BAJA SAE

Engineering Design Notebook

SR23 F.S. 2022-2023

Shocker Racing Baja SAE, Wichita State University, Wichita KS

Lead Designer: Adam Six

Start Date: January 1st, 2023

Completion Date: TBD

Table of Contents:

Abstract:

This notebook will serve as the main documentation for all things developed for "Deadlight" (the new and improved Baja SAE car). My roommate and longtime friend, Trevor Fruci and I came up with the name late one night as we were jealous of how the Formula team, our sister team, had much cooler names for their cars than we did. Deadlight, if it truly gets fabricated, should be the car that will put the Wichita State Baja team back on the map, on the podiums of competitions as we once were in the early 2000's. This notebook will be written as spoken word, for easy digestion when new members join the team. It is imperative to the team's success that there is a strong understanding of how and why everything works and goes together regardless of what discipline you study, or what subteam you are on. It is the job of the engineer to effectively help and communicate with others to create something not only coherent, but something to benefit others.

Introduction:

This design journal will cover all things engineering regarding a Baja SAE/mini-Baja style vehicle. The systems that make up the vehicle are: suspension, brakes, steering, drivetrain, ergonomics, chassis, electrical, and aerodynamics.

Each system will have a section regarding: defining issues, research, brainstorming possible solutions and deciding, developing the solution, testing, and finalizing the product. At the end of each section will contain possible improvements that could be made on the next iteration of the vehicle. The purpose of designing an entire vehicle like this from the ground up is to put my engineering knowledge to the test and to showcase the variety of knowledge I have outside of electrical engineering. I see myself as a jack-of-all-trades, thus if I can make a coherent vehicle with fabrication plans I prove myself beyond doubt that I am a more than capable engineer.

Goals:

Car Goals:

- Hit 50/50 weight distribution
- Full digital-twin
- Improve serviceability
- Decrease weight by 100 lbs.
- Develop calculator & code for easier/faster designing

Sub-team Goals:

- Suspension
  - Incorporate anti-dive & anti-squat geometries
  - Simulate model using ADAMS Car
  - Decrease fabrication complexity
- Brakes
  - Model functioning calipers
  - Improve rotor integrity
  - Include bias bar
- Steering
  - Improve tie-rod mounting integrity
  - Decrease caster from 15 deg to 12 deg
  - Remove slack in steering column
- Drivetrain
  - All-Wheel Drive System

    - 40 mph top speed
    - Reduce size of gearbox
    - CVT Tuning control system/simulation
    - Decrease package size
    - Electronic CVT
- Ergonomics
    - Composite seat
    - Widen seat bolsters
    - Create cutouts for harness to go through
    - Lengthen cockpit, decrease cockpit height
- Chassis
    - Incorporate harpoints from subsystems into design
    - Reduce primary/secondary tubing size
    - Design a chassis that doesn't look like the rest of the field
- Electrical
    - Linear potentiometers on shocks
    - Speed/RPM gauges
    - Three-axis accelerometer
    - Fuel meter
    - Odometer
- Aerodynamics
    - Include drag reducing components
    - Fenders for water-based hazards (keep driver clean)
    - Minimal panels with zeus fasteners
    - Flow simulations

Suspension

Daily Journal:

01/30/23

The first step to any good design, especially in a race series, is to outline and study the rules & constraints set by the governing body. Fortunately, there really aren't any major constraints set by SAE regarding suspension. In rule B.1.6 - Limitations the width must be 64 inches MAX at static ride height, and the courses are designed for vehicles maxing out at 64 inches (5' 4") in width by 108 (9') inches in length.

Issues:

The issues from Bertha (Shocker Racing's 2022 Vehicle) was that most things were blindly designed and thrown together without proper research, math, and analysis. This was a recurring issue that is starting to be addressed, as the team now documents most things and are hounded by those in leadership roles. In my short time driving this vehicle, it has a tendency to nose dive, the weight transfer is backwards in a turn, the ride height is 3 inches different from the design to the real world due to the shock absorbers used (ride height is adjusted with air, but that also affects the rebound/compression rates, and the rear suspension was sloppily thrown together. The issues with the suspension system stems from a lack of knowledge when it was designed (I should know, I was the one who designed it) as I had no one to help me learn the ins and outs of this complex system, and the fact that the chassis was designed without incorporating the hard points from each system into the design. Fitting components to the chassis instead of the other way around is extremely difficult and severely limits you on what design you are looking for.

There isn't any data on Bertha as it was still being put together the day before competition and was never truly tested, thus some numbers will be pulled out of thin air for the first iteration and will be honed in on during the simulation & analysis portions of the design. The issues and whatnot I am trying to tackle in the suspension design is to correct the roll-axis, incorporate anti-dive and anti-squat geometries, and design the suspension to achieve a roll gradient between 1.5deg/g and 3.0deg/g (typical rates for a race car and a sport vehicle, such as a Chevy Corvette) to drastically improve the dynamics of the vehicle while turning, accelerating, and braking.

Preliminary Analysis

Referencing *Race Car Vehicle Dynamics* by Milliken and Milliken, Chapter 16 - Ride and Roll Rates, I was able to write MatLab code for the ride & roll rates, wheel center rates, and installation ratios to give me an idea of how Bertha would perform on the track. The MatLab code produced a roll gradient of 1.65 deg/g, a roll angle of 1.80 deg, and front & rear spring rates of 45.28 lbs and 118.67 lbs respectively. There is no way that this setup would work in the grand scheme of everything, as the front would quite literally bottom out from the sheer unsprung weight. The rear would sag a fair amount. This is also an assumption, as I am still gaining a solid understanding of an air shock and would love to see it in action.The force from the vehicle falling would be much greater than shocks resistance and would very easily bottom out in a full performance setting. Therefore, I would like to move away from air shocks and to standard coilovers as they lack complexity and it makes the math a little easier to do and understand. The simplicity would highly benefit the team.

02/01/23

Brakes

Today I wrote the MatLab code for the brake calculator (mostly). I need to clean it up and add more comments as to why certain numbers were chosen and store data into a matrix. The data within the script is based off of some Wilwood calipers that are fairly small in size, which in turn means I am able to use a larger brake rotor to reduce the force needed from the driver.

I need to go through Bertha's old part set and redo the math for everything, which will take a while but will give me actual numbers to compare the new designs to.
My design goals are as follows:

- Incorporate brake bias
- Increase pedal ratio
- Have as many parts/components to be the same for easy manufacturing and assembly.

