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Baja Lab Report

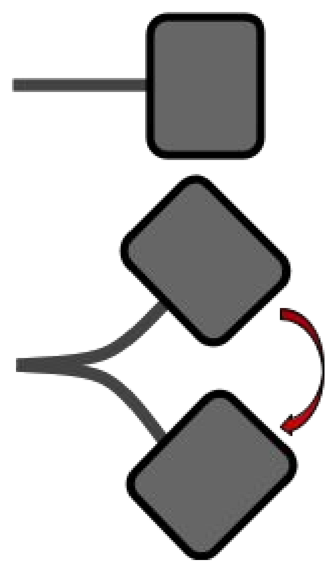
Introduction

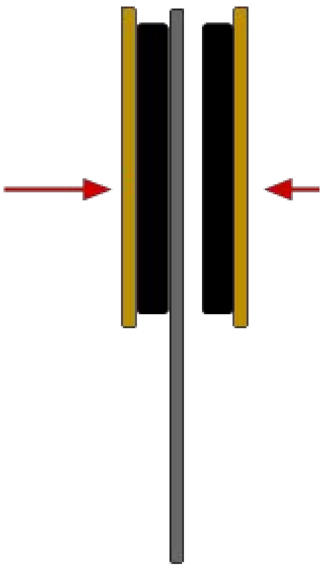
When I first entered Baja, I had a limited understanding of car manufacturing and general mechanical engineering. A friend of mine had initially shared his positive experience with his Baja team at Johns Hopkins University, so I decided to join Baja here at Cornell. My job on this team is to create the brake rotors for OD12. Given my little prior knowledge of the whole brake system, I set out to understand how exactly a hydraulic braking system worked on a 400 pound off-road vehicle. I looked at different rotors and analyzed how they would contribute to the car's braking system. I compared *simple solid rotors, vented rotors, and slotted rotors.* Looking back at previous year designs, I noticed these three were all slotted rotors, but I wanted to compare the different rotors to better understand why slotted rotors were the most optimal. Furthermore I explored the idea of using inboard brakes and floating rotors on our future cars. My objective for the brake rotors was to create a light brake rotor design that could withstand the hostile environment that the car will be driving in, while simultaneously creating a Brake rotor that is both responsive and reliable. The most crucial obstacle was to assure that the rear brake rotors are strong enough to withstand the extra force provided when the cutting brakes are applied. Lastly I focused on reducing weight, experimenting with different dimensions, and optimizing the rotor slots in order to reduce brake wear.

Initial Research

Inboard Brakes:

During the research process, I stumbled upon an inboard brake system. I find this concept interesting, as it reduces unsprung weight, one of my main concerns when thinking about how to design the rotors. By reducing the unsprung weight, you increase the dampening of the unsprung weight when an object is hit. This allows for more contact time between the wheel and the terrain, and better handling. Furthermore, it makes the braking system less vulnerable. The obvious obstacle is the complexity that comes with designing this system. It also requires an inboard system that will add more weight to the unsprung system. There are also complications in managing air flow, renewing brake pads, extra stresses on the axle, etc. I decided that this wasn't an easy task for me given the circumstances, but I do think it is something that we could come back to.

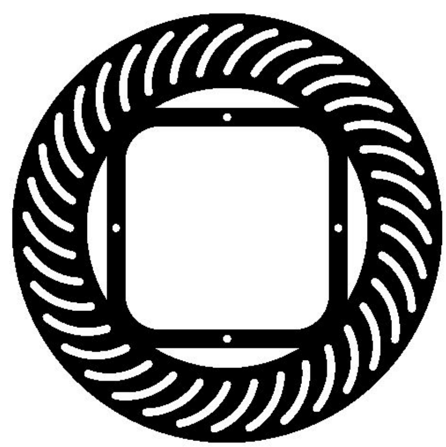




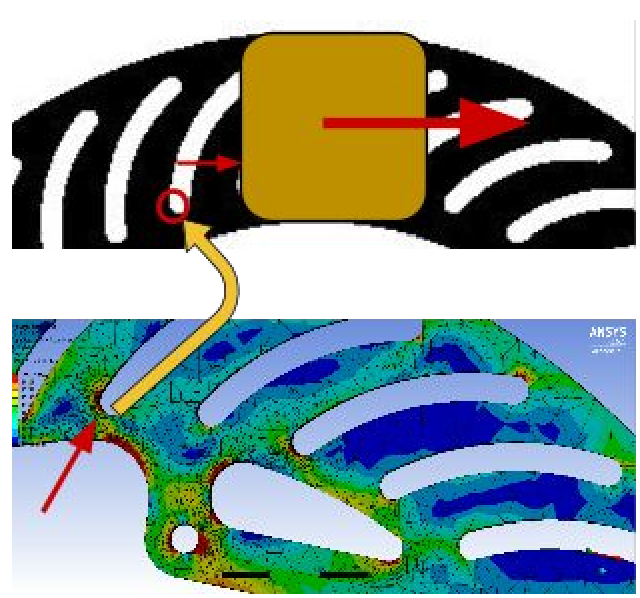
Floating Brake Rotors:

I also looked into the possibility of using floating brake rotors. This allows the outer ring to expand accordingly so that rotor would move until it's centered within the caliper. This would help eliminate the problem we had in previous years, where the rotors would bend due to the brake pads hitting the rotor at different times, shown on the diagram to the left. Ignoring the inevitable increase in weight, there are a few problems that encouraged me to sway away from this idea. Firstly, the bearings on our hubs have increased this year, allowing very little 'floating' room. Secondly, the floating calipers on our car now have already done a good job solving the problem. On this year's design, I opted for a thicker rotor without any consequences on the weight. The thicker rotor solved many problems which I will discuss later on.

Brake Rotor Geometry

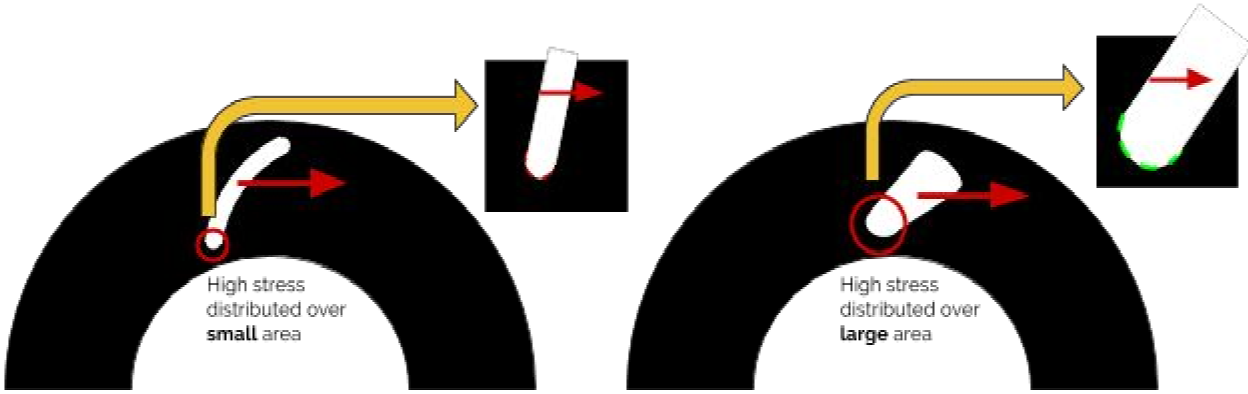


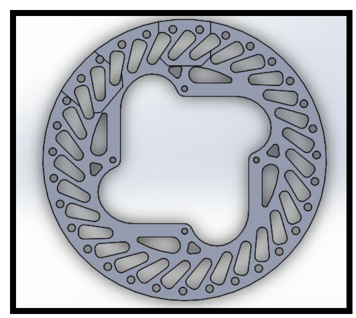
The initial brake rotor geometry was based off of last year's design. The slits are curved backwards in order to allow the dirt caught in the brake rotors to be pushed out by the brake pads. The wider hub bearings allow me to experiment with a new way to attach the rotors to the hub. I think that because the attachment points are closer to the outer ring, the triangular attachment from previous years would be unnecessary. After running this model through ANSYS I was able to confirm where the stress points were. There is an outward force applied by the hub attachment points that weakens the structure. Consequently I reverted to the original triangular design. A second issue is that the force provided by the brake pad onto the rotor slots provides a strain on the lower end of the slit, outlined in the images to the right. The other stress points in the attachment points are very hard to reduce without increasing the thickness of the rotor. This is one of the contributing factors to my decision.



New Slot design:

For inspiration, I studied the rotors on my mountain bike. By opening the base of the slit, and eliminating the curve, you reduce the stress. This is demonstrated by the diagram:





By getting rid of the curve and increasing the width of the slit, the brake pad no longer pulls on the slit at a large angle to the horizontal, and it is distributed more evenly. By flaring out the back end of the slit, the brake rotor can push out dirt and rocks that get stuck in the rotor with ease.

