Critical Design Review

Submitted To:
Inst. Chris Ratcliff
GTA Clayton Greenbaum

Created By:
Team O

Emma Garber
Jenna Ruch
Bethany Rupnow
Connor Warholic

Engineering 1182
The Ohio State University
Columbus, OH
24 March 2017

Executive Summary

The goal of this project was to build an autonomous Advanced Energy Vehicle (AEV) to transport R2D2 units on a monorail network system while using energy management to use as little power as possible while completing the task. The overall goals of the AEV included traveling to a gate to trip a sensor, waiting for a specified time period, picking up R2D2, and traveling back to the drop off area in the same way. The mission had to be completed within two and a half minutes.

In order to achieve these goals various designs were initially created. By using screening and scoring methods, the best parts of these designs were picked out and in Performance Test 1, two final designs were created and compared again using screening and scoring methods followed by observing how each of them ran in test runs. Based off this, the superior vehicle was chosen. In Performance Test 2, two codes were written. One using a coasting method and the other using a servo brake. These codes were tested to determine which achieves the stated goals the best. After the vehicle and code were chosen, in Performance Test 3 the efficiency of the vehicle was tested by changing the amount of power used at a given time. Small changes in the code and vehicle design were changed to test how it affected the efficiency

It was found in Performance Test 1 that the use of a long vertical vehicle was superior to one of a similar design that was horizontal. The long design also improved the balance of the vehicle. When they were tested using the same code the vertical one ran quicker and smoother showing a greater efficiency. In performance test two it was found that although the use of coasting to stop takes less power, it also shows less consistency. The use of a servo motor showed great consistency with little differentiation and very little difference in power usage. Based on these conclusions, it was decided that the best code incorporates coasting to slow down and reduce power consumption as well as a braking to improve consistency. In Performance Test 3, the edits in the code led to the discovery that using short bursts of power and coasting the rest of the way is most efficient.

Although the AEV completed a run using 330. 2 J with a 1192 J/kg energy to mass ratio, in the final testing stage the vehicle was unable to complete the mission at hand. This was do to a complete system failure starting with the breaking of the sensor port which likely led to the damaging of the sensors and sensor cables. The damage to the sensors was determined using a sensor testing program that showed when the wheels were moving in the forward directions the sensors read random forward, reverse movement. Because the code used the sensors to determine the location of the vehicle and trigger the changes in motor speed and direction the vehicle would only run at one speed and direction the entire track. The physical breakdown of the AEV was compounded by the errors in the servo command library that at times led to the code running an infinite loops.

In order to fix these problems the only solution is to replace the arduino board, sensors, and sensor wires and to use an alternate breaking method that does not use servo command in order to avoid the creation of infinite loops. It is recommended that tests of equipment are conducted as soon as something seems off with the technology in order to allow enough time to change parts and make appropriate changes to the code.

Table of Contents

Introduction……………………………………………………………………………….……4
Experimental Methodology……………………………………………………….……..4
Results…………………………………………………………………………………….……..7
Discussion……………………………………………………………………………………....10
Conclusion & Recommendations…………………………………….…………..17
Appendix………………………………………………………………………………….....19

List of Tables and Figures

Figure 1: Lab 1 Setup……………………………………………………………………………4
Figure 2: Reference AEV Design…………………………………………………………………5
Figure 3: Efficiency of propellers chosen for final design…………………………7
Figure 4: Power vs Time Phases…………………………………………………………………8
Table 1: Breakdown of Supplied Energy…………………………………………………8
Table 2: Energy/Mass Ratio……………………………………………………………………10
Table 3: Concept Screening……………………………………………………………………11
Figure 5: AEV Prototype 1 Construction……………………………………………12
Figure 6: AEV Prototype 2 Construction……………………………………………13
Table 4: Concept Scoring………………………………………………………………………13
Figure 7: Servo Brake……………………………………………………………………………15
Figure 8: Final Design……………………………………………………………………………16
Figure 9: Full semester team schedule……………………………………………19
Figure 10: SolidWorks Model 1…………………………………………………………20
Figure 11: SolidWorks Model 2…………………………………………………………21

Introduction

The team was tasked to create and develop an Advanced Energy Vehicle designed to complete a run around an overhead track, pick up R2D2 halfway through, and return securely with the additional cargo. The team went through a number of performance tests to determine which design and code would be most effective and energy efficient. This report will describe the steps taken by the team during each lab and performance test to determine which decisions would give the AEV the most successful and consistent runs.

Experimental Methodology

The majority of this project was used by experimenting with various aspects of the AEV. The first lab was designed to get the team comfortable with using the different lab equipment. The team used the Arduino microcontroller, 2 propeller motors, USB cord, a battery, and Arduino sketchbook to complete this lab. The team compiled the AEV parts together, as seen in Figure 1 below, and used a code provided to practice uploading codes to the AEV.

Figure 1: Lab 1 Setup

In Lab 2, the team initialized the external sensors on the reference AEV, as seen in Figure 2 below. The team then installed and tested the reflectance sensors, while constantly checking for errors. The team then used a code given to the team for the outside track to test the propellers and sensors. While this testing was occurring, a team member was also introduced to a wind tunnel. Here, a team member would test various propellers and analyze the data using MATLAB to determine which propeller would be the most effective to use for their AEV.

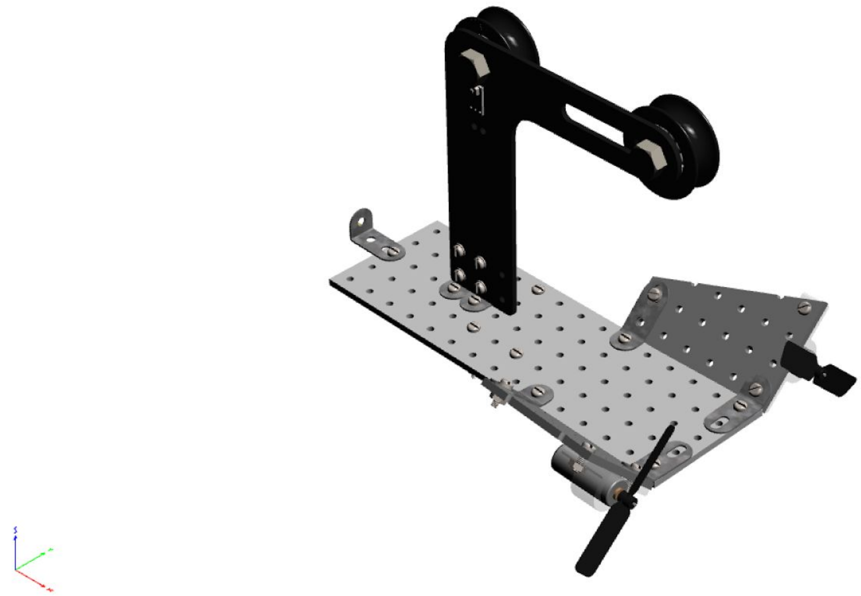


Figure 2: Reference AEV Design

The third lab focused on creative design thinking, where each group member developed orthographic drawings of their own AEV design. The team came together with important qualities of each design to develop a cohesive first draft. Each individual and group design was then analyzed and compared in Lab 5 using concept screening and scoring guides.

