Memo

Northern Arizona University

To:	Doctor John Tester
From:	SAE Mini Baja Drive-Train Team
CC:	Abdulrahman Almuflih, Andrew Perryman, Caizhi Ming, Zan Zhu, Ruoheng Pan
Date:	12/14/2013
Re:	Final Design and Prospected Prototype Cost

Comments: The information below is based on the final presentation that the drive-train team presented to you on Monday, December 9, 2013. This Material is subject to change pending the results of the future meeting of the entire Baja Team.

Purpose

This memorandum is to inform or client, Dr. Tester, that as proscribed at the beginning of the fall semester of 2013 our team has designed a drive train to be installed in the Mini Baja vehicle. This design takes the donated Briggs and Stratton engine and uses three main concepts to achieve the goals we have set for ourselves at competition. The first stage is to attach a Continuously Variable Transmission to the engine. Because we are using a transmission or gear box after this component, it acts more as a torque converter than a transmission. Secondly, we have selected a four stage transmission to implement in conjunction with the CVT. This will allow the driver to shift between; a high gear ration, low gear ratio, reverse, and neutral if they so desire. Finally, to acquire the final gear ratio the team desired, we designed a three to one secondary reduction from the transmission to the final output shaft. Along with this design we have researched the cost of these parts and assumed an initial cost of the prototype.

Final Budget

The costs that were equated for the budget analysis are based on retail prices, which would be the worst case scenario. We have found that more likely than not we will be able to obtain these parts through donations or at the very least at a discounted price because we are a team of students. We included all minor components for the main parts described above; keys, chains, shaft material, etc. We also estimated half shafts in our budget, which we estimated to be a large amount of the cost because we do not want to use rebuilt parts if possible. The total estimated cost of our prototype is $ 2,058. This includes a $200 buffer for shipping fees.

SAE Mini Baja Drivetrain

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Team 02

Final Proposal

REPORT

Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design I – Fall 2013

Department of Mechanical Engineering

Northern Arizona University

Flagstaff, AZ 86011

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Nomenclature

- G: Gravity
- G1: Component force of gravity along the incline
- G2: Component force of gravity perpendicular to the incline
- Tt: Total torque
- D: Wheel diameter
- W: Total weight
- ∂: Slope of the hill
- r_{cvt} : CVT ratio
- r_{cvt-h}: CVT high speed ratio
- r_{cvt-l}: CVT low speed ratio
- r_{gb}: Gearbox ratio
- r_{gb-h}: Gearbox high speed ratio
- r_{gb-l}: Gearbox low speed ratio
- N_{cvt}: Efficiency of CVT
- r_r: Second reduction ratio (Sprockets)
- r_t: Total ratio
- T: Torque on the wheel
- W_s: Total weight of shaft
- L: Shaft length
- Ka: Surface factor
- Kb: Size factor
- Kc: Loading factor
- Kd: Temperature factor
- Ke: Reliability factor
- Kf: Miscellaneous-Effects factor
- Kt or Kts: Stress-concentration factor

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Abstract

The single person off-road vehicle sales have increased 1.4% just this past year. The increased market demands higher quality products to stay competitive against other brands. The Society of Automotive Engineers (SAE) hosts events like the Baja competition event where engineers strive to maximize the potential of their products through design. At Northern Arizona University, three teams are assigned to complete a frame, suspension design, and drive-train to compete in this competition. Our team is tasked with the drive-train design. The main objective is to design and build a drive-train that will succeed in the acceleration, traction, maneuverability, and endurance events. The clients for this project are Dr. John Tester and the SAE organization. To satisfy all the customer needs, lists of engineering requirements were generated to evaluate against the customer needs and prioritize our design objectives.

To successfully design the best drive-train, a preliminary evaluation was performed for three design concepts which are CVT, Automatic, and Manual transmission. Our team evaluated the advantages and disadvantages of all three concepts. After evaluations and through decision matrices, our team decided to choose the CVT with secondary gear box for the drive-train system.

After the concept generation and selection stage, a full engineering analysis is performed to maximize the system potential. The wheel diameter, total weight, and slope of the hill were assumed at 23 inches, 600 lb, and 40 degrees respectively. The total torque of the system was calculated to be 369.6 lb.ft. Based on the previous events for acceleration results, the maximum velocity is estimated to be 34 mph. Based on the calculations; the chosen CVT is *PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600* from CVTech-AAB Inc. Moreover, the chosen gearbox is *ATV/UTV Gearbox T03* from GaoKin Inc. The shaft diameter was calculated to be 25.33 mm. Based on the shaft diameter, the bearing selection and key size were determined.

After the full analysis of the system, a list of the required parts to build it was generated along with the price to acquire them. The total estimated cost to build this drive-train is $2451. Moreover, the estimated labor cost to build 4000 unit is $542,286. As for the bill of materials, it is estimated to be $33,511,996 based on the whole sale costs approximated at 50% of the listed retailed price.

Based on all of the analysis performed, this drive-train will be successful in the SAE UTEP Baja competition. Theoretically, this design has satisfied all customer needs and met all engineering requirements. Also, this design fits within the parameters designed by the frame team for the drive-train.

Chapter 1. Introduction

1.1 Introduction

The Baja Vehicle Design is a competition sponsored by the Society of Automotive Engineering (SAE) and hosted in different locations across the country. Teams of students from different universities will design and build a Baja vehicle to compete against each other. All teams will use the 10 hp OHV Intek provided by Briggs & Stratton Corporation. The teams will have to build the vehicle to fit that engine and maximize their designs to meet the design objectives and win the competition. For the capstone senior design project, the Baja vehicle was assigned to three teams each with a separate task. All teams must collaborate together to design the vehicle. The tasks assigned to the teams are the frame design, suspensions design, and drive-train design. In this report, drive-train first stage analysis is discussed where customer needs, product specifications, and project plan will be identified and explained.

1.2 Objectives

The main objective of this project is to design and build a Baja vehicle that meets the client and stakeholders requirements and needs. Our client is the Society of Automotive Engineering (SAE) and they are the sponsor of the competition who sets the rules and regulations. The stakeholder is Dr. John Tester who will oversee the project progress to make sure that our teams design will win the competition. To win the competition, the Baja vehicle will be run through a series of events to see if it finishes them successfully. These events include acceleration, traction, maneuverability, specialty, and endurance events. Our team will design and build a drive-train with all these objectives in mind to ensure winning the competition. Based on the information obtained from the stakeholder and provided by the SAE, specific objectives are set by our team to maximize the drive-train design. Objectives include choosing a transmission that can have reverse so that the Baja vehicle can succeed in the maneuverability event. Moreover, the gear ration has to be maximized so that the resulted torque will win the acceleration and traction events. Finally, the sprocket materials will have to be chosen carefully so that the drive-train will have better endurance. This will result in low maintenance to be needed and will successfully complete the endurance and specialty events.

1.3 Needs Identification

1.3.1 Customer Needs and Engineering Requirement

Customer Needs described by Engineering Requirements. These are the needs that the team has discussed and established as what the customer wants to see in this product. Requirements are needs that are nonnegotiable and in this case describe the engineering properties we use to measure the established needs. The Engineering requirements for our design are Safety, Desirable acceleration, Ability to climb the hill, Ability to pull an excess load, Durability, Long maintenance period, large max velocity, Ability to reverse, and Inexpensive.

For safety, no matter how well the system works, if it's not safe than it can't be used. Safety is of large importance. The related specification is material strength (Kpa). Any number of tests can be done to make sure that the product is durable. It would not make sense to do long term test so some equivalent short term stress test would measure what kind of stresses the system could potentially handle.

For desirable acceleration, in order to success our Baja vehicle project, the vehicle must reach the peak acceleration of the engine provided. It is a key point to win the acceleration competition. The related specification is power efficiency. The efficiency will be measured by calculating the amount of power transferred from the motor to the wheels.

For ability to climb the hill, in order to complete all the events in the competition, the vehicle must be able to climb a hill with the highest velocity that it can. The vehicle also needs to complete the whole hill course to even place no matter how great the velocity is. The related specification is torque (N.m). To measure the transferred torque, the team will calculate it by using gear ratio from the CVT transmission and secondary gear box.

