ME 486C Engineering Model Summary

Front Suspension	**Zachary Biehl**
	Jared Bonds
	Dylan Wisniewski
Drivetrain	**Erik DiMaria**
	Claire Pescatore
	Logan Gerard Wilson
Rear Suspension	**Samuel Larios**
	Robert Gerlinger
	Tanner Bunch

Top Level Design Summary

For the 2022-2023 academic year, using the existing frame from the 2021-2022 team, a new team is tasked with new suspension (front and rear) and drivetrain to compete in the 2023 SAE Baja Competitions being held in Washougal, Washington on May 30, 2023. All sub-teams will be responsible for updating the cockpit. From the original project description given at the beginning of the year, the 2023 SAE Baja Team has been provided with the challenge to have all new suspension and drive train designs compared to the original description of having to complete the Baja with the 2022 components. This was a change because the 2022 Baja team duplicated the year prior and Northern Arizona University would like to see a variance to these designs. The designs of each sub-team system are below.

System QFD/ House of Quality

Project: SAE Baja: Drivetrain
Date: 1-20-23

Legend

A	2020-2021 NAU
B	Oregon State University
C	Virginia Tech.

#	Technical Requirements (correlations)	1	2	3	4	5	6	7	8
1	Reduce weight								
2	Improve complexity	++							
3	Reduce material usage	-	+						
4	Increase durability	-							
5	Team Cohesiveness		-						
6	Reduce Design/Production time		+	++		-			
7	Adhere to Rules								
8	Increase handling	+			++	++			
9	Competitive vehicle	++			+	++			-

#	Customer Needs	Customer Weights (%)	Reduce weight	Improve complexity	Reduce material usage	Increase durability	Team Cohesiveness	Reduce Design/Production time	Adhere to Rules	Increase handling	Competitive vehicle	1 *Poor*	2	3 *Acceptable*	4	5 *Excellent*
1	Meets all Design Req.	5							9					A		BC
2	Meets all Safety Req.	5							9					A		BC
3	4WD Compatible	4	1	3				3	9	9		BC				A
4	Low Cost	3	3	3	9			9						AB	C	
5	Production/Manufacturing Capability	5		6	3	3		9							A	BC
6	Competitive in events	3	3			3	3				9					ABC
7	Avoid Internal Discourse	5					9								ABC	
8	Deadline Management	5	3			3	3			1						ABC
9	Improve Previous Design	2		9	6		9			9	9					ABC
	Technical Requirement Units		kg	*	$	MPa	*	Hours	*	kN	*					
	Technical Requirement Targets		15	*	*	TBD	9	9	*	*	*					
	Absolute Technical Importance		66	60	48	39	80	81	99	48	63					
	Relative Technical Importance		3	4	9	8	7	2	1	5	5					

Figure 1: Drive Train QFD

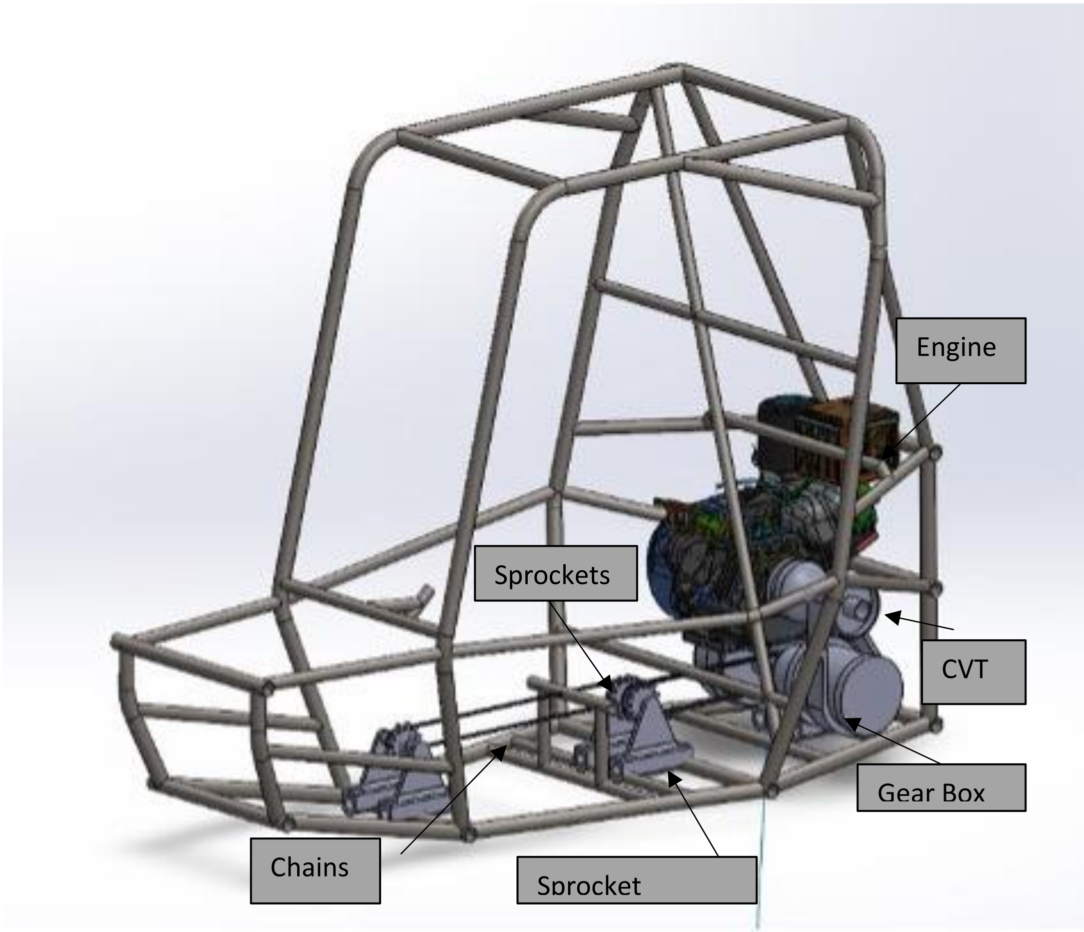

Figure 2: Drive Train CAD

From figure 2: Drivetrain sub-team has a double chain system linking the front to the back of the frame with sprockets connected to the drive shafts into the gearbox and CVT. This system will drive the entire vehicle, rolling the car which impacts the suspension sub-teams. The two chains connecting to the system will assist in making this vehicle all-wheel drive. Chain drive connects to a gearbox. Our gear box has two pinions and two gears that will be made of steel alloy, encased by aluminum. The most recent decision our team has made has been to manufacture steel reuleaux triangle's shafts in the machine shop which will cut down in costs. This shape of the shaft eliminates the use of keys and keyways inside the gearbox and allows our team to make changes in house. From there we also will have a CVT that our team gathered from the previous team, this will allow the engine to operate at a constant RPM while the vehicle moves at varying speeds. The CVT connects from the top shaft of the gear box to the engine. Sprockets are held by sprocket holders at the front, middle and rear of the vehicle. These sprockets are holding the chain tight to control the movement of the drive shafts.

