
2016 BEARCATS BAJA BRAKING SYSTEM

A Baccalaureate thesis submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Richard T. Best

April 2016

Thesis Advisor:

Dean Allen Arthur

TABLE OF CONTENTS

TABLE OF CONTENTS.....	2
LIST OF FIGURES	2
LIST OF TABLES	3
ABSTRACT.....	3
INTRODUCTION & PROBLEM STATEMENT.....	3
INTRODUCTION	3
PROBLEM STATEMENT	4
RESEARCH SUMMARY	4
MAIN DESIGN GOALS	4
RESEARCH.....	5
DISC BRAKES VS DRUM BRAKES.....	5
INTEGRATED (IN-BOARD) REAR BRAKES	6
ROTORS.....	6
CALIPERS	7
PEDALS	8
MASTER CYLINDERS	8
RESULTS	9
COST GOAL	9
WEIGHT GOAL.....	9
ACKNOWLEDGEMENTS.....	9
WORKS CITED	10
APPENDIX A: SURVEY RESULTS	10
APPENDIX B: QFD.....	11
APPENDIX C: SCHEDULE	12
APPENDIX E: BUDGET (COST AND WEIGHT).....	13

LIST OF FIGURES

Figure 1: Disc Brakes.....	5
Figure 2: Drum Brakes.....	5
Figure 3: Integrated Brakes.....	6
Figure 4: Out-Board Brakes.....	6
Figure 5: Brake Rotor.....	7
Figure 6: Brake Rotor FEA.....	7
Figure 7: Wilwood PS1 Caliper.....	7
Figure 8: Pedals in Pieces.....	8
Figure 9: Pedals Assembled.....	8
Figure 10: Pedal FEA.....	8

Figure 11: Master Cylinder.....9

LIST OF TABLES

Table 1: Master Cylinder Calculations.....9
Table 2: Survey Results.....11
Table 3: QFD.....11
Table 4: Planned Schedule.....12
Table 5: Actual Schedule.....12
Table 6: Cost Budget.....13
Table 7: Weight Budget.....13

ABSTRACT

Initially, the University of Cincinnati Baja team intended to design a new vehicle from the bottom up and take it to compete in the 2016 Baja SAE competition. Due to confusion of sign up dates for this event, we were not able to register in time to compete in this competition this year. This report will provide details about how the braking system was designed; research, designing, and manufacturing of this system.

INTRODUCTION & PROBLEM STATEMENT

INTRODUCTION

Baja SAE is an international intercollegiate annual competition put on by SAE (Society of Automotive Engineers). The main objective in the Baja SAE competition is to design and fabricate a vehicle that is all-terrain with four wheels. During the competition, the vehicles will compete in 4 events; the hill climb, pavement acceleration and braking, maneuverability course, and the endurance race. There is also a technical inspection on the car by representatives of SAE to evaluate whether or not the car is safe enough before going into competition. The University of Cincinnati Bearcats Baja will not be competing in a collegiate competition this year.

The main objective for this year’s team was to design a vehicle that was lighter weight, had better performance capabilities, and cost less than the vehicle made from two years ago. To meet these goals, the team is focused on a weight goal of 312 pounds or 512 pounds (including the

diver). Regarding the performance boost, the team focused on a new frame design as well as a new suspension design for better maneuverability. A new drive terrain was used to convert more power from the motor to the wheels of the vehicle. A lighter, more cost effective breaking system is used to assist in the improvements.

The braking system in any vehicle is a main component in its performance. For example, for any street car a test of 0-60 mph is tested as well of how little of a distance the car can stop from 60 mph. This system can also provide not only braking performance but acceleration and handling performance by reducing the weight of the system. The designers of this system must work with front suspension, steering, drive terrain, and rear suspension designers.

