SAE Baja Design
Final Design Presentation
Team Drivetrain

By
Abdulrahman Almuflih, Andrew Perryman,
Caizhi Ming, Zan Zhu, Ruoheng Pan

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Introduction

- Introduction of Competition
- Goal Statement
- Objectives
- Needs Identification
  - Customer Needs
  - Engineering Requirements
  - Quality Function Deployment (QFD)
- Product Specification
  - Requirements
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Introduction of Competition

- Sponsored by SAE
- Project Description: Design and build Baja vehicle
- Participants: over 100 universities
- The engine is provided: common ground
- The Baja competition project in NAU:
  - Frame design
  - Suspension design
  - Drive-train design

Goal Statement

- To build a rigid and durable Baja vehicle that can successfully complete all of the SAE competition events.

Objectives

- Satisfy the client and stakeholder needs and requirements.
- Build a drive-train for the Baja vehicle so that it can complete the following tests successfully:
  - Acceleration
  - Traction
  - Maneuverability
  - Specialty
  - Endurance

Customer Needs

- Most important customer needs:
  - Ability to climb the hill
  - Ability to pull an excess load
  - Able to reverse
  - Large max Velocity
  - Durability
  - Inexpensive

Engineering requirements

- Customer Needs described by Engineering Requirements
  - Material strength (Kpa)
  - Torque (N-m)
  - Power efficiency (%)
  - Velocity (m/s)
  - Cost ($)

Quality Function Deployment (QFD)

	Engineering Requirements for Drive-train							
Customer Needs	Customer Weights	Cost	Size	Torque	Weight	Velocity	Material strength	Power effeciency
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							

Product Specification

- 2014 Collegiate Design Series Baja SAE rules govern the requirements and constraints of our design.
- This was provided to us through SAE and explicitly states what is legal and illegal in the competition.

Requirements

- All requirements were implied not stated.
- Select and Design a transmission given a specific motor that will allow you to complete multiple strenuous tasks.
- This transmission should be able to withstand repeated performances of each task.

Constraints

- Because we are required to design for this part there were not too many constraints specifically for the drive-train.
- The Briggs & Stratton motors are governed at 3800 RPMs.

Concept Generation and Selection

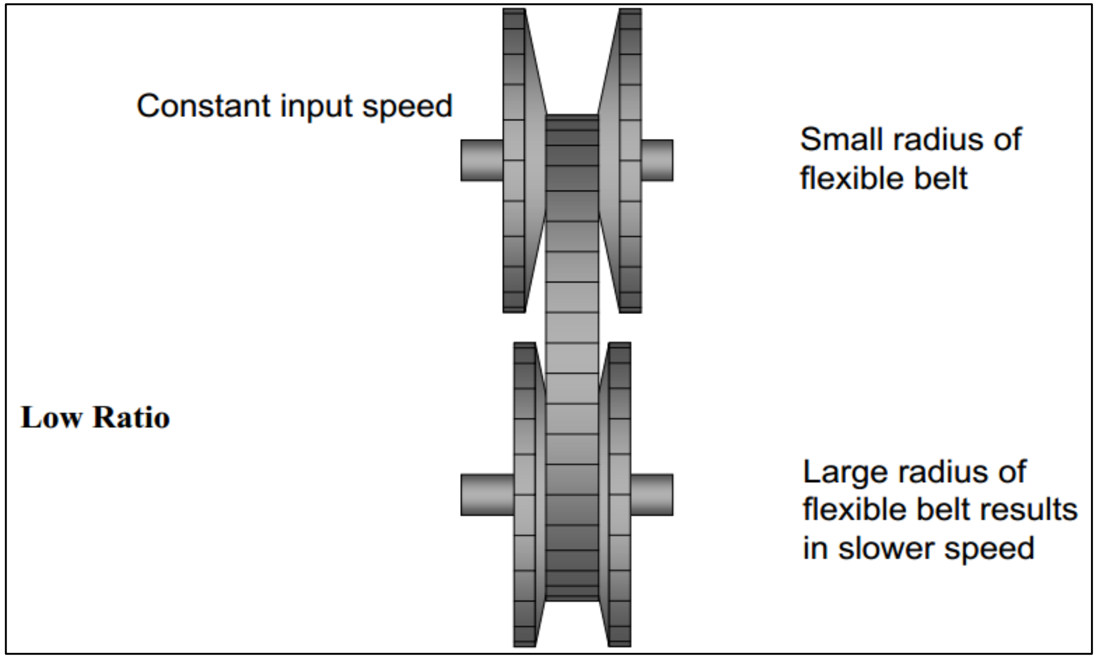
- Concepts Generation
  - Objective
  - Continuously Variable Transmission
  - Automatic Transmission
  - Manual Transmission
- Concept Selection
  - Decision Matrix

Objective

- The purpose of our team is to design the best possible drivetrain for the specific use of a single seat off road Baja.
- Our most pressing issue is the identification of the best possible transmission.
  - CVT
  - Automatic
  - Manual

Continuously Variable Transmission (CVT)

- Transfer the range of power and torque from engine continuously.
- The specific CVT is the Pulley drive



Source: cloudfront.net

Continuously Variable Transmission (CVT)

Advantages

- Do not need to shift gears
- Transfer the power continuously
- Good fuel efficiency
- Have a wide range of gear ratio

