Steering & Front Suspension Design

SAE Mini Baja

Preliminary Proposal

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2017-2018

LUMBERJACK MOTORSPORTS

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I - DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

Contents

II - BACKGROUND

1 - Introduction

The Mini Baja Collegiate Design Competition is sanctioned through the Society of Automotive Engineers (SAE) every year in three locations in the United States as well as four international competitions. This project entails designing, building and testing a single person Baja buggy from the ground up. Our team will be designing the vehicle strategically in correspondence with our customer's requirements and related engineering standards set in place. When the vehicle has finished going through a rigorous testing and re-design process, we will be attending competition in Portland, Oregon against schools from all over the world. Some criteria that we will be graded based on is our performance on track, as well as a design/sales presentation. This project caries great relevance with sponsors from all aspects of engineering. Some of these companies that recruit through this project and are involved in the competition include SolidWorks, Honda, Briggs and Stratton, Polaris, Cummins, Volvo, Space X, and ANSYS. This project sets a great foundation for these companies to build upon when it comes to design, manufacturing, testing, and product development.

2 - Project Description

SAE has put in place a design description of the guidelines that are to be followed and a specific scope of the project. This is a broad project description to allow for each team to interpret the path that they believe best fits the goal. Following is a direct statement from the 2018 SAE Baja rulebook.

> "Each team's goal is to design and build a single-seat, all-terrain, sporting vehicle whose driver is contained within the structure of the vehicle. The vehicle is to be a prototype for a reliable, maintainable, ergonomic, and economic production vehicle which serves a recreational user market, sized at approximately 4,000 units per year. The vehicle should aspire to market-leading performance in terms of speed, handling, ride, and ruggedness over rough terrain and off-road conditions. Performance will be measured by success in the static and dynamic events which are described in the Baja SAE® Rules, and are subject to event-site weather and course conditions." – [1]

This design description will assist the team on how to prioritize our engineering requirements and which will carry more weight moving forward. A sales and design presentation will also be performed at the competition, this will prioritize organization and having reasoning for each aspect of engineering on our vehicle.

III - REQUIREMENTS

In this project, there are very little requirements for front suspension design put in place by SAE. There are many safety requirements to assure safety of the event personnel, the team members, and the drivers during the events. Although our team feels that there are some key design characteristics that if followed, will greatly increase our chances of placing well in the competition. The customer's requirements as well as the engineering requirements will be listed below, weighted, and explain the reasoning behind the importance to our project.

1 - Customer Requirements (CRs)

The customer requirement associated with the front-end design are embodied by the project description set forth by SAE stated earlier. The design of the front-end of the vehicle must follow safety, economic, reliable, maintainable, and mass producible standards. Customer requirements regarding the SAE rulebook were weighted above five because of their relative importance to our objective. Other customer requirements that are associated with the static and dynamic events include: appearance, lightweight, ease of manufacturing, and inexpensive. The event customer requirements are important to the performance of the vehicle during competition and were weighted below five. Both types of customer requirements selected for front-end design are important to achieve a high ranking during competition.

2 - Engineering Requirements (ERs)

Engineering requirements were established from knowledge of previous Baja designs and information collected from the competing Baja teams. This information was used to develop the technical requirements and set general dimensions for the front-end design. The technical requirements for the front-end design are wheelbase, track width, ground clearance, wheel size, weight, strength, brakes, turning radius, and cost. These engineering requirements were compared to high ranking Baja teams from previous competitions to set target values.

3 - House of Quality (H.o.Q.)

The customer and engineering requirements were supplemented into a QFD to acquire the relative technical importance of the technical requirements (Figure 1). Priority technical requirements for front-end design include strength, spring rate, weight, and cost. These priority technical requirements are imperative to designing a front-end that meets the customer requirements. The other technical requirements that serve as a foundation for the front-end are ground clearance, brakes, turning radius, wheelbase, track width, and wheel-size. These secondary requirements are important to the performance of the vehicle, but are less impactful on customer requirements. Moving forward on front-end design; the focus will be toward the priority technical requirements established by the QFD. The target values of these technical requirements should all be met because they are critical to the success of the front-end design.

System QFD

Front-End

Project: SAE Baja

Date: 10/5/2017

Correlation	
++	Strong Positive
+	Positive
	No Correlation
-	Negative
--	Strong Negative

Technical Requirements

Technical Requirements	Wheelbase	Trackwidth	Ground Clearance	Suspension	Steering	Weight	Strength	Brakes	Turning Radius	Cost
Wheelbase										
Trackwidth										
Ground Clearance										
Suspension	-		++							
Steering	-	+								
Weight	+	-								
Strength			+	++		++				
Brakes					+	--	+			
Turning Radius	++	--								
Cost	+	-	+	+		--	++	+		

Customer Needs	Customer Weights	Wheelbase	Trackwidth	Ground Clearance	Spring Rate	Wheel size	Weight	Strength	Brakes	Turning Radius	Cost
Durable	9			7	9		5	9			3
Maneuverable	7	9	7	7		3				9	
Reliable	9				7			9	5		
Maintainable	9			1				3	1		
Appearance	3	1	1	1							1
Economic	3										1
Safety	7							9	9		3
Lightweight	5					1	9	5			7
Ease of Manufacturing	5				5		3	5			5
Inexpensive	3				3		7	9			9
Mass Producable	7				1	1	3	3			
Technical Requirement Units		in.	in.	in.	lb/ft	in	lb.	lbf	in	in.	$
Technical Requirement Targets		58	50	11	100	25	315 w	7000	0.5	108	20,000
Absolute Technical Importance	1278	66	52	124	185	33	147	350	117	63	141
ATI (percent)		0.05	0.04	0.1	0.14	0.03	0.12	0.2739	0.09	0.05	0.11033
Relative Technical Importance		7	8	5	2	9	3	1	6	7	4

Figure 1 QFD for the Front End of an SAE Vehicle

Part of our decision process came with designing a House of Quality. This assisted our team in ranking our engineering requirement to better understand what should be a priority when moving forward with design.

As expected from our research, our weight, strength and cost of our components showed to be the most important aspects of the front design portion of the Baja vehicle. Knowing how our engineering requirements rank help us better prioritize our compromises that have to be made in design.

V - EXISTING DESIGNS

1 - Design Research

Some of our design considerations came from past vehicles entered and their associated results. This can be a good or bad result; the main aspect to study is why this result occurred. Many past competitions have kept data on each vehicle that passed through the technical inspection process. This data is easily accessible through SAE's website and was very helpful for the front-end design team to gather ideas and parameters to follow. These parameters include ride height, track width, wheelbase, etc. Track width and wheelbase were the main values we were looking into narrowing down through our analysis.

2 - System Level

When designing a whole car, there are many sub systems that interact for each given input. The front suspension of a car can be extremely well engineered, but a poor steering our rear suspension can throw the balance off completely. This introduces the importance of a full system that works towards a single goal. For our SAE Baja team, that one goal is to design vehicle that is rides the thin line between lightweight and high strength. The systems that our team is assessing are identical to the designs that we are considering for our front-end application. These will be explained in depth with pros and cons of each possible route and which we believe suites our vehicles goal the best.

3 - Black Box Model

When analyzing the front-end portion of the Baja vehicle, the main dynamic phenomenon occurs with steering and suspension articulation working together. Our design must be able to take in all inputs and assess proper outputs that will allow our vehicle to handle well and perform well during competition. Our mechanical inputs include steering link rotary motion put in place by the driver through the steering wheel. This goes into a gear box that speeds up the driver's inputs by up to a 12:1 ratio. This travels linearly out to the steering linkages which interact with our tires. This system is what connects the driver and our vehicle course of motion. These inputs working as one should allow the drivers inputs to strategically be routed to the track surface for optimal traction and maneuverability. Shown below in Figure 2 is the block box model that shows our flows of energy through the vehicle.

Figure 2 Black Box Model for the Front of an SAE Vehicle

The outputs include traction to the surface, which relies heavily on tire selection and weight distribution of the car dynamically. Noise and heat transfer follow closely with the traction due to frictional forces. This whole system is working in unison to help our car optimize movement and weight transfer for traction purposes.

