BUV Powertrain 2020

A Baccalaureate thesis submitted to the
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in partial fulfillment of the
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Bachelor of Science

in Mechanical Engineering Technology

by

Connor Brady

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Thesis Advisor:

Professor Moise Cummings

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The world is always in need of cheap and reliable transportation. The Basic Utility Vehicle is designed for third world countries that need exactly that. A way to get from point A to point B while providing utility. These vehicles have the goal to provide water and other vital resources in areas of the world where there are no paved roads and normal vehicles are too costly to operate. The Institute of Affordable Transportation (IAT) puts on a competition every year for schools to design the best all-around BUV. The vehicle is to be as simple as possible, as reliable as possible in order to get its job done effectively. A simple design allows for ease of manufacturing and low maintenance, The vehicle will have safety features and have the ability to haul barrels of water. It will have considerable ground clearance to drive off road and use standard automotive components. The IAT lays out very specific design specifications for all teams follow, these include size of the vehicle, drivetrain limits, and required safety features.

PROBLEM DEFINITION AND RESEARCH

Problem Statement

Since 2000, every year the institute for affordable transportation hosts an annual BUV design competition. In this competition College students across the country compete to have the best BUV design who want to improve transportation in under privileged countries (1). These vehicles must be designed to be simple and must be able to go across any terrain to carry heavy loads with supplies, such as water, to various destinations. The vehicle must be able to be fabricated and maintained at low costs (1). The basic utility vehicles used by IAT have a unique three wheel design (2).

I will be in charge of the drivetrain portion of this design. For 2020 the engine must be an 11hp unmodified that runs on either gas or diesel. The transmission used will be a Tough Torque KT35. The transmission has reverse and has two forward speeds not counting any variable drive features.

BACKGROUND

The IAT has its headquarters in Indianapolis. Will Austin founded the Institute of Affordable Transportation in the year 2000 after he realized the quality of life was dependent on cheap transportation. (1) They are a nonprofit charity devoted to improving the lives of the world's poor by providing simple, low-cost vehicles in order to facilitate community transformation. (1) Americans commonly take our transportation and lifestyle for granted. In other countries the ability to get in a vehicle and get resources is sparse.

RESEARCH

SCOPE OF THE PROBLEM

BUVs open up possibilities for faster water delivery to remote villages, for quickened access to medical care and for the safe transport of people and goods through rugged terrain. Today there are over 90 BUVs serving in 19 countries across Africa and Central America. (1)

The success of a BUV depends on the weight of the vehicle, and the vehicle’s ability to hold and transport large amounts of water. Because of this, the strongest, most lightweight material will be used to build the chassis and frame of this vehicle. (3)

The course that the BUV competition is held on is 2.2 miles long with mostly mud and some grass to simulate the tough environment of foreign countries. There are three sections through wooded areas that have hills with up to ten degrees pitch, obstacles, and possibly a water obstacle. The pond for the irrigation task is in the middle of the course. The vehicle must back up to the pond to fill or to dump water. All dumped water must be return to the pond and not dumped on the bank of the pond. The irrigation task must be performed every third lap from the last irrigation task. The vehicle's PTO using electric, hydraulic, or mechanical pumps are the only automated features permitted for the pumping operation.

Manual filling is allowed in place of automated pumping The teams score 10 points for each lap completed plus 15 points for each drum full of water carried on that lap. (4)

CURRENT STATE OF THE ART

Figure 1: Example of BUV in this case made by Purdue

Most modern All Terrain Vehicles do not meet the design specifications of this competition. Either they have too much power, the payload isn't high enough or they do not even come close to the price point. Some common models shown below.

The most recent version of the BUV drivetrain that the University of Cincinnati is shown below. It was a very effective design that used a driveshaft, a Comet Model 770 centrifugal Clutch along with the 10hp Briggs and Stratton and the KT35 transmission. (3) This design never made it to competition but it seems like it would have worked extremely well.