PROBLEM STATEMENT

The Braking system for the 2016 Bearcat Baja car can be improved by reducing the weight and the cost but keeping the reliability and performance of the system. The main objective for the brake team is to design and fabricate a system that is better than the previous years. Since the rear drive axil is a straight axil (meaning it has no differential), the breaking system design includes a rear in-board braking style which will eliminate a lot of weight by utilizing less parts. New pedals will also be created in house to lessen more weight and reduce cost. We will work closely with the steering, drive-terrain, front suspension, and rear suspension teams to create this design.

RESEARCH SUMMARY

The previous car used an integrated (In-Board) braking system for the rear brake and thought that was a great idea because it keeps the weight down and less parts are required. However, the problem with the previous design was that it was hard to perform maintenance on the setup due to the bolt not being easily accessible. From the previous cars we saw a trend of weight being reduced each year and that is was helped us set up our goals.

MAIN DESIGN GOALS

The fundamental first design goals:

- Reduce Weight
- Reduce Cost
- Ease of Maintenance

Weight is a huge factor pertaining to the performance of the Baja car. Even though the braking system doesn't weigh much to start with, the less weight means the car will stop faster, accelerate faster, and increase maneuverability. This will help the car perform better in all events

during the competition. The lighter materials that can be employed the better, but that also means that we need to make sure that the materials will be durable enough to handle use in the Baja car. An integrated braking system in the rear will also help keep the weight of the car down.

The cost of the braking system is largely dependent on what materials will be utilized and what components will be purchased to be employed in the system. There will be some components that are machined in house and I will have to take into account the cost of machining and manufacturing these components.

Ease of maintenance was considered when installing the floor board and the integrated rear brake. The floor board should be easy to take off in case someone needs to get to the master cylinder. The integrated rear brake must be made so that the rotor can be unbolted and replaced with ease, collaboration with drive terrain will be needed for this feature.

RESEARCH

DISC BRAKES VS DRUM BRAKES

The first thing we looked at was if we would use drum brakes or disc brakes in our system. A disc brake is a type of brake that uses calipers to squeeze pairs of pads against a disc in order to create friction that retards the rotation of a shaft, such as a vehicle axle, either to reduce its rotational speed or to hold it stationary. The energy of motion is converted into waste heat which must be dispersed. Hydraulic disc brakes are the most commonly used form of brake for motor vehicles but the principles of a disc brake are applicable to almost any rotating shaft. Compared to drum brakes, disc brakes offer better stopping performance because the disc is more readily cooled. As a consequence, discs are less prone to the brake fade caused when brake components overheat. Disc brakes also recover more quickly from immersion (wet brakes are less effective than dry ones). Disc brakes were decided for the car.

Figure 1: Disc Brakes



Figure 2: Disc Brakes



INTEGRATED (IN-BOARD) REAR BRAKES

The second thing we looked at in the braking system was if we were going to incorporate an inboard braking system (with the brake disc on the rear drive axil) in the rear or an outboard (with the brake discs at the wheels). Because the 2014 car had a solid axil output shaft, they used a single inboard rear brake where the brake rotor was directly connected to the output shaft. The inboard system would require more braking force to be generated from a single rotor but would utilize less parts. We decided to use an inboard rear braking system. Ease of maintenance was a main focus for the drivetrain team this year, so designing a rotor coupler and caliper mount so that all bolts were easily accessible was a top priority and a significant improvement over last years design. It was decided to have the caliper bolt to a bracket which was in turn bolted directly to the case. This design should give easier access to the caliper and to the rotor in the event that they ever need to be quickly changed out.