4 - Functional Model/Work-Process Diagram/Hierarchical Task Analysis

Breaking each functional system down for the entire vehicle begins with the design. To have a smart designed vehicle the design must derive from the most basic yet important aspects. The FEA of the frame allows for a light, yet strong body for the vehicle. The brake design allows for the front and rear end teams to develop an accurate and effective spring constant for their suspension designs. The drive train calculations will allow for the rear end team to send their required specifications to the CVT client and allow for the delivery of a tuned transmission. The team will then take these developments and use them in further developments to create a smart designed final vehicle.

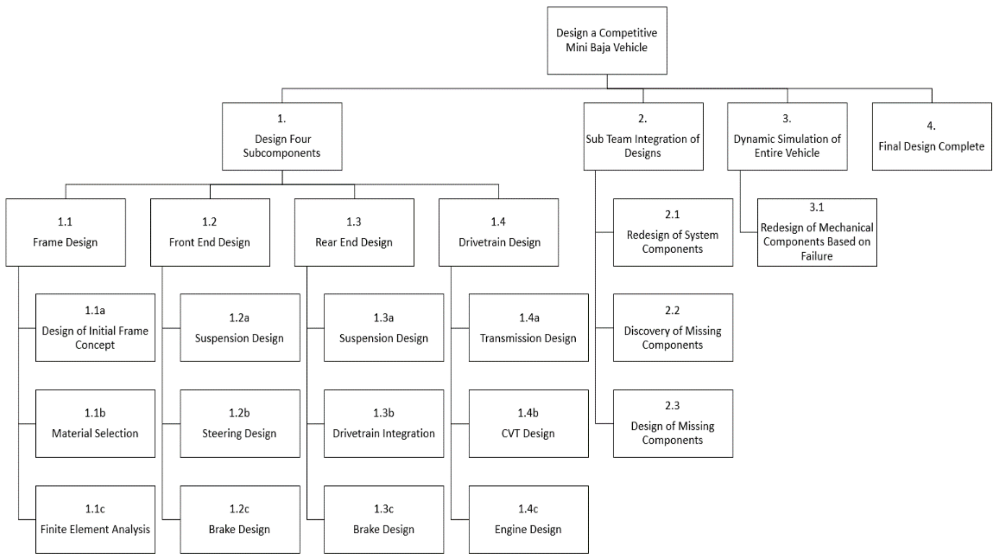


Figure 3 Functional Model for a Complete SAE Vehicle

For the rear-end sub team, the focus was to create a smoothly articulating suspension design that is strong, yet durable. Starting by designing a full CAD model, we will mock our whole suspension up with shocks to assess high stress points and travel issues. Some issues that we are prepared to solve are bump steer problems and excessive camber change. These calculations will be made to result in a better preforming design and the system will restart until a final design has been decided upon. As seen in Figure 4 the process is shown to be a continuous cycle that is only completed when the requirements for the design are met to a satisfactory level.

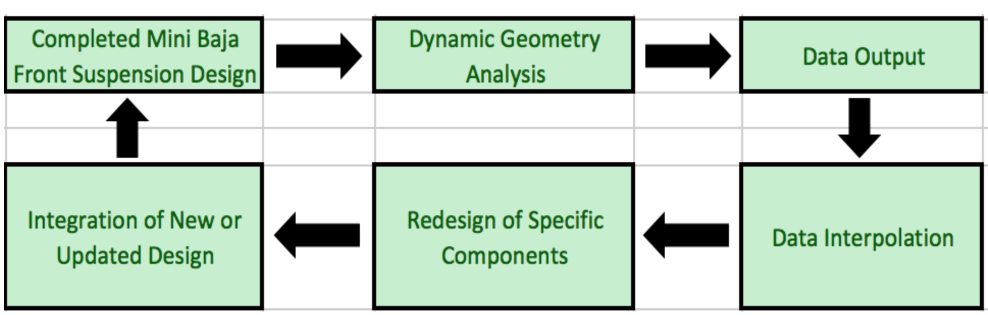


Figure 4 Design Cycle for the Front of an SAE Baja Vehicle

By using this cycle, our sub team can design a structurally sound front suspension that functions as designed to under off-road conditions.

5- Subsystem Level

Our front suspension design can be divided into multiple systems that must cooperate with each other to function properly. Even with a smoothly articulating front suspension, steering linkage angles and pickup points that are off can result in an undrivable vehicle. Every component must not only do their job, but also work in unison with the other sub-systems. Sub-systems that will be analyzed include the overall suspension type, the steering geometries, and steering mechanisms.

6 - Subsystem #1: Suspension System

For proper front-end design of a vehicle, designers must understand the functional goals of their design. These goals will vary between applications as the situations for each. As the Society of Automotive Engineers (SAE) Mini Baja Collegiate competition requires an off-road prototype vehicle that "must be capable of safe operation over rough land terrain including…rocks, sand, logs, steep inclines, mud, and shallow water…" [1], our design will have to meet specific goals. For off-road purposes, several on-road goals become irrelevant while others become more important. With a few goals in mind, our front-end design team can begin choosing our best possible fit. The five main focal points of our design are as follows, in no particular order:

1. < 10' turning radius
2. Maintain tire patch through body roll
3. Minimize scrub through articulation
4. Minimize bump steer
5. 10" wheel travel

With the above goals defined, we can ensure that our design will meet all the major requirements.

6.1 - Existing Design #1: Equal and Unequal Length Double A-arms

Equal and unequal double A-Arm front suspension are the most widely used suspension geometries, especially for most competitive off-road applications. This setup routes the shock through the middle of the upper a-arm, and mounting to the lower a-arm. The better of the two for our application is the unequal length arms. The equal length arms gain positive camber during body roll and cornering which hinders traction. Unequal arms can be positioned to maintain maximum tire patch through body roll. Figure 5 displays an example of unequal length a-arms on an SAE Mini Baja competition vehicle. The unequal length a-arm design allows for a truly custom and optimized geometry. From a manufacturing perspective, the unequal length a-arm setup is simple to fabricate and allows for different fabrication methods (tubular arms (Figure 5), boxed arms (Figure 6), machined from billet materials (Figure 7)]

Figure 5 Double A-Arm Suspension Geometry, Fabricated from Round Tubing

Figure 6 Double A-Arm Suspension Geometry, Boxed-Style Fabrication

Figure 7 J-Arm Suspension Geometry, Billet Machined Upper Control Arm

Table 1: Pros and Cons of Equal and Unequal length double a-arms

Pros	Cons
Strong	Design Intensive
Lightweight	Average Wheel Travel
Low Scrub Through Articulation	Low Front Weight Distribution
Minimal Camber Change	
Maintains Tire Patch	

6.2 - Existing Design #2: Twin I-beam

The Twin I-Beam front suspension is best known for its application on older model Ford pickup trucks. They can provide extreme amounts of wheel travel which is greatly beneficial in off-road competition applications. This benefit alone is the main reason some racers still utilize this setup. When designed correctly, although sacrificing ground clearance, a Twin I-Beam setup can be strong, simple, and articulate well in typical SAE Mini Baja events.

Figure 8 shows the front suspension design of the 2016-2017 SAE Mini Baja team from Northern Arizona University. The wide front track width offers a substantial amount of stability and articulation. Steering becomes very complicated with this setup and presents significant amounts of fabrication difficulty due to the precision required to function properly.

Figure 8 Twin I-Beam Suspension Geometry

Table 2: Pros and Cons of Twin I-beam

Pros	Cons
High Wheel Travel	Camber change is extreme
Simple Design	High amounts of scrub through articulation
Strong	Less Ground Clearance
More Front Weight distribution	Bump Steer values are normally high
	Over Complicates Steering

6.3 - Existing Design #3: McPherson Strut

The McPherson Strut style front suspension is also a viable option for design. This application routes the dampening mechanism in place of an upper control arm. The damping mechanism is attached directly to the top end of the steering knuckles. Though not commonly used in off road designs, an SAE Mini Baja type vehicle can benefit from the favorable light-weight design. This design only requires a single lower a-arm, which makes design much simpler. Figure 9 illustrates the use of a McPherson Strut style suspension setup on an SAE Mini Baja vehicle.

