Bearcats Baja SAE Competition
2019 Front Suspension System

A Baccalaureate thesis submitted to the
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by

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ABSTRACT

Suspension design is one of the most complex systems on a Baja SAE vehicle. The terrain that must be covered is extreme and the horsepower is limited. Suspension design for this competition is one of the most varied items seen at race. Baja SAE takes students from the design phase all the way through manufacturing and assembly. My task for the 2019 Baja team was to design a new strong front suspension that will fit the previous year's frame

Introduction

The front suspension of the car is designed to absorb the initial impact of obstacles and make driving as smooth as possible for the operator. The overall task of the suspension system in relatively for various subsystems to remain coupled. The system as a whole must retain structural integrity, absorb forces encountered off road, and maximize tire contact. We will encounter various obstacles, such as rocks, fallen trees, deep mud and sharp turns. The suspension must maintain tire contact with the ground while the vehicle is traveling over rough terrain and provide comfortable driving for the occupants of the vehicle.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

A front suspension system is designed to maximize friction between the road surface and the tire to improve passenger comfort and provide steering stability. In the previous years ago, engineering student had built a front suspension as a Baja project but their geometry was not followed correctly which caused clearance issues throughout the competition. The goal of this project is to design and build a strong front suspension that will complete the off-road conditions down into static and dynamic events during competition.

BACKGROUND

Society of Automotive Engineers (SAE) is a standard developing organization for engineering professionals as a sponsor, particularly in the automotive, aerospace, and commercial vehicle industries. Baja SAE competition originated at the University of South Carolina in 1976, under the direction of Dr. John F. Stevens, and became major projects for university teams. The history of control problems with a front suspension caused by lifting a wheel is less severe when the spring reaches its unloaded shape than they are. Thus the wheel has to limit the suspensions downward travel to a point within safe limits for the linkages and shock absorbers. Small changes can be used to adjust the handling to a camber of -2 to ±5 ° depending on the type of front suspension desired and the tire. Often, we realize that too much camber will cause a decrease in braking performance due to a reduced contact surface size due to excessive camber variation in the suspension geometry. Below are some assessments of problem history and parameters that were not attributed to previous concepts.

Front suspension requirements	Target	Acceptable range
Static Ride Height	7"	6-12"
Maximum width	57"	<65"
Front Track width	52"	50-55"
wheelbase	67"	60-80"
camber variance	2°	±5°
Suspension Travel	11"	7-14"
Full compression Travel	7"	6-8"
Full Extension Travel	5"	4-6"

Figure 1: parameters design

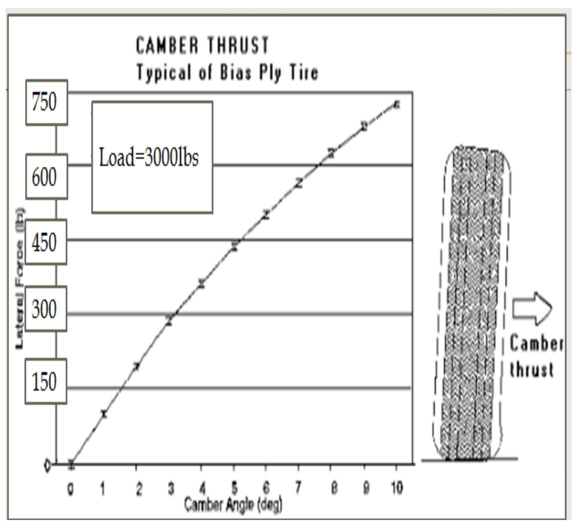


Figure 2: camber angle conditions

RESEARCH

SCOPE OF THE PROBLEM

A suspension geometry system is a linkage that allows the wheel to move relative to the body and support loads during movement. The articulated front suspension resulted in a lack of performance in terms of acceleration, ground clearance and traction on all terrain and off-road conditions. Thus, the wheels are misaligned with the potholes and curbs that damage the springs, and then affecting the control arms on the alignment system. However, the steering will not be centered when you go straight and tire wear will be increased.

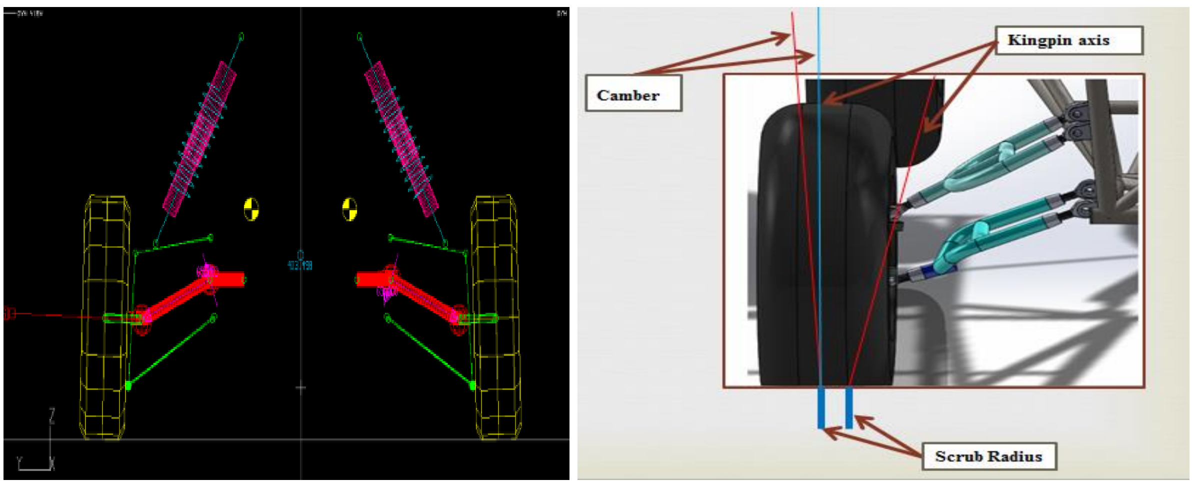


Figure 3 Geometric concepts

The front suspension flexed then the wheels would turn without input force from the operator. I will propose to design and build a strong suspension capable to resist and protect the control arms and tie rod to solve a bump steer and allows the car to have greater ground clearance and zero bump steer during competition. However, we're going to concentrate on the basic geometric of camber, caster, and toe-in as well to solve a bump steer. Suspension also be aware of some geometric such as camber angle, scrub radius, and kingpin inclination should be adhered if you want your car to handle well. This project will respect the objective below based on the previous project a few years ago. The front suspension would simulate real technical design projects and the resulting challenges would be enhanced to:

- Increase suspension travel.
- Improve Camber and toe change.
- Increase ground clearance.
- Increase strength-to-weight ratio.
- Improved ride quality.
- Maintain safety, reliability and low weight.
- Improved stability, durability and control.
- Followed SAE standards regulations.

