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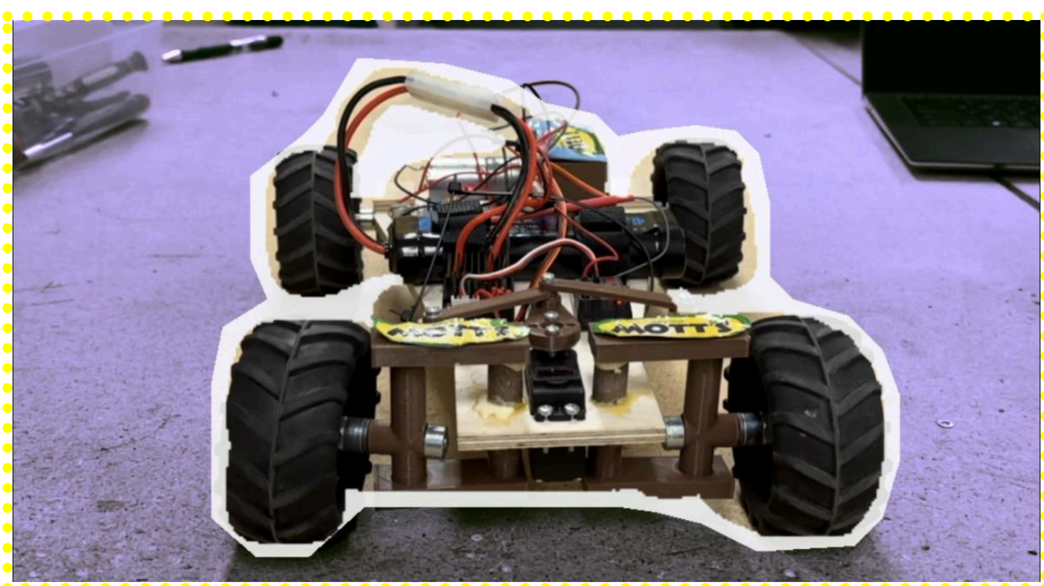
Alex M., Bryant N., Brady C., Darcy M.

ENGR 7A: Introduction to Engineering

University of California, Irvine

Fall 2023



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Executive Summary

ENGR 7A is the first portion of the two-quarter Introduction to Engineering course offered to UCI engineering Freshman. The main objective of this course is to teach its students the various processes and disciplines related to creating a remote control rover. Early on, the students were divided into various groups. Our group consisted of 7 individuals, all of different majors. We early on declared ourselves "Team Motts" when a group member decided to snack on the brand gummies during our first meeting. Few of us had experience with research design and manufacturing and even fewer had experience with electronics. As the course progressed, we would find ourselves dedicating much time building on these skills.

The project began with applying what we learned in lectures and labs onto our weekly action plans. Starting with the 3D CAD design modeling of the rover and its components on SolidWorks. Estimating our costs and collecting the information for the PO form. Then onto the safety protocols and procedures that go into the physical fabrication of the chassis and other smaller wooden parts. The soldering and positioning of the electronics soon followed. Lastly was the testing and evaluation of the end product. As a group, we met **every Thursday from 2pm to 3 pm.** Our assigned roles directed each of our contributions during and outside the meeting times.

Of course, throughout this whole process, there were many revisions and adjustments done to address issues we faced along the way.
Some of the issues included:

- Fabrication difficulties in original chassis design and steering design
- No space for wheel and motor compartments
- No way to mount rack
- Excessive friction

These issues were solved during labs and weekly meetings. New designs were made for the chassis and steering mechanisms, and different approaches were sought for any issues regarding positioning. Re-printing was also done for 3D components that were misprinted or had gone through revisions in order to fit into new designs.

For the most part, our rover took inspiration from the mechanisms of past accomplished rovers in the same course. Uniquely, our rover also took influence from the mechanisms of remote control toy cars.

Notably, the Ackerman steering system we used was quite different from most other teams as it incorporated rods and a 3D servo motor adapter.

Each member contributed their strengths towards the completion of a rover that not only followed the guidelines set upon us, but also exemplified the creativity of its members. The end product accomplished just that. The Team Mott's rover is able to remotely be controlled to accelerate, reverse, turn, and climb over a ramp, all while proudly flaunting the Motts brand.

Problem Definition

Introduction

Over the course of ten weeks, we were tasked with the assignment of fabricating a remotely controlled rover. Going into this project, we had general ideas of aspects desired in our rover such as a low center of gravity, speed, and high torque. Our holistic view of the rover developed as the weeks progressed. We were able to implement what we learned through labs and lectures into our designs, such as ackerman steering and a gear train. Designing and constructing a rover was something novel to the entire team, so the development of the rover was a learning process as well .

Technical Review / Background

The purpose of the rover was to traverse celestial bodies neighboring Earth, and to collect data and samples. In 1970, the Soviet Union developed the first ever rover which was designated the name Lunokhod 1. However, one the earliest records of a remotely controlled vehicle comes from a 1954 article, about a man by the name of David Swinder, which showcases his remote controlled vehicle to the chief test driver of Ford. Rovers have come a long way from Lunokhod 1, with many having developed more specific tasks than just to curiously explore extraterrestrial planes. For example, the most recent rover launched was ‘Perseverance’ by NASA is currently journeying across Mars to look for “signs of past life”, as well as for the ability for humans to live on Mars.

In total transparency, our designs were primarily influenced by what we learned in lab and lecture, but cemented through further research. Designs such as the ackerman steering, gear ratio, materials and center of mass were instructed to us in lecture, which were implemented into our rover as a result.

Resources:

Howell, E. (2016, December 20). *Lunokhod 1: 1st successful Lunar Rover*. Space.com. https://www.space.com/35090-lunokhod-1.html

RCModels 1954 Ford Motor Company Concept. Thirteen point seven billion. (n.d.). https://palmeter.com/rcmodels-1954-ford-motor-company-concept/

Urbain, T. (2023, May 14). *How many Rovers & Landers are currently on Mars?*. StarLust. https://starlust.org/how-many-rovers-are-on-mars/

What makes a Rover? - chabot space and science center. (n.d.). https://chabotspace.org/wp-content/uploads/2020/04/What-Makes-a-Rover-1.pdf

Design Requirements

Size requirements:

(a) Overall width must be smaller than 10 inches.

(b) Overall length must be smaller than 16 inches.

Structure requirements

(a) Your team will design and fabricate the rover structure.

(b) Using an off the shelf chassis is not allowed.

(c) Off the shelf steering mechanisms or individual linkage components are not allowed.

(d) You are allowed to use raw materials purchased externally with the permission of your TA or technical staff.

(e) 3D printing of the steering mechanism and any associated attachments is allowed, but must be counted toward your budget.

Power and propulsion requirements

(a) The use of internal combustion engines (gas and glow fuel engines) is prohibited.

(b) Rover must be able to operate for at least 10 minutes without replenishing/recharging its energy source.

(c) On/off switch is required and must be easily accessible.

(d) Battery must be easily removable.

Safety requirements

(a) Must include a gear guard to protect against any contact with the gears when in motion.

(b) No protruding sharp objects. All sharp corners must be filed or sanded down.

(c) All wires must be neat and away from any moving parts. This includes, rotating axles, motor shafts, servos, linkages, and gears.

(d) All wires and connectors are to be completely covered and insulated.

Cost requirements

(a) Total as-built replacement cost of the rover must be less than $250 If you decide to incorporate 3-D printing, the budget must be less than $275.

(b) The cost must be broken down into a Bill of Materials (BOM)/Parts List, in which the Fair Market Value (FMV) of each component must be listed.

