SAE Baja - Drivetrain

Project Proposal

Ricardo Inzunza, Brandon Janca, Ryan Worden

December 3, 2014

NORTHERN ARIZONA UNIVERSITY

SAE

Overview

- Introduction
- Needs and Constraints
- QFD/HOQ
- Problem Definition and Project Goal
- Transmission Choices
- Decision Matrix
- Design Analyses and Calculations
- Gantt Chart
- Conclusion

Introduction

- Choosing which transmissions to begin analyzing
- Continued research and analysis to further the understanding of the designs
- Gantt Chart

Needs and Constraints

Dr. John Tester, Client

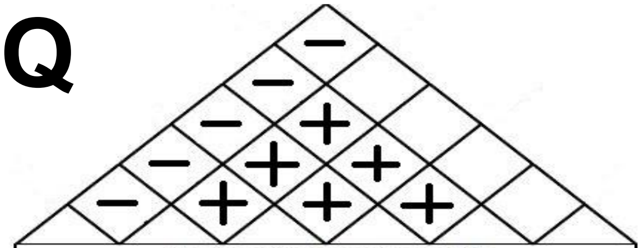
- Lightweight - vehicle is required to be, at most, 450 pounds in weight

Constraints

- Must use provided engine - Briggs & Stratton 10 horsepower OHV Intek
- Design drivetrain within SAE Baja rules
- Complete a 100 feet trial in 4 seconds on level, dry pavement
- Able to climb an incline of at least 60 degrees
- Possible to manufacture in NAU Machine Shop

Worden

QFD/HOQ



High -9
Medium - 5
Low - 1
None - 0

Customer Needs	Weighted %	Cost	Weight	Volume	Acceleration	Hill Climb Angle	Safety	NAU Baja 2013-14
		↓	↓	↓	↑	↑	↑	
Lightweight	30%	9	9	9	9	9		
Reverse Gear	20%	5	9	9				X
Reliable	30%	9	9	1			9	X
Manufacturing Limitations	10%	9	9	9	9	9		X
Inexpensive	10%	9	9	5	9	9	9	
Units		$	lbs	in^3	sec	Degrees	F.O.S.	
Score		8.2	9	6.2	4.5	4.5	3.6	
Weighted Percentages		22.78%	25.00%	17.22%	12.50%	12.50%	10.00%	
Targets		2500	100	1000	4	65	>2	
NAU Baja 2013-14		3000	160	1809.5	5.879	40	10	

Worden

Problem Definition and Project Goal

Design and develop a drivetrain that is able to attain the desired torque and speed for the SAE Mini Baja in order to place in the top 10 in the Hill Climb and Acceleration challenges against competing universities.

Transmission Concepts

- Automatic
- CVT Belt
- CVT Gear
- Direct Drive
- Manual
- Sequential

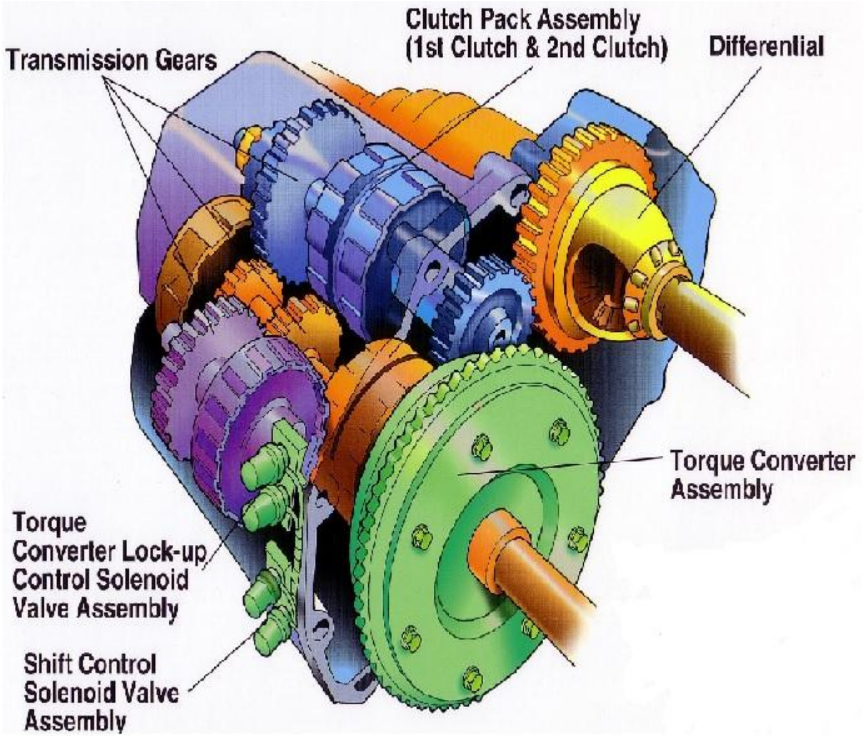
Automatic Transmission

Pros:

- High gear ratio range
- Reliable
- Reverse gear capable

Cons:

- Cost
- Medium efficiency
- Size
- Extremely difficult to design



(Automatic Transmission)

