2018 University of Cincinnati SAE Baja – Rear Suspension

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by

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ABSTRACT

The University of Cincinnati Baja SAE team competes against schools across the country by designing, building, and racing Baja type vehicles. This report will go through the redesigned rear suspension of the previous years (2017) Baja vehicle. With a desired outcome of this project being to provide a suspension solution that would perform better than the previous design. This report will go into detail about the design selection, manufacturing and results

ROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

The #6 University of Cincinnati Baja car currently has many different flaws in its design. As it sits now the rear suspension allows both rear axles to slide out of the rear differential as the suspension flexes. The current ground clearance for the car is far below the desired height that is needed for competition. We are unable to fit all team members into the current car under SAE Baja regulation, this will have to be addressed as well.

BACKGROUND

The goal in Baja SAE is to design, build and race off-road vehicles that can withstand elements of rough terrain against many different colleges around the country. These vehicles are often similar in appearance to dune buggies with large tires and a complete role cage that completely protects the driver. One main component of these cars is the suspension which allows for the cars to travel over rough terrain at high speeds by conforming to the terrain. This is made possible by combining long wheel travel, high ground clearance, strong structural frame ect.

The University of Cincinnati currently has three cars that are in various stages of their life. The most recent is the #6 car which currently sits as a completed car however it has never been certified for competition and has many design flaws. The remaining two completed cars are both still fully functional and certified, which will serve as great models for testing.

We are proposing a redesign of multiple aspects of the #6 Baja car that include but not limited to; front and rear suspension, cage design, ergonomics and a dynamometer. These improvements are needed for the car to be fully capable within the requirements for the 2018 SAE Baja competition. These will be completed in time for the Spring 2018 competition where we will have the car certified for competition, as well as be competing.

RESEARCH

SCOPE OF THE PROBLEM

The problem with the #6 Baja is that the current design of the car does not meet the requirements of the Baja SAE 2018. This problem is being addressed so the Baja team will be able to compete in the 2018 competition in Maryland. Each individual project is important due to the car needing to meet the requirements given in the Baja SAE Collegiate Design Series 2018 Rules (1) to be certified to compete.

CURRENT STATE OF THE ART

*Previous configuration of rear suspension.

The car that will be used will be the #6 car that was built in 2016. Currently the rear suspension on the #6 Baja car has many different flaws in its design. As it sits now the design allows both rear axles to slide out of the rear differential as the suspension flexes. The current ride height has very low ground clearance that does not allow proper clearance to move across uneven terrain. The placement of the rear Fox air shocks results in a rough and uncomfortable for the driver while allowing for little suspension travel adding to driver discomfort and overall performance. Many of the mounting points for support links, trailing arms, and wheel hubs have bent and need to be properly designed so this will not happen again. All of the above and more will need to be dressed in order for the #6 car to be ready for competition in Spring 2018.

END USER

The objective of BAJA SAE is to not only design a car competitive for competition, but to design it for the recreational user market. We are competing to have our car selected for manufacture by a fictitious firm. The prototype vehicle needs to demonstrate reliability, ergonomics, and competitiveness all while being economically valuable for manufacture and profitability by the fictitious firm.

The end user of the car will be the 2018 UC Baja team competing at the Maryland competition in April. Here we will be judged on acceleration, hill Climb, maneuverability and suspension. The car must be able to pass all tests without failures to prove reliability. On top of the physical events, we are also graded on our engineering design though both a submitted design report and on-site evaluation of the car. (1)

The rear suspension will have to be designed to pass or exceed each of the test specified by the SAE Baja rulebook. This includes but not limited to; sufficient ground clearance to clear obstacles, proper rebound and spring rates to allow fast movement over uneven terrain and ease of maintenance/replacement parts.