Product Deliverables

(a) The RC rover

(b) Final design report

(c) The final Bill of Materials/Parts List

(d) Preliminary and final Gantt charts

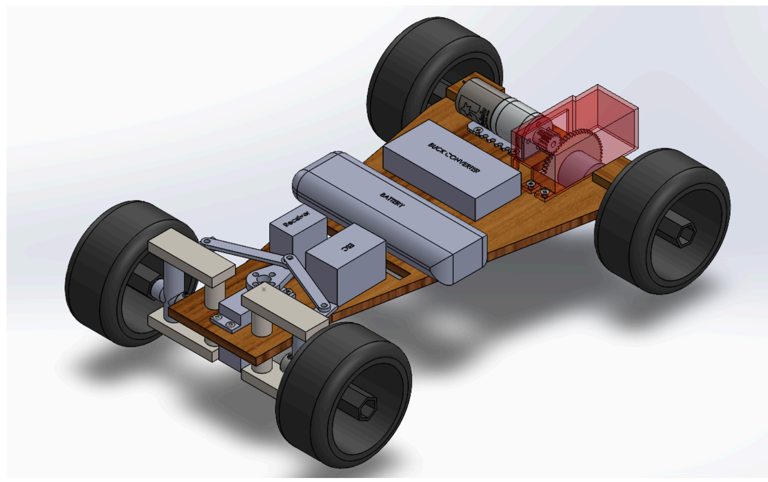
(e) All design drawings and schematics

(f) The oral presentation (PowerPoint slide file)

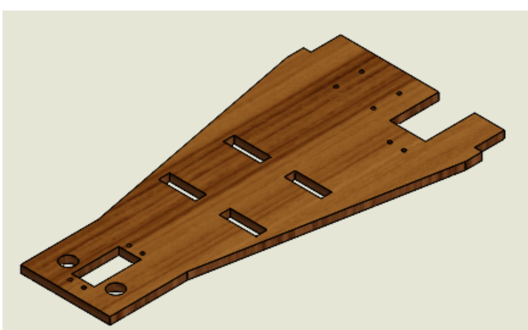
Design Description

Summary of Design

The final design of our rover is pictured to the right. It includes the steering system, the drive train, and the electronics all connected by a wooden chassis. The steering system is at the front of the rover. It controls the direction that the front wheels are pointing by turning a servo motor. The drivetrain is in the back and controls the direction and the speed of the back wheels.

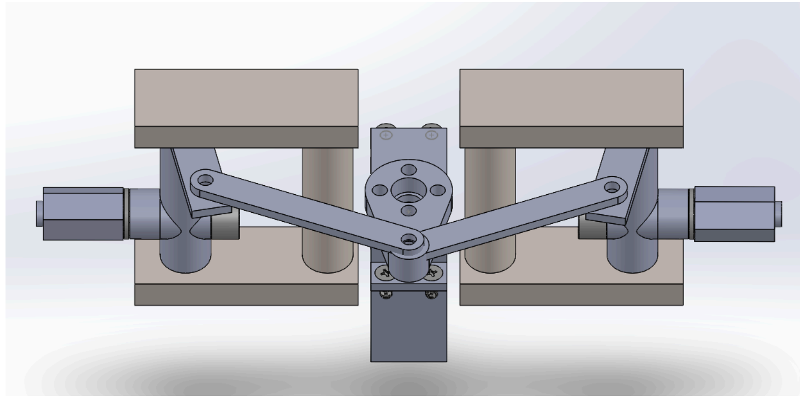


The gray parts in the middle of the steering system and rear axle are the electronics. The battery is placed in the middle because it is the heaviest part. This keeps the center of gravity close to the middle of the rover, lowering the chances of the rover tipping over or being unstable. The battery is attached to the chassis via velcro straps that go through holes cutout in the chassis. The buck converter is attached to the chassis with 2 M3 screws. The other electronics, including the ESC, On/Off switch, and receiver are attached to the chassis with double sided tape. Each of the parts are strategically placed to be near the other parts that they are plugged into. This keeps the wires neat in the final design.

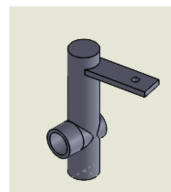


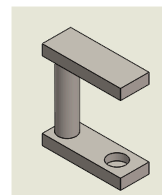
We chose to use 85 mm wheels, as they were the largest available wheels for this project. The large wheels made traversing rough terrain and driving over the peak of the ramp easier. The overall dimensions for the entire rover came out to be 13.94 inches by 9.43 inches, which fits the requirements that the size needs to be within 16 inches by 10 inches.

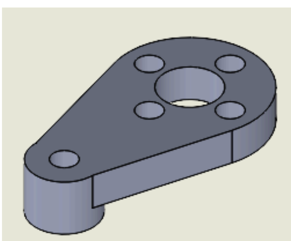
Design Details



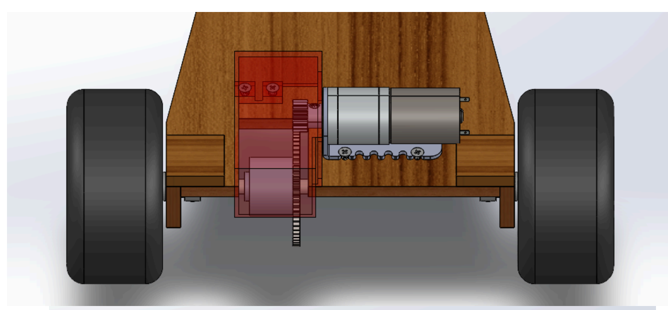
For the steering system, we decided to 3D print the majority of the parts. The servo motor is attached to the chassis with 4 M3 screws, and goes through a hole in the chassis to hold it lower. Connected to the servo horn is a 3D-printed adaptor (pictured below) that screws into the servo horn and attaches to two rotating rods on the other end. This piece holds the rods farther away from the axis of rotation, therefore compounding the amount of linear motion when the servo rotates. Those two rods are each connected with M3 screws to a rotating part that holds the 2-inch D shafts, which connect to the wheels. These rotating parts are held up by connectors (tan pieces) that allow them to rotate and secure them to the chassis. In total, including the wheels, the width of the steering system is 9.4 inches, which is within the maximum of 10 inches.