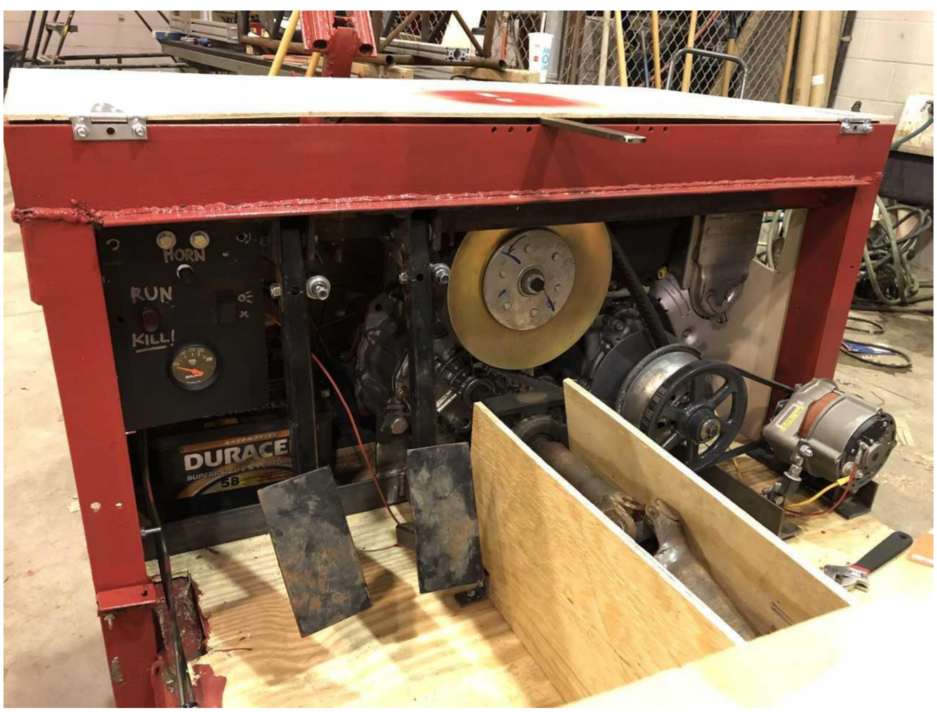


Figure 2: 2018 BUV Drivetrain

Figure 3: 2011 BUV Drivetrain

In 2011 the team decided to use a more complex chain and belt drive design. The drivetrain consists of a torque converter, side shaft and two 40 tooth sprockets. (5) I see this design being too complex with a lot of power loss through the various methods of power transfer. The design used in 2013 was very similar to the one used in 2011. The drive train is made up of 5 primary components: the 10 HP Briggs & Stratton engine, the 780 Series CVT, the intermediate shaft, the 1:1 chain drive, and the KT35 Tuff Torq transmission. There is much flexibility in this design. Center distances between the chain drive and the torque converter had to be maintained. The transmission, engine, and intermediate shaft were all capable of moving in the vertical axis to facilitate any changes due to team members modifying their design or obstacles the team runs into during fabrication. (6)

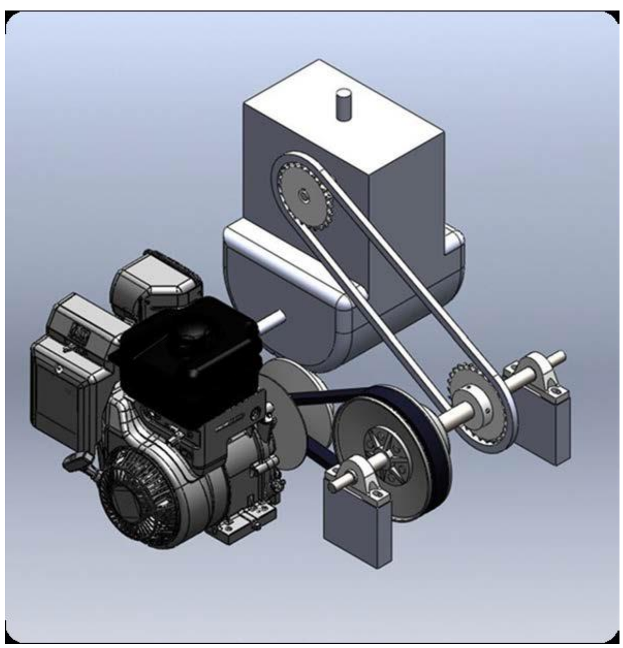


Figure 4: 2013 BUV Drivetrain

Figure 5: 2013 Senior Design BUV Vehicle

Although the 2013 drivetrain worked fine in the course, in 2014 the team changed the design to a single belt which is a lot simpler and offers more power to be transferred to the wheels. The drive train system designed for the 2014 BUV vehicle is comprised of five primary elements: a 10hp Briggs & Stratton engine, 780 Series CVT, 780 Series Torque Convertor, KT35 Tuff Torq transmission, and a drive belt. This drive train system was designed to be durable and handle the conditions associated with rugged terrain. However, the design was constrained by torque convertor and the CVT. These two components mandated that the engine output shaft and the transmission input shaft be in line with each other. With this constraint, the components' elevations were still able to be changed. This allowed for the transmission to be placed in a position that would allow the angle of the drive shaft to be optimal, and the forces on the rear end to be minimized. (4)

The 2017 Design team did not include any detailed pictures of their drivetrain design but they chose to use a clutch and driveshaft concept. The BUV had a successful drivetrain that could move in both a forward and backward direction. The engine and transmission performed great together and allowed the vehicle to run smoothly. The combinations of both design concepts really went well and was inexpensive because most the equipment was donated. (7)