Lab 4 had the team download data collected by the AEV during a test run using MATLAB. The team was tasked to convert Arduino data to physical parameters, which would allow the team to analyze each run from that point on. Lab 6 was an open lab period for the teams, marking the halfway point of the process. During this, the team used the track and their AEV to determine what edits to the code would be made for a more consistent run. In Lab 7, the team was tasked to look specifically at energy efficiency while comparing propeller driven and coasting test runs. This lab allowed the team to insure that the sensors were working correctly and the team was using the correct propellers for their code.

During the first performance test, the team was specifically tasked to decide between two potential AEV designs. The team constructed both AEV's with the parts provided to them the first day of the project. In addition, the team individually bought a plastic hand to act as a brake for more consistent stops. The team constructed both potential designs, downloaded the same code for both AEV's, and ran both on the track. After downloading the data from the AEV's run using a MATLAB program, EEPROM. This program converted the AEV's data into physical parameters, and, therefore, the team was able to compare the two designs quantitatively. After analyzing the data, the team would make the executive decision of which design to continue.

The second performance test challenged the team to develop two different codes. The team would experiment with Arduino Nano program and servo motor controls specifically. Then, the team ran the first code with the final design on the track, downloaded the data, and repeated with the second code. From observing each test on the track and analyzing the data, the team decided which code was more efficient and successful for their AEV.

The team was then challenged to increase their energy efficiency during the third performance test. During this test, the team focused on the brakes and the motor speed used throughout the run. The team specifically used the EEPROM conversions and MATLAB program mentioned in lab 4 to compare test runs and determine if the AEV energy to mass ratio was acceptable.

The fourth, and final, performance test was the team’s final chance to run before final testing. There, the team used all available resources to make small edits to their code for more efficiency during the runs. The team’s run would be evaluated by a staff member for a final grade of the run.

Results

Below, Figure 3 shows a graph of propeller propulsion efficiency vs propeller advance ratio. Specifically, this graph shows the propeller the team decided to use on their AEV, which was the 3030 propeller in pull configuration. This graph displays that the propulsion efficiency increased as the advance ratio increased. Additionally, the point of highest propulsion efficiency was around 20%, which was why this propeller was chosen by the team. The value of the propulsion efficiency allowed the team to determine how much energy the system was wasting. Because the maximum point of the graph occurred at a lower power setting than the other blades and configuration, the team chose this propeller.

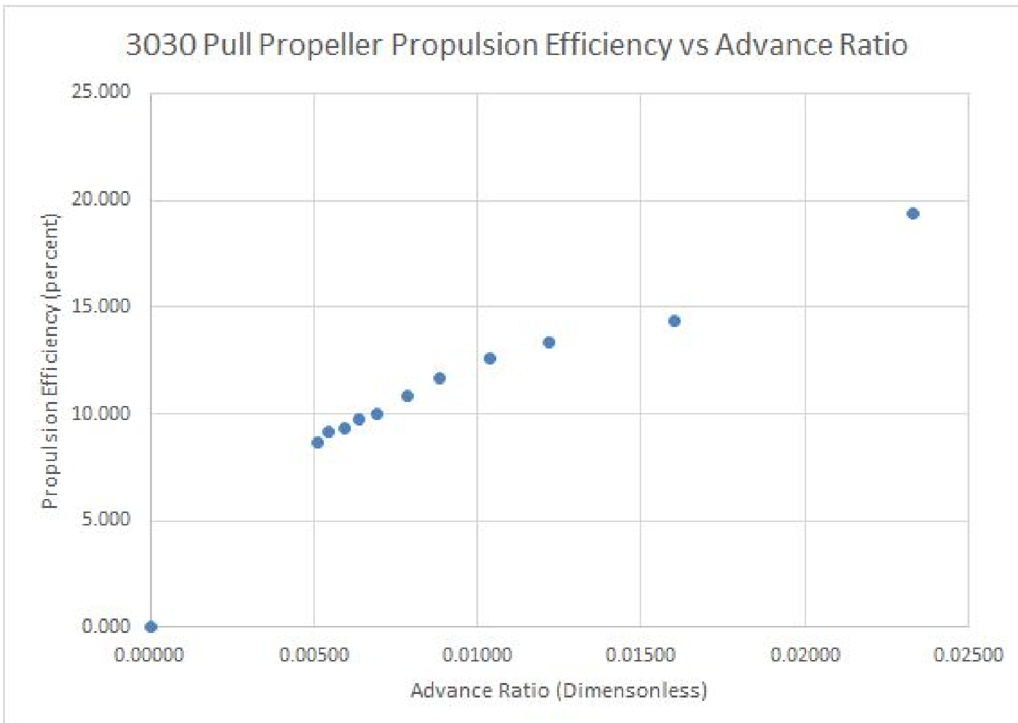


Figure 3: Efficiency of propellers chosen for final design

In Figure 4 found below, the power used by the AEV is displayed against time. This data is broken down into phases, each of which represent a different command or series of commands in the code. By using this graph, the team was able to determine how time each phase of the code took, as well as the distance covered in that phase. Additionally, the energy consumption of each phase was found by calculating incremental energy. The total energy used could also be found.

