Critical Design Report

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Executive Summary

The AEV Project, short for Advance Energy Vehicle, was presented to the team at the beginning of the semester as a long-term group project which would give the members an opportunity to hone their skills in project management, teamwork, design, and technical communication. The team was asked to construct a small vehicle to be run on an overhead monorail track mounted to the classroom ceiling. Through use of external sensors, propellers mounted on motors, construction parts, and the Arduino-based control system, the team was given the objective of constructing an AEV that could perform the mission spelled out in the Mission Concept Review.

The Mission Concept Review spells out a *Star Wars*-based scenario in which the Rebel Alliance require a low-power transportation method. Preparing for war against the Galactic Empire, the Alliance need a way to move their R2D2 units from their construction point on one side of the planet to the interceptor aircrafts on the other side. With little power available on these remote planets, the low-power requirement would be a must. An optimal AEV would successfully - and consistently - pick up the precious cargo on a caboose and deliver it to the other end while maintaining stability. A key criterion of success was to obtain an optimal (minimal) energy/mass ratio.

Over the course of the semester, the team worked through a number of lab procedures focused on the AEV. Tests to simulate the conditions of the MCR in the form of a scale model were set up in the lab classrooms, with overhead tracks fixed to the ceilings. A gate was placed at the halfway point of each of the four tracks, which would lower after seven seconds if a first sensor was tripped, but deactivate if a second sensor slightly further down the track was tripped. A magnetic caboose at the end of the track represented the R2D2 cargo units to be picked up and delivered.

At first, the team performed simple tasks in order to become acquainted with the many components in the AEV kit. Alongside this, the group learned of many various programming techniques which were used in accordance with the Arduino, the AEV's controller. Other topics such as data analysis and propeller efficiency were also explored. These labs were generally guided and very structured, but in the latter half of the semester, labs became more open. The group continually worked on the AEV's design, mainly focusing on completing the MCR.

In the second half of the semester, the group participated in several different labs dubbed "Performance Tests". These labs focused on refining specific elements of the AEV design. The first Performance Test focused on the physical design, allowing the group to compare which design was best suited for completing the MCR. In this lab, the group had decided upon their final design. The second test focused on code, and the final test placed a focus upon energy

optimization. Throughout these Performance Tests, the group continually improved upon many aspects of the final AEV design. At the end of these three Performance Tests, the group's AEV was tested in its ability to complete the MCR. The group's AEV completed the MCR flawlessly. The scores the AEV received are located in the appendix, under Table 4.

From the successful results obtained by the group in the final test, the group recommends to the Rebel Alliance the use of an AEV similar to their design. Such a design has been proven to consistently be able to execute the mission they require. However, as energy use for the group's design was capable of being lowered, the group advises the Rebel Alliance to look into alternative braking methods for stopping the vehicle at the desired points.

Table of Contents

List of Figures and Tables

Introduction

The AEV lab allowed students to experience many applicable concepts, such as project management, teamwork, communication, the design process, and documentation. Students were placed into groups of four, and worked together to complete one objective: create an Advanced Energy Vehicle capable of performing a specific scenario. Each team was tasked with brainstorming, creating and coding an AEV to complete the scenario. Working together, teams forged through the design process multiple times, while documenting every major event, in order to finally create a vehicle capable of efficiently completing the MCR. The following text was written to convey the culmination of Team J's efforts throughout the semester. The results recorded below show the final AEV's ability; results from other prototypes and other supplemental experiments are also included below. An experimental methodology, discussion, and conclusion are also included to provide further analysis.

Experimental Methodology

The AEV lab consisted of many different tasks. All of these tasks helped the group learn various tactics used in order to create the AEV that will best satisfy the aforementioned MCR. To begin, the group first became acquainted with various Arduino IDE function calls and the overall assembly of the AEV. The group started by fitted two propellers onto two motors, ensuring that the dull side was facing away from the motor casing. Then, the group attached the motors to the arduino board, which is the central hub for all of the AEV's actions. A diagram of the correct configuration is included below.