For ability to pull an excess load, the traction event will be provided, if local terrain does not support a significant hill climb. Therefore, for our project to be successful, the vehicle must be able to pull an excess load on a flat surface as fast as it can. The related specification is torque (N.m). To measure the transferred torque, the team will calculate it by using gear ratio from the CVT transmission and secondary gear box.

For durability, since the Baja vehicle needs to complete multiple events in the competition, it must be able to uphold peak performance during the tests as well as competition events. The related specification is cost ($). To measure the cost, a breakdown of each material used on one product will be calculated. It will be measured in dollars per unit.

For long maintenance period, since the Baja vehicle will go through many tests and competition events, a longer maintenance period will save much of our time. It will also make the whole system more reliable. The related specification is cost ($). To measure the cost, a breakdown of each material used on one product will be calculated. It will be measured in dollars per unit.

For large max velocity, in order to win the competition, it must go as fast as possible. The related specification is velocity (m/s). To measure the velocity, the team will time how long it takes to go through a significant distance.

For ability to reverse, in order to handle all the different competition events, the vehicle must be able to reverse and adjust its position. Optimally this will save time the case of a misjudged obstacle or is the vehicle gets stuck. The related specification is torque (N.m). To measure the transferred torque, the team will calculate it by using gear ratio from the CVT transmission and secondary gear box.

For Inexpensive, because of our limited budget, the team must consider the cost of all the materials used. Making it performs the best under the limited budget is the largest point we should focus on. The related specification is cost ($). To measure the cost, a breakdown of each material used on one product will be calculated. It will be measured in dollars per unit.

1.3.2 Quality Function Deployment

The QFD is a chart that takes the weighted importance of all customer needs and plots them against engineering properties required to compute the required analysis of those needs. It can be useful to define the needs but more importantly it makes for a great communication tool. For instance you would draw up a QFD and display the weighted importance of each need. Then you would present this to your customer. If the customer believes that the weights are sufficient and accurate then you may move as planned in you project.

Table 10.The Quality Function Deployment (QFD)

Customer Needs	Customer Weights	Cost	Size	Torque	Weight	Velocity	Material strength	Power effiecency
	Engineering Requirements for Drive-train							
Safety	7	3			3	1	9	
Accelarate fast	8	1	3	9	3	3		9
Able to climb the hill	10	1		9	3	3		3
Able to pull an excess load	10	1		9	3	1		3
Durability	9	3					9	
Long maintenance period	5	3	3				9	
Drive fast	10	1		3	3	9		3
Able to reverse	8			9				
Inexpensive	7	9	1		1		3	
	Raw score	164	46	354	142	161	210	162
	Relative Weight	13%	4%	29%	11%	13%	17%	13%
	Unit of Measure	Dollors	m^3	N.m	kg	m/s	Kpa	ul
	***ul--> Unitless by method**							

1.4 Product Specification

The Gantt chart is a diagram, as seen below, that shows the whole project plan laid out over time. We did this because the Gantt chart can keep us on track, and it will remind us what we should be doing next. The purpose of this item is to be able to track our progress good or bad and so that superiors are able to track you as well. These projections can also be used to estimate cost of labor and salary if this is applicable.

Based on the Gantt chart, the first step is to meet with the client, because we need to figure out what the customer needs are. And this will be done at 9/16/13.

During the period, 9/17/13 to 10/7/13, we will do project research, which is included the search of CVT and Secondary reduction, since our group is working on the drive train part.

After we finished the searching part, we will do calculations by using equations to figure out what the gear ratios for our secondary reduction are, and how many torque we can transfer from engine to the wheels, and how fast the car can run. We are also going to calculate the safety factor for our drive train parts and the shear forces add on the rear axle. The calculations will be finished between 10/7/13 to 10/18/13.

In the final analysis process, we will spend 4 days to rerun the numbers and equations to make sure we order the right parts for our project.

From During 18 days, we will do the parts choosing and ordering. The parts choosing is by using the data we get from our calculation to choose the parts we need from different company's products. And then, we order the parts.

3D models for our parts will be done in 18 days. We will make 3D models for parts and assemble them will be on next semester.

In the next semester, after we finished the 3D assembly, we can start to build the secondary reduction from 11/15/13 to 12/20/13.

Installing the CVT will be our next task. It will take about one week. We will spend another week to install the secondary reduction after we finish the CVT installation.

Different tests will be done until from 3/5/14 to 4/17/14, which is included the manual testing and fuel testing.

Chapter 2. Concept Generation and Selection

2.1 Introduction

This report will explain and depict the concept generation and selection of the SAE Baja Team's drivetrain. The contents should describe our three concepts in depth, depict them so that you might be able to visualize the concept and outline the advantages and disadvantages of each possible selection. Furthermore, our decision matrix will plot the three choices against each other to visually confirm which choices is the best for our particular problem. The criteria that the matrix is based on will be clearly displayed below with explanations of the criteria and why this stands out as a criteria. The report will wrap up with a clarification of our teams status and where we need to be in the near future.

2.2 Concept 1- Continuously Variable Transmission

2.2.1 Introduction for CVT

A Continuously Variable Transmission (CVT) is one kind of automatic transmission that can transfer the range of power and torque from the engine to the drivetrain continuously.

2.2.2 Explanation for CVT

There are three different types CVT. Friction drive is the first type of CVT that we want to introduce. There are two different discs in this system, the driving disc is connected with the engine and the driven disc is connected to the drive axle. These discs are connected perpendicularly as shown in **Figure1** .The main concept of this type is using friction between two discs to change the gear ratio.

The second type of CVT is a pulley drive. This type of CVT changes gear ratio by moving two sheaves of one pulley closer together and moving two sheaves of another pulley farther apart while the two pulley are connected by a V-belt. There are many different pulley drive CVT since the belts are built out of different materials. We desire to use a rubber V-belt, which can be used for low torque and engine power, since the rubber belt cannot handle high amounts of torque and power. Another option could be a metal V-belt, which is used by Nissan, Toyota. Audi and Subaru's CVT designs. These belts are designed to handle more torque than the metal V-belt we would consider in our CVT.

The last type of CVT is Toroidal CVT. By using one pair of rollers between the input disc and output disc. The transmission can change the gear ratio to allow the vehicle to have enough torque at low speed but at the same time have a power full high end speed.

2.2.3 Advantages for CVT

- Does not require you to shift gears.
- Allows power to be transferred continually.
- Good fuel efficiency.
- Has a wide range of gear ratio.

2.2.4 Disadvantages for CVT

- The system cannot handle too much torque.
- Does not naturally incorporate a reverse.

2.3 Concept 2 – Automatic Transmission

2.3.1 Introduction for AT

The automatic transmission is one of the possible concepts for the Baja drive train design. This transmission system is a type of motor vehicle transmission that can automatically change gear ratios as the vehicle cycles from low rpms to high rpms.

2.3.2 Explanation for AT

A Planetary Gear System is the basic construction for an automatic transmission system. It contains a ring gear, more than two planet gears, and a sun gear. The sun gear is connected to the drum, while the planet gears are connected to the carrier. For our Baja vehicle drivetrain this concept would provide; a high speed shift, low speed shift, reverse shift and a free release neutral. For the low speed shift, the ring gear is connected to the input shaft from the engine, the planet gears are connected to output shaft, and the sun gear is locked in place. For the high speed shift, a ring gear is connected to the input shaft from the engine, the planet gears are connected to output shaft and locked into a fixed position, and the sun gear is unlocked. For the reverse shift, the ring gear is connected to the input shaft from the engine, the sun gear is connected to the output shaft, and the planet gears are fixed in position. The clutch pack locks the drum in place as well as the carrier, thus allowing the transmission to move between gears. For the free release neutral, this system releases both clutch and band simultaneously. The construction of the planetary system is shown by the followed **Figure 7** and **Figure 8.**

2.3.3 Advantages for AT

- Good performance on rough road. The gears in automatic transmission are never physically moved and are always engaged to the same gears. While the vehicle passing through rough road, there is no power loss due to shifting gear.
- Easy to drive. Automatic transmissions don't need the driver to shift gear while driving. Thus, the driver can focus more on the road.
- Low failure rate. Automatic transmission avoid many abrasions from shifting gear.