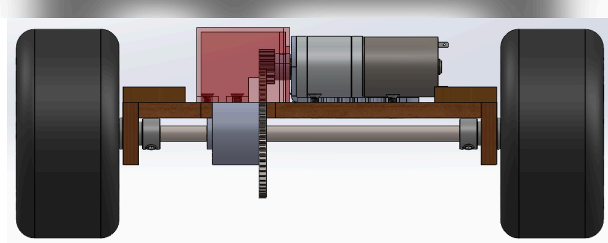






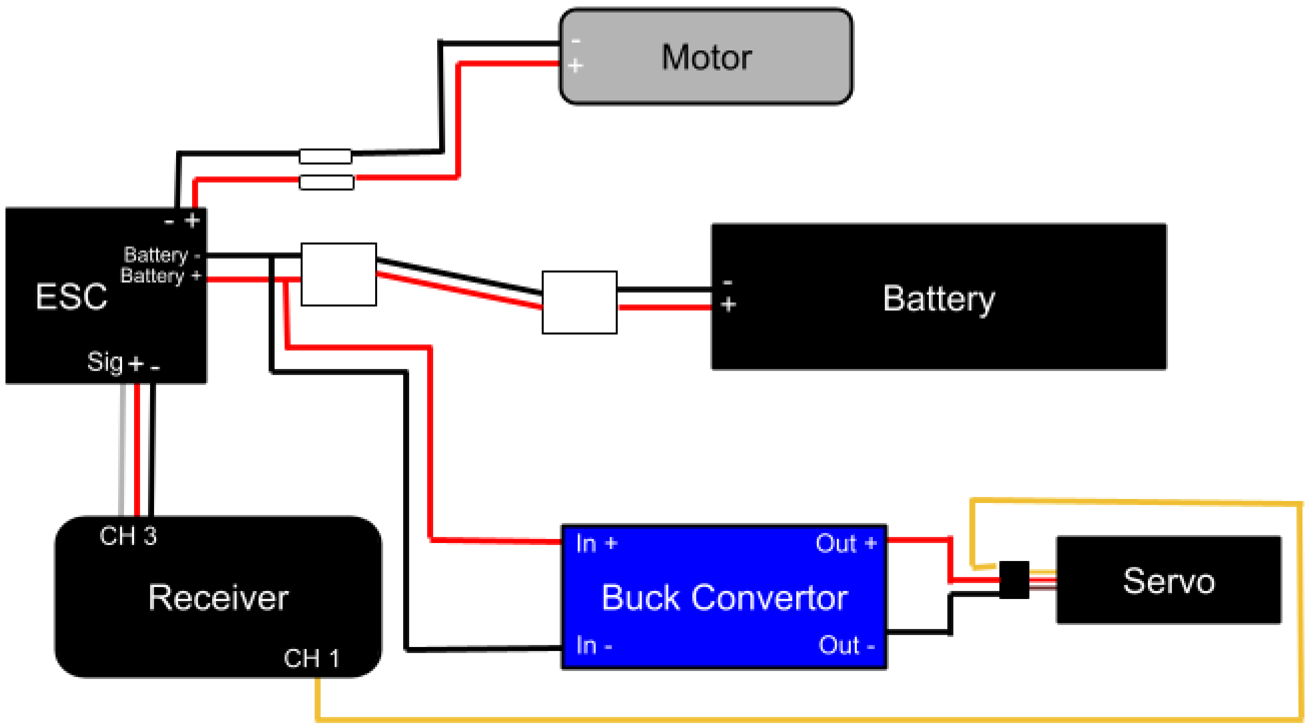
The drive train of our rover is in the back. This system is quite simple in that it just secures the 8-inch D shaft to the chassis and connects it via a gear train to the motor. The D shaft is held up using wooden cutouts. They are glued to the chassis, and have other wooden cutouts glued on top of them to reinforce them. This is because these connections hold up the weight of the rover. The D shaft is below the chassis to raise the rover as high as possible. This raises the center of gravity, but it allows the rover to go over the ramp on the obstacle course. There is a cutout in the wooden chassis to allow the gear to spin and connect to the motor, which is screwed into the chassis using the motor mount. The transparent red piece in the image is a 3D printed gear





guard that connects to the chassis with M3 screws. The gear guard is put over the gear to protect any foreign objects from interfering with the gear and the motor.

Wiring Diagram



The above image is a computer-generated diagram of the entire wiring network. All wires are color coded; **red representing the positive charge** and **black representing the negative charge**. We incorporated the following electronics: servomotor, Electronic Speed Controller (ESC), battery, buck convertor, motor, and a receiver. We powered the ESC and the buck converter with a 3600 mAh battery. The ESC controls the speed of the motor. The buck converter steps down the 7.2 V from the battery to a constant 5 V, and feeds this into the servo motor. The receiver is connected to both the servo motor as well as the ESC. This takes input from the transmitter and controller both the servo and the motor allowing us to remotely control the rover.

Action Item Report

Task Assignment

Each week during the quarter (besides Week 1), we met on Thursday from 2-3pm at the most convenient and appropriate location. In Week 2, each member of the team was assigned a role as listed below.

- Team Captain: Alex
- Electronics: Brady
- CAD Design: Bryant
- Research: Darcy, Emely
- Fabrication: Christine R,. Christine Y.

We treated the team member who was in charge of each respective job as the leader in getting their job done. For example, if Bryant needed help completing the CAD Design, it was his job to delegate the tasks to other team members. This way, although everyone was assigned one job, everyone had an opportunity to partake in every task.

The following is the Action Item Report for each week:

- **Week 2**:
    - Assigned Roles (Team Captain, Electronics, CAD Design, Research, Fabrication)
    - Created Team Name
        - Named after Mott's fruit snacks!
    - Began researching rover designs and steering systems

- **Week 3**:
    - Created Gantt Chart
    - Designed Chassis in SDW
    - Continued researching steering systems

- **Week 4:**
  - Redesigned Chassis
    - Our first chassis design was deemed too hard to replicate by the TA's
  - Designed Steering System
  - Decided on Gear Ratio
    - 64T
  - Designed Rear Axle System
  - Created PO Form

- **Week 5:**
  - Redesigned Steering System
    - Originally Rack and pinion. Reasons included being too hard to replicate and its specifications
    - Our new steering system is much easier to fabricate and fits the steering mechanism
  - Began brainstorming Extra Credit Video
    - Timelapse of work progress
  - **PO Form: Due November 3**

- **Week 6:**
  - Created Gear Guard
  - Finalized SDW Design
  - Put all parts into CAD assembly
  - **Final Solidworks design: due November 10**

- **Week 7**:
  - Fabricated Chassis
    - Setback: our chassis blew up and we had to re-fabricate another chassis
  - Fabricated Rear Axle System
  - **Preliminary presentation slides: due November 17**

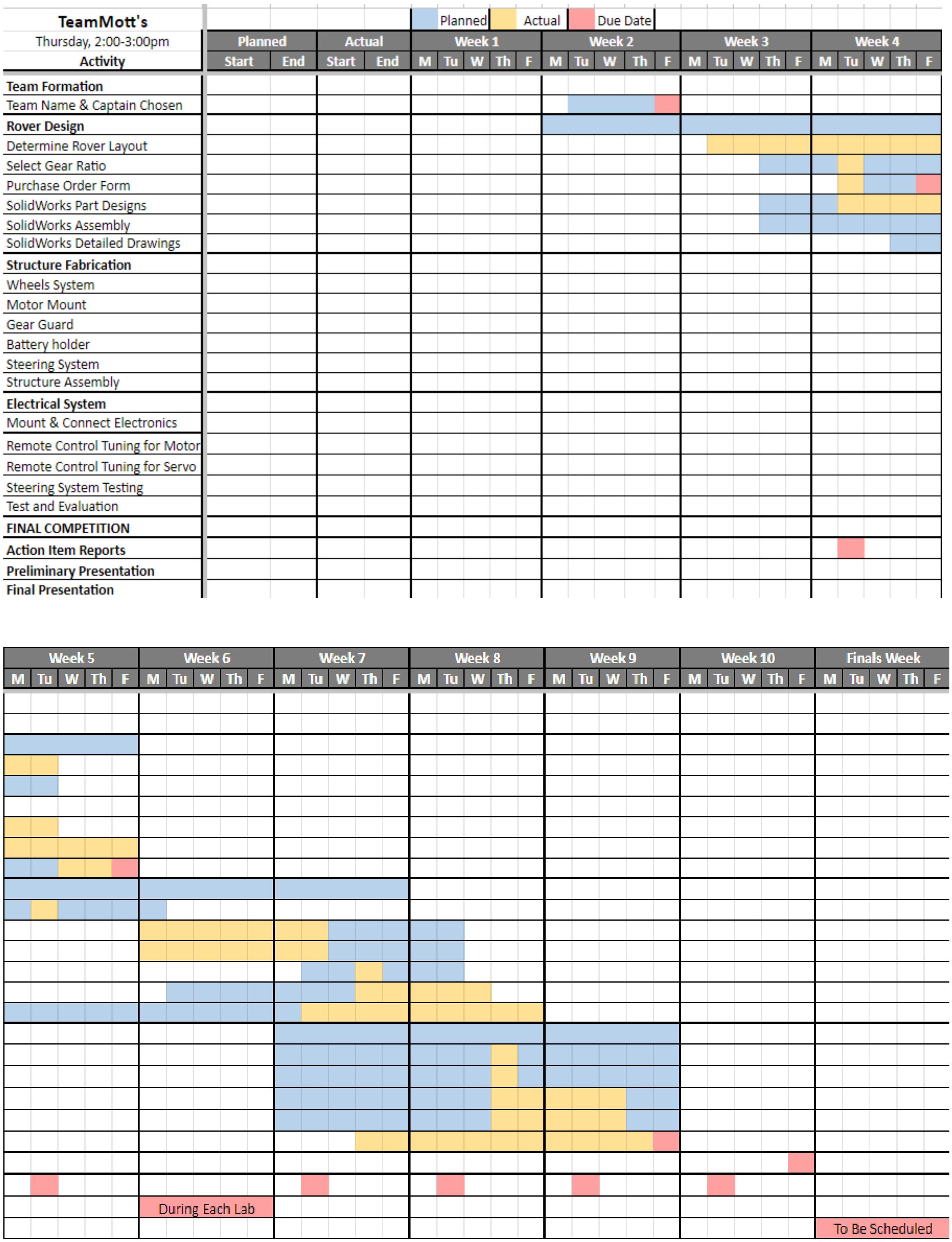
- **Week 8:**
    - Fabricated Steering System
    - Signed up for open lab days
        - Assembled Electronics
        - Tested Electronics
    - **Rover: turned in on November 22**

