Baja Drop Testing & Project Management

Senior Design Proposal 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

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Abstract

Seniors at the University of Cincinnati, studying to receive their Bachelor's in Mechanical Engineering Technologies must complete a senior design project. The project challenges students to design and manufacture a mechanical system that is presented at the end of their final semester. Baja SAE is a series of intercollegiate design competitions organized by the Society of Automotive Engineers as a senior capstone project. The following document outlines the team structure and responsibilities, and analyzes data from the standard drop test.

Problem Statement

Perform a real-world stress analysis on the 2018-19 Baja car that records the stress implemented on the rear shock mount locations during a 4 ft drop. Currently there is no physical test or representation of the reactions the Baja car encounters after landing from a height of 4 ft.

Research

Background of the Problem

Baja SAE is composed of a series of competitions that simulate real-world engineering design problems and their challenges. Students are instructed to design and build off-road vehicles that will survive extremely rough terrain. The objective is to design and build a single-seat, all-terrain, sport vehicle that encompasses the driver. The Baja car should simulate a reliable, maintainable, ergonomic, and economic production vehicle which serves a recreational user market.

The purpose of the competition is to provide students with an opportunity to design, plan and manufacture a prototype, similar to introducing a new product to the consumer industrial market. Teams compete to have their designs accepted by a fictitious manufacturing firm. Students must work together to design, build, test, promote, and race a vehicle within the limits of the rules, as well as financial support for their project.

The vehicle must be able to withstand harsh punishment from various types of territory. Baja SAE events include rock crawling, endurance racing, hill climbing, maneuverability, speed courses, etc. Throughout these courses the car will experience various impacts and loads, one common test is a 4 ft jump. For the vehicle to go to competition this must be tested to ensure operator safety.

State of the Art

<u>Analysis Software</u>

The primary form of conducting stress analysis is digitally through various forms of software. Currently, the industry uses CAD programs to model the structure of the frame. After the model is complete, engineers can then implement software that performs a finite element analysis. This shows the points where the structure will fail based on the amount of applied force, material, type of force applied and more. There are various types of software that can be used to perform finite element analysis, these include SolidWorks, Pro – e, ANSYS, and CATIA.

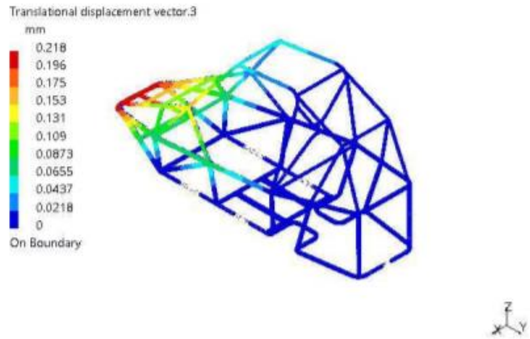

Figure 1: SolidWorks (Static Analysis of Roll Cage)

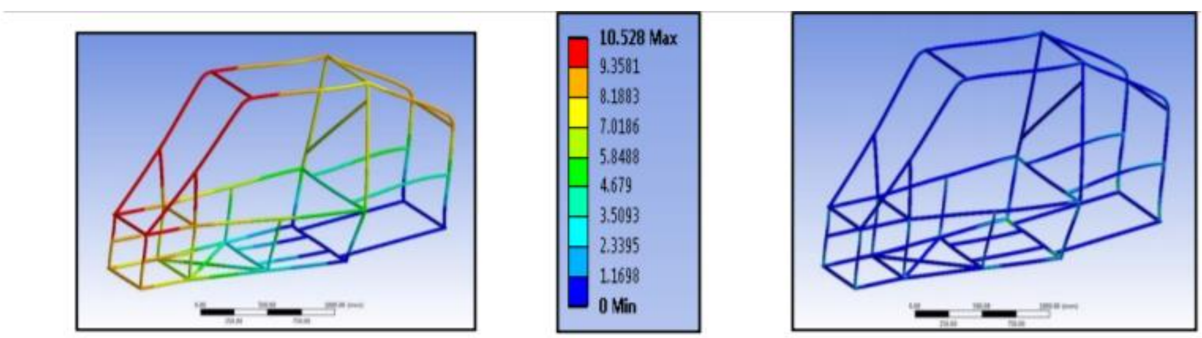

Figure 2: Pro – e (Stress Analysis of Roll Cage for an All-Terrain Vehicle)