2.3.4 Disadvantages for AT

- Lower fuel efficiency. The shifting process in automatic transmissions are completed by hydromantic system. This process causes power loss.
- Higher price. Due to the complex construction of automatic transmission, the price of it is higher than the other transmission systems.
- Higher maintenance cost. This system requires more frequent maintenance than the other systems we are considering.

2.4 Concept 3 – Manual Transmission

2.4.1 Introduction for MT

A manual transmission is composed of two main set of gears. The first set of gears is the one connected to the engine to transfer the power. The second set of gears is the one with the gear selector fork, which switches between the different gear ratios. The ratios are set from low gear ratio to higher gear ratio. The first gear has the lowest gear ratio which provides higher torque but lower speed. As the driver switches from low gears to higher gears, the gear ratio will increase and thus provides a higher speed but lower torque.

2.4.2 Explanation for MT

To further explain how manual transmission works, a five speed manual transmission, commonly used in cars, is used as an example. In a five speed manual transmission, there are three forks controlled by three rods that are engaged by the shift lever as shown in Figure (X). It can also be seen that the shift lever has a rotation point in the middle. When moving the gear shifter right and left, it engages different forks. When moving the gear shifter forward and backward, it engages one of the gears within the gear selected fork, (Figure (X). In manual transmission, the reverse option can be added easily. In Figure (X), it can be seen that by simply adding the Idler gear, the gear output gear will start spinning in the opposite directions to the other gears providing a reverse option.

2.4.2 Advantages for MT

- In manual transmissions, the driver has the ability to lower the gear to achieve higher rpms, which will allow the vehicle to complete a hill climb obstacle.
- A manual transmission allows for a better acceleration as the driver chooses to switch gear at the appropriate time to maximize the acceleration.

2.4.3 Disadvantages for MT

- Low drivability; the complexity of how a manual transmission functions makes it harder for most people to use.
- The weight of the manual transmission is heavier compared to the CVT and automatic transmissions.

2.5 Concept Selection

Table 11. Decision Matrix

Concepts	CVT	AT	MT	WEIGHT
Durability	1	2	3	10%
Maintenance	2	1	3	5%
cost	1	2	3	15%
Reversibility	2	3	1	10%
Drivability	3	2	1	25%
Acceleration	3	1	2	15%
Energy Efficiency	2	1	3	10%
Weight	3	2	1	10%
Weighted Total	2.25	1.8	1.95	100%

Due to the result of our decision matrix, CVT is the concept we choose finally.

Description of all criteria:

- Durability: The ability for the transmission to withstand wear, force or pressure. How well the transmission works in different situations.
- Maintenance: The time period for the transmission to been maintained, like changing transmission oil. The distance of the transmission that can be used before being maintained.
- Cost: Money needed spend to purchase the transmission.
- Reversibility: Whether the transmission has reverse function or not.
- Drivability: The quality of being easy or pleasant to drive.
- Acceleration: The increase rate of speed. How fast can the Baja with this transmission accelerate to a certain speed?
- Energy Efficiency: The ratio between the energy output to axel and the input energy from the engine.
- Weight: The mass or quantity of matter contained by the object in consideration.

2.6 Project Plan

2.6.1 Progress Update

Currently our team is behind in our current project plan. There are multiple outstand events that must take place before we can progress as planned. Firstly, we were behind on our calculations because the team had prior obligation that we were all more concerned with. Thus, we have dedicated the Wednesday of October 29th to finish the calculation without fail. Secondly, we need money. The Baja Team has put together a proposal to be distributed to local and related businesses as well as family members to fundraise the appropriate budget. Until we have reached this budget the physical ordering of our parts has been put on hold. This is reflected in the project plan, so hopefully we will be able to order by the end of November.

2.6.2 Gantt chart

The figure below (**Figure 16)** is the outline of our current project plan which is followed by the visual representation of this outline.

Chapter 3. Engineering Analysis

3.1 Introduction

This report will go into further depths of the actual engineering analysis and formulation of the SAE Baja Team's drivetrain. The contents describe the formal equations that describe our concept generation as well as the layouts and explanations of the final system the group is preparing. Below we have generated a gear ratio from our given constraints, reasonable assumptions and our goal speed and torque. We analyzed two different concepts, an automatic transmission and a continuous variable transmission. The analysis of ratios and torque revealed substantial evidence that the continuous variable transmission far exceed the capability of the automatic gear box that we had intended to use.

3.2 Goal

3.2.1 Torque

In the hill climb event, the Baja vehicle will be expected climb an incline of significant difficulty. The team assumed the incline to be approximately 40 degrees. Through the inspection of previous courses, as a group we felt this would be the maximum angle in any hill climb we might encounter. In order to complete the incline, the force on two wheels will need to be greater than the component force of gravity along the incline, which is G1 in the **Figure 11.**

$$G1 = G \times \sin\partial = 600\text{lb} \times \sin 40 = 385.67\ lb$$

$$\text{Force per wheel} = 192.83\ lb$$

$$\text{Torque per wheel} = 192.83 \times \frac{D}{2} = 192.83 \times \frac{23}{2} \times \frac{1}{12} = 184.8\ lb - ft$$

$$\text{Total torque } (T_t) = Total\ torque\ on\ the\ wheel = 369.6\ lb - ft$$

From the result above we know that the minimum torque that needs to be transferred to the final output shaft is 369.6 lb-ft. Based on the result, team has set 380 lb-ft as our goal for max torque that can be transferred to the final output shaft.

3.2.2 Speed

Table 12. Tennessee 2013 Acceleration Event

Rank	Car No	School	Team	Time Run 1	Time Run 2	Best Time	Acceleration Score (75)
1	1	Cornell Univ	Big Red Racing	3.870	3.861	3.861	75.00
2	52	Michigan Tech Univ	Blizzard Baja	3.950	3.872	3.872	74.70
3	6	Univ of Maryland - Baltimore County	UMBC Racing	3.902	3.957	3.902	73.86
4	78	Univ of Maryland - College Park	Terps Racing	3.906	3.974	3.906	73.75
5	73	LeTourneau Univ	Renegade Racing	3.935	3.916	3.916	73.48
6	3	Rochester Institute of Technology	RIOT Racing	3.999	3.924	3.924	73.26
7	44	Ohio Northern Univ	Polar Bear Racing	3.945	3.955	3.945	72.67
8	36	Universite de Sherbrooke	Sherbrooke Racing Team	4.011	3.992	3.992	71.37
9	57	Univ of Wisconsin - Madison	UW Baja	4.129	4.037	4.037	70.13
10	45	Univ of Arkansas - Fayetteville	Racing Razorbacks	4.043		4.043	69.96

(Source: sae.org)

From the table we can see the top team have an average time of 4 seconds to finish a 100 foot course. Assuming that the Baja keeps accelerating with the average acceleration during that time. We can calculate the maximum velocity

Distance = Max Velocity × time ÷ 2

Max velocity = Distance × 2 ÷ time

= 100 × 2 × 0.68 ÷ 4

= 34 mph

Based on the result, 35 mph is the goal for max speed that the team has set out to obtain.

3.3 Analysis for CVT system

The analysis of the continuously variable transmission essential provide the gear ratios that would be required to obtain the goals introduced previously. Through the analysis the team was forced to make specific assumption and decisions on criteria such as wheel diameter and total weight. Unfortunately we were unable to acquire such information as a total weight of the vehicle or an exact degree for the slope of the Hill Climb event. Thus, these became assumptions along with the frontal area of the vehicle. These are all clearly laid out below.

Based on the information we got from the previous Baja design, we chose the following CVT: *PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600* from CVTech-AAB Inc. The design for the reduction system has changed from two sets of sprockets to a gearbox with one set of sprocket. Chosen Gearbox: ATV/UTV Gearbox T03 from GaoKin Inc. Because the gearbox we chose is a 5 speed gearbox (parking, neutral, high speed, low speed and reverse), which gives our drivetrain the ability to reverse. From the result of our following calculation, the ratio of chosen CVT and gearbox will give us enough speed and torque to meet our goal.

3.3.1 Analysis for torque and speed

a. Assumption and Variable

- Wheel diameter(D): 23 inch
- Total weight (W): 600 lb (including the driver)
- Slope of the hill (∂): 40 degree
- CVT: High speed ratio (r_{cvt-h}): 0.45 Low speed ratio (r_{cvt-l}): 3.1
- Gearbox: High speed ratio (r_{gb-h}): 2.734 Low speed ratio (r_{gb-l}): 5.682
- Second reduction ratio (Sprockets) (r_r): 3:1
- Efficiency of CVT(N_{cvt}): 88%
- Total ratio (r_t)
- Torque on the wheel (T)

b. Calculations

From the graph above we obtain the RPM and torque output from the engine. Then we calculated the following with our assumptions:

- Start RPM for CVT is 800 rpm and high speed ratio occur at 3600 rpm, assuming ratio varies linearly, we find the following relationship:

$$r_{cvt} = \begin{cases} 0 & \text{for} \quad rpm<800 \\ 3.1 - \frac{2.65\times(rpm-800)}{2800} & \text{for} \quad 800<rpm<3600 \\ 0.45 & \text{for} \quad 3600<rpm \end{cases}$$

- Total ratio (r_t) = $r_{cvt} \times r_{gb} \times r_r \times N_{cvt}$
- T = Torque output from engine$\times r_t$
- Speed = $\frac{D\times RPM\times\pi}{total\ ratio\times12\times60} \times 0.68 = \frac{23\ in\times RPM\times\pi}{total\ ratio\times12\times60} \times 0.68$

With the equation above we made the tables below showing how speed and total torque vary with the increase of engine rpm.

Table 13. Torque and speed with high gearbox ratio

Engine rpm	Torque output (lb-ft)	CVT ratio	Total ratio	Torque on wheel (lb-ft)	Speed (mph)
1800	13.20	2.107	15.209	200.757	8.08
2000	13.70	1.929	13.920	190.704	9.80
2200	14.10	1.750	12.631	178.098	11.89
2400	14.30	1.571	11.342	162.193	14.44
2600	14.45	1.393	10.053	145.270	17.65
2800	14.52	1.214	8.764	127.259	21.80
3000	14.50	1.036	7.476	108.395	27.39
3200	14.40	0.857	6.187	89.088	35.30
3400	14.20	0.679	4.898	69.548	47.37
3600	13.80	0.500	3.609	49.803	68.07

Table 14. Torque and speed with low gearbox ratio

Engine rpm	Torque output (lb-ft)	CVT ratio	Total ratio	Torque on wheel (lb-ft)	Speed (mph)
1800	13.20	2.107	31.608	417.228	3.89
2000	13.70	1.929	28.929	396.334	4.72
2200	14.10	1.750	26.251	370.137	5.72
2400	14.30	1.571	23.572	337.082	6.95
2600	14.45	1.393	20.894	301.911	8.49
2800	14.52	1.214	18.215	264.480	10.49
3000	14.50	1.036	15.536	225.275	13.18
3200	14.40	0.857	12.858	185.149	16.98
3400	14.20	0.679	10.179	144.540	22.79
3600	13.80	0.500	7.500	103.503	32.76

From the table above we can see that the max speed of our Baja on the flat ground is about 68 mph. This is an ideal speed which is so hard to reach in real life. What usually happen in the competition is that, the engine rpm cannot always increase to its max value because of the complicated situation of the course. The table tells us that at about 3200 rpm, the speed will be about 35 mph, which is exactly what we want in the competition.

The table 5 shows the max torque we can get on the wheel is 417.228 lb-ft, which meets our goal.

3.3.2 Analysis for shaft, bearing and key

The final shaft will be set between two rear wheels, and it will be connected with the second sprocket. Figure 14 shows the connection and position of the shaft. The final shaft will transfer the power and torque that comes out from gearbox to two rear wheels. From the research of shaft design, the group decided to use 1040 Steel as the material of the shaft, since 1040 Steel always been used for making small vehicle output shaft.

1. Assumption and variables

- Total weight (W_s): 600 lb (including a driver)
- The shaft length (L): 20 in
- Material: 1040 Steel
- Shaft diameter: ⅞ in (from shaft design research)
- Temperature: 20 Celsius
- Reliability: 90%
- Force apply on the shaft: 1600 lbf (the worst situation)
- Surface factor Ka

- Size factor Kb
- Loading Factor Kc
- Temperature factor Kd
- Reliability factor Ke
- Miscellaneous-Effects factor Kf
- Stress-concentration factor Kt or Kts

2. Calculation

The group used the shaft diameter calculation Matlab code to calculate the diameter of the shaft. The Matlab code will be posted on the Appendix.

From the shaft design research, the group knew that the diameter of output shaft should around 7/8 in, and the force apply on the shaft at the worst situation is around 1600 lbf.

The group used the equations below to calculate the diameter of the shaft

$$Se = Ka \times Kb \times Kc \times Kd \times Ke \times Kf \times Sut$$

$$Dl = \left(\frac{16 \times 2}{\pi}\right) \times \left(\sqrt{\frac{4 \times (Kf \times Moment)^2}{(1000 \times Se)}}\right) + \left(\sqrt{\frac{3 \times (Kfs \times Torque)^2}{(1000 \times Sut)}}\right)$$

- The surface factor $Ka = a \times Sut^b$ = 0.9128
- The size factor $Kb = 0.879 \times d^{-0.107}$ for 0.11 <= d <= 2
- Loading Factor Kc = 0.59 when the shaft is applied torsion
- Temperature factor $Kd = \frac{\mathrm{ST}}{\mathrm{SRT}} = 1$ when the temperature is 20 Celsius
- Reliability factor Ke=0.897 by the assumption which the reliability of the shaft is 90%
- Miscellaneous-Effects factor $Kf = 1 + q \times (Kt - 1) = 1.42$ where q=0.7, qts=0.8
- And Kt=1.6, Kts=1.3.
- The moment that applied on the shaft is 3616.96 KN mm. The group got the moment by using the equation

$$Moment = Force \times Distance$$

- And the torque that applied on the shaft is 565376 Nm. The group got the torque from CVT calculation.

Input the moment, torque and variables into equations, the group got the shaft diameter, which is D=25.38mm. Based on the shaft diameter D, our team chose the bearing that can fit the shaft diameter. The key was selected based on the shaft diameter. The width of the key is 3/16 inches, the H is 1/8 inches, the keyway depth is 1/16 inches.

3.4 Continuously Variable Transmission Set-Up

The CVT has initial high ratios of .45 and low ratio of 3.1. The gearbox has high ratio of 2.734 and low ratio of 5.682. This however were not ideal for the goals that have been established. Thus, the group had to consider a secondary reduction. For the volume provided to us by the frame team, which is approximately 6.3 cubic feet, our team put together this simple lay out of the reduction system as seen in Figure 1. In Figure 2 we depict how the engine, CVT and reduction system might sit with in the frame. As you can see because of the odd shape of the rear, to optimize the space, the engine should be mounted approximately 17 inches above the bottom of the frame. This can be visualized in Figure 3. This will allow for ample space to implement the reduction system and eventually our braking system.

The reduction contains 2 sprockets with different teeth: n1 = 36 and n2 =12, which give us a 3:1 reduction ratio.

Chapter 4. Cost Analysis

For the SAE Mini Baja competition as a competing team we are required to create and present a Sales Presentation to a hypothetical manufacturing company. This imaginary company is prospecting to produce a Mini Baja at four thousand units per year. Thus, this will set the base criteria for our calculations and tables. Our team also assumed that out of 365 days this company would only be producing units for approximately 261 days of the year. With these two criteria established we were able to; create a Bill of Materials, estimate the manufacturing costs, cost of man power, total cost of production, and approximate the Payback period.

Table 15. Manufacturing Hours

Part	Half Shaft	Keys	Short Shaft	Drive Shaft	Hours per Unit	Hours per Day
Individual	.65 Hours	.25 Hours	.35 Hours	.50 Hours		
Drive Shaft	1.3 Hours	.75 Hours	.35 Hours	.50 Hours	2.9 Hours	43.5 Hours

Table 16. Budget for Drivetrain

Part	Price($)	Quantity	Comments	Total
Engine	200	1	Ship fee	200
Gearbox	400	1	GaoKin	400
CVT	580	1	CV-Tech	580
Shaft	29	1	Metals Depot	29
Bearing	15	2	Polaris	30
Key	5	4	Metals Depot	20
Sprocket	16	4	G & G	64
Chain	15	1	G & G	15
Half-shaft	260	2	Polaris	520
Shipping	200			200
Total Price (include tax)				2058

Table 17. Bill of materials

12 tooth sprockets	36 tooth sprockets	Half shafts	2 feet 1040 Steel Shaft	Engine	CVT	Gearbox	Chain	Total
10,120	30,360	526,000	5,700	979,980	1,160,000	800,000	5836	3,511,996

Table 18. Total estimated man hours

Total work units	Complete units per day	Total work hours per person	Number of labors	Work hours per person per day	Hourly Wage($)	Total cost of labors
4000	15	2086	10	8	26	542,286

Chapter 5. Conclusion

The purpose of our team is to design the best possible mini Baja vehicle drivetrain. Based on the information provided by SAE, the team came up with customer needs and turned it into our engineering requirements. By doing pre-research, the team suggested three design concepts, which were Manual, Automatic, and Continuously Variable Transmission. After researching the advantages and disadvantages for the three initial concepts, the team analyzed the top two concepts, which are the Automatic and CVT. The desired torque and speed for our vehicle were

290 lb-ft and 40 mph. The analysis resulted in the CVT producing 300.19 lb-ft of torque and 51.70 mph of speed, which were higher than Automatic's analysis result. Based on the analysis, the team chose the CVT and gearbox to ber implemented in the 2014 SAE Mini Baja. The chosen CVT is *PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600* from CVTech-AAB Inc, which has high speed ratio of 0.45, low speed ratio of 3.1. The chosen gearbox is 02-A from GaoKin Inc, which has high speed ratio of 2.734, low speed ratio of 5.682, and a reverse gear. Through the selection of these parts, the team designed a proper output shaft with diameter 25.38mm. The final analysis results show that the maximum speed of our Baja vehicle is 35 mph, and the maximum torque is 417.228 lb-ft. The results reached our team's goals, and the team will start building in January when all parts have arrived and the frame team has completed the frame.

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Appendix A

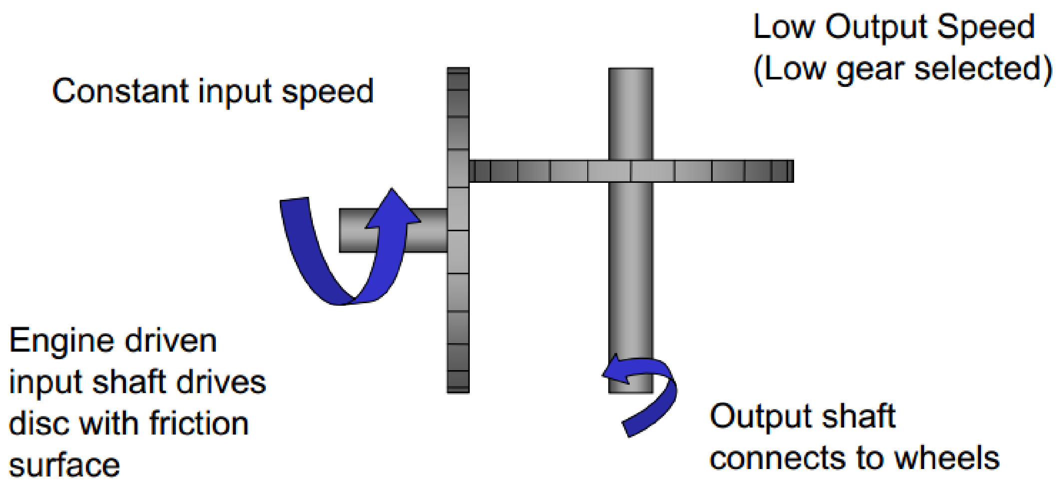


Figure 1.Friction Drive CVT Basic Concept (Source: cloudfront.net)

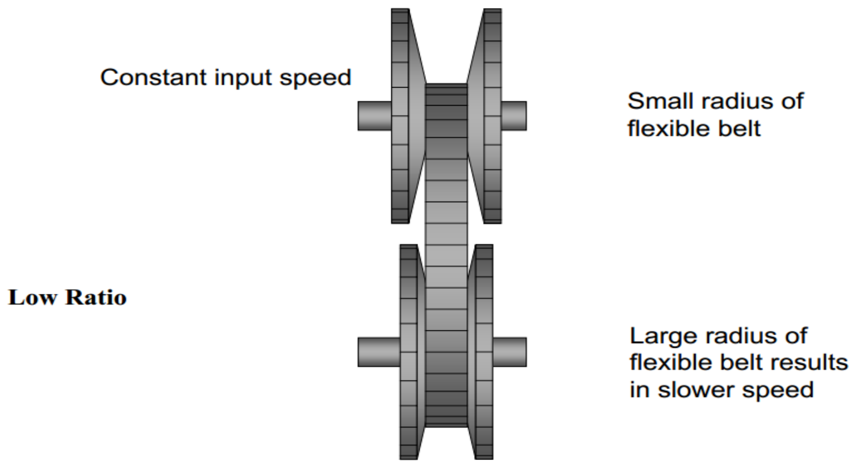


Figure 2. Pulley Drive CVT Basic Concept (Source: cloudfront.net)

Figure 3. Rubber V-belt CVT (Source: atvriders.com)

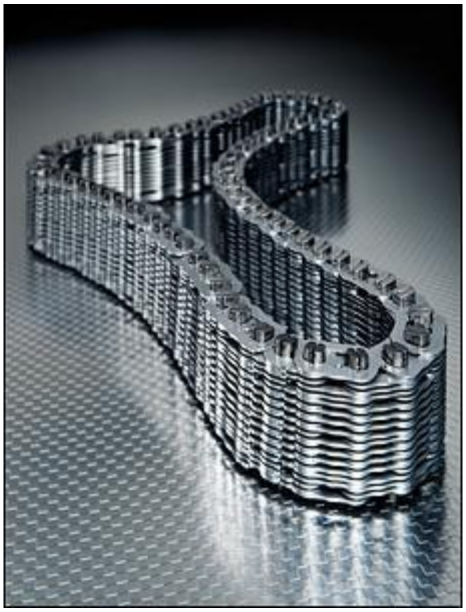


Figure4. Chain V-belt CVT (Source: autospeed.com)

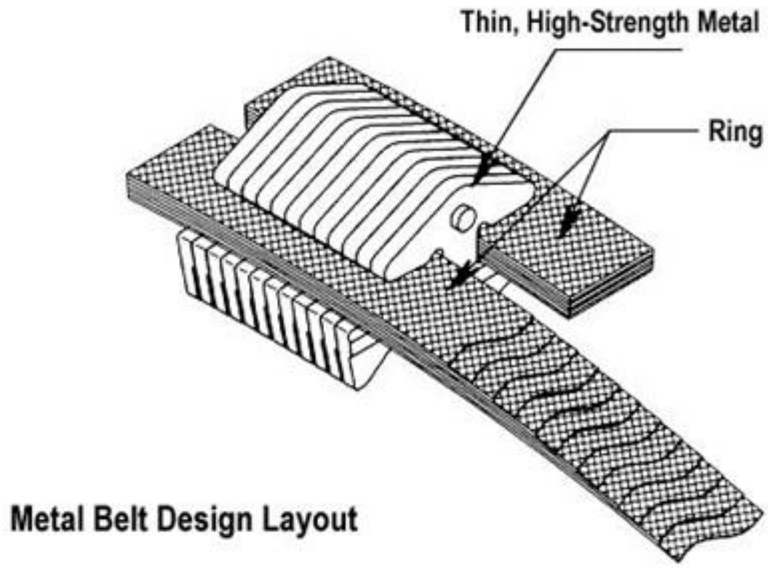


Figure 5. Metal V-belt CVT (Source: insightcentral.net)