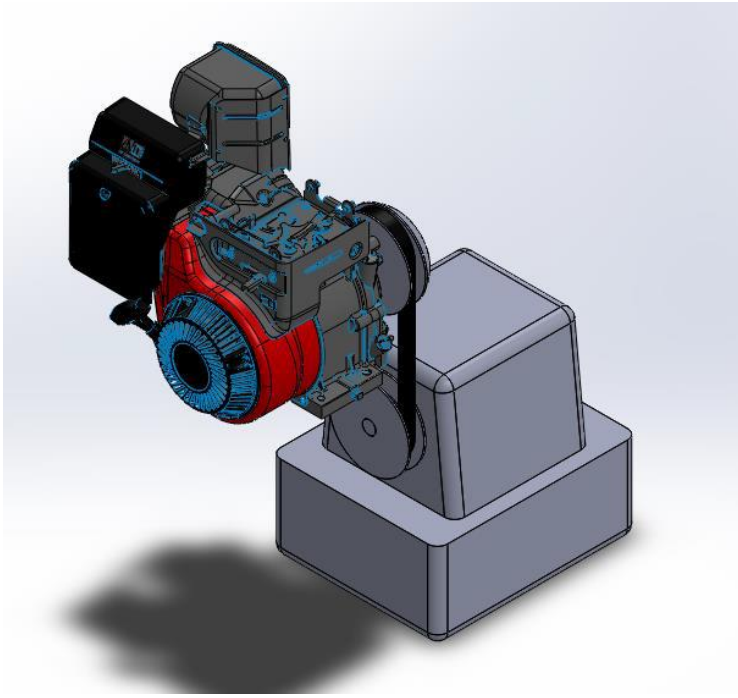


Figure 6: 2014 BUV Drivetrain

END USER

The end customer must have a reliable vehicle, it must be easy to maintain, made of components that will last at least 10 years, it must be able to travel across rough terrain in a timely manner while carrying a considerable amount of payload, in this case, water, and overall be an accessible vehicle to poorer countries that don't have access to regular forms or methods of transportation.

CONCLUSIONS AND SUMMARY OF RESEARCH

In summary, the simplest designs have worked in the past so our team will base our drivetrain design based on this concept. That being said our design will be a similar concept to what was used in the 2018 BUV design, using a customized driveshaft, a Comet Model 770 centrifugal Clutch along with the 10hp Briggs and Stratton and the KT35 transmission.

CUSTOMER FEATURES

- Price
- Ease of Assembly
- Ease of Maintenance
- Reliability
- Safety
- Cargo Capacity
- Maneuverability
- Off-Road Capability

PRODUCT OBJECTIVES

- Must use an 11hp unmodified engine that is either gas or diesel (relative weight 13.2)
- The vehicle must be able to last 10 years using automotive components (relative weight of 14.8)
- Vehicle must cost less than $2500 (relative weight of 13.5)
- The ability to power auxiliary equipment at approximately 1000 rpm (relative weight of 10.6)
- The bed must hold two, but may hold three 55 gallon standard steel drums, weighing 1376 lbs (relative weight of 11.3)
- A water pump with the ability to fill 55-gallon drums from within 15 feet of a pond. All pumping equipment and hoses must be carried on the vehicle during the event. Pump driven form PTO device only. (relative weight of 10.8)
- Maximum speed of 20 MPH (relative weight of 12.3)
- Vehicle must safely carry one person (relative weight of 13.5)

QUALITY FUNCTION DEPLOYMENT

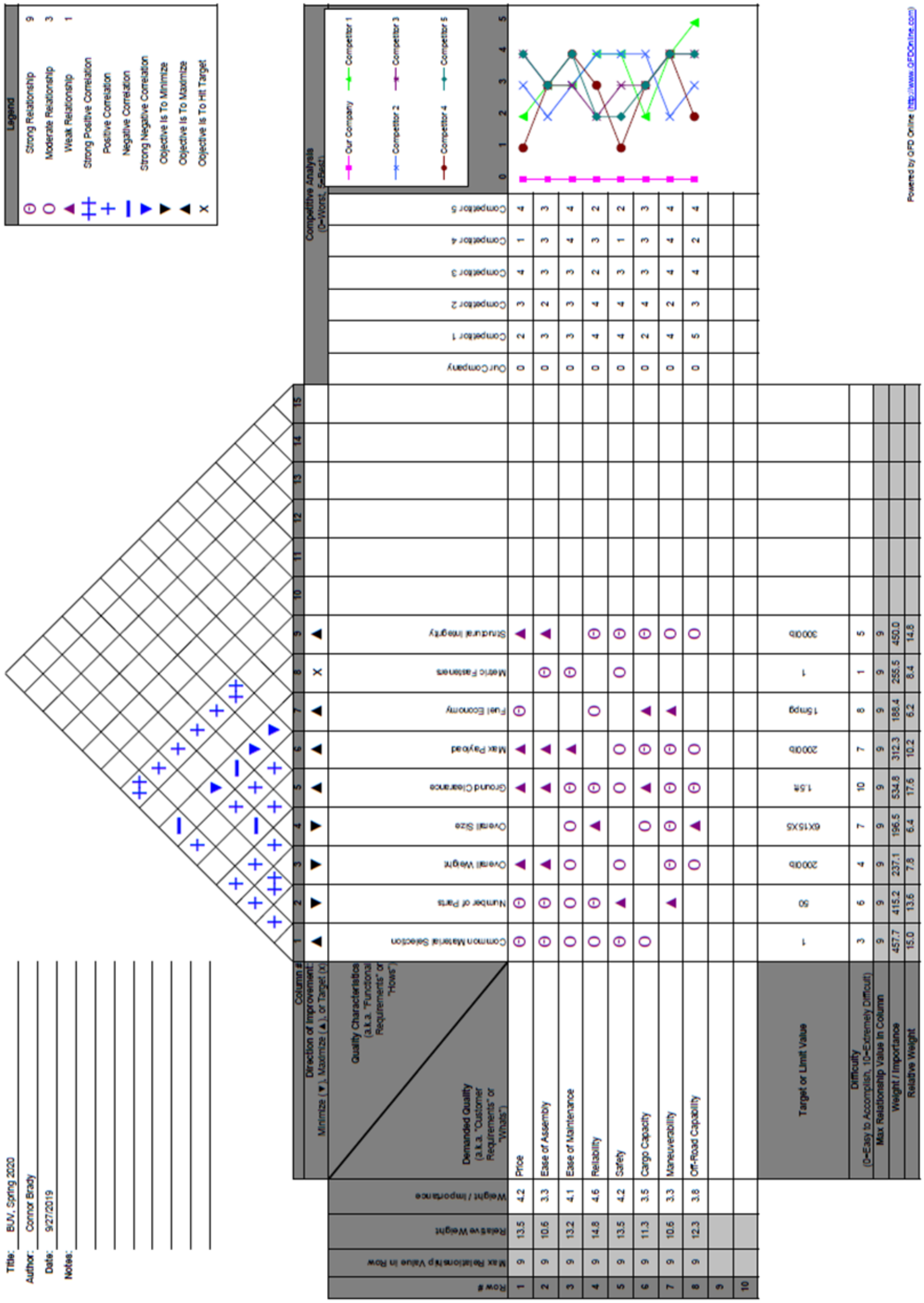
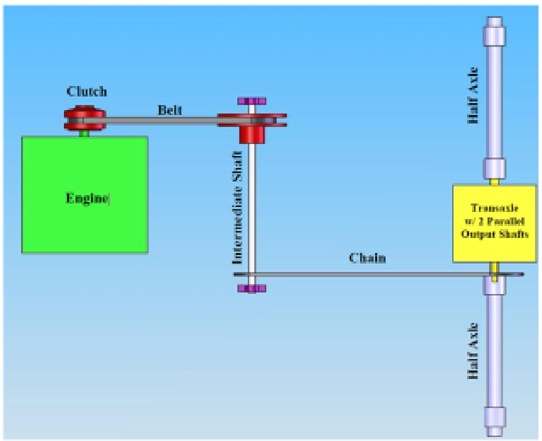