02/02/23

Brakes

I cleaned up the MatLab code a smidge, but some further cleaning needs to be done regarding how easy it is to look at, comments, and display results that allow one to choose their hardware and design constraints. I am referencing an MIT research and design paper for the braking system of an FSAE car, and can be found here. The paper has been extremely useful in terms of what equations to use, terminology, and how to go about designing and testing a braking system that includes a bias bar. I am using the estimated weight of Bertha, its distribution, the CG height, and the wheelbase of 578 lbs, 0.4 front weight distribution, 20 inches, and 60 inches. I estimated driver input of 70lbs as it seemed like a reasonable number to go with, but will be hitting the gym on a calf raise machine to see the realistic force applied to the pedal.

I have decided to go with a 2.0 pedal ratio and a brake bias of 63/37, Wilwood 1/2 inch bore master cylinders, Wilwood GP200 brake calipers, and 8 inch brake rotors. The braking torque requirements were 297.21 lb-ft for the front axle and 100.16 lb-ft for the rear axle. The pedal ratio with the 1/2 inch master cylinders result in a 314.44 lb-ft front and 184.67 lb-ft rear braking torques, which are 5.8% and 84.4% greater than their requirements respectively. A proportioning valve should be implemented in the rear for certain, but I would also like to implement one for the front system for driver preference once the bias bar has been set.

To calculate the max deceleration, I used the kinematic equation Vf^2 = Vi^2 + 2adx. I assumed a velocity of 25 miles an hour (this was gathered from when I asked other teams what they achieved during their test) and a stopping distance of 20 ft. This resulted in a deceleration of 1.0438 g's.

```
%% Braking Force per Axle
W = 578;
W_dist = 0.4;
W1 = W * W_dist;
W2 = W - W1;

V = 25*5280/3600; % mi/hr * 5280ft/mi * 1hr/3600sec
stop_dist = 20; % ft

h = 20/12;
l = 60/12;
decel = V^2/(2*stop_dist)/32.2;
W1_braked = W1 + W*decel*(h/l);
W2_braked = W2 - W*decel*(h/l);
```

The GP200 has a total area of 1.5 in^2 and two pistons, and the brake pads have an average coefficient of friction of 0.35. I determined my bias starting point by dividing the weight on the rear axle by the weight on the front axle which gave .337 as the result. I rounded down just a smidge to 0.33 rear bias and 0.67 front bias. In MatLab, I created an array of bore sizes to compare all of the master cylinders I was considering (Tilton and Wilwood), and made an array of pedal ratio sizes. I iterated through the pedal ratios and built a matrix of braking torques for the front and rear axles and viewed the entire matrix to search for the number that I wanted (I took the required braking torque and increased it by 5% to give some safety).

```
%% Pressure required to stop the car
u_tire = 0.75;  % Coefficient of Friction to ground
r_tire = 11/12;
F_zF = W1_braked;
F_zR = W2_braked;
T_brakingF_Req = r_tire * F_zF * u_tire
T_brakingR_Req = r_tire * F_zR * u_tire

F_driver = 70;
r_rotorF = 8;
r_rotorR = 8;
no_piston = 2;  % two pistons per caliper
A_C1 = 1.5;
A_C2 = 1.5;
u_pad = 0.35;
BB_f = 0.63;
BB_r = 0.37;

bore = [13/16, 15/16, 3/4, 5/8, 7/10, 7/8, 1, 1/2];
A_MCF = (bore/2).^2 * pi;

PR = linspace(2, 5, 7);

for x = 1:length(PR)
    new_T_F(x,:) = (F_driver * PR(x) * BB_f * 2 * r_rotorF * u_pad * A_C1)./A_MCF./12;
    new_T_R(x,:) = (F_driver * PR(x) * BB_r * 2 * r_rotorR * u_pad * A_C2)./A_MCF./12;
end
disp(T_brakingF_Req*1.05)
new_T_F
disp(T_brakingR_Req*1.05)
new_T_R

% PR = 3.5;
% new_T_F = (F_driver * PR * BB_f * 2 * r_rotorF * u_pad * A_C1)./A_MCF./12;
% new_T_R = (F_driver * PR * BB_r * 2 * r_rotorR * u_pad * A_C2)./A_MCF./12;
```

```
>> BrakeCalculator

T_brakingF_Req =

  297.2131


T_brakingR_Req =

  100.1619

  312.0738


new_T_F =

  119.0776   89.4405  139.7508  201.2411  160.4282  102.6740   78.6098  314.4392
  148.8470  111.8006  174.6885  251.5514  200.5352  128.3425   98.2623  393.0490
  178.6164  134.1607  209.6262  301.8617  240.6423  154.0111  117.9147  471.6589
  208.3858  156.5209  244.5639  352.1719  280.7493  179.6796  137.5672  550.2687
  238.1552  178.8810  279.5015  402.4822  320.8564  205.3481  157.2196  628.8785
  267.9246  201.2411  314.4392  452.7925  360.9634  231.0166  176.8721  707.4883
  297.6940  223.6012  349.3769  503.1028  401.0705  256.6851  196.5245  786.0981

  105.1700


new_T_R =

   69.9345   52.5285   82.0759  118.1892   94.2197   60.3006   46.1677  184.6707
   87.4181   65.6607  102.5948  147.7365  117.7747   75.3758   57.7096  230.8383
  104.9017   78.7928  123.1138  177.2838  141.3296   90.4509   69.2515  277.0060
  122.3853   91.9250  143.6327  206.8311  164.8845  105.5261   80.7934  323.1737
  139.8689  105.0571  164.1517  236.3784  188.4395  120.6012   92.3353  369.3413
  157.3525  118.1892  184.6707  265.9258  211.9944  135.6764  103.8772  415.5090
  174.8361  131.3214  205.1896  295.4731  235.5493  150.7516  115.4192  461.6767

>>
```

The code definitely needs more comments to make it easier for anyone else to understand what's going on, but for now I feel that I can move on from brakes.

Drivetrain

I am excited now that I get to start on the drivetrain today! My design goals are as follows:

- AWD system over a 4WD system
- Design front, rear, and center differentials
- Develop the fully electronic CVT (I'm very excited about this)

I created a decision matrix to take the bias out of deciding what kind of system I want to run with. I was deciding between all-wheel drive, four-wheel drive (gears), four-wheel drive (chain), and selectable four-wheel drive (gears). I will be going with the four-wheel drive (gears) system as it scored the best in the DM. I also made a decision matrix for the transmission system. I was deciding between the Gaged CVT and the fully-electronic CVT. They scored very similarly, but the eCVT beat out the mechanical CVT. Part of this is because the mechanical

CVT is so common, that the eCVT would stand out in the field, as well as the adjustability on the eCVT is much, much better (tuned by electronics, analog tuning rather than “digital” or discrete, the mechanical CVT has set points to adjust tuning for the spring).