Figure 3: Integrated Brakes

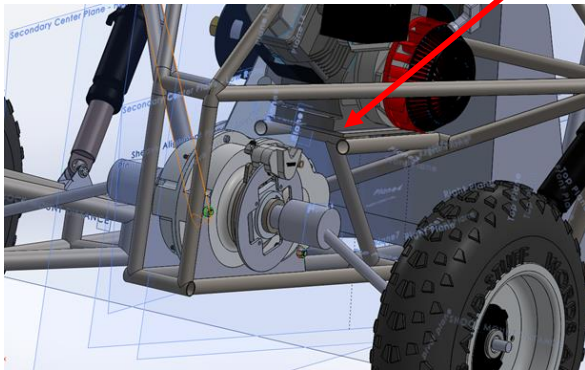


Figure 4: Out-Board Brakes



ROTORS

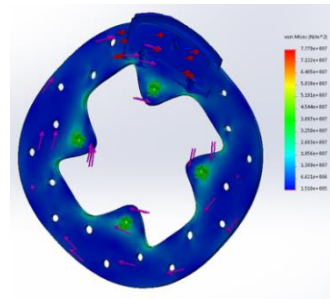
The brake rotors are a part of the system that can be enhanced to gain performance as well as limit weight. There are different types of rotors that include slotted, drilled, and plain rotors. Plain rotors are not used in most racing applications so we ruled that one out which left us with two options; slotted and drilled. We originally decided slotted due to the capability of flinging mud out of the rotor while the wheel is rotating. Upon further research, dilled rotors were decided due to the cost effectiveness and the braking performance was little to no difference. The front two wheels will require a rotor each and the rear only requires one rotor due to the inboard

rear braking system. We decided to manufacture our own because we needed a custom fit to mount onto the inboard hub design. The front rotors chosen for our application are EBC off-road brake rotors. These EBC rotors are designed to be off-road, which makes them a great fit for an all-terrain vehicle. Because they are made out of steel instead of stainless steel, they will work more effectively when the brake pads from the caliper activates and applies pressure to them. The rear only requires one rotor due to the integrated braking system. It was manufactured in house due to constraints of the drive terrain housing, it is made out of steel as well. FEA was conducted on the rear rotor to insure that the mounting holes would not shear off due to stress it would see during braking at full force.

Figure 5: Brake Rotor



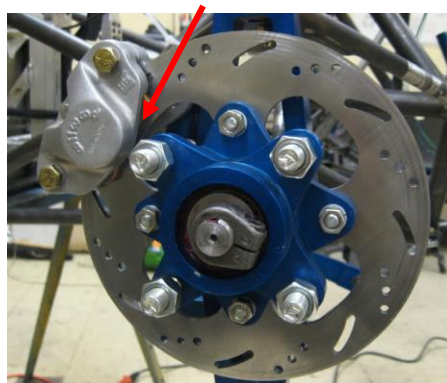
Figure 6: Brake Rotor FEA



CALIPERS

The caliper was the next item we looked at. The caliper transfers braking fluid to force the brake pads to compress against the rotor, thus slowing the vehicle down. We decided to utilize Wilwood PS1 calipers because we already had one spare Wilwood PS1 caliper; this would help reduce the cost of the system because only two more are required. The pads that fit onto this caliper are of a sintered steel material. This material works best when it is activated against a steel rotor and not a stainless steel rotor (our rotor material is steel). These calipers are also made from aluminum which will continue the trend to cut weight from the system.

Figure 7: Wilwood PS1 Caliper



PEDALS

The brake pedal was designed to meet the requirements of the pedal ratio needed to add 150 lbf to the master cylinders. The brake pedals would also be machined and welded in house, which means that a simple design will be used. The ratio 3.77:1 was used because of the ease of manufacturing factor. The original plan was to cut them out of an aluminum block using a plasma cutter that was in the victory parkway machine shop, but due to complications the plasma cutter was not in service. This was remedied by using manual mill and band saw machines. After the pedals were cut out, they were TIG welded together for strength. Proper FEA testing was applied before manufacturing them to insure that there will be no failure mode.

