SAE Baja

Drivetrain Preliminary Report

Rhyan Brogmus

David Woods

Sam Hunker

2017-2018

Project Sponsor: Society of Automotive Engineers International

Faculty Advisor: Dr. John Tester

Sponsor Mentor: Professor David Willy

Instructor: Dr. David Trevas

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

Table of Contents

1 BACKGROUND

1.1 Introduction

The driving system in the SAE Baja contains a drivetrain that connects the transmission to drive axles. For the drivetrain to work, it much contain an engine, a clutch system, a gearbox, and axles that drive the wheels. The engine is provided by the Society of Automotive Engineers International (SAE). It has 10 horsepower and has a compression ratio of 8.1 to 1 [1]. This Baja that has been designed, manufactured, and tested will be competing against other universities worldwide at the Oregon SAE Collegiate Baja Competition.

1.2 Project Description

Baja SAE® is an intercollegiate engineering design competition for undergraduate and graduate engineering students. The object of the competition is to simulate real-world engineering design projects and their related challenges. Each team is competing to have its design accepted for manufacture by a fictitious firm. The students must function as a team to design, engineer, build, test, promote and compete with a vehicle within the limits of the rules. They must also generate financial support for their project and manage their educational priorities. Each team's goal is to design and build a single-seat, all-terrain, sporting vehicle whose driver is contained within the structure of the vehicle. The vehicle is to be a prototype for a reliable, maintainable, ergonomic, and economic production vehicle which serves a recreational user market, sized at approximately 4,000 units per year. The vehicle should aspire to market-leading performance in terms of speed, handling, ride, and ruggedness over rough terrain and off-road conditions. Performance will be measured by success in the static and dynamic events which are described in the Baja SAE® Rules, and are subject to event-site weather and course conditions. [2]

1.3 Original System

Last year, the Baja's drivetrain consisted of the engine, CVT, a Spicer gearbox, and CV axles. The CVT was mounted between the engine and the Spicer gearbox. The CVT was bought and not tuned giving the less than optimal results. The Spicer gearbox consisted of reverse, neutral, and drive gear. The reverse also had a switch that could be used for the rear light engagement. Custom pins were made to lock the differential for more traction. The CV axles were originally bought and not the right length for the rear end geometry. The axles were cut in half, sleeved with a metal pipe, and then welded at the ends of the sleeve to make it longer. One of the axles had a disk brake attached to it to apply braking power to the entire rear end due to the custom pins that locked the differential.

2 REQUIREMENTS

2.1 Customer Requirements

For this project, the sponsor mentor at Northern Arizona University (NAU) is Professor David Willy. He has been advising and helping the team to be successful against other school for competition.

Customer requirements	**Weighting (10)**	**Justification**
Durability	10	The vehicle design will be going through a lot of terrain. It must be able withstand the race to succeed on this competition.
Acceleration	8	SAE has a competition for having great acceleration. To gain more points
Cost	5	The team has set weight restrictions and the team is trying to be successful.
maneuverability	7	The gear box has a lot parts and it must be able to function properly.
Accessibility	8	During the competition, parts will be fatigued and we must have access to fix the parts that have been broken.
Safety	6	The drivetrain must be safe to be around and not injure the driver or people around the vehicle.
Motor Power	*restricted*	It can not be modified because the engine is provided by SAE. SAE judges make sure it has not been modified before the race.

Table 1: Customer requirement(CR), weight and justification

2.2 Engineering Requirements

Our top engineering requirements involve top speed, tire size, gearing ratios, axle strength, length and operating angles. For top speed, our target value is 40 mph. This can be achieved by running 25-inch tires with a 1:1 CVT ratio. It is critical that drive axles be extremely tough and do not fail during competition, which can be determined by material hardness and yield strength. Axles should have a yield strength of at least 63 ksi and Rockwell hardness of at least B90 (properties of chromoly 4130, a medium-carbon steel alloy). Since operating angles are a function of joint life, angles should be between 22 and 31 degrees to accommodate rear suspension travel and maximize joint life and overall efficiency. The drive axles must not cause the car's wheelbase to exceed 52 inches.