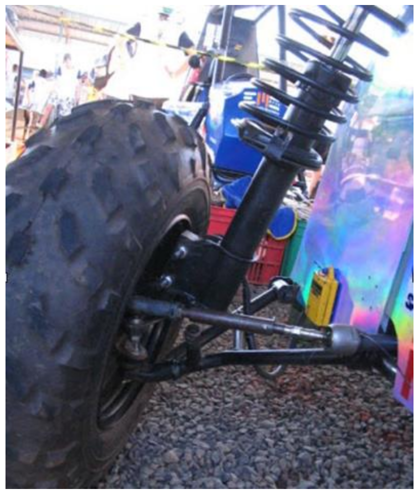


Figure 9: McPherson Strut Suspension Geometry

Table 3: Pros and Cons of McPherson Strut

Pros	Cons
Lightweight	Less Adjustability
More Potential Leg Room	Places Higher Stress on Weaker Members
Less Design Work (Simplified)	Higher C.O.G.
	Less Horizontal Load Support

7- Subsystem #2: Steering Geometries

There are two general types of steering that are effective in the SAE Mini Baja applications: Ackerman Steering and Parallel Steering. Many on-road vehicles on the market today use a combination of parallel and Ackerman steering to reap the benefits of both geometries. The sections below illustrate the two different geometries and discuss the benefits and drawbacks of each for the intended application.

7.1 - Existing Design #1: Ackerman Geometry

Ackerman steering design incorporates different wheel angles for the inside tire and the outside tire during turning. This design is best used for slow-speed (35 MPH and lower) and tight radius maneuvering. Figure 10 below displays a two-dimensional depiction of Ackermann Steering design.

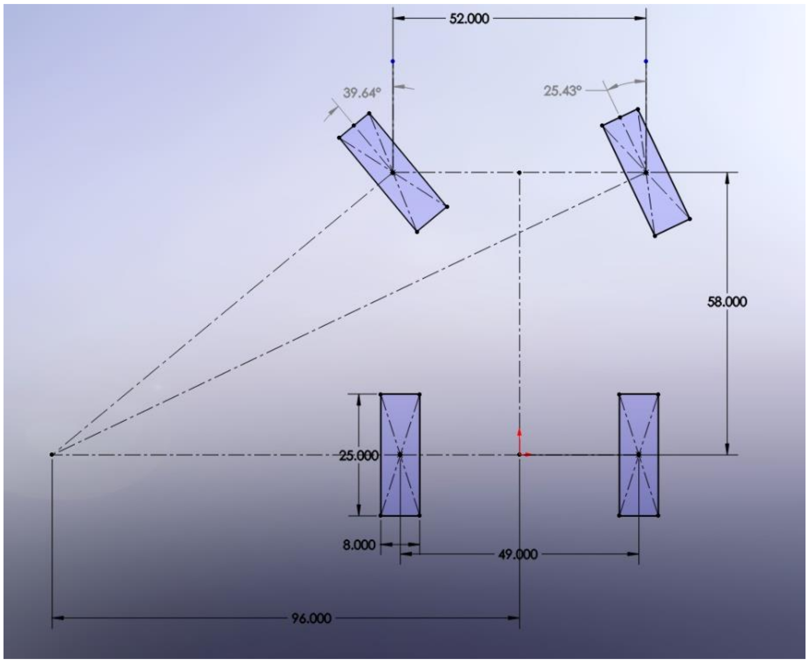


Figure 10 Two-Dimensional Representation of Ackerman Steering Geometry, as seen from top of vehicle

7.2 - Existing Design #2: Parallel Geometry

Parallel steering geometry positions both the inside wheel and the outside wheel at the same angle off-center. This design is highly beneficial for applications such as high-speed (35 MPH and up) and large radius maneuvering. Many road cars and racecars use a combination of parallel and Ackermann geometries. Since the steering arcs are not concentric, as seen in Figure 11, parallel steering geometries cause the outside tire to understeer heavily in low-speed corners which hinders traction and makes maneuverability more difficult.

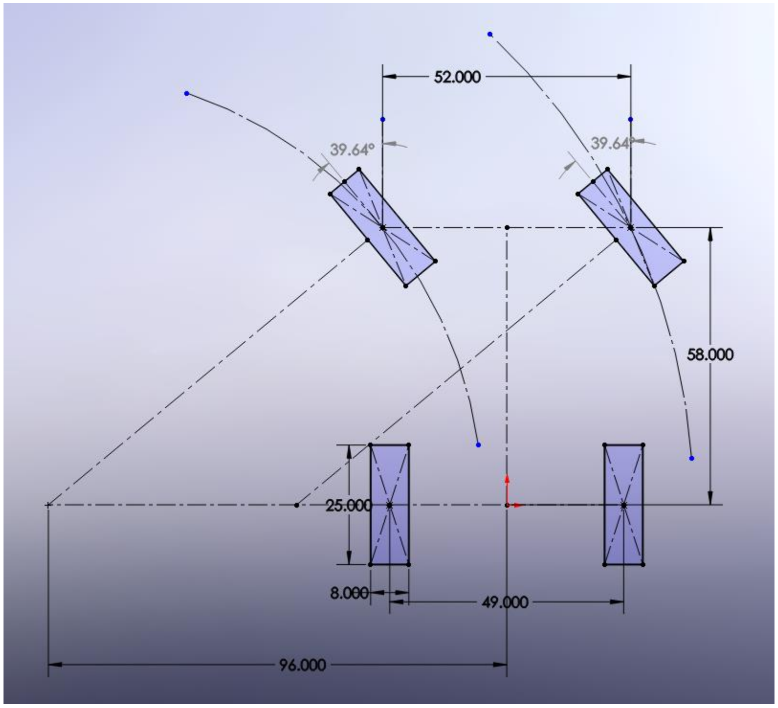


Figure 11 Two-Dimensional Representation of Parallel Steering Geometry, as seen from top of vehicle

8- Subsystem #3: Steering Mechanisms

There are several types of steering mechanism in use in the automotive industry. These can be broken into two categories: hydraulic and mechanical systems. The hydraulic systems are much too complicated and add a significant amount of unnecessary weight, so they will not be discussed in this report. Discussions of possible mechanical systems are in the sections below.

8.1 - Existing Design #1: Rack and Pinion

The rack and pinion steering mechanisms are very popular in small-frame, lightweight vehicles and some older cars due to their simplicity and ease of manufacture. Calculations for gear ratios are also quite simple and make design for the system uncomplicated. Figure 12 below depicts a rack and pinion steering mechanisms.

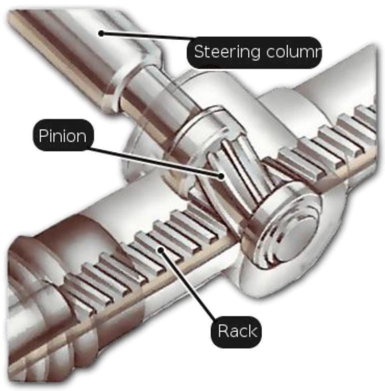


Figure 12 Rack and Pinion Steering Mechanism

The pinion and the rack are closely meshed, leading to minimal backlash during operation. This mechanism is a viable and inexpensive mechanism considering manufacture of the unit is possible in the NAU Machine Shop.

8.2 - Existing Design #2: Recirculating Ball/Steering Box

The recirculating ball mechanism is significantly more complex and expensive than the rack and pinion mechanism and is not feasible for in-house manufacture. This system is most common in heavy trucks and larger SUV's. The system utilizes many ball bearings as a form of lead screw, but instead of the screw advancing when spun, the block advances. The ball bearings in the system reduce the wear and friction of other components. The entire system is very resistant to shock and vibration which makes it a very appealing option for the intended applications. Figure 13 is a two-dimensional depiction of the mechanism. From the figure, we can see that this system is significantly more complex and very difficult for in-house manufacture.

