2016 BEARCATS BAJA
REAR SUSPENSION

A Baccalaureate thesis submitted to the
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Bachelor of Science

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by

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Thesis Advisor:

Professor Allen Arthur
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ABSTRACT

It was the initial intent of the University of Cincinnati Baja team to design a car from the ground up and compete in the 2016 Baja SAE design competition. Unfortunately, due to inadequate project management from the team as a whole, we were unable to register in time to compete in the international competitions held this year. This thesis will explain in detail the major phases of researching, designing, and fabricating the rear suspension on the 2016 Baja Car.

INTRODUCTION

Baja SAE is an annual competition hosted by the Society of Automotive Engineers (SAE) that promotes intercollegiate competition through off-road races and events. Many Universities from around the world go through the process of designing and building small off-road vehicles. The proposition of this competition is to push these vehicles in a barrage of off road events in the hopes that the car will endure the abuse and ultimately win. Events during the competition will commence throughout the day and will eventually lead up to a four hour endurance race at the end. These vehicles need to be designed to be structurally sound, dynamic, and cost effective. The only similarities between the competing vehicles are the Briggs and Stratton engines that propel them. This places all of the emphasis on each sub-system design. The implication is that each sub-system must work together efficiently as a cohesive unit in order to ensure the best possible performance from the vehicle.

Each year when designing a new car, the subsystems will be broken down into teams. The rear suspension team is responsible for all suspension components from the middle of the car to the rear. This sub-system plays a vital part in the overall handling, speed, endurance, and braking of the vehicle. The rear suspension will affect how well the car performs over obstacles and how responsive it is to the driver. Furthermore the rear suspension team works closely with the frame and drivetrain teams to ensure all aspects are taken into consideration and the car can be assembled properly. During actual competition, there is an evaluation by representatives of SAE to thoroughly judge the comprehensive design of the vehicle. Since we will not be going to competition this year, it has been agreed to have a formal technical inspection hosted by Associate Dean of Undergraduate Affairs Allen Arthur. This technical inspection serves as an alternative way to prove that the rear suspension design meets all requirements for the SAE International Baja rules and could function during competition.
REAR SUSPENSION SYSTEM DESIGN

PROBLEM STATEMENT
The Rear Suspension sub-system for the 2016 Baja car can be improved by focusing on improving handling, reliability, and making the system more dynamic. The overall goal of the rear suspension team is to design a system better than that of previous years. This system will provide a solid foundation to the rear of the car by supporting it through all terrain; with an emphasis on obstacles.

RESEARCH SUMMARY
Originally the idea was to incorporate a double wishbone A-arm style design in order to make the rear suspension stronger and more reliable. However, it was later decided to switch to a trailing arm design. This set-up better allows the rear suspension team to meet our goals.

MAIN DESIGN GOALS
The fundamental first design goals:
- Improve handling
- Reduce collective weight of the system
- Make maintenance less cumbersome
- Reduce the overall cost

To start, the first goal was to improve the handling of the vehicle especially with flexibly articulating over obstacles. The Baja SAE competition’s maneuverability event is formed to assess a vehicle’s handling ability over a standard Baja terrain (4). This event may have hazards such as ruts, rocks, drop-offs, or logs. The concept behind free standing trailing arms is that they will provide the wheel travel and independent motion needed in order to confidently take on obstacles. They also will not stag roots and branches much like A-arms would. It has also been noted through competition that an A-arm suspension was susceptible to drive axle disengagement if a member was to fail.

The rear suspension will account for approximately 25% of the total vehicle weight. Regarding the reduction of weight, the trailing arm design was determined to be the best choice. The goal weight for the rear suspension design was decided to be 60 lbs. Because this system was going to be designed as a stand-alone trailing arm system, there were not any lateral linkages. Therefore, this meant that there were a lower number of total components in the rear suspension which lead to savings in weight. Another option that was employed was to design new bearing carriers made from 6061 Aluminum rather than using the cast Polaris Bearing carriers. Lastly, Fox Air Shocks will be used on this design. They will provide a necessary adjustability but will cut down on weight due to the absence of a steel spring or
When considering the design of the suspension on the 2016 UC Baja car one thing always sticks out; that is the topic of maintenance. No matter how durable you make a competition car there always seems to be things that need adjustment or mending. This occurs because the team is constantly pushing the car to limit in each event. When things do break, they need to be easy to mend or replace to insure that we get the maximum use of the car’s capabilities in all events. Due to the nature of SAE Baja and automotive sports in general, there are many adjustments and servicing will have to be done on the vehicle. It is also very possible that a lot of the work done to the car will be done out of the shop, in the pits, or even in the field. This makes ease of maintenance imperative to the design of the rear suspension. This suspension needs to be easy to work on and easy to service during competition. The rear suspension design must also refrain from being too cumbersome to work around when service is required to the gearbox, engine or frame. The elimination of lateral linkages allow for effortless access to the vital systems located in the rear of the car.