Engineering Requirement (ER)	**Targets**	**Rationale**
Weight	<100 lb	The team has set weight restrictions to make the vehicle as light as possible.
Top Speed	40 MPH	The team has a high-speed target to have keep up with competitors.
Strength	Unbreakable	The team wants to complete the competition without much failure to the drivetrain.
Torque	>=10 ft*lb	The wheels need as much torque as the motor can give for various events during competition.
Disassembly time	<10 min	In case something happens to the drivetrain, we must be able to disassemble and assemble after fixing the issue quickly.
Material Selection	Chromoly > 4340	The axles must not fatigue under load during competition.

Table 2: Engineering Requirement (ER)

2.4 House of Quality

The House of Quality (HoQ) is based on the customer and Engineering requirements.

System QFD

Project:SAE BAJA Drivetrain Sub team
Date: 0/4/17

Correlation	
.++	Strong Positive
.+	Positive
	No Correlation
.-	Negative
.--	Strong Negative

Frame Characteristics										
Weight										
Top speed		.++								
Strength		.++	.+							
Cost			.++	.+						
Disassembly Time			.+	.++	.+					
Manufacturer		.+	.+	.++	.+	.++				
Stability		.+	.+	.++	.++	.++				
# of Parts		.++	.+	.++	.-	.++				
Material Selection		.++	.+	.++	.+	.+	.++	.++	.++	
#REF!			.+	.+		.--	.+	.++	.+	.++

		Technical Requirements								
Customer Needs	**Customer Weights**	Weight	Top speed	Strength	Cost	Disassembly Time	Manufacturer	Stability	Torque	Material Selection
Maneuverability	7	4	4	10	7	7	7	10		7
Acceleration	8	7	10	7	10				8	
Reliable	10	1	1	10	1		7	4	14	7
Maintainable	8		1	4	4		10	10	7	7
Accessiblility	8		7		10	1	7	7		
Durabiliy	10	4	7	4	7	10	4	4	7	7
Safety	6		1	10	10	7	7	7		10
Lightweight	7	7	10	10	10		10	10	10	10
Ease of Manufacturing	8			4	4	10	4	4	7	7
Inexpensive	5		1	4	4	7	1	1	4	10
Mass Production	7	4	4	4	1	10	1	1	7	7
Technical Requirement Units		lb	ft/2^2	kpsi	$	hours	in	deg	ft*lb	in
Technical Requirement Targets		70	6200	58	20	196	.25x0.09	1x0.095	20	4130
Absolute Technical Importance	3922	211	361	508	510	384	451	442	525	530
ATI (percent)		###	0.092	0.130	0.130	0.098	0.115	0.113	###	0.135
Relative Technical Importance		10	6	7	4	7	8	8	4	8

3 EXISTING DESIGNS

The drivetrain team has access to the previous Baja design, which was designed under old SAE Baja rules. The rules have been changed and updated so we must make the design that fits the requirements of the new rules. Since the rules have not been changed much, we can still research what went well and what needs to be re-engineered from the old Baja vehicle.

3.1 Design Research

The Research done consisted of three parts: last year's mini Baja, last year's competition, other drivetrain alternatives. The prior Baja is something to be considered as it was fully functioning before competition. We can assess how last year's Baja was working with its drivetrain to see what we can improve.

The competition research gave us information on how the prior Baja performed as well as information pertaining to what other teams were using on their drivetrain. At competition, the drivetrain seemed to hold up until the brake test course where only three wheels locked instead of four. The custom pins that locked the differential sheared making only one real wheel lock when braked. The Spicer was opened and the differential was manually locked by welding the spider gears together. Lots of other competitors were using gearboxes they manufactured themselves. When talking with some competitors, they started out using the Spicer gearbox. As they started improving their Baja, they ended up making the gearbox themselves and haven't gone back to the Spicer.