CONCLUSIONS AND SUMMARY OF RESEARCH

As the 2018 University of Cincinnati Baja team we are going to address the stated problems above. Each of these issues will be addressed individually with different team members, each member's projects are listed below. Each project was chosen to complete an integral part that is needed to compete in the 2018 competition. (1)

I am proposing a complete redesign of the rear suspension of the #6 car that will address and fix the issues stated above. This will be completed in time for the Spring 2018 competition and will be key in getting the #6 car ready to be certified for competition.

CUSTOMER FEATURES

Weighted importance of design specifications:

- 0.1 - Safety
- 0.25 - Suspension travel
- 0.2 - Ground Clearance
- 0.15 - Weight
- 0.15 - Reliability
- 0.1 - Maintenance/Ease of Replacement
- 0.05 - Cost

PRODUCT OBJECTIVES

- Safety
  - Design will adhere to SAE rules
  - Specifications will consider the weight of the driver up to 250lbs
- Suspension travel
  - Utilization of new Bilstein XVA Shocks adjustability
  - Improved shock travel from ~2" to ~6.5"
  - Have desired ride height not be at bottom of shock limit to allow for more rebound.
  - Fully independent
- Ground Clearance
  - Ground clearance at ride height will be 11.5" from the center of the rear end to bring closer to where other cars are at.
- Reliability
  - Design must hold up to 2018 competition
  - Must account for the weight of different riders
  - Robust while keeping weight down to a minimum
- Maintenance/Ease of Replacement
  - Use of standard parts as much as possible
  - Each side be independent from on another
  - Use of standard tools as often as possible
- Cost
  - Must not exceed given Baja budget
  - Receiving sponsorship from Bilstein for new coil over shocks

	Customer Requirements	Importance wt	1 Lightweight	2 Driver Escape <5seconds	3 10" Suspension Travel	4 14 inch Ride Height	5 Climb 45 Degree Incline	6 Reduce Specialty Bolts/Tools	7 Use Off Shelf Parts	8 Accelerate (Top 33.3%)	9 Capture 95th Percentile Males	10 Brakes Lock All 4 Tires	CP	
			Engineering Requirements (units)										Customer Satisfaction Rating (0.00 - 1.00)	
1	Accelerate Quickly	0.15	9		1	1	9			9				
2	Complete Endurance	0.15	3		9	9	3			3		9		
3	Safe	0.10		9	1	1	1				9	9		
4	Clear Tall Obstacles	0.10	1		9	9	3			3		1		
5	Climb Steep Hills	0.10	9		3	3	9			9		1		
6	Low Maintanence	0.10	3		3	3		3	3			1		
7	Low cost	0.05						9	9					
8	Drive Fast	0.10	9		1	1	3			9				
9	Ergonomic	0.05	3	9							9	1		
10	Brakes Quickly	0.10	9		1	1						9		
	Total Importance	1.00												
	Engineering requirement Importance		5.05	1.35	3.3	3.3	3.4	0.75	0.75	3.9	1.35	3.5		
Performance	Current Product													
	New Product Targets													

House of quality for the 2018 University of Cincinnati Baja Car. My design of the rear suspension affects clearance of obstacles, low maintenance, and safety.

DESIGN ALTERNATIVES AND SELECTION

The 2018 team was fortunate to get sponsored by Bilstein for shocks on the entire car. This was a great sponsorship and decreased everyone's costs significantly. However, this did limit the designs due to having a fixed size of shock. The shocks that we received from Bilstein were considerably longer than the previous year, which is why a new shock mounting location was necessary. Many different shock locations were considered, however due to the size and compression length of the shocks only one was found to fully utilize the range of movement. The new top mounting location was in the middle of the rear pillar on the frame, with the lower mounting location being on top of the trailing arm directly in line with the center of the wheel. The new shock location can be seen in red in figures 1 and 2.

