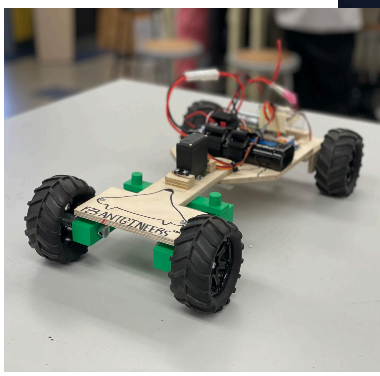

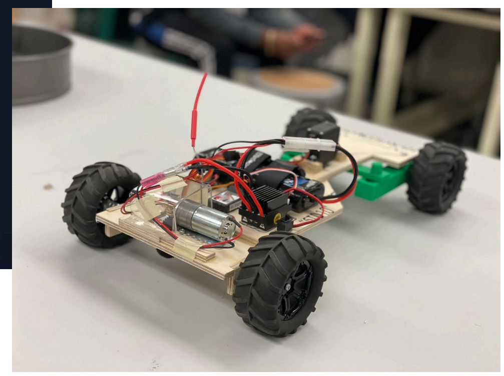

<u>**The Antgineers:**</u>

Kaden Dadabhoy
Aras Vakilimafakheri
Eric Wen-Jie Hsiao
Karlos Miguel Taluban
Robert Joshua Esqueda
Abdullah Al Halwan

ENGR 7A: Introduction to Engineering, University of California, Irvine

Fall 2023

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Executive Summary

During the Fall quarter of 2023, our team, the Antgineers, embarked on a 10-week journey to design, build, and test a remote-controlled rover from scratch. Our mission was not only to construct a rover that complied with size and safety requirements, but also to compete against 56 other teams in a race to complete a predetermined track in the fastest time.

The main objective that our team set was to build a functional and compliant rover that could set a competitive track time. Since the majority of us also had little to no experience in CAD (Computer Aided Design) or fabrication, we also set a goal to act as sponges and absorb as much as possible in the quarter.

Our project began with a simple hand-drawn sketch of our rover's chassis. Our initial design was a combination of a rectangle and a triangle, with a basic layout for electronics and a rudimentary steering concept. This sketch, although flawed, was pivotal in aligning our team's vision, laying the groundwork for future modifications and CAD modeling.

The process of designing the rover in SolidWorks was significantly more challenging and time-consuming than we initially expected. When we were about halfway through our CAD, we realized that our initial steering design was impractical, risking damage to the servo motor due to excessive weight. Essentially, we were back to square one. However, after an abundance of brainstorming and proof-based modeling, related to steering systems, we ended up deciding to implement a unique concept that utilized cylinders and slots. Additionally, as the steering design changed, the CAD was further adapted. Most notably, the steering system required the implementation of a Chassis Extension piece, which increased the overall length to be right under the constraint of 16 inches. The rover also needed the gears in the rear to be lowered, and required larger tires in order to get sufficient ground clearance. From the time that we started modeling that initial rough sketch, to the time we finished the CAD, the rover's chassis was split into three core subassemblies, which we named: the Rear Drivetrain Chassis, the Main chassis, and the Chassis Extension. The overall look of the rover ended up resembling a longboard. From our first CAD based, off of the rough sketch, to the final CAD, we were constantly changing and editing a lot of the parts.

The fabrication of the rover along with the assembly of the electronics was fairly straightforward. The chassis was fabricated out of birch plywood, since it is light, strong, and easy to work with. The steering mechanism was 3D printed, since it is an intricate design and difficult to fabricate. The gear guard was fabricated out of polycarbonate, since it is light, bendable, and easy to attach. During fabrication, we only ran into two issues. One being a faulty ESC (Electronic Speed Controller) that needed to be replaced. The other issue being that the screws provided to us could not penetrate our chassis, preventing us from being able to mount the servo. We overcame this problem by buying pointed screws that could penetrate our chassis.

While testing the rover, we realized the turn radius of the steering system did not meet our expectations. With the submission deadline approaching, we had no time to make the appropriate adjustments to set a competitive track time. However, we realized that we were able to get around the track if we just made a lot of three-point turns. The other issue was that our rover struggled with ramp clearance, which we addressed by creating a semicircular clearance guard for smoother traversal.

Due to our steering not being up to par, our lap times were not competitive. We ended up placing 49th (out of 56). Therefore, we did not complete all parts of our main objective. We did, however, complete our subgoal of learning a lot. We believe the rover would have been a lot more competitive if we had time to fix our steering mechanism; however, we also acknowledge that our rover is simply too long to compete for the fastest lap time.

Problem Definition

Introduction

This design project served as an introduction to the essentials of engineering design processes for all of us. The project's primary objective was to design, build, and test a remote-controlled (RC) rover while adhering to certain constraints. This task challenged us to bridge the gap between theoretical ideas and practical application, be it in manufacturing a conceptual steering mechanism or making design choices based on practical benefits. The ability to continuously make that connection is an essential tool to acquire in our journey as aspiring engineers. The project was framed around specific deliverables, including the RC rover construction (both preliminary and final), a comprehensive bill of materials, preliminary and final Gantt charts, and an oral presentation.

The central goal of our team was to transition from having minimal practical experience in design and fabrication to successfully delivering a fully functional, competitive RC rover. This endeavor presented a multifaceted problem: not only did we need to develop technical skills in areas like CAD modeling and fabrication, but we also had to cultivate effective teamwork and collaboration for the duration of the project. These challenges were critical to address, as they were fundamental to the success of our rover and project as a whole. More importantly, learning how to address these challenges is essential to our ability to perform on any engineering project, particularly as professionals in the field.

Technical Review / Background

From a historical standpoint, rovers have been designed to be planetary exploration devices that aim to gather information from other planets. Though, in a broader context, manual and autonomous rovers have been associated with the field of engineering in which mechanical devices transport goods, objects, people, or themselves between locations. Early rover designs, which mainly pioneered the concept of remote control vehicles on Earth, were initially engineered to be used by the U.S. military during the start of World War II. Following the era of World War II, rover technology was then applied to the realm of consumerism, with the rise of remote control rovers as a hobby and pastime during the 1960s. From this, advancements in mechanics lead to the dispatchment of the Soviet Unions' *Lunokhod 1* in 1970, which became the first robotic rover on the moon, marking a historic achievement in engineering. From the 21st century onwards, rovers have found their place in various industries, spanning from construction, to agriculture, to mining, acting as a technological marvel that aims to improve their respective fields.

During the design and construction phases of our own rover, our team conducted extensive research regarding the possible parts and electronics we could choose to implicate into our rover. Some notable design ideas we integrated during this phase would be the choice of a 52 tooth gear for our rover's rear drive train system. This decision was made by taking into account the benefits and downfalls of implementing various toothed gears into our rover's system and how each choice would affect the rover's final performance, including its overall speed and its overall torque. This led to our decision of a 52 tooth gear. This gear enables a compromise of both speed and torque, without sacrificing too much of one for the other. Another prominent mechanical design choice our team made was to integrate an Ackerman steering system. This choice was made after researching different steering linkage designs, which included a rack and pinion system, parallel system, or Ackerman system. We selected to implement a four bar linkage design, which ideally lead to an ease of fabrication, allows for a smaller turning radius, and avoids tire skidding. Furthering our research regarding our steering system, we decided to 3D print the entirety of our system due to its complex nature that would be hard to fabricate with traditional tools. Though, the main chassis of our rover was constructed out of plywood that our team fabricated, which we chose for its strength to weight ratio, meaning it would allow for our rover to have minimal weight while also being able to support its core mechanical and electrical components. The final choice our team made is the use of 85mm wheels, which allowed for higher clearance from the ground, and for better overall stability. This was implemented with the goal of clearing the course set out for our rover, which would require moderate ground clearance in order to traverse its obstacles. All of these small choices together, influenced by our research, defined our rover.

References:

Howell, Elizabeth. "Lunokhod 1: 1st Successful Lunar Rover." Space.Com, Space, 20 Dec. 2016, www.space.com/35090-lunokhod-1.html

Adam, TTPM. "The History of the R/C Car." TTPM, 14 Mar. 2016, ttpm.com/the-history-of-the-rc-toy-infographic/

Design Requirements

Our rover had to comply with certain requirements, including:

Cost and Structural Requirements:

- ➔ Our rover had to comply with these cost & structural requirements:
    1. The overall width of the rover must be shorter than 10 inches, and the overall length of the rover must be shorter than 16 inches.
    2. The rovers must be fully designed and fabricated by our team.
    3. The use of any premade chassis, steering mechanisms, or individual linkage components was prohibited.
    4. We are allowed to use raw materials and/or 3D printing.
        a. The total cost of the rover including 3D printing must not exceed $275.
        b. The total cost of the rover without 3D printing must not exceed $250.

Electrical Requirements:

- ➔ Our rover had to comply with these electrical requirements:
    1. Our rover must be able to operate for at least 10 minutes without needing to recharge.
    2. Our rover must have an easily accessible on/off switch.
    3. The battery must be easily removable from the rover.
    4. The use of an internal combustion engine is prohibited.

Safety Requirements:

- ➔ To prevent a dangerous environment and avoid injuries, our rover had to comply with these safety requirements:
    1. The rover must have a gear guard for protection against unwanted contact with the gears when in motion.
    2. The rover cannot have any protruding sharp objects, and all corners of the rover must be dull.

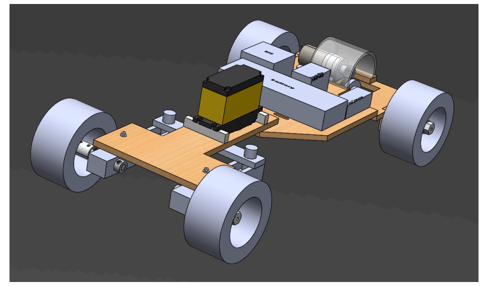
3. All wires must be neatly arranged and away from any moving parts. The wires and connectors must also be completely covered and insulated to avoid any electrical issues.

Project Deliverables:

- ➔ Our team had to produce certain deliverables throughout this project:
  1. A functional RC rover that complies with the requirements and can complete the course.
  2. A Bill of Materials, which is essentially a parts list where all the parts, the quantities, and the total cost, are listed.
  3. SolidWorks drawings of the entire rover.
  4. A Preliminary Presentation, where we presented the progress we have made, at around the halfway point of the project.
  5. A Final Presentation, where we presented the project as a whole, including the timeline, the SolidWorks drawings, the strengths, the drawbacks, our struggles, etc.
  6. A Final Design Report, where all aspects of the project are displayed and explained clearly and understandably.

Design Description

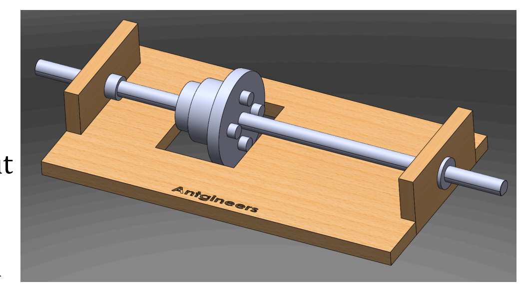
Summary of Design



The final CAD of our rover is pictured to the right. Our rover changed significantly from our preliminary designs to what we put on the track. Ultimately, our rover design was reduced down to three subassemblies, which we called: Rear Drive Train, Main Chassis, and Steering. The rover in its final form stands at 9.50 x 15.95 inches, putting us just below the dimensional constraint. It also satisfies safety requirements, as all edges were sanded down to ensure the safety of any user. Furthermore, to prevent accidents involving the gears in the Rear Drive Train, a gear guard was fabricated. Using SolidWorks, we were able to find the center of gravity at ≅ 4.64 inches in the x-direction (width) and ≅ 6.81 inches in the y-direction (length), when the furthest back and furthest left corner (the back left wheel, by the buck converter) of the rover was mated as the origin of the assembly file. Having run some manual calculations using the masses of the various components of our rover, we concurred that the SolidWorks calculations were a good estimate of the actual center of mass. This comes to no surprise as the majority of our rover's weight is in the rear end due to our electronics configuration.

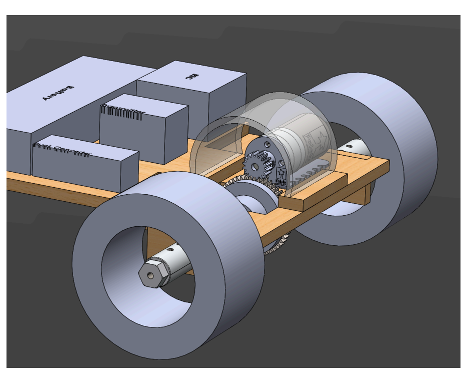
As a team, we made some design choices based on theoretical benefits. The most important of these included selecting the 85mm wheels for greater ground clearance on our rover, as well as the 52 tooth gear in order to sit in the perfect medium between torque and linear speed.

Rear Drive Train



The purpose of a rear-wheel drive system is to deliver the power from the engine, in our case the motor, to the rear wheels, which in turn push the car forward. Our Rear Drive Train (RDT) subassembly shares the same innate design as an assembly that we had built as a part of our homework. However, we made some modifications, making it fully integrable to our rover design. The modifications include a larger cut out for our gear mount as well as the gear itself. As well as some dimensional changes to the platform and axle mounts which gives more bottom clearance on the rover, along with more space for the motor and gear guard. The RDT's skeletal CAD is pictured to the right.

Our RDT serves as the host for our motor, gear guard, drive gear, and pinion gear. The pinion gear on the motor forms a gear ratio with the fifty-two tooth gear on our 8-inch D-shaft, which applies the torque needed to move the rover forward. The full subassembly, with the electronics, gear guard, and wheels, is pictured below:

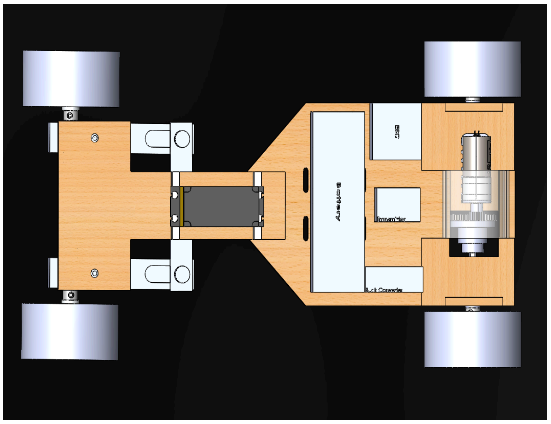


The main reason behind separating our RDT from the main chassis was to remedy a wheel height imbalance that we had initially. However, this decision later was shown to be even more worthwhile, as it made the fabrication process much easier. Almost like the idea of interchangeable parts, when it comes to industrial materials, having our RDT separate from the main chassis meant that we could make changes and substitutions to certain parts much more efficiently and quickly. The whole subassembly was ultimately attached to the main chassis via wood glue.

Main Chassis

The portion of the rover that we like to call the Main Chassis is pictured to the right. It was originally conceived to be one longboard style piece, but was reduced down to the arrow shaped piece that is displayed. This change in design was done, as previously discussed, mainly to remedy an imbalance in the wheel heights. However, much like the RDT subassembly, it proved more useful to have the Main Chassis be separate from the RDT and Steering subassemblies, as it made working on those two much easier.