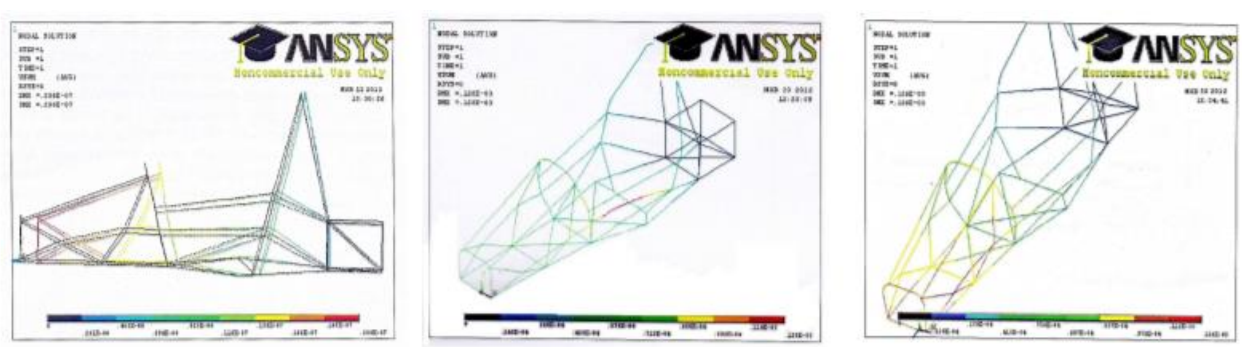

Figure 3: ANSYS (Analysis of a Roll Cage Design against Various Impact Load and Longitudinal Torsion for Safety)

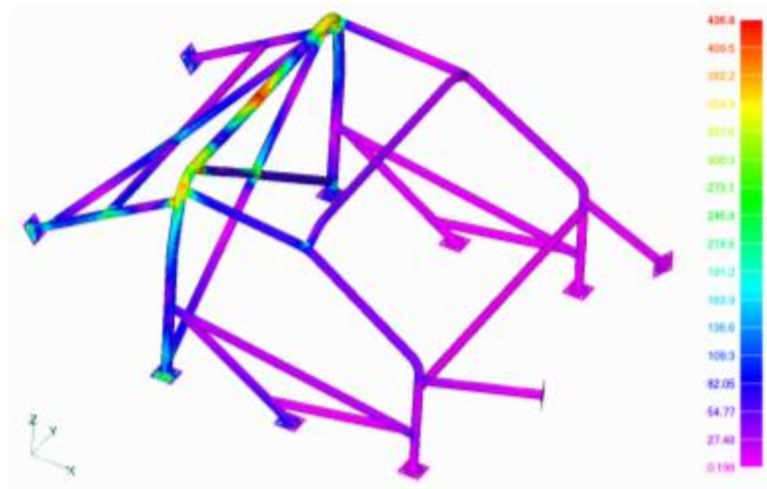

Figure 4: CATIA (Roll Cage Design and Validation for a Rally Vehicle)

The four figures above illustrate how each software highlights the key stress points of each frame. The display of each model changes from software to software, but traditionally the scale stays the same. You can see how the color progression starts with blue/purple and transitions to red depending on areas of high stress. Software's like these are the primary method used for testing the stress points of structural members.

<u>Strain Gauges</u>

There are five main types of strain gauges mechanical, hydraulic, resistance, optical and piezoelectric.

A mechanical gauge, also known as a crack monitor, uses cracks in the material to find how much stress the component is under. This is used by individuals like building inspectors to evaluate support beams.

A hydraulic gauge uses two pistons containing fluid, one large and one small, the unit is wrapped around the component and the small piston is observed. As the component is put under stress the fluid in the small piston moves and provides a stress recording.