Figure 7:House of Quality

DESIGN

Design Concept 1: Clutch- Chain Drive



Pros:

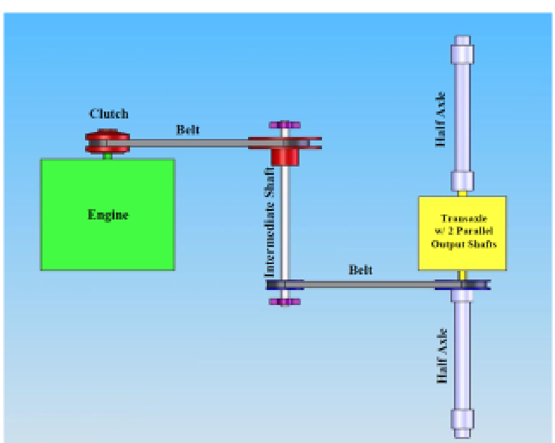
- Efficient transfer of power with minimal power loss
- Chain is easy to clean if mud gets on it
- Ease of maintenance in general

Cons:

- The main con of this setup is the safety aspect where the chain could break and possibly hit the driver of the vehicle or another nearby person

Figure 8: Design Concept 1: Clutch- Chain Drive

DESIGN CONCEPT 2: CLUTCH – BELT DRIVE



Pros:

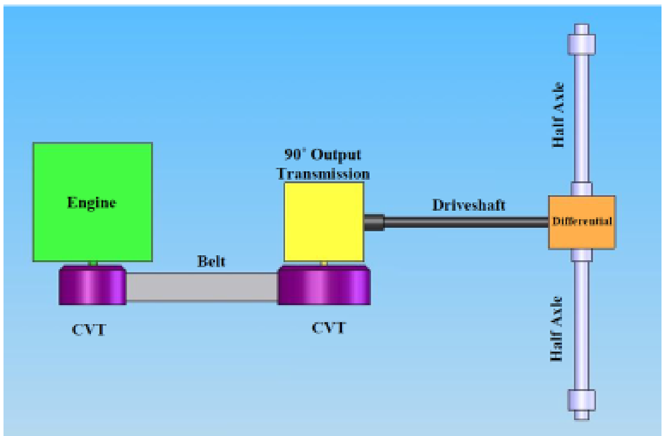
- Parts are very inexpensive
- Belt is easy to clean if mud gets on it
- Ease of maintenance in general

Cons:

- A belt drive is less efficient than a chain drive, more power will be lost, which means less power to make it up a slope.

Figure 9: DESIGN CONCEPT 2: CLUTCH – BELT DRIVE

DESIGN CONCEPT 3: CVT – DRIVESHAFT



Pros:

- Very safe design with mostly enclosed components
- Driveshaft provides direct power to differential

Cons:

- A CVT uses an enclosed belt drive, this may cause a maintenance issue and suffers from the same power loss as a belt drive
- A CVT is an expensive component

Figure 10: DESIGN CONCEPT 3: CVT – DRIVESHAFT

Design Selection: Using engineering characteristics that applied to the drivetrain, each concept was rated with a relative score on a scale from one to five (five being the best). The concept with the highest total rating was decided to be the best possible solution. There was a tie between “Clutch and Belt Drive” and “CVT and Driveshaft” which both scored a total of 4.2 out of 5. We combined parts of each concept to create the best possible option. Instead of using a CVT, it was decided to use a Clutch and Driveshaft concept