System						
	Cost	Complexity	Reliability	Weight	Packaging	*Total*
AWD	4	4	3	5	3	19
4WD Gears	3	3	2	3	2	13
4WD Chain	2	2	3	2	5	14
Selectable 4WD	3	4	3	4	3	17

1 - Best Rank
5 - Worst Ranking
Lowest Score wins

Transmission								
	Cost	Complexity	Reliability	Weight	Packaging	Adjustability	Creativity	*Total*
eCVT	5	4	3	3	4	1	1	21
CVT	4	1	3	2	3	5	5	23

AWD requires two differentials and a transfer case, all of which I would need to design and package. If I didn’t want to design everything, the cost of buying each part would also be rather expensive. Getting everything to work coherently would be much harder than slapping a chain to two driveshafts, but the gears mean it would be rather reliable. The issues with the chain stem from the impacts the car generally experiences could cause the chain to bounce and slap itself, and including at the very least a single tensioner would increase the packaging. Having multiple tensioners adds to the complexity and though smaller in size, creates a pain to put together. The mechanical CVT is the simplest option to implement, but it is very overused in the field and I can use the eCVT as a stage in the transmission I want to develop for full road vehicles.

Tomorrow, I will need to develop a set of equations to determine how much power actually gets transmitted to the wheels and how fast I can actually go.

02/06/23

Drivetrain

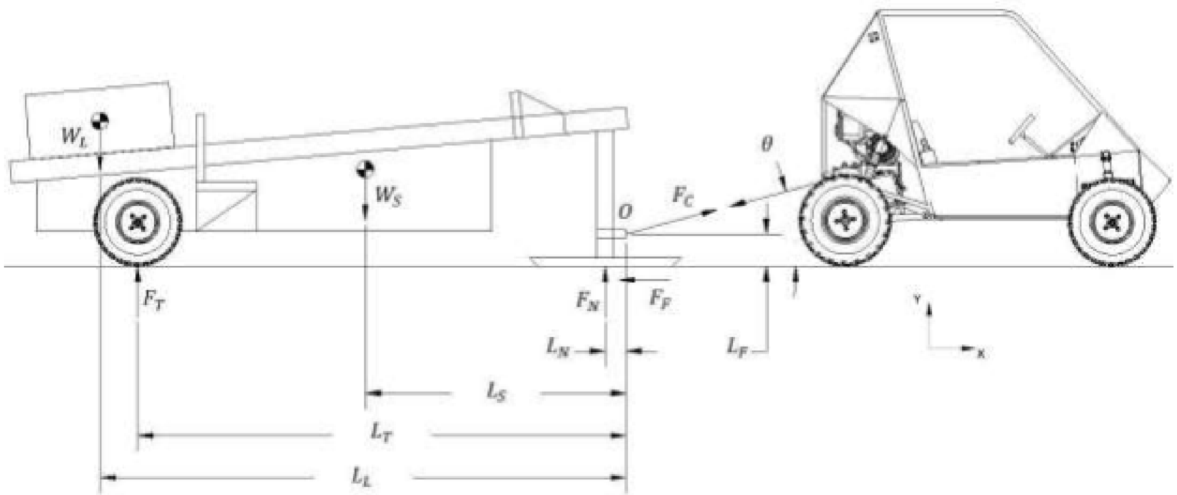
Today I wrote some more Matlab code to help solve for the high and low end gear ratio requirements. As I want to achieve a top speed of 40 mph, I need to knead the code in a way where I can determine the vehicle requirements to get me that speed. Using Bertha as the base estimate, incorporating 4WD, and accounting for drag, the new car should hit about 35 mph in real life. So the top speed is close, but not quite what I want. As this set of math determines my requirements, I can exceed the high end ratio to push to that magical 40 mph. To help the car get there, I have to make sure I decrease the weight as much as possible, decrease aerodynamic drag (it is insanely high at 1.08), and decrease the frontal area of the car.

As I was developing the excel calculator, I was looking through an old design paper from *Zips Baja* at The University of Akron. Though it has been very helpful in aiding me to an understanding of design points and equations, there are a handful of typos that I had to make sense of. The equation they used for the driving force, which is the force of aerodynamic drag plus the force of rolling resistance, they didn't square v_max in aerodynamic drag, which really messed up the math and set me back from finishing the calculator to use as a check for when I wrote the code.

$$F_{DRIVING\ MAX} = \frac{1}{2} * \rho_{air} v_{max} A_{Frontal} C_D + C_{RR} W_{CAR}$$

Luckily, I had help from some of the FSAE members and helped me diagnose my issue.

I used the Newton-Raphson method to find the maximum velocity of the car, which ended up at just over 35 miles an hour and found my high end gear ratio to be 6.71. {REFERENCE THE APPENDIX FOR CODE} For the low end ratio, I used Zips' model for a car during a sled pull and worked through the model with the below equations.



$$F_C = \frac{-W_L*(L_L-L_T)+W_S*(L_T-L_S)}{L_T\frac{\cos\theta}{\mu}+L_T\sin\theta-L_N\frac{\cos\theta}{\mu}-L_F\cos\theta}$$

$$T_{Low\ GR} = \frac{11}{12} * F_C * \cos\theta \quad \text{(ft-lbs)}$$

Fc is the force on the cable, WL is the payload weight, LL is height of the hitch point on the sled, LT is the length of the hitch point to the axle on the sled, LS is the length of the hitch point to the CG on the sled, theta is the angle of the cable from the hitch point to the tow point (angle of the cable), LN is the length of the hitch point to the support plate on the sled, LF is the length of the hitch point to the CG of the payload on the sled, WS is the sled weight, and mue is the coefficient of friction between the sled and the ground.

Without accounting for every detail/drag/whatever else shows up, I need a 4.02 gear ratio to hit 40 mph. I am going to shoot for this number as if I can manage, great, if not, anything better than 6.7 will do more than okay. Now onto the actual design of the system.

The system will consist of the mandated engine, a planetary gearbox with an electric motor, an open front differential, a limited slip rear differential, and portal hubs. According to Milliken and Milliken in RCVD, “For racing applications it has often been found that locking out the center differential gives the best results” (page 733) works out great for me as I did not want to have a center differential, meaning it would be “locked out.” Due to a major lack of capability from my part (I am an electrical engineer, and designing a limited slip differential is far beyond my comprehension at the moment and would drastically increase my timeline to complete this project), I will be designing open differentials that can be manually locked from the cockpit. By having an open differential mode, the car will have a much easier time moving around and the locked mode would ensure power is always delivered to the wheels regardless of slippage. This would be the easiest design to do while still having some performance added to it, rather than having a locked differential in the rear and an open in the front.