The main chassis serves as the host of most of our rover's electronic components. The four slots in the middle of the design holster velcro belts that keep the battery in place while the rover is in motion. As shown below, our ESC, Receiver, and Buck Converter are aligned horizontally behind the battery. This placement of electronics made the most sense for our design and solved our wire management problems, as we were able to comfortably place loose wires on the chassis using tape and zip ties, making our rover neat and tidy. The Main Chassis was attached to the Steering and RDT subassembly via wood glue. The final CAD of the Main Chassis (in the complete rover assembly) is shown from a bird's eye view below:

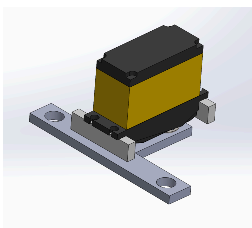


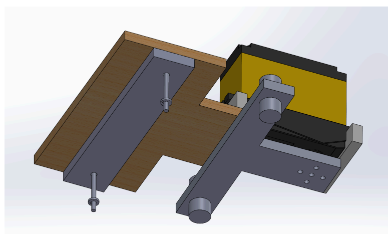
Steering

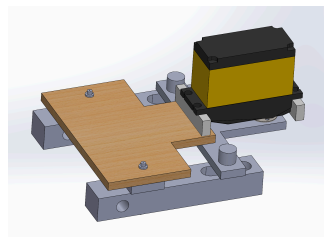
The goal of any steering mechanism is to transfer rotational motion from one source, into motion that turns two wheels. Our goal aimed for that, and more. Our steering design is as an Ackerman steering system, with a four-bar linkage design. The goal of an Ackerman steering system is to achieve a turn radius that does not involve sliding the wheels along the ground, unlike a parallel steering system. The parts that move and make up the steering are all 3D printed out of ABS plastic.

To achieve an Ackerman steering system, a T-shaped link connected to the servo, henceforth referred to as the "servo-link", is needed to achieve uneven steering. The servo link would rotate and cause two other links that the wheels are attached to turn, henceforth referred to as "wheel links". By the nature of the servo link's T-shape, and the nature of circular motion, this would cause uneven steering to occur. The servo link rotates on the tail end, and due to that, one side of the link becomes closer to the wheels, the point of revolution, as it rotates. Although, with this, it becomes hard to make adjustments to desired specifications as at any one point, there are three points of revolution in the steering system, each with various and fluctuating rates of change.

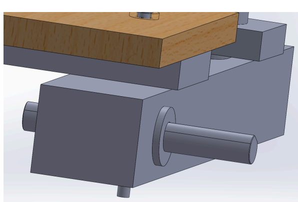
To assemble the steering, you must first screw in the servo link to the servo horn. There are five holes perfectly aligned to do the job, and you must orient the servo link with the horizontal part of the T facing forward. Next, a flat and straight link, dubbed the chassis link, aligns into the chassis holes all the way at the front end of the chassis extension. The chassis link only serves to be an anchor and a spacer for the wheel links. After the chassis link, and the wheel links are aligned to their respective left and right screw holes, where the wheel links are facing slot-side up, and the servo link is slotted in. Then you can begin screwing the wheel links to the chassis. After that is done, the steering system is complete, and all that is needed is the attachment of the wheels.

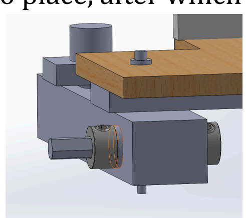

Servo-link attached.

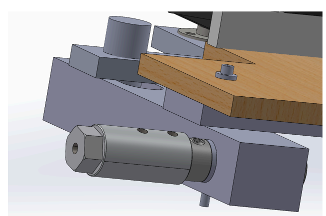

Straight link screwed into chassis.

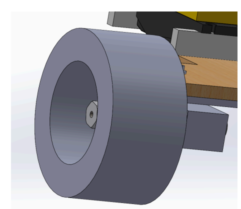

Wheel links screwed and slotted in.

The attachment of the wheels begins inserting the sleeve bearings into the .38 inch diameter holes on the sides of the wheel links. Then the 2 inch drive shafts should be inserted into the sleeve bearings such that a screw shaft collar can be attached on the “inward” portion of the drive shaft. Two shaft collars should be screwed onto the drive shaft at each opposing side to lock the shaft in place. After that, a shaft hub should be slipped in and screwed onto the “outer” side of the shaft. This is where the wheel will be attached. There should be a hexagonal shoot for the hexagonal protrusion of the collar hub for the wheel to slip into place, after which a screw should be able to lock both into place.


Sleeve and shaft inserted.


Shaft collars screwed on.

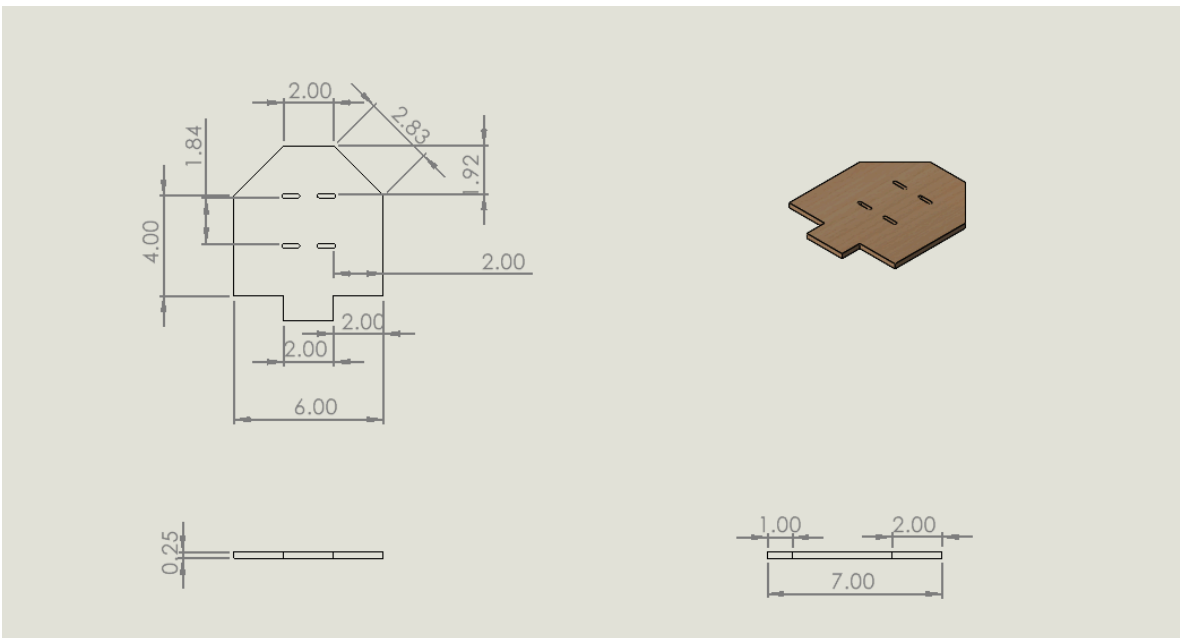

Shaft hub screwed on.


heel screwed on.

Design Details

Main Chassis Design Details

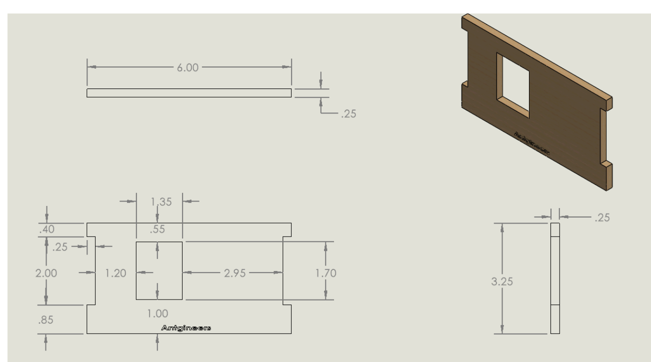
The main chassis is fabricated using one piece of birch plywood, which was cut down to our desired design. The plywood available to us was ¼ of an inch thick, and therefore our main chassis is the same thickness. It is 6 inches in width and 7 inches in length, featuring slots that begin 1.92 inches from the front with 1.84 inches between them and are 2.0 inches from the back. The back also includes a fishtail cutout that is 2 inches wide and 1.0 inch in length. The front side features two diagonal cutouts, each 2.83 inches in length and about 30 degrees from the front horizontally. The drawing for the piece is pictured below:



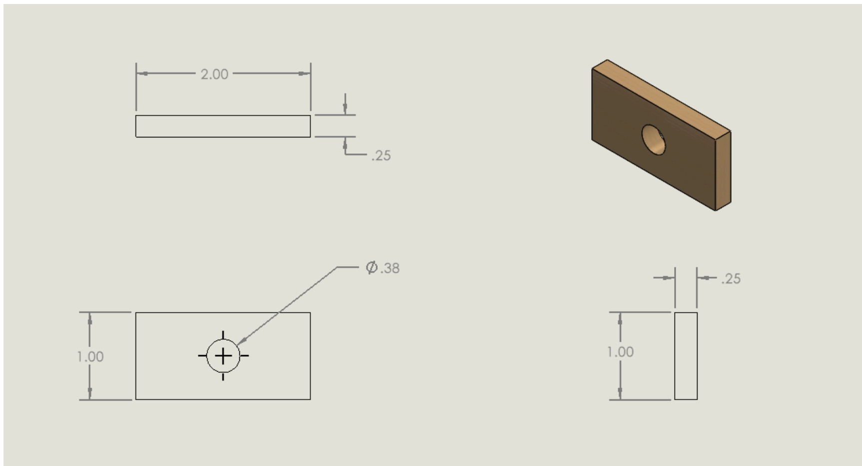
Rear Drive Train Design Details

The Rear Drive Train (RDT) has two main structural features: the platform and two axle mounts.

The platform is also made entirely out of birch plywood and cut using machinery to mimic our desired design. Given it is one singular sheet of plywood, it has a thickness of 0.25 inches, exactly the same as that of the main chassis. It is 6 inches in length and 3.25 inches in width. The platform features a 1.7 inch by 1.35 inch cutout in the middle. This cutout serves the function of allowing our drive gear and the gear's mount to elevate through the platform. This allowed us to solve two major problems, our imbalance in wheel heights as well as bottom clearance for ramp and cone traversal. The platform also includes two slit cutouts on either side that are used to house the axle mounts. The SolidWorks drawing of the platform is pictured to the right.



The two identical axle mounts are arguably the most simple in design. Made entirely out of birch plywood, they share the same thickness as the platform and main chassis. They are 2 inches in length and 1 inch in width, featuring a 0.38 inch diameter circular cut out in the center. Although simple in design, they serve the purpose of holding our 8 inch driveshaft in place, a key component in the functionality of our rover. The drawing for the part is included below:

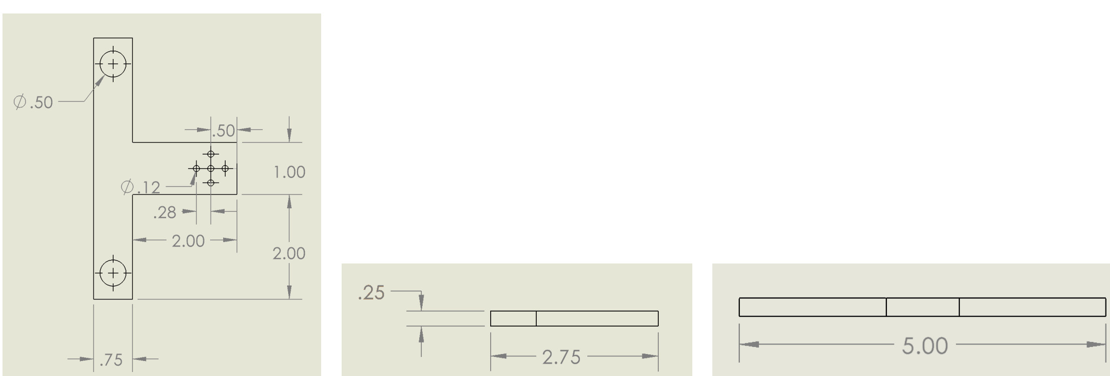


Our Rear Drive Train takes heavy inspiration from the assembly that we were tasked with modeling and fabricating during the first few weeks of instruction. Our main reasoning behind the minimal change in design came down to our comfort with being able to replicate something we already had experience building. Overall, this subassembly proved as functional as we expected.

Steering Design Details

The Steering is made out of 4 main unique components: a T-shaped Servo Link, a Wheel Link, a cylindrical Rotator Piece, and a Chassis Link.

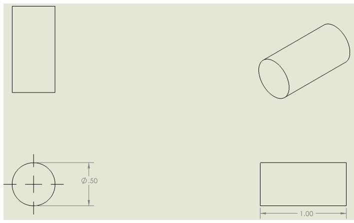
The Servo Link is 2.75 inches long by 5 inches wide in total. When laid flat on a surface, it is about 0.25 inches tall. The horizontal segment of the T shape is 0.75 inches wide. On each end is a 0.5 inch diameter hole, with the center of the hole being 0.5 inches away from their respective end segments. The tail end of the Servo Link is about 1 inch wide, and 2 inches long. At the tail end are five 0.12 in. diameter holes, with one at the center, and four in a circular pattern around the center. The center hole's center is 0.5 inches away from the end of the link, and from the sides too.



Servo link's dimensions top, front and right sides respectively.

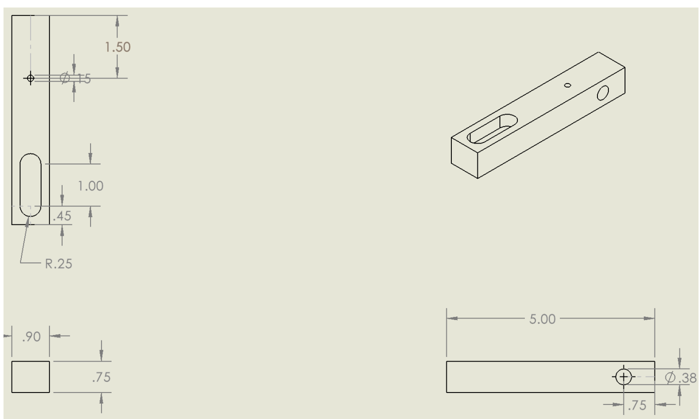
The Rotator Piece is a cylinder that is 0.38 of an inch in diameter, is 1 inch long, and fits into the 0.38

of an inch diameter holes on the Servo Link.



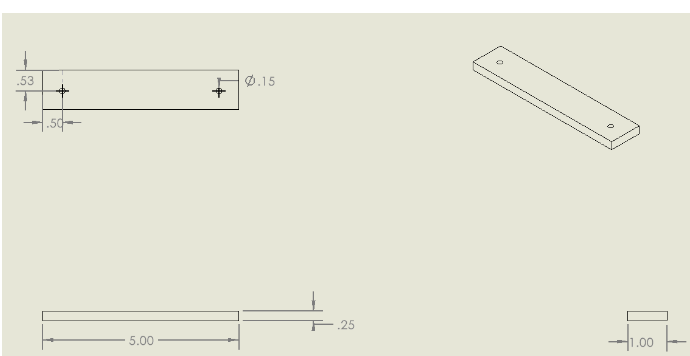
Rotator piece

The Wheel Links are rectangles that are 5 inches long by 0.9 of an inch wide by 0.75 of an inch tall. At the top side of the link, there is a 1.5 inch long slot, from the top to the bottom. The semicircle segments at each end of the slot is 0.25 of an inch in radius. The center of the radius of the “bottom” semicircle is 0.45 of an inch away from each side. On the same side, there is a 0.15 inch screw hole centered 1.5 inches away from the top end of the link. Finally, at the left and right side of the link is a 0.38 of an inch in diameter through hole, centered 0.75 of an inch away from the end, and 0.45 of an inch away from the other sides.