Design Criteria	Weight Factor	Clutch and Chain Drive	Clutch and Belt Drive	CVT and Drive Shaft
Price	10%	4	4	4
Ease of Assembly	20%	4	5	5
Ease of Maintenance	25%	3	4	4
Reliability	20%	4	4	4
Safety	15%	3	4	4
Cargo Capacity	10%	4	4	4
	Score	22	25	25
Price		0.4	0.4	0.4
Ease of Assembly		0.8	1	1
Ease of Maintenance		0.75	1	1
Reliability		0.8	0.8	0.8
Safety		0.45	0.6	0.6
Cargo Capacity		0.4	0.4	0.4
	Total Rating	3.6	4.2	4.2

Table 1:Concept Decision Matrix

Engine Selection:

We chose to use a 10 hp engine that was provided to us by Dave Conrad. It’s a Briggs and Stratton 10 HP-Series INTEK I/C that has been used in past years and was available for us to use. Coming in at 10hp it is within the design criteria for the competition and being provided at no cost to us there was really no other option that made sense. We modified the mounting position of the engine and trans to under the drive seat. In order to do this we cut out some of the inner frame to make room for the existing trans/engine mount. We then drilled holes on each end of the two supports, made sure the spacing was correct for the engine and trans to be mounted and then bolted the mount to the frame. A support was then welded directly in front of the mount on the frame to ensure the integrity. This modification allowed use to lower the center of gravity from previous years. The driveshaft angle was also decreased which will prevent it from binding up.

Figure 11: Engine and Transmission Mount

Transmission Selection:

We chose to use a Tuff Torque KT35 which was also provided to us at no cost from the 2018 BUV, it has forward, neutral as well as reverse gears. This transmission came out of a John Deere Gator 4x2 which makes it perfect for a cheap reliable option and allows us a top speed of 20 mph which meets the criteria for competition. This transmission was mounted on the same rails that were mentioned above for the engine. The engine had adjustment for proper belt tension, so the transmission was mounted fixed in one spot and not adjustable. The shifter from the 2018 design worked just fine so we didn't change it.

Clutch Selection:

A clutch is vital in this vehicle's operation, we used a Comet model 770 centrifugal clutch which was included with the engine and trans provided to us. It was also originally used on a John Deere Gator which means they will work perfect together. It is rated for much higher of an rpm range than our engine can produce which means it will be very reliable and durable. This clutch engages automatically so it is very user friendly.

Figure 12: Comet 770 Centrifugal Clutch

Driveshaft Coupler:

An intermediate shaft coupler will be used and has already been manufactured by Dave, to couple the driveshaft to the transmission. This same coupler was used on the 2018 design.

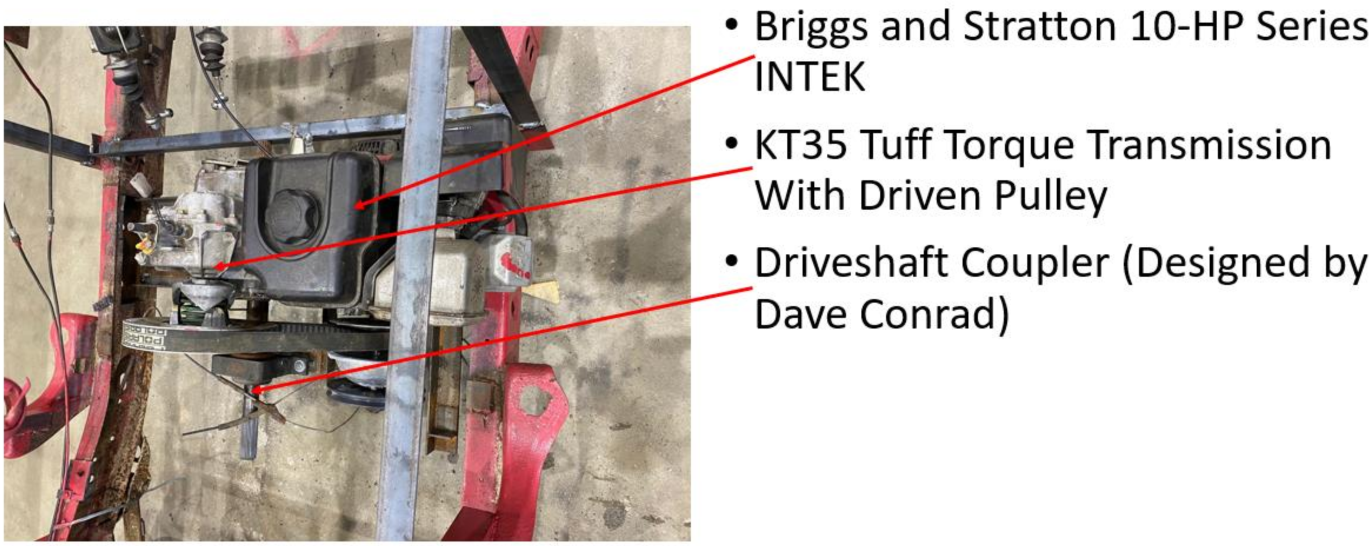


Figure 13: Engine/Clutch/Trans

Driveshaft Selection and modification:

Due to all of the changes we made to the mounting position of the engine, we had to find a new driveshaft from the junkyard. I pulled it from a 1994 blazer and shortened the driveshaft by about a foot, this was done on the fly so I don't have an exact measurement. We then welded it back together and made sure the angle was enough that the driveshaft wouldn't bind, the picture below shows what this looked like after installing into the vehicle.