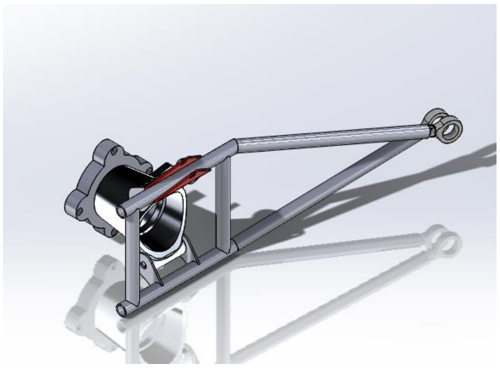


Figure 1

Figure 2

After new shock mount locations were decided upon the next issue was to ensure full utilization of our new shocks. This was done by creating a block diagram in SolidWorks shows in Figure 3. The block diagram set the rough dimensions for the support links that would determine the range of movement for the suspension. The block diagram allowed for a simulation of the suspension movement, and the support link geometry provided a range of movement with a >1 degree of change in camber. Which was sufficient for the design constraints.

However, during this process a new problem had come to light. The onboard CV axle was now going to be operating at a maximum of 20 degrees. This was an issue as the onboard CV axle at the time was only able to provide an operating angle of 13 degrees. This issue was due to the rarity of the spline pattern of the rear differential only matching up to that of certain late model cars whose operating angle was much shallower than current ATV CV axles that are currently used on the majority of SAE Baja cars. To overcome this the old spline shaft was taken off the current set of joints (in silver on figure 4) and then put onto an existing set of ATV axle CVs (shown in black Figure 4) The splines of the ATV joint were faced off to make way for the spline shaft that would fit into the differential. They correct shafts were then MIG welded onto the high and ATV shafts creating a custom high angle onboard CV joint specific for our application. This higher angled joint was needed to accommodate the desired ride height.

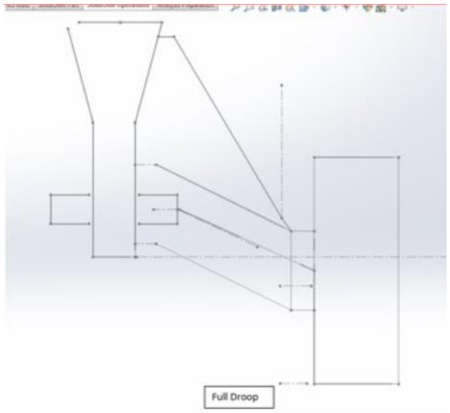


Figure 3

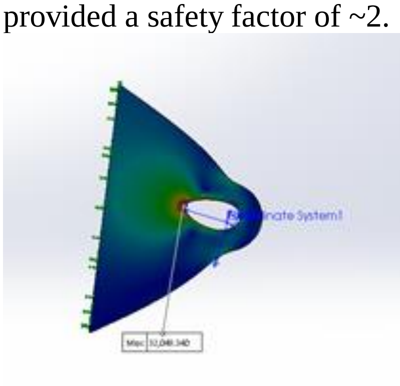
Figure 4

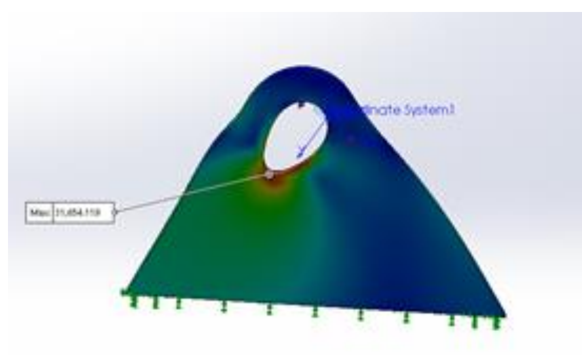
LOADING CONDITIONS

The loading conditions for the rear suspensions were design to be as small as possible, the new shock locations allowed for a more vertical shock position which minimized the lever arm created by the trailing arm of previous years. However, the shock mounts themselves were going to be subjected to a higher range of movement than previous years so a change in design was needed.

