Section: ENES 100 Section 0201

Team: POG (Group 1) - Data Extraction

Assignment: MS9 Final Design Briefs

Contributions:

Name	Contribution(s)
Alex Paul	6 | Troubleshooting and Iteration and outline for 7 | Teamwork and Project Management
Cory Tran	Worked on the propulsion portion of the MS9 design brief.
Seth Boledovic	Mission briefs, construction for mission, formatting, images.
Isabelle Bryden	worked on electronics brief; updated schematics in circuit lab
Zam Nwosu	Worked on electronics brief, sensor details and information.
Alex Yogiaveetil	Worked on teamwork and project management brief
Joshua Sambrano	Engineering drawings, chassis construction, 3d printing & fastening, images, CAD
Noah Wigglesworth	General formatting, constructing a prototype, mission, engineering drawings sections.

Milestone 9: Final Design Briefs

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ENES 100-0201: Introduction to Engineering Design

P.O.G. - Group 1

Dr. John Cummings

May 15th, 2023

0 | Contents

1 | Constructing a Prototype

Mission Requirements

Chassis

1. Total OTV mass including chassis must be no heavier than 3 kg.
2. Pre-built chassis assemblies may perform functions from at most two of the following categories: (1) motors / gearmotors; (2) wheels / tires / treads; (3) suspension; (3) transmission / differential / drivetrain; (5) motor controllers.
3. No building-systems or robotics kits such as Lego, Knex, Vex are allowed.
4. There must be an Aruco tracking marker with dimensions between 50x50mm and 100x100mm with a 15mm white border placed on the top of the vehicle/chassis.
5. No exposed pins, nails, razor blades, or other dangerously sharp objects are permitted on the OTV/chassis.
6. Total as-built replacement cost must be less than $320.

Mission

1. Navigate to within 150 mm of the pylon with the data extraction arm above the pylon.
2. Lower the arm into a pylon and ensure a good data connection.
3. Extract and transmit the duty cycle of the signal square wave to within 5 percent.
4. Identify and transmit the material in the base of the pylon.
5. Raise the data extraction arm and back away from the pylon.

Propulsion

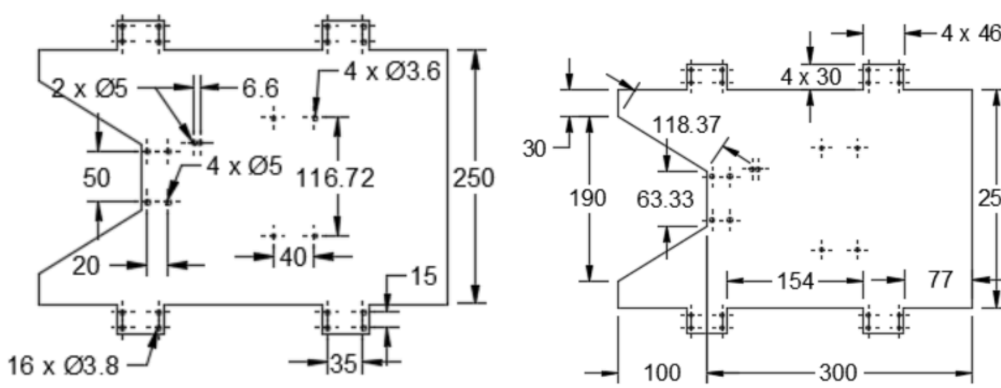
1. Navigate through the arena moving forwards and backwards within the required time frame.
2. Generate enough torque to steer in both directions while navigating through the arena.
3. Generate enough torque to clear the log.
4. Use wheels powered by DC gearmotors to actuate the propulsion system.

Electronics

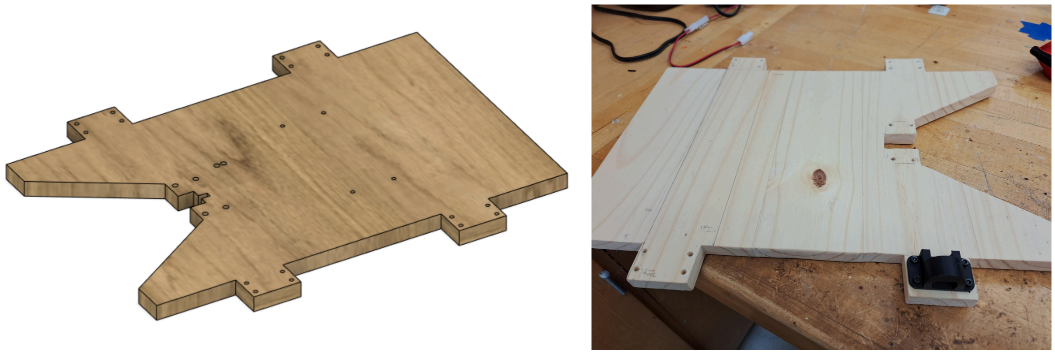
1. Lithium-ion, lead-acid batteries, and the use of combustion engines are prohibited
2. Must be able to run all systems at full power for 10 minutes without recharging
3. All batteries must be rechargeable
4. All batteries must be operated with a mechanical kill switch at all times
5. Only exception to this requirement is single cell 9V batteries if used to power the microcontroller
6. Batteries with exposed leads for recharging must be equipped with male/female Tamiya (or similar) connectors
7. OTV must be controlled by an Arduino compatible microcontroller

Chassis Construction

The chassis is made of thick birch plywood. It was first trimmed down to its intended 15-mm height using the planer and then cut to its width and length using the vertical bandsaw. Cutting with the bandsaw was tricky, as the designed cutout included a triangle shape. This required attacking the wood at a certain angle and using multiple cuts. We also had to account for the extrusion of four rectangles, where the motor mounts would be later placed.

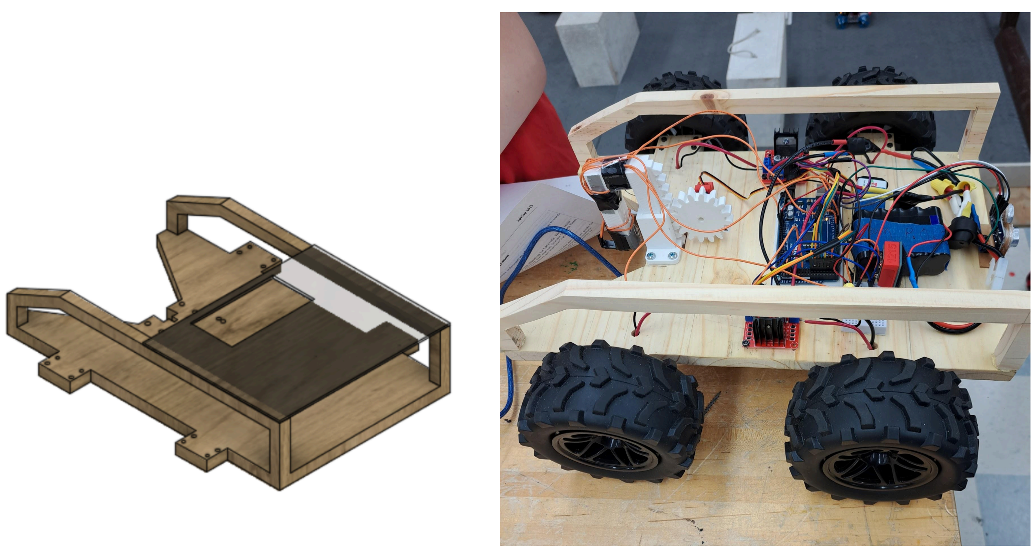


Dimensioned drawings of the chassis and cutouts.



Rendering of chassis and the chassis after being cut to the proper dimensions.

The outer structure of the OTV was built with the same wood that constructed the chassis. Two cutouts were made via the vertical bandsaw that represented each end of the structure, and they were sanded afterwards for a smooth finish. A “sunroof”-type acrylic cover was placed on the back of the OTV, where the Aruco marker is placed. A 50 mm x 120 mm rectangular cutout was made 10 mm from the front end of the sunroof in order to access the Arduino and wiring.



A rendering of the proposed chassis sunroof and the OTV with the newly-cut roof supports installed.

3D Printing and Fastening

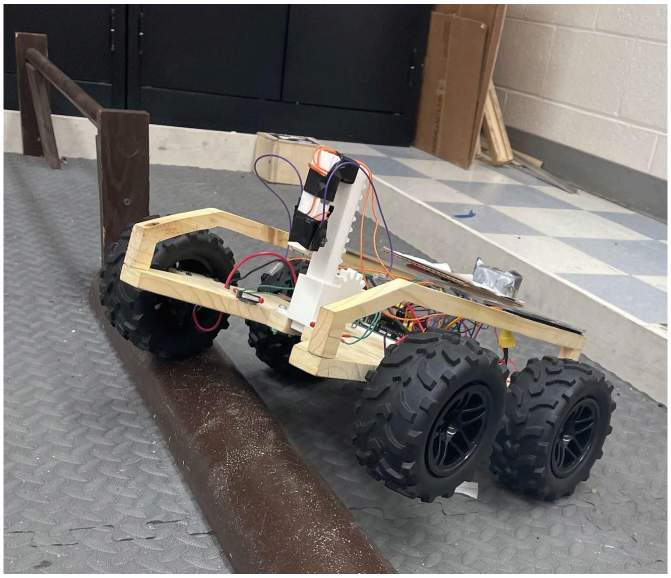
The mounts for the motors and Arduino were 3D-printed using PLA as well as the parts for the arm (gear, rack, pinion, base, and the actual arm). The arm assembly was pinned down using 5-mm bolts (see below), while M3 bolts were used to mount the other components. The tires, along with the hex wheel adapters and supporting bolts, were also assembled from their respective kits. The H-bridges were mounted onto the chassis with screws and two limit switches were fastened at the back of the chassis cutout. The ultrasonic sensor was glued to its mount and fastened to the rear of the chassis.

Velcro was placed near the center of the chassis and attached to both the 9V and 12V batteries. They held the batteries in place and would hold them when the OTV was tilted on the traversable obstacle while allowing them to be switched out for charging.

Propulsion and Wiring

First, the high-gauge stranded battery wires were prepared. This included wires for the tamiya connector and cutoff switch system. These wires were cut and soldered according to schematics and were prepared with heat-shrink tubing. These wires were trimmed and reconnected with wire nuts a number of times after full installation to help with wire management. Then, power and ground wires were prepared for the motors. 8 high-gauge stranded wires were cut and carefully soldered to the motors. The motors were then friction-fit into their mounts and secured from vibration with hot glue, with their gear boxes protected by a layer of electrical tape.

The motor wires were routed through a hole in the chassis and screwed into the H-bridges. The Arduino was wired with small, 22-gauge wires and was connected to the H-bridges as well as all sensors, actuators, and the 9V battery, per our schematics. The wheels were then screwed into the hex adapters and the hex adapter screws were tightened onto the axles of the motors.

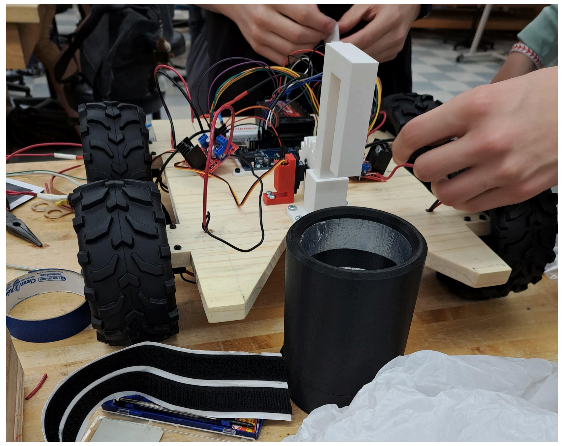


The fully wired OTV hitting some terrain.

Mission Construction

After 3-D printing all relevant parts of the mission apparatus they were attached to the chassis. First the arm base was fastened to the front of the chassis flush with the front through the use of 5mm bolts after making a small cutout that matched the dimensions of the arm with the bandsaw. This was done to ensure the arm could go directly through the chassis and allowed the top of the arm to reach deep into the pylon for the reed switch to detect magnetism.

The next step was mounting the servo, with the custom printed mount. In order for the servo to fit in the mount a hole was drilled through the back to feed the wiring through. The gear was then superglued to the servo directly, with precautions being taken to ensure the gear would rotate properly and not shift while in place. The arm was put into the base and the servo mount was bolted through the chassis at the correct distance in which the gear lined up perfectly with the pinion on the back of the arm. The arm was placed in a position to ensure that full translation would occur when the servo turned.



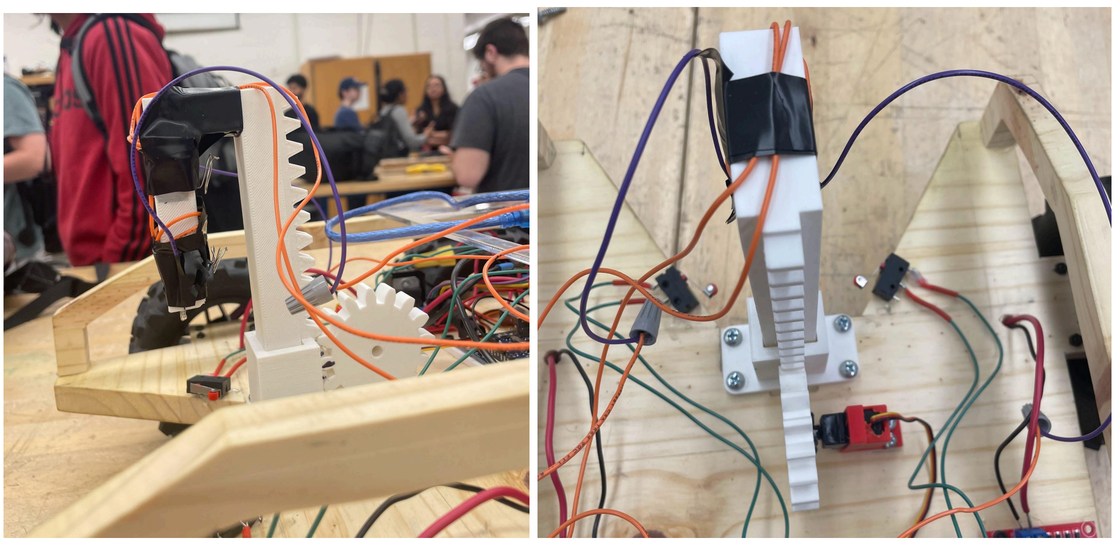
Team members carrying out the first test of the arm assembly.

The final piece of mission construction revolved around mounting the reed switch and wiring for duty cycle measurement. Marks were placed on the arm in order to line up the wiring with the two "nodes" on the inside of the pylon. Wire was then stripped to expose the metal directly and taped onto the arm in a spring like form to ensure a good connection when the arm was translated into the pylon. Wires were soldered onto the ends of the reed switch and it as well was taped onto the base of the arm at the furthest point, to ensure that it would not hit the rim of the pylon but still be close enough to read the magnetism of the puck.

2 | Mission

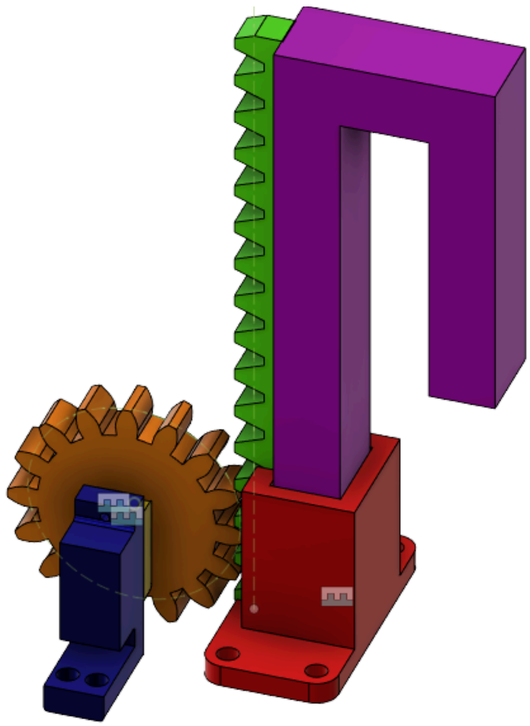
Mission Structure

Our mission apparatus utilizes a data extraction arm controlled by an HS-53 servo motor. The servo motor is attached to a 40.5mm gear, which interacts in a rack and pinion format with the U-shaped arm. This system is able to raise and lower the arm into and out of the pylon +/- 65mm.



The fully assembled arm is seen here attached to the chassis.

The arm-rack is 3D-printed from PLA plastic and is attached inside of a 3D-printed vertical rail. The rail is permanently fixed to the chassis using fasteners which prevents unnecessary arm motion and enables up/down translation. The arm is centered on the front of the OTV with the arm reaching out over the triangular cutout in the chassis. The arm rail is placed at the base of the cutout.



A CAD rendering of the arm assembly

The HS-53 servo motor is mounted in a custom 3-D printed case made from PLA plastic which is attached to the base with fasteners. The case is placed perpendicular to the rack for the gear and the gear is super glued onto the servo itself. This allows the gear to be rotated by the servo with full torque and allows for arm translation the full distance.