02/07/23

Drivetrain

So I have to sacrifice something. Whilst working on the drivetrain and refusing to let go of the eCVT, I am leaning towards reducing the max speed of the car. With all of the gear connections and assuming a 0.99 efficiency of gears, I should have a drivetrain efficiency of 95%, which means I should get close to 35 mph and 475 lb-ft of torque. I can reasonably assume a 90% driveline efficiency due to how these cars are made, so if it gets any better I will guarantee my theoretical goals of 34.76 mph and 425 lb-ft of torque.

As far as designing the gears goes, I need to actually design the gears other than the number of teeth. I am making a SolidWorks file where I can create my own standard gears and (hopefully soon) internal gears. Said calculator will have the works - pressure angle, diametral pitch, pitch diameter, base diameter, outside diameter, face width, teeth, and some other information that is in the file that I just don’t want to pull out right now. I have attached the work for my ratios and CVT development (though the CVT still needs some work). The worksheet also has the tires in meters, as I found a conversion form online that needed it in meters, this will be an update in the future to change it back to freedom units. Another thing I would like to calculate with actual drivetrain numbers now is what my theoretical acceleration will be, but I will need to have a control model set up. As of right now, I only need to accelerate 0.51 g’s to place first in a short course acceleration event (basing off of results from New York 2022). Starting tomorrow, I get to work on the cockpit and ergonomics! How exciting!

	Inputs															
Gear	*Pressure Angle*	*Teeth*	*D*	*P*	*B*	*O*	*C*	*C*	*F*	*RPM (Low)*	*RPM (High)*		Carrier	2200	RPM		
Sun		91								3600	-3600			3600	RPM		
Planet		11											Tire Radis	0.279401	meters		
Ring		114								1082.45614	6829.82456						
Pinion		19								1082.45614	6829.82456						
Counter		55								373.9393939	2359.39394		**Required**		**Theoretical**		
Bevel Pinion		14								373.9393939	2359.39394		34.76413	mph	36.89054	mph	33.20148
Bevel Counter		43								121.7477097	768.174771		425.5179	lb-ft	500.0208	lb-ft	450.0187
Hub Pinion		11								121.7477097	768.174771						
Hub Counter		15								89.28165375	563.328165						

Baja SAE Restricted Kohler CH440							
Engine Speed (RPM)	3600	3400	3200	3000	2800	2600	2400
Torque Net Corrected (ft-lb)	13.5	14.5	15.4	16.6	17.4	18.1	18.5
Power Net Corrected (HP)	9.3	9.4	9.4	9.5	9.3	9	8.5

Requirements				
Max Speed	34.76413	mph	50.98739067	ft/sec
Max Torque	425.5178743	lb-ft		
Max Acceleration	0.507035112	g's	16.32653061	ft/sec

Acceleration

Inputs	Value	Units	Notes	Calculated	Value	Units	Notes
Distance	100	ft		Acceleration	16.32653061	ft/sec^2	
Time	3.5	sec		Acceleration	0.507035112	g's	
Air Density	0.00238	slugs/ft^3		Max Driving Force	40.22140592		
Frontal Surface Area	14	ft^2	Place Holder, need estimate	Max Theoretical Power	4702.5	lb-ft/s	
Coefficient of Drag	1.08			Max Power Available	4389.00143	lb-ft/s	
Coefficient of Rolling Resistance	0.068			Max Power Available	7.980002601	hp	
Driveline Efficiency	90%			Gear Reduction	6.777659876		
Realistic Efficiency	95%						

Vehicle Specs	Value	Units	Notes
Gross Weight	578	lbs	
Front Weight Distribution	0.4		
Rear Weight Distribution	0.6		
Front Axle Weight	231.2	lbs	
Rear Axle Weight	346.8	lbs	
CoF Tire-to-Asphalt	0.788		
CoF Tire-to-Dirt	1.183		

Sled Pull/Low Gear

Inputs				Calculated			
Tire Size	0.916666667	ft	T_r	Cable Tension	536.0135111	lbs	F_C
Angle of Cable	0.523598776	rad	theta	Torque	425.5178743	lb-ft	T_{max}
Payload Weight	1000	lbs	W_L	Minimum Driving Force	227.732	lbs	$F_{D,min}$
Hitch Point Height on Sled	4	ft	L_L	Maximum Driving Force	341.887	lbs	$F_{D,max}$
Hitch Point Length to Axle	11	ft	L_T	Max Theoretical Torque	626.7928333	lb-ft	$T_{traction\ limited}$
Sled Weight	1000	lbs	W_S	Gear Reduction	33.88069369		
Hitch Point Length to CG	6	ft	L_S				
Hitch Point Length to Support Plate	2	ft	L_N				
CoF Sled to Surface	0.45	ft	mue				
Hitch Point Length to CG of Payload	0.5	ft	L_F				

02/08/23

Ergonomics

Ergonomics today, but I have little motivation and energy to do this as I have gotten about half as much sleep as I should get in the past few days. At the very least, I would like to set up the plan of attack, get some research in, and create a CAD file to set up the ergonomics of the driver. I will be the only person driving this car, so I will be setting it up to match me. However, I will still make sure that the vehicle is rules compliant.