FEA

To better distribute the load on the shock mounts a wider base was used, this allowed for there to be plenty of material between the shock and the frame and any given operating angle. An FEA was done on each of the shock mounts at the highest and lowest angle to ensure the safety of the mounts. The material for the shock mounts is 1/8th" thick 4130 steel, with a maximum yield stress of 70ksi. The maximum force that would be going through the mounts would be a worst-case scenario at ~12,000lbf. After putting this into a bearing load on each mount the FEA provided a maximum stress at the shock mounts to be 31ksi which provided a safety factor of ~2.





Figures 5 and 6 respectively top and bottom shock mounts at worst case loading conditions.

The shock mounts on the top of the trailing arm mounts was set at an angle to provide as little of angular deflection as possible during the entire range of movement. The FEA of the trailing arms showed the largest amount of strain being put on the member that the lower shock mount would attach too. The trailing arms were chosen to be made out of 4130 Alloy steel tubing with an OD of 7/8" and an ID of 0.709" with a maximum stress of 70ksi. This material was chosen as it was easily weldable and had a high yield strength. A second FEA was done shown in Figure 7 that to show the stress that would result with the shock mounts welded on the tubing. The same ~12,000lbf bearing load was placed on the shock mounts, and the result was a maximum stress of ~38ksi which yielded the lowest safety factor at any location to be 1.84. This was determined to be sufficient as there will be structural rigidity added with the addition of mounting the wheel hub.

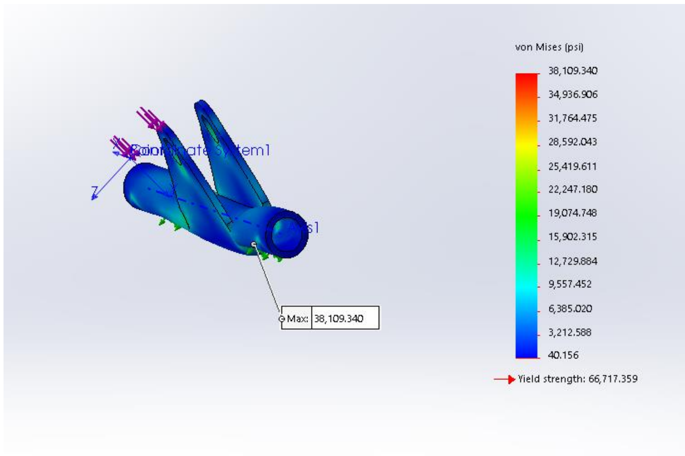


Figure 7 – Shock Mount on Top of Trailing Arm

CALCULATIONS

The worst-case scenario for maximum force exerted on the suspension was assumed to happen when falling from a 4-foot jump, landing on both rear wheels at the same time. Calculation shown in Equation 1

$$F = \frac{250kg(9.81\, m/s^2)(1.21m)}{0.203m}$$

$$F = 14{,}618\, N = 3286\, lbf$$

Equation 1 - Force on wheel from falling 4 feet

The side impact force was determined by assuming that the maximum side loading to be when the car was sliding sideways at 6.7 meters per second and came to a complete stop while hitting an object such as a tree or rock. This can be seen in Equation 2.