Wheel link dimensions

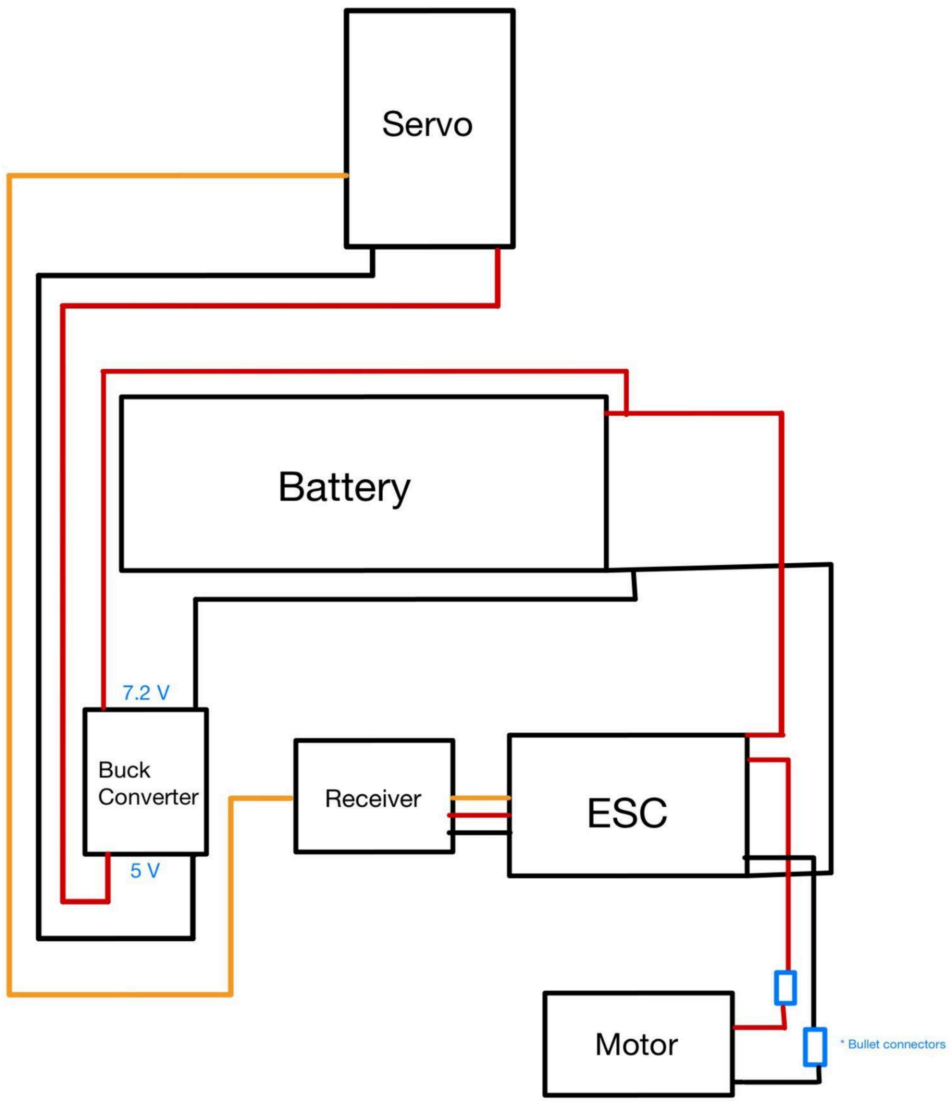
Lastly is the Chassis Link, which is just 5 inches long by 1 inch wide by 0.25 of an inch tall rectangle. At each end is a 0.15 of an inch screw hole. The screw hole is centered 0.5 of an inch away from their respective ends, 0.53 of an inch from one side, and 0.47 of an inch from the other side.



Chassis link

Wiring Diagram

The wiring diagram for our rover is presented below. Positive wires are denoted in **red**, while negative wires are denoted in **black**. Signal wires are labeled in **orange** on the diagram. This diagram below provides an accurate representation of the electronic component placement on our rover:



To receive both power and signals, the servo motor is connected to the buck converter and the receiver, respectively. The buck converter is essential because it takes the 7.2 volts that the battery produces, and converts it into 5 volts, which the servo requires to operate. For the brushed motor, the ESC is utilized for both power and speed control. The receiver acts as a link between the servo and the ESC-controlled motor, enabling the operator to manage the rover's turning and speed. To power the ESC and subsequently the motor, the battery is directly attached to the ESC. This configuration ensures efficient and coordinated operation of the rover's electronic components.

Action Item Report

Task Assignment

During week one, our team established that from week two onwards, we would meet in the Science Library, every Tuesday at 11am. During these weekly meetings, we would complete any group related task, figure out solutions to problems we encountered, and set or modify our timelines. Additionally, every week Kaden, the Team Lead, sent a weekly overview, in our group chat, that consisted of important dates, tasks, sign-ups for open labs, goals, etc.

Listed below is the Action Item Report from each week:

- **Week 2**
  1. We finalized each person's main role and sub-role(s).
     a. **Team Lead** - **Kaden**
     b. **CAD** - **Aras (Lead)**, **Karlos (CAD Steering Lead)**, & Kaden
     c. **Fabrication** - **Eric (Lead)**, Kaden, Aras, Karlos, Robert, & Abudllah
     d. **Electronics** - **Eric (Lead)** & Karlos
     e. **Research** - **Robert (Lead)**, Kaden, Eric, & Abdullah
     f. **Budgeting** - Robert & Abdullah
  2. We started our initial research.
  3. We started brainstorming the Initial Rover Layout Idea.
- **Week 3**
  1. We completed the sketch of the Initial Rover Layout Idea.
  2. We completed our initial research.
  3. We started on the Solidworks CAD.
- **Week 4**
  1. We completed & submitted the P.O. form.
  2. We brainstormed steering concepts.
  3. We continued working on the Solidworks CAD (chassis).
- **Week 5**
  1. We picked a steering concept to base our CAD on.
  2. We continued working on the Solidworks CAD (chassis & steering).
- **Week 6**
  1. We finished the initial SolidWorks Drawings/Assemblies (chassis & steering).
  2. We revised the steering CAD, due to concerns about the initial design snapping.
- **Week 7**
  1. We revised the chassis CAD, in order to be more practical to fabricate.
  2. We submitted a 3D Printing Request for our Steering Mechanism.
  3. We started the chassis fabrication and steering assembly.
- **Week 8**
  1. We finished up the chassis fabrication and steering assembly.
- **Week 9**
  1. We started and completed the assembly of the Electronics.
  2. We started and finished the fabrication of a Gear Guard.
  3. We started Testing & Tuning.
  4. We fabricated and implemented a Clearance Guard.
  5. The rover was completely done.
  6. We started on the Final Presentation's PowerPoint.
- **Week 10**

1. We set a track time with our rover.
2. We finished the Final Presentation's PowerPoint.
3. We started on the Final Design Report.

- ➔ **Finals Week**
    1. We presented our Final Presentation.
    2. We finished the Final Design Report.

Gantt Chart

Weeks 1-5 (Finals Week)

Antgineers
Thursday 1-2:50pm

Planned | Actual | Due Date

Activity	Planned Start	Planned End	Actual Start	Actual End	Week 1	Week 2	Week 3	Week 4	Week 5
Team Formation	W = Week								
Team Name & Captain Chosen	W1	W2							
Rover Design	W2	W4	W3	W4					
Determine Rover Layout	W2	W4	W3	W3					
Select Gear Ratio	W3	W4	W4	W4					
Purchase Order Form	W3	W5	W4	W4					
SolidWorks Part Designs	W3	W4	W4	W4					
SolidWorks Assembly	W3	W6	W4	W6					
SolidWorks Detailed Drawings	W3	W6	W6	W6					
Structure Fabrication	W7	W8	W7	W8					
Wheels System	W7	W8	W7	W8					
Motor Mount	W7	W8	W7	W8					
Gear Guard	W7	W8	W8	W9					
Battery holder	W7	W8	W7	W8					
Steering System	W7	W8	W7	W8					
Structure Assembly	W7	W7	W7	W8					
Electrical System	W7	W8	W8	W10					
Mount & Connect Electronics	W7	W8	W8	W9					
Remote Control Tuning for Motor	W8	W9	W10	W10					
Remote Control Tuning for Servo	W8	W9	W10	W10					
Steering System Testing	W8	W9	W8	W10					
Test and Evaluation	W8	W9	W9	W10					
FINAL COMPETITION	W10	W10	W10	W10					
Action Item Reports									
Preliminary Presentation									
Final Presentation									

Weeks 6-10

Antgineers
Thursday 1-2:50pm

Planned | Actual | Due Date

Activity	Planned Start	Planned End	Actual Start	Actual End	Week 6	Week 7	Week 8	Week 9	Week 10
Team Formation	W = Week								
Team Name & Captain Chosen	W1	W2							
Rover Design	W2	W4	W3	W4					
Determine Rover Layout	W2	W4	W3	W3					
Select Gear Ratio	W3	W4	W4	W4					
Purchase Order Form	W3	W5	W4	W4					
SolidWorks Part Designs	W3	W4	W4	W4					
SolidWorks Assembly	W3	W6	W4	W6					
SolidWorks Detailed Drawings	W3	W6	W6	W6					
Structure Fabrication	W7	W8	W7	W8					
Wheels System	W7	W8	W7	W8					
Motor Mount	W7	W8	W7	W8					
Gear Guard	W7	W8	W8	W9					
Battery holder	W7	W8	W7	W8					
Steering System	W7	W8	W7	W8					
Structure Assembly	W7	W7	W7	W8					
Electrical System	W7	W8	W8	W10					
Mount & Connect Electronics	W7	W8	W8	W9					
Remote Control Tuning for Motor	W8	W9	W10	W10					
Remote Control Tuning for Servo	W8	W9	W10	W10					
Steering System Testing	W8	W9	W8	W10					
Test and Evaluation	W8	W9	W9	W10					
FINAL COMPETITION	W10	W10	W10	W10					
Action Item Reports									
Preliminary Presentation					During Each Lab				
Final Presentation									

Evaluation

Calculations

Mass/Weight:

Mass = $(.2302kg + .3063kg + .2035kg + .1939kg)$ **= .9339kg = 2.059lbs**

- The mass was measured using a scale.

Weight = $(.2302kg + .3063g + .2035kg + .1939kg) * 9.81m/s^2$ **= 9.162N**

Predicted Drive Time:

$Current\ Draw\ of\ Servo\ @\ 6\ Volts\ =\ 2.5A$

- (https://components101.com/motors/mg996r-servo-motor-datasheet)

Our Servo operates at 5 Volts, so we need to use P=IV to solve for this value.

$P\ =\ 2.5A\ *\ 6V\ =\ 15\ Watts$

$Current\ Draw\ of\ Servo\ @\ 5\ Volts\ =\ \frac{Power}{Volts} = \frac{15\ Watts}{5\ Volts} = 3A$

$Current\ Draw\ of\ Motor\ =\ 5A$

- (https://www.pololu.com/product/3201)

$Battery\ Capacity\ =\ 3600mA\ *\ h\ *\ (\frac{1A}{1000mA})\ =\ 3.6A\ *\ h$

$Total\ Current\ Draw\ =\ Current\ Draw\ of\ Motor\ +\ Current\ Draw\ of\ Servo\ @\ 5\ Volts$

Predicted Drive Time = $\frac{Battery\ Capacity}{Total\ Current\ Draw} = \frac{3.6A*h}{(5+3)A} = .45h * \frac{60\ mins}{1\ h}$ = **27 mins**

Mechanical Advantage Discussion:

The reason the gear choice matters, is due to the concept of Mechanical Advantage. Mechanical Advantage is a number that is calculated by dividing the teeth of the driving gear by the teeth of the driven gear. A larger Mechanical Advantage will have more torque and less speed, while a smaller Mechanical Advantage will have more speed and less torque.

Stall Weights & Torques:

The stall weights, torques, and mechanical advantages for each gear are listed below:

Output Gear # of Teeth	Input Gear # of Teeth	Gear Ratio (Mechanical Advantage)	Output Stall Mass (kg)	Output Stall Weight (N)	Output Stall Torque (N*m)
52T (Our Gear)	16	3.25	**2.013**	**19.74753**	**0.3134920388**
40	16	2.5	1.749	17.15769	0.2723783288
64	16	4	2.795	27.41895	0.4352758313

- cccc

Reasoning for our Gear Choice:

When choosing a gear, we realized that our rover was going to be quite heavy, so that meant that we needed a large mechanical advantage in order to support our rover. Therefore, we immediately ruled out the 40 tooth gear as it had the smallest mechanical advantage, of only 2.5. We then ruled out the 64 tooth gear because we reasoned that the increased torque is not worth the tradeoff in speed. Furthermore, we chose the 52 tooth gear because we were able to get enough torque for our rover, while not sacrificing too much speed.

Turning Radius:

$$Turning\ Radius\ =\ \frac{Wheel\ Base\ Length}{tan(angle\ of\ turn)} = \frac{Wheel\ Base\ Length}{\left(\frac{Triangle\ Leg\ of\ Fully\ Turned}{Triangle\ Leg\ when\ not\ Turned}\right)} = \frac{13.50in}{\left(\frac{(1/44)in}{2.03125in}\right)} = 1206.56in$$

$$1206.56\ in * \frac{1ft}{12in} = 100.55ft$$

- ❖ We found the lengths of a leg's of the triangle by using three rulers. One ruler was parallel to the wheels when they were unturned, and one ruler was parallel to the wheels when they were fully turned, and the third ruler was used to measure the distance between the first and second rulers. We only recorded the measurements of the first and third ruler, being (2.03125 inches and (1/44) inches, respectively).

Test Plan

In summary, we used SolidWorks to design the components of the rover, ensuring precision in our measurements. Simple calculations and simulations were performed for critical parts, including the steering mechanism. The steering radius was a significant concern both before and during fabrication. We discussed potential adjustments with our TA to address this issue. Despite being functional in simulations, the steering mechanism proved ineffective on the real track following the fabrication process.

In the design phase, we paid close attention to our rover's center of mass. We strategically positioned electronic components on the chassis body to contribute to a favorable center of gravity. However, as our understanding of the rover evolved, we made adjustments to the placement of electronic components. After installing these components, we conducted a weigh-in to determine the rover's center of gravity and implemented necessary changes to enhance stability. These minor adjustments proved effective in improving the overall stability of our rover as it navigated the track. The most significant thing we considered while fabricating was how the steering mechanism would be attached to the rover itself. The original plan was to attach multiple layers of plywood together for the chassis and then mount the steering mechanism along with the servo. However, during fabrication, we had to do a lot of measurements and testing to ensure we had the most accurate mounting for these integral parts. We tried different setups and made adjustments until it worked just how we wanted. Each little tweak was important to make sure the rover could steer smoothly.

Following the successful mounting of our steering mechanism, we began simple testing with our steering mechanism. We tested the turning radius and developed a better understanding of our rover's strengths and weaknesses. Particularly, we identified a major issue with the turning radius of our steering mechanism. Our steering faced challenges, particularly in handling tight corners and turns on the track. Recognizing this limitation prompted discussions on potential solutions for the steering design. However, due to the constraints of our tight timeline, implementing substantial improvements proved impractical. Despite being unable to make significant alterations to the steering design, we implemented minor tweaks. One notable adjustment involved shaving down our wooden chassis, which successfully provided additional turning clearance for the wheels, contributing to improved steering performance. Additional test runs on the practice track proved that our turning radius does not have major adverse effects on the rover's capabilities when it comes to finishing the track under requirements.

With final improvements made, and the rover finalized, we did a few final test runs on the track and tackled a possible issue with navigation over the ramp. The solution we came up with for this concern was to include a polycarbonate clearance guard on the bottom of our rover. The clearance guard was strategically designed to elevate the rover and enhance its momentum when crossing the apex of the ramp. Initially designed for a 45-degree angle ramp, we later discovered that the track featured a 30-degree angle ramp instead. Despite this change, the clearance guard still offered valuable support, providing an extra layer of stability as the rover maneuvered through the other obstacles on the track.