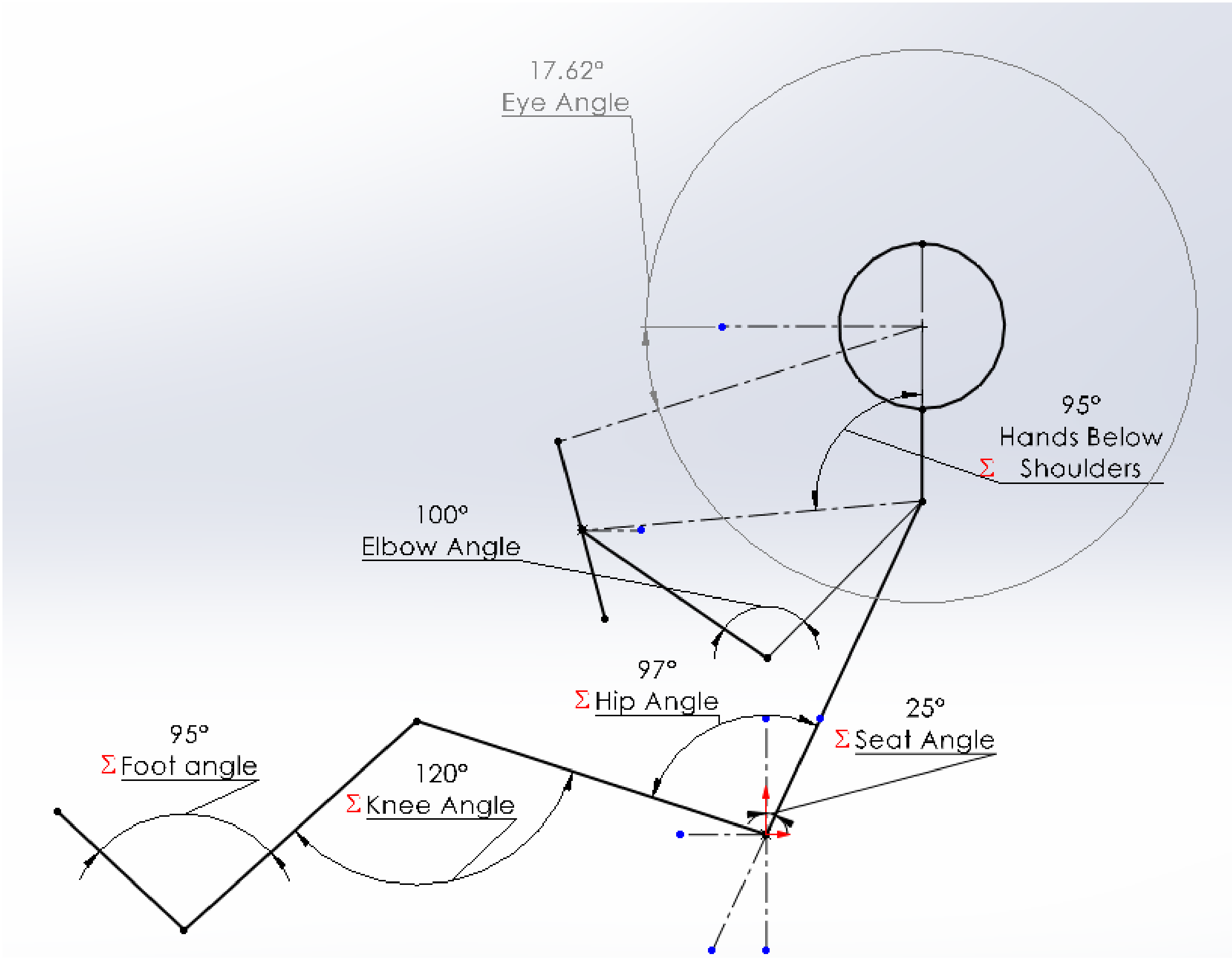
02/09/23

Ergonomics

Before I really dive into the nitty-gritty of the cockpit design, I need to go through the rules and do some research first. Rule B.1.2 - Ergonomic Design states that the vehicle must be designed to fit the 95th percentile male height and the 5th percentile female height in the country where the competition is being held. As the competitions this team competes in is in the United States, I will be using those numbers (6’ 2” for men, 4’ 11” for women, See Appendix). Granted, I will be making the base vehicle around me entire and later updating the components to be adjustable.

The components that make up the cockpit and ergonomics are the following: seat, steering wheel, pedals, harness, kill switch, and the dashboard. As the rules state that the vehicle must accommodate a 6’ 2” male, I will ensure that someone of that height can fit, but as they are only two inches taller than me, that shouldn’t be an issue. On the other hand, a 4’ 11” women is just over a foot shorter than me, which means I should make an adjustable pedal and adjustable steering wheel. For now, I am going to focus on the seat.

Rule B.4.5 - Seats state that the seat “shall be designed for the upright seating position, … The upright seating position is defined by the angle of the driver’s back to a horizontal line, … The seat back angle for an upright seating position is greater than 65 deg.” I measured my limbs and with the assistance of sim racing rig setup guides and feeling out the angle in real life, I have decided on how I am going to set up my positioning. I’ve attached the SolidWorks file that has all of my angles for how I will be sitting in the car. Since this will be my personal vehicle, I am going to reiterate that this is specifically built for me.



By setting the full driver arrangement, it means my steering wheel placement had to be set as well as my pedal angles. Until the chassis starts its development, I really can't continue with the seat any longer. All in all, I really need to start setting hardpoints and start part design (to an extent, to include mounts into the chassis) so I can get the chassis set up. Tomorrow, I will be working on the rear suspension, and I should be able to set all hardpoints pertaining to the chassis, getting that much closer to finishing this project. The sooner I can get the base vehicle design done, the sooner I can really develop the control module for the eCVT (I am excited to actually do this, I've been talking about this for close to 7 months at this point).