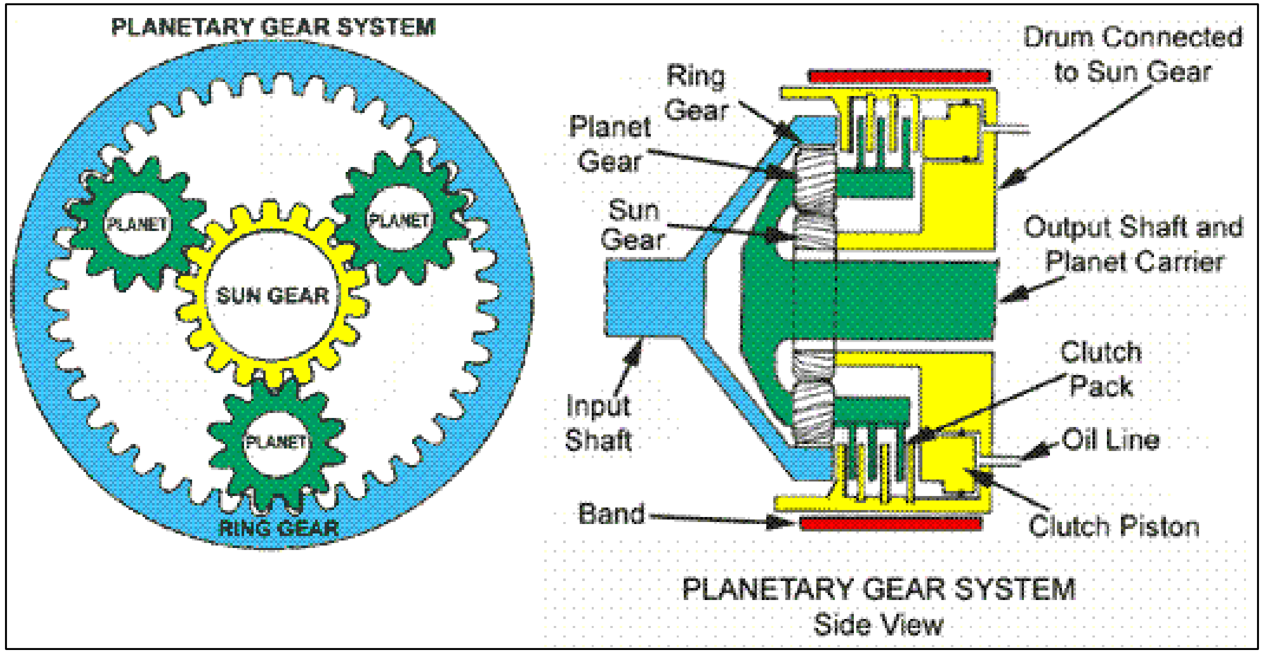
Disadvantages

- The system cannot afford too much torque.
- Do not have a reverse.

Automatic Transmission

- Can automatically change gear ratios as the vehicle cycles from low rpm to high rpm.

Planetary Gear System



Source: carparts.com

Automatic Transmission

Advantages

- Good performance in rough road.
- Easy to drive.
- Low failure rate.

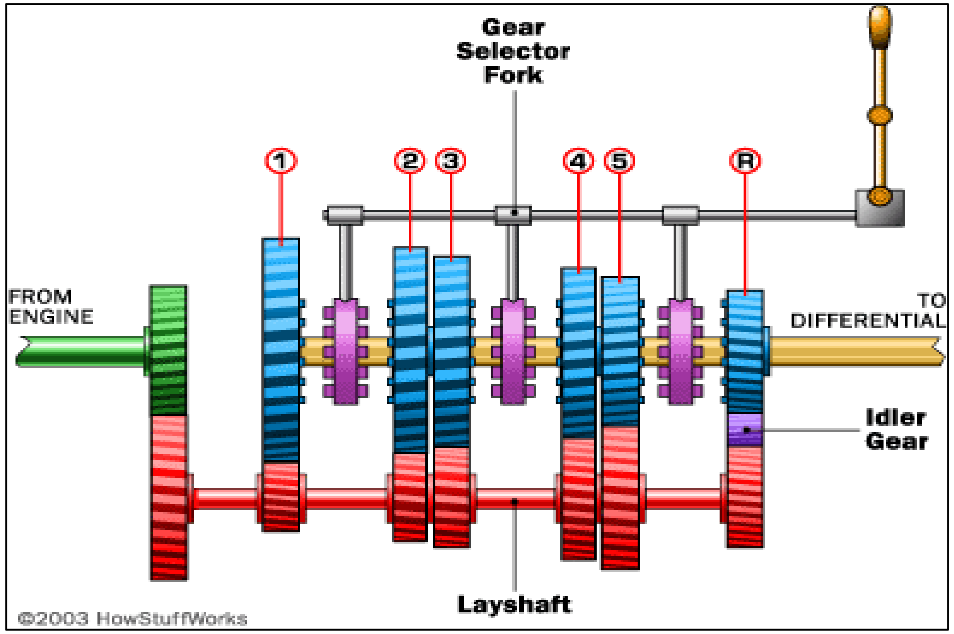
Disadvantages

- Lower fuel efficiency.
- Higher price.
- Higher maintenance cost.