- Four Common point to characterize a front suspension related to the drive conditions:
  - **Camber**: Angle between the vertical axis of the vehicle and the vehicle axis of the tire.
  - **Caster**: Angle between the steering axis and vertical axis of the tire.
  - **Kingpin axis**: Angle between the vertical axis and the imaginary axis.
  - **Scrub Radius:** the distance from the kingpin axis to the center contact patch of the tire

CURRENT STATE OF THE ART

Front suspension system is currently designed with a short and long arm as the requirement type of Baja suspension in the front and rear. Basically on the actual technologies presenting in the market, we have to consider two categories of suspension such as an independent suspension system and dependent suspension system. Today these two designs are building to allow the wheel to move relative to the body and some elastic element to support loads while allowing that motion. I compared and contrasted the novelty of them around the world, and come on with some arguments regarding our front suspension.

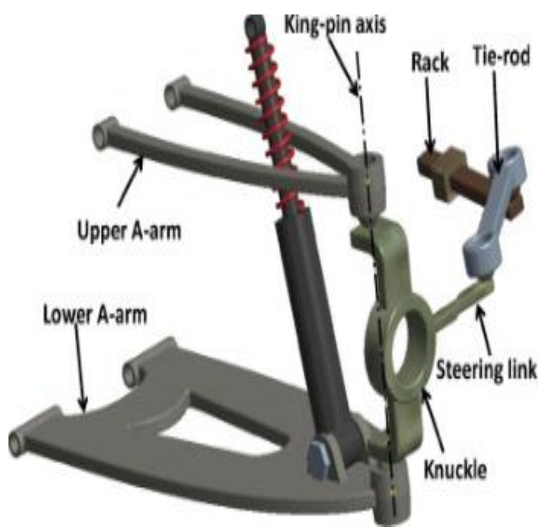
<u>Double wishbone suspension</u>

Advantages

- Increase strength to weight ratio
- Provide more driver space
- Improve handling and control
- Absorb frontal impact forces
- Maintain safety, reliability and low weight
- Reduce vibrations and cambering effect
- Increase stability and durability
- Improve ground clearance

Disadvantages

- Increased components and complex
- More expensive than other systems



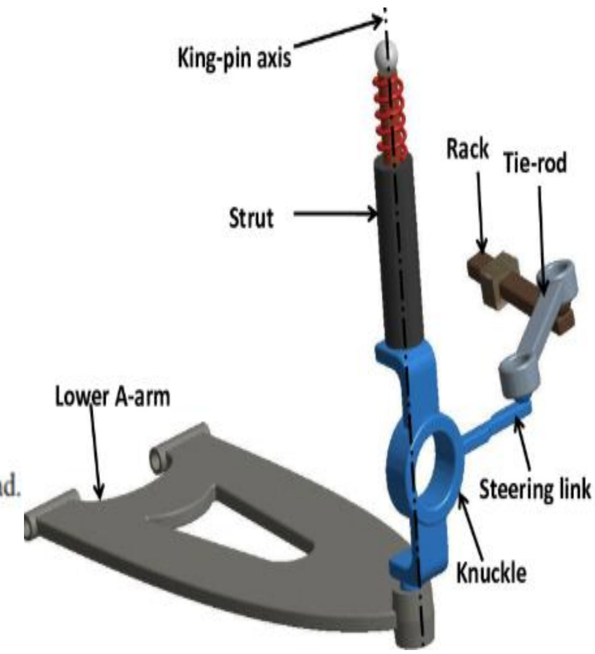
<u>MacPherson Strut suspension</u>

Advantages

- Ease of manufacturing
- Low cost and lightweight.
- good component integration.
- Reduce the overall weight.
- Minimize vibration during the travel.
- less space than a double wishbone.
- more simplicity and low un-sprung weight.

Disadvantages

- Increased scrub radius.
- Cannot allow vertical movement.
- Lack of camber adjustments which changes under load.
- Limited travel and reduce handling abilities .
- Small suspension travel.



Suspension components are more likely to wear on front-wheel drive cars during static and dynamic events. I will say that based on the comparisons between both technologies; there would also be a link with the customer's requirements that can be missed.as well.

END USER

Customers expect a good product from the designer. Therefore, the front suspension would meet all geometry missed from the previous year, and would compare them to evaluate the result. Team and I will focus on building a new product that will maximize the vehicle load and allow for all terrain conditions during the travel. Their needs will be assigned to us and will ensure that satisfaction is accurate during the process.

CONCLUSIONS AND SUMMARY OF RESEARCH

Therefore, we tried to introduce the problem on the basis of the statement and to understand a little bit to find a solution. The next point was to approach the problem and look for any evidence of its cause and how to handle it. After that, I introduce the problem into different comparisons to determine exactly what was missing in the past and configure the client's needs to give a different suggestion to convince the user. In the end, I also started looking for the solution to solve the requirements of the current situation.