In regards to cost of the rear suspension design, the decision was made to set a maximum budget of $2,000. This was concluded after finding the reported budgets of the 2013 Baja rear suspension ($1,939) and the 2014 Baja rear suspension ($1,954). There was an initial push to try and obtain funding through sponsorships. Companies that were contacted about possible sponsorships included Bilstein, Ransohoff and Fifth Third Bank. Unfortunately, there was never a response from Bilstein or Fifth Third even after multiple attempts of trying to contact them. Ransohoff was able to provide us adequate 4130 steel material to fabricate the trailing arms and shock mounting tabs. Not having as many components also provided the means to cut back on cost. Lastly, the frame material from the 2012 Baja car was recycled and reused as material to construct trailing arms for the 2016 car. The 2016 rear suspension total cost ended up coming to $1,181.

DESIGN SPECIFICATIONS
Vehicle Specifications:
- Rear Track Width: 47”
- Wheel Base: 63”
- Camber Change Rate: 1.5° (+/-)
- Static Camber: 0°
- Static Toe: 0°
- Firewall to Rear Axle: 21.1”
- Ground Clearance (Rear): 11.2”
- Vertical Wheel Travel: 9.8”
- System Total Weight: 64.83 lbs
The rear suspension architecture on the 2016 vehicle is a true trailing arm design and does not consist of lateral linkages. This design provides the most optimal way to meet the initial goals set out. The finished track width exceeded the initial track width objective of 46 inches. This track width was determined in order to accommodate the vehicle during events where the course was narrow and tough to navigate. Even though the mark was missed by an inch, it was accepted since the extra inch could have come from minor errors while building the car. The wheelbase is comparable to UC Baja vehicles by being around 60 inches. Static camber and toe were built and designed to be neutral. Having neutral camber and toe aids the goal of improved obstacle handling. However, there is an overall camber change of 1.5° in the positive and negative direction as the wheel travels. This value was found using a magnetic compass fixed upon the wheel as the trailing arm was articulated up and down.

The final rear suspension design was straightforward with only eight major components. The wheels and tires used were similar to the set-up on the 2013 Baja car. They were comprised of 6061 aluminum Douglas Blue Label wheels and 21” x 7” x 10” Kenda Klaw XC tires. This combination was selected because of its prior success with previous UC Baja teams and this allowed us to save money by reusing wheels and tires already found in the shop.

The spherical bearings and cups were from Pegasus Auto racing and were both made of high strength 4130. The gas shocks that were selected were Fox Float 3 Factory Series. These provided lower weight than coil-overs and adjustability through adding and withdrawing gas. The Float 3’s had a total travel of 5.25 inches. They were also used in the front suspension design. The wheel hubs and drive axles came from a Polaris Sportsman 300 much like past Baja cars.

The components that were fabricated were the trailing arms and the bearing carriers. The trailing arms were constructed with 4130 steel tubing from the leftover frame of the 2012 Baja Car. The bearing carriers were machined from a 6 inch diameter 6061 aluminum cylinder.
The final weight ended up exceeding the goal by 4.83 lbs. This was the result of using frame tubing from the 2012 Baja car that was thicker than the material included in the 3D model. More details will be explained in the Design Fabrication section.

![Figure 2: Axle & Bearing Carrier View](image)

FINITE ELEMENT ANALYSIS

Primary Assumptions:
- Vehicle Weight (+ Driver): 600 lbs
- Vehicle Mass (+ Driver): 18.63 slugs
- Top Speed: 30 mph (44 ft/s)
- Friction Factor: 0.9 (rubber to asphalt)

Front of Wheel Impact – Testing Parameters:
- Mass: 18.63 slugs
- Half Top Speed: 22 ft/s
- Decel Distance: 0.42 ft
- Average Speed: 11 ft/s
- Decel time: 0.04 s
- Acceleration: 580.8 ft/s^2
- Force: 10,822.41 lbf
- Spin Adjustment: 50% of total force
- Adjusted Force: 5,411.2 lbf

![Figure 3: Front of Wheel Impact Bearing Carrier](image)

- Max Force: 37 ksi
- Yield Strength: 45 ksi
- Factor of Safety: 1.2
Side of Wheel Impact – Testing Parameters:

- Mass: 18.63 slugs
- Impact Speed: 10 ft/s
- Decel Distance: 0.08 ft
- Average Speed: 5 ft/s
- Decel Time: 0.02 s
- Acceleration: 600 ft/s^2
- Force: 11180.12 lbf
- Spin Adjustment: 25%
- Adjusted Force: 2795 lbf