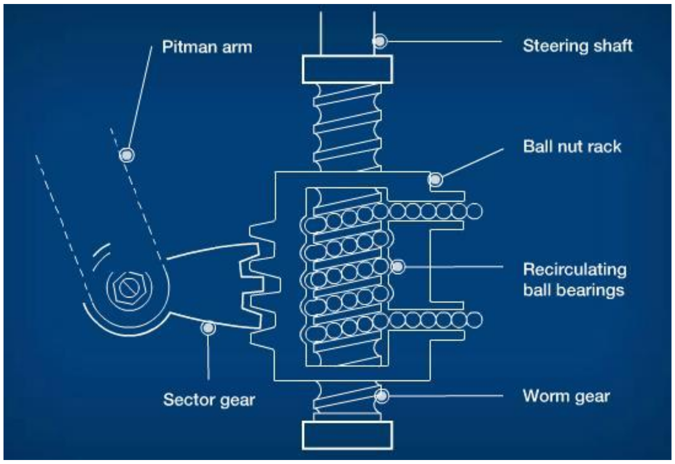


Figure 13 Recirculating Ball/Steering Box Steering Mechanism

VI - DESIGNS CONSIDERED

As the suspension geometries, steering geometries, and steering mechanisms have been designed, tested, and refined through the years, the team will not be re-designing the base designs for the SAE Baja. This section will instead, cover our base design decision, derived from the existing designs, and the justifications of those decisions.

1 - Design #1: Suspension – Unequal Length Double A-Arm

Taking into consideration all the points related to each suspension type, there are a few that will not be practical for our application. The Twin I-Beam and McPherson Strut designs both are going to sacrifice either ground clearance, weight, strength, or adjustability. Which are all directly related to the goals provided for our front suspension to conform to. This leaves us with Double A-Arm suspension being our all-around strong, adjustable, and lightweight option. This design, specifically unequal length a-arms, will be complicated and require heavy geometry work. In the long run this will be the most feasible option for a successful front suspension.

2 - Design #2: Steering – Ackerman Geometry

As the SAE Mini Baja competition consists of many tight turns and low-speed cornering scenarios, the logical design base is the Ackerman geometry. Considering the parallel geometry causes a great amount of understeer in the outside tire, especially in the SAE competition events, the geometry is ruled out entirely. Ackerman geometry will allow the vehicle to maintain traction to the outer wheel through cornering. This is critical because most of the weight is transferred to the outer tires during cornering. Understeer in the outside tire will lead to understeer in the entire vehicle, which hinders the overall performance of the vehicle. Fabrication of Ackerman steering geometries is feasible but will require precision when manufacturing the steering knuckles and determining the rack and pinion ratios.

2.1 - Two – Dimensional Steering Calculations

The Front-End team began tackling the complex geometries of the steering by starting with two – dimensional calculations. This method is a start; however, it does not incorporate critical design features such as kingpin, castor, camber and toe angles.

Wheel angles can be determined with Equations 3-1 and 3-2. When applied into a spreadsheet program such as Microsoft Excel, these calculations become very simple to alter and reach optimized wheel angles based on parameters that have been previously determined.

Equations 3-1, 3-2

$$\delta_i = \frac{L}{R - \frac{t}{2}}$$

$$\delta_o = \frac{L}{R + \frac{t}{2}}$$

In the above equations, δ_i is the angle of the inside tire, δ_o is the angle of the outside tire, L is the wheel base, R is the turning radius, and t is the track width. Figure 14 below displays the preliminary calculations executed in Microsoft Excel.

Wheelbase (in)	Track width (in)	Desired Turning Radius (ft)	Desired Turning Radius (in)	δ_i (rad)	δ_o (rad)	δ_i (deg)	δ_o (deg)	Difference
58	52	7	84	1	0.527273	57.29578	30.2105	27.08527759
58	52	7.5	90	0.9063	0.5	51.9243	28.64789	23.27641043
58	52	8	96	0.8286	0.47541	47.47365	27.23898	20.23466874
58	52	8.5	102	0.7632	0.453125	43.72573	25.96215	17.76357638
58	52	9	108	0.7073	0.432836	40.52628	24.79967	15.72661731
58	52	9.5	114	0.6591	0.414286	37.76313	23.73682	14.02630447
58	52	10	120	0.617	0.39726	35.35272	22.76134	12.59137795
58	52	10.5	126	0.58	0.381579	33.23155	21.86286	11.36868888
58	52	11	132	0.5472	0.367089	31.35052	21.03263	10.31789294
58	52	11.5	138	0.5179	0.353659	29.67103	20.26314	9.407887141
58	52	12	144	0.4915	0.341176	28.16233	19.54797	8.614360469

Figure 14 Preliminary Steering Angle Calculations

From extensive research, we have found that desired wheel angles should be no more than 50 degrees. This extreme angle causes a high moment on the steering knuckle and suspension components in directions that would require more strength and material to avoid failure. Based on the calculations above and the facts mentioned previously, eight feet is the lowest feasible turning radius. As one of our front-end goals is to achieve a turning radius of less than ten feet, the last four calculations are obsolete, though they do provide some insight as to how the steering angles change as the turning radius is adjusted. Figure 15 below is a two-dimensional depiction of the Ackerman steering with an eight-foot turning radius and other previously determined dimensions.

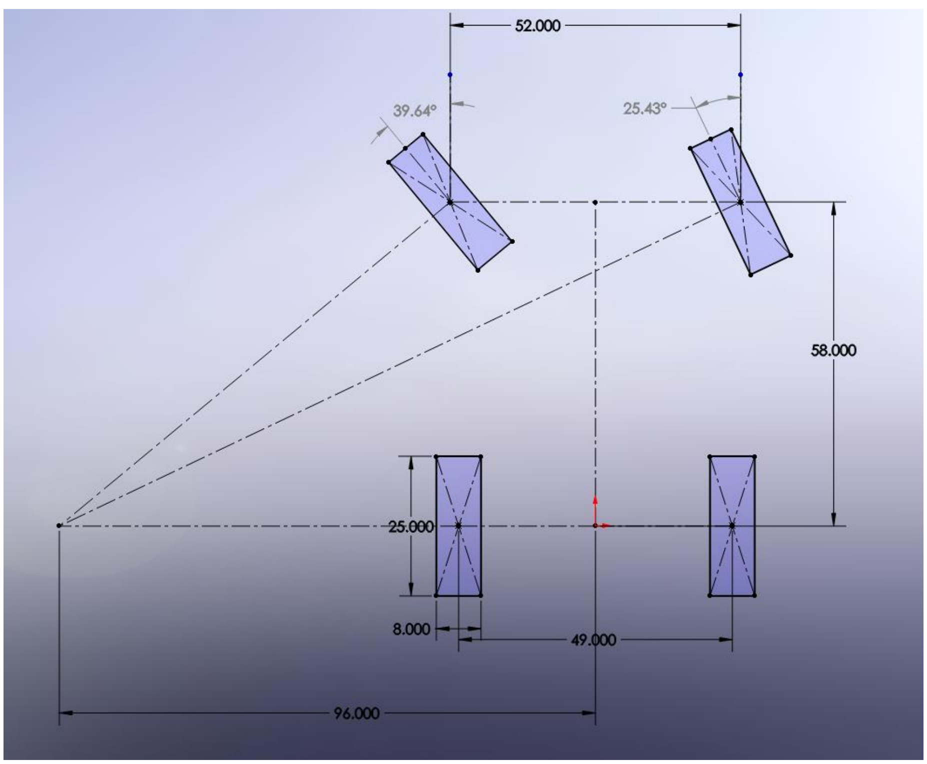


Figure 15 Ackerman Steering Geometry

The depiction above is an idealized geometry with the instantaneous center (IC) or turn center in this situation, is co-linear with the rear axle. A more realistic situation assumes some slip angle in the rear tires leading to the forward movement of the IC, which adjusts the steering angles and the turning radius. The front and rear track width, along with the wheelbase were previously determined values based on data from the 2015 SAE Oregon Competition. For more information regarding how these values were attained, see the report in Appendix A – "2015 SAE Mini Baja, Portland, OR, Results and Analysis".