CUSTOMER FEATURES

Sometimes the feature is easily mapped to the problem or needed, but most often unspecified. You will indicate an important part of the communication with the customers. Some of them are also more relevant to a specific sub-client ranked of our product. In the table below, the green color represents the essential for the needs of our customers, based on evaluations of the technical characteristics.

ranked	Engineering Requirements	Number of strong	Number of medium	Number of weak	Importance weight (survey & interview)
1	Acceleration 0-20 (mph^2)	1	2	0	0.10
2	Turning Radius (ft)	1	0	0	0.10
3	Factory of Safety (SF)	1	0	2	0.15
4	Ground Clearance (in)	1	0	1	0.10
5	Wheel Travel (in)	0	1	0	0.05
6	45 Degree Incline (Degrees)	1	1	0	0.05
7	Materials Cost ($)	3	1	0	0.10
8	Braking Distance (ft)	1	1	2	0.10
9	Leg Room (in)	1	0	1	0.10
10	Weight (lbs)	2	3	1	0.15
11	Sustains Drop (ft)	0	2	1	0.15
12	Torque (lbf)	2	2	0	0.05
13	Speed (mph)	0	2	1	0.10
14	Stiffness (lbs/in)	0	2	1	0.05

ranked	Customer feature	Customer Importance	Customer Satisfaction rating
1	Accelerates Quickly	1.5	4
2	Maneuvers Easily	0.9	2
3	Meets Safety Specifications	1.6	4
4	Drives Over Large Obstacles	1	3
5	Climbs Steep Grade	0.3	4
6	Low Maintanence	0.5	3
7	Cost Efficient	3.2	3
8	Brakes Quickly	1.2	3
9	Ergonomical	1.1	3
10	Light Weight	3.2	4

Figure 4: Engineering requirements & Customer needs.

PRODUCT OBJECTIVES

The product objectives were to combine information receiving from the customer features and engineering requirements based on the research I did and feedback from the survey or interviews. However, the ranked provided the importance features and satisfaction from the customers to decide how the design will be built. So below is how each features weight will be assigned to meet our customer needs.

- **Accelerates quickly (10%)** --- Baja vehicle will move faster and accelerated quickly.
- **Turning radius (10%)** ---- vehicle must be able to turn without hitting an obstacle.
- **Meets Safety Specifications (15%)** --- performed safety standards and Design criteria .
- **Driver over large Obstacles (10%)** ---- suspension geometry must be considered correctly.
- **Climbs steep grade (5%)** --- vehicle will be meeting the entire specifications requirement in the design project.
- **Low Maintenance (5%)** --- components will be maintaining correctly with simple tools.
- **Cost efficient (10%)** – cheaper material cost and flexible.
- **Brakes quickly (10%)-** act quickly on the vehicle.
- **Light weight (15%)-** reduce weight and simply design.

QUALITY FUNCTION DEPLOYMENT

			Engineering Requirements (units)														Customer Satisfaction Rating (0.00 - 1.00)			
		Importance wt.	Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees)	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)				
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B	C
1	Accelerates Quickly	0.10	9									9		9	3		0.6	0.6	0.5	0.6
2	Maneuvers Easily	0.10		9		1				1		3				3	0.5	0.7	0.9	0.7
3	Meets Safety Specifications	0.15			9				3	1	1		1				0.2	0.8	0.7	1
4	Drives Over Large Obstacles	0.10				9	3						3	3		1	0.6	0.6	0.7	0.7
5	Climbs Steep Grade	0.05	3					9				1		9	1		0.4	0.7	0.8	0.5
6	Low Maintanence	0.05							9								0.7	0.5	0.8	0.6
7	Cost Efficient	0.10							9			3					0.6	0.5	0.6	0.8
8	Brakes Quickly	0.10			1					9		3					0.7	0.8	0.7	0.7
9	Ergonomical	0.10									9						0.6	0.7	0.8	0.6
10	Light Weight	0.15	3		1			3	9	3		9	3	3	3	3	0.7	0.7	0.9	0.9
	Total Importance	1.00																		
	Engineering requirement importance		1.5	0.9	1.6	1	0.3	0.5	3.2	1.2	1.1	3.2	0.9	2.1	0.8	0.9				
Performance	Current Product		2	1	1	2	3	2	3	3	3	4	2	3	3	2				
	competitor A		3	2	4	3	3	3	2	4	4	3	3	3	3	3				
	competitor B		2	2	3	3	2	2	3	4	3	4	3	2	3	3				
	competitor C		1	1	4	2	2	1	3	4	1	4	4	2	2	2				
	New Product Targets		4.5	4	5	3.5	4	4	3.5	4	4.5	4	5	4.5	3.5	4				

Interaction Matrix

	Engineering Requirement	Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees)	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Acceleration 0-20 (mph^2)	1		-3	-3	-9	-9	3	1	-9	-9	3	-9	9	3	-1
Turning Radius (ft)	2			-3	-3	-3	-9	-1	-9	-9	-9	-9	-1	-1	1
Factory of Safety (SF)	3				-3	-3	1	9	3	1	1	3	-3	1	-3
Ground Clearance (in)	4					9	1	1	-3	-9	3	3	-9	-9	3
Wheel Travel (in)	5						1	3	-3	-9	3	9	-3	-3	9
45 Degree Incline (Degrees)	6							1	-9	-9	3	-3	9	3	1
Materials Cost ($)	7								3	-3	9	3	3	3	3
Braking Distance (ft)	8									-9	9	-9	-3	9	3
Leg Room (in)	9										-9	-9	-9	-9	-9
Weight (lbs)	10											3	3	9	1
Sustains Drop (ft)	11												-9	-9	9
Torque (lbf)	12													3	3
Speed (mph)	13														1
Stiffness (lbs/in)	14														