The other drivetrain alternatives are using U-Joints in place of CV axles. U-Joints would be easier to manufacture and design. They would also be easier to replace if broken and also more cost effective. The downside to using U-Joints as opposed to CV axles is that CV axles are more durable and the load is equally distributed at the joint through bearings. The U-Joint would have a universal bearing that rotates about 4 points.

3.2 System Level

Since this report is the drivetrain subsystem, the system level component designs are talked about in Section 4; Designs Considered.

3.3 Functional Decomposition

This Black Box Model depicts the important functions that our project must accomplish.

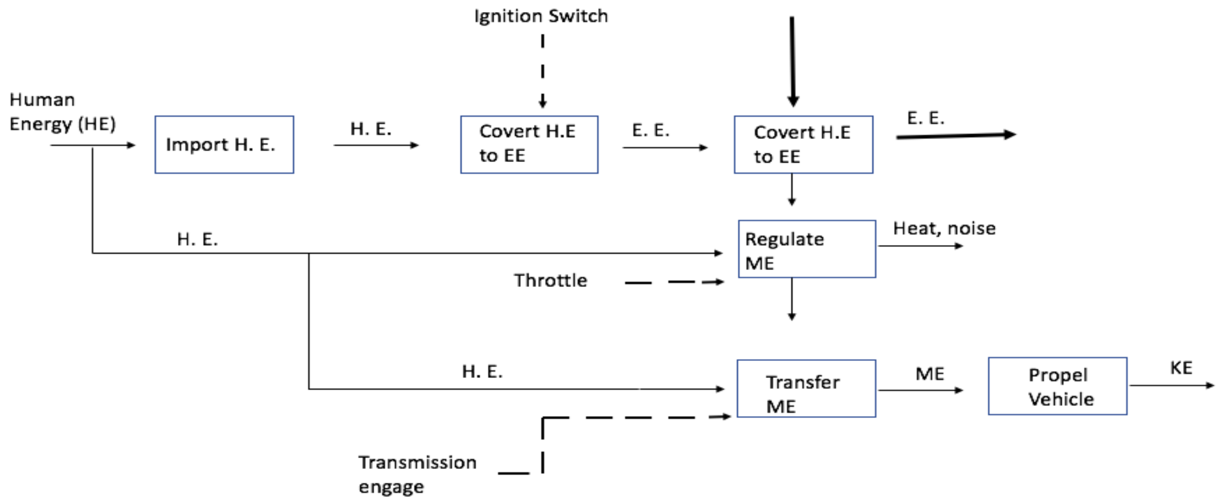

Figure 1: Functional Model of Drivetrain

3.4 Subsystem Level

Drivetrain is a subsystem of the entire SAE Baja project. This report is focusing on the drivetrain components.

4 DESIGNS CONSIDERED

There are 3 subsystems within drivetrain and 2 designs each to choose from. The first subsystem is the clutch component. To get power from the engine to the gearbox, we have narrowed down our options to a CVT or a centrifugal clutch. The centrifugal clutch in Figure 3 is easy to maintain and cheap. However, there is a big power loss from the centrifugal clutch as there is no way to alter the timing on the friction point so, we lose acceleration. The CVT in Figure 2 uses centripetal motion to change the gear ratios by the tension on the belt. By tuning the CVT right, the Baja can get more acceleration. The problem with the CVT is we can't change the weights during competition. To compensate the different torque requirements for each event, Gaged CVT makes a backshifter to work with their CVT that manually changes the tension on the belt. This would give us the tunability we need for a variety of events.