Manual Transmission

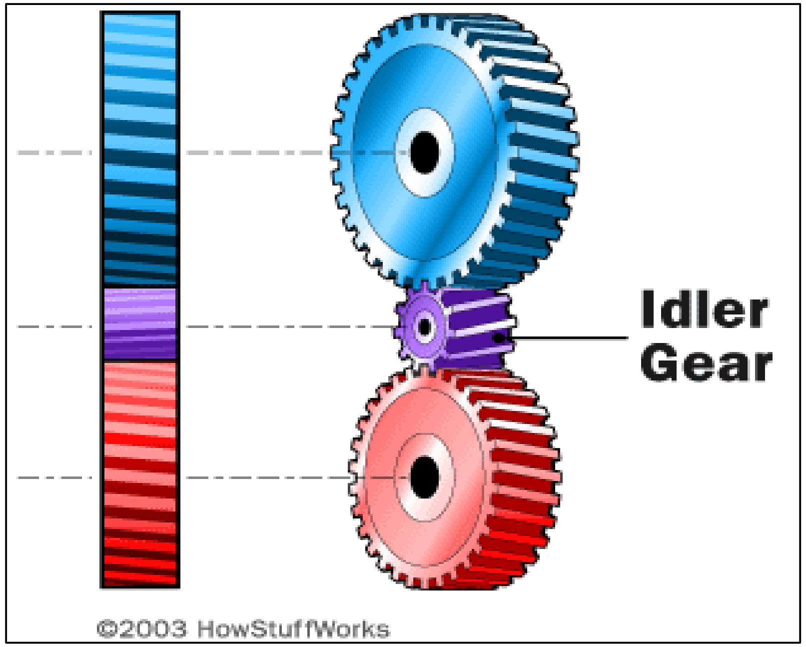
- Switch between the different gear ratios manually.

Manual Transmission Basic Concept



source: howstuffworks.com

Idler Gear



Source: howstuffworks.com

Manual Transmission

Advanteges

- The driver has the ability to switch gears for higher rpm which helps in hill climbing.
- Allow for a better acceleration as the driver can switch gear to maximize torque.

Disadvantages

- Low drivability.
- Low efficient comparing with CVT transmission.

Concept Selection

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%

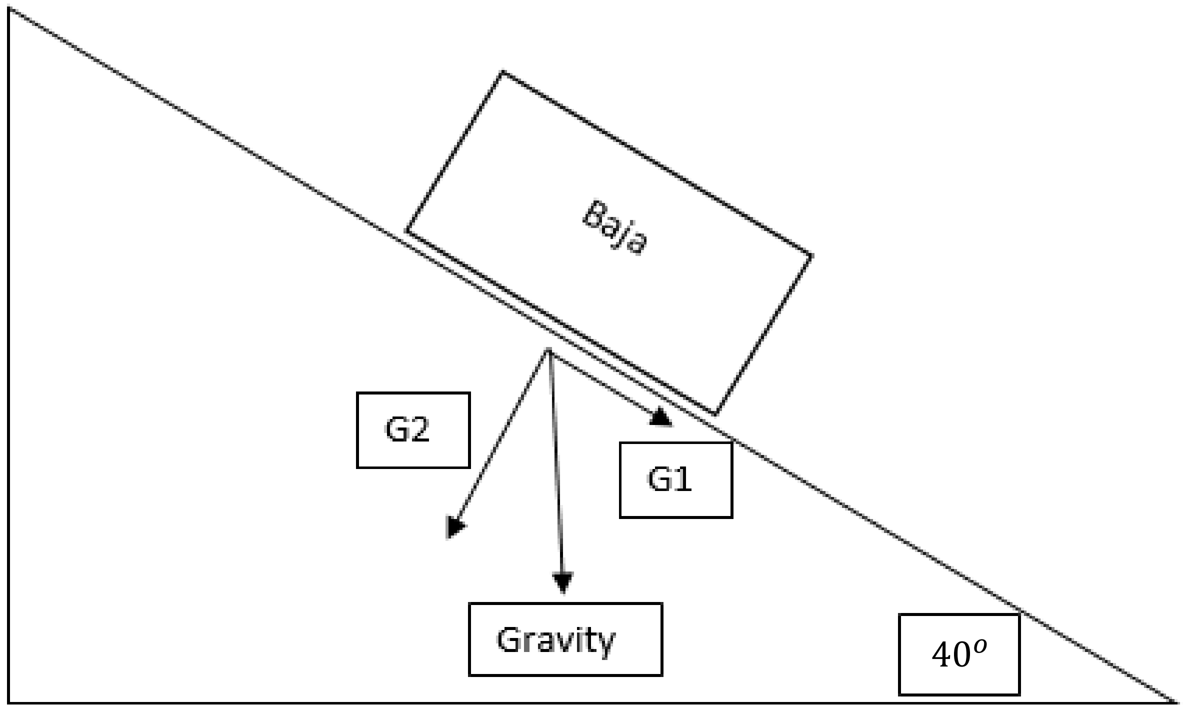
Engineering Analysis

- Assumptions
- Goal
- Calculations
  - Ratio and Torque
  - Shaft, Key and Bearing
- Results
- Final Design

Assumptions

- Wheel diameter(D): 23 inch
- Total weight (W): 600 lb (including the driver)
- Slope of the hill (∂): 40 degree

Goal (Hill Climb)



Goal (Hill Climb)

- G1 = G × sin ∂ = 600lb × sin 40 = $385.67\ lb$
- Force per wheel = $192.83\ lb$
- Torque per wheel = $192.83 \times \frac{D}{2}$ = $192.83 \times \frac{23}{2} \times \frac{1}{12}$= $184.8\ lb - ft$
- Total torque $(T_t) = 369.6\ lb - ft$

Goal (Acceleration)

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

Goal (Acceleration)

- The top teams averaged 4 seconds to finish a 100 ft course.
- Assuming constant acceleration, we can calculate the maximum velocity:

$$\text{Distance} = \text{Max Velocity} \times \text{time} \div 2$$

$$\begin{aligned}\text{Max velocity} &= \text{Distance} \times 2 \div \text{time} \\ &= 100 \times 2 \times 0.68 \div 4 \\ &= 34 \text{ mph}\end{aligned}$$

