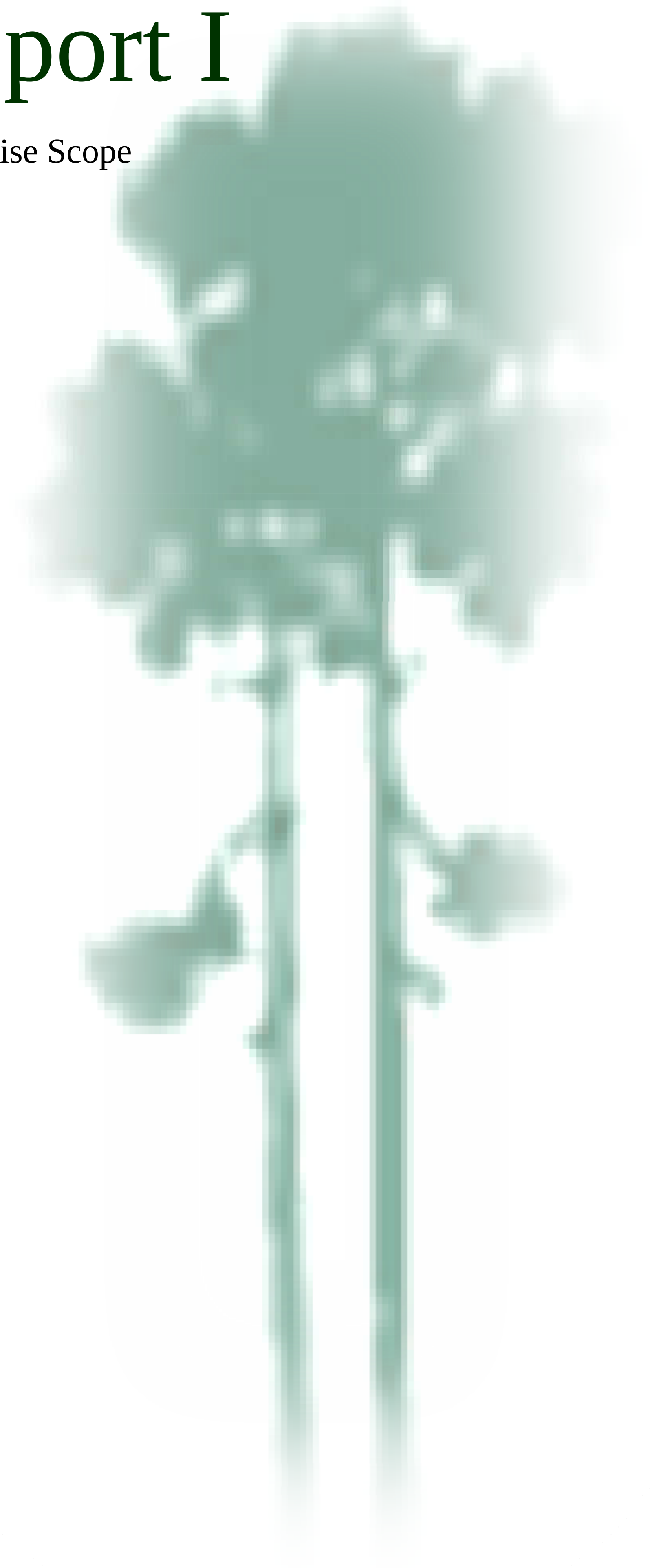

Midterm Report I

Underground Robotic Gopher Tortoise Scope

Team 21 (E19)

Team Members:
Jane Bartley (ME jeb12b)
Bridget Leen (ME bbl110)
Jordan Muntain (ME jlm11y)
Lester Nandati (ME lvn12)
Colin Riley (ECE cpr11e)
Sina Sharifi-raini (ECE ss11v)

Submitted To:
Dr. Frank
Dr. Gupta
Dr. Helzer

Date: 10/31/2014

Florida A&M University 1982 Florida State University
College of Engineering

Tall Timbers
Research Station & Land Conservancy

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Abstract

Tall Timbers Research Station and Land Conservancy has provided Team 21 the task of the creation of a more affordable burrow scope for the purpose of studying gopher tortoises. The final product should include an infrared camera that is able to traverse a burrow up to 15 meters in length and is connected to a screen that can not only display the image but also capture and record the footage; the entire system should be waterproof and cost less than 1000 dollars. It is still early in the timeline of producing this product, however steps have already been taken towards the completion of the system. The sponsor, Tall Timbers, has been contacted and an onsite field assessment has been completed in order to observe the environment that the final system will be operating in. The current technology Tall Timbers possesses for the scoping of gopher tortoise burrows has also been studied, the downfalls of the system observed, and improvements for the future system noted. A midterm presentation has been completed and the initial construction of a prototype has begun. Extensive research has been done on both rover options as well as camera and housing possibilities. The first functioning prototype is to be completed by mid November. Testing of the prototype will begin in early December, at which time a mock burrow will be built in order to simulate the real world conditions the scope will be facing at Tall Timbers.

Introduction

Tall Timbers Research Station and Land Conservancy’s primary research focus is the ecology and management of fire-dependent ecosystems and wildlife. One resident of these ecosystems is the gopher tortoise, which is a candidate species for federal listing.[1] Because of this, it is imperative that conservation groups such as Tall Timbers study these reptiles in order to have some chance of increasing their population numbers. Conservation and research groups use a standard method to survey gopher tortoise borrows in order to achieve accurate population estimates. This requires scoping all burrows in a specific radius in entirety to obtain precise occupancy data. Because the market scopes are very expensive, Tall Timbers was driven to create their own scope which is heavy, very cumbersome to use, and often has limited visibility resulting from clumped mud on the lens. This senior design team has been given the task to design a more economical scope that is lightweight, easy to use, and reproducible for other conservation groups studying gopher tortoises and other burrowing species. The Midterm I report provides the reader with background regarding the project, as well as the team’s need and goal statements. A detailed analysis of each mechanical as well as electric design is then provided along with a detailed schedule and visual Gantt Chart.

Project Definition

A. Background Research

Many species find refuge in the burrow of a gopher tortoise. Due to the large effect this tortoise has on its surrounding ecosystem it is considered a keystone species.[2] This fact makes the study of the animal so imperative, especially for a research station such as Tall Timbers which specializes in fire ecology studies. Gopher tortoises however are not the only burrowing animals that require a scope in order to be studied; there are also burrowing owls, foxes, prairie dogs and many other small mammals.

Figure 1. Sandpiper Technologies INC. Peeper 2000

To meet this need for research equipment, Sandpiper Technologies, INC. introduced the Peeper 2000, which can be seen in Fig. 1. This system consists of a head mounted video display, a camera probe, a battery charger and a case. The system has the benefits of being lightweight as well as waterproof. Sandpiper Techs scopes include the Peep-A-Roo, which is 1 inch in diameter and 4 meters long, and the Peeper Video Probe, which is 2.3 inches in diameter and long enough to reach the end of tortoise burrows. These systems however have the major drawback of costing 6,000 dollars apiece, as of their most recent catalogue.[3] This is generally out of the budget of research centers such as Tall Timbers, leaving them still without a scope. In order to meet this need, Tall Timbers built their own scope for a total of about 500 dollars. It is however outdated and slightly crude in design, consisting of an infrared camera connected via long detachable wires to a portable DVD player. The wires are protected by thick rubber hosing. This hosing has proven to be heavy as well as not easily navigated through the burrow, and the DVD player is not waterproof.

The creation of a scope that is on the technological level of Sandpiper's Peeper 2000 while also costing less than 1000 dollars would be pivotal for research centers such as Tall Timbers, and could do a great deal of good for the advancement of the study of many burrowing keystone species, not only the gopher tortoise.

B. Need Statement

As stated, the current scope consists of a basic infrared camera that is connected to a tube and wired to a DVD player. The design is cumbersome for several reasons. In order to use the scope, the user must physically push the camera down the tortoise burrow. Thus, the camera can easily dig into the ground and get blocked by dirt. It is difficult to navigate the scope, as there is nothing to help it move forward, backwards or navigate turns. Because of this lack of maneuverability, many parts of the burrows are unreachable for observation. Often, the camera will be flipped over or rotated while attempting to go around obstacles. Consequently, the user may no longer be able to determine which side is up or down.

The scope, which involves three large components, is heavy and bulky. By the end of the day, the sponsor related that her hands would be covered in blisters from having to physically handle the heavy equipment for eight or more hours. Furthermore, after a burdensome day of work, any results the user does find will have to be handwritten, since there are no video or picture-capturing capabilities with the current model.

When the weather is inclement problems are amplified. If it is raining, the device is at risk due to the fact that it is not waterproof, and there are open wired connections. Further, water could ruin the infrared camera itself, leading to costly repairs or replacements. Also, the scope could run into obstacles and does not have enough shock resistance to handle unexpected impacts. Finally, in the common case that the lens fogs up or is covered with dirt or mud, the user must pull out the scope, clean it, and start the process over from the beginning.

Buying a manufactured scope is typically not an option for research centers such as Tall Timbers. It is a non-profit organization, and does not have the budget for a system that can cost up to $6000. Thus, research stations like these are stuck in a financial trap, and are unable to get adequate tools for underground research.

Final Needs Statement:

In all, there is a need for gopher scopes to have improved weather and impact durability, greater mobility, data-acquisition capability, and reduced weight, space and cost.

C. Goal Statement and Objectives

Due to the fact that this system will be used in the field, it is essential for it to be resistant to water as well as dirt, and be able to withstand temperatures from 0 to 100°F. It should be resistant to shock as well in case it is dropped or hits any obstacles. The battery life should last up to 8 hours in order to complete full days of field testing and the entire system should fit into a backpack and weigh no more than 50 pounds.

Gopher tortoises begin to burrow as soon as they hatch with some of their burrows being as small as 4 to 6 inches; because of this, the scope should not be more than 4 inches wide or high. Not disturbing the animals in the burrow is important as well, therefore the camera will be infrared and the rover will move as quietly and quickly down the burrow as possible. The camera should be able to record images, capture still photos and take temperature and humidity readings in the burrow. The entire system should also cost less than 1000 dollars.

The main goal is to design a mechanism that has testing sensors, better durability, and more advanced video capabilities than the current system in order to enhance the surveying process of gopher tortoises.

D. Constraints

- The rover must not be more than 6 inches wide
- The entire system must remain under 50lbs
- The total cost must not exceed $1000
- The entire system must be water proof

- The battery has to have a life of at least 8 hours
- The camera must be infrared

Below in Table 1 is a summary of the desired subsystem features that will be explained in more detail in the following sections.

Table 1. Summary of Desired Subsystem Features

Subsystem	**Features**
Power	8 hours of operation
Camera	Infrared
	Tilt/Pan
	Screen
Maneuverability	Cornering
	Anti-flipping
Data Acquisition	Temperature
	Humidity
	GPS
	Depth
	Recorded video
User Interface	Control Switches and Display
Tether	Durable
	Flexible
	10-15 meters in length

Design and Analysis

A. Functional Analysis

There are several primary specifications that affect the overall design of the scope. The most important of these is cost. The cost for the entire final design should be no more than 1000 dollars and ideally only 500 dollars. The weight and size of the final design is also important to consider, as one person must be able to carry the scope for several miles. For this reason, the full system must weigh no more than 50 pounds and fit in a backpack.

Several of the mechanical subsystems have additional specifications that must also be considered when creating the final design. In order to fit into even the smallest of gopher tortoise burrows, the rover should be approximately four inches in diameter. It will also need to be maneuverable enough to make tight turns, and have good enough traction to be able to function in wet and muddy conditions. It will be designed so that it doesn't flip over while navigating the burrow.

The rover will also need to be able to protect the electronics from the environment both while it is operating underground and while it is being carried in a back-pack. This means that the materials used to build the body of the rover will have to be water-resistant, dirt-resistant and shockproof. However, creating a durable rover has a tendency to conflict with the need of the camera to be able to illuminate the inside of the burrow. In order to overcome this, a material that is both durable and transparent to infrared light will need to be used to design the body of the rover.

An objective of the final design is minimal invasiveness. Considering this, a specially designed infrared camera must be used for this design as well as infrared LEDs. It is also necessary that researchers be able to adjust the view of the camera without having to reposition the entire rover. To accommodate this, the camera will be mounted onto a pan and tilt system that will provide a field of vision of at least 120° side-to-side and 90° up-and-down.

Gopher tortoise burrows have an average length of ten meters. Therefore, the length of the tether will be approximately ten to fifteen meters. Similar strength and durability requirements are needed for the tether to effectively protect the wires connecting the user interface and power subsystems to the rover. The sheath covering the tether will need to be durable enough to protect the wires while they are being dragged along the ground by the rover. The tether must also be strong enough to withstand being used as a retrieval mechanism for pulling the rover out of burrows. However, the strength of the tether will be limited by that fact that it also must be light enough for its weight to be pulled by the rover, as well as flexible enough to be coiled around a spool and easily carried by the researcher.

A data acquisition unit will also need to be attached to the rover to collect temperature and humidity data. The unit should be small enough that it does not alter the overall form factor of the rover and it should also weigh as little as possible. To facilitate this, only the temperature and humidity sensors will be housed in the data acquisition unit while the microcontroller to interpret and display their output will be located outside the burrow as a part of the user interface. The sensors will be required to output updated temperature and humidity readings to the user interface at least once every thirty seconds.

Finally, the power subsystem will be required to power the final design for an entire work day. This means that the batteries should be able to provide enough power to operate the rover for eight hours. Based off of preliminary design choices, it is estimated that the design will require 35 watts to operate. This means that the battery will have to supply 280 watt-hours of energy to run the design at full power for eight hours.

B. Design Concepts

Analytical and computational work

The three designs encounter the same design issues. The first concern is the bending of the body. Thus, an analysis was done in order to determine the resulting moment felt by the chassis body. If this body cannot withstand the forces acting on it, then it would be impossible to mount a device to it without it failing. This concern is especially notable for the design orientation where the camera system is mounted to the front of the chassis, ahead of the body. Hence, a finite element analysis was done on the chassis body frame to see if it would deform. For the initial prototype, the chassis body is compressed polycarbonate material (which is the weakest out of all the parts' materials). Hence, if the system were to fail, it would first and foremost fail at the mating between the camera system, and the chassis body. The stress analysis is seen in Figure 2.