$$F = \frac{1}{2} * (250kg) * \ (6.7\ m/s)^{\ 2}$$

$$F = 5{,}619\, N = \ \mathbf{1{,}263}\ \boldsymbol{lbf}$$

Equation 2 – Side Impact Force

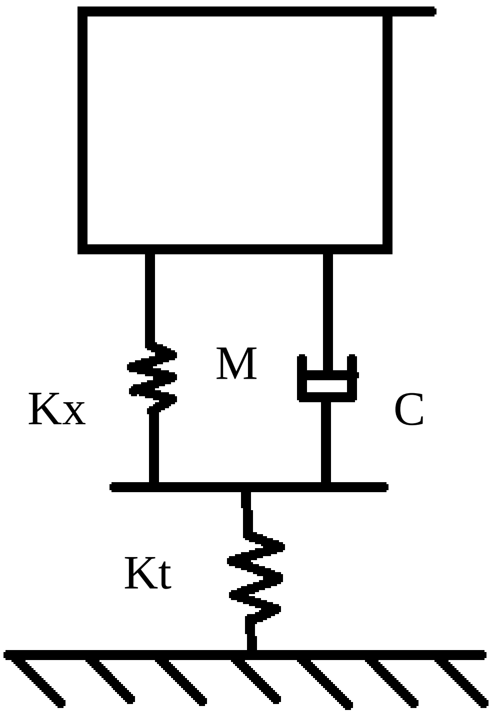


Figure 8 – Model of System

$$m\left(\frac{d^2x}{dt^2}\right) + C\left(\frac{dx}{dt}\right) + Kx = 0$$

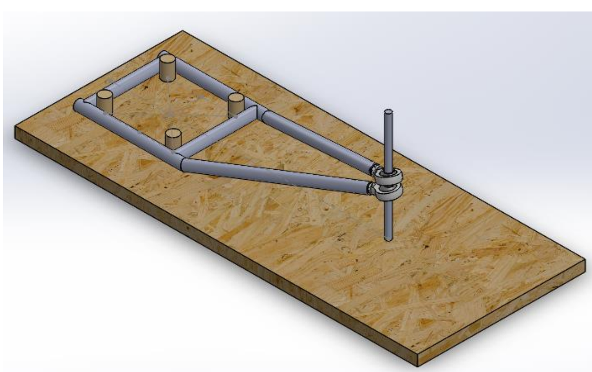
Equation 3 – Model of system

A model of the system was then made to make sure a stable system was in place. The mass of the car and drive, shocks and the spring rate of the tire were predetermined. This meant that selecting a spring rate for the coil overs was going to determine the stability of the system.

Due to the low tire pressures that are inherently ran in Baja races as well as the light weight of the car, the spring rate of the tire was removed from the equation due to have so little effect.

MANUFACTURING

A large emphasis was placed on manufacturing and making the process as simple as possible for this redesign. Because of this a the traditional spherical bearings that were attach the trailing arms to the frame were replaced by two separate hiem joints that would have concentric centers. This allowed for 2 less fish mouth joints as well as eliminating the need to press the bearings in, this set up can be seen in Figure 9.



The trailing arms were also designed to be symmetrical between the right and left side of the car. Allowing for spares to be kept of both sides and interchanged between left and right hand side. This was accomplished by keeping the center line of the wheel hub and the center line of the hiem joints co-linear. So that whichever way the arms were oriented the wheel would be positioned the same.

Figure 9 – Assembly Fixture of Trailing Arms

The fixture was designed to make assembly easy and efficient, minimizing fish mouth joints while allowing for easy set up. Once all of the pieces were cut to length they were tacked and TIG welded together.

All of the shock mounts as well as the lateral link brackets were cut via the CNC plasma cutter in the weld shop at Victory Parkway. Some finish grinding was needed to remove burrs however tolerances were held tight enough on the plasma cutter to forgo any additional machining on those parts.

Figure 10- Top shock mount

Figure 11- Lateral Link Mounts on Frame

The lateral links used ¾” OD aluminum rod with a right handed and left-handed thread on either end. This allowed for adjustability without taking the link off the car.

Figure 12 – Assembly of Suspension

Once the trailing arms, lateral links and shock mounts were fabricated they were attached to the frame. Then the desired maximum droop was set for each side of the car by placing a jack under the frame, letting the trailing arms fall freely on the ground. With the maximum droop in place, it was not possible to weld the shocks which were at full extension in place. This gave an accurate placement for the shock mounts achieving the desired ride height.

