

Utility Terrain Vehicle (UTV)

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
University of Cincinnati

in partial fulfillment of the
requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

Spencer Clingerman

October 2021

Thesis Advisor: Amir Salehpour, MS

Other Team Members:

Nabeel Chaudhry

Kaevon Salehpour

Graham O'Meara

Table of Contents

Problem Statement	4
Research	4
Background of the Problem.....	4
Applicable Standards (3).....	5
State of the Art	5
End User	6
Summary of Research	6
Quality Function Deployment.....	7
Customer Features.....	7
Engineering Characteristics.....	7
House of Quality	8
Product Objectives	9
Concepts Drawings	10
Concept 1:	10
Concept 2:	11
Concept 3:	12
Design	13
Drive Train Layout.....	13
Gear Reduction Schematic	14
Engineering Calculations	15
New Gear reduction Schematic.....	16
FEA and Factor of Safety.....	17
Bill of Materials	19
Fabrication and Assembly.....	20
Planned Fabrication Methods.....	20
Mounting Plate	20
Mounting Brackets	22
Bushing for Shaft Diameter Reduction.....	23
Resultant Drivetrain	24
Electrical.....	25
Accelerator Pedal	27

Paneling.....	28
Steering.....	28
Before and After.....	29
Testing and Proof of Design.....	30
Engineering Characteristics Tested.....	30
Testing Methods.....	31
Testing Results.....	33
Shaft Failure.....	33
Drivetrain Redesign.....	34
Project Management.....	35
Proposed Budget.....	35
Actual Budget.....	35
Proposed Schedule.....	35
Actual Schedule.....	36
Plan to Finish.....	36
Conclusion.....	36
References:.....	37

List of Figures

Figure 1.....	10
Figure 2.....	11
Figure 3.....	12
Figure 4.....	13
Figure 5.....	14
Figure 6.....	16
Figure 7.....	17
Figure 8.....	17
Figure 9.....	18
Figure 10.....	19
Figure 11.....	20
Figure 12.....	21
Figure 13.....	21
Figure 14.....	21
Figure 15.....	22
Figure 16.....	22
Figure 17.....	23

Figure 18	23
Figure 19	24
Figure 20	24
Figure 21	25
Figure 22	26
Figure 23	26
Figure 24	27
Figure 25	28
Figure 26	29
Figure 27	29
Figure 28	30
Figure 29	31
Figure 30	32
Figure 31	32
Figure 32	33
Figure 33	34
Figure 34	34

List of Tables

Table 1	7
Table 2	33
Table 3	35
Table 4	35

Problem Statement

Continue the design and fabrication of the UTV that was started by a prior senior design group. The UTV still requires additional design work, modification to existing design, and analysis of all involved designs, as well as the majority of the fabrication. Utilizing CAD tools, we will complete the design and analysis portion. We will also utilize basic manufacturing processes to fabricate the UTV.

Research

Background of the Problem

Over the years, Utility Terrain Vehicles (UTV) have become increasingly common for professional and recreational usage. UTVs can trace their origins back to the Willys Jeep of the 1940's, but more recently, the 1988 Kawasaki Mule, which was one of the first UTVs marketed specifically for farm and other commercial use (1). They allow the user to traverse various terrains and they assist in the moving of heavy items and equipment from one place to the next. Their designs have been improved dramatically, but the cost continues to rise. A price tag of at least \$7,000 is to be expected and many UTV models can easily surpass \$10,000 (1). Our goal is to design a basic and easily maintained, affordable UTV for everyday usage to increase worker productivity, while also decreasing the chance of injury due to physical strain.

This UTV is needed for the transportation of maintenance equipment and personnel. Maintenance workers fix a plethora of issues in all different locations around manufacturing plants, construction sites, universities, stadiums, and office complexes. These workers can walk upwards of 13,000 steps per day, which is 30% more than recommended for the average person (2). Our target audience needs a product that can reliably and practically transport them and their tools/parts around to the location of their tasks in order to limit strain on their bodies. A small, yet durable UTV with a bed that can effectively carry a couple maintenance crew members and their equipment is the perfect solution to this problem (3).

There are many different UTVs boasting assorted designs currently on the market today. Common features on UTVs today include all wheel drive, roll cage, and off-road tires (4). Some UTVs are quite minimalistic, some are high tech and extremely rugged. Our target audience for this finished product is maintenance crews. Therefore, we do not necessarily need incredibly expensive, fast, and high-tech designs for off-road usage, we need more dependable, easily repaired, and practical designs for driving workers and tools around manufacturing facilities and job sites to perform work.

We have divided our UTV design into four main components; the drivetrain, suspension, braking system, and chassis. Our main goal for this vehicle is to provide maintenance crews with a practical and useful asset that can withstand the environments of factories and/or outdoor job sites. Since maintenance crews are usually relatively handy and knowledgeable about how things work, we aim to make our UTV easily modifiable or repaired. Most all the parts used on the UTV are going to be off the shelf (OTS) parts, which will make it easier for a maintenance worker to fix and manipulate.

Applicable Standards (3)

- Four or more wheels (ANSI/OPEI B71.9-2016)
- Intended to transport persons and cargo (ANSI/OPEI B71.9-2016)
- Non-straddle seat (ANSI/OPEI B71.9-2016)
- Controlled by pedals and steering wheel (ANSI/OPEI B71.9-2016)
- Top speed of at least 25 mph (ANSI/OPEI B71.9-2016)
- Maximum of 80” in overall width (ANSI/OPEI B71.9-2016)
- Maximum of 4000 lbs. in gross vehicle weight rating (ANSI/OPEI B71.9-2016)
- Minimum cargo capacity of 350 lbs. (ANSI/OPEI B71.9-2016)

State of the Art

Dual Clutch Transmission (DCT)

The Honda Pioneer 1000 utilizes a dual clutch transmission (DCT) with six forward gears and one reverse gear (5). The DCT operates by employing two different clutches to shift gears, one for even gears and one for odd gears. Since there are two clutches, one can engage while the other disengages, resulting in quicker, more effective shifting. However, the DCT setup also means greater complexity and difficulty when it comes to maintenance. There’s two clutches and physical gears within the unit, so there’s always a chance of burning up a clutch or grinding/breaking gears. DCT allows for the driver to choose between a fully automatic or semi-manual setting. Paddle shifters can be used to change gears, or the driver can allow the vehicle’s computer to decide when to shift (6).

Continuously Variable Transmission (CVT)

The Kawasaki Teryx 1000 utilizes a continuously variable transmission (CVT) (7). The CVT is a relatively simple transmission, as it doesn’t include any gears at all, rather two pulleys, a drive and driven, and a belt, that produce a desired gear ratio. Each pulley has a tapered sheave. The belt moves along the sheave to produce different speeds, resulting in different gear ratio, and vehicle speeds (6). The lack of gears allows for a smooth change in gear ratio and easier maintenance. There is still the issue of the belt slipping, or breaking entirely, but a belt can be somewhat easily replaced. CVT is likely the most reliable of the commonly used, state of the art transmission variants.

Manual Transmission

The Yamaha YXZ1000R utilizes a manual foot clutch transmission with five sequential speeds and reverse (8). Since the transmission is sequential, the driver can shift to the next or the previous gear but may not skip gears, which helps prevent the driver from shifting into the wrong gear and causing potential damage to the transmission. The manual transmission operates using a

foot pedal to engage the clutch while the driver shifts into their desired gear (6). A foot clutch comes with its limitations and problems though since not everyone knows how to operate a manual clutch. Similar to the DCT, the clutch on a manual transmission can burn or gears can be grinded, especially if the driver is inexperienced with a foot clutch. The usage of a clutch and gears also results in greater maintenance difficulty. However, a manual clutch does give the driver a large amount of freedom. The driver can decide when to change gears and which gear they want to use.

End User

The ideal end user will be employed in roles such as facility maintenance and construction. The end user will use the UTV to transport items such as tools or construction materials over long distances. The age range of the end user is ideally 18 to 65 years old. They will be able bodied men and women. The end user will possess some minor mechanical knowledge and a state issued driver's license.

Summary of Research

Overall, each transmission style has its own advantages and disadvantages, but in order to obtain our goal of a simplistic, practical, and easily maintained UTV, the CVT style is the best. CVT allows for a smooth drive and quick repairs if they're needed. CVT will solve the problem of transporting maintenance workers and their tools/parts by providing a drive train that can handle moderate to large loads, automatically adjust gear ratios for optimal transportation, and allow for quick/easy transmission upkeep. Also, anyone with a normal driver's license can hop in a UTV with a CVT and drive off without worrying about a foot clutch or DCT paddle shifters, so it's perfect for our end user, who may not have experience operating a manual or semi-manual transmission. CVT is simple and reliable and the best option for our maintenance transportation UTV.

Quality Function Deployment

Customer Features

Our group conducted a survey on the importance of certain features of a UTV. We surveyed 31 people who work in either a maintenance role or in the construction industry. We used the results of this survey to create the table below.