Front Suspension Sub-Team:

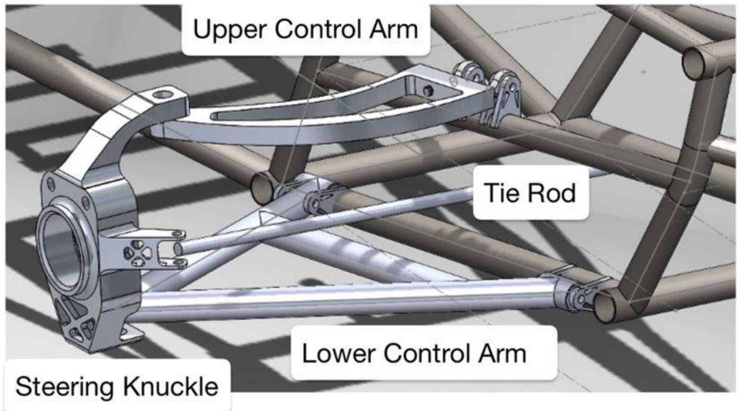

Figure 3 3: Front Suspension CAD V1

Figure 4 4: Front Suspension Final Prototype

From Figure 1: Front Suspension CAD V1, there are four items that keep the front end connected and working in synchronous. The main purpose of these components is to keep a parallel line of action allowing the wheel to remain in the adjustments throughout the full wheel travel. In our design we have investigated the cause of bump steer, and the area that contributes to this is the overall length of the tie rod. Having a steering rack at an optimal length directly contributes to the length of the tie rode. The front suspension team analyzed this and found that a 12in steering rack will allow for minimal bump steer. Bump steer is when the angle of the front wheels change as the suspension is cycled through the travel, "from bump to bump." Knuckle, the component where the main members of the front end come together. This is a main area that the front suspension team can cut weight as pervious years did not to an adequate FMEA, with front suspension utilizing the fact that the overall weigh of the vehicle around 350lbs, the front knuckle design is sufficient to survive impacts while remaining as light as possible. As an engineering requirement of 4x4, the front suspension team has developed a J-arm as the upper control arm to move the sock mount to the lower A-arm. This allows for a low center of gravity and keeps the shock out of the way where the axle will be located. The redesign of the upper control arm is to simplify the manufacturing process as well as cut down on price, as the team can now manufacture the upper control arm out of 4130 steel, rather than purchasing more aluminum and using the CNC. All together this allows for the front suspension team to answer all of the ER and CR.

Customer requirements, many of them are directly correlated with the SAE Baja competition. From the competition regulations the requirements that were selected were to meet design and safety needs. These are mandatory customer and competition needs that if not followed properly can result in disqualification. In addition to those, 4WD is also required this year by SAE Baja. Next from our client David Willy was low production cost and manufacturing capability. Professor Willy mentioned that based off our own skill levels and the resources we have allocated to us we should design parts and concepts with an honest understanding of our ability. Next, also from Professor Willy was to avoid internal conflict. Previous NAU Baja teams have struggled with this aspect and as a result this has become a client need to successfully complete this project. After that is the team's most important customer requirement which is to create a system that is competitive in all events. There is a great deal of variety with the Baja competitions and our client would like our vehicle to perform well in all individual competitions. Finally, rounding out the customer needs is deadline management and the ability to improve the overall design from previous NAU teams.

1. Meets all Design Req. – 10%
2. Meets all Safety Req. – 10%
3. 4WD Compatible – 10%
4. Low Cost – 10%
5. Production/Manufacturing Capability – 10%
6. Competitive in events – 20%
7. Avoid Internal Discourse- 10%
8. Deadline Management – 10%
9. Improve Previous Design - 10%

Engineering requirements either come from Professor David willy or from student research and knowledge. First up for ERs is the reduction of as much weight as possible. Racing speed comes down to two factors, weight, and power. In this competition power is regulated amongst all collegiate teams, thus weight plays a massive factor in performance. Next is to improve the overall suspension travel. This is beneficial in all competition aspects. After that the group chose to select material usage as another ER. This will mean the team will conserve money to allow for an adequate budget for travel and emergency costs. Durability was also selected by the group as a key requirement. Time is critical in the competition setting and by dedicating less time to fixing broken components the group can maximize its time for actual racing. The group has also chosen to select drivetrain compatibility and competition rules into the team ERs. These are mandatory requirements that should not be neglected. Additionally, the team has placed an emphasis on vehicle handling. These factors can be seen in handling time and steering angle.

1. Reduce weight - Pounds (lbs)

2. Improve Suspension Travel - Inches
3. Reduce material usage - $
4. Increase durability – psi/ksi
5. Drivetrain Compatibility - Y/N
6. Minimize Design/Production time - Hours
7. Adhere to Rules - Y/N
8. Increase handling - Seconds
9. Increase Steering Angle - Degrees

System QFD/ House of Quality

Project: SAE Baja: Front Suspension
Date: 01-28-23

Legend
A 2021-2022 NAU
B Oregon State University (4th Place)
C Virginia Tech. 5th Place

		1	2	3	4	5	6	7	8	9
1	Reduce weight									
2	Improve Suspension Travel	++								
3	Reduce material usage	++	+							
4	Increase durability	+		+						
5	Drivetrain Compatability		+							
6	Minimize Design/Production time			+		-				
7	Adhere to Rules									
8	Increase handling	+	+			++		++		
9	Increase Steering Angle		+			++		+	++	

			Technical Requirements									Competition Review				
	Customer Needs	Customer Weights	Reduce weight	Improve Suspension Travel	Reduce material usage	Increase durability	Drivetrain Compatability	Minimize Design/Production time	Adhere to Rules	Increase handling	Increase Steering Angle	1 Poor	2	3 Acceptable	4	5 Excellent
1	Meets all Design Req.	10.00%	1	1		6	9				3	A				BC
2	Meets all Safety Req.	10.00%				9	3		9				A			BC
3	4WD Compatible	10.00%		3			9	3	9	1	6	A				BC
4	Low Cost	10.00%		3	9	3					3			ABC		
5	Production/Manufacturing Capability	10.00%			3			9					A		BC	
6	Competitive in events	20.00%	9	6	6	6			3	3	6	A				BC
7	Avoid Internal Discourse	10.00%					3	3				A		BC		
8	Deadline Management	10.00%					6	6	3			A				BC
9	Improve Previous Design	10.00%	3	9	6	6	9			6	3	A				BC
	Technical Requirement Units		lbs	inches	$	MPa	*	Hours	*	kN	Degees					
	Technical Requirement Targets		100	24	$1,400	TBD	N/A	200 Approx.	N/A	TBD	50 Degrees					
	Absolute Technical Importance		2.2	2.8	3	3.6	3.9	2.1	2.7	1.3	2.7					
	Relative Technical Importance		7	4	3	2	1	8	5	9	5					

Figure 5 5: Front Suspension QFD

Rear-end sub-team

Our decision process was narrowed down by utilizing a black box model, then a full functional model for the rear suspension. As a team we presented ideas through our client then moved forward completing a decision matrix to get our final concept idea. It is vital we use the same criteria needed within the customer needs, because our final design should reflect our house of quality requirements. The final design features a trailing arm with two supporting lateral links. The trailing arm has a slight bend out towards the tire and orients the hub parallel with the side of the car. The shock mount is placed on the top of the trailing arm. The end of the trailing arm features some avocado tabs and two tubing lateral links. On the ends of the links there will be heims to create adjustability to the overall geometry of the suspension system. The appropriate sizing, dimensions, and geometrical orientation will make this design successful. The image below represents our prototype.