RESULTS

The final assembly of the rear suspension was successful, a ride height of 11.5 was established along with a wheel base of 54”. The wheel travel was unable to be completely tested due to an over calculation of spring rate. We were able to get a wheel travel of 8” however, with still ~2.5” of travel left in the shocks a lighter weight spring should bring this up to the desired 10.5” The weight of the system did end up a few pounds heavier than the previous suspensions, this was due to the use of coil overs which are inherently heavier than air shocks that were previously used. Due to the increase in adjustability and performance we receive from the coil overs, this extra was justified.

The original plan to test the suspension was going to be a drop test from 4 ft. Where the rear wheels would both hit simultaneously while the front wheels were 1.5 feet higher than the rear, simulating a jump. A strain gauge would read the maximum stress on the shock mounts which we could then derive the force and compare it to the calculated force.

However, due to difficulties in the logistics of dropping he car from the desired 4 ft. we were forced to push the rear of the car off a 3ft. ledge located at Victory Parkway shown in Figure 13

The results from the strain gauges came back unusable. The strain gauge data collection was the responsibility of another Baja teammate however, due to unforeseen technical difficulties we were unable to get usable data. This was due to the frequency that the strain gauge system took the readings, the time between reading was so large and the compression of the drop so short there was no data taken during the compression of the shocks. This was due to having 4 strain gauges collecting data at one time. It turned out that for every gauge you add to the system it halves the frequency of collection. With 4 gauges, we were only recording at 1/16th of normal.

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

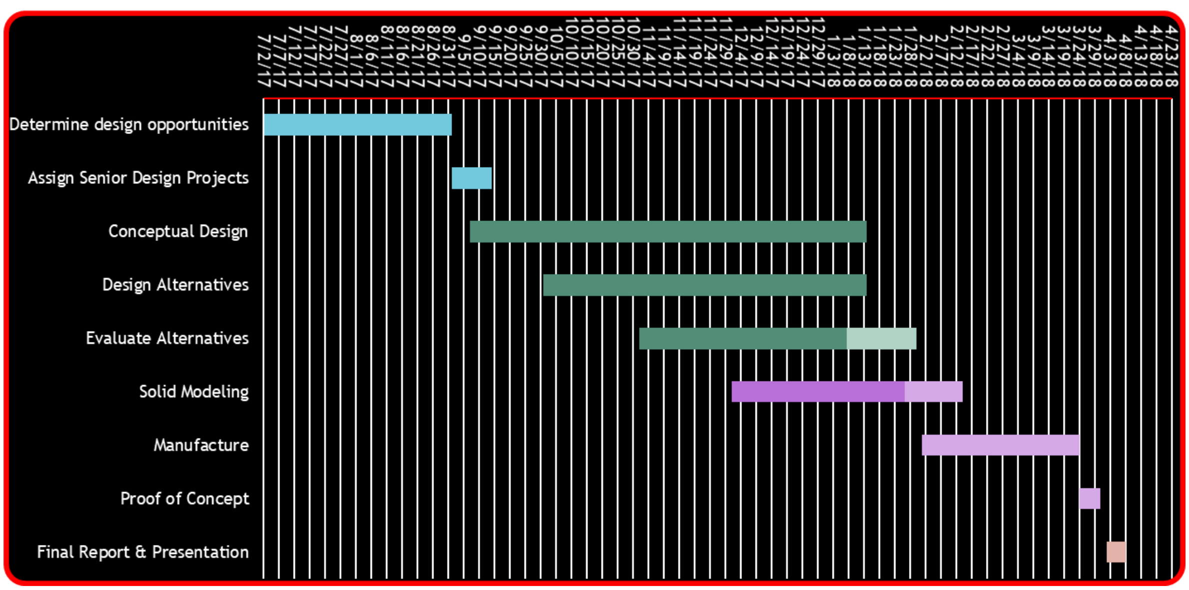
Proposed budget was $2,000.00 which was based off previous years suspension costs.