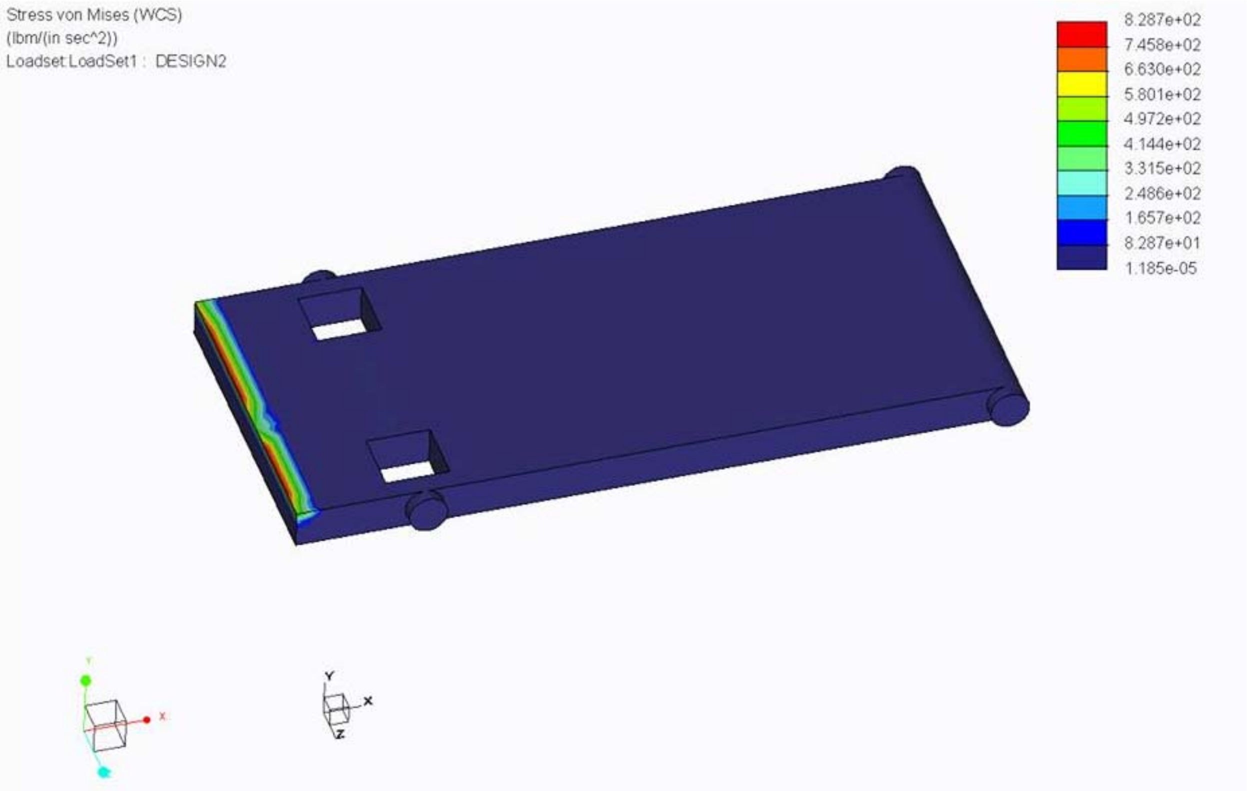


Figure 2. Von Mises stress analysis for Chassis body

As seen in Fig. 2, the body undergoes very little deflection. This is expected due to the light load produced from the weight of the camera system. Hence, the body is under no serious threat to deform. Perhaps after repeated testing, the material along the frame’s edge (where the stress reaches a maximum) will show signs of wear and will hollow around the location of the camera system, but this is for the prototype alone. For the final product and later prototypes, which will use a more durable, strong, and shock resistant material, the load will have a negligible effect on the structural integrity of the chassis. Hence, mounting the camera to the body will not cause materials to fail. The biggest concern would be not allowing the chassis to turn over. The camera can be fastened to the chassis toward the rear, distributing the weight of itself along the length of the chassis body (hence, eliminating the tendency to tip over on its own).The most common cause for tipping forward would be the rover encountering an obstacle, effectively causing it to ‘trip’. Yet, external obstacles and disturbance forces cannot be quantified simply because it is impossible to determine the magnitude of such unknown forces. Hence, the threat of the rover tipping will have to be physically tested with the prototypes.

A second issue is the power of the motor to move the rover. MATLAB is utilized to determine the motor torque available, and compare it to the resistance of motion found by friction or gravity acting on the rover. The calculations in Appendix A-3 show that the power of the motor is magnitudes larger than the resistance that the camera system delivers by means of gravity. Because the camera system is cased, and closed off from outside obstacles, the resistance due to the physical mass of the camera system is the *only* load that the smallest motor will deliver. The MATLAB code shows the estimated maximum torque provided to the wheels of the tread. By means of these calculations, it can be concluded that the rover exceeds the minimum power and material stability requirements needed to function properly.

Manufacturing considerations

A possible obstacle in the manufacturing of this system is that it has been stated that ideally the rover should be able to be reproduced by other research outfits. This means that all manufacturing should be kept to a level that can be imitated by an individual without deep knowledge in the areas of electrical or mechanical engineering. To make this possible, only tools that are readily available will be used and detailed instructions on the steps of building will be outlined. Considering different levels of knowledge however, there will be multiple levels of difficulty in building the rover; meaning that if one chooses, there will be instructions available to build a more advanced yet more difficult version. This more advanced version will be the one build for Tall Timbers Research Station and Land Conservancy.

Design advantages, strengths and weaknesses

Three chassis designs are being considered for this project: a linear track, a tri track, and a wheeled chassis. One design objective of the system is optimum subterranean maneuverability. The linear track and tri track systems excel in this area because tracks distribute the weight of the rover more evenly across the ground and put less pressure on the ground; because of this the rover will not be as likely to sink or get stuck in soft terrain. Also, the greater surface area of the treads provides more traction on the terrain. Although the linear and tri track chassis both accomplish this, the linear track performs better because of its geometry. The two track chassis also provide more stability than the wheeled system, especially on inclines. Therefore they are able to handle going over obstacles easier than the wheeled chassis is. The tri track chassis handles obstacles the best out of the three designs because of its geometry.

The rover also needs to operate quickly and quietly. In this area the wheeled design has the edge because it requires less torque than the tracked chassis to move down the burrow and is therefore quicker. The wheeled design is also rather simplistic, so the noise created by the wheels is minimal and thus does not cause as much a disturbance to the gopher tortoise. The wheeled design has an advantage in agility as well considering it can turn more easily than either tracked chassis.

Creating a durable system is another objective that needs to be met. The linear and tri track chassis are not as durable as the wheeled chassis due to the fact that they contain multiple parts for operation which can possibly get jammed; the tread belt of the track can get misaligned from the chassis and stop the operation. On the other hand, the two tracked chassis are not able to get punctured and they do not rely on tire pressure to be operational. In this way the tracked systems are more durable than the wheeled design. Some other flaws of the two tracked chassis are that they are more expensive, and require more power to operate than the wheel design.

Along with the three designs of the chassis, three designs for the camera placement are possible: within the body of the chassis, in front of the chassis, and on top of the chassis. The camera within the body of the chassis is advantageous considering the fact that it maintains compactness of the rover resulting in easier portability. In addition, since the camera is contained within the body of the chassis it is not as likely to get damaged with this design as with the designs where the camera is placed in front of the rover or on top of the chassis. Placing the camera within the body or on top of the body decreases the amount of cost because it does not require additional parts. However, placing the camera on top of the body will cost more than placing it within the body because of the housing needed to encapsulate it. Placing the camera within the body makes it more challenging to maintain a diameter of four inches for the body, and the pan and tilt view of the camera is limited by the body of the system; placing them in front or on top of the body of the system does not limit either aforementioned factor. The design with the camera within the body and the design with the camera on top of the body will not have as great of visual quality as the design with the camera within the body. This is due to the fact that the footage from the camera in front of the body is not influenced by the vibrations of the chassis while moving through the terrain, and since the camera is in front of the chassis and connected by a rod, the camera will have an upright orientation at all times. If the system flips while the camera is within the body, the camera orientation is inverted, and if the system flips while the camera is on top of the system, the orientation will be skewed and the rover will be inoperable.

After weighing the significance of each advantage and disadvantage of all the designs for the chassis and camera placement, the linear two tracked chassis and camera placed within the body were the designs decided upon to use for prototyping.

C. Evaluation of Designs

Below in Tables 2 through 5, the decision matrixes for both the mechanical components of the design as well as the electrical components of the design have been displayed in order to select which design was most suitable for each separate category. How these matrixes were constructed is explained in more detail in the following section.

Table 2. Decision Matrix for Mechanical Design of Chassis

		Design		
Category	**Weight**	Linear Treads	Triangular Treads	Wheels
Size/Weight	9	5	3	6
Stability	7	6	6	4
Power Consumption	7	4	4	7
Noise/Invasiveness	4	5	5	5
Durability	7	5	6	2
Subterranean Maneuverability	8	8	6	3
Reproducibility	4	5	4	5
Portability	5	4	4	6
Cost	7	5	4	6
Total		**309**	**267**	**281**

Table 3. Decision Matrix for Mechanical Design of Pan and Tilt System

		Design		
Category	**Weight**	Inside Chassis	Outside Chassis	Turret Camera
Size/Weight	9	10	7	4
Stability	3	10	3	6
Noise/Invasiveness	2	8	2	5
Durability	7	9	4	4
Subterranean Maneuverability	3	7	6	4
Reproducibility	4	4	7	6
Portability	3	8	4	6
Visibility	7	3	9	10
Cost	8	8	6	5
Total		**345**	**273**	**256**

Table 4. Decision Matrix for Electrical Design for Microcontroller Selection

		Design	
Category	**Weight**	Raspberry Pi B+	Beagle Bone Black
Power Consumption	3	5	5
Memory	5	8	8
Overall Cost	7	7	7
Expandability	5	7	6
Interface	10	9	8
Community	3	7	4
Processor	8	7	10
Graphics	4	10	7
Total		**376**	**364**

Table 5. Decision Matrix for Electrical Design for Microprocessor Comparison

		Design		
Category	Weight	Arduino Micro	Arduino Uno	Arduino Mega
Power Consumption	3	7	5	5
Overall Cost	7	8	7	3
Size	10	10	3	1
Interface	8	4	7	8
Processor	5	4	7	8
Total		**229**	**185**	**150**

1. Criteria, Method

Chassis

The three distinct chassis options being looked at by the team are compared in table 1. They are as follows: linear treads, triangular treads, and wheels. The first category being used to determine which chassis is optimum is size and weight. Since the design of the scope has a strict chassis size constraint of approximately four inches, this category has been given a weight factor of 9. Stability is also an important factor when dealing with the design of the chassis system. Since the rover is going to be very small and very light, it is important that it does not flip when traveling over the rocky terrain inside the burrows. The stability category, therefore received a weight factor of 7. Power consumption is another important item to consider when deciding on a rover design due to the fact that the entire system is going to be powered for an entire day without the ability to be recharged. This category, received a weight factor of 7. Noise/invasiveness was also considered. It is important that the rover system is a minimal disturbance to any animals that might be living in the burrow. This is not as important of a constraint however and since the rover is so small, there will not be very much noise being made therefore it received a weight factor of 4. The next category was durability, which is one of the rovers main design constraints. It is required by Tall Timbers that the rover be waterproof, shock proof, and dirt resistant, therefore this category received the weight factor of 7. The most important category next to size and weight is subterranean maneuverability. If the rover is not able to move down the burrow in a quick and efficient manner, then the burrow will not be able to be scoped. This category therefore, received a weight factor of 8. The next category is reproducibility. The sponsor desires a product that is reproducible, but the main goal is something that is able to scope burrows in an efficient manner. Therefore this category received a weight factor of 4. Portability is also something important to consider when looking at the chassis design due to the fact that the entire scoping system has to fit compactly into a backpack. Since it is known that all of the chassis are relatively the same size and weight, this category was given a weight factor of 5. The last category that was considered was cost. As previously mentioned, Tall Timbers is a non-profit research center and therefore does not have the funds to purchase most of the scopes on the market at this time. Therefore it is desirable for the team to build this scope as cheaply as possible while also keeping the rest of the categories in mind. Cost, therefore, received a weight factor of 7.

Pan and Tilt System

There were three distinct pan and tilt system placement options which are outlined in Table 2: inside the chassis, outside the chassis, and a turret camera. The first category that would determine which system was optimal was size and weight. Since the scope has strict size constraints, it is important that the pan and tilt system are as compact as possible. This category therefore has been given a weight factor of 9. Stability is also an important factor to look at, but since the pan and tilt system will be placed onto the rover system itself the stability is not as much of a factor. Therefore, the stability factor in this case received a weight factor of 3. The next category that was considered was noise/invasiveness. Since the pan and tilt system along with its motors will be placed inside a Plexiglas box, the noise will be dampened as is therefore not as much of a factor. Therefore this category was given a weight of 2. Durability is one of the main design constraints of the entire scoping system. As previously stated, the entire system has to be waterproof, shock proof, and dirt resistant. Due to the importance of this, durability received a weight of 7. The next category was subterranean maneuverability. Since the pan and tilt system is not actually moving along the burrow, but is instead being used to observe what is taking place inside it, this category was given a weight factor of 3. Reproducibility was the next category considered and though the sponsor desires something that is reproducible, the main goal is to have a product that can scope burrows in an efficient manner. Therefore, this category received a weight factor of 4. The next category was portability. Since the pan and tilt system is mounted on the chassis body, portability is not as much of a concern and therefore received a weight factor of 3. The main function of the pan and tilt system deals with visibility, which is the next category. The pan and tilt system needs to be able to look around the burrow in order to observe not only the tortoises, but also the other creatures that share its burrow. Due to this high importance, this category received a 7. The last category was cost. As previously stated, it is desirable to build this scope as cheaply as possible while also taking the other categories into account. Therefore, cost was given a weight factor of 8.

Microcontroller

The microcontrollers were evaluated using the criteria summarized in Table 4. The least important criteria was determined to be the power consumption and processor weighted 3 and 5 respectively. Similar to the microprocessors, the power used by different microcontrollers is fairly uniform and relatively small and so does not have a large effect on the design. Unlike the microprocessors, the processor of the microcontroller is not a major deciding factor. All of the microcontrollers being considered had processors that were more than sufficient to meet their performance requirements.

The deciding factors for the microcontrollers were the overall cost, interface and size. These were weighted 7, 8 and 10 respectively. The overarching goal of this project is to make a scope cheaper than the competition. With this in mind, the team was careful to only consider inexpensive options. The interfacing capabilities of the microcontroller are important for the same reasons they were important to the microprocessor. The microcontroller will have to send and receive data from the microprocessor as well as control four motors and read inputs from two sensors. This will require a fair number of GPIO pins to achieve. Size was the most important factor because the microcontroller will be located on the rover. In order to keep the rover under four inches in diameter while still fitting treads, motors batteries and a camera, very little room has been left for the electronics. In order to meet all of the design requirements and still fit this form factor, each piece of electronic equipment used on the rover will need to be as small as possible.

Microprocessor

In order to evaluate the different microprocessor options introduced in section 3.2 the design team came up with the criteria summarized by the decision matrix in Table 5. The least important criteria were decided to be power consumption and community each of which were weighted as a 3 (out of 10). While power consumption is an important consideration for the overall design, the difference in power usage between most microprocessors is small enough that it does not have a large impact on the design. Similarly, while having a community of consumers that use the microprocessors can aid in programming and make spare parts easier to obtain, it is not thought to be important enough to heavily influence which microprocessor we use.

The mid-tier criteria were determined to be the graphics, memory, expandability and overall cost. These were weighted at 4, 5, 5 and 7 respectively. Graphics are a necessity because the end-user must have a live feed of the camera input. It is also one of the major performance differences between the two microprocessors being considered and it is important that this difference be accounted for in the decision matrix. Memory is weighted as average importance because it is needed to record video and images along with keeping the operating system of the microprocessor onboard. Expandability refers to the number of add-on devices that have been designed specifically for the microprocessors by manufactures such as Adafruit and SparkFun. These add on devices can give the microprocessors LCD screen or temperature sensor capabilities without the team having to design custom options. However, since this is not a necessity to complete the design, it was given a lower weight. Cost was given a slightly higher weight since a major part of the design is to make the rover cost effective. The cost category does not just account for the cost of the microprocessor, but also the cost of the necessary peripherals such as microSD cards or USB cables.

The most critical criteria were determined to be the processor and interface capabilities; weighted 8 and 10 respectively. The microprocessor will be the hub for the majority of the data being input and output to our system. The processor will need to have a high enough clock speed in order to make the device function with as little lag as possible and ensure a good end-user experience. What connectivity options are available on the microprocessor will also determine how well the final design works. Available input and output ports can include but are not limited to USB, HDMI, RCA, GPIO, I2C and CAN. The more options available, the more likely a product that will be compatible and meet the criteria will be found.

2. Selection of Optimum Ones

Mechanical Design of Chassis

The first category that was analyzed was size/weight. None of the chassis designs scored very high in this category due to the fact that it is difficult to purchase them in such a small size. The triangular tread design however, would be the largest in the vertical direction due to the shape of its treads; therefore it scored the lowest out of the three. The next category was stability; both the linear as well as the triangular tread designs scored the same due to the fact that their treads allow for more surface area and therefore greater stability. The wheeled design has less surface area and therefore scored less than the other two designs in this category. Power consumption was also considered and the wheeled chassis out scored both the linear and traingular treaded chassis due to the fact that the wheeled chassis requires less torque. The next category was noise/invasiveness. All of the chassis scored the same in this category due to the fact that all are equipped with the same number of motors and therefore would all make approximately the same amount of noise. The next category was durability. Both of the treaded chassis scored high in this category due to the fact that they are compact and will have treads that are designed for all terrain. The wheeled chassis however, is not nearly as durable as the treaded chassis and scored low in this category. Subterranean maneuverability was the next category and the linear treads outscored all of the other designs. Treads are specially designed to maneuver over obstacles and since the linear treads do not have any open spaces that rocks or dirt can be trapped in as compared to the wheeled and triangular tread design, it has the most maneuverability. The next category was reproducibility and all of the designs scores were fairly even. The triangular treaded chassis scored slightly lower than the other two designs due to the complex shape of its treads. Portability was the next category; the wheeled design scored higher than both treaded designs due to the fact that the wheeled design is easier to clean and place in a backpack. With the treads larger surface area, there is more dirt and cleaning required. The last category was cost and again the wheeled design was rated highest due to its simplicity. Treads are often more expensive due to their complex nature and therefore both the linear and triangular tread designs were ranked lower. After all of the scores were summed the linear chassis had the highest overall score of 309 and therefore was the design that was chosen for the mechanical design of the chassis.

Mechanical Design of Pan and Tilt System

The first category that was analyzed was size/weight. The pan and tilt system located inside the chassis scored the highest out of all three designs due to the fact that it is the smallest so it can fit inside the chassis body. The turret camera is slightly larger and would have to be placed on top of the chassis body, which would add unnecessary height. Stability was the next category analyzed and again the pan and tilt system inside the chassis ranked highest since being placed inside the chassis body makes it the most stable. The least stable design was the pan and tilt system placed outside the chassis. This design could potentially cause an imbalance in weight and could result in the chassis flipping over. The turret camera ranked in the middle of the two designs due to the fact that it is attached to the chassis body, but it is not inside it like the first design. The next category that was considered was noise/invasiveness and the pan and tilt system outside of the chassis body scored the lowest out of the three designs. This is due to the fact that it is sticking out from the chassis body, while the other two designs are within the chassis body. Durability was considered next and both the pan and tilt system located outside the chassis as well as the turret camera scored low due to the fact that, if dropped they would be more prone to breaking since their systems are not surrounded by the chassis wall. Then next category that was considered was subterranean maneuverability. The turret camera scored the lowest here due to the fact that it would sit very high on the chassis body and would have the potential to scrape the top of the borrow. Reproducibility was considered next and the pan and tilt system inside the chassis scored the lowest due to the fact that it will be completely made from scratch. The other two systems will have off the shelf parts and will be able to be assembled in a more simplified manner. The next category that was considered was portability. The pan and tilt system outside of the chassis body scored the lowest in this category due to the fact that it sticks out from the chassis body. This makes it more difficult to store compactly in a backpack. Visibility was also considered and the pan and tilt system inside the body of the chassis scored the lowest due to the fact that body of the chassis will obstruct some of the visibility of the pan and tilt system. The turret camera scored the highest in this category due to the fact that it rests on the top of the chassis body and nothing is obstructing it from having a complete 360-degree view. The last category was cost. The pan and tilt system inside the chassis scored the highest in this category due to the fact that is can be made with relatively cheap parts. After all of the scores were summed the pan and tilt system inside the chassis had the highest overall score of 345 and therefore was the design that was chosen for the mechanical design of the pan and tilt system.

Electrical Design for Microcontroller Selection

Using the criteria described previously, the Raspberry Pi B+ (RPi) and BeagleBone Black (BBB) were compared as options for the microprocessor. The two microprocessors were found to be identical or nearly identical in several categories. These categories included power consumption, memory, and overall cost. In all of these categories the two microprocessors received the same scores.

In terms of categories where the RPi and BBB received different scores, the BBB was determined to be much more capable than the RPi only in terms of processing power. The BBB uses an ARM8 chip with a clock speed of 1 GHz. In comparison the RPi only has a ARM7 chip with a 700 MHz clock speed.

The RPi received higher scores in the community, expandability, graphics and interface categories. The community and expandability scores go hand in hand since they are both based off of the popularity of the product. The RPi is much more popular than the BBB among tech enthusiasts and hobbyists. Because of the large community that has formed around building projects with the RPi there are many forums, websites and other resources dedicated to learning how to use it. There is also an abundance of coding examples and libraries of functions that the team can borrow from. The size of the community has also driven manufactures to create many add-on kits specifically for the RPi. These kits make it easy to expand the capabilities of the RPi using kits such as motor drivers, LCD displays and other sensors.

In the graphics category the BBB was found to be adequate despite receiving the lower of the two scores. With a PowerVR SGX30 GPU that performs at 1.6 GFLOPS the BBB is powerful enough to processes and display the video from many mid-range cameras. However, the RPi's dual core GPU is capable of 24 GFLOPs making it 15 times more powerful than the BBB. Having a more powerful GPU would allow the design team to replace the current camera with one of higher resolution without having to change any hardware if the need arises.

In terms of interface capabilities the BBB is often considered to have an advantage over the RPi. The BBB has twice as many GPIO (general purpose input/output) pins as the BBB which allow it to send and receive signals from a large number of external sensors. The BBB also has a more extensive selection of CAN, SPI and I2C options than the RPi. However, for this project it was decided that USB would be the most utilized connection. The RPi has four USB 4.0 connections compared to the BBB's one.

As can be seen by the above analysis, the Raspberry Pi B+ is a very capable board with a small price tag. It has the ability to connect to all of the peripherals the project will require and provide excellent processing speeds and video handling capability. For this reason it was decided that the Raspberry Pi B+ was betters suited for this project than the BeagleBone Black.

Electrical Design for Microprocessor Comparison

Using the criteria listed in the decision matrix in Table 5, the three Arduino boards were compared. There was very little difference between the boards in terms of power consumption. In the categories of interface and processor the Mega easily won with the Uno not far behind. With that said the Micro still provides sufficient processor speeds and interfacing capabilities for this project, despite being far less capable than the Mega or Uno. The Micro's strong suites are in the heavily weighted size and cost category. The Mirco is about five times smaller than both the Uno and the Mega and is the least expensive of the three. Since the Micro was by far the best option in terms of size and cost, and provides adequate processor and interface options, the design team selected it for use on the prototype.

Methodology

A. Schedule

The Gantt Chart shown in the appendix provides a visual timeline for the project and the tasks that need to be achieved during the Fall 2014 semester.

Fall 2014 Overview

- Initial Start/Sponsor Contact
  - Week 1-3
  - Introduce ourselves to all parties involved.
  - Meet with sponsor and faculty advisors.
  - Construct Code of Conduct
- Complete Needs Assessment
  - Week 3-5
  - Also create initial website. This will be updated and maintained throughout the semester.
- Component Breakdown
  - Week 6-8
  - Layout individual components of tortoise scope functionality
  - Decide on overall initial design (decision matrix)
  - Begin theoretical analysis
  - Research all subsystems
- Create a Design for the Rover
  - Week 7-8
  - Decide on a chassis design
  - Decide on a CAM/pan and tilt design
  - Design camera housing
- Presentation 1: Conceptual Design
  - Week 8-9
  - Initial CAD model
  - Prepare for presentation
- First Functioning Prototype
  - Week 9-11
  - Assembly of prototype
  - Begin testing of first prototype
- Begin Testing
  - Week 11-13
  - Create a mock burrow
  - Test maneuverability on dry and wet terrain
  - Assess design and possible solutions to problems encountered
- Presentation 2: Interim Design Review
  - Week 13
  - Prepare for presentation

- Finalize Refined Design
    - Week 13-15
    - Develop a workable prototype
- Presentation 3: Final Design Presentation
    - Week 15

B. Resource Allocation

Tether

Construct Electrical Component of Tether: 4 hours of work will be used to build the electrical component of the tether. This will include connecting the wires to the rover and user interface and properly grounding the wires. Lead EE Colin Riley will be responsible for this task.

Construct Mechanical Components of Tether: 4 hours will be used to construct a sheath for the tether as well as connect a reinforcing cable. Another 36 hours will be used to construct a spooling device. Project Leader Jane Bartley will be responsible for this task.

Rover

Assemble Prototype Chassis: 2 hours will be used to assemble the prototype chassis and gear box. Jordan Muntain will be responsible for this task.

Assemble Final Chassis: 72 hours will be used to assemble the final chassis, gear box and Plexiglas housing. Jordan Muntain and Lester Nandati will be responsible for this task.

Control Chassis using a Game Pad: 72 hours will be used to program the microprocessor to read inputs from the Game Pad and use them to control the motion of the rover through the microcontroller and motor drivers. Sina Sharifi-Raini and Colin Riley will be responsible for this task.

Collect Temperature and Humidity Data using the Microcontroller: 12 hours will be used to program the microcontroller to read inputs from the temperature and humidity sensors. Colin Riley will be responsible for this task.

Camera

Build Pan and Tilt System: 24 hours will be used to build the pan and tilt system and mount the camera onto it. Lester Nandati will be responsible for this task.

Connect Camera to Microprocessor: 5 hours will be used to connect the camera to the microprocessor and display video to an eternal monitor. Sina Sharifi-Raini will be responsible for this task.

Record Video: 3 hours will be used to program the microprocessor to record video from the camera. Sina Sharifi-Raini will be responsible for this task.

User Interface

Connect LCD Display to Microprocessor: 4 hours will be used to program the microprocessor to display video to the LCD display. Colin Riley will be responsible for this task.

Display Temperature and Humidity data: 2 hours will be used to program the microprocessor to display the temperature and humidity data collected by the microcontroller onto the LCD display. Sina Sharifi-Raini will be responsible for this task.

Display Video: 2 hours will be used to program the microprocessor to display the video captured by the camera onto the LCD display. Sina Sharifi-Raini will be responsible for this task.

Build Case for User Interface: 5 hours will be used to build a water proof and dirt resistant case for the user interface. Bridget Leen and Jane Bentley will be responsible for this task.

Power

Mount Battery to Rover circuit: 2 hours will be used to mount the battery to the chassis body and connect it to the rover electronics. Colin Riley and Jordan Muntain will be responsible for this task.

Mount Battery to User Interface circuit: 2 hours will be used to mount the battery to the user interface and connect it to the rover electronics. Colin Riley and Jordan Muntain will be responsible for this task.

Testing

100 hours will be used to test all of the subsystems. This will include testing the maneuverability of the rover in rough terrain, testing the strength and flexibility of the tether, testing the battery life and the visibility of the camera. The entire team will be responsible for this task.

- Testing maneuverability
- Testing Tether strength
- Testing video quality
- Testing Battery Life
- Testing Pan and Tilt system
- Testing Data collection

Conclusion

It is evident that the underground robotic gopher tortoise scope is a device that has a significant role in both biological and ecological research, but also has major obstacles that are preventing it from being used more prominently. The problems that researchers often face include a lack of durability, no video or picture capturing capability, no mobility, and poor ergonomics. High-end rovers may mitigate many of these problems, but are inaccessible for many non-profit research institutes such as Tall Timbers due to their typically large price tags.

Thus, Team 21 is assigned with devising a means to scope these underground burrows. The team will try to set the needs outlined by the sponsor as the main priority, while considering the budget for production and the cost of the final product. As a result, a layout of steps to reach the end goal is tentatively proposed, but may change based on resources, time and availability, and unexpected circumstances. This process will start with a component breakdown, extensive research into the feasibility of each subsystem, and a final decision on the overall initial design. From there, calculations and product design and assembly will be produced. Finally, building the product, including prototype testing and final product fabrication, will occur.

Team 21 has broken down the project into its main mechanical and electrical components. Decision matrices were created in order to aid in the design selection process and each design was also modeled in CAD as well as sent through a thorough analysis. It was concluded that the most suitable design would include a chassis with a linear tread and a pan and tilt system that is embedded inside the chassis. For the electrical components, the most superior microcontroller was the Arduino Micro while the selected microprocessor was the Raspberry Pi. These final designs implement the objectives specified by the sponsor. This can be seen for example in the pan and tilt system and the fact that it is both waterproof and dirt resistant due to the Plexiglas housing. Also, the sponsor is looking to scope very small burrows (approximately 4” in diameter), therefore rover that was chosen will be small enough to maneuver inside these small burrows as well as overcome any obstacles in its path.

Regarding future work, the team will begin to construct the first prototype and begin initial testing. Also, more clarity on current obstacles faced by the sponsor can be determined by continued contact with Tall Timbers. Similarly, the group will meet with the Mechanical Engineering and Electrical Engineering sponsors to gain more insight into design possibilities and critique of designs. With regular contact with advisors and with the sponsor, this project’s ultimate goal of a gopher tortoise scope should be within reach.

References

[1] Service, U.s. Fish & Wildlife. "Section 4 of the Endangered Species Act." Candidate Species (n.d.): n. pag. Http://www.fws.gov/. U. S. Fish and Wildlife Service Endangered Species Program, 2011. Web. 25 Sept. 2014. <http://www.fws.gov/endangered/esa-library/pdf/candidate_species.pdf>.

[2] "Examples of Keystone Species." YourDictionary, n.d. Web. 25 September 2014. <http://examples.yourdictionary.com/examples-of-keystone-species.html>.

[3] Sandpiper Technologies, Inc. "2006-7 Catalog." Metal Finishing 104.6 (2006): 67. Sandpipertech.com. Sandpiper Technologies, Inc, 2006. Web. 25 Sept. 2014. <http://sandpipertech.com/Sandpiper_Tech_Web_2006_Catalog.pdf>.

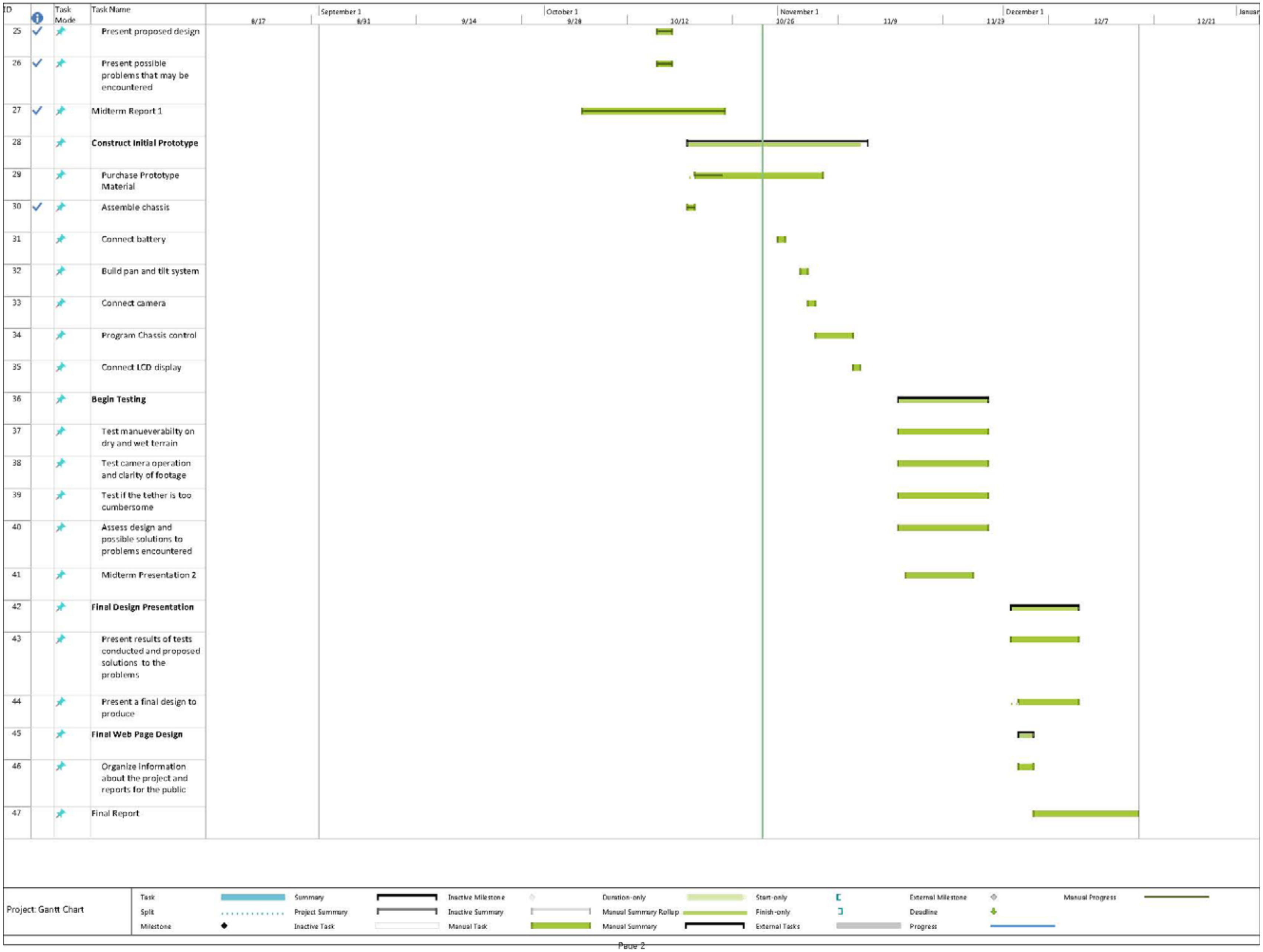
Appendix

A-1 Gantt Chart

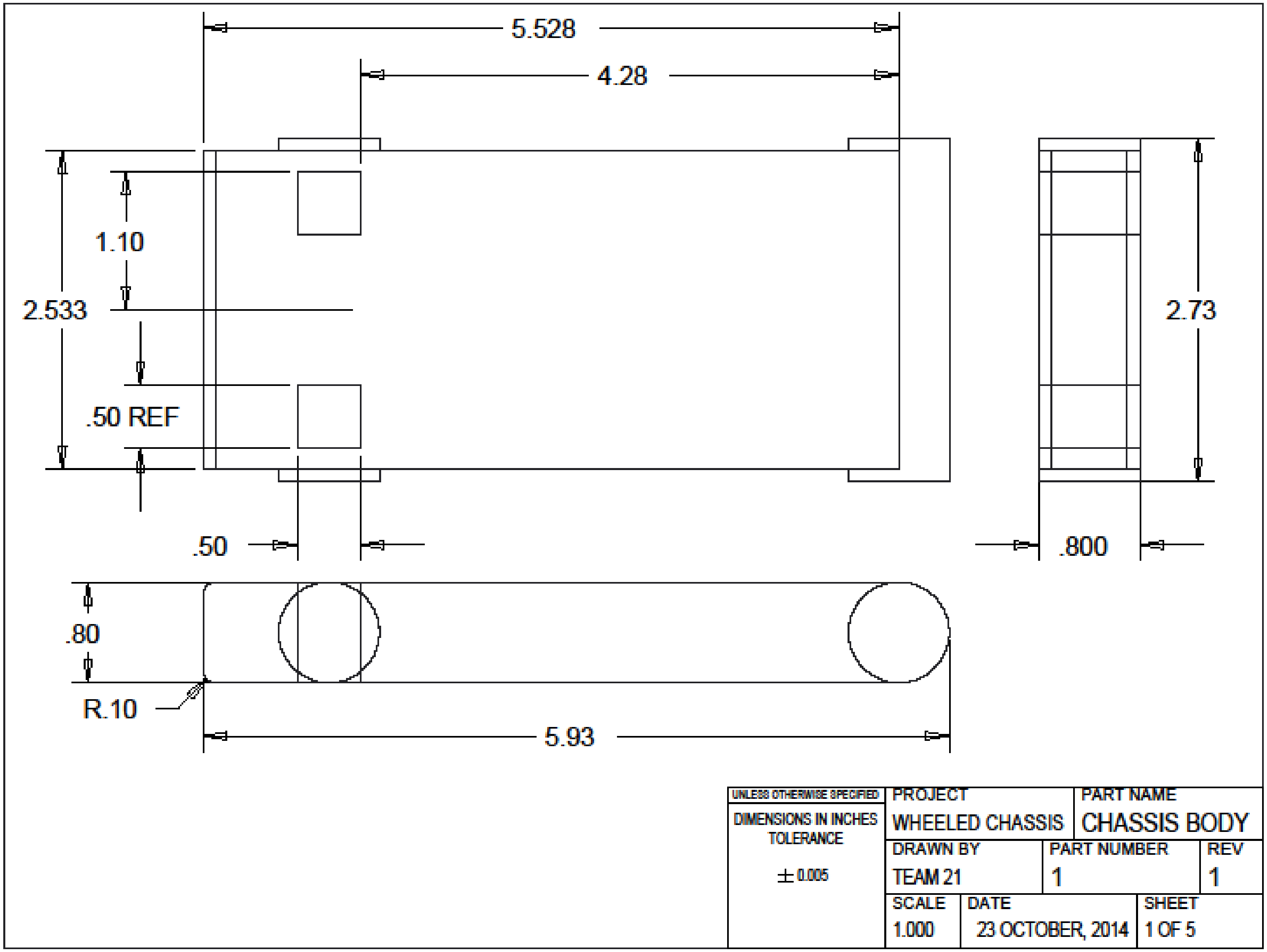
ID		Task Mode	Task Name
1	✓	📌	Project Assignment
2	✓	📌	Ice Breaker
3	✓	📌	**Meet with Project Sponsor**
4	✓	📌	Determine the need of the project
5	✓	📌	Operate the current system
6	✓	📌	**Code of Conduct**
7	✓	📌	Define group member roles and the process for meetings
8	✓	📌	Meet with Academic Advisor
9	✓	📌	Needs Assessment
10	✓	📌	Initial Web Page Design
11	✓	📌	**Component Breakdown**
12	✓	📌	Research chassis types
13	✓	📌	Research different cameras/pan and tilt systems
14	✓	📌	Research camera placement options
15	✓	📌	Research appropriate user interfaces and microcontrollers
16	✓	📌	**Create a design for the rover**
17	✓	📌	Decide on a chassis
18	✓	📌	Decide CAM/Tilt and Pan
19	✓	📌	Decide on a type of camera
20	✓	📌	Decide on whether to build or purchase a pan/tilt system
21	✓	📌	Decide on where the camera will be placed on the chassis
22	✓	📌	How the electronics will be connected
23	✓	📌	How the video will be displayed
24	✓	📌	**Midterm Presentation 1**

Project: Gantt Chart

Page 1



ID	ℹ	Task Mode	Task Name
25	✓	📌	Present proposed design
26	✓	📌	Present possible problems that may be encountered
27	✓	📌	Midterm Report 1
28		📌	**Construct Initial Prototype**
29		📌	Purchase Prototype Material
30	✓	📌	Assemble chassis
31		📌	Connect battery
32		📌	Build pan and tilt system
33		📌	Connect camera
34		📌	Program Chassis control
35		📌	Connect LCD display
36		📌	**Begin Testing**
37		📌	Test manueverabilty on dry and wet terrain
38		📌	Test camera operation and clarity of footage
39		📌	Test if the tether is too cumbersome
40		📌	Assess design and possible solutions to problems encountered
41		📌	Midterm Presentation 2
42		📌	**Final Design Presentation**
43		📌	Present results of tests conducted and proposed solutions to the problems
44		📌	Present a final design to produce
45		📌	**Final Web Page Design**
46		📌	Organize information about the project and reports for the public
47		📌	Final Report



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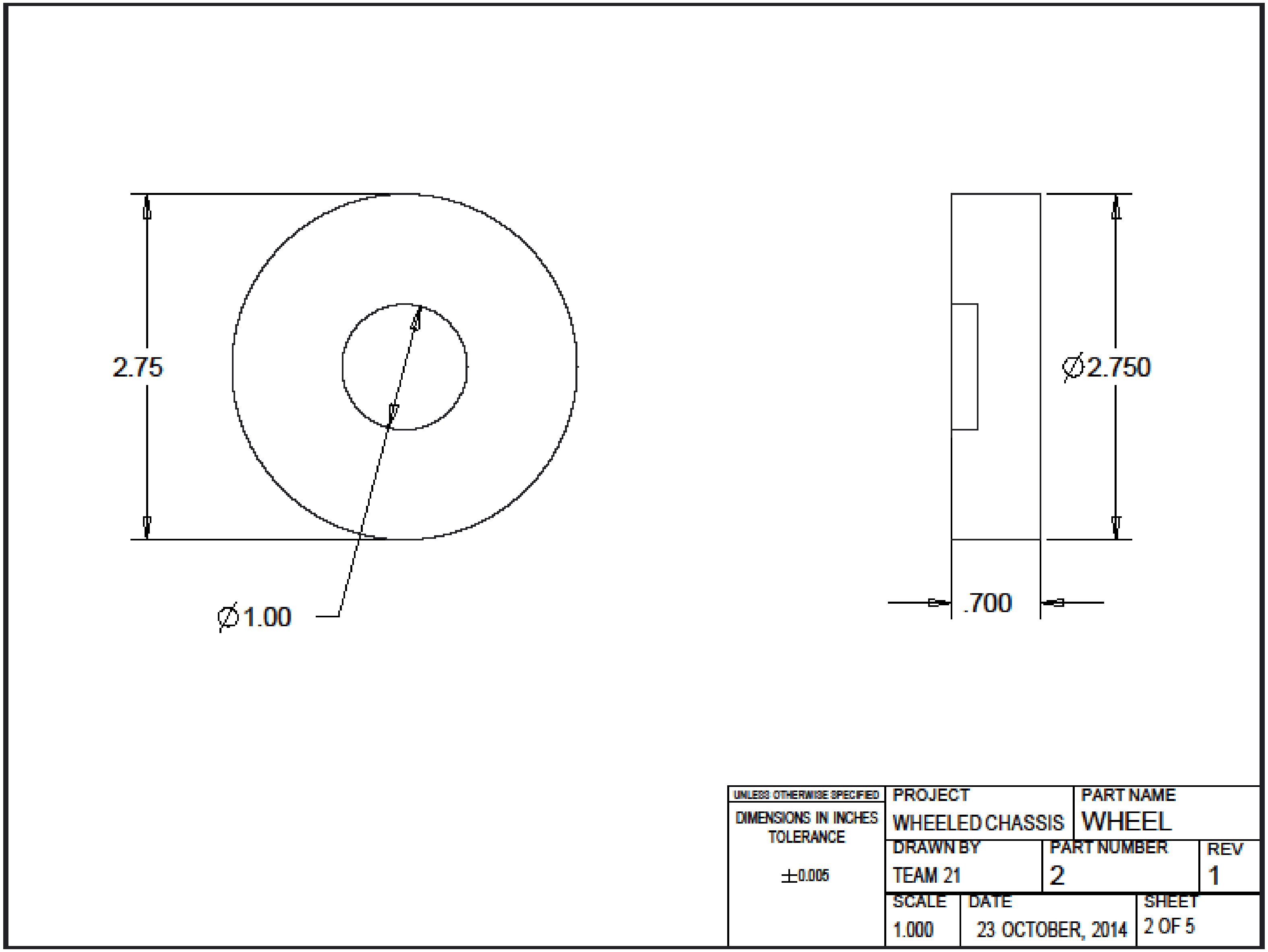
	SCALE 1.000	DATE 23 OCTOBER, 2014	SHEET 1 OF 5



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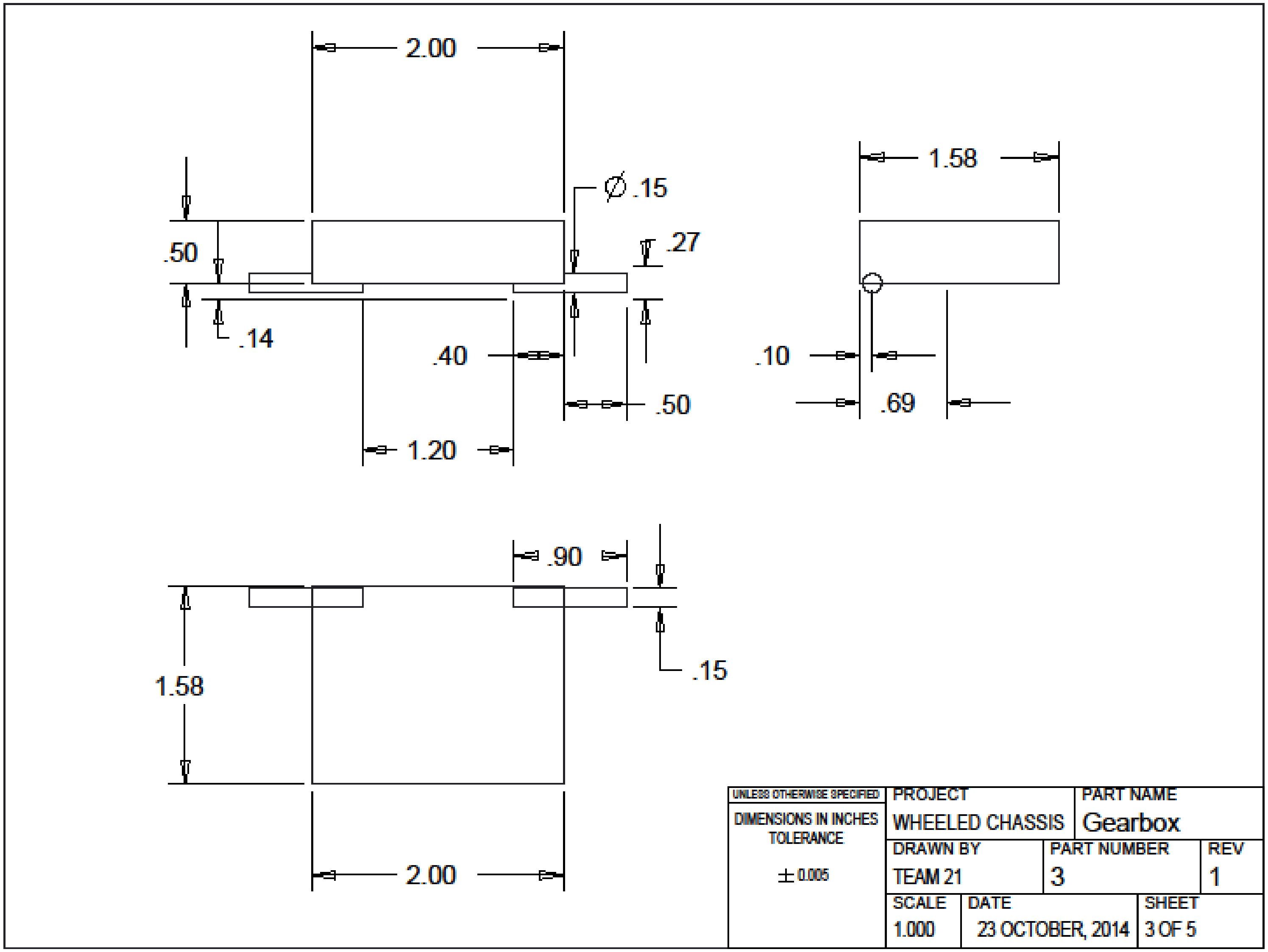
	SCALE 1.000	DATE 23 OCTOBER, 2014	SHEET 2 OF 5



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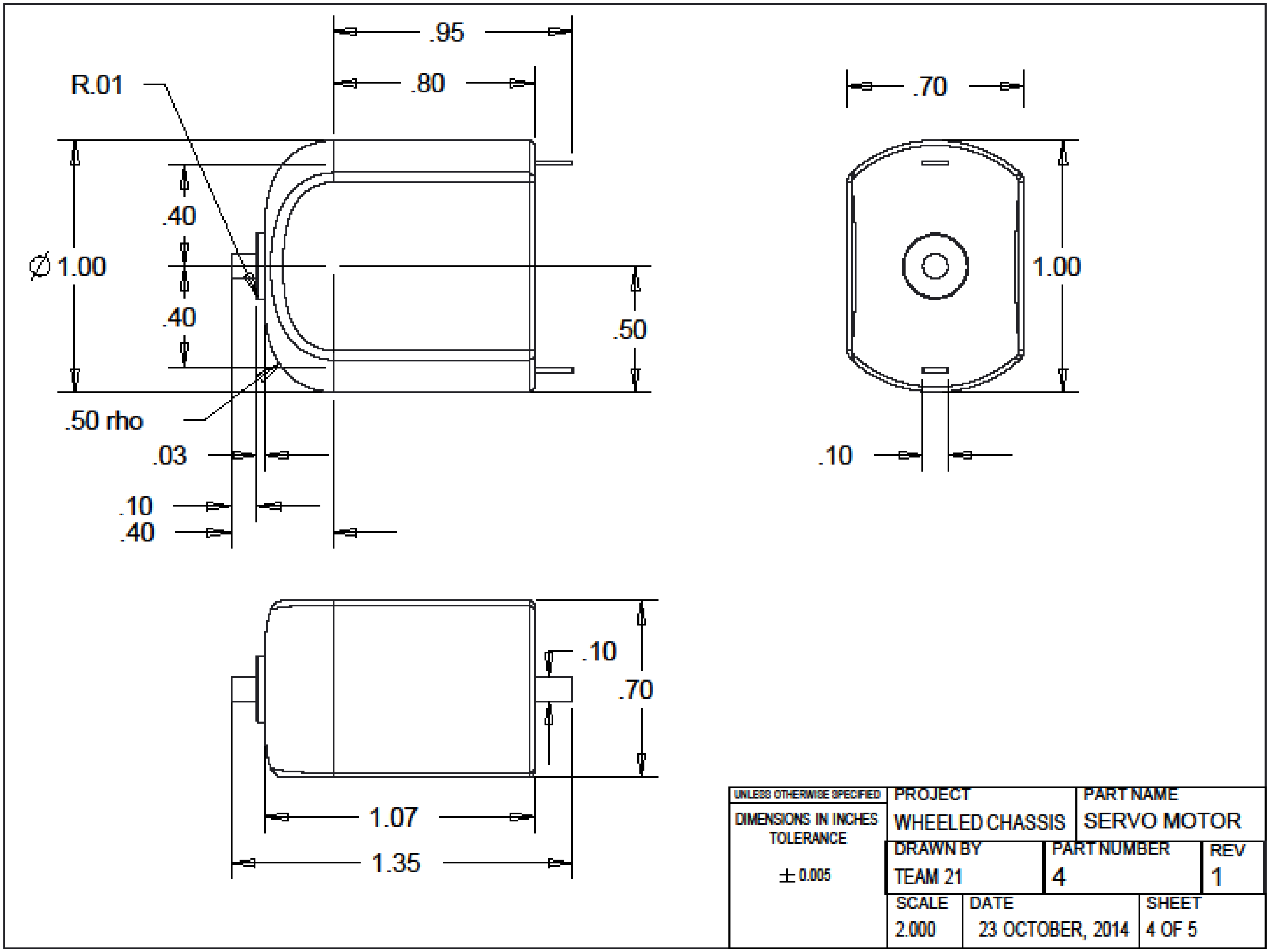

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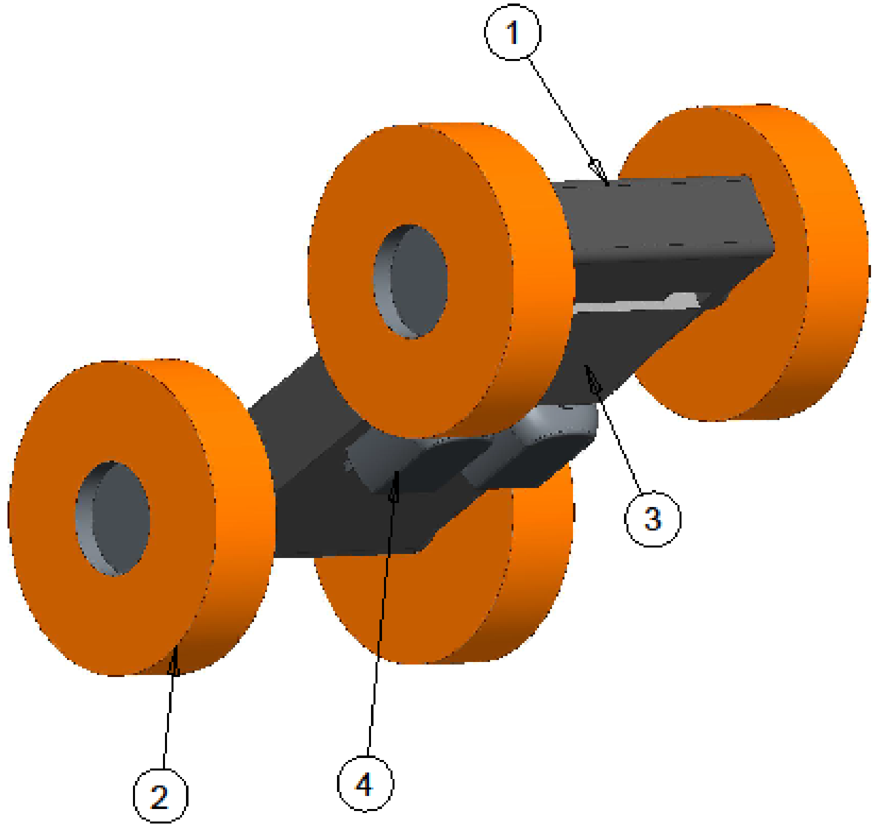
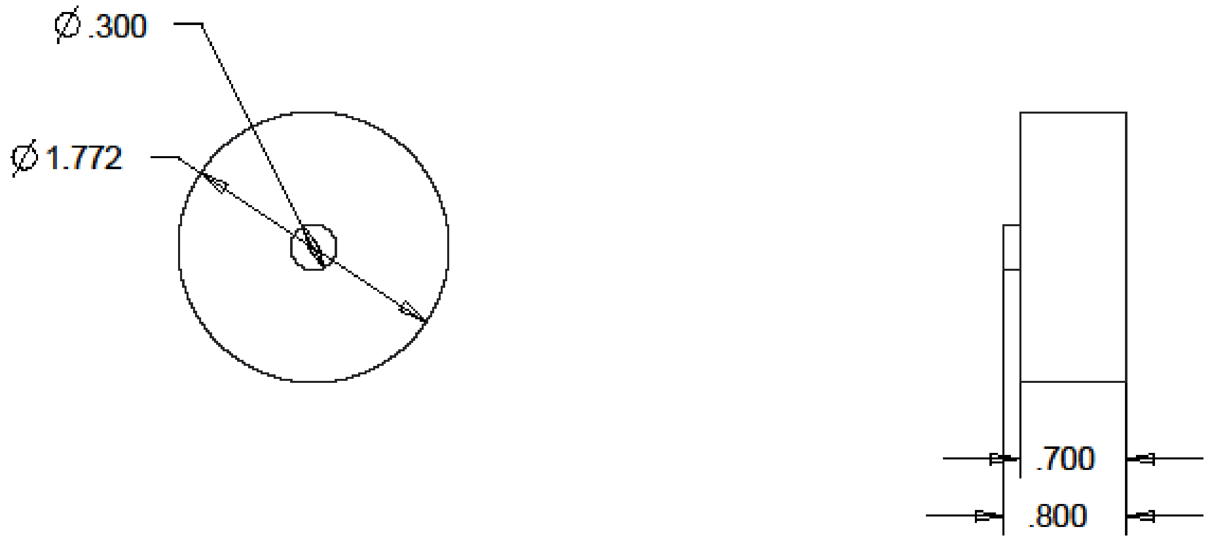


NUMBER	PART
1	CHASSIS BODY
2	WHEEL
3	GEARBOX
4	SERVO MOTOR

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCE ± 0.005	PROJECT WHEELED CHASSIS	PART NAME ASSEMBLY	
	DRAWN BY TEAM 21	PART NUMBER 5	REV 1
	SCALE 0.750	DATE 23 OCTOBER, 2014	SHEET 5 OF 5



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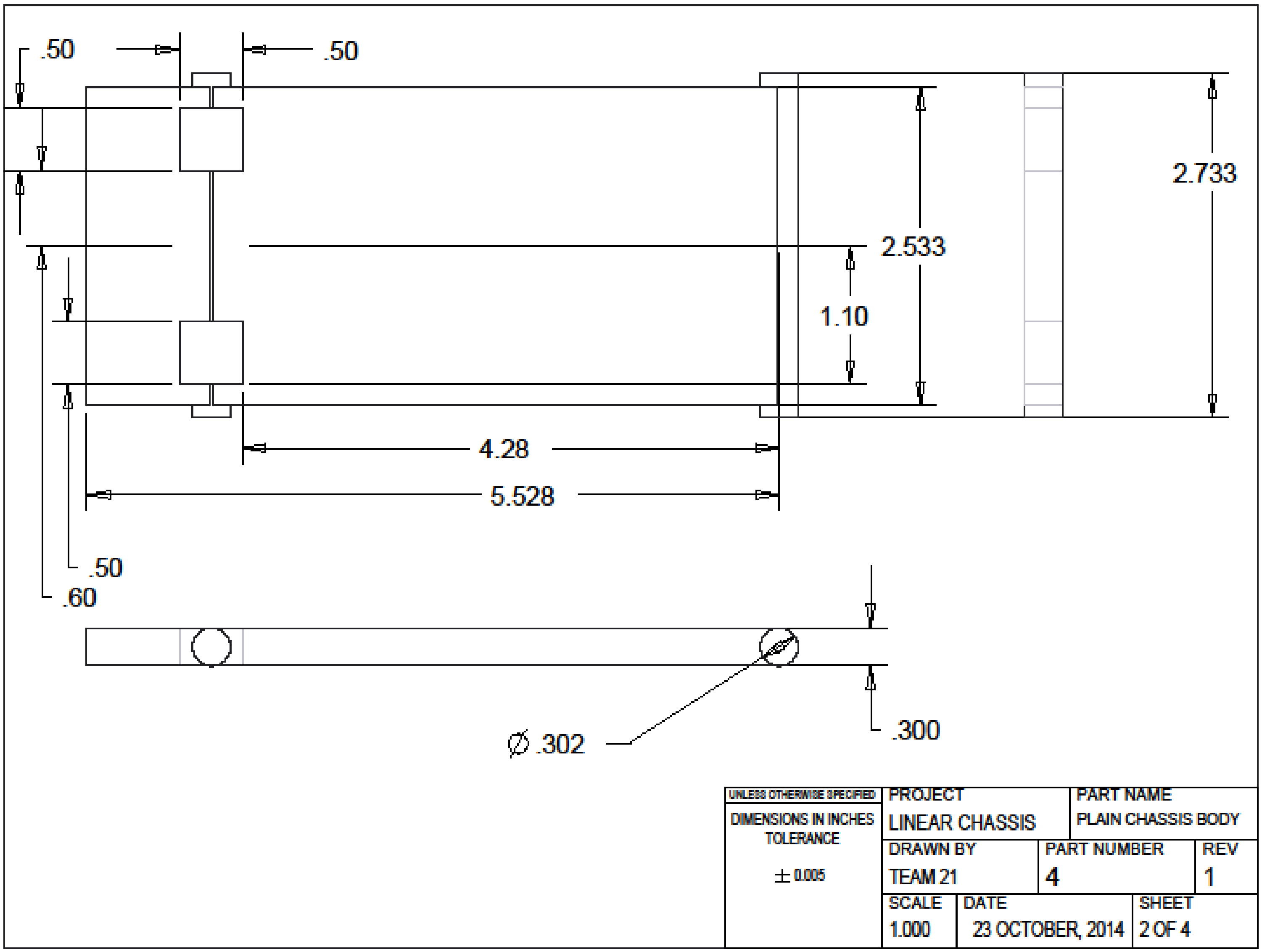
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DIMENSIONS IN INCHES
TOLERANCE
± 0.005
PROJECT
LINEAR CHASSIS
PART NAME
PLAIN CHASSIS BODY
DRAWN BY
TEAM 21
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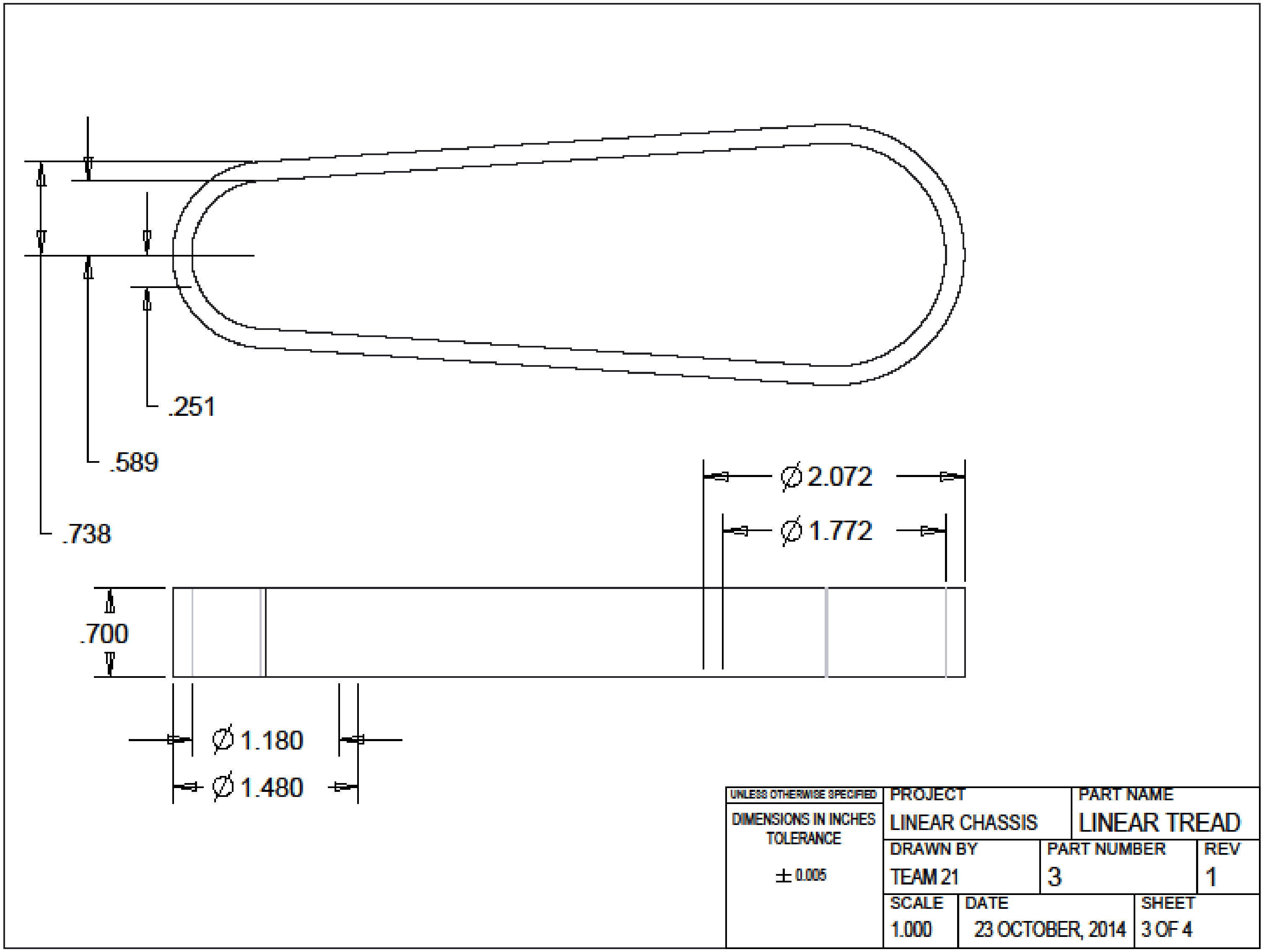
2 OF 4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PROJECT
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PART NAME
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SHEET
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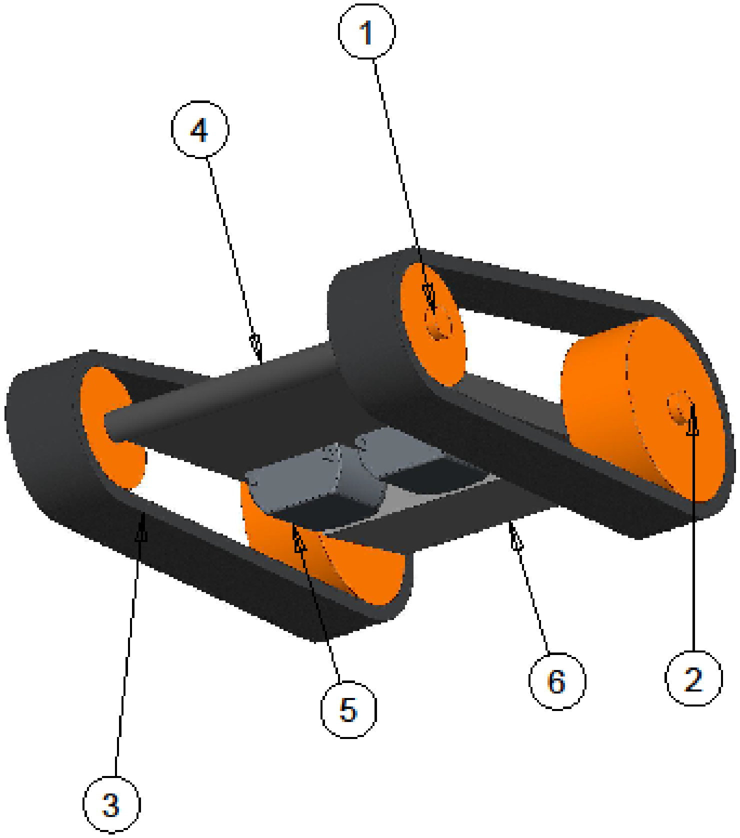

NUMBER	PART
1	FRONT WHEEL
2	REAR WHEEL
3	LINEAR TREAD
4	PLAIN CHASSIS BODY
5	SERVO MOTORS
6	GEAR BOX

UNLESS OTHERWISE SPECIFIED	DIMENSIONS IN INCHES TOLERANCE ± 0.005
PROJECT	LINEAR CHASSIS
PART NAME	SUBASSEMBLY
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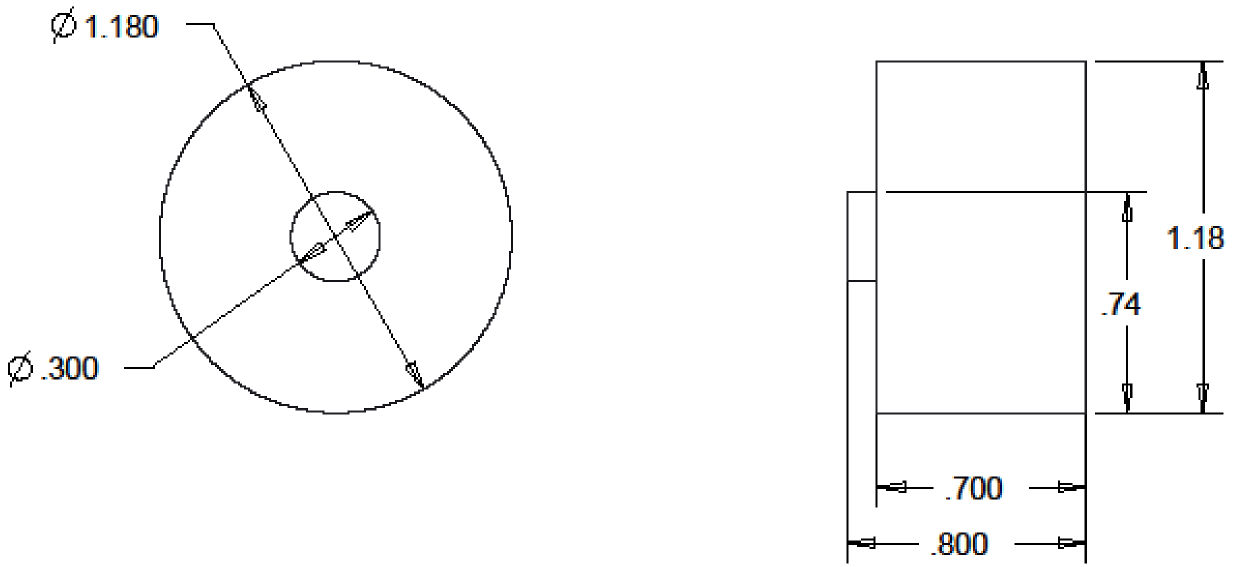
PART NUMBER	4
REV	1
SCALE	1.000
DATE	23 OCTOBER, 2014
SHEET	4 OF 4



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	SCALE	DATE	SHEET
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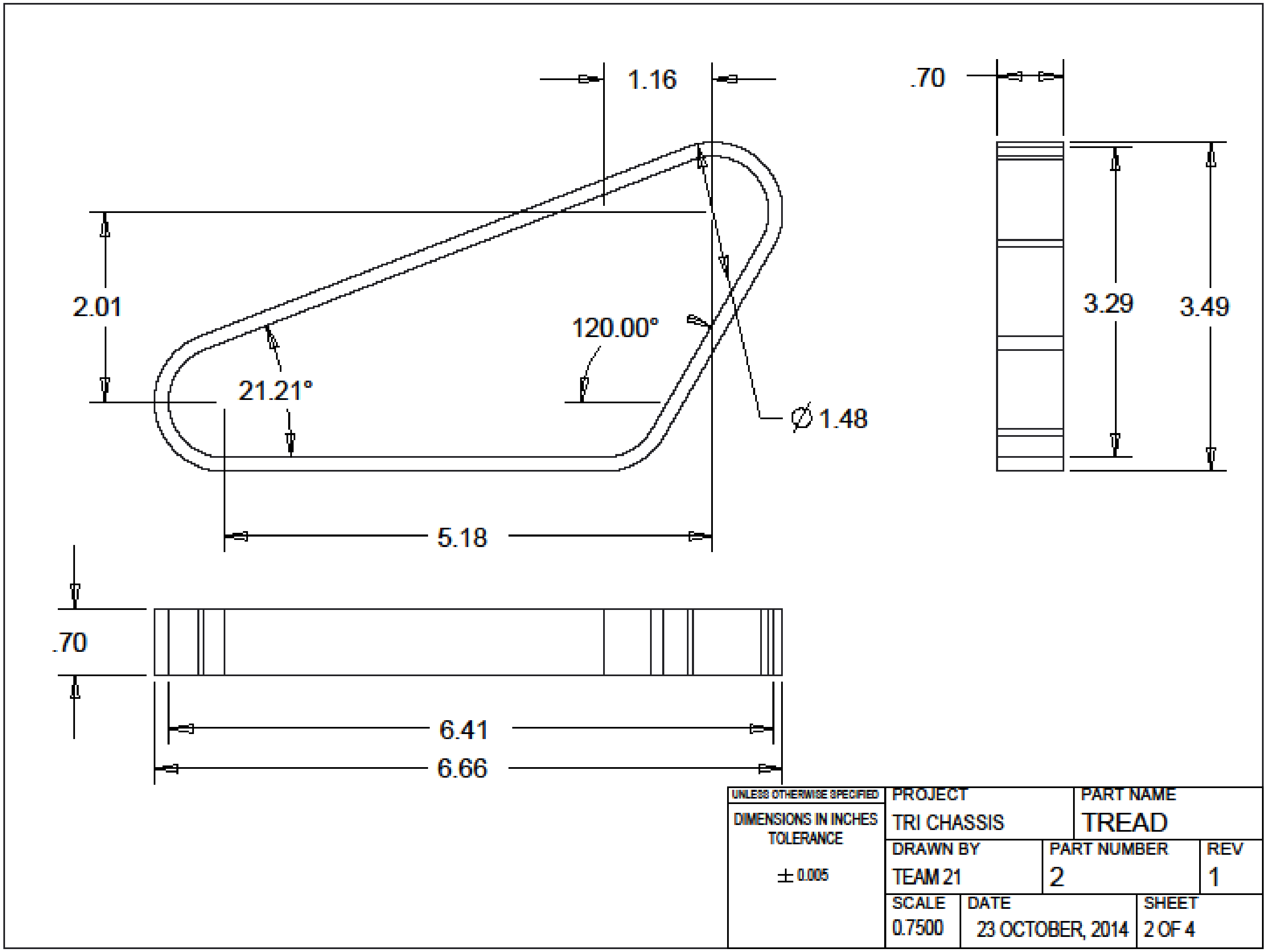

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
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±0.005

PROJECT
TRI CHASSIS

PART NAME
TREAD

DRAWN BY
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PART NUMBER
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DATE
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SHEET
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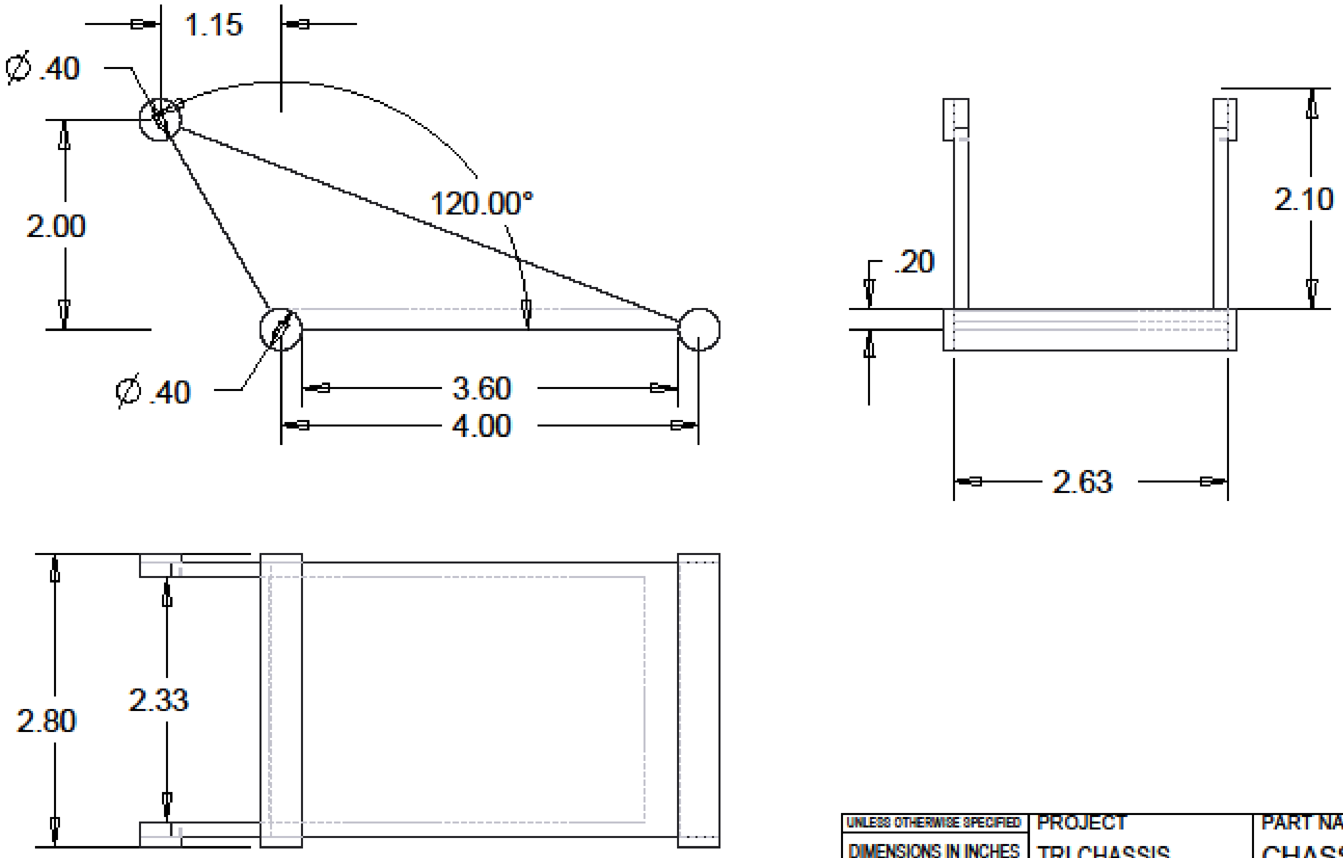

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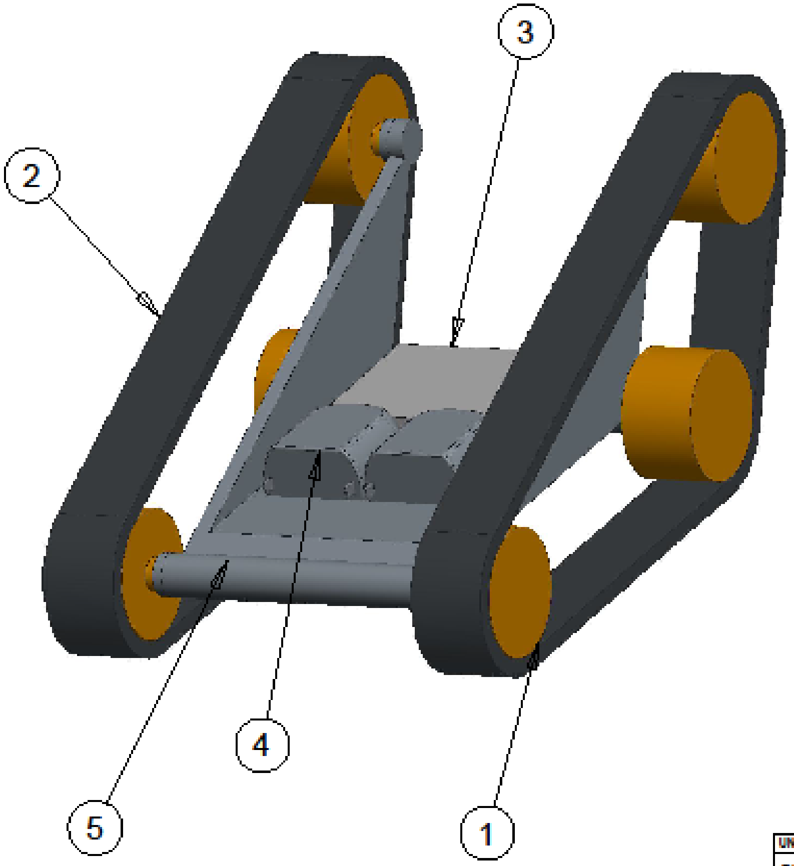
	SCALE 1.000	DATE 23 OCTOBER, 2014	SHEET 3 OF 4



NUMBER	PART
1	FRONT WHEEL
2	TRIANGULAR TREAD
3	GEARBOX
4	SERVO MOTOR
5	CHASSIS BODY

UNLESS OTHERWISE SPECIFIED	PROJECT		PART NAME	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	TRI CHASSIS		TRI CHASSIS BODY	
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	SCALE	DATE	SHEET	
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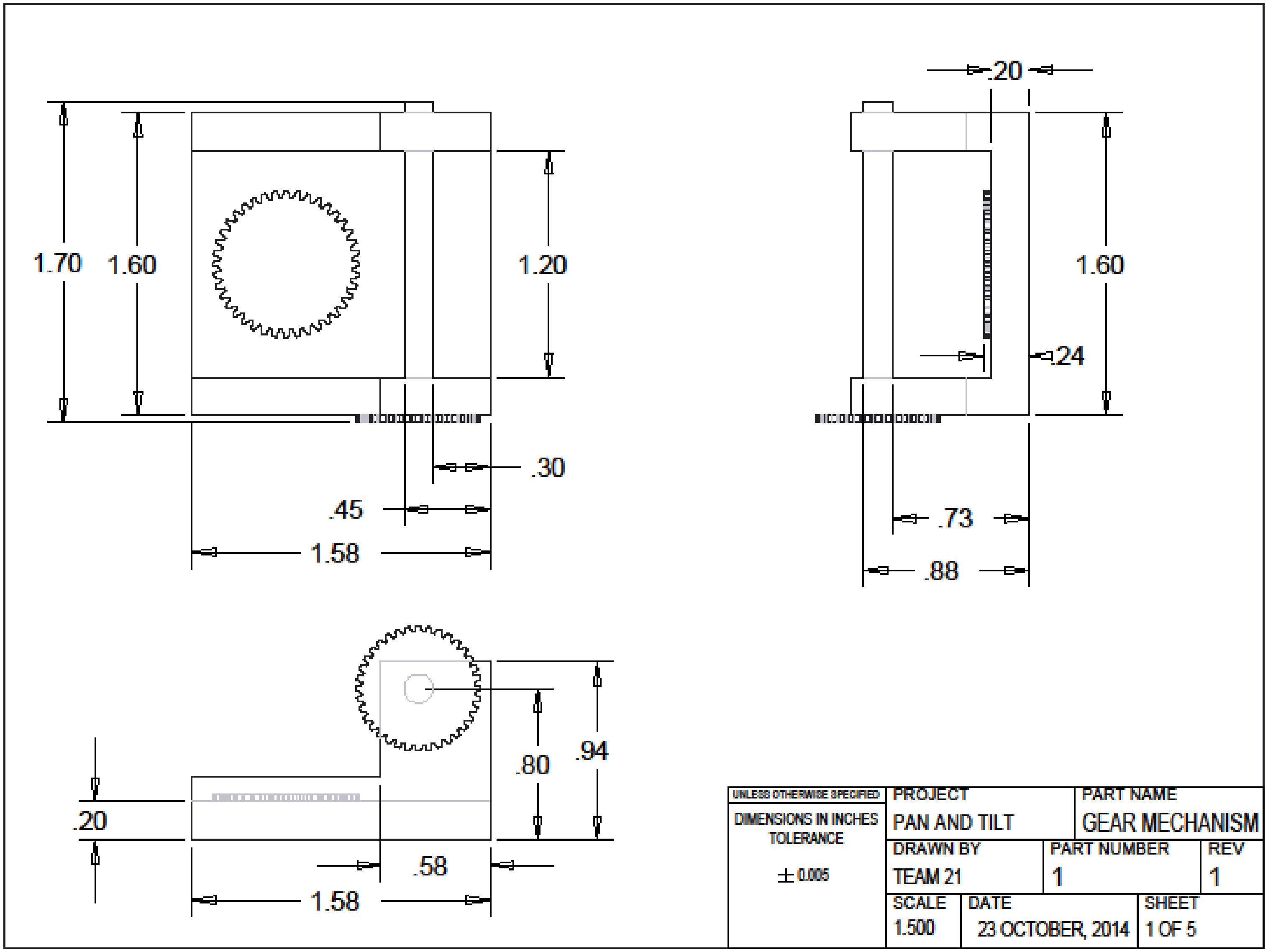
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UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCE
± 0.005
PROJECT
PAN AND TILT
PART NAME
GEAR MECHANISM
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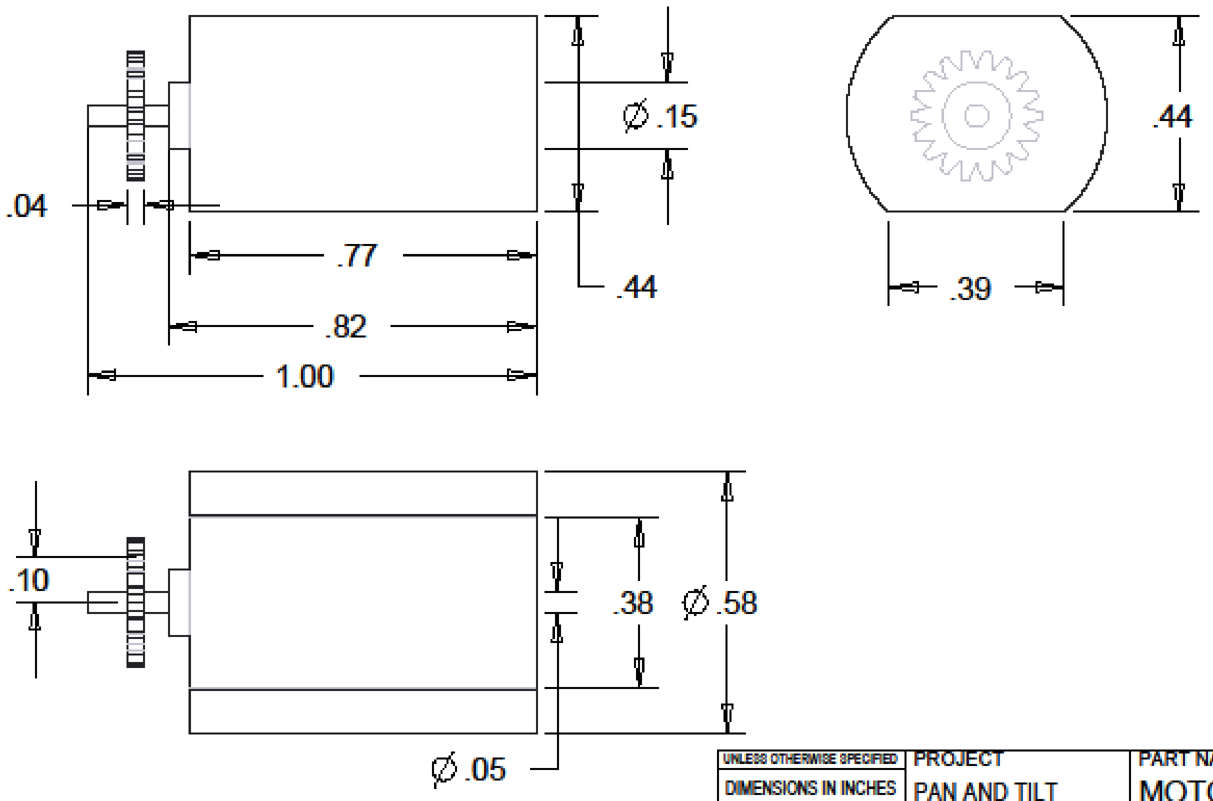
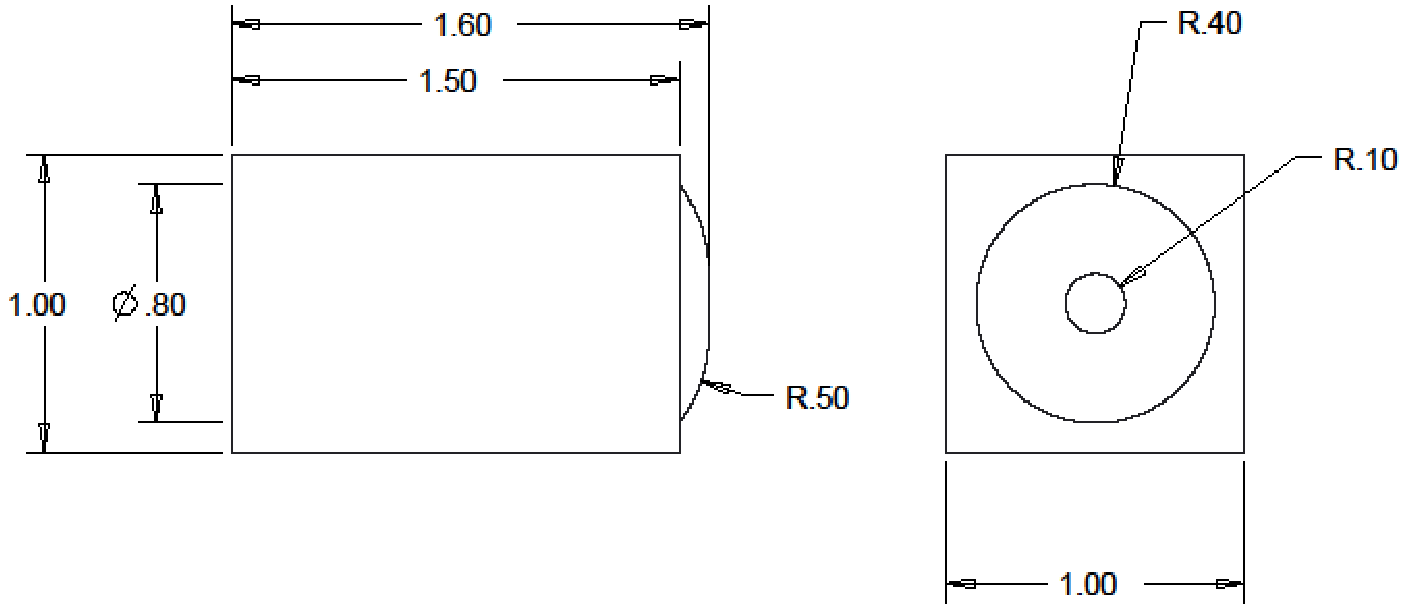
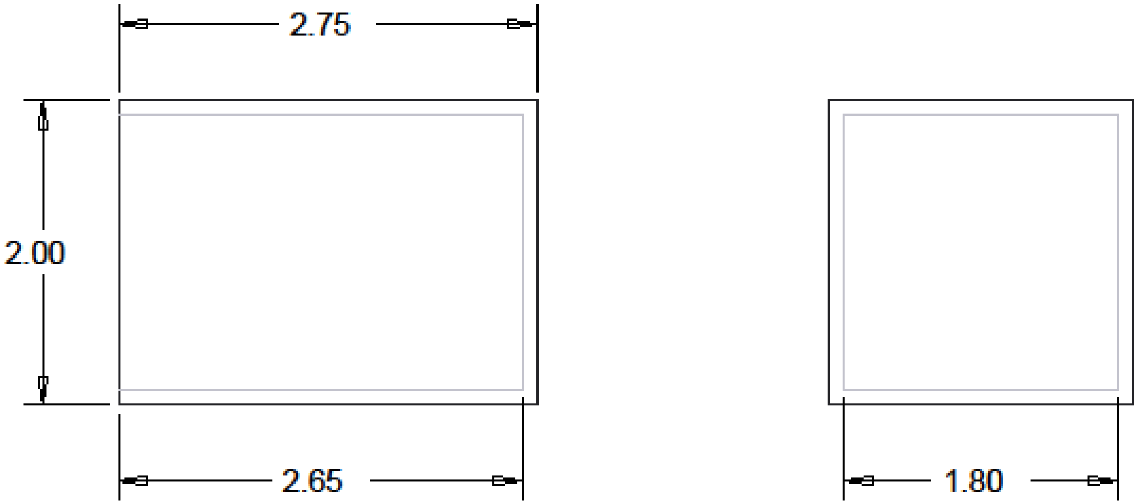


UNLESS OTHERWISE SPECIFIED	PROJECT		PART NAME
DIMENSIONS IN INCHES TOLERANCE ± 0.005	PAN AND TILT		MOTOR
	DRAWN BY	PART NUMBER	REV
	TEAM 21	2	1
	SCALE	DATE	SHEET
	3.000	23 OCTOBER, 2014	2 OF 5

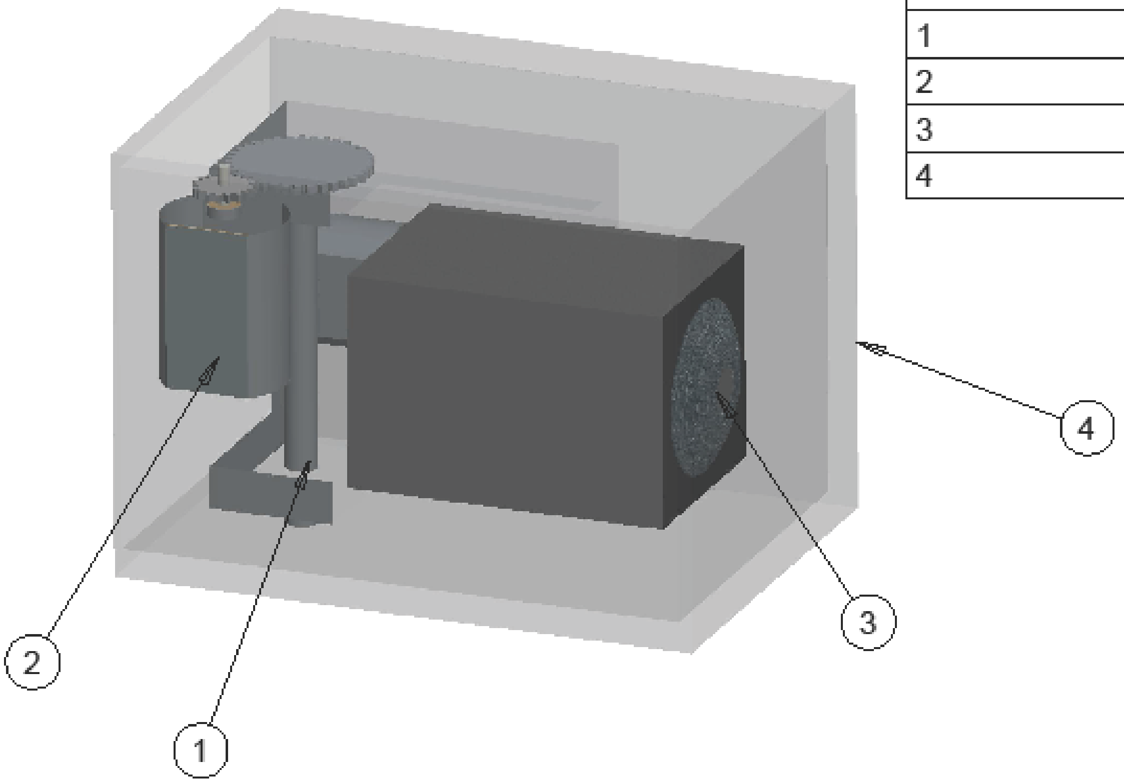


UNLESS OTHERWISE SPECIFIED	PROJECT PAN AND TILT		PART NAME CAMERA	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	DRAWN BY TEAM 21		PART NUMBER 3	REV 1
	SCALE 2.000	DATE 23 OCTOBER, 2014	SHEET 3 OF 5	

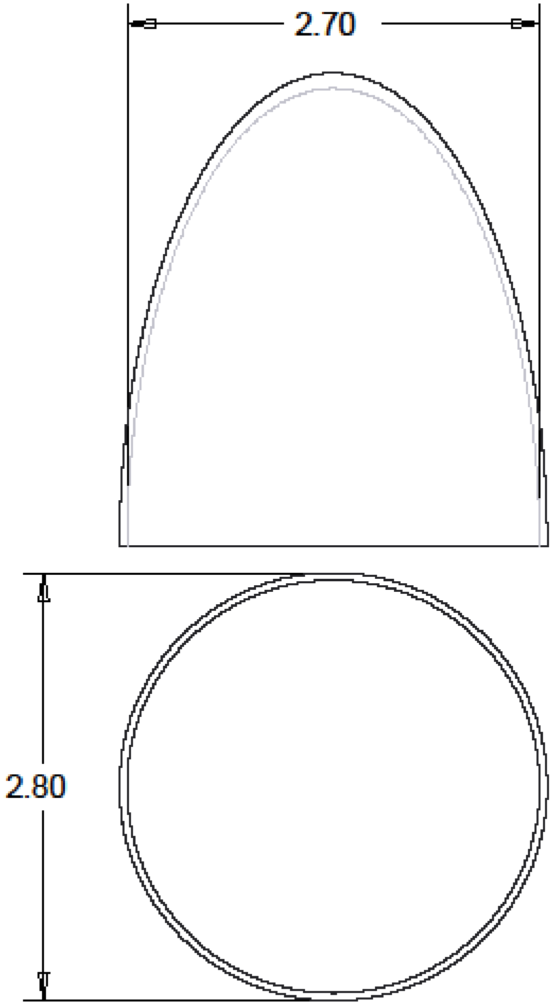


UNLESS OTHERWISE SPECIFIED	PROJECT		PART NAME	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	PAN AND TILT		CASING	
	DRAWN BY		PART NUMBER	REV
	TEAM 21		4	1
	SCALE	DATE	SHEET	
	1.000	23 OCTOBER, 2014	4 OF 5	

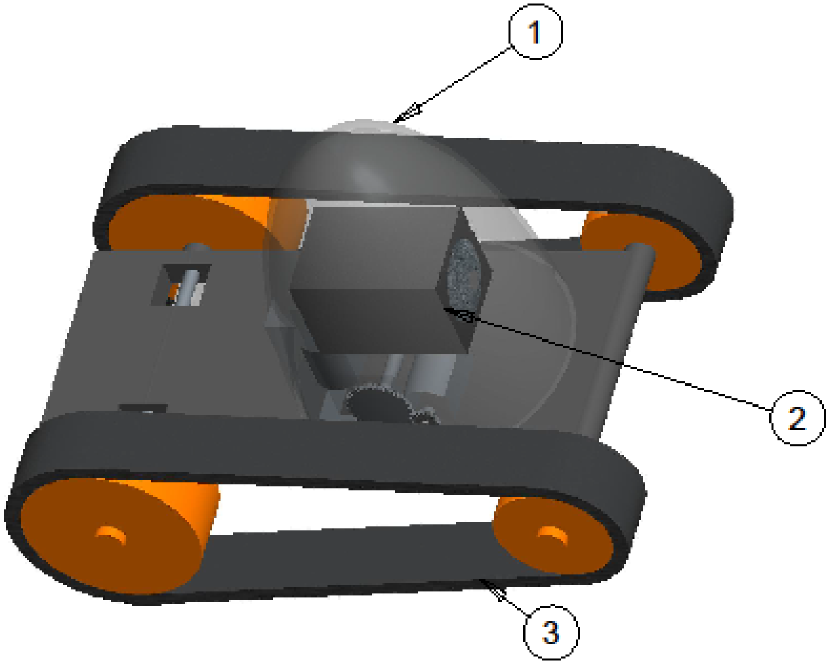
NUMBER	PART
1	GEAR MECHANISM
2	MOTOR
3	CAMERA
4	CASING



UNLESS OTHERWISE SPECIFIED	PROJECT PAN AND TILT		PART NAME ASSEMBLY
DIMENSIONS IN INCHES TOLERANCE ± 0.005	DRAWN BY TEAM 21	PART NUMBER 5	REV 1
	SCALE 1.500	DATE 23 OCTOBER, 2014	SHEET 5 OF 5



UNLESS OTHERWISE SPECIFIED	PROJECT	PART NAME	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	BUBBLE CAMERA	TURRET CASING	
	DRAWN BY	PART NUMBER	REV
	TEAM 21	1	1
	SCALE	DATE	SHEET
	1.000	23 OCTOBER, 2014	1 OF 2



NUMBER	PART
1	TURRET CASING
2	CAMERA SYSTEM
3	PLAIN CHASSIS

UNLESS OTHERWISE SPECIFIED	PROJECT	PART NAME	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	BUBBLE CAMERA	CAMERA ASSEMBLY	
	DRAWN BY	PART NUMBER	REV
	TEAM 21	2	1
	SCALE	DATE	SHEET
	1.000	23 OCTOBER, 2014	1 OF 2

A-3 MATLAB calculations for design analysis

```
%Motor Torque Calculations for Rover
clc
clear all


mass_max = .05; %kg
distance_max = .02; %m

M = mass_max*9.81*distance_max;


Y = ['Maximum Moment Caused by Camera and Mounting: ', num2str(M)];
disp(Y)

for i=1:1:2
H = input('Enter Motor Power in W ');
d = input('Enter wheel diameter in mm ');
w = input('Enter rotational speed in rpm ');
Wt = 60000*H/(pi*w*10);
T = (d/2)*Wt;
disp(' ')
X = ['Torque ' num2str(i),' = ', num2str(T)];
disp(X)
disp(' ')
disp(' ')


end
```

```
Maximum Moment Caused by Camera and Mounting: 0.00981

Enter Motor Power in W 5.94

Enter wheel diameter in mm 10
```

```
Enter rotational speed in rpm 12530


Torque 1 = 4.527

Enter Motor Power in W 8

Enter wheel diameter in mm 10

Enter rotational speed in rpm 300


Torque 2 = 254.6479
```