An electrical resistance strain gauge uses a small strip of foil containing wires, when the strip is placed on the component, after stress is applied, the wires will either begin to separate or grow closer. This reading is then sent to your computer or monitoring circuit to provide a stress measurement.

Optical strain gauges are primarily used on glass and plastic, polarized light is shined at an angle towards the material. Some of the light is reflected and some is transmitted as the material deforms, the relative amounts of transmitted and reflected light illustrate the stress applied to the material.

Finally, piezoelectric, piezoelectricity is generated when you push or pull various types of crystals or ceramics, the displacement in the material creates tiny electrical voltages between their opposing faces. A piezoelectric gauge is used to measure that voltage and therefore the stress applied to the material.

End User

The primary end users of this product include, the members of the Baja team, the members of the SAE competition and, potentially, future recreational users. This product is specifically design for the SAE Baja competition, therefore the end users include all involved. One team will receive the opportunity manufacture and endorse their design as a full-time production vehicle for recreational users.

Summary of Research

The primary method for conducting stress analysis on structural members is through various forms of software. These methods can prove very effective by providing both a visual and statistical representation of how the frame will react under stress. However, there does not appear to be any form of physical testing done in the industry. By introducing strain gauges, we can test the physical stress from the force applied on the frame at different positions. These prove to be equally, if not, more effective than today's software.

Quality Function Deployment

Customer Features

1. Meets Safety Specifications
2. Light Weight
3. Accelerates Quickly
4. Maneuvers Easily
5. Drives Over Large Obstacles
6. Cost Efficient
7. Brakes Quickly
8. Ergonomic
9. Climbs Steep Grade
10. Low Maintenance

Engineering Characteristics

- Acceleration 0-20 (mph^2)
- Turning Radius (ft)
- Factory Safety (SF)
- Ground Clearance (in)
- Wheel Tavern (in)
- 45 Degree Incline (°)
- Material Cost ($)
- Breaking Distance (ft)
- Leg Room (in)
- Weight (lbs)
- Sustains Drop (ft)

- Torque (lbf)
- Speed (mph)
- Stiffness $\left(\frac{lbs}{in}\right)$

House of Quality

			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 Requirements	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														

Table 1: House of Quality & Interaction Matrix

Product Objectives

Rank	1	2	3	4	5
Durable					
Safety					
Lightweight					
Ease of Use					
Cost Effective					
Ergonomics					
Speed					
Acceleration					