Actual spending listed in Table 1

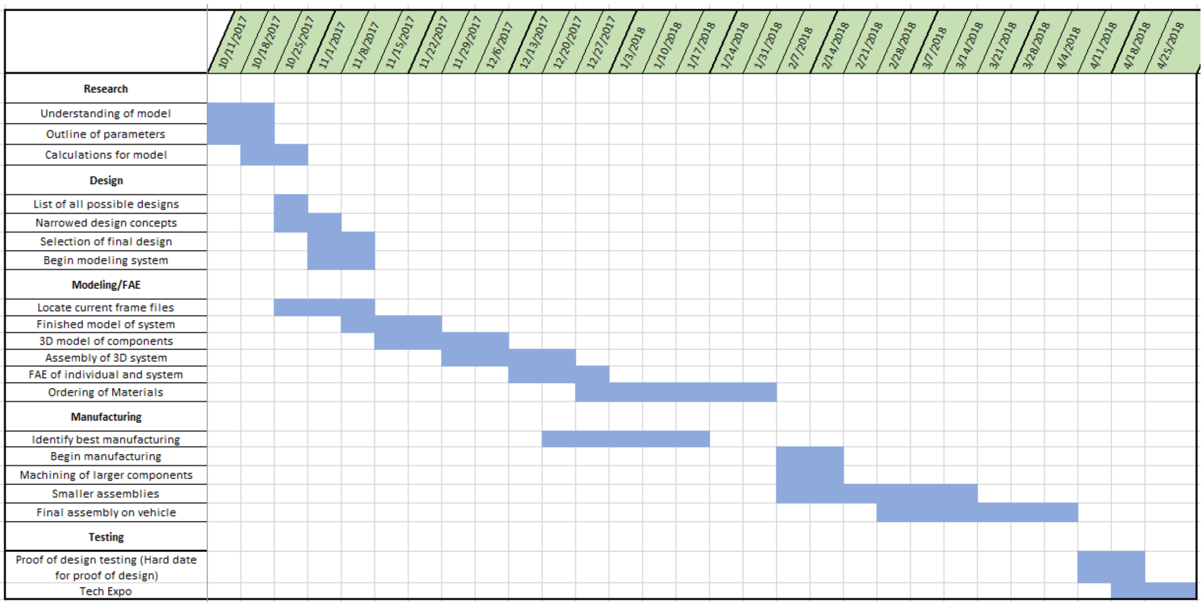
#	Supplier	Quantity	Part	Deisctription	Price / Part	Total
1	McMaster Carr	2	4459T288	36"x36"x1/8" 4130 Alloy Steel	$164.40	$328.80
2	Bilstein	2	33-252506	XVA Series Shock 46mm Monotube Shock Absorber	$0.00	$0.00
3	Hyper Coil	6	N/A	2.25 ID Coilovers, Multiple sets for different scenarios	$100.00	$600.00
4	McMaster Carr	4	89955K168	4130 Alloy Steel Round Tube 7/8" OD 0.759 ID 6 ft	$36.66	$146.64
5	McMaster Carr	2	89955K879	4130 Alloy Steel Round Tube 7/8" OD 0.709 ID 6 ft	$41.55	$83.10
6	McMaster Carr	6	6960T1	1/2"-20 Super Swivel Joint Right-Hand Thread	$20.36	$122.16
7	McMaster Carr	6	6960T1	1/2"-20 Super Swivel Joint Left-Hand Thread	$20.36	$122.16
8	McMaster Carr	10	4483T6	Nylon/PTFE Insert, 1/2"-20 Thread High-Load Rod End	$18.34	$183.40
9	Misc Ficture Hardware	1	N/a	Misc. Hardware Needed For Fixturing	$100.00	$100.00
10	Misc. Hardware	1	N/A	Misc. Hardware For Assembly	$100.00	$100.00
11						$0.00
12						$0.00
					TOAL	$1,786.26

Table 1 – Spending

PROPOSED SCHEDULE



ACTUAL SCHEDULE



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