Customer Features	Average Score
Safety	4.32
Cost	3.68
Reliability	4.45
Maneuverability	3.84
Load/Capacity	3.23
Fuel Efficiency	3.29
Noise	2.84
Overall Size	2.77

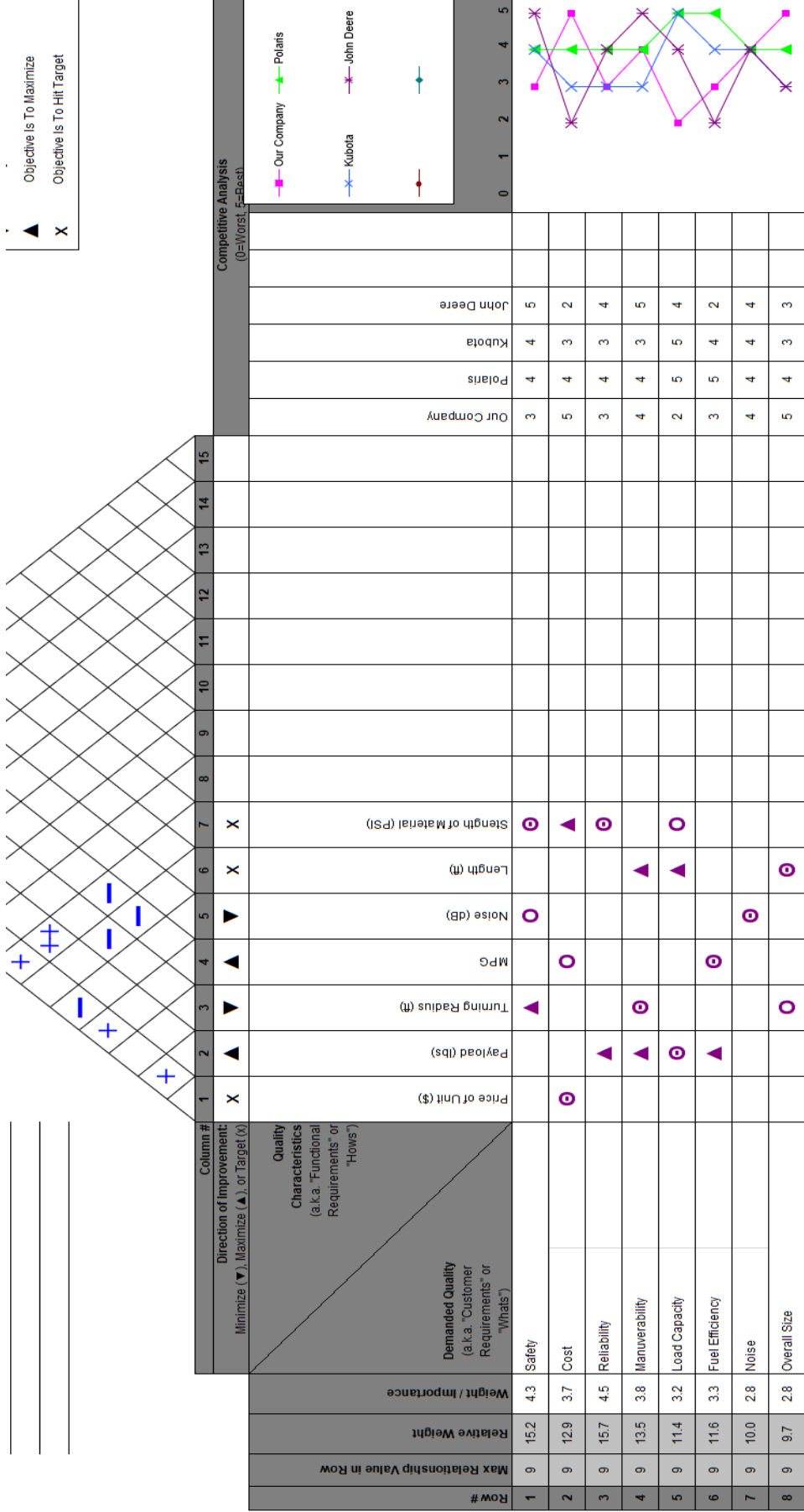
Table 1

Engineering Characteristics

Using our data found via our survey, we decided upon the engineering characteristics below

- 1) Material Strength (psi)
- 2) Unit cost (\$)
- 3) Life of product (miles)
- 4) Turn Radius (ft)
- 5) Payload (lbs.)
- 6) Fuel Efficiency (mpg)
- 7) Noise (dB)
- 8) Length (ft)

House of Quality



Target or Limit Value	8,000	500	12	15	94	5	36,000
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	2	7	7	6	2	1
Max Relationship Value in Column	9	9	9	9	9	9	9
Weight / Importance	116.5	143.0	166.0	143.0	135.5	112.6	324.8
Relative Weight	10.2	12.5	14.5	12.5	11.9	9.9	28.4

Product Objectives

Based on our House of Quality the engineering characteristics are listed below in order of importance, with the first on the list being most important. We will prioritize these characteristics according to their percentage of importance.

- 1) Strength of Materials (28.4%)
 - Select strong metals and plastics for framing/siding
- 2) Turning Radius (14.5%)
 - Include smooth, reliable suspension and steering column
- 3) MPG (12.5%)
 - Limit unnecessary weight
- 4) Payload (12.5%)
 - Install space for tool/equipment storage
 - Install supports at crucial weight bearing locations
- 5) Noise (11.9%)
 - Equip some sort of muffler
- 6) Price (10.2%)
 - Eliminate unneeded expenses
- 7) Length (9.9%)
 - Remain mindful of size of frame

Concepts Drawings

Concept 1:

The first concept is a dual clutch transmission (DCT). The DCT allows the user to operate the vehicle as either an automatic or semi-manual. The upside to operating as both automatic or semi-manual is that the driver can choose to either let the transmission shift itself or they can change gears as needed for specific driving conditions; the driver has additional control over the transmission. Also, since there's two clutches, one for even gears and one for odd gears, one clutch can engage while the other disengages, allowing for quicker, smoother gear shifts. However, this increases the complexity of the transmission. As seen in the model, there are many gears and moving parts within the DCT. This increased complexity can lead to maintenance and reliability issues. Also, the driver can cause unnecessary wear or damage to the transmission if they constantly switch gears while in the semi-manual mode. Due to the complexity of the transmission and the possibility of user error, the DCT is not the best option for the UTV.

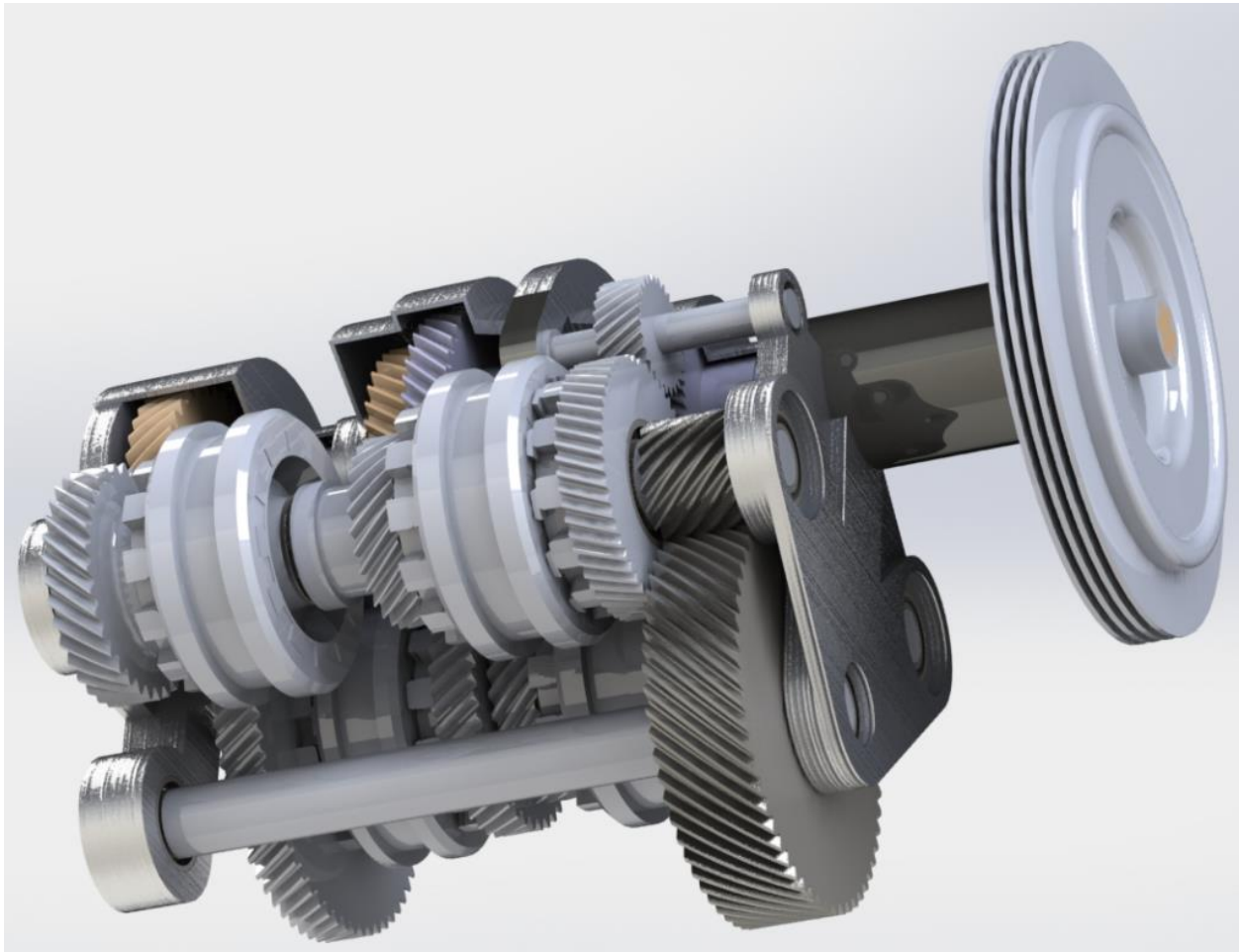


Figure 1

Concept 2:

The second concept is a continuously variable transmission (CVT). The CVT is common in many small to mid-sized vehicles, like Hondas. The CVT operates using a belt and pulley system. The pulleys are tapered and actuated by a spring, allowing the belt to travel along a continuously variable track, resulting in a seemingly endless array of tensions, and almost infinite gear ratios. This massive range of gear ratios allows the transmission to perform in all different types of situations and there's never the issue of changing gears, the transmission just actuates the pulleys. The CVT is simple and reliable because it only has a few moving parts. It's also cheap because of its simplistic design, which is perfect for our UTV. The CVT offers the right combination of simplicity, durability, and reliability for our project.