Table 2: Baja Vehicle Objectives

Design

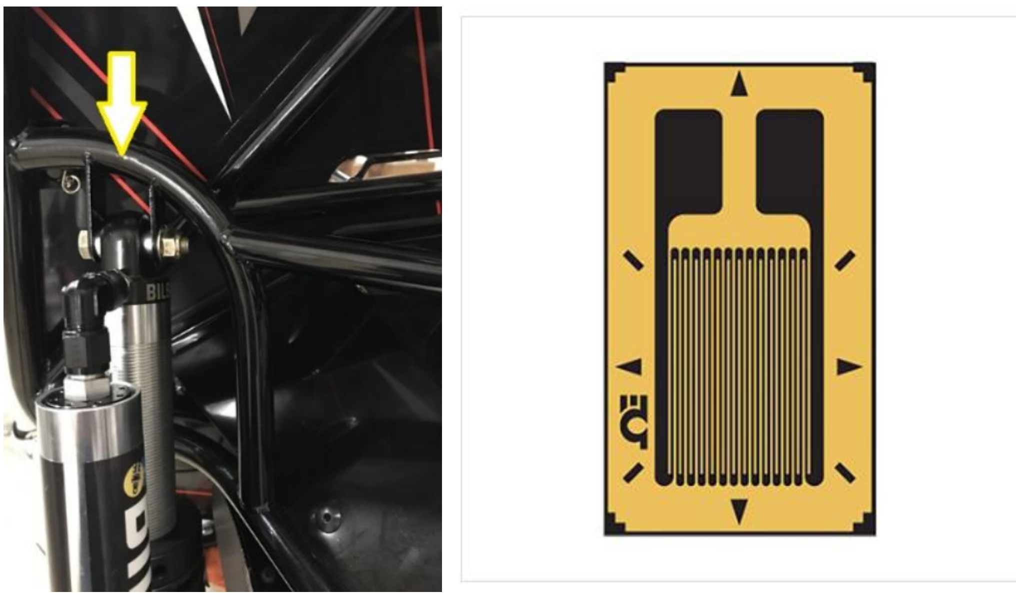

Figure 5: Gauge Location & Omega SGD-13/350-LY43

The testing design included two Omega SGD-13/350-LY43 strain gauges one mounted at the location shown in Figure 5 and another mounted at the same location on the opposite side of the vehicle. Each strain gauge was mounted using traditional Loctite super glue, the gauges were then soldered to wires connecting to the data logger.

Figure 6: OM-DAQXL Data Logger

During each drop an Omega OM-DAQXL multi-channel data logger was secured to the vehicle and used to record the force each member experienced. The system continuously logged data throughout the drop process. After testing this data was reviewed and compared to the FEA.

Equations Used

- $PE = mgh$
- $v = \sqrt{2gh}$
- $KE = \frac{1}{2}mv^2$
- $F_{avg\ impact} = \frac{\Delta KE}{\Delta x}$
- $\Delta KE = average\ impact\ force \times \Delta x$

Testing

Trial 1	2 ft
Trial 2	4 ft
Trial 3	6 ft

Table 3: Data Set-up

Three separate drop heights were determined for testing, the first trial would be a simple 2 ft drop. The second trial would be the more standard 4 ft drop, and the final trial would be 6 ft from the bottom radius of the tires to the ground.

Figure 7: Drop Test

The Baja vehicle was suspended using a 50 ft 1400 lb rated rope, a 3-ton crane (located at Victory Parkway Campus), and the hitch on a truck as shown in Figure 7. The rope was looped around the hitch and held as an anchor point as the crane lifted the vehicle to the designated height. The Baja car was secured to the crane with tires level to ground. When the correct height was reached the rope would be released and the car would descend evenly to the ground.

Results

During testing there was an error collecting data, therefore we were only able to get one clear recording from the 6 ft drop. This could be due to user error and construction; the resulting data was collected and the max force both shock mounts experienced during drop were compiled into Table 4 below.

Shock Mount Location (From back of Car)	Force (N)
Right	570.9
Left	582.1

Table 4: Drop Force Data

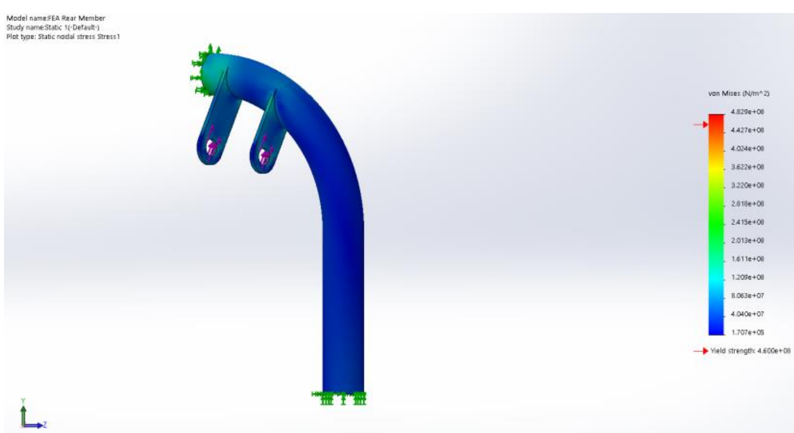

Figure 8: Shock Mount FEA

After collecting the data an FEA was conducted to verify that the material did not experience any permanent deformation. During calculations it was found that each tab experienced 2505.415 N during a 6 ft drop. Based on the FEA conducted below, the yield strength of the material is 4.600e + 008 $\frac{N}{m^2}$. This means that during a 6 ft drop the shock mounts will retain their structure and strength. This surpasses SAE Baja standards and verifies that the vehicle is ready for competition.

Project Management

Responsibilities

My responsibilities as team manager included establishing meeting dates/times, conducting all purchase requests, communicating with sponsors, communicating information between team members, overseeing projects, and provide support where necessary. At the beginning of senior design, we broke the team down into 10 individual projects, which can be seen in Table 5.