Results & Discussion

We were able to design, build, and test a rover that complied with all regulations and set a track time of 2 minutes and 36 seconds. However, that time was not competitive, and therefore, we didn't fully complete the main objective. Despite not fully completing our main objective, we did complete our other goal by learning as much as possible.

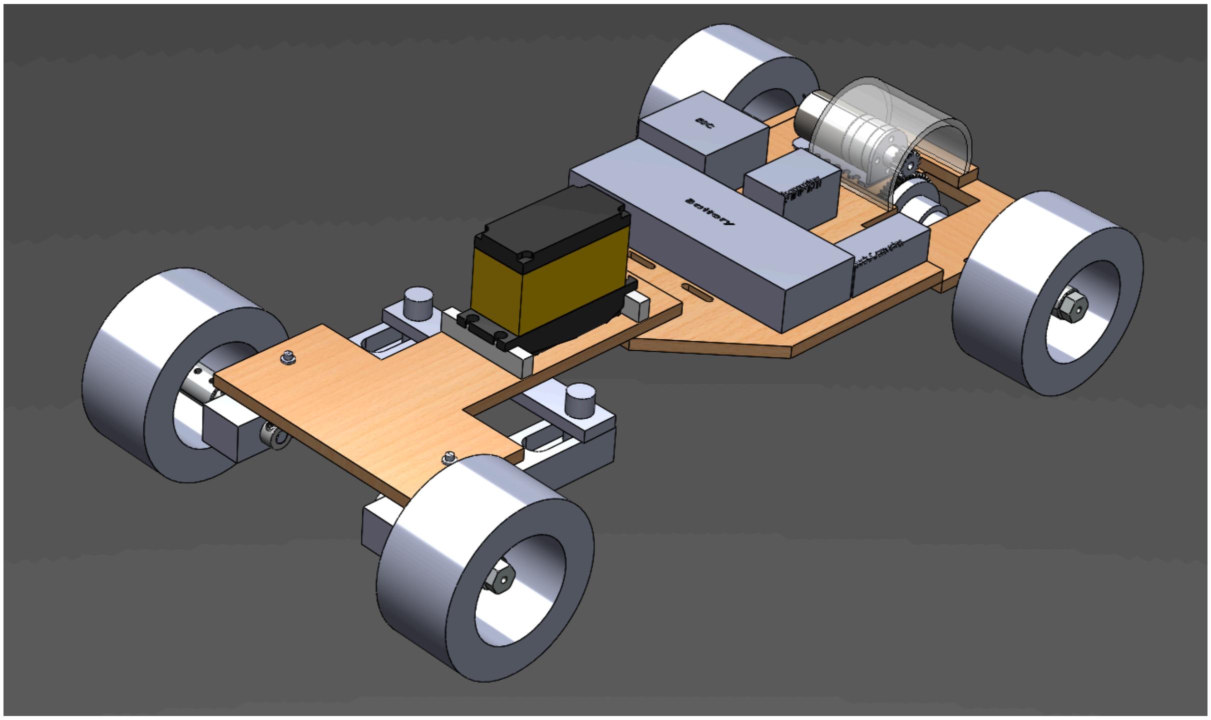
The reason our rover was not competitive was due to our rover not being able to complete the track turns quickly. Our rover had to make many three point turns in order to complete one turn on the track, ultimately holding our rover back. If we had time to shorten the bars and extend the slots on the steering mechanism, we believe that the turning radius would have decreased substantially, making us more competitive. However, we are skeptical that this change would have put us in a position to compete for the top ten. The current steering mechanism requires the Chassis Extension piece, which increases our turning radius, and makes it impossible for our rover to be as agile as the top rovers.

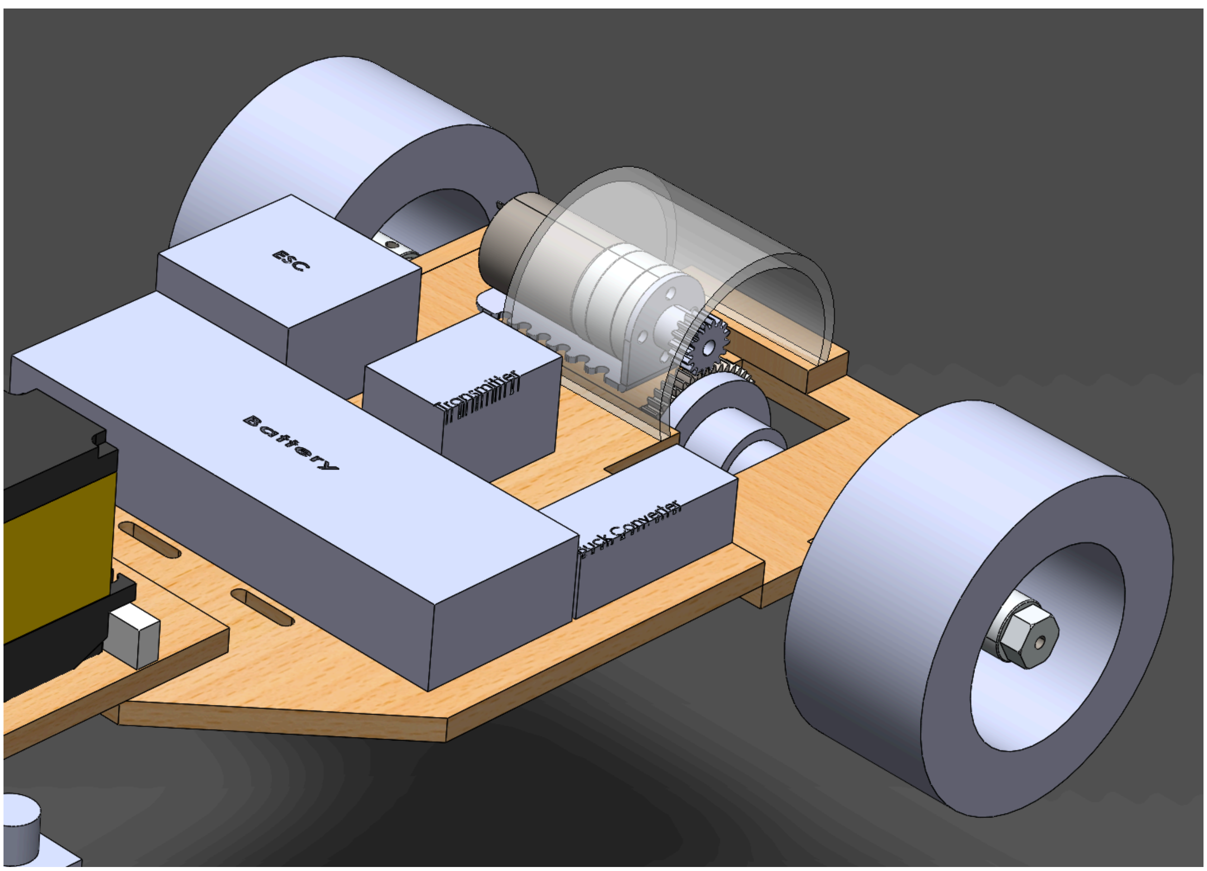
Since the course layout greatly rewards agile rovers, the current design of our rover would need to be drastically overhauled. Our rover is rigid, durable, heavy (weighs 2.095lbs), and has a center of mass slightly towards the rear. These traits are the opposite of an agile rover. Instead of our rover being very close to 16 inches long, we would need to revamp it in a way where it is no more than ten inches long, in order to be competitive. Aforementioned, this also means that our steering design would need to be completely revamped. Since the chassis and the steering need to be revamped, we would basically have to start from scratch, to make a rover that can compete for a top place.

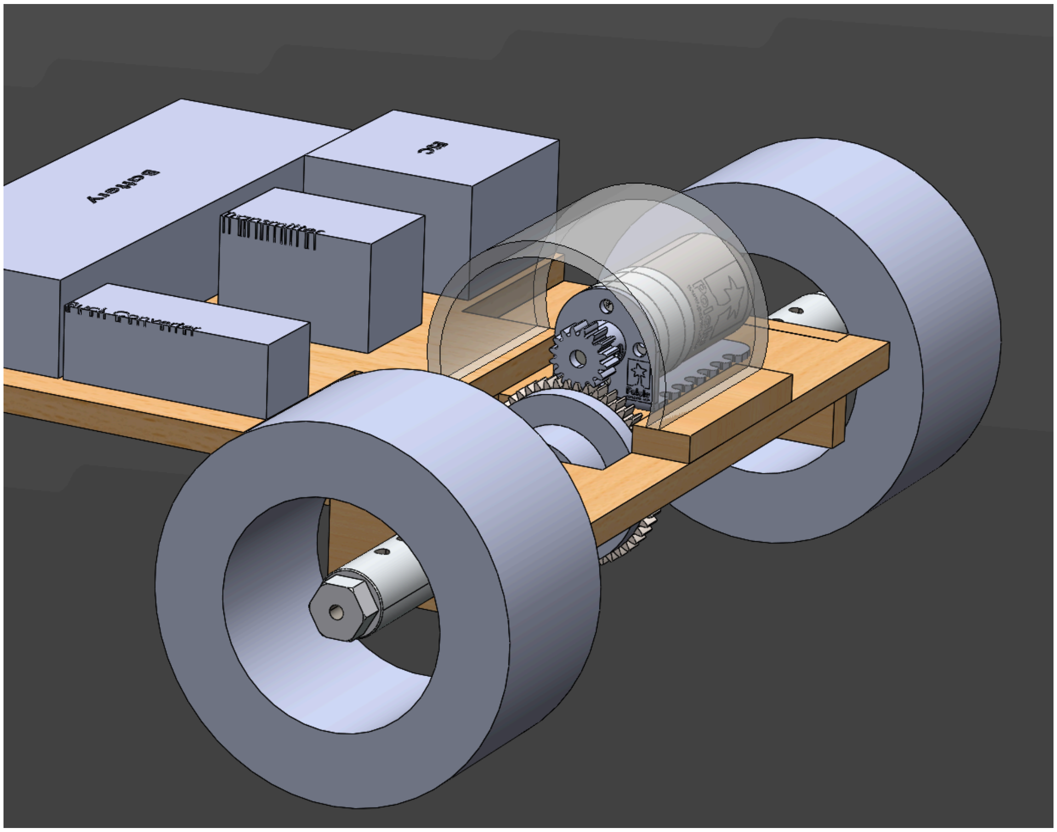
Through analyzing why this rover can't be competitive in its current form, we have learned that we should have analyzed the main characteristics that a successful rover would have based on the track given, before designing a rover. We ended up being so focused on designing a rover that resembles a real life car and making sure that it works, to the point where we lost focus on the drawbacks of that design for the course we were competing on. We built a rover that may succeed in a different environment, like a drag strip, or perhaps a NASCAR circuit (if the steering had the small improvements), but unfortunately does not perform well on twisty tracks.

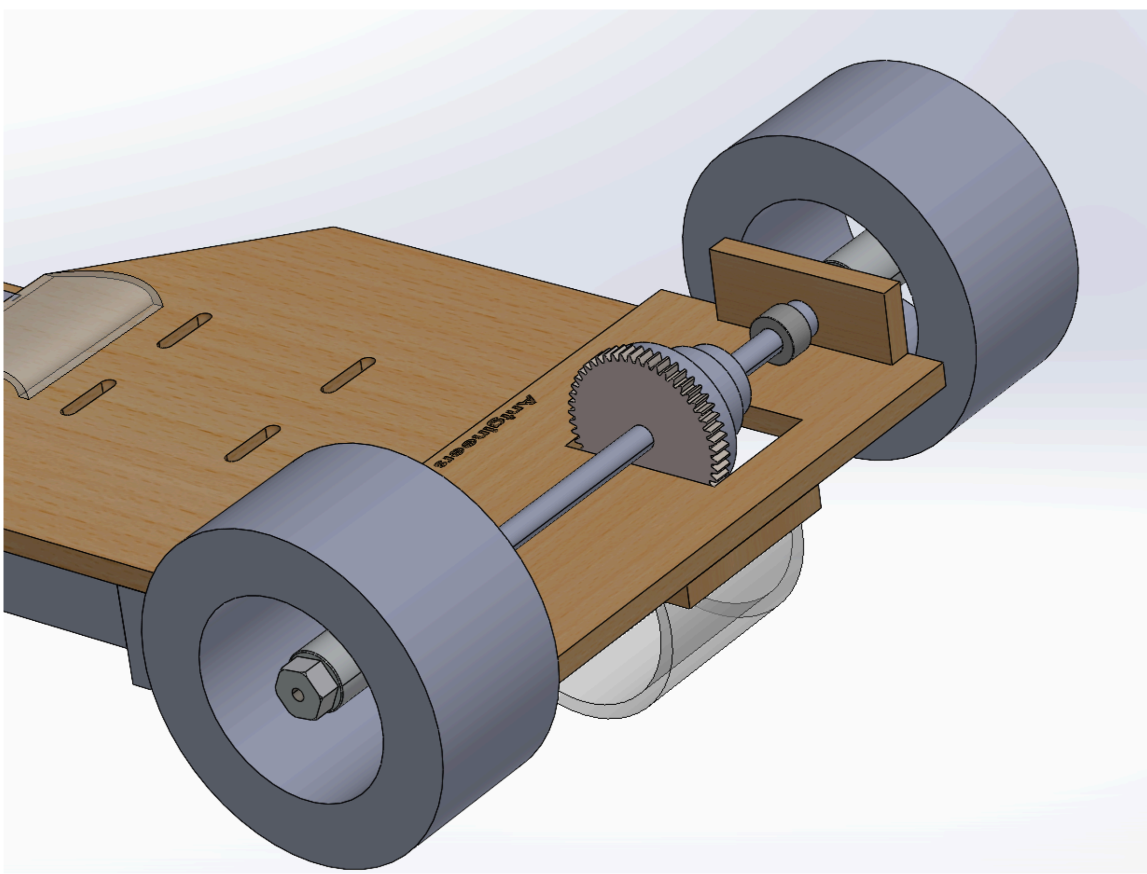
While our rover left much to be desired in its performance, there are still a lot of positive things to takeaway from this journey. Our team went from having little or no CAD experience to designing a rover that can, at least, complete the course. Our team also went from having little fabrication experience to successfully fabricating our CAD design, with almost no discrepancies, and in a timely manner. Furthermore, our team was able to quickly adapt and solve problems like our rover getting stuck at the apex of the ramp, in a quick, creative, and engineering manner, by adding a clearance guard. Finally, despite a tremendous lack of experience, our team was able to meet all the deadlines. In the future, we plan to implement all of these lessons that we have learned, in order to engineer a better rover.