- **Week 9:**
    - Tested Rover
    - Adjusted Steering System

- **Week 10:**
    - **Competitions (12/6 @ 1pm, 12/7 @ 3pm)**
        - First round: 8th place
        - Second round (top 10 round): 6th place

- **Finals Week**
    - **Final presentation, video, and design report due on day of presentation (12/11 @ 4pm)**

Gantt Chart


Planned
Actual
Due Date
TeamMott's
Thursday, 2:00-3:00pm
Activity
Planned
Actual
Start
End
Start
End
Week 1
Week 2
Week 3
Week 4
M Tu W Th F
Team Formation
Team Name & Captain Chosen
Rover Design
Determine Rover Layout
Select Gear Ratio
Purchase Order Form
SolidWorks Part Designs
SolidWorks Assembly
SolidWorks Detailed Drawings
Structure Fabrication
Wheels System
Motor Mount
Gear Guard
Battery holder
Steering System
Structure Assembly
Electrical System
Mount & Connect Electronics
Remote Control Tuning for Motor
Remote Control Tuning for Servo
Steering System Testing
Test and Evaluation
FINAL COMPETITION
Action Item Reports
Preliminary Presentation
Final Presentation
Week 5
Week 6
Week 7
Week 8
Week 9
Week 10
Finals Week
During Each Lab
To Be Scheduled

Evaluation

Calculations

Estimated Weight of Vehicle:

$$Weight \approx \Sigma(W_{Each\ component}) = W_{Battery} + W_{Chassis} + W_{ESC} + W_{Motor} + W_{Servo} + W_{Buck\ Converter} + ...$$
$$... + W_{Wheels} + W_{D-Shafts} + W_{3D\ Printing}$$

$$Weight \approx 0.367\ Kg + 0.2\ Kg + 0.1\ Kg + 0.082\ Kg + 0.22\ Kg + 0.016\ Kg + 0.17\ Kg + ...$$
$$... + 0.072\ Kg + 0.1 Kg = \mathbf{1.39\ Kg}$$

The actual weight of the Rover is 1.2 Kg, which is 0.19 Kg less than our estimated weight. This is likely due to inaccuracies in the listed weights for each part and rounding.

Predicted drive time:

$$DC\ Motor\ Stall\ Current = \frac{(Battery\ Voltage)}{(12V/5A)} = \frac{7.2V}{(12V/5A)} = 3A$$

$$Servo\ Stall\ Current = 3A$$

$$Drive\ Time = \frac{(Battery\ Capacity)}{(DC\ Motor\ Stall\ Current)+(Servo\ Stall\ Current)} = \frac{3.6Ah}{3A+3A} = 0.6\ Hours = \mathbf{36\ Minutes}$$

Gear Ratio:

There were 3 options for the gear: 40T, 52T, and 64T. The higher the gear ratio, the *higher the torque*, but the *lower the speed*. The torque and the speed can be found using the following formula where N_2 is the number of teeth on the output gear and N_1 is the number of teeth on the input gear.

$$Mechanical\ Advantage = \frac{N_2}{N_1} = \frac{T_2}{T_1} = \frac{\omega_1}{\omega_2}$$

Using this formula, the Torque and the Speed for each gear is listed below. Also, the Stall Mass can be experimentally measured by finding the lowest mass that the motor cannot lift using each gear. It is also listed below.

- **40T:**
  - Torque = 0.2895 Nm
  - Speed = 0.4 ω_{Motor}
  - Stall Mass = 1.672 Kg
- **52T:**
  - Torque = 0.3716 Nm
  - Speed = 0.308 ω_{Motor}
  - Stall Mass = 1.967 Kg
- **64T:**
  - Torque = 0.4574 Nm
  - Speed = 0.25 ω_{Motor}
  - Stall Mass = 2.756 Kg

Since the exact mass was unknown at the time, and the speed loss using the 64T gear was not too significant (0.25 times the input speed instead of a max of 0.4 times the input speed), we chose to use the 64T gear. This choice valued torque and therefore controllability over speed. Another reason for this choice was that, while moving up the ramp on the course, the rover would need a higher torque in order to not stall and be unable to drive up the ramp.

Turning Radius:

$$Turn\ Radius = \frac{Wheelbase}{tan(angle)} = \frac{27\ cm}{tan(57\ degrees)} = \boldsymbol{17.53\ cm}$$

Test Plan

The Rear axle system, which includes the motor, gear guard, and rear wheels, was tested throughout the design process. We first combined all the parts in a Solidworks Assembly, and created mates so the system would interact as it would after fabrication. We moved the axle below the chassis to raise the rover and to make it easier to pass over obstacles. After we were satisfied that the system was working properly, we added sleeve bearings and shaft collars to the assembly. The system was then fabricated and assembled. We glued an extra piece of wood to the chassis to strengthen the bond from the rear axle mount to the chassis, and we loosened the fit of the sleeve bearings to allow the D-Shaft to rotate with less friction. After we were satisfied that the system was working properly, we did our full integration test.

The Steering System was tested in a similar way. We first made our design on Solidworks and used mates to create the assembly. We made sure that the wheels moved as predicted when moving only the servo horn. We made adjustments to minimize material and optimize the turn radius. We also ensured that the 2 inch D-Shaft, sleeve bearings, and shaft collars could fit, and we changed connections from PLA on PLA to M3 Screws. We also ensured that the model was less than 10 inches wide so the rover would follow the guidelines. After we were satisfied with the CAD, we fabricated the steering system. To test it, we first held it off the ground to make sure nothing would break while we first tested the turning. We determined that we needed a smaller turn radius, so we redesigned the servo adapter to be longer. The servo adapter also snapped when driving over the cones, and there were screws that stopped the system from using its full range of motion, so we redesigned one to be stronger and better fitted to the design. When we tested the rover, we noticed that the turn radius when turning right was too large because the rod was hitting a screw on the servo horn. To fix this we moved the screws to only the holes opposite from that rod.

The testing of the electrical system was quick. We connected all the parts (while not connected to the chassis) according to the wiring diagram. After adjusting the buck converter voltage and ensuring the servo and motor operated as planned, we attached all the parts to the Chassis. We then did a full integration test with no problems.

Results & Discussion

Overall, the rover performs well. **Our rover ran the course in 26.75 seconds, which is 8th fastest out of 56 teams.** Because we were top 10, we competed in the final competition on a harder course. We finished with a time of 36 seconds plus a 10 second penalty for hitting a cone. This awarded us 6th in the competition. Our rover fits all the requirements, and it is stable and relatively lightweight. The rover drives at a fast speed, but not too fast that it is uncontrollable, so the choice of gear ratio was good. The rear axle system is very stable and durable. It does its job perfectly, and there is very little that we would do to the system to make it better. However, if we were going to make another rover, there are some things we would change.