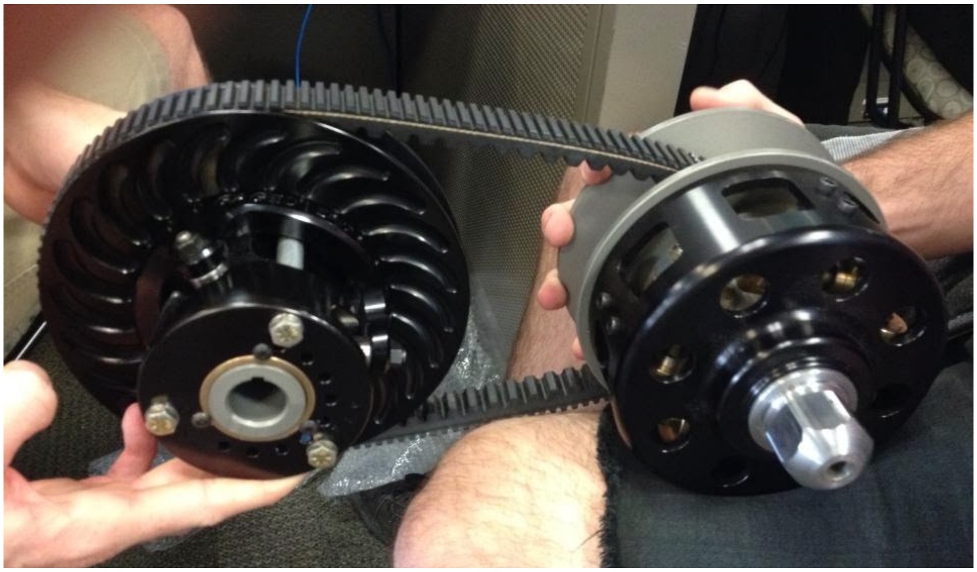

Figure 2: UCSB Racing 2013 Gaged CVT

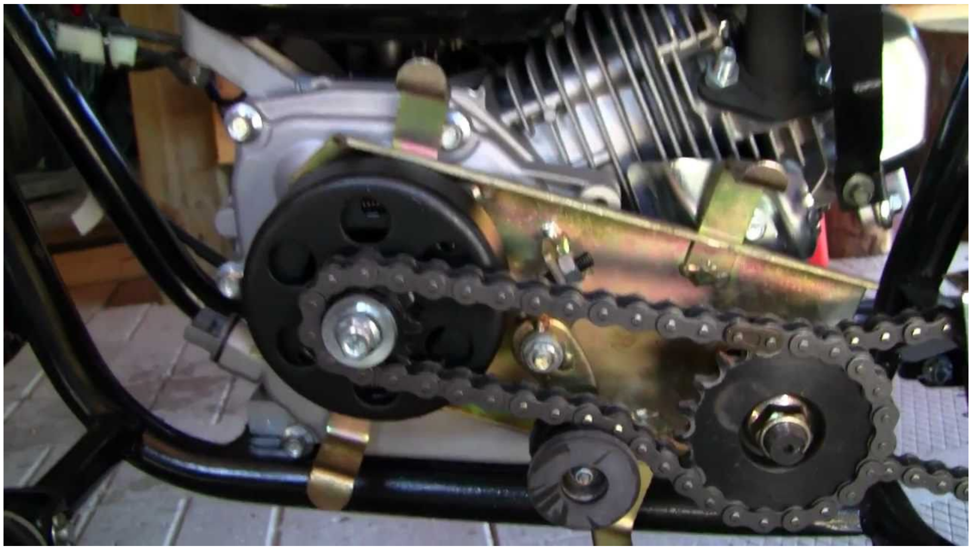

Figure 3: Baja Warrior Centrifugal Clutch

Between the CVT and the Axles, the gearbox reduces the overall ratio. The two-major designs are buying a gearbox or making our own gearbox. NAU Baja has previously used the Spicer gearbox, shown in Figure 5, that has a reverse, neutral, and forward gears. While researching at the 2016 Baja competition in Gorman, California, we discovered that many teams used the Spicer gears, but many designed their own gearbox. For the teams that designed their own gearbox, they started out with the Spicer product. They commented how it was a reliable gearbox, but after manufacturing their own, they saw improvements in overall torque to the wheel as the gearbox was made for that specific Baja vehicle. If we make our own gearbox, there are three designs we can make; a simple gear reducer, a gearbox with reverse, neutral and forward, or a gearbox with a low and high gear. The simple gearbox can be shown in Figure 4 and is the easiest to design and manufacture. The two gearboxes with multiple gears will require a more complex design to make a sequential shifter. The complex gearbox will give us a variety of options to maneuverability, but may negatively impact the durability. For the gearbox ratio, Table 3 shows the different ratios at an engine RPM of 3600 and a CVT ratio of 1:1.

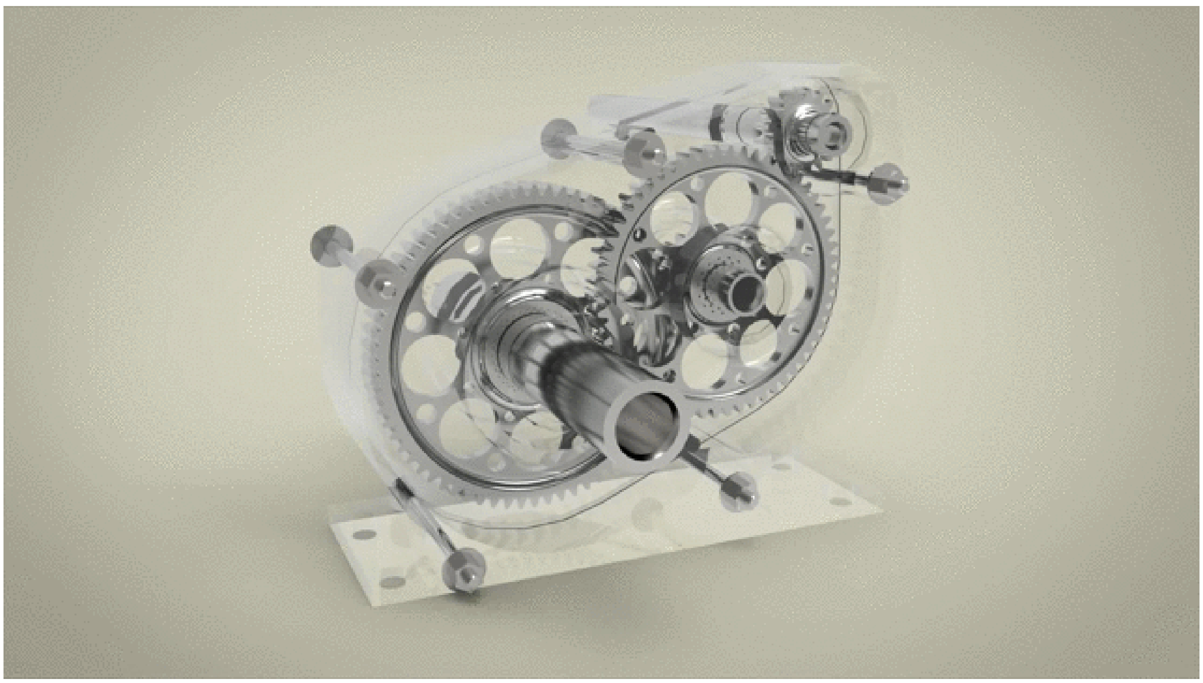

Figure 4: UR Baja SAE 2016-2017 Drivetrain Design

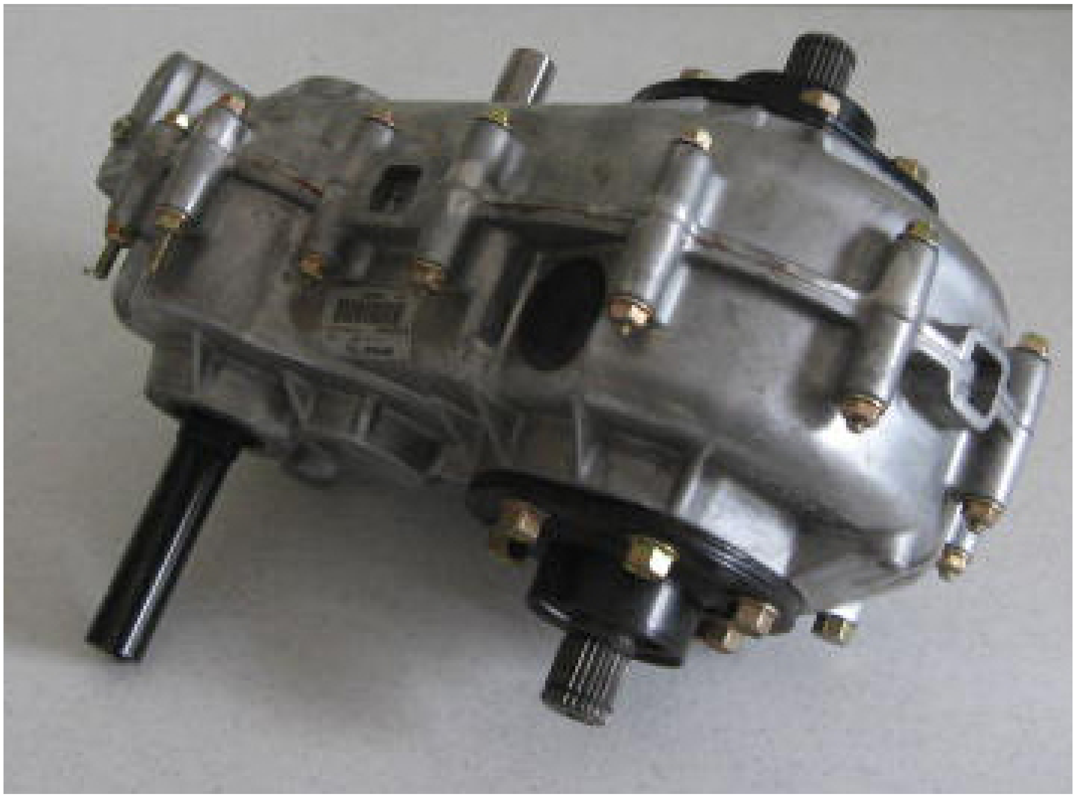

Figure 5: Spicer Gearbox

CVT Ratio	1															
Reduction Ratio	Tire Size (in)															
Max Speed (mph)	16	18	19	20	21	22	23	24	25	25.5	26	26.5	27	28	29	30
30	5.71198664	6.42598497	6.78298414	7.1399833	7.49698247	7.85398163	8.2109808	8.56797996	8.92497913	9.10347871	9.28197829	9.46047788	9.63897746	9.99597663	10.3529758	10.709975
32	5.35498748	6.02436091	6.35904763	6.69373435	7.02842106	7.36310778	7.6977945	8.03248122	8.36716793	8.53451129	8.70185465	8.86919801	9.03654137	9.37122809	9.7059148	10.0406015
34	5.03998821	5.66998674	5.984986	6.29998527	6.61498453	6.92998379	7.24498306	7.55998232	7.87498158	8.03248122	8.18998085	8.34748048	8.50498011	8.81997938	9.13497864	9.4499779
36	4.75998887	5.35498748	5.65248678	5.94998609	6.24748539	6.54498469	6.842484	7.1399833	7.43748261	7.58623226	7.73498191	7.88373156	8.03248122	8.32998052	8.62747983	8.92497913
38	4.50946314	5.07314603	5.35498748	5.63682892	5.91867037	6.20051182	6.48235326	6.76419471	7.04603615	7.18695688	7.3278776	7.46879832	7.60971905	7.89156049	8.17340194	8.45524339
40	4.28398998	4.81948873	5.0872381	5.35498748	5.62273685	5.89048623	6.1582356	6.42598497	6.69373435	6.82760903	6.96148372	7.09535841	7.22923309	7.49698247	7.76473184	8.03248122
42	4.07999046	4.58998927	4.84498867	5.09998807	5.35498748	5.60998688	5.86498629	6.11998569	6.37498509	6.50248479	6.6299845	6.7574842	6.8849839	7.1399833	7.39498271	7.64998211
44	3.89453635	4.38135339	4.62476191	4.86817043	5.11157896	5.35498748	5.598396	5.84180452	6.08521304	6.2069173	6.32862156	6.45032583	6.57203009	6.81543861	7.05884713	7.30225565
46	3.72520868	4.19085977	4.42368531	4.65651085	4.88933639	5.12216194	5.35498748	5.58781302	5.82063856	5.93705133	6.05346411	6.16987688	6.28628965	6.51911519	6.75194073	6.98476628
48	3.56999165	4.01624061	4.23936509	4.46248956	4.68561404	4.90873852	5.131863	5.35498748	5.57811196	5.6896742	5.80123643	5.91279867	6.02436091	6.24748539	6.47060987	6.69373435
50	3.42719199	3.85559098	4.06979048	4.28398998	4.49818948	4.71238898	4.92658848	5.14078798	5.35498748	5.46208723	5.56918698	5.67628673	5.78338648	5.99758598	6.21178547	6.42598497

$$\omega_{Engine} = \omega_{Wheel} \times R_{CVT} \times R_{Gearbox}$$

$$\omega_{Wheel} = \frac{63360 \times V_{max}}{D_{Wheel} \times \pi \times 60}$$

Table 3: Gear Ratio Calculations

After the gearbox, the wheels get power from the axles. The two types of axles we are considering are universal-joint (U-Joint) axles, which can be seen on the bottom of Figure5, and constant velocity axles (CV), which can be seen on the top of Figure 6. U-Joint axles would be easier to manufacture. They consist of a universal bearing between the two yokes that may be greaseable. The downside to using U-Joints is the range of extension is limited. At a certain angle, the U-Joint will start binding and cause damage if severe. CV axles can take more load at the joints because the loads are equally distributed by a bearing. For this reason, the joint will never bind and the operating angle range is much higher. The downside is that the CV joint is a closed system with a boot over the joint with grease inside. If the rubber boot gets punctured for any reason, water may enter the joint and cause damage. The CV joint is also harder to manufacture and will need to be outsourced to a company.

Figure 6: CV Joints vs. U-Joints

5 DESIGN SELECTED

5.1 Rationale for Design Selection

The drivetrain design selection is based off three subcomponents. Gaged CVT has been selected with a backshifter to get the car moving off the line. Gaged CVT is a professional CVT manufacturer that makes quality CVTs. Gaged also will be going to the Oregan SAE Baja race to be there in case something happens to the CVTs that he sold to the various Baja teams. The CVT support is critical as he knows more about the CVT he made himself than we do. The backshifter was also bought to make the gearbox a simpler design and to make the engine run optimally. This backshifter allows the user to manually adjust the tension in the belt thus changing the CVT ratio on the fly. It will make the gearbox design simpler because the backshifter can relieve all tension in the CVT belt and therefore the car will act as if it were in neutral. For this reason, the gearbox will not need a neutral. The engine will run optimally because, when driving, the driver can give the car full throttle and keep it in the engines most efficient RPM range and drive the car by changing the ratio. This allows the maximum amount of power and torque to be transmitted to the rear wheel. The gearbox will consist of a simple gear reduction of 6.69: 1, which on Table 3 is a maximum speed of 40 MPH with a wheel diameter size of 25 inches. Reverse is not needed as the wheel base of the car will be made small to give more maneuverability. The low-high gearbox will not be used either because the backshifter and the CVT can be tweaked to fit the torque range needed for the various events in Oregan. As for the CV vs U-Joint axles, the axle type used will be determined when we get quotes from different companies.

Citations

[1] Briggs Racing. (2017). *Model 19*. [online] Available at: http://www.briggsracing.com/racing-engines/model-19 [Accessed 7 Oct. 2017].

[2] BAJA SAE Collegiate Design Series Baja SAE® Rules 2018. (2017). Society of Automotive Engineers International.