Figure 2

Concept 3:

The third concept is a traditional manual transmission. The manual transmission is almost obsolete nowadays, but still has its advantages. For example, the driver has complete control over the gear selection. This freedom to choose which gear the vehicle operates in allows the user to customize the transmission output to their desired needs. However, like the DCT, the manual transmission operates by using multiple gears that must lineup properly with one another, as seen in the model. Unlike the DCT, the driver must maneuver the gears into the right position by correctly operating the foot pedal clutch and moving the gear shifter. This large amount of user input can result in large amounts of wear to the clutch and gears or even total transmission failure. The driver must know how to operate a manual transmission in order to drive something with a manual transmission, but that requirement doesn't fit our end user, which is supposed to be any maintenance worker with a license, not any maintenance worker with a license AND the ability to operate a manual transmission. Therefore, the manual transmission is not the best option for our UTV.

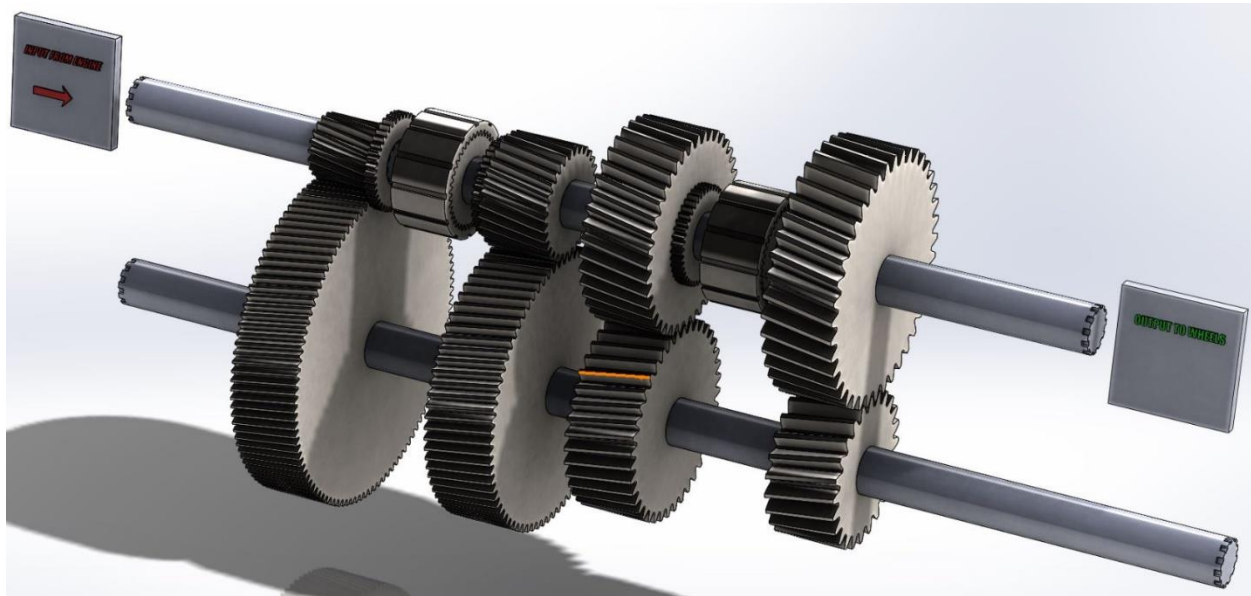


Figure 3

Design

Drive Train Layout

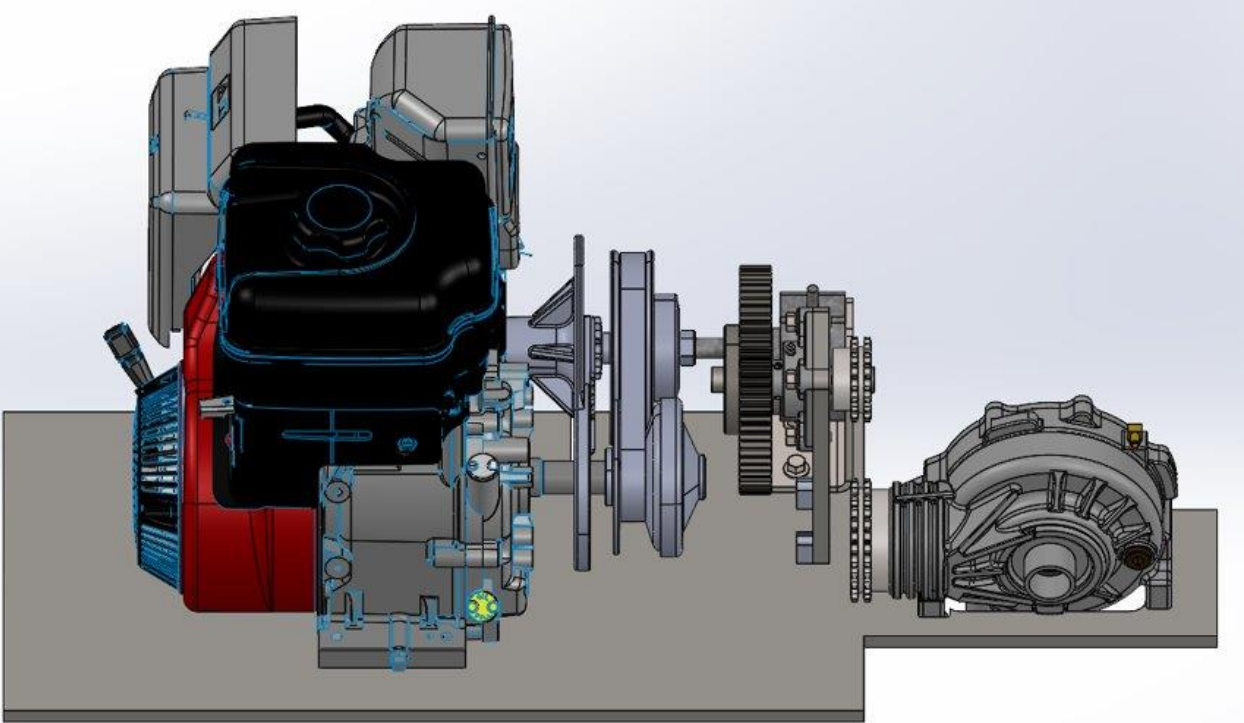


Figure 4

Gear Reduction Schematic

- Power is transferred from the engine shaft, through the CVT transmission to the forward reverse gearbox, which is where the bottom left of the schematic begins. Power is transferred from the attached 20 tooth spur gear to a 40 tooth spur gear, which is connected via a shaft to a 20 tooth sprocket. A chain is attached to the sprocket and connects to a 30 tooth sprocket. Finally, a shaft connects the 30 tooth sprocket to the differential.

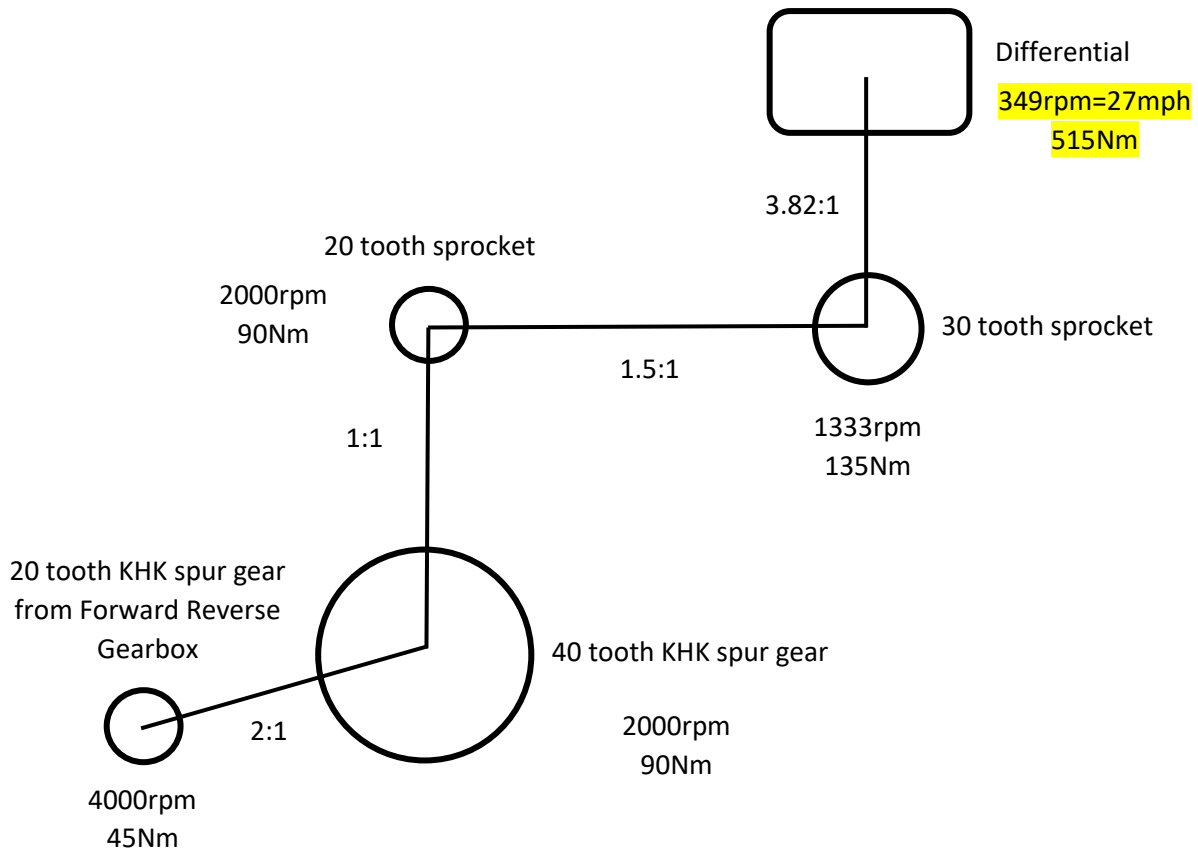


Figure 5

Engineering Calculations

- Power required to move fully loaded, 1800 lb. UTV up 10% grade at 15mph:

