SAE Baja - Drivetrain

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Team 11

Midpoint Review Report

Document

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Contents

1.0 Introduction

The Northern Arizona University Chapter of the Society of Automotive Engineers (SAE) has instructed our team to design and build a vehicle for the Baja SAE Series. This entails designing a single seat off-road vehicle capable of performing in the top 10 in the collegiate competition at Portland, Oregon from May 27-30, 2015. This competition is a challenge for colleges to design an off-road vehicle capable of exceptional performance and customer appeal. The performance aspect of the vehicle is measured from the accomplishments of the vehicle in 5 dynamic events: the Acceleration, Hill Climb, Maneuverability, Rock Crawl, and Endurance challenges.

The Drivetrain Team is responsible for the design of the engine through to the wheels. This will include the engine, transmission, differential, and any power transmitting shafts. The engine is a constraint in our design, as SAE requires the use of a Briggs & Stratton Model 20 engine. This specific model of engine proposes a challenge due to its maximum power output being 10 horsepower. Our particular engine, however, is only 8.5 horsepower, which was discovered through the use of a dynamometer.

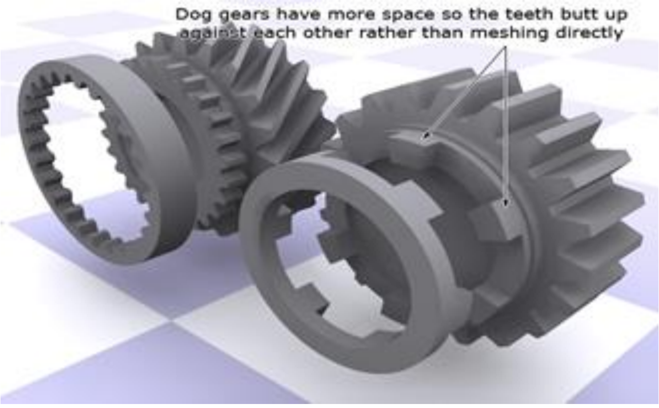
This year's Drivetrain Team has set a goal of placing in the top ten in two specific events: Acceleration, and Hill Climb. These events were chosen because the overall performance in these events depend greatly on the design and execution of the transmission design. The set performance goals to achieve this objective are to complete a 100 foot distance in 4 seconds from a complete stop, and for the vehicle to be able to drive up a hill of about 60 degrees. The contents below describe how the Drivetrain Team chose between six transmission concepts, to then analyze the sequential transmission, to implement into the NAU Baja for the May 2015 competition.

1.1 Project Goal

In last year’s competition the NAU Baja placed 58th in the acceleration test and 64th in the hill climb test. The goal the team has for this project is to design a drivetrain that will be competitive and place in the top 10 for the acceleration and hill climb tests against other competing universities.

2.0 Sequential Transmission

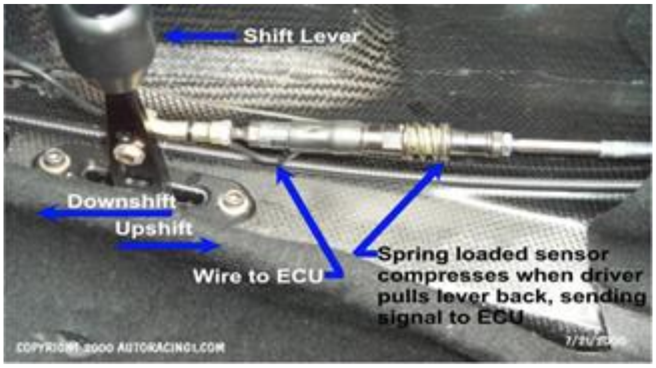
The design concept chosen as the solution was a sequential transmission. The sequential transmission is a derivative of the manual transmission with slight differences in the shifting mechanism. As seen in Figure 2.1, there is a difference in the geometry of the dog rings and the way which the gears and dog rings engage.