Figure 5: QFD and HoQ

Design research

- Single arm

Double Arm

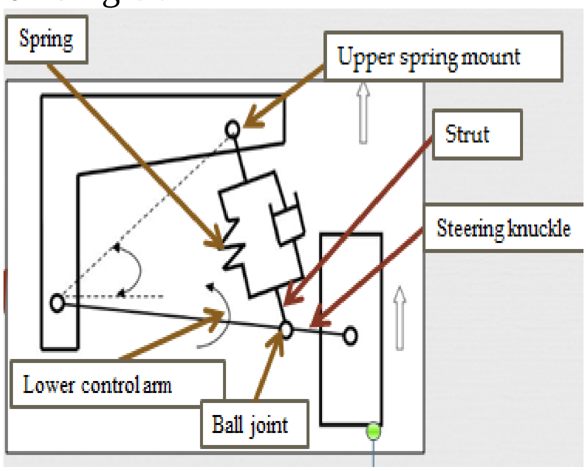


Figure 6 MacPherson strut suspension

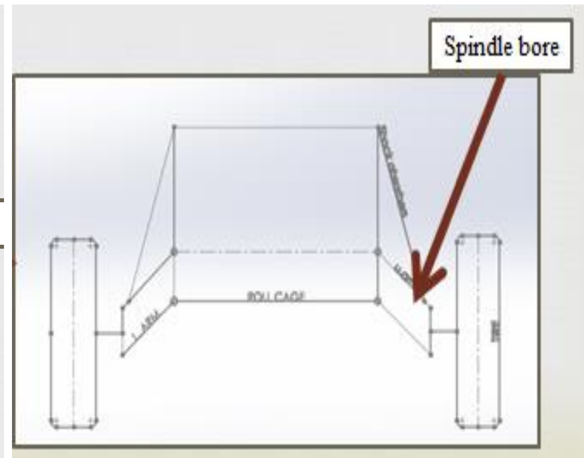


Figure 7 : Double wihbone suspension

DESIGN

After going through the advantages and disadvantages of each design, I decided to use a double wishbone suspension. It provides the car with the most travel and be robust enough to handle the rough terrain and obstacles it would face during the travel.

Design alternatives and selection

1. **Alternative 1**: Double Wishbone Suspension (bend at 45° and 60°)

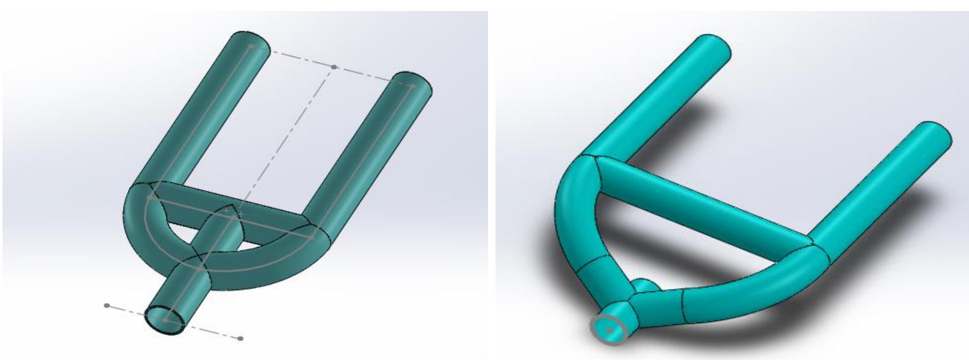


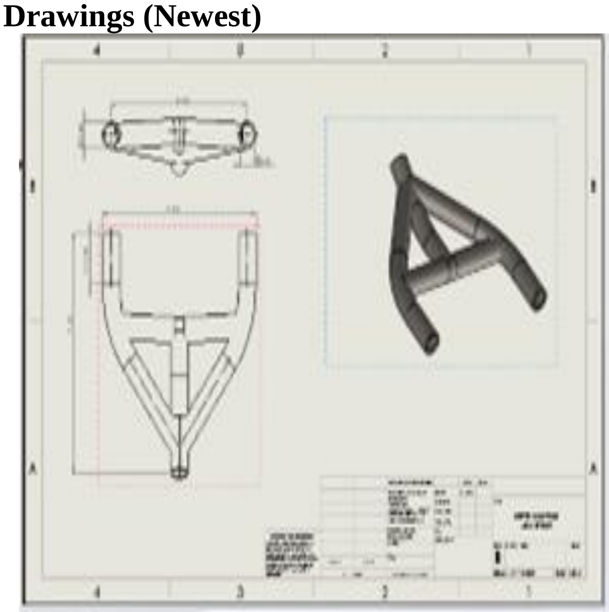
Figure 8: optimized upper Arm and Lower Arm

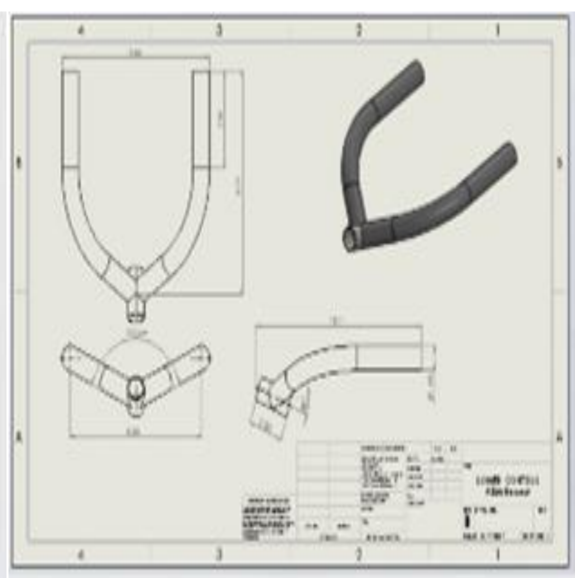
2. **Alternative 2**: Double Wishbone Suspension (bend at 45° and 50°)

I selected this concept based on the flexibility of the attachment angle to increase strength and improve control with heim joints over ball joints that requires more attention.