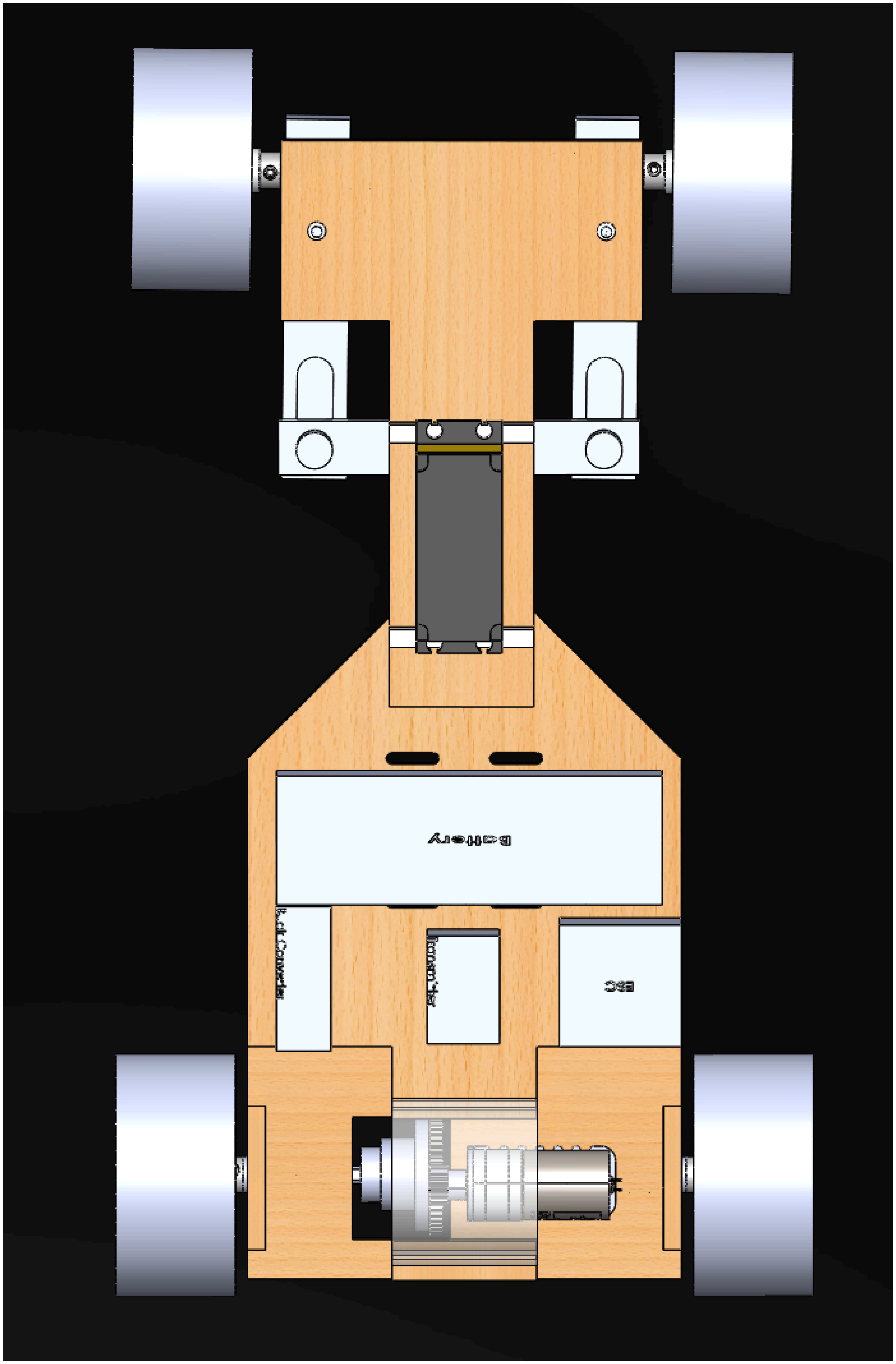
Appendix A: SOLIDWORKS Drawings

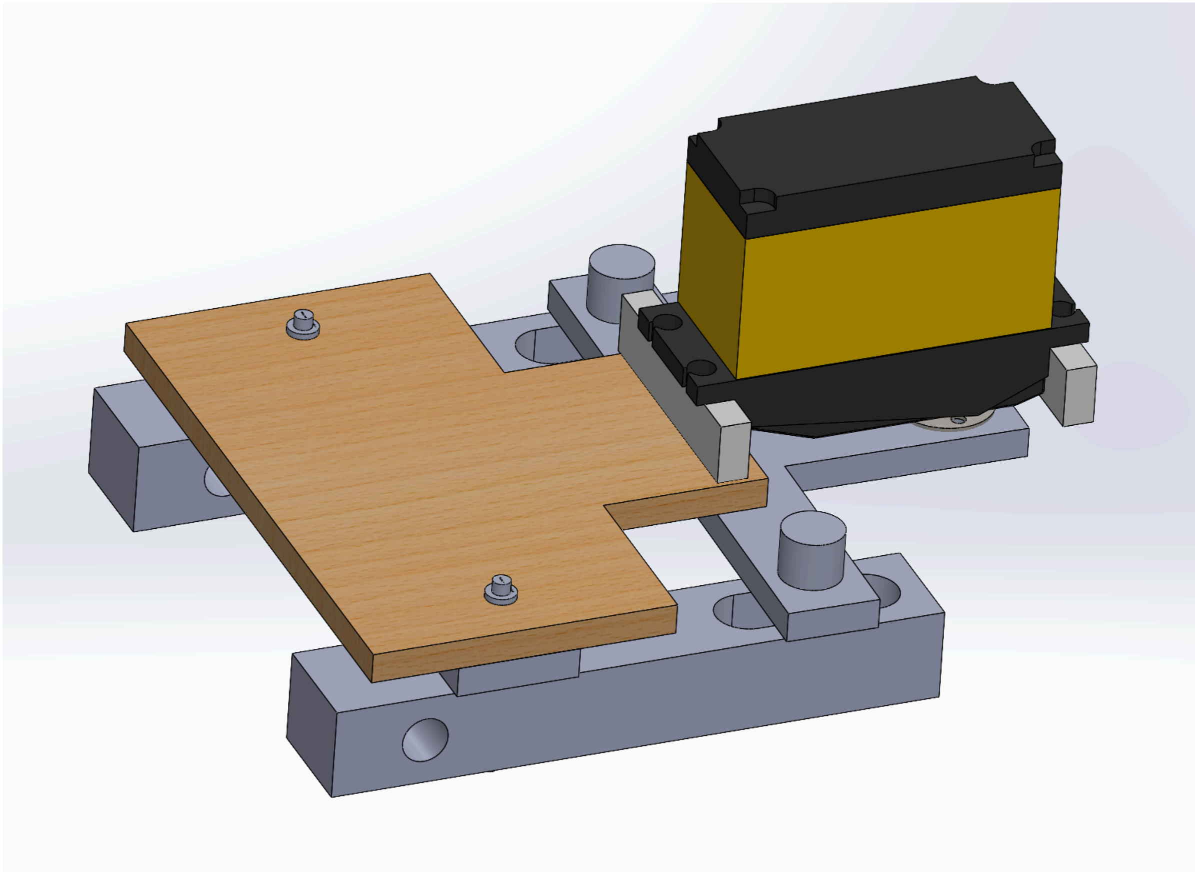


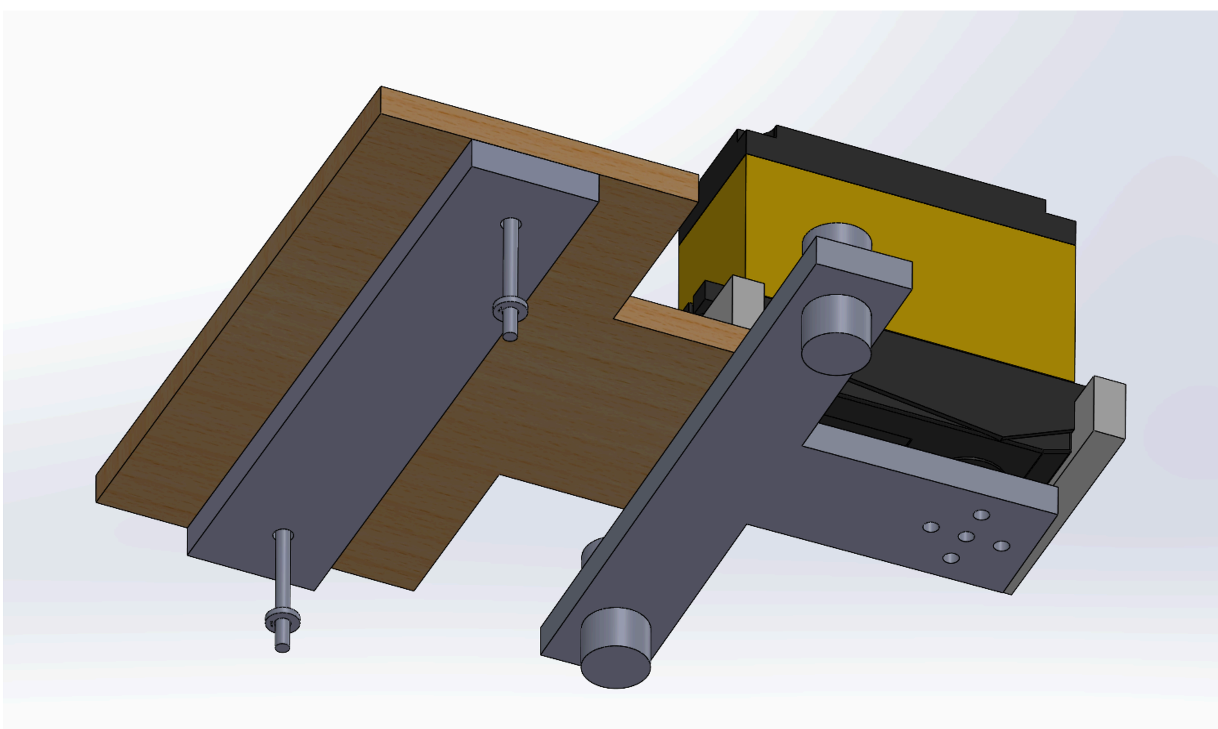


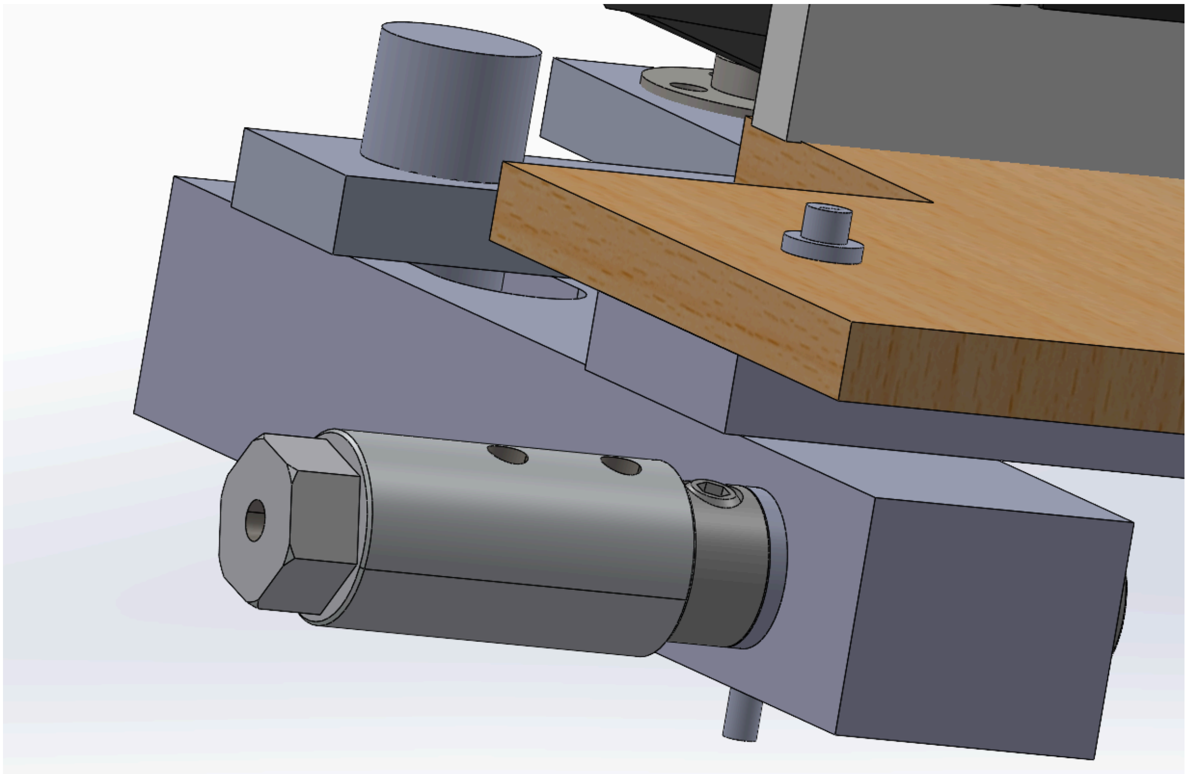


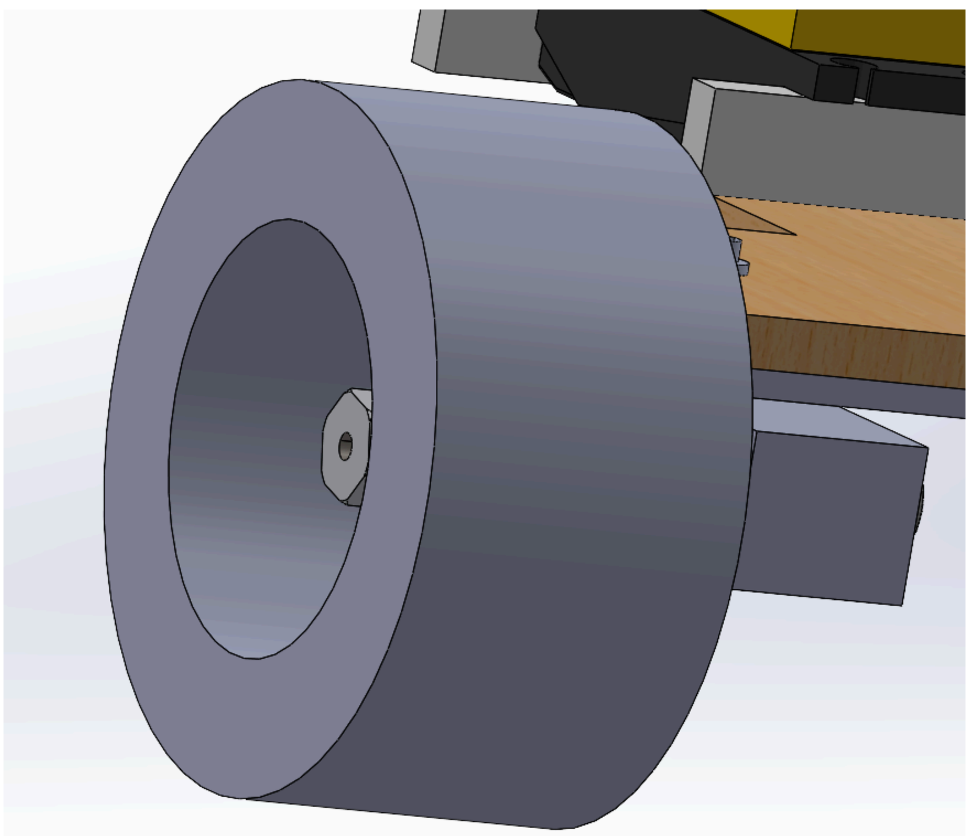












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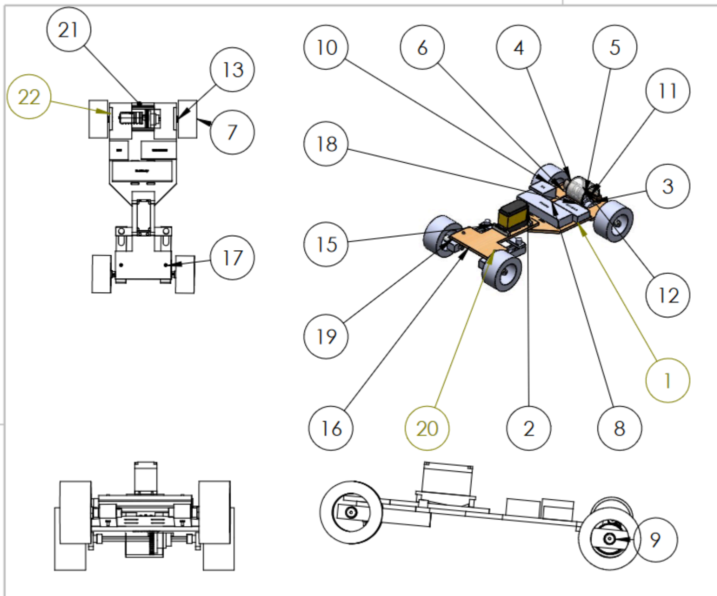

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2	SERVO	1
3	REAR ASSEMBLY	1
4	GEARMOTOR	1
5	PINION GEAR	1
6	MOTOR MOUNT	1
7	85mm WHEEL	4
8	BATTERY	1
9	WHEEL ADAPTER	4
10	ESC	1
11	52T GEAR	1
12	GEAR GUARD	2
13	SHAFT COLLARS	4
15	SERVO SUPPORT	2
16	CHASSISEXTENSION	1
17	WASHER	4
18	BUCKCONVERTER	1
19	STEERING_ASSEMBLY	1
20	40mm SCREW	2
21	CHASSIS EXTENSION BACK	1
22	AXLE MOUNT	2

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
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TWO PLACE DECIMAL ±
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INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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	NAME	DATE
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Q.A.		

