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Clutch Analysis and Design for the Wildcat Pulling Team Quarter Scale Tractor Drivetrain

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Executive Summary

The University of Kentucky (UK) Wildcat Pulling Team competes in the annual ASABE International Quarter Scale Tractor Student Design Competition. In 2022 the team placed 3rd overall in the competition, missing 1st place by 23 points. The loss in points was due to the clutch subassembly having issues related to maneuverability, manufacturability, and serviceability. The goal of this project was to redesign the 2022 tractor's drivetrain for the new 2023 competition tractor.

Background research was conducted on three types of clutches: manual, electric, and centrifugal. The electric clutch and centrifugal clutch with manual override were tested to determine their viability for the application. The electric clutch does not allow for easy maneuverability due to its high starting acceleration by instantaneous connection of the magnets. Changing the duty cycle and ramp duration could decrease the starting acceleration; however, the rider still experienced significant starting whiplash, and there were concerns with durability. The centrifugal clutch automatically engages at 2700 rpm threshold and is inactive below that threshold. A hydraulic throwout bearing was used to manually override the engagement threshold on the centrifugal clutch to engage at lower speeds. This configuration showed positive results, as no significant power loss was observed, and the configuration worked as anticipated without any wear on any of the parts. Test results indicated that the centrifugal clutch configuration was the better choice for this application. The final design is a belt-driven system with two cantilevered shafts connected on the backplate with a removable cover, improving access for serviceability.

Introduction

Each year, the American Society of Agricultural and Biological Engineers (ASABE) hosts the International Quarter Scale (IQS) Tractor Student Design Competition. The goal of the competition is to fulfill the primary concern of industry that engineering students lack design experience when entering the workforce. Through this competition, students get hands-on experience designing the frame, drivetrain, hitch, operator controls, weight brackets, and other components which are then evaluated against a set of highly competitive and strict rules [1]. The teams' professional skills are also assessed in a portion of the competition. To have a full evaluation of the tractor, the competition is split into seven events that must be tested including: a written defense, a design defense, team presentation, design judging, tractor pull, durability test, and maneuverability test [2].

In 2022, the University of Kentucky Wildcat Pulling Team returned to competition (following a brief disruption due to the COVID-19 pandemic) along with 24 other teams. The team placed 3rd overall but had low gradings in certain events, like maneuverability (placed 15th), durability (placed 8th), and design defense (placed 15th), scoring 0/100, 80/200 and 52/82 points respectively in these areas. While the points available for these events are small compared to the more important categories like the written design, team presentation, and tractor pulling, these three areas combine for a substantial 16% of the total points available. In all other categories the team placed within the top 5 and was 23 points behind 1st place, so missing about 10% of the total possible points for the overall competition in these three categories made a large difference in the team's overall success (See Appendix A).

All teams have historically had difficulties excelling in both the maneuverability event and the tractor pull [3]. As seen in Appendix A, 15 of the 24 teams received no points in the maneuverability category. These two events are antithesis of each other. Pulling requires pull engagement, maximum power, and speed, while maneuverability requires maximum precision and control. While most of the drivetrain is built for both purposes, the clutch used plays an extremely important role in both events. However, identifying a single clutch that can provide maximum power and maximum precision is a challenge. This opposition in optimizing performance is very apparent, as teams that often do well in the pull traditionally do not do well in the maneuverability event, and vice versa. Few teams have discovered a perfect clutch or clutch combination that maximizes points in both categories. Filling the knowledge gap and finding the right clutch combination could lead to a significant point gain in the 2023 competition.

The clutch is an essential part of a tractor drivetrain. The clutch transfers the power from the engine crankshaft to the driveshaft using friction [4]. Power is transferred with parallel disks on either side of a disconnected shaft, where one end is rotating via a motor or a pulley. The disks get pushed together through centrifugal, magnetic, or mechanical force causing an engagement of a stationary shaft on the other side of the clutch [5]. An example of a coil clutch is shown in Figure 1. The springs push the disks together causing an engagement. The form of engagement is different in different clutches, but the principle of two plates connecting to create a pathway of movement is something all the clutch options have in common. In some cases, this engagement is instantaneous, where in others the plates are meant to slip on each other before fully engaging, causing a lower starting acceleration. Both mechanisms have their advantages and disadvantages. An instantaneous engagement where it is ensured that those plates will stay together, like in the case of a magnetic force keeping the plates together, is beneficial for the tractor pull section of the competition, where the tractor needs as much energy that the engine can produce. Gradual engagement is necessary for an enjoyable, smooth, and safe riding experience. The measurement of a gradual engagement indicates a level of comfortability as the tractor goes from still to moving. Signs of an unreasonable starting acceleration indicate head whiplash or the rider being thrown from the seat. Gradually engaging clutches also must stay engaged after a certain specific rotational speed threshold depending on the clutch. However, staying above this threshold can be difficult since the engine output speed is lowered during the pulling event. Additionally, the slippage is not as efficient, creating heat and wear on the disks.

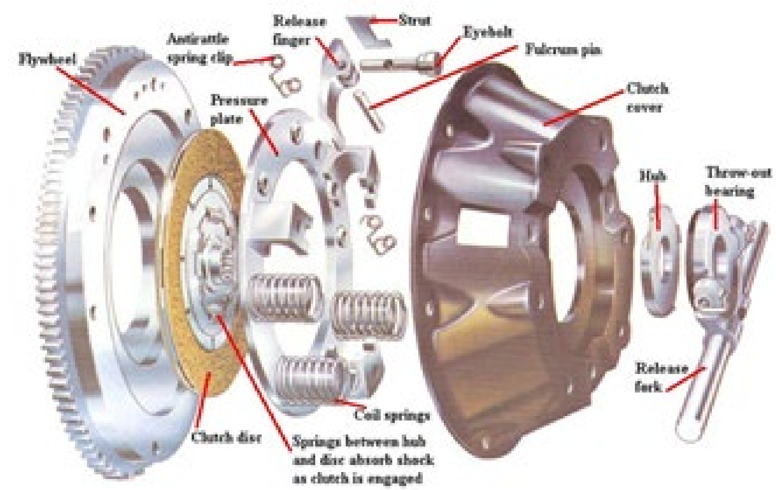

Figure 1 Exploded view of a coil clutch [6]

Objectives

The goal of this research is to provide a clutch design that can improve the score for the 2023 quarter-scale tractor over the previous year's competition score. The specific areas for improvement are maneuverability, serviceability, and manufacturability. This clutch is one component of the drivetrain design that is the focus of the Biosystem and Agricultural Engineering Senior Design group: The UK Wildcat Pulling Team Drivetrain team [7]. The assistance of this team was key to understanding the importance of an improved clutch design.

The main objectives of this paper include:

1) Comparing different types of clutches and clutch configurations to evaluate and discuss the important differences between each type. This evaluation will not only assist the competition team this year but also will be a categorized document that can be referenced in future iterations of the Wildcat Quarter Scale Tractor design. Researching alternatives is important to developing a new design.
2) Identifying the best clutch for the quarter scale competition application. The selected configuration will be tested to determine the total power output and the activation acceleration.
3) Designing a new clutch configuration with shielding and auxiliary components to interface with other subassemblies of the drivetrain and overall tractor to address certain needs specified by the Wildcat Pulling Team.
4) Documenting and reflecting on the author's specific contributions over the entire project since this paper is in addition to the overall senior design project.

This paper is mainly the author's contributions. However, since it is part of a larger project, additional help and contributions are acknowledged and indicated when appropriate.

Background

The Wildcat Pulling Team's 2022 tractor is the Wildcat 3122. This tractor uses a dual, parallel clutch design. Figure 2 shows the configuration of the clutch subassembly. The subassembly includes a mechanical 6-disk centrifugal clutch and an electric magnetic clutch, along with a timing belt pulley connecting the upper crankshaft to the bottom driveshaft. The centrifugal clutch is activated at 2700 rpm, allowing for a smooth engagement [8]. This smooth engagement makes the centrifugal clutch a good choice for maneuverability.

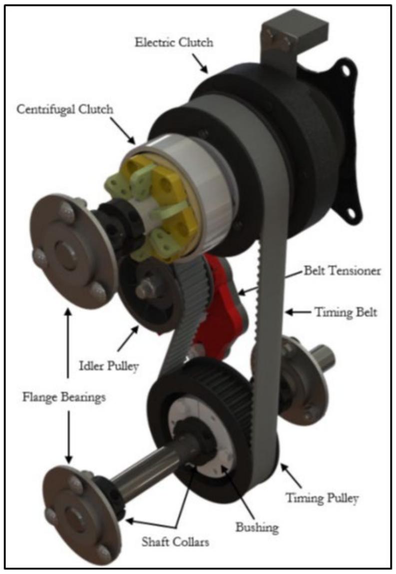

Figure 2: The Wildcat 3122 dual clutch assembly [8]

The electric clutch is ideal for pulling due to its ability to engage instantly without slipping and will stay engaged once activated. This clutch can transmit 40 hp from the engine to the transmission and is typically used for agricultural purposes [9]. Competition teams must use a 31 hp Briggs & Stratton engine, so 40 hp is more than enough for this application. The combination of the centrifugal and electric clutch works well together, with the gradual start from the centrifugal clutch and the total, unmoving engagement of the electric clutch; however, this configuration has a few drawbacks. One drawback is the rider acceleration at the clutch engagement. The centrifugal clutch engagement is at too high of an engine speed, resulting in a higher starting acceleration as the time of full engagement is the same regardless of the engine speed. Alongside that, the centrifugal clutch is unreliable and has been seen to break for many other teams during competition [3]. The use of a centrifugal clutch also requires perfect alignment, leading to a belt-system being necessary for this design where the clutch is held in place. This need for perfect alignment was addressed in the 2022 design by having the clutch fixed in place on both ends of the housing. The entire clutch system must be removed to change and service the belt. This configuration was found to be detrimental during the manufacturability portion of the design defense.

1. Different Clutch Varieties

Many clutch types are used from trucks to tractors to even large stationary machinery. The main three types of clutches are: manual, electric, and centrifugal. Each clutch type has different properties that may be ideal in certain situations, but not necessarily for the application in a quarter-scale tractor. The main purpose of the clutch is to distribute power. Power lost due to inefficiencies in the clutch is not ideal. For the tractor pull, the most important element is the torque [10]. A higher torque provides a stronger pulling force to pull the weight down the track. Power, torque, and speed are related, however, and that relationship is critical to understanding why certain clutches may work better than others. Power (hp) is calculated as

$$P = \frac{T \cdot n}{5252} \quad (1)$$

where T = torque (ft-lb), n = speed (rpm), and 5252 is a unit conversion factor from ft-lb·rpm to hp.

2. Manual Clutches

A manual clutch is often found in automobiles, and the operator controls the clutch engagement. The clutch engagement was provided through a linkage from the pedal in the driver's cab to the clutch. The pedal mechanism can be either a mechanical linkage, cable, or hydraulic circuit [11]. A pressure plate is fixed on one side of the clutch to release and engage the disks that are manually controlled via the clutch pedal (Figure 3). There are two main types of pressure plates: coil spring and diaphragm [11]. The coil spring has one large central spring on the back of the pressure plates to move the back plate. This spring contracts via the clutch pedal being pushed in, disengaging the disk connection by moving the pressure plate away from the disks (Figure 4). This type of clutch is most suited for heavy-duty applications as the main large spring can be changed and adjusted for different applications. The diaphragm pressure plate is the most commonly used and referred to when talking about a manual clutch. Instead of a central spring, long spring bars fan out around the main pressure plate bearing. As the clutch pedal is depressed, the spring bars are compressed forcing the bars and plate together and disengaging the connected clutch disks (Figure 4) [12]. The diaphragm design requires less force to control and takes up less space compared to a spring design [13].