Members	**Responsibilities**
Nic Thome	Project Manager/Drop Testing
Gabriel Njoh	Front Suspension
Ryan Bross	Rear Suspension
Shawn Brown	Body
Chad Tschaenn	Frame
James Spychala	Brakes
Phil Lapresto	Pedals/Shifter
Rob Pohlman	Gear Box
Nick Kelly	Steering/Wiring
Nick Schmitt	Carbon Fiber

Table 5: Responsibility Break Down

Meeting Days & Times

During the first semester the team was split into two separate groups and would meet on two separates due to class schedules. The first semester meeting times can be seen below. The objective was to keep similar projects working and meeting at the same time. For example, front suspension, rear suspension and frame guys would all meet at the same time and day.

First Semester Meeting Schedule					
Member	Time	Day	Member	Time	Day
Nic Thome	1:30 pm - 2:30 pm/2:30 pm - 3:30pm	Friday - Nov 2	Jimmy Spychala	5 pm - 6 pm	Wednesday - Oct 31
Shawn Brown			Phil Lapresto		
Ryan Bross			Rob Pohlman		
Chad Tschaenn			Nick Schmitt		
Gabriel Njoh			Cason Williams		
Nick Kelly					

Table 6: First Semester Schedule

During the second semester the entire team was able to meet on Wednesday's from 3:00 – 4:00 pm, this is important especially because the second semester was primarily consumed with manufacturing and debug. The first semester consisted almost entirely of design which made having two separate meeting times acceptable because files can be shared and communicated digitally.

Initial Timeline

	September	October	November	December	January	February	March	April
Research								
Concept Selection								
Design								
Winter Presentation								
Order Materials								
Manufacture								
Debug								
Testing								
Tech Expo								
Spring Presentation								

Table 7: Initial Timeline

Final Timeline

	September	October	November	December	January	February	March	April
Research								
Concept Selection								
Design								
Winter Presentation								
Order Materials								
Manufacture								
Debug								
Testing								
Tech Expo								
Spring Presentation								

Table 8: Final Timeline

At the beginning of the SAE Baja project our team established the timeline shown in Table 7. By the first week of April we had planned to finish testing and have the car ready for Tech Expo. Due to lead times, design complications, and debug the timeline shifted back slightly with ordering and manufacturing leading all the way into April. Despite these issues the team was still able to complete the vehicle for Tech Expo and further testing was moved to after the event.

Budget & Cost

Previous Budget Range	$20,000-$25,000
Estimated Budget	$15,000
Total Cost	$12,836.10

Table 9: Budget & Total Cost

The 2018-19 Baja car was very different than previous years in both design and quality as well as cost. Previous teams were allotted anywhere from $20,000 - $25,000 to build a car, our team was only given a budget of $15,000. After completing the project, the total cost of the 2018-19 Baja car was $12,836.10 this is well below the budget we were given, and at least $7,000 lower than any previous budget. A lot of this was due in part to the list of sponsors below, each of these companies helped fund various components on the Baja car.

Sponsors

- Valvoline
- Bilstein
- D & D Racing Engines
- Machintek
- Precision Tool
- Morelands
- Battery Men

Valvoline funded our program with $5,000, Bilstein provided over a $1,000 in shocks, D & D Racing Engines sold us all roll cage and suspension material at wholesale cost. Machintek water jetted various pedal components for us without including labor cost, Precision Tool machined a set of custom CV shafts for no cost, Morelands provided us with pedal components at wholesale value and Battery Men provided our team with the battery that powers our vehicle. Without these sponsors it would not have been possible to create the quality and performance vehicle we have this year. The outcome of our design could not be a better representation of the support shown by each one of these companies.

Conclusions

The 2018-19 Baja car is a complete success. The quality and performance of this build surpasses any previous car built before. Our team was able to incorporate innovated designs, higher quality construction, and modern style to manufacture our representation of the University of Cincinnati Baja team and the 2019 MET/ME class. The 2018-19 car is a competition ready vehicle that we hope to have around for years to come.