02/14/23

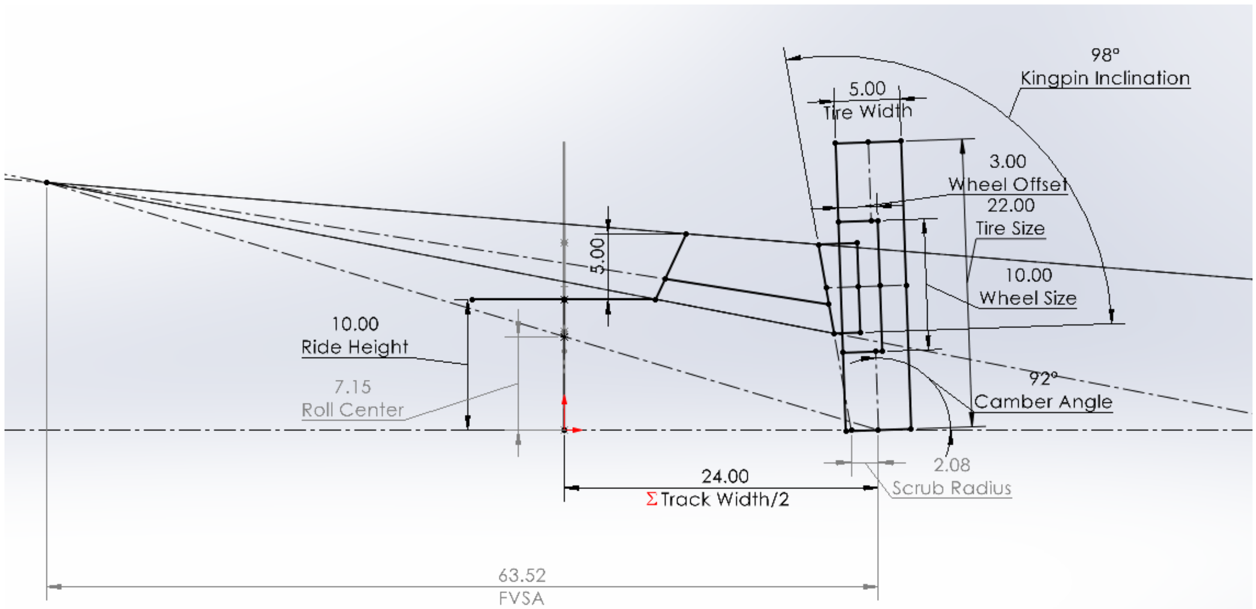
Suspension

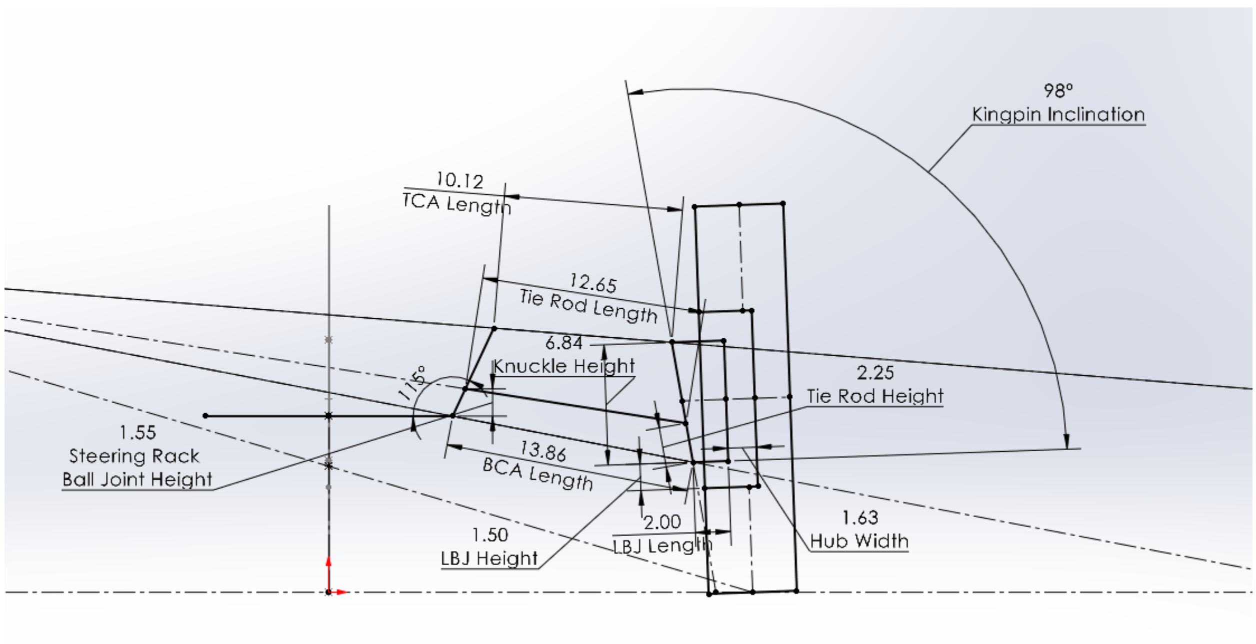
I am trying to finish the suspension today. That means 100% finalizing the front and more or less designing the rear. Realistically, I can complete this task by the end of tomorrow, but I would like to get it done ASAP so I can spend time working on the controller for the transmission.

The goal for the front was to focus on the minimal camber change through the vehicle's travel and deal with the roll center later. By dealing with the RC later, I can ensure the tires aren't going to snap off the car like the past two models the team has produced. The issue is the prioritization of the RC height. Reducing the camber change through travel means the camber won't change drastically when the car gets lifted (this is mainly due to the suspension test, as the event at Rochester was brutal and I want to ensure a car that is more than capable of handling something that intense). The front view swing arm (FVSA) is 63.52 inches, thereby providing a camber change rate of 0.902 degrees per inch with a roll center height of 7.15 inches. I originally chose my FVSA to be 60 inches, but the vertical hardpoint on the chassis would be easier to hit if it wasn't an odd number as the shop we have doesn't have the most precise manufacturing. Static camber is set to 92 degrees, but can be adjusted later with the mounts for tuning purposes. Rideheight is 10 inches to mainly ensure the half shaft from the front differential to the wheel is as parallel as feasibly possible. The front track width is 80% of the wheelbase (60 inches) resulting in a front track width of 48 inches. The rear track width is set to 75% of the wheelbase resulting in 45 inches. Though the suspension will have quite the travel to it, I am limited by the angle of the half shafts. I am also operating under the assumption that technically, the half shafts are not a controlling member as they do not limit the degrees of freedom of the suspension, but just the range in which the suspension is allowed to operate. The differentials will be sitting lower than the bottom of the car and will have tubing and shielding to help prevent damage to those and the driveshaft. The bottom of the car is to be 14 inches as the steering rack the team uses at the moment is 14 inches, and I will continue to use this number/steering rack as we have extras that need to be used (save some money!).

There is a series on youtube from a professor at UC Berkeley going over race car design (here) and he states that on average a vehicle that has its track widths between 70% and 80% is the most agile and stable the vehicle can be. I have also been told this by many other teams in my years at Baja that, since enough people have told me it to be true, I've accepted it as fact. That said, I should really figure out why, but for now it's a fair assumption. My scrub radius from the previous year has decreased from over 4 inches to 2.08 inches, as this vehicle does not have a kingpin angle (which I didn't include last year to help with other angles.

On to ride and roll rates.