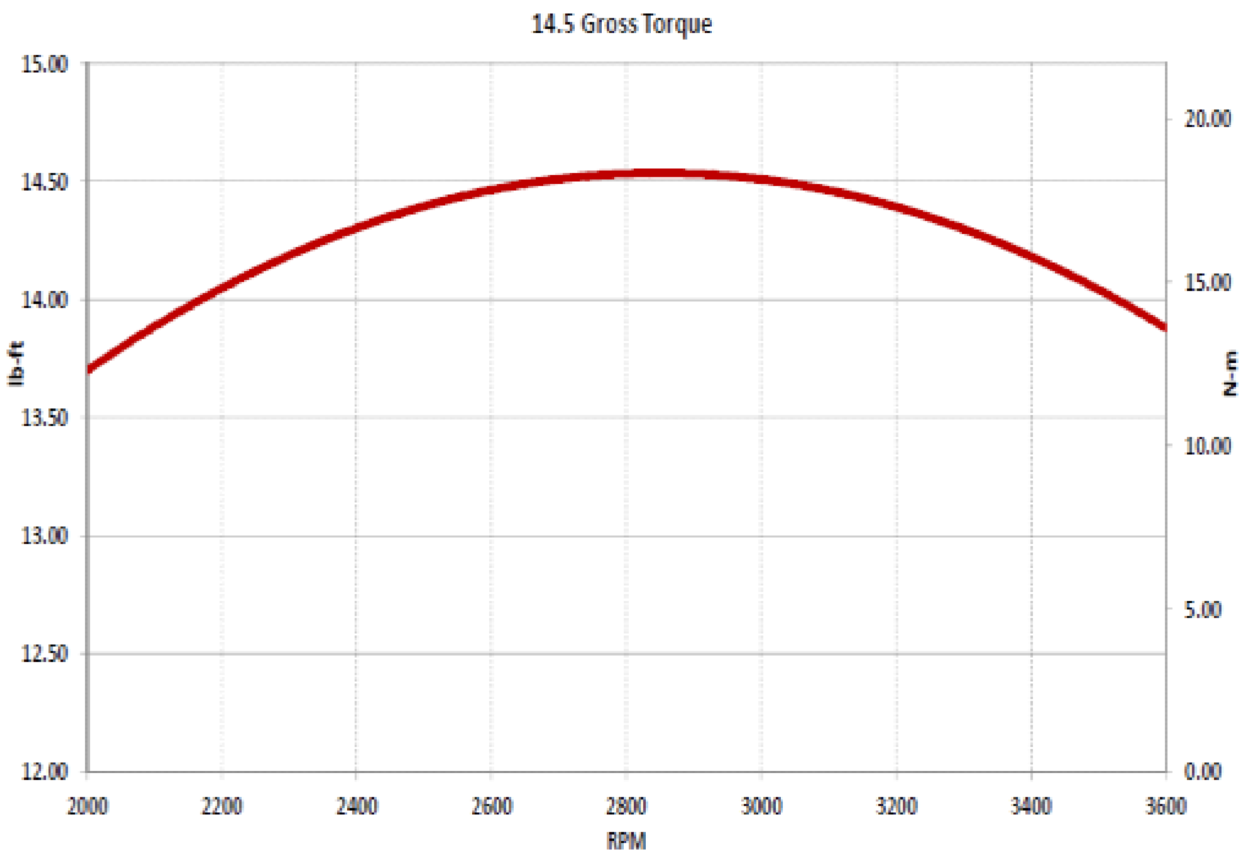
Variables

- Chosen CVT: *PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600* from CVTech-AAB Inc.

  High speed ratio (r_{cvt-h}) : 0.45 Low speed ratio (r_{cvt-l}) : 3.1
- Chosen Gearbox: *ATV/UTV Gearbox T03* from GaoKin Inc.

  High speed ratio (r_{gb-h}): 2.734 Low speed ratio (r_{gb-l}): 5.682
- Second reduction ratio (Sprockets) (r_r): 3
- Efficiency of CVT(N_{cvt}): 88%
- Total ratio (r_t)
- Torque on the wheel (T)

Torque Curve



Source: Briggs & Stratton

Calculations (Ratio and Torque)

- 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 = $\frac{D\times RPM\times\pi}{total\,ratio\times12\times60}\times 0.68 = \frac{23\,in\times RPM\times\pi}{total\,ratio\times12\times60}\times 0.68$

Calculations (Ratio and Torque)

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

Calculations (Ratio and Torque)

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

Calculations (Shaft)

- Equation:

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

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

Calculations (Shaft)

Factors:

$Ka = a \times Sut^{b}$=0.9128

$Kb = 0.879 \times d^{-0.107}$

Kc = 0.59

Kd = $\frac{\text{ST}}{\text{SRT}}$ = 1

Ke = 0.897

K$f = 1 + q \times (Kt - 1) = 1.42$

qts = 0.8

q = 0.7

Kt = 1.6

Kts = 1.3

Moment = 3616.96 KN-mm

Torque = 565376 N-mm

Result:

D = 25.38mm

Bearing selection

- Based on the shaft diameter D = 21.15mm our team chose the bearing that can fit the shaft diameter.