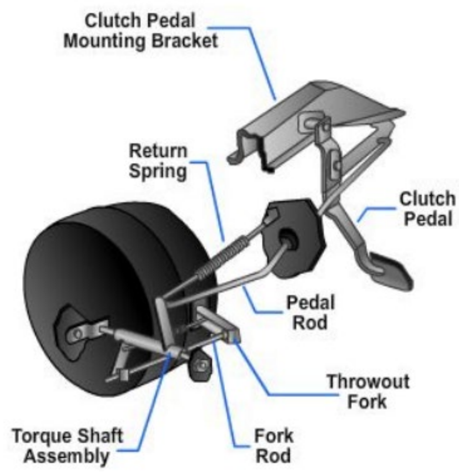

Figure 3: Example of a manual clutch [14]

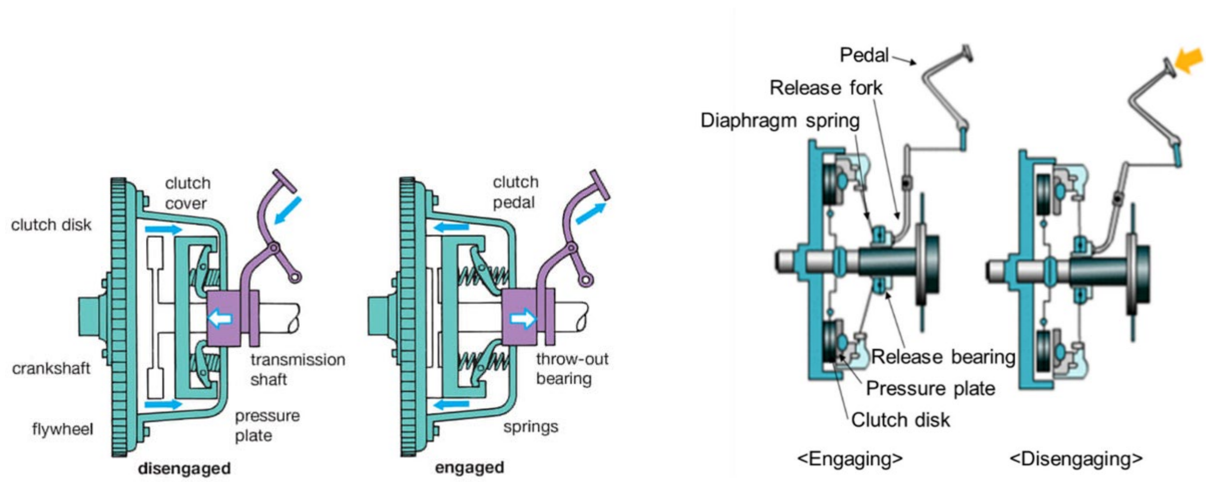

Figure 4: Example of a spring manual clutch [4] (left) and diaphragm clutch [15] (right) actuation. As the pedal is pushed in, the springs contract (left) and bars move in (right), removing the connection between the pressure plate and the clutch disk.

The main advantage a manual clutch provides is reliability and controllability. With the use of a clutch in cars, it is well known for heavy-duty applications. Additionally, the system is completely controlled by the operator via a pedal. This control allows for a range of speeds and the ability to control the rider's acceleration. Despite its advantages, a manual clutch may be excessive for the application in the quarter scale tractor drivetrain. To start, these systems are very expensive. To replace a clutch, it can cost anywhere between $1,229 and $1,419 (in 2020 dollars) [16]. This type of clutch also requires some training to be able to use it effectively, as it is not immediately intuitive to operate. On top of this, a manual clutch would be an over engineered solution as they are used for very high horsepower applications like cars, with power in the hundreds of horsepower, way more than the 31 hp used for the tractor engine. Space is also an issue with this clutch as it requires many parts and is a larger piece of equipment compared to other clutch options.

3. Electric Clutches

Electric clutches use magnetic force to connect the clutch disks together to create engine engagement. These clutches can be controlled via a servo controller and are versatile in every degree of engineering [17]. The configuration of these clutches is two metal disks on either side of the crank shaft that connect via a magnetic connection activated manually through an electric charge (Figure 5) [18]. The effectiveness of this connection is dependent on the power rating of the clutch and the magnetic ability to keep the two disks together via the electrical flux.

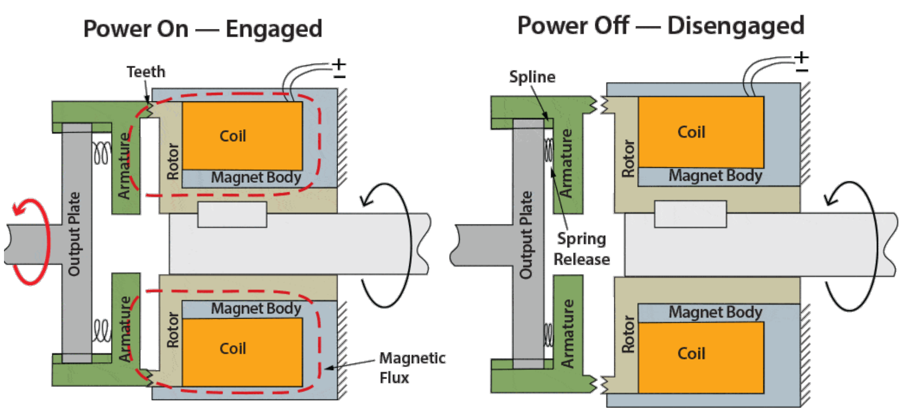

Figure 5: Example of electric clutch actuation [19]. When the power is turned on (left), the coils are energized and draw the armature towards the magnetic body, engaging the clutch. As the power is turned off (right), the spring contracts and brings the armature back towards the output plate and disengages the clutch.

The main advantage of an electric clutch is its reliability to stay engaged. The clutch is simply activated by the push of a button to activate the electronic elements. From anecdotal evidence, the electric clutch has been used for many years in competition by the Wildcat Pulling Team and has never broken [3]. Additionally, if the clutch is rated appropriately, the engagement of the clutch disks is very reliable because of the magnetic connection. It is more likely that the engine will stop working before the clutch disconnects [20]. On top of this, the electric clutch is extremely efficient. A magnetic engagement is one that is an instantaneous connection. Once the clutch is engaged, the disks are immediately pushed together, giving no room for energy loss through friction like the other clutch types. Since there is almost no friction, there is not as much heat generated inside the clutch housing. A major advantage to using a magnetic clutch is its simplicity. This piece can be fixed on either side of a shaft and will not move from that position. Where other clutches may need some piece to stay aligned, this is not the case for the electric clutch and this component can be used without a pulley system.

The electric clutch is a reliable option but has significant shortcomings. To start, the biggest advantage of using an electromagnetic clutch is the secure, reliable, and instantaneous connection. While those traits are great for applications in pulling, the instantaneous connection is detrimental to the maneuverability portion of the competition. The advantage of having slipping disks is to create a lower starting acceleration. In the case of the electric clutch, this connection is instantaneous, throwing the rider from their seat and turning the tractor from stopped to full speed. There are some ways to work around this, however. To start, electric clutches are controlled via a servo controller. This controller can be programmed to adjust the duty cycle and ramp duration [21]. By changing these parameters, the clutch can be programmed to have a softer connection and have time for slipping to create a softer start. Soft start controllers are sold that assist in creating a smoother starting connection. A soft start controller can also help with extending belt and mechanical life and eliminate engine stalling [22]. If the problem with the acceleration can be solved, this clutch may be a solid option for the tractor design.

4. Centrifugal Clutches

A centrifugal clutch has flyweights, often called shoes, that when experiencing a rotational force will fly outwards, pushing in springs to physically force the disks together causing an engagement. These clutches often have many disks that push into each other and are held together via friction [23]. These disks initially slide together and rotate as they are pushed into the adjacent disk to create a more gradual acceleration. As speed increases, the flyweights exude more force on the springs and the disks are pushed together harder, resulting in more torque that can be transferred for pulling applications (Figure 6) [24].

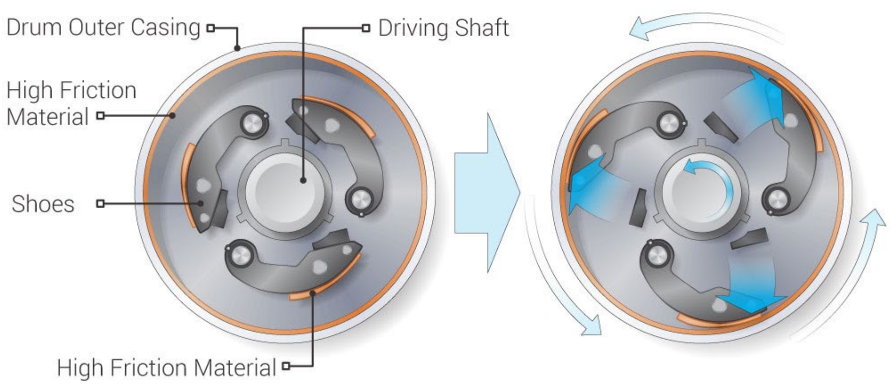

Figure 6: Example of centrifugal clutch actuation [25]. As the clutch starts spinning, the centrifugal force on the flyweights moves the weights outwards to create a friction connection with the disk engaging the other end of the shaft.

Since the engagement depends on the rotational speed of the flyweights, this clutch will automatically engage, requiring no user input besides speed control. Additionally, the many disks that are pushed together slip as each disk becomes activated. This slipping causes a more gradual acceleration since the engagement is slowed by the disks sliding past each other and losing rotational energy in the form of frictional heat. If the tractor is above a certain speed this clutch will not disengage, and as engine speed is increased, more torque will be transferred through the drivetrain.

While the centrifugal clutch seems easy to use and fits the purpose of a successful clutch to use in maneuverability, there are some downsides for the application of a quarter scale drivetrain. Since this clutch has multiple disks and relies on slippage, many opportunities for these metal disks to wear over time exist. Also, if one disk becomes disengaged, the whole system fails as there will no longer be a complete connection. To start, the automatic engagement of the clutch is not as ideal as it initially seems. For example, the lowest speed for the purposes of this competition was roughly 2700 rpm [26]. As the tractor is loaded during the pulling section, a tradeoff between torque and speed is observed, as indicated by Equation 1. If the speed threshold of the centrifugal clutch is too high, once enough torque is distributed the speed will drop below the threshold, disengaging the clutch. As the tractor goes through the pull, the clutch will most likely disengage prematurely, leading to a massive point loss in the biggest category of the competition. To work around this, a way to manually engage the clutch to keep it engaged may be the key combination to an effective clutch.

5. Clutch Selection Rationale

Each clutch type has its own advantages and disadvantages, but every design must have criteria to judge each design option. The tractor design must follow the ASABE IQS A-Team Rulebook [1]. This rulebook lays out all the necessary safety requirements that an eligible tractor must follow. Each clutch option was evaluated on the following criteria:

- **Costs:** The project budget must be less than $8,000, with significantly less going into the clutch subassembly. One factor to consider is the comparison between a manufacturer's retail price and a subsidized price that is a more realistic cost to the team based on the removal of labor costs due to help from volunteers.
- **Serviceability:** A significant component of the competition evaluation is the serviceability. Part of the judging is to completely remove the clutch from the tractor in less than 2 minutes [27]. The new design must comply with this rule, or a substantial number of points will be deducted. How the clutch attaches to the system is critical to having a serviceable product.
- **Maneuverability:** The ability to control clutch engagement is critical to the new design. A heavy emphasis is placed on improving this control by lowering the initial acceleration to be able to maneuver at low speeds, since the team failed in the maneuverability section of the 2022 competition. The level of speed controllability is critical to having a device that is easily maneuvered. Another aspect to improving maneuverability is creating an enjoyable riding experience for the driver by both having something easy to operate and not accelerating the driver too quickly.
- **Manufacturability:** The efficiency of the system should be the same or better than last year's design. Additionally, manufacturability is another point of judgement. Making a simple and easily replicated design is essential to the overall design of the clutch mechanism and the drivetrain as a whole. This criterion is essential to creating an ideal clutch design. The clutch determines the type of shielding that needs to be created around the piece. A design that is more compact requires less parts to create the piece and overall labor to assemble.

With all these factors to consider, maneuverability is the most important criteria for the clutch design, followed by serviceability and manufacturability, with cost being a way to eliminate complicated options but is overall not as critical as the other criteria under consideration. A few options of clutches can be eliminated by following these specific criteria. To start, the manual clutch is far too expensive and bulky for this application. While the manual option is perfect for both the pulling category (due to its high-power transferability) and maneuverability (due to its overall controllability), the high price, large size, complex design, and lack of availability for less powerful systems eliminates this clutch from consideration. A summarized comparison of the three clutch types can be found in Table 1.

Based on the remaining options, the best candidates are the electric clutch and the centrifugal clutch. The electric clutch is reliable and may be programmable. A motor servo controller can be used to adjust the slippage of the disks, resulting in a lower starting acceleration. Additionally, if this adjustment works, the electric clutch is ideal as it allows for a simpler design, like an inline driveshaft configuration. On top of this, efficiency increases by 2% when the drivetrain moves to an inline design, due to the lack of a belt system as seen in the 2022 design (Figure 2) [8] [28]. Alternatively, another option is to continue using a centrifugal clutch. The centrifugal clutch only engages at high speeds, which is not ideal for low-speed applications like the maneuverability course. However, one possibility is to incorporate components of other types of clutches to allow this centrifugal clutch to work better at lower speeds. One option is a manual hydraulic throwout bearing that pushes the clutch together to engage. The hydraulic bearing is only necessary at low speeds, like engaging soft movement in maneuverability and keeping the clutch engaged during the pulling portion of the competition, as the clutch automatically fully engages at higher speeds.

Table 1: Comparative analysis of the different clutch types for the application in the quarter scale drivetrain based on a 40 hp engine.

Clutch Type	**Cost**	**Serviceability**	**Maneuverability**	**Manufacturability**
Manual	$900- $1,500 [29] [30]	**Pros:** - Widely used, a lot of knowledge on how to fix **Cons:** - Complicated design - Many parts - Hard to install	**Pros:** - Operator controlled - Gradual engagement - A lot of controllability **Cons:** - Has a learning curve to operate	**Pros:** - Mass produced for automotive industry **Cons:** - Complicated design - Disks wear down over time
Electric	$150- $500 [31] [32]	**Pros:** - Simple design - Easy to replace **Cons:** - Hard to fix simple parts without total replacement	**Pros:** - Stays engaged completely - Operator engaged - No learning curve to operate **Cons:** - Engagement is instantaneous - No gradual acceleration	**Pros:** - Simple design - Few parts - Easy to install - Durable **Cons:** - Cannot be created in shop - Requires some knowledge of electronics
Centrifugal	$400 [33]	**Pros:** - Parts (disk, housing) are easily replaced - Simple design **Cons:** - Requires perfect alignment, taking more time to install	**Pros:** - Auto-engages - Gradual starting acceleration - No learning curve to operate **Cons:** - Requires speed threshold to engage - Will disengage under threshold	**Pros:** - Simple parts **Cons:** - Any misalignment will cause clutch to malfunction - Springs need to be exactly set for proper performance

Methodology

The biggest concern the Wildcat Pulling Team had with the clutch used in the 2022 competition was the ability for it to be durable and able to complete the maneuverability category of the competition. The electric clutch and the centrifugal clutch have potential to fit the function needed for their application, but both clutches must be modified in some way to reach that potential. This testing was completed with the assistance of the senior design team, along with support from Dr. Michael Sama[1], Brett Childers[2], and Dan Workman[3].

1. Electric Clutch Modification Testing

The goal of this test is to modify the servo controller code on the Ogura GP 51560900 electromagnetic clutch to adjust the speed and strength of the engagement for a smoother ride. The Ogura GP clutch had been favored by the team in previous years because of its reliability. However, instantaneous engagement does not allow for easy movement. The rider must stop and start again to move, leading to the rider being thrown from their seat at every engagement, resulting in an inefficient and uncomfortable driving experience.

Due to the lack of the electric clutch disks slipping, a test was conducted to determine the best conditions for controlling the engagement of the clutch by modifying the servo controller code and adjusting the electrical output to the electromagnet. The servo controller was reprogrammed using a Danfoss Plus+1 system. The conditions evaluated include different combinations of the ramp duration and duty cycle. Ramp duration determines the amount of time (in seconds) between the activation of the servo controller and actuation of the clutch engagement. With a slower ramp duration, the clutch takes more time before it is fully engaged, potentially allowing for more slipping or a gradual engagement. Duty cycle is a percentage of the pulse width module (PWM) output of the clutch. By changing the PWM, the overall strength of the clutch is modified as the electromagnets receive less power to engage. The testing conditions can be seen in Table .

To conduct this experiment, the centrifugal clutch was removed from the 2022 tractor to provide an accurate representation of how a single magnetic clutch system would function. After reprogramming the clutch, a rider turned the tractor into 3rd gear and started the tractor. The rider stopped and started the tractor three times per trial. The "Physics Toolbox Accelerometer" App (Vieyra Software), a recording accelerometer, was attached to a rider to record the starting acceleration of the tractor. Four treatments and factory setting (baseline) conditions were assessed by changing the duty cycle and ramp duration (Table 2).

Table 2: Testing conditions for the electric clutch verification

Test	Duty Cycle (%)	Ramp Duration (s)
Baseline	100	2
T1	100	5
T2	50	5
T3	25	5
T4	10	2

[1] Associate professor, Department of Biosystems and Agricultural Engineering
[2] Engineer Technician Associate, Agricultural Machinery Research Laboratory
[3] Engineer Aid Principal, Agricultural Machinery Research Laboratory

2. Centrifugal Clutch with Hydraulic Throwout Bearing Testing

A centrifugal clutch with a hydraulic throwout bearing was evaluated to determine the logistics of this configuration to manually engage the centrifugal clutch. In concept, the hydraulic throwout bearing extends and rotates with the clutch, physically pushing the disks together and engaging the centrifugal clutch. Some concerns occur with the overall durability of this configuration and whether the hypothesized outcome will work at all. By using the throwout bearing, the centrifugal clutch can be activated at speeds lower than the engagement threshold speed (2700 rpm for this application) and gently push on the clutch to create more slipping in the clutch for a slower engagement. Instead of a button like the electric clutch, the hydraulic throwout bearing is activated via pushing on a pedal. This mechanism is like the manual pedal, but works in opposite, as pushing the pedal in extends the bearing, engaging the centrifugal clutch.

To evaluate whether the clutch engaged with the use of a throwout bearing, a temporary version of the final design (See Appendix B) was placed on an engine dynamometer (DYNOmite Land & Sea water-break dynamometer). The engine was turned on and the engine speed was adjusted below the 2700 rpm minimum to activate the 4-disk, 6-spring Bully centrifugal clutch. The throwout bearing was extended manually by a pedal pushing fluid from a hydraulic cylinder into the throwout bearing. As the throwout bearing is pushed in, the engagement and movement of the bottom driveshaft were recorded. Additionally, any wear in the throwout bearing or the clutch flywheels was recorded.

Once the bearing was confirmed to work without substantial damage, a dynamometer pull was conducted to determine the peak power output. A dynamometer pull simulates a load on the system. As the dynamometer is tuned, more torque is applied to the engine. As shown in Equation 1, an indirect relationship between torque and rotational speed exists, so as the torque increases, the rotational speed decreases. The throwout bearing was activated the entire time the dynamometer was loaded, and the torque and speed were recorded.

Results and Discussion

Additional evaluations of the electric clutch and the centrifugal clutch were conducted to verify the optimal selection for the final design. The electric clutch must significantly decrease the rider acceleration while also providing a durable option to withstand the pulling application. The centrifugal clutch must be able to engage manually without any damage to any elements in the configuration.

1. Electric Clutch Testing Results

For the electric clutch testing, the maximum duty cycle and ramp duration were adjusted to determine whether these parameters, or some combination of these parameters, could decrease rider acceleration at the moment of clutch engagement. Finding the right combination is key since the duty cycle must not be decreased significantly from the factory settings as the overall magnetic strength of the clutch head may be impacted. The testing results can be seen in Figure 7.

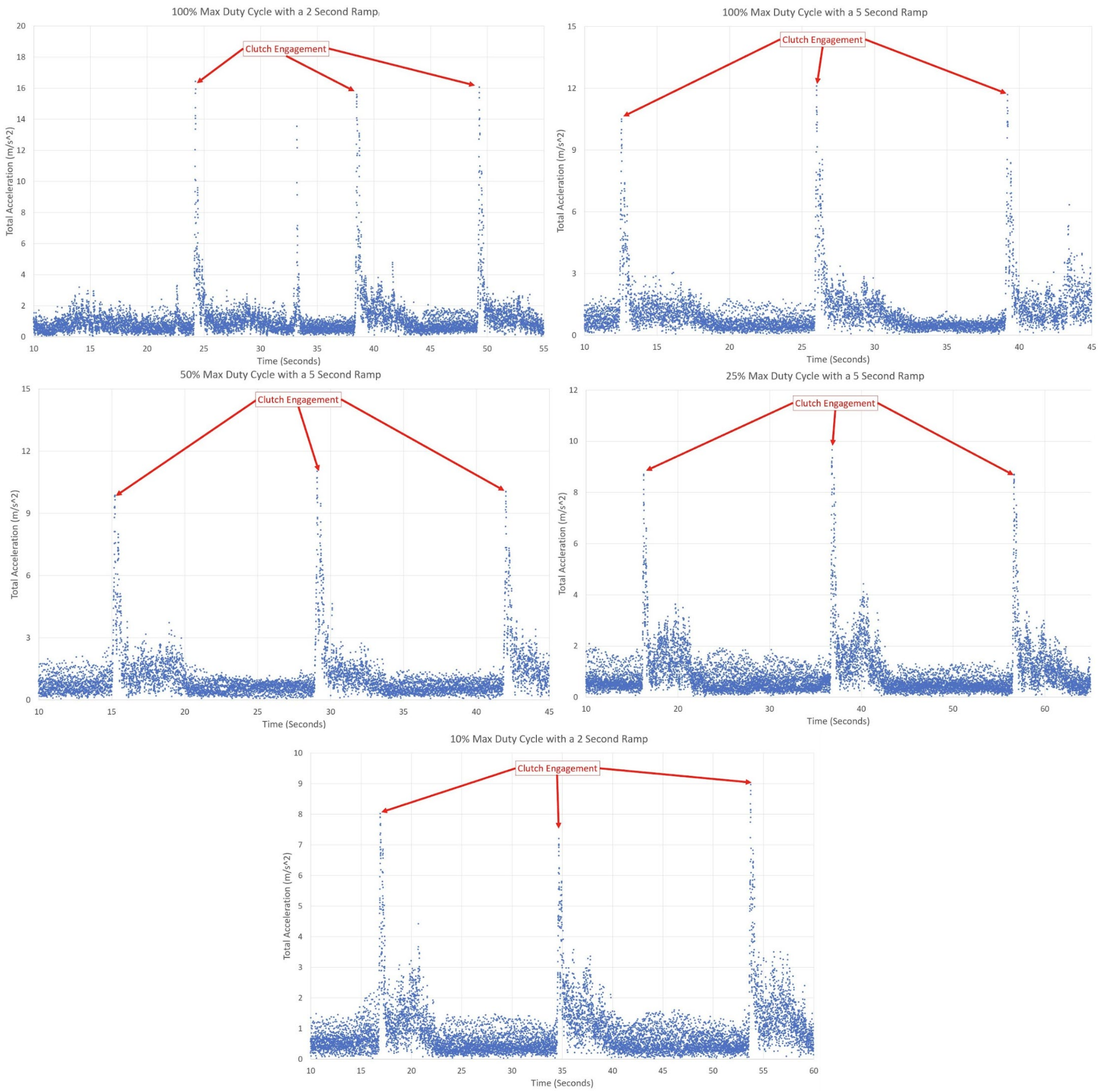

Figure 7: Graphed accelerometer data for the electric clutch testing. The peaks are points of clutch engagement, showing the starting acceleration for each trial.

Based on the data in Table 3, the acceleration decreased significantly by adjusting the ramp duration and duty cycle. Comparing test 1 (T1) to the baseline conditions, the acceleration decreased by 24% when the ramp duration increased by 3 seconds. By increasing the ramp duration, the electrical output takes longer to reach its full potential. The coils (Figure 5) are energized slower creating a more gradual attraction of the magnetic disks. However, despite the numerical difference in acceleration during test 1, from the rider's experience, this acceleration felt very similar to the baseline test. It appears that the perceived rider acceleration decreased along with the duty cycle but did not change when decreasing the ramp duration.

Table 3: Reported values of electric clutch testing with testing conditions.

Test	Duty Cycle (%)	Ramp Duration (s)	Maximum Acceleration (m/s^2)			
			Trial 1	Trial 2	Trial 3	Average
Baseline	100	2	16.5	15.8	16.1	16.1
T1	100	5	10.5	12.4	11.8	11.6
T2	50	5	10.0	11.4	10.1	10.5
T3	25	5	8.8	9.9	8.7	9.1
T4	10	2	8.1	7.3	9.0	8.1

While there was a numerical decrease in acceleration, changing the electric clutch parameters did not make the biggest difference when it came to how the rider felt. From the qualitative data, the rider still experienced their head whipping back and showed very little to no difference in positioning as the tractor started. Despite the rider feeling like the acceleration changed when the duty cycle changed, the slope of the peaks did not change, determining how quickly that acceleration change was for the rider. In Figure 7, there is no slope to the peaking data, it is virtually a vertical line, indicating that the peak acceleration was felt almost instantaneously of the clutch engagement. Additionally, the rider still appeared discomforted as their head snapped back once the tractor started. Videos of the trials showing the rider's experience can be found on the team website [34].

Beyond there being little physical looking or feeling of difference in acceleration, the electric clutch does not seem like a viable choice due to the conditions needed to operate the device. Changing the duty cycle limits the total power output to the energized coils. By decreasing the duty cycle, the clutch's magnetic strength is decreased. This decrease in strength has the team concerned that the clutch may fail during the pulling portion of the competition due to inactivating prematurely since the clutch cannot hold together pulling such a significant load. The team had additional concerns about the durability of the clutch by changing the ramp duration. The ramp duration makes the connection between the disks slower, allowing for more opportunities for the clutch disks to slip and create a gradual acceleration like the centrifugal clutch slipping. While the clutch did not appear damaged during testing, it was impossible to view the inside disks to see any damage and, regardless, the testing was over a short period of time with limited use of the clutch adjusted in this manner to see any damage. Electric clutches are not designed to slip, and their disk surfaces are not high friction materials like those seen in centrifugal and manual clutch disks. Using a device past its intended use is never a good idea and could potentially be very dangerous. For these reasons, the electric clutch will not be used in this tractor design as the testing did not result in significant enough changes with a major drawback of affecting the quality of the device.

The rider testing works as a good baseline trial for the use of a single electric clutch, but the testing has a few shortcomings that prevented a definitive answer. Experimental practices could have been improved to show a better understanding of the specific impact changing the ramp duration and duty cycle had on the starting acceleration. The experiment could have been designed to hold one of the constraints constant while changing the other in equal intervals to better represent the change in acceleration based on the conditions. Beyond changing the experimental design, it would have been beneficial to see if the team's suspicions were correct in assuming the electric clutch does not have the longevity for the required application. More tests could have been conducted to really show wear and perhaps to determine if the device could handle the stress of an example tractor pull. The clutch should have been taken apart at certain points to evaluate the extent of damage to the disk. While taking apart the clutch may be excessive, this would be the only way to truly determine if the clutch would have the longevity for the application.

2. Centrifugal Clutch Testing Results

The biggest concern with the centrifugal clutch was the need for it to be activated at such a high speed (2700 rpm). No options were available that activate at lower speeds and adjusting the mechanism to work at lower speeds can be dangerous and break the device beyond repair. A new way to manually override the clutch was considered as there was a need to replace the electric clutch, which was the manual override for the 2022 tractor. An automotive hydraulic throwout bearing was used and tested with the centrifugal clutch. This test used a dynamometer to simulate a running engine and loaded engine would act with the hydraulic bearing. This served multiple purposes: to test if the hydraulic bearing would engage the centrifugal clutch, if the hydraulic bearing would cause physical damage to anything in the system, and to get a power curve to compare the power of the stock engine to the clutch system. The data recorded was both quantitative and qualitative, with recorded dynamometer data for a simulated pull and a visual analysis of the clutch activation.

The centrifugal clutch worked as expected based upon visual observation. The clutch activated softly as the pedal for the throwout bearing was activated and stayed activated as a load was applied. No visual damage to either device was apparent, which was the biggest concern of the team. However, this design had a few brass spacer pieces that did see significant wear as testing continued, affecting the distance between the throwout bearing and the clutch head. The wear was so significant the bearing was too far away to properly activate the clutch. Additionally, the entire system got extremely hot. While heat in the area was not measured, heat could be felt radiating off the configuration from 3" away. While this significant heat is not something to be ignored, the clutch was activated for a long period of time and the clutch and system is designed to handle such high heats based on their material makeup.

Based on the quantitative data in Figure 8, the peak power of the throwout bearing setup shows to be 23.1 hp compared to the stock engine peak power of 24.9 hp. The stock engine data was taken on the same engine simply using a belt and pulley system without any clutches or other attachments. A belt system was used to obtain a realistic baseline for the power as the engine used is old and will not distribute the total 31 hp that it promises. The testing of the baseline system does distribute more power than the throwout bearing tests, however, during testing there were complications with the engine governor not being able to adjust correctly, causing the manual output of the engine to be lower than the stock 31 hp. This governor would not allow for adjustment and, thus, the curve shows less power distributed. Theoretically, the only place of power loss would be the belt. The throwout bearing and clutch should distribute 100% of the power that enters the system since there is no slipping of the clutch on the rotating shaft (just slipping between the disks of the clutch). The slipping of the disks in the clutch reduces power output at engagement but once the disks are stuck together and fully engaged, power should never dissipate from the system. More importantly from these tests is to demonstrate the importance of the throwout bearing with the centrifugal clutch. At 2700 rpm, the clutch would disconnect, having the system lose all the consistently applied torque after the engagement threshold. Additionally, this test provides evidence that the hydraulic clutch will function well for the pulling competition since there was a total engagement for the entirety of the dynamometer tests.

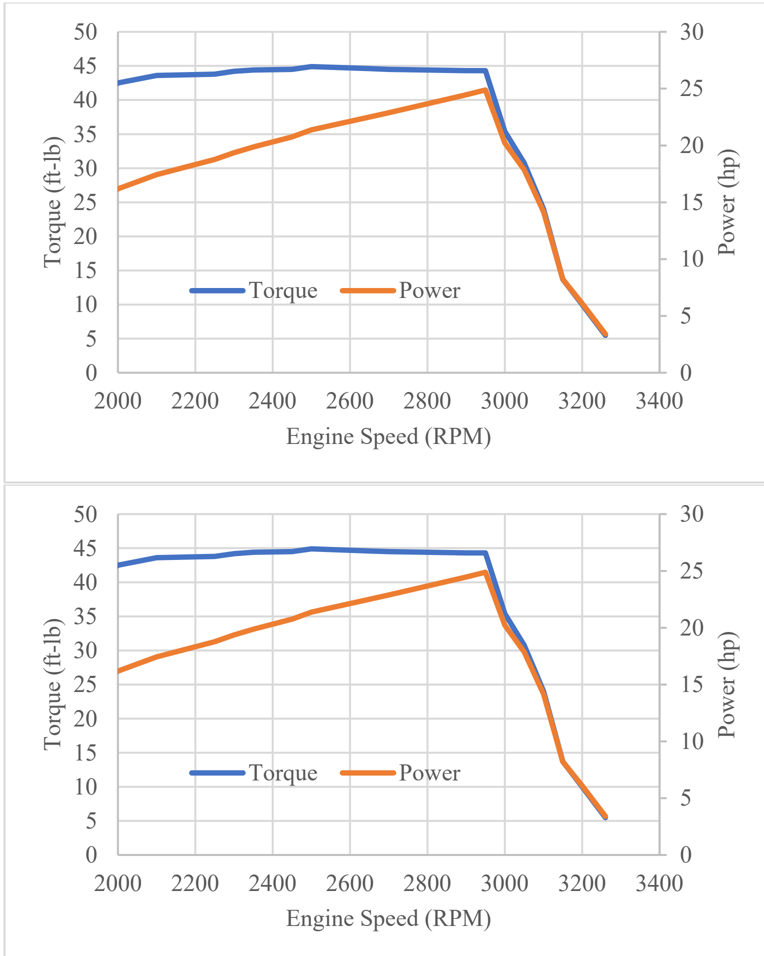

Figure 8: Testing results of the base engine with a belt system (top) and the centrifugal clutch-throwout bearing configuration (bottom). Both configurations were done of the same engine and dynamometer. The graphs show the torque vs speed and power vs speed.

Overall, the centrifugal clutch with manual override via an automotive hydraulic throwout bearing showed to be successful. While it does have some shortcomings in the brass spacer being worn down and the system producing heat, the throwout bearing is a simple and compact solution that has been proven to work. The advantage of doing this testing is being able to change the design for the final based on the observations from this test. To start, a spacer must be made to keep the spacing of the throwout bearing to the clutch consistent. Also, the pedal for the hydraulics was slightly uncomfortable to activate as it required a lot of force to fully engage and keep engaged. This could be changed by increasing the lever arm of the pedal or decreasing the size of the hydraulic cylinder to increase the pressure in the system. Additionally, the tensioner arm for the belt was a fixed tensioner and would shift away from the belt, releasing pressure and decreasing system efficiency. A key aspect of the final design was implementing a spring tensioner that can be used to push the belt in more as the belt wears out but be able to pull back to remove the belt. All these changes can be implemented into the final design to create a more refined protype.

3. Design Aspects

Since testing of the centrifugal clutch with the throwout bearing showed promise and the concerns with the electric clutch were unresolved, the senior design team proceeded with a design around the centrifugal clutch. The centrifugal clutch requires precise alignment to work properly. The disks do not engage if not aligned correctly due to the uneven rotating weights that cause the pushing force on the disks. Centrifugal clutches use belt and pulley systems where, instead of activating the other side of a shaft, the clutch instead activates the rotating pulley. A belt and pulley system connects the engine crankshaft with the clutch to the driveshaft, attached to the transmission. The belt transfers 98% of the power from the engine to the driveshaft below [28]. While this 2% inefficiency is not ideal, there is no alternative to using a belt with a centrifugal clutch design, and overall is a very marginal energy loss.

To improve on last year's design, the driveshafts are cantilevered between the engine and the driveshaft making the system more compact. A more compact and simplified design compared to the previous year was desired. The 2022 clutch subassembly had massive serviceability concerns as the rotating shafts were wedged between two housing plates. The two sides the shafts were not easily removable due to their attachment to the housing, leading to the belt being almost completely inaccessible. To replace the belt the entire housing had to be taken apart, threatening misalignment of the clutches when reassembling the subsystem. The changes in the new design have a cantilevered belt that has a free-floating end, leaving an open face which allows all the parts to be easy to assemble while maintaining access to the belt, significantly increasing serviceability over the 2022 design. Additionally, the system is far more compact. While some space is saved due to the removal of the electric clutch, the throwout bearing takes its place. The removal of a secondary shaft on the crankshaft saves the most space. In the previous year's design, there is a quick-disconnect coupler connecting the engine crankshaft and secondary shaft that holds the clutch subassembly. This coupler takes up around 4" of linear space on the shaft and must be shielded, adding weight and bulk to the engine area. The new design removes this secondary shaft and replaces it with an extension to the crankshaft. The shaft is overall 10.75" shorter than the 2022 design, and the whole subassembly can be attached straight to the engine, removing the need for separate housing around the quick-disconnect coupler. To further reduce the bulk, a custom pulley was created to fit around the centrifugal clutch. With a more compact design, the shafts could then be cantilevered. A reduction in size is important to avoid system failure by the system collapsing in on itself due to too large of a moment arm on the top and bottom shaft.

With the design limitations of implementing the centrifugal clutch, the configuration is relatively rigid on the possible design variations. The piece that can change significantly is the clutch subassembly housing. As the rules state, the housing must be encapsulated by at least ¼" thick aluminum or 1/8" thick steel and does not have a hole larger than ¼" in diameter anywhere in the structure [1]. Aluminum is used mainly if a piece is CNC-milled, where steel is more versatile as it can be plasma cut and bent into different shapes. Depending on the complexity of the part, the different metals have their own advantages and disadvantages. A design that was more compact and featured the cantilevered shafts was desired.

3.1 Milled Aluminum Housing

The team developed a more fitted and sleek housing design to encapsulate the clutch subassembly. The best way to get a fitted housing is to use milled aluminum. Some major advantages to using aluminum are that it can be shaped to a specific outline via CNC milling and is significantly lighter than steel. One disadvantage is that the CNC mill is only so big and for a subassembly of this size, the design may not physically be able to be machined due to the limitations of the available milling equipment.

The housing featured in Figure 9 consists of two milled aluminum pieces: a backplate and cover. The backplate has holes to fix the piece directly onto the engine. This backplate has specific fittings for an idler pulley and outside flanges to use to clamp the fixture shut. The cover is a simplified mirror of the backplate, as it does not have any holes and is simply a cover with flanges to match with the backplate. The two pieces are held together with 1" bolts.

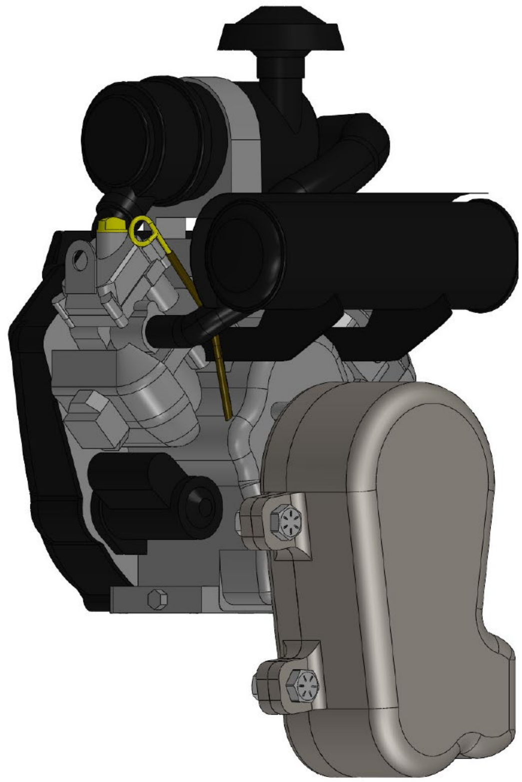

Figure 9: Aluminum milled clutch shielding with the Briggs & Stratton Engine.

While this design was fitted to the clutch subassembly, it was far from a good option due to the inability to mill the shielding as designed since the cover was too thick. The shape of the shielding was something the team highly admired, but the inability to mill the parts due to the size and specific rounding requirements eliminated this design as a housing option. Additionally, a 1” bolt was significantly too large for this application.

3.2 Contoured Sheet Metal Housing

To build off the milled housing design, the main feature the team loved was the contoured design. Since aluminum could not be used to create this contoured design, a sheet metal part was created instead. While steel is far denser than aluminum, its advantages are its ability to be welded and cut via plasma cutting. While aluminum can be welded, the melting point is much lower than that of steel, leading to potential warped parts, being overall much trickier than welding steel. On the other hand, steel parts can be bent and welded together to make nicely fitted structures.

The housing in Figure 10 is a similar structure to the milled aluminum housing in Figure 9 except it is made of sheet steel instead. The housing consists of a backplate and cover like the original design. The side cutout is intended for the idler pulley tensioner, providing a large enough space for any selected tensioner. The backplate has all holes necessary to mount to the engine and house other attachments like a throwout bearing spacer, a bottom driveshaft bearing, and a belt tensioner. On the other hand, the cover is a more complicated design. The cover incorporates bent pieces along with side walls that are welded in place. The bending process requires over 90 degrees of clearance space between bend angle to be able to bend, thus some sides could be bent while others could not. To reduce the number of welds necessary, the larger sides were picked to be bent. The cover was attached to the backplate through bolts going into the weldnuts on the backplate. The advantage of this design is the cover can be removed completely, allowing the clutch subassembly to be accessible.

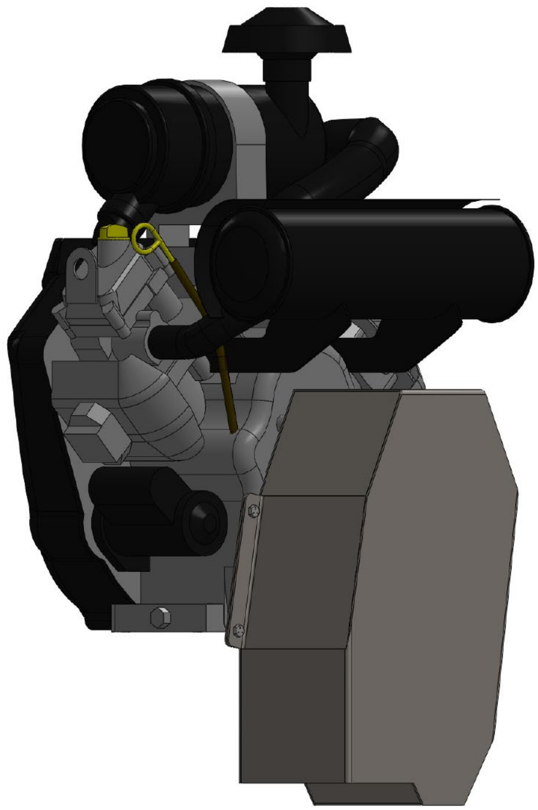

Figure 10: Contoured sheet steel clutch shielding with Briggs & Stratton engine.

While this design is possible to fabricate, it is not ideal due to the complexity of some of the components. First off, there are a lot of parts to weld onto the cover. The shaping is very interesting but looks clunky with the extra box on the side for the idler pulley. Additionally, the flanges did not look good, and some would be inaccessible due to the tractor frame covering some of the holes. Without the nice molding that the milled aluminum would provide, the design looks clunky and overengineered without a purpose. This overengineering could cause the team to lose points in their design defense due to not having a functional reason for the complicated design. While the idea of an attached backplate and removable cover is still good, the design needs to be reduced significantly to be manufactured easier and be more aesthetically pleasing.

3.3 Simplified Sheet Metal Housing

The main critiques from the contoured sheet metal housing are that the flanges on the outside should be incorporated to face inwards, and the design was far too complicated. Matching the specific pieces to the spot that needed to be welded, along with bending some parts and not others was confusing and unnecessary. A simpler cover design could be incorporated instead of the complicated shape of the contour housing.

The design in Figure 11 is like the contoured sheet metal housing but improves from it by having an elongated octagon shape and the flanges welded toward the inside of the housing. The individual components that require welding to create the cover are reduced to four and are all the same piece to avoid confusion during assembly. Additionally, this housing is more compact than the contoured housing. In the top half, size is significantly reduced, and the size of the bottom half is similar to the contoured housing. An advantage of the cover-type housing is the ability to completely remove the lower driveshaft. In previous years' designs, it was nearly impossible to remove the driveshaft for repair. In the new design, the bottom shaft is removed at the transmission end and can be slid out the clutch end.

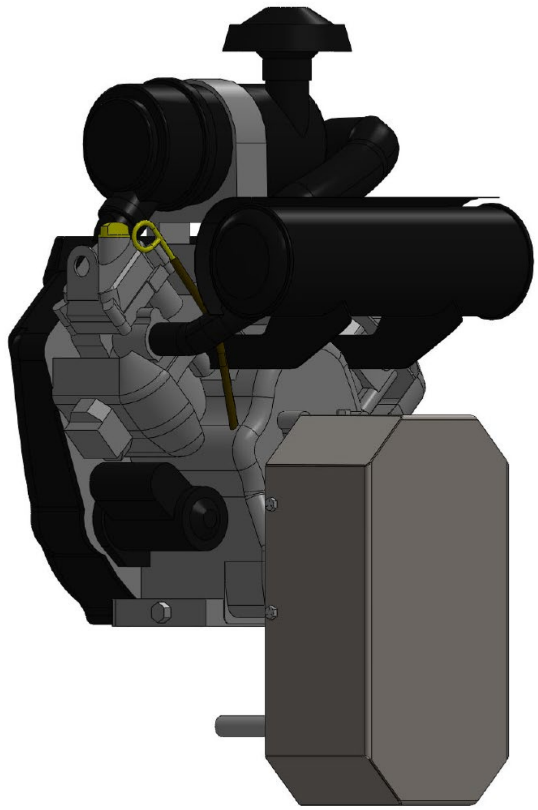

Figure 11: Simplified sheet steel housing in full assembly with portion of lower driveshaft and Briggs & Stratton engine. The welded sides are the four corners of the clutch cover.

Fabricating the housing required a variety of techniques. The housing was made completely of 11-gauge sheet metal. The sheet metal was cut via a plasma cutter and cleaned using chisels and grinders to remove excess slag. The sheet steel was hand bent in a panel bending machine to create another dimension. Four small wall pieces were welded to create the overall frame of the cover. To create a perfect fit, the backplate had to be ground down to fit completely inside of the cover. Four pieces of angle ¼" iron was cut to 1" sections and welded to the backplate to create flanges. Holes that aligned with the holes in the cover were drilled into the welded angle iron and weldnuts to the back of the holes to create stationary location to insert the bolts. The backplate was welded to the engine mount, creating a sturdy design that should not cause misalignment. Another fabricated piece is the throwout bearing spacer. The spacer was machined from aluminum via a CNC-mill. Future improvements of the design would have the spacer be slightly thicker to have the throwout bearing closer to the centrifugal clutch, and replacing the tensioner belt with a smaller, less spring loaded, tensioner.

Motivations and Reflection

My academic background is in Food and Bioprocess Engineering, and I do not come from a farming background or know anything about cars or motored vehicles, so the entirety of this project was something completely foreign to me. Starting this project, I was interested in doing a completely mechanical project, as it could have impacts for my future in creating food systems. When selecting this design project, I wanted something with more autonomy and support, and working on the drivetrain for the quarter scale tractor was the best option as I not only had people on the team that knew the project's needs on my senior design team, but I also had the support of the entire club and faculty advisors who specialized in the machine systems field.

A big part of this project was working in the AutoCAD software SolidWorks to create a design. I had some experience in simpler AutoCAD software to make some 3D printed parts for other class projects, but completely fabricating something that needed to be exact and standardized was new to me. My first experience in SolidWorks was redesigning the drivetrain for the first tractor design iteration. This process had me making parts, fetching parts from parts databases, assembling the product, and creating drawings of both the individual parts and the assemblies. This required making some sheet metal parts along with modifying pre-drawn models. While creating models in SolidWorks was very important to our process, the purpose of creating these models was to actually fabricate them. The most rewarding part of the design process was getting a physical product. I have close to no experience working with metal, bolts, or machinery in general, so this fabrication step was something I struggled to find myself useful compared to my group members who had been working with these tools for most of their adult lives. As I was tasked to do parts of the fabrication, I felt far more confident in my abilities, and I found myself being far more essential to the building process than I had originally thought. I now know how to work a plasma cutter, bend sheet steel, work with a multitude of hand tools, and have a better look into what goes into fabrication. I wish I had pushed myself harder to be braver to use some of the bigger tools, but from barely knowing how to use a drill before building a tractor, I think I made enough progress to make myself proud.

As the project continued, the most prevalent theme is change in iterations. To start, the design initially relied on the electric clutch, completely changing the drivetrain from the 2022 design and not looking recognizable to the final 2023 design. Testing the electric clutch, the team determined the electric clutch alone was just not going to work for this application. The team had to adjust the design and did the testing with the hydraulic throwout bearing and centrifugal clutch and discovered this configuration would work great for this application. Based on the clutch changes, the entire design had to switch again. The new clutch configuration off the engine was developed by Dr. Sama, and I had complete control over the design of the housing, bottom driveshaft, and belt tensioner. The iterative process was used a lot as I consulted with the team and faculty advisers to see possible changes to the design. The milled aluminum housing had only been developed to the base design before the team decided it would be physically impossible with the available machines to make the part as designed. This is where I had to pivot and use the advice of those around me to create a sheet steel housing instead. This design progressed further as the bottom driveshaft and tensioner were fleshed out more than the previous iteration before it was finally evaluated. Upon evaluation, the design was deemed too complicated and hard to fabricate, so I had to pivot again. Thankfully, everything but the housing was created well so only those parts had to be remodeled. Even during fabrication some changes had to be made to the piece. The flanges welded to the backplate were supposed to be plasma cut sections that were welded on. From fabrication, these pieces were far too small and would be difficult to weld, so we switched to using angle iron instead. This process can be frustrating as all those hours I put into working in SolidWorks felt wasted because I did not ask questions soon enough to make the change or did not want to make a change out of laziness. Overall, I look back at the original designs and I ask myself what I was thinking when looking at the sleekness and simplicity of the final design. I think the best designs are the right balance of both simple and effective. As the iterative process continues, it can be too easy to focus on only functionality and effectiveness but creating an over engineered design is wasting materials and resources.