Worden

Direct Drive Transmission

Pros:

- Cost
- Simplicity of design
- Size
- Weight
- Highly efficient

Cons:

- Static gear ratio
- Not reverse gear capable

(Direct Drive)

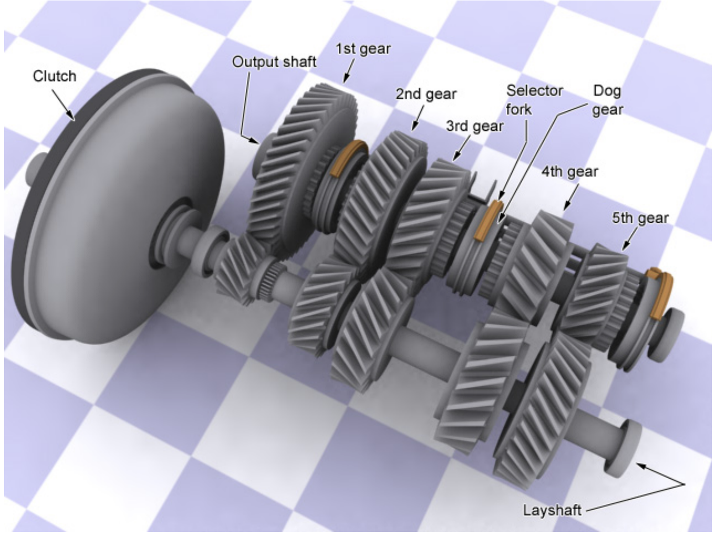
Manual Transmission

<u>Pros:</u>

- Reverse capable
- Reliable
- Cost effective

<u>Cons:</u>

- Extra weight from clutch
- Loss of power between shifts

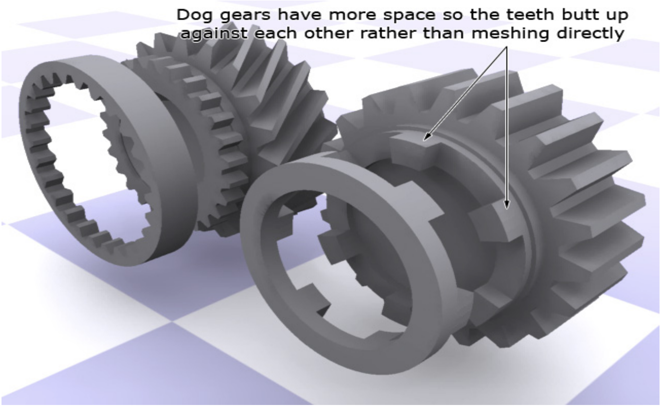


(Representation of Manual Gearbox)

Sequential Transmission

Pros:

- Little loss of power
- Lightweight and compact
- Simple to operate
- Stronger and more reliable



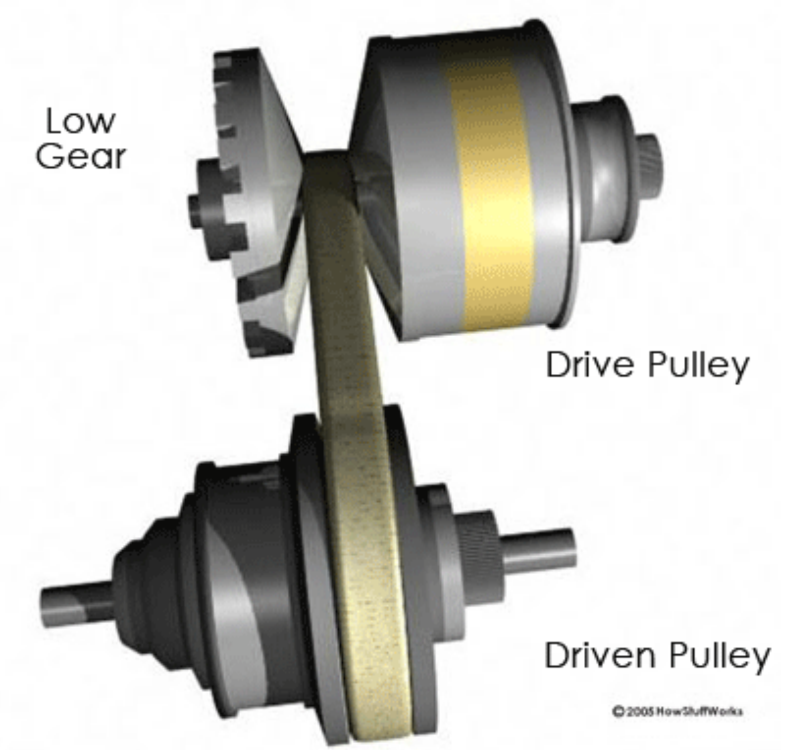
(Sequential Dog ring compared to Manual Dog ring)

Cons:

- Difficult to integrate reverse and clutch
- Possible increased cost

Janca

Continuous Variable Transmission (Belt)



(CVT Picture)

Pros:

- Ease of use
- Size
- Weight

Cons:

- Cost
- Efficiency
- Reliability
- Reverse gear

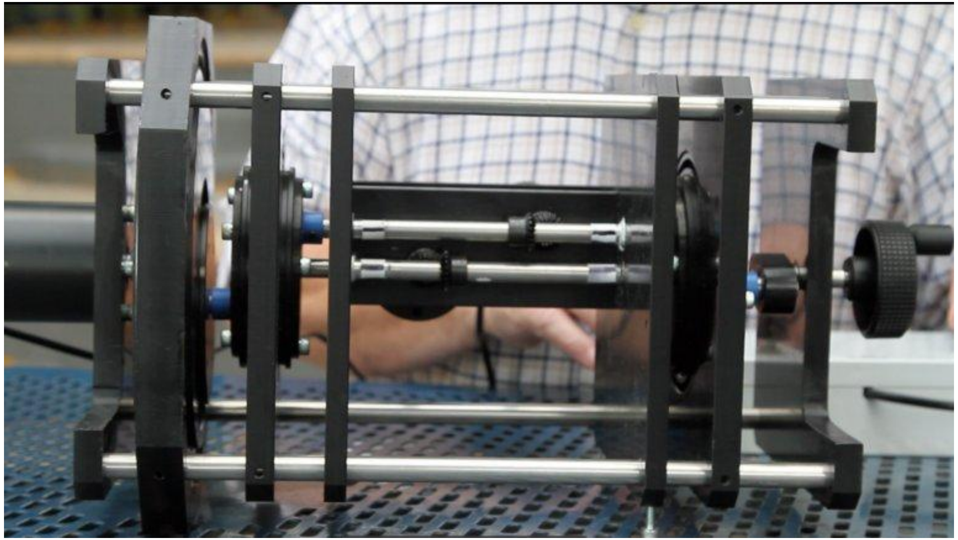
Continuous Variable Transmission (Gears)

Pros:

- Ease of use
- Variability of gear ratios
- Efficiency
- Reverse gear

Cons:

- Cost
- Weight
- Simplicity of design



(Gear CVT)

Janca

Original Decision Matrix

Scale 1-5 5 = Best, 1 = Worst	Cost	Gear Ratio Range	Efficiency (Loss of Power)	Weight	Simplicity of Design	Reliability	Size/Volume	Reverse Gear Capable	Total
Sequential	3	5	5	4	3	4	4	3	3.95
Manual	3	5	4	3	4	4	3	4	3.85
CVT Belt	2	3	2	3	5	2	5	1	2.35
CVT Gear	2	5	4	3	3	4	3	5	3.85
Automatic	2	4	3	3	2	4	2	4	3.2
Straight (One Gear Ratio)	5	2	5	5	5	5	5	1	3.75
Customer Weighting	15%	15%	20%	10%	5%	10%	5%	20%	

Janca

Manual versus Sequential

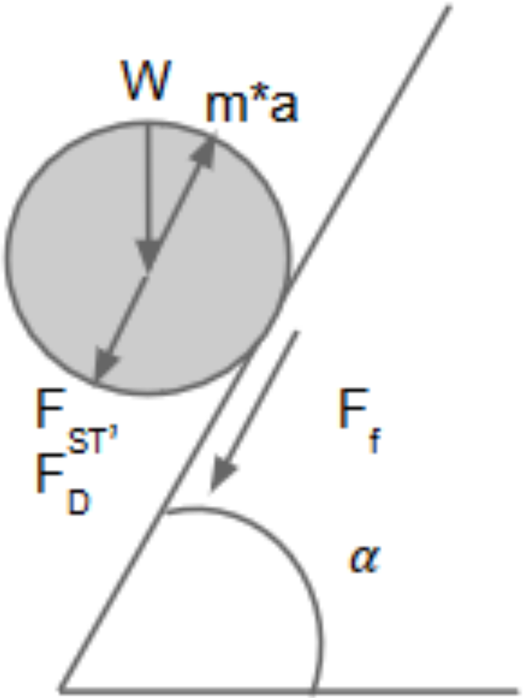
Manual:

- Reverse gear capable
- Simple design

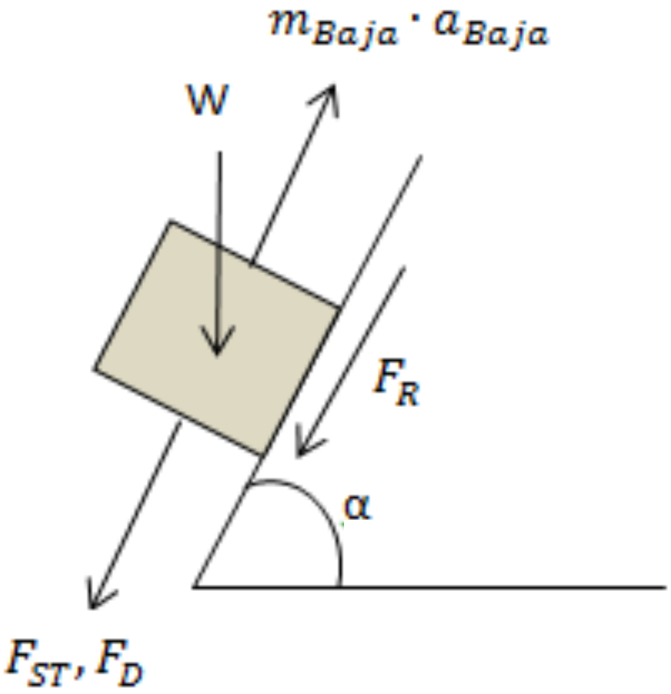
Sequential:

- Efficient
- High gear ratio range
- Fast gear selection

Hill Climb Free Body Diagrams



FBD of Wheel



FBD of Vehicle

Calculations - Hill Climb, Vehicle

- Givens/Assumptions:
  - W = 600 lb
  - f_R = 0.16
  - c_W = 0.62
  - $P_{Z, B}$ = 8.5 hp = 4675 lb*ft / s
  - α_{St} = 60°
  - A = 9.98 ft^2
  - ρ_{air} = 0.00228 slug/ft^3
  - v = 5 mph = 22/3 ft/s

- Equations Used:

$$F_{St} = m_F \; g \; \sin\alpha_{St}$$

$$F_L = \frac{1}{2} \rho_L \; c_W \; A \, v^2$$

$$F_R = f_R \; m_F \; g \; \cos\alpha_{St}$$

$$F_{Z,B} = F_R + F_{St} + F_L + F_a$$

$$P_{Z,B} = F_{Z,B} \; v$$

Results - Hill Climb, Vehicle

- Results
  - F_{St} = 519.615 lbf
  - F_f = 48 lbf
  - F_L = 0.379 lbf
  - $F_{Z, B}$ = 567.994 lbf
  - $v_{vehicle}$ = 5.616 mph = 8.236 ft/s

Calculations - Hill Climb, Wheel

- First Gear Ratio Assumptions:
  - Assume F_{total} = 600 lb
  - Assume $v_{vehicle}$ = 6 mph
  - P = 8.5 hp, α = 60°
  - 22 in diameter tire, R = 11 in
  - N_{min} = 1800 rpm
  - N_{max} = 2800 rpm

- Equations Used:

$$\omega = \frac{v}{r}$$

$$R = \frac{\omega_A}{\omega_B} = \frac{N_B}{N_A}.$$

$$\tau = F \times r$$

Janca

Results - Hill Climb, Wheel

- Results
    - ω = 91.67 rpm
    - Gear $Ratio_{min}$ @1800rpm = 19.63:1
    - Gear $Ratio_{max}$ @2800rpm = 30.54:1
    - **Gear $Ratio_{avg}$ = 24.1:1**
    - T_{wheel} = 550 lb*ft

Calculations - Acceleration

- Assumptions
  - Distance = 100 ft
  - Time = 4 seconds
  - a = 12.5 ft/s^2
  - v = 23 mph
  - m = 18.65 lbm
  - R = 11 in
  - A = 9.92 ft^2
  - c_W = 0.62
  - ρ_L = 0.00228 slug/ft^3
  - f_R = 0.014

- Equations Used:

$$x = x_0 + v_0 t + \frac{1}{2} a_c t^2$$

$$F = ma$$

$$F_R = f_R \, m_F \, g \cos \alpha_{St}$$

$$F_L = \frac{1}{2} \rho_L \, c_W \, A \, v^2$$

Results - Acceleration

Results:

- $F_{total, High}$ = 250 lbf
- $F_{total, Low}$ = 241 lbf
  - High Ratio = **6.2 : 1**
  - Low Ratio = **11.1 : 1**
  - Total Time = 4.25 seconds