Figure 8: Pedals in Pieces

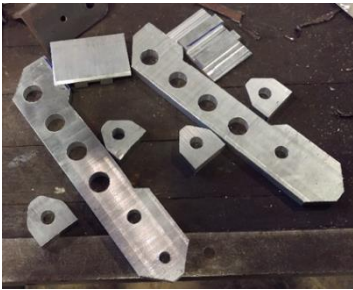
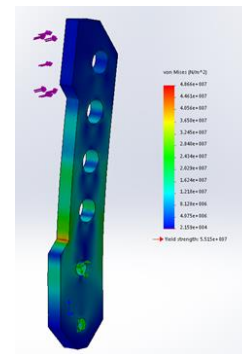


Figure 9: Pedals Assembled



Figure 10: Pedal FEA



Master Cylinders

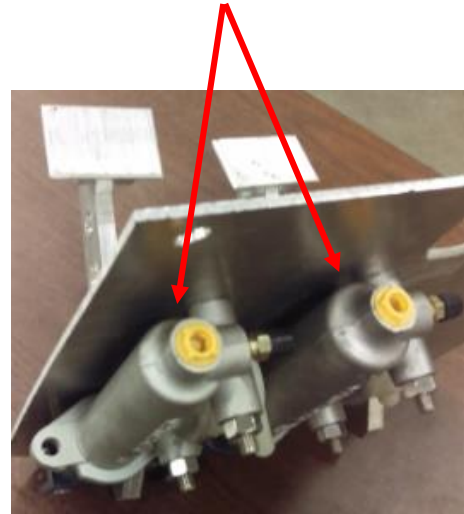
The master cylinders play a large role in the design phase. The master cylinders will have to be able to transfer the right amount of pressure to the brake caliper pistons. The master cylinders that were chosen are a Wilwood master cylinder with a 1 1/8 inch bore and a Wilwood master cylinder with a 5/8 inch bore. Through our calculations we found that they will provide more than enough pressure when given a 150 lbf driver input force when paired with a 3.77:1 pedal ratio (lever arm ratio for master cylinder input force). It was determined through research on the internet that the average driver applies 150 lbf to the brake pedal. The pedal ratio was decided

based on the pedal configuration and verified by the average driver foot size. The design includes an inboard rear braking system to assist in achieving our cost and weight goal.

Table 1: Master Cylinder Calculations

Master Cylinder Sizes			
Radius of center to tire (in)	12	Safety Factor	1.5
Distance of center to pad (in)	3.2		
Coef of Friction (tire and road)	0.7		
Coef of Friction (Pad and Rotor)	0.4		
Pedal Ratio	3.77		
Drive input force (lbs)	150		
Total input force	565.5		
Total Weight (lbs)	515		
Weight (front)	180.25		
Weight (front per tire)	90.13		
Weight (rear)	334.75		
Caliper Piston Area (in ²)	0.79	(4 pistons per one caliper)	
Front		Rear	
At the wheel		At the wheels	
Wheel force (per tire) = Brake force (per tire)		Wheel force (per tire) = Brake force (per tire)	
2271.15 = (3.2*x)*(.4*4)		4217.85 = 3.6*x*.4*2	
Force Required from pads (lbs)	887.17	Force Required from pads (lbs)	1464.53
At the Calipers		At the Calipers	
Pressure = Force/Area		Pressure = Force/Area	
Pressure = 443.58/(.79*4)		Pressure = 718.03/(.79*4)	
Pressure Required at caliper per tire (psi)	280.75	Pressure Required at calipers total (psi)	926.92
Master Cylinder		Master Cylinder	
Pressure = Force/Area		Pressure = Force/Area	
280.75 = (650/2)/(p1*r*2)		926.92 = (650/2)/(p1*r*2)	
Area of Master Cylinder Piston (in ²)	1.007126	Area of Master Cylinder Piston (in ²)	0.305043
Bore Size (according to chart)	1.1/8 in	Bore Size (according to chart)	5/8 in

Figure 11: Master Cylinders



RESULTS

COST GOAL

In 2014 the budget was set at \$1,771.00 and they ended up spending about \$1,100.00 since for this year we thought a budget of \$1,100.00 would be a great goal to meet and possibly beat. Unfortunately we ended up spending just a little above our budget at \$1,238.24 (\$138.24 difference).

WEIGHT GOAL

The 2014 the weight budget was set to 16 pounds. We thought it would be ambitious to set a goal weight for this year to 14 pounds. We ended up beating our goal at 13.71 lbs (0.29 lbs difference).