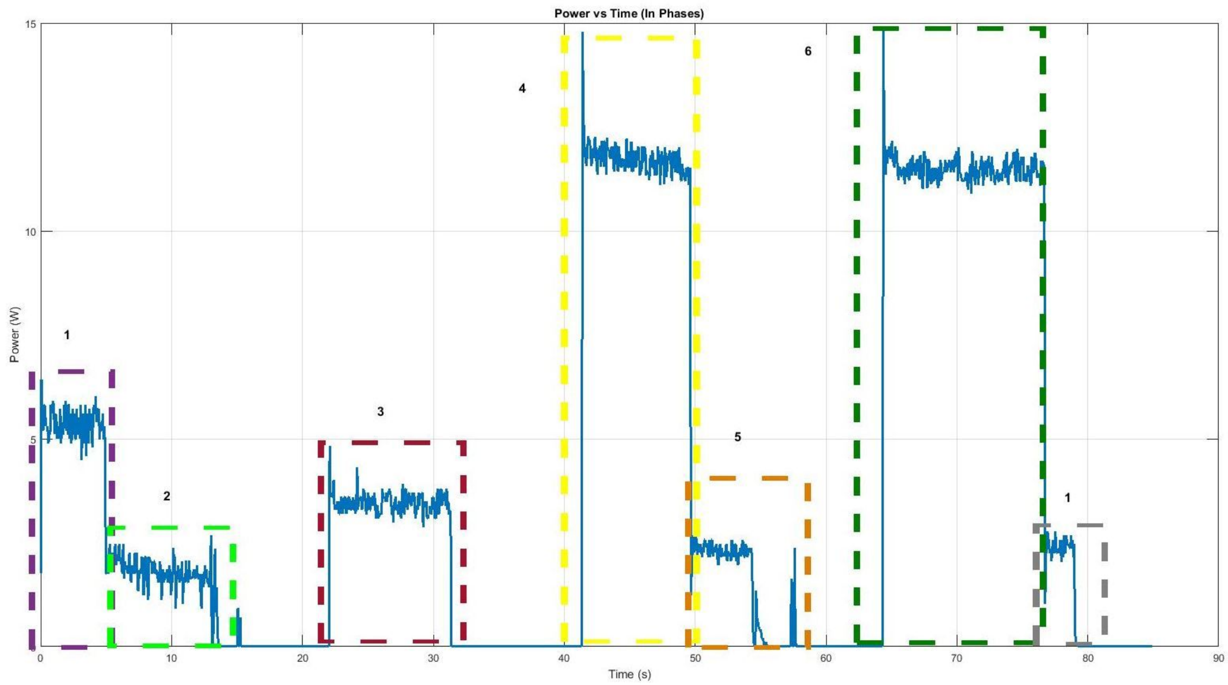


Figure 4: Power vs Time Phases

Table 1 below summarizes the information found through the previous figure. This includes time, distance, and power for each phase. The lines of code corresponding to each phase was also included in this table for reference. The table also displays the total energy use of 330.2 J at the end, which is the sum of the energy used in each phase.

Table 1: Breakdown of Supplied Energy

Phase	Arduino Code	Time (s)	Distance	Supplied Power (Joules)
1	motorSpeed(4, 22); goToAbsolutePosition(150);	4.9810	1.8972	26.6479

2	motorSpeed(4,13);
	goToAbsolutePosition(472);
	brake(4);
	
	rotateServo(115);
	goFor(2);
	
	rotateServo(25);
	goFor(7);
		11.9390	4.1292	15.1357

3	motorSpeed(4, 20); goToRelativePosition(340);	9.6600	4.0176	32.1936

4	reverse(4);
	motorSpeed(4, 40);
	goToAbsolutePosition(700);
		8.5200	3.8440	97.3357

5	motorSpeed(4,15);
	goToAbsolutePosition(542);
	
	brake(4);
	
	rotateServo(130);
	goFor(3);
	
	rotateServo(10);
	goFor(7);
		10.7400	1.9468	11.4240

6	motorSpeed(4,40); goToAbsolutePosition(150);	12.4200	4.8608	142.4071

7	motorSpeed(4,15);
	goToAbsolutePosition(14);
	
	brake(4);
	
	rotateServo(130);
	goFor(3);
	
	brake(4);
		5.8200	1.5004	5.3885

			Total Energy Used:	330.23 Joules

From the two figures above, you can see the code being applied and the amount of energy it is using. The code used starts with a higher motor speed when it first begins moving before dropping down to a very slow speed when approaching the gate. This low speed allows the servo brake to stop the AEV almost instantly. When the AEV approaches the cargo, it starts at a consistent speed and then cuts engine power and coasts into the cargo. On the return, it implements the same slowing down and braking procedure previously described, as well as for stopping at the final drop off. Intuitively, the AEV draws much more power while carrying the heavy load of the cargo. A majority of the power used was used in phases 4 (which used 97 J) and 6 (which used 142 J), both of which are phases in which the AEV is accelerating to a rather high speed while carrying cargo. In retrospect, the team believes these values could have been reduced drastically. Other improvements the team believe they could have made are applying more coasting to the code in order to use less energy over prolonged periods of the motors running, as well as reducing the motor speed for the return trip once the AEV collected the cargo.

Table 2: Energy/Mass Ratio

Total Energy Used (Joules)	Mass of AEV (Kilograms)	Energy / Mass (J/kg)
330.2	0.277	1192

When the team was approaching final testing, some issues arose that prohibited them from completing or even attempting a final run. The data being used in the graphs and tables above are taken from a successful run that the team performed in the week approaching final testing. The AEV had a final mass of 277 g, or .277 kg. It used a total energy of 330.2 J. This gave the AEV a final energy/mass ratio of 1192 J/kg. The data can be seen Table 2 above. This was relatively average compared to the final tests of the other groups in class.

In terms of performance, the AEV did very well up until final testing. In the week of final testing, the group had to replace an arduino, a sensor, sensor chords, a whole board, a port, and almost another sensor and servo. Before it was necessary for these replacements, however, the AEV was running very stable and consistently. The team was most impressed with the stability of their vehicle and its smooth acceleration. The brake was working very effectively and consistently, allowing the team to alter their stopping point precisely. They were able to adjust where their AEV stopped by a half inch at a time (the conversion of a mark to inches) until it gave them the results they were looking for. Since the AEV approaches the gates so slow as well, the AEV stops almost instantly once the brake is applied. This made developing code much easier.

Discussion

The team tested two initial prototypes in Performance Test 1. These prototypes developed through analyzing and comparing each team member's design from the initial creative process. This was done by brainstorming a list of criteria desired by the team for the AEV and creating a concept screening and scoring table which can be seen in Table 3 below. This table tested four team member's designs including a collaborative team design for qualities including balance, durability, and ease of mission completion. The outcome of the table showed the team which designs were worth continuing, revising, or combining. As a result, designs were revised and combined in order to create the two AEV prototypes used in Performance Test 1.

Table 3: Concept Screening

Success Criteria	Reference	Design A	Design B	Design C	Design D	Design E
Balance	0	-	-	+	-	+
Durability	0	+	0	0	-	+
Low mass	0	-	+	0	-	-
Cost	0	-	0	-	0	+
Ease of Mission Completion	0	+	+	+	0	0
Aerodynamics	0	-	-	0	+	+
Sum +'s	0	2	2	2	1	4
Sum 0's	6	0	2	3	2	1
Sum -'s	0	4	2	1	3	1
Net Score	0	-2	0	1	-2	3
Continue	Combine	No	No	No	Combine	Revise

The first prototype tested was a design using cross shaped plastic piece oriented vertically. On one side of the plastic piece, the Arduino was placed. On the other side, the battery was held inside a bracket. Two motors with 3030 propellers were placed in the forward facing direction with one above the other. The choice of propeller was based on the results of System Analysis 1, which allowed the team to determine the most efficient propeller and direction. From that lab, the team saw that the 3030 pull propeller would be the most efficient for an AEV design. One propeller was on the extruded arm of the cross, while the other was near the bottom. Additionally, near the arm of the AEV, a metal bracket was attached to a plastic bracket and placed extending from the main body. This feature functioned as the attachment and carrying piece for the cargo aspect of the mission. This design was mainly developed because of its durability, low mass, and ease of mission completion. The first prototype, referred to as the vertical design, can be shown in Figure 5 below.