COMMENTS:
Balloon
Bill of Materials

NEXT ASSY | USED ON
APPLICATION

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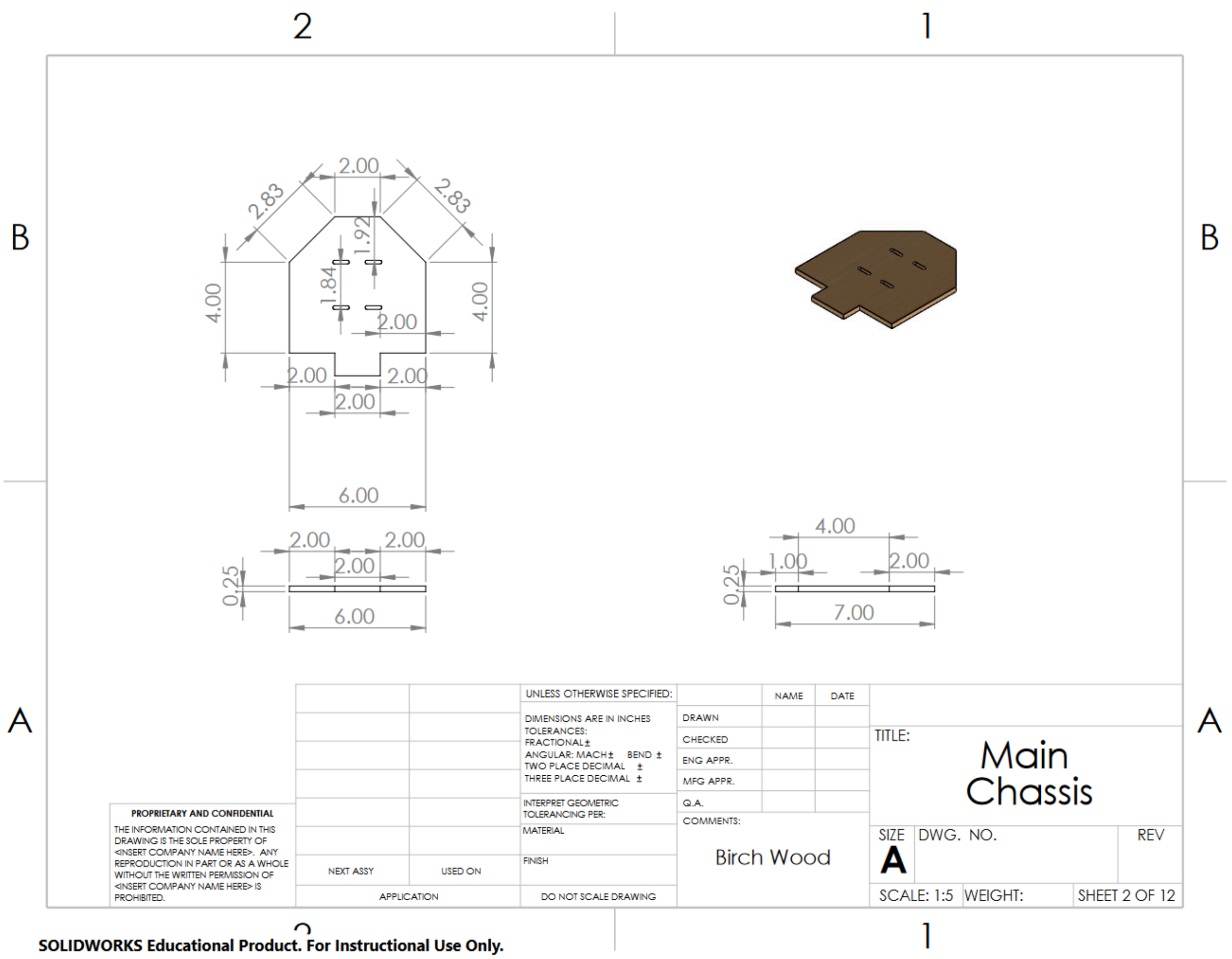
2 1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TITLE:
Main Chassis
SIZE
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WEIGHT:
SHEET 2 OF 12
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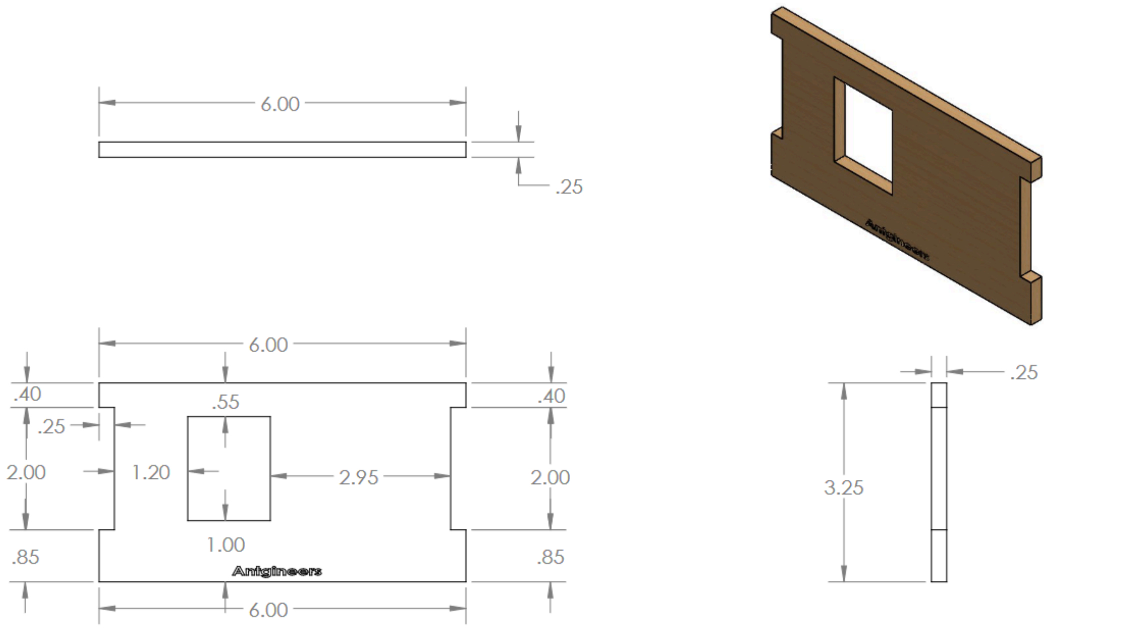

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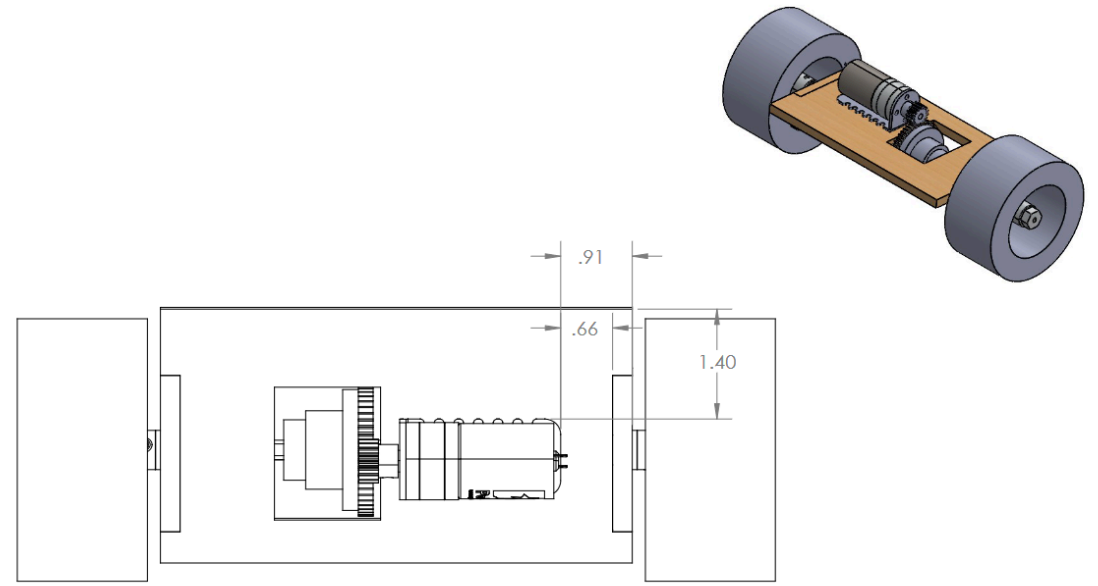

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Q.A.		

COMMENTS:

Birch Wood

TITLE:

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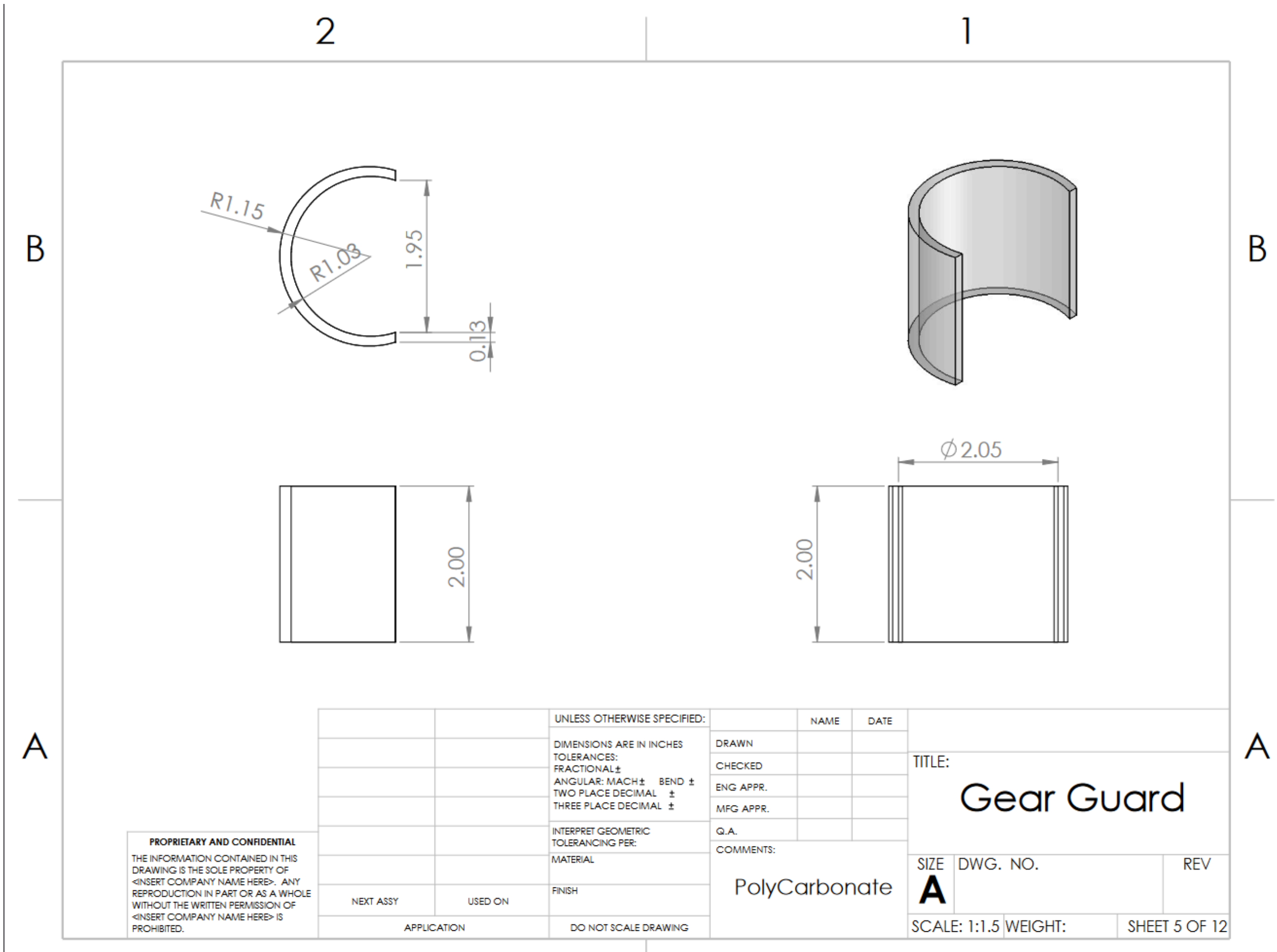