Key selection

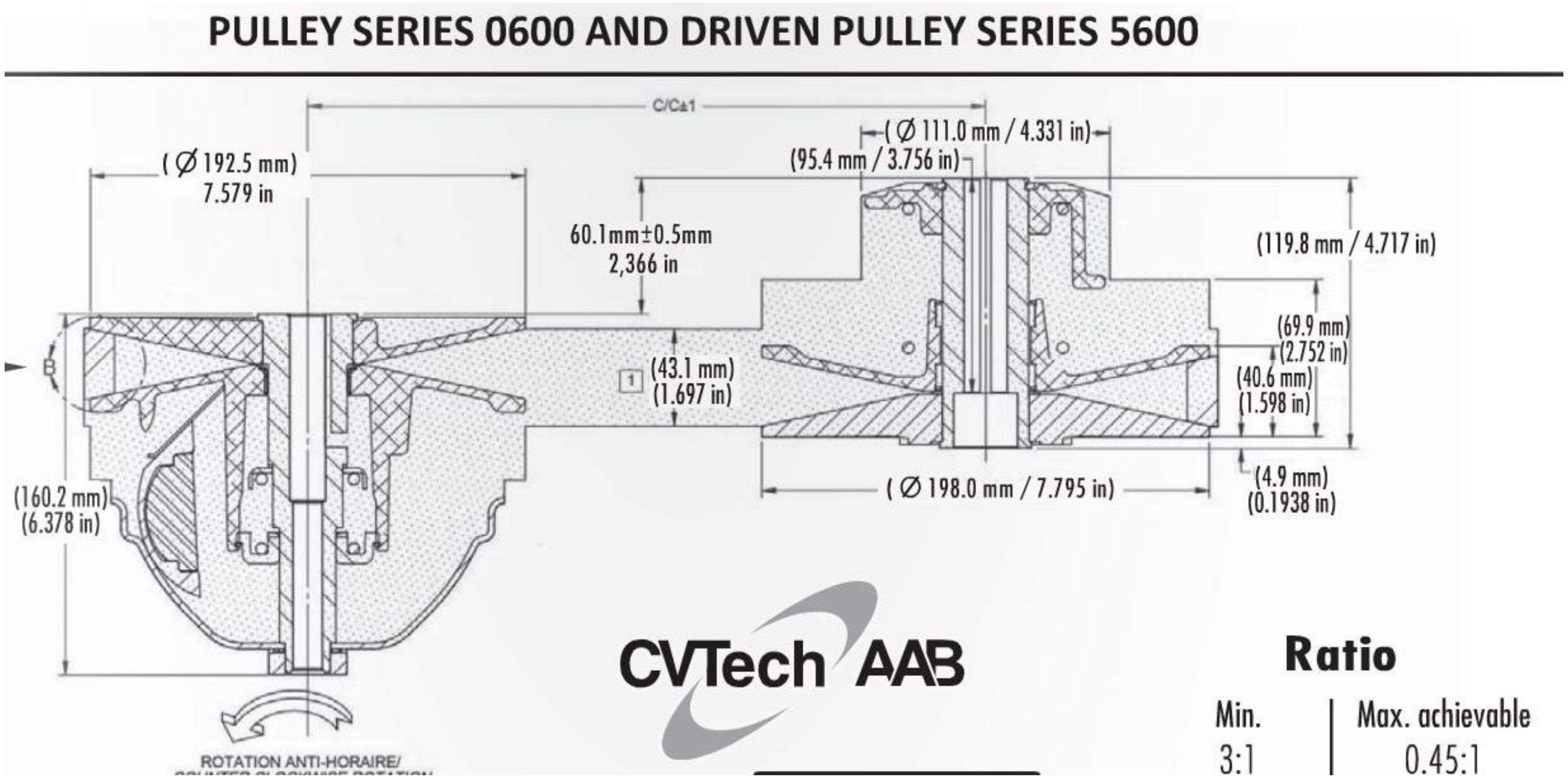
Table 7-6 from machine design book shows that

Shaft diameter		Key Size		Keyway Depth
Over(in)	To(incl.) (in)	W(in)	H(in)	(in)
9/16	7/8	3/16	1/8	1/16

