Milestone 9: Final Design Report



Lightning VicQueen

Hot Wheels

Mission: Fire Suppression

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Constructing a Prototype

Our OTV chassis base was constructed out of PLA, laser cut to the dimensions shown in Figure 18 in the engineering drawings section, which served as the “base” of our OTV.

On the bottom of each of the corners we attached aluminum “U” shaped legs that give the OTV a table-like appearance. The legs are extrusion channels with pre-built evenly spaced holes that made attaching components and routing wires straightforward. These legs have the dimensions shown in Figure 1.

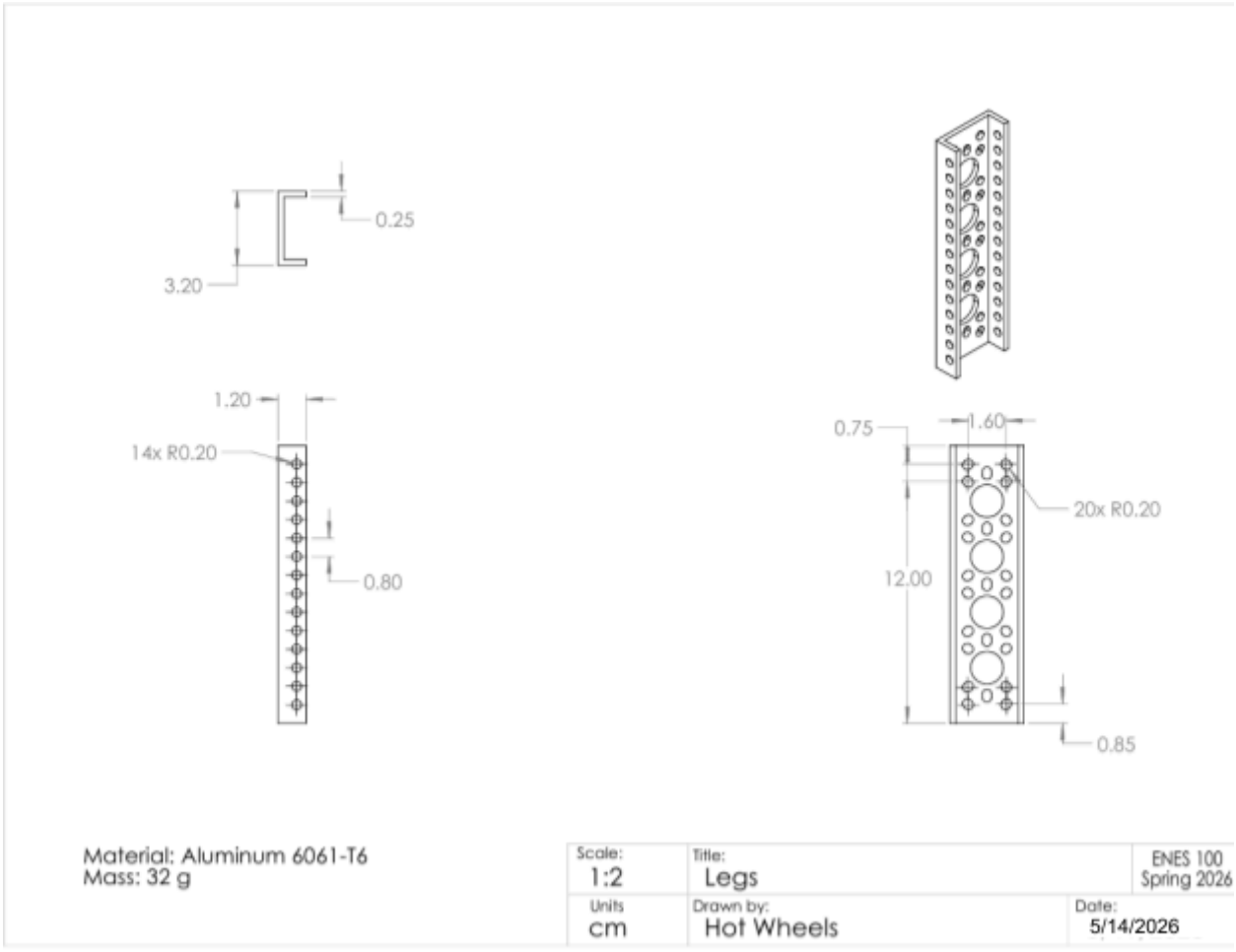


Figure 1. Chassis Legs

These legs were connected to the PLA base plate via 3D printed PLA brackets fastened with M4 screws. PLA was used for the base plate because it is strong, light, and allows for components to be screwed directly into it. We drilled holes into the PLA base and brackets to screw everything into place. These brackets have the dimensions shown in Figure 3 in the engineering drawing section.

At the bottom of the aluminum legs 3D-printed PLA mounts for the motors were attached to the aluminum legs using M4 screws. They have the dimensions shown in Figure 22 in the engineering drawing section.

These motors were connected to the wheels using a hex adapter, which was fastened using a screw and washer.

After realizing we needed more stability, we added PLA strips. They were cut with a vertical band saw. We drilled holes in these strips and used M4 screws to attach them midway along the lengths to increase stability, as shown in Figures 15 and 23.

Mission

To discuss our mission apparatus and control algorithm, it makes sense to first discuss all of the requirements and constraints we were working around. Once aligned with the mission site, we had to Identify and transmit which topography direction (A, B, C) is pointed towards the OTV's starting location, Measure and correctly transmit the number of active flames present (with the knowledge that the middle flame will always be on), and Contain the fire by extinguishing all flames except for the middle flame. Further, we had to ensure that any part of the OTV that is intended to be in proximity of a flame must be non-flammable, that Candles must remain in the arena on the candle pedestal at all times when lit, and that we did not use materials that leave a residue to extinguish the flames.

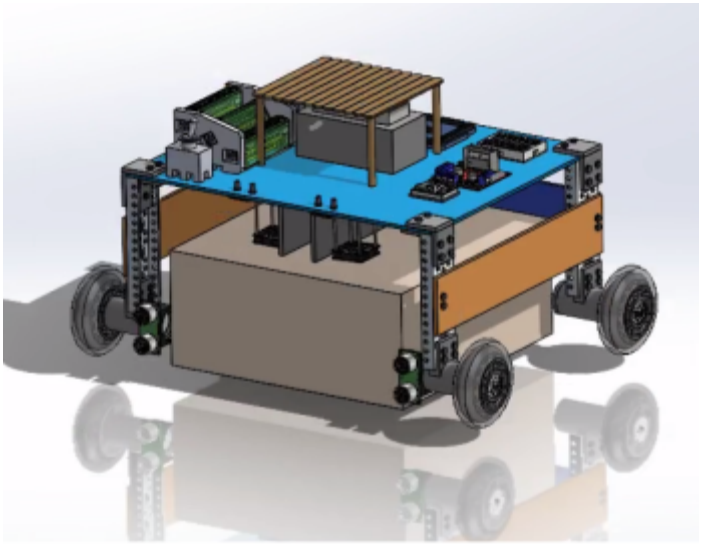


Figure 2. Angled side view of OTV on top of mission site

Following the constraint of interactability with the flames without damaging the OTV, we chose to approach the mission site from above with fireproof materials, and maintain enough distance between the OTV and the site that heat would be dissipated before reaching our OTV. The electrical components of our OTV for the most part were mounted to the PLA base of the chassis. The components found on top of the OTV include two H-bridges, a bread-board, the wifi module, a power converter, the battery and Elegoo mega, as visible in Figure 2.

Our fans and motors run off our 12V battery. Our Arduino, ultrasonic sensors, and heat sensors run at 5V via a buck converter stepping down from 12V. This arrangement provides sufficient power for the fans while maintaining stable voltage for the control electronics.

The H-bridges were attached to the PLA base by screwing holes in the PLA in the desired location, followed by using screws and nuts to fasten the H-bridge to the PLA. The wifi module and Elegoo mega were attached the same way as the H-bridges were. The bread-board came with an adhesive bottom allowing us to stick it straight onto the PLA base. The power converter was attached using double sided adhesive tape. The battery was placed in a PLA printed hold which was glued to the PLA base using Epoxy. This allowed for easy removal when the battery needed

to be charged and stored. Over the battery and holder was placed a table made of popsicle sticks (Figure 16), wooden skewers that were cut to desired lengths and hot glue. This was held in place by drilling holes into the top of the OTV where we wanted the legs of the table. This allowed the table to have vertical movement, but not horizontal, allowing removal to interact with the battery. The lack of horizontal movement was crucial to maintaining consistent reads from the vision system, as the Aruco marker was taped atop the vision system.

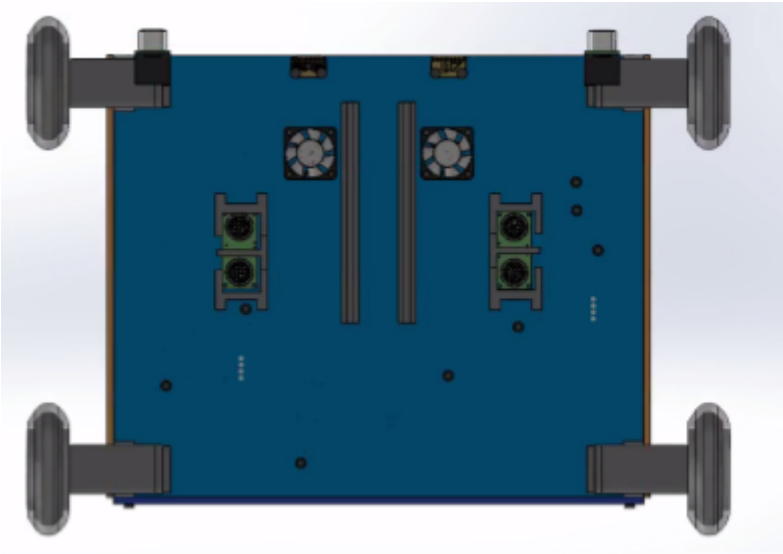


Figure 3. Bottom View of OTV

Our mission apparatus mounts entirely to the underside of our PLA base plate (Figure 14). This is so that once our OTV drives over and aligns with the pedestal, everything is positioned directly above the candles with no additional adjustment needed. This eliminates mechanical complexity.

We use two UMLIFE 40x40x10mm brushless DC blower fans (12V, 0.08A each) mounted at the front edge of the base plate underside, hanging off stripped wires (Figure 4), spaced to match the lateral candle spacing on the pedestal. The 5V fans available in the classroom did not produce enough airflow to reliably extinguish the candles, so we switched to 12V fans. Using two fans allows both outer candles on one side of the pedestal to be extinguished simultaneously. They face downward and each is hooked up directly to the power distribution board.

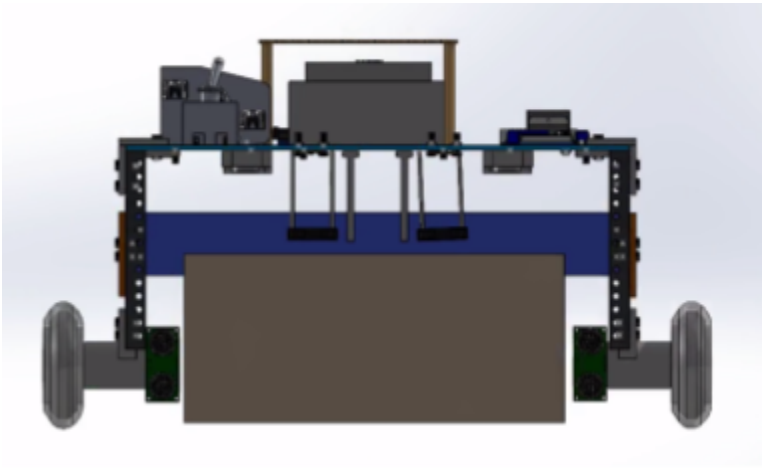


Figure 4. Front of OTV on top of mission site

Two IR Flame/Heat Sensor Modules mount flush beside the fans at the same front edge via M2 screws, also facing downward. We chose this module because it is accurate enough for our needs, and was available at the school store for instant experimentation. Flame sources sit 2 to 8 cm below our sensors when our OTV parks over the pedestal, due to variations in topography height, which does not cause enough variation to prevent our modules from working.

We use two fans and two heat sensors because our wiring constraints cannot support four heat sensors. Two sensors means two passes regardless, so two fans lets us extinguish both candles in each pass simultaneously. We place them at the front edge because the candle layout always puts two candles farther from our starting position and two closer, so two passes cover all four efficiently (Figure 7).

Two HC-SR04 ultrasonic sensors are screwed into 3d-printed PLA mounts which are glued directly into the underside of the base plate (Figure 7). The two sensors, one on the left and one on the right, face downward to scan the topography surface. They run at 5V, work reliably from 10 to 25 cm, and resolve distance to about 3 mm. All four sides of the pedestal topography have distinct heights, so a left versus right comparison reliably identifies the orientation. We chose this over rotating the OTV to scan all sides because rotation introduces inconsistency and adds complexity, and our OTV is too small to rotate on the mission site. Two more ultrasonic sensors on our OTV's front legs are glued onto 3D printed PLA mounts, which are glued onto

our motor mounts, facing forwards (Figure 10, Figure 11), for pedestal alignment during approach and obstacle detection after the mission.

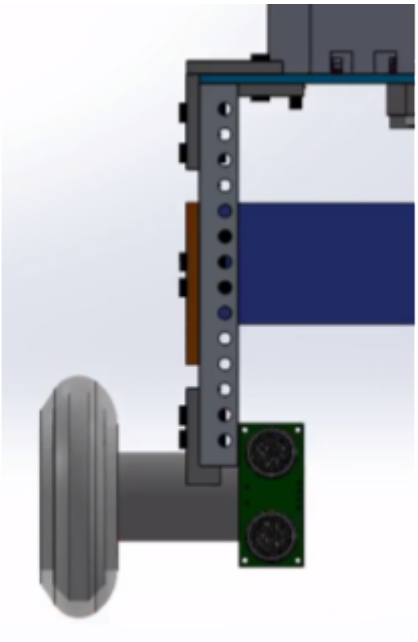


Figure 5. One side of front of OTV showing distance sensor

Lastly, we also have 3d printed walls glued onto the bottom of our OTV to prevent our Fan's airflow from affecting the middle flame. These walls are 12.7cm by 5.48 cm by .4 cm, as visible in Figures 7 and 10.



Figure 6. Flowchart of Control Algorithm

Once on the mission site, our OTV follows the flowchart shown in figure 9 To achieve all the mission objectives, it first aligns the IR modules with the front two candles on the mission site. Then, it detects which of those are lit. It then proceeds to line up the fans with the front two candles on the mission site, and ‘wobble’ back and forth to create a turbulent air flow, which is only possible due to the fans being hung from wires. This extinguishes these flames. It then repeats this process for the further two candles on the mission site. Finally, it aligns with the middle of the site, reads distances, and uses experimentally determined data to determine which way the mission is oriented.

Propulsion

In regards to the propulsion of our OTV, our main challenge involved driving over the 5cm-high log. Other than this case, our OTV was under mostly low-stress situations that required relatively low speed, torque and power. As far as requirements, our basic limitations included being able to power all systems at full power for 10 minutes, not using lithium or lead acid based batteries, having rechargeable batteries, and covering any exposed leads on the batteries with connectors. Some other challenges regarding propulsion included being able to turn accurately in order to align with our mission site, orient properly around the obstacles, and also navigate around the obstacles.

As to maintain our size in order to orient the OTV entirely on top of the fire mission site, we needed to limit the space that our motor and motor mounts took up on the inside of our OTV. Because of this, we chose to mount our motors horizontally entirely under our legs, as shown in Figure 14. Our motors were mounted using a 3-D printed mount that limited all sides of potential motion, as pictured in Figure 22. These mounts were screwed into the legs for rigid structure. The motors have a 4mm d-shaft so we used a 12mm hex hub adaptor to fasten into the wheels as the wheels have 12mm hex hubs in the rims. This configuration insured a rigid mount for our propulsion system. As far as steering, we used a skid steer system. To turn we would power one side of the motors forward and the other side backwards. This way the entire OTV would turn mostly in place.

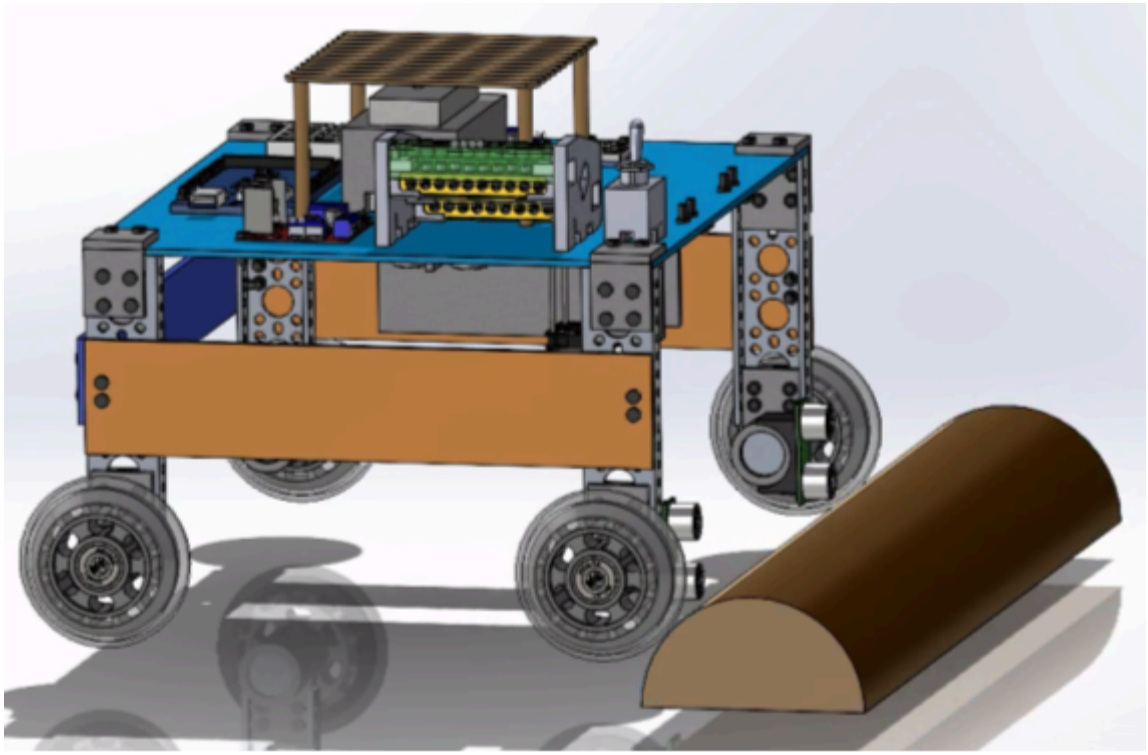


Figure 7. OTV Going Aligning with the Log

As for our choice of wheels and motors, we knew we would need large enough wheels and strong enough motors in order to overcome the log. As a result of our choice to drive over the 5cm-high log, we chose wheels with a 12.7 cm diameter and 3 cm tread. As well as this, we decided to use four wheel drive to help with turning as well as overcoming the log. Before choosing a motor, we did some basic calculations to help limit our options.

We made initial calculations based on our 1.4kg weight and even center of mass, we created a free body diagram, as depicted in Figure 8, which we used to calculate the torque under the lowest stress situation, resting on flat ground.

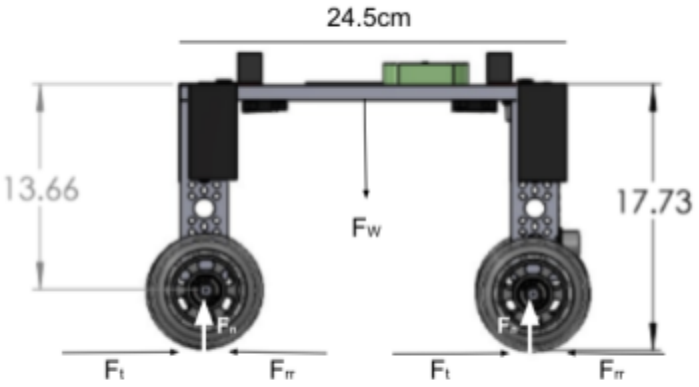


Figure 8. Free-Body Diagram

$\sum F_y = 0 = 4F_N - F_W$

$F_W = mg = 1.4kg \times 9.8\frac{m}{s^2}$

$F_W = 13.72N$

$0 = 4F_N - 13.72N$

$F_N = 3.43N$

$\sum F_x = 0 = 4F_T - 4F_{RR}$

$F_{RR} = F_N \times C_{RR}$

$C_{RR} = 0.02$

$F_{RR} = 3.43N \times 0.002$

$F_{RR} = 0.0686N$

$F_x = 0 = 4F_T - 4(0.0686N)$

$F_T = 0.0686N$

$r = 3.81cm$

$\tau = F_T \times r = 0.0686N \times 3.81cm$

$\tau = 0.26N - cm$

$F_W = mg = 1.4kg \times 9.8\frac{m}{s^2} = 13.72N$

$radius\ of\ wheel = R = 3.8cm$

$radius\ of\ log = r = 5cm$

$arm\ lever = \mathscr{R} = (R + r + d)sin\theta$

$\Delta y = R - r = 1.2cm$

$cos\theta = \frac{\Delta y}{R + r} = \frac{1.2cm}{8.8cm}$

$\theta = 82.2^\circ$

$pivot\ point\ to\ center\ of\ mass = d = 12.25N - cm$

$\mathscr{R} = (r + R + d)sin\theta = (21.5)\sin 82.2^\circ$

$\mathscr{R} = 21.3cm$

$\tau = \mathscr{R} \times F_W = 21.3cm \times 13.72N$

$\tau = 292.236N - cm$

Per wheel: $\frac{\tau}{2} = \frac{292.236N - cm}{2} = 146.118N - cm$

With these values, we calculated the angle at which the wheels will be climbing the log as well as the torque that would be required to overcome this angle. Knowing that this is the highest stress situation our OTV would be under, we chose a motor with torque, current, and speed that

would match this situation. The motor we chose has a stall torque of 245.17 N-cm and a no-load speed of 28 rpm. Furthermore, we used our calculated torque to ensure that our motor would run at a reasonable speed and safe current under the most ideal and least ideal situations that our OTV might be under. We defined a reasonable speed as anywhere between 10-20 cm per second. This was based on what we perceived would be necessary for overcoming the log as well as knowing that we could power the motors at lower power to go slower.

$$\frac{\tau}{\tau_{stall}} = \frac{0.26N - cm}{245.17N - cm} = 0.0011$$

Operating at 0.11% capacity

$$\omega = \omega_{free}\left(1 - \frac{\tau}{\tau_{stall}}\right)$$

$$\omega = 28rpm(1 - 0.0011) = 27.969rpm$$

$$\omega = 27.969rpm \times \frac{2\pi}{60} = 2.93\frac{rad}{s}$$

$$v = \omega r = 2.93\frac{rad}{s} \times 3.81r = 11.159\frac{cm}{s}$$

$$I = \frac{\tau}{\tau_{stall}} \times \tau_{stall} = \frac{146.118N - cm}{245.17N - cm} \times 1.6A$$

$$I = 0.95A$$

$$I = \frac{\tau}{\tau_{stall}} \times \tau_{stall}$$

$$I = 0.0011 \times 1.6A = 0.00176A$$

Based on all of these calculations, we justified our motor selection and represented the relationship between the speed, torque, and current in Figure 9. Our motor would be able to handle the high stress situation of driving over the log while also running at a relatively low speed for turning and navigating around our mission site and obstacles.

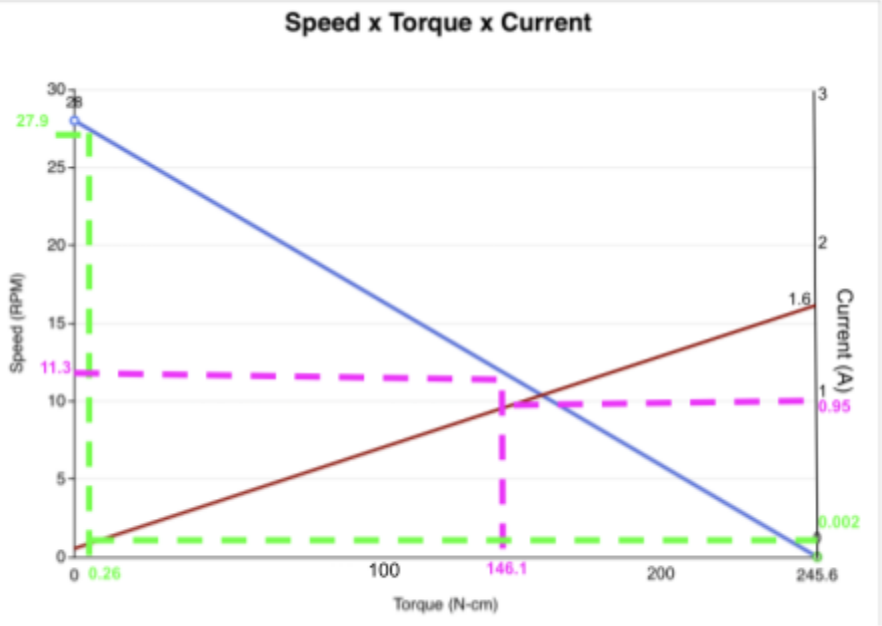


Figure 9. Speed x Torque x Current Graph

After our initial calculations we were prepared to construct our propulsion system and make adjustments throughout testing. One major problem we encountered was one of our motors breaking. This impacted our entire OTV and turning system. We bought a new motor which had an entirely different torque, rpm, and current. We also did not know the calculations for this new motor, so it was difficult to integrate it into our OTV. We powered the new motor at 80% in order to have it match as close as we could to our original motors. As well as this, we added some new components to our OTV which increased its weight. Finally, we ended up using a set of wheels from the school store instead of the ones we used in our original calculations. All of this impacted our OTV's propulsion system.

We measured our OTV's actual running linear speed using arena measurements and a timer. This could pose some margin of error. However, we measured our actual running linear speed to be approximately 9.6 cm/s. From this, we calculated our speed to be approximately 14.4 RPM. From both of these calculations, we calculated our operating torque to be approximately 100 N-cm. This also is justified when we use our new RPM on our SpeedxTorquexCurrent Graph, as depicted in Figure 10.

Our angular speed of 1.51 rad/s is lower than our predicted 2.93 rad/s while our operating linear speed is also lower than our predicted 11.15 cm/s, at 9.6 cm/s. All these differences can be explained by the changes we made to our design throughout testing and building. Firstly, we

used larger wheels for our OTV which lowered our overall linear and angular speed. As well as this, our RPM increased due to our decreased torque and change in wheel size. Our original torque calculation was 146.1 N-cm, however our new calculation showed that we operated at approximately 100 N-cm. This change is likely due to our increase in weight as we added new components and structure to our OTV as well as increasing our wheel radii. This caused a different ratio in force to leverarm, decreasing our operating torque.

$$RPM = \frac{60v}{2\pi r} = 14.4 \ RPM$$

$$v = 9.6 \ \frac{cm}{s}$$

$$\omega = \frac{v}{r} = \frac{9.6}{6.35} = 1.51 \frac{rad}{s}$$

$$\tau = \frac{P}{\omega} = \frac{1.5}{1.51} = 1 \ N - m$$

$$\tau = 100 \ N - cm$$

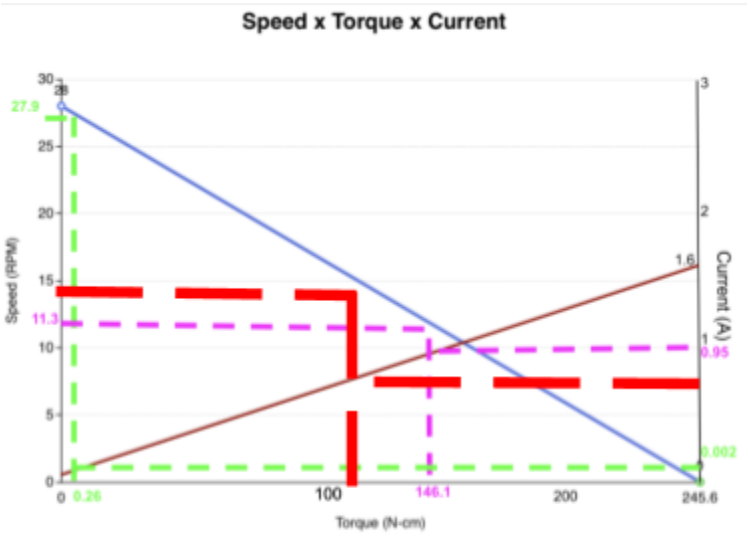


Figure 10. Updated Speed x Torque x Current Graph

Electronics

We must power our OTV by a maximum allocated time of 5 minutes, and we need the OTV to go directly over the mission site, to then navigate to the end of the course through all the obstacles, over the finish line log. One challenge associated with this process is finding a battery

that can handle the operating and maximum current of all the OTV components. The fans and motors draw significant current and require a battery with an acceptable maximum discharge value, or a high C-Rate, that can handle the current drawn. Another problem will be navigating the OTV through the vision system and sensors. The OTV must precisely respond to the signals given by the sensors and vision system to properly align with both the mission site and the navigation path. Thus, the precision of our OTV's alignment is dependent on the accuracy of the vision system's signal of direction and the ultrasonic sensors' signal of obstacles. We must ensure that our components are accurate enough to keep our OTV within a reasonable margin of error from our goals.

We will be using the Tenergy NiMH 12V 2000mAh Battery Pack w/ Bare Leads to power the OTV because it is affordable and has a maximum discharge C-Rate of 1, meaning that although its max is 1C, the 3.615C that could affect the battery at motor stalling would not last long enough to cause any major damage. The typical operating current would be 1.1108A, which would create a C-Rate of just 0.5604. This battery will also be able to last approximately 1.80 hours at a standard operating current with minimal stalling, which is plenty of time for the OTV to function. The battery must also be 12V, as the fans necessary to blow out the candles must be at least 12V. The OTV's direction will be detected through the vision system, connected by the WIFI module. Our Arduino will get the theta of our OTV from the vision system to then compare that theta to the theta we need for proper alignment. Potential walls and obstacles will be detected via ultrasonic sensors.

Battery: Tenergy NiMH 12V 2000mAh Battery Pack w/ Bare Leads, Discharge rate under 1C

Expected Standard Current Drawn Calculations:

Cooling Fan: 0.08A * 2 = 0.16A

Arduino Elegoo: 0.05A * 1 = 0.05A

L2985 Module: 0.03A * 2 0.06A

Ultrasonic Sensor: 0.02A *4 = 0.08A

IR Heat Sensor: 0.0004A * 2 = 0.0008A

Motors: 0.085 * 4 = 0.34A

WIFI Module: 0.32 * 1 = 0.32A

Other Constant components: Negligible/None

Total: = 1.1108A

Corresponding Power Outputs according to Voltage and Current:

P=IV, just take current calculation and add the components corresponding voltage:

Cooling Fan: 0.08A * 2 * 12V= 1.92W

Arduino Elegoo: 0.05A * 1 * 12V = 0.6W

L2985 Module: 0.03A * 2 * 12V = 0.72W

Ultrasonic Sensor: 0.02A *4 * 5V = 0.4W

IR Heat Sensor: 0.0004A * 2 * 5V= 0.004W

Motors: 0.085 * 4 * 12 = 4.08W

WIFI Module: 0.32 * 1 * 3.3V = 1.056W

Other Constant components: Negligible/None

Total Power Usage: 8.78W

Runtime:

2000mAh -> 2Ah, at an expected standard operating current of 1.1108A, 2Ah/1.1108 = 1.80 hours.

Power will be directed via the battery to the two H-bridges that will both connect to two motors. The motors will be powered and grounded by the h-bridges, while the logical signals

will be sent directly from the Arduino digital pins to the H-bridges through the IN1 – IN4, and the EnA and EnB pins. The Fans will be powered constantly throughout the mission via the Power Distribution Board, directly powered by the 12V battery. All of the connections were updated to go through a breadboard instead of a buck converter like originally planned, as the buck converter we received did not work. This change consequently results in an Arduino more susceptible to internal damage, but our material limitations required us to make this change. Our circuit connections are demonstrated through Figure 11 and Figure 12 below. The specific pins used are also detailed via a chart on the right hand side of the image in Figure 12.

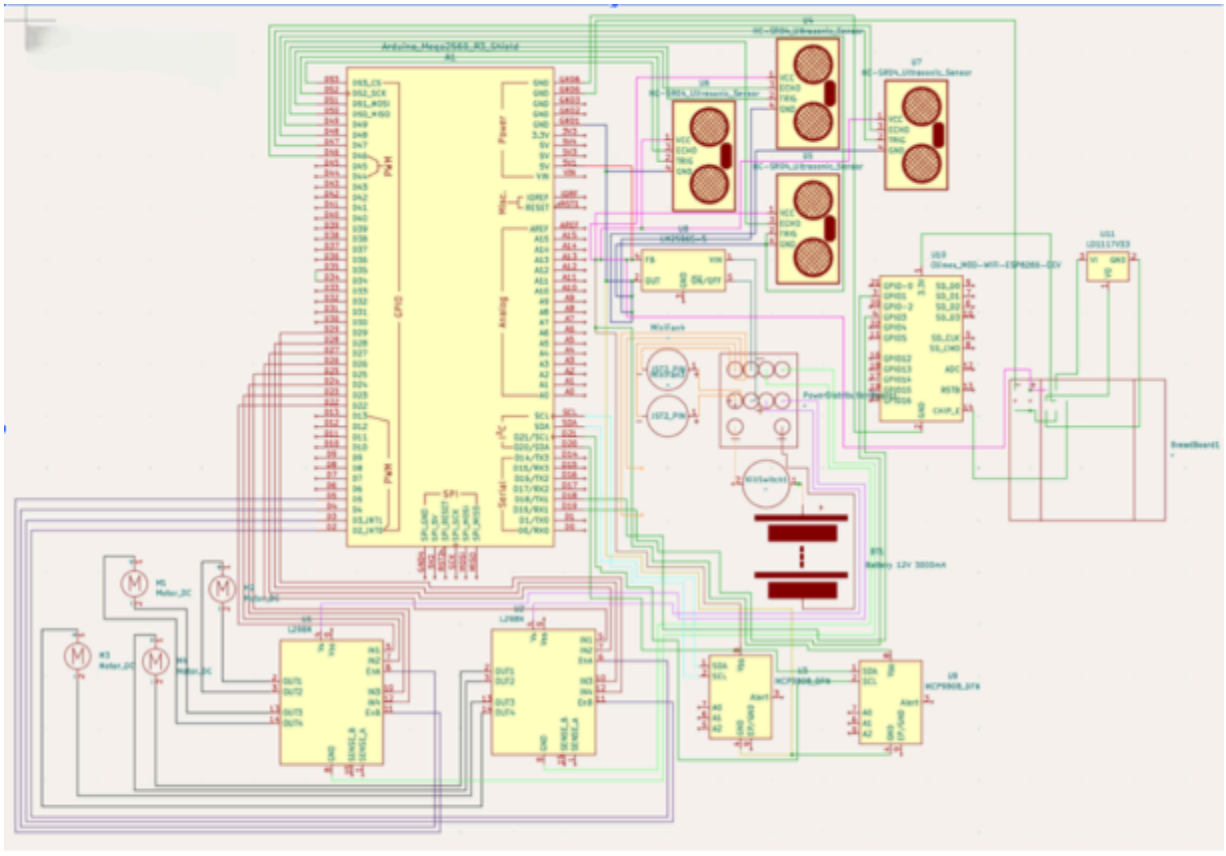
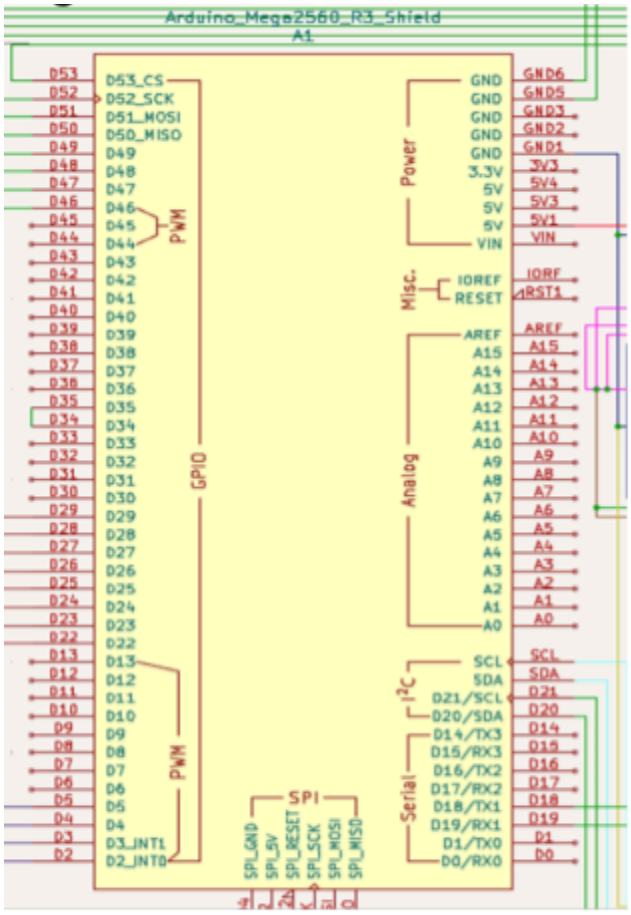


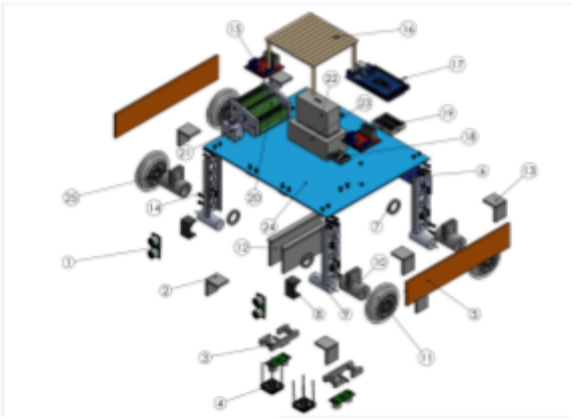
Figure 11. Electrical Circuit Schematic



1	Ardunio Mega Pins used	Used By
2	D53	Ultrasonic Sensor #1
3	D52	Ultrasonic Sensor #1
4	D51	Ultrasonic Sensor #2
5	D50	Ultrasonic Sensor #2
6	D49	Ultrasonic Sensor #3
7	D48	Ultrasonic Sensor #3
8	D47	Ultrasonic Sensor #4
9	D46	Ultrasonic Sensor #4
10	D29	H-Bridge #1
11	D28	H-Bridge #1
12	D27	H-Bridge #1
13	D26	H-Bridge #1
14	D25	H-Bridge #2
15	D24	H-Bridge #2
16	D23	H-Bridge #2
17	D22	H-Bridge #2
18	D2 PWM	H-Bridge #1
19	D3 PWM	H-Bridge #1
20	D4 PWM	H-Bridge #2
21	D5 PWM	H-Bridge #2
22	D18 TX1	Wifi Module
23	D19 RX1	Wifi Module
24	GND1	Buck Converter
25	5V	Buck Converter
26	SCL	Temp Sensor #1
27	SDA	Temp Sensor #1
28	D21 SCL	Temp Sensor #2
29	D20 SDA	Temp Sensor #2
30	GND5	Breadboard
31	GND6	Wifi Module

Figure 12. Arduino Pin Assignment Chart

Sustainability



#	PART Name	QTY.	Mass (g)	Cost ($)
1	Ultrasonic Sensors	4	8.7	3.95
2	L-Bracket	4	6.59	0
3	Ultrasonic Sensor Base Mounts	2	7.97	0
4	12V Fans	2	22	5.99
5	Side Leg PLA Supports	2	52.65	0
6	Back Leg PLA Supports	1	47.38	0
7	Motor Mount Backing	4	1.24	0
8	Ultrasonic Sensor Leg Mounts	2	4.59	0
9	12V Motor	4	47	31.95
10	Motor Mount	4	15.1	0
11	Wheel	4	160	18.97
12	Fan Wall	2	31.5	0
13	L-Bracket	4	6.59	0
14	Metal Leg	4	32 g	5.99
15	H-Bridge	2	30	4.95
16	Marker Table	1	15	0
17	Arduino Mega	1	34	22.99
18	Wifi Module	1	2	0
19	Breadboard	1	10	3.95
20	Power Distributor	1	54.4	8.99
21	Kill Switch	1	23	5.69
22	12V Battery	1	255	36.49
23	Battery Mount	1	40.17	0
24	Base PLA	1	237.6	5
25	Hex Adaptor	4	0.28	8.39

Total Mass: 2 kg
Total Cost: $313.30

Scale: 1:4	Title: Bill of Materials	ENES 100 Spring 2026
Units: cm	Drawn by: Hot Wheels	Date: 5/14/2026

Figure 13.
Bill of Materials

EoL potential:

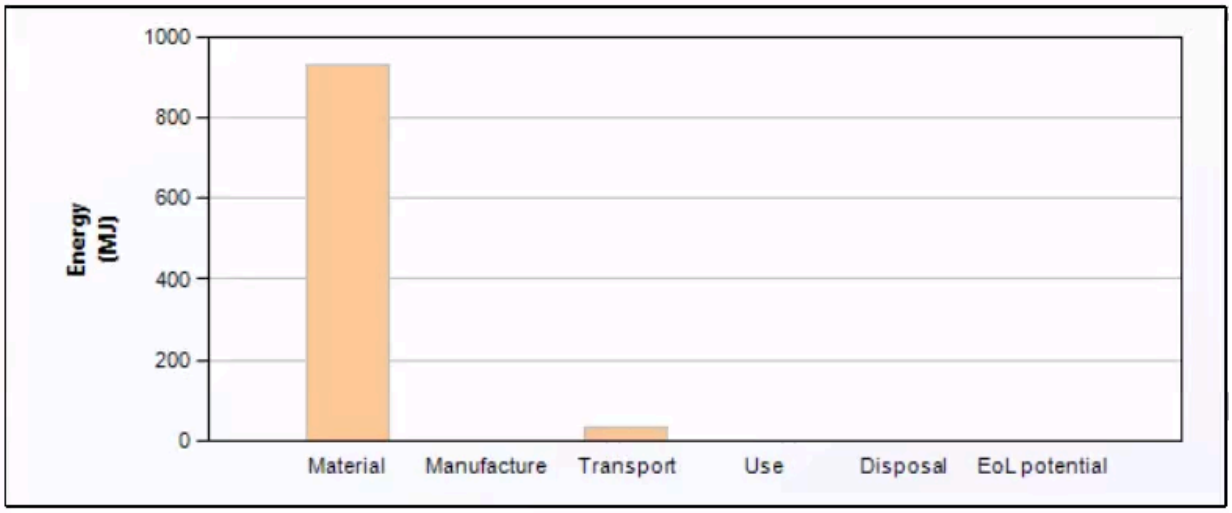
Component	End of life option	Energy (MJ)	%
Ultrasonic Sensors	Landfill	0	
L-Bracket	Landfill	0	
Ultrasonic sensor base mounts	Landfill	0	
12V Fans	Landfill	0	
Side Leg PLA supports	Landfill	0	
Back Leg PLA supports	Landfill	0	
motor mount backing	Landfill	0	
ultrasonic sensor leg mounts	Landfill	0	
12v motor	Landfill	0	
motor mount	Landfill	0	
wheel	Landfill	0	
fan wall	Landfill	0	
Metal Leg	Landfill	0	
H-Bridge	Landfill	0	
Marker Table	Landfill	0	
Arduino Mega	Landfill	0	
Wifi Module	Landfill	0	
Breadboard	Landfill	0	
Power Distributor	Landfill	0	
Kill Switch	Landfill	0	
12v Battery	Downcycle	0	
battery mount	Landfill	0	
Base PLA	Landfill	0	
Hex adapter	Landfill	0	
Total		**0**	**100**

Ansys
GRANTA EDUPACK

Eco Audit Report

Energy Analysis

Summary



	Energy (MJ/year)
Equivalent annual environmental burden (averaged over 0.4 year product life):	2.41e+03

Detailed breakdown of individual life phases

Material:

Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass (kg)	Energy (MJ)	%
Ultrasonic Sensors	Printed circuit board assembly	Virgin (0%)	0.0087	4	0.035	4.5	0.5
L-Bracket	PLA (general purpose)	Virgin (0%)	0.0066	4	0.026	1.2	0.1
Ultrasonic sensor base mounts	PLA (general purpose)	Virgin (0%)	0.008	2	0.016	0.72	0.1
12V Fans	ABS (injection molding, platable)	Virgin (0%)	0.022	2	0.044	4.2	0.5
Side Leg PLA supports	PLA (general purpose)	Virgin (0%)	0.053	2	0.11	4.7	0.5
Back Leg PLA supports	PLA (general purpose)	Virgin (0%)	0.047	1	0.047	2.1	0.2
motor mount backing	PLA (general purpose)	Virgin (0%)	0.0012	4	0.005	0.22	0.0
ultrasonic sensor leg mounts	PLA (general purpose)	Virgin (0%)	0.0046	2	0.0092	0.41	0.0
12v motor	Fan	Virgin (0%)	0.047	4	0.19	46	5.0
motor mount	PLA (general purpose)	Virgin (0%)	0.015	4	0.06	2.7	0.3
wheel	Styrene butadiene rubber (SBR, 30% carbon black)	Virgin (0%)	0.16	4	0.64	70	7.5
fan wall	PLA (general purpose)	Virgin (0%)	0.032	2	0.063	2.8	0.3
Metal Leg	Aluminum, commercial purity, 1-0	Virgin (0%)	0.032	4	0.13	25	2.7
H-Bridge	Integrated circuit (large)	Virgin (0%)	0.03	2	0.06	4.8e+02	51.6
Marker Table	Aspen (populus tremuloides) (I)	Virgin (0%)	0.015	1	0.015	0.33	0.0
Arduino Mega	Printed circuit board assembly	Virgin (0%)	0.034	1	0.034	4.4	0.5
Wifi Module	Integrated circuit (large)	Virgin (0%)	0.002	1	0.002	16	1.7
Breadboard	ABS (high-impact, injection molding)	Virgin (0%)	0.01	1	0.01	0.96	0.1
Power Distributor	ABS (high-impact, injection molding)	Virgin (0%)	0.054	1	0.054	5.2	0.6
Kill Switch	Stainless steel, austenitic, AISI 304, 1/2 hard	Virgin (0%)	0.023	1	0.023	1.4	0.2
12v Battery	NiMH, rechargeable battery (for laptops)	Virgin (0%)	0.26	1	0.26	2.4e+02	25.3
battery mount	PLA (general purpose)	Virgin (0%)	0.04	1	0.04	1.8	0.2
Base PLA	PLA (general purpose)	Virgin (0%)	0.24	1	0.24	11	1.1
Hex adapter	Brass, CuZn30, C43600, hard (arsenical 70/30 brass)	Virgin (0%)	0.028	4	0.11	9.2	1.0
Total				**54**	**2.2**	**9.3e+02**	**100**

*Typical: Includes 'recycle fraction in current supply'

Manufacture:

Summary

Component	Process	Amount processed	Energy (MJ)	%
Total				100

Transport:

Summary

Breakdown by transport stage

Stage name	Transport type	Distance (km)	Energy (MJ)	%
12V fans	40 tonne (6 axle) truck	4.5e+03	8.2	25.3
12v motor	Ocean freight	1.2e+04	4.6	14.2
wheel	40 tonne (6 axle) truck	4e+02	0.73	2.2
metal leg	40 tonne (6 axle) truck	3.5e+02	0.63	2.0
arduino mega	40 tonne (6 axle) truck	5.2e+02	0.94	2.9
power distributor	40 tonne (6 axle) truck	4.5e+03	8.2	25.3
kill switch	40 tonne (6 axle) truck	5e+02	0.91	2.8
hex adapter	40 tonne (6 axle) truck	4.5e+03	8.2	25.3
Total		**2.7e+04**	**32**	**100**

Breakdown by components

Component	Mass (kg)	Energy (MJ)	%
Ultrasonic Sensors	0.035	0.51	1.6
L-Bracket	0.026	0.38	1.2
Ultrasonic sensor base mounts	0.016	0.23	0.7
12V Fans	0.044	0.64	2.0
Side Leg PLA supports	0.11	1.5	4.8
Back Leg PLA supports	0.047	0.69	2.1
motor mount backing	0.005	0.072	0.2
ultrasonic sensor leg mounts	0.0092	0.13	0.4
12v motor	0.19	2.7	8.5
motor mount	0.06	0.88	2.7

Metal Leg	0.13	1.9	5.8
H-Bridge	0.06	0.88	2.7
Marker Table	0.015	0.22	0.7
Arduino Mega	0.034	0.5	1.5
Wifi Module	0.002	0.029	0.1
Breadboard	0.01	0.15	0.5
Power Distributor	0.054	0.79	2.5
Kill Switch	0.023	0.34	1.0
12v Battery	0.26	3.7	11.5
battery mount	0.04	0.59	1.8
Base PLA	0.24	3.5	10.7
Hex adapter	0.11	1.6	5.1
Total	**2.2**	**32**	**100**

Use:

Summary

Static mode

Energy input and output type	Electric to mechanical (electric motors)
Country of use	North America
Power rating (W)	8.7
Usage (hours per day)	0.16
Usage (days per year)	40
Product life (years)	0.4

Relative contribution of static and mobile modes

Mode	Energy (MJ)	%
Static	0.2	100.0
Mobile	0	
Total	**0.2**	**100**

Disposal:

Component	End of life option	Energy (MJ)	%
Ultrasonic Sensors	Landfill	0.007	1.3
L-Bracket	Landfill	0.0053	1.0
Ultrasonic sensor base mounts	Landfill	0.0032	0.6
12V Fans	Landfill	0.0088	1.7
Side Leg PLA supports	Landfill	0.021	4.1
Back Leg PLA supports	Landfill	0.0095	1.8
motor mount backing	Landfill	0.00099	0.2
ultrasonic sensor leg mounts	Landfill	0.0018	0.4
12v motor	Landfill	0.038	7.3
motor mount	Landfill	0.012	2.3
wheel	Landfill	0.13	24.7
fan wall	Landfill	0.013	2.4
Metal Leg	Landfill	0.026	4.9
H-Bridge	Landfill	0.012	2.3
Marker Table	Landfill	0.003	0.6
Arduino Mega	Landfill	0.0068	1.3
Wifi Module	Landfill	0.0004	0.1
Breadboard	Landfill	0.002	0.4
Power Distributor	Landfill	0.011	2.1
Kill Switch	Landfill	0.0046	0.9
12v Battery	Downcycle	0.13	24.6
battery mount	Landfill	0.008	1.5
Base PLA	Landfill	0.048	9.2
Hex adapter	Landfill	0.022	4.3
Total		**0.52**	**100**

Engineering Drawings

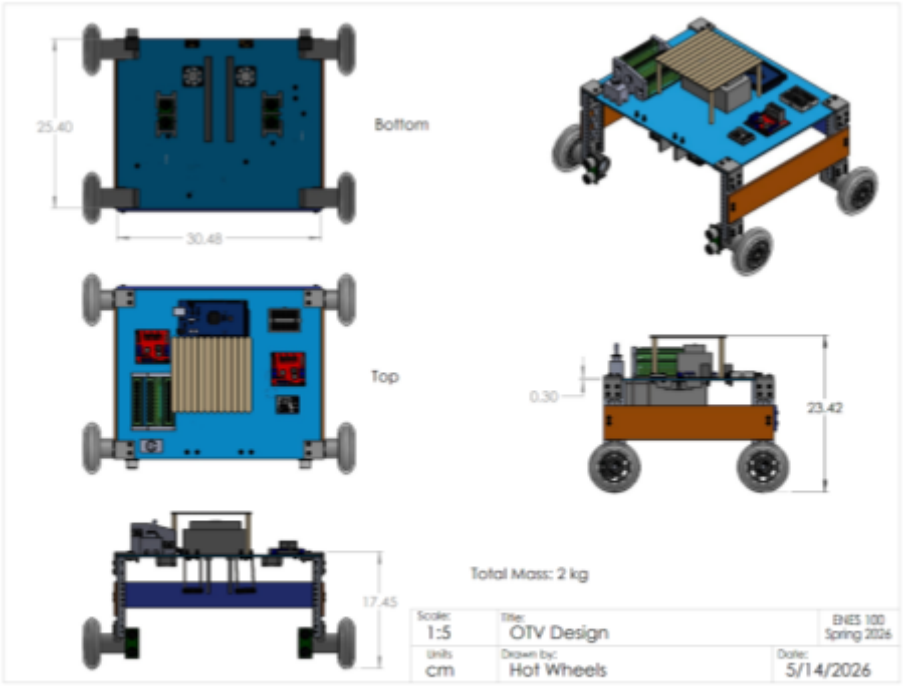


Figure 14. Full OTV Engineering Drawing

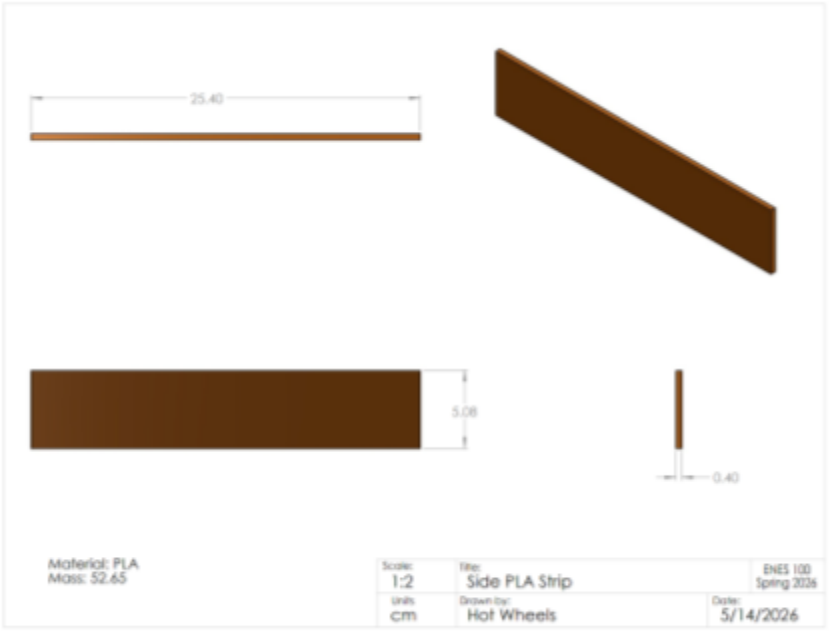


Figure 15. Side PLA Strip



Figure 16. QR Code Stand

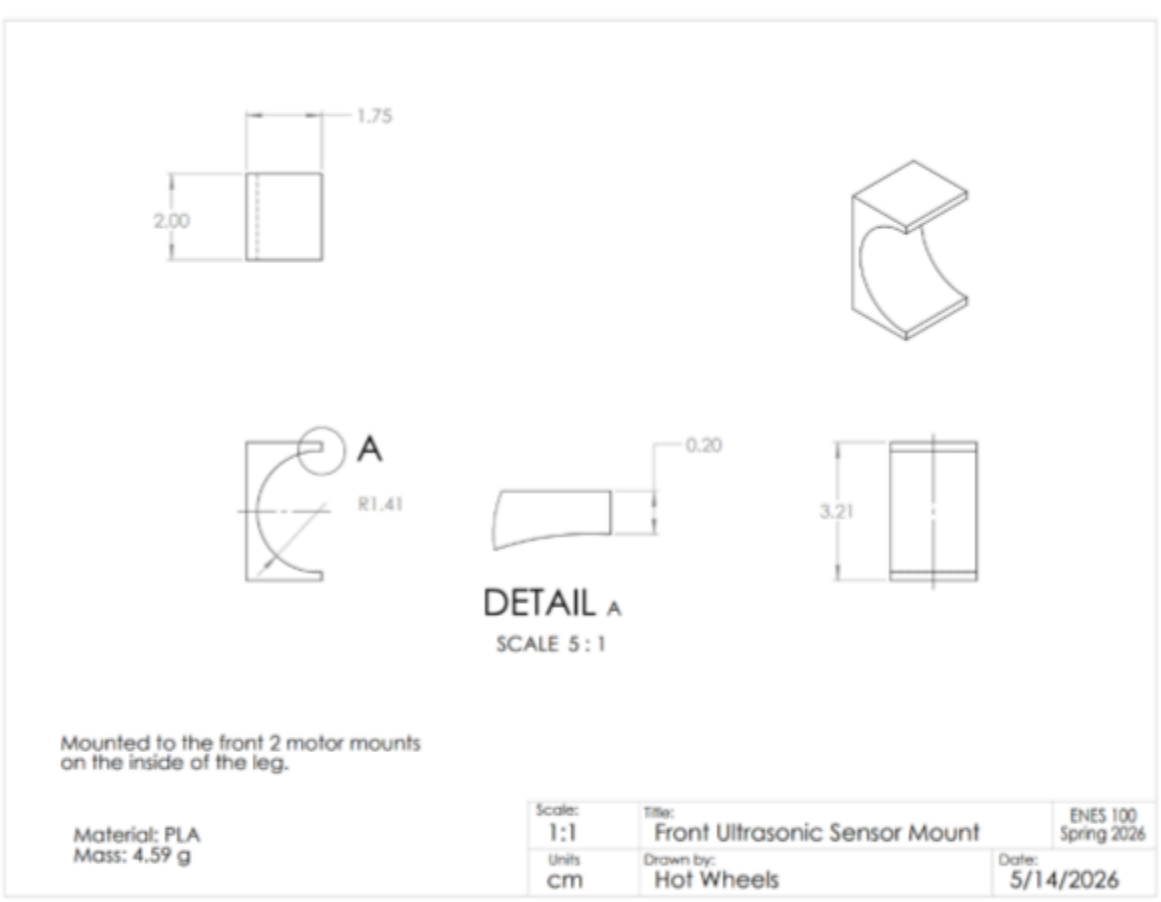


Figure 17.
Engineering Drawing: Front Ultrasonic Sensor Mount

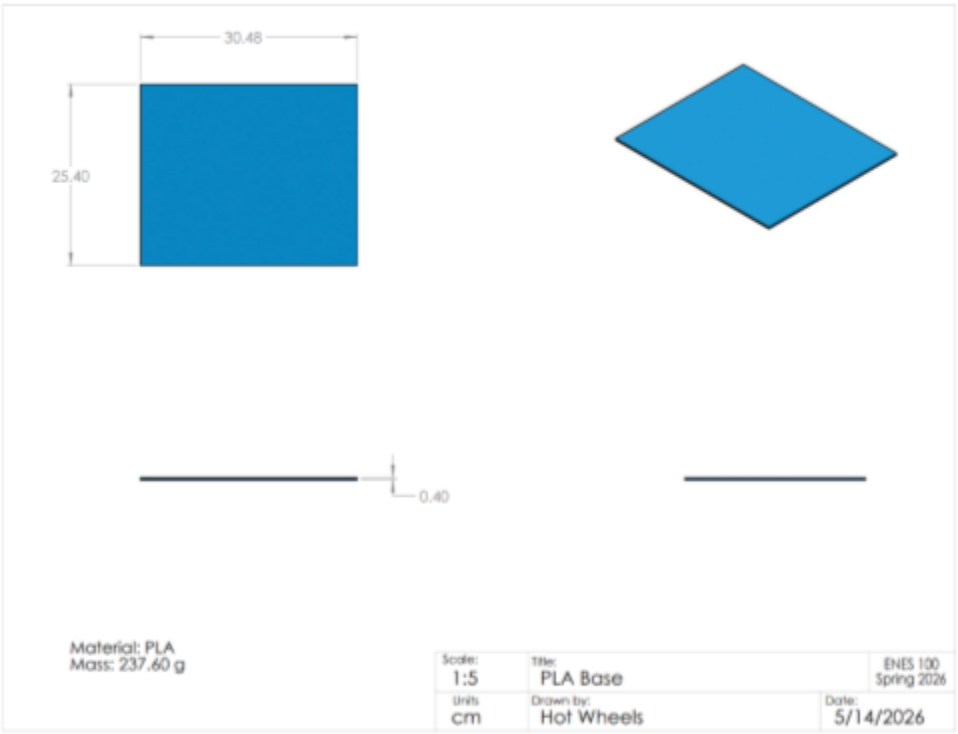


Figure 18. OTV Base

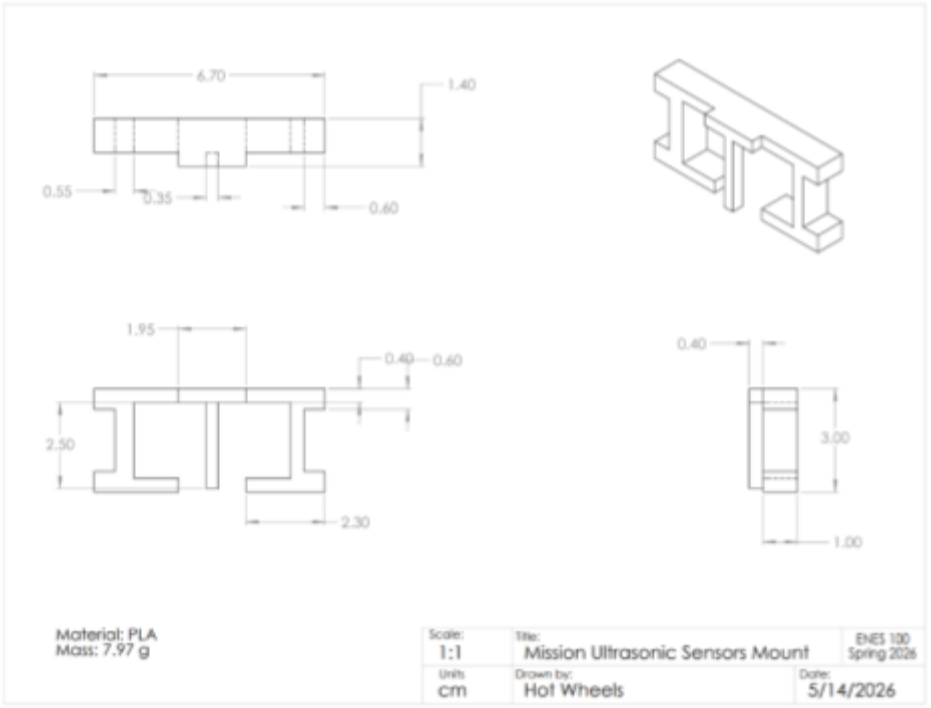


Figure 19.
Engineering Drawing: Mission Ultrasonic Sensor Mount

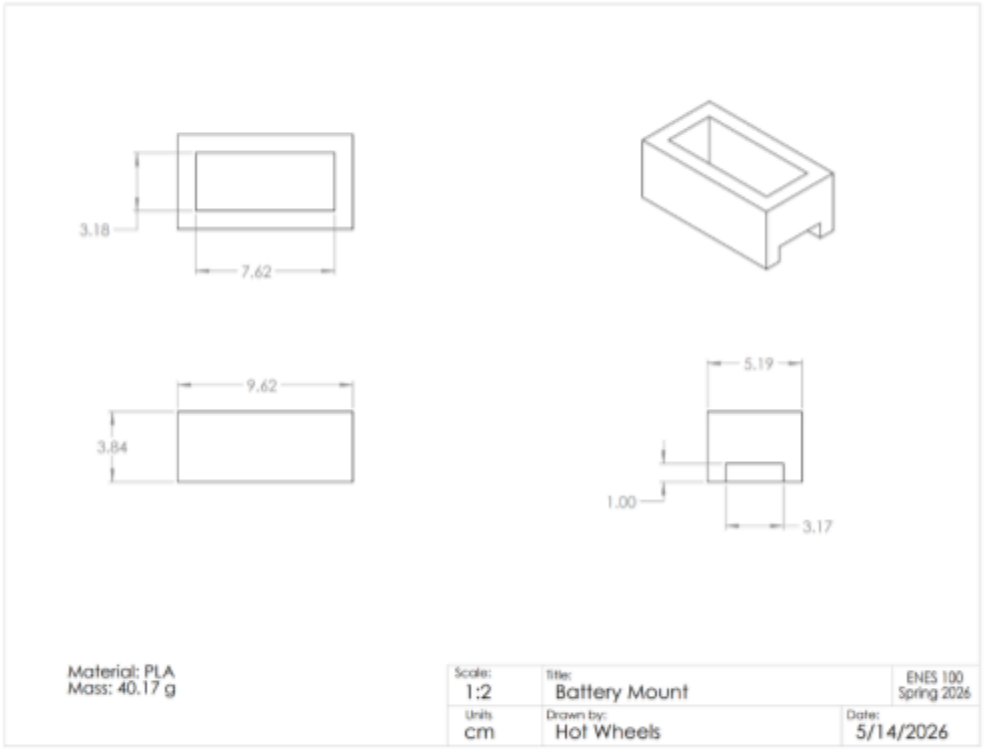


Figure 20.
Engineering Drawing: Mission Battery Mount

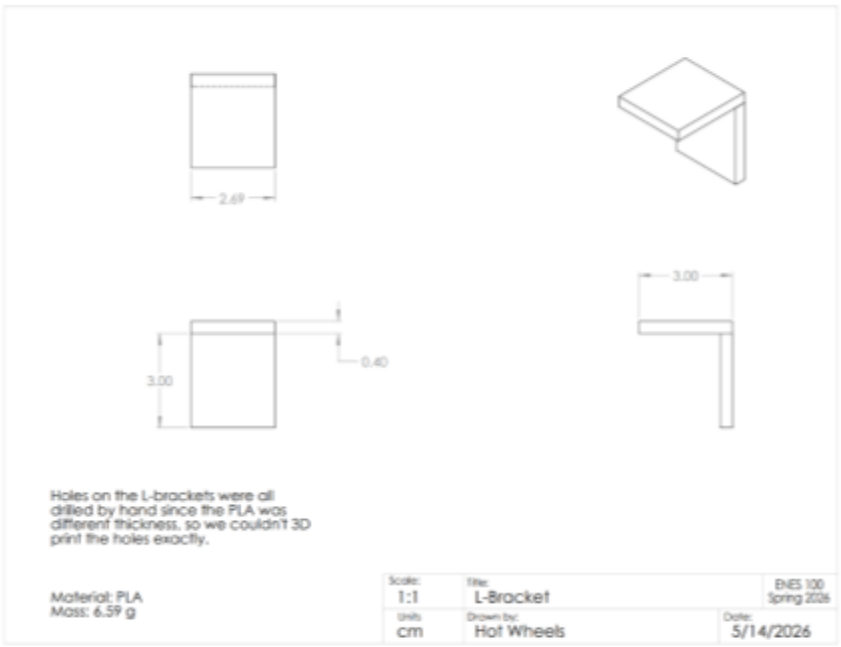


Figure 21.
Engineering Drawing: L-Bracket

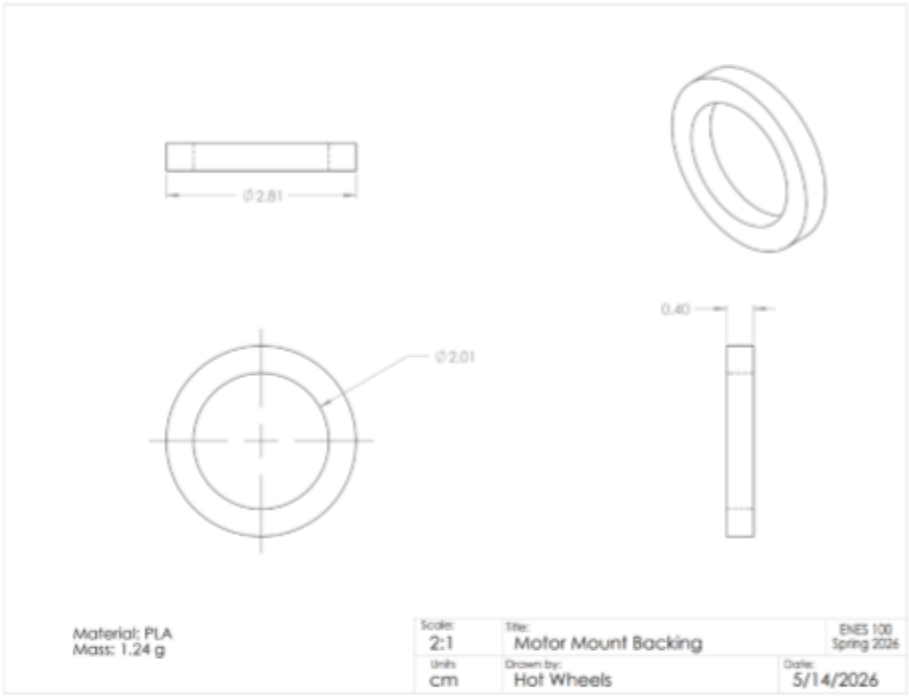


Figure 22.
Engineering Drawing: Motor Mount Backing

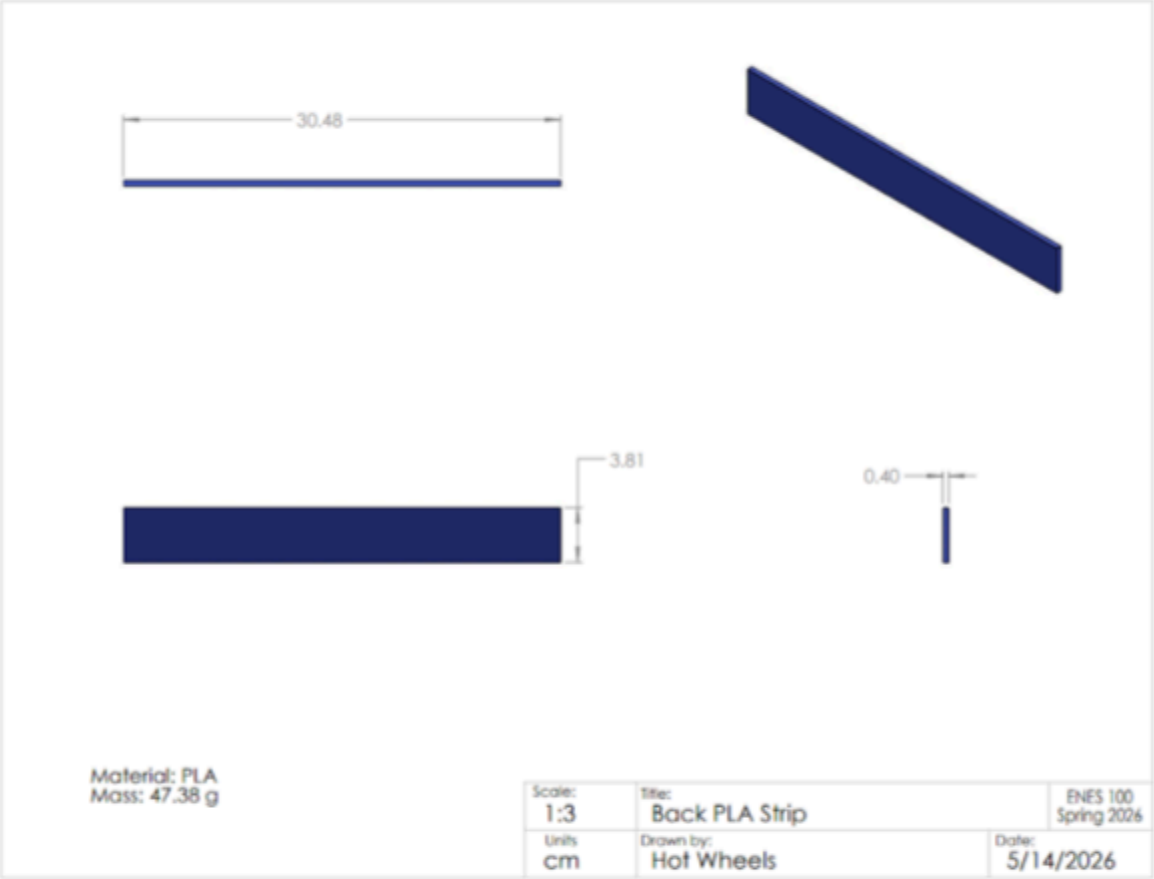


Figure 23. Back PLA Strip