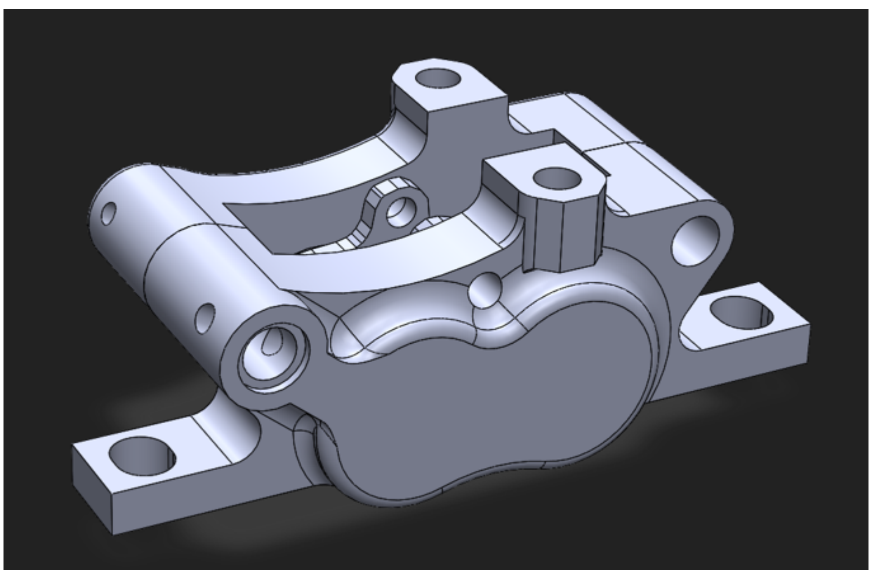
Cornell University Baja Racing Team

Fall 2021

Brake Calipers



Technical Report

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Contents

1 Overview

In this report, the design choices for the OD18 Brake Calipers will be discussed. These decisions were made based off research from past year's vehicles as well as information learned at the Oktobaja Competition earlier this semester. These changes were enforced early in the season, and the rest of the semester was spent validating and bringing these innovations to life.

2 Brake Caliper

This section details everything an individual needs to know about the OD18 Brake Caliper and the improvements that were made from previous Brake Calipers.

2.1 Abstract

This season's brake calipers adopt a fixed caliper design. This means that they stop the car by having pistons squeeze on both sides of a brake rotor, contacted by brake pads sitting on the caliper's surface. Upon actuation, the pistons push high friction brake pads against the rotors and the resulting frictional force slows the car down and eventually to a halt. According to the competition rules, the calipers are required to be part of a hydraulic system which must be pressurized by a foot actuated pedal.

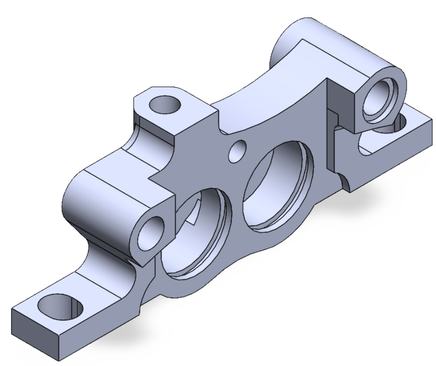

Figure 1: Inboard Half of Custom Fixed Caliper.

2.2 Design Requirements, Objectives, & Constraints

Requirements:

- Lock the wheels of a moving vehicle
- Ensure the safety of the driver in the case of a collision

Objectives:

- Save manufacturing hours by designing Caliper around purchasable components
- Design a Caliper that can be used on both sides of the car
- Design a system that can accommodate Inboard Braking in the rear
- Provide mechanical advantage that enables the locking of wheels under reasonable foot force

Constraints:

- Withstand a pressure of 2450 psi
- Withstand the normal force applied by brake pads
- Package nicely with ample clearance in the corner assembly
- Package nicely with ample clearance in the rear gearbox assembly
- Dimensions must be standard bike and car sizes