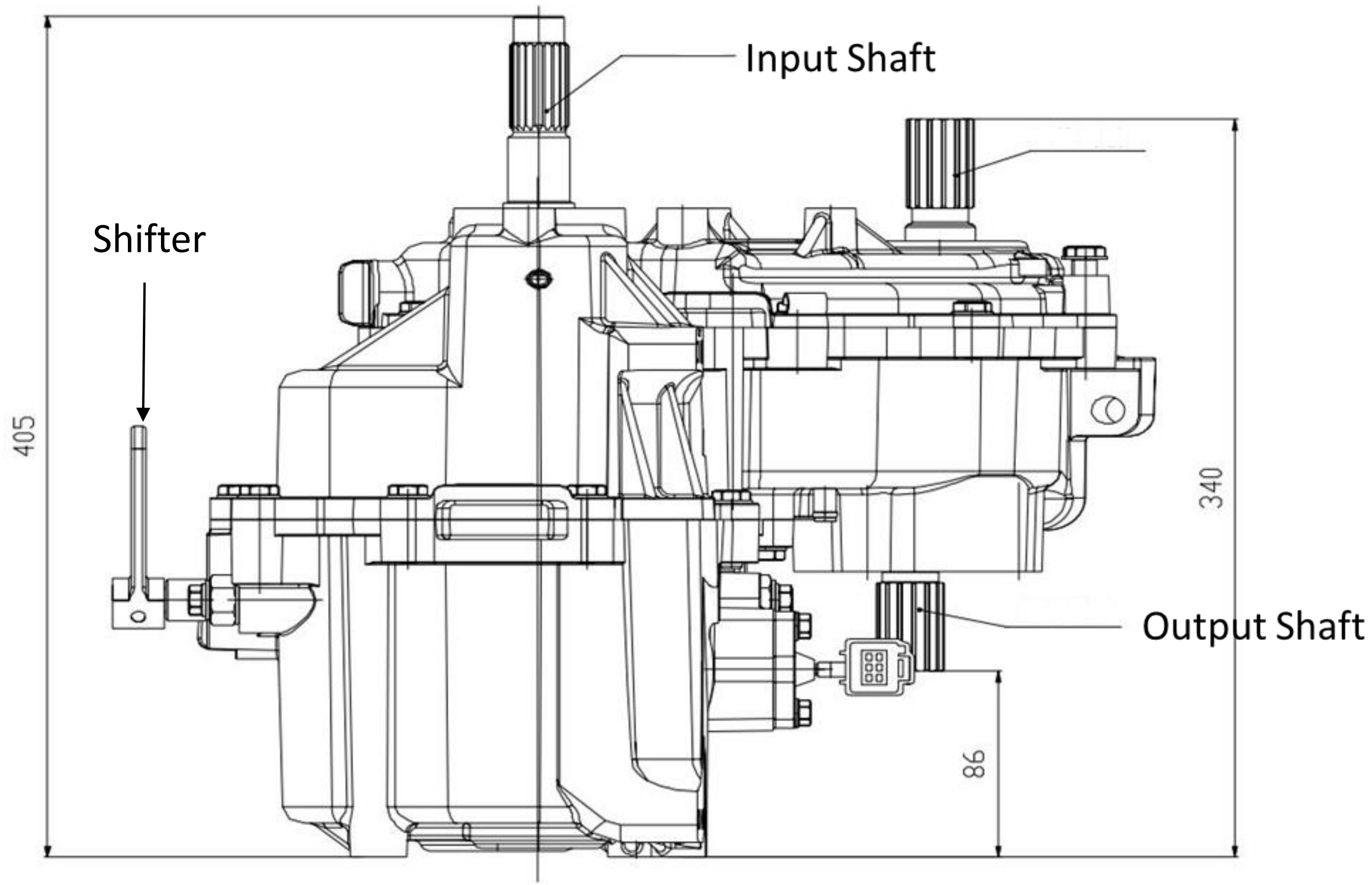
Analysis (Results)

- CVT : 0.45 high speed ratio to 3.1 low speed ratio
- Gearbox: 2.734 high speed ratio, 5.682 low speed ratio
- Max torque on the wheel: 417.228 lb-ft
- Max speed: 68.07 mph
- Out put shaft diameter: D = 25.38mm