First, the steering system has a few concerns. **The connection from the steering system to the 2 inch D-Shafts are a little unstable and wobbly.** This is because the hole for the sleeve bearing is the same diameter all the way through, and does not take into account the length of the sleeve bearing. For this reason, the 3D printed connection could break under a stronger weight. To fix this problem, we could make the hole shorter, so it is just the length of the sleeve bearing. This would reduce the torque on the plastic and reduce the shaft's ability to wobble.

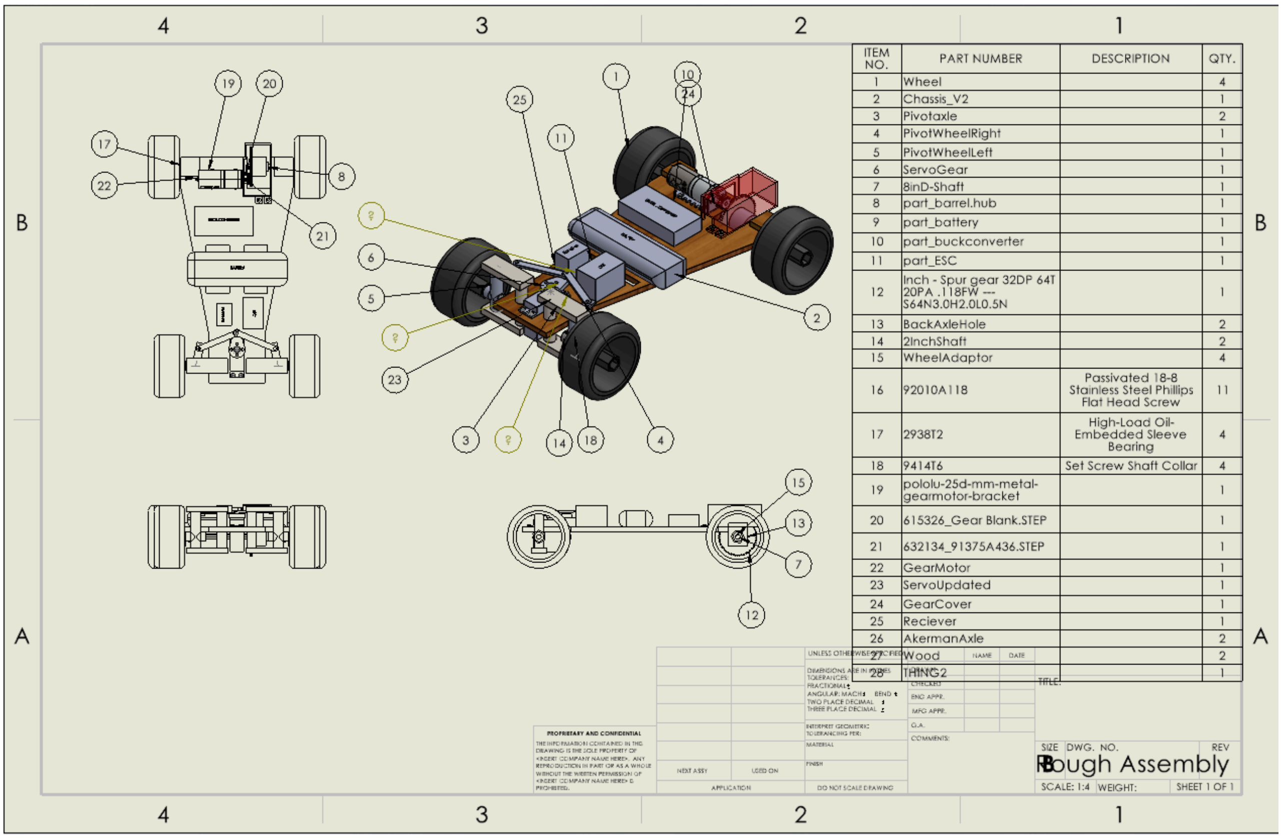
Also, one of the rotating parts in the steering system is PLA on PLA. This creates more friction than if the connection was just an M3 screw. The simple fix is to make the steering system shorter, so all the connections can be M3 screws.

Another problem is that the connection from the wheel mount to the chassis is made with glue. This means that the connection is not as strong as it could be, and it is difficult to take apart if changes need to be made. It also made fabrication difficult, causing the parts to be not completely straight. Additionally, because this connection was made with glue, it came loose after a lot of testing, meaning we had to re-glue it. We ended up having to attach an extra piece of wood to make the connection more sturdy. With all of these considerations in mind, the steering system would need a redesign to have all M3 screw connections, bigger, more durable parts, and stronger, less wobbly connections to the D-Shafts.

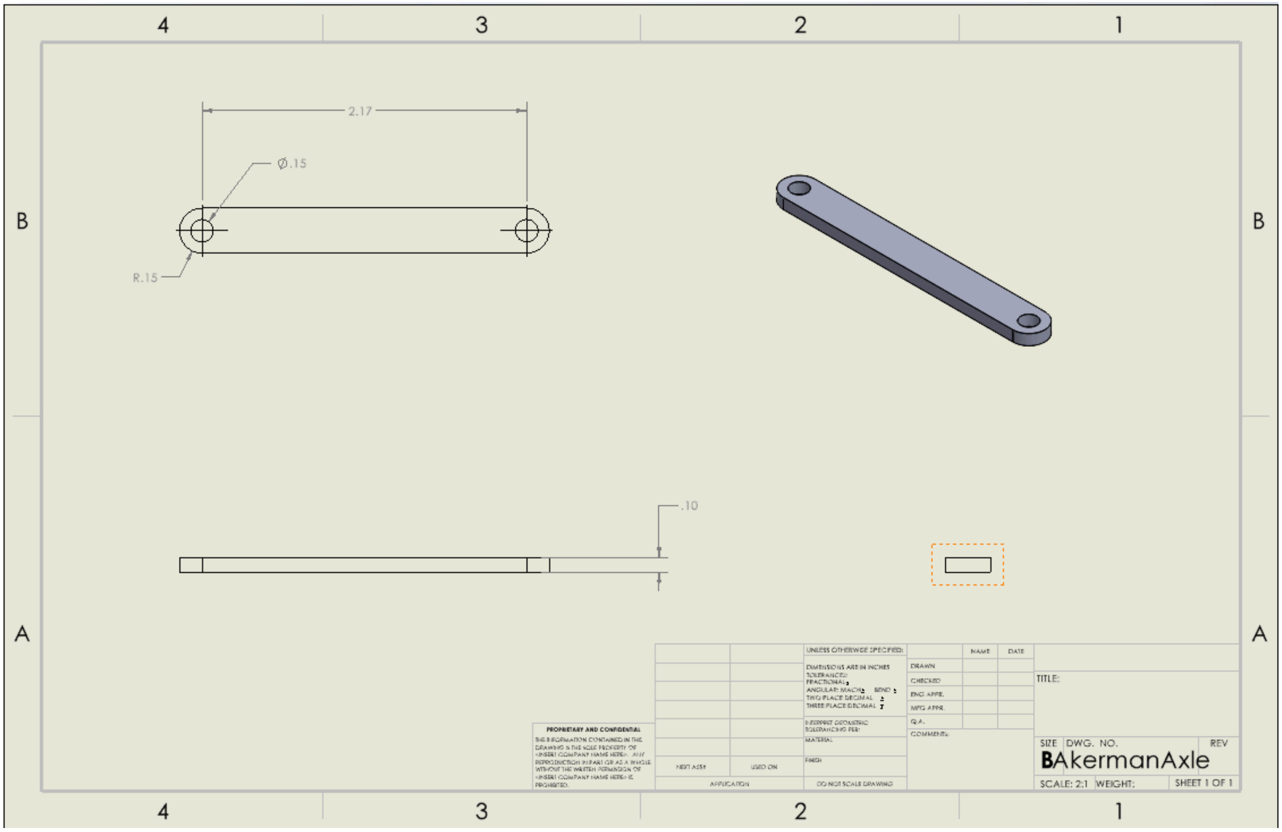
The last change we would make is to **make the chassis shorter.** We overestimated how much space the electrical components would take, so we had room to shorten the chassis. Our rover can go over the ramp obstacle on the course, but it touches the top, so it could get stuck if it does not have enough speed. If we shortened the chassis or lowered the rear wheels, it would go over the ramp much easier.

