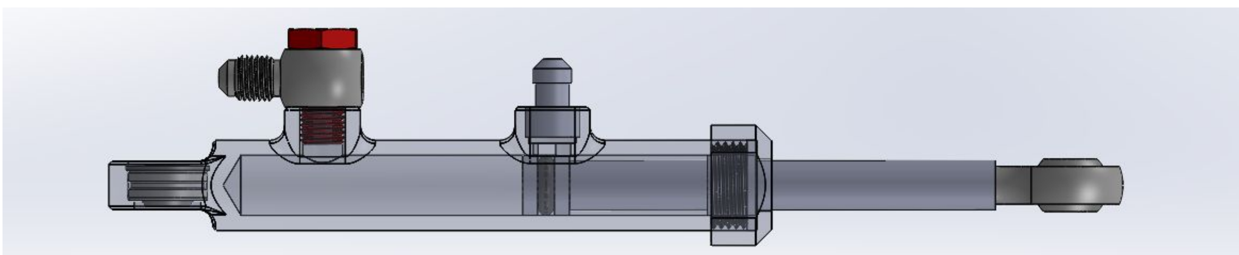




Most of these parts can be either 3D printed or bought off McMaster. The only piece that requires machining is the pedal stem (to prevent lateral movement if the stem were 3D printed).

Master Cylinders

The master cylinders have undergone a huge change in the last year and many people don't actually know or understand why this change was made. As of M14, the masters ave essentially doubled in size, due to a much larger piston. The new piston is extended to be the same length as a full stroke, which is crucial to prevent our seals from rupturing from sudden pressure changes. In previous models, we've had issues with our bleed and our seals never lasted longer than a couple of days. Once the seals deformed, the fluid bled/got contaminated with dirt. By extending the piston for the full length of the stroke, there is no longer a big pressure change near the seals. We were able to remove the seal at the cap of the master, allowing outside air to easily come into the back end of the piston, without contaminating the fluid. An image of the longer piston is shown below:



One last thing to note about the master cylinders, the seal used at the piston used to a be a U-cup. A U-cup seal is a unidirectional seal that seals in only one direction. It's benefit is that isn't as stiff providing less resistive force. We realized this year that by being unidirectional, the seal does not help with retraction. We had some retraction issues towards the end of last year and we believe this was the cause.

Calipers

When there are calipers there are two options, there are fixed calipers and there are floating calipers. Each have their benefits and their drawbacks. One important thing to note is that with floating calipers you want to use fixed rotors, and for fixed calipers you want to use floating rotors. Floating rotors are rotors that allow for some movement along the axis, to account for misalignment.

Fixed Calipers

We used fixed calipers from 2005, when Baja first arrived to cornell, until 2017. They worked, but had lots of issues with retraction and often would deform our rotors after about a month of driving. The retraction issues were due to a couple of factors, firstly, we didn't have proper seals, so we had a lot of fluid contamination. Secondly, a fixed calliper has a lot of channels and our machining practices aren't perfect. Any error can cause leaking/contamination and ultimately retraction issues. We also used fixed rotors, so any misalignment between the calipers and the rotor would deform the rotor which would in turn damage the calipers.

Floating Calipers

In the last two years we moved to floating calipers. Floating calipers push one piston until it reaches the rotor, then pulls back on the rest of the calliper frame until the other brake pad reaches the rotor. At this point you start applying a force equally on both sides of the rotor, braking the vehicle. A fixed rotor would be used here. We had much better retraction with this system, mainly because it was a much simpler design with less moving parts. We used less seals and less reservoir ports. We also now include a wave spring inside the piston to help improve retraction. It’s true that you have to push against the springs when braking, but the mechanical advantage of the pedal makes this spring force insignificant. This year we are considering using a fixed calliper in the rear inboard brake system, or even replacing the whole system with bike calipers which are smaller, cheaper, and more reliable than our custom calipers.

Conclusion

One of the aspects of Cornell Baja that makes us such a dominant team in the SAE competition is that we have been around for 14 years. There is a lot of trials and errors throughout the years, and in order to continue being dominant, we need to ensure that information gets carried on to new members. Baja alumni are hard to reach sometimes, especially for people who have never met them. I will continue serving my role on the team next semester as an advisor, but will also help a lot when it comes to machining. I am a Blue apron so I will be valuable when it comes to machining the brake pedal, calipers, master cylinders, and other non brake parts for the car. Hopefully this report will be useful for future members joining the brakes team, and will give them a headstart on whatever project they are working on.