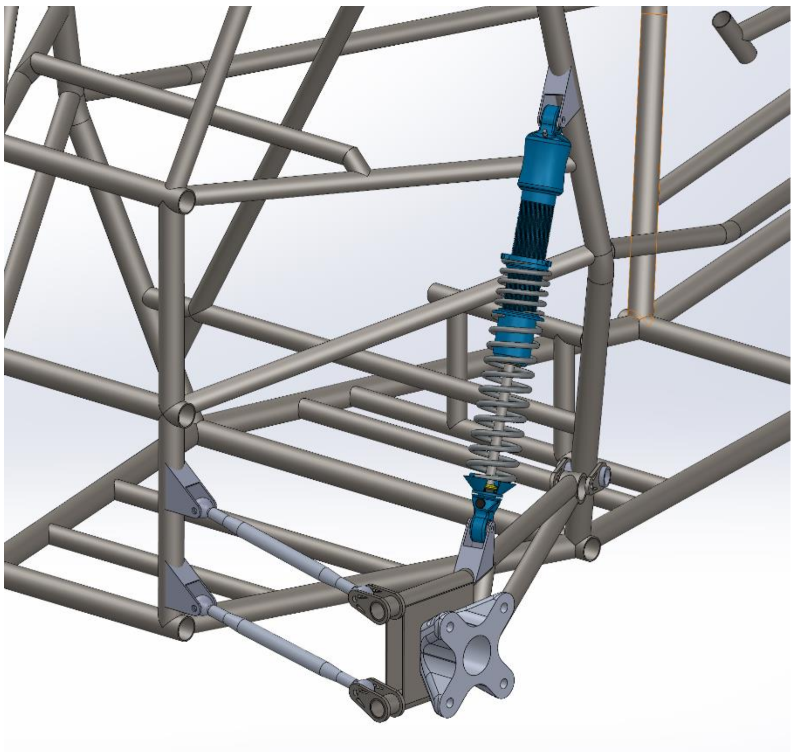

Figure 6 6: Rear Suspension CAD

The first protype follows the design in the Solid works file. It is composed of PVC and 3D printed parts to replicate the Lifesize Design. It gave the team experience in fabrication and helped lead into the next design process.

Figure 77: Rear Suspension Prototype V1

The 2nd prototype below depicts the same style of rear end suspension with some slight modifications. After the first protype and some Solid works stress analysis, it was decided to eliminate the shock mount member to reduce weight without hurting the integrity of the design. We also replaced the front mounting point with a hyme to add more toe in/out adjustability. The avocado tabs were also eliminated to reduce weight and improve the geometry performance throughout the suspension cycle. The hub in the image below is a simple mockup to help envision the final design.

Figure 8 8: Rear Suspension Prototype V2

The next steps are to manufacture the final design. Parts are being ordered and the components that need fabricated are under way. Some slight modifications and design adjustments may be required during the manufacturing process.

System QFD/ House of Quality

Project:	SAE Baja: Rear Suspension
Date:	01-28-23

Legend

A	2021-2022 NAU
B	Oregon State University (4th Place)
C	Virginia Tech. 5th Place

		1	2	3	4	5	6	7	8
1	Reduce weight								
2	Improve Suspension Travel	++							
3	Reduce material usage	+	+						
4	Increase durability	+		+					
5	Team Cohesiveness								
6	Minimize Design/Production time			+		-			
7	Adhere to Rules								
8	Increase handling	+				++		++	
9	Competitive Vehicle	++				++		+	++

			Technical Requirements									Competition Review				
	Customer Needs	Customer Weights	Reduce weight	Improve Suspension Travel	Reduce material usage	Increase durability	Team Cohesiveness	Minimize Design/Production time	Adhere to Rules	Increase handling	Competitive Vehicle	1 Poor	2	3 Acceptable	4	5 Excellent
1	Meets all Design Req.	15.00%							9		3		A			BC
2	Meets all Safety Req.	15.00%							9				A			BC
3	Clearance	10.00%	1	3					6	6			A			BC
4	Low Cost	5.00%	3	3	9	3		9			6		AB	C		
5	Production/Manufacturing Capability	15.00%		6	3			9				A			BC	
6	Compete in all types of terrain	15.00%	3			9			6	6	6	A				BC
7	Avoid Internal Discourse	5.00%					9					A		BC		
8	Deadline Management	10.00%	3				3			1		A				BC
9	Improve Previous Design	10.00%		9	6		9			9	9					BC
	Technical Requirement Units		lbs	inches	$	MPa	*	Hours	*	kN	Degees					
	Technical Requirement Targets		100	24	$1,400	TBD	N/A	200 Approx.	N/A	TBD	50 Degrees					
	Absolute Technical Importance		1	2.3	1.5	1.5	1.7	1.8	4.2	2.5	2.6					
	Relative Technical Importance		9	7	8	3	2	5	1	6	4					

Figure 9: Rear Suspension QRD

For the rear suspension, our customer requirements were aligned mostly with the rules set by SAE for the competition. Our first few customer needs were directly from the rules, which was to meet design and safety regulation of the competitions, as if this were not met properly, our team would then be disqualified. From our client David Willy it was important that we kept everything low cost and that we would not overestimate the project as whole as well as within sub teams when it came to manufacturing and designing. Another main request was to avoid internal discloses as previous teams failed to do so and maintaining a relationship with our client is especially important. To assist with this, our client stated to have great deadline management to prepare for anything to go wrong. Lastly was to improve the overall design from previous years, making it unique and able to compete in all aspects of the competition as we want to score high as a team and represent NAU highly.

1. Meets all Design Req. - 15%
2. Meets all Safety Req. - 15%
3. Clearance – 10%
4. Low Cost -5%
5. Production/Manufacturing Capability – 15%
6. Terrain Type – 15%
7. Avoid Internal Discourse - 5%
8. Deadline Management – 10%
9. Improve Previous Design - 10%

The team's engineering requirements came from both our client as well as research done by our sub-teams for what we believed seemed fit. First, we wanted to reduce weight, this is very important as most competitive cars keep their weight around or below 300lbs as the more we weigh with the same amount of power the lower the performance. By meeting our specs for competition and designing the most efficient suspension geometry will give us the most impact reduction. By reducing material usage, it will save us money to use throughout the rest of the project. Increasing the durability will ensure our design life cycle which could then save us much more time and money making it more durable. With our designs we want to make sure we do the best when it comes to how we align the rear end to maximize our handling. Lastly, it is to have a competitive vehicle that can compete in every aspect as we are going to be faced with many different obstacles that we must score high in within the competition.