$$P = \frac{F_T v}{\eta}$$

$$F_r = cW \rightarrow F_r = 0.012(816.5kg * 9.81m/s^2) \rightarrow F_r = 96.11N$$

$$F_p = W \sin \alpha \rightarrow F_p = (816.5kg * 9.81m/s^2) \sin(10) \rightarrow F_p = 1390.90N$$

$$P = \frac{(96.11N + 1390.90N)(6.7m/s)}{0.85}$$

$$P = 11721.14W = 15.72hp$$

- From the above calculation we can determine that we need an engine larger than the original 8hp engine acquired by the prior groups
- Torque required to move fully loaded, 1800 lb. UTV with 26" wheels to 30mph in 8 sec:

$$F = ma$$

$$F = \left(\frac{1800}{32.2}\right)(5.5ft/s^2)$$

$$F = 308lbf$$

$$\tau = Fr$$

$$\tau = 308lbf(1.08ft)$$

$$\tau_{wheels} = 333ft - lb \text{ or } 452Nm \text{ at the wheels}$$

$$\tau_{engine} = \frac{452Nm}{11.46 \text{ gear reduction}}$$

$$\tau_{engine} = 39.44Nm \text{ at the engine}$$

New Gear reduction Schematic

- New 22HP Predator V-Twin engine acquired in order to provide additional power necessary to obtain desired speed and torque output. Power is transferred from the engine, to the CVT, through the forward/reverse gearbox, to a roller chain and sprocket, and finally a differential.

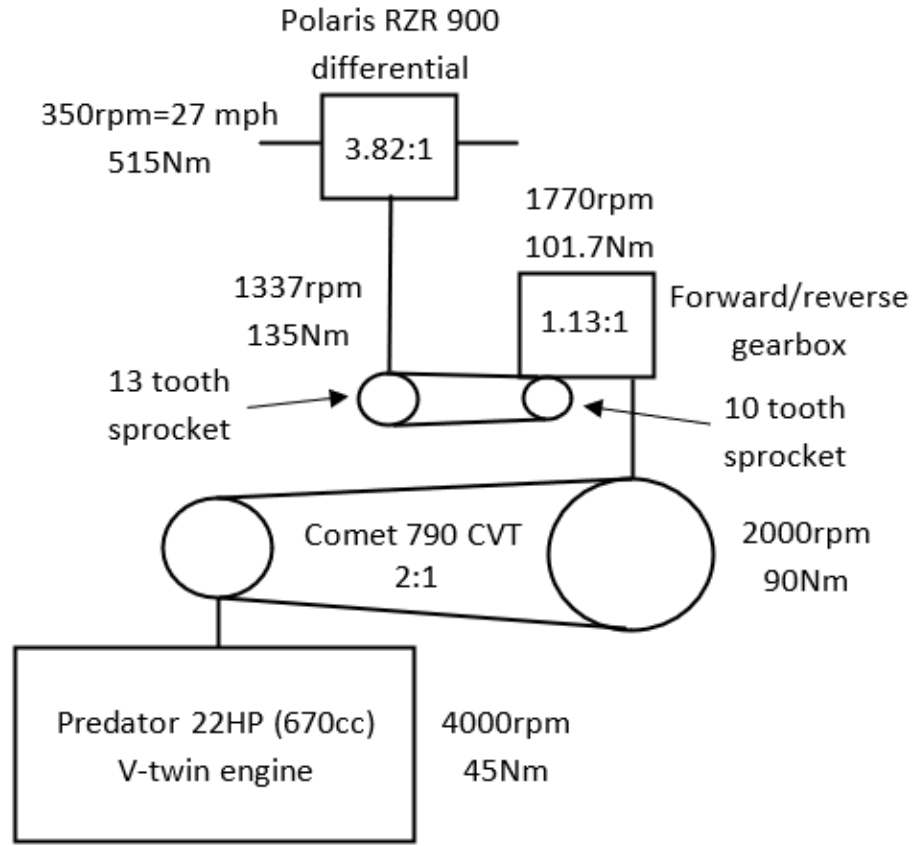


Figure 6

FEA and Factor of Safety

Engine Mounting Plate

- 12 gauge ASTM A36 steel with 618 lb. load (3x amplification factor of real world 206 lb. load the plate will carry in order to simulate a dynamic load within a static analysis)

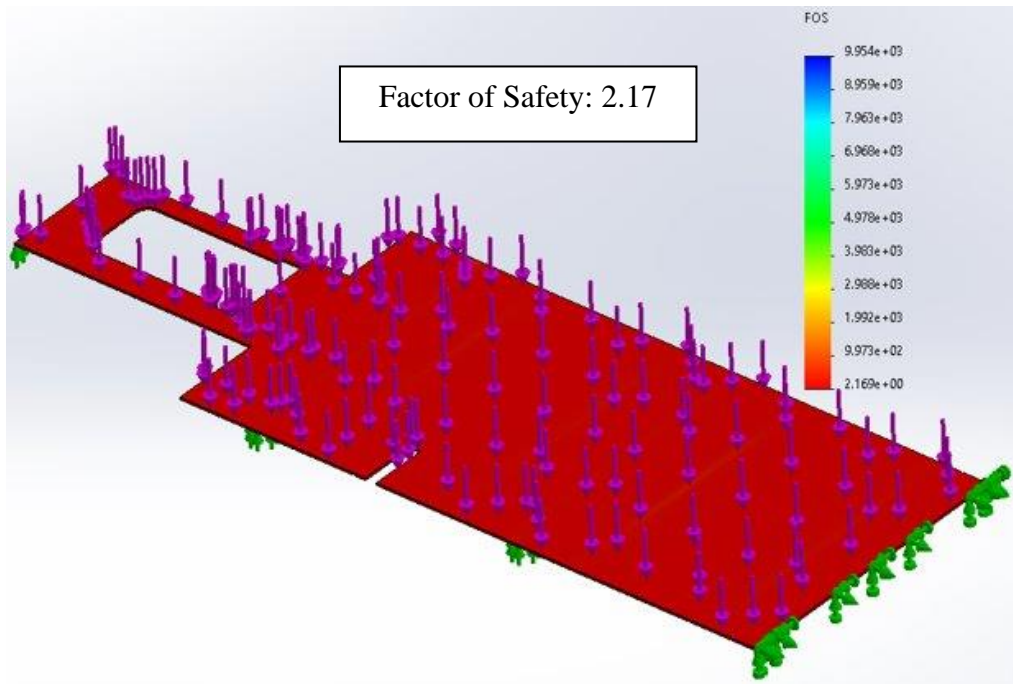


Figure 7

Forward Reverse Gearbox Mounting

- 16 gauge ASTM A36 steel with 42 lb. load (3x amplification factor of real world 14 lb. load the plate will carry in order to simulate a dynamic load within a static analysis) and 45Nm of torque, as outlined in *Figure 5*.

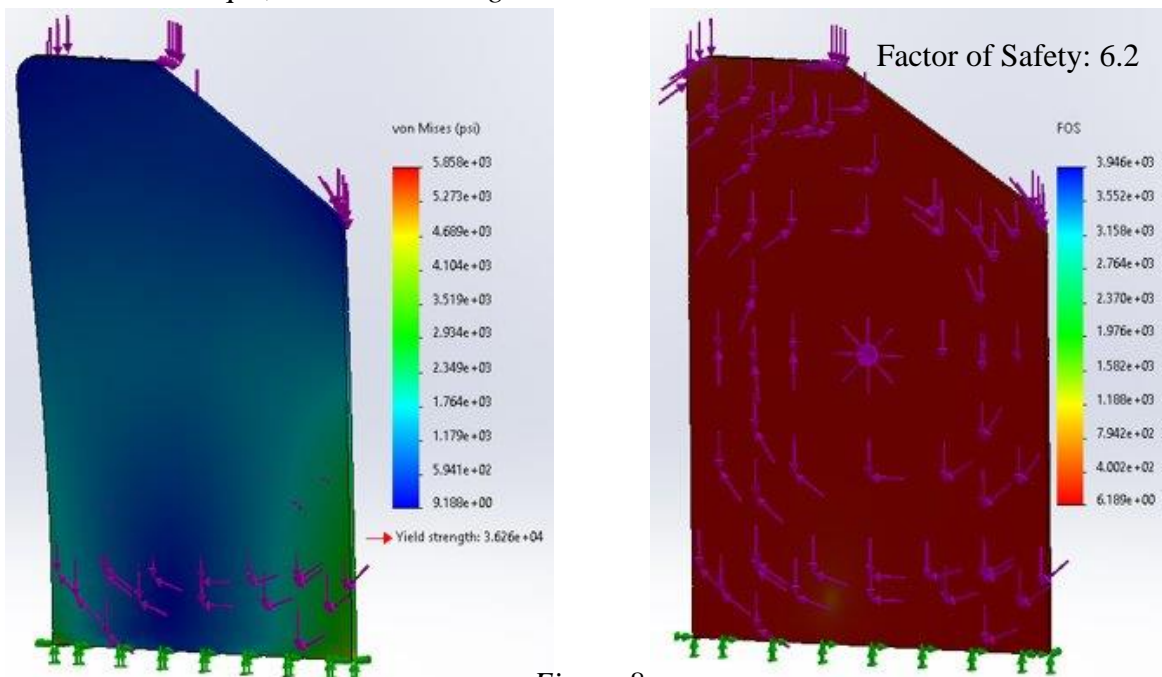


Figure 8

Gear/Sprocket Mounting

- 16 gauge ASTM A36 steel with 30 lb. load (3x amplification factor of real world 10 lb. load the plate will carry in order to simulate a dynamic load within a static analysis) and 90Nm of torque, as outlined in *Figure 5*.