Appendix A: SOLIDWORKS Drawings

Final design drawings, individual parts, and full assembly, updated from Week 5 submission.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Wheel		4
2	Chassis_V2		1
3	Pivotaxle		2
4	PivotWheelRight		1
5	PivotWheelLeft		1
6	ServoGear		1
7	8inD-Shaft		1
8	part_barrel.hub		1
9	part_battery		1
10	part_buckconverter		1
11	part_ESC		1
12	Inch - Spur gear 32DP 64T 20PA .118FW --- S64N3.0H2.0L0.5N		1
13	BackAxleHole		2
14	2InchShaft		2
15	WheelAdaptor		4
16	92010A118	Passivated 18-8 Stainless Steel Phillips Flat Head Screw	11
17	2938T2	High-Load Oil-Embedded Sleeve Bearing	4
18	9414T6	Set Screw Shaft Collar	4
19	pololu-25d-mm-metal-gearmotor-bracket		1
20	615326_Gear Blank.STEP		1
21	632134_91375A436.STEP		1
22	GearMotor		1
23	ServoUpdated		1
24	GearCover		1
25	Reciever		1
26	AkermanAxle		2
27	Wood		2
28	THING2		1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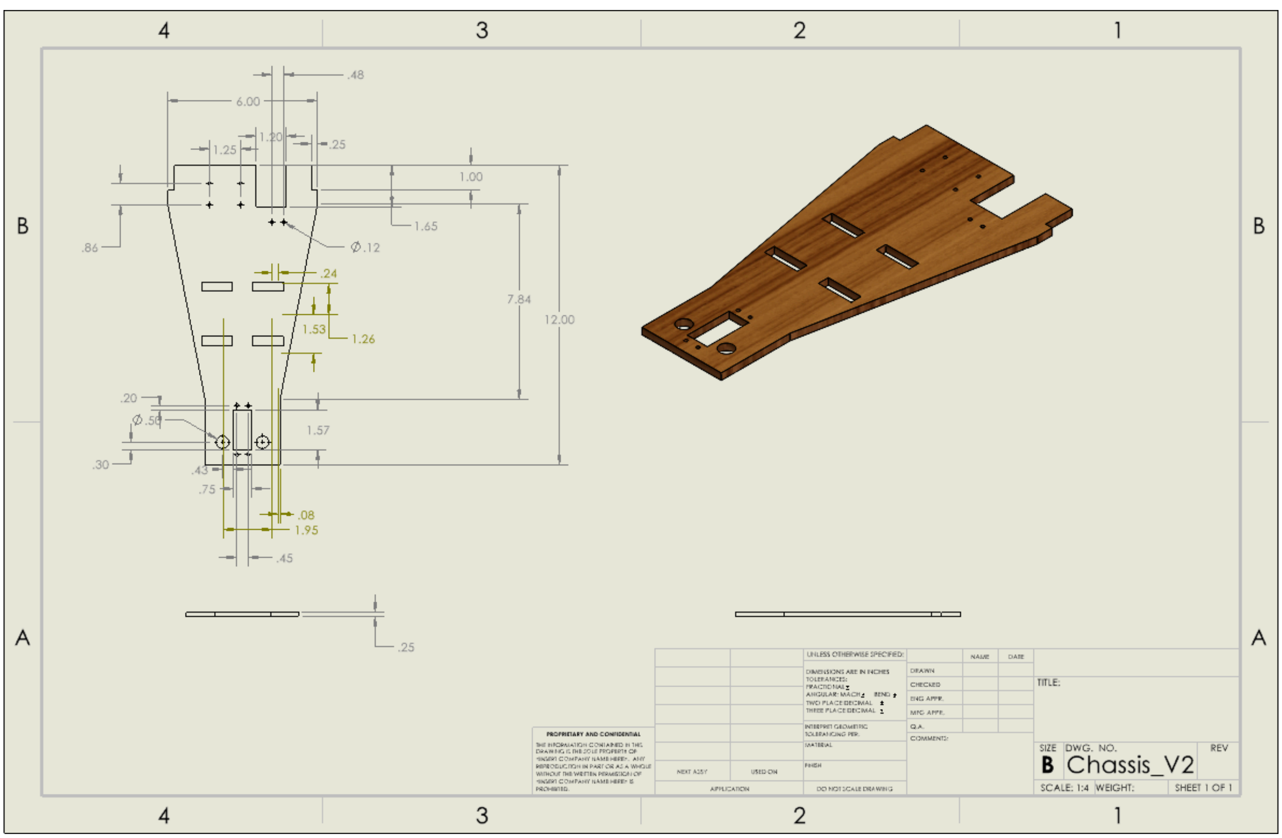
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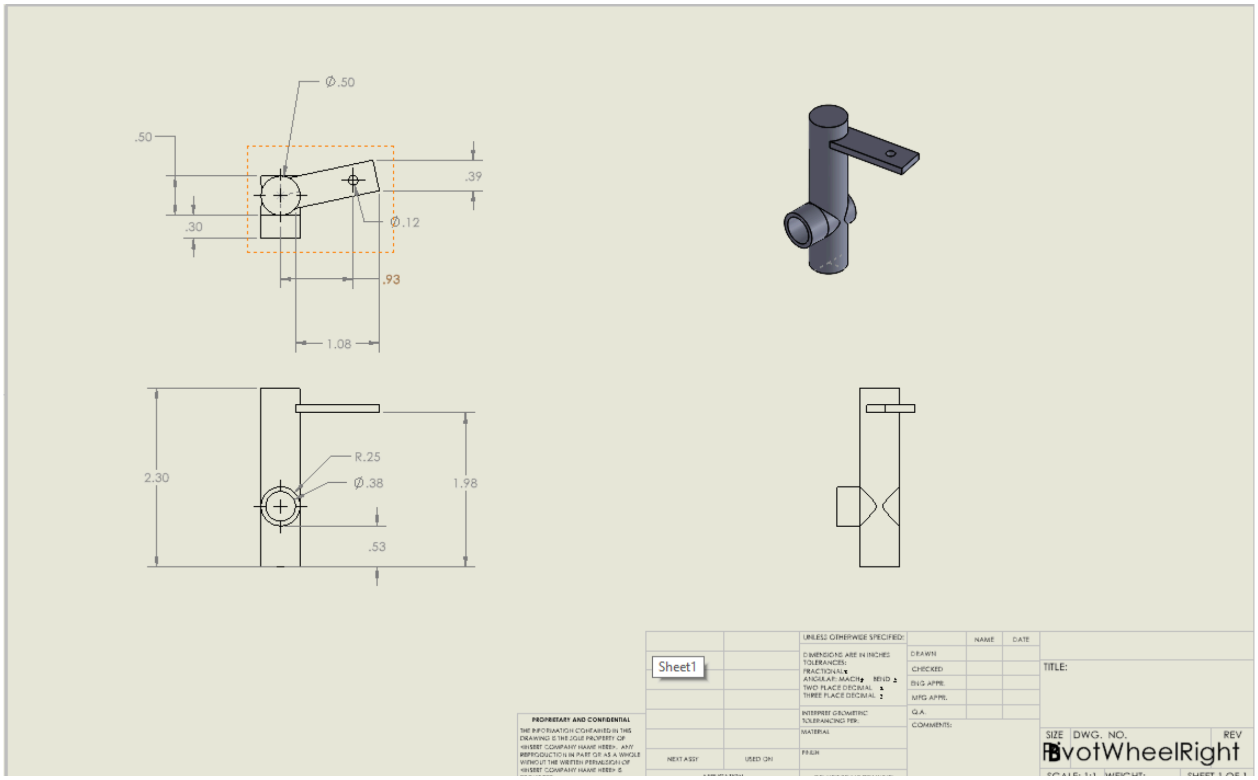
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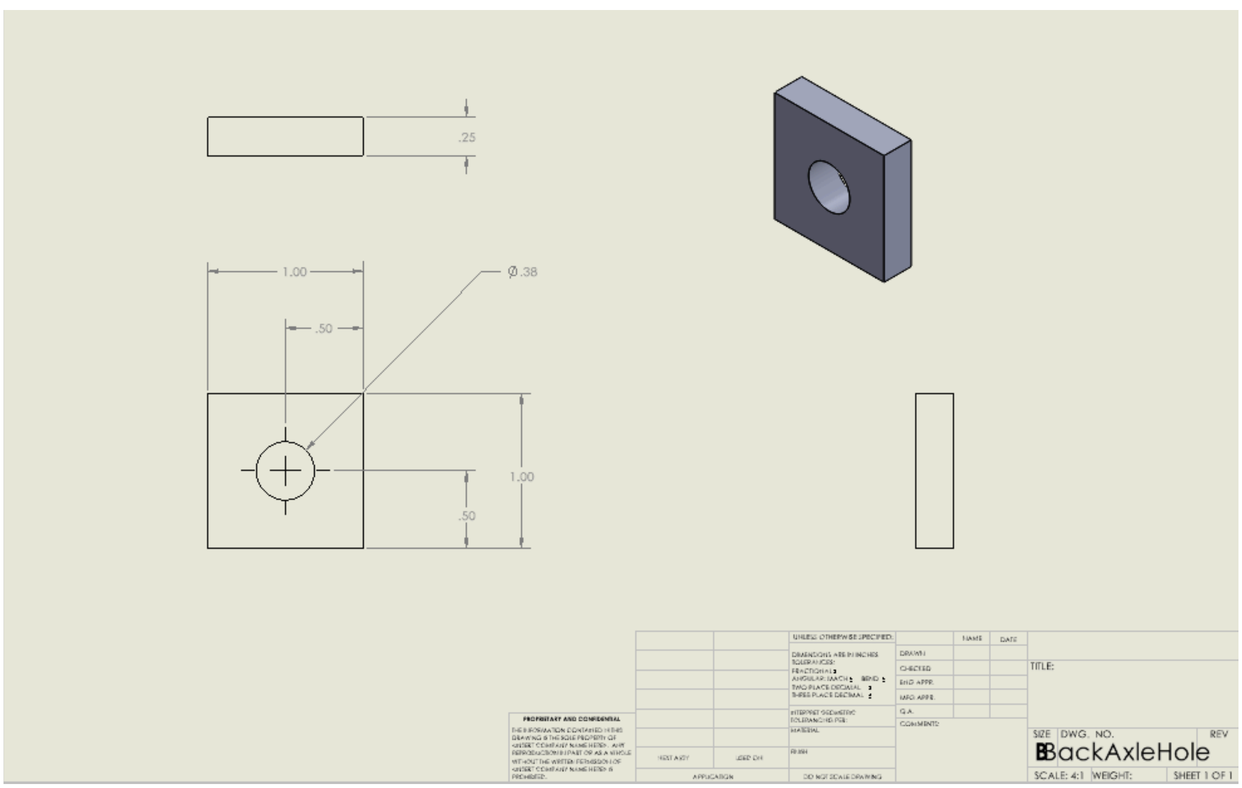
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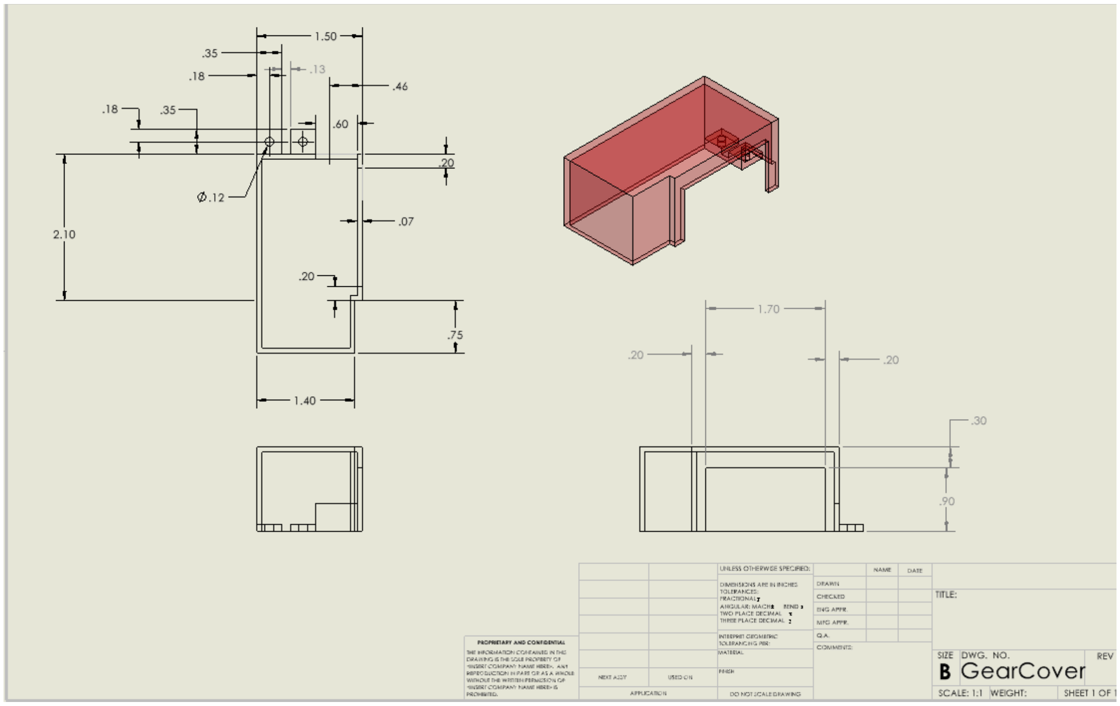