1. Reduce weight – Pounds (lbs)
2. Meet Hydraulic Specs - Inches
3. Reduce material usage - $
4. Increase durability - MPa
5. Team Cohesiveness – minutes/hours
6. Minimize Design/Production time - minutes/hours
7. Adhering to Rules
8. Increase handling
9. Competitive Vehicle

Summary of Standards, Codes, and Regulations

All standards, codes and regulations listed below are applicable to the design and functionality of the 2023 SAE Baja vehicle. Multiple SAE codes for the vehicle were found in the rulebook for the 2023 SAE competition. For the vehicle to pass inspection and be able to compete all specified standards, codes, and regulations must be adhered to. The reason is to ensure safety of everyone in or attending the competition and keep the vehicle regulated. Lighting codes that require working break lights on the vehicle are specified in the rulebook. Backup alarm systems are under code for safety of others around the vehicle while in operation. Standards for gear design provided by AGMA are used in the gearbox design. ANSI standards are used when proportioning the teeth on the spur and helical gears. Guidelines and regulations for geometric dimensioning and tolerancing are put in practice to aid in the manufacturability of the designs. All standards, codes, and regulations listed in this document are important to the design and functionality of the vehicle being designed and will also ensure compliance with the competition requirements set by SAE.

Table 1: Standards and codes

Standard Number or Code	**Title of Standard**	**How it applies to Project**
J586	Stop Lamps for Use on Motor Vehicles Less Than 2032 mm in Overall Width	Our vehicle must have brake lights
J759	Lighting Identification Code	Code specifies certain lighting requirements that must be in line with the vehicle

J994	Alarm – Backup – Electric Laboratory Tests	Defined a set of requirements for backup alarms on the vehicle
J1741	Discriminating Back-Up Alarm Standard	Evaluates the performance of the backup alarm
AGMA-1003-H07	Tooth Proportions for Fine-Pitch Spur and Helical Gearing	Allowing for meshing without interference with the gearbox system.
AISI S202-20	Code of Standard Practice for Cold-Formed Steel Structural Framing	For the steel welding we needed to fix the back of our frame and how that applies to structural framing.
ASME Y14	Guideline for the design language of geometric dimensioning and tolerancing	Dimensioning and geometric equations used to gear and shaft equations.
ASTM A1003/A1003M-15	This specification covers coated steel sheet used in the manufacture of cold-formed framing members, such as, but not limited to, studs, joists, purlins, girts, and track	For the sheet metal used for CVT casing and the chain guard.
AWS D:1.3	Structural Steel Welding Code	For the restructuring of our frame to fit the engine.
ANSI100-H07	Tooth Proportions for Fine-Pitch Spur and Helical Gearing	For all parameters in our gears.
ISO/TS 16949	Technical specifications for automotive vehicles.	Follow specifications given by engines and any automotive moving part.
SAE	SAE BAJA Rules and Regulations 2023	Our vehicle must comply to these rules and regulations in order to complete and pass inspection in order to compete.
J1147_201801	Welding, Brazing, and Soldering- Materials and Practices	This applies to our project because we need to follow practices for welding our components together. This includes welding sections of the frame for structural support.

J836/3_202111	3D CAD for SAE J826 H-Point Machine	This applies to our project because our rear suspension needs to be modeled before it can be manufactured
J836_201801	Automotive Metallurgical Joining	This applies to our project because we are welding different materials together. Our frame components are made of chromoly and other members are made of 304 steel.
J826/2_201610	2-D CAD Template for SAE J826 H-Point Machine	This applies to our project because our rear suspension needs to be modeled before it can be manufactured. Creating 2D drawings ensures that machinists know how to manufacture certain parts.

Summary of Equations and Solutions

The conditions that led to our analyzed “load cases” all lead into each design component of front suspension, rear suspension, and drivetrain. All these components impact performance and play a critical role while the car is in motion. Fundamental forces of the suspension and drivetrain are measured to estimate the normal and shear force while competing in the competition obstacles. The vehicle will undergo various situations operating over obstacles such as mud, rocks, barriers, logs, and many other potential load cases. Some of these situations may undergo more force than “regular” operation on flat terrain. It is important to analyze all subsystems in the “worst case” scenario. This will ensure safety factors are high enough to withstand the highest amounts of force endured. The calculations below are divided into each sub-team along with the design process and equations/software used.

Front Suspension:

Within the Front Suspension subsystem, the three most important areas we chose to analyze were the Outer CV Axle Splines, Lower Control Arms, and Upper Control Arms. The Outer CV Axle Splines will be press fit into the wheel hub, this press fit is the only force counteracting the torque transmitted from the drivetrain. Through some research and Excel Calculations the press fit that we will be utilizing can support far more torque than we expect to see. With our current motor and gear ratio we plan to see only about 6.5 ft-lbs of torque while the max this setup can support is 219 ft-lbs. The next order of business was the load that the lower control arms. Through various load calculations based on the estimated final weight, plus driver weight, and including jumps and landings, the lower control arms are expected to see 220lbs of force under the worst-case scenario. With the chromoly steel tubing that we purchased these values do not even approach the yield strength. Lastly the team analyzed the camber and toe angle effects under max suspension bump and rebound. With the final suspension setup and estimated weight of 450lbs with a driver the max camber is expected to range from approximately -1 degree to -3 degrees, while the toe angle is expected to range from 1 degree to -1 degree. Both angles are measured over a 3-inch travel distance.

Rear Suspension:

Following our first steps in the design process the rear end team utilized Lotus Shark Software. From the start we began to draw out designs that would work with our existing frame, assuring they abide by the SAE competition rules, and then began to create a model on SolidWorks. This allowed our team to find critical points within the rear suspension system and apply them to Shark Software. By creating an accurate representation of what we want our actual model to look like we were able to test some of the functions on the Shark Software showing our sub team how components would perform. Such as toe and camber angle, it would show us by providing graphs of information of each and many more that are not so applicable to the rear end. Figures of the rear end shark model will be shown within the appendix.

For the Rear trailing arms, the rear suspension team utilized Solidworks remote load feature. The team applied 200 lbf on each trailing arm member without the supporting hub casing/rear end links. The rear suspension team plans to make further adjustments to the dimensions once we determine the rear axle locations. Then the team will be able to properly determine the maximum amount of load the rearend suspension can withstand while competing.

Drive Train:

After comprehending what our team might have to go through in the competition, drivetrain decided to match our designs with the parameters that would best suit the teams' scenarios and the teams' placements and way the drivetrain system is designed is to satisfy basic requirements. We knew that the components to the gearbox had to withstand what the engine would output as well as contain a casing that is secured tight so no more issues would arise unnecessarily. Given the safety factors that our team came up with, we decided that the little extra boost above one would account for extra safety, accounting for less breakage or unforeseen consequences. With the rotational torque coming from the engine/CVT into the gearbox, the team knew that most of the stress would be in the middle shaft inside our gearbox, naming it the "critical gear”. If that gear was above the safety factors designated, and with the already extra boost, the team knew the design would be more than safe from breakage. With the shaft it was just another deciding of what parameters and dimensions would allow for a minimum safety factor of 1. All equations and parameters used will be in appendix A.