Figure 14: Driveshaft Modification

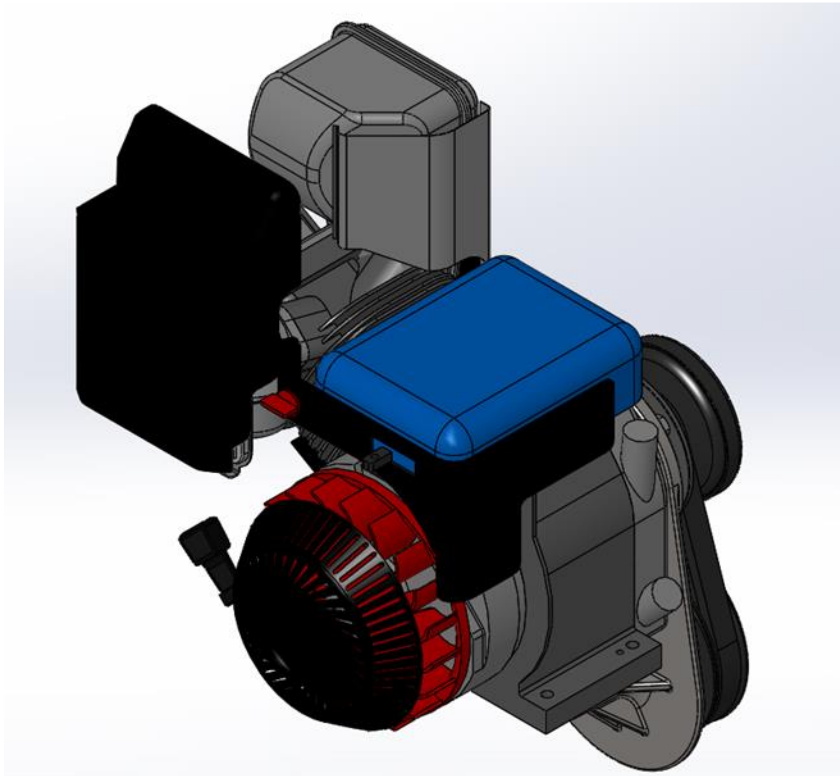


Figure 15:10HP Briggs and Stratton Series INTEK I/C, Comet 770 centrifugal Clutch

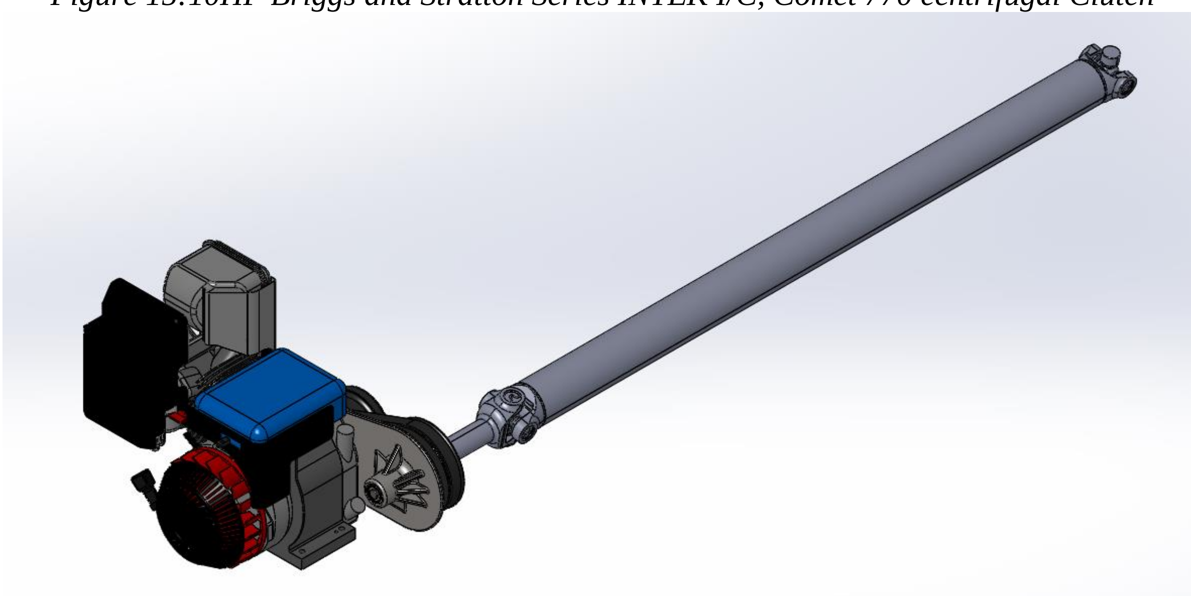


Figure 16:DRIVETRAIN ASSEMBLY

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Component	Budget
10 HP Briggs and Stratton	$350.00
KT35 Tuff Torque Transmission	$150.00
Comet 770 Clutch drive pulley	$200.00
Comet 770 Clutch driven pulley for trar	$150.00
CVT Belt	$50.00
S10 Drive shaft	$140.00
Bolts and fasteners	$60.00
4140 steel	$60.00
Included Components	($500.00)
Total	$660.00