Figure 4: Front of Wheel Impact Trailing Arm
- Max Force: 55.5 ksi
- Yield Strength: 75 ksi
- Factor of Safety: 1.4

Figure 5: Side of Wheel Impact Trailing Arm
- Max Force: 65.4 ksi
- Yield Strength: 75 ksi
- Factor of Safety: 1.2
Six Foot Drop (on one wheel) –

Testing Parameters:
- Mass: 18.63 slugs
- Impact Speed: 19.65 ft/s
- Decel Distance: 1 ft
- Average Speed: 9.825 ft/s
- Decel Time: 0.108 s
- Acceleration: 193.06 ft/s^2
- Force: 3597.42 lbf
- Wheel Offset: 1.6 in (0.133 ft)
- Bearing Width: 0.795 in (0.0663 ft)

DESIGN FABRICATION:
All fabricated components for the 2016 rear suspension were built in house by the rear suspension team. These parts were created by utilizing the Baja shop and machine shop in OCAS on Victory Parkway as well as the machine shop at main campus.

The trailing arms were made of 4130 steel tubing. This tubing was recycled from the frame of the 2012 Baja car that was no longer in use. Reusing material once again allowed us to save on material cost. However the wall thickness of the tubing was .05 inch thicker than the original model. The extra thickness solidified the FEA results but created a heavier trailing
arm than originally thought. At the preliminary stage of fabrication, the frame of the 2012 car was cut using a Dewalt Angle Grinder with a cut off wheel. Using a cut list generated from the part drawings, the tubing was cut to the appropriate sizes for each component of the trailing arm. The separate components were welded together using the TIG welder located in the UC Baja and BUV shop. These tubes were set up on a jig to insure the right angles were met before being welded. Once the tubing was welded, the bearing cups were welded to the new trailing arms. The last element to the trailing arms was the shock mounting tabs. Ransohoff supplied a 36” x 36” sheet of 4130 with a thickness on 0.100”. The tabs were cut from the sheet using an angle grinder with a cut off wheel, and then were welded to the trailing arms. The trailing arms were painted satin black using Rust-Oleum Protective Enamel.

Figure 8: Raw Material

Figure 9: Completed Trailing Arm

The bearing carriers were the next major components to be constructed. Prior to machining, the stock piece was a 6 inch diameter cylinder that was 6 inches in length. Using the large drill press, a starting hole of 1.25” was drilled in the center of the cylinder. The cylinder was cut in half using the band saw in the OCAS machine shop. Each half was individually set up on a lathe and bored to the diameter of the wheel bearings -0.002” to insure snug fitment. The pieces were then turned and machined down to the outside diameters specified on the drawing. Each carrier was then faced to the correct height. A specialized boring bar was created to be used to machine the snap ring groove. After the grooves were made, the bearing carriers had the installation holes drilled into them using a drill press. A lot of machining techniques were used in creating these carriers. It was challenging but proved to be a fun and informative learning experience under the wings of the machine shop staff.
Figure 10: Drilling into Cylinder

Figure 11: Pre Machining

Figure 12: Post Machining
CONCLUSION
Unfortunately with the absence of competition this year, it is undetermined as to whether the 2016 rear suspension design will compare or excel past previous designs. There also has not been any testing to the vehicle because the car has not yet been completed. The only evaluation is the technical inspection scheduled on Monday, April 25.

Regardless, the rear suspension design succeeded in being more cost effective. With a final cost of $1,181, this design was nearly $1,000 less than the suspension in 2014. The rear suspension design was also very close on its weight goal; however it was still exceeded by a small margin. The two goals that have yet to be tested are the handling and the ease of maintenance.

Even though the car was never fully completed and competition was never experienced, the designing and fabrication was a rewarding experience. A lot was learned about the intricacies of project management and how motivating a team of peers can be a difficult endeavor. Much information was obtained in the art of welding and preparing materials for joining. Machining also provided its own learning curve for the rear suspension design team. All-in-all, this senior design project has now laid the foundation for the next team to come in and finish the vehicle while improving upon its short comings.