3 - Design #3: Steering Mechanism – Rack and Pinion

Proper steering for our vehicle is vital for success in this project and competition. The driver must have swift control of the direction of the vehicle without a twitchy handling characteristic. A rack and pinion steering box will be an attainable goal to incorporate into the Baja project due to the low cost and high customizability. This design will allow for a light weight and simplistic application to be made for the steering system. Many gear ratios can be chosen from to design around a given steering speed our team decides upon for a comfortable driver feel and handling characteristic.

VII - CONCLUSIONS

Now with our final design selection complete, we will now be designing specifically for the unequal double wishbone front suspension. This suspension will allow us to meet all of our customer and engineering requirements for the project. By meeting these requirements, our team believes we are setup to have a properly functioning suspension that will be integrated with the other sub-systems easily. Moving forward in the design process for this semester will include having 3-D steering calculations complete, a full CAD package running, spring constants needed for our shocks, and more. Appendix B contains a timeline with due dates associated with the different checkpoints throughout the semester. This schedule will be useful in order to keep our sub-team on task and in unison with another team's progress as well. Keeping our five main focal points in mind during the semester will assist us in implementing a successful front suspension sub-system.

1. < 10’ turning radius
2. Maintain tire patch through body roll
3. Minimize scrub through articulation
4. Minimize bump steer
5. 10” wheel travel

Moving forward, the team is going to strive to hit our design checkpoints and stay on task with our project's workload during this semester.

VIII - REFERENCES

[1] – Baja SAE, Collegiate Design Series, Baja SAE Rules, 2018

VIIII - APPENDICES

Appendix A: “2015 SAE Mini Baja, Portland, OR, Results and Analysis

LUMBERJACK MOTORSPORTS

2015 SAE Mini Baja
Portland, OR

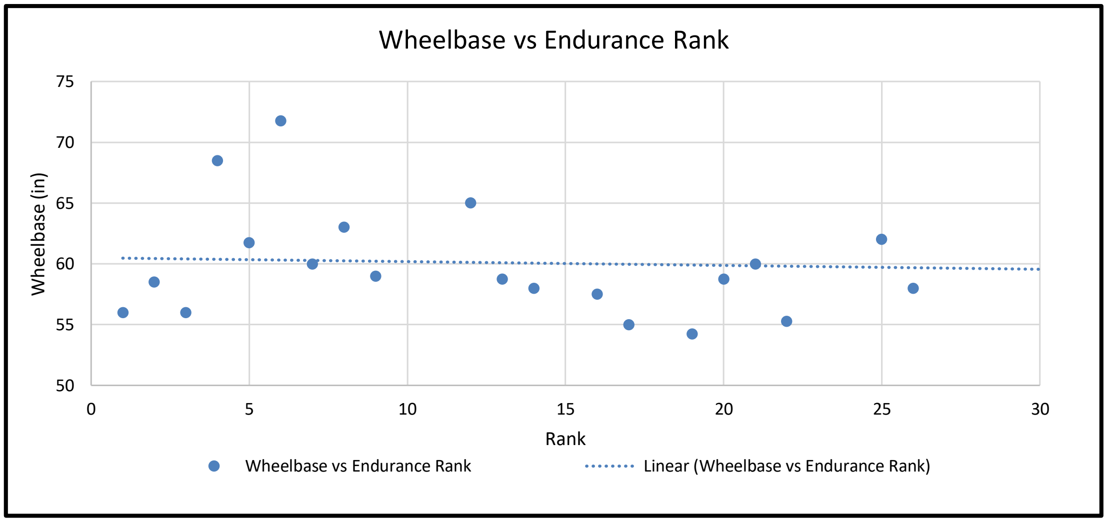
Results and Analysis

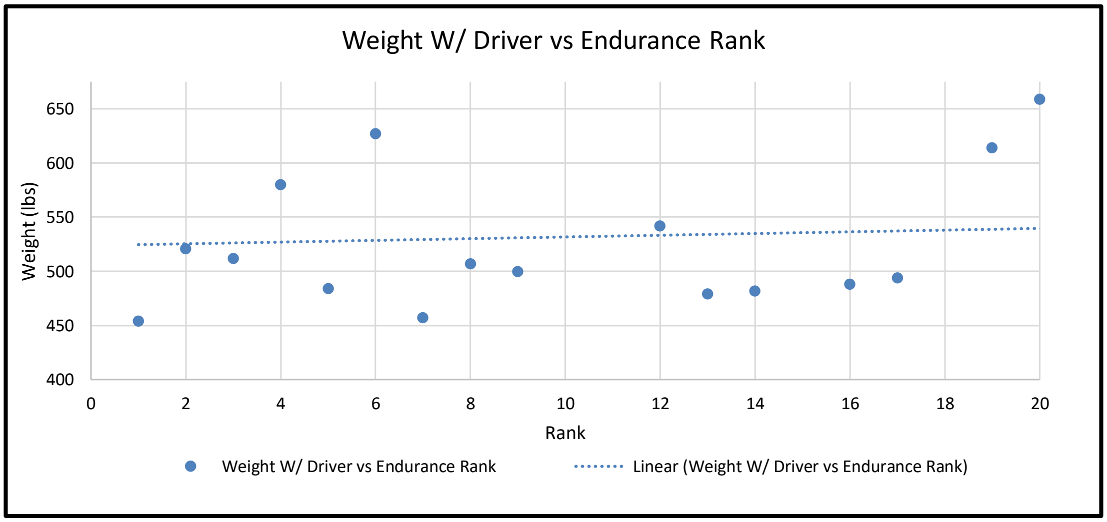
Zachary Rischar

September 8, 2017

Endurance

Rank	University
1	Univ of Michigan – Ann Arbor
2	Oregon State Univ
3	Univ of Wisconsin - Madison
4	California State Poly – Pomona
5	Ohio Northern Univ