Table 2: Proposed Budget

Component	Actual Spent
10 HP Briggs and Stratton	included
KT35 Tuff Torque Transmission	included
Comet 770 Clutch drive pulley	included
Comet 770 Clutch driven pulley for transmission	included
CVT Belt	included
S10 Drive shaft	$28.00
Bolts and fasteners	included
4140 steel	included

Table 3: Actual Spent

SCHEDULE, PROPOSED /ACTUAL

Milestone	Estimated Date
Design Agreement	10/4/2019
1st Submodel Iteration	10/18/2019
Development Sharing	10/25/2019
2nd Model Iteration	11/1/2019
BOM	11/8/2019
System Integration/ Complete CAD Model	11/22/2019
Fabrication	1/17/2020
Testing 1	3/2/2020
Modifications 1	3/4/2020
Testing 2	3/16/2020
Modification 2	3/18/2020
Testing 3	3/25/2020
Modifications 3	3/30/2020
Tech Expo	April

Table 4: Proposed Schedule

Milestone	Estimated Date
Design Agreement	10/4/2019
1st Submodel Iteration	10/18/2019
Development Sharing	10/25/2019
2nd Model Iteration	11/1/2019
BOM	11/8/2019
System Integration/ Complete CAD Model	11/22/2019
Fabrication	1/17/2020
Testing 1	N/A
Modifications 1	N/A
Testing 2	N/A
Modification 2	N/A
Testing 3	N/A
Modifications 3	N/A
Tech Expo	N/A

Table 5: Actual Schedule

Looking at the original proposed schedule we did fall behind by a week or two. Complete fabrication was not finished before spring break started. The frame and frame and powertrain were finished before this time but the vehicle was about a week away from testing which was planned to be completed when spring break was over. The controls, steering system and irrigation system still needed work. All fabrication was canceled when the COVID-19 virus had reached our area and the school shut down.

PLAN TO FINISH

Pictured below is the final picture I took before leaving for spring break when we were told fabrication would no longer continue. As you can see we were very close to being finished. The drivetrain and frame were completely done. The irrigation system just needed a little more plumbing installed and a water pump installed. The controls and steering needed considerably more work but I think as a team we would have had it done in a week and ready to test.

Figure 17: Final Fabrication Progress

Planned Testing:

- Ensure engine Starts
- Ensure the vehicle can drive under its own power
- Test both forward gears and reverse
- Test vehicle on rough terrain
- Check welds on Driveshaft for integrity
- Check speed via GPS

Sustainability and Material Usage

As a team we did a poor job of getting materials in a timely manner, this was due to the fact of needing much more raw material than we anticipated, and this pushed our progress back therefore. There were some restrictions that Dave Conrad put on our modification plan, because the frame was donated by him. All in all we got over those hurtles and would have finished fabrication on time if there was not a global pandemic stopping us.

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APPENDIX A- IAT BUV DESIGN SHEET

This spec sheet is from the BUV.org, which is IAT's website. These are all the specs of the BUV model currently in production and this is what BUVs for the competition are supposed to be modeled off of. The only difference is that BUVs for the competition can have any engine with a maximum of 11 horsepower. It can be diesel powered like the IAT's model or gas powered like our car and the teams of previous years cars.

Features

- Affordable: $6500 US($)
- Durable: automotive parts
- Utility: power water pump, mill, compressor, etc.

Specifications

- 10 hp engine - diesel
- 1250 lb vehicle weight and low ground pressure
- 12' length x 63" width
- 2-wheel drive with differential
- automotive hydraulic brake

Automotive Grade Components

- axle / tires / wheels / hubs
- brakes / suspension / frame
- expected life: 20+ years for auto parts

Service / Maintenance

- common "off-the-shelf" parts
- easy access to engine and drivetrain
- 95% less parts than a typical car

Performance

- 1750 lb payload
- 40% gradeability - high torque
- 30+ mpg diesel
- Turns sharp like a scooter
- 20 mph max speed

Safety

- Low center of gravity
- Excellent driver visibility
- Controlled speed - 20 mph max
- Hydraulic brakes