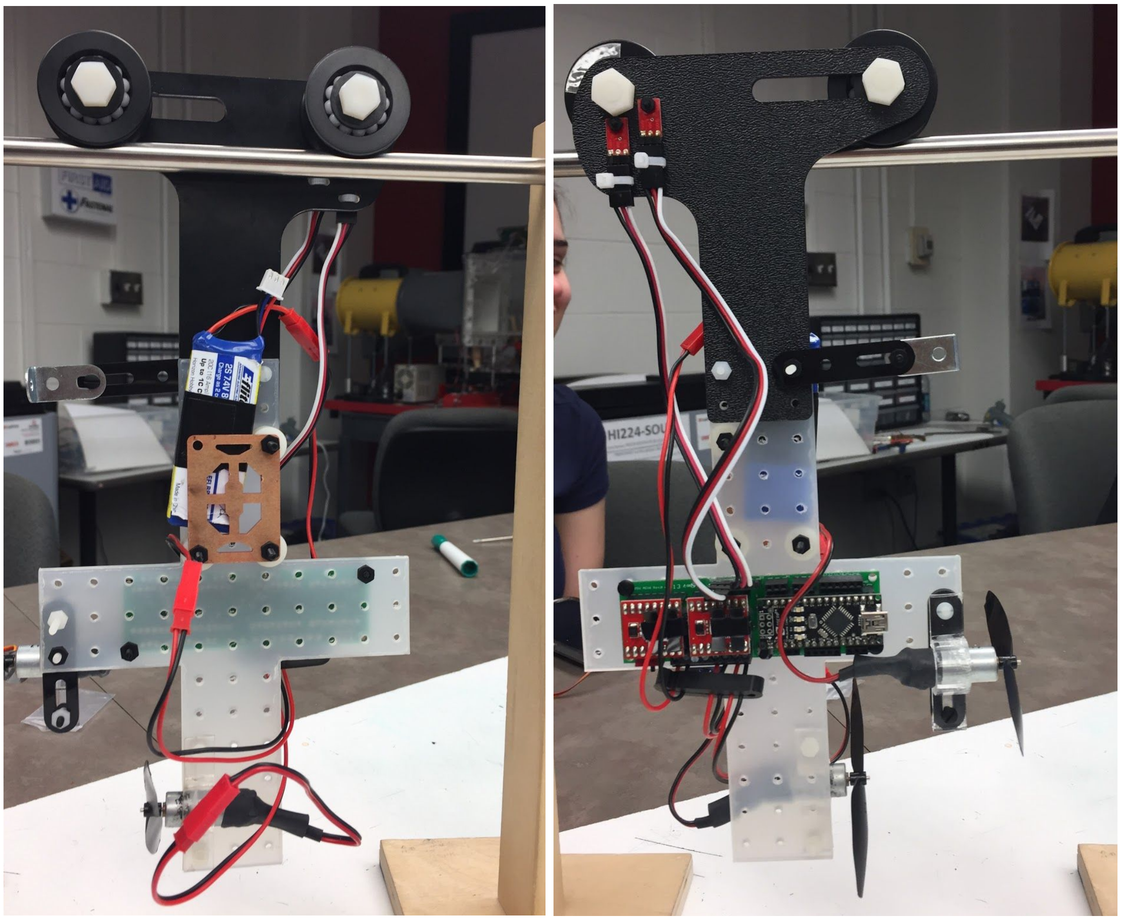


Figure 5: AEV Prototype 1 Construction

The second prototype was a design using the same cross shaped plastic piece, but oriented horizontally. The Arduino was placed on the top side of the center of the plastic piece. Directly beneath this on the bottom side was the battery held in place again by a bracket. On each end of the extended parts of the cross, a propeller was placed in the forward direction. Once again, the metal and plastic brackets were connected and extended from the main body in order to pick up the cargo. Besides the obvious change in main orientation, most components were kept about the same as in the first prototype. Specifically, the same propellers were used in the same direction, the same plastic piece was used, and no additional materials were added. This was purposefully done in order to reduce the number of variables that could affect changes in efficiency. The goal of this prototype was to explicitly test how the orientation affected the performance of the vehicle. The second prototype, referred to as the horizontal design, can be shown in Figure 6 below.

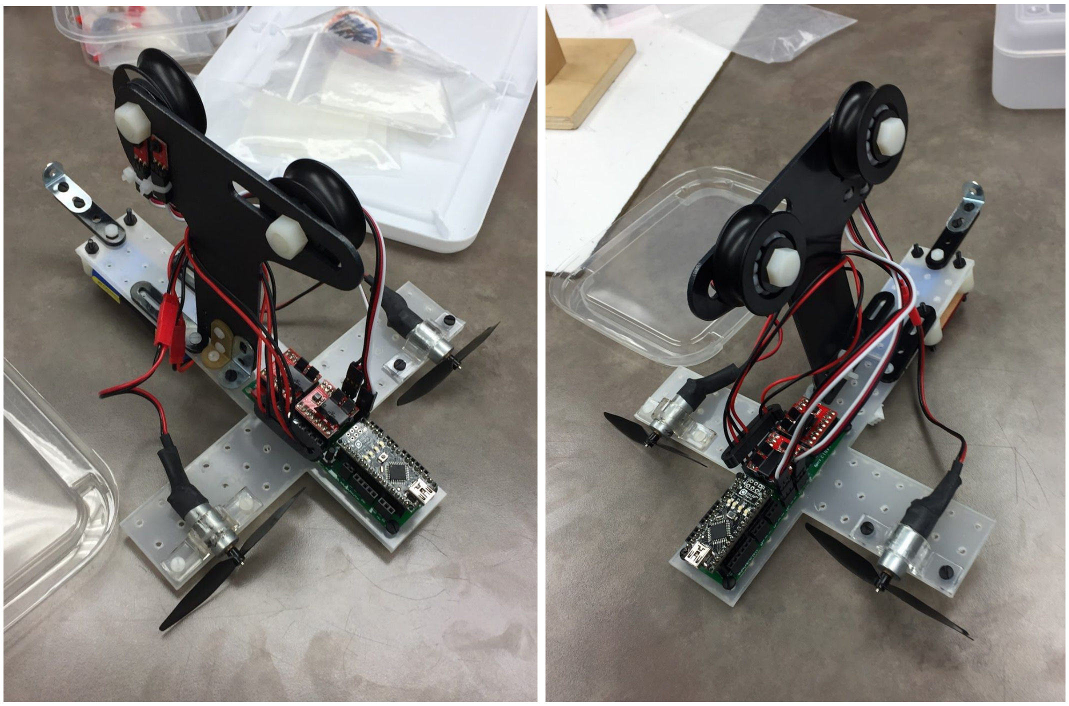


Figure 6: AEV Prototype 2 Construction

During Performance Test 1, the horizontal design was constructed and tested first. One problem observed by the team during this run was the lack of balance in this design. When traveling along corners on the track, this AEV seemed to have a difficult time and seemed to sway back and forth after completing the turn. Additionally, the aerodynamics of this design appeared to be poor. The team noticed the AEV to have difficulty accelerating when starting from a resting position. After this test, the vertical design was constructed. Using the same code as before, the team tested and observed the run of this AEV. The vertical design accelerated and traveled much faster than the horizontal design did using the same power setting. This led the team to deduce that the vertical design was more energy efficient, as the speed was increased without the power being increased. Additionally, the vertical design had no issues with balance. A concept scoring table was created to further compare the prototypes against all the criteria. This is shown below in Table 4. The concept scoring further confirms defends the advantage of using the vertical design. Because of this, the team decided to proceed with the development of Prototype 1 rather than Prototype 2 for use in the final design.

Table 4: Concept Scoring

		Reference		**Prototype 1 (Vertical)**		**Prototype 2 (Horizontal)**	
Success Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Balance	20%	2	0.40	4	0.8	3	0.60

Durability	25%	3	0.75	3	0.75	2	0.50
Low mass	10%	4	0.40	3	0.30	3	0.30
Cost	10%	3	0.30	3	0.30	2	0.20
Ease of Mission Completion	30%	3	0.90	4	1.20	5	1.50
Aerodynamics	5%	2	0.10	5	0.25	3	0.15
Total Score			2.85	3.60		3.25	
Continue?			No	Develop		No	

In Performance Test 2, the team used the vertical AEV design developed in the previous lab to test different codes. The first code was created which used coasting as the sole method of stopping before the gate, cargo, and final drop off area. Furthermore, the team attempted to use a strategy of using a faster speed for a shorter amount of time rather than a slower speed for a longer amount of time in order to reduce energy consumption. This was based on the results of System Analysis 2, in which the team analyzed energy use of various aspects of a trial code. The team recognized that this, combined with coasting, was the most energy efficient method, as it required motors to be turned off well before the stopping area and not be used for an extended period of time. However, when the team developed this code they realized this method was inconsistent and the AEV did not stop in the same location between runs. It was necessary for the code to be flexible in different tracks and with different batteries, and the method of coasting did not fulfill this. Because the team was using a different battery each lab period and testing on two different tracks, this added more potential error. Deciding it was in their best interest to compromise some energy efficiency in order to complete the mission consistently and reduce potential error, the team began to develop a brake using a Servo. To build this, the team attached an eraser to the arm of the Servo. Over the eraser the team placed a Tiny Hand, which allowed the arm to reach the rod of the track and provide an optimal amount of friction to stop the AEV. This lead to the development of a second code which used the newly created brake. The brake can be seen in Figure 7 below.

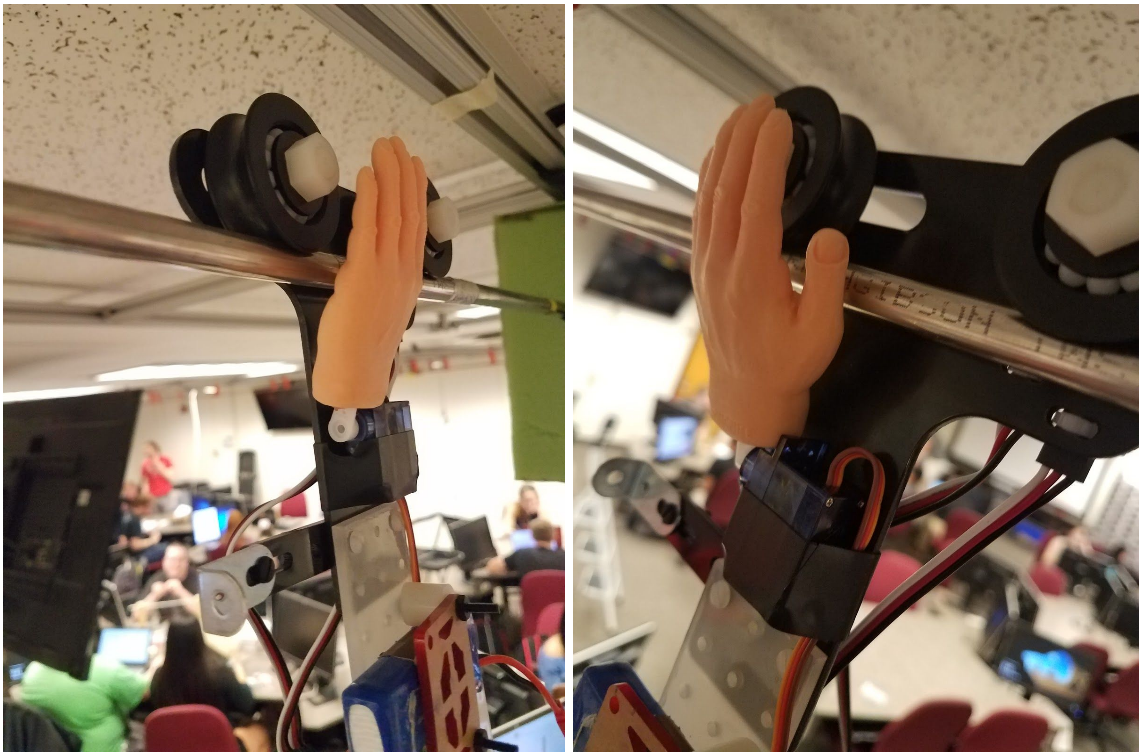


Figure 7: Servo Brake

After the brake was added, the team saw many positive results. The AEV was able to stop immediately after the brake was activated. Through calculations and trial and error, the team was able to determine the marks the AEV needed to stop at for each phase of the mission. Once the code was developed in full, the design was repeatedly tested for consistency. The team found that the brake allowed the AEV to stop at the correct locations each run and complete the mission successfully. For this reason, the team incorporated the brake into the final design. A picture of the final design, including the Servo motor can be seen in Figure 8 below.

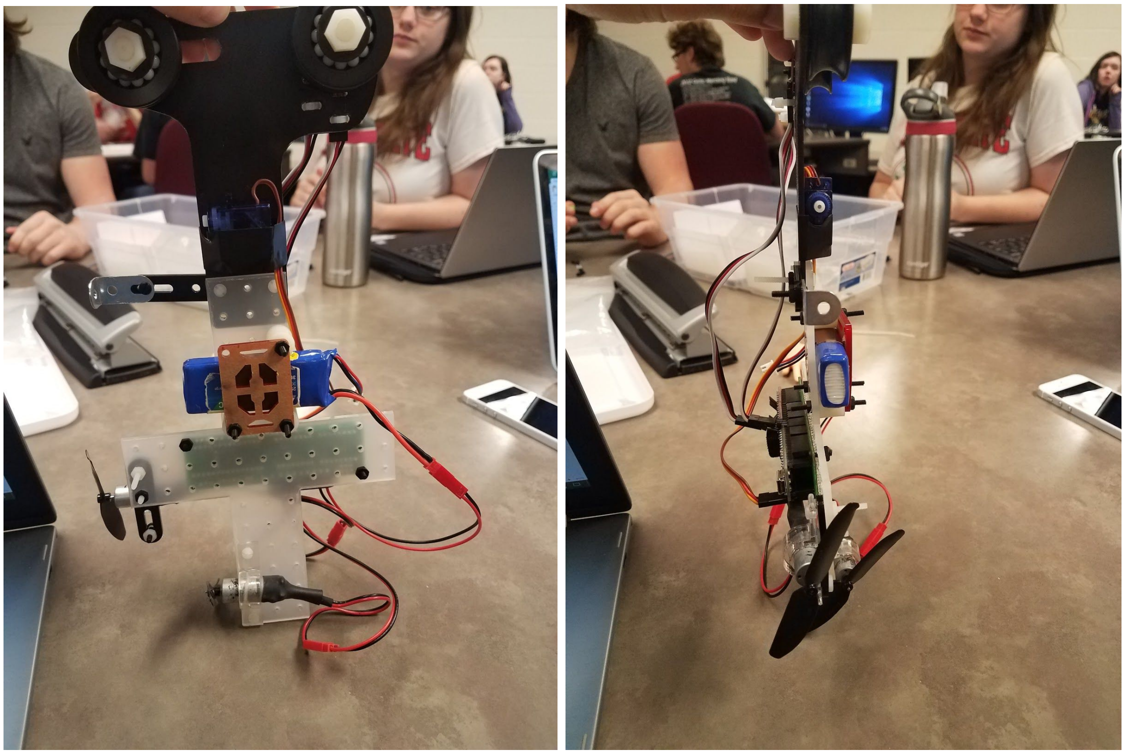


Figure 8: Final Design

The total cost of the final design was $224.02. The breakdown of each part used, the cost, and quantity can be shown in the SolidWorks model, Figure 10, in the appendix. To reduce the cost of the overall system, the team attempted to use a minimal amount of materials as well as only use materials provided in the kit. Though the option was available to create a part using the 3D printer, the team decided against this in order to reduce cost. Additionally, the team only used parts that were crucial to the functionality of the design. For example, only one piece of plastic was used in the design to hold the Arduino, propellers, and battery, which were all required to properly run the AEV. No other excess parts were used, and every piece of the AEV served a purpose.

Though the development of the brake produced mostly positive results, the team experienced many difficulties after it was installed. The first sign of this was when the AEV continued to stop in the same, incorrect location during every run, regardless of the position marks or power level that was set. Because the vehicle stopped in the same location for a wide range of set marks, this was determined to be an error in the code rather than the sensors. It was assumed by the team after much troubleshooting that the commands regarding the Servo had caused a glitch in the code. After a few days of trying to fix this, the AEV returned to performing as normal, but the error was never specifically identified. The use of the Servo added potential error to the performance of the AEV, and may have affected the operation and overall results.

During the week of final testing, the AEV completed a few successful runs. The team continued to refine the design and change power settings slightly in order to be more efficient. However, during this process the AEV stopped functioning correctly. During the run, the AEV would begin as expected but never continue on to the next command in the code. This caused the AEV to travel the same speed the entire length of the track, never slow down or stop, and finally crash into the gate. The team assumed the error was in the sensors because if the marks were registering properly, the next line of code would have been executed. The team then proceeded to run a reflectance sensor test and replace the sensors that was not registering. Additionally, the team replaced the wheel with the reflectance tape. The AEV was tested again and still was not functioning properly. Upon recommendation from the team's GTA, the Arduino was replaced. This still did not remedy the problem, as the reflectance sensor tests were still not giving conclusive results. Later it was discovered that one of the ports on the control board was almost completely disconnected, and this was assumed to be the cause of the issues. However, at this point, the team had run out of time in the lab periods and were unable to get the AEV working properly again. For this reason, the team's AEV was unable to complete a final test. Data reported for the final test was taken from a successful run completed prior to the breakdown of the AEV.

Conclusion & Recommendations

The final design of the AEV featured a vertical hanging base with the battery and board attached to opposite sides of the base and centered. The propellers both faced the front of the AEV and were slightly offset from each other as one was attached to the jut of the cross shape of the base and the other was attached slightly further back and below on the bottom of the base. The servo brake was attached to the black wheel arm and was designed to flip a hand around and squeeze the rail the AEV rides on, slowing it down due to friction. The magnet to pick up the cargo was attached near the top of the AEV and protrudes out over the front of the vehicle. It is secured to a plastic extension to make it extend over the propellers to be able to pick up the cargo. The design was effective because mostly everything was attached centered on the base and as low as possible. This made the AEV very stable and resistant to swaying on its way around turns. The final code used the brake when approaching gates and the drop off zone. However, it coasted into the cargo pick up. The AEV would accelerate to a higher speed and then once it got moving, it would drop to a lower speed where it was barely moving. It dropped to this low speed to make it easier to stop at a precise moment or position.