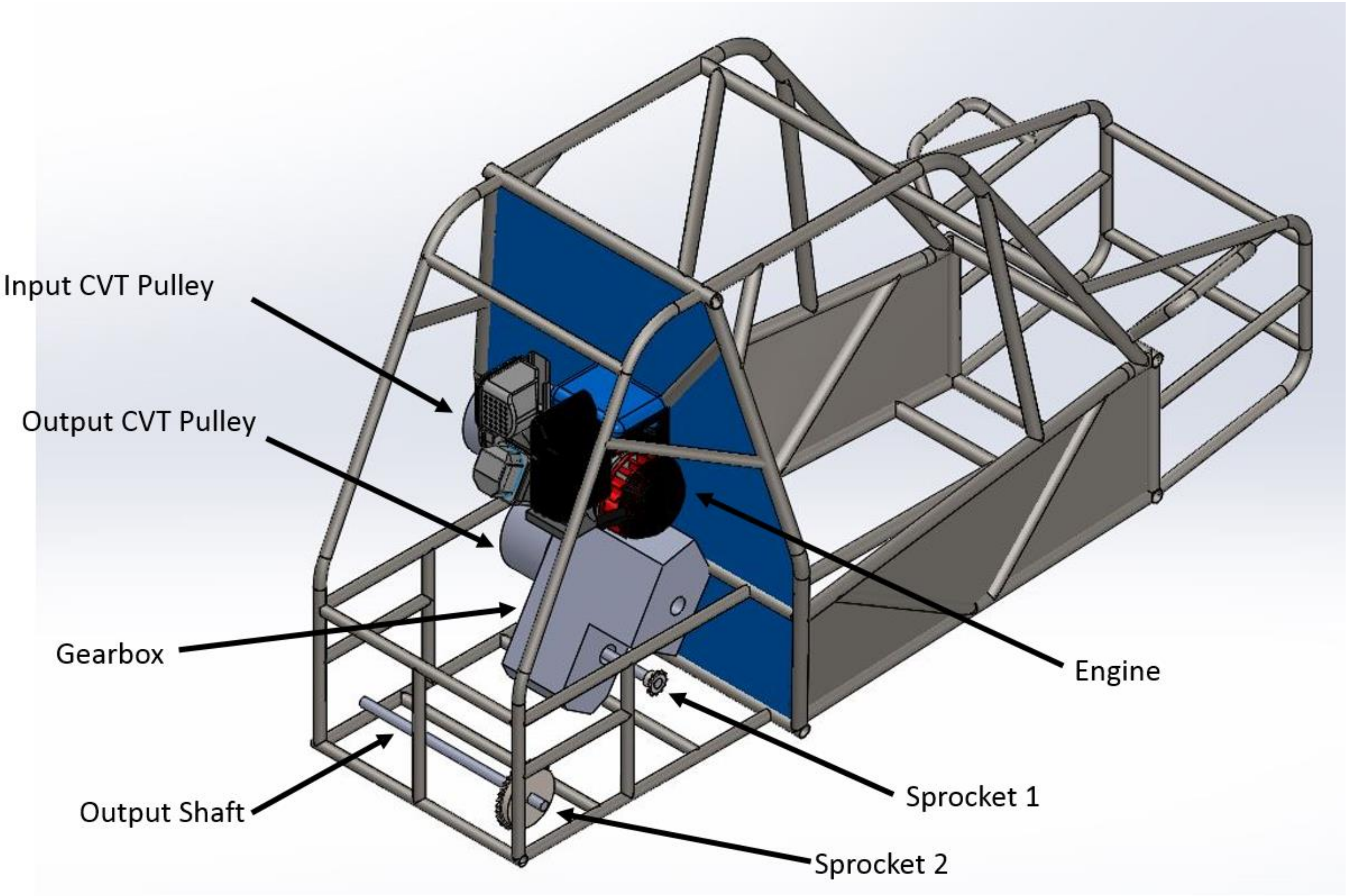
Chosen CVT


PULLEY SERIES 0600 AND DRIVEN PULLEY SERIES 5600
C/C±1
(Ø 111.0 mm / 4.331 in)
(95.4 mm / 3.756 in)
(Ø 192.5 mm)
7.579 in
60.1mm±0.5mm
2,366 in
(119.8 mm / 4.717 in)
(69.9 mm)
(2.752 in)
(43.1 mm)
(1.697 in)
(40.6 mm)
(1.598 in)
B
1
(160.2 mm)
(6.378 in)
(Ø 198.0 mm / 7.795 in)
(4.9 mm)
(0.1938 in)
CVTech AAB
Ratio
Min.
3:1
Max. achievable
0.45:1
ROTATION ANTI-HORAIRE/

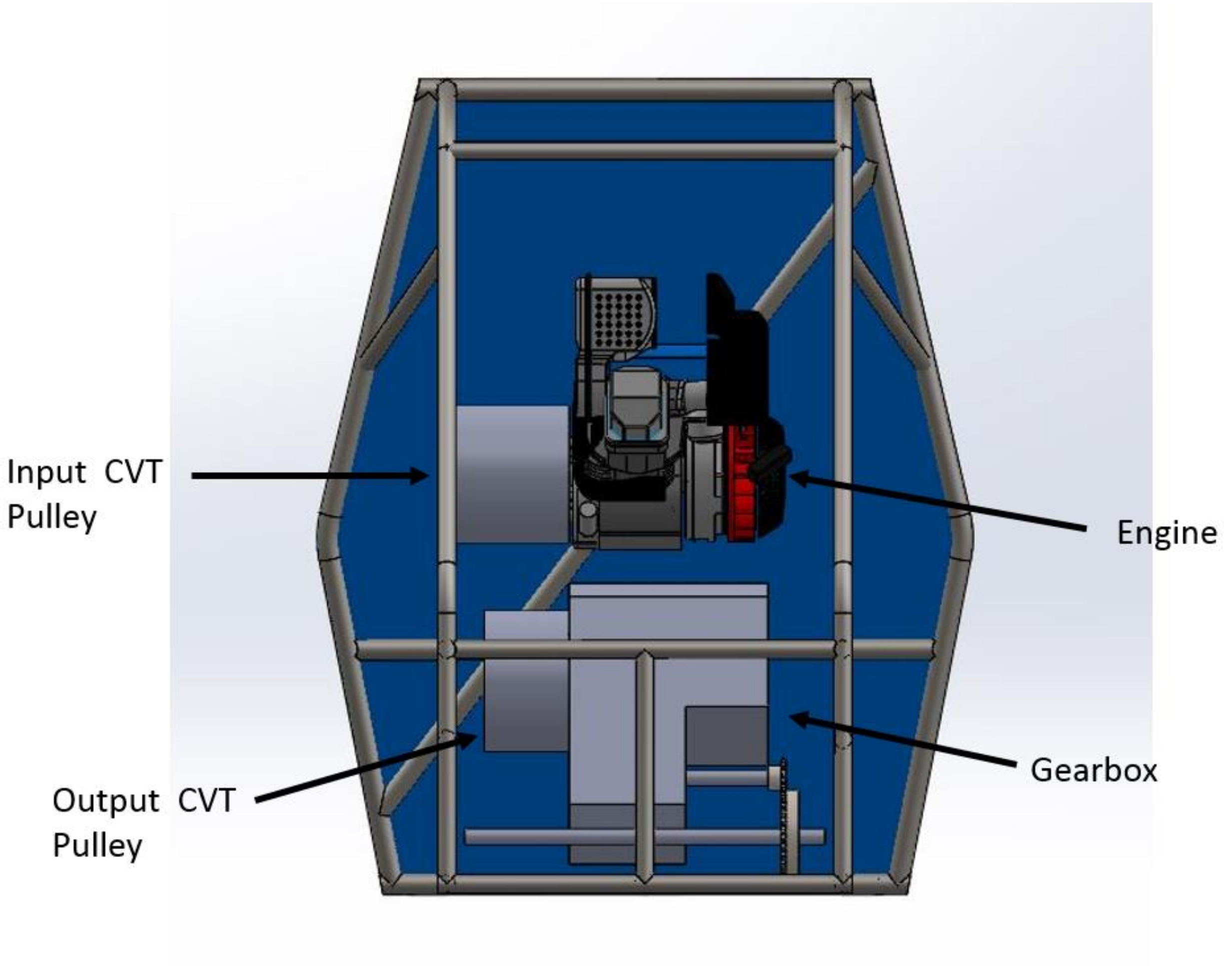
Chosen Gearbox



Final Design (CAD)