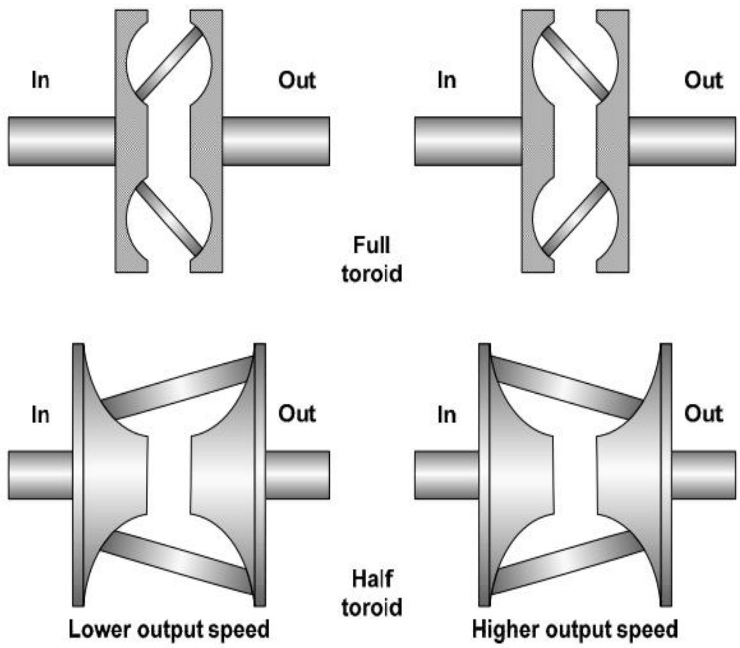
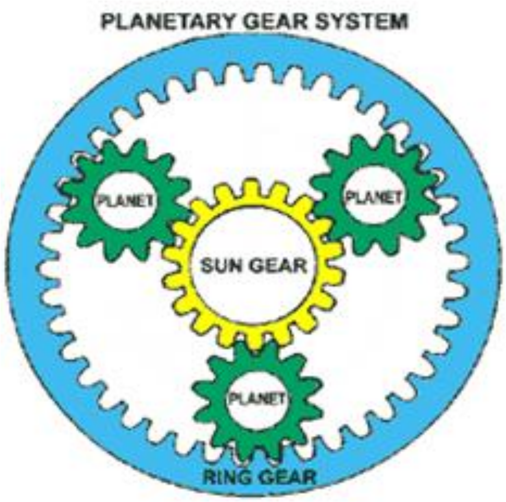


Figure 6. Toroidal CVT Basic Concept (Source: cloudfront.net)



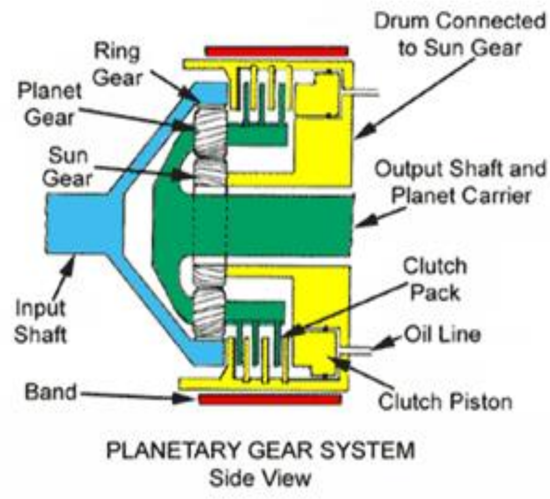


Figure 7. Planetary Gear System *Figure 8. Planetary Gear System*

(Source: carparts.com)

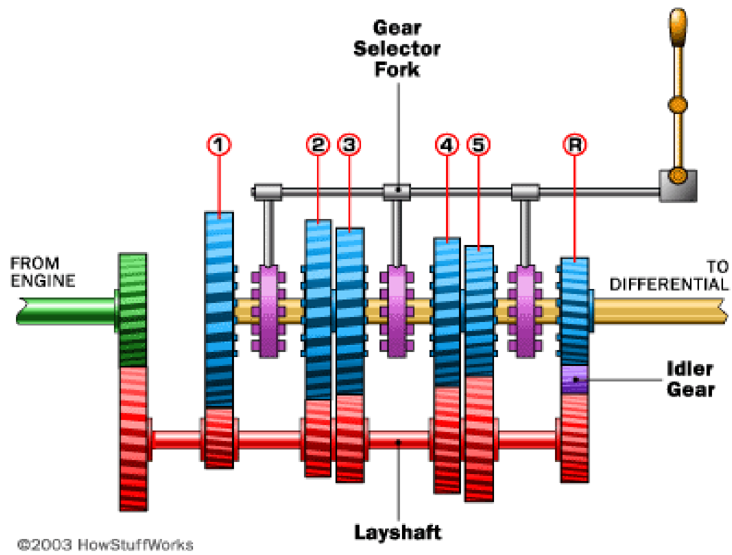


Figure 9. Manual Transmission (Source: howstuffworks.com)

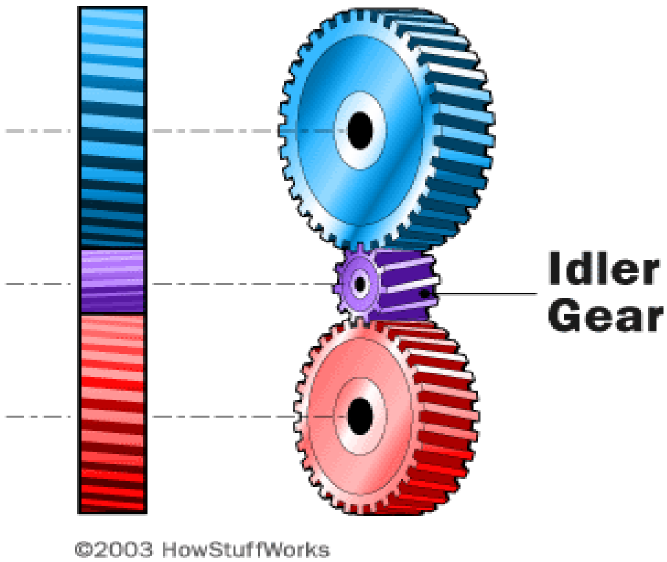


Figure10. Idler Gear (Source: howstuffworks.com)

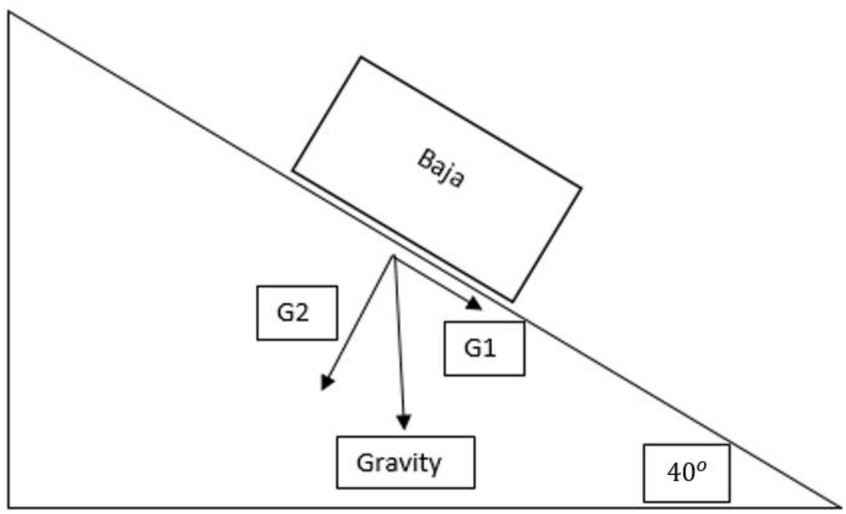


Figure11. Free Body Diagram of Baja for Hill Climb Event

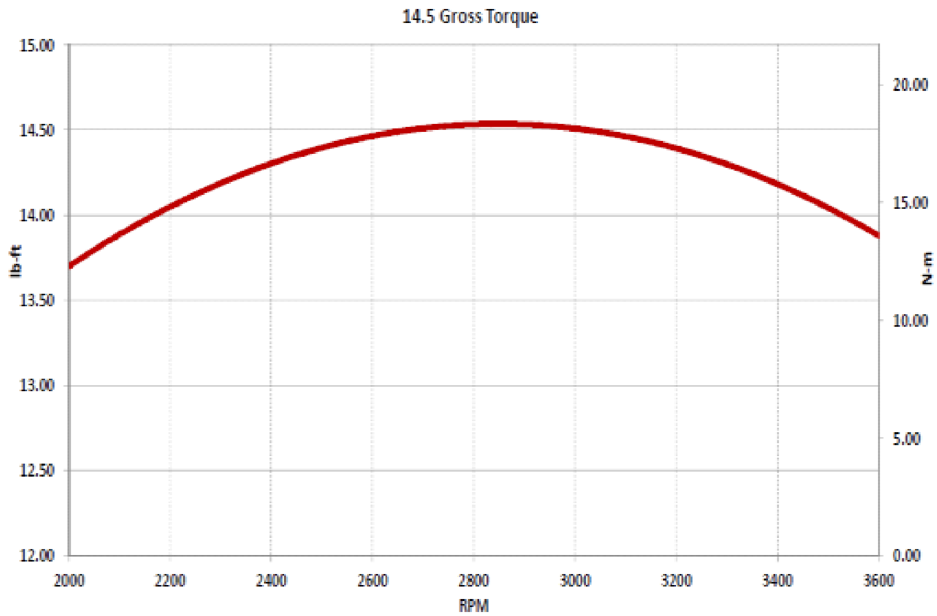


Figure12. Motor Torque Curve. (Source: Briggs & Stratton)

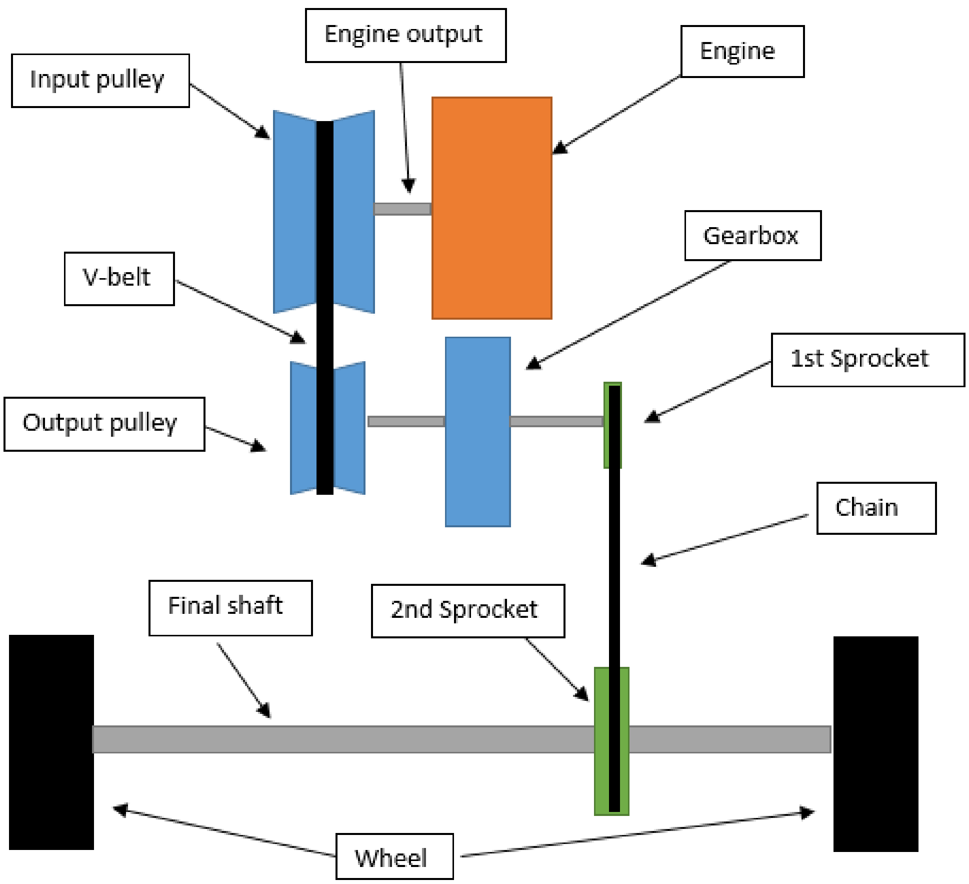


Figure13. Basic Concept of CVT Drivetrain System

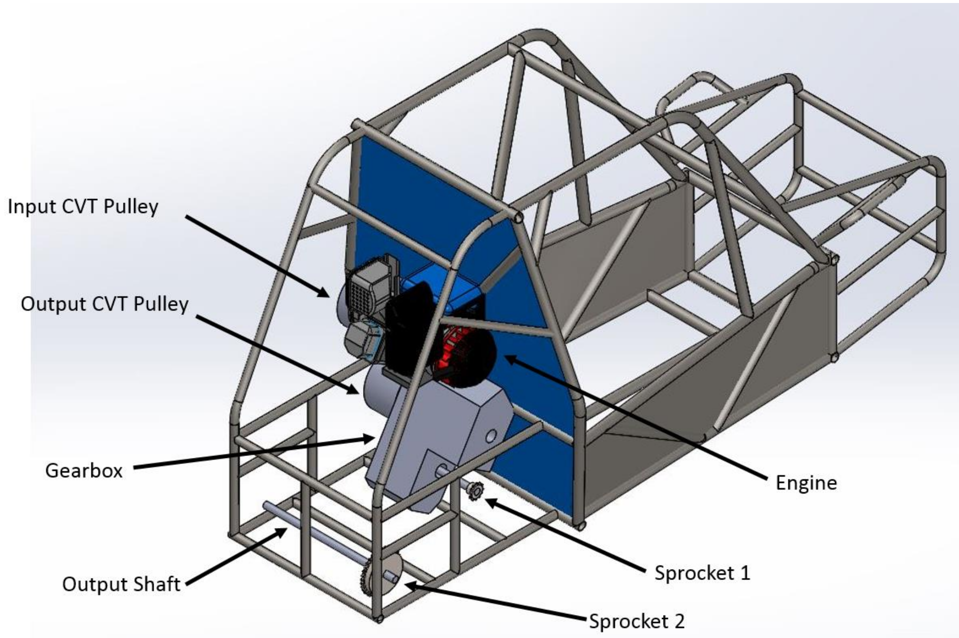


Figure14. 3-D Drawing of CVT Drivetrain System

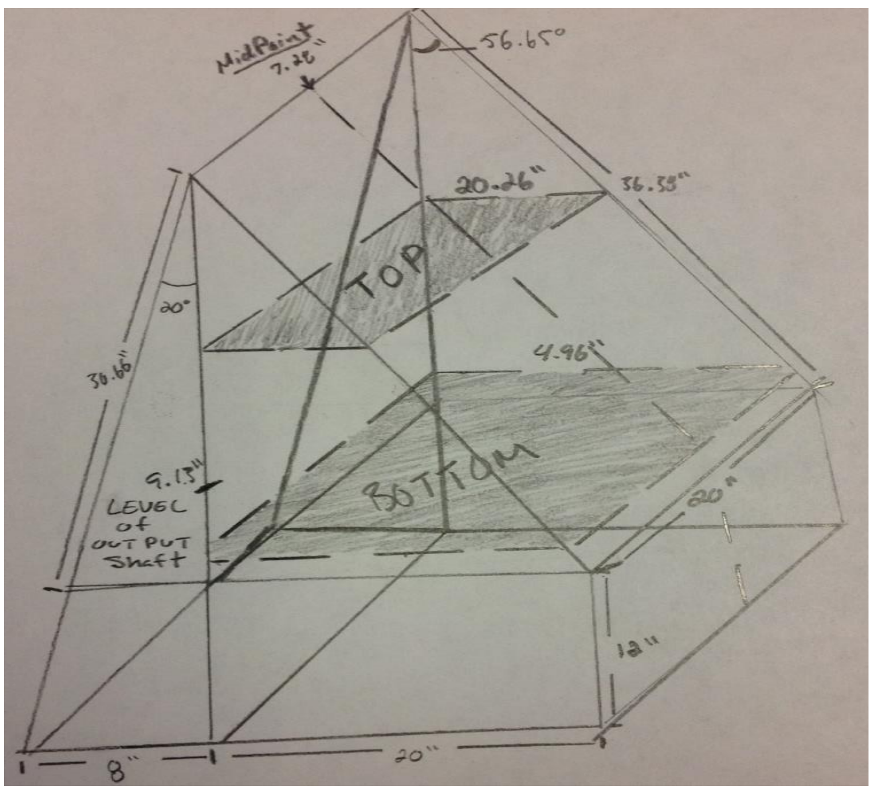


Figure15. Simple depiction of the lay out of the rear of the frame and the prospected optimal placement of the engine