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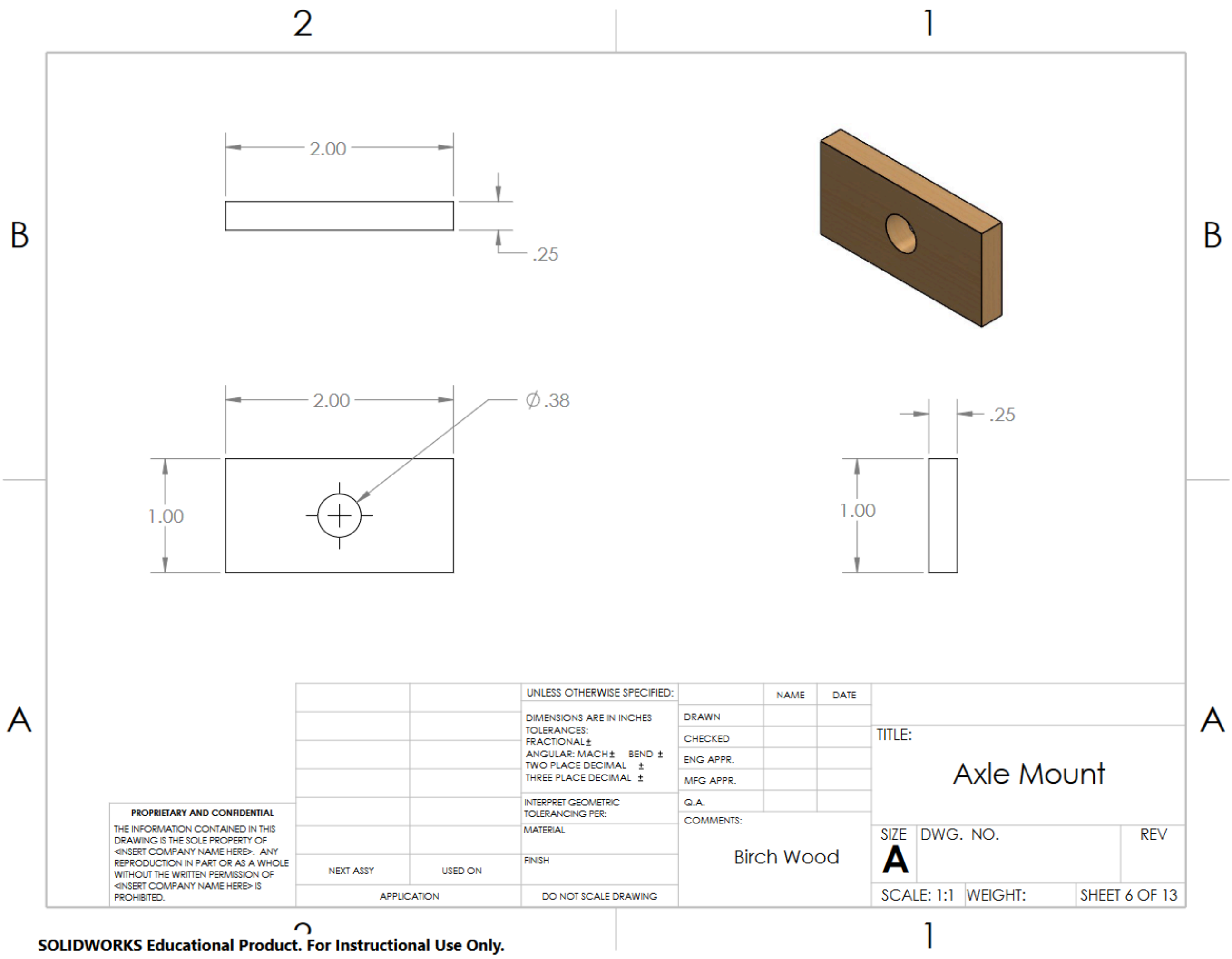
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SHEET 6 OF 13
NEXT ASSY
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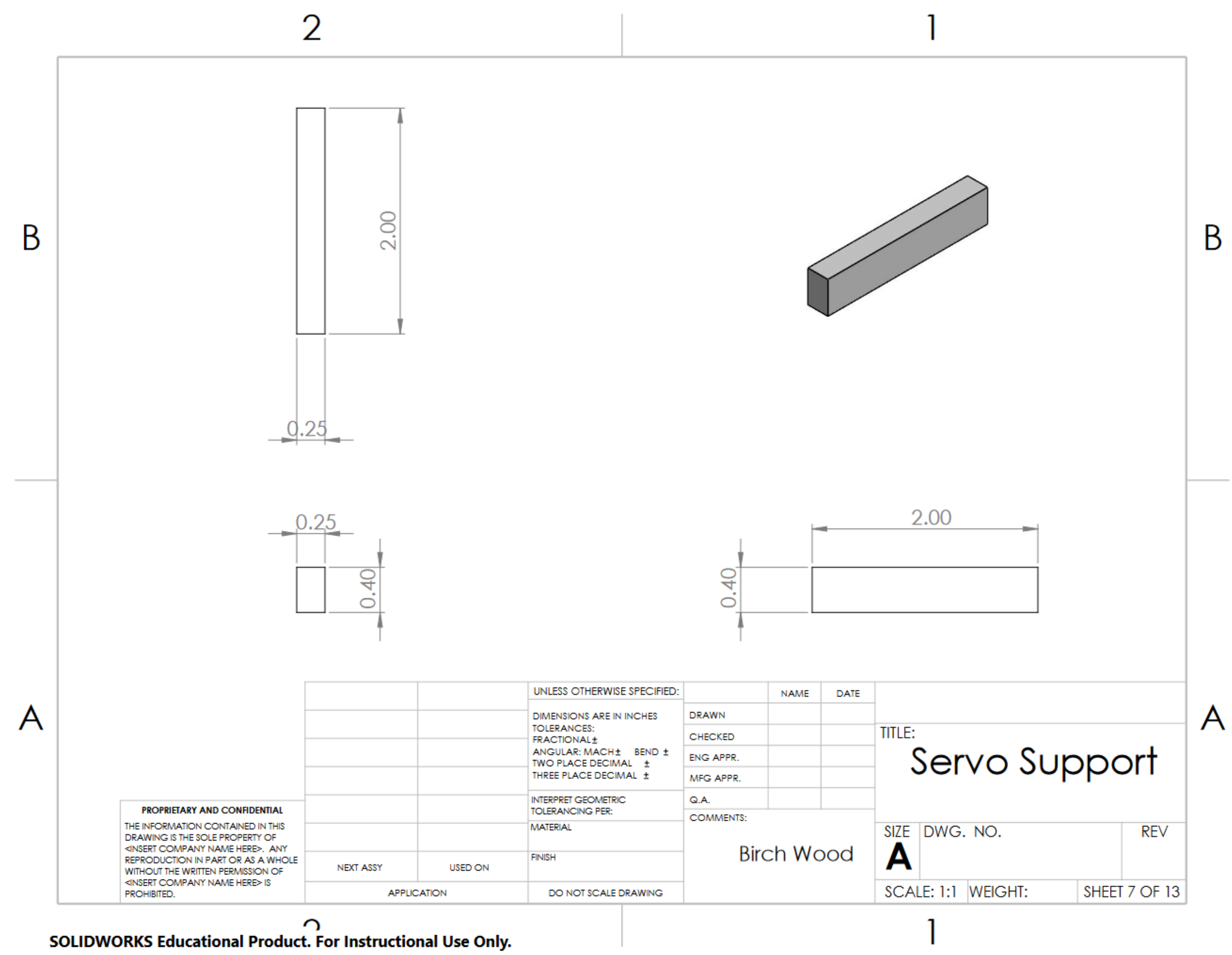
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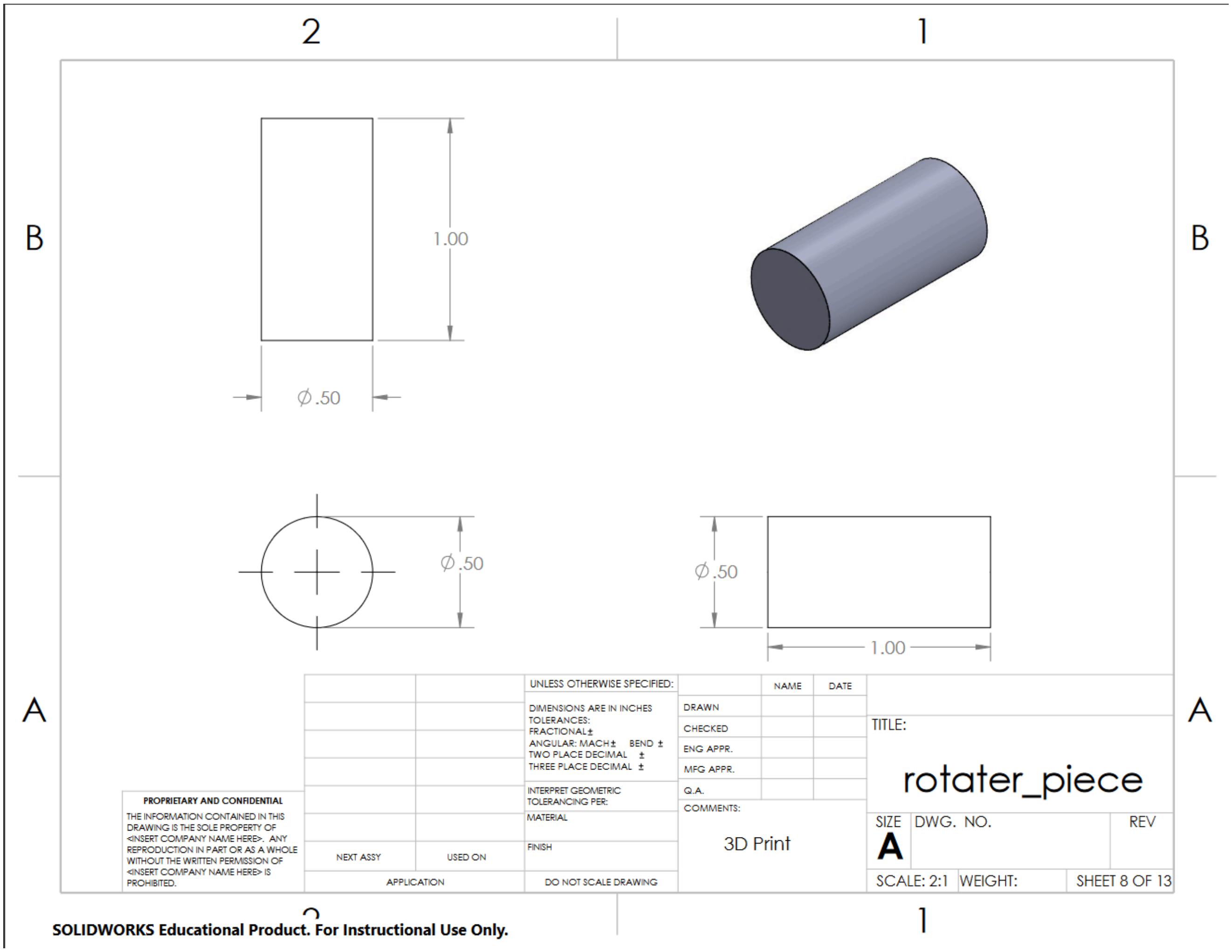
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Q.A.
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SHEET 8 OF 13
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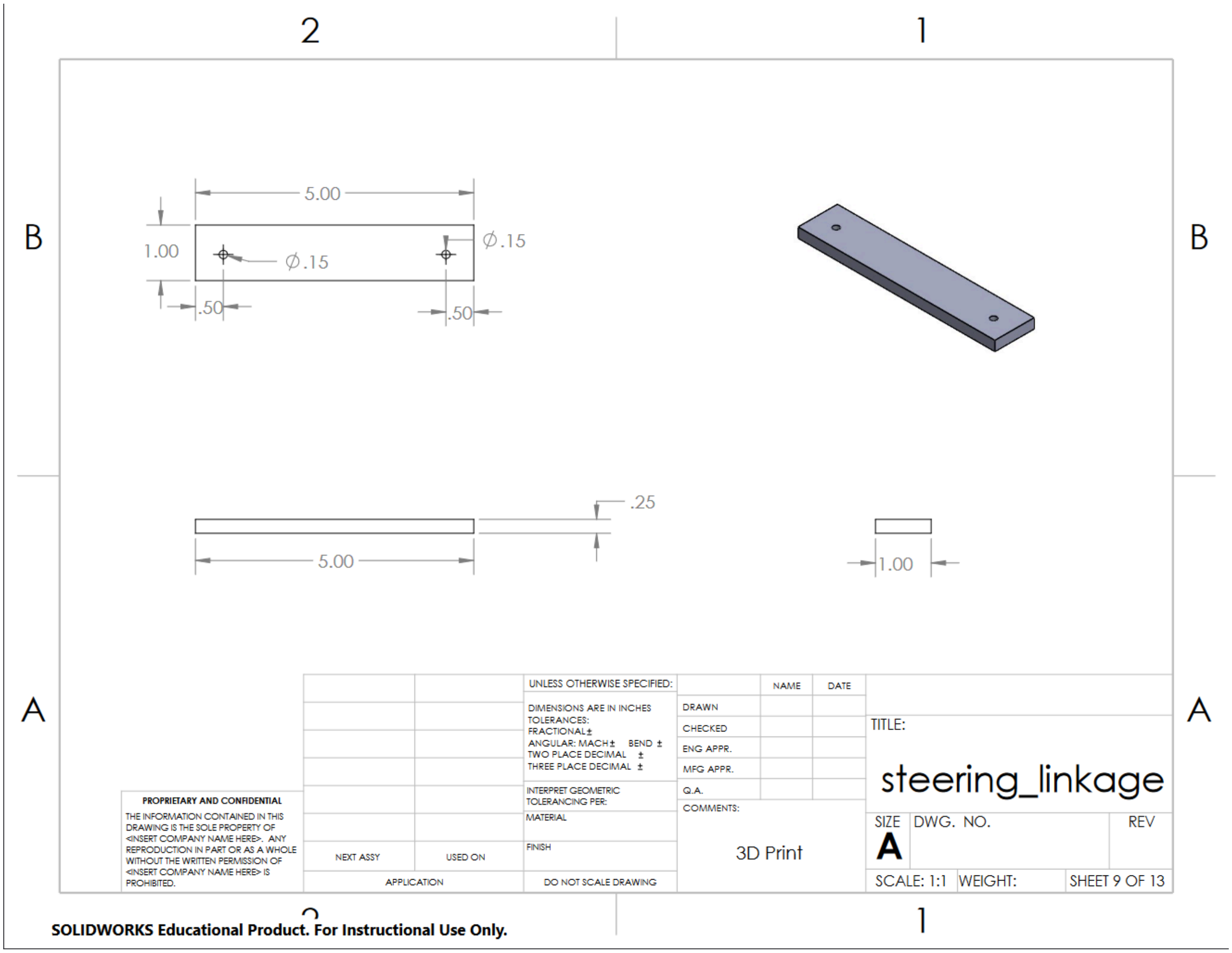
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TOLERANCING PER:
MATERIAL
FINISH
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DATE
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
3D Print
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SIZE
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DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 9 OF 13
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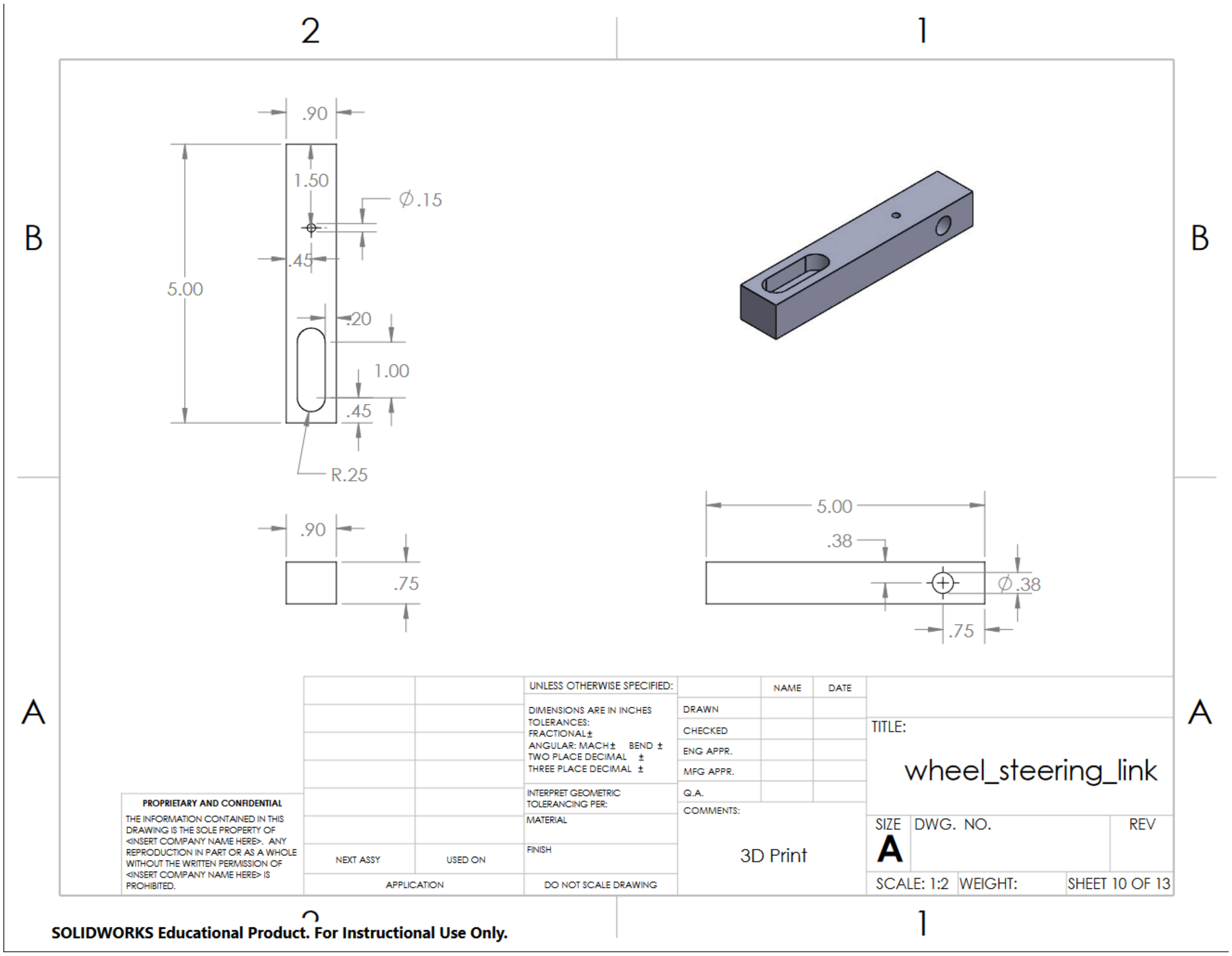