Adjusting the rear rotor to withstand force from cutting brakes

Last year the rear rotors failed under the extra force resulting from the cutting brakes. In order to account for this force, I calculated the force that would be provided on a rear wheel if the brakes were locked ($F_f = \mu_s N$). Below are the calculations:

$R = \text{radius of tire} \qquad r = \text{radius of rotor}$

$F_f = \text{frictional force on tire by ground}$

$F_c = \text{frictional force on rotor by caliper}$

$W_{car} = \text{weight of car} \qquad N = \text{normal force on tire}$

$F_f \times R = \mu_{ground} \times N_{ground}$

$F_f \times R = F_c \times r$

Assume: $\mu_{ground} \approx 1.2$

$F_f \times R = 1.2 \times 112.5$

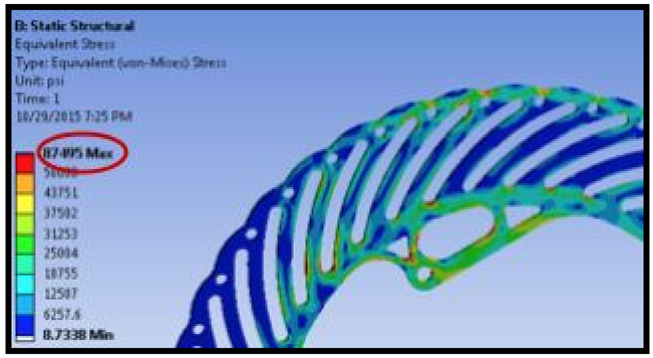
$F_c \times r = 1.2 \times 112.5$

$r = 3.7 in$

$F_c \times 3.7 = 1485$

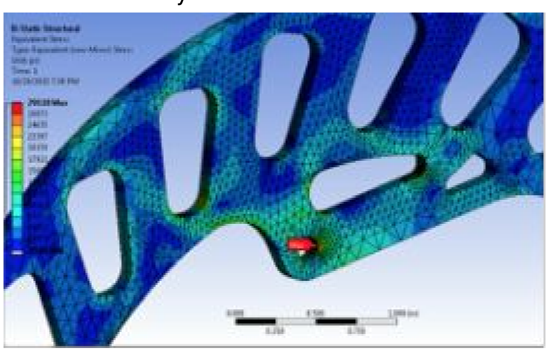
$F_c = 401 lb$

I ran this load case OD11's rotor that broke in ANSYS to see if it would break. The highest stress was 87,495 psi, which is 24,395psi over the 4130 steel yield strength (63,100psi).



This led me to believe that my load case was correct, but to ensure that the rotors are strong enough, I bumped up the load case to 525 in ANSYS. In designing the rotors, I aimed for a factor of safety of at least 2.

Below are my ANSYS results:

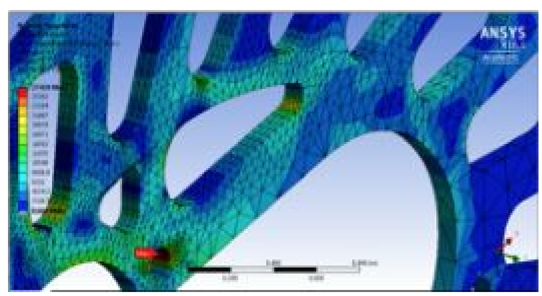


Factor of safety: 2.5

Front

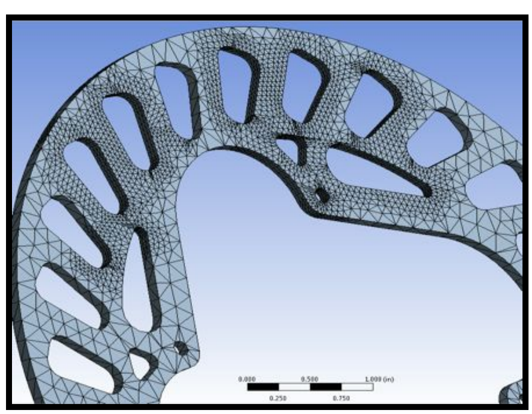
Rear

Factor of safety: 2.3



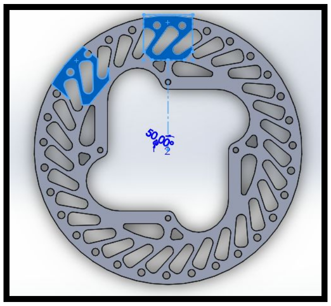
The load case for the front rotor was taken from last year's model. I applied three loads on each rotor:

Forces	**Magnitude**
Cylindrical support	Fixed
Frictionless support	Fixed
Brake force (Front)	525 lb



Brake force (Rear) *Increased from last year to account for cutting breaks*	525 lb

These load cases were fairly probable, but I wanted to be confident that they would perform under extreme conditions. The image to the right shows the mesh that I used.