Figure 9: optimized upper Arm and Lower Arm

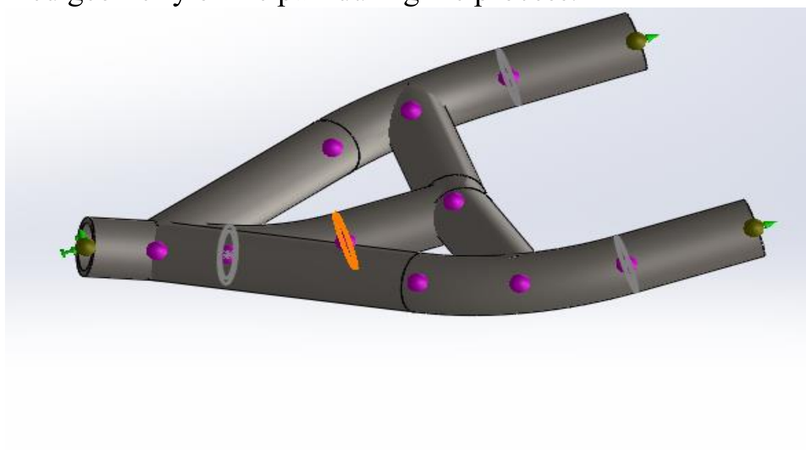
Drawings (Newest)

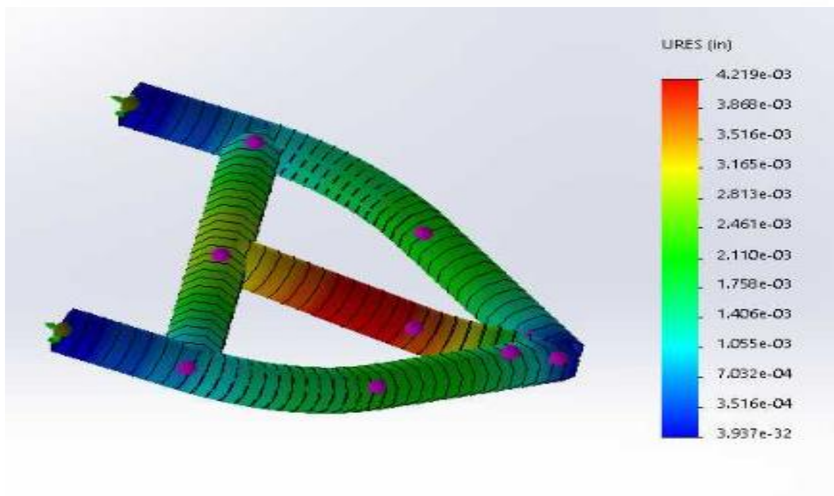




Loading Conditions

The purple dot represents where the material was applied to all the bodies while green dot represents the fixed geometry of the part during the process.





The maximum stress seen here was 4219.3 psi which was below the yield strength of the material 66717 psi and deformation 0.127in and located at the stress concentration points at the upper and lower arm. The maximum areas of stress occurred at weld joints and top of heim joints connected to spindle bore. The resultant normal stress is 0.00 ksi tensions at the misdpan top and 0.00 ksi compressions at the midspan bottom during the applied forces.

Design Analysis

- **FEA Calculations**

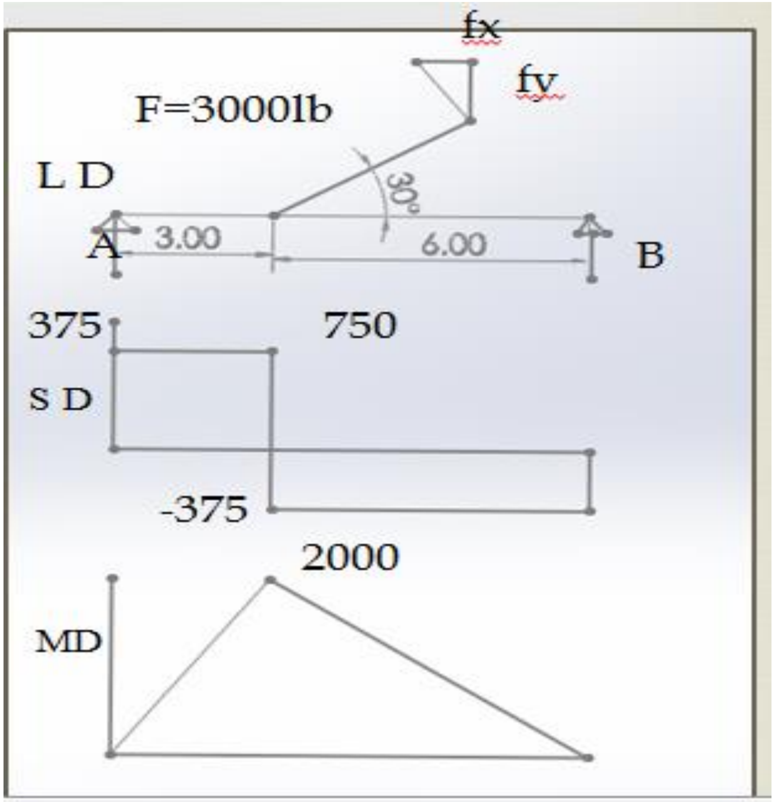
After the car was dropped during the testing, one can assume the original velocity to be zero, thus eliminating it from the equation.

- $V2 = 2gh = sqrt(2gh) = sqrt(2 * 32.2ft\ s * 6ft) = 19.65\ ft/s^2$

The total weight of the car was estimated 475lbs to determine the mass and The kinetic energy will determine to find the average force from the falling car.

- $F = ma$ ➔ $m = F\ a = m = 475lbf / 32.2ft = 14.8$ slugs
- $KE = (1/2)mv^2 = (0.5)*(14.8)*(19.65)^2 = 2857ft.lbf$
- Favg=2857ft.lbf/0.89=3214lbf

The reaction forces and shear forces have to be calculated to determine bending stress and total stress equations.