(Figure 2.1, Manual (left) Vs. Sequential (right) dog ring [1])

Because the sequential dog ring has a square geometry and more room to engage to the gear, it allows the gear and ring to engage at different speeds, as opposed to a manual gearbox which requires both the gear and ring to be spinning at the same 1:1 ratio in order to engage the two. This means the clutch does not have to be engaged each time the operator wants to shift from one gear ratio to the next.

There is also a different manner in which the sequential transmission selects each gear ratio. The shifting mechanism and selector work by only allowing the operator to shift either up or down a single step in gear ratio. If the operator desires to select 4th gear from 2nd gear, he/she must engage 3rd gear from 2nd gear, and then 4th gear from 3rd in sequence. The gear selection can be achieved by use of a shift lever as seen in Figure 2.2.



(Figure 2.2, Sequential Shift Lever [2])

There are many advantages when using a sequential transmission. First, there is little loss of power because the clutch does not need to be engaged in between each shift. This means there will be a minimal amount of time that there is no power being transmitted to the wheels, which, in effect, means an increase in performance when accelerating. Also, sequential transmissions are generally smaller and more compact, which also means that the gearbox will be lighter as well. The sequential transmission is also easy to operate because the clutch needs to be used only when starting from a stop. Each gear shift after is completed by pulling or pushing a lever which will engage the gear ratio below or above the current gear. Finally, the sequential transmission is more reliable and stronger than a standard manual transmission. A countershaft is generally used to transmit power to the gear ratios, which means that the gears in a sequential transmission will experience about half the force of a normal manual transmission.

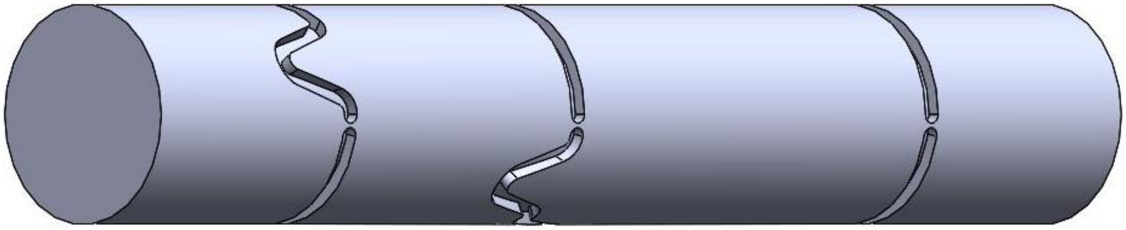
There are a few disadvantages of using a sequential transmission as well. Most sequential transmissions do not have a reverse integrated into the design of the gearbox, as they are generally used on motorcycles and off-road applications where reverse is not needed. It will be a difficult task to integrate a reverse into a pre-existing design. Also, if the team decides to integrate a reverse into an existing transmission, it will be an added expense to the production.

3.0 Updated CAD Models

This section will show an update of the teams Computer aided design of the gearbox. There are a few CAD models which have been updated, as well as a few others that have been newly designed.

3.1 Shifting Shaft

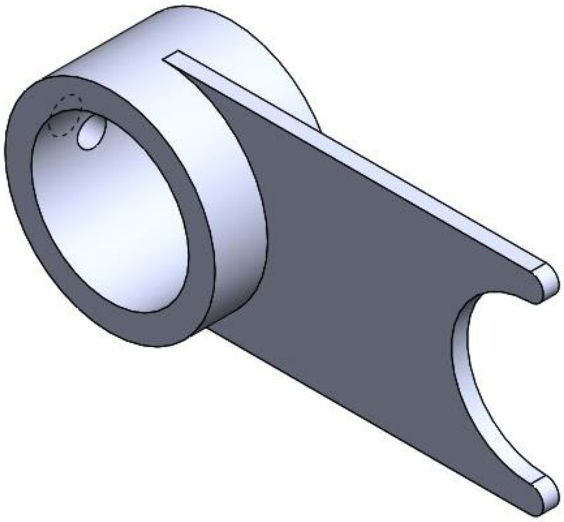
One of the first components of the shifting assembly to engage and disengage gears, is the cylindrical shifting shaft. This shaft allows the driver to sequentially shift up or down through gears by the use of this shaft. As seen below in Figure 3.1, the shaft is rotated in order to select a gear. The shaft has grooves cut into the outside cylinder walls, in order to create the geometry needed to change gears. This shifting shaft works directly in conjunction with the shift fork. The shaft is to be made of a low grade steel, it will be 2" in diameter, and will be hollow in order to save weight.