High Ratio - $\frac{F_{Total,High}}{2} \times \frac{13R}{12}$

Low Ratio - $\frac{F_{Total,Low}}{2} \times \frac{10R}{12}$

Janca

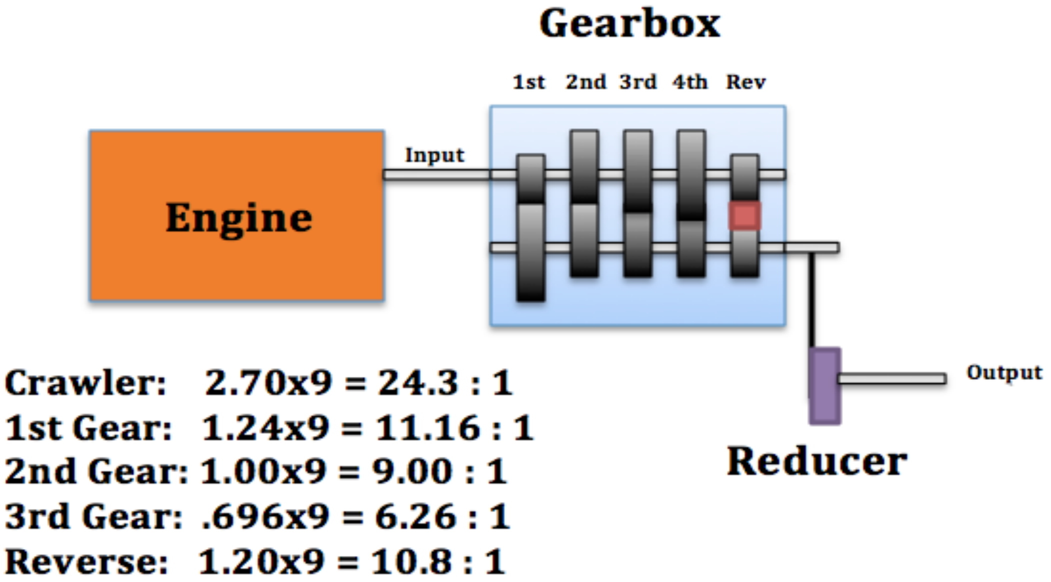
Gear Ratios

<u>Engine to Gearbox Ratio:</u> **1 : 1**

<u>Gear Box Ratios</u>

- Crawler: **2.70 : 1**
- 1st: **1.24 : 1**
- 2nd: **1 : 1**
- 3rd: **0.696 : 1**
- Reverse: **1.20 : 1**

<u>Reducer Ratio:</u> **9 : 1**



Gear Specification

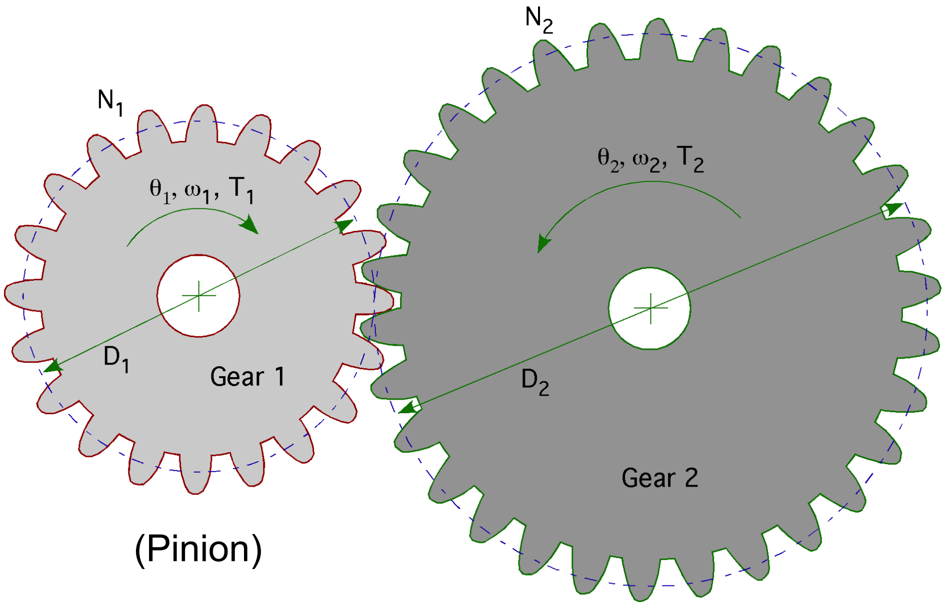
Gearbox

Crawler -	**Pinion**: 15	**Gear**: 41
1st Gear -	**Pinion**: 25	**Gear**: 31
2nd Gear -	**Pinion**: 28	**Gear**: 28
3rd Gear -	**Pinion**: 33	**Gear**: 23
Reverse -	**Pinion**: 15	**Gear**: 15
		Gear 2: 18

Reducer -	**Pinion**: 10	**Gear**: 90

Gear Material: 7075-T6 Aluminum

Minimum Factor of Safety: 6.2



(Pinion)

(Gear)

Shafts

Input shaft M_a = 578 lb-in Output shaft M_a = 578 lb-in

Input shaft T_m = 192 lb-in Output shaft T_m = 528 lb-in

DE-Goodman:

$$\frac{1}{n} = \frac{16}{\pi d^3}\left\{\frac{1}{S_e}\left[4(K_f M_a)^2 + 3(K_{fs} T_a)^2\right]^{1/2} + \frac{1}{S_{ut}}\left[4(K_f M_m)^2 + 3(K_{fs} T_m)^2\right]^{1/2}\right\}$$

- Shaft Material: 4340 Normalized Steel
- 0.5 inch diameter solid shaft
- Factors of Safety: Input shaft = 2.94