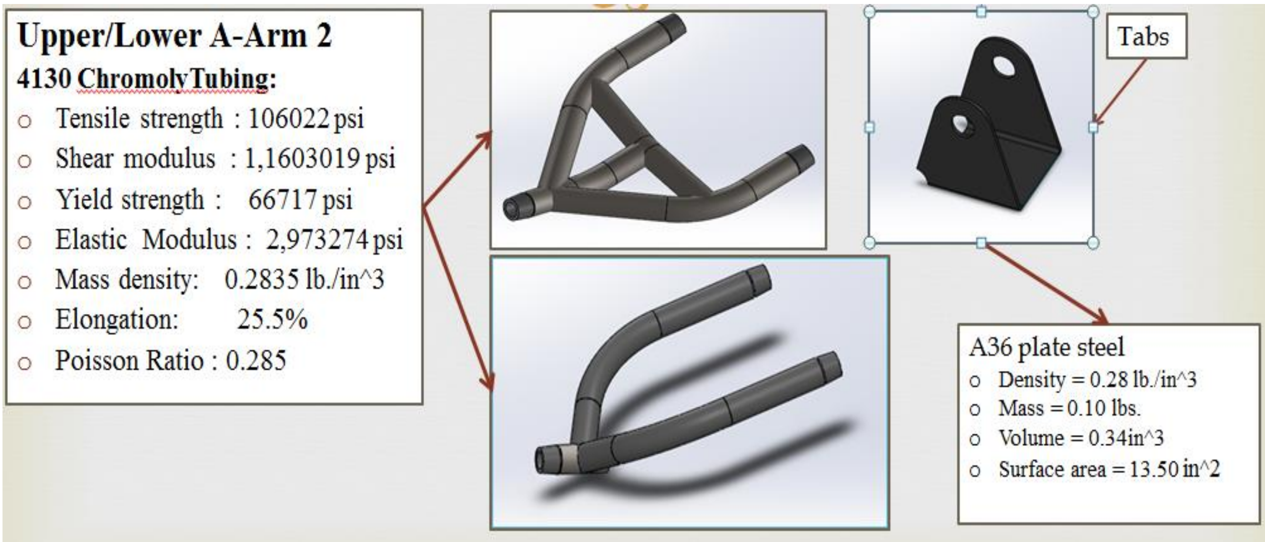


- Area=.7853(1^2-0.91^2)
    - =0.135 in^2
- Stress =F/A
    - =3000/0.135= 22222 psi
- Reaction Forces
  ∑M=3.Fy- 6B=0 B=3(750)/6=-375lb.
  ∑F=A+375- 750=0 A=375 lb.
- Shear stress
  $\tau = Fy/2A$ = 375/0.27=1389 psi
- Bending stress Iy=π/64(D4-d4)
  Sb=MC/I
  Sby=(2000(0.5))⁄(π/64(1^4−0.91^4))= 35,769 psi

- Maximum shear stress
  $t$max $=((\sigma/2)\text{^}2 + \tau\text{^}2)^{1/2} = ((22222/2)^2 + (1389)^2)^{1/2} = 11197$

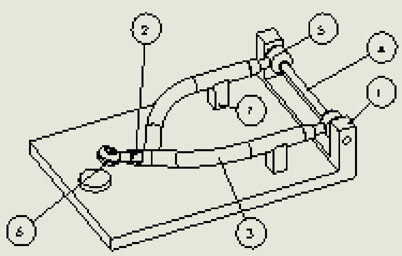
Therefore, the shear stress for grade 10 bolts was 100 ksi, which left a safety factor of 2.2 based on the strength of the applied material.

Component Selection

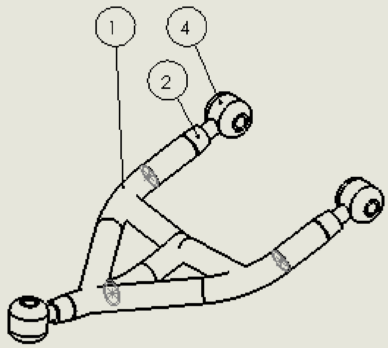


I selected 4130 chromoly tubes to build the control arms and other components to improve weldability and flexibility. While tab was made with A36 plate steel supported the shock force during compression and tension.

Bill of Material



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Lower A Arm Jig Base		1
2	Tube Bung		3
3	LOWER CONTROL ARM Newest		1
4	Through Rod		1
5	Heim Width		2
6	Heim Width no mis alignments		1
7	Support arms1		2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	UPPER CONTROL ARM REDUE		1
2	Tube Bung		3
3	Upper shock Tab		1
4	Heim Width		3

Manufacturing

During the manufacturing phase, all parts of the front suspension were manufactured and manufactured in a workshop located at the Victory Parkway campus .The first steps consisted of cutting, grinding, and turning and organized the tubes. Second step was to manually bend the tubes, used the horizontal and vertical milling machines and drill presses, after notching the tubes to create the hole between each tube. Third steps were welding process to insert tube bung and tabs with GTAW welding, and followed assembly process. The last steps was painting all parts fabricated. All the front suspension tubes were the material was selected and purchased by the team member. After a few weeks, the material arrived to build a front suspension system with only one extra section of six feet was ordered for manufacturing. The properties of this material were 4130 chromoly steel tubing with yield strength of 67 ksi. Characteristics were obtained in Solidworks for the analysis. The team and I proved that this material was perfectly resistant to the front suspension system. The entire tubes were measured and cut to approximate length using a tape measure and an angle grinder. The last lengths were obtained using a pipe cutter and a shutter disc to ensure the parts coupled tightly for welding. This allowed manufacturing in +/- 0.010 inches and can be showing below:

Figure 10: tube notching steps

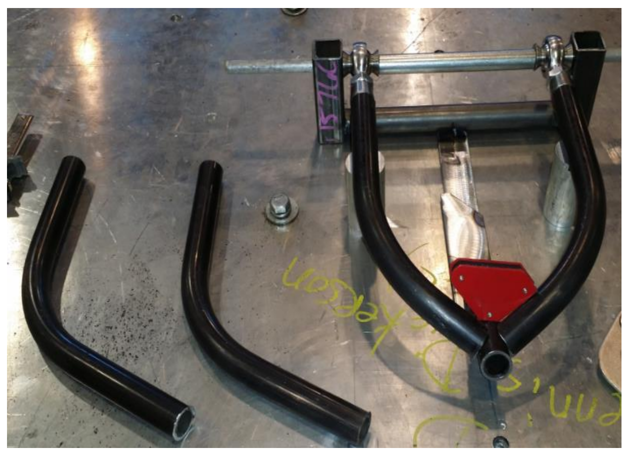


Figure 11: alignment tube setup

After notching all the tubes in figure 10, we followed the welding process figure 11. A welding jig has been created so that the process can be fast and accurate. Then we used also the same welding jig for the upper and lower arms as well.