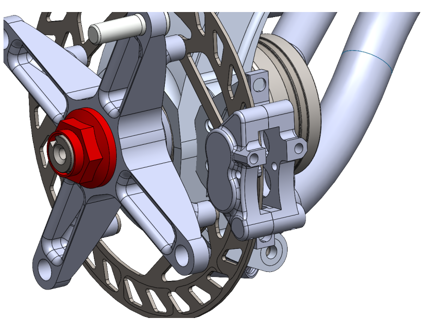

Figure 2: Front Corner Assembly

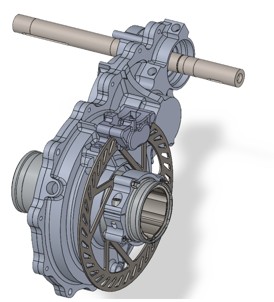

Figure 3: Rear Gearbox Assembly

2.3 Initial Research

The most important aspect of each season begins with research and understanding what went right and wrong the previous years. Therefore, I looked at the previous fixed calipers our team utilized. In this section, I will talk about the aspects I wanted to retain and those I wanted to remove while designing my version of the calipers.

2.3.1 Shimano Calipers

Retain:

- Mineral Oil Usage
- Compact design
- Highly Effective Sealing

Remove:

- Not custom
- Only manufactured as a right caliper

2.3.2 OD16 Calipers

Retain:

- Piston Seal Groove Chamfer
- Compact Design
- 2-piece Calipers
- Epoxy Set Screws for Sealing

Remove:

- Fluid Pathing
- Radial Bracket Mounting
- Machining Ops

2.3.3 OD17 Calipers

Retain:

- Fluid Pathing
- Overall sizing
- Effective Sealing
- Mounting design
- Machining efficiency

Remove:

- 1-piece Caliper
- Lee Plugs

2.3.4 Research Conclusion

After reading through the various tech reports and seeing the calipers in action, the conclusion to my research involved 5 main characteristics. I decided that I wanted to design a caliper which used mineral oil, had purchasable components, had minimal operations, was a 2-piece caliper, and the same caliper could be used in all applications. These characteristics would reduce both manufacturing time and unique components on the car, making the Spring semester a lot less taxing on the team, and increase available time for testing.

2.4 Design Iterations

Through the semester, the brake calipers saw many different design iterations. Many of these were vetoed during design reviews due to complexity of part and increase in system weight. Since inboard braking is only worthwhile if the overall system reduces in weight, implementing a larger caliper in the rear was counter intuitive and foolish.

2.4.1 Rear Inboard Caliper Original Design

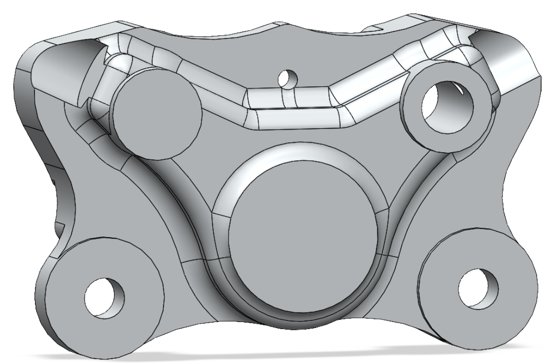

Figure 4: Inboard Half of First Inboard Caliper Design

The first caliper design saw a design that was standard mounted to the bracket, but had a significant increase in individual weight. A major issue was that the mounting point was too low to be mounted to the gearbox