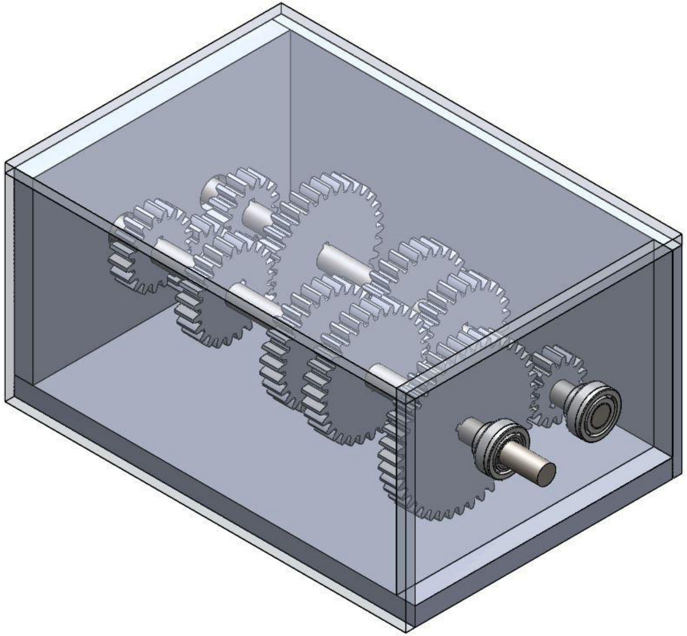
  Output shaft = 2.00

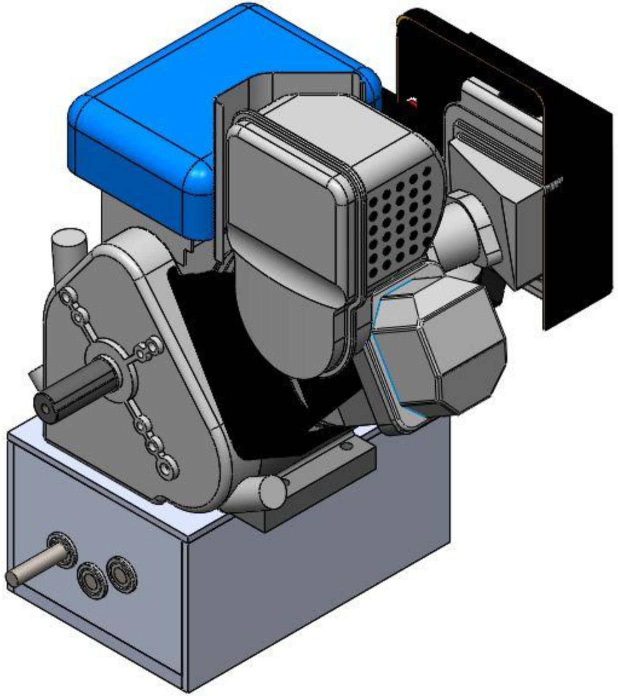
Bearings

- McMaster-Carr Open Steel Ball Bearing
  - Shaft Diameter = 0.5 inches
  - Outside Diameter = 1.125 inches
  - Width = 0.375 inches
  - Dynamic Load Capacity = 600 pounds

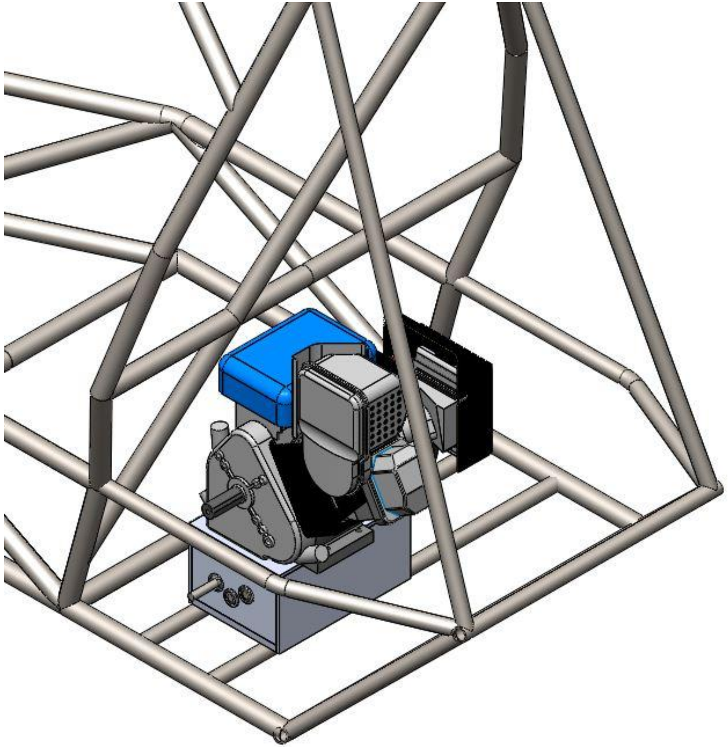
- Factor of Safety: 2.3

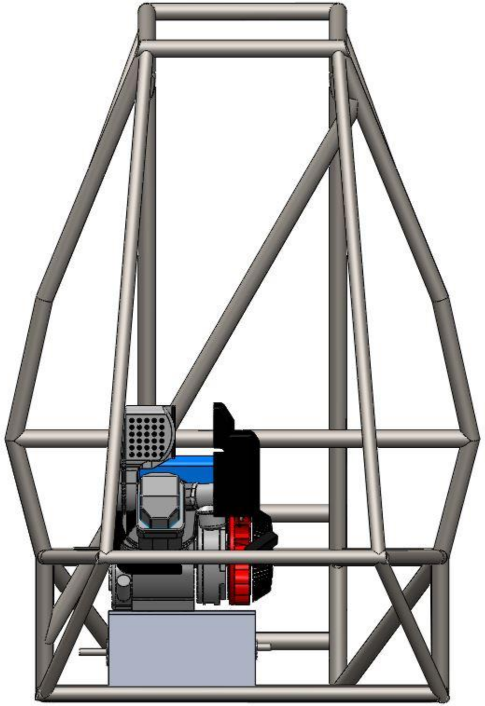
CAD Drawing





Overall Assembly





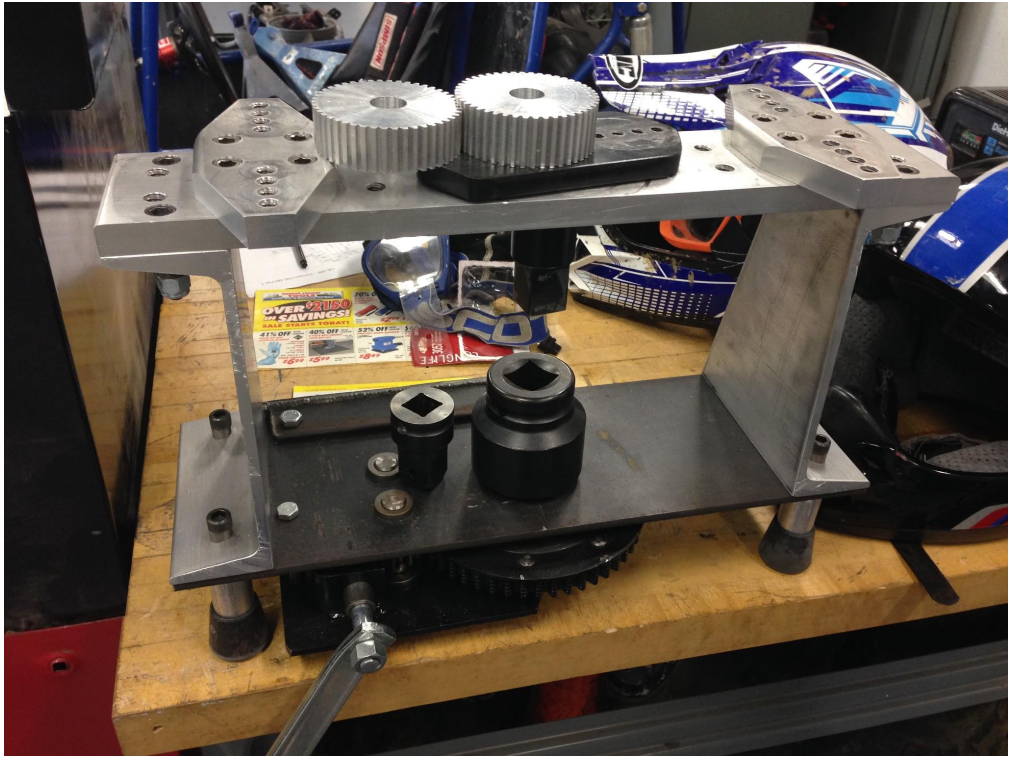
Bill of Materials

Materials	Quantity	Cost for One Unit of Material	Overall Cost of Each Material	Free/Donated
7075 T6 Aluminum (4" diameter, 2' bars)	1	$307.44	$307.44	x
7075 T6 Aluminum (3" diameter, 5' bars)	1	$298.87	$298.87	x
7075 T6 Aluminum (2" diameter, 4' bars)	1	$87.24	$87.24	x
6061 T6 Aluminum (0.5" thick, 1'x3' plates)	1	$164.92	$164.92	x
6061 T6 Aluminum (0.25" thick, 1'x3' plates)	1	$76.69	$76.69	x
4340 Normalized Steel (5/8" inch diameter, 5' bar)	2	$95.64	$191.28	x
Bearings	6	$7.36	$44.16	
Clutch	1	$300.00	$300.00	
Differential	1	$400.00	$400.00	x
80 tooth sprocket	1	$25.00	$25.00	
10 tooth sprocket	1	$10.00	$10.00	
		Total	$1,905.60	
		Total, subtracting free/donated	**$379.16**	

Manufacturing of Gearbox

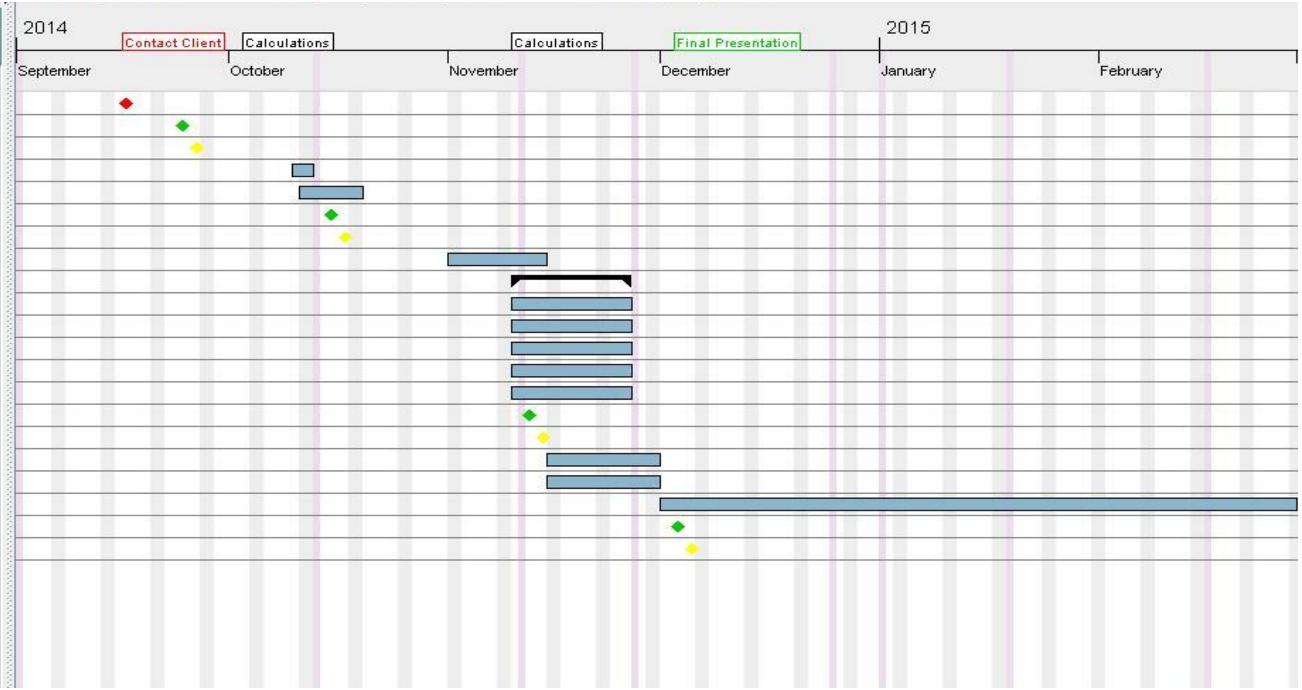
- Can manufacture gears on site at the NAU Machine Shop
- Will either order or turn down metal received from Industrial Metal Supply Co.
- Purchasing bearings from McMaster-Carr and a clutch online

Manufacturing of Gearbox



Gantt Chart

Name	Begin date	End date
Contact Client	9/16/14	9/16/14
Presentation 1	9/24/14	9/24/14
Report 1	9/26/14	9/26/14
Test Motor	10/10/14	10/12/14
Gear Train Selection	10/11/14	10/19/14
Presentation 2	10/15/14	10/15/14
Report 2	10/17/14	10/17/14
3D Models for Parts	11/1/14	11/14/14
Calculations	11/10/14	11/26/14
Gear Ratio Calculations	11/10/14	11/26/14
Torque Calculations	11/10/14	11/26/14
Velocity Calculations	11/10/14	11/26/14
Shear Stress Calculations	11/10/14	11/26/14
Safety Factor Calculations	11/10/14	11/26/14
Presentation 3	11/12/14	11/12/14
Report 3	11/14/14	11/14/14
Parts Choosing	11/15/14	11/30/14
Parts Ordering	11/15/14	11/30/14
Manufacturing of Transmission	12/1/14	2/28/15
Final Presentation	12/3/14	12/3/14
Final Report	12/5/14	12/5/14



Inzunza

Conclusion

- Selected, designed, and analyzed a sequential transmission
- Will begin to manufacture the gears during the month of December
- Will order the metal for the shafts and housing through Industrial Metal Supply Co. (IMS)
- Will purchase bearings and a clutch

References

- 2015 Collegiate Design Series: Baja SAE Rules
  http://bajasae.net/content/2015%20BAJA%20Rules%20.pdf
- Tester, John T., PhD, Associate Professor Northern Arizona University, personal communication, Sept. 2014.
- SAE Mini Baja 2013-2014 NAU Chapter Webpage: http://www.cefns.nau.edu/capstone/projects/ME/2014/SAE-MiniBaja/
- Transmissions Textbook: Lechner, G., Harald Naunheimer. Automotive Transmissions: Fundamentals, Selection, Design and Application. Berlin: Springer, 1999.
- Mating Pinion and Gear Picture http://www.daerospace.com/MechanicalSystems/GearDescFig2.png

References

- NAU Student Chapter of SAE "2006 Mini Baja," www.cens.nau.edu/~jtt3/Minibaja06, April 2006
- The Transmission Bible: Transmission, or Gearbox? http://www.carbibles.com/transmission_bible.html
- Direct Drive and Manual Picture http://alooroea.blogspot.com/2011/05/manuel-transmission.html
- Belt CVT Picture http://auto.howstuffworks.com/cvt2.htm
- Gear CVT Picture http://www.gizmag.com/steve-durnin-ddrive-d-drive-infinitely-variable-transmission-geared/15088/picture/114606/
- Automatic Transmission Picture http://hdabob.com/Transmission.htm

Questions?