Three manufacturing challenges was encountered during this process. The first steps was to have much attention each week during cut to rough length , depending on the section tubes we have in the shop. Second challenge was to remake the lower suspension arm on the side angle to allow a good turning radius of the steering. Third challenge was one of the major to build a welding jig that could fix and align the parts correctly.

Figure 12: lower arm

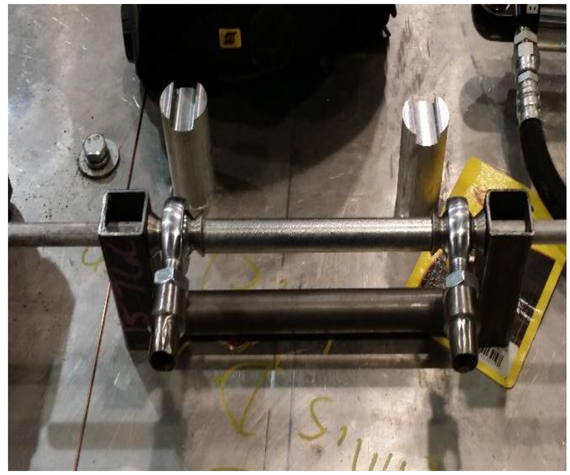


Figure 13: assembly jig setup

The shock tabs were created on the upper control arm and other tabs mounted on the frame. We all manufactured on the plasma cutter at VP Lab. The last piece manufactured was a threaded tube bung that was welded on top of the upper suspension arms for easy camber and caster adjustment.

Figure 14: Control arms & shock mount

RESULTS AND PROOF OF DESIGN

After manufacturing all parts, painting and final assembly, the final weight came out at 500 lbs to increase the total weight of the car and the driver. While the car had a ground clearance of 14 inches measured from the front bar. Front track width was 52 inches and the maximum width 57 inches which was the design parameter. We maintain the total compression and extension travel at 7 and 5 inches for a good reason to allow shocks to jump enough during the travel as well. However, the shock was reduced to 3 inches, which gave 8 of 11 inches of travel. Over this distance, the toe change was minimized to 2° by 11 inches of tire travel to improve the embossed direction and get control of the car at all moment. The Baja car has been tested for approximately 8 hours in total was used at the dirty turtle offroad park, Kentucky Acres. They have approximately 270 hectares of unpaved and ungroomed trails which are perfect for imitating and surpassing the conditions our team arrived the same day after the morning rain with a temperature of 65 degrees. This gave us a better opportunity to test a car with wet working conditions that dragged and slid it and put on weight in the form of mud. Throughout the tests, no part of the front suspension was broken, except for problems with the drive shaft.

Figure 14: car testing on hill climb

Figure 15: complete car after testing process

PROJECT MANAGEMENT

- **BUDGET, PROPOSED/ACTUAL**

Proposed Budget

FRONT SUSPENSION PARTS				
Parts	QTY	Price	Total	Source
Mounting Nuts for subassembly	1	$9.98	$9.98	McMaster-Carr
Mounting Washers for subassembly	1	$4.98	$4.98	McMaster-Carr
4130 Alloy Steel Tubing for Lower and Upper control Arms	1	$82.99	$82.99	McMaster-Carr
Shock Nuts	1	$9.89	$9.89	McMaster-Carr
Shock Washers	1	$4.45	$4.45	McMaster-Carr
Shock Bolts	1	$9.85	$9.85	McMaster-Carr
Shock Absorbers with coil spring	2	$90.98	$181.96	Advance Auto Parts
Lower Control Arm Bolts	2	$7.75	$15.50	McMaster-Carr
Upper Control Arm Bolts	2	$5.98	$11.96	McMaster-Carr
Delrin Bushing For Lower A Arm	2	$15.00	$30.00	McMaster-Carr
Ball joints for Lower and Upper A Arms	2	$27.00	$54.00	McMaster-Carr
Heim Hex Nuts	1	$9.05	$9.05	McMaster-Carr
Rod ends for A Arms	2	$4.99	$9.98	McMaster-Carr
Hub Spacer	2	$12.99	$25.98	American Racing Hub
Total Cost			$460.57	

- Actual Budget

Parts	Qty	Price	Total	Source
4130 Chromoly rd tube 1"ODx0.095 Wall Thick	1	$82.99	$82.99	Mc Master-carr
Threaded insert tube bung	12	$8.25	$99.00	Mc Master-carr
male heim joints	12	$5.99		Mc Master-carr
Bolts + nuts	12	$9.89	118.68	Advanced auto parts
Lower/Upper arms Jig attachment	1	$60.99	$60.99	Advanced auto parts
Shock absorber w/ coil spring	2	$150.89	301.78	Mc Master-carr
Total cost			$663.44	

Figure 16- Budget

The actual budget was not the same with the proposed budget increasing to $200 for the completion of all parts. Expenditures are not bad enough compared to the proposed budget.

SCHEDULE, PROPOSED /ACTUAL

Monthly	Project Planning	Research	Design Phase	Modeling	Material Ordering	Manufacturing Phase	Testing
August	Observation						
September							
October		End up of research					
November							
December			End up of design	End up of design			
January					End up of ordering		
February							
March						End up of building	Checkup
April							End of final Project

The proposed and actual schedule doesn't change through the manufacturing process. This schedule flow explains how to achieve the 2019 Baja SAE project on time frame.