Table 2: Load Cases and FOS

Sub-Team	Part	Load Case Scenario	Material	Min. F.o.S.
Front Suspension	CV Axle Outer Spline	Under acceleration 8.5 N-m of torque being transmitted through the front axles, Stress concentration on the outer surface of spline. (Spline will be press fit into hub)	Steel	25
	Lower Control Arm	220 lbs of force transmitted through each of the lower control arms	Chromoly Steel Tubing	2.4
	Upper Control Arm (J-Arm)	Under max Bump and Rebound, the max Toe and Camber angles are expected to be -3 degrees and -1 degree respectively.	Chromoly Steel Tubing	N/A

Rear Suspension	Bearings	The weight of the vehicle as it completes dynamic movement causes compressive loads against the housing.	Steel	TBD
	Trailing arm	The trailing arm is controlled by a shock spring/dampener that soaks up the energy caused from terrain changes. The control arm endures compression and tension loads at the shock mounting point.	Chromoly	TBD
	Links	The links attached to the trailing arm with experience axial loads as the vehicle is cornering or bumping into terrain from the side.	ABS	TBD
	Axle	Under acceleration of X N-m of torque transmitted from the gear box to the axle, Wall thickness of the lightened section is crucial to not fail.	Steel	TBD
	Hub	After impact of the tires through the dynamic movement over obstacles, the wheel inflicts various forces on the studs/hub.	Aluminum	TBD
Drivetrain	Gears (Bending)	Calculated torque range will be exerted in rotational energy onto the gears from the given engine that then tells the teams if the design for the gears is good enough to meet the criteria.	Steel	1.5
	Gears (Contact)	Calculated torque range will be exerted in rotational energy onto the gears from the given engine that then tells the teams if the design for the gears is good enough to meet the criteria.	Steel	1.2
	Gearbox Shafts	Calculated torque and weight by excel spreadsheet to meet safety criteria given certain parameters from materials etc...	Steel/Aluminum	1
	Bearings	Calculated torque and weight by excel spreadsheet to meet safety criteria given certain parameters from materials etc... Chosen on diameter and documented through order sheet.	Steel/Aluminum	1

Flow Charts and other Diagrams

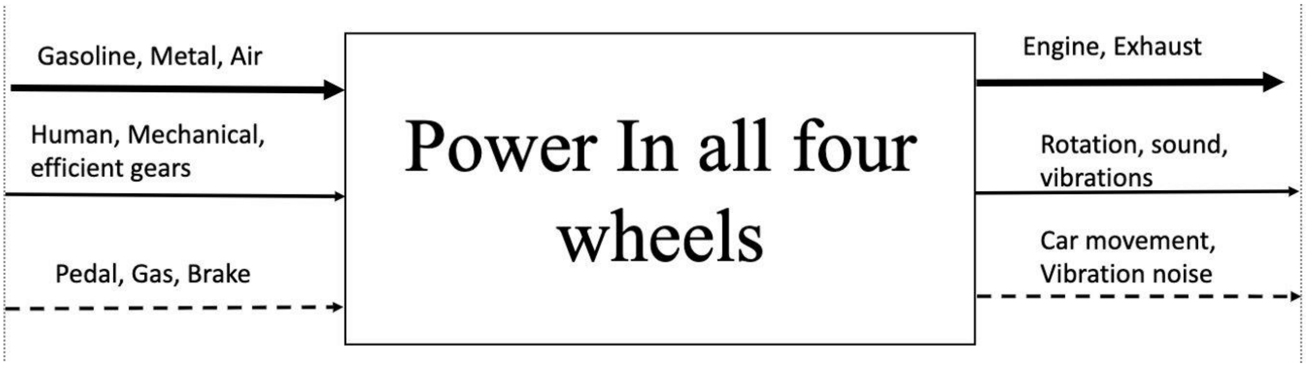

Figure 10:10 Black Box Model

Power needs to go into the car, which comes from the engine, which needs to be transmitted in a way that power is transmitted to all four wheels. A human is included as one must be piloting the car, with pedals gas and brakes included as they are required to activate the inputs to the car. The inputs are required to power all four wheels, or at the very least be capable of all wheel drive. The outputs are listed in a way that shows all the possible results from the inputs.

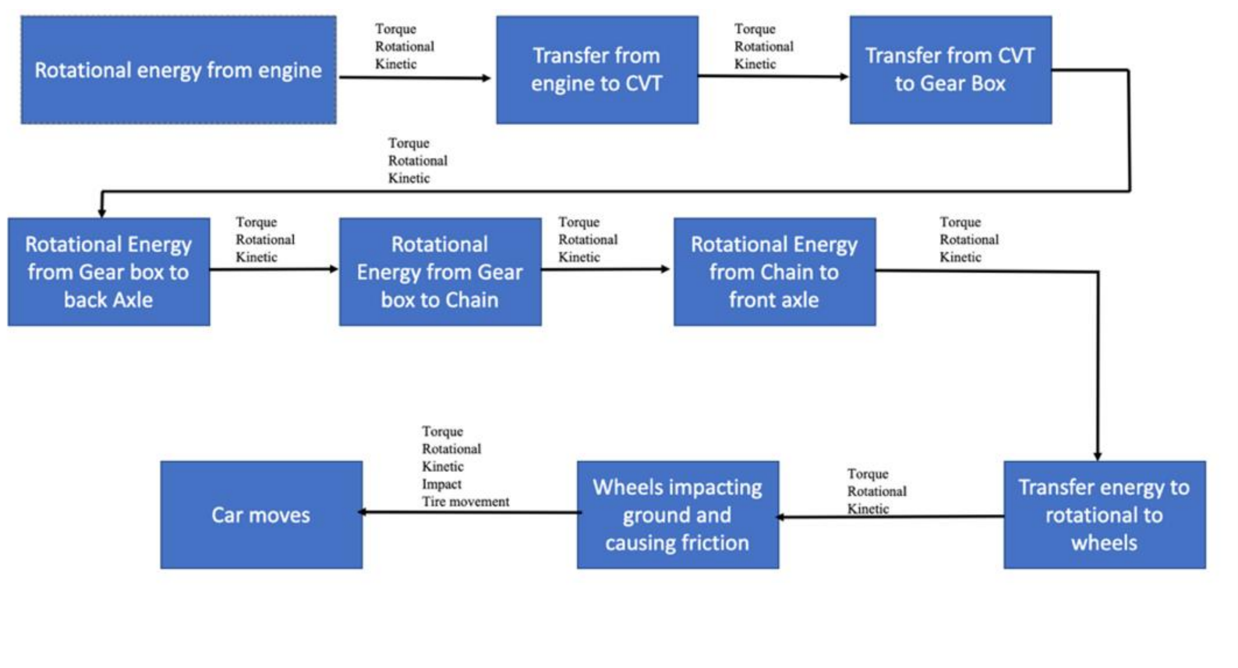

Figure 11:11 Functional Model

The functional model goes over the steps required to get the car moving. Power from the engine goes into the CVT which is fed into the gearbox. The gearbox and CVT are required to ensure the car operate at an optimal speed and torque for each competition. Figure 7a goes over the torque speed characteristics of the engine that were used for the previous calculations.