(Figure 3.1, Shifting Shaft Design)

3.2 Shift Fork

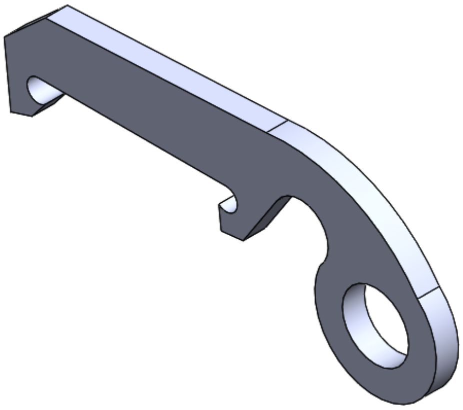
The shift fork is another component within the shifting assembly. The shift fork connects directly to the shift shaft, and to the dog collars as well. As seen in Figure 3.2 below, the shift fork has a round inner cylinder with a hole on top. This inner cylinder is to fit directly over the outer diameter of the shifting shaft, and the hole on top will allow for a pin to be fastened in place. This pin will also be fastened down into the grooves of the shifting shaft, and will follow the geometry of the shifting shaft, as the shaft is rotated. The grooves on the shaft will force the shift fork to the left or right to engage the dog collar into a gear, or stay straight in order for the dog collar to be disengaged from a gear. The shifting shaft will be made of a low grade carbon steel, as it will not see any significant loading from the gears.



(Figure 3.2, Shift Fork Design)

3.3 Shift Finger

Another component of the shifting assembly is the shift finger. This shift finger is what will allow the driver to convert a translational movement of pushing or pulling a shift lever, to a rotational movement that will rotate the shifting shaft accordingly. As seen below in Figure 3.3, the shift finger features two hooks. These hooks will be responsible for grabbing and pulling, or pushing the shifting shaft. The shifting shaft will have 5 smaller cylinders protruding from the base of the shaft. The shift finger will engage with these small cylinders and either push or pull them to rotate the shifting shaft, in order to obtain the desired gear. The shift finger will be made out of low grade carbon steel because there is no significant force exerted on the part itself.

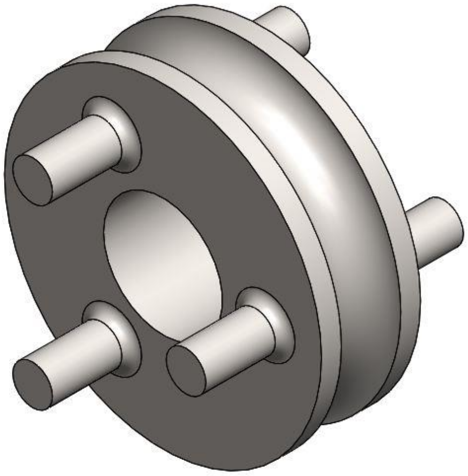


(Figure 3.3, Shift Finger Design)

3.4 Dog Collar

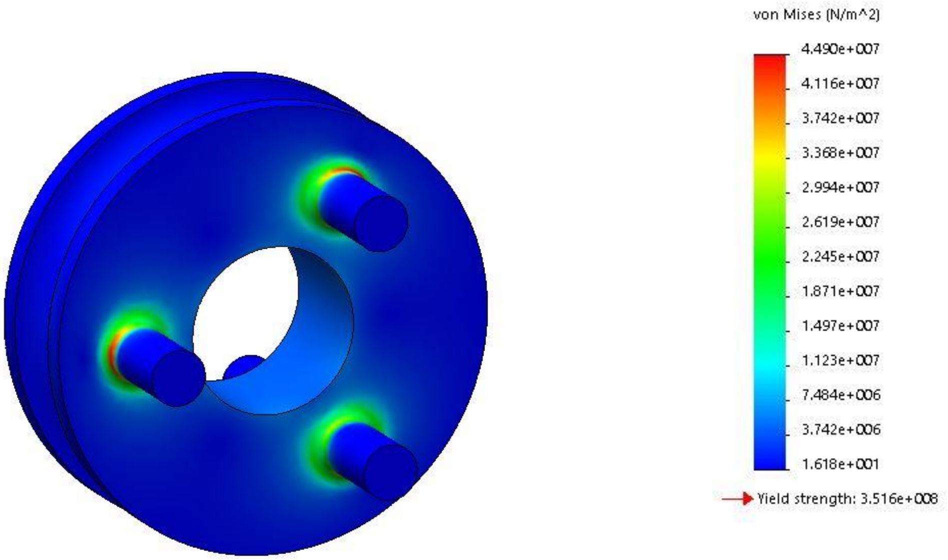
The final component in the shifting assembly is the dog collar. The dog collar is the component of the shifting assembly that will physically engage with the gears on the input shaft. As seen in Figure 3.4 below, the dog collar features 3 cylinders protruding from either side, an extruded hole cut in the middle, and a groove on the outside width of the cylinder.

The dog collar is what acts as the mediator between the gears and the shaft. The 3 cylinders are what engage to the gear, and translates the rotation of the gear, to the rotation of the shaft. The dog collar is also fixed to the shaft with 3 keyways that will not allow it to rotate on the shaft, but will allow the part to slide left and right on the shaft. In order for the dog collars to move left or right to engage the gear, the shift fork will connect to the groove of the dog collar. The shift fork will fit over the groove of the dog collar, and move as it follows the geometry of the shifting shaft, resulting in the movement of the dog collar to the left or right.



(Figure 3.4, Dog Collar Design)

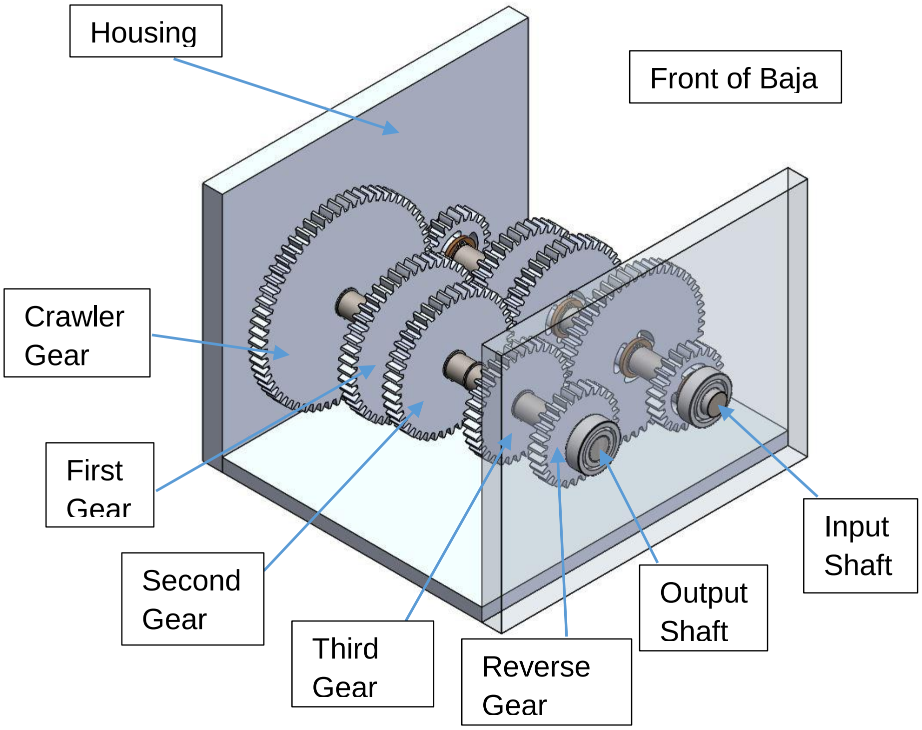
The team decided to make the dog collar out of AISI 1020 steel. This type of steel is lower grade, but because it is still stronger than our aluminum gears, it should be able to withstand just as much force. In Figure 3.5 below, the team performed a stress analysis on the dog collar using SolidWorks FEA simulation. The pins were fixed in place and a torque of 16 ft-lbs was applied in the center hole. The result of the simulation was a factor of safety of **7.8** using a very conservative torque. This simulation confirms that the dog collar will be able to withstand the stress generated by the torque of the motor.



(Figure 3.5, Dog Collar Finite Elemental Analysis)

3.5 Final Assembly

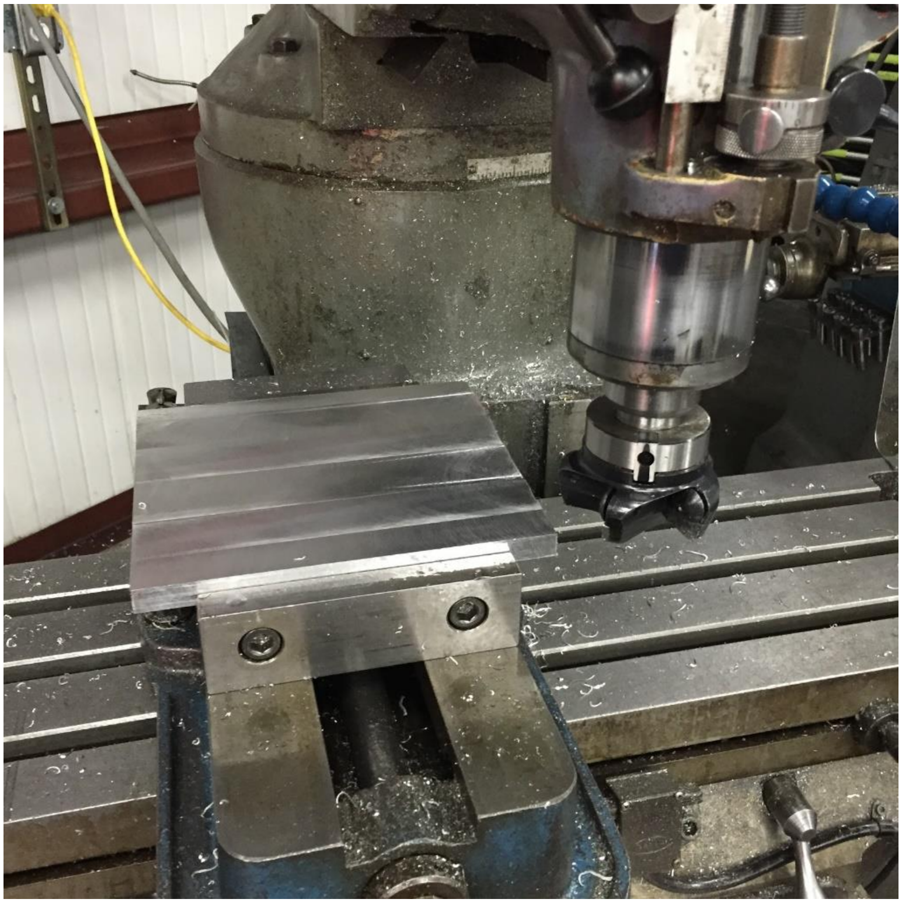
Shown below in Figure 3.6 is the updated CAD model of the overall gearbox design. It includes the housing and each gear, shaft, bearing, dog collar, and bushing that the Drivetrain Team is planning on implementing into the transmission.



(Figure 3.6, Gearbox Design Model)

4.0 Gear Manufacturing

As stated before, this year the Drivetrain Team decided to manufacture our own gears out of 7075-T6 Aluminum. In order to do this, there were numerous steps that had to be completed; first, the team had to face some of the aluminum plates that were donated to us by Industrial Metal Supply Company. This was done by using one of the NAU Machine Shop's mills with a five-flute fly cutting tool, shown below in Figure 4.1.



(Figure 4.1, Facing Aluminum Plates)

Once this was completed, the team then had to use G Code to plan out the gear profiles for the Machine Shop’s Tormach CNC Mills. This was tedious, as each gear profile had to be coded to be perfectly designed to each gear, since some have dog collar slots, while others do not. Also, almost every gear is a different size, and each one had to be cut in a different location on each aluminum plate. After that, the gear blanks were then cut out on the CNC Mills, shown below in Figure 4.2.

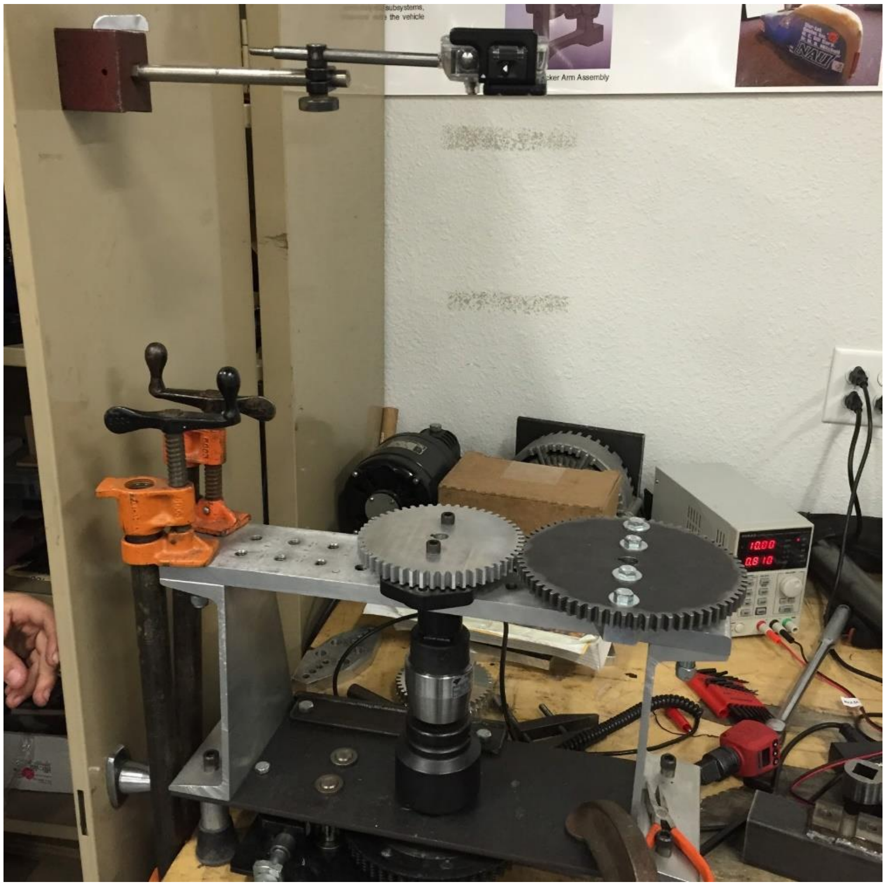
(Figure 4.2, Cutting out Gear Blanks)

After cutting the gear blanks, the team then had to code the tooth-cutting process, tailored to each specific gear size. Finally, the gear teeth were cut into each gear profile by the new FADEC machine, donated to the NAU Machine Shop by David Decausin. The final gear products are shown below, in Figure 4.3.

(Figure 4.3, Finished Gears)

5.0 Gear Testing

Testing is a crucial part to any design. On top of finite elemental analysis, the Drivetrain Team decided to build a testing apparatus, shown below in Figure 5.1. This apparatus was designed to try and shear an aluminum gear tooth against a steel one.



(Figure 5.1, Gear Shear Testing Apparatus)

The results of the shear test confirmed what the Drivetrain Team's hand calculations, FEA, and thinking showed, which was that the gears will not shear due to the torque provided by the engine given to us by SAE. 600 ft-lbs of torque was applied to the aluminum gear (230.8 ft-lbs per tooth), and the only damage to the teeth were slight indentations against each tooth. The maximum torque calculated from our gearbox will be 40 ft-lbs, with 15.4 lbs of force on each tooth. Not only did this test confirm a factor of safety to be 15 on the gears, but also that these gears will not break due to any torque applied from the gearbox.

6.0 Bill of Materials

Listed below are the materials that still need to be ordered by the Drivetrain Team. These materials were all ordered on Friday March 13, 2015 through the ME Special Projects account.

Table 1: Bill of Materials

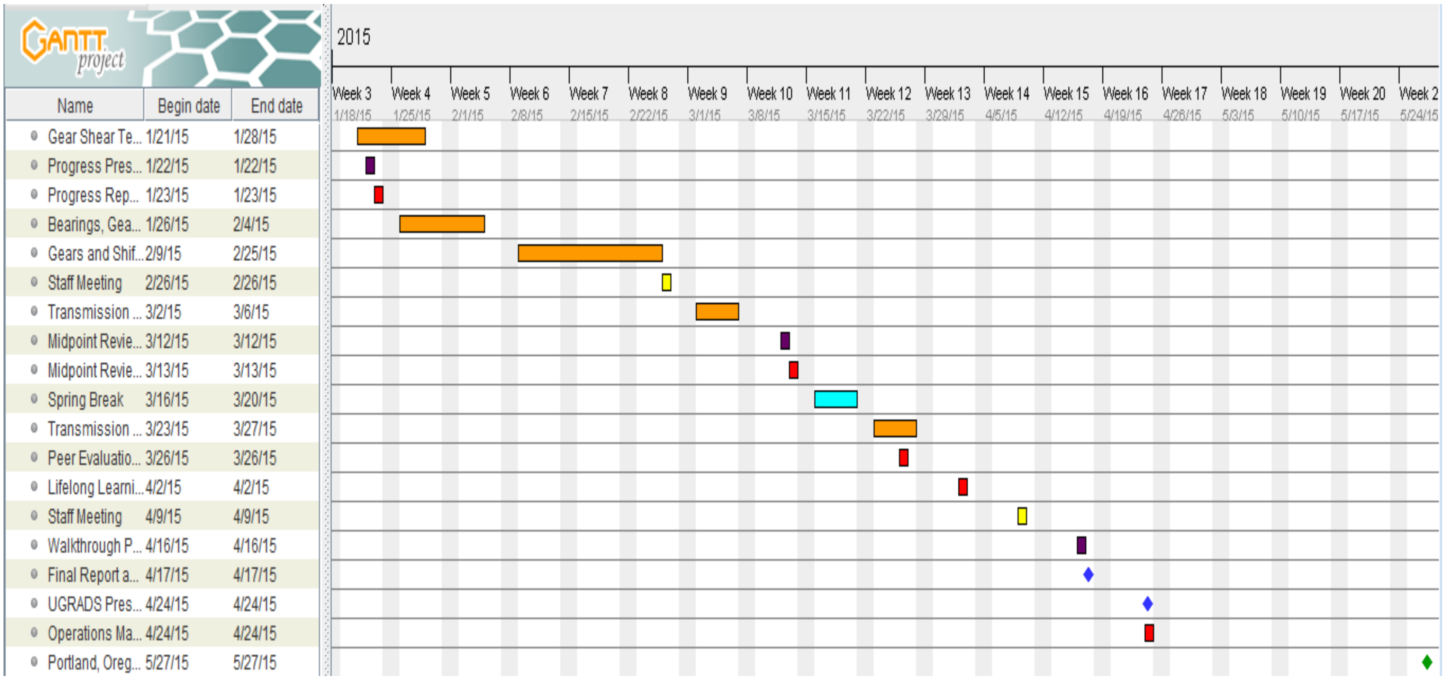
Materials	Quantity	Cost for One Unit of Material	Overall Cost of Each Material
Bronze Bushings	15	$3.60	$54.00
Retaining Rings	1 box of 50	$7.67	$7.67
Drive Shaft Bearings	8	$15.84	$126.72
Input Shafts (0.75" Diameter)	1 36" shaft	$41.68	$41.68
Output Shafts (0.75" Diameter)	1 36" shaft	$79.46	$79.46
Shifting Shaft (0.75" Diameter)	1 36" shaft	$153.31	$153.31
Shifting Shaft Bearings	3	$23.11	$69.33
		Total, excluding shipping costs	**$532.17**

7.0 Future Machining and Assembly

Still to be completed is the building of the gear shafts, shift forks, shift fingers, shifting shafts, and housing. The gear and shifting shafts are being ordered through McMaster-Carr. Once the shafts have been received, the Drivetrain Team will be machining them, as well as the shift forks and fingers and housing, to fit their respective designs.

8.0 Project Plan

Below is an updated Gantt chart for the Spring 2015 semester. The chart is color coded: orange signifies any gear or transmission building, purple represents any presentations, red highlights any deliverables, yellow shows any staff meetings with Dr. Kosaraju, light blue is for spring break, blue marks the UGRADS report and presentation, and green portrays the competition starting date in Portland, Oregon.



Name	Begin date	End date
Gear Shear Te...	1/21/15	1/28/15
Progress Pres...	1/22/15	1/22/15
Progress Rep...	1/23/15	1/23/15
Bearings, Gea...	1/26/15	2/4/15
Gears and Shif...	2/9/15	2/25/15
Staff Meeting	2/26/15	2/26/15
Transmission ...	3/2/15	3/6/15
Midpoint Revie...	3/12/15	3/12/15
Midpoint Revie...	3/13/15	3/13/15
Spring Break	3/16/15	3/20/15
Transmission ...	3/23/15	3/27/15
Peer Evaluatio...	3/26/15	3/26/15
Lifelong Learni...	4/2/15	4/2/15
Staff Meeting	4/9/15	4/9/15
Walkthrough P...	4/16/15	4/16/15
Final Report a...	4/17/15	4/17/15
UGRADS Pres...	4/24/15	4/24/15
Operations Ma...	4/24/15	4/24/15
Portland, Oreg...	5/27/15	5/27/15

(Figure 7.1, Gantt chart)

9.0 Conclusion

In conclusion, the Drivetrain Team chose to use and analyze the design of the sequential transmission for the Baja vehicle, due to its superiority over the manual transmission, for the Baja Team's purposes. After selecting which transmission to implement into the vehicle, the team calculated the forces against the vehicle in the Hill Climb Challenge. Using this data, the Drivetrain Team then calculated the gear ratios needed to climb up the hill in a reasonable amount of time. From there, the team assumed moving 100 feet in around 4 seconds for the Acceleration Test, letting the vehicle's top speed hit around 35 miles per hour; gear ratios again were calculated to take these values into account. Afterwards, Team Drivetrain compared the gear ratios needed for the Hill Climb and Acceleration Tests, respectfully, which led to the final gearbox assembly.

10.0 References

[1] *Crash Gearboxes or Dog Boxes* [Online]. Available: http://www.carbibles.com/transmission_bible.html

[2] M. Cipolloni and D. Cipolloni (2000, August 2). *Shift without lifting – how it works!* [Online]. Available: http://www.autoracing1.com/markc/000802ShiftWithOutLift.htm