CONCLUSIONS

The customer requirements and product objectives of this car have been met. Even if the team could not get to the SAE Baja competition, this car should behave very well in competition. His behavior against an older car clearly indicated that this car would do well with good experience of this project in off-road racing. Our test conditions were realistic and frequent to use of the FEA. The real-world experience of the off-road race have created realistic loading conditions in the most demanding of the front suspension which can generate to the vehicle in the future.

Project Summary

The project summary was covering the entire detail during all researching and manufacturing process. All decisions made in this project were towards adhering to the competition rules and ensuring the proper functioning of all components; to minimize the risk of failure and ensuring the protection of the driver.

RECOMMEN DATIONS

I would recommend that all engineering students pay more attention to geometry when working on a front suspension with camber. The camber is manifested by a modification of the handling qualities of a particular suspension design in off-road conditions. On the other hand, the camber can improve the maximum acceleration in a straight line and traction is optimal when the camber angle is zero and the tread is flat on the road. You should be avoiding clearance issued by solving anti-dive geometry under braking weight during the travel.

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APPENDIX A

- **DEFINITIONS, ACRONYMS, ABBREVIATIONS**

‘,ft: Foot “: Inches ***d***: Decompression distance f: Force g: Gravitational constant h: Height KE: Kinetic energy lb: Pound lbf: Pound force lbm: Pound mass m: Mass s: Second Slugs: English unit of mass FPS: feet per second MPH: miles per hour psi: pounds per square Inch ksi: Kips per square inch τ: Shear Stress

APPENDIX B

- **QFD & HoQ**

	Customer Requirements	Importance wt.	Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees)	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)	Customer Satisfaction Rating (0.00 - 1.00)			
			Engineering Requirements (units)																	
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B	C
1	Accelerates Quickly	0.10	9									9		9	3		0.6	0.6	0.5	0.6
2	Maneuvers Easily	0.10		9		1				1		3				3	0.5	0.7	0.9	0.7
3	Meets Safety Specifications	0.15			9				3	1	1		1				0.2	0.8	0.7	1
4	Drives Over Large Obstacles	0.10				9	3						3	3		1	0.6	0.6	0.7	0.7
5	Climbs Steep Grade	0.05	3					9				1		9	1		0.4	0.7	0.8	0.5
6	Low Maintanence	0.05							9								0.7	0.5	0.8	0.6
7	Cost Efficient	0.10							9			3					0.6	0.5	0.6	0.8
8	Brakes Quickly	0.10			1					9		3					0.7	0.8	0.7	0.7
9	Ergonomical	0.10									9						0.6	0.7	0.8	0.6
10	Light Weight	0.15	3		1			3	9	3		9	3	3	3	3	0.7	0.7	0.9	0.9
	Total Importance	1.00																		
	Engineering requirement importance		1.5	0.9	1.6	1	0.3	0.5	3.2	1.2	1.1	3.2	0.9	2.1	0.8	0.9				
Performance	Current Product		2	1	1	2	3	2	3	3	3	4	2	3	3	2				
	competitor A		3	2	4	3	3	3	2	4	4	3	3	3	3	3				
	competitor B		2	2	3	3	2	2	3	4	3	4	3	2	3	3				
	competitor C		1	1	4	2	2	1	3	4	1	4	4	2	2	2				
	New Product Targets		4.5	4	5	3.5	4	4	3.5	4	4.5	4	5	4.5	3.5	4				

Interaction Matrix

Engineering Requirements	Engineering Requirement	Acceleration 0-20 (mph^2)	Turning Radius (ft)	Factory of Safety (SF)	Ground Clearance (in)	Wheel Travel (in)	45 Degree Incline (Degrees)	Materials Cost ($)	Braking Distance (ft)	Leg Room (in)	Weight (lbs)	Sustains Drop (ft)	Torque (lbf)	Speed (mph)	Stiffness (lbs/in)
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Acceleration 0-20 (mph^2)	1		-3	-3	-9	-9	3	1	-9	-9	3	-9	9	3	-1
Turning Radius (ft)	2			-3	-3	-3	-9	-1	-9	-9	-9	-9	-1	-1	1
Factory of Safety (SF)	3				-3	-3	1	9	3	1	1	3	-3	1	-3
Ground Clearance (in)	4					9	1	1	-3	-9	3	3	-9	-9	3
Wheel Travel (in)	5						1	3	-3	-9	3	9	-3	-3	9
45 Degree Incline (Degrees)	6							1	-9	-9	3	-3	9	3	1
Materials Cost ($)	7								3	-3	9	3	3	3	3
Braking Distance (ft)	8									-9	9	-9	-3	9	3
Leg Room (in)	9										-9	-9	-9	-9	-9
Weight (lbs)	10											3	3	9	1
Sustains Drop (ft)	11												-9	-9	9
Torque (lbf)	12													3	3
Speed (mph)	13														1
Stiffness (lbs/in)	14														

APPENDIX C

- ## Budget

Parts	Qty	Price	Total	Source
4130 Chromoly rd tube 1"ODx0.095 Wall Thick	1	$82.99	$82.99	Mc Master-carr
Threaded insert tube bung	12	$8.25	$99.00	Mc Master-carr
male heim joints	12	$5.99		Mc Master-carr
Bolts + nuts	12	$9.89	118.68	Advanced auto parts
Lower/Upper arms Jig attachment	1	$60.99	$60.99	Advanced auto parts
Shock absorber w/ coil spring	2	$150.89	301.78	Mc Master-carr
Total cost			$663.44	

APPENDIX D

- Flow processes

Monthly	Project Planning	Research	Design Phase	Modeling	Material Ordering	Manufacturing Phase	Testing
August	Observation						
September							
October		End up of research					
November							
December			End up of design	End up of design			
January					End up of ordering		
February							
March						End up of building	Checkup
April							End of final Project