The mission's requirements are fulfilled by using a number of data collection sensors. A reed switch is used to determine the magnetism of the puck at the base of the pylon. A set of wire-spring contacts are attached to the inside face of the arm and contact the data outputs upon actuation. The wire carries the voltage output from the pylon to the Arduino for measurement. This voltage is recorded over a given time period and averaged in order to calculate duty cycle. This result and the magnetic reading are transmitted to the lab computer.

Mission Sensors and Actuators

Our mission utilized a combination of a servo motor and 5 sensors to complete its mission objectives

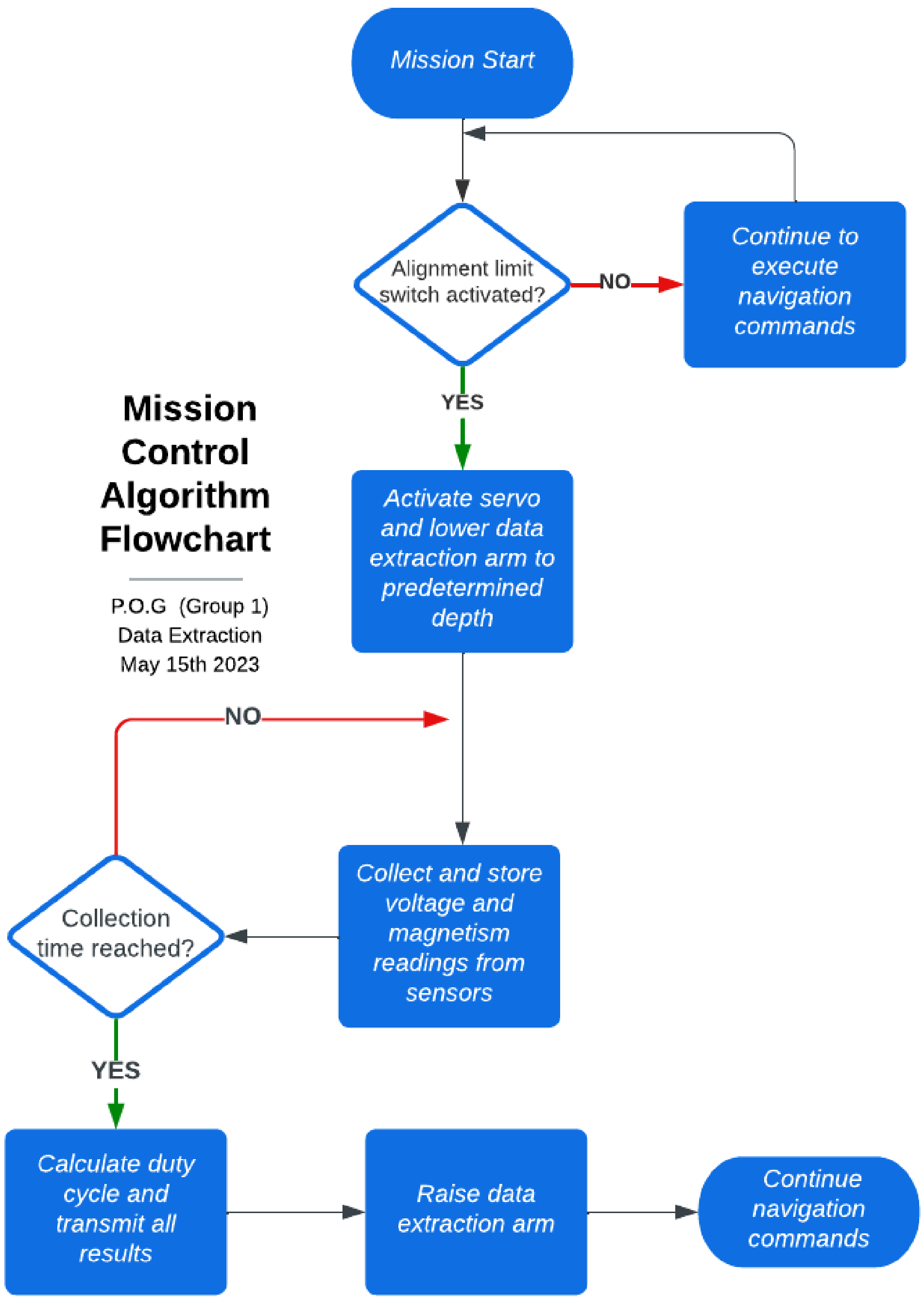
(Figure 2a) Sensor and Actuator Table

Sensor	**Qty**	**Description**	**Power**	**Attachment**
Reed Magnetic Switch	1	Magnetic sensor, can detect a magnetic field from 0 - 40 mm away.	DC 5V. See table in section 4 for current draw.	Electrical tape
HS-53 Servo Motor	1	Rotary actuator used to rotate gear for arm movement. 180 degree rotation, stall torque: 26.53 oz-in (1.91 kg.cm).	4.8-6V. See table in section 4 for current draw.	5mm screws @ 40mm length, gorilla glue
HiLetgo Micro Limit Switch	2	Used to detect the physical presence of an object. Triggered when physically pressed. 20 x 10.5 x 6.5mm (L x W x H)	AC 125V - 250V. See table in section 4 for current draw.	Hot glue
Wire-spring contacts	2	Used to connect to the payload data ports and read voltage for duty cycle.	5V. N/A current draw	Electrical tape

Flowchart of Control Algorithm

Our mission concept of operators (CONOPS) followed the structure below.

(Figure 2b) Flowchart



3 | Propulsion Modeling

Propulsion Details

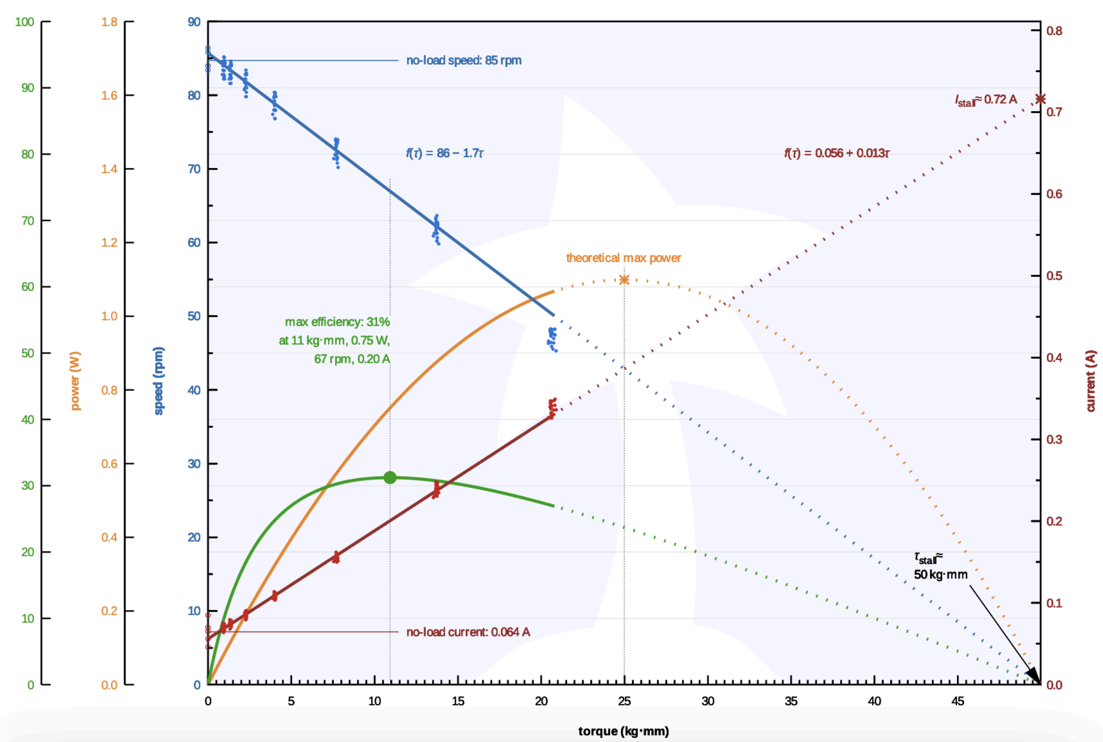
Our propulsion system consists of 4 wheels and 4 DC gearmotors. The motors will be located underneath the chassis and will be held by 3D printed motor mounts. We are using large (0.068 meter radius) rubber tire wheels with a positive offset to emulate an off-road system in order to navigate through the tough terrains of the arena. The motor selected is a Pololu 12V Metal Gearmotor (HPCB) with a No-Load Speed of 85 RPM and a Stall torque @ 12V of 5.0 kg cm. Our drivetrain will be 4WD (4-Wheel Drive) and our steering system will include a skid steering which involves controlling the speed and direction of the left and right wheels independently.

Predicted Motor Behavior

(Figure 3a) Characteristic Graph

Operating point is at max efficiency, torque is 11 kg ˙ mm (1.1 kg ˙ cm)

Angular speed is: angular speed = 67 rpm ˙ (2π rad /1 rev) ˙ (1min/60s) = 7.02 rad/s



(Figure 3b) Motor Specifications

Dimensions

Size:	10 × 12 × 26 mm[1]
Weight:	9.5 g
Shaft diameter:	3 mm[2]

General specifications

Gear ratio:	379.17:1
No-load speed @ 12V:	85 rpm[3]
No-load current @ 12V:	0.08 A[4]
Stall current @ 12V:	0.75 A
Stall torque @ 12V:	5.0 kg·cm[5]
Max output power @ 12V:	1.1 W[5]
No-load speed @ 6V:	43 rpm[6]
No-load current @ 6V:	0.04 A[6]
Stall current @ 6V:	0.38 A[6]
Stall torque @ 6V:	2.5 kg·cm[6]
Extended motor shaft?:	Y
Long-life carbon brushes?:	Y
Motor type:	0.75A stall @ 12V (HPCB 12V - carbon brush)

Performance at maximum efficiency

Max efficiency @ 12V:	31 %
Speed at max efficiency:	67 rpm
Torque at max efficiency:	1.1 kg·cm
Current at max efficiency:	0.20 A
Output power at max efficiency:	0.75 W

Torque Required for Straight Line

Assuming weight 3kg and C = .01

$$F_n = mg = (3kg)(9.81\frac{m}{s^2}) = 29.43N$$

$$r_{wheels} = 0.068m$$

$F_{RR} = (0.01)(29.34N) = 0.2943N$

$\frac{0.2934N}{4\,Wheels} = 0.073575\frac{N}{Wheel}$

$(0.073575N)(0.068m) = 0.00500\ Nm\ per\ wheel = 0.5\ Ncm\ per\ motor$

Torque Required for Skid Steering C = 0.8 (Max Torque Needed)

Assuming worst case (C = 0.8)

$F_N = (3kg)(9.81\frac{m}{s^2}) = 29.43N$

$r_{wheels} = 0.068m$

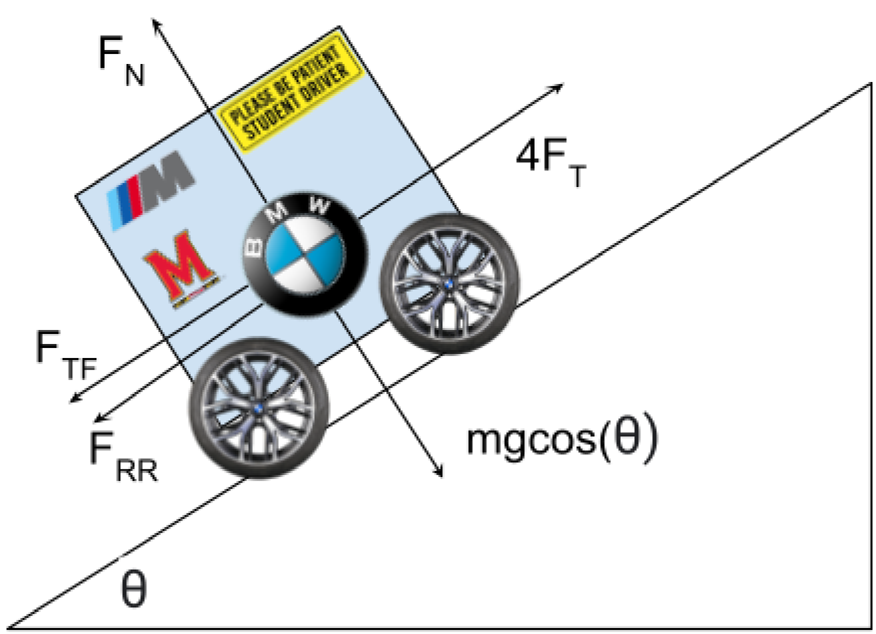
$F_{RR} = (0.8)(29.43N) = 23.544N$

$\frac{23.544N}{4\,Wheels} = 5.886\frac{N}{Wheel}$

$(5.866\frac{N}{Wheel})(0.068m) = 0.4\ Nm\ per\ wheel\ and\ for\ each\ motor = 40\ Ncm$

Torque Required To Go Over Bump

Free-body diagram



Assuming C = 0.01

$F_{TE} = F_{RR} + F_{TF}$

$F_{RR} = C \cdot m \cdot g \cdot cos(\theta) = (0.01)(3kg)(9.8\frac{m}{s^2})cos(45^{\circ}) = 0.207889N$

$F_{RR} = C \cdot m \cdot g \cdot cos(\theta) = (0.01)(3kg)(9.8\frac{m}{s^2})sin(45^{\circ}) = 20.788N$

$F_{TE} = \frac{21.0N}{4\,Wheels} = 5.25\frac{N}{Wheel}$

$4F_{T} - 4F_{TE} = F_{T} = F_{TE}$

$F_{T} = 5.25N$

$F_{T} = \frac{T}{r} = T = F_{T} \cdot r = (5.25N)(0.068m) = 0.357Nm = 3.64\,kg\,cm$

Operating Linear Speed (At Max Efficiency)

$v = 68\,rpm \cdot \frac{1min}{60s} \cdot \frac{2\pi\,rad}{rev} \cdot 0.068m = 0.484\frac{m}{s}$

Operating Current (At Max Efficiency)

Current at max efficiency @ 12 V is 0.20 A

Actual Motor Behavior

Actual Operating Linear Speed

$v = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i} = \frac{(1.575m) - (0)}{(7s) - 0} = 0.225\,\frac{m}{s}$

Actual Operating Angular Speed

$\omega = \frac{v}{r} = \frac{(0.225\,m/s)}{(0.068m)} = \frac{3.3rad}{s} \cdot \frac{1rev}{2\pi rad} \cdot \frac{60s}{1min} = 31.5\,rpm \approx 32\,rpm$

Operating Torque

The operating Torque of our motors with an angular speed of 3.3 rad/s (approx. 32 rpm) is 5.2 kg · mm as tested.

Operating Torque Comparison

Compared to the operating torque that we predicted above which was operating at max efficiency, the torque calculated here was about half of the predicted torque. This difference is due to the fact that we did not want to operate the motors at max efficiency in fear of overconsumption. The mounting of the motors into the motor mounts also contributed to the big difference in actual torque because the motor mounts weren't printed to scale which meant that our team had to figure out how to mount the motors as properly as we could which could have an influence on the torque output.

4 | Electronics

Electronic Components Overview

1. Communication
    a. ESP8266 Wi-Fi Module
        i. Used to communicate with the vision system.
2. Mission
    a. Limit Switch
        i. Used for the detection of OTV contact with the pylon.
    b. Reed Switch
        i. Used to determine if the material in the base of the pylon is magnetic
    c. Servo Motor
        i. Controls the mission arm's - up and down motion.
3. Navigation
    a. Ultrasonic Sensor
        i. Transmits pulses and listens for the reflected pulses. Will be used to help with obstacle avoidance by calculating how far the OTV is from an obstacle (with code).
        ii. Was chosen because it provides for precise measurement of the distance away an obstacle is from the OTV
4. Propulsion
    a. DC Motors
        i. Control the 4 wheels of the OTV; four motors allow for four wheel drive
    b. H-Bridges
        i. Allow for control of the direction and speed of the motors via the Elegoo

Battery Details

Battery A (12V)

- 12V rechargeable Tenergy NiMH (Nickel-Metal Hydride) battery
- Capacity of 2000 mAh (2Ah)
- Maximum continuous discharge rate of 2A (1C)
- Dimensions are 73.5 x 53.5 x 30.5mm (L x H x W)
- Weight is approximately 9 oz / 255g

Battery B (9V)

- 9V rechargeable Tenergy NiMH battery
- Capacity of 200 mAh
- Maximum continuous discharge rate of 200 mA (1C)
- Dimensions are 48.5 x 26.5 x 17.5 mm (L x W x H)
- Weight is 35g

Current Draw Calculations

The electronic components powered by the 9V battery are in parallel, so the total current draw for this circuit is the sum of the current draw of each component. The total operating current draw is 190mA and the total maximum current draw is 370mA (see Table 3a). This was calculated by summing the operating current draw and maximum current draw, respectively, of each component.

The electronic components powered by the 12V battery are in parallel, so the total current draw for this circuit is the sum of the current draw of each component. The total operating current draw is 0.94A, and the total maximum current draw (which occurs when the motors are run at stall) is 3.565A (see Table 3b). This was calculated by summing the operating current draw and stall current draw, respectively, of each component.

(Table 3a) 9V Battery Powered Circuit Current Draw Calculations

Component	**Operating Current Draw**	**Maximum Current Draw**
ESP8266 Wi-Fi Module	140mA	170 mA
Elegoo Mega	Approximately 50mA	Approximately 200mA
Limit Switch 1	0mA (doesn’t draw current)	0mA (doesn’t draw current)
Limit Switch 1	0mA (doesn’t draw current)	0mA (doesn’t draw current)
Reed Switch	0mA (doesn’t draw current)	0mA (doesn’t draw current)
Total (All)	**190mA (0.19A)**	**370mA (0.37A)**

(Table 3b) 12V Battery Powered Circuit Current Draw Calculations

Components	**Operating Current Draw**	**Maximum (stall) Current Draw**
DC Motor 1	0.20A	0.75A
DC Motor 2	0.20A	0.75A
DC Motor 3	0.20A	0.75A
DC Motor 4	0.20A	0.75A
Servo Motor	125 mA	550 mA
Ultrasonic Sensor	15mA	15mA
Total (All)	**0.94A (940mA)**	**3.565A (3565mA)**

Run-time Calculations

The electronic components powered by the 9V battery have an operating current draw of 190mA (see table 3a). The 9V battery has a capacity of 200mAh.
Runtime for 9V battery = 200mAh / 190mA = 1.05 hours

The electronic components powered by the 12V battery have an operating current draw of 0.94A (see table 3b). The 12V battery has a capacity of 2000 mAh (2Ah).
Runtime for 12V battery = 2Ah / 0.94A = 2.13 hours

The runtime for the 9V battery is shorter than the runtime of the 12V battery, and since both are needed for the OTV to function, the runtime of the OTV is limited by the runtime of the 9V battery.

The runtime for the OTV is 1.05 hours (63 minutes). It can be run for 63 minutes without recharging.

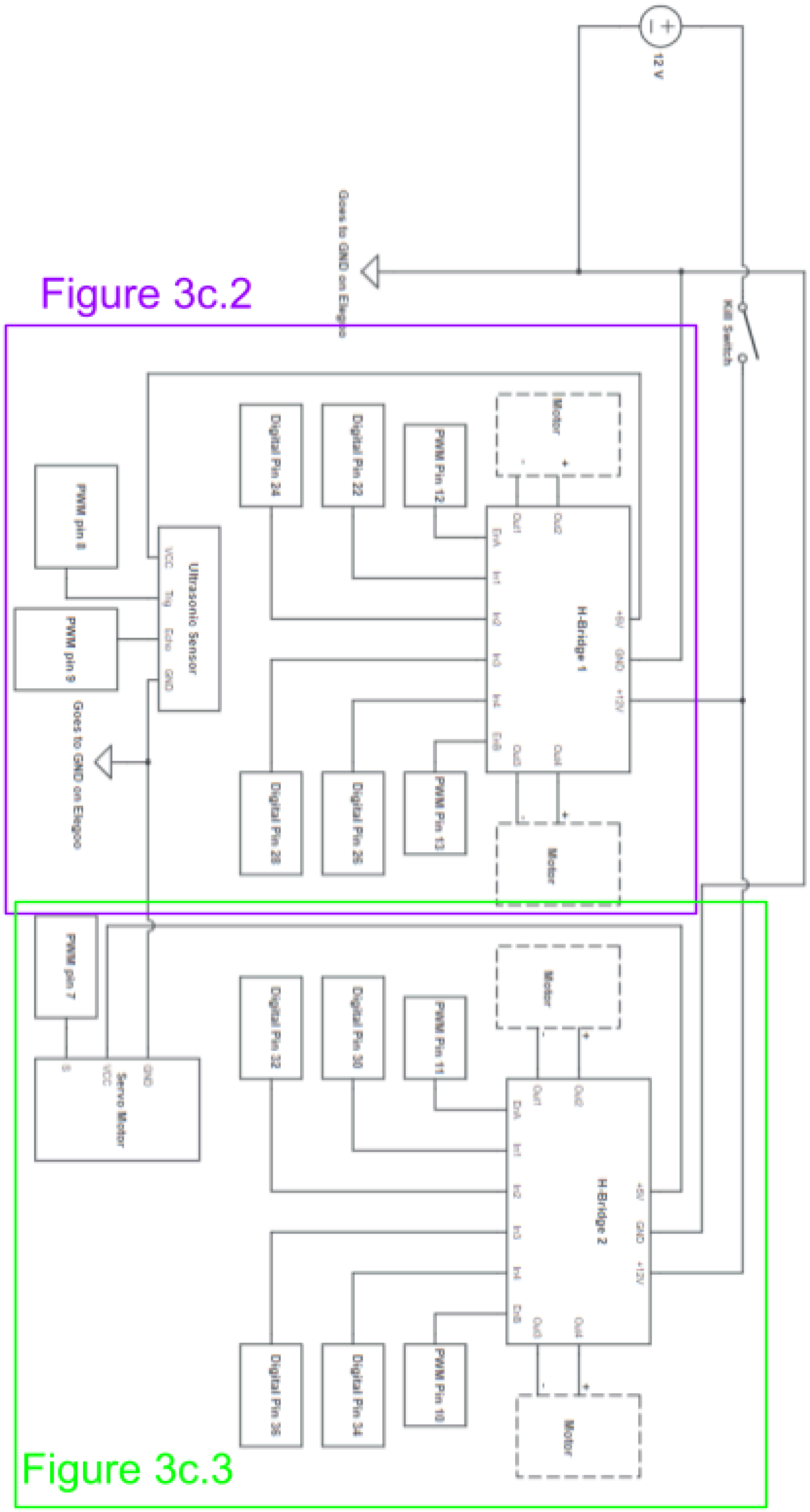
Power Modulation Details

The 12V battery powers the propulsion actuators (which are four DC motors), mission actuators, and sensors. There are two H-bridges that each control two motors. The positive lead from the 12V battery goes into the 12V input of each H-bridge. Each H-bridge connects to two DC motors and six pins on the Elegoo. The H-bridges and negative lead from the 12V battery connect to a common ground (GND pin on the Elegoo). The ultrasonic sensor receives its power from the 5V out on one h-bridge, and the servo motor receives its power from the 5V out on the other h-bridge. The ultrasonic sensor and servo motor connect to a common ground on the Elegoo. See figures 3c.1-3c.3 for detailed schematics of the connections. See figures 3e.1 through 3e.5 for detailed pin assignments.

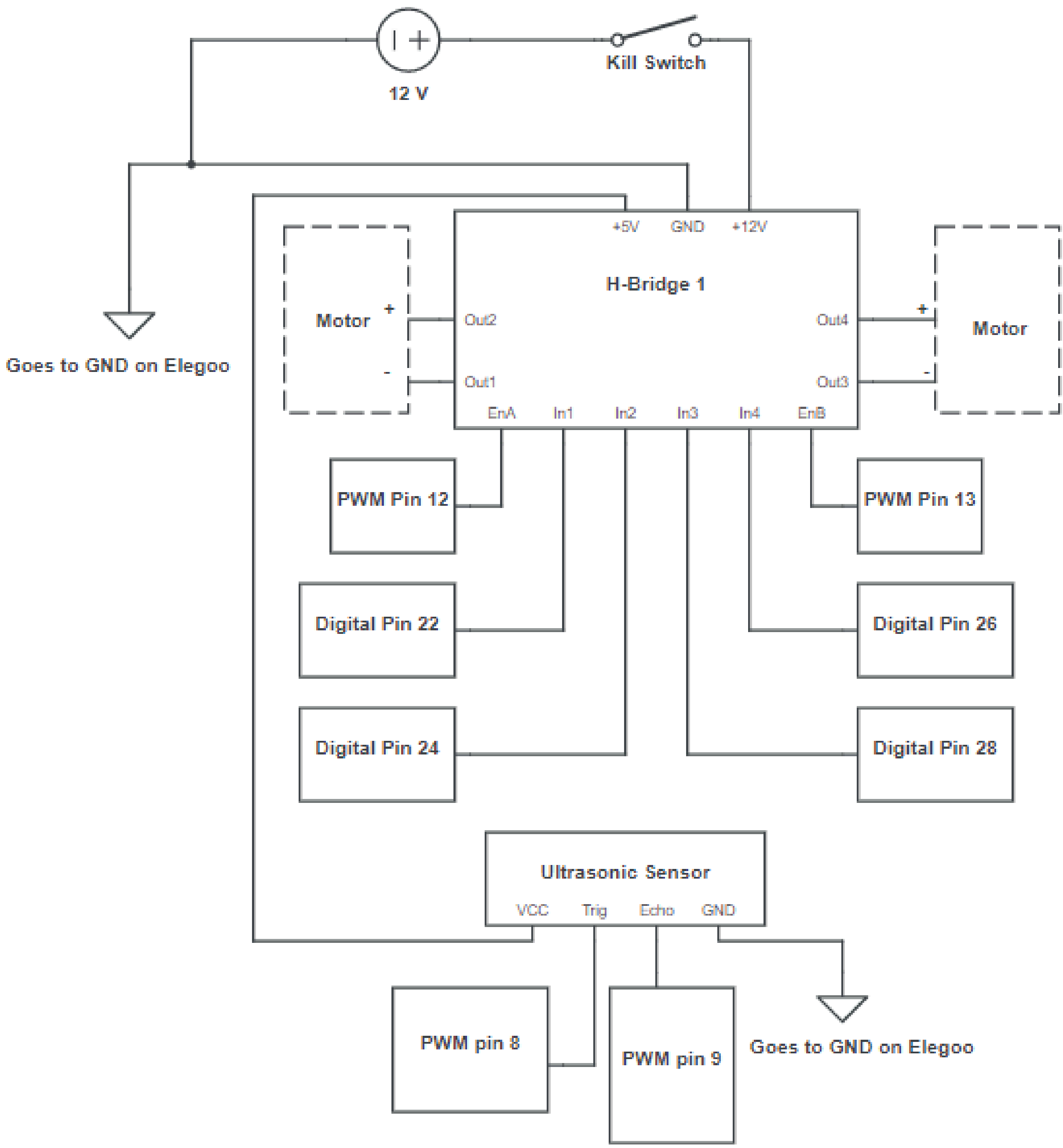
The 9V battery powers the Elegoo, which powers the ESP8266 Wi-Fi module. The Elegoo receives its power from the 9V battery. The Wi-Fi module receives its power from the 5V pin on the Elegoo. The wire used for extracting the duty cycle, the reed switch, and the limit switches are also part of this circuit, though they draw no current. The Wifi module, reed switch, and limit switches connect to a common ground on the Elegoo. The copper wire, which is used to extract the duty cycle, connects the pylon signal node to digital pin 42 and the pylon ground node to a GND pin on the Elegoo. This GND pin is a separate ground pin from the common ground. See figures 3d.1-3d.6 for detailed schematics of the connections. See figures 3e.1 through 3e.5 for detailed pin assignments.

Circuit Schematics

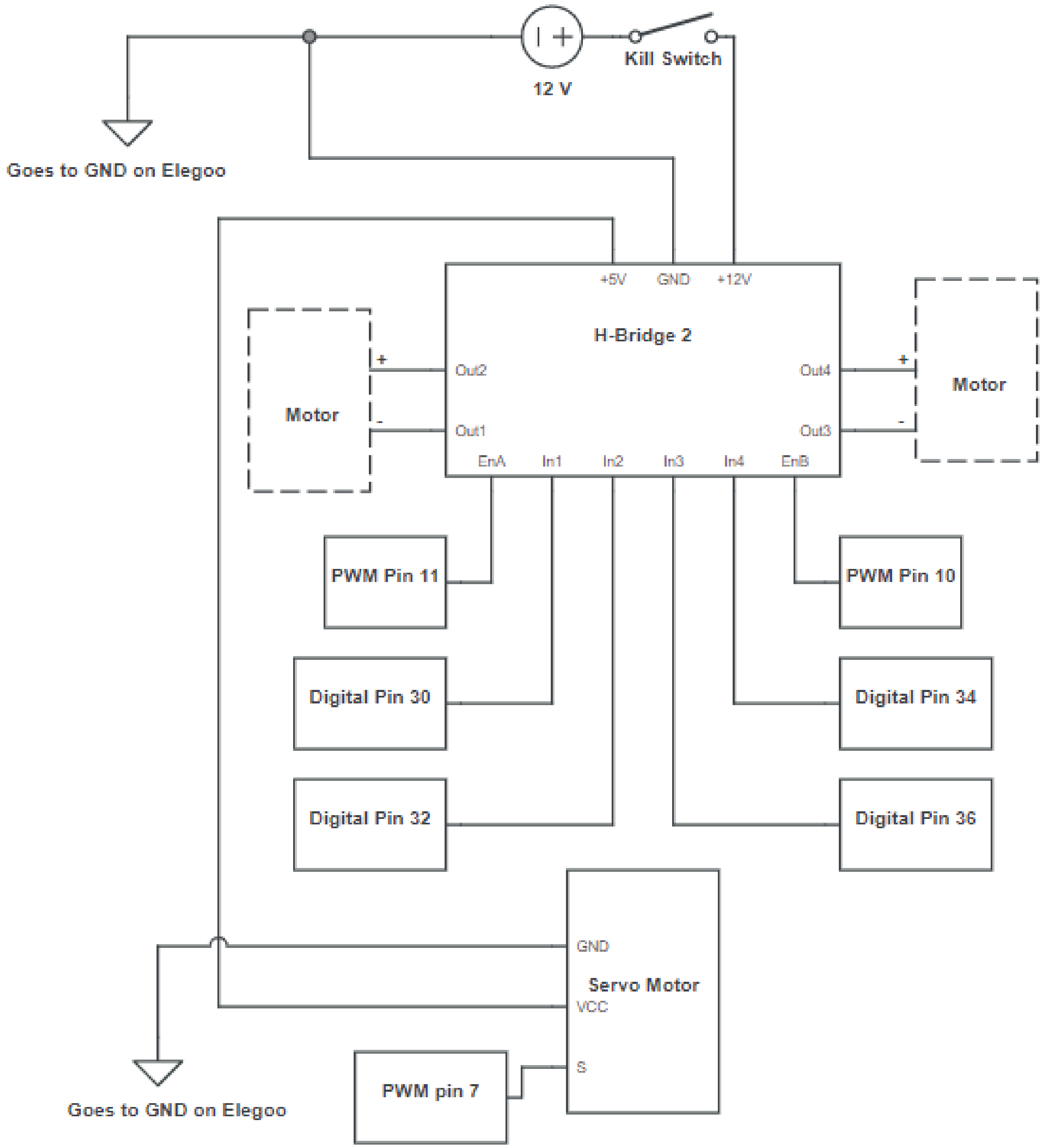
(Figure 3c.1) Overall Schematic of Components Powered by 12V Battery



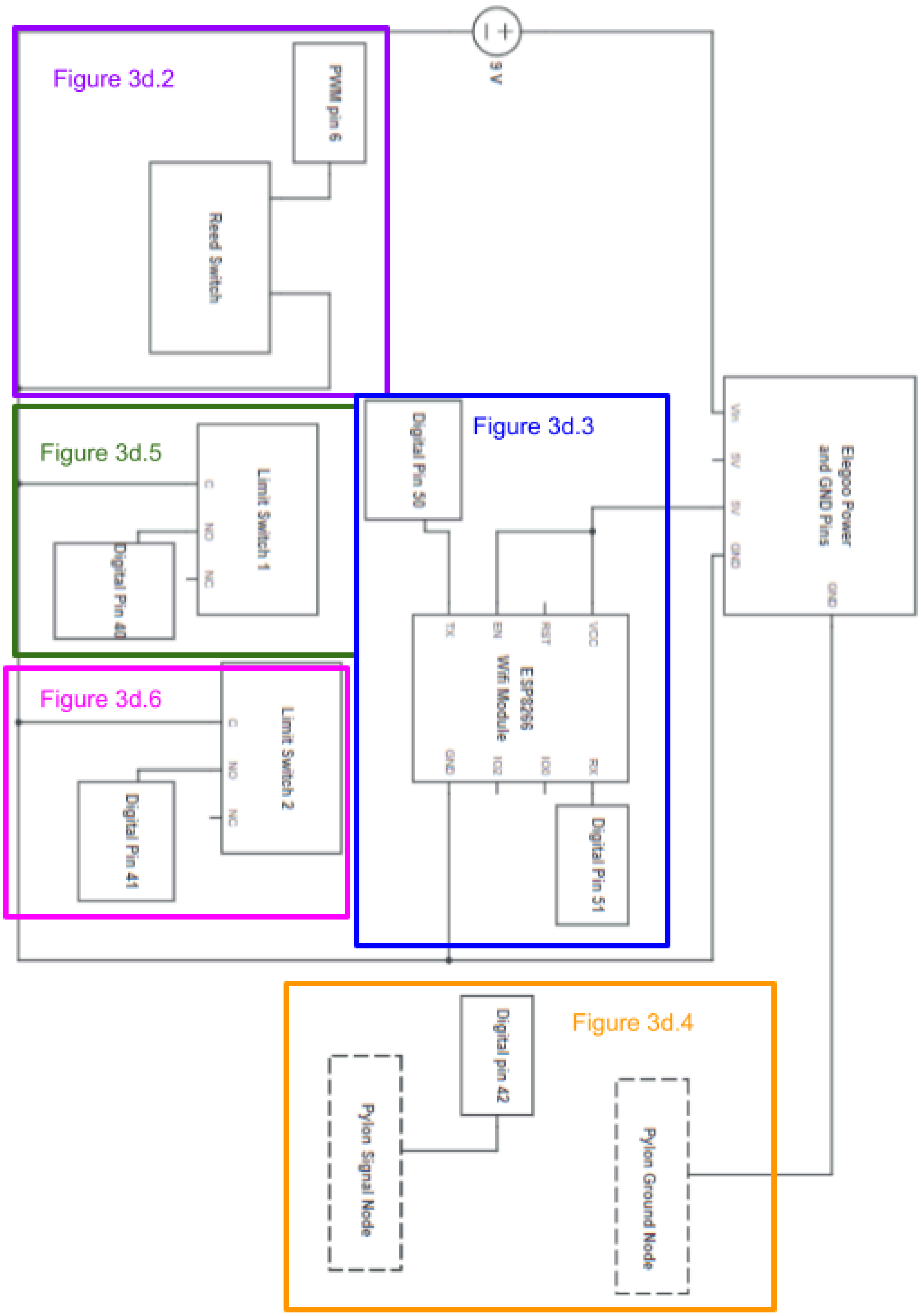
(Figure 3c.2) H-Bridge 1 and Ultrasonic Sensor Schematic



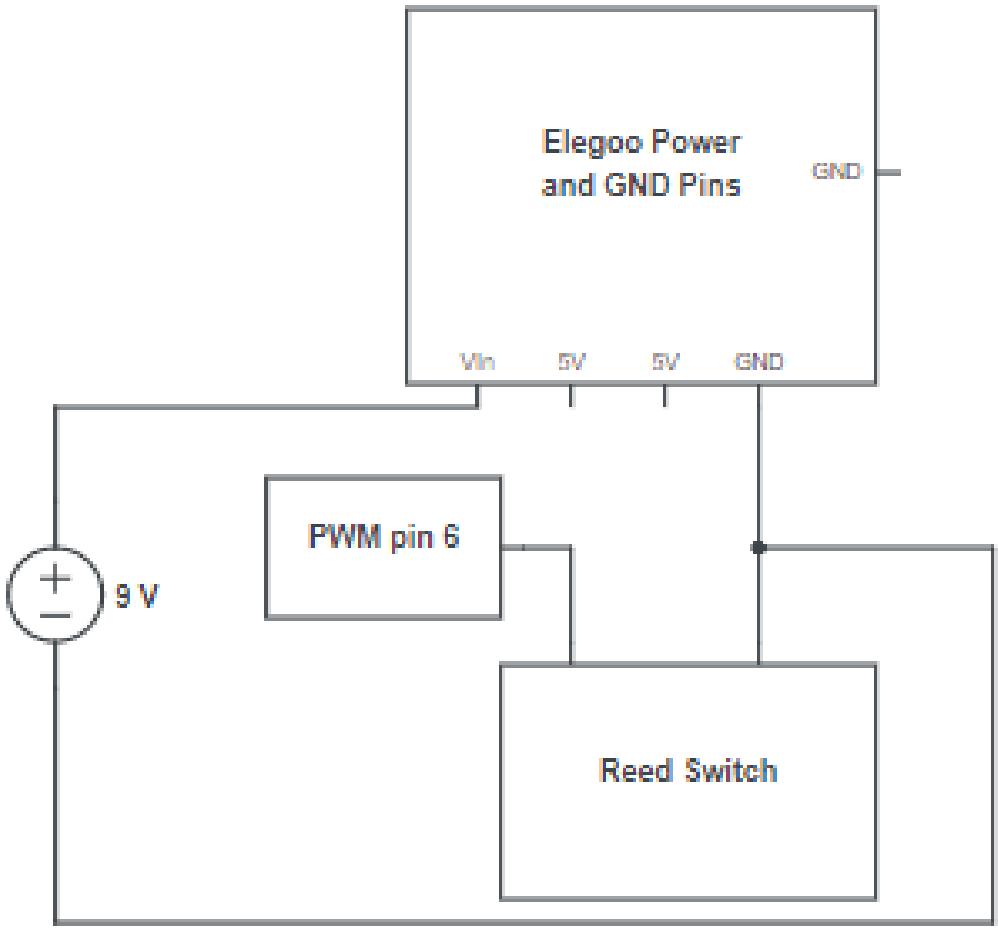
(Figure 3c.3) H-Bridge 2 and Servo Motor Schematic



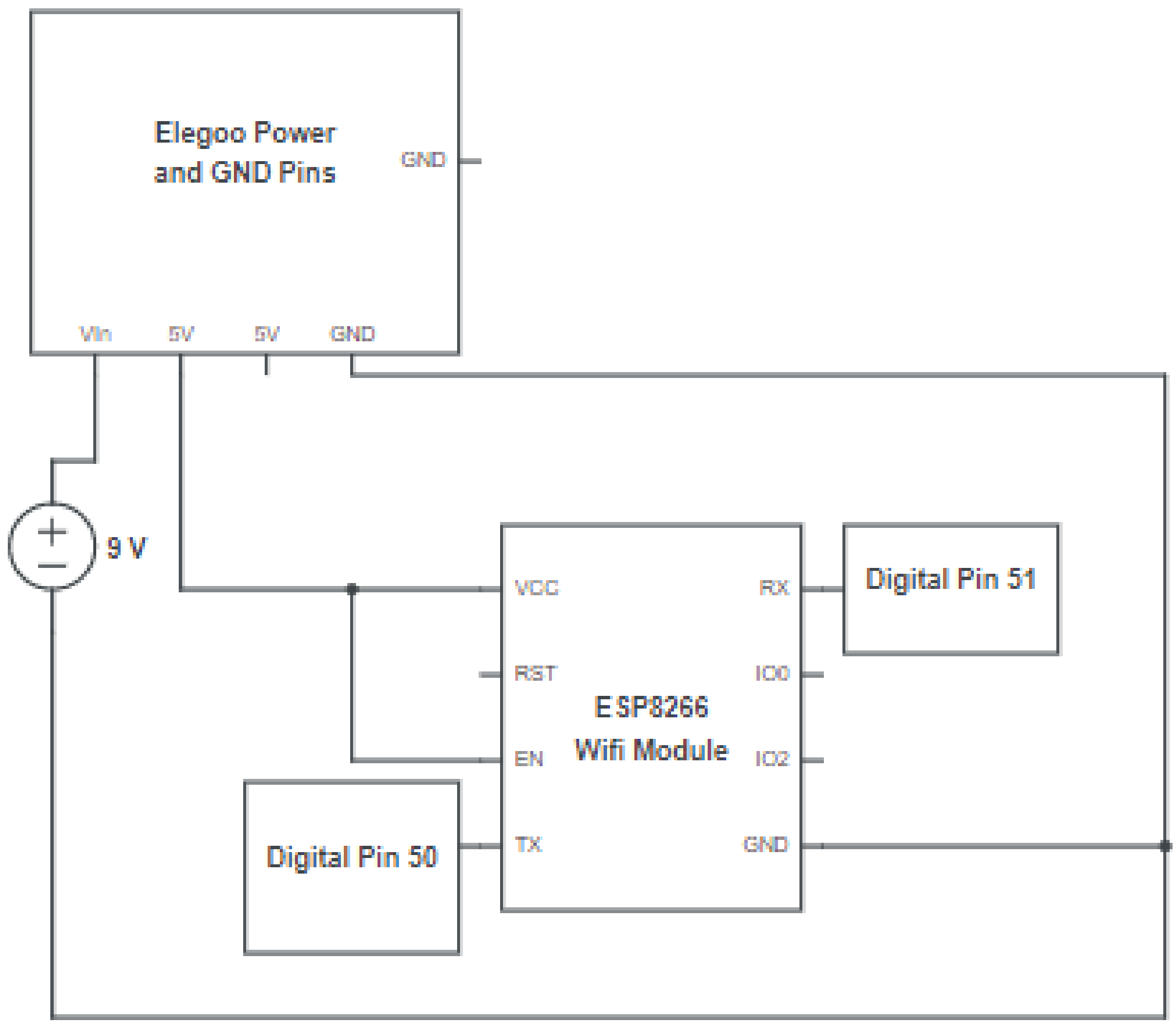
(Figure 3d.1) Overall Schematic of Components Powered by 9V Battery



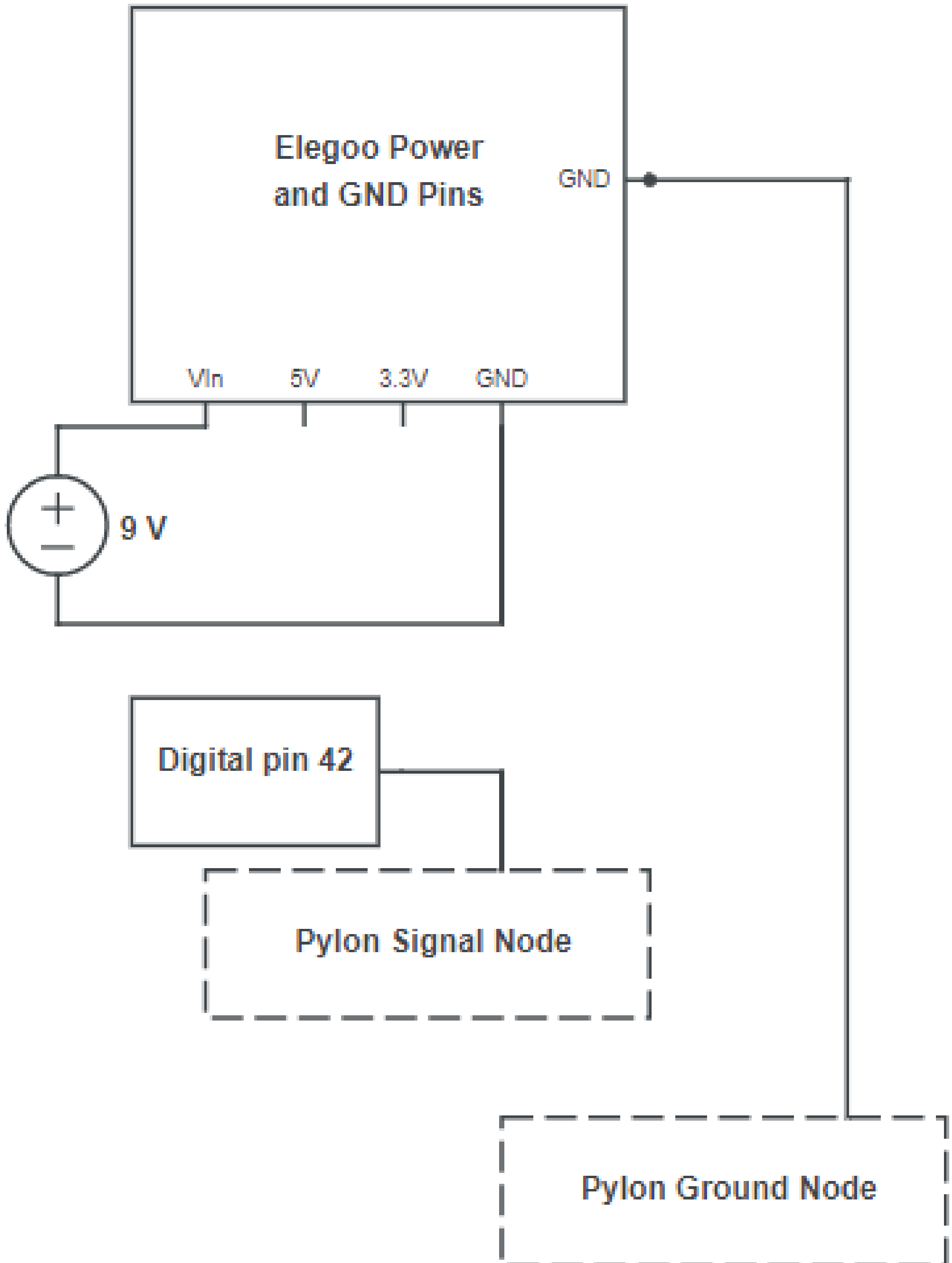
(Figure 3d.2) Reed Switch Schematic



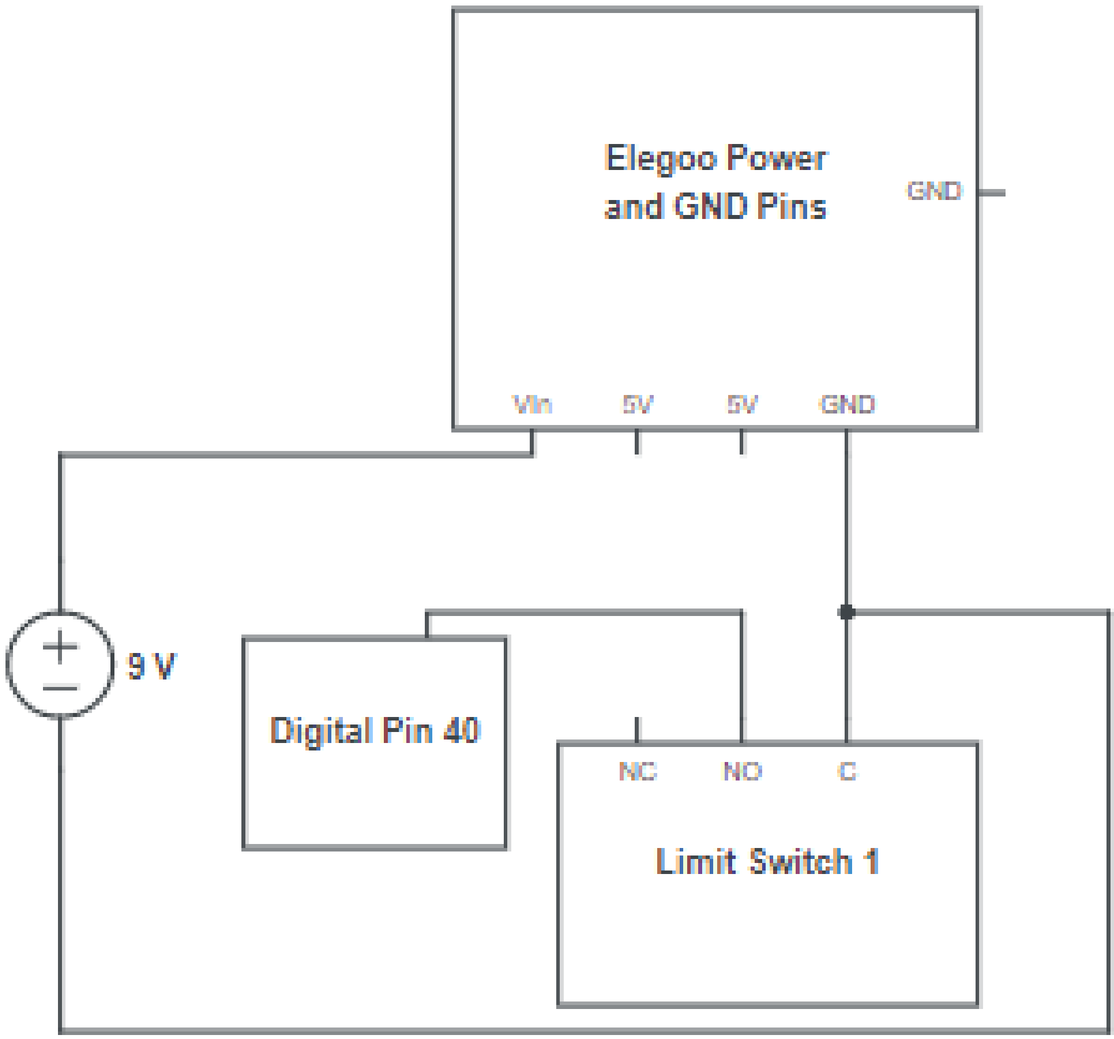
(Figure 3d.3) ESP8266 WiFi Module Schematic



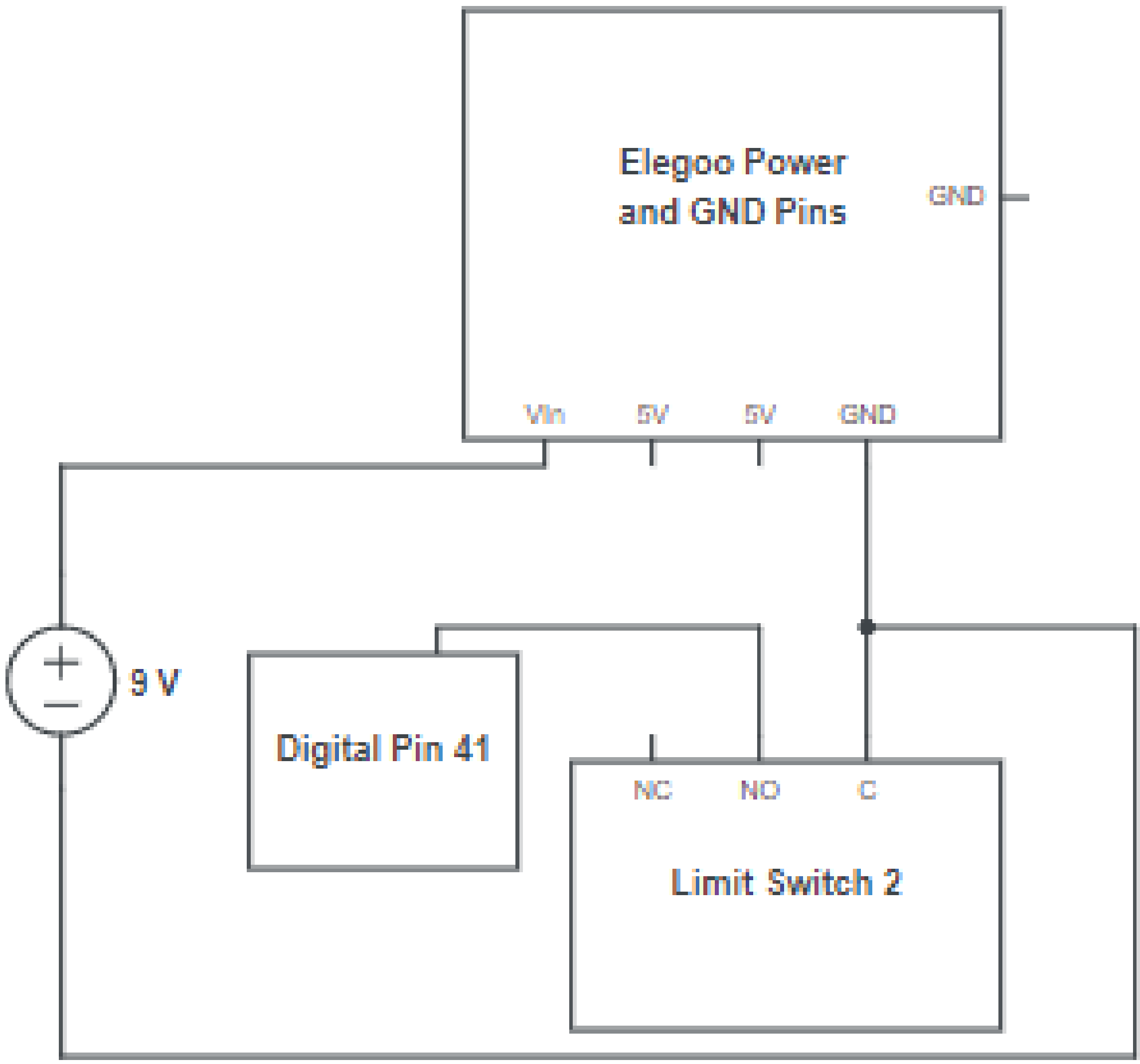
(Figure 3d.4) Pylon Signal Schematic



(Figure 3d.5) Limit Switch 1 Schematic



(Figure 3d.6) Limit Switch 2 Schematic



Pin Assignment Charts

Figures 3e.1 through 3e.5 show the assignments for each pin on the Elegoo Mega.

(Figure 3e.1) PWM Pins

Pin	**Connected Component**
1	none
2	none
3	none
4	none
5	none
6	Reed Switch
7	S pin of servo motor
8	Trig pin of ultrasonic sensor
9	Echo pin of ultrasonic sensor
10	EnB pin of H-Bridge 2
11	EnA pin of H-Bridge 2
12	EnA pin of H-Bridge 1
13	En-B pin of H-Bridge 1

(Figure 3e.2) Digital Pins (Without PWM)

Pin	Connected Component	Pin	Connected Component
22	In1 pin of H-Bridge 1	38	none
23	none	39	none
24	In2 pin of H-Bridge 1	40	NO pin of limit switch 1
25	none	41	NO pin of limit switch 2
26	In4 pin of H-Bridge 1	42	Pylon signal node
27	none	43	none
28	In3 pin of H-Bridge 1	44	none
29	none	45	none
30	In1 pin of H-Bridge 2	46	none
31	none	47	none
32	In2 pin of H-Bridge 2	48	none
33	none	49	none
34	In4 pin of H-Bridge 2	50	Tx pin of wifi
35	none	51	Rx pin of wifi
36	In3 pin of H-Bridge 2	52	none
37	none	53	none

(Figure 3e.3) Communication Pins

Pin	Connected Component	Pin	Connected Component
TXO→1	none	RX2 17	none
RXO←0	none	TX1 18	none
TX3 14	none	RX1 19	none
RX3 15	none	SCA 20	none
TX2 16	none	SCL 21	none

(Figure 3e.4) Power Pins

Pin	Connected Component	Pin	Connected Component
GND	GND pins of H-Bridge 1 and H-Bridge 2 Negative lead of 12V battery	GND	GND pins of, ultrasonic sensor, servo motor, and ESP8266 WiFi module C pins of limit switches Reed Switch
RESET	none	GND	Pylon ground node
5V	VCC pin of ESP8266 WiFi module	Vin	none
5V	none	OREF	none

(Figure 3e.5) Analog Pins

Pin	Connected Component	Pin	Connected Component
A0	none	A8	none
A1	none	A9	none
A2	none	A10	none
A3	none	A11	none
A4	none	A12	none
A5	none	A13	none
A6	none	A14	none
A7	none	A15	none

5 | Compiled Engineering Drawings

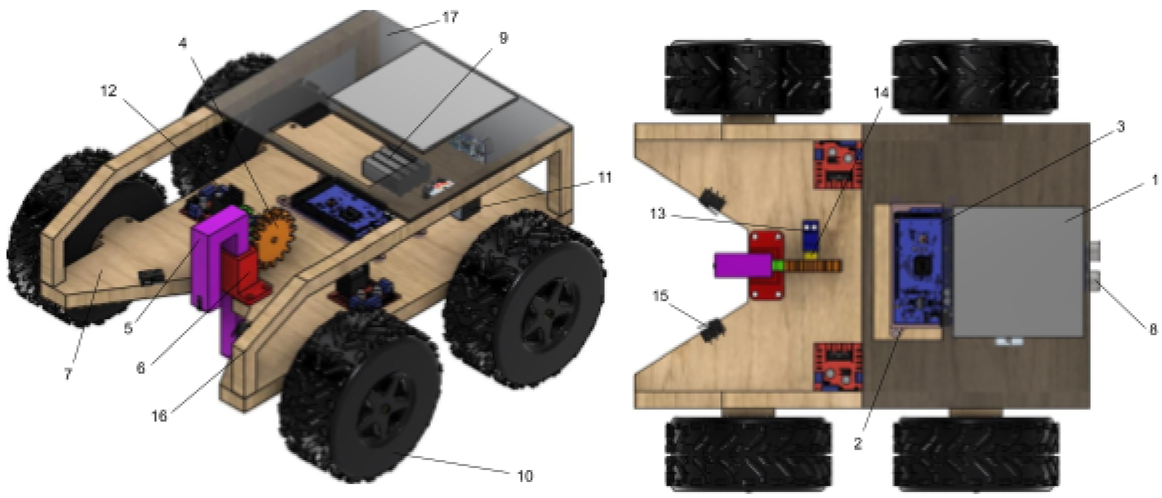
Bill of Materials

BILL OF MATERIALS

MISSION	Data Extraction	TEAM NAME	P.O.G. - Group 1

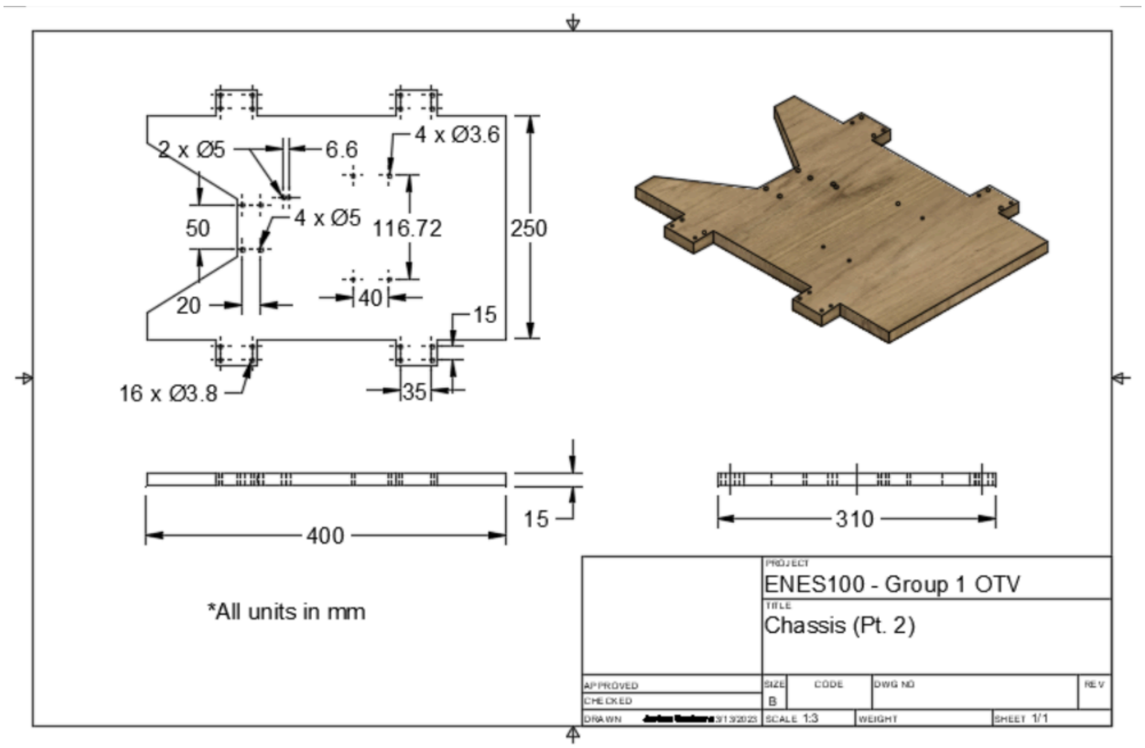
COMP. #	COMPONENT NAME	MANUFACTURER	VENDOR	MODEL #	DESCRIPTION	MASS (g)	COST	ORDERED	RECEIVED
1	Wifi module	N/A	N/A	N/A	In-class	5	$0.00	N	N
2	Limit Switch	HiLetgo	Amazon	03-01-1546	Used for the detection of OTV contact with the pylon.	4.01	$5.99	3/9/23	3/12/23
3	Plywood Sheet	Lowe's	Lowe's	N/A	Used to build chassis, 15mm x 400mm x 250mm, 15.75 x 9.84 x 0.6	1060.5	$7.32	3/11/23	3/11/23
4	Distance Sensor (ultrasonic)	10Gtek	Sparkfun	HC-SR04	Used to for obstacle avoidance	13	$4.50	3/9/23	3/12/23
5	Servo motor	ServoCity	Servo City	HS-53	Used to power arm movement	8	$13.49	3/9/23	N
6	Wheels	Hobbypark	Amazon	19-2733	4 wheels for movement	703	$29.97	3/9/23	3/12/23
7	Hex Wheel Adapters (w/ screws)	Pololu	Pololu	2682	Used to connect wheels to drive motors, 12mm for 3mm shaft	20.4	$9.90	3/9/23	N
8	Motors	Pololu	Pololu	4799	Actuators used for OTV movement, 12 V	38	$93.80	3/9/23	N
9	Reed magnetic switch	N/A	N/A	N/A	Used to test material magnetism, received in class	5	$2.00	N	N
10	ELEGOO MEGA Microcontroller	ELEGOO	Amazon	EL-CB-003	Controls sensors and actautors	63.5	$20.99	3/9/23	3/12/23
11	12V Battery	Tenergy	Amazon	19676	Used to power electronic devices	225	$21.99	3/9/23	3/12/23
12	9V Battery	Tenergy	Amazon	10002	Used to power microcontroller	35	$9.99	3/9/23	3/12/23
13	H-bridge	Honbay	Amazon	L298N-1P	Used for motor control	54	$11.98	3/9/23	3/12/23
14	Copper wire	N/A	N/A	N/A	Used to detect voltage for duty cycle, 26 gauge, 25 ft	10	$0.00	N	N
15	Kill switch	MULTICOMP PRO	Newark	SPC21159	Shuts off entire system if needed	45	$2.19	N	N
16	3D print-Gear	N/A	N/A	N/A	Arm movement	19.6	$1.96	N	N
17	3D print-Rails	N/A	N/A	N/A	Holds arm	4.9	$0.49	N	N
18	3D print-Arm	N/A	N/A	N/A	Used to compelte mission, carries hall sensor and wiring	194	$19.40	N	N
19	3D print-Gear Track	N/A	N/A	N/A	Arm movement	13	$1.30	N	N
20	3D print-Servo Case	N/A	N/A	N/A	Holds servo	4.9	$0.49	N	N
21	3D print-Motor Mount	N/A	N/A	N/A	Holds wheel motors	47.55	$4.76	N	N
22	3D print-Arduino Mount	N/A	N/A	N/A	Holds Arduino	149.7	$14.97	N	N
					TOTAL	2723.06 g	$277.48		
					REMAINING	276.94 g	$42.52		
						MASS	**COST**		

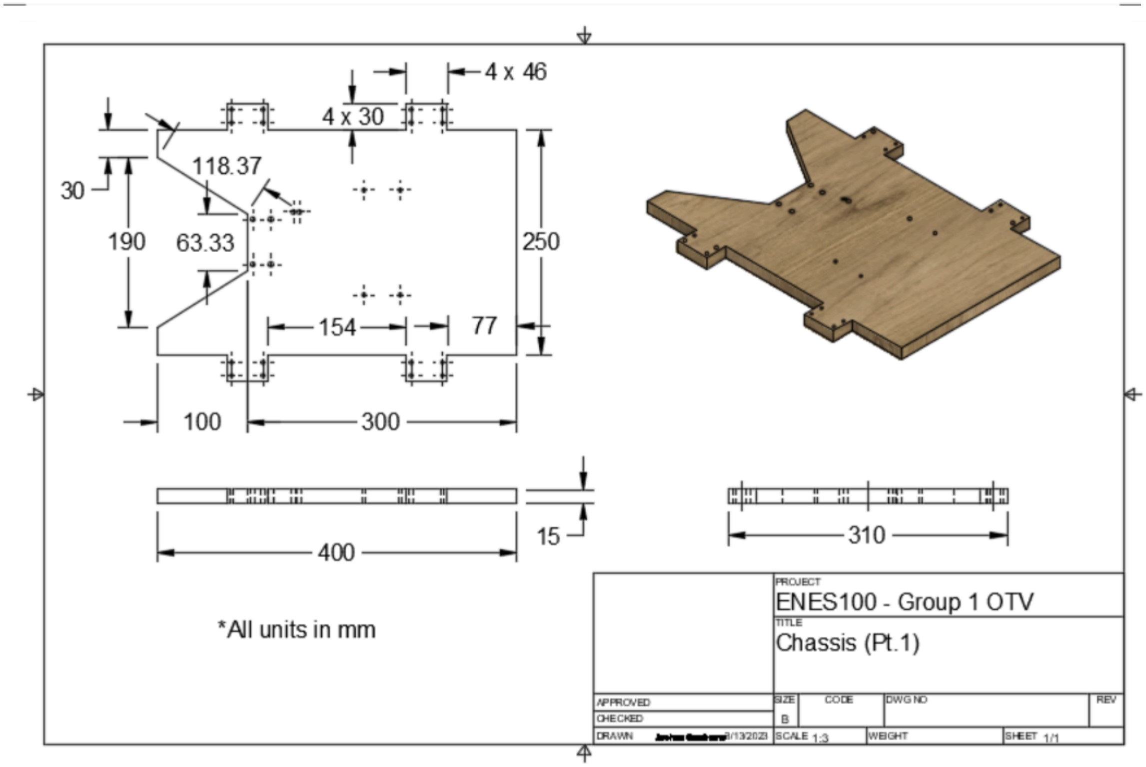
Color 3D Image



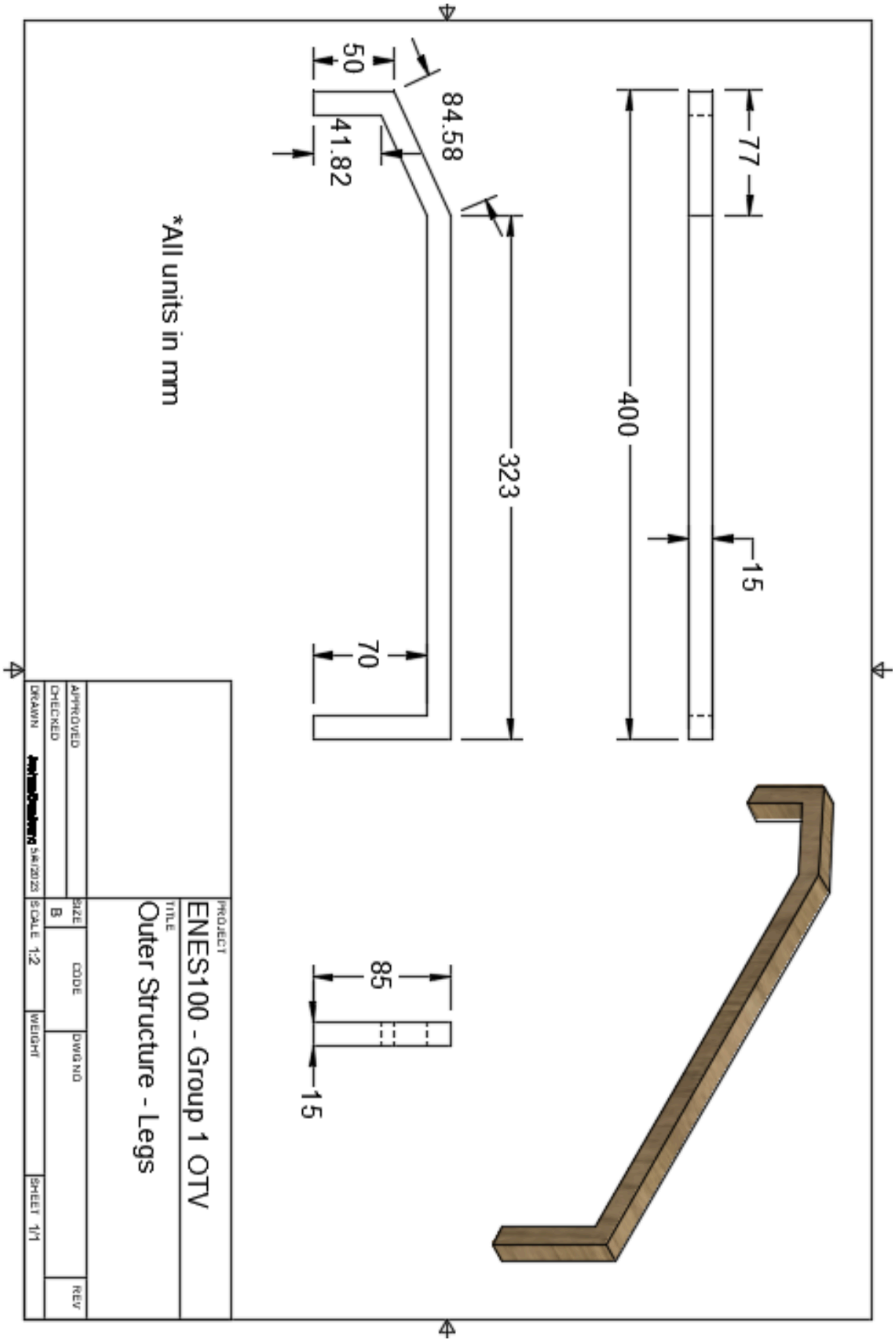
#	Component	#	Component
1	Aruco Marker	10	Wheels
2	Arduino Holder	11	9 V Battery
3	Arduino Microcontroller	12	Gear Track
4	Gear	13	Servo Case
5	Data Extraction Arm	14	Servo Motor
6	Base (for the arm)	15	Limit Switch
7	Chassis	16	Side Structure
8	Distance Sensor	17	"Moonroof"
9	12 V Battery		

Chassis

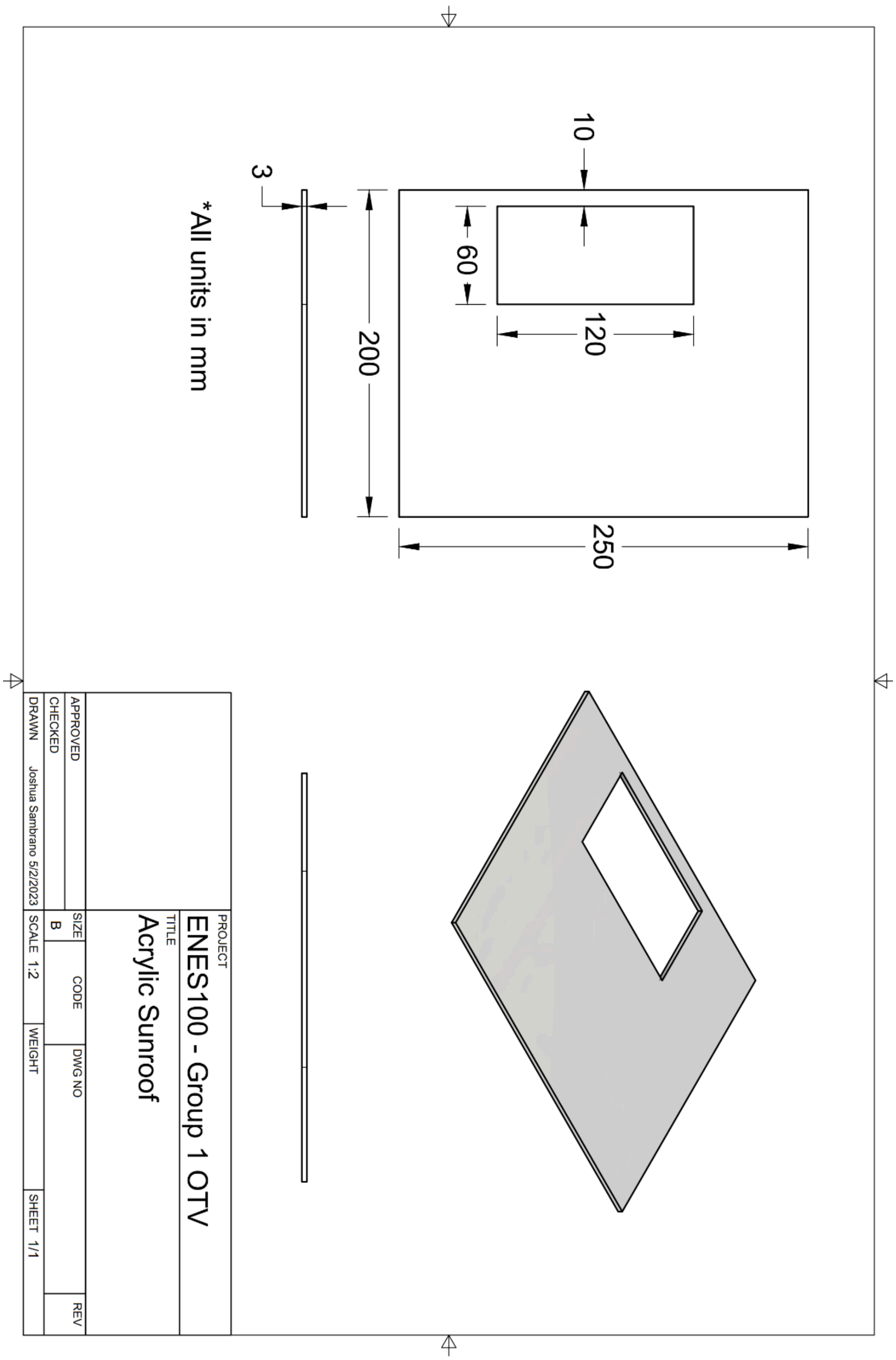

2 x Ø5
6.6
4 x Ø3.6
50
4 x Ø5
116.72
250
20
40
15
16 x Ø3.8
35
400
15
310
*All units in mm
PROJECT
ENES100 - Group 1 OTV
TITLE
Chassis (Pt. 2)
APPROVED
CHECKED
DRAWN
SIZE
B
CODE
DWG NO
REV
SCALE 1:3
WEIGHT
SHEET 1/1


4 x 46
4 x 30
118.37
30
190
63.33
250
154
77
100
300
400
15
310
*All units in mm
PROJECT
ENES100 - Group 1 OTV
TITLE
Chassis (Pt.1)
APPROVED
CHECKED
DRAWN
SIZE
B
CODE
DWG NO
REV
SCALE 1:3
WEIGHT
SHEET 1/1

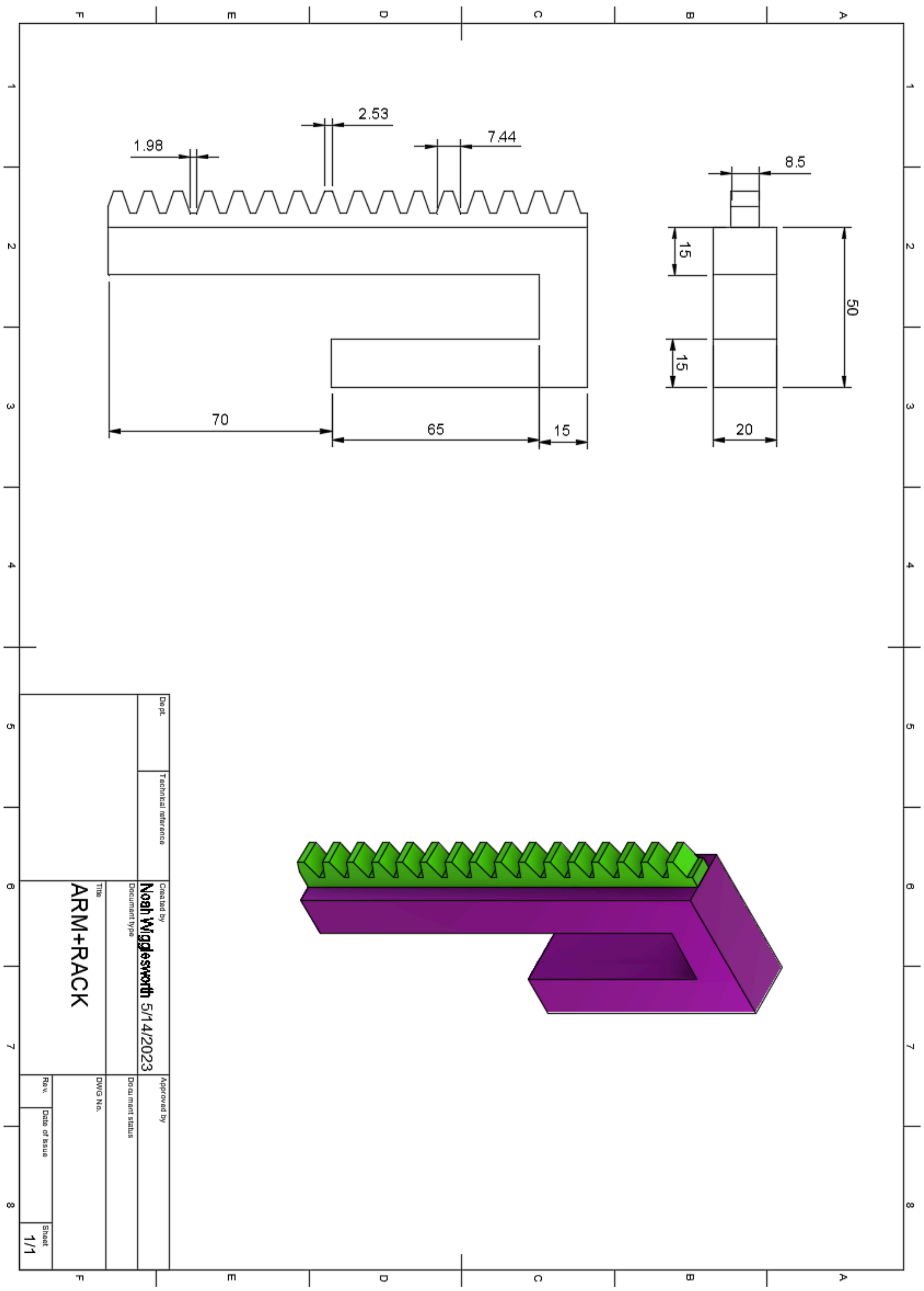
Chassis Roof Support



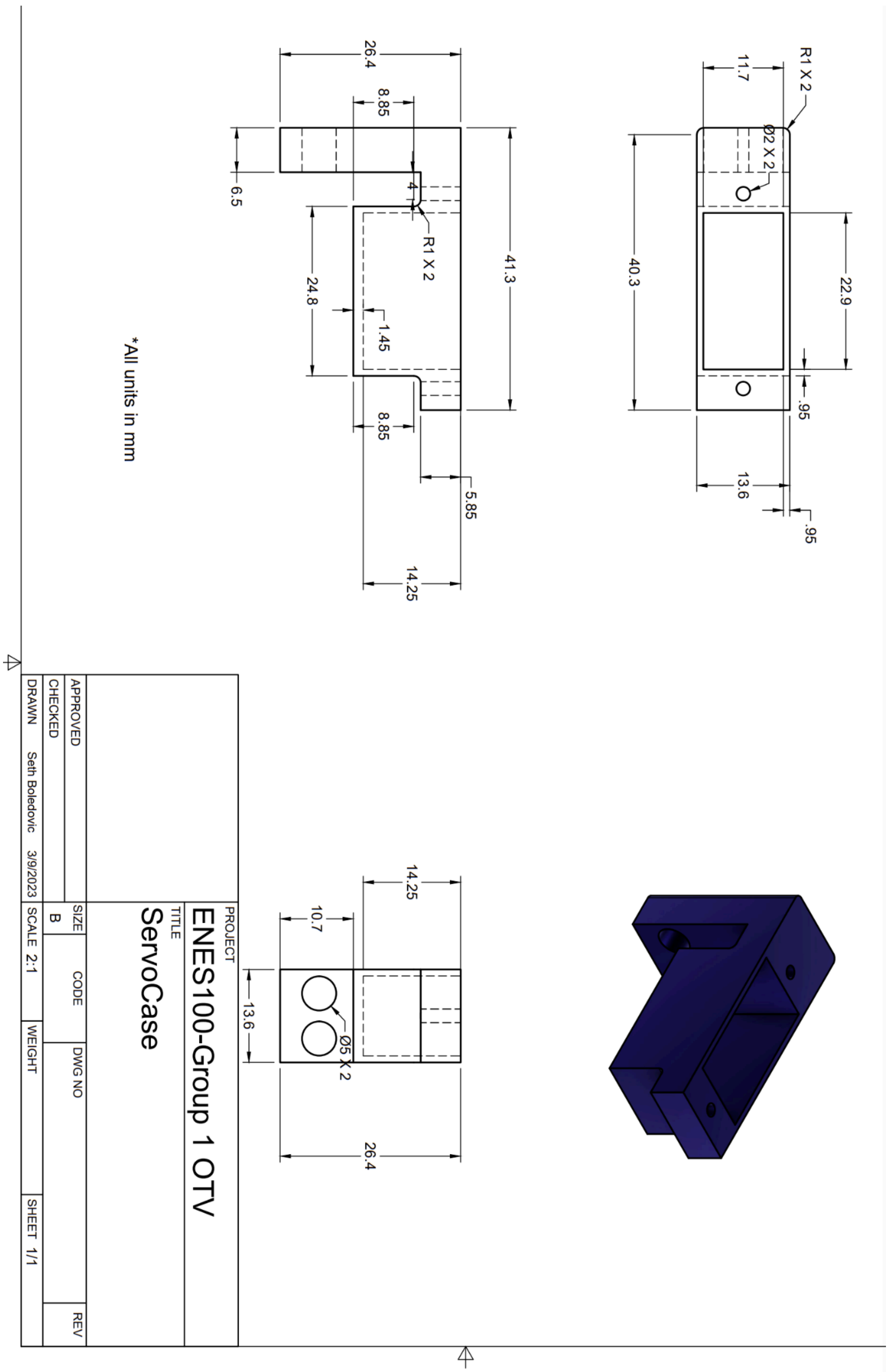
Chassis Roof



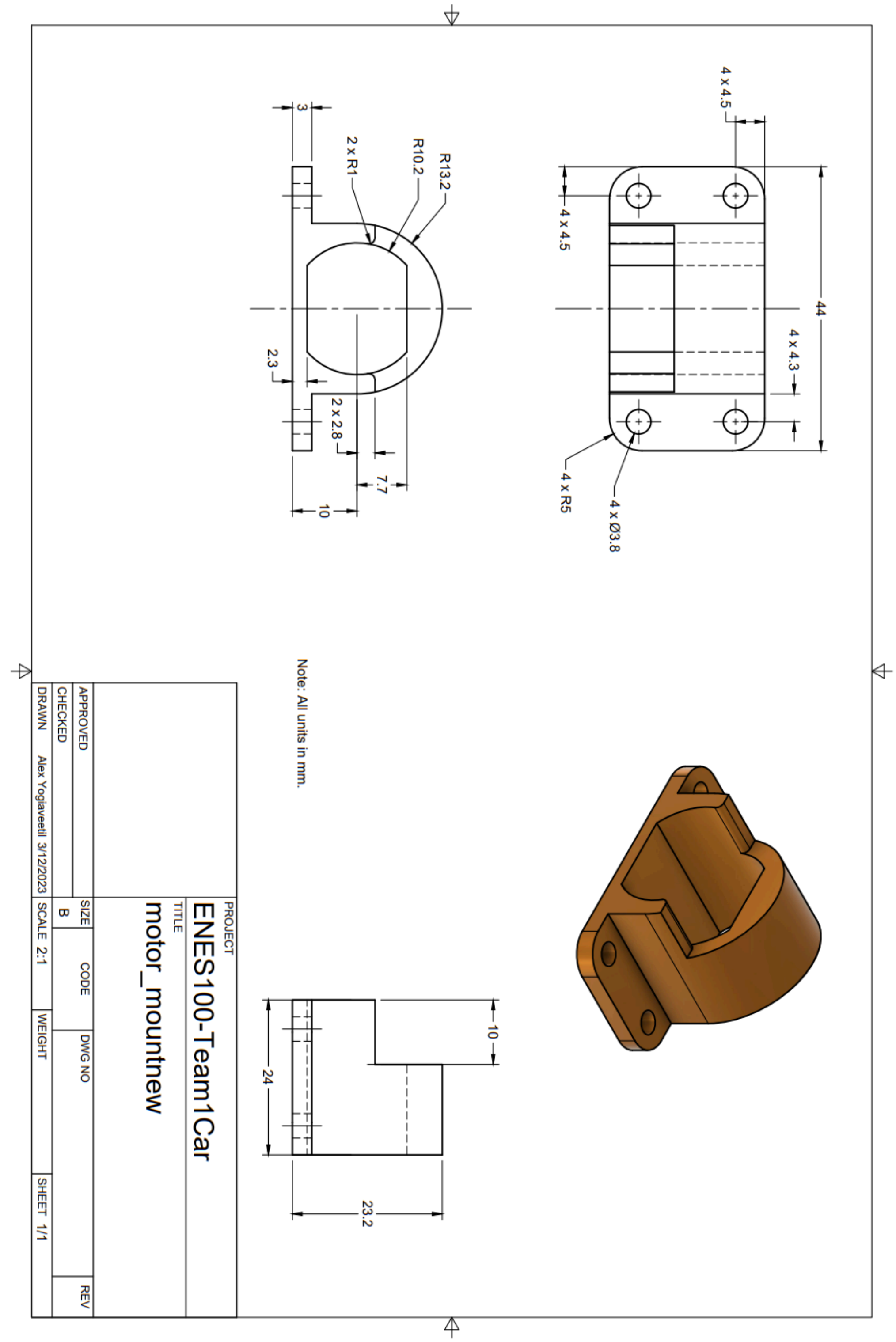
Data Extraction Arm Assembly



Servo Case

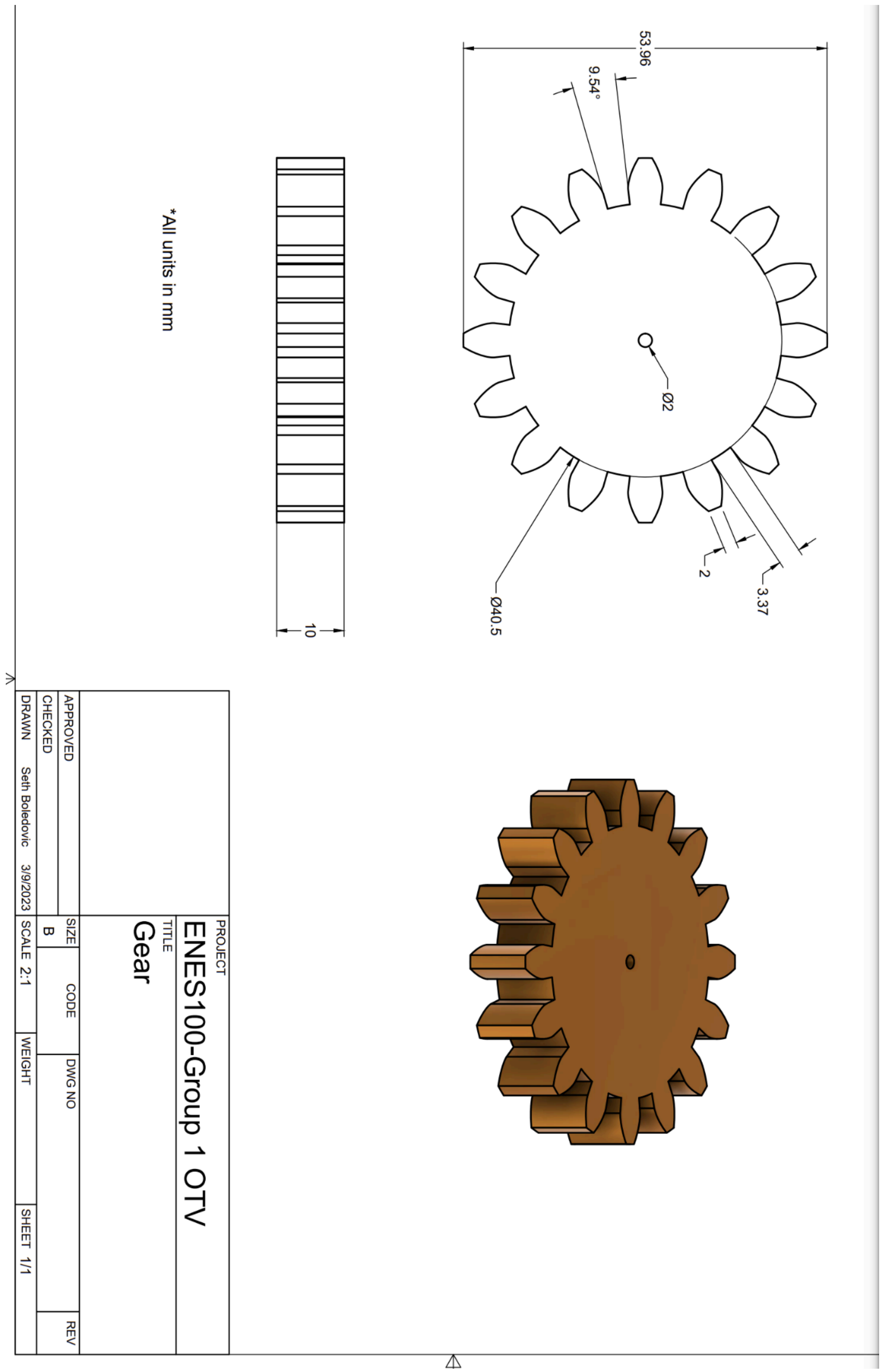

26.4
8.85
6.5
R1 X 2
41.3
24.8
1.45
8.85
5.85
14.25
11.7
R1 X 2
Ø2 X 2
40.3
22.9
.95
13.6
.95
*All units in mm
14.25
10.7
13.6
Ø5 X 2
26.4
PROJECT
ENES100-Group 1 OTV
TITLE
ServoCase
APPROVED
CHECKED
DRAWN Seth Boledovic 3/9/2023
SIZE B
CODE
DWG NO
REV
SCALE 2:1
WEIGHT
SHEET 1/1

Motor Mount

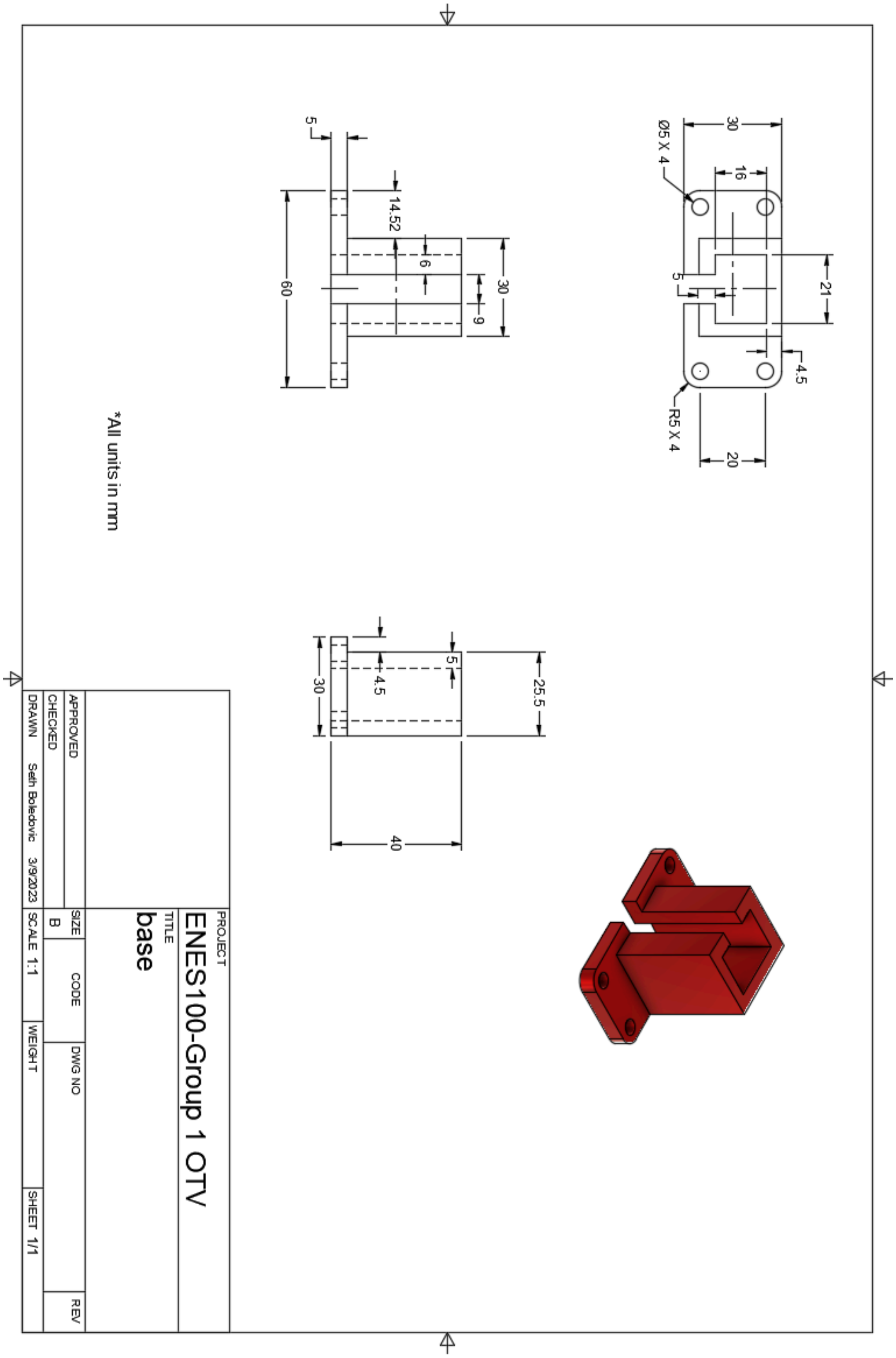


PROJECT
ENES100-Team1Car
TITLE
motor_mountnew
APPROVED
CHECKED
DRAWN Alex Yogiaveetil 3/12/2023
SIZE
B
CODE
DWG NO
REV
SCALE 2:1
WEIGHT
SHEET 1/1
Note: All units in mm.
2 x R1
R10.2
R13.2
3
2.3
2 x 2.8
7.7
10
4 x 4.5
4 x 4.5
44
4 x 4.3
4 x R5
4 x Ø3.8
10
24
23.2

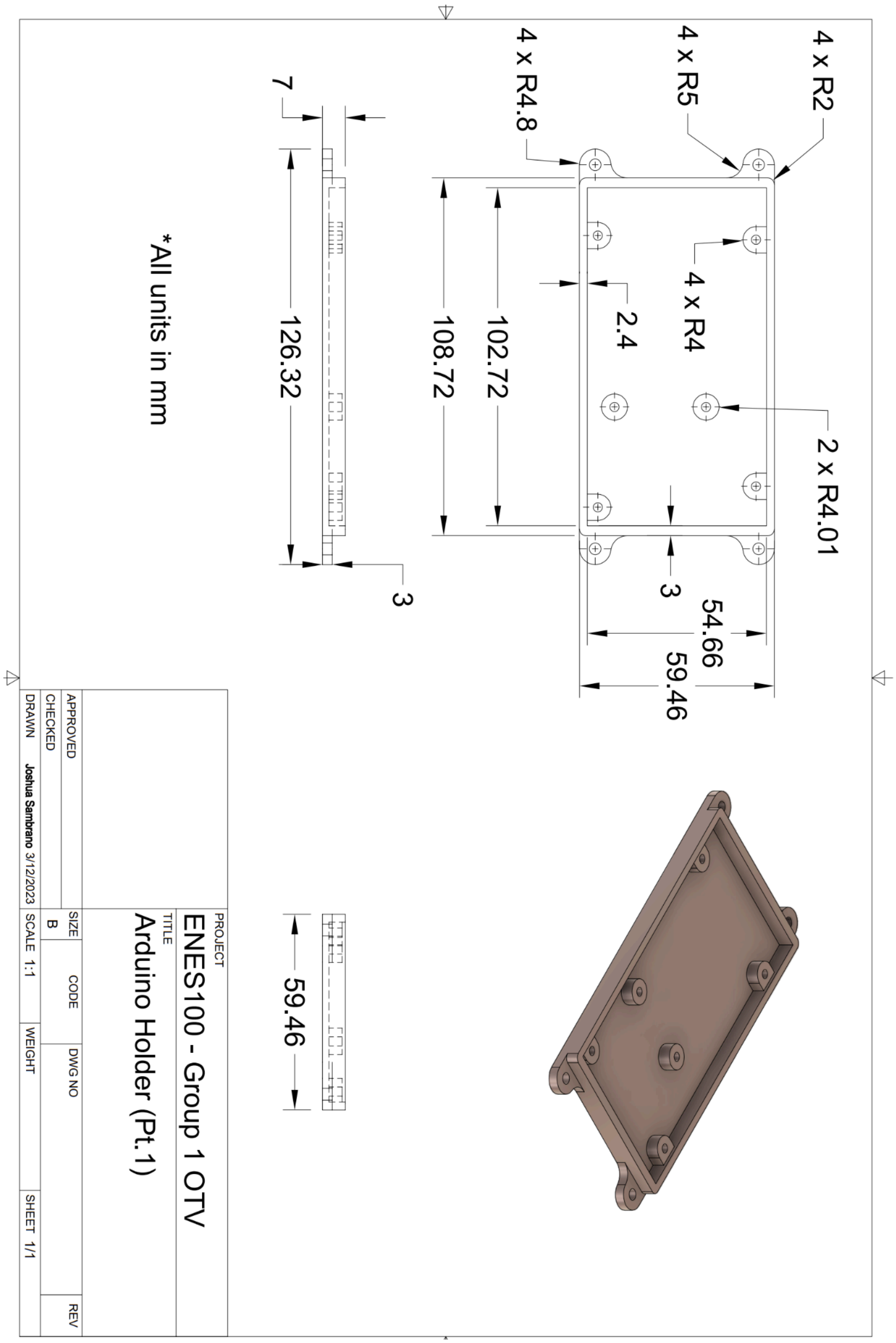
Arm Gear

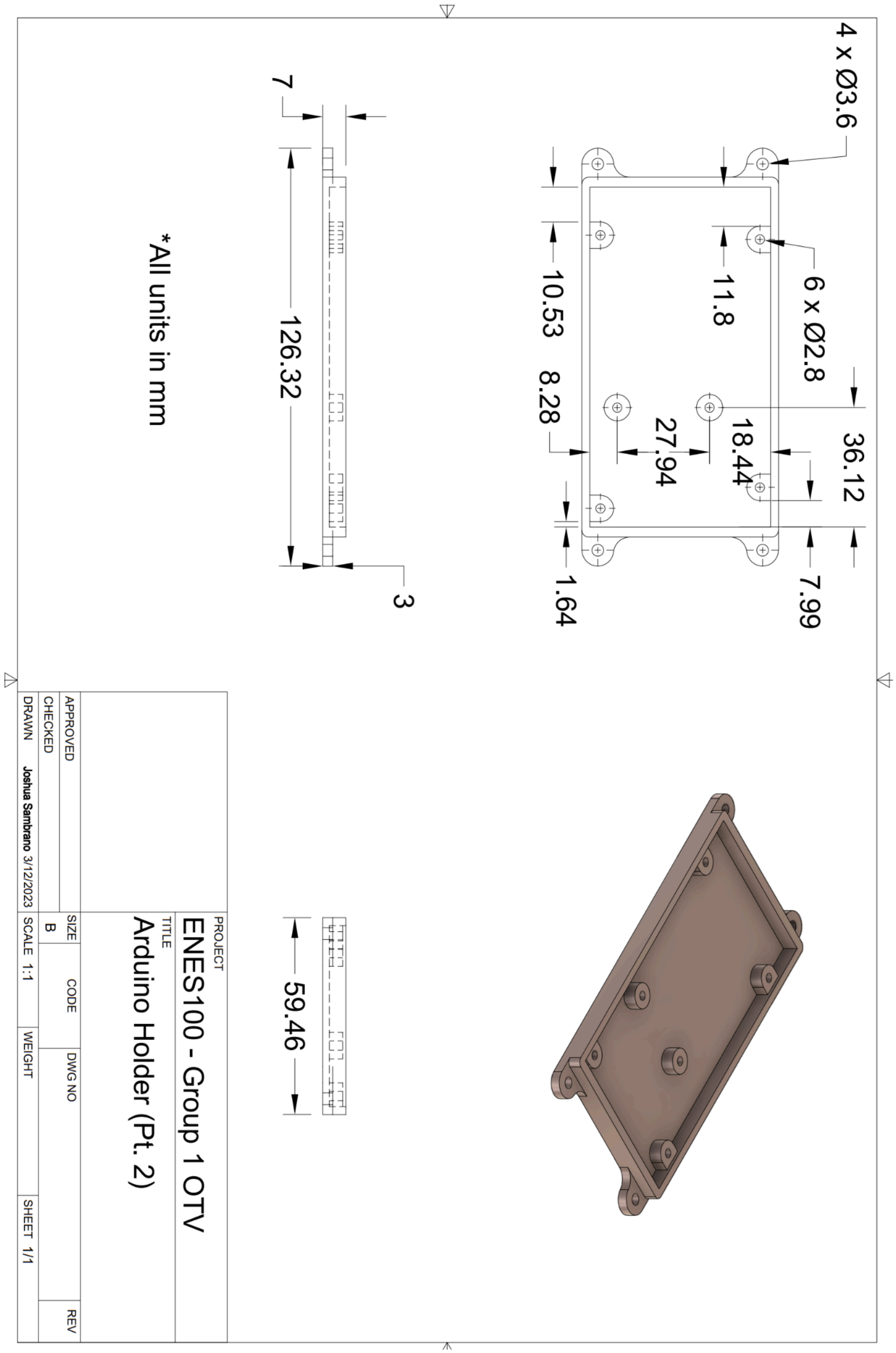

53.96
9.54°
Ø2
2
3.37
Ø40.5
10
*All units in mm
PROJECT
ENES100-Group 1 OTV
TITLE
Gear
APPROVED
CHECKED
DRAWN Seth Boledovic 3/9/2023
SIZE B
CODE
DWG NO
REV
SCALE 2:1
WEIGHT
SHEET 1/1

Arm Base

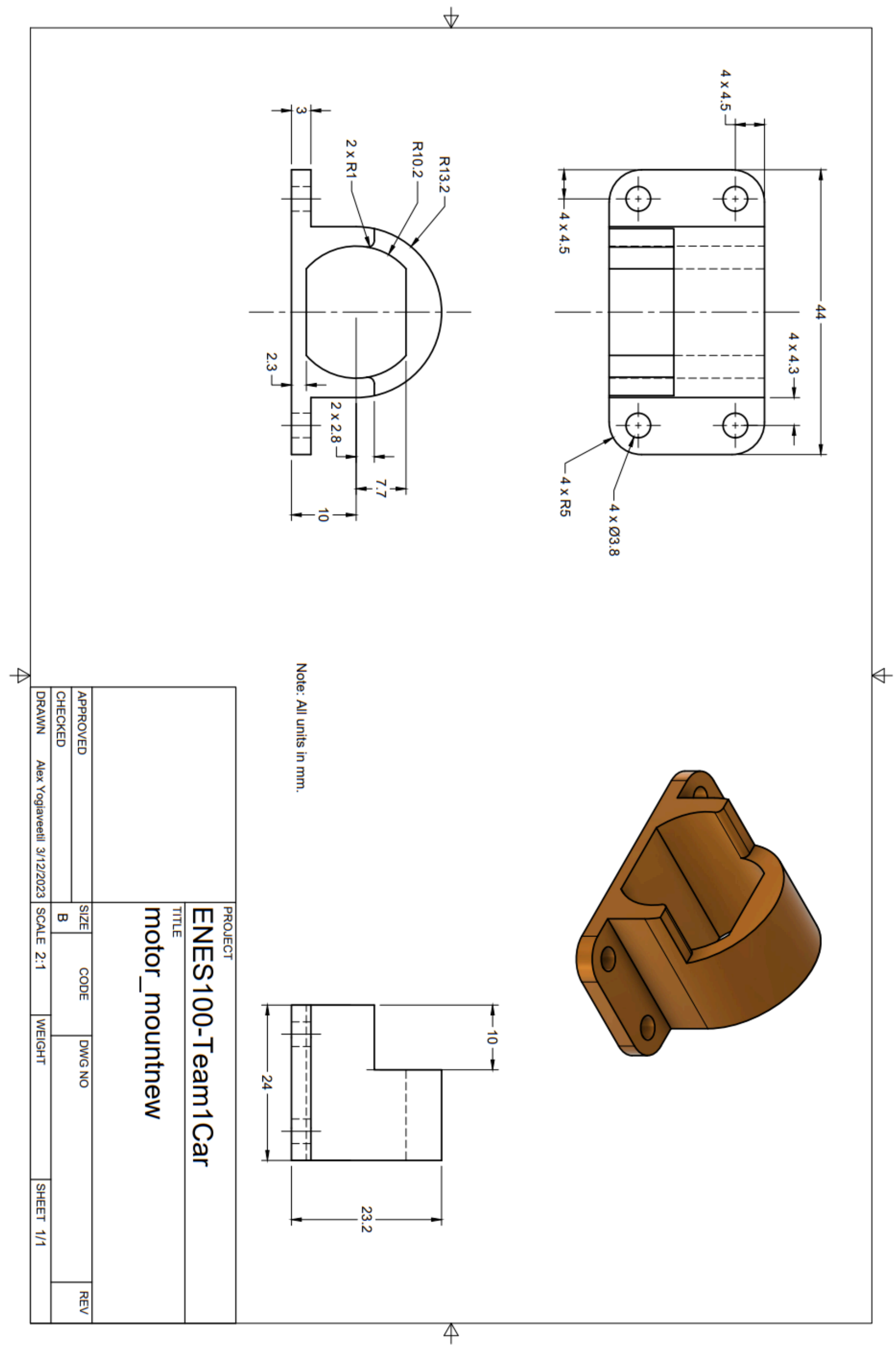

*All units in mm
PROJECT
ENES100-Group 1 OTV
TITLE
base
APPROVED
CHECKED
DRAWN
Seth Boledovic
3/9/2023
SIZE
B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1
Ø5 X 4
R5 X 4
30
16
21
4.5
20
5
14.52
6
60
9
25.5
40

Arduino Holder

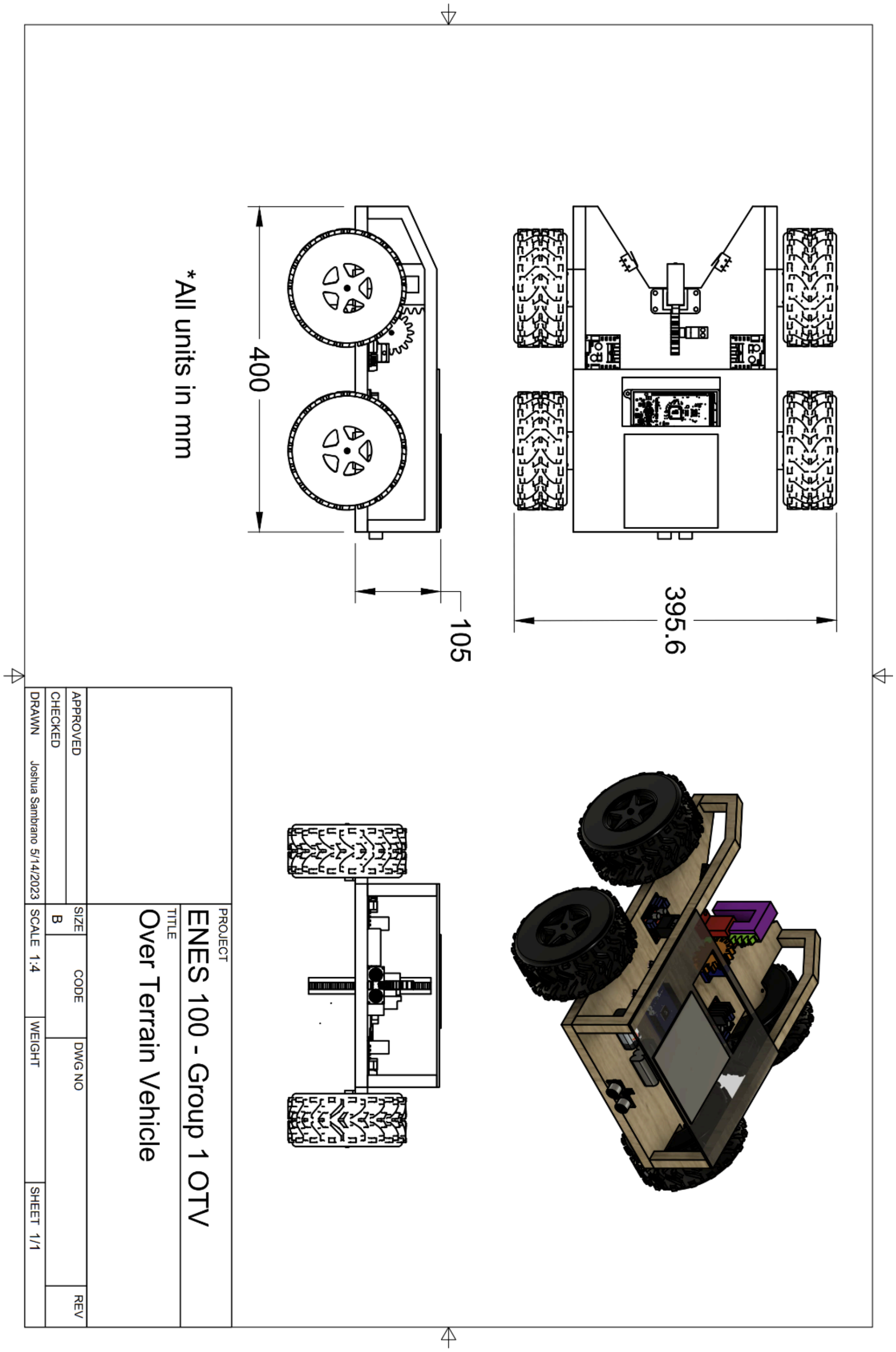



4 x Ø3.6
6 x Ø2.8
11.8
10.53
8.28
27.94
18.44
36.12
7.99
1.64
7
126.32
3
59.46
*All units in mm
PROJECT
ENES100 - Group 1 OTV
TITLE
Arduino Holder (Pt. 2)
APPROVED
CHECKED
DRAWN
Joshua Sambrano 3/12/2023
SIZE
B
CODE
DWG NO
REV
SCALE 1:1
WEIGHT
SHEET 1/1

Motor Mount


PROJECT
ENES100-Team1Car
TITLE
motor_mountnew
APPROVED
CHECKED
DRAWN
Alex Yogiaveetil 3/12/2023
SIZE
B
CODE
DWG NO
REV
SCALE 2:1
WEIGHT
SHEET 1/1
Note: All units in mm.
4 x 4.5
4 x 4.5
44
4 x 4.3
4 x R5
4 x Ø3.8
3
2 x R1
R10.2
R13.2
2.3
2 x 2.8
7.7
10
10
24
23.2

Four View Assembly



6 | Troubleshooting and Iteration

Our team used multiple different instances of troubleshooting within the woodshop while cutting the main frame of the chassis and the side structures that hold the "sunroof"/Aruco marker stand. Since we chose to construct our chassis out of pine with a height of fifteen millimeters this restricted us from using the laser cutter and limited us to tools among the woodshop. With our plan of making exact and detailed cuts in mind, we came to the conclusion that the bandsaw and jigsaw were our most efficient options after using the planer to shorten the height down to fifteen millimeters. While cutting the pine wood sheet we encountered multiple unexpected problems regarding making precise cuts to scale. The first issue we ran into was the rectangular cutouts that allow for the motor mounts to stick out and attach to the wheel. Since the jigsaw is unable to make inside cuts at ninety degree angles, we were forced to troubleshoot. We came up with the solution of making multiple diagonal cuts along the inside rectangular cut we intended to remove. With multiple precise diagonal cuts up to the top of the intended rectangular cutout, we were able to cut into the inside rectangular cutout halfway. This gave us enough room to make straight cuts from the middle of the rectangle to the outer sides and in the end achieve the ninety degree angles we had hoped for.

Upon creating the side structures of the chassis that act as supports for the "sunroof"/Aruco marker stand, we realized that our last sheet of birch plywood had a crack down the middle and was too large to cut with the jigsaw. By cutting the sheet of plywood down the middle and along the crack with a table saw we were able to create two sturdy and smaller sheets of plywood that fit within the jigsaw machine. However, we ran into even more problems while cutting the side structure to scale. Since we dimensioned our side structures to be fifteen millimeters thick and four hundred millimeters long, we experienced binding. We learned that when cutting long and thick sheets of plywood, the jigsaw blade is prone to getting caught and jammed in the wood because of how thin and susceptible to bending the blade is. In order to pry the jigsaw blade out of the wood we used a screwdriver as a wedge and pulled on the wood at the same time to slowly wiggle the blade out. To avoid any further instances of binding, we figured it would be best to use the bandsaw as opposed to the jigsaw as the bandsaw has a larger blade that would be less likely to catch and get stuck in the plywood. In addition, we used a straight edge attachment within the bandsaw so that the cut would be straight and the blade would have an even smaller chance of getting wedged into the plywood. This method worked a lot better than the plain jigsaw and we were able to finish all of our plywood cutouts in the woodshop without further problems.

7 | Teamwork and Project Management

How did your team's approach to decision-making change over time? Looking back, what approach was most effective and why?

Our team's approach to decision-making changed over the course of the semester to suit what we needed. Before the building phase of the project, we focused primarily on brainstorming as many different possibilities and solutions. By generating as many ideas as possible, we had the ability to choose from many different choices, and we could maximize the most potential creative ideas. Once we decided on which design we were moving forward with, we generated CAD renderings of each of the parts to make sure that we would be able to prototype it. When we transitioned into the build phase, we changed our approach to decision-making to be more progressive and make decisions based on the problems that we ran into. There were many examples of how our initial design is completely different from what we ended up building, because we had to tweak many aspects of the design when we ran into an issue. For example, originally our vehicle's chassis was just a slab of wood that was dimensioned properly and cutouts that allowed it to complete the mission objectives. However, this made wire management difficult, since there were a bunch of exposed wires on the top of the chassis. That is a hazard, since one of the wires could become damaged, compromising the whole mission. Therefore, we designed a sort of roll cage for our vehicle. It consisted of structures that connected to the side of the chassis, and a piece of acrylic that acted as a "sunroof." This served as a solution to the wire management issue, because the wires were no longer exposed and covered by the acrylic. The sunroof was attached with velcro, so that it could be easily removed to access the components inside. The sunroof also served as a place to put the Aruco marker and keep it flat. Our most effective method was prototyping and brainstorming alternative solutions for problems that we ran into that saved time. For example, when we ran into problems with the gearbox on the motor, we ordered the gearbox we needed on Amazon instead of ordering a whole new motor because the new motors would not come in time. We even used this method before the build phase, while we were still brainstorming and designing our over-terrain vehicle. For example, we were thinking about going over the hump, since we were worried that the data extraction arm would be too big to fit under the obstacle. To enable our vehicle to make the trek over the hump, we decided to purchase big wheels. But when we decided on the wheels that we were going to use, we came across a problem. The motors that we were getting were a lot smaller than the wheels, and the shaft on the motor that delivers torque would not be able to connect. Not wanting to change the motors so that we can stick to the budget, we started to look into any possible alternative ways to solve the problem. After some research online, we found an adapter that connected the motors shaft to the hex-shaped hole in the wheel. This minor detail allowed us to be able to continue with our chosen preferred design.

8 | Supplemental Brief - Teamwork and Project Management (Cont.)

How did the team stay encouraged to persist through failure?

Throughout the entire development process, the team encountered failures, or lack of success, across all areas, time and time again. Despite all the roadblocks encountered this semester, one could commend the team for heading into each troubleshooting process with a growth mindset and open mind, and remaining team-oriented.

When any of the subcategories or areas of design underperformed, no member ever resorted to assigning blame or abandoning the mission, no matter how complex the problem seemed to be, or how tedious the task would be to resolve it. It would have been easy to concede, and lower expectations, maybe even eliminate them, but instead, each team member fully adopted an engineering mindset, where they utilized their problem-solving skills and took on progressive attitudes, unequivocally. Failure and shortcomings were used as opportunities to work towards becoming better engineers, and everyone on the team did.

Collectively, the team would brainstorm possible solutions for whatever issue the OTV was experiencing. As said, this was done by all team members, regardless of whether they had a role in that specific sub-team or not, so ideas were collected from all different backgrounds and experience levels, and taken into consideration. The entire semester was made of a lengthy run of trial-and-error learning. Ideas, concepts, and best guesses were thrown around and made use of by different people. There was not a single plan, design area, or component that went into the development phase without the input of multiple members, and everyone's awareness of project details was made sure and reinforced. Each member was able to encourage and push the other, ensuring that no teammate gave up, slacked off, or fell behind, improving our team dynamic as a whole.

As most know, attitudes are contagious. It is apparent when negativity is being spewed, the same way it is apparent when positivity is being emitted. The right attitude can make or break a team. It can be the difference between success and failure and separates a fruitful work environment from a disagreeable one. Taking this into account, the team made sure to counter every letdown with determination.

Communication, along with critical thinking and problem-solving are essential engineering skills, just as must so as the technical skills – such as the machine learning and materials training done in class – that come from being a professional engineer. When assistance was needed, and it frequently was, all members felt comfortable asking. Everyone was able to receive constructive criticism with an open mind, which furthered the development of the OTV, allowing the team to draw from different approaches.

So, while the desired results with the OTV data mission may not have been achieved, there is no doubt that each team member walked out with increased confidence as an aspiring engineer, a better understanding of the professionalism that goes into cultivating a healthy and productive team environment, and the knowledge of how to effectively collaborate through difficulty. These are key lessons that will be brought into future classes, work environments, and collaborative spaces in general.