ACKNOWLEDGEMENTS
Thanks to the University of Cincinnati for their support for the Bearcat Baja team and for providing excellent facilities to conduct research and create the vehicles. Thanks are also due to the OCAS faculty for assisting the team with fabrication, machining, and insight when creating the car. Most notably, thanks to Nicholas Platniotis for dedicating many extra hours teaching useful machining techniques and mentoring us to complete the rear suspension system. Lastly, a very special thanks in due to our faculty advisor Dean Allen Arthur. His patience with the team was much appreciated. Also he still managed to dedicate his own time being with us and guiding us, even though there were more pressing matters to attend to.
WORKS CITED

APPENDIX A: DEFINITIONS AND ABBREVIATIONS

Camber Angle – Angle made by the wheels in the vertical axis of the wheels
Deceleration Distance – Distance traveled after impact until completely stopped
Deceleration Time – Time from average speed to zero speed at impact
OCAS – Ohio Collage of Applied Science
SAE – Society of Automotive Engineers
Shocks – Or shock absorber, a mechanical component for absorbing bumps, jolts, and vibrations on a vehicle
Spin Adjustment – Adjustment based on the vehicles tendency to rotate on impact
Toe Angle – angle that the wheels make with the longitudinal axis of the vehicle
Trailing Arm – Suspension links that run parallel to the side of the vehicle and are perpendicular to the drive axle
APPENDIX B: TECH INSPECTION REQUIREMENTS

ARTICLE 13: STEERING, SUSPENSION AND FLOTATION SYSTEMS

B13.1 Flotation Systems – Water Competitions Only (there will be no water competition in 2013)
Vehicles participating in water events must be statically stable in roll and pitch while floating. Flotation buoyant cavities must be closed (non-floodable), with a maximum cell diameter of 10 mm (0.4 in.). Tires, frame tubes, casings, and other vehicle equipment must also be closed if contributing to buoyancy, but are exempt from the maximum cell diameter requirement.

ARTICLE 14: FASTENERS

B14.1 Fasteners in the driver restraint systems must meet the following guidelines (new)

B14.2 Fasteners Captive
Fasteners must be made captive through the use of NYLON locknuts, cottered nuts or safety wired bolts (in blind applications). Lock washers or thread sealants do not meet this requirement.

B14.3 Fastener Grade Requirements
Threaded fasteners utilized must meet or exceed either, SAE Grade 5, Metric Grade 8.8 and/or AN/MS specifications. See Figures below.

Acceptable SAE Bolt Grades:

Grade 5: 3 radial dashes 120° apart

Grade 6: 4 radial dashes 90° apart

Grade 7: 5 radial dashes 72° apart

Grade 8: 6 radial dashes 60° apart

Acceptable Military Specification Bolt Grades:

B14.4 Thread Exposure
Threaded fasteners used must have at least two (2) threads showing past the nut.

B14.5 Socket Head Cap Screws

B14.5.1 Socket head cap screws, also known as “internal wrenching bolts” or “Allen head bolts”, must meet one of the following requirements:
APPENDIX C: RESEARCH

Wheels and Tires

Through a Baja forum I found that a popular choice was to go with aluminum wheels and a mildly-aggressive all terrain tire. The reason for the selection is because all terrain tires are great for all around use (obstacles, dirt, mud, etc.) and the aluminum wheels offer great weight reduction which is very important in racing. “There are myriad options available for tires, but keeping the weight to a minimum is a common theme among baja teams” (2). With wheels and tires there are so many options that experimentation through trials is how we may get our best data to decide what set up we want to go with.

Douglas Blue Label Specs –
Weight: 3.65 lbs
Bolt Pattern: 11” x 11” x 5.5”
Material: 6061 Aluminum

Double wishbone and trailing arm suspension

This idea is influenced by how the World Rally Cross set up their cars. The double wishbone suspension consists of an upper and lower control arm with a knuckle in the center to hold the hub. This design might increase weight but is very sturdy and will give the driver better handling capability. Trailing arm suspensions require fewer components but can be more difficult to manufacture. The major pro of a trailing arm suspension is that it allows the
rear suspension to slide over obstacles rather than ram into them.

![Figure 13: Trailing Arm Suspension Example](image)

**Coil Over Shocks vs. Gas Shocks**

Between Gas shocks and coil overs, which one has the most universal use and which is the easiest to maintain. The article from *Buggynews* made it very clear that the choice of shock very much depended on the type of terrain the car is going to be used on. “The best combination for desert /high speed for extended runs (hours) / whoops / jumps etc ...for serious racing for hours on end, at high speed is double or triple Bypass shocks in combination with Coil Carriers” (3). The only issue here is that a majority of our races will be conducted on mud and clay. The article further states that from a maintenance stand point, gas shocks are easier to adjust and are more universal for different applications. After doing some light research, gas shocks seem more ideal due to our events being low speed and more obstacle based.

![Figure 14: Gas Shock Model](image)
APPENDIX D: BUDGET

2013 Reported: $1,939
2016 Total: $1,181

- Negotiated pricing discounts
- Designed for the elimination of components
- Recycled material from non-functioning vehicles
- Negotiated tab material sponsorship

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Cost Breakdown
APPENDIX E: SCHEDULE

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APPENDIX F: WEIGHT ANALYSIS

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2016 Reported Weight: 64.83
Goal Weight: 60
Weight Difference: 4.83
% Difference: 8%

APPENDIX G: DRAWINGS