I had the privilege of managing a very talented team of individuals that worked together to build a Baja car to the exact specifications necessary for competition. The car was able to withstand a 6 ft drop with little difficulty, which not only certified it for competition, but is also a display of the quality of work completed this year. The 2018-19 Baja car will be a fierce competitor for years to come and we hope to see it at events in the future.

Recommendations

For future Bearcats managing Baja and conducting drop testing here are some recommendations to improve on the flaws included in this report. During future drop testing, research the correct adhesive and strain gauge for your material, this will help the data logger collect more accurate readings. I also recommend using strain gauge bolts, these are bolts with the strain gauge mounted inside their structure and can record the force the bolt is experiencing.

By using strain gauge bolts, you can directly correlate the FEA to the real-world testing. A bolt can be placed inside the CAD system and the force can be applied directly at its location. This will help eliminate inaccuracies in data collection and the FEA. When working with the Omega OM-DAQXL multi-channel data logger make sure to properly solder and wire each strain gauge to the proper location. Purchasing the proper strain gauge can eliminate this issue, but also increases cost dramatically. When working under a lower budget you must take this into account as the project manager.

Project manager includes various responsibilities, organization is extremely important when keeping track of purchasing and purchase requests. Always keep an excel file documenting all purchases and returns as well as a designated folder for purchase requests. This provides the project manager with two separate forms of documentation when reviewing budgets and funding. The entire team is the project managers responsibility, so they must take control when necessary. As the project manager you must not be afraid to let members know when they are lacking and ensure the continuous progression of the project. Always stay on top of things and get the team started early, it’s better to be finished two weeks ahead than the night before and you must always prepare for obstacles. Good luck future Baja members.

References

1. *Static Analysis of Roll Cage.* **Chakraborty, Santanu and Neopaney, Hemant K.** 2, s.l. : International Journal of Emerging Technology and Advanced Engineering, 2014 , Vol. IV. ISSN.

2. *Analysis of a Roll Cage Design against Various Impact Load and Longitudinal Torsion for Safety.* **C.D., Naiju, et al.** CCXXXII, s.l. : Trans Tech Publications, 2012, Vol. 232.

3. *Roll Cage Design and Validation for a Rally Vehicle.* **Pavlovic, A. and Zivkovic, M.** s.l. : FME Transactions, 2016, Vol. XLIV.

4. *Stress Analysis of Roll Cage for an All Terrain Vehicle.* **Mevawala, Denish S, et al.** s.l. : IOSR Journal of Mechanical and Civil Engineering, 2014. ISSN.

5. **SAE International.** SAE International. *www.sae.org.* [Online] SAE International, 2018. [Cited: October 11, 2018.] https://www.sae.org/attend/student-events/baja-sae-rochester/about.

6. **Woodford, Chris.** How strain gauges work. *Explain That Stuff.* [Online] February 24, 2018. [Cited: October 11, 2018.] https://www.explainthatstuff.com/straingauge.html.

Appendix A

Definitions, Acronyms, Abbreviations

CAD – Computer-Aided Design

FEA – Finite Element Analysis

ME – Mechanical Engineering

MET – Mechanical Engineering Technologies

SAE – Society of Automotive Engineers

Appendix B

Calculations

Assuming

Weight of car: $500\ lb \cong 227kg$;

Height of drop: $6ft \cong 1.829m$

Compression: $8in \cong 0.203m$

$$v = \sqrt{2gh}$$

$$v = \sqrt{2\left(9.81\frac{m}{s^2}\right)(1.829m)}$$

$$v = 5.987\frac{m}{s}$$

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}(227kg)\left(5.987\frac{m}{s}\right)$$

$$KE = 4068.793\ J$$

$$F_{avg\ impact\ total} = \frac{KE}{\Delta x}$$

$$F_{avg\ impact\ total} = \frac{4068.793\ J}{.203m}$$

$$F_{avg\ impact\ total} = 20043.317\ N$$

$$F_{avg\ impact\ per\ tab} = \frac{\left(\frac{20043.317\ N}{4}\right)}{2} = 2505.415\ N$$