ACKNOWLEDGEMENTS

This project would not have been achievable without the help of the team members on all of the different sub-systems. Advics has also been a generous donator over the last 3 years. Other donations are from AIC (UC), Meritor Inc, Ford, and CEAS. I would especially like to thank the team advisor and Dean Allen Arthur. Without him or his expertise about Baja cars, the University of Cincinnati's Baja team would not be what it is today.

WORKS CITED

“Disc brake.” *Wikipedia*. Wikipedia, (Last updated) 17 April 2016. Web. 8 August 2015
https://en.wikipedia.org/wiki/Disc_brake

“Master Cylinder.” *Wikipedia*, Wikipedia (Last updated) 15 February 2016. Web. 17 November 2015. https://en.wikipedia.org/wiki/Master_cylinder

“Master Cylinder.” *Your Mechanic*. Your Mechanic Web. 17 November 2015.

<https://www.yourmechanic.com/services/brake-master-cylinder-replacement>

“Brake System.” *Official Baja SAE Forums*. Sorter, Bolt, Web. 17 November 2015.
http://forums.bajasae.net/forum/brake-system_topic734.html

“Baja SAE Rules & Important Documents.” *Students.sae.org*, Student.sae.org. Web. 2015. 17 November 2015. <http://students.sae.org/cds/bajasae/rules/>

APPENDIX A: SURVEY RESULTS

Attached Survey:

Baja Braking System Customer Survey

This survey will be used to prioritize customer features pertaining to the suspension of the 2015 University of Cincinnati Baja car.

Please circle your choices based on the importance of each item.

(1 = Low Importance 5 =High Importance)

Cost of System:	1	2	3	4	5	N/A
Stopping Power:	1	2	3	4	5	N/A
Pedal Response:	1	2	3	4	5	N/A
Ergonomics:	1	2	3	4	5	N/A
Weight of System:	1	2	3	4	5	N/A
Reliability:	1	2	3	4	5	N/A

Results:

Table 2: Survey Results

	Average
Cost of System	4
Stopping Power	5
Pedal Response	3
Ergonomics	2
Weight of System	4
Reliability	5

APPENDIX B: QFD

Table 3: QFD

Goals		Weighting Factor	Calipers	Brake Pads	Master Cylinder	Brake Fluid	Location of brakes
Reliability	5		5	4	3	4	4
Serviceability	5		4	5	4	1	4
Stopping Power	4		1	0	5	5	5
Ease of Use	4		0	4	5	1	0
Cost	3		5	-1	1	0	4
Score:			64	58	78	49	72

APPENDIX E: BUDGET (COST AND WEIGHT)

Table 6: Cost Budget

Cost Report					
	Material	Manufacturing	Quantity	Unit Cost	Cost
Front Rotors	Steel	EBC Braking	2	\$ 105.97	\$211.94
Rear Rotor	Steel	In house	1	\$ 65.67	\$65.67
Calipers	Aluminum	Wilwood	3	\$ 84.95	\$254.85
Pads	Sintered Steel	Wilwood	2	\$ 51.74	\$103.48
Master Cylinders	Aluminum	Wilwood	2	\$ 75.53	\$151.06
Pedal Assembly	Aluminum	In house	1	\$ 50.00	\$50.00
Brake Lines	Stainless Steel	Spiegler	1	\$ 305.00	\$305.00
Hardware		Various	1	\$ 96.24	\$96.24
				Total	\$1,238.24
				Budget	\$1,100
				Delta	(\$138.24)

Table 7: Weight Budget

Weight Total			
	Weight (lbs)	Quantity	Combined Weight
Front Rotors	1.28	2	2.56
Rear Rotor	1.48	1	1.48
Calipers	0.93	3	2.79
Master Cylinders	1.2	2	2.4
Pedal Assembly	3.28	1	3.28
Brake Lines	1.2	1	1.2
		Total	13.71
		Goal	14
		Delta	0.29