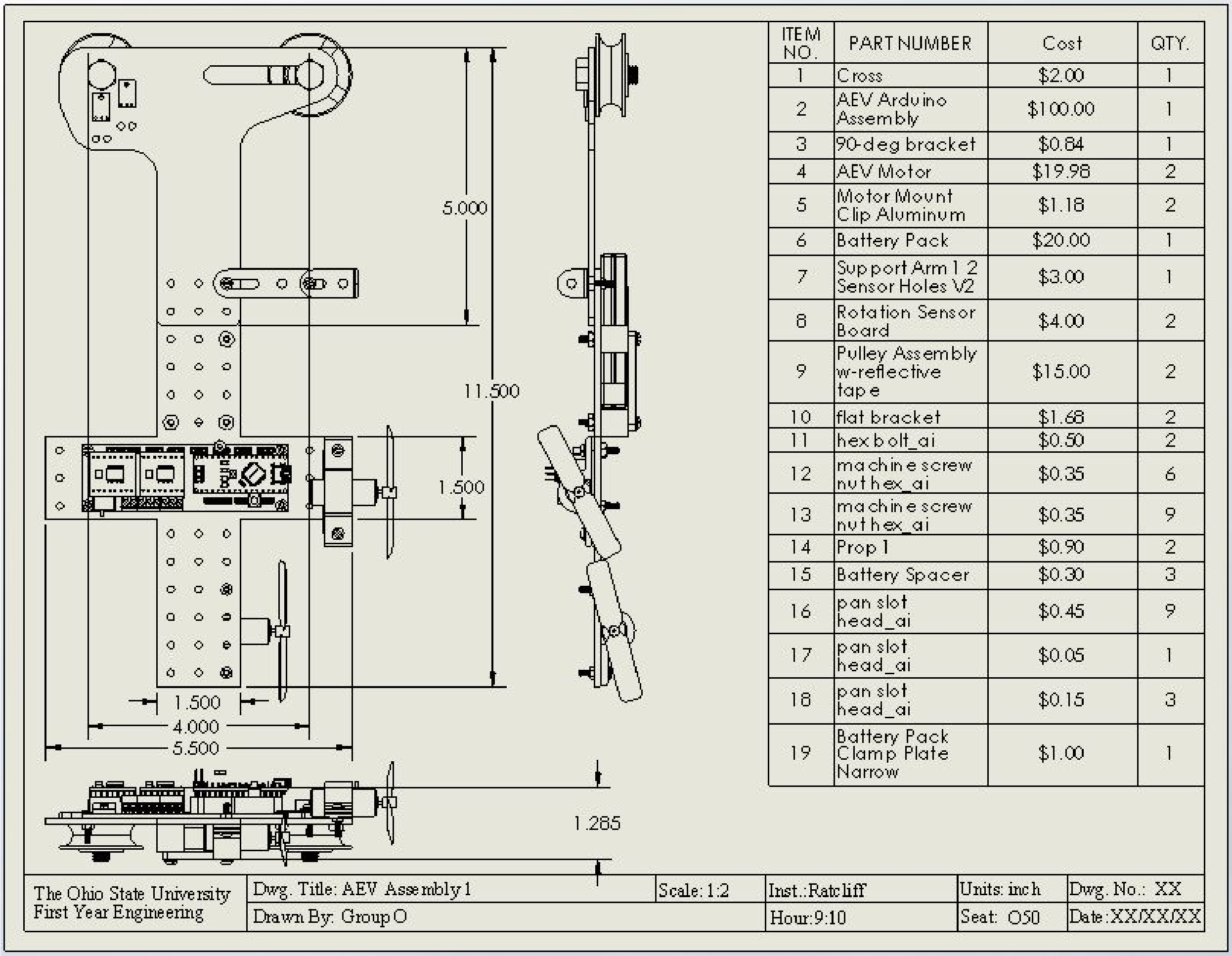
Obstacles that prohibited the team from their final testing were not scarce by any means. At first, the team thought their sensors were no good. After replacing the sensor that wasn't registering marks, the team realized their AEV still wasn't working. They were able to run only simple code that didn't involve servo commands or long distance parameters. This caused them to replace the arduino to see if that was the problem. After the arduino didn't fix the issue, they realized that one of the ports on the main board that the sensors plug into was snapped off the board. They then replaced the whole board. After their code still wouldn't run correctly, they determined it must have been the other sensor they didn't replace. At this point, however, it was too late to fix it as they had run out of class time.

In the end, the team's AEV was unable to run a successful final run due to a plethora of inconveniences and obstacles presented in the final week of testing. In the time leading up to final testing, however, the AEV was performing rather well, completing near full runs every time the team tested it. Given more time, the team believes they could have fixed the issues at hand, but the timing of the downfall ultimately cost the team their final testing. The AEV had a mass of 277 g and used a total energy throughout the run of 332.2 J. This gave the AEV a energy to mass ratio of 1192 J/kg. This was average when compared to the data of the rest of the class. Due to the obstacles mentioned above such as equipment failure, the team had little time to focus on improving the efficiency of their code. However, given more time, they believe there was much room for improvement due to the large power intake the AEV was using once it picked up the cargo.

Appendix

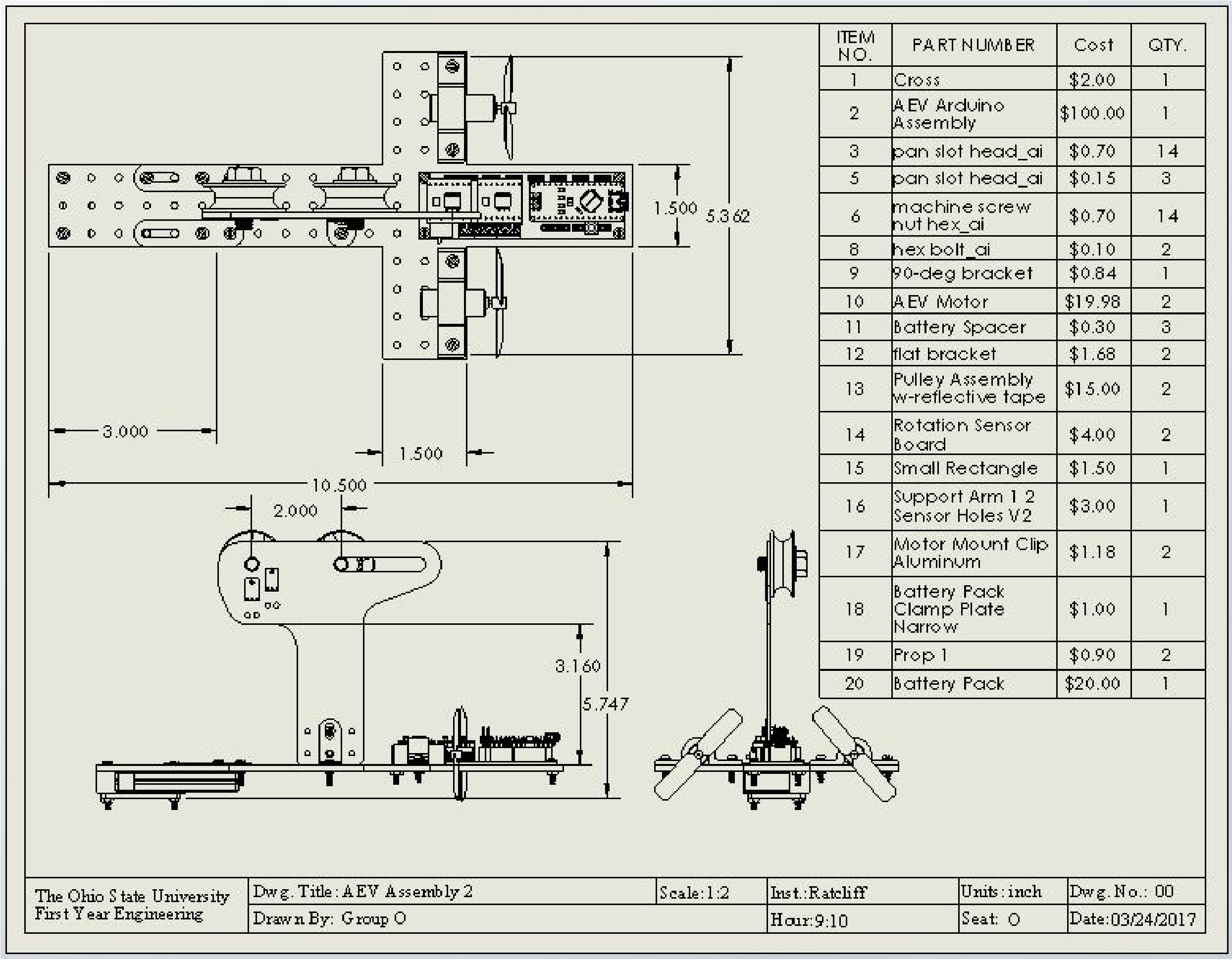
Lab / Performance Test	Tasks	Team Member (w/ Percentages)				Start Date	Finish Date	Due Date	Estimated Time
		Emma	Jenna	Bethany	Connor				
Lab 0: Introduction to AEV and Mission									
	Introduction and Mission Definition	25	25	25	25	13-Jan	13-Jan	13-Jan	1.5 hr
Lab 1: Arduino Programming Basics									
	Arduino Programming Basics Lab	25	25	25	25	20-Jan	20-Jan	20-Jan	1.5 hr
	Progress Report 1	25	25	25	25	20-Jan	26-Jan	27-Jan	2 hr
Lab 2: External Sensors, System Analysis 1									
	Sensors and System Analysis Lab	25	25	25	25	27-Jan	27-Jan	27-Jan	1.5 hr
	Progress Report 2	25	25	25	25	27-Jan	3-Feb	3-Feb	2 hr
Lab 3: Creative Design Thinking									
	Creative Design Thinking Lab	25	25	25	25	3-Feb	3-Feb	3-Feb	1.5 hr
	Progress Report 3	25	25	25	25	3-Feb	9-Feb	10-Feb	2 hr
Lab 4: System Analysis 2, Design Analysis 2									
	System and Design Analysis Lab	25	25	25	25	10-Feb	10-Feb	10-Feb	1.5 hr
	Progress Report 4	25	25	25	25	10-Feb	17-Feb	17-Feb	3 hr
	Update Project Portfolio	100	0	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 5: Screening and Scoring Design Tests									
	Screening and Scoring Lab	25	25	25	25	17-Feb	17-Feb	17-Feb	1.5 hr
	Progress Report 5	25	25	25	25	42783	42790	42789	3 hr
	Update Project Portfolio	100	0	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 6: Open Lab									
	Open Lab	25	25	25	25	24-Jan	24-Jan	24-Jan	1.5 hr
	Progress Report 6	25	25	25	25	24-Jan	5-Mar	5-Mar	3 hr
	Update Project Portfolio	100	0	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 7: Energy Modeling									
	AEV Energy Modeling Lab	25	25	25	25	3-Mar	3-Mar	3-Mar	1.5 hr
	Progress Report 7	25	25	25	25	3-Mar	9-Mar	9-Mar	3 hr
	Update Project Portfolio	100	0	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 8: Performance Test 1									
	Lab Proficiency Quiz	25	25	25	25	9-Mar	9-Mar	9-Mar	0.5 hr
	Performance Test 1 - Design	25	25	25	25	9-Mar	21-Mar	21-Mar	3.5 hr
	PDR Presentation Worksheet	25	25	25	25	1-Mar	9-Mar	9-Mar	1 hr
	Update Project Portfolio	0	100	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 9: Performance Test 2									
	Performance Test 2 - Code	25	25	25	25	23-Mar	28-Mar	28-Mar	3.5 hr
	Preliminary Design Report Due 9B	25	25	25	25	20-Mar	23-Mar	24-Mar	5 hr
	Update Project Portfolio	100	0	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 10: Performance Test 3									
	Performance Test 3 - Energy Efficiency	25	25	25	25	4-Apr	7-Apr	7-Apr	3.5 hr
	Progress Report 8	25	25	25	25	28-Mar	4-Apr	4-Apr	3 hr
	Update Project Portfolio	0	100	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 11: Performance Test 4									
	Performance Test 4 - Final Testing	25	25	25	25	11-Apr	14-Apr	14-Apr	3.5 hr
	Progress Report 9	25	25	25	25	7-Apr	11-Apr	11-Apr	3 hr
	Oral Presentation Draft Powerpoint	100	0	0	0	4-Apr	4-Apr	7-Apr	1.5 hr
	Update Project Portfolio	0	100	0	0	N/A	N/A	21-Apr	0.5 hr
Lab 12: CDR Oral Presentation									
	Oral Presentation	25	25	25	25	4-Apr	18-Apr	20-Apr	1.5 hr
	Finish Project Portfolio	50	50	0	0	N/A	19-Apr	21-Apr	0.5 hr
	Critical Design Review	25	25	25	25	11-Apr	21-Apr	21-Apr	5 hr

Figure 9: Full semester team schedule



Estimated Weight	277 g
Estimated Cost	$224.02

Figure 10: SolidWorks Model 1



ITEM NO.	PART NUMBER	Cost	QTY.
1	Cross	$2.00	1
2	AEV Arduino Assembly	$100.00	1
3	pan slot head_ai	$0.70	14
5	pan slot head_ai	$0.15	3
6	machine screw nut hex_ai	$0.70	14
8	hex bolt_ai	$0.10	2
9	90-deg bracket	$0.84	1
10	AEV Motor	$19.98	2
11	Battery Spacer	$0.30	3
12	flat bracket	$1.68	2
13	Pulley Assembly w-reflective tape	$15.00	2
14	Rotation Sensor Board	$4.00	2
15	Small Rectangle	$1.50	1
16	Support Arm 1 2 Sensor Holes V2	$3.00	1
17	Motor Mount Clip Aluminum	$1.18	2
18	Battery Pack Clamp Plate Narrow	$1.00	1
19	Prop 1	$0.90	2
20	Battery Pack	$20.00	1

Estimated Weight	300 g
Estimated Cost	$234.97

Figure 11: SolidWorks Model 2