SAE Baja 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	9.0	8.5

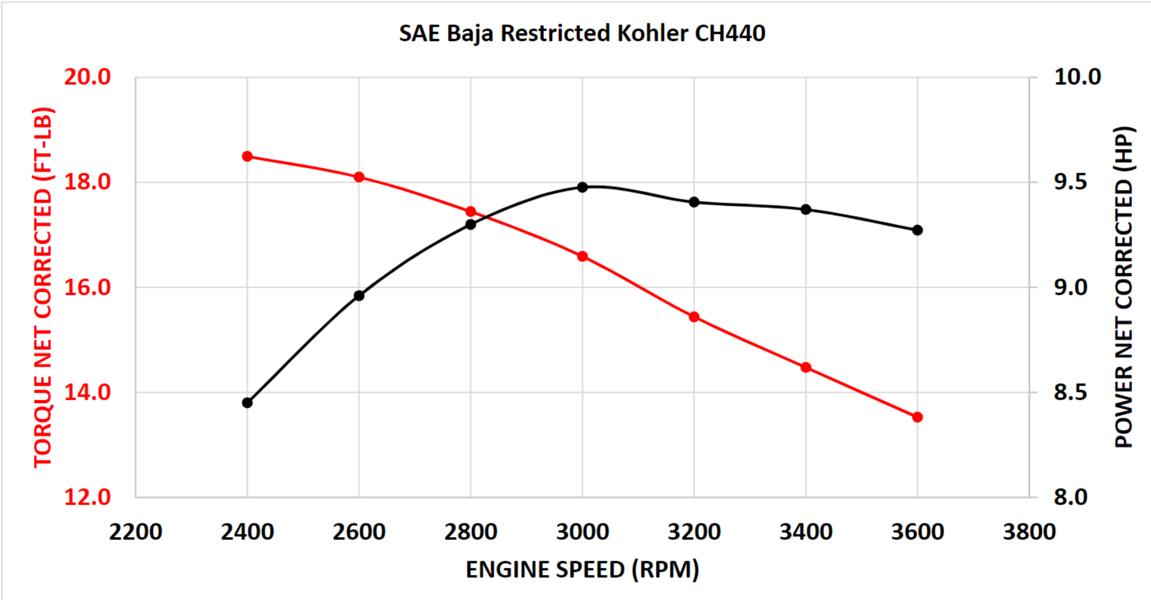

Figure 12: Kohler Torque Speed Characteristics

For the final design chosen, the energy from the gearbox is transmitted to a chain that runs from the back to the front of the car to provide all wheel drive. The power is then transferred to the wheels which provides the required force to move the car.

Moving Forward

Front Suspension:

Moving forward the front suspension team still has some areas to address. Within the next few weeks to months the front suspension team will focus on carrying out steering calculations which will also include modifying and fabricating a new steering rack to achieve the desired steering throw while staying in compliance with little to no bump steer. Another area of importance will be the spring rate and dampening adjustment and fine tuning. Suspension performance steering will play a massive role in the way the vehicle handles and ultimately performs in competition. Once these calculations have taken place the front suspension team plans to begin fabrication on the knuckles, hubs, and control arms.

Rear Suspension:

Rear suspension will spend the next few weeks finalizing the design of the rear hubs, performing axial load calculations, and beginning fabrication. Fabrication will be limited to components not reliant on drivetrain's output shaft location. Elements that could begin getting manufactured include the rear links, trailing arm plates, and eventually rear hubs. Then, once drivetrain does finalize the output shaft location the rear suspension team can begin fabricating the complete trailing arm assembly to be bolted up to the chassis.

Drivetrain:

The drivetrain sub team will focus the next few weeks on modeling the various components including the engine, CVT transmission, and gearbox in Solidworks. From the modeling, tabs and mounting brackets will be made to ensure the powertrain does not move during testing or driving. Next, the group will perform chain and sprocket force analyses to ensure that under full acceleration and maximum torque those components won't fail. Once all these calculations have taken place the drivetrain team will begin fabrication of mounts and gearbox components.

Appendix A: Summary of Equations and Solutions

Figure 13:13 Outer CV Axle Spline

Figure 14 14: Upper and Lower Control Arms

Table 1: Press Fit Calculations

Shaft	
Young's Modulus, *Ei* (PSI)	29,000,000.0
Poisson's Ratio, *vi*	0.340
Shaft Internal Diameter, *di* (inch)	1.000
Shaft Nominal Diameter, *d* (inch)	1.250
Shaft Upper Tolerance (inch)	0.001
Shaft Lower Tolerance (inch)	0.001
Shaft Maximum Diameter (inch)	1.251
Shaft Minimum Diameter (inch)	1.251
Hub	
Young's Modulus, *Eo* (PSI)	29,000,000.0
Poisson's Ratio, *vo*	0.340
Hub Outer Diameter, *do* (inch)	1.50
Hole Nominal Diameter, *d* (inch)	1.250
Hole Upper Tolerance (inch)	-0.001
Hole Lower Tolerance (inch)	0.000
Hole Maximum Diameter (inch)	1.249
Hole Minimum Diameter (inch)	1.250
Pressure Generated between Shaft and Hub	
Maximum Radial Interference, δmax (inch)	0.0006
Minimum Radial Interference, δmin (inch)	0.0010
Max Pressure Generated, pmax (PSI)	2,572
Min Pressure Generated, pmin (PSI)	4,594
Force Required to Engage/Disengage Shaft and Hub	
Width of Hub, w (inch)	2.08
Friction Between Shaft and Hub, μ	0.20
Area of Contact, A (inch^2)	8.17
Force Required, maximum (lbs)	4,202
Force Required, minimum (lbs)	7,504
Torque that can be transmitted without slip	
Torque, maximum (ft-lbs)	219

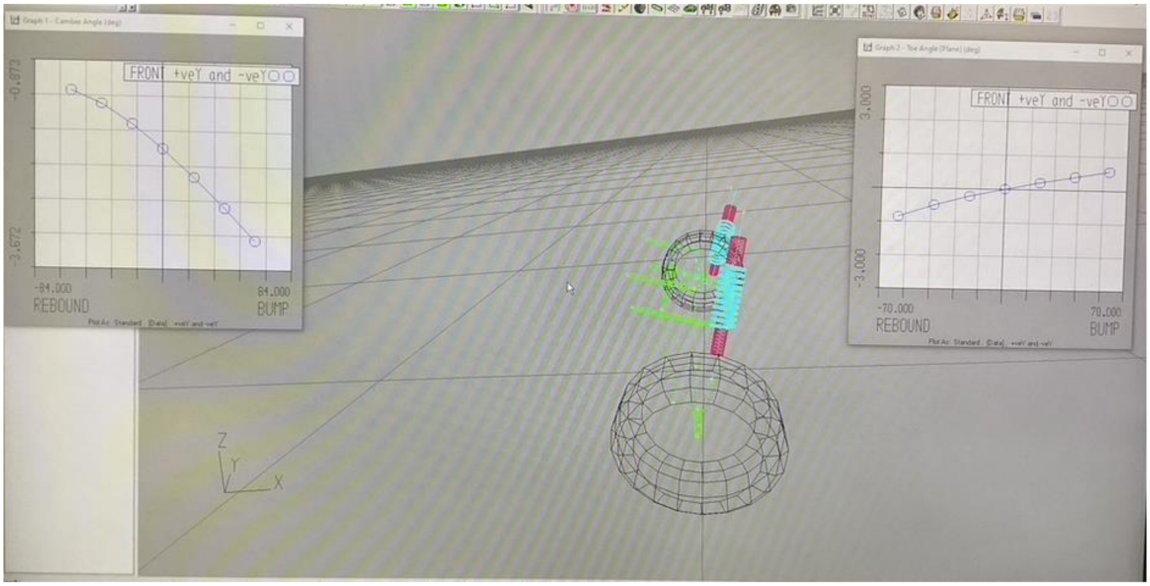

Figure 15 15: Shark Camber and Toe Angles for front end

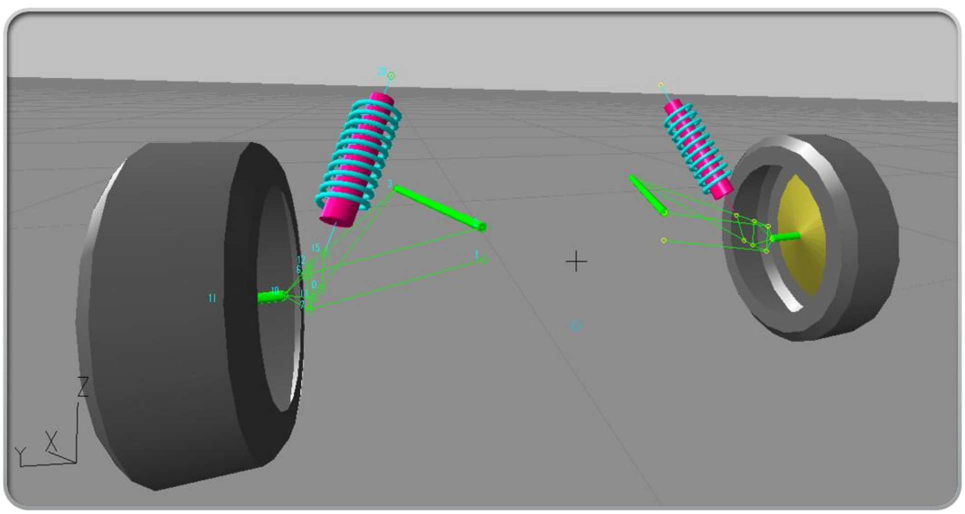

Figure 16 16: Shark Model for the rear end

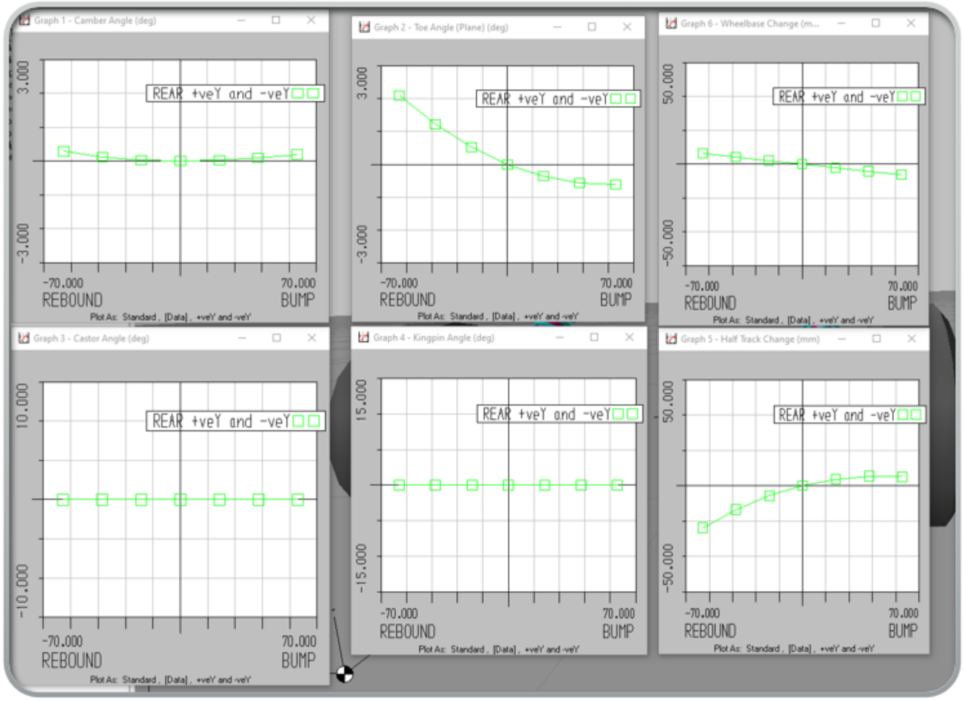

Figure 17 17: Shark Graphs for the rear end suspension

Erik DiMaria Claire Pescatore Logan Gerard Wilson Givens:		Gear Ratio (Mg)	Module	NP 1st half	NP 2nd half	Min # of teeth in pinion (to avoid interference, Np)	# of teeth in gear (Ng)	Pitch Line Diameter (mm)	RPM	H,in(power in KW)
Rpm	2800	Gear 2: (4:1)	3	2.442466334	6.271370763	48	144	144	557.8125	14.9142431
load (output KW)	10.43997017	Gear 3:(4:1)	3	2.442466334	6.271370763	18	54	54	1487.5	14.9142431
Pressure Angle (degrees)	0.342020143	Gear 4: (5:1)	2	3.419452868	4.338356498	32	64	64	1487.5	14.9142431
Output pinion (cycles)	10^7	Gear 5(5:1)	2	3.419452868	4.338356498	17	34	34	2800	14.9142431
Full Depth teeth (k)	1									

	Pitch Line Speed(m/s)	Torque (N*mm)		Tangential Force(N)	Total Force (N)
Gear 2	4.21	255338.53	Force(Gear2,3)	3546.107208	3773.69
Gear 3	4.21	95751.95		3546.107208	
Gear 4	4.98	95751.95	Force(Gear4,5)	2992.027957	3184.05
Gear 5	4.98	50868.23	Force (Gear 5)	2992.027957	3184.05

GEAR 2

Symbol	Name:	Bending SF	Wear SH	Calculations:	Comments:		
Wt	Tangential Load	X	X	3546.107208		SF (requirements)	>1.5
Ko	Overload	X	X	1.75	(Medium shock to Heavy Shock)	SC (requirements)	> 1.2
QV	Quality Control	X	X	12	(Chosen)		
A	Part of qulaity control	X	X	106			**Safety Factors:**
B	Part of quality control	X	X	0		**SF**	**4.117446812**
Kv	Dynamic (velocity)	X	X	1	m/s	**SC**	**1.527609631**
Vt	Max speed for quality	X	X	54.08	m/s		
Ks	Size	X	X	1	(since module <5 and pitch diamter >5)		
Face	Face of gear	X	X	30	(rushgear.com)(mm)		
Cpf	For Km	X	X	0.032815556	25<b<425mm		
Cma	For Km	X	X	0.1455079	For Commerical,closed Gearing		
Km	Load Distribution	X	X	1.178323456			
KB	Rim-Thickness	X		1	Set to 1 for now		
J	Geometry for bending strength	X		0.42	Figure 14.6		
Cp	Elastic coefficient		X	191	sqrt(MPA) (table 14-8)		
Cf	Surface Condition		X	1	Assumption		
I	Geometry for pitting resistance		X	0.135974302			
St	AGMA Bending Strength	X		301.5	N/mm^2 figure 14-2		
YN	Stress cycle f for bending strength	X		1.440993028	at 10^7 cycles(look at new Yn equation)		
KT	Tempurature	X	X	1	Assumption		
KR	Reliability	X	X	1	Assumption		
Sc	AGMA Surface Endurance strength		X	1088	figure 14-5, hb of 400(mpa)		
CH	Hardness-Ratio		X	1	Assumption		
ZN	Stress cycle f for pitting resistance		X	1.210357578	Figure 14-15 (change like YN)		
Sigma	Stress for bending	X		105.5166995			
Sigma C	Stress fot contact		X	862.0455237			