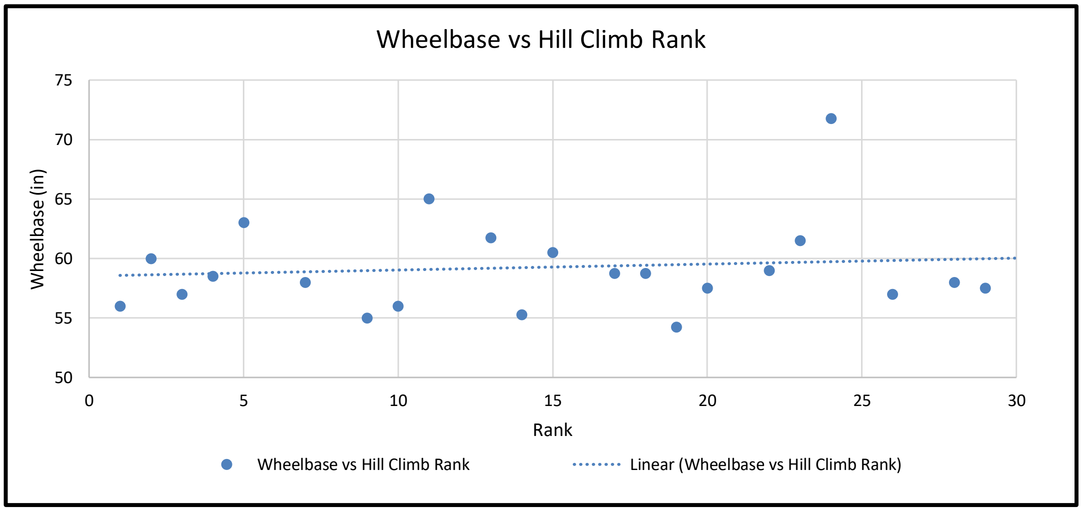


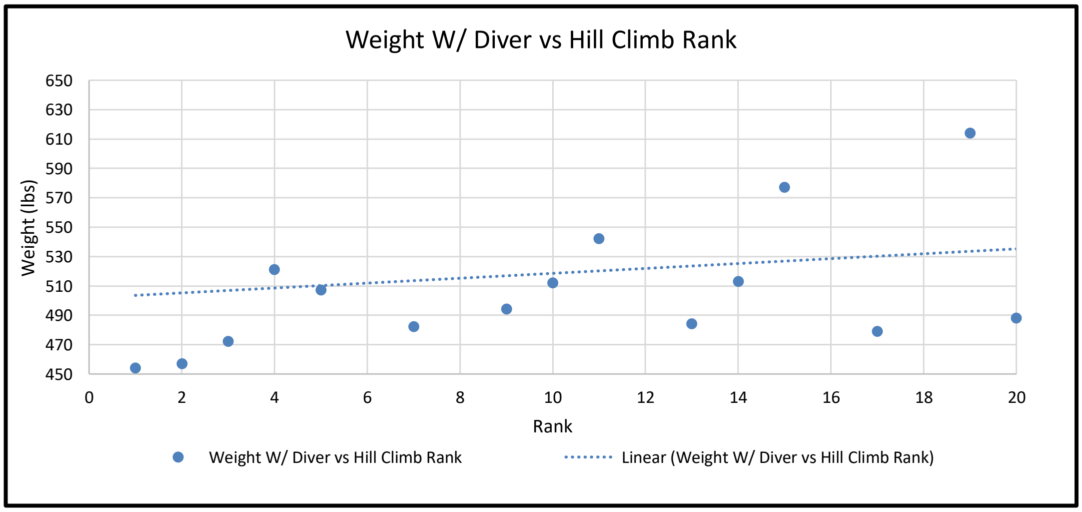


1

Hill Climb

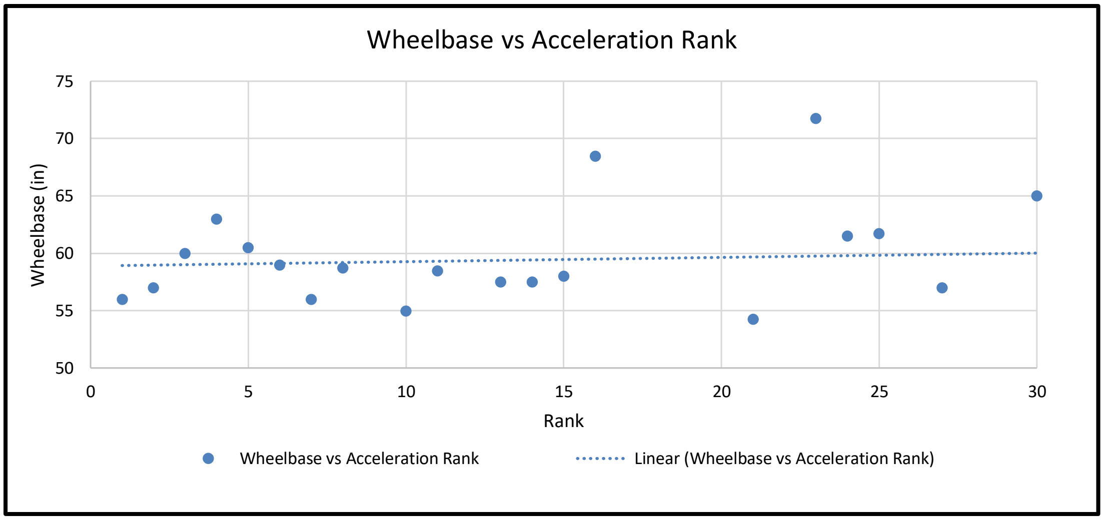
Rank	University
1	Univ of Michigan – Ann Arbor
2	Cornell Univ
3	Univ of Arkansas – Fayetteville
4	Oregon State Univ
5	Rochester Institute of Technology

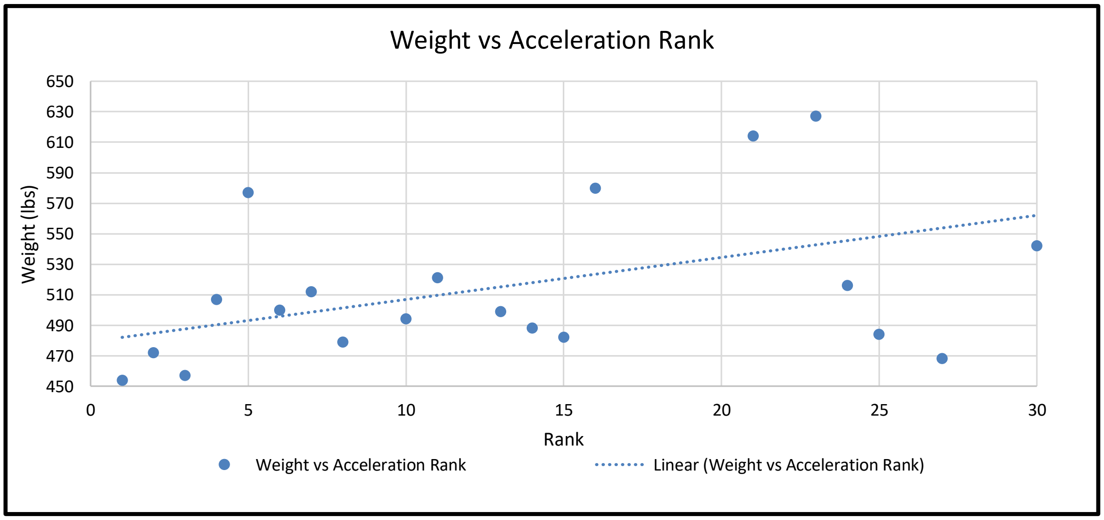




Acceleration

Rank	University
1	Univ of Michigan – Ann Arbor
2	Univ of Arkansas – Fayetteville
3	Cornell Univ
4	Rochester Institute of Technology
5	Auburn Univ





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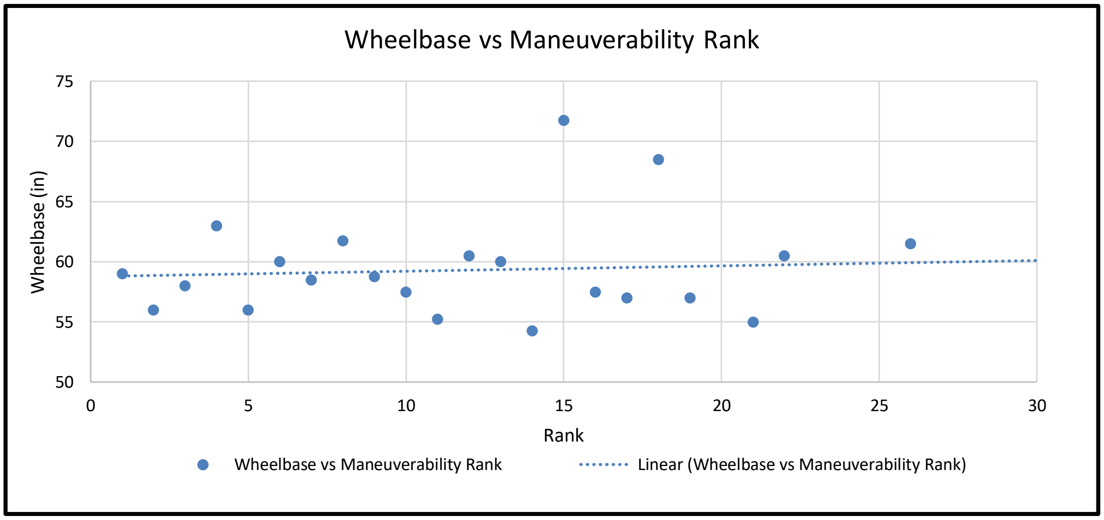
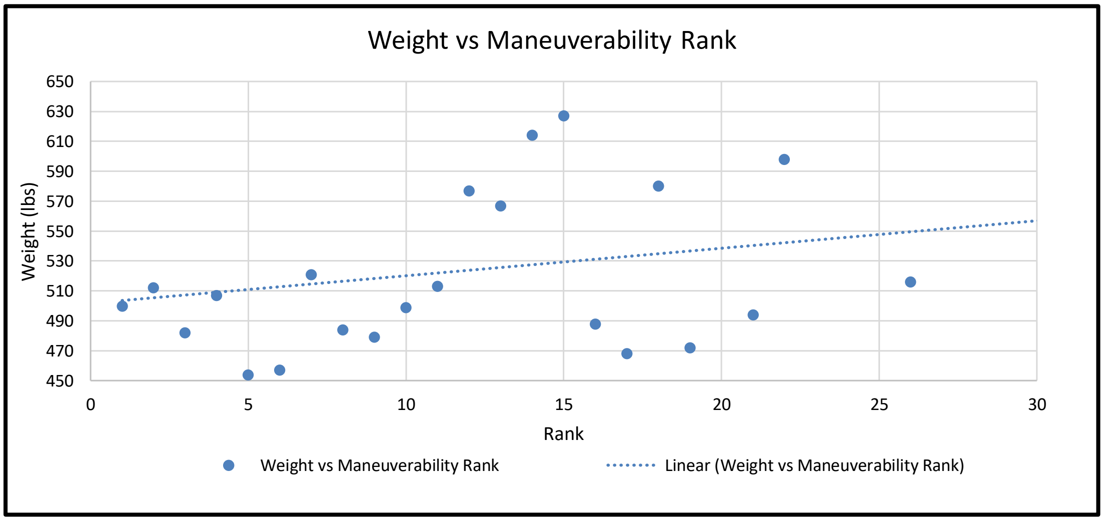
Maneuverability