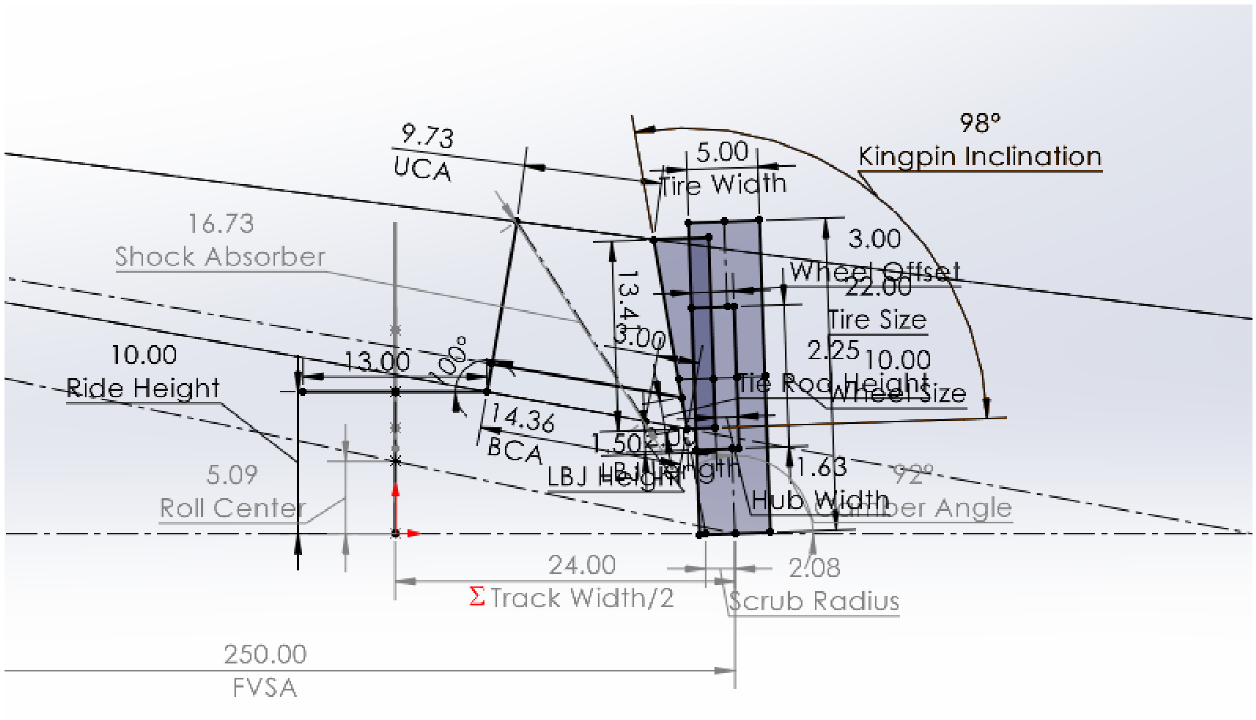




02/15/23

Suspension

So I had to make some tweaks to the front suspension so I could ensure I would be able to make good use of the shocks. After dealing with air shocks, I want to switch to coilovers. Sure, they are heavier, but the tolerance within this shop is horrendous and the car can sit properly level after manufacturing. This is the new setup which has even less camber gain and an upper ball joint towards the top of the tire. Some numbers stayed the same, but I decreased the bottom width of the car to better aid the steering rack ball joints.



On to the rear suspension. With the rear, We have had a really bad issue in the past with overloading the half shafts and thus power transmission has been terrible. I originally wanted to run with a floating differential in the rear which would reduce the chassis tubing and more or less create a swing arm for the differential. I still will have independent rear suspension as the actuation of the suspension being completely separate is highly important for a race car. This is an off-road race car despite what anyone else says, and we can just pass it off as a “consumer vehicle.” There are a few different types of rear suspension that are more than plausible to run, but I will use a design matrix to reduce the bias in deciding what system to roll with.