Figure 18: Gear equations/factor of safety requirements

GEAR 3

Symbol	Name:	Bending SF	Wear SH	Calculations:	Comments:		
Wt	Tangential Load	X	X	3546.107208			
Ko	Overload	X	X	1	(uniform shock)		
QV	Quality Control	X	X	10	(Chosen)		
A	Part of qulaity control	X	X	83.77638527			**Safety Factors:**
B	Part of quality control	X	X	0.396850263		SF	**3.046360454**
Kv	Dynamic (velocity)	X	X	1.12521692	m/s	SC	**1.945766884**
Vt	Max speed for quality	X	X	33.53936221	m/s		
Ks	Size	X	X	1.05	(since module <5 and pitch diamter >5)		
Face	Face of gear	X	X	30	(rushgear.com)(mm)		
Cpf	For Km	X	X	0.032815556	25<b<425mm		
Cma	For Km	X	X	0.1455079	For Commercial, Closed Gearing		
Km	Load Distribution	X	X	1.178323456			
KB	Rim-Thickness	X		1	Set to 1 for now		
J	Geometry for bending strength	X		0.27	Figure 14.6		
Cp	Elastic coefficient		X	191	sqrt(MPA) (table 14-8)		
Cf	Surface Condition		X	1	Assumption		
I	Geometry for pitting resistance		X	0.180269313			
St	AGMA Bending Strength	X		301.5	Mpa		
YN	Stress cycle f for bending strength	X		1.119665255	at 10^7 cycles		
KT	Tempurature	X	X	1	Assumption		
KR	Reliability	X	X	1	Assumption		
Sc	AGMA Surface Endurance strength		X	1088			
CH	Hardness-Ratio		X	1	Assumption		
ZN	Stress cycle f for pitting resistance		X	1.100153749	Figure 14-15		
Sigma	Stress for bending	X		110.8138972			
Sigma C	Stress fot contact		X	615.164791			

GEAR 4

Symbol	Name:	Bending SF	Wear SH	Calculations:	Comments:		
Wt	Tangential Load	X	X	2992.027957			
Ko	Overload	X	X	1	(uniform shock)		
QV	Quality Control	X	X	8	(Chosen)		
A	Part of qulaity control	X	X	70.7222106			**Safety Factors:**
B	Part of quality control	X	X	0.629960525		SF	**2.622672395**
Kv	Dynamic (velocity)	X	X	1.261785793	m/s	SC	**1.447536164**
Vt	Max speed for quality	X	X	23.79395879	m/s		
Ks	Size	X	X	1	(since module <5 and pitch diamter >5)		
Face	Face of gear	X	X	20	(rushgear.com)(mm)		
Cpf	For Km	X	X	0.011350909	25<b<425mm		
Cma	For Km	X	X	0.5638	For Commerical, closed Gearing		
Km	Load Distribution	X	X	1.575150909			
KB	Rim-Thickness	X		1	Set to 1 for now		
J	Geometry for bending strength	X		0.42	Figure 14.6		
Cp	Elastic coefficient		X	191	sqrt(MPA) (table 14-8)		
Cf	Surface Condition		X	1	Assumption		
I	Geometry for pitting resistance		X	0.180269313			
St	AGMA Bending Strength	X		301.5	Mpa		
YN	Stress cycle f for bending strength	X		1.119665255	at 10^7 cycles		
KT	Tempurature	X	X	1	Assumption		
KR	Reliability	X	X	1	Assumption		
Sc	AGMA Surface Endurance strength		X	1088	Mpa		
CH	Hardness-Ratio		X	1	Assumption		
ZN	Stress cycle f for pitting resistance		X	1.100153749	Figure 14-15		
Sigma	Stress for bending	X		128.7156852			
Sigma C	Stress fot contact		X	826.8997406			

Figure 19: Gear equations/factor of safety requirements

Shaft 2 (middle shaft with pinon and gear)		
Descriptions	**1020 CD Steel D1**	Untis and Assumptions
Diameter(Location of gear)	30	mm
W(t)2-3	3546.107208	N
W(r)2-3	1290.677471	N
W(t)4-5	2992.027957	N
W*4-5	1089.009116	N
Total Force (2-3)	3773.69	N
Total Force (4-5)	3184.05	
Gear 3 Diameter	54	mm
Gear 4 Diameter	64	mm
T on shaft Between Gear 3	95744.89461	N*mm
T in Shaft Between Gear 4	95744.89461	(N*mm)
Length 1/3	15	mm (assumption)
Length 2/3	35	mm (assumption)
Full Length	60	mm (assumption)
Reaction_B	957.9246856	(N) Assume total Length = 60mm, gear 4 to point A = 30mm, Gear 3 to point A = 10mm
Reaction_A	1421.761902	(N)
Moment @ Gear 3	21326.42853	N-mm
Monent @ Gear 4	9579.246856	N-mm
Max Moment	21326.42853	N-mm
Max Stress (Sigma)	11.0363876	Mpa
Max Shear (TAU)	19.21924535	Mpa
Kt	1.5	Assume generous fillet radius
Kts	1.7	Assume generous fillet radius
Ka	3.583113211	
Kb	0.86172702	
Kc	0.59	Assumption (torsion)
Kd	1	Assumption
Ke	0.814	Assumption for 99% reliability
r/d	0.02	From table
q	0.67	From Graph 6-26
Qs	0.72	
r	0.6	mm
Kf	1.335	
KFs	1.504	
Sut	0.468843496	Gpa
Se'	0.234421748	GPa
A	0	
B	249.4158731	
Se	0.347619842	Gpa
Small d, (shoulder point 1)	9.217642637	mm
nf	50.75368397	
T_max	11.37317187	Mpa
Ny	17.14561269	

Figure 20: Shaft equations/factor of safety requirements

Rpm Reversed	Torque (n*mm)	rpm - mph	Tire Dimensions	
557.8125	8319.35123	**38.16823106**	Radius (in)	11.5
1487.5	22184.93661	101.7819495	Height (in)	23
1487.5	22184.93661	101.7819495	Wheel Diameter (in)	10
2800	0.005326515	191.589552	Width (in)	7
			Circumference	72.256631
			Circuference to miles	0.00114041
	Vehicle Weight	500	Assume (lbs)	
	Vehicle Mass	15.52795031	slugs	
	initial speed	0	mph	
	final speed	38.16823106	mph	
	time	0.002777778	assume 10 sec (hr)	
	Acceleration	**1.706272907**	**(m/s)^2**	

Figure 21: Equations to obtain required speed