APPENDIX B – BUV COMPETITION SPECIFICATIONS

BUV Farm Tanker & Transporter

2020 Design Specifications:

Engine	Use up to 11 horsepower unmodified engine. An auxiliary fuel tank may be added.
Exhaust	Stock muffler, which may be relocated, with additional heat shields as needed.
Gauges	An engine temperature indicator located in view of the driver.
Fuel	Retail pump fuel and oil with provisions to prevent spilling fuel on a hot engine.
Transmission	It is builder's choice, to meet event conditions, but should have reverse****** and should have at least two forward speeds****** not counting any variable drive features.
Power Takeoff	The ability to power auxiliary equipment****** at approximately 1000 rpm.
Electrical	A 12 volt 35 amp or larger automotive alternator and an automotive battery are required******.
Cargo Bed	The bed must hold two, but may hold three 55 gallon standard steel drums**. The drums must be located on their sides with features to verify they are full. The drums must be located as low as possible in the bed. The drums must not be stacked in any manner. The front of the cargo bed must have a 16 inch minimum high bulkhead between the driver and the cargo. The other sides of the bed must be a minimum of 8 inches high. Drums should be easily removable for cargo**and not have any holes that would leak water.
Roll Bar	A minimum height of 36 inches above the surface the driver will sit upon. The roll bar must be completely padded above the seat height. It must have a cross member that covers the ends of the vertical structures, and adequate bracing to prevent the roll bar from collapsing.
Driver Safety	A helmet is required for each person aboard the vehicle. Seat belts are at the option of the team and the team advisor.
Safety Items	To participate in the event, you must have the following safety items: 1. An engine shutoff device marked with a nine-inch red streamer located within reach of the driver. 2. A ***dead man*** throttle with the spring located directly on the throttle linkage of the engine and not on the throttle control devices of vehicle. A ***dead man*** to neutral directional control valve is required on hydraulic powered vehicles. 3. Guarding from all moving parts and Padding of all sharp or dangerous areas. 4. Automotive horn, a fire extinguisher with a rating of 5 B-C or higher, and a high visibility safety flag above the vehicle.
Brake System	A redundant brake system****** that will prevent total brake failure if a brake line is severed anywhere on the vehicle. The brakes must be located at the wheels and not on the drive-line. A front wheel brake is not required on three wheeled vehicles. The parking brake is not considered the redundancy that is required. Hydraulic drives may use reverse for redundancy.
Parking Brake	A parking brake capable of overcoming the engine power. It may be on the drive-line.
Tires	Agricultural tread, or aggressive tire chains are required. Chains must remain with the vehicle.
Towing	Each vehicle must have a 20 foot looped-end tow strap. No hooks allowed. There must be an attachment point at the front of the vehicle for towing. The trailer ball will be the rear attachment point for towing.
Trailer Hitch	A 1-7/8 inch trailer ball must be mounted at a height of 15 inches above the ground when the vehicle is unloaded.
Speed	Maximum of 20 MPH.
Load	Maximum of 165 gallons of water, weighting roughly 1376 pounds.
Water Pump	Ability to fill 55-gallon drums from within 15 feet of a pond. All pumping equipment and hoses must be carried on the vehicle during the event. Pump driven form PTO device only.
Name Plate	The school name and team number displayed in 4-inch font on all sides of the vehicle.

APPENDIX C – ENGINEERING CALCULATIONS

Minimum Force to climb a 15-degree slope

I. Max payload = 3,000 lbs

II. $Fmin=\mu\times\cos(\sigma)$

III. $Fmin=(0.6\ ft)\times(3{,}000\ lbs)(\cos(15°))=1{,}738.7\ lbs$

Minimum Torque Required

I. $rwheel=1.08\ ft\ while\ loaded\ (1"\ flattening)$

II. $Tmin=Fmin\times rwheel$

III. $Tmin=1{,}738.7\ lbs\times1.08\ ft=1{,}877.8\ ft\cdot lbs$

Gear Ratios

I. $Dtire=28\ in,\ engine\ rpm=3{,}600$

II. $Vmax=20\ mph,\ engine\ torque=14\ ft\cdot lbs$

III. $Min\ High\ Gear\ ratio=(rpm\times Dtire)/(mph\times336)$
$=(3{,}600\ rpm\times28\ in)/(20\ mph\times336)=15{:}1$

IV. $Min\ Low\ Gear\ ratio=Tmin/Tengine$
$=(1{,}877\ ft\cdot lbs/14\ ft\cdot lbs)=134{:}1$

Gear Ratios between clutch and transmission

- Product specs:

▪ Clutch high gear ratio = 0.76:1
▪ Transmission low gear ratio = 3.95:1
▪ Transmission gear ratio = 15:1

- $High\ gear\ ratio=clutch\ high\ gear\times trans.gear\ ratio=0.76\times15$

High gear ratio = 11.4:1

- $Low\ gear\ ratio=clutch\times trans.gear\ ratio=3.95\times15$

Low gear ratio = 59.25:1

Intermediate Pulley Ratio

I. $Intermediate\ Pulley\ Ratio=\min\ low\ gear\ ratio$

II. $low\ gear\ ratio=13459.25=2.26{:}1$

Final High Gear Ratio

I. $Final\ high\ gear\ ratio=clutch\ high\ gear\ ratio\times trans.gear\ ratio\times intermediate\ pulley\ ratio$

II. $Final\ high\ gear\ ratio=0.76\times15\times2.26=25.76{:}1$

Final Low Gear Ratio

I. $Final\ low\ gear\ ratio=clutch\ low\ gear\ ratio\times trans.gear\ ratio\times intermediate\ pulley\ ratio$

II. $Final\ low\ gear\ ratio$=3.95 ×15 ×2.26=133.91:1

Performance

I. $Final\ Top\ Speed$= rpm × $DtireFinal\ high\ gear\ ratio$ ×336

II. $Final\ Top\ Speed$= (3,600 rpm) × (28 in)(25.76) ×(336)=11.65 mph

III. $Final\ Torque$= $Tengine$×$Final\ low\ gear\ ratio$

IV. $Final\ Torque$=14 $ft\cdot lbs$ ×133.91=1,874.74 $ft\cdot lb$