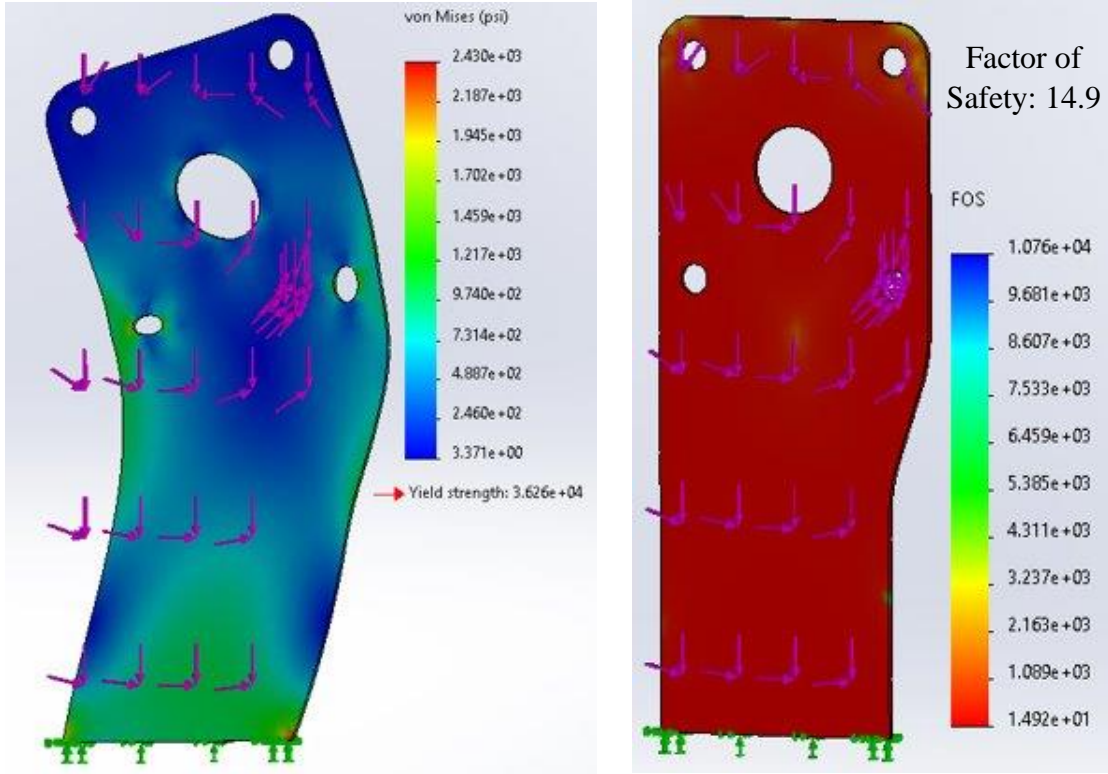


Figure 9

Bill of Materials

Part Name	Manufacturer Part Number	OEM Part Number	Quantity	Price	Link	Total Price
POLARIS - NUT	7547237	164103	16	\$2.90	http://www.ad	\$46.40
POLARIS - RIM, FLAT BLACK, 8 inch wide	1520263-463	164104	4	\$133.92	http://www.ad	\$535.68
POLARIS - VALVE, RIM	1525017	102703	4	\$2.90	http://www.ad	\$11.60
POLARIS - NUT, CASTLE	7547337	123952	4	\$2.18	http://www.ad	\$8.72
POLARIS - PIN, COTTER	7661404	102708	4	\$2.18	http://www.ad	\$8.72
POLARIS - WASHER, CONE	7555796	102706	8	\$5.44	http://www.ad	\$43.52
POLARIS - KIT-SERVICE HUB W/BEARING	2204717	548821	2	\$76.12	http://www.ad	\$152.24
POLARIS - STUD, Front	7518654	164106	8	\$2.90	http://www.ad	\$23.20
POLARIS - DISC, BRAKE, FRONT	5250068	164107	2	\$47.12	http://www.ad	\$94.24
POLARIS - RING, RETAINING	7710440	132032	2	\$11.20	http://www.ad	\$22.40
POLARIS - CARRIER, BEARING, RH	5135443	164110	1	\$105.31	http://www.ad	\$105.31
POLARIS - CARRIER, BEARING, LH	5135442	164111	1	\$157.54	http://www.ad	\$157.54
POLARIS - HUB, REAR WHEEL	5135113	130783	2	\$75.24	http://www.ad	\$150.48
POLARIS - STUD, Back	7518378	133220	8	\$1.45	http://www.ad	\$11.60
POLARIS - DISC, BRAKE, REAR	5248250	130782	2	\$54.38	http://www.ad	\$108.76
POLARIS - BOLT, Back	7515522	103326	8	\$2.54	http://www.ad	\$20.32
POLARIS - BEARING, CARRIER, WHEEL	3514635	132030	2	\$42.05	http://www.ad	\$84.10
26X8-12 Tires			4	\$100.00		\$400.00
POLARIS - ASM., FRONT BRAKE CALIPER, LH	1911186	121132	1	\$252.29	http://www.ad	\$252.29
POLARIS - ASM., FRONT BRAKE CALIPER, RH	1911187	121133	1	\$252.29	http://www.ad	\$252.29
POLARIS - ASM., REAR BRAKE CALIPER, RH	1911545	162714	1	\$243.59	http://www.ad	\$243.59
POLARIS - ASM., REAR BRAKE CALIPER, LH	1911544	300260	1	\$243.59	http://www.ad	\$243.59
FRONT Brake, Caliper Mounting, BOLT	7518760	122057	4	\$6.16	http://www.ad	\$24.64
REAR Brake, Caliper Mounting, SCREW, CAP	7512365	102879	4	\$1.45	http://www.ad	\$5.80
REAR Brake, Caliper Mounting, WASHER STEEL	7558402	102877	4	\$0.72	http://www.ad	\$2.88
REAR Brake, Caliper Mounting, LOCK WASHER	7552901	102878	4	\$0.72	http://www.ad	\$2.88
POLARIS - WELD-CONTROL ARM UPR FR LH BI	1018203-458	OEM599182	1	\$122.66	http://www.ad	\$122.66
POLARIS - WELD-CONTROL ARM UPR FR RH BI	1018204-458	OEM599183	1	\$122.66	http://www.ad	\$122.66
POLARIS - WELD-CONTROL ARM LWR FR LH BI	1018205-458	OEM599184	1	\$122.66	http://www.ad	\$122.66
POLARIS - WELD-CONTROL ARM LWR FR RH BI	1018206-458	OEM599185	1	\$122.66	http://www.ad	\$122.66
POLARIS - TUBE, PIVOT	5136324	OEM162986	4	\$15.22	http://www.ad	\$60.88
POLARIS - BUSHING, A-ARM, LONG, GREY	5436973	OEM162988	8	\$6.89	http://www.ad	\$55.12
POLARIS - ZERK, FITTING, THREADED	7080433	OEM105184	4	\$1.45	http://www.ad	\$5.80
POLARIS - BALL-JOINT, 8MM, 5140	7061220	OEM1130933	4	\$51.84	http://www.ad	\$207.36
POLARIS - RING, RETAINER	7710533	OEM121633	4	\$2.54	http://www.ad	\$10.16
POLARIS - SCREW, FLANGE	7518458	OEM162999	4	\$7.61	http://www.ad	\$30.44
POLARIS - NUT, FLANGE	7547313	OEM101353	4	\$1.45	http://www.ad	\$5.80
POLARIS - NUT, NYLOK	7547405	OEM163000	4	\$0.72	http://www.ad	\$2.88
POLARIS - SCREW, FLANGE	7516733	OEM163001	4	\$6.89	http://www.ad	\$27.56
Rear Shocks - ALREADY PURCHASED						
Front Shocks - ALREADY PURCHASED						
Rear Control Arms - ALREADY PURCHASED						
Solid Shaft Collar	1276675		1	\$2.15	https://www.su	\$2.15
3/4" Pillow Block Bearing	120412P		1	\$10.40	https://www.s	\$10.40
3/4"x36" Keyed Shaft	12982753		1	\$25.35	https://www.s	\$25.35
Husqvarna Fuel Tank	581290101		1	\$93.99	https://www.a	\$93.99
Polaris Prop Shaft	1332904		1	\$69.50	https://www.g	\$69.50
22HP Predator V-Twin Engine			1	\$949.99	https://www.h	\$949.99
Polaris RZR 900 Differential	1334309		1	\$899.99	https://www.e	\$899.99
13 Tooth 3/4" Bore 40 Pitch Roller Chain Sprocket	1212313		1	\$5.95	https://www.s	\$5.95
3/4" Bolt Flange Bearing	1204122C		1	\$10.70	https://www.s	\$10.70
#40 Roller Chain	1116340		1	\$23.25	https://www.s	\$23.25

Figure 10

Fabrication and Assembly

Planned Fabrication Methods

- Utilize tools at the Victory Parkway Campus North Lab to manufacture and assemble parts
- Utilize tools such as:
 - Mig Welder
 - Plasma cutter
 - Lathe
 - Drill press
 - Hand tools (wrench, ratchet/socket, screwdriver, Allen wrench, mallet, measuring tape)
 - Power tools (drill, jigsaw, chop saw, grinding/cutting wheel)

Mounting Plate

- Blank sheet metal measured and marked appropriately
- Plasma cutter was used to cut out the shape of the mounting plate (Figure 11)
- Angle grinder was used to smooth the edges of the plate
- Cutting wheel used to remove slots for frame bars (Figure 12)
- Mig welder used to secure the mounting plate to the rear section of the frame (Figure 13)
- Template used to locate mounting holes on the bottom of the differential and then laid out onto the mounting plate for differential installation (Figures 14 and 15)