Final Design (CAD)



Cost Analysis

- Budget
- Labor Fee Calculation
- Bill of Materials

Cost Analysis

	Price($)	Quantity	Comments	Total
Engine	200	1	Ship fee	200
Gearbox	400	1	GaoKin	400
CVT	580	1	CV-Tech	580
Shaft	28.5	2	Metals Depot	57
Bearing	15	4	Polaris	60
Key	5	4	Metal Depot	20
Sprocket	16	4	G & G	64
Chain	15	2	G & G	30
Half-shaft	260	4	Polaris	1040
Shipping	200			200
Total Price (include tax)				2451

Labor Fee Calculation

- Units per week: 80 units
- Complete units per day: 16 units
- Time per unit job: 5 hours
- Hours of work per day: 80 hours
- Number of laborers: 10 people
- Hourly wage: $26

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

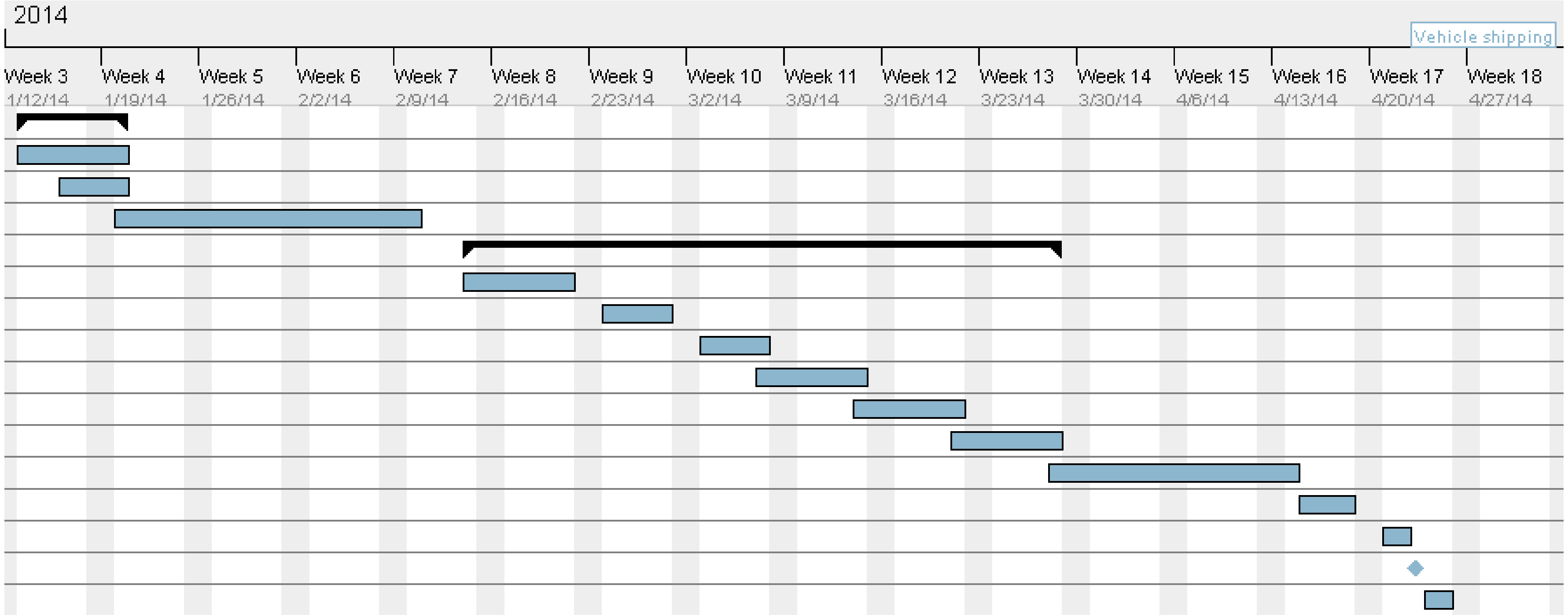
Bill of Materials

- These prices are based upon whole sale costs or approximately 50% of listed price.

12 tooth sprockets	36 tooth sprockets	Half shafts	2 feet 1040 Steel Shaft	Engine	CVT	Gearbox	Chain	Total for single unit	Total
10,120	30,360	526,000	5,700	979,980	1,160,000	800,000	5836	879	3,511,996

Project plan- Spring 2014

Name	Begin date	End date
Parts counts	1/13/14	1/20/14
Count parts recieved	1/13/14	1/20/14
Confirm parts recieved	1/16/14	1/20/14
Starts building	1/20/14	2/10/14
Testing	2/14/14	3/28/14
First perfomance test	2/14/14	2/21/14
Analyze performance re...	2/24/14	2/28/14
Refining and tuning	3/3/14	3/7/14
Second performance test	3/7/14	3/14/14
Analyze performance re...	3/14/14	3/21/14
Refining and tuning	3/21/14	3/28/14
Final test	3/28/14	4/14/14
Test performance check	4/15/14	4/18/14
Prep vehicle for shipping	4/21/14	4/22/14
Vehicle shipping	4/23/14	4/23/14
Compete in the SAE events	4/24/14	4/25/14



Conclusion

- Final design: CVT, 4 step gear box, and 3:1 sprocket reduction.
- Our drive-train will be successful in the SAE Baja Competition.
- This drive-train has theoretically satisfied all costumer needs.
- We have designed it to fit the parameters of the frame team.
- Our team will order parts on schedule and commence building.

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