02/16/23

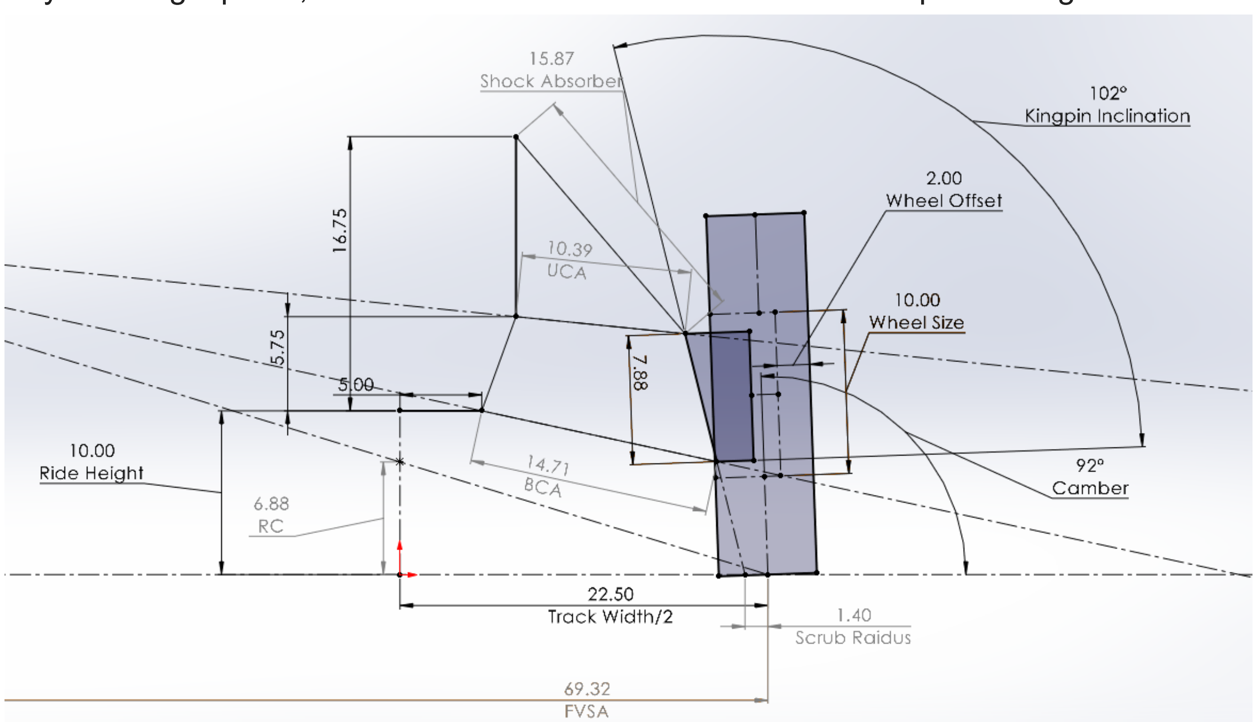
Suspension

For the sake of sanity and time, I will only need to decide between a 4-link, trailing arm, and dual wishbone. Trailing arm would reduce the tubing on the chassis but but the arm itself would need to be strengthened. The four link has been used by WSU in the past in the years that the team performed exceptionally well (towards the end of the run though) and would have limited tubing on the chassis. Dual wishbone would need better mounts/more tubing on the chassis to make have decent mounts, but would guarantee travel. All in all, I believe the four link suspension to be the best mostly because it will be fairly easy to incorporate into the chassis, there will be plenty of travel to match the front, and the links will be easy to manufacture as they will be simple straight links, and would reduce the need to strengthen them compared to the trailing arm. The only major issue that will arise will be the incorporation of the shock absorber as I want to prevent putting the absorber on the upright. If I need to and the integration is extremely easy, I might as well (at least for the first iteration of the car). I am going to go to a concert tonight so I can't work any further on this, but I have all day tomorrow to work on this so I can knock out the rear suspension in no time flat (with math). I have some base points/ideas for general race car setup so deciding on ride and roll rates should be too bad. I am very excited to get parts designed and analyzed so I can finish up this project and have some quality engineering work to add that much more to my resume. Once everything gets finalized, and I am doing the amount of work that would normally take the team about a year to fully produce a car, I will be right on par with the production of just about every Baja team, and this work will hopefully get the new team to really get some ideas to produce a quality vehicle. At the end, I will present this project to the new team, create a technical design report, fill out all competition documents, and publish the design (except for the eCVT, I will patent it first).

02/17/23

Suspension

Woo, it's Friday, time to finish the suspension. Once I can do the major components math and whatnot done, I can start working on the controller for the eCVT as I really want to nail down the transmission for jobs. I want to have more camber gain on the rear tires for cornering. As I plan on sending it into corners, having the outside tire gain a load of camber to increase the surface area between the tire and the ground will be beneficial. Without proper simulations and testing I don't know how much I really need, but once again this is a first draft. The shock placement is temporary, as this is only in a single plane, and the shock will move across a different plane altogether.



I still need to design the steering knuckles and rear uprights. I don't know whether I want to start work on the chassis or start part design once I finish the geometry for the suspension. Though this project is allowing me to put my knowledge and engineering skills to work, I really wish I had someone working on this with me so I can speed up the development. I am getting impatient and - though it's a boatload of fun to design cars - I am excited to just finish up the project.

Some things to keep in mind for chassis though: Make a “person” in SolidWorks to check spacing and sizing as this car is supposed to be rules compliant, I will most likely need to add some extra tubing/plating to guarantee the cockpit is rules compliant. At some point, I will modify the design before it gets made, as I want the product that gets built to have two seats and a much larger engine, though building the spec car would be a blast to roll up to the new team and race around with them and help with baseline testing for both their and my benefits.

Moving forward to steering geometry. The next iteration should feature a shorter spindle length to provide a negative scrub radius. This is because a negative scrub will create a stabilizing effect when a front drive wheel loses traction forcing the opposing wheel to turn slightly due to compliance in the steering rack, correcting the course of the car. In general, a negative scrub keeps the vehicle traveling in a straight line. Depending on what I can manage for a turning radius of the car, I might be able to modify the front scrub to become negative.

02/22/23

Suspension

I noticed some errors in my suspension scripts (ride and roll rates). My ride frequencies were calculated incorrectly which meant I was getting spring rates that sounded dramatically incorrect. Something to note as well: The closer the CG is to the roll axis, the less the roll gradient and roll angle will be, regardless of spring rates. After fixing the script, I am designing for a suspension that will hit 121 cycles/oscillations per minute (cpm). This is on par with an older Indy car without ground effects. Generally speaking, the higher the cpm, the stiffer the car will handle. On Bertha, the CG was around 5 inches away from the roll axis, so as an estimate for now until I can estimate the weight of the vehicle through CAD, I will be using this number to estimate my ride and roll rates. Until I get a better estimate, I will hold off on choosing springs as my calculator says I need front springs around 43 lb/in and 53 lb/in in the rear, with an allowed jounce travel of 4 inches. Though this sounds really soft, it is an off road car and reasonably just needs a lot of suspension travel.

```
>> K_s

K_s =

   43.3112   52.7991
```

Drivetrain

So I have an interview on Friday regarding systems engineering. It's time to get the control system for the drivetrain/transmission underway. Choosing a motor would make my life easy as far as fabrication and assembly, however, designing an electric motor would be way more beneficial in the long run (more electrical engineering experience and would make my life easier at the moment). By designing my own electric motor, I can get the design constraints that I want for performance, and will give at least something to show for the controls interviews I have coming up, as the entire system of the drivetrain is extremely complex.At some point, I will be talking to Dr. John Watkins (the controls systems professor at Wichita State, who also taught at the naval academy) regarding the full system, as I can design the electric motor.

https://ctms.engin.umich.edu/CTMS/index.php?example=MotorSpeed&section=SystemModeling

02/23/23

Drivetrain

So to add an extra wrench into the mix, I have decided I might as well design an electric motor while I'm designing the drivetrain. I mean, if I am already designing all of the gears, I should especially design an electric motor as an electrical engineer, right? Due to the automotive application, an IPM (interior permanent magnet) takes the cake as far as usage goes. An IPM motor has the magnets imbedded in the rotor making the motor extremely sound mechanically. IPM motors have a high magnetic saliency ratio ($L_q > L_d$), meaning the motor has the capability of generating torque by using both magnetic and reluctance torque components. These motors use less power compared to traditional motors (such as the SPM, or surface permanent magnet) and the magnet won't detach due to the force created within the motor.

A constraint that I need to keep in mind is that I only have 18 amps to toy with in regards to this, so even though I could make a motor more than capable of hitting my goals easily, I'm severely bound by the amperage from the alternator available to the teams. I will say, I am VERY excited to design this.As the electric motor here is only used to control the output speed of the transmission, I don't necessarily need to consider the max output torque of the motor. Using to the Willis Gear Equation for a Planetary Gear set and the excel calculator tool I've made, if I spin the electric motor fast enough, before speeding the engine up, I can make the car reverse! I've been wanting a reverse on the car for a while, but creating that mechanism in the time I was on the team was never feasible just because of the manpower available was so limited.

Appendix:

Dark Green 1	**Journal Input Date**
Blue	BAJA Rules
Red	Resource/Article/Book

B.1.2 - Ergonomic Design As a prototype of a commercial product, the design intent must accommodate drivers of all sizes from the 95th percentile male (in the country in which the competition is held) to the 5th percentile female. All drivers shall meet the roll cage minimum clearances, and fit into a comfortable driving position, while wearing the entire required driver's equipment. All drivers shall be able to comfortably reach all of the vehicle's controls.

Cockpit

https://www.hermanmiller.com/research/categories/white-papers/the-evolution-of-anthropometrics-and-user-control/#:~:text=In%20this%20database%2C%20a%2095th,between%20military%20and%20civilian%20databases.