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wheel_steering_link
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SHEET 10 OF 13
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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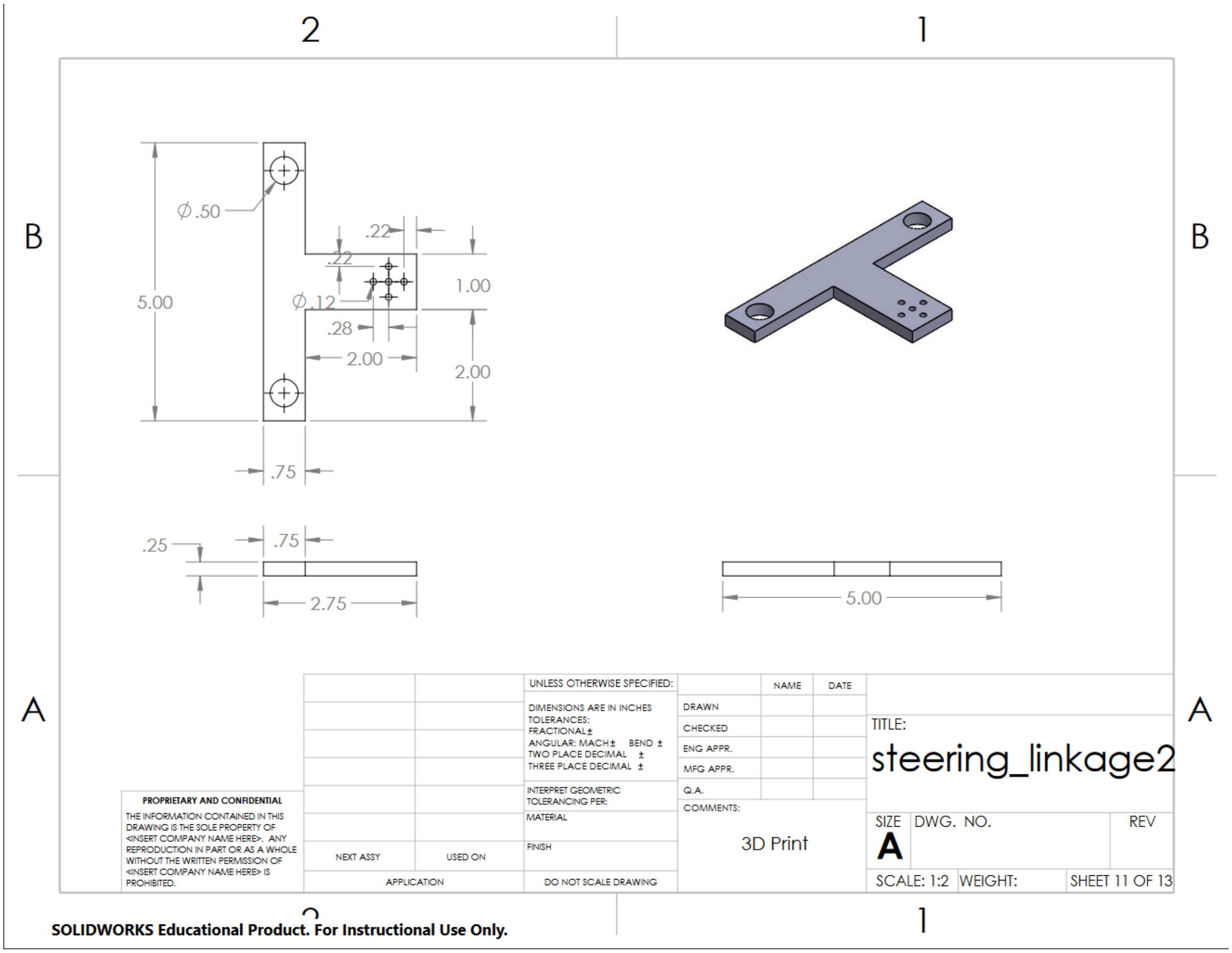
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TOLERANCES:
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INTERPRET GEOMETRIC TOLERANCING PER:
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NAME
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COMMENTS:
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steering_linkage2
SIZE
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SHEET 11 OF 13
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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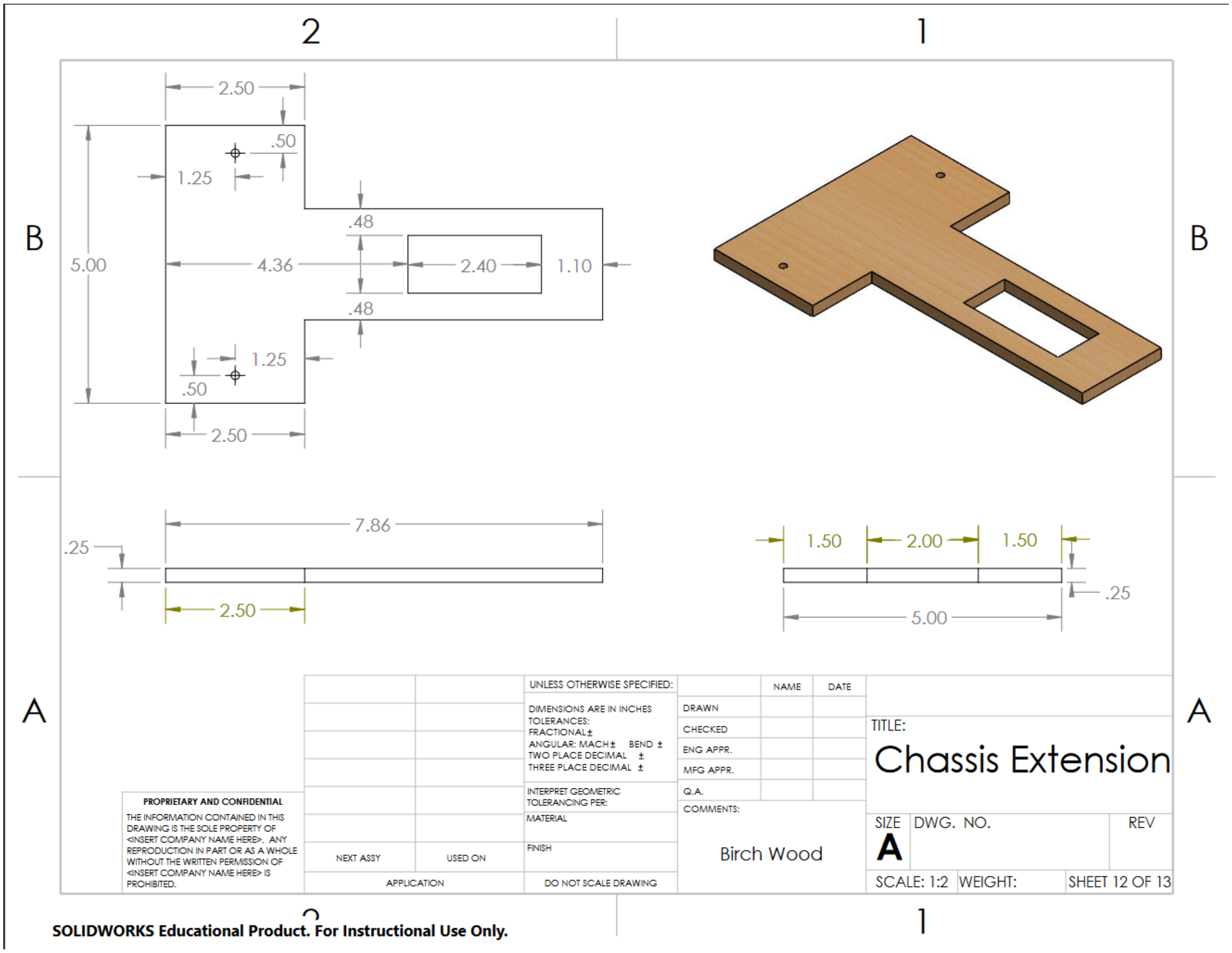

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DO NOT SCALE DRAWING
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MFG APPR.
Q.A.
COMMENTS:
Birch Wood
TITLE:
Chassis Extension
SIZE
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DWG. NO.
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SCALE: 1:2
WEIGHT:
SHEET 12 OF 13
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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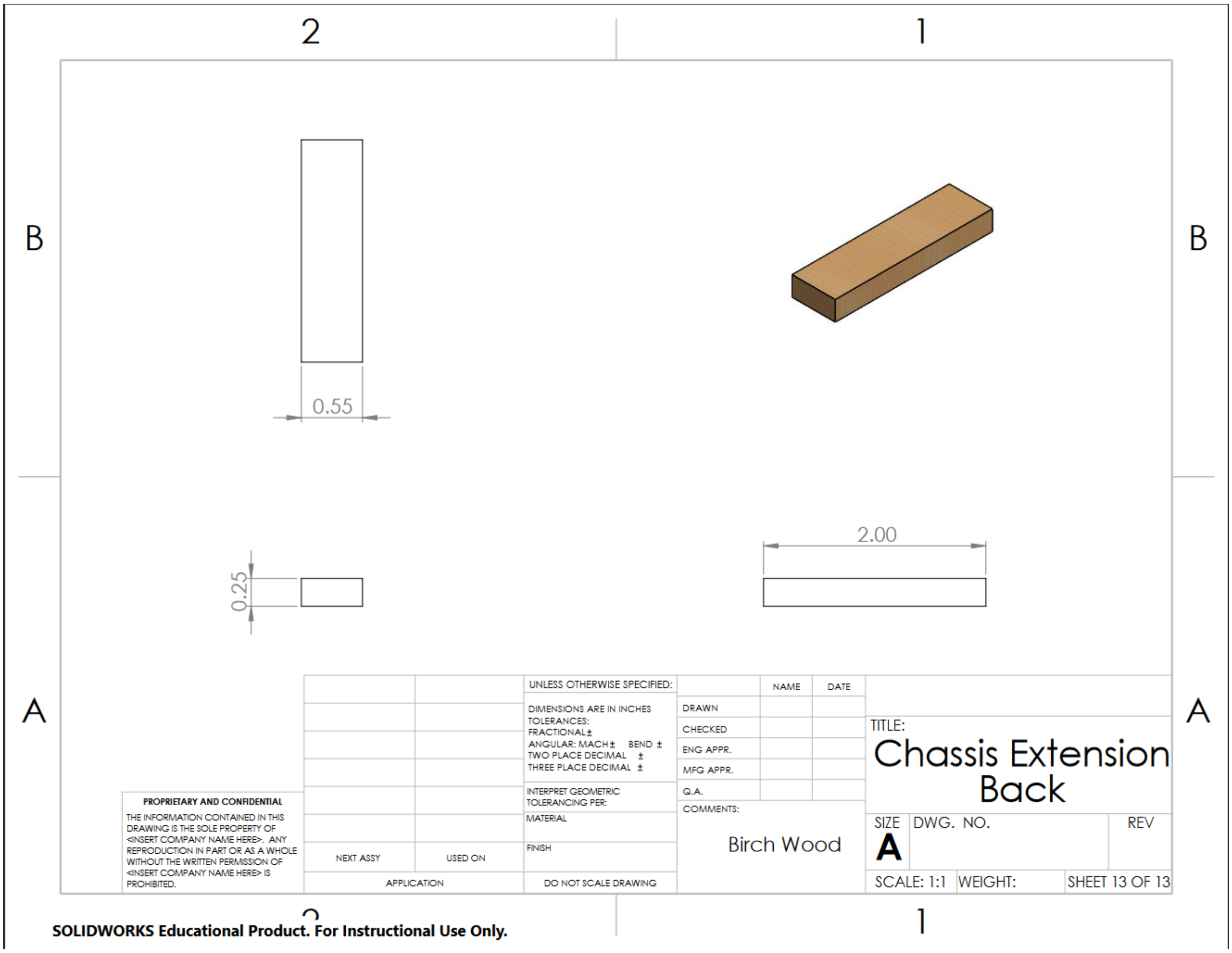
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DO NOT SCALE DRAWING
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Birch Wood
TITLE:
Chassis Extension Back
SIZE
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DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 13 OF 13
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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Appendix B: Bill of Materials

PURCHASE ORDER FORM

The Henry Samueli School of Engineering

One PO per team. Parts will be given to you after submitting the PO. The gears and wheels will be given on a first come first served basis.

Requested By:* Antgineers (Team Name) **Team Captain E-Mail:*** kdadabho@uci.edu

Lab Instructor Name:* Kristin Roher **Lab Section, Day, and Time:*** Thursday 1PM

Account Name:* ENGR 7A **Date of Request:*** 10/29/2023

Account*	Fund*	Sub	Project	% (If split	Amount	Accounting Review
ENGR 7A	56123	03	7A	100%	$232.29	
				0%	$0.00	

Quantity*	# of Units in package*	Company*	Item Description*	Catalog/ASIN #*	Price*	Estimated Extended Price*
4	4	Amazon	85mm Wheels	B07BS9QJ8L	$18.50	$18.50
1	4	Amazon	Servo	B07MFK266B	$27.99	$7.00
1	4	Amazon	Buck Converter	B079N9BFZC	$14.99	$3.75
1	1	Amazon	Transmitter + Receiver	B00KHJ262Y	$60.00	$60.00
1	1	Pololu	4.4:1 Gearmotor	3201	$28.95	$28.95
1	2	Amazon	Battery	B07VLKP6RJ	$34.99	$17.50
1	2	Pololu	Motor Mount Bracket	2676	$7.95	$3.98
1	10	Amazon	Servo Horn - 25T	B07D56FVK5	$9.99	$1.00
2	1	Servocity	2" D-Shaft	2101-1250-0200	$1.69	$3.38
1	1	Servocity	8" D-Shaft	2101-1250-0800	$3.69	$3.69
4	1	McMaster	1/4" Sleeve Bearing	2938T3	$0.92	$3.68
1	1	Servocity	52T Gear	RHA32-36-52	$5.44	$5.44
8	1	McMaster	1/4" Shaft Collar	6432K12	$1.49	$11.92
1	2	Amazon	Brushed ESC	B087NF55VD	$23.46	$11.73
1	1	Servocity	16T Pinion Gear	615326	$7.99	$7.99
1	1	Servocity	1/4" D-Bore Gear Hub	545692	$2.80	$2.80
1	1	N/A	1/4" birch baltic plywood 12"x12"	N/A	$2.78	$2.78
1	1	N/A	1/16" polycarbonate 12"x12"	N/A	$3.61	$3.61
4	2	Pololu	1/4" Wheel Adapter	2686	$4.95	$9.90
1	1	UCI Engineering	3D Printing (4 Hours)	N/A	$8.00	$8.00
					Subtotal	$215.58
				*Tax rate:	7.75%	$16.71
				TOTAL ORDER PRICE		$232.29

P.O. Form Chart: