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Design and Manufacture Of A Tick Collecting Robot

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Design and Manufacture Of A

Tick Collecting Robot

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ABSTRACT

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The overall goal of this research project is to fully design, manufacture, and test a robot for tick collection. The robot will be designed to collect ticks in regions with thickly branched vegetation specifically including shrubs, trees, and leaf liter. The robot will be useful to biologists who collect ticks for research or disease control purposes because it will reach areas that are inaccessible to human-powered collection methods, and thus provide them with a more accurate estimate of the tick density in a given region. Obtaining a more precise tick density is crucial because it provides more detailed information about certain regions and the likelihood of encountering a tick species that transmits a harmful disease.

The robot design incorporates several features that will enable it to succeed in tick collection. The small, compact size of the robot will allow the robot to maneuver in between obstacles such as branches and trees in the environment. The primary method of collection that will be implemented is dragging. The environment that the robot is designed to navigate is the Albany Pine Bush, which contains an uneven terrain, mainly consisting of dirt, shrubs, and leaf liter and the robot chassis is designed for this environment.

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<u>Electronic Attachments:</u>

Motor Control: An excel spreadsheet designed for the user to input estimated parameters to determine the amount of torque and power required for the robot.

Weight: An excel spreadsheet designed to input the weight of individual parts and in using different materials and orientations can determine the total weight of the robot.

Solid Works Design: A folder with all initial and final Solid Works parts and drawings. Some initial assemblies are included.

1. Introduction

1.1 – Project Description

The overall goal of this research project is to fully design, manufacture, and test a robot for tick collection. The robot will be designed to collect ticks in regions with thickly branched vegetation specifically including shrubs, trees, and leaf liter. The robot will be useful to biologists who collect ticks for research or disease control purposes because it will reach areas that are inaccessible to human-powered collection methods, and thus provide them with a more accurate estimate of the tick density in a given region.

1.2 Tick Background

Ticks are blood-sucking arthropods that survive off of the blood of other living organisms, such as mammals, birds, and even reptiles. Over 850 tick species have been identified all over the world and there are two main families of ticks, Ixodidae (hard ticks) and Argasidae (soft ticks). The tick species is responsible for transmitting the most amounts of pathogens of any blood sucking arthropod, and the diseases transmitted are very concerning to humans [1].

Generally, most species of ticks will go through three main life stages: larvae, nymph, and adult. This cycle takes about three years and it will not be able to survive without a host's blood [2]. The life cycle of a tick corresponding to the time of the year is shown in Figure 1.1.

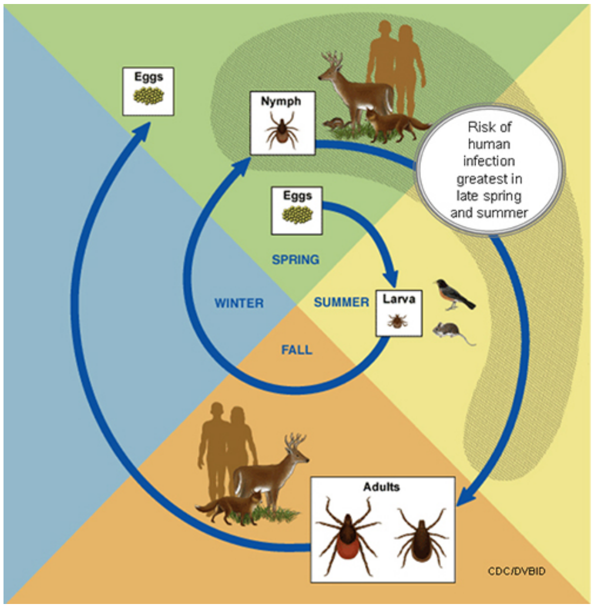


Figure 1.1 – The life cycle of a tick [2].

Ticks are able to find a host because they can detect an animal's breath, mainly the CO2 while exhaling, and are also attracted to the animal's body heat, moisture, and sometimes vibrations [3]. They are not able to fly or jump, so the tick will climb onto a potential host from a position called questing. During questing, the tick will use its rear pair of legs to hold onto a leaf or stem keeping the front pair of legs reaching out. Once a host brushes up against the legs, the tick is then able to climb onto the host and begin to find a place on the skin that is thin enough to have a successful meal.

Ticks are very dangerous to these animals, especially humans, because of their capability to carry and transmit harmful diseases. They are able to transmit the disease in a process called feeding, which can take anywhere from ten minutes to a few hours, where the tick cuts the host's skin, inserts a feeding tube, and secretes a substance to remain firmly on the host. In the United States, the American dog tick (*Dermacentor variabilis*), blacklegged tick (*Ixodes scapularis*), brown dog tick (*Rhipicephalus sanguineus*), gulf coast tick (*Amblyomma maculatum*), lone star tick (*Amblyomma americanum*), western-blacklegged tick (*Ixodes pacificus*), and the Rocky Mountain wood tick (*Dermacentor andersoni*) are the seven different tick species that bite humans [3]. Some of the main diseases that these species carry are anaplasmosis, babesiosis, Powassan disease, and Lyme disease [5]. Lyme disease is of interest for researchers because the number of infected people is increasing and it is the most common disease spread by ticks. The tick species that this project will be focusing on is the blacklegged tick (*Ixodes scapularis*). The terrain that was selected for the design was the Albany Pine Bush. The blacklegged tick is very abundant in the Pine Bush and upon completion of the project in the spring; the robot will collect the nymph stage of the tick, as shown in Figure 1.1

There are many different ways to collect ticks including dragging, flagging, CO_2 traps, live traps, and walking. Flagging is very similar to dragging in the sense that a cloth is used to collect the ticks. However, flagging involves putting the cloth on a long pole, like a flag, and sweeping it across the grass or leaf litter to collect ticks [7]. A CO_2 trap is simply a small box or device that emits carbon dioxide to attract ticks. The trap will typically have a piece of cloth, similar to the dragging and flagging cloth, to catch the ticks and a piece of dry ice to emit carbon dioxide. According to an article in the *Journal of Medical Entomology* written by Terry L. Schulze, Robert A. Jordan, and Robert W. Hung, ticks usually respond well to CO_2 traps and sub adult stages are the most common stages of tick collected [7]. Live traps include placing traps in the environment and trapping different species of mice or other animals with fur and examining the host for ticks. In one study from *The Journal Experimental and Applied Acarology*, the traps were baited with food such as peanut butter and were set around the perimeter of a specific region to attempt to catch the white-footed mouse (*Peromyscus Ieucopus*) [8]. The last method of collection is walking. The researcher wears overalls made of the material used for the drag cloth and walks through the environment collecting ticks.

The most common method carried out by researchers is dragging. Dragging involves taking a cloth, which can be any size but typically is around 1m x 1m and made of denim or corduroy, and dragging it along the ground while catching ticks on the surface. The cloth is usually dragged along an open area without a lot of shrubs or trees because the cloth needs to be as flat to the ground as possible and would have trouble getting through the difficult obstacles without losing some of the ticks. After a certain amount of distance covered with the cloth, or a certain amount of time collecting, a tick density for that region is estimated by the amount of ticks collected in that given area. Dragging will be the method of collection used for the robot. Currently, dragging is primarily successful in very open regions of grass or leaf liter. Dragging sometimes takes place in between trees and shrubs, but the issue is maintaining good contact between the terrain and the cloth. The robot method would enable the cloth to collect ticks in those difficult to reach areas and ideally equalize the efficiency of dragging in any type of terrain. An article from *The Journal of Vector Ecology*, stated,

> […] We could not confirm a clear trend in the relative effectiveness of these two methods (flagging versus dragging) as shrub density increased. Dragging was difficult at our sites with the highest shrub densities because the drag frequently caught on the vegetation and often rode over the top of the shrubs, well above the leaf liter layer. Conversely, when unimpeded, drags may have collected more ticks than flags because a larger collecting surface area contacted the leaf litter, even if both methods used the same size material [6].

This quote shows some of the difficulties of dragging and why the robot method would be useful.

1.3 Objectives

The goal for the fall term is to complete the entire detailed design of the robot. The three main subsystems that need to be designed are the tick collection system, the moving platform (including the chassis, power train, and steering), and the controls system. The fall term will also consist of applying for grant money, the Presidential Green Grant and the Student Research Grant, to fund the robot parts. A full Solid Works model will be constructed to help visualize the different parts and how the parts will work together. An analysis will also be completed on the chassis to verify it can withstand the given environmental conditions.

The goal for the winter term is to complete the control system and manufacturing of the robot. The control system will be designed to allow the robot to move autonomously in the environment with the capabilities of being controlled by the user. Autonomous control will be useful and implemented in more open areas, while user control will be more useful in regions with more obstacles and a highly uneven terrain. The robot will ideally be completed and functional by the end of winter term and ready for physical testing in the early spring.

2. Design Requirements

2.1 – Primary Subsystems

A functional decomposition was completed to determine the primary subsystems of the robot and understand the functional requirements of the robot. The functional decomposition can be found in Figure 2.1 on the following page. From the functional decomposition, it is apparent that the three primary subsystems are the tick collection system, controls system, and the moving chassis. Some of the main functions of these subsystems are to collect ticks, move on the terrain, protect the robot from the environment, and control the speed of the robot.

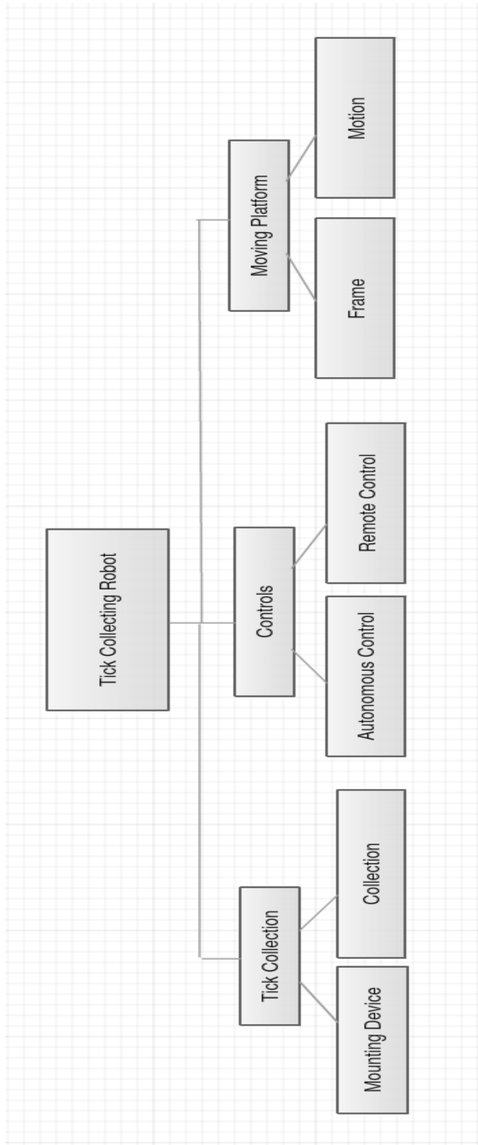


Figure 2.1 - Functional decomposition of the tick-collecting robot.

2.2 - Requirements

Generating a list of design requirements was the first step in the design process. Professor Kathleen LoGiudice from the Biology Department at Union College described some of the features and specifications that the project should require. Professor LoGiudice is the “customer” for the robot as she is actively involved with tick collection and tick research at Union College.

To define the design requirements, it was important to understand the nature of the challenge. The terrain will mainly consist of dirt, sand, leaf litter, trees, and shrubs, and branches. The distance between trees was estimated at about 2 ft, an average branch diameter was estimated to be 0.5 in, and the branches were assumed to be primarily pitch pine wood. Pitch pine is a predominant type of wood in the Albany Pine Bush and has an elastic modulus of 1.43 Msi and a density of approximately 52 lb/ft^3. The terrain will most likely be flat with obstacles and therefore the maximum angle of the incline was assumed to be 30º. The physical environment was used to identify most of the design requirements, although many could not be quantified.

The most important design requirements were those relating to performance, safety, geometry, and materials. For performance, the robot must be able to navigate on the uneven terrain and the design should minimize the likelihood of getting stuck. Autonomous control will be implemented in areas with fewer obstacles and remote control will be used when the robot is likely to get caught on an obstacle. The robot should to be able to drive over a branch as opposed to pushing the branch out of the way. The decision for driving over obstacles is justified in the “Motor Selection” section of the report. The robot should also be successful in collecting ticks from the environment and be able to move at the average human walking pace, 5.72 ft/s. Currently, it is undecided whether or not it is necessary to implement a vision system or a tracking system to retrieve the robot after it begins collecting.

There were no specific geometric specifications provided, but in order to navigate through shrubs, trees, and other obstacles it was important to design a small robot in both length and width. The maximum length of the robot should be 14 in and the maximum width of the robot should 12 in. The robot should also be low to the ground to be able to get under some of the low hanging branches and the height should not exceed 5 in. The size should be small enough to maintain a small turn radius to get out of different situations and obstacles. The cloth size is typically 1x1 m, but this is not a standard size. There are no specifications on the size of the cloth for dragging and the cloth size selected will be discussed further in the design of the collection system.

For materials, it was essential to have a lightweight vehicle, approximately 10-12 pounds, to allow the robot to move, but have enough weight to maintain traction on the terrain. The material selected should be able to avoid being damaged when encountering any obstacles and the material should be able to withstand water damage to protect the electronic system. Also, the cloth material should be made of denim or corduroy, which are the most common materials used to collect ticks.

For safety, the robot must be safe to use for the user and safe for the user to repair if damaged. The electronic components should be covered to avoid water damage and potential hazards for the user. The environment should also remain undamaged while the robot is being used.

Some of the other design requirements include energy, time, manufacturing, cost, standards, and transport. The design requirements for each primary subsystem can be found in Tables 2.1, 2.2 and 2.3.

Table 2.1 – Design requirements for the control system.

Subsystem	**Design Requirement**	**Details**
Control System	Energy	Must be able to operate for at least one hour without failure.
	Time	Time to drag differs study to study.
	Cost	Stay below a reasonable budget of about $800.
	Manufacturing	Relatively simple to wire and code. Use electronics such as Arduino.
	Geometry	Parts must be contained in the chassis.
	Safety	Protected from water damage. Safe for the user to touch electronics.
	Performance	Full RC and autonomous control Move at the average human walking speed (v = 5.72 ft/s).

Table 2.2 – Design requirements for the moving platform.

Subsystem	**Design Requirement**	**Details**
	Cost	Stay below a reasonable budget of about $600.
	Manufacturing	Parts can be machined and assembled within two weeks.
	Transport	Easily transportable. Small, compact.
	Geometry	Small. Length < 14 in; Width < 12 in

Moving Platform		Maintain small turning radius (~10 in). Low to ground. Height < 5 in.
	Safety	Safe for user (no sharp edges). Does not damage the environment
	Performance	Move on the terrain. Avoid getting stuck on obstacles. Possibly implement a vision and/ or tracking system.
	Materials	Lightweight (10-12 lbs), but maintain traction. Protect electronics. Withstand maximum forces without large deformations.

Table 2.3 – Design requirements for the tick collection system.

Subsystem	**Design Requirement**	**Details**
Tick Collection	Manufacturing	Simple to attach cloth.
	Transport	Must be able to be easily removed and replaced
	Materials	Denim or corduroy
	Geometry	No specific dimensions (typically 1x1 m).
	Performance	Collect ticks in the environment

3. Alternative Concepts

The "Alternative Concept" section will show preliminary ideas for the dragging system and discuss the primary differences between tank treads and wheels. Questions will be presented and answered to help guide a decision between tracks versus wheels. The remainder of this section will discuss the differences between the different tread styles and conclude with some of the attributes and risks of the resulting design.

3.1 – Dragging System

The dragging system design is only in the rough draft stages. Some different cloth shapes and possible attachments were sketched, but a model of the dragging system is not complete. The four possible shapes for the cloth can be found in Figure 3.2.

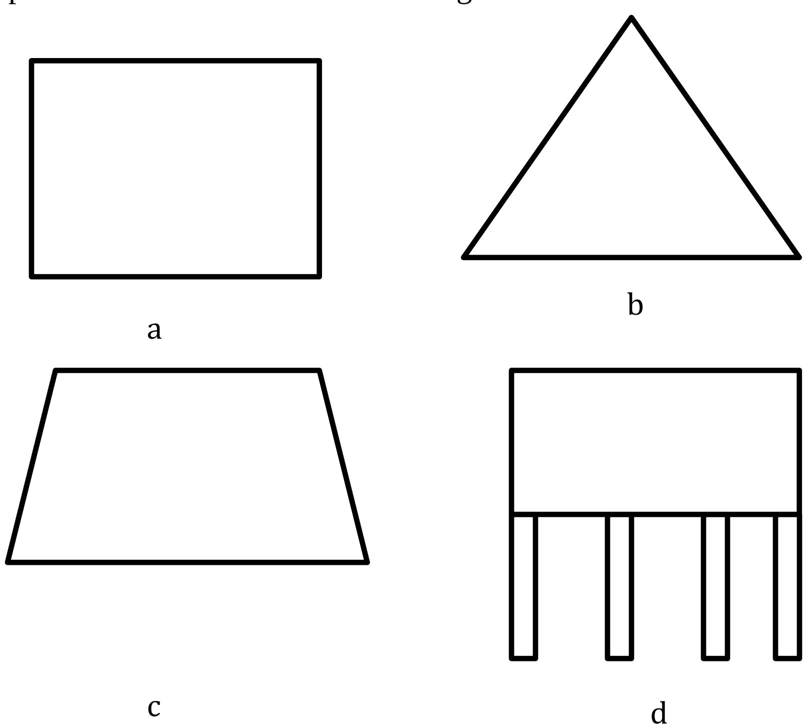


Figure 3.2 – Four different shapes for the cloth.

The shape shown in Figure 3.2 (a) is the most common shape used for the dragging method. The other shapes could also be successful in collecting ticks, but without the design of the attachment to the chassis it is unknown which shape will be optimal. The design in Figure 3.2 (d) has a few complications because the fringes could move around freely and that causes the potential for ticks to fall off of the cloth. To maintain good contact between the cloth and the ground, the design of the attachment to mount the cloth should be located in the rear of the robot. This will allow the cloth to be dragged behind the robot as opposed to resting underneath the robot, which was discussed as one potential design option.

3.2 Treads vs. Wheels

The decision between using a tank tread design versus a design with wheels was very important in the design process. There were five main questions that were asked to help ease the final decision and a list of advantages and disadvantages of each system was generated. Small remote control tanks and cars were purchased for preliminary testing of the terrain and to demonstrate the capabilities of each system.

Some of the advantages of tank treads are that they perform better at higher torques and lower RPM. They are able to move on uneven terrain and drive over obstacles. Also, tank treads provide more traction and lower ground pressure than wheels because the contact area with the ground is much larger, which can also reduce the amount of skidding. However, some of the disadvantages of tank treads include that treads are more likely to break and are much harder to fix than wheels. The design of tank treads is more complex, the cost is significantly greater, and treads require multiple parts that have the ability to get worn down faster and potentially fatigued. The last main disadvantage of treads is the potential to get leaves or branches caught inside making it hard for the user to operate the robot.

On the other hand, some of the advantages of wheels are that they operate at higher speeds and have higher maneuverability. It is harder for “stuff” to get caught in the wheels and the design of a wheeled system is slightly easier. Wheels would be much simpler to build; they are lightweight, and much cheaper than threads. The disadvantages of wheels are that wheels have a much greater chance to get stuck on the uneven terrain and not be able to move. Wheels have less traction and higher ground pressure than treads, resulting in a greater tendency to skid.

The first and most important question that was asked was which system will be more likely to drive over or through obstacles and provide sufficient mobility? An article from Into Robotics from 2013 and an army vehicle study in 1998 guided the answer to this question. Into Robotics claims the main disadvantage of wheels is their ability to drive over obstacles. They state for a wheels vehicle to climb over an obstacle, it must be at least twice as tall as the obstacle; however, the maximum height of the robot, per the design requirements, is 5 in. They also state the continuous tracks can move on rough terrain easier and can also “ascend and descend stairs, surmount obstacles, or cross ditches [9].”

The study conducted in 1998 by the army compared tracked and wheeled vehicles. This is applicable in terms of the differences between the two systems, but the scale was for much larger vehicles that the robot. The study defined mobility, per the 1988 Mobility Analysis for the TRA- DOC Wheeled-Versus-Track Study, as “the ability to move freely and rapidly over the terrain of interest to accomplish varied combat objectives.1 Mobility is thus measured by a system’s freedom of movement (percent of the terrain over which the vehicle is mobile) and its average speed or travel time over that terrain [10].” Based off of this definition, the study was able to conclude that, “tracked vehicles offer the best solution for a versatile platform that is required to operate over diverse terrain, including extremely difficult ground…[10].” Wheels would be able to provide more road speed, but tracks provide the best solution for off-road applications. Even though this was tested for larger vehicles, the information was very valuable in deciding between tracks and wheels.

The next question was which system will be easy to build and not break easily? The answer to this question was wheels based off of the list of advantages and disadvantages provided by Into Robotics. They state that breaking easily is a main disadvantage of tracks because the tracks can get dislodged much more easily than wheels. One important advantage of wheels is simplicity. Wheels have less moving parts, which means there are fewer parts that can be damaged [9].

The last question that was asked was which system will be more likely to succeed? Based off of the information presented previously, it is believed that the tread design will be more likely to succeed mainly due to the ability of treads to get over obstacles easier and are much less likely to get stuck on the uneven terrain. However, there is the option to convert from treads to wheels if the tread design becomes overly challenging.

Preliminary testing of a remote control car and tank were carried out. Some key observations of these tests showed that the RC tank’s treads, see Figure 4.7 below, had an easier time moving on dirt and a wooded terrain. The terrain tested was a region at Union College with dirt, trees, and branches comparable to the Albany Pine Bush environment according to Professor Kathleen LoGiudice. The RC car was not able to move on the dirt at all because it did not have a sufficient amount of torque, however it appeared that the wheels would be stuck in the dirt much more easily. Also, after seeing the car and tank drive, it was crucial to reduce the speeds of the robot to operate at higher torques and move slower. It was difficult to obtain experimental evidence to make the decision between tracks and wheels, but due to its ability to drive on the uneven terrain and operate at higher torques while maintaining good traction ultimately shifted the decision to design using tank treads over wheels.

3.3 Tread Options

After selecting tank treads over wheels, it was important to start the design of the treads. After looking at different remote control tanks online and other online research, the tank tread options were limited to the ones shown in Figure 3.3.

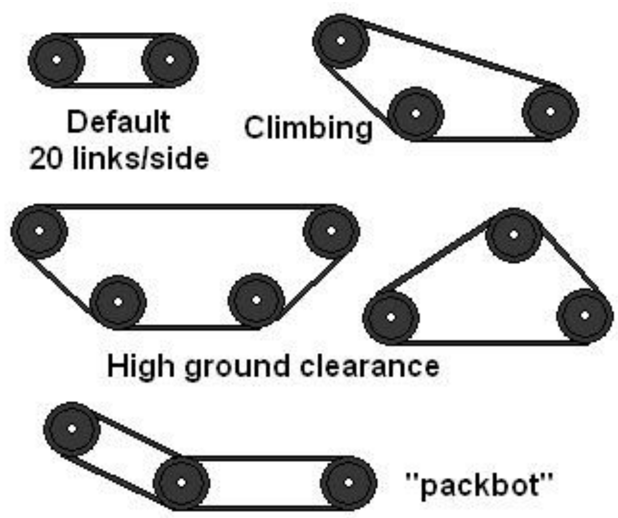


Figure 3.3 – Multiple tank tread designs [11].

The “default” style tread, the top left image of Figure 3.3, is a very common, simple design. Videos of this style show this design is capable of getting over obstacles, has a good turn radius, and operates well at both low and high speeds. The climbing design and the high ground clearance design would be able to get over obstacles and have a greater ability to climb than the default style.

Sketches of the default, high ground clearance, and climbing tread styles were drawn to compare the strengths and weaknesses of each. The sketches include a top and side view of the tread designs labeled default, high ground clearance, and climbing in Figure 3.3. The high ground clearance design was a good option for designing the tracks. This design would be able to drive over obstacles, but this design was much more complex than the default style treads. A similar decision was made with the climbing tread design. The climbing design appears it would be successful in climbing over obstacles, but the default style tread was a much simpler design. All three designs would be able to climb over obstacles, but due to the simplicity of the design and ease of manufacture, the default style treads was selected for the robot. Due to its simple design and manufacture, the user could be capable of repairing the treads if they were damaged in the environment.

3.4 Conclusions

There were many important conclusions that can be drawn from the "Alternative Concept" section. The differences between wheels and treads were identified and compared in order to ultimately select a continuous track design. The different types of tread styles were compared, which led to the decision to design the default style treads.

The resulting design includes a continuous track system. Attributes such as the ability to drive over obstacles, operating at higher torques and lower speeds, and maintaining ground traction were the primary reasons the continuous track system was selected over the wheels.

Tracks would be more likely to succeed on the uneven terrain of the Albany Pine Bush environment.

The continuous track system design also presents some risks and uncertainties. One main risk includes the tracks have a greater tendency to break than wheels. Tracks have more moving parts than wheels and therefore a part is more likely to be damaged in the environment. The last main risk is that branches, leaves, and other features of the environment will be more likely to get caught in the tracks. If a branch gets stuck in the tracks, it will be difficult for the robot to move.

4. Detailed Chassis Design

4.1 Overview

The detailed design of the robot chassis as represented by a Solid works model can be found in Figure 4.1, an isometric view, and in Figure 4.2, a top view. The outer body is a piece of aluminum sheet metal and the top is covered by a 0.125 inch piece of clear Lexan. The assemblies in Figure 4.1 and Figure 4.2 are able to show the design for mounting the motors and the sprockets to the chassis through the use of a pair of linear flange bearings, aluminum shafts, and flexible shaft couplings, and will be discussed in detail in the “Drive Train” subsection. The electronic components are located in the middle of the chassis protected from the outside environment. The sprockets for the continuous track design are shown, but the treads were unable to be modeled in Solid Works, however they will rest on the sprockets and remain in contact with the ground.

Some of the key functions of the chassis are highlighted below. The electronic components will provide power to the motors and allow the motor shaft to output torque to the sprockets. These components, an Arduino board and a RC receiver will also be used to implement autonomous and remote control and dictate the speed and direction of the robot. The metal body will house the different parts and protect the robot from the environment and provide a structure to support the forces from the environment. The sprockets and tracks will allow the robot to drive over obstacles and maneuver on the terrain. The bearings and shaft couplings will provide support for the shafts connecting the sprockets to the chassis. The shaft couplings will be able to transmit the power and torque from the motors to the sprockets to enable the robot to move.

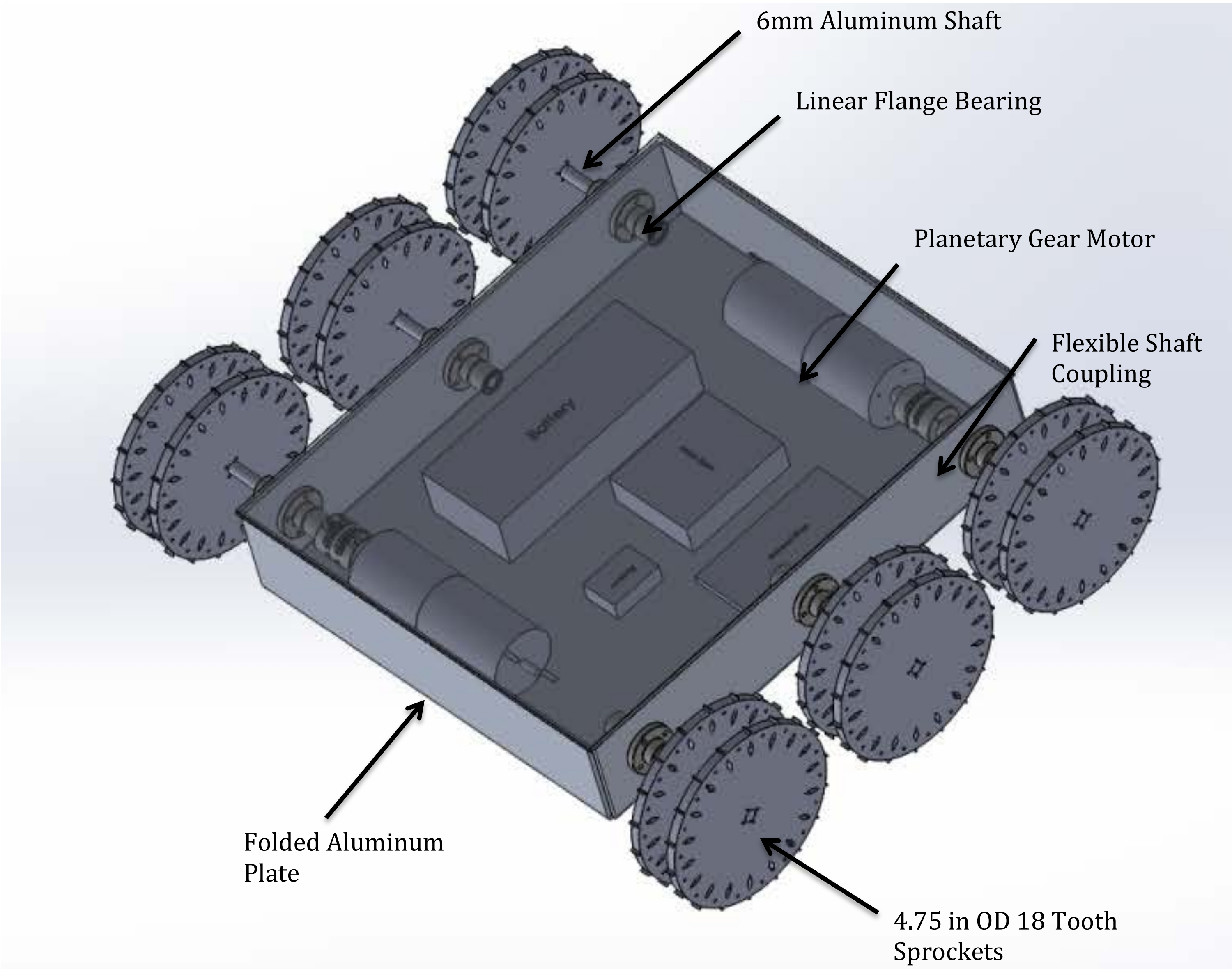


Figure 4.1 – Isometric view of the chassis design.

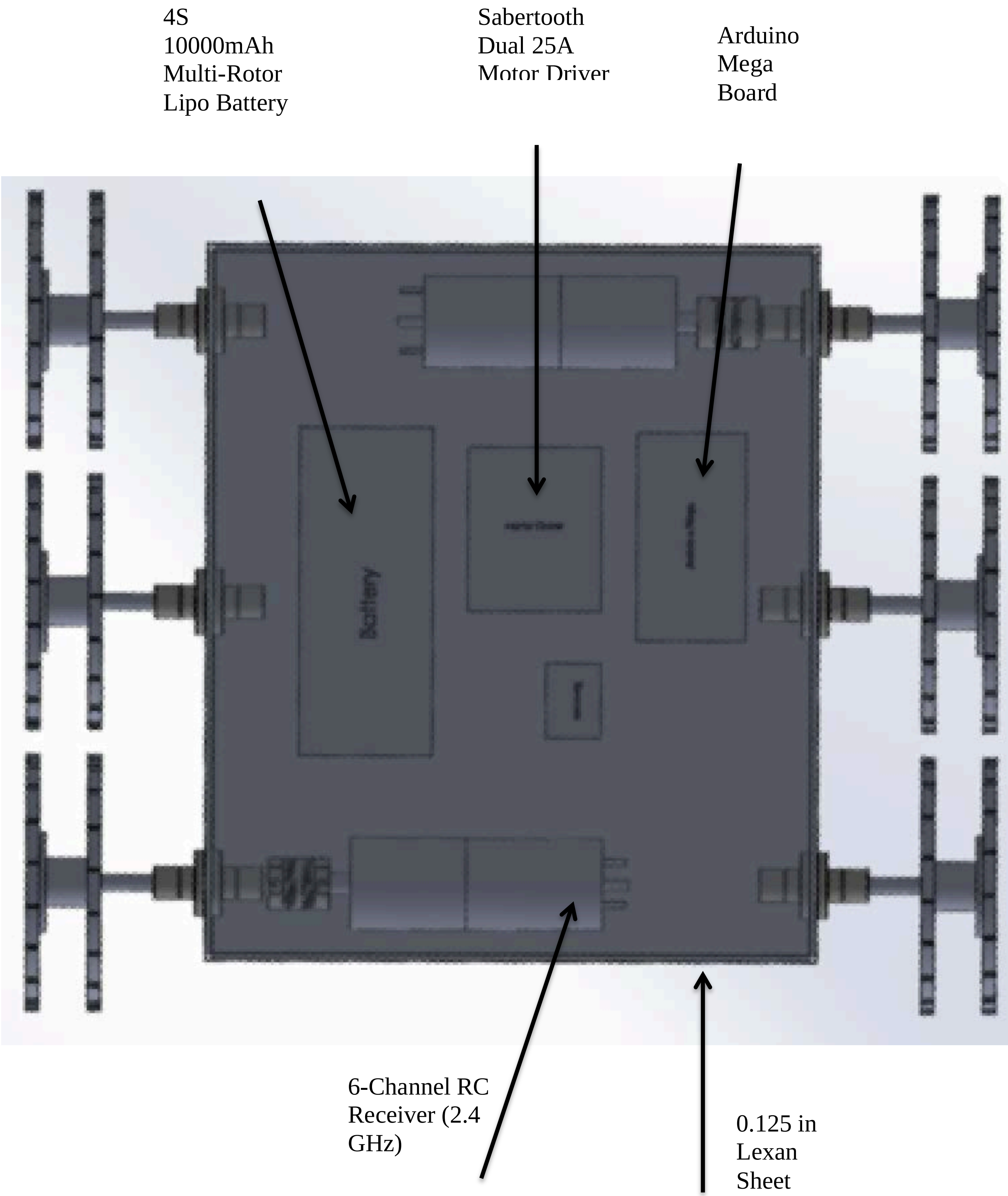


Figure 4.2 – Top view of the chassis design.

4.2 Electronics

The electronic components were selected to achieve both remote and autonomous control for the control system of the robot. Figure 4.3 represents a schematic to show how all of the components will work together to control the robot. In Figure 4.3, the battery selected is a 14.8 V Multistar four cell 10000 mAh Lipo battery. The battery will be used as the power supply for the motor driver, which has a built in 5 V power output. The motor driver is a Sabertooth dual 25A driver. The driver is able to control the speeds of two motors, and is rated to 25 A because the motor stall current is 22 A. The driver also has a built in electronic speed controller (ESC) and a battery eliminator circuit (BEC). The BEC takes the voltage from the main Lipo battery and reduces it to power other electrical components and the ESC is able to control the speed of the motors. The motors selected and detailed specifications can be found in the "Motors" section of the report.

The 5 V power output of the motor driver will be sufficient to power the Arduino board and the RC receiver. An Arduino Mega was selected and this component will be responsible for switching between autonomous and RC control, but primarily used for autonomous control. A code will be written and uploaded to the Arduino board in order to dictate the speed and direction of the robot. The last component is the RC receiver. The receiver has 6 channels and operates at a 2.4 GHz frequency. The receiver will be in constant communication with a 2.4 GHz transmitter, which outputs different signals for different functions. The channels on the receiver will control the turning and direction of the robot to carry out functions dictated by the user and one of these channels should be a switch, which will act as a switch between RC and autonomous control.

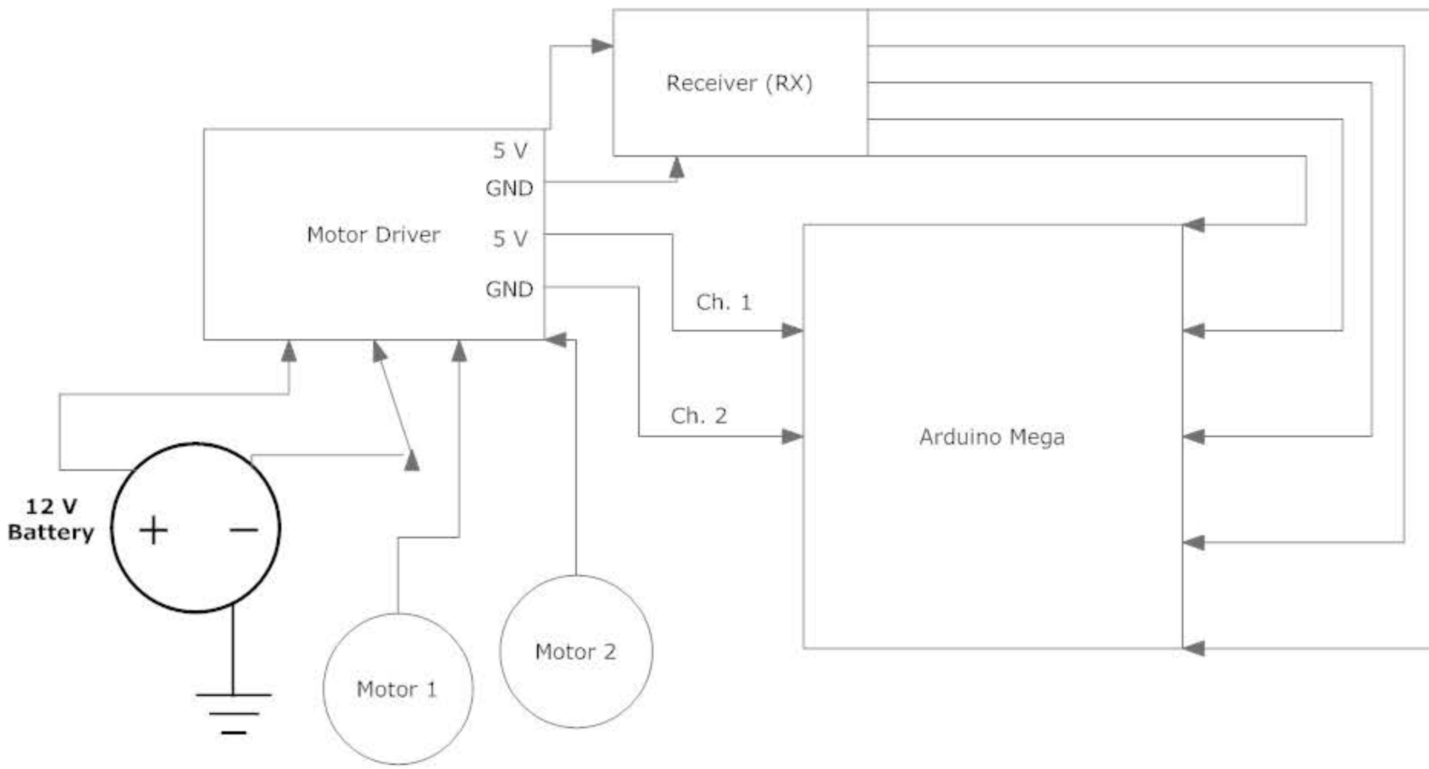


Figure 4.3 – Wiring diagram with components for the control system.

4.3 Motors

The selection of motors was one of the most important decisions in the design process. The motors must provide enough power and torque to allow the robot to move on the uneven terrain, approximately 25 ft-lb/s and 1.3 ft-lb respectively. They must provide enough power to overcome obstacles such as branches and leaf litter. The limited design requirements involving the robot speed and unknown parameter of the power requirement to climb over an obstacle made it very difficult to estimate the amount of torque and power needed to drive. Many parameters that describe the vehicle and parameters that describe the branches in the environment were unknown and had to be estimated. The battery must supply the motors with enough current to last for approximately one hour in the environment. The battery outputs 10000 mAh, and the stall current of the motor is 22 A. This means there should be two batteries to supply 20000 mAh combined to allow the robot to operate for approximately one hour.

The free-body diagram that was used to represent the robot on the terrain, an incline representing the worst-case scenario on the terrain, can be found in Figure 4.4.

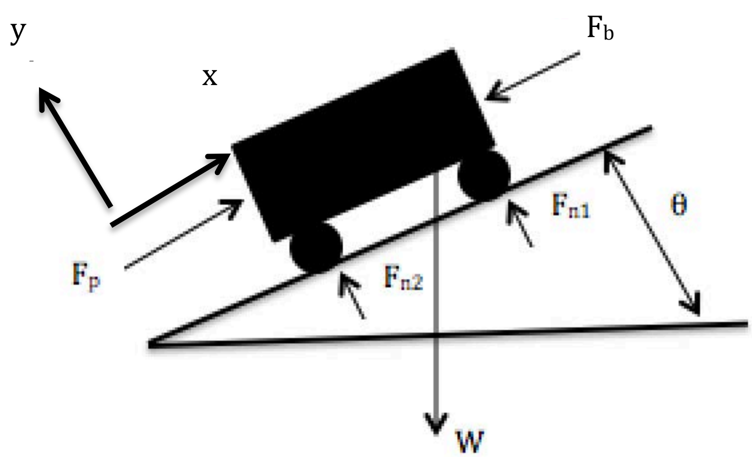


Figure 4.4 – Free-body diagram of the robot on an incline slope.

The normal forces, F_n, were not required because the forces in the y-direction were not needed. Assuming the robot will be traveling at a constant velocity, the acceleration term in Newton's Third Law of Motion, shown in Equation (1), equals 0. Therefore, the net of the external forces in the x-direction equals zero, Equation (2).

$$\Sigma F_x = m*a_x \tag{1}$$

$$\Sigma F_x = 0 \tag{2}$$

In Figure 4.4, the x-direction is the direction along the incline of the slope and the y-direction is perpendicular to the incline. Therefore, the sum of the forces in the x-direction can be found in Equation (3) and rearranged in Equation (4) to determine the force required to move the robot, F_p,

$$F_p - F_b - W\sin\theta = 0 \tag{3}$$

$$F_p = F_b + W\sin\theta \tag{4}$$

where W is the weight of the vehicle, θ is the angle of the incline, and F_b is the resisting force due to the branches. F_b was calculated by modeling the branch as a cantilever beam. The displacement, length, and diameter of the branch were estimated from visual observation. These branch parameters can be found below in Table 4.1. Branches were measured and the average distance between tree trunks was calculated to find an average branch length in a region with at Union College comparable to the Albany Pine Bush. The robot displacing a branch was treated as a point load, so that the force could be calculated from the deflection equation for a cantilever beam shown in Equations (5)

$$F_b = \frac{3\delta EI}{L^3} \tag{5}$$

where δ is the displacement of the branch, L is the length of the branch, E is the elastic modulus of the branch, and I is the area moment of inertia of the branch (which is assumed to be a solid cylinder), which can be found using Equation (6).

$$I = \frac{\pi d^4}{64} \tag{6}$$

where d is the branch diameter.

The force, F_p, calculated using Equation (4), the required speed of the vehicle, and the assumed radius of the wheels were used to calculate the power and torque required for the robot to move simultaneously up the incline and through the branches:

$$P_{req} = F_p * v \tag{7}$$

$$T_{req} = F_p * r_w \tag{8}$$

where v is the velocity of the robot and r_w is the radius of the wheel.

The variables assigned values based on the design requirements include the weight, W, the slope of the incline, θ, vehicle speed, v, the wheel radius, r_w, branch length, L, branch diameter, d, and branch displacement, δ as reported in Table 4.1.

Table 4.1 – Assumed values of the input parameters.

Input Parameters		
Variable	**Value**	**Unit**
Weight	10	lb
Incline Angle	30	º
Velocity	5.72	ft/s
Wheel Radius	3	in
Branch Length	20	in
Branch Diameter	0.5	in
Branch Displacement	2	in

Using these input values, the output parameters were calculated using Equations (3)-(8) with the electronic attachment "Motor Selection". The results are shown in Table 4.2.

Table 4.2– Preliminary estimations of the forces, power, and torque required.

Output Parameters (No Plate)		
Variable	**Value**	**Unit**
Fp	8.29	lb
Fb	3.29	lb
P (required)	64.29	W
P (required/motor)	32.15	W
T (required)	2.07	ft-lb
T (required/motor)	1.04	ft-lb

It was essential to select motors that could exceed these power and torque requirements. For a brushed, permanent magnet DC motor, the linear relationship between torque and angular speed and the parabolic relationship between power and angular speed is illustrated by Figure 4.5.

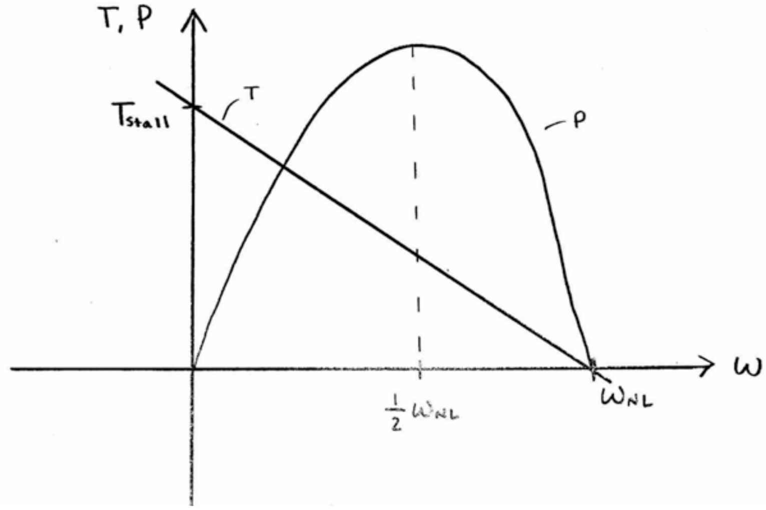


Figure 4.5 **-** Relationship between torque and angular speed for a brushed, permanent magnet DC motor.

T_{STALL} is considered the stall torque and ω_{NL} is the no load speed. The peak of the parabola, at $0.5\omega_{NL}$, is the maximum mechanical power and the optimal operating point. To calculate the maximum power and torque from a given motor, use Equation (9) and Equation (10).

$$T_{max} = \frac{1}{2} * T_{stall} \tag{9}$$

$$P_{max} = \frac{1}{4} * T_{stall} * \omega_{NL} \tag{10}$$

Where P_{max} is the maximum mechanical power of the motor and T_{max} is the torque of the motor when operating at $0.5*\omega_{NL.}$ These calculations for a variety of motors can be found in the electronic attachment Motor Selection. Ultimately, the motor that was selected was the PG71 Planetary Gearbox w/ RS775 Motor and Encoder from AndyMark; see Figure 4.6.

Figure 4.6 - The PG71 Planetary Gearbox w/ RS775 Motor and Encoder [12].

Some of the motor's specifications and output found using Equation (9) and Equation (10) can be found in Table 4.3 as well as the estimated power and torque requirements for the robot.

Table 4.3 – Motor specifications and output power and torque.

Variable	**Value**	**Unit**
Tstall	16.6	ft/lb
ω No Load	75	RPM
Pmax	32.6	ft-lb/s
Tmax	8.03	ft-lb
P(req/motor)	23.71	ft-lb/s
T(req/motor)	1.04	ft-lb

Typically to select a motor, it is important that the maximum torque from the motor is much greater than the torque required for the robot and that the maximum power output from the motor is much greater than the power required for the robot, i.e. $T_{max} >> T_{req}$ and $P_{max} >> P_{req}$. In this case, the maximum torque was greater than the torque required and similarly with the power requirements, as shown in Table 4.3. The PG71 was able to meet the given guidelines for motor selection, which is why it was selected for this application.

After selecting the motors, other electronic parts, and the mechanical parts for the chassis, some of the values of the parameters that were previously assumed could now be refined, including the radius of the wheel and the weight of the vehicle. These parameters as well as the new power and torque requirements, assuming the motor is unchanged from the maximum power and torque shown in Table 4.3, can be found in Table 4.4.

Table 4.4 – Known vehicle parameters with the updated power and torque requirements.

Variable	**Value**	**Unit**
Wheel Radius	4.75	in
Weight	11.02	lb
P(req/motor)	25.17	ft-lb/s
T(req/motor)	1.74	ft-lb

The general guidelines for motor selection are still met, however the maximum power is only slightly greater than the power required.

To reduce the power and torque requirements, the chassis design may include an angled skid plate in the front. An example of a skid plate on an RC tank can be found in Figure 4.7, the same tank used for the preliminary testing of an RC tank.

Figure 4.7 – RC tank used for testing and to visualize the use of a skid plate [13].

This RC tank was successful in getting over obstacles using the skid plate, however the speed of this tank was much greater than the speed of the robot. For this application it can be used to get over obstacles and reduce the amount of resisting branch force. The incline can allow for the branch to come in contact with the robot at an angle (α), reducing the branch force to F_b* sin (α). The attachment "Motor Selection" was then modified to include the angled front of the chassis and the power and torque required can be found in Table 4.5.

Table 4.5 – Incline of the skid plate and the new power and torque requirements.

Variable	**Value**	**Unit**
Plate Incline	30	º
P(req/motor)	20.59	ft-lb/s
T(req/motor)	1.43	ft-lb

Therefore, these motors should be able to handle the power and torque requirements presented by the uneven terrain with many obstacles.

One other decision that was made about the branch force was to assume the robot would be displacing the branch in the vertical direction opposed to driving through it. Driving through the branch to displace it produced a significant increase in the resisting branch force, making the power and torque requirements too high to be able to purchase a motor for a reasonable price. If the branches were lifted over or under the robot with the use of a skid plate, then the branch forces would decrease significantly requiring less power and torque from the motors.

4.4 Drive Train

The drive train system is crucial for transmitting the power and torque from the motors to the wheels to allow the robot to move. In robotic applications, there are many different designs of drive trains, some of the main ones including direct, chain and sprocket, and gear drive. Direct drive connects the motor shaft directly to the wheels usually with parts in between for supporting the shafts. An unexploded side view of the direct drive train designed is shown in Figure 4.7.

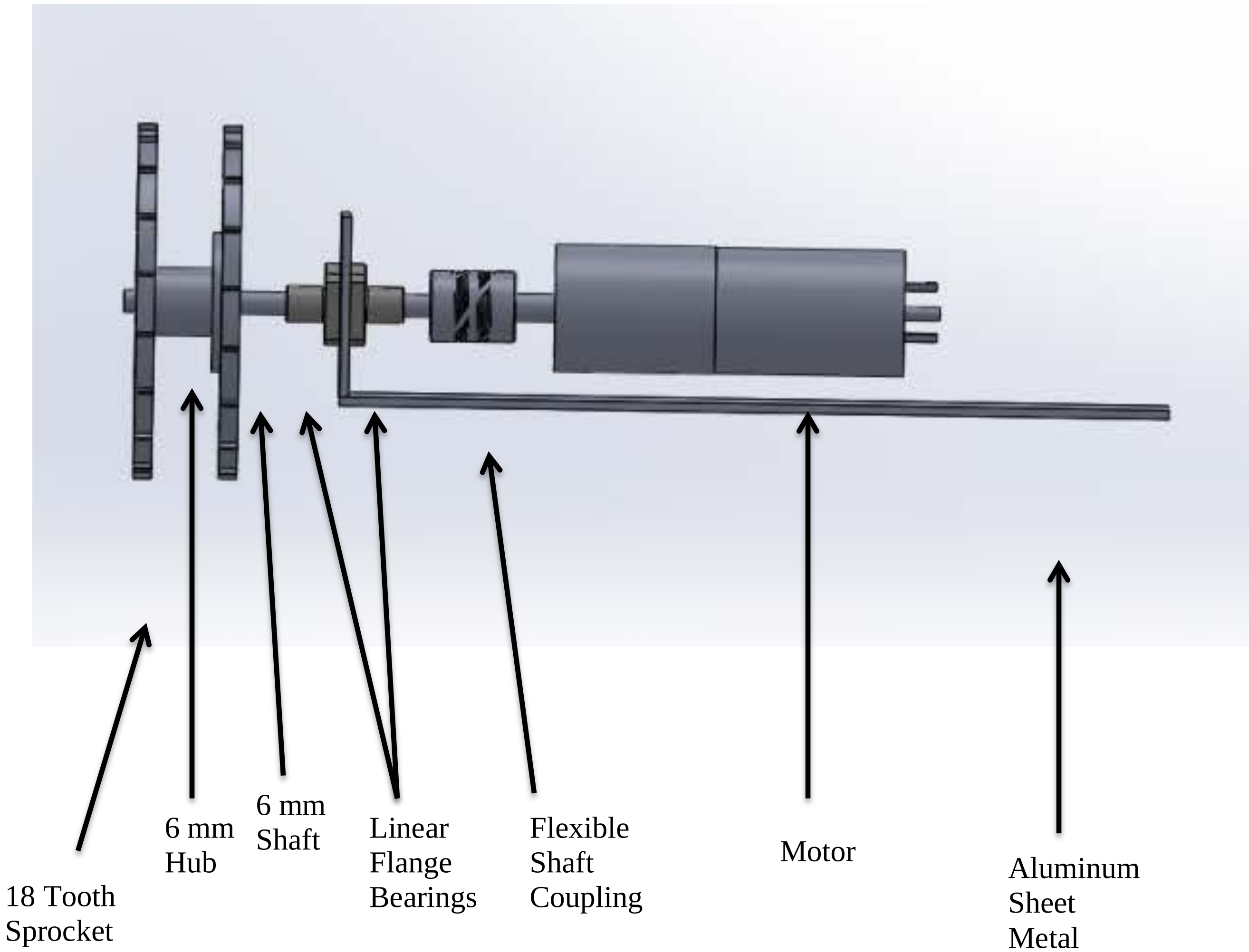


Figure 4.7 – Side view of the drive train design.

The motor supplies the power and torque to the sprockets through a 10mm shaft. The flexible shaft coupling functions as an adapter connecting the 10 mm motor shaft to a 6 mm aluminum shaft. A pair of 6 mm linear flange bearings mounted to the chassis supports the 6 mm shaft. The 6mm shaft then connects to the sprockets via hubs specifically designed for these sprockets. The sprockets are used instead of wheels because of the tread design. In between the sprockets, connecting them together is a 6 mm hub. This sprocket was designed based off of the physical part sold by Lynxmotion. It is designed to pair with a set of tracks that will be discussed in the Tread System section of the report. There will be eighteen teeth per sprocket and the outer diameter is 4.75 inches.

4.5 Tread System

It was determined that the best way to succeed in building a tread system was to use the tracks provided by Lynxmotion. The tracks could come in 2 or 3-inch widths and can be ordered in lengths of approximately 28 inches. The advantage of using these tracks is that the pitch, 1.07 inches, is already determined, and the sprockets are designed specifically for these tracks. The tracks and sprockets must be assembled, but are able to be made in custom lengths to fit any application. The track and sprocket system from Lynxmotion is shown in Figure 4.10.

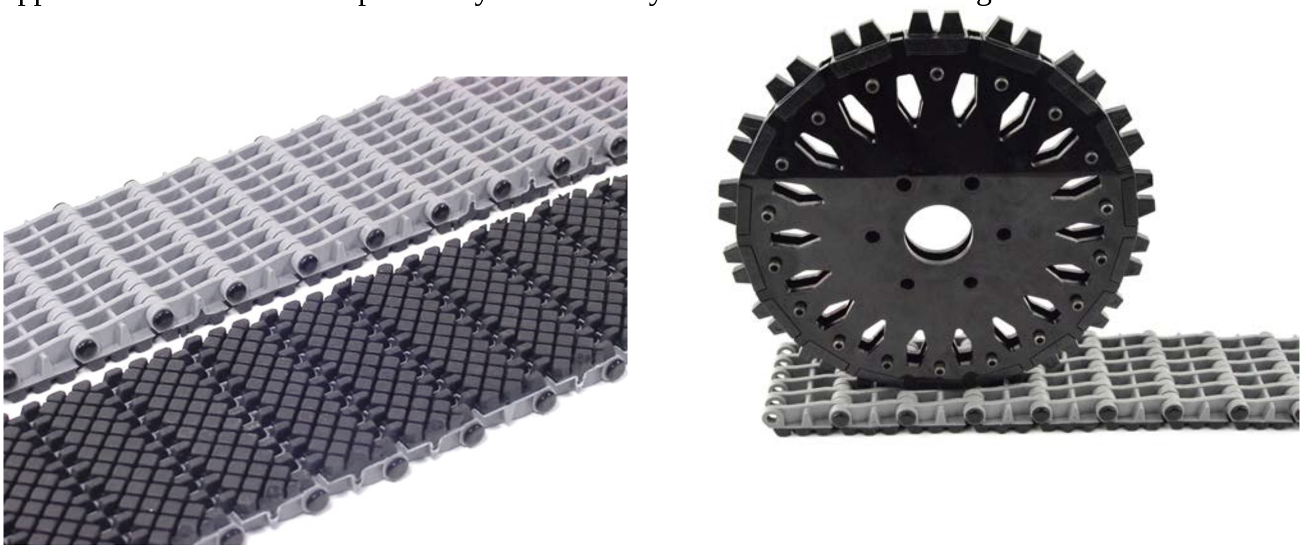


Figure 4.10 – The track and sprocket for the tread system made by Lynxmotion [14].

The total length of the tracks is crucial in determining how many set of the tracks would need to be purchased. The total length was calculated using Equation (11) from [15]:

$$L = 2C + \frac{\pi}{2} * (D1 + D2) + \frac{(D1-D2)^2}{4C} \qquad (11)$$

where L is the length of the tracks, C is the distance from the center of the first wheel to the center of the last wheel, and D1 and D2 are the pitch diameters of the first and last wheel respectively. In this case D1 and D2 are both equal to 4.75 in and the last term in Equation [13] is equal to zero. The belt length should be a whole number because the tracks provided come in lengths of 28 inches, about 26 links. Due to the length of the chassis and the location of the shafts, the length of the belt was determined to be 35.5 in, almost exactly 33 links. This made the distance between each wheel to 0.3944 in and the distance, C, between wheels approximately 10.3 in.

4.6 Structure

The robot, as per the design requirements, should be lightweight and approximately 10-12 pounds. Because of this requirement, it was necessary to choose a material for the body of the chassis that was lightweight, but also strong enough to avoid being damaged in the environment. It should be strong enough to support the loads supplied by the motors and support the maximum stresses exerted by parts of the drive train.

The material chosen was 5052 aluminum. The body of the chassis will be comprised of 0.125 in thick aluminum sheet metal that is capable of being folded up like a box, see Figure 4.11. The folds will strengthen the material and provide a lightweight chassis to house the electronics and other drive train components.

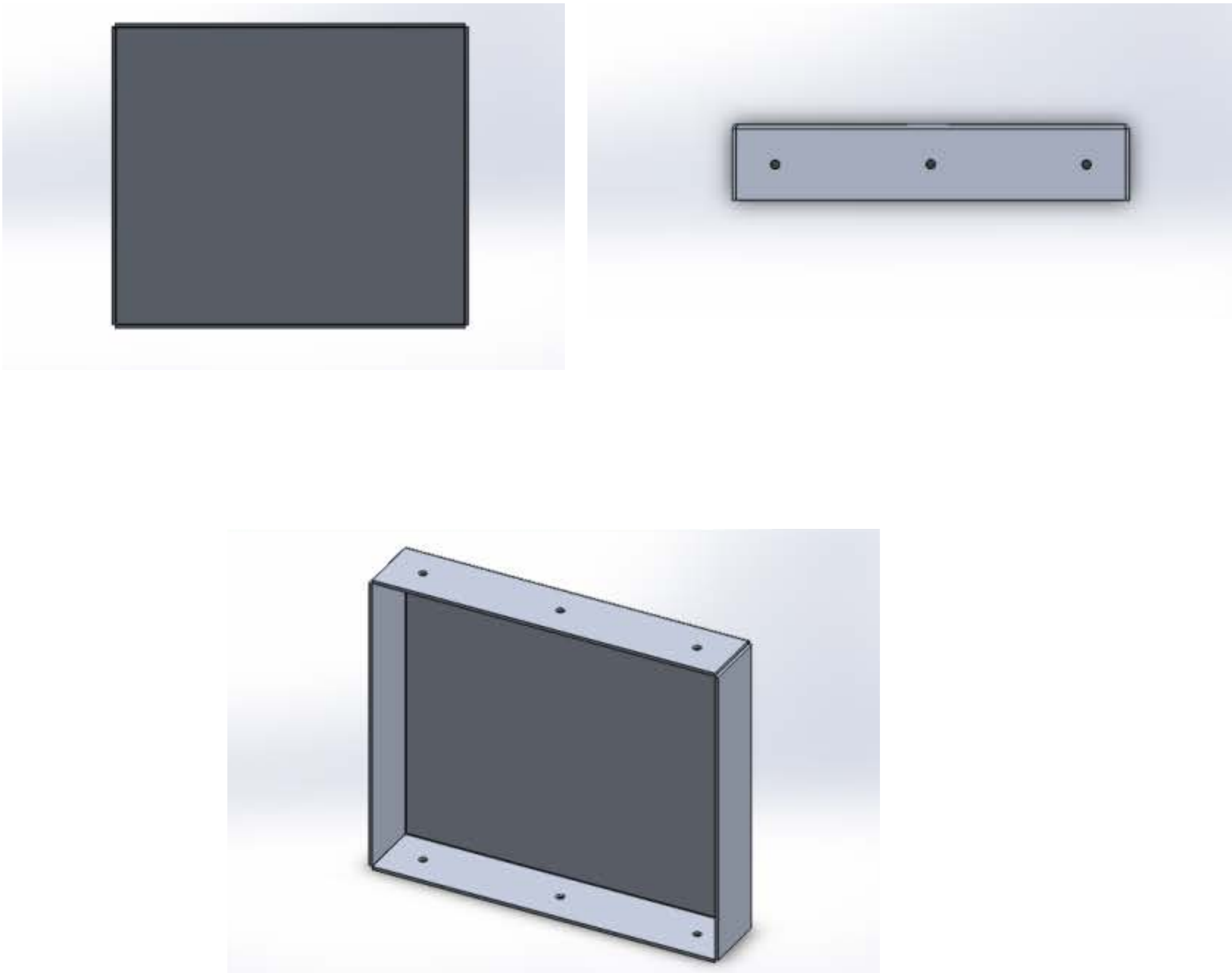


Figure 4.11 – Top, right, and isometric views of the chassis designed using sheet metal.

The length of the chassis body is 13.0 in, the width is 11.5 in, and the wall height is 2.5 in. The unfolded piece of sheet metal, represented as a DXF file to be used by the machinists, can be found in Figure 4.12.

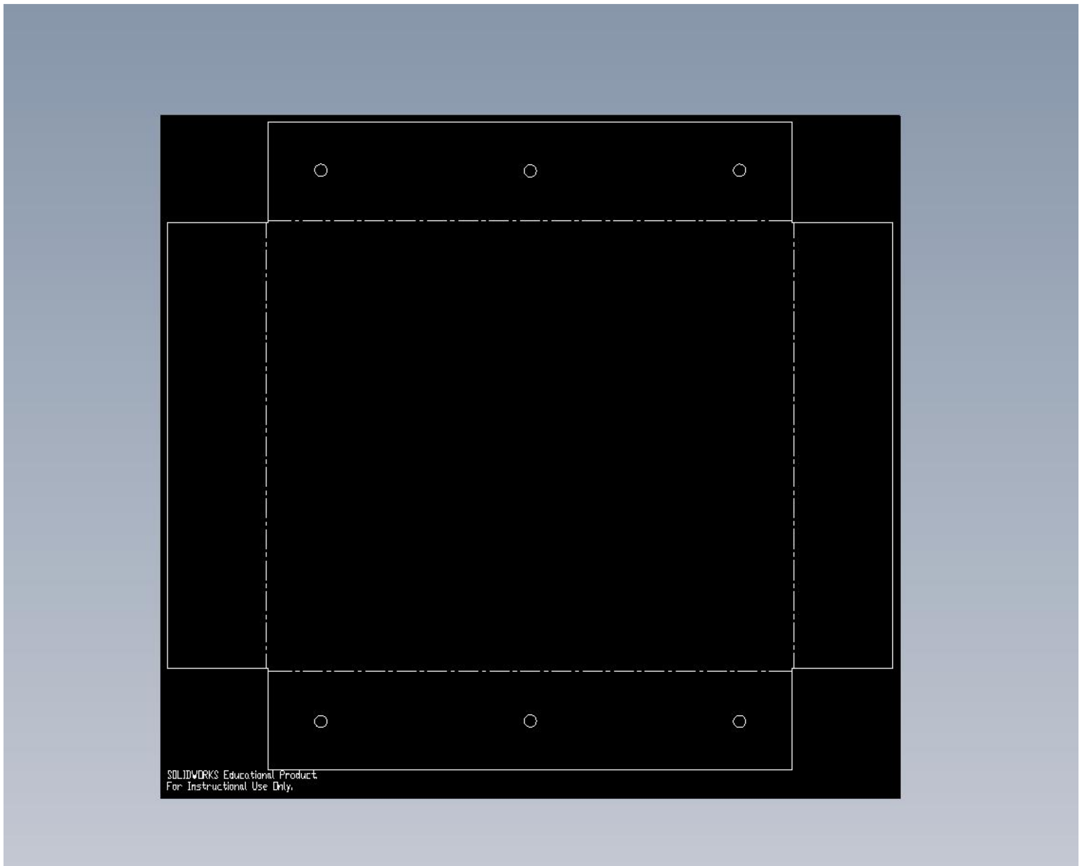


Figure 4.12 – DXF file of the chassis body sheet metal unfolded.

In Figure 4.12, the solid lines represent the actual outlines of the piece of sheet metal, and the dashed lines represent the fold lines for the machinists. The piece will be cut using the water jet, which will allow the holes for mounting the shafts and bearings to be cut simultaneously.

The total weight of the robot was calculated in the electronic attachment Weight. Each part of the drive train, control system, chassis body, and tread design were included to fully understand the weight of the vehicle. The weight of the electronic components can be found in Table 4.4 and the drive train components in Table 4.5.

Table 4.4 – The weight of all of the electronic components.

Electronics	
Part	**Weight (lb)**
Motor 1	2
Motor 2	2
Motor Driver	0.007
Battery	1.77
Receiver	0.02
Arduino	0.015

Table 4.5 – The weight of all of the drive train components.

Drive train / Treads	
Part	**Weight (lb)**
6 Sprockets	1.32
Belt	N/A
2 Couplings	0.06
6 Flange Bearings	0.72
4 6mm Shafts	0.18
2 Hubs	0.26

The total weight of the vehicle is approximately 11.02 lb. This is just an approximate weight because the weight of the tracks from Lynxmotion is unknown and will not be known until after fully manufacturing the robot.

A finite element analysis, FEA, was completed to ensure the chassis body would be able to withstand the maximum forces and stresses without large deformations. The fixtures and loads applied represent the worst-case scenario that the robot would experience. A mesh was generated and refined to observe if the results would converge, meaning as the mesh gets finer and finer, the stresses and deflections do not change significantly. Two analyses were run only changing the location of the load while keeping the boundary conditions and materials the same. The fixtures, loads, and mesh generated can be found in Figure 4.13.

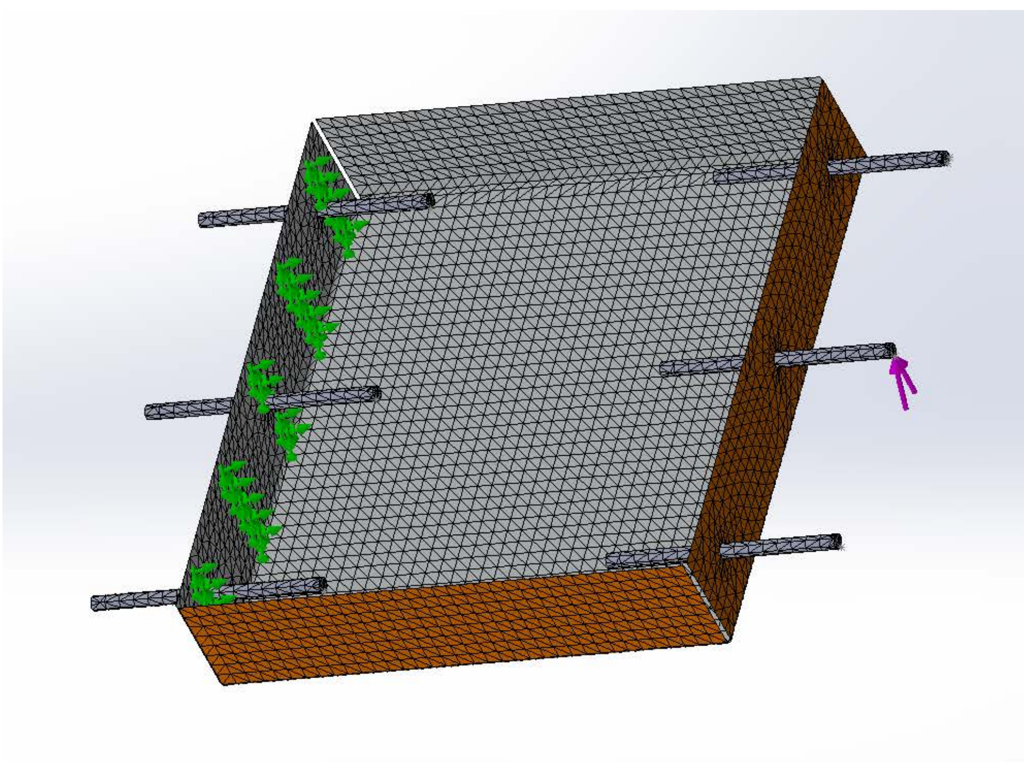


Figure 4.13 – Fixtures, loads, and mesh generated for the finite element analysis.

The material used in the analysis was aluminum 5052, the load was applied to the end of the shaft, like a cantilever beam, and the wall opposite to the load was completely fixed from translations and rotations. The load used in the analysis was 36 lb, which is three times the weight of the vehicle. The yield stress of the aluminum is 31 ksi and the elastic modulus, E, is 10200 ksi [16]. This is the worst-case because the robot should not be encountering 3gs of force and the walls of the chassis will not be completely fixed.

The first analysis applied the load to the first shaft, instead of the middle shaft in Figure 4.13. The results of the analysis can be found in Figure 4.14 and Figure 4.15, the von Mises stresses and displacements, respectively.

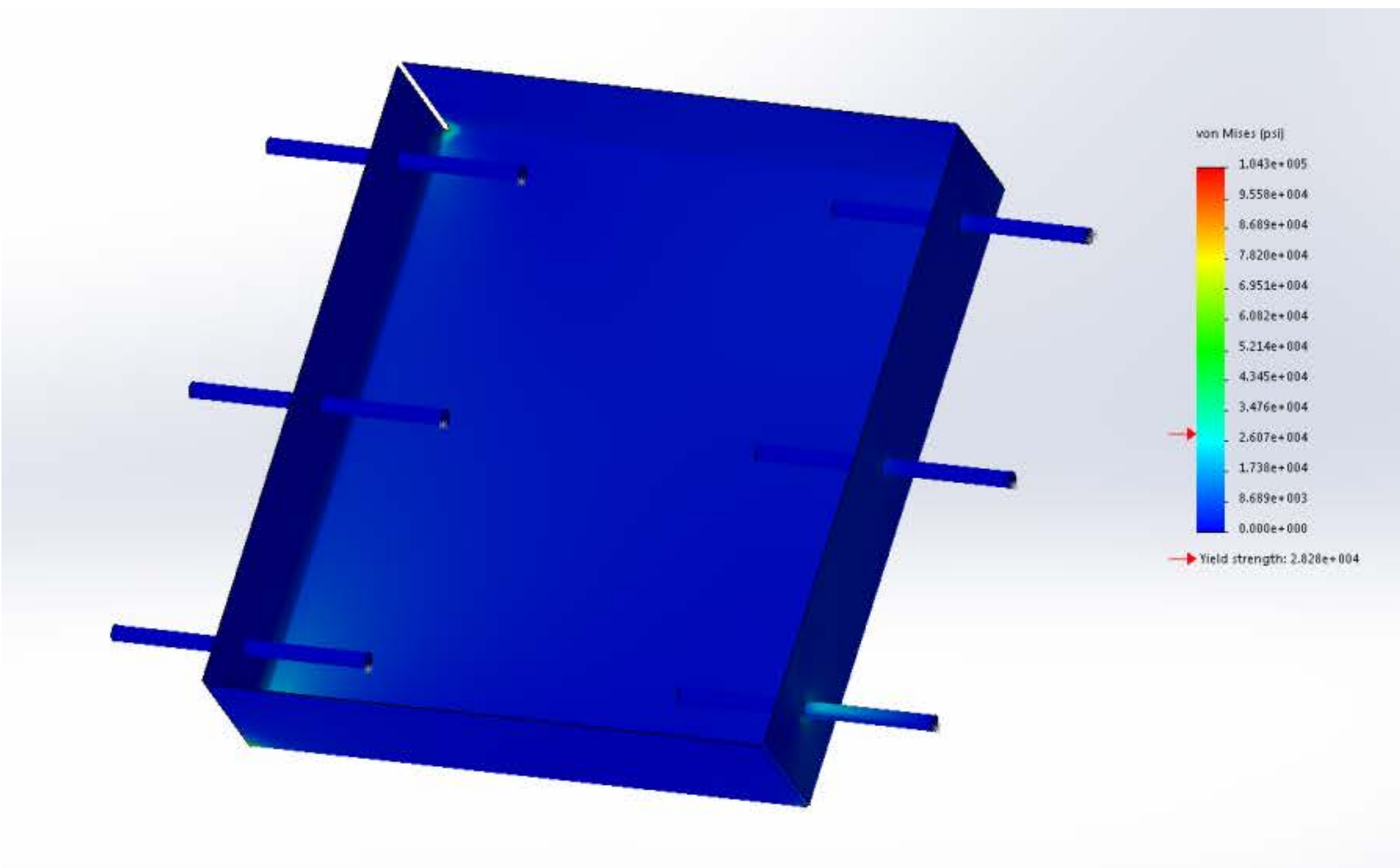


Figure 4.14 – The von Mises stresses for the first loading.

A quick calculation, using Equation (11) below, was completed to verify the validity of the finite element results.

$$\sigma = \frac{Mc}{I} \tag{11}$$

where M is the moment caused by the applied force, c is the distance away from the shaft's neutral axis, and I is the area moment of inertia of the shaft. Equation (11) yielded a stress of 30.5 ksi, which is the same order of magnitude to the von Mises stress results.

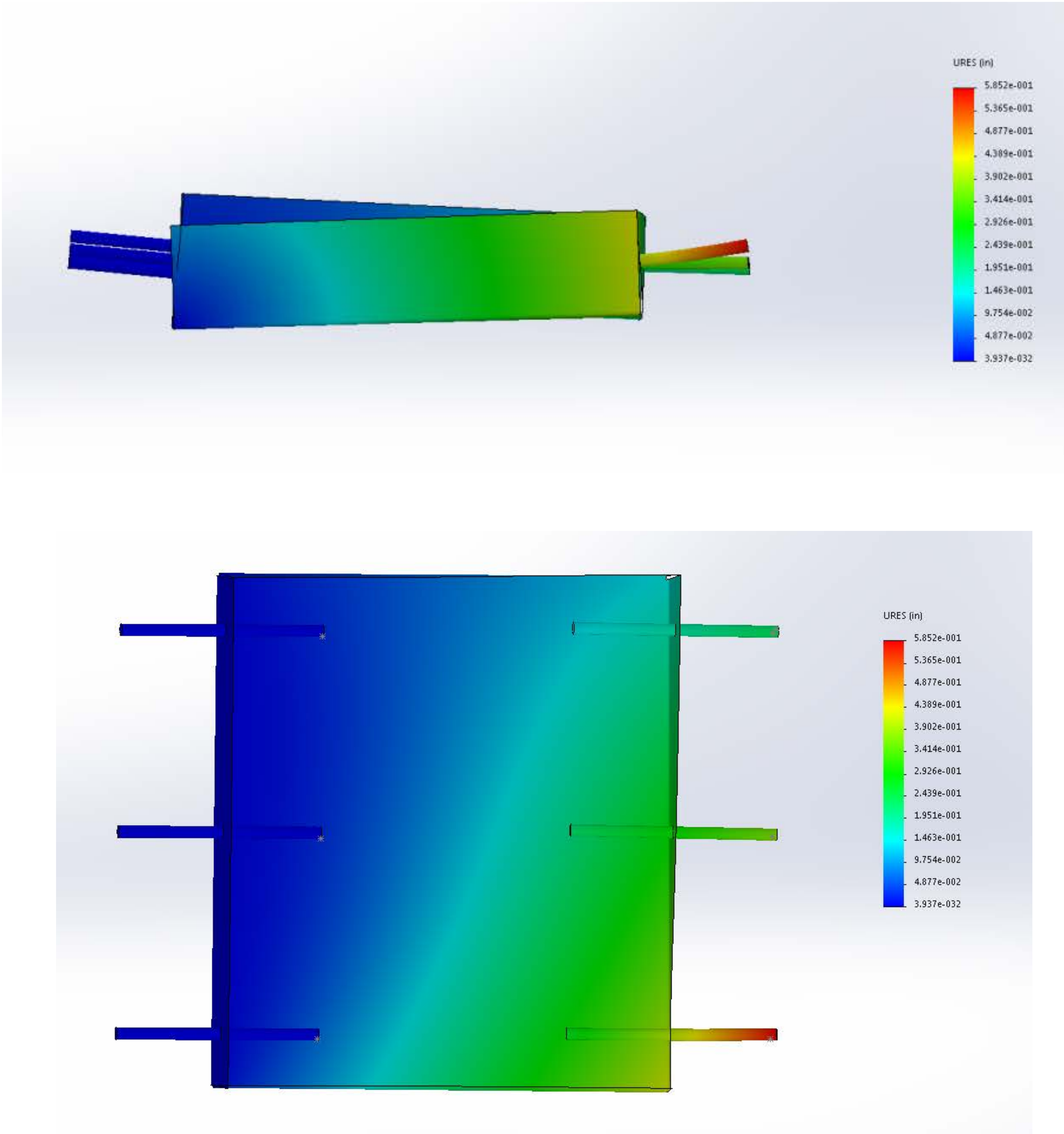


Figure 4.15 – Displacements for the first loading and the side view of the deformed result.

As shown in Figures 4.14 and 4.15, the maximum stresses and displacements are located on the shaft where the load is applied. The stresses on the chassis body are less than the yield stress of aluminum and the displacements are small enough to accept. Also, there will be bearings, shaft couplings, and a hub to take some of the load that were not included in the analysis model. The next analysis completed was moving the load to the middle shaft. The results of this analysis can be found in Figure 16 and Figure 17.

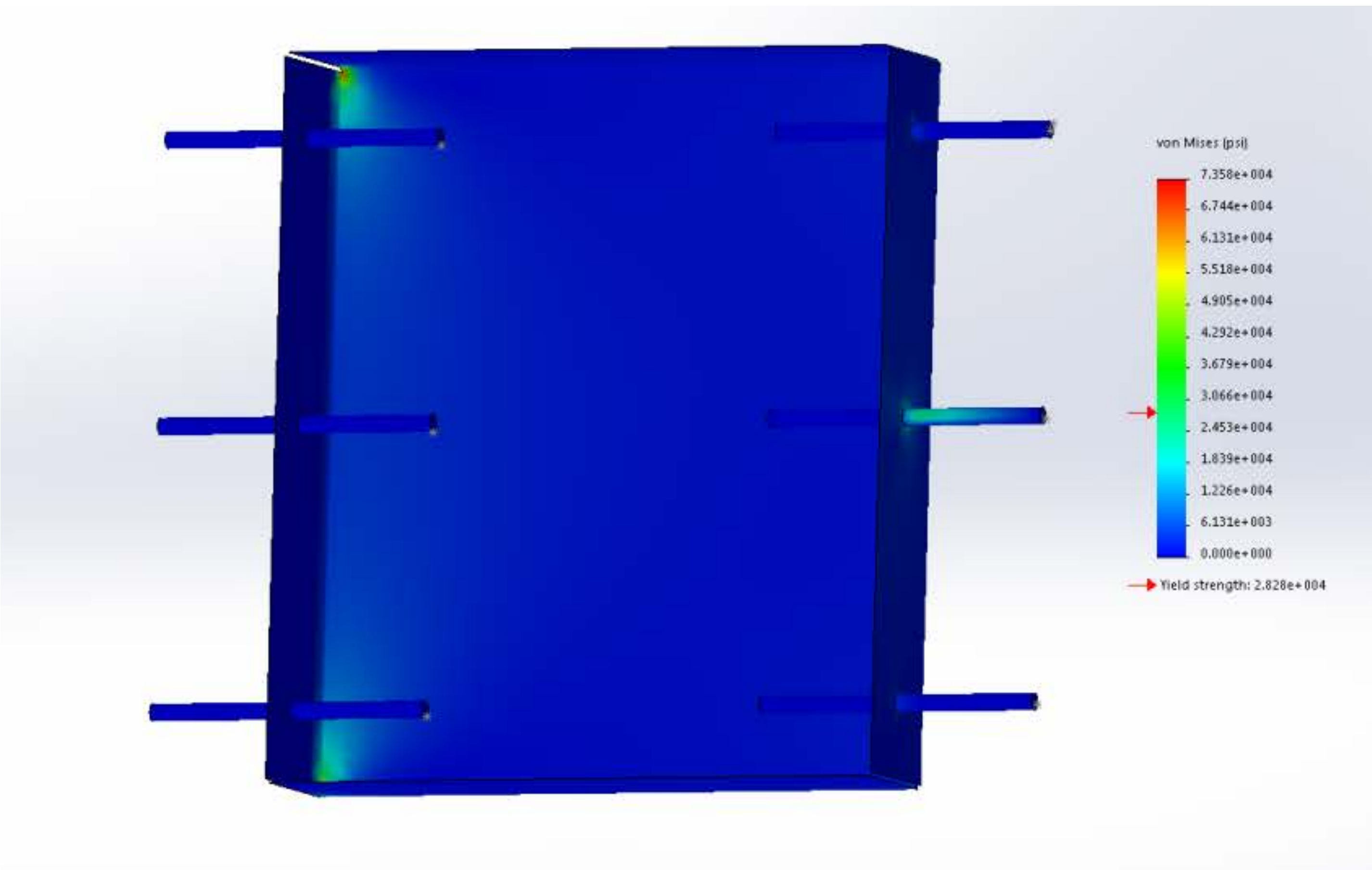


Figure 4.16 – The von Mises stresses for the second loading.

The stresses in the corners, also present in Figure 4.14, are due to the boundary conditions and the way Solid Works models the sheet metal. The chassis will not have the spaces in the corners causing stress concentrations.

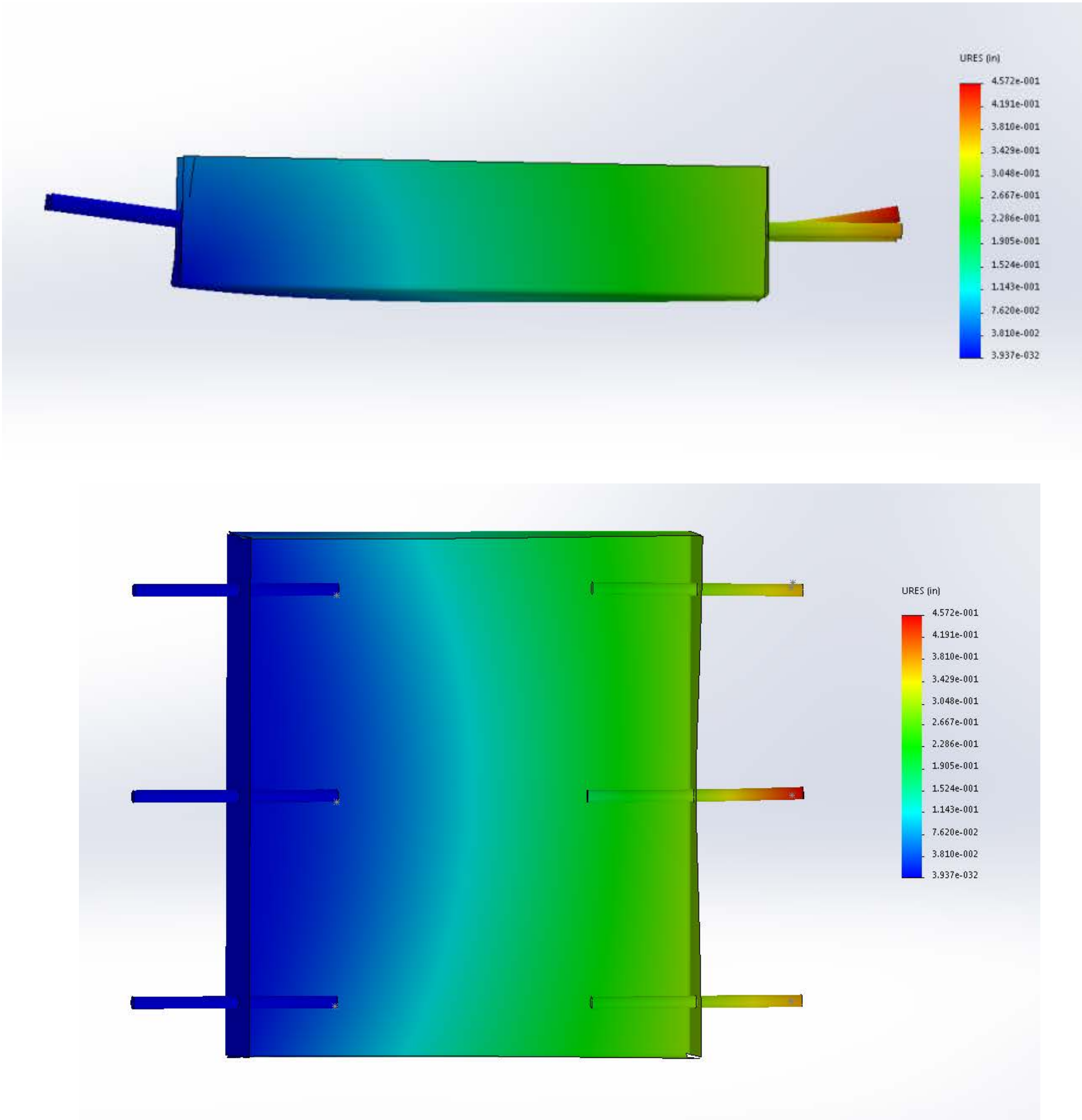


Figure 4.15 – Displacements for the first loading and the side view of the deformed result.

This analysis showed similar results in the stresses and displacements. Because the maximum stressed and displacements were located on the shaft being loaded, it was suggested to use steel shafts instead of aluminum. The steel shafts will be much stronger than the aluminum and reduce the magnitudes of the stresses and displacements. If necessary, another analysis can be performed that includes the bearings and possibly more support on the chassis body to further reduce the maximum stresses and displacements.

4.7 - Conclusions

The attributes of the chassis design include the electronic system, the motor selection, the drive train, and the chassis structure. The electronic components to implement autonomous and remote control were selected and understanding of how the components will work together was developed. The motor selection was a crucial decision and the power and torque requirements for the robot were satisfied. The drive train was also important to be able to transmit the power and torque from the motors to the sprockets, while maintaining enough support so the shafts do not experience forces and moments large enough to produce large deformations. The finite element analysis was able to show that the chassis body will be able to withstand the maximum stresses without large deformations. The maximum displacement is large, but the fixtures and loading describe the worst-case scenario and therefore the displacements are acceptable. The attributes listed will be crucial in developing the moving platform to succeed in the environment. The cost of the electronic components can be found in Table A.1 and the cost of the mechanical parts can be found in Table A.2 all in Attachment A.

There are a few main concerns relating to these tracks that will have to be addressed. First, the assembly of the tracks is relatively simple, but the connection between the tracks is made of Nylon fasteners. The concern is that if there is too much force or stress is applied to the tracks, the fasteners will loosen causing the track system to break. If this occurs, the robot will not be able to move and the user will have to reassemble the tracks. A similar concern is if branches or leaves get caught in the tracks causing them to break. This will not be a good experience for the user and will have to be addressed in the final tread system design after manufacturing. The last concern is that the material on the outside of the tracks will not provide enough traction for the robot to move over the terrain. The material of the tracks is not provided by Lynxmotion and it is unknown whether the robot, with this tread design, will maintain traction over obstacles and not get caught on dirt or other parts of the terrain.

5. Final Chassis Design

5.1 – Photo Gallery

A top view of the final chassis design can be found in Figure 5.1. An isometric view of the final chassis design can be found in Figure 5.2. The Lexan cover to house the electronics is the only key component missing from the figures of the final chassis design.

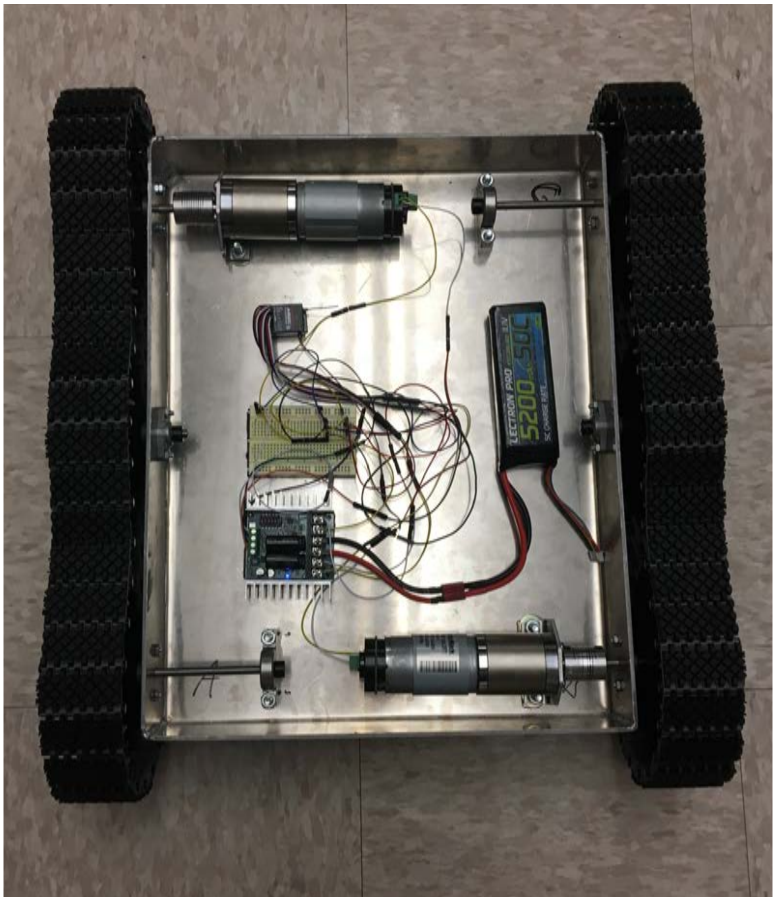


Figure 5.1 – Top view of final chassis design.

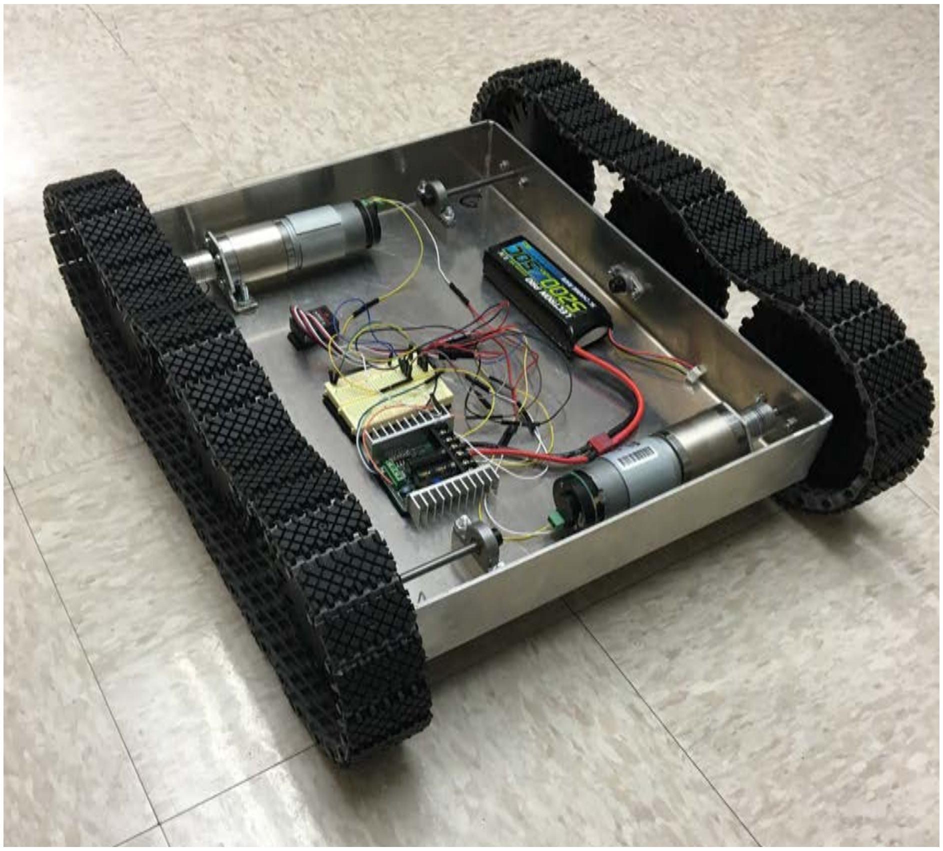


Figure 5.2 – Isometric view of final chassis design.

Figure 5.3 shows the drive train system that was ultimately chosen for the chassis. Lastly, Figure 5.4 illustrates the electronics and control system for the robot. Figure 5.5 shows a side and top view of the tread system with sprockets used in the final design. Changes to the chassis from the original design, represented by the Solid Works model in Figures 4.1 and 4.2, are discussed in section 5.2 “Modifications.”

Figure 5.3 – Drive train of final chassis design.

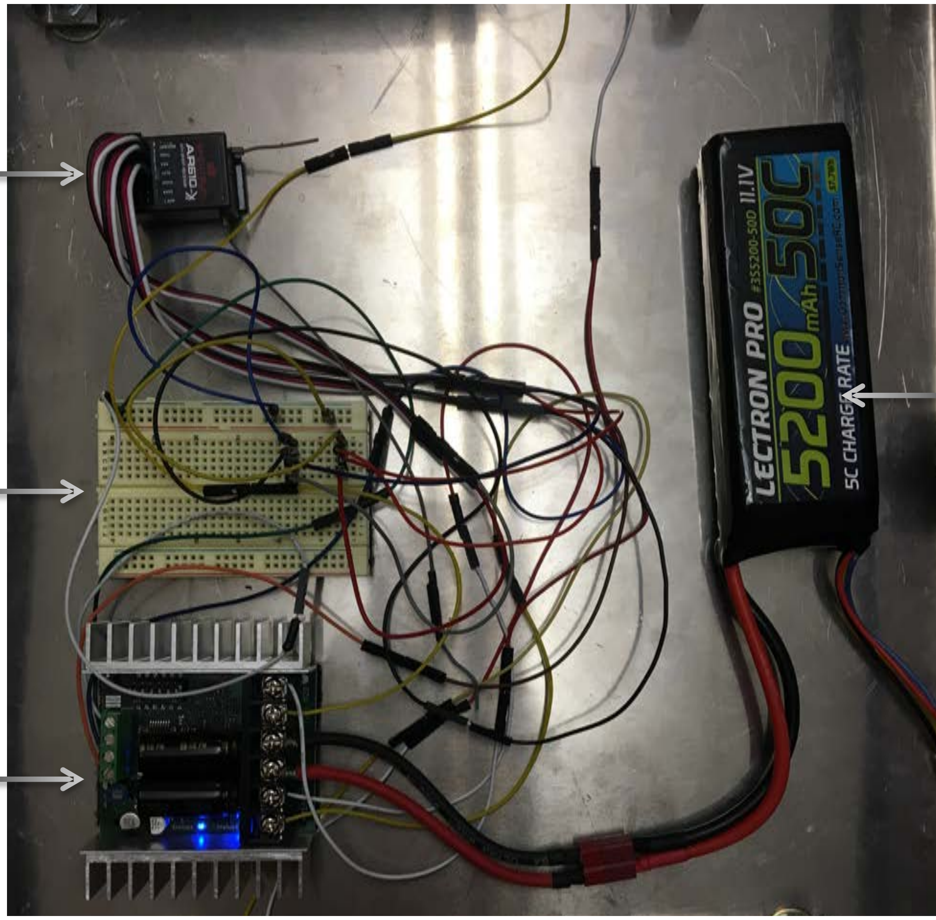


Figure 5.4 – The electronic subsystem for the final chassis design. Note the transmitter is also included, but was not included in the image.

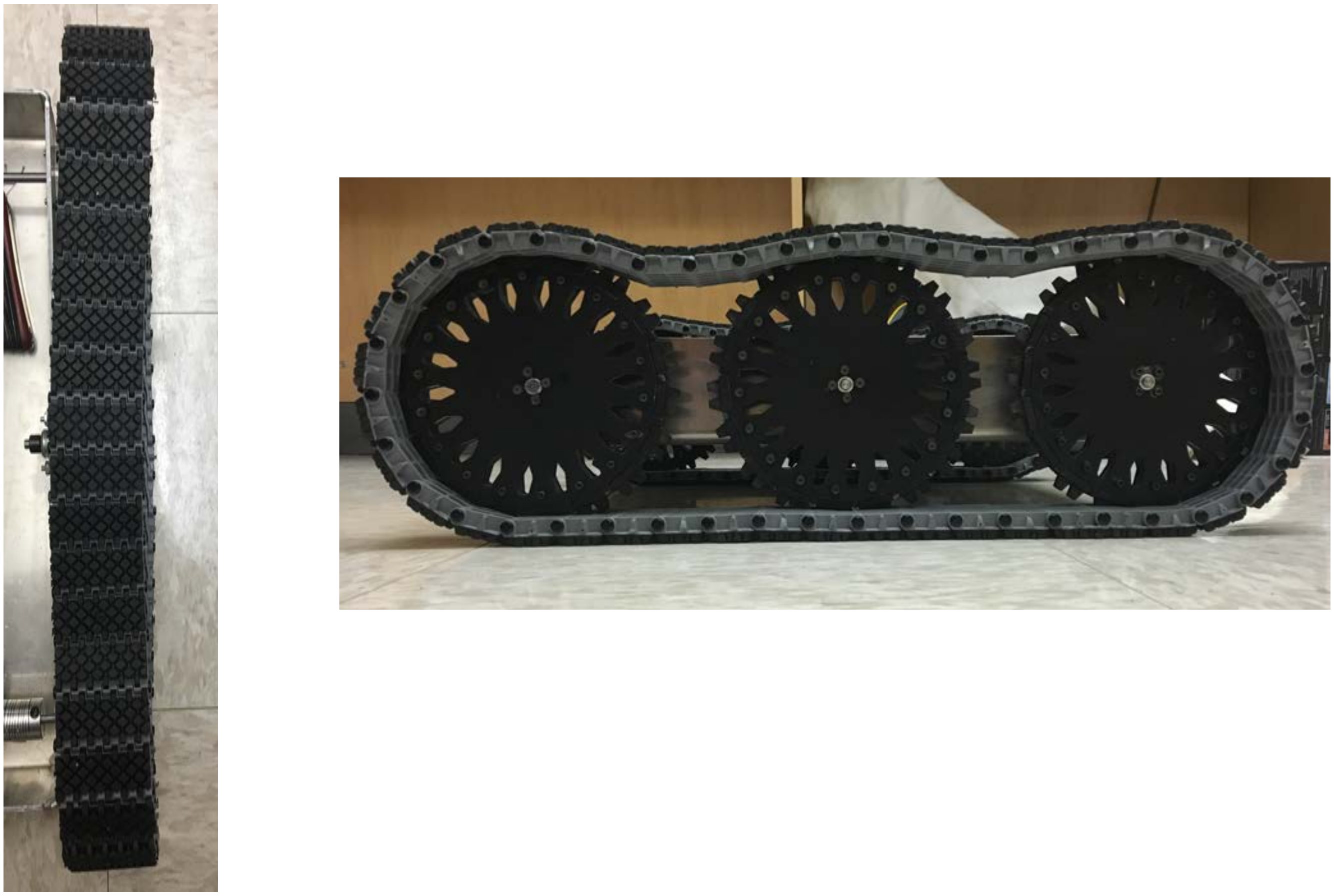


Figure 5.5 – Top and side view of the tread system for the final chassis design

5.2 – Modifications

Modifications to the chassis were made for various reasons. Some decisions were made based on recommendations from the machinists to meet the design requirement of ease of manufacturing. Some decisions were made based off of the project timetable and the project goal to deliver a final product to the consumer. Other decisions were made as improvisations in order to successfully implement the main subsystems.

The first main design modification was the overall chassis size. The dimensions of the original chassis can be found underneath Figure 4.11 in the section “Detailed Chassis Design.”

New dimensions were needed to account for the proper spacing between sprockets for the tread system. The locations of the sprocket centers were not accurate because they did not account for the sprocket teeth biting into the actual treads. The new dimensions of the chassis can be found in Table 5.1. Because of this change, the dimensions of the Lexan cover also had to be adjusted to be able to cover the entire body.

Table 5.1 – The final dimensions of the chassis body.

Dimension	**Value**	**Unit**
Length	16.90	in
Width	13	in
Height	2.5	in
Thickness	0.125	in

The drive train and bearing design was also modified for the final design. First, the linear bearings were all replaced by sleeve bearings because the linear bearings would cause too much damage to the shafts over a shorter period of time. The sleeve bearings would allow the shafts to freely rotate, adding some friction, but would support the moments and forces the shafts would encounter. The bearing design for the drive shaft and the two idler shafts were also modified to provide better support. For the drive shaft, the pair of linear bearings, shown in Figure 4.7, were replaced by only one sleeve bearing on the outside of the chassis. The middle idler wheel bearing design remained unchanged besides the change in bearing type. Lastly, to provide more support for the bending moment, a sleeve bearing was placed a distance away from the inner wall of the chassis. The bearing was raised with a small aluminum block and secured to the chassis using ¼’’- 20 bolts.

Because of the availability of the bearings, the shaft sizes were adjusted to 0.25 in and made of steel. The hub for the sprocket is 6 mm (.23 in) and therefore the shafts were machined at the ends to be able to smoothly fit into the hub. A flat was also added to the drive shafts to ensure a better connection between the shaft and sprocket. This was included because initial testing showed the shaft would loosen in the hub after only ten minutes of use. The shaft lengths for the motor and two idler wheels were adjusted based off of bearing location.

The last main modification was in the electronic system. The Arduino Mega board, shown in the wiring diagram in Figure 4.3, was discarded. This was because of the complexity of implementing autonomous control and the time required to develop an Arduino code to control the robot. Only RC control was implemented using the Sabertooth motor driver. Now, the signal from the transmitter is sent through the receiver. Once reaching the receiver, the signal then is sent directly to the motor drivers to control motor speed and direction. Also the battery originally chosen was not able to be shipped. Therefore, two Lectron Pro 11.1 V - 5200mAh 50C Lipo Battery Pack with Deans-type Connector batteries were purchased to supply power to the motors, motor driver, and receiver.

5.3 – Conclusions

Images of the final chassis design can be found in Figures 5.1 – 5.5. Modifications were implemented to the final chassis design that were not initially included in the detailed design. One of the main changes was the key dimensions of the aluminum sheet metal for the body. These were adjusted to account for the spacing of the sprockets for the tread design. Some other modifications include the types of bearings and locations of the bearings for the drive train and the idler wheels. The shaft length and diameters were adjusted to be able to support the loads and moments the chassis would encounter. The decrease in diameter at the ends of the shafts was necessary to fit into the sprocket hub and a flat was added to add more contact surface for the setscrew in the hub. The only modification to the electronic system was the elimination of the Arduino Mega board and the concept of autonomous control was discarded for the time being. Some of the main concerns with the final chassis design are detailed in section 8.2 “Future Work.”

6. Collection System Design

6.1 – System Requirements

The collection system was the last main subsystem that was designed. The method of collection that was chosen was dragging, mentioned in section 1.2 “Tick Background”, and includes the dragging of a cloth in an open area. As the cloth is dragged, ticks ideally will be collected on the surface. The first system design should be simple. After evaluation of its performance, then the design can be adjusted and include a more complex system. The initial designs can be found in section 6.2 “Alternative Concepts.”

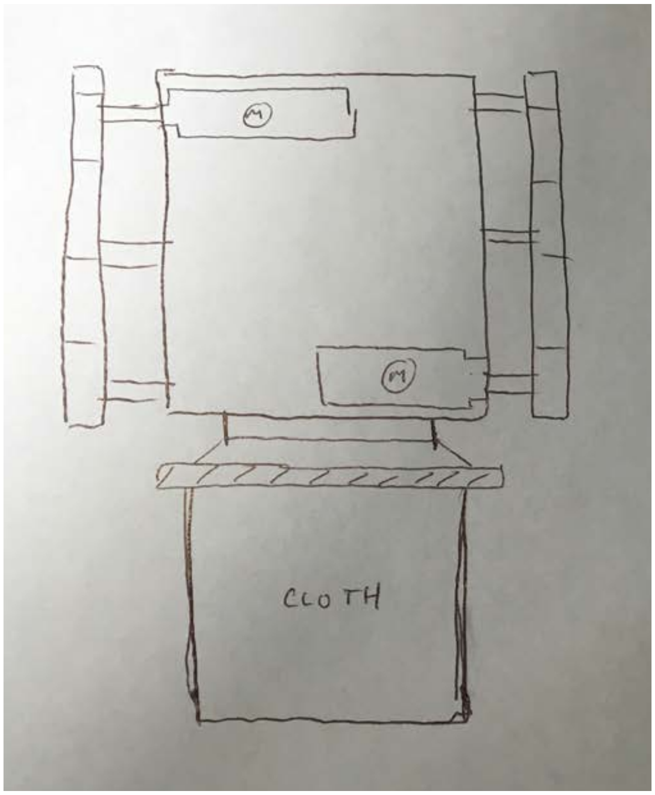
The initial design requirements, described by Professor LoGiudice and shown in Table 2.3, related to manufacturing, geometry, transport, materials, and performance. Some of these requirements relate to the initial design of the collection system. The drag cloth material would be made of denim or corduroy and the size of the cloth could be arbitrary. The size of the cloth should scale with the size of the robot, but different dragging studies vary the cloth dimensions. The cloth should be able to be simply attached, which means a relative ease of manufacture. The cloth should also include a function that allows it to remain in contact with the ground surface. Lastly, it should be easily removed and replaced to facilitate the user’s tick collection.

6.2 – Alternative Concepts

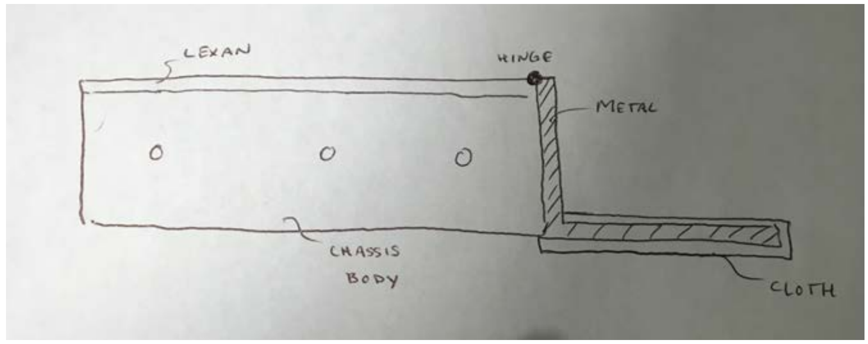
The first, simple concept that was designed was a rigid attachment to the back of the chassis to drag the cloth. The attachment would not be able to be adjusted and provides enough support to ensure the cloth would remain attached to the back of the chassis. The flaws in the design include the inability of the cloth to move and adjust itself if it were to get stuck on a branch or caught in the environment. The benefits of the design include simplicity, ease of manufacture, and would be useable in a reasonable timetable. A rough sketch of a top view of the design can be found in Figure 6.1 (a).

The next collection system that was designed included a mechanism that allowed for the cloth location to be adjusted. The design would be hinged to the back of the chassis and include a servomotor or system to act similarly to a forklift. The benefits to this design are being able to adjust the cloth, possibly using a channel on the transmitter – receiver system, to avoid the cloth restricting the robot's mobility. The cloth would be able to be lifted to avoid obstacles and also could be maneuvered to be released if caught on a branch. A rough sketch of a side view of the design can be found in Figure 6.1 (b).

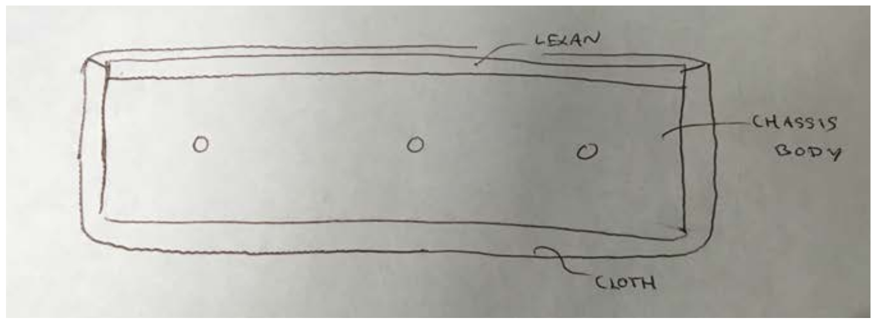
The last, most complicated design for the collection system was a design acting as a conveyor belt. The belt could either be attached directly to the tread system or a new belt system could be designed over the top and bottom of the chassis body. This system seems unreasonable to design because of the complexity and the cloth resting on the treads defeats the purpose of the tread system and increasing traction. With more time and more detailed design, this system would be beneficial because it would also rest under the robot. The amount of area of the cloth in contact with the ground would increase. However, the user would have a more difficult time removing the cloth to collect the ticks and replacing it to continue collecting. A rough sketch of a side view of the design can be found in Figure 6.1 (c).



(a)



(b)



(c)

Figure 6.1 – (a) A top view of the first, simple collection system design. (b) A side view of the second collection design implementing a forklift. (c) A side view of the last concept design using a conveyor belt configuration.

6.3 – Detailed Design / Prototype

The collection system that was designed was the first, simple design. A prototype was developed and attached to the robot chassis for preliminary testing. An image of the drag cloth system typically used for tick collection can be found in Figure 6.2. The length and width of the cloth are 36 in and 40 in, respectively.

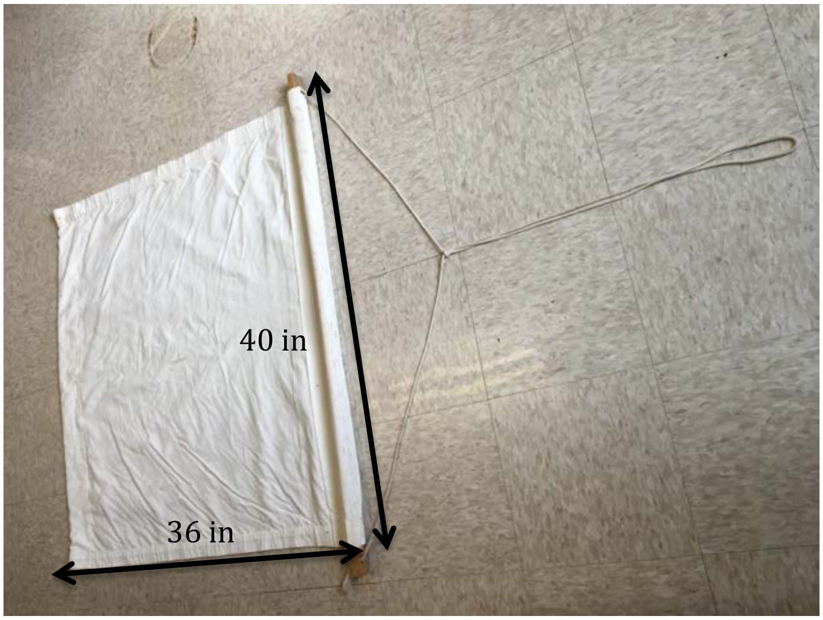


Figure 6.2 – A typical drag cloth system for tick collection.

An image of the first prototype of the collection system can be found in Figure 6.3. The length and width of the cloth are 23 in and 17.5 in, respectively.

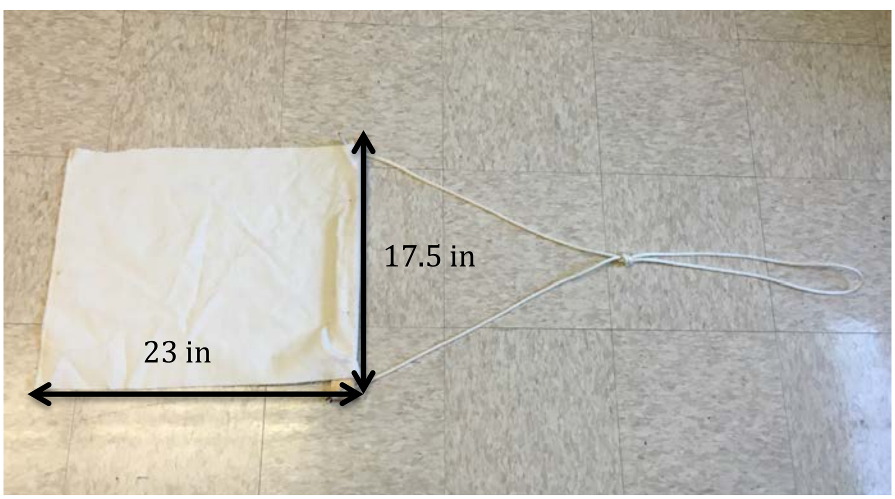


Figure 6.3 - The first prototype of the collection system.

Images of the collection system physically attached to the chassis body can be found in Figure 6.4.

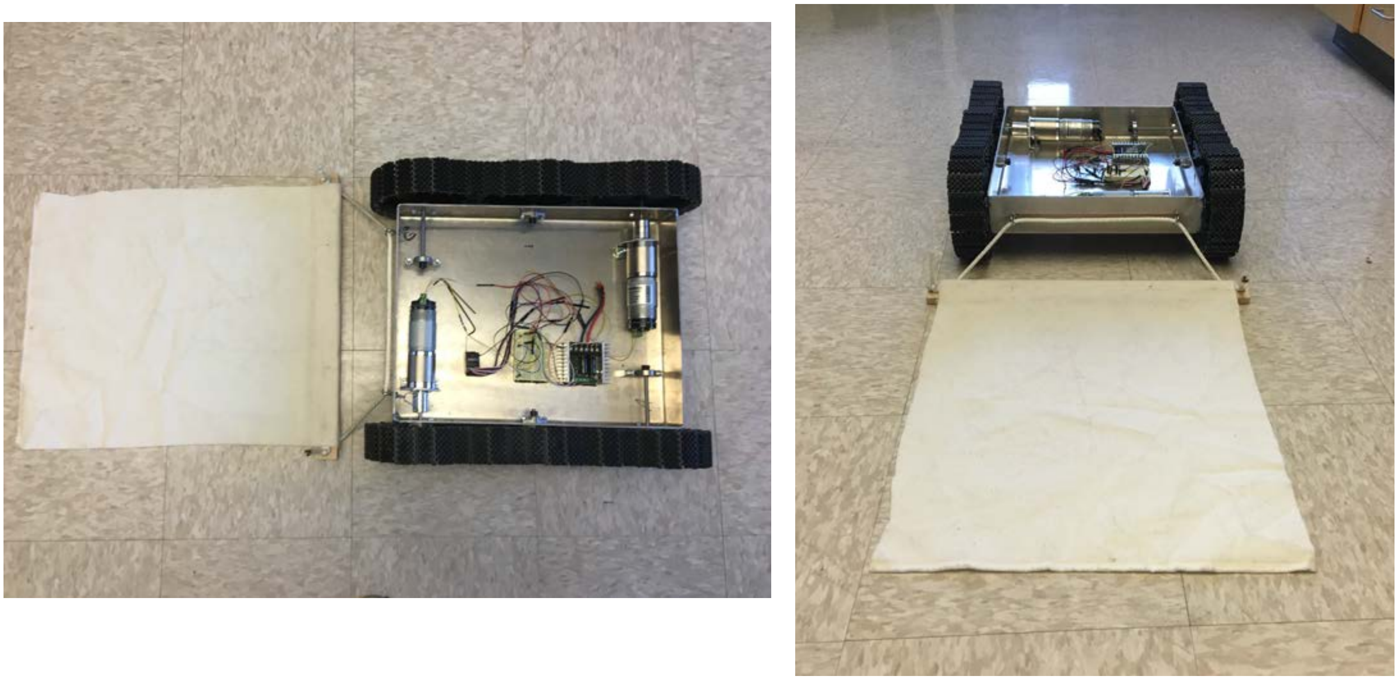


Figure 6.4 – A top view and back view of the drag cloth connected to the back of the chassis.

An evaluation of the cloth system performance will be completed in the spring. This evaluation will include metrics such as its ability to maintain contact with the ground when traveling in a straight line both forwards and backwards, turning with both large and small turn radii, and lastly when climbing over obstacles. Modifications to the design of the collection will be made if the current, simple system is inadequate.

<u>6.4 – Conclusions</u>

The collection system was the last subsystem designed to complete the entire detailed design of the robot. Professor LoGiudice helped to understand the design specifications that were crucial to the system. The cloth material is corduroy and the dimensions of the cloth were chosen arbitrarily to be 17.5 in by 23 in. Alternative concepts were sketched to brainstorm different configurations of the collection system. Currently, it was decided to keep the first iteration of a prototype simple to prove the concept of small scale robot dragging would work. The drag cloth is attached rigidly to the chassis body. This system replicates the current dragging system shown in Figure 6.2.

The design of the collection system has benefits and drawbacks. The first benefit is ease of manufacturing and short amount of time required to build a prototype. The design is very simple and does not incorporate any electronic adjustments. The main drawback of this system is also its simplicity. If the cloth gets stuck on a branch or obstacle, there is no way to try to lift the cloth or maneuver the cloth to remove it from an obstacle. The design is rigid and follows the robots motion, but in certain cases it would be more beneficial for the collection system to adjust itself to account for tight turns or small areas with obstacles. This is one aspect of the design that could use more design iterations to succeed in the environment.

7. Results

<u>7.1 – Evaluation of Chassis / Collection System</u>

The original design requirements provided the metrics used in Table 7.1, which evaluates the final robot design. The corresponding list of requirements referenced in the table can be found below.

Some of the key metrics that needed measurement were speed, turn radius, and obstacle height. Speed will be measured by recording the time the robot takes to travel a certain, known distance. The speed test will be completed multiple times to record the average speed of the robot and the standard deviation. The distance can be on flat ground or can be on an incline with a known angle of elevation. Obstacle height will be varied from 0.5 to 5.0 in to test the ability to climb. If the robot is capable of climbing over a 5.0 in obstacle, the height will be increased until a maximum is reached. Turn radius will be measured roughly by tracing the path of the robot as it turns. The diameter of the circle that the robot traces will be measured multiple times to determine the average turn radius and standard deviation.

Some of the key metrics that were measureable were the total cost, dimensions, machined parts, and overall visual quality of the robot. Currently, the cost of the robot is $1264, which is less than the allotted $1300 from Union College grant money. The dimensions of the robot expanded because of the locations of the sprockets. This is not ideal because to maneuver through the environment, it would be more beneficial to be smaller in size. The total number of machined parts was 9, a relatively low number that did not require a high degree of difficulty to manufacture. Lastly, the robot does look visually appealing and was rated an 8 out of 10, based on overall appearance, number of sharp edges, and opinions of other Union College engineering students.

Table 7.1 – Metric evaluation table of the chassis and collection system design.

Metric #	**Requirement #**	**Metric**	**Importance Scale (5=very important, 3=average 1=not very important)**	**Units**	**Target Value**	**Measured Value**
1	1	Total Cost	4	$$	$1,300	$1,264
2	2	Weight	5	lb	12	16.4
3	3	Flat Line Speed	4	ft/s	5.72	1.67± 0.04
4	3	Incline Speed	3	ft/s	3.5	N/A
5	4	Turn Radius	3	ft	2	1.1 ± 0.07
6	5	Dimensions (LxWxH)	4	in	13x11.5 x2.5	16.9x13 x2.5
7	6	Cloth Size (LxW)	3	in	20x20	17.5x23
8	6	Cloth Material	2	N/A	Denim or Corduroy	Corduroy
9	7	Straight Line Test	3	m	10	
10	8	Visual Test (1-10)	3	N/A	5	8
11	9	# Sharp Edges	2	#	<5	0
12	10	# Parts To Machine	3	#	10	9
13	11	Min. Obstacle Height	4	in	1	1
14	11	Max. Obstacle Height	1	in	5	4.5

15	12	Outdoor Mobility (1-10)	5	N/A	7	5

Corresponding List of Requirements:

1. The total cost of the system should be less than $1400 ($800 for electronics and $600 for mechanical parts)

2. The weight of the robot should be between 10-12 lb.

3. The speed of the vehicle should be close to the average human walking speed or 5.72 ft/s.

4. The turn radius should be small, less than 2 ft.

5. The dimensions of the robot should be small, about 14 in length and 11 in width.

6. The cloth dimensions must be less than 1m x 1m. The material is denim or corduroy.

7. The robot should move on a straight line for 10 m.

8. The robot should be presentable as a consumer product.

9. Must reduce the number of sharp edges exposed to the user.

10. For ease of manufacture, the machined parts should be minimized.

11. The robot should climb over at least a 1 in obstacle and at most a 4-5 in obstacle.

12. The robot should easily move on the outdoor terrain.

7.2 – Conclusions

It was necessary to evaluate different metrics for the final design of the robot to verify most of the main design requirements were met. Some metrics such as vehicle speed, weight, turn radius, and minimum and maximum obstacle heights are not included in Table 7.1 because field-testing outside has not been completed. These tests as well as actual field-testing will be completed in the spring. Field-testing is important because it will be the first time there will be a direct comparison between collection methods. The values inputted in Table 7.1 are from indoor testing on tile floor. The incline speed was unable to be obtained, but the flat line speed was slower than expected. This is most likely due to an increase in estimated weight and additional features that were added. The outdoor mobility was lower than expected because the rubber treads had a significant amount of traction on the grass, making it difficult to turn easily. The maximum obstacle height was determined to be 4.5 in. After 4.5 in, the robot became almost completely vertical and therefore was not able to successfully climb over the obstacle. However, the robot did perform very close to the predicted values, in Table 7.1 above.

The total cost of the robot, mechanical and electrical parts, was lower than the expected amount. The dimensions of the robot increased from the original design specifications mainly due to the locations of the sprockets for the tread system. Visually, the robot looks good and is presentable for a user. There are no sharp edges that would cause harm to the user. Lastly, there were not many parts that required machining, which ultimately led to a relatively simple manufacturing process.

Some benefits of the final design are the ease of manufacturing and safety for the user. Some drawbacks include the size and weight of the robot was greater than expected. This leads to having a stronger structure to prevent any damage from the environment, but it required more power from the motors to get over obstacles or drive up inclines. The size of the robot prevents it from maneuvering in between very small locations, but the larger area of the robot and cloth will enable it to collect more ticks in the given region. After further evaluation of the robot's performance, it will be clearer to discuss the benefits and drawbacks of the final design.

8. Conclusion

8.1 – Summary of Accomplishments

Overall, the design and manufacturing of a tick-collecting robot was challenging and required implementing the design process. The general approach to the project was to define the problem, identify design specifications, and then brainstorm before producing the best design. Once a solution was selected, the Solid Works design was completed prior to beginning the manufacturing process. After manufacturing, testing was completed to help determine aspects of the design that could be improved prior to delivering a product to the consumer and for the future enhancements of the project.

In the fall, the detailed design of the chassis was completed. First, design requirements were listed, assisted by Professor Keat and Professor LoGiudice, and a functional decomposition was completed to determine the primary subsystems and functions of the robot. Next, the pros and cons of tank treads versus wheels were determined, which ultimately led to the decision to use treads for this application. Treads provide a better option to maneuver through the uneven terrain in the environment of the Albany Pine Bush. The next accomplishment includes estimating parameters to determine the torque and power requirements of the motors for the robot. Once the motors were selected, the drive train was designed. The drive train configuration chosen was direct drive to the sprockets for simplicity and bearings to support the shafts, both drive and idler, were initially selected. Aluminum 5052 was selected for the chassis body material and a finite element analysis was completed to ensure the body could endure the stresses and moments from the environment and obstacles.

The winter focused on implementing the control and collection systems. The electronic system was designed on paper in the fall. The first few weeks of the winter focused on purchasing all of the parts for the mechanical and electronic design. Currently, an RC system, transmitter and receiver, control the robot, but in the future it would be beneficial to implement autonomous control. The machinists helped fold the chassis using the sheet metal function in Solid Works and also helped machine the shafts that would drive the robot. As the manufacturing process was taking place, many issues arose. These included the type of bearing, design of the drive shaft, and how to fix the shafts to the chassis. Once these were addressed, testing was conducted to show the robot was capable of moving forwards, backwards, turn, and climb over obstacles, Once the robot was moving, a simple dragging design was selected from the alternative concepts and the prototype was built mimicking a conventional drag cloth system. The cloth system was added to the back of the chassis.

The next steps are to fully evaluate the chassis and calculate parameters such as vehicle speed, flat and incline, turn radius, weight, and determining the maximum obstacle height the robot can climb over. After the chassis is evaluated, it will be crucial to physically test the chassis in an actual tick environment. It would be extremely useful to directly compare the robot method to conventional dragging. This would help understand whether or not the system can serve as a viable option for experimenters sampling ticks in different areas. The robot, after testing and evaluation, will be fully ready to be used by the biology department at Union College. Ideally, it will be able to assist researchers in collecting ticks in different environments with obstacles. It will also provide the user with more safety when collecting ticks because they don’t have to be actually walking through the environment.

8.2 – Future Work

The conclusions of section 5.3 highlight some of the enhancements that could be made to further improve the performance and quality of the tick-collecting robot. For the near future, experimental results will be produced after field-testing to directly compare the robot method to conventional dragging. Also, the chassis will be evaluated for performance and understanding the chassis' capabilities.

Many enhancements could be made to improve the robot's performance to approach the standards of biologists who experimentally collect ticks through dragging. First, in order to increase user safety, the robot control system should include autonomous control. Currently, the robot uses RC control, but this still requires the user to be in the field using the transmitter. Autonomous control coupled with RC control would be beneficial because the robot could be out in the environment on its own and if there are any complications or any changes, the user can override the autonomy and dictate where the robot goes. If it gets caught on an obstacle or stuck in the environment, the user can use RC control to help get the robot out of a difficult situation that the micro controller cannot process.

Some other enhancements could be made to the mechanical system to improve the robot's capabilities. The drive shaft should have a collar or a pin setup to ensure the shaft is driving the sprocket. Currently, a flat was added to the shaft to increase contact area for the setscrew, but over time this could loosen causing problems for the user. If the connection loosens, then the drive shaft will spin freely in the sprocket and the drive train will not function. The drive train could also be adjusted to guarantee the robot's functionality. Direct drive was the simplest configuration for the allotted project time, but gear drive or chain drive may be a better system overall. Direct drive does have advantages, but if the shaft-hub connection is not perfect, then the tread system may be affected. In the spring term, a new shaft design was used to increase the contact between the setscrews and the sprocket hub. Longer setscrews were purchased and a dimple was placed in the shaft. This dimple was added so that the setscrew would sit firmly and the hub and shaft would be better connected. Currently, this system does work better than the previous, but is not the perfect system.

Another main issue that should be corrected is the tread system. Currently, the belt is not fully tensioned and has more slack than expected. This is a major concern when driving over obstacles, especially uneven or large obstacles. As the robot descends over the obstacle, the belt is released from the teeth of the sprockets. When the belt loses contact, it can either shift to a new position or fall off entirely. This is a major concern for the user because it is rather difficult to adjust the treads and even more difficult to put the treads back on, especially if the user is in the middle of the woods. A belt-tensioning device will be extremely useful to mitigate this problem and provide the user with confidence that the system will fully function for the entire time of operation. An initial belt-tensioning device was implemented to the robot and can be found in Figure 8.1. This device was built using PVC rollers mounted to an aluminum frame and serves to increase the tension in the belt to avoid losing contact between the sprocket teeth and treads.

Also related to the treads, it is recommended to reduce the spacing between the sprockets. This would also decrease the amount of tread material that is in contact with the ground at one time. This can be implemented by removing the middle sprocket and potentially reducing the size of the chassis body. After initial testing outdoors, it was determined that it was too difficult to turn in thick grass because there was too much material in contact with the ground at once. This change can also eliminate the need for a belt tensioner if the proper amount of tread is used.

Lastly, the reduction in sprockets and tread length could also correspond to adding additional sprockets to different spaces in the treads. This would mean increasing the amount of teeth in contact with the treads at one time, but also help in guiding the sprockets. The sprockets would have a reduced tendency to move laterally, which can help solve issues with turning and overall motion. Reducing the amount of motion of the treads and sprockets left to right would definitely increase the maneuverability of the robot and provide the consumer with an improved product.

Figure 8.1 – A side view of the rollers and plate added to provide more tension to the belt.

Lastly, for the future, a better collection system design should be implemented. Currently, a very simple design was built and placed on the robot chassis, but once fully evaluated, it may show the design's limitations. The cloth setup is rigid and does not have any capabilities of adjusting. The cloth may get stuck on a branch or get caught in the environment. With the simple system, there is nothing the user can do to fix this, but with a cloth system that is controlled by electronics or have an adjustable feature, it would easy for the user to get out of a difficult situation. More brainstorming and prototyping would be involved to enhance the collection system, but it is extremely important to optimize the collection system to serve as a feasible option for future tick collection.

9. Acknowledgements

I would like to thank all of the people who have contributed to the completion of this project:

- Professor William Keat, Professor, Department of Mechanical Engineering
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- Rhonda Becker, Secretary, Department of Mechanical Engineering
- Stan Gorski, Technology Coordinator, Department of Mechanical Engineering
- Paul Tompkins, Supervisor, Engineering Lab
- Robert Harlan, Technician, Engineering Lab
- Presidential Green Grant
- Student Research Grant (SRG)

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11. List of Attachments

Attachment A – Itemized budget for the chassis design.

Table A.1 - Individual and total costs of the components for the chassis funded by the Presidential Green Grant

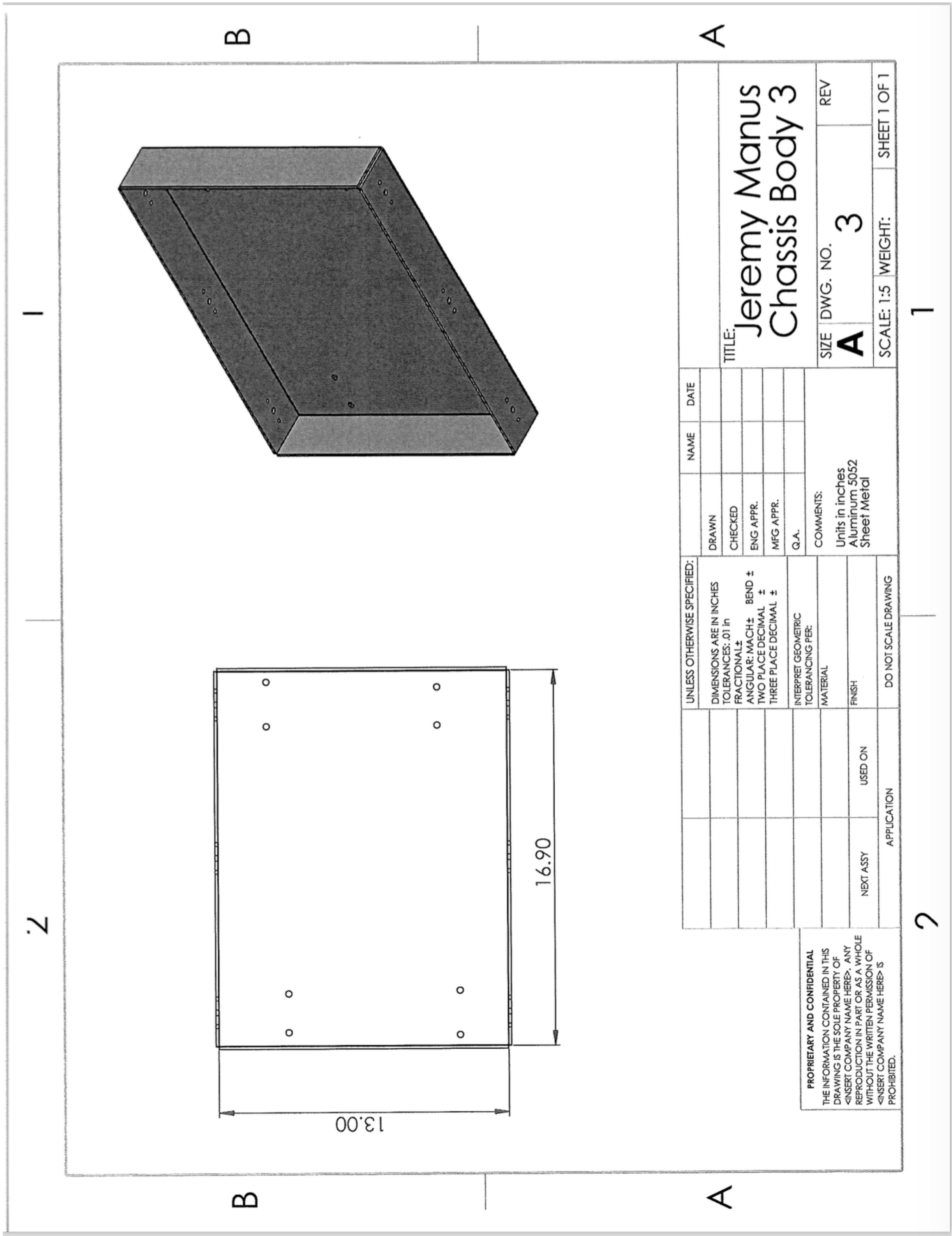
Part Name	Part Number	Cost	Quantity	Total Cost	Total Plus Shipping
PG71 Planetary Gearbox w/ RS775 Motor and Encoder	am-2971	89.00	2	178.00	297.99
ARDUINO MEGA 2560 REV3	ATmega2560	45.95	1	45.95	59.38
DX6e Transmitter System with AR610 Receiver	SPM6650	179.99	1	179.99	169.99
Sabertooth dual 25A motor driver	2X25 V2	119.99	1	119.99	See Motor
Light Duty Two-Bolt Flange-Mounted Ball Bearings	4575N33	10.23	8	81.84	81.84
Oil-Embedded Mounted Sleeve Bearings	5912K1	9.83	2	19.66	19.66
Lectron Pro 11.1 volt - 5200mAh 50C Lipo Pack	N/A	64.95	2	129.90	129.9
LiPo Battery Bag	N/A	3.42	2	6.84	7.84
1/4" Shaft Collar	9414T6	1.02	8	8.16	8.16
PVC		1.42	5	7.10	7.10

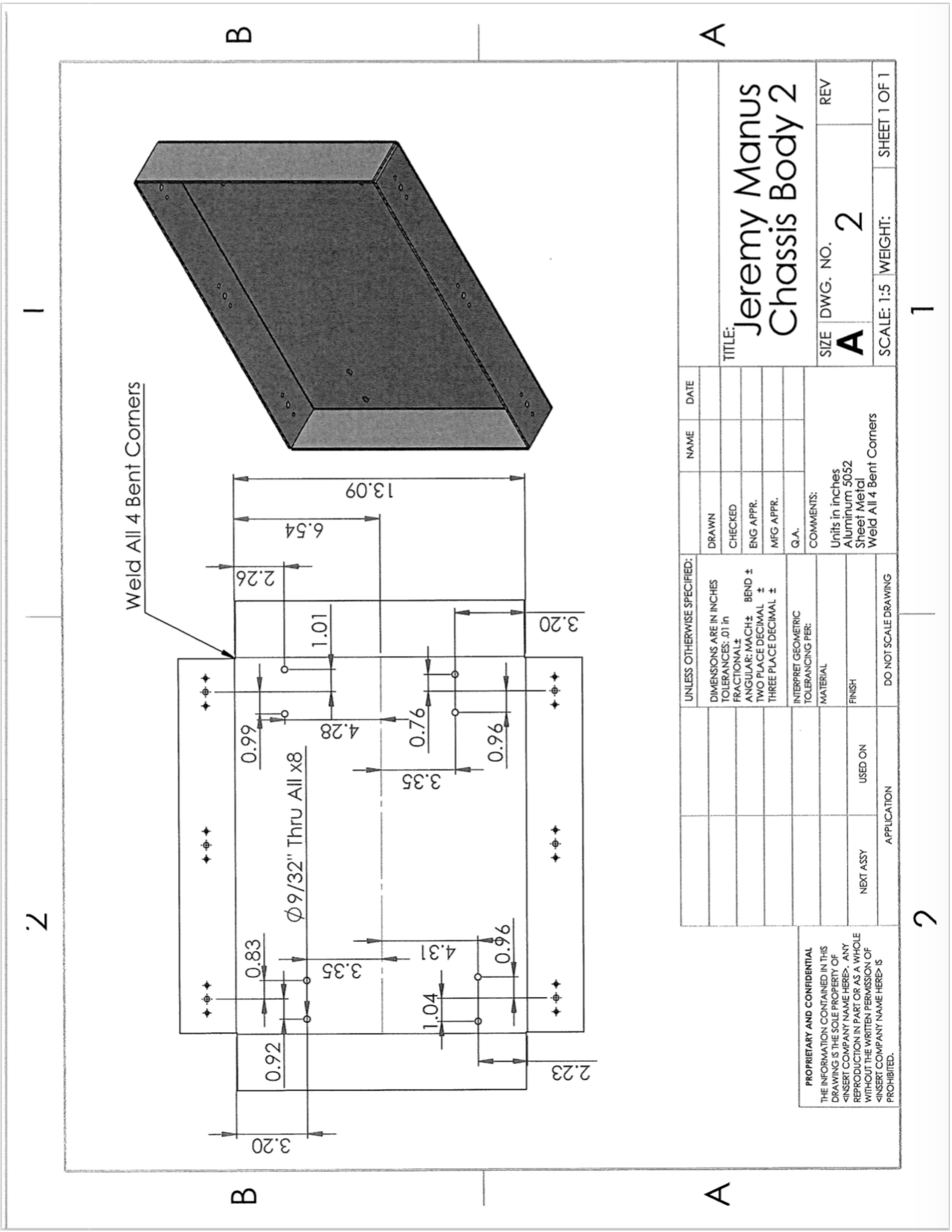
10-32 Set Screws		7.76	1	7.76	13.50
			Total Cost	785.19	795.36

Table A.2 – Individual and total costs of the mechanical parts for the funded by the Student Research Grant (SRG)

Part Name	**Part Number**	**Cost**	**Quantity**	**Total Cost**
Aluminum 5052 Sheet (36 x 36 in)	ASH5052/125	73.92	1	73.92
MTS Track - 2" Wide x 26 links ~28" (single)	TRK-03	31.19	3	93.57
MTS 18T Sprocket (With Hub)	MTS-18T-S	20.12	6	120.72
.25in x 10mm Aluminum Flexible Shaft Coupling	SKU: 86009680	47.28	2	94.56
.25in 4140 Steel Rod (24in long)	N/A	15	3	45
Lexan Sheet (24x24 in) - (From Paul Tompkins)	N/A	0	0	0
Deans Ultra Male Pigtail with Leads	N/A	4.15	2	8.3
Servo Extension Cable 6" Female - Female	779	1.76	10	17.6
Planetary Gear Motor Bracket	am-2197	9	2	18
18-8 Stainless Steel Hex Screws - (Purchased Separately)	92949A050	0	0	0
			Total Cost	471.67

Attachment B – Solid Works drawings of key components.

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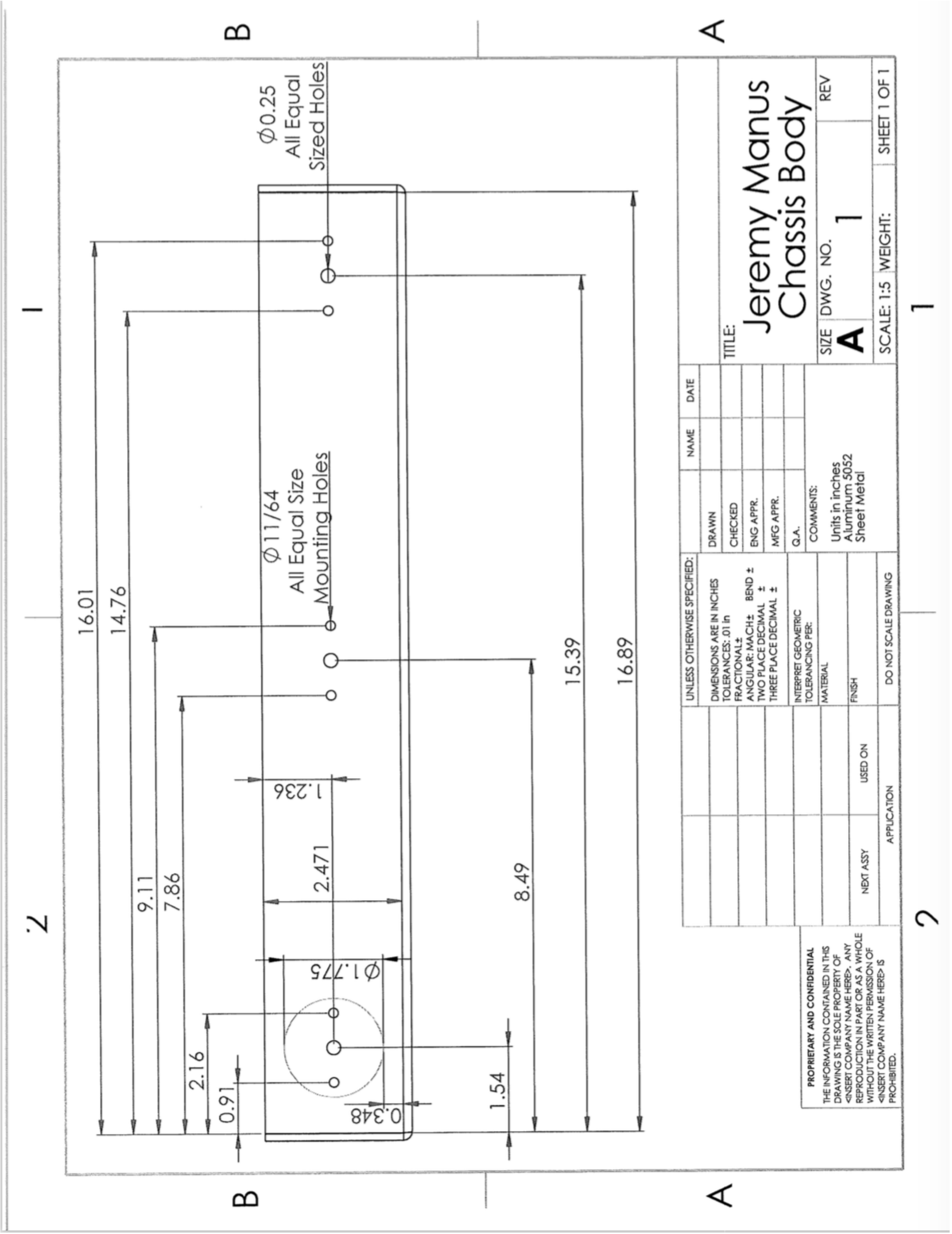
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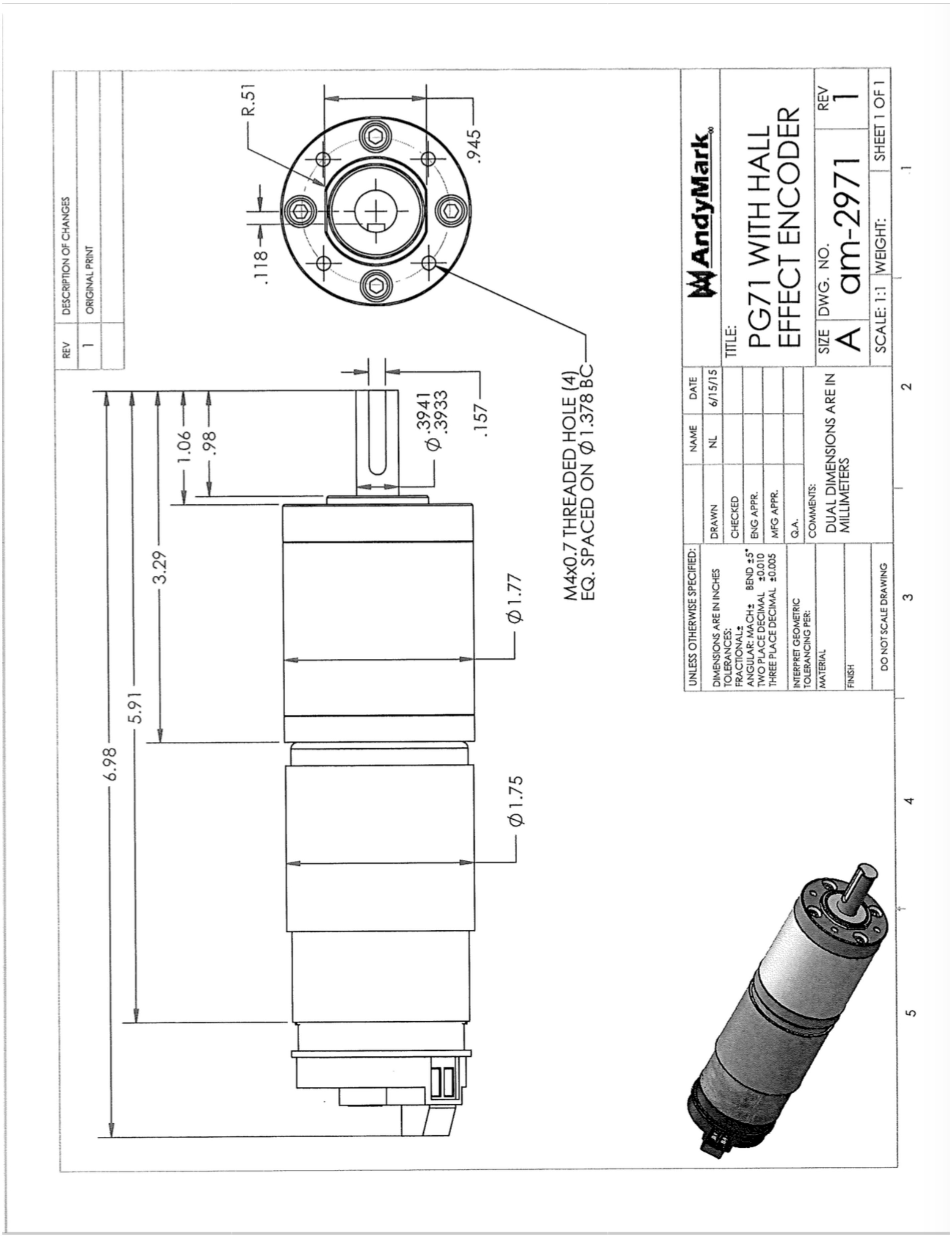
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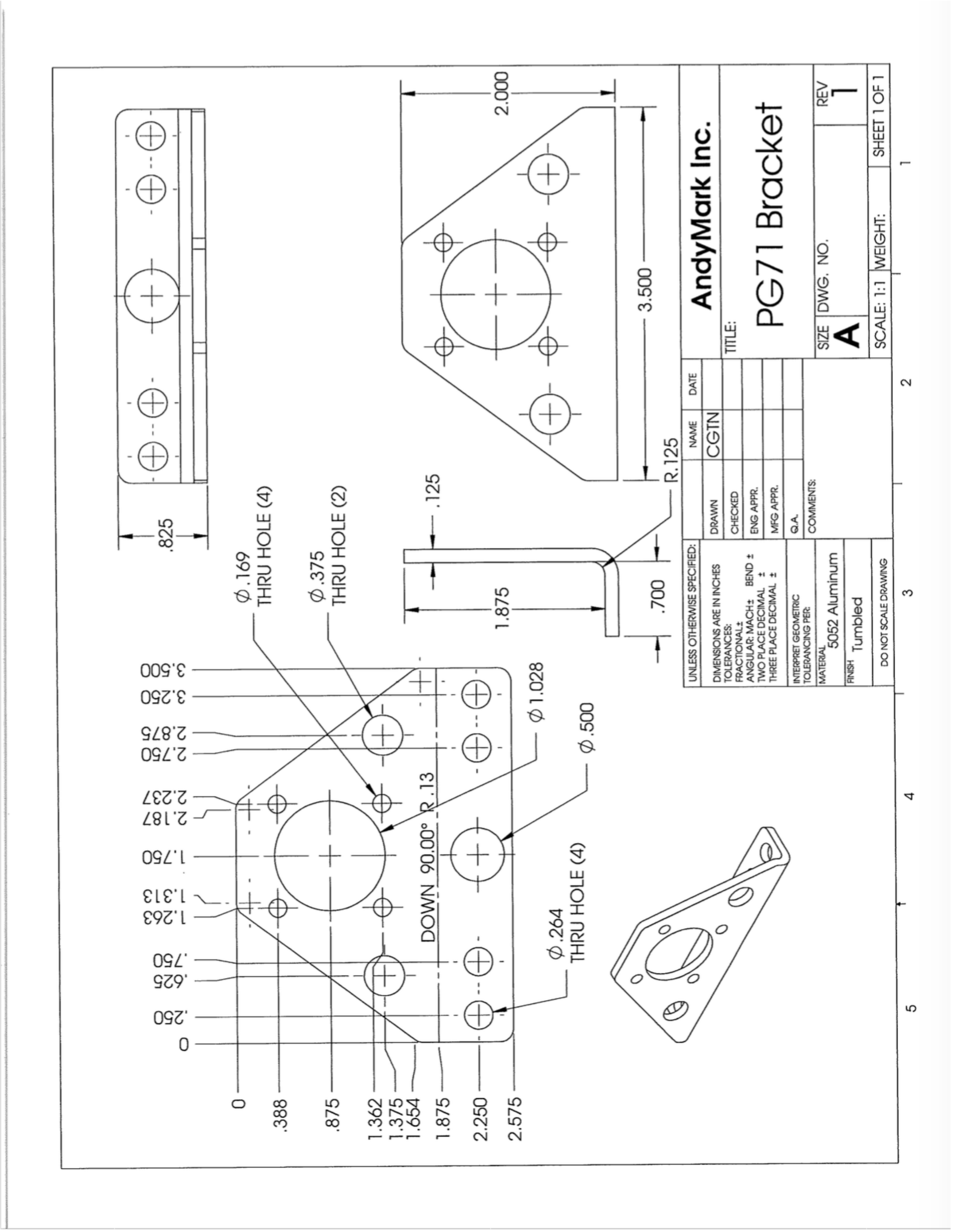
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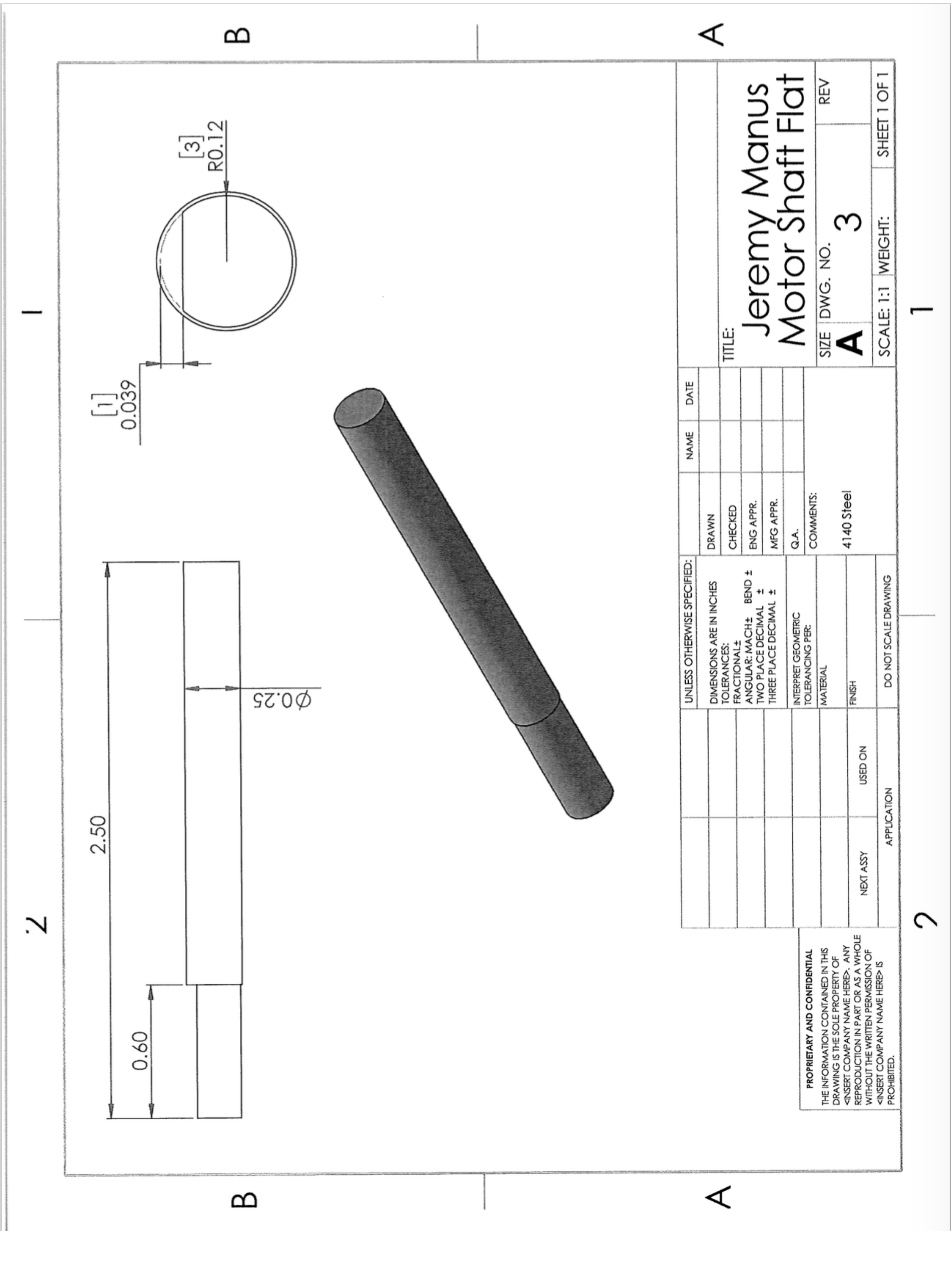

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SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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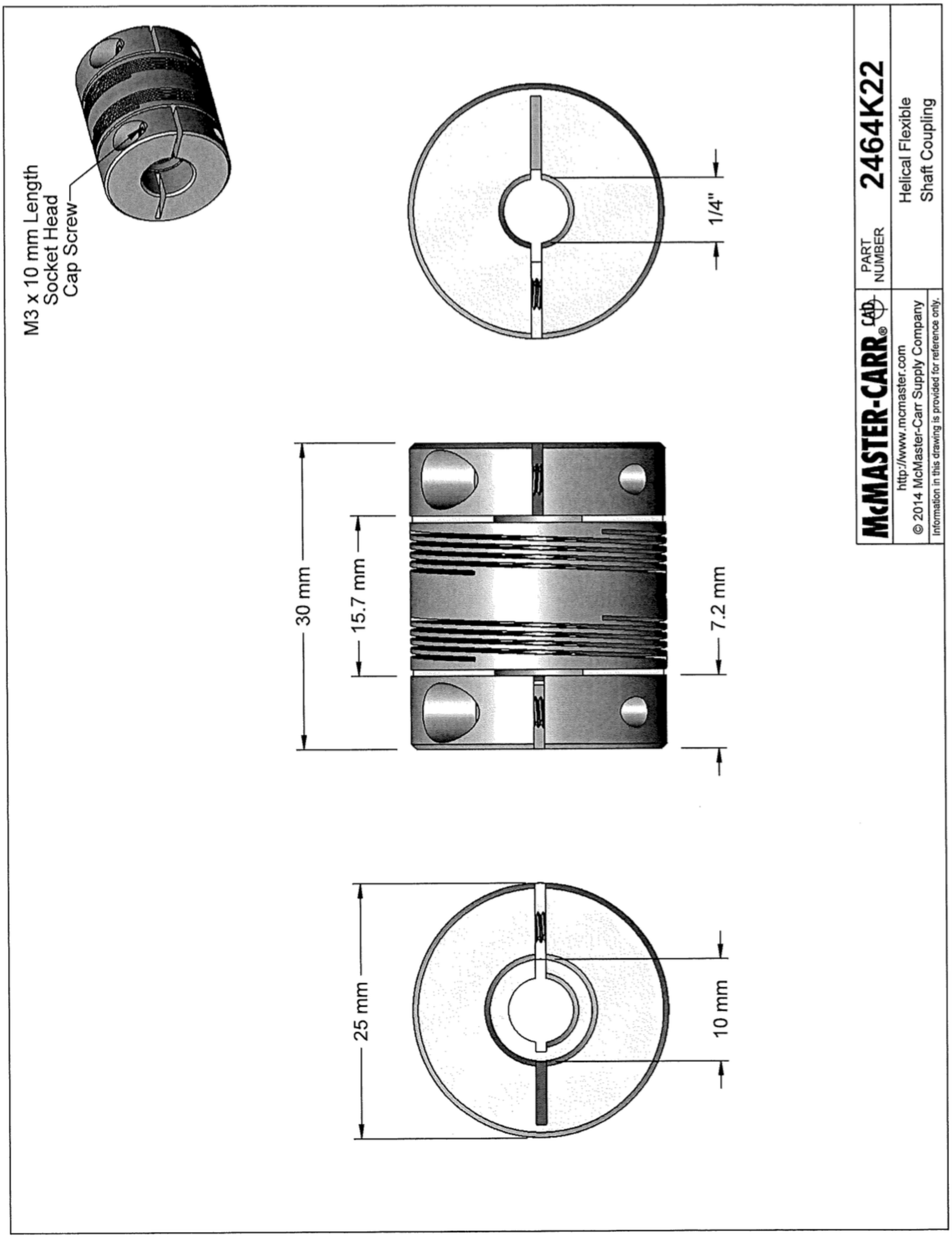
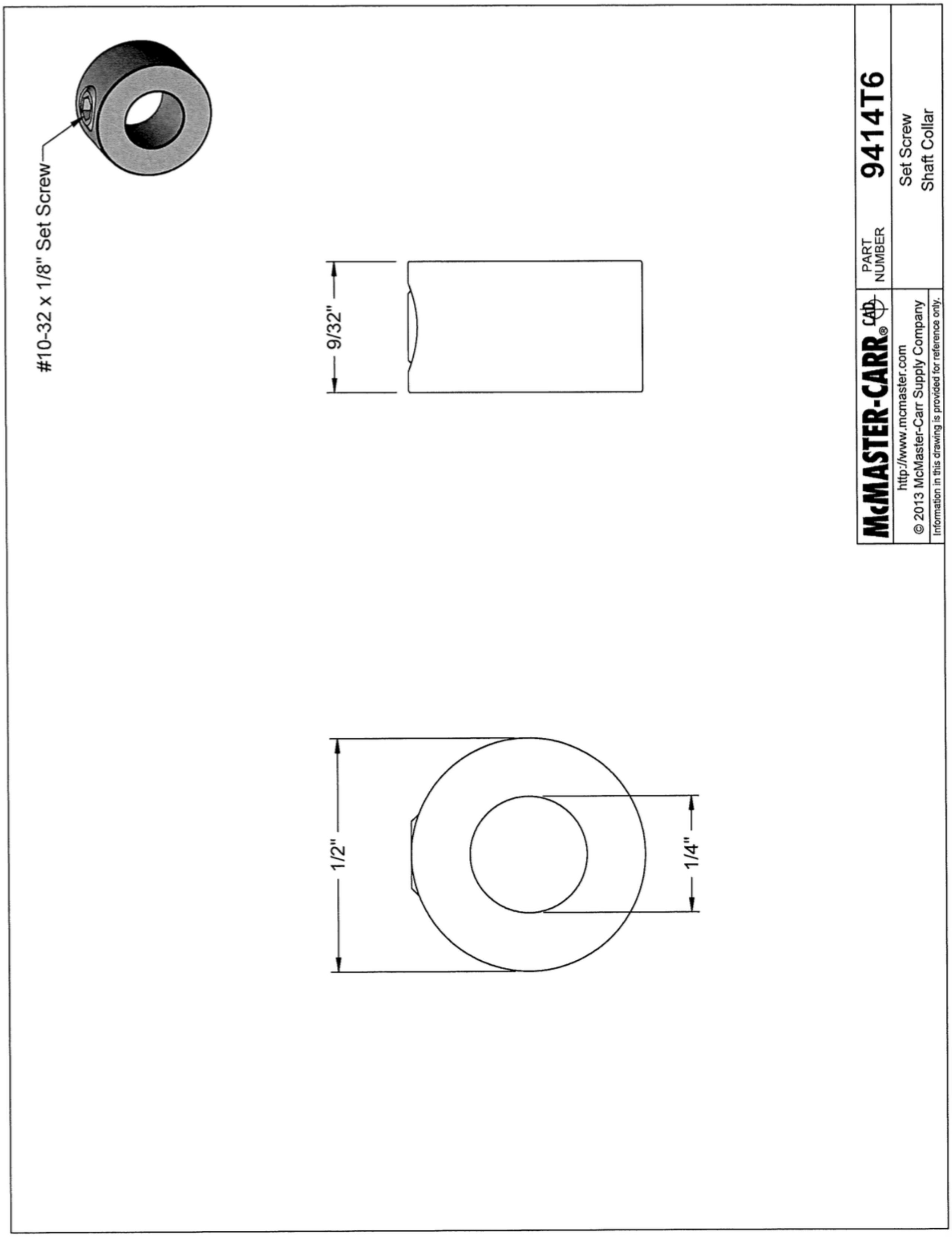

M3 x 10 mm Length
Socket Head
Cap Screw
1/4"
30 mm
15.7 mm
7.2 mm
25 mm
10 mm
McMASTER-CARR®
CAD
PART NUMBER
2464K22
http://www.mcmaster.com
© 2014 McMaster-Carr Supply Company
Information in this drawing is provided for reference only.
Helical Flexible
Shaft Coupling


#10-32 x 1/8" Set Screw
9/32"
1/2"
1/4"
McMASTER-CARR
PART NUMBER
9414T6
Set Screw
Shaft Collar
http://www.mcmaster.com
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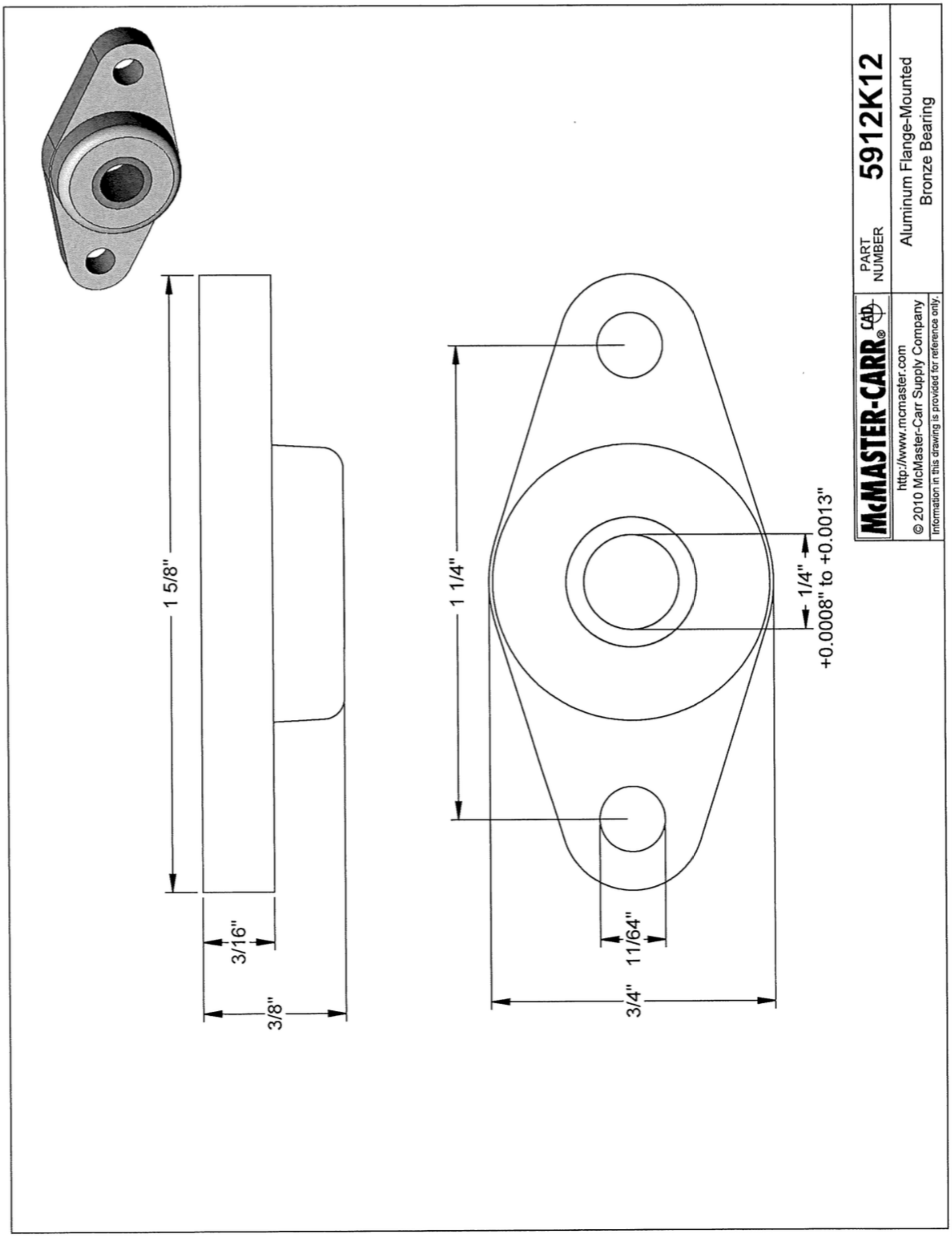
1 5/8"
3/16"
3/8"
1 1/4"
11/64"
3/4"
1/4"
+0.0008" to +0.0013"
McMASTER-CARR® CAD
http://www.mcmaster.com
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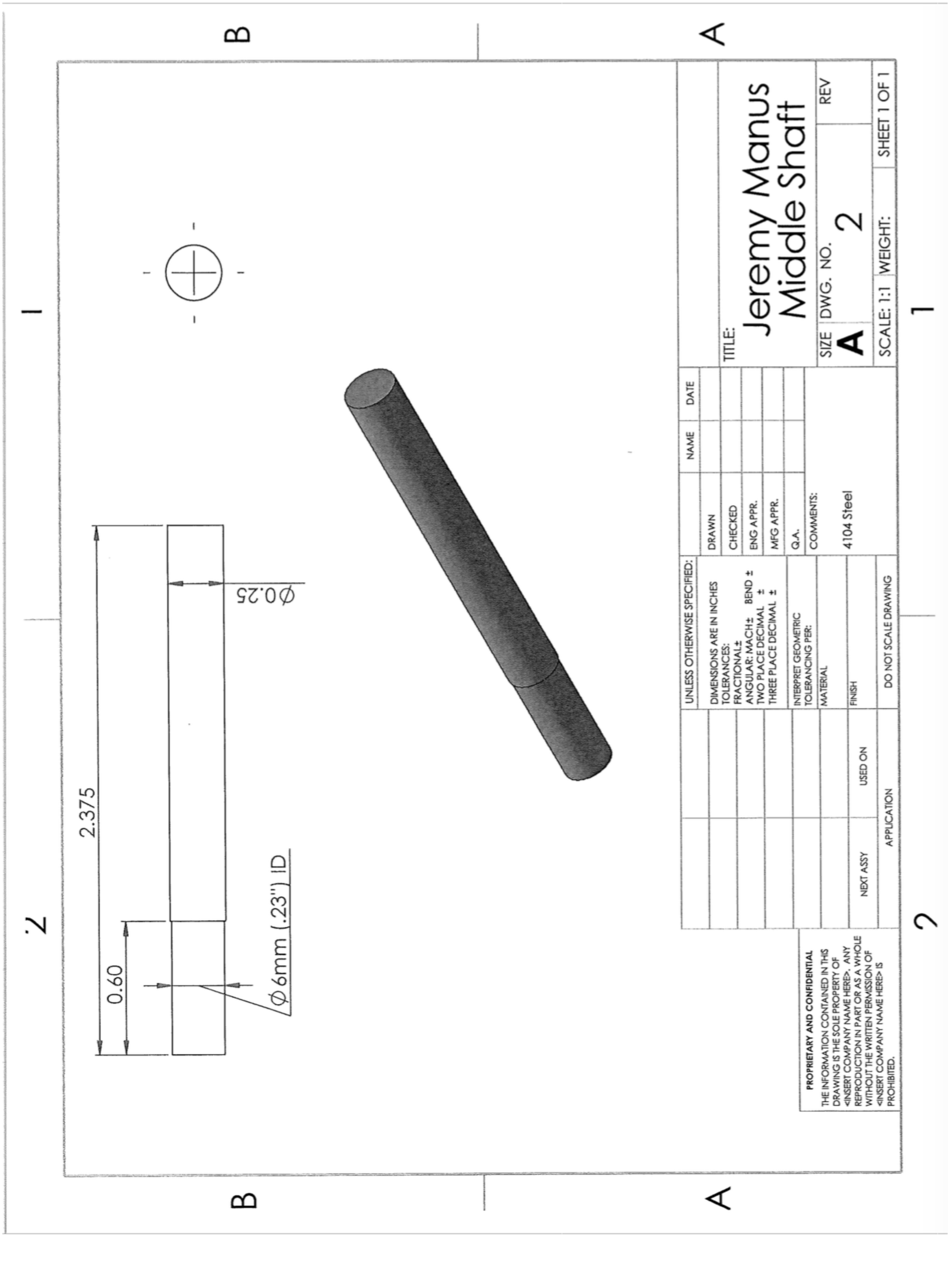
PART NUMBER
5912K12
Aluminum Flange-Mounted
Bronze Bearing


2.375
0.60
Ø0.25
Ø 6mm (.23") ID
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
4104 Steel
NAME
DATE
TITLE:
Jeremy Manus
Middle Shaft
SIZE
A
DWG. NO.
2
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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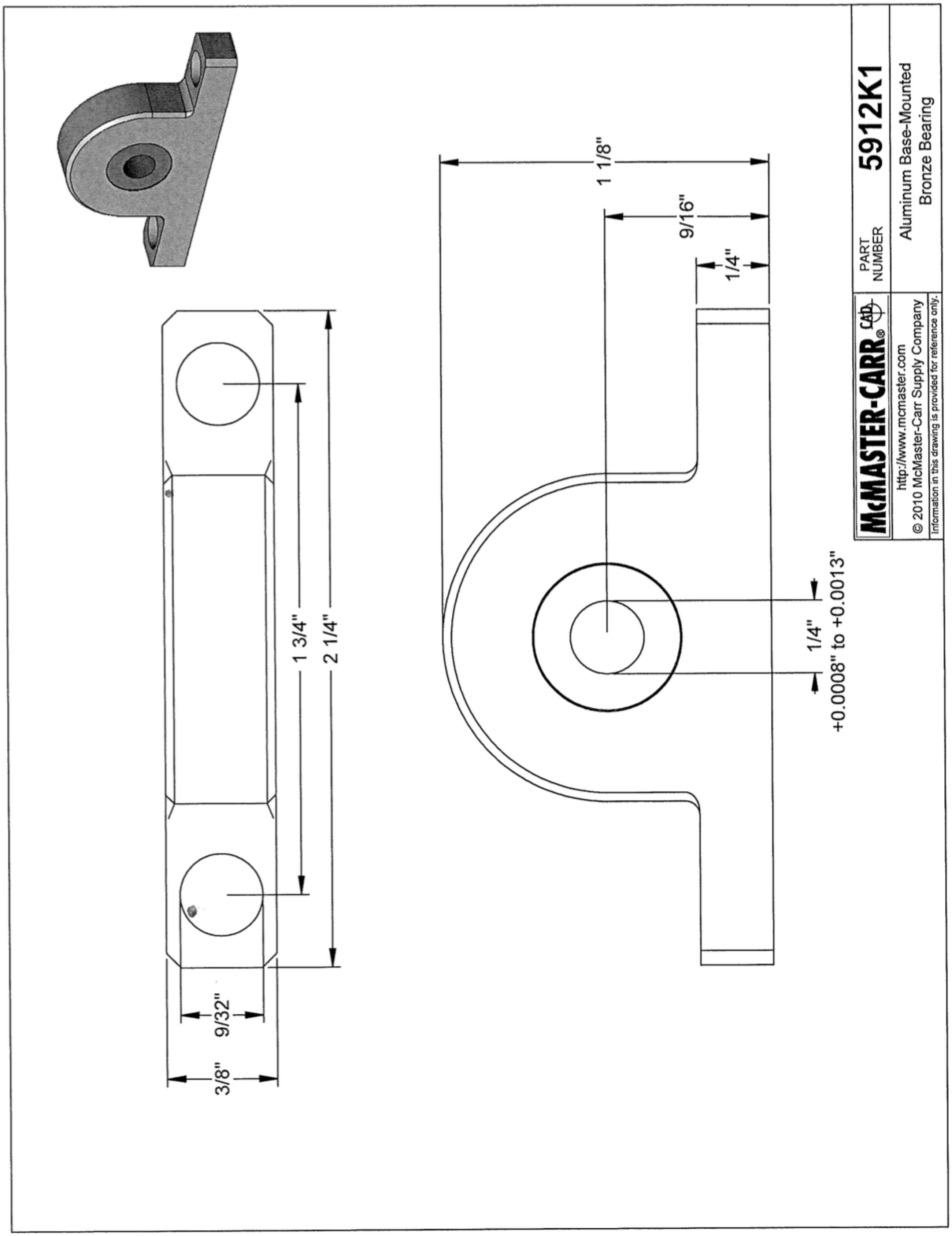
1 1/8"
9/16"
1/4"
1 3/4"
2 1/4"
9/32"
3/8"
1/4"
+0.0008" to +0.0013"
McMASTER-CARR
PART NUMBER
5912K1
Aluminum Base-Mounted Bronze Bearing
http://www.mcmaster.com
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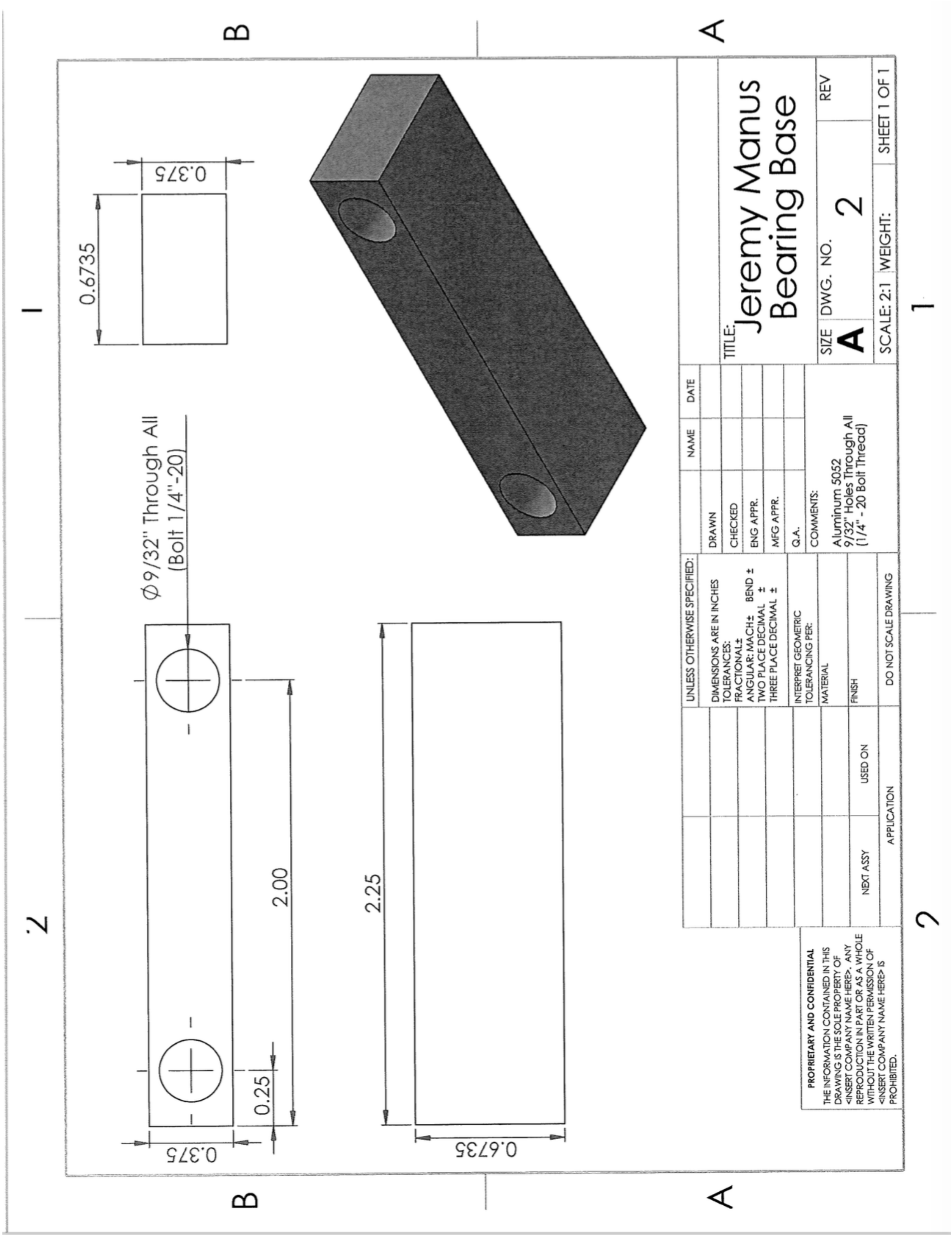
Ø9/32" Through All
(Bolt 1/4"-20)
0.375
0.6735
2.00
0.25
2.25
0.6735
0.375
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Aluminum 5052
9/32" Holes Through All
(1/4" - 20 Bolt Thread)
TITLE:
Jeremy Manus
Bearing Base
SIZE
A
DWG. NO.
2
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
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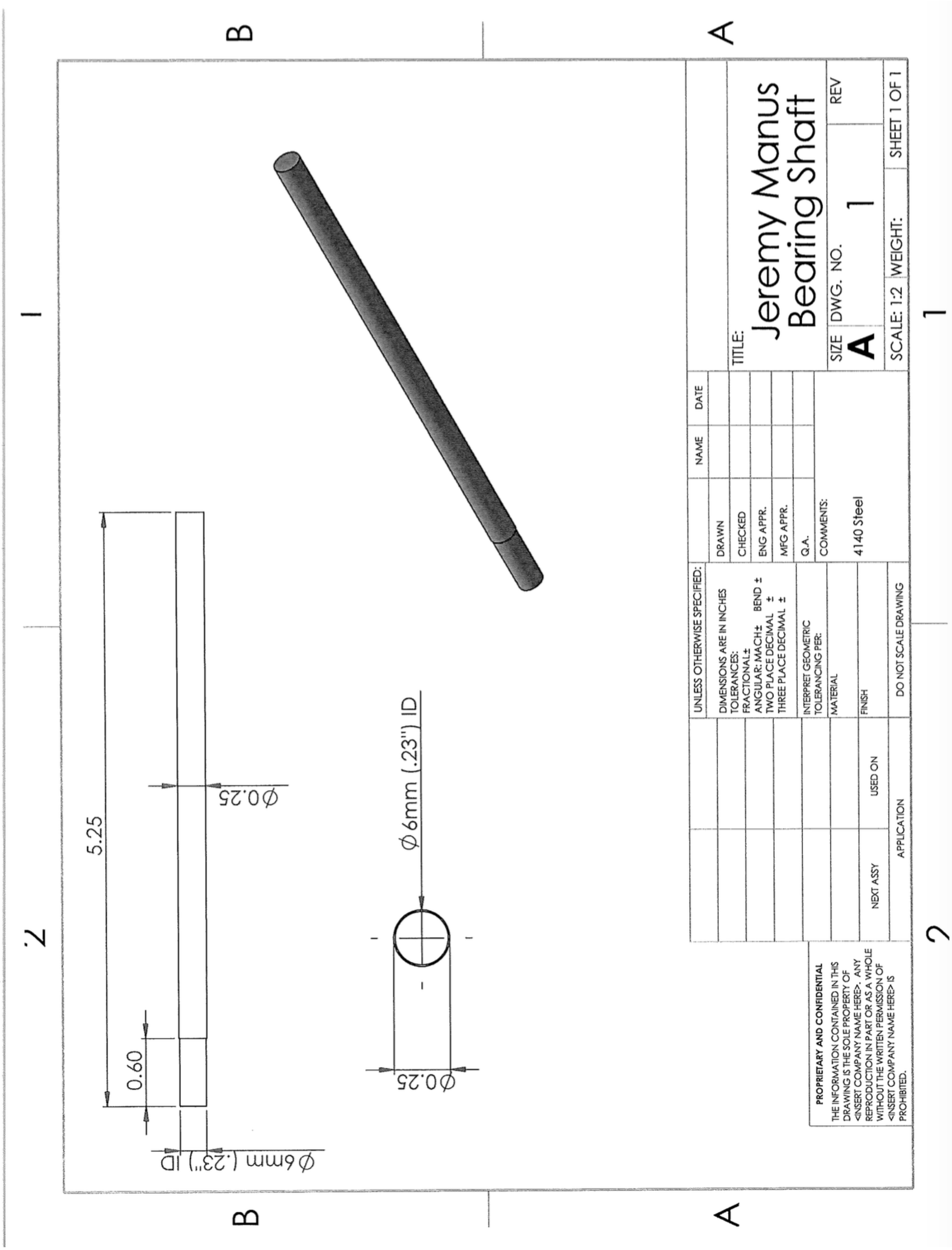
B
A
2
1
5.25
0.60
Ø0.25
Ø6mm (.23") ID
Ø0.25
Ø6mm (.23") ID
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
4140 Steel
TITLE:
Jeremy Manus
Bearing Shaft
SIZE
A
DWG. NO.
1
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
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Attachment C – Information to initial Arduino programming for autonomous control.

This attachment outlines the implementation of an Arduino micro-controller for the control system to use autonomous control. Arduino is able to input and process signals sent from the transmitter to the receiver in an RC system. Figure C.2 shows the wiring diagram of the integrated autonomous and RC control for the controls subsystem of the robot. The Arduino code that should be used is still being configured and the initial code for setting up the PWM pins and implementing the pulseIn() function can be shown. This code simply takes the signal from the receiver and outputs a number between 1000 and 2000 showing the position of the throttle / aileron (right stick) or elevator / rudder (left stick). Then, the signal is output using the function servo.writeMicroseconds, which will take the pulse length and process it to determine the position of the motor based off of the pulse. Four different Arduino pins will be used to input the pulses from the receiver and directly output them to the motor driver. This is important because the RC function on the motor driver can still be used, rather than processing an analog signal, which would require the addition of a low pass filter found in Figure C.1.

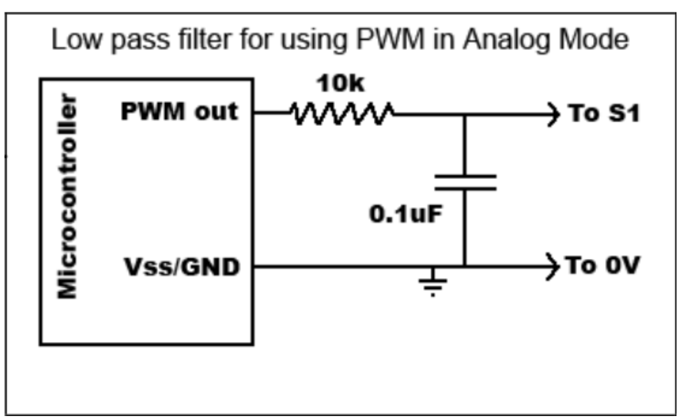

Figure C.1 – Low pass filter to be used if the motor driver processes an analog signal, taken from the instruction manual for the motor driver.

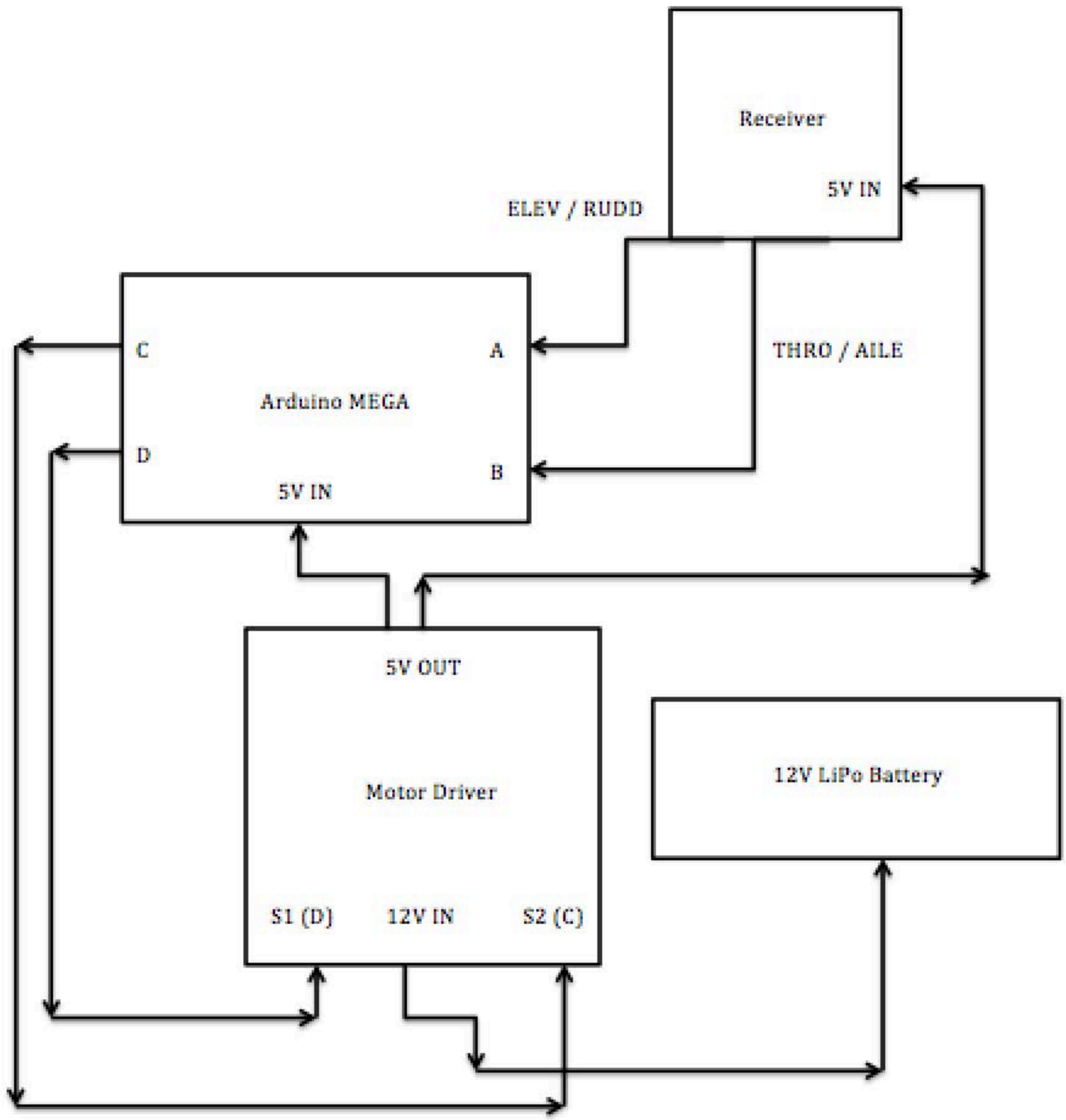

Figure C.2 – Wiring diagram for both RC and autonomous control.

Code 1:

```
#include <Servo.h>
Servo motorA;
Servo motorB;

int ch1; // Here's where we'll keep our channel values
int ch2;

void setup() {

  pinMode(2, INPUT);
  pinMode(5, INPUT);
  motorA.attach(7);
  motorB.attach(9);

  Serial.begin(9600);
}
void loop() {

  ch1 = pulseIn(2, HIGH, 25000); // Read the pulse width of
  ch2 = pulseIn(5, HIGH, 25000); // each channel
```

```
  motorA.writeMicroseconds(ch1);
  motorB.writeMicroseconds(ch2);

  Serial.print("Channel 1:"); // Print the value of
  Serial.println(ch1);        // each channel

  Serial.print("Channel 2:");
  Serial.println(ch2);

  delay(100);
}
```

Attachment D - Sourcing information for critical components.

Sprockets With Hub:

http://www.lynxmotion.com/p-1113-mts-18t-sprocket-6mm-hub.aspx

Tank Treads:

http://www.lynxmotion.com/p-1117-mts-track-2-wide-x-26-links-28-single.aspx

Motor:

Part:

http://www.robotshop.com/en/pg71-planetary-gearbox-rs775-motor-encoder.html

Specifications:

Physical specs:

Overall Length: 6.26 inches

Maximum Diameter: 1.775 inches

Output Shaft size: 10mm (0.393") diameter with 4mm (0.157") keyway

Weight: 2 pounds

Mounting Holes: M4x0.7 threaded hole (4) x 9mm deep

Electrical connection geometry: 3/16" wide spade connectors (2)

Gear Material: Steel, formed from powdered metal

Body material: Steel

Lubrication: This gearbox is pre-greased and needs no further lubrication

Encoder:

Pulses per revolution: 7

Operating voltage: 5VDC

Pinout:

Pin 1: 5Vdc

Pin 2: Gnd

Pin 3: Encoder Output Cha. A

Pin 4: Encoder Output Cha. B

Performance specs:

Gearbox reduction: 71:1

Total counts per revolution: 497

Voltage: 12 volt DC

No load current: 0.6 amps

Tested gearbox output power: 44 Watts

Stall torque: 16.6 ft-lbf

Stall current: 22 amps

Minimum torque needed to back drive a non-powered PG71: 1.3ft-lb

Maximum torque applied at shaft which breaks gearbox: 39 ft-lbs

Motor Driver:

Part:

http://www.robotshop.com/en/dimension-engineering-sabertooth-2x25.html

Manual:

http://www.robotshop.com/media/files/pdf/dimension-engineering-sabertooth-2x25-detail-specs.pdf

Battery:

https://www.amazon.com/Lectron-Pro-11-1-volt-Deans-type/dp/B00T3FTRR0/ref=sr_1_1?s=toys-and-games&ie=UTF8&qid=1484233756&sr=1-1&keywords=Lectron+Pro+11.1+volt+-+5200mAh+50C+Lipo+Pack

Transmitter and Receiver:

http://www.horizonhobby.com/dx6e-6ch-system-w--ar610-receiver-spm6650

Arduino:

https://www.pololu.com/product/1699

Battery Charger:

https://hobbyking.com/en_us/imax-b6-ac-dc-charger-5a-50w-with-us-plug-copy.html?countrycode=US&gclid=CICQo5Osp9QCFcmCswodZhcATg&gclsrc=aw.ds

Aluminum Sheet Metal and Steel Rods: Albany Metal Supermarket