My experience with Senior Design was overall very positive. The composition of the team allowed us to really lean on each other's strengths. I think I am a diligent worker that can do most of the documentation part of design and will complete any assignment given to me, but I have no experience in fabrication or machine parts in general. My other group members were both experienced in the field of fabrication and overall machine inner workings but did not necessarily love the documentation side. One of my partners was extremely well versed in design in AutoCAD. He mentored me in using the software and was an amazing check for whether my ideas were viable. Overall, his role was to filter and change any parts the other group members had made to make the whole drivetrain more cohesive. We also helped each other out with completing the engineering drawings for every component. My part on this team was filling in the gaps where other people needed help while also wanting to own a specific part of the tractor, which for this design is the clutch. Beyond the senior design small group, our faculty advisors were a lot of help in consulting on the more technical mechanics and presentation parts of the class. For instance, after the failure of the electric clutch, Dr. Sama helped us by not only suggesting the throwout bearing with the centrifugal clutch, but he even designed the engine crankshaft configuration for us to use for testing and on the real tractor. The team did not have quite enough technical skills to complete this task and we were able to have someone with far more experience guide us. While I did a large portion of the clutch design, a great design does not reflect just one person's ideas.

Overall the biggest physical contributions I had for the final senior design project include: proofreading milestones and updating the website, taking photos over the entirety of the project, writing procedures for testing, completing the clutch design in SolidWorks along with some of the drawings for the subassemblies, completing the first iteration of the driveshaft in SolidWorks with drawings for all parts in the assembly, contributing to the final bill of materials, design package, and design report, completing the entirety of the poster and producing the poster voice-over presentation, along with participating in all of the testing and fabrication activities and every meeting.

Conclusion

The goal of this project was to change the UK Wildcat Pulling Team's drivetrain for the new 2023 tractor for the ASABE International Quarter Scale Tractor Student Design Competition. The previous design used an electric and centrifugal clutch in parallel but had issues related to the maneuverability, manufacturability, and serviceability that needed to be addressed for the next iteration. There are several different types of clutches: manual, electric, and centrifugal. A manual clutch allows for better maneuverability due to pedal control but is very expensive and complicated. An electric clutch allows for instant engagement at a click of a button, but this does not allow for easy maneuverability as the instant engagement provides a large starting acceleration. A centrifugal clutch uses rotational force to engage at a certain speed threshold automatically allowing for smooth maneuverability, but the clutch only activates above the rotational speed threshold, which is too high for this application. The team decided to test the electric clutch and centrifugal clutch with manual override to determine their viability for the application. The electric clutch had the duty cycle and ramp duration modified to adjust the starting acceleration. The adjustments did not work as the rider still experienced significant starting whiplash and there were concerns with durability. The centrifugal clutch used a hydraulic throwout bearing to manually override the engagement threshold on the centrifugal clutch. The testing done of this configuration showed positive results as there was not a significant power loss and the configuration worked perfectly to engage the centrifugal clutch smoothly and gradually below the speed threshold of 2700 rpm without any wear on any of the parts. Based on the success of the centrifugal clutch testing, the throwout bearing with the centrifugal clutch configuration was selected for use in the final design and mounted directly to a cantilevered engine crankshaft. An iterative design process was used to find the most ideal housing design for the clutch subassembly. The final design is a belt driven system with two cantilevered shafts connected on the backplate with a completely removable cover, allowing for significant serviceability.

Acknowledgements

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Appendix A: 2022 Competition Placements

In 2022, the University of Kentucky Wildcat Pulling Team returned to competition (following a brief disruption due to the COVID-19 pandemic) along with 24 other teams. The team placed 3rd overall but had low gradings in certain events, like maneuverability (placed 15th), durability (placed 8th), and design defense (placed 15th), scoring 0/100, 80/200 and 52/82 points respectively in these areas. While the points available for these events are small compared to the more important categories like the written design, team presentation, and tractor pulling, these three areas combine for a substantial 16% of the total points available. In all other categories the team placed within the top 5 and was 23 points behind 1st place, so this 16% of the score made a large difference in the team's overall success.

The tables below include the overall scoring for the ASABE 2022 International Quarter Scale Tractor Design Competition. The overall winner was South Dakota State University, with the University of Kentucky placing 3rd overall. The highlighted entries are individual category results for the University of Kentucky (Figure 12). Points for each category are indicated in Table 4. The overall competition placements can be found in Table 5.

RANK		OVERALL	WRITTEN DESIGN	DEFENSE OF DESIGN	TEAM PRESENTATION
1	1	South Dakota State University	Iowa State University	University of Nebraska	University of Nebraska
2	2	University of Missouri	Kansas State University	University of Manitoba	University of Saskatchewan
3	3	University of Kentucky	University of Saskatchewan	University of Saskatchewan	University of Kentucky
4	4	Iowa State University	University of Manitoba	Iowa State University	South Dakota State University
5	5	University of Nebraska	University of Kentucky	North Dakota State University *	Iowa State University
6	6	North Carolina State University	University of Nebraska	McGill University *	Kansas State University
7	7	Universite Laval	North Carolina State University	University of Illinois *	Universite Laval
8	8	University of Saskatchewan	Oklahoma State University	South Dakota State University *	North Carolina State University
9	9	North Dakota State University	South Dakota State University	Kansas State University	North Dakota State University
10	10	Kansas State University	Universite Laval	North Carolina State University	Purdue University
11	11	Purdue University	University of Missouri	University of Missouri	University of Missouri
12	12	Cal Poly State University	North Dakota State University	Penn State University	Texas A&M University
13	13	University of Illinois	University of Illinois	Oklahoma State University *	Oklahoma State University
14	14	Texas A&M University	Purdue University	Ohio State University *	Cal Poly State University
15	15	Penn State University	Texas A&M University	University of Kentucky	Penn State University
16	16	Oklahoma State University	Penn State University	Universite Laval	University of Tennessee - Martin

RANK		DESIGN JUDGING	TRACTOR PULL	DURABILITY	MANEUVERABILITY
1	1	Iowa State University	Universite Laval	North Carolina State University *	North Dakota State University
2	2	University of Nebraska	University of Kentucky	Iowa State University *	University of Saskatchewan
3	3	University of Kentucky	University of Missouri	University of Missouri	Universite Laval
4	4	University of Saskatchewan	University of Nebraska	South Dakota State University	Cal Poly State University
5	5	North Carolina State University	South Dakota State University	Cal Poly State University	Texas A&M University
6	6	South Dakota State University	Cal Poly State University	Universite Laval *	North Carolina State University
7	7	University of Missouri	University of Saskatchewan	Penn State University *	University of Missouri
8	8	Universite Laval	University of Illinois	University of Kentucky *	Iowa State University
9	9	Kansas State University	North Carolina State University	Texas A&M University *	Purdue University
10	10	North Dakota State University	Purdue University	University of Saskatchewan	University of Wisconsin Platteville *
11	11	Oklahoma State University	Kansas State University	North Dakota State University	University of Tennessee - Martin *
12	12	Purdue University	Texas A&M University	University of Illinois *	University of Nebraska *
13	13	Texas A&M University	North Dakota State University	Purdue University *	University of Manitoba *
14	14	Cal Poly State University	Iowa State University	Oklahoma State University *	University of Illinois *
15	15	Penn State University	Penn State University	University of Wisconsin Platteville *	University of Kentucky
16	16	University of Illinois	McGill University	University of Tennessee - Martin *	University of Georgia *

*Figure 12: Abbreviated 2022 competition team placements. A * indicates tied score [35]*

Table 4: Category point breakdown [27]

Category:	Written Design	Defense of Design	Team Presentation	Design Judging	Tractor Pulling	Durability	Maneuverability
Points Associated:	500	85	500	420	600	200	100
% Importance:	20.8%	3.5%	20.8%	17.5%	24.9%	8.2%	4.2%
Points awarded in 2022 competition:	478	52	465	387	583	80	0

Table 5: Overall placements in the 2022 competition [35]

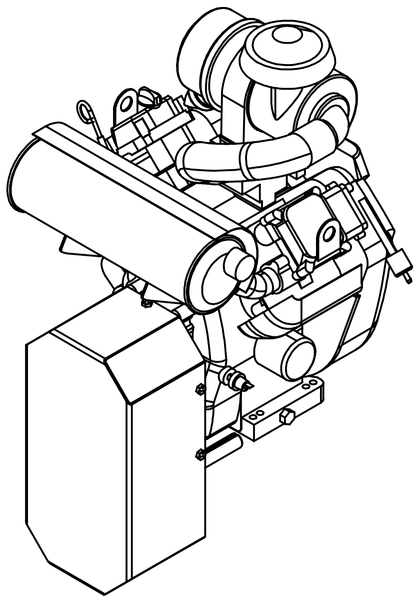
TOTAL	Placement	2405
South Dakota State University	1	2167
University of Missouri	2	2164
University of Kentucky	3	2144
Iowa State University	4	2120
University of Nebraska	5	2092
North Carolina State University	6	2077
University Laval	7	2062
University of Saskatchewan	8	2036
North Dakota State University	9	1931
Kansas State University	10	1793
Purdue University	11	1773
Cal Poly State University	12	1742
University of Illinois	13	1721
Penn State University	14	1381
Oklahoma State University	15	1376
University of Tennessee - Martin	16	876
McGill University	17	860
University of Manitoba	18	651
University of Wisconsin Platteville	19	366
Ohio State University	20	245
Texas A&M University	21	172
University of Georgia	22	148
Auburn University	23	101
Minnesota State University Mankato	24	101

Appendix B: Clutch Design Drawings

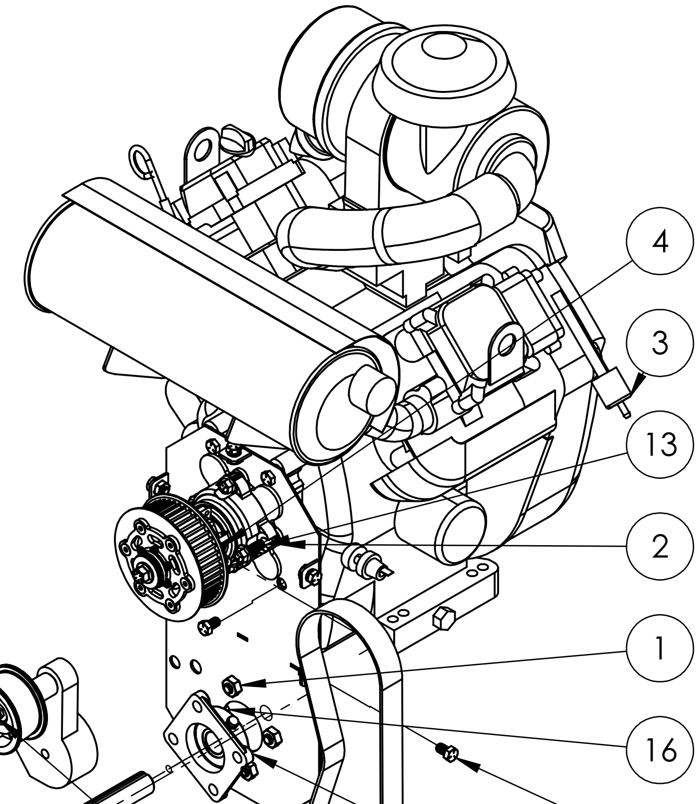
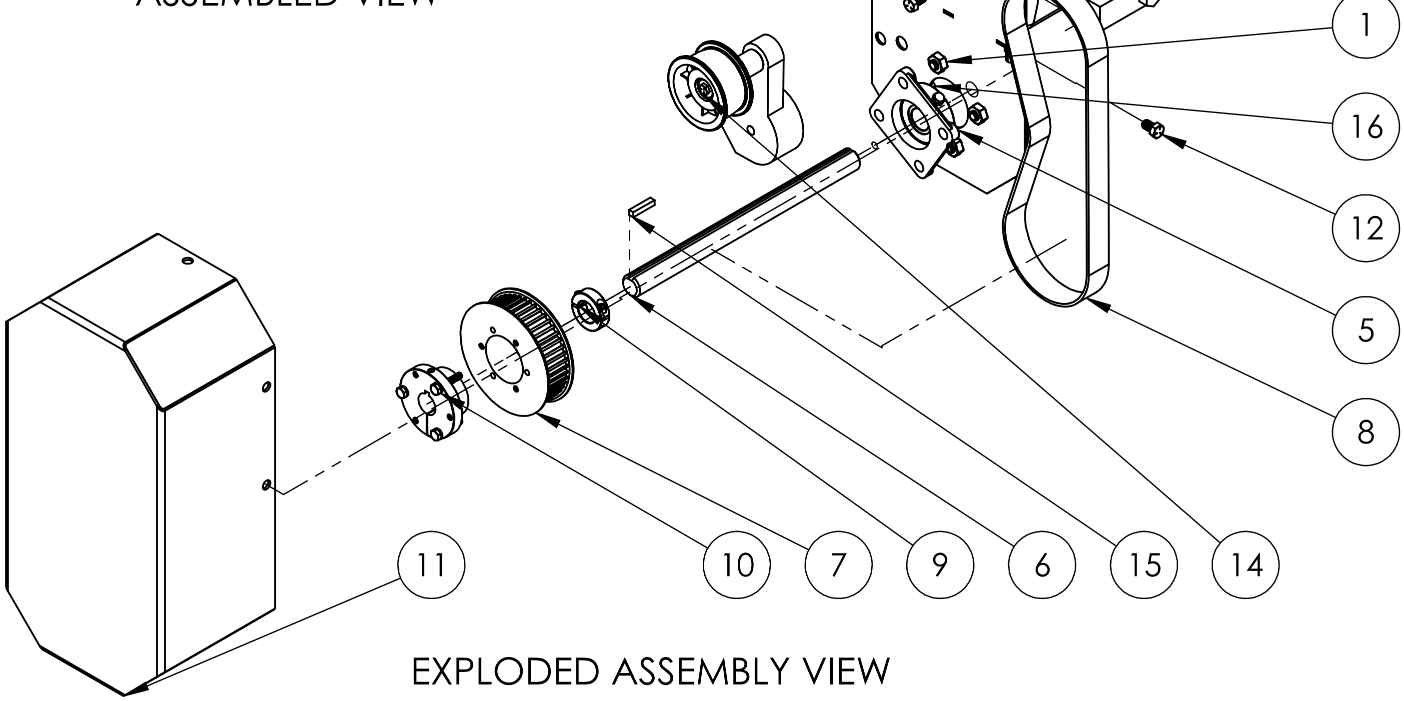
This appendix includes the assembly drawings of the clutch system. As the clutch system was a subassembly of the overall quarter scale tractor drivetrain design, the senior design group assisted in making drawings for the system. All the assemblies were modeled by the author of this thesis using either created pieces or open-source parts like hardware and devices like the engine, throwout bearing, and centrifugal clutch.

2 1

B B



ASSEMBLED VIEW

EXPLODED ASSEMBLY VIEW
SCALE 1:8

A A

Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

College of Engineering
Department of Biosystems and Agricultural Engineering

COURSE: BAE402		DRAWN BY: Lauren Doyle	
PART DESCRIPTION: Clutch Subassembly	MATERIAL: N/A	UNITS: inches ☒ mm ☐	
	FINISH: N/A	SCALE: 1:12	DATE: 3/21/2023
PART NUMBER: DT23150	WEIGHT: 140.55 lbs.	SHEET NO: SHEET 1 OF 2	

2 1

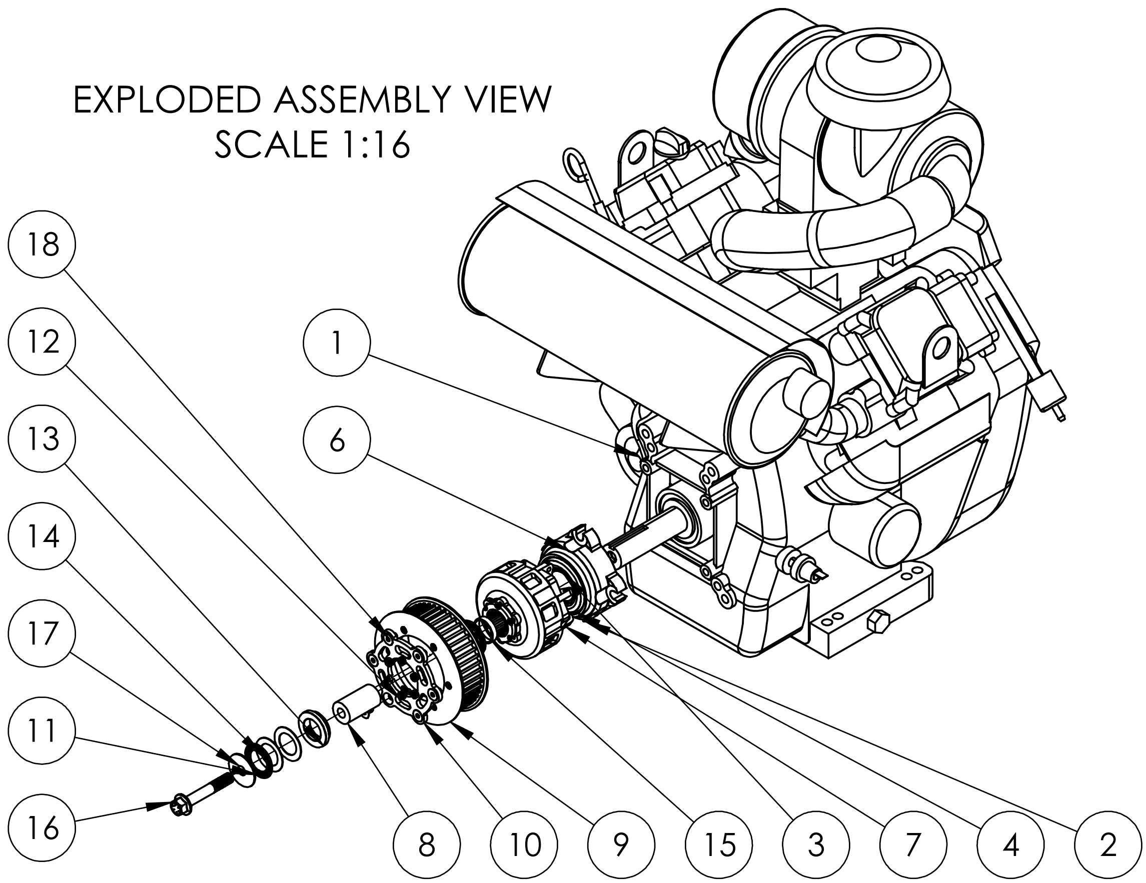
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT23153	Clutch Mounting Plate	1
2	DT23130	Throwout Bearing Spacer Plate	1
3	DT23148	Engine Crankshaft Clutch Assembly	1
4	DT23095	Throwout Bearing	1
5	DT23131	Mounted Ball Bearing with Four-Bolt Flange	1
6	DT23171	1045 Carbon Steel Keyed Rotary Shaft	1
7	DT23098	High-Strength HTD Timing Belt Pulley	1
8	DT23133	Timing Belt	1
9	DT23162	Clamping Two-Piece Shaft Collar	1
10	DT23	Quick-Disconnect Bushing	1
11	DT23138	Clutch Cover	1
12	HW23047	Medium-Strength Grade 5 Steel Hex Head Screw	9
13	HW23030	Zinc-Plated Grade 5 Steel Flanged Hex Head Screws	4
14	DT23140	Belt Tensioner	1
15	DT23163	Machine Key	1
16	HW23037	Medium-Strength Grade 5 Steel Hex Head Screw	4

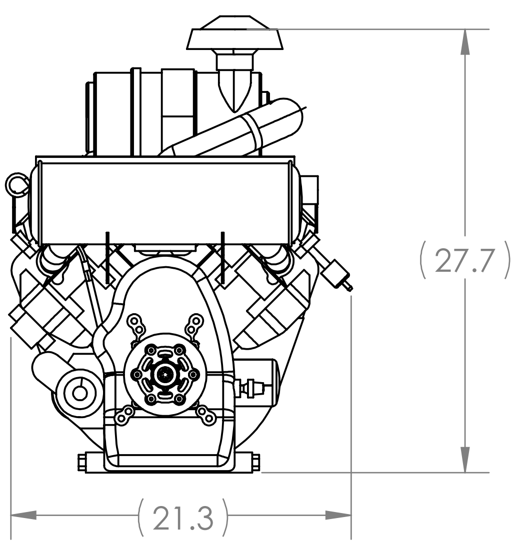
Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

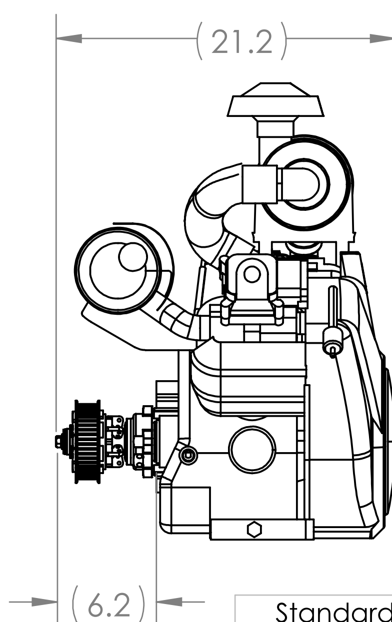
College of Engineering
Department of Biosystems and Agricultural Engineering

COURSE: BAE402
DRAWN BY: Lauren Doyle
PART DESCRIPTION: Clutch Subassembly
MATERIAL: N/A
UNITS: inches ☒ mm ☐
FINISH: N/A
SCALE: 1:12
DATE: 3/21/2023
PART NUMBER: DT23150
WEIGHT: 140.55 lbs.
SHEET NO: SHEET 2 OF 2

EXPLODED ASSEMBLY VIEW
SCALE 1:16







Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

NOTES:
1. APPLY SILICON GREASE TO BOTH THRUST BEARINGS
2. AFTER ASSEMBLY ENSURE ENTIRE SUBASSEMBLY SLIDES ONE AND OFF ENGINE CRANKSHAFT WITHOUT BINDING OR INTERFERENCE

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Department of Biosystems and Agricultural Engineering

COURSE: BAE402		DRAWN BY: Lauren Doyle	
PART DESCRIPTION: Engine Crankshaft Subassembly	MATERIAL: N/A	UNITS: inches ☒ mm ☐	
	FINISH: N/A	SCALE: 1:16	DATE: 12/7/2022
PART NUMBER: Clutch Assembly	WEIGHT: 113.45 lbs.	SHEET NO: SHEET 1 OF 2	

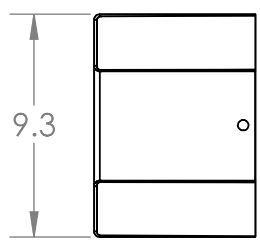
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT23149	Reference Engine	1
2	DT23143	Throwout Bearing Housing	1
3	DT23144	Throwout Bearing Piston	1
4	DT23145	Throwout Thurst Bearing	1
5	DT23146	Throwout Bearing Snap Ring	1
6	DT23147	Throwout Bearing O-Ring	2
7	DT23096	Bully Clutch	1
8	DT23171	1045 Carbon Steel Keyed Rotary Shaft	1
9	DT23111	High-Strength HTD Timing Belt Pulley	1
10	DT23099	Clutch Adapter Plate	1
11	DT23101	Needle-Roller Thrust Bearing	2
12	HW23042	18-8 Stainless Steel Socket Head Screw	6
13	DT23103	Multipurpose Flanged Sleeve Bearing	1
14	DT23104	Thrust Washer	3
15	DT23105	Spacer Sleeve	1
16	HW23045	High-Strength Grade 8 Steel Hex Head Screw	1
17	DT23106	Mounting Washer	1
18	HW23046	18-8 Stainless Steel Hex Drive Flat Head Screw	6

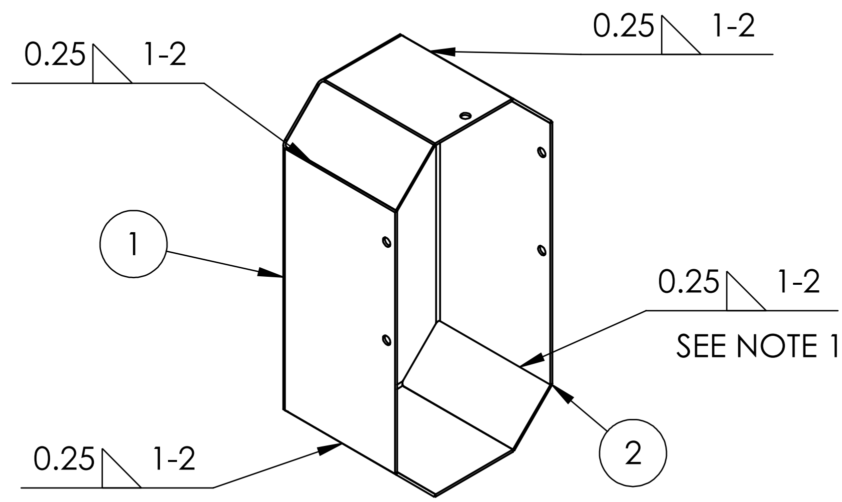
Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

College of Engineering
Department of Biosystems and Agricultural Engineering

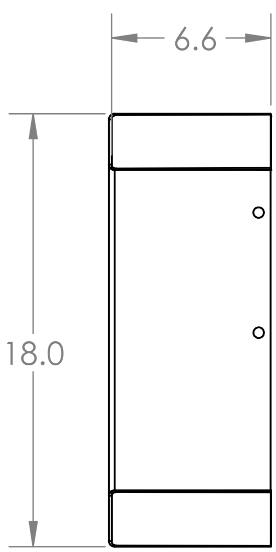
COURSE: BAE402
DRAWN BY: Lauren Doyle
PART DESCRIPTION: Engine Crankshaft Subassembly
MATERIAL: N/A
UNITS: inches ☒ mm ☐
FINISH: N/A
SCALE: 1:16
DATE: 12/7/2022
PART NUMBER: Clutch Assembly
WEIGHT: 113.45 lbs.
SHEET NO: SHEET 2 OF 2

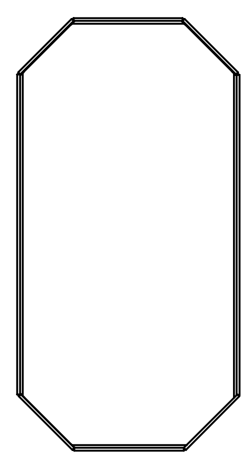
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT23136	Clutch Cover Piece	1
2	DT23137	Clutch Cover Side Piece	4





ASSEMBLY VIEW





NOTES:
1) FILLET WELD ACROSS ENTIRE PLATE
2) PAINT BLACK

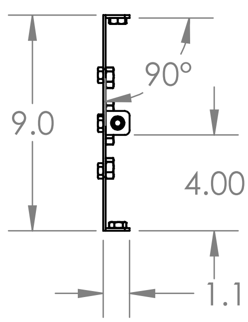
Standard Tolerances

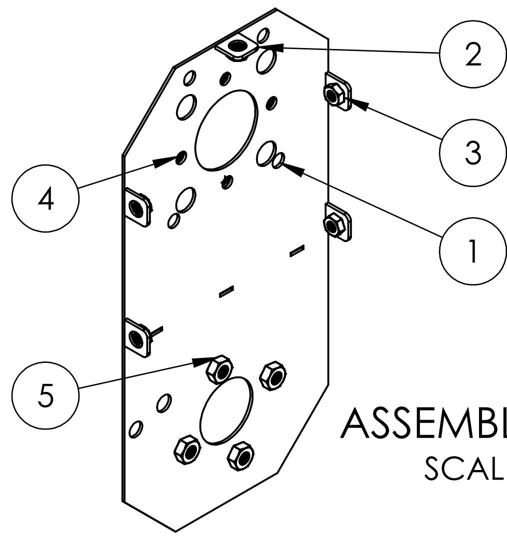
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

College of Engineering
Department of Biosystems and Agricultural Engineering

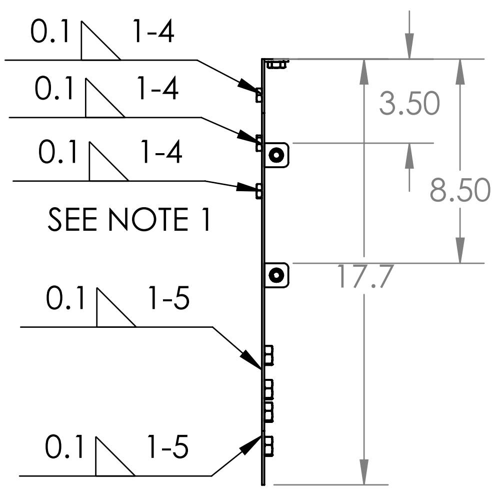
COURSE: BAE402		DRAWN BY: Lauren Doyle	
PART DESCRIPTION: Clutch Cover	MATERIAL: N/A	UNITS: inches ☒ mm ☐	
	FINISH: Painted	SCALE: 1:8	DATE: 3/20/2023
PART NUMBER: DT23138	WEIGHT: 15.55 lbs.	SHEET NO: SHEET 1 OF 1	

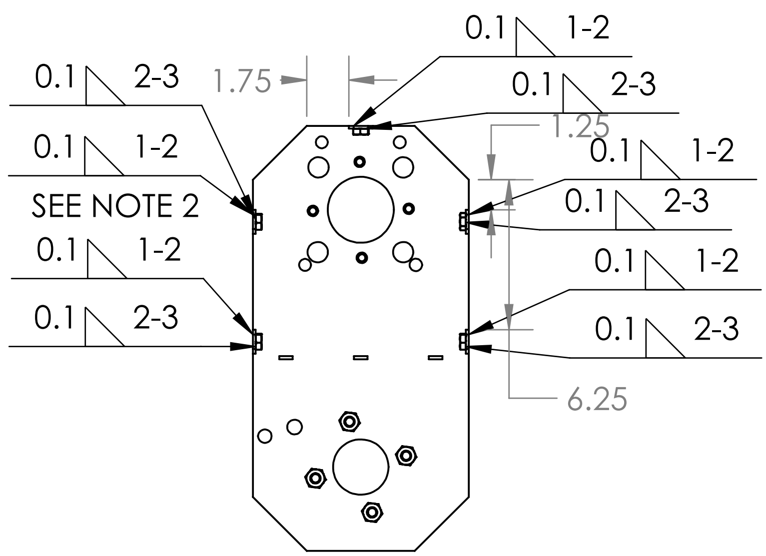
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	DT23151	Clutch Back Mounting plate	1
2	DT23152	Clutch Back Plate Mounting Tabs	5
3	93560A160	Steel Hex Weld Nut	5
4	94846A205	Medium-Strength Steel Thin Hex Nut	4
5	93560A260	Steel Hex Weld Nut	4





ASSEMBLY VIEW
SCALE 1:6





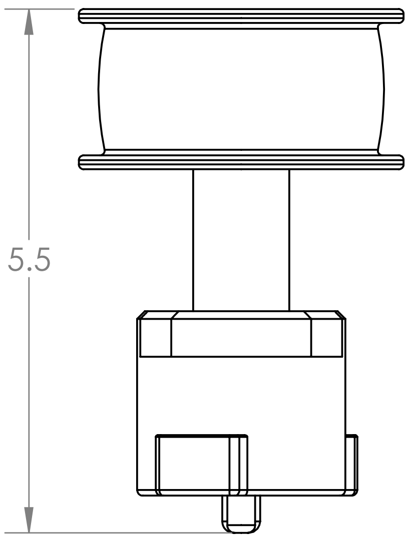
Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

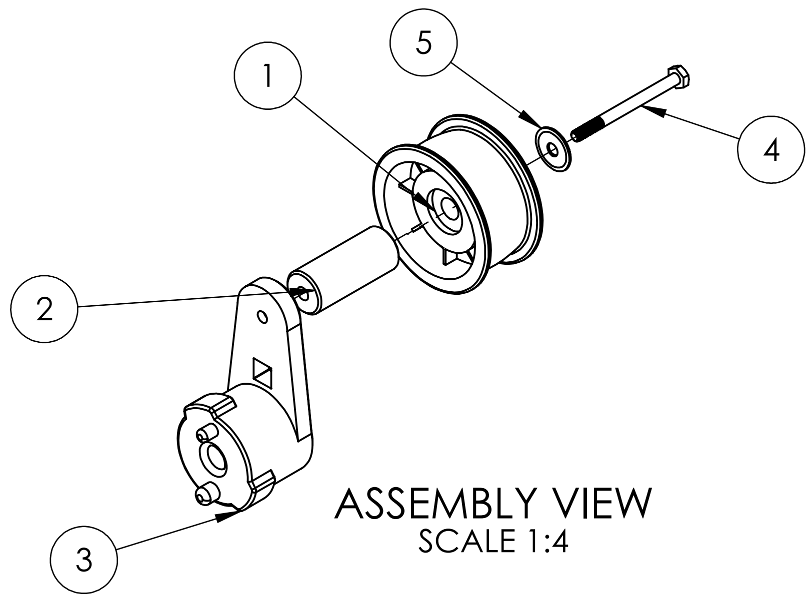
NOTES:
1) EVERY NUT GETS 3 SPOT WELDS
2) WELD ENTIRE EDGE OF 2 TO 1 AT 90 DEGREES

College of Engineering
Department of Biosystems and Agricultural Engineering

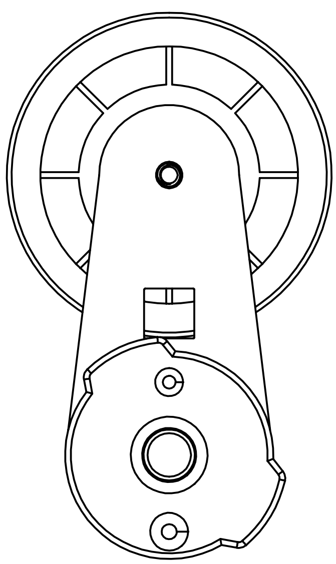
COURSE: BAE402
DRAWN BY: Lauren Doyle
PART DESCRIPTION: Clutch Mounting Plate
MATERIAL: N/A
UNITS: inches ☒ mm ☐
PART NUMBER: DT23153
FINISH: Painted
SCALE: 1:8
DATE: 3/20/2023
WEIGHT: 3.94 lbs.
SHEET NO: SHEET 1 OF 1

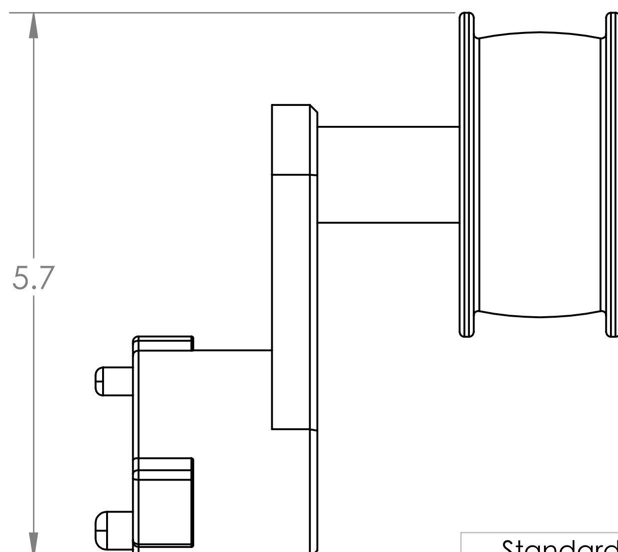
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6235K79	Idler Pulley	1
2	DT23141	Idler Pulley Spacer	1
3	DT23142	Automatic Belt Tensioner	1
4	91247A554	Medium-Strength Grade 5 Steel Hex Head Screw	1
5	91525A120	316 Stainless Steel Washer	1





ASSEMBLY VIEW
SCALE 1:4





Standard Tolerances	
Significant Figures	Tolerance
.001"	+/- .005"
.01"	+/- .03"
.1"	+/- .1"
Angles	+/- 2 degrees

College of Engineering
Department of Biosystems and Agricultural Engineering

COURSE: BAE402
DRAWN BY: Lauren Doyle
PART DESCRIPTION: Belt Tensioner
MATERIAL: N/A
UNITS: inches ☒ mm ☐
FINISH: N/A
SCALE: 1:2
DATE: 3/22/2023
PART NUMBER: DT23140
WEIGHT: 0.94 lbs.
SHEET NO: SHEET 1 OF 1