Appendix B

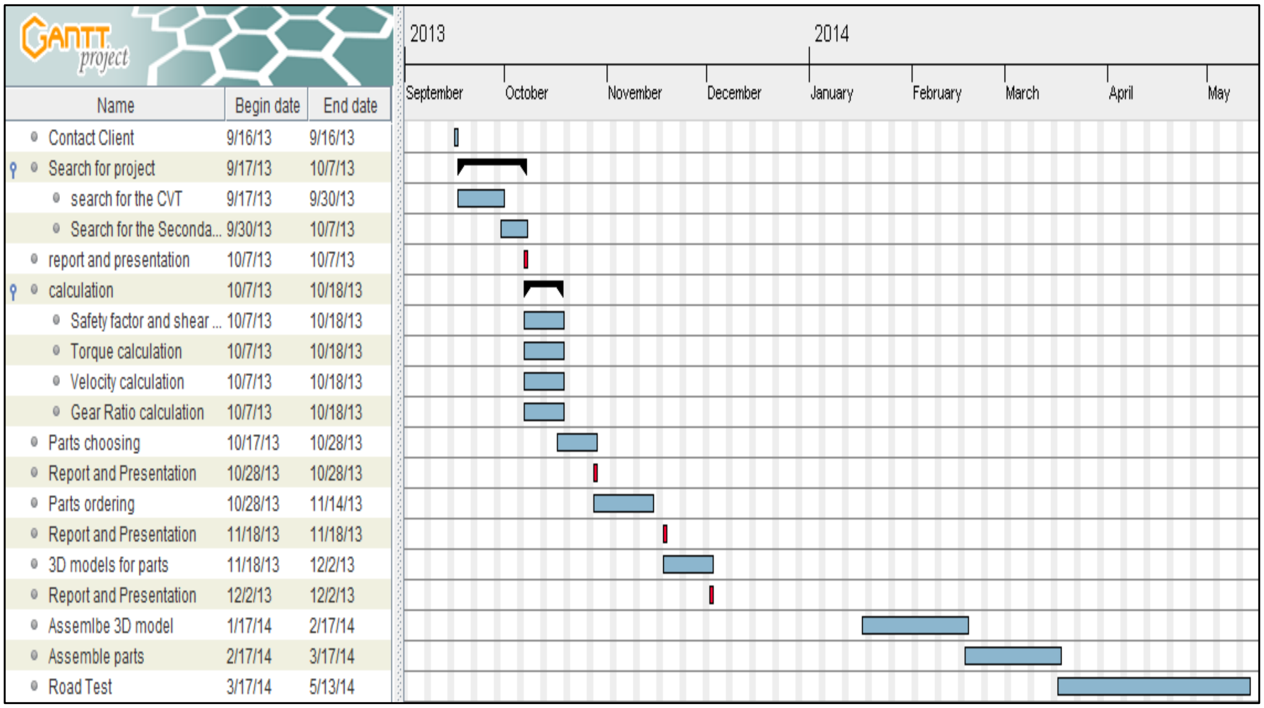


Figure 16.This diagram depicts our project plan over the course of the school year.

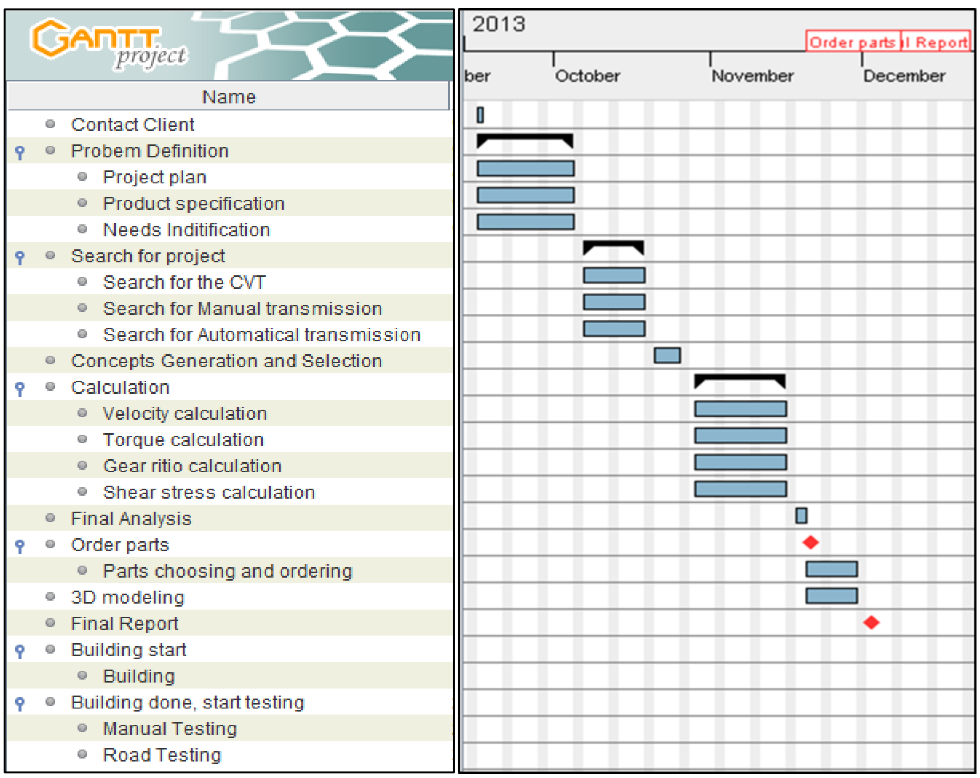


Figure17. Gantt Chart Outline

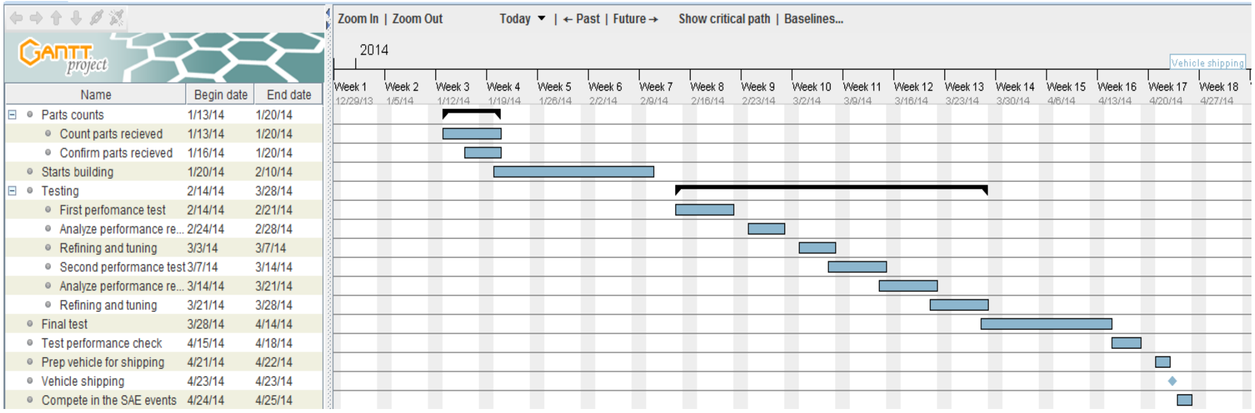


Figure 18. Spring 2014 Gantt chart