1.50
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1.40
1.70
.20
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.30
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UNLESS OTHERWISE SPECIFIED:
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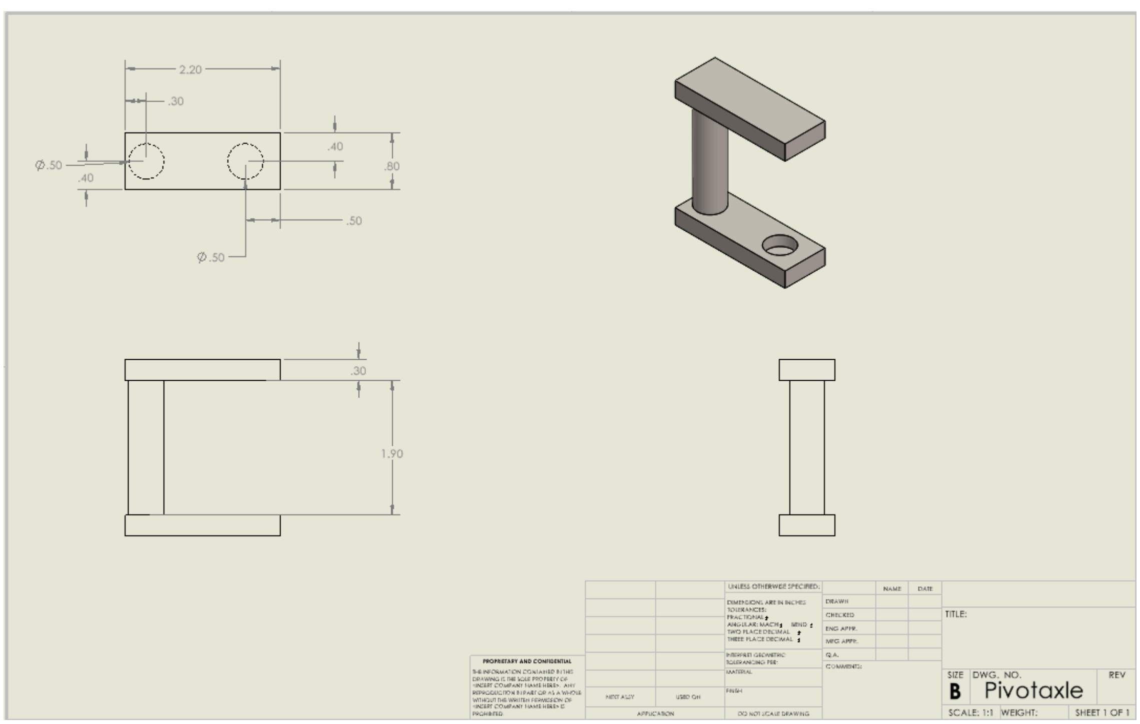