Rank	University
1	California State Poly – SLO
2	Univ of Wisconsin – Madison
3	Ecole De Technologie Superieure
4	Rochester Institute of Technology
5	Univ of Michigan – Ann Arbor





Maneuverability

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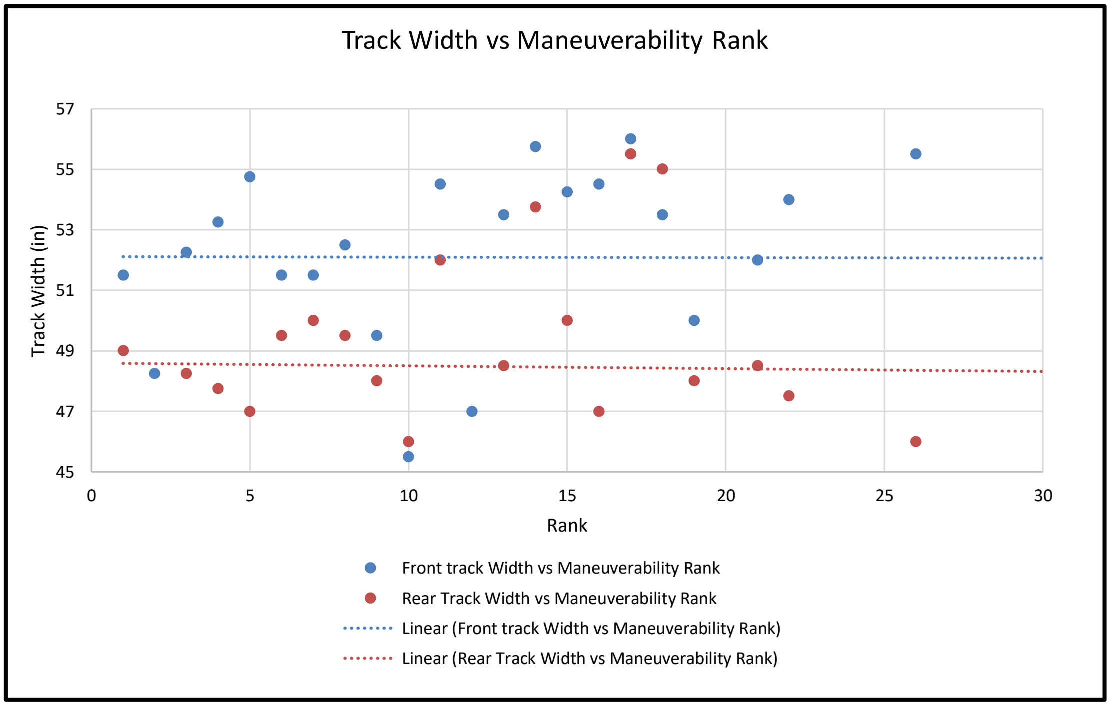
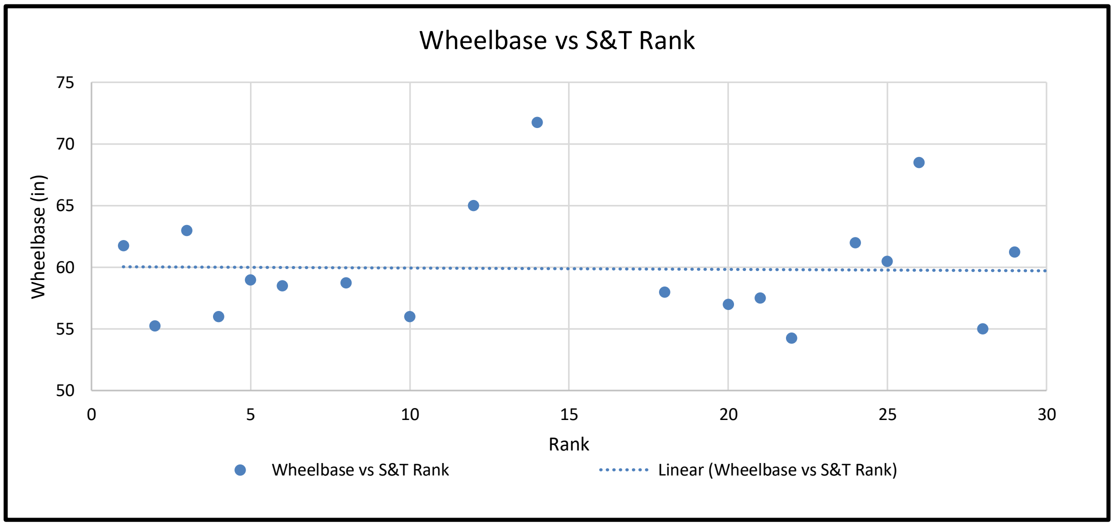
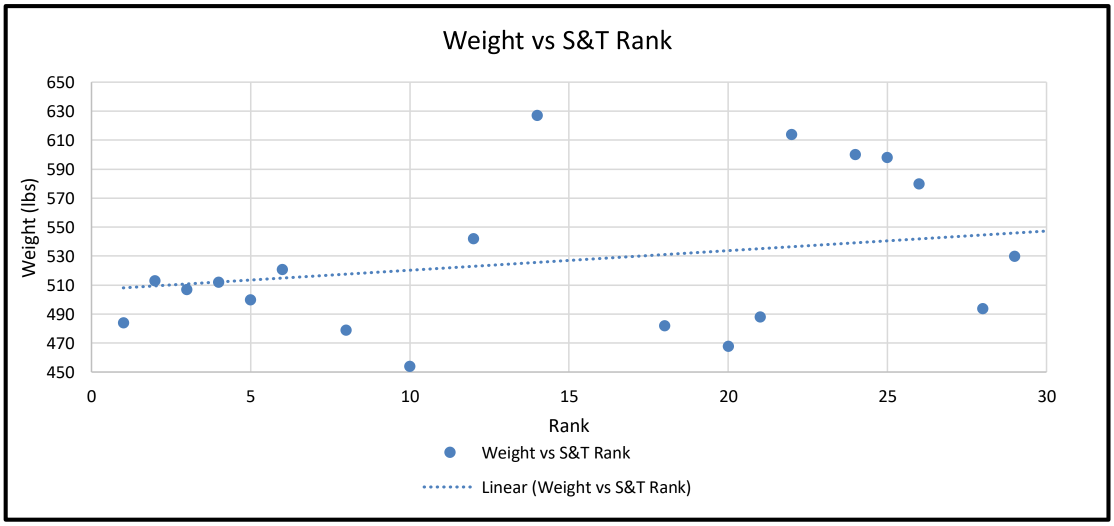


1

Suspension & Traction

Rank	University
1	Ohio Northern Univ
2	Arizona State Univ – Polytechnic
3	Rochester Institute of Technology
4	Univ of Wisconsin – Madison
5	California State Poly - SLO





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Suspension & Traction

Rank	University
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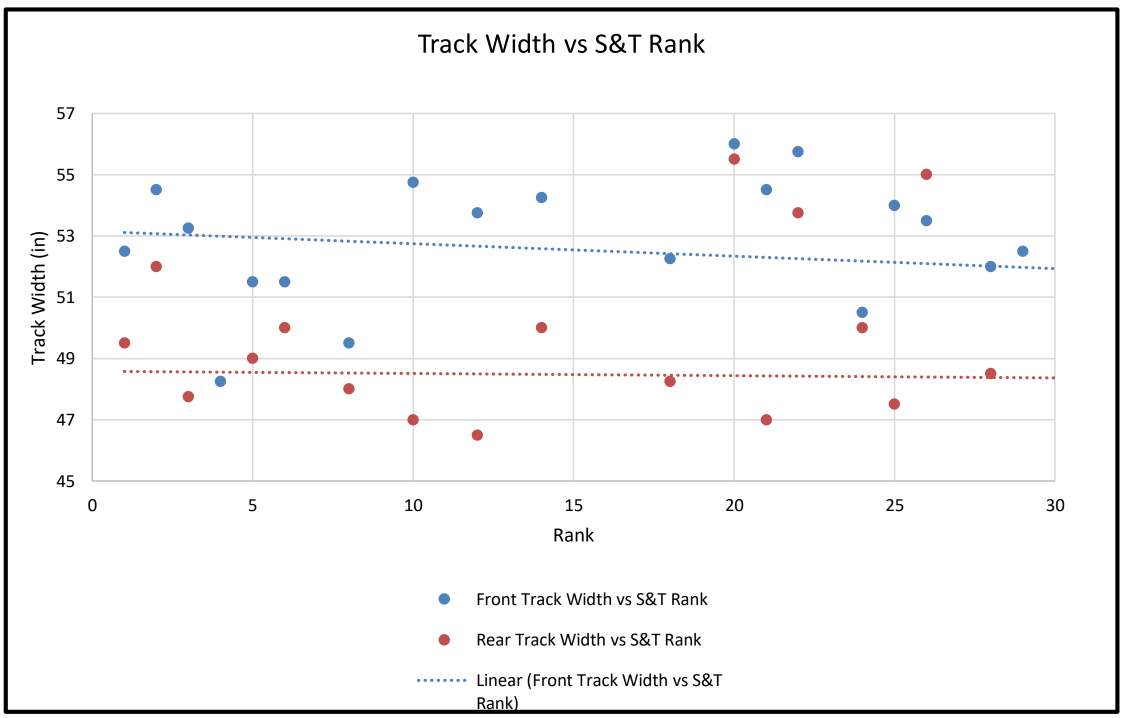

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Suspension & Traction

Rank	University
1	Ohio Northern Univ
2	Arizona State Univ – Polytechnic
3	Rochester Institute of Technology
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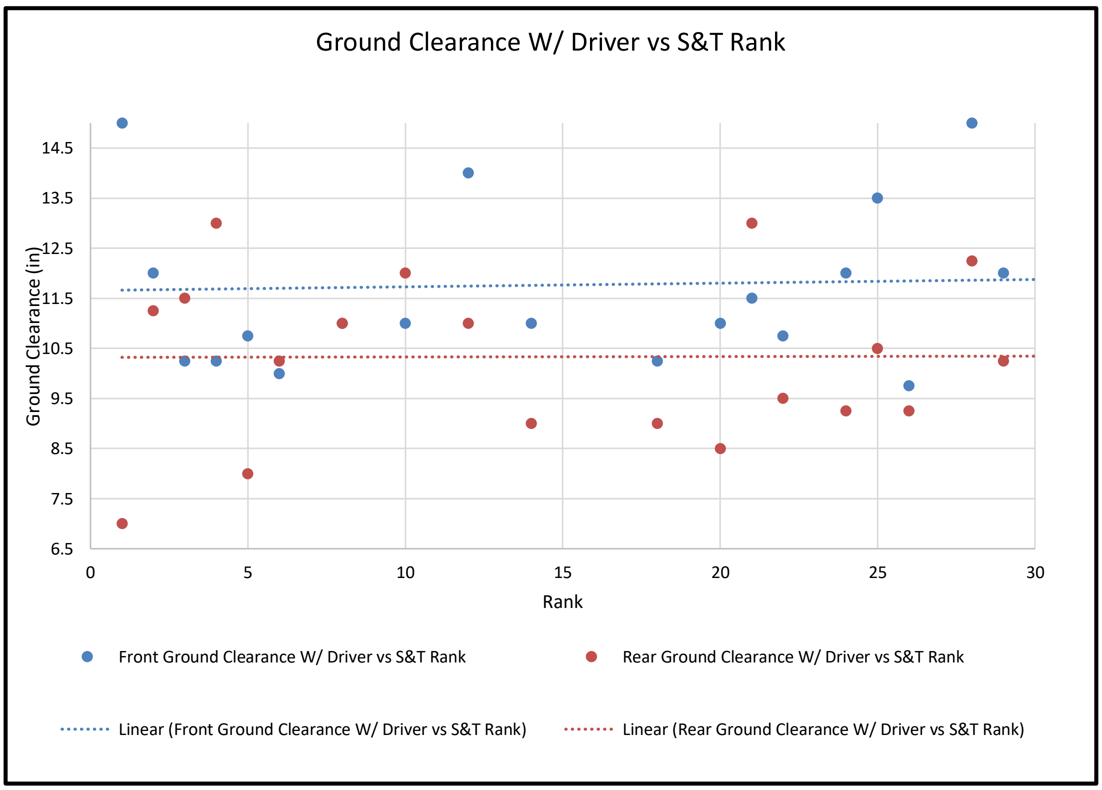
5	California State Poly - SLO



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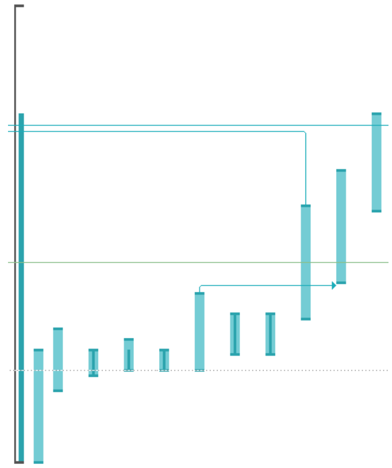
Appendix B: First Semester Timeline



	Front End Design	**65 days**	**Mon 8/28/1**	**Fri 11/24/17**					**18%**
	Front End Research	16 days	Mon 8/28/17	Mon 9/18/17					0%
	Rack and Pinion Ratios	10 days	Mon 9/11/17	Fri 9/22/17					0%
✓	Rough Steering Calculations	3 days	Thu 9/14/17	Mon 9/18/17					100%
	Lotus Software Workstation	4 days	Fri 9/15/17	Wed 9/20/17					50%
✓	Determine Front End Goals	2 days	Fri 9/15/17	Mon 9/18/17					100%
	Blue Shock Re valving	11 days	Fri 9/15/17	Fri 9/29/17	30				0%
✓	Determine Design Base	6 days	Mon 9/18/17	Mon 9/25/17					100%
✓	Determine Steering Type	6 days	Mon 9/18/17	Mon 9/25/17					100%
	Design for Frame Pickup Points	16 days	Mon 9/25/17	Mon 10/16/17	9				0%
	Blue Shock Spring Rate	16 days	Mon 10/2/17	Mon 10/23/17		29			0%
	Final Design in CAD	15 days	Mon 10/16/1	Fri 11/3/17					0%