2.4.2 Rear Inboard Caliper High Mount Design

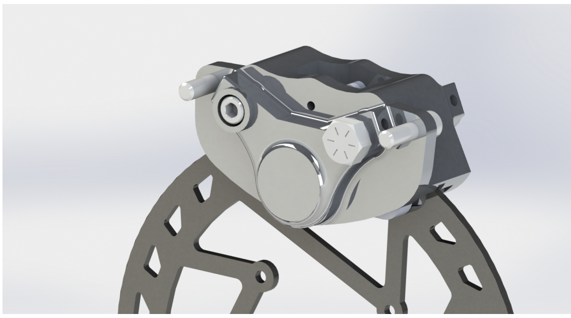

Figure 5: High-Mount Inboard Caliper-Rotor

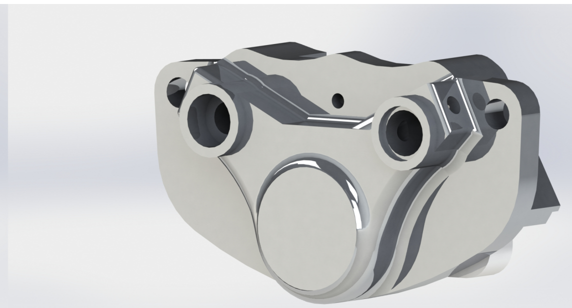

Figure 6: High-Mount Inboard Caliper

The next caliper design saw a design that was could be mounted easier to the gearbox but once again, the weight increase was way too large to justify the switch to an inboard braking system.

2.4.3 Front Outboard Caliper

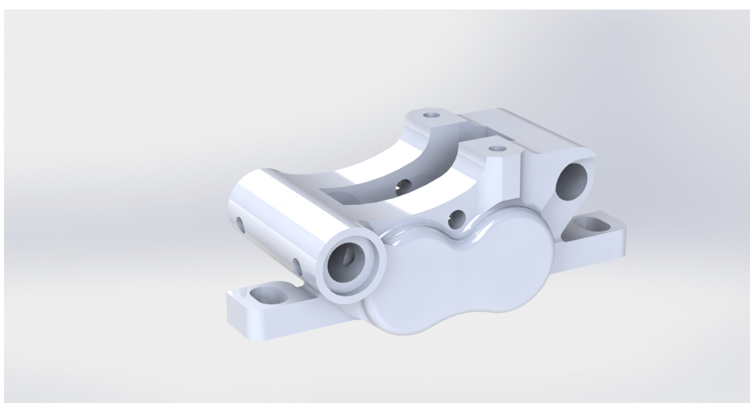

Figure 7: First Iteration of a Front Outboard Caliper

With the success the team saw in the previous years regarding custom fixed calipers, the main goal was to create a caliper that kept the pros of the last 3 calipers we used. This was the initial design for the front calipers. The biggest struggle that was faced in the initial weeks was designing two separate calipers - 1 for the front and 1 for the rear. In reality, this doubled the design projects and made things very difficult for the person in charge of the calipers.

2.4.4 Final Decisions

The design process allowed me to see the struggle and issues with having 2 different calipers on the car. I realized how much additional work needed to be done in order for this to happen, so the executive decision was to have 1 caliper be applicable to all uses on the car: Outboard Left, Outboard Right, and Inboard Rear. This was a risky decision but one I thought was completely achievable. We would have to go against previous practices but the pros were too sweet to be outweighed by the cons.

2.5 High Level Description - Final Design Choices

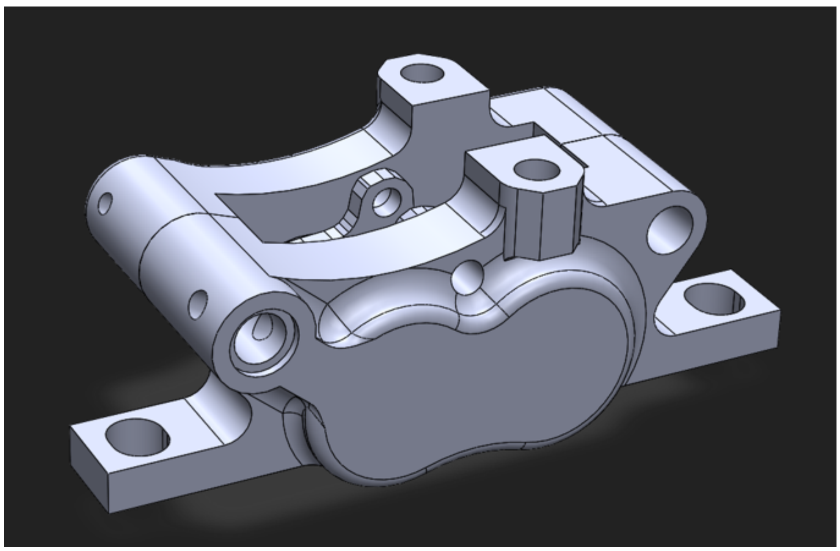

Figure 8: Final OD18 Design

This year, the front, rear, left, and right calipers are interchangeable. This is a huge design benefit as it reduces the number of unique components that need to be manufactured. Additionally, all dimensions were designed around purchasable components, so most of the hardware for the caliper has already been bought. This reduces manufacturing hours and the need to make difficult parts like the fluid bolt.

2.5.1 Pistons

In previous years, the use of a larger and smaller piston was to compensate for the moment created by the braking force. However, after further testing, the wear in the brake pads was minimal so it was a design choice this year to have both pistons be identical. By doing so, the left and right calipers can be identical as there is no need for mounting direction.

2.5.2 Fluid Bolt, Connecting Bolt, Banjo Bolt, & Bleed Nipple

This year, we spent many hours sourcing for a reliable seller that sold bike components. Thankfully, we found one that sold all these components together. Conveniently, all components are M6x1.0 threaded which makes the consistency of the caliper ideal.

2.5.3 Brake Fluid: Mineral Oil

As mineral oil is a lot more pleasant to bleed the car with, a large design goal for the brakes subteam was to continue using this. Additionally, it makes the sourcing of Fluid Seals much easier, especially for the master cylinder. Previously, the limiting factor to using mineral oil was that we were unable to find a brake pressure switch that was compatible with mineral oil. However, after extensive digging this semester, we found a pressure switch with the specifications that are compatible with our applications. This was a huge win for our team and allowed us to use Buna O-Rings for fluid sealing.

2.5.4 Brake Pads and Pad Axle

These will be similar to previous seasons. Previously, the sides of the brake pads had to be sanded down in order to fit into the housing of the caliper. To combat this, I have extended the length of the caliper to allow for the easy change-outs of brake pads.

2.5.5 Fluid Pathing

This has been one of the most challenging aspects of a caliper design especially for a team that manufactures it in house. Having an off-angled hole through three quarters of a caliper is extremely dangerous. There is a high chance the drill bit snaps. Therefore, this season, I will be using a T-slot cutter at the back end of the piston bore to connect the pistons and enable for streamlined fluid pathing. Since the pistons are smaller than the rotor webbing, I was unable to have a straight hole drilled for fluid pathing like OD17's. Therefore, I still needed an off-angled hole in the caliper but the trade off now is that the distance the drill needs to travel is significantly less.

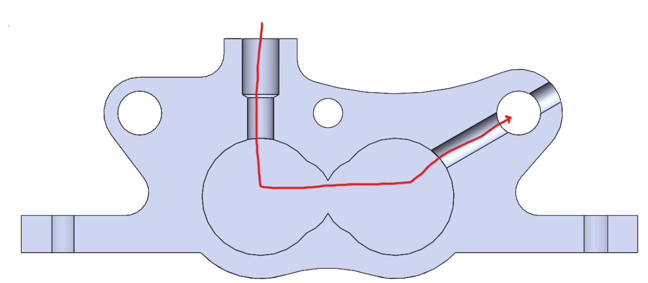

Figure 9: Fluid Path: Inboard

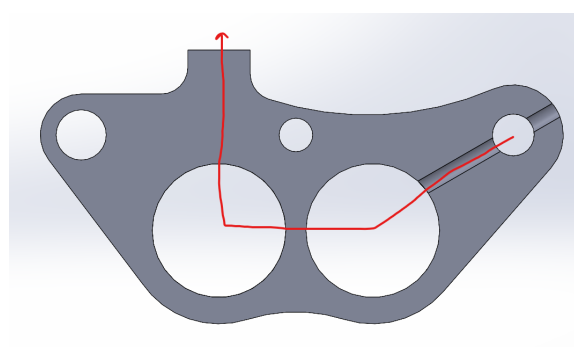

Figure 10: Fluid Path: Outboard

2.6 Finite Element Analysis

Since this year's design was a 2-piece caliper, each piece was analysed separately. The max pressure was calculated to be 2450psi and this was using a 250lb foot force on the pedal. This load case takes the caliper and applies the max pressure the driver can produce to all surfaces contacted by fluid. It also applies the pad reaction force on the face that contacts the brake pad. This force is calculated from the theoretical locking pressure, which is very similar to OD17's values.

2.6.1 Inboard Side

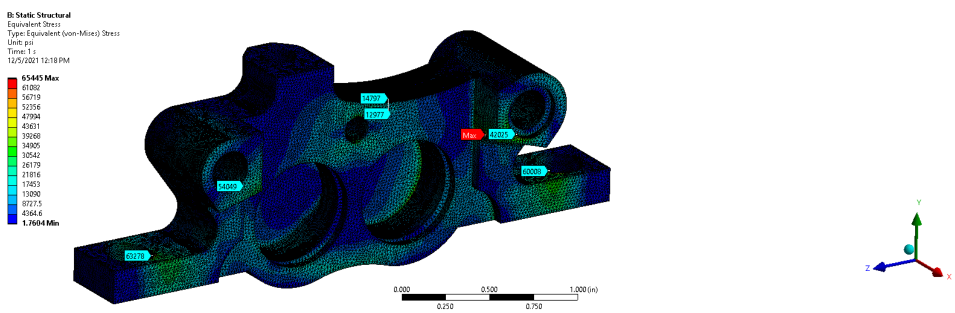

Figure 11: Final ANSYS of the Inboard Side

The caliper sees high stress concentrations at some edges. These continued to increase as the mesh size was refined (Spheres of Influence), suggesting that these were boundary conditions.

2.6.2 Outboard Side

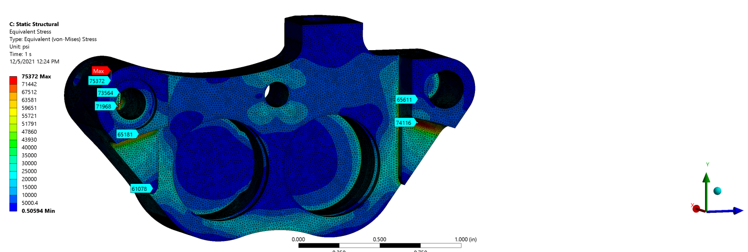

Figure 12: Final ANSYS of the Outboard Side

The outboard side behaved similarly to the inboard side of the 2-piece caliper.

2.7 Manufacturing

There is still a significant amount of work that needs to be put in to figure out the details of manufacturing. However, the most important operations will be discussed.

2.7.1 Operations

First we begin with a premachine on the top side of the stock which corresponds to either the bleed nipple or the banjo hole. Next we begin with operation 1 which involves most of the material clearing and cutting of bore holes, fluid pathing, and piston seal grooves. On top of that, respective holes will be drilled.

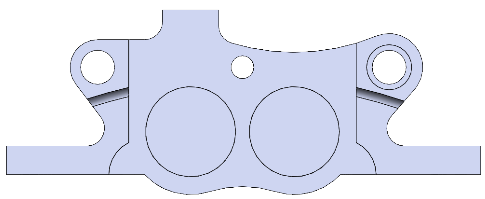

Figure 13: Operation 1

Next, we will flip the stock and do the back cutout as well as the chamfer of the piston back extension. After this op, the entire caliper shape should be finalized and all that needs to be done is the holes for fluid connections.

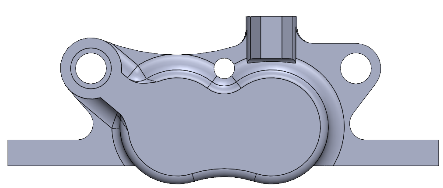

Figure 14: Operation 2

For the last operation, the caliper will be placed in the fixture plate and a vertical hole will be drilled through the top side of the caliper. This will be dimensioned off the flat surface of the caliper as shown in Figure 15.

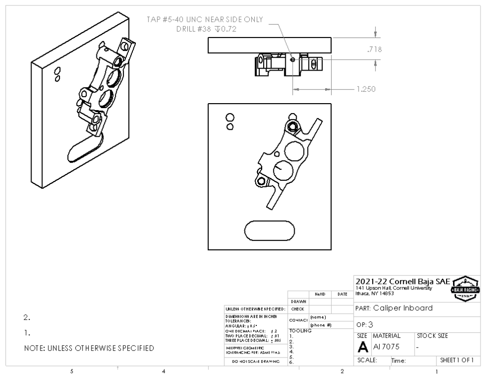

Figure 15: CAD Drawing of Operation 3 Setup

2.7.2 Fixture Plate

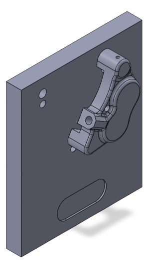

Figure 16: Fixture Plate with Caliper

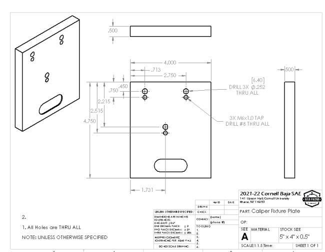

Figure 17: Fixture Plate CAD Drawing

The fixture plate will assist in the drilling of off-angled holes for fluid pathing.

2.8 Current Status

Currently the calipers are pending CAM, and then they will be ready to be machined for OD 18 which will begin in early January. All tooling and stock has been purchased and awaits arrival.

2.9 Future Improvements

Since the calipers have not been manufactured and we are unsure of the quality of the design, it is difficult to identify issues at the moment. Nonetheless, a suggestion I have for the next caliper design is to separate the piston bores a little more so a larger O-Ring can be used. Currently, the O-Ring has an OD of 1mm, which might not be enough to be effective piston retraction. This will be tested in the Spring and identified in the next Technical Report. Another suggestion I have is to pay more attention to the packaging in the corners as the width of the caliper caused issues with the hubs. Sourcing a shorter piston would solve this problem.

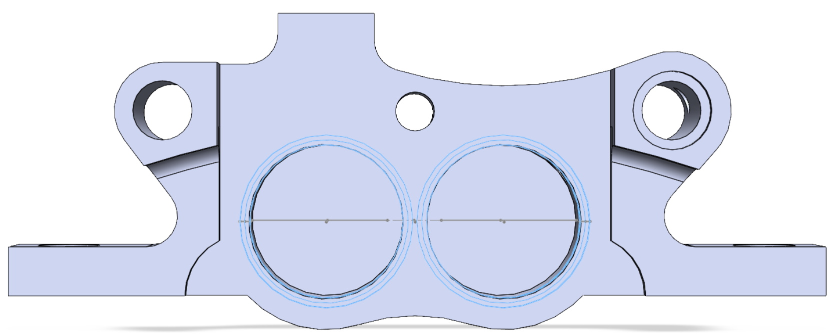

Figure 18: Sketch of Piston O-Ring Seals

3 OD18 Brake System

In previous years, there has been a calculated 60-40 bias in the front to rear due to dynamic loading. This meant that by removing one caliper in the back, we could just compensate for the difference in locking torque with the bias bar. This meant that the single caliper in the rear would realistically see twice the force from previous years. After trial and error, the following values were selected for OD18's Brake System. Analyzed with a 250lb foot force on the brake pedal with a 3.5 mechanical advantage on the pedal. This was also calculated with the newly found coefficient of friction of 0.25 between the brake pads and the rotors. The final decision was to run a 55-45 bias to the rear.

3.1 Inboard Braking

Values of Interest:

- Max Pressure: 2450 psi
- Max Torque: 2430 lb*in
- Locking Torque: 1920 lb*in
- Brake Force: 764 lbf
- Required Pedal Force to lock: 186 lbf

3.2 Outboard Braking

Values of Interest:

- Max Pressure: 2005 psi
- Max Torque: 1990 lb*in
- Locking Torque: 1700 lb*in
- Brake Force: 625 lbf
- Required Pedal Force to lock: 186 lbf

4 Appendix

4.1 References

- Tanner Hallett's Fall 2019 Technical Report
- Benjamin Collin's Fall 2020 Technical Report
- Brake Calcs Google Sheet
- Brake System Calcs Google Sheet