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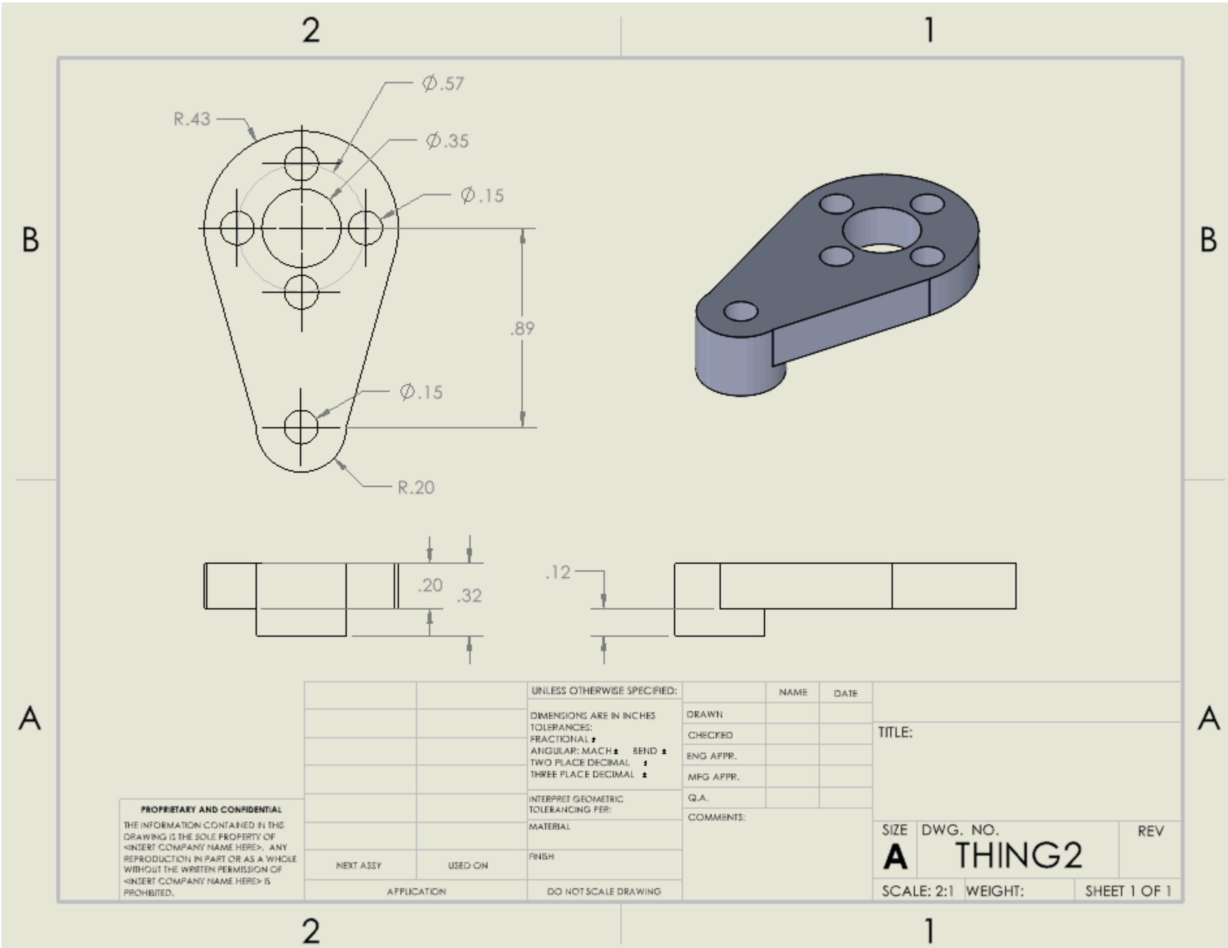
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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
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ANGULAR: MACH ± BEND ±
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SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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Appendix B: Bill of Materials

Quantity*	# of Units in package*	Company*	Item Description*	Catalog/ASIN #*	Price*	Estimated Extended Price*
4	4	Amazon	85 mm Wheels	B07BS9QJ8L	$18.50	$18.50
1	1	Serviocity	64T Gear	RHA32-36-64	$6.16	$6.16
1	1	Pololu	4.4:1 Metal Gearmotor 25Dx48L mm HP 12V	3201	$28.95	$28.95
1	4	Amazon	Servo	B07MFK266B	$20.99	$5.25
1	2	Amazon	320A 6-12V Brushed ESC Speed Controller	B087NF55VD	$23.46	$11.73
1	4	Amazon	5A DC-DC Adjustable Buck Converter 4~38v to 1.25-36v	B079N9BFZC	$14.99	$3.75
1	1	Amazon	6 Channel Digital Transmitter and Receiver Radio System	B00KHJ262Y	$60.00	$60.00
1	2	Amazon	7.2V 3600mAh RC NiMH Battery	B07VLKP6RJ	$34.99	$17.50
2	2	Pololu	25D mm Metal Gearmotor Bracket	2676	$7.95	$7.95
1	10	Amazon	Servo Horn Metal Aluminum 25T	B07D56FVK5	$9.99	$1.00
2	1	Servocity	1/4" D-Shaft (Stainless Steel, 2" Length)	2101-1250-0200	$1.69	$3.38
1	1	Servocity	1/4" D-Shaft (Stainless Steel, 8" Length)	2101-1250-0800	$3.69	$3.69
4	1	McMaster	1/4" Sleeve Bearing	2938T3	$0.92	$3.68
8	1	McMaster	1/4" Shaft Collar	6432K12	$1.49	$11.92
4	2	Pololu	12mm Hex Wheel Adapter for 6mm Shaft	2686	$4.95	$9.90
1	1	Servocity	1/4" D-Bore Barrel Hub	545692	$2.80	$2.80
1	1	Servocity	4mm Bore 32 Pitch, 16T Shaft Mount Pinion Gear	615326	$7.99	$7.99
1	1		1/4" birch baltic plywood 12"x12"		$2.78	$2.78
1	1		3D Printing - 7 hrs		$28.00	$28.00
					Subtotal	**$234.92**
				*Tax rate:	7.75%	$18.21
					TOTAL ORDER PRICE	**$253.13**