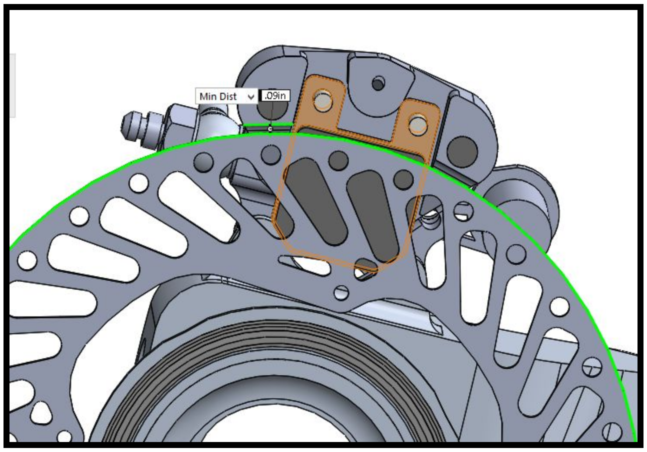
The image to the left shows where I chose to position the brake pads when testing my load cases. I placed split lines in SOLIDWORKS strategically to ensure that more than one location was tested. The images above show the location with the lowest factor of safety.

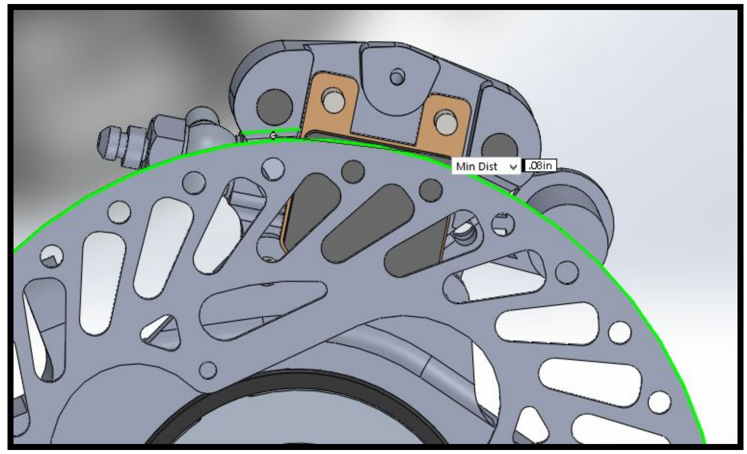
The max stress points on my rotors were located at the hub attachment points. The only way I could effectively reduce the stress was to increase the thickness of the rotor from 0.09 to 0.1. This increase ultimately solves three problems from previous years:

1. It reduces the stress put on the hub attachment points
2. It provides a more rigid structure which is less inclined to bend out of shape if the calipers don't clamp against the rotor at the same time.
3. It makes the rotor as a whole stronger

Concerns

One of our biggest concerns was being able to fit the rotors and the calipers inside the wheel rim. Last year there was some rubbing between the caliper and the rim, so providing enough clearance between all the unsprung components while still being able to fit everything within the rim was a big challenge. We had to see where we could increase clearance and where we couldn't between the different unsprung parts. My concern was creating enough clearance between the caliper and the rotor, while maintaining as much of the rotor against the brake pad as possible. In the end we were able to manage a 0.09 inch clearance on the front rotor and 0.08 inch clearance on the rear rotor. We felt comfortable that this would be enough room. Furthermore, we were able to ensure that that the brake rotor made full contact with the brake pad.





Front Rotor **Rear Rotor**

Conclusion and Skills Acquired

Ultimately my rotors were able to succeed in a few areas. In this model, the brakes are stronger. The rear rotor can withstand cutting brakes. Furthermore, the thicker rotors reduce deflection. In my opinion creating the rotors is an exciting and challenging introduction to the Baja team and on an even larger scale, mechanical engineering. This kind of assignment challenged me to think about several different pertinent concepts and parts within the Baja car's development. It also made me think about finding creative ways to improve small inefficiencies within the current brake system.

I also became more familiar with learning how to use programs such as SOLIDWORKS, ANSYS, and AUTOCAD. Beyond that, however, I learned and integrated myself further into the dynamics of Baja team. I explored the other parts of the car system and worked with the rest of the team to work in a collaborative environment. Working with my team has helped me improve my team-building skills towards solving different parts of the same system. I truly feel like I could strive in an environment like this and bring about a valuable presence on the team. The rotors were a simple design to make on SOLIDWORKS, which allowed to me to experiment a lot with the design. I also was able to attain a sufficient understanding of Ansys which will prove useful on future projects.