Figure 11



Figure 12



Figure 13



Figure 14

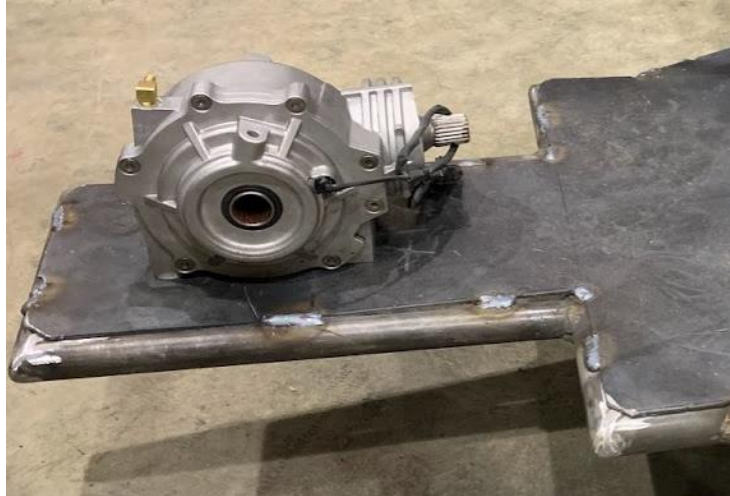


Figure 15

Mounting Brackets

- Plasma cutter was used to cut out the mounting brackets from the blank sheet metal
- Drill press was used to extrude holes for nuts and bolts to secure bearing mounts and forward reverse gearbox to the mounting brackets
- Mig welder was used to secure the mounting brackets to the mounting plate (Figure 16)
- Additional gussets were cut and welded onto the designed mounting brackets (Figure 17) in order to provide additional rigidity and safety factor

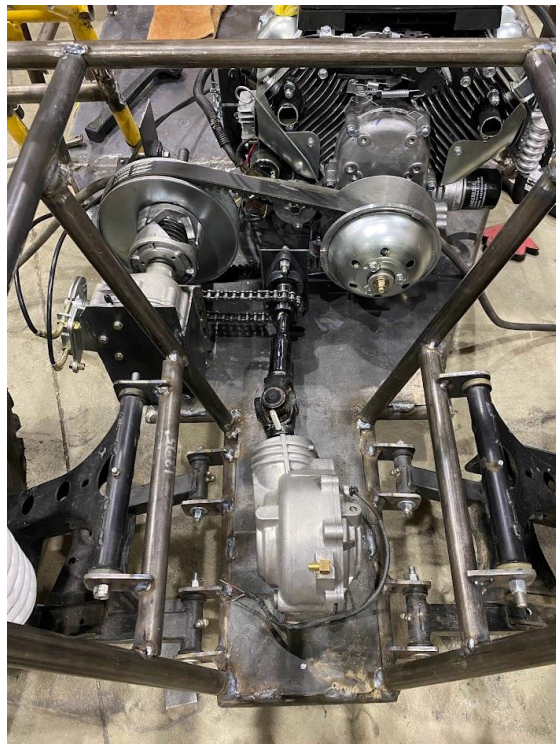


Figure 16

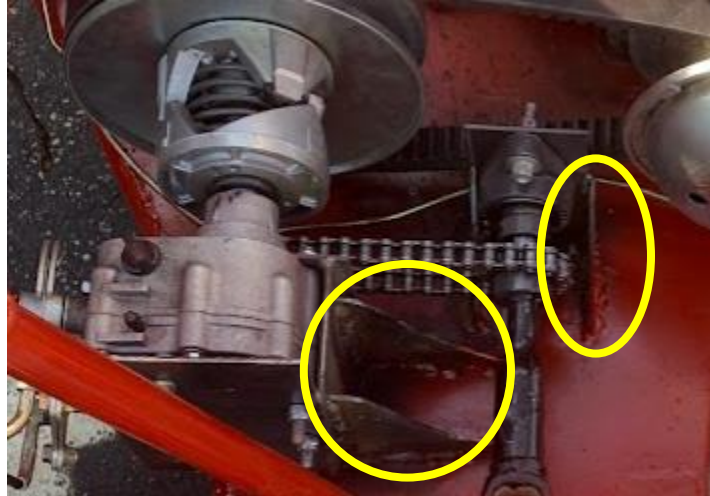


Figure 17

Bushing for Shaft Diameter Reduction

- Polaris differential input shaft has a very specific spline. Therefore, a Polaris prop shaft with a U-joint was purchased in order to properly couple the drive shaft, which is connected by chain and sprocket to the forward/reverse gearbox, to the differential. The Polaris prop shaft is a hollow tube with a different inner diameter (1.375") than the outer diameter (0.75") of the drive shaft we purchased and connected out sprocket to. A bushing had to be machined to connect the two shafts.
- Lathe was used to turn a blank cylindrical piece of metal down to ~1.375"
- A hole was bored into the bushing at 0.75" so the drive shaft could slide into the bushing
- Holes were drill pressed into the prop shaft and the bushing was welded into place at those holes to provide torsional stiffness (Figure 18)
- The drive shaft was installed into the bushing/prop shaft assembly and welded together to form a solid shaft with a properly sized spline at the U-joint and properly sized outer diameter for the sprocket to be installed (Figure 19)



Figure 18



Figure 19

Resultant Drivetrain



Figure 20

Electrical

- Headlights, taillights, brake lights, speedometer/GPS sensor, speedometer backlight, and differential output solenoid were all added to the UTV
- The ignition switch also had to be connected to the battery
- Headlights, taillights, and speedometer backlight were all connected to one switch (Figure 22)
- Differential solenoid to connect the input shaft to the output shafts on the differentia, as well as the speedometer/GPS sensor were connected to a different switch (Figure 22)
- A pressure sensor was integrated into the hydraulic brake lines in order to automatically illuminate the taillights when the brake pedal is pressed
- The negative terminal on the 12V car battery was grounded to the frame, allowing the frame to act as a ground for all electronics, thus not requiring a negative wire to be run all the way from each electronic unit to the battery
- 22 gauge wire, as well as wire nuts, wire strippers, zip ties, and electrical tape were used to cut, connect, and restrain wiring (Figure 21)



Figure 21

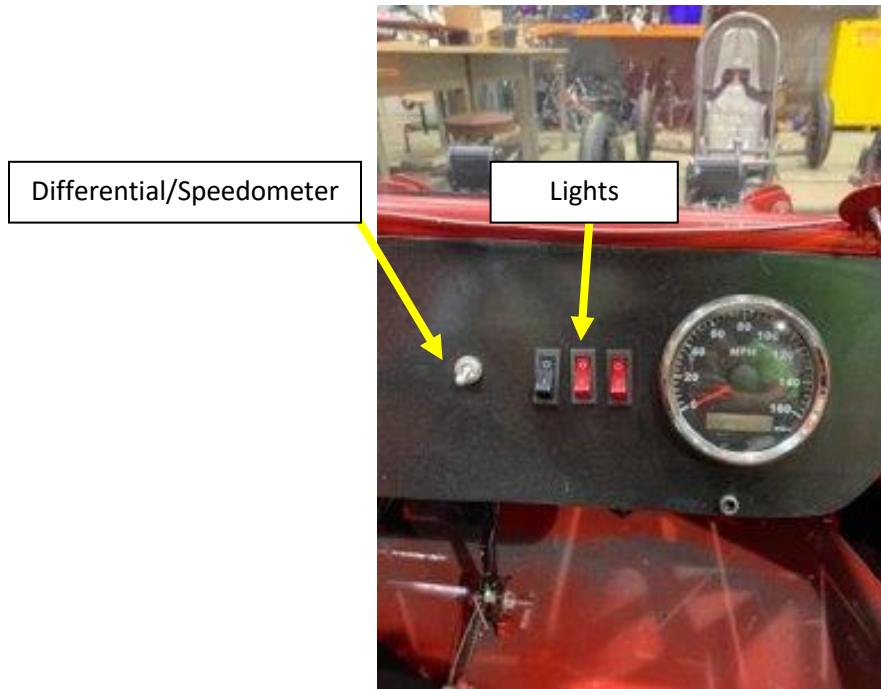


Figure 22

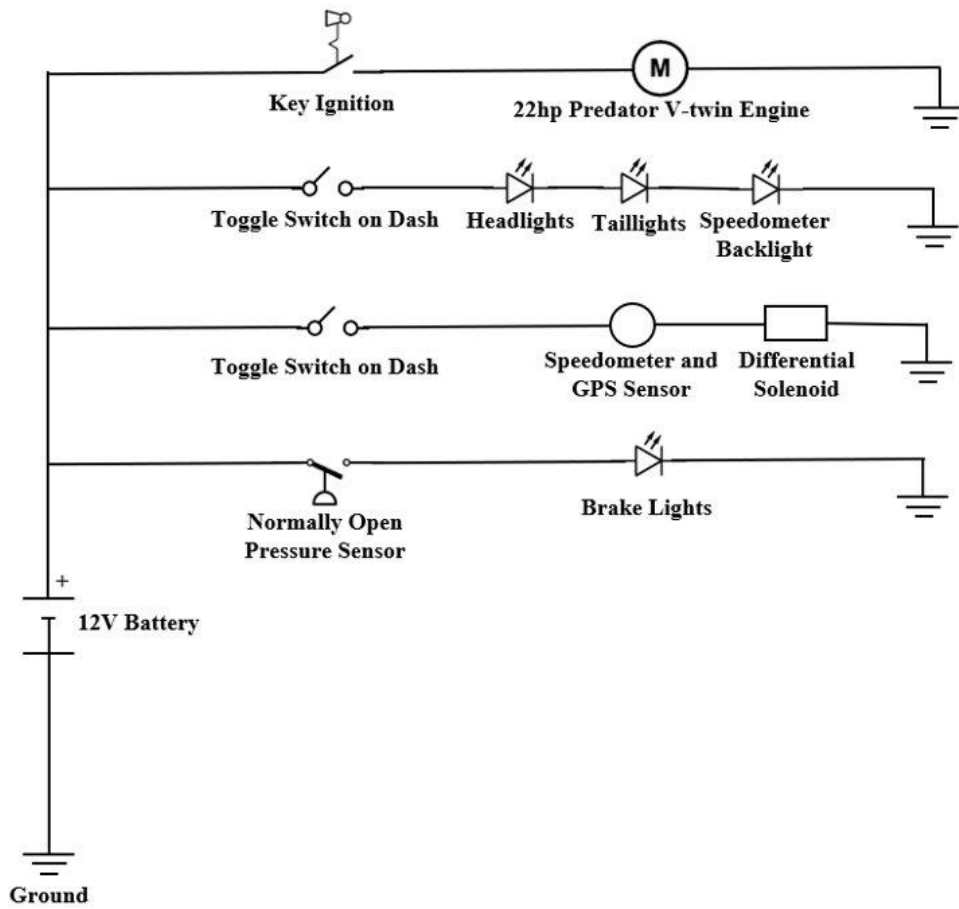


Figure 23

Accelerator Pedal

- Manufactured three mounting brackets to hold the pedal
- Mig welded the brackets onto the floor plate in the cab
- Used a bolt through two of the brackets to create a pivot shaft for the pedal to rotate about
- Connected a spring to the pedal and third mounting bracket to force the pedal to return to a neutral state after force from the driver's foot is removed from the pedal; this ensures the engine doesn't continue to accelerate after the driver has removed their foot from the accelerator
- Accelerator cable was connected to the pedal and calibrated so the accelerator valve on the engine only begins to open after force is applied to the pedal by the driver; if the cable to too tight, the UTV will begin accelerating without any input from the driver, resulting in a potentially dangerous situation



Figure 24

Paneling

- Polycarbonate plastic sheets were purchased to panel the exterior of the UTV
- Gaps between frame bars were measure and templates were laid out onto the blank plastic sheets
- Jigsaw was used to cut the plastic to the desired dimensions for each panel
- Black paint was sprayed onto both sides of each panel
- Circular punch press was used to create small, round tabs, which were welded into the corner of each panel location on the frame (Figure 25)
- Panels were aligned to each gap and holes were drilled through both the panels and corresponding circular mounting tabs
- Self-tapping screws were used to fix the panels to the circular mounting tabs (Figure 25)

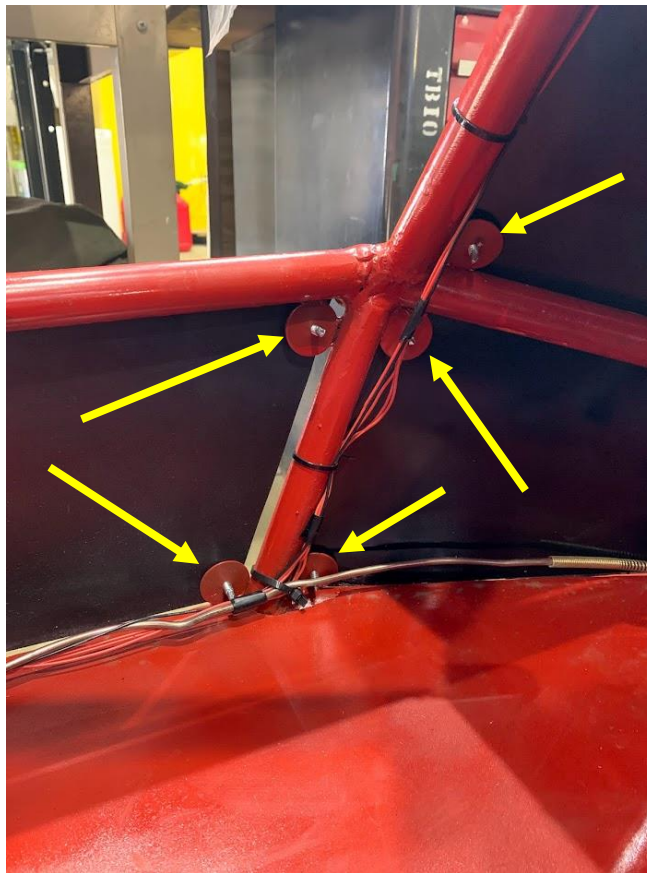


Figure 25

Steering

- Mounted rack and pinion to existing bracket with nuts and bolts
- Connected tie rods into wheel knuckles
- Manufactured a coupler to elongate the tie rod (Figure 26)
- Installed steering wheel to the dashboard using existing mounting bracket
- Aligned front wheels to ensure proper steering

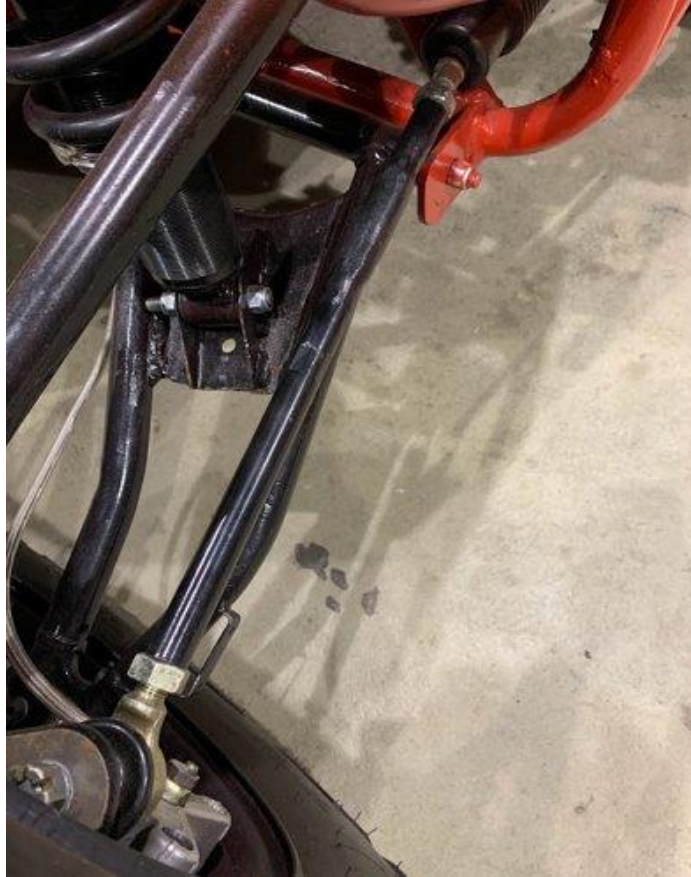


Figure 26

Before and After

- Existing frame (November 2021)



Figure 27

- Finished UTV (April 2022)



Figure 28

Testing and Proof of Design

Engineering Characteristics Tested

- Top speed
- Braking distance
- Payload capacity
- Turning radius
- Overall dimensions (weights and width)

Testing Methods

- **Top speed:** Position UTV on a straight, level surface and accelerate until engine can no longer produce a higher velocity; note speed on speedometer once max velocity is reached.
- **Braking distance:** Accelerate to top speed and setup wide angle, slow motion camera to capture braking process; note where braking begins in the video and correlate the video to physical setting to measure distance necessary to come to a full stop.
- **Payload capacity:** Load three grown men into the bed and observe whether the suspension can support the weight or not; put two grown men in the cab as well. ANSI/OPEI B71.9-2016 requires a UTV to carry at least 350 lbs. of payload (3). As seen in Figure 29, the UTV can comfortably carry 3 grown men (~500 lbs.) in the bed.



Figure 29

- **Turning radius:** Align the UTV in the parking lot and mark the outward facing, front tire. Turn the wheel all the way to one side and begin to turn. Conclude the test once the UTV has completed a full 180° turn and measure the distance of the same outward facing, front tire from the beginning mark. This measurement is the turning diameter. Therefore, divide the value by two in order to obtain the turning radius. Desired turning radius for the UTV is set at 25ft because a 2020 Polaris RZR's turning radius is about 22ft (9).

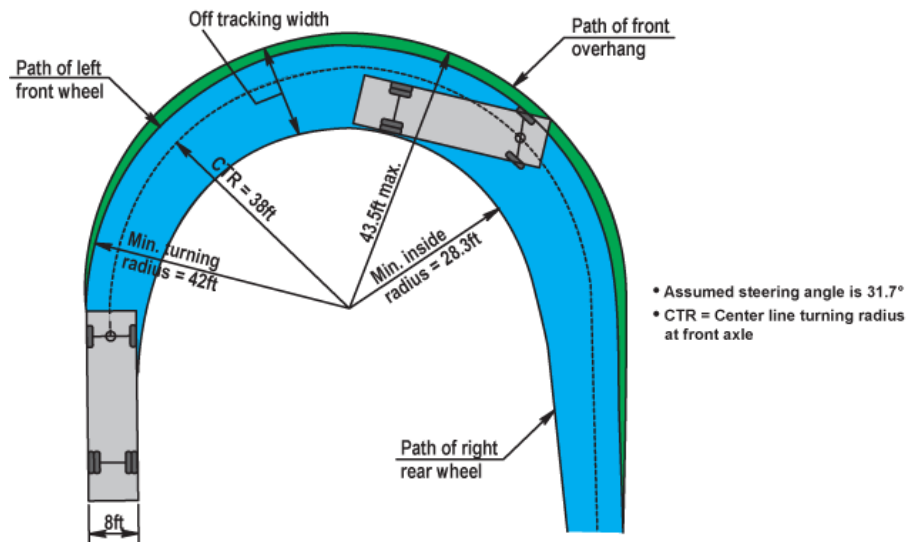


Figure 30

- **Weight:** A shop crane was utilized to test the overall weight of the UTV. The crane was set to a limit of 1 ton (2000 lbs.) and connected to the UTV. The crane was raised and the UTV lifted off the ground, proving that its weight is less than 2000 lbs. and thus in compliance with the ANSI/OPEI B71.9-2016 standard for a UTV.



Figure 31

- **Width:** The UTV was placed on level ground and a tape measure was used to measure the UTV at its widest point.

Testing Results

Characteristic Tested	Desired Value	Value Achieved
Top speed	25 mph	25 mph
Braking distance	30 ft	TBD
Payload capacity	>350 lbs.	~900 lbs.
Turning radius	~25 ft	~23 ft
Weight	<4000 lbs.	<2000 lbs.
Width	<80"	54"

Table 2

Shaft Failure

- During the testing phase, the input shaft on the forward/reverse gearbox sheared while trying to drive up a very steep hill near the Victory Parkway Campus. The steep hill caused the CVT to shift into its lowest gear/highest torque setting in order to drive the UTV up the hill. This shaft was not tested using FEA because it was a supplier part purchased by the previous UTV group, and therefore it was not expected to fail. This shaft failure meant some testing for the UTV could not be conducted, as indicated by the “TBD” in the “Value Achieved” section of Table 2. However, with the existing drivetrain, the UTV did achieve about 10 mph and the brakes do function properly.

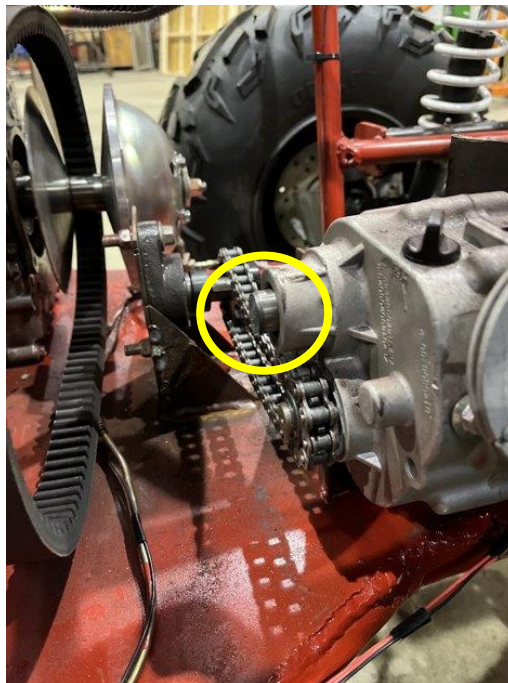


Figure 32

Drivetrain Redesign

- Due to the shaft failure, the drivetrain had to be redesigned in order to make the UTV drivable again. It was decided that a Schafer Driveline forward/neutral/reverse gearbox and differential would be purchased and installed into the UTV. The Schafer gearbox will eliminate the need for the old gearbox, as well as the chain and sprocket connected to the driveshaft, U-joint, and existing differential.

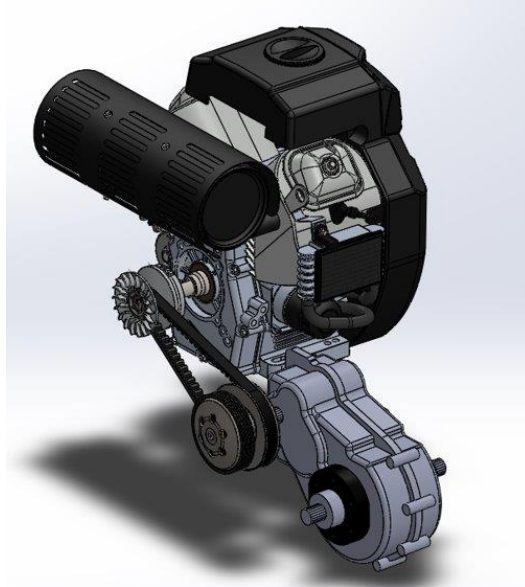


Figure 33

- The new drivetrain setup was completed and produced a more robust driving experience. The UTV was able to achieve the top speed of 25 mph, as well as scale the steep hill that caused the original drivetrain to fail. The UTV can also traverse offroad terrain. When the CVT is in a 1:1 ratio, the new drivetrain should achieve 30 mph and a top speed of 51 mph when the CVT is in its maximum ratio of 0.59:1. Braking distance has still not been tested.

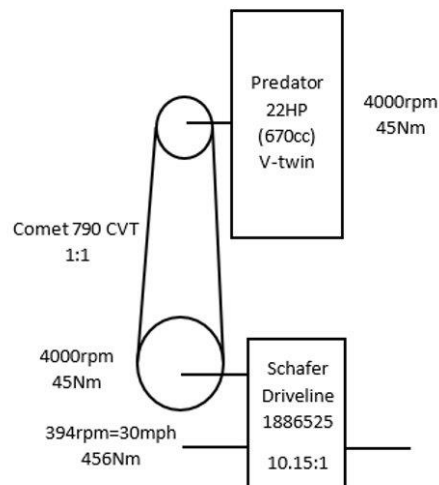


Figure 34

Project Management

Proposed Budget

- Given the purchased components that the group already has, and the frame already having been built, we set a budget limit of \$8,000 to complete the project.
- \$1,050 remaining for materials, like tube steel, steel plates, sheet metal, etc.)

Component	Cost
Suspension	\$1,250
Drivetrain	\$2,500
Brakes	\$1,100
Wheel Assembly	\$2,100
Total	\$6,950

Table 3

Actual Budget

- While the proposed budget was \$8000, due to the shaft failure and other various purchased parts, the final cost of the UTV was likely more in the range of \$10,000.

Proposed Schedule

Remaining Components Put on Order	12/10/21
Components Arrive	01/10/22
Assembly Start	01/10/22
Finish Assembly	04/01/22
Begin Testing	04/04/22
Tech Expo	04/15/22

Table 4

Actual Schedule

- Due to the Covid-19 pandemic, the first two weeks of the spring 2022 semester were conducted virtually, meaning we did not have the opportunity to get into the lab and physically work on the UTV until January 24. As a result of this two week delay, our schedule had to be adjusted. The shaft failure also caused a setback to the schedule, since the drivetrain had to be rebuilt and retested.

Assembly Start	01/24/22
Finish Assembly	04/13/22
Tech Expo	04/14/22
Begin Testing	04/15/22
Final Presentation	04/26/22
Finish Redesigned Drivetrain Assembly and Testing	04/28/22

Plan to Finish

- After completing the assembly of the redesigned drivetrain, the UTV is functionally finished. The UTV runs and drives as it was intended.

Conclusion

This project required a great deal of preparation and team cooperation in order to materialize. Each aspect had to be designed in conjunction with one another to ensure that all the parts would fit and function together and achieve the desired deliverables. Supplier and off the shelf parts had to be selected based off engineering calculations and parts to be manufactured by the team had to be designed within CAD and tested using FEA to ensure their factor of safety. This project also required a lot of physical assembly. Due to time constraints, multiple aspects of the UTV had to be fabricated at the same time, once again requiring a large amount of team cooperation. We were rather inexperienced regarding fabrication of such a vehicle, but we were able to apply our classroom knowledge of engineering principles, as well as what we learned during manufacturing and welding lab to completely assemble the UTV. Despite many setbacks, including two weeks of virtual learning to begin the semester and a gearbox shaft failure during final testing, we were able to assemble and finish the UTV, successfully fulfilling all the outlined ANSI standards required to call a vehicle a UTV.

References:

1. Threewitt, Cherise. 2021 UTV Segment Buying Guide. *US News & World Report*. [Online] October 29, 2020. [Cited: October 7, 2021.] <https://cars.usnews.com/powersports/utvs>.
2. How Many Steps We Take at Our Jobs Everyday. *FitMyFoot*. [Online] [Cited: October 7, 2021.] <https://fitmyfoot.com/blogs/active-meaningful-years/how-many-steps-we-take-at-our-job-everyday>.
3. ANSI/OPEI B71.9-2016. *ANSI Webstore*. [Online] [Cited: October 7, 2021.] <https://webstore.ansi.org/standards/opei/ansiopeib712016-1636646>.
4. Filip. What Features are Typical on UTVs? *UTV Ride*. [Online] June 30, 2020. [Cited: October 7, 2021.] <https://utvrider.com/typical-utv-features/>.
5. *Honda Powersports*. [Online] [Cited: September 16, 2021.] <https://powersports.honda.com/sxs/recutility/pioneer-1000/specifications>.
6. Henry, William. UTV Transmission Guide: CVT vs DCT vs Manual. *Dirt Portal*. [Online] June 19, 2020. [Cited: September 16, 2021.] <https://www.dirtportal.com/utv-transmission-guide-cvt-vs-dct-vs-manual/>.
7. KAWASAKI TERYX KRX 1000 COMPLETE SPECS, PRICING & OPTIONS. *UTV Action*. [Online] November 1, 2019. [Cited: September 16, 2021.] <https://utvactionmag.com/kawasaki-teryx-krx-1000-complete-specs-pricing-options/>.
8. YXZ1000R. *Yamaha Motorsports*. [Online] [Cited: September 16, 2021.] https://www.yamahamotorsports.com/pure-sport-side-by-side/models/yxz1000r?utm_source=google&utm_medium=cpc&utm_campaign=SxS+-+Pure+Sport&utm_term=yamaha+yz&keyword=yamaha%20yz&gclid=Cj0KCQjw1ouKBhC5ARIsAHXNMI_BNUK_ohKEREzgFXJd7lD2vXl-g185IrcYbfqD3CBmGxj.
9. Model Archive. *Polaris Off Road*. [Online] 2020. <https://rZR.polaris.com/en-us/2020/4-seat/rZR-pro-xp-4/rZR-pro-xp-4-cruiser-black-2020-rZR/>.