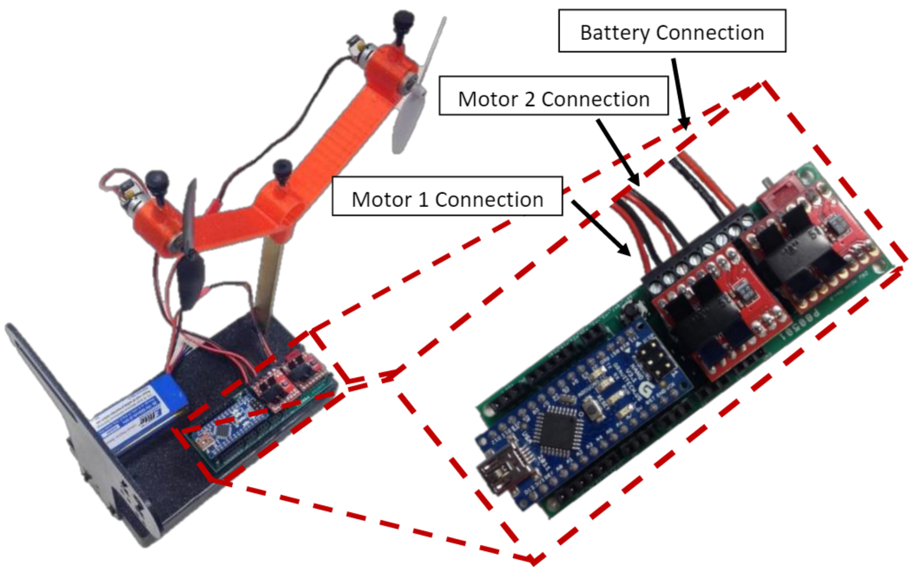


Figure 1:Motor and Arduino Connection

Proceeding this, the group then downloaded the AEV sketchbook. The sketchbook allows for Arduino programming. After the sketchbook was set up, the group proceeded to code the AEV to perform certain two given scenarios, using functions such as motorSpeed(); and goFor();. The code was written, and then, using the Arduino IDE, was uploaded to the AEV and tested. There was an upload button at the top right of the Arduino IDE which was used. This is shown below.

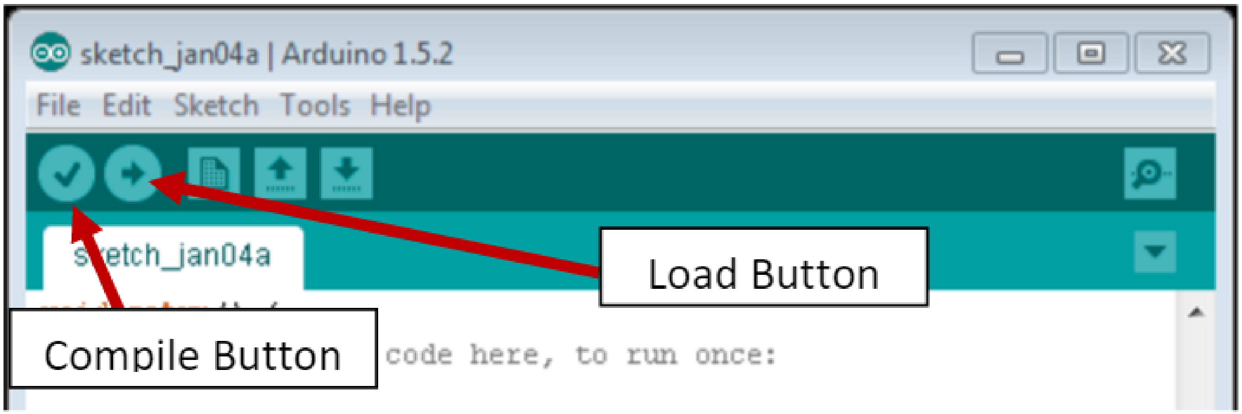


Figure 2: Compile and Load Button in Arduino

After that, the group then created the sample AEV. This AEV was important, as it was used to test multiple simple things at first. A picture of the sample AEV is located below.

Figure 3: Sample AEV Assembly

Below the wheel furthest from the propellers, the team fixated two reflectance sensors, using zip-ties. These sensors are the AEV's means of determining distance, and will be very helpful in the near future. A diagram of the set-up is located below.

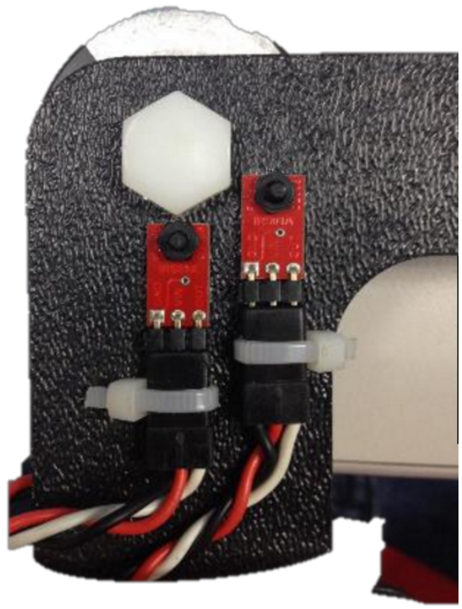


Figure 4: Reflectance Sensor Setup

After the sensors had been set up, the group used the reflectanceSensorTest(); command to verify that the sensors were working properly. Any issues were solved by fixing the polarity and configuration of the motors and the sensors. A program was then written to have the AEV perform a certain scenario.

Following this, the group observed two different propeller configurations, the 3030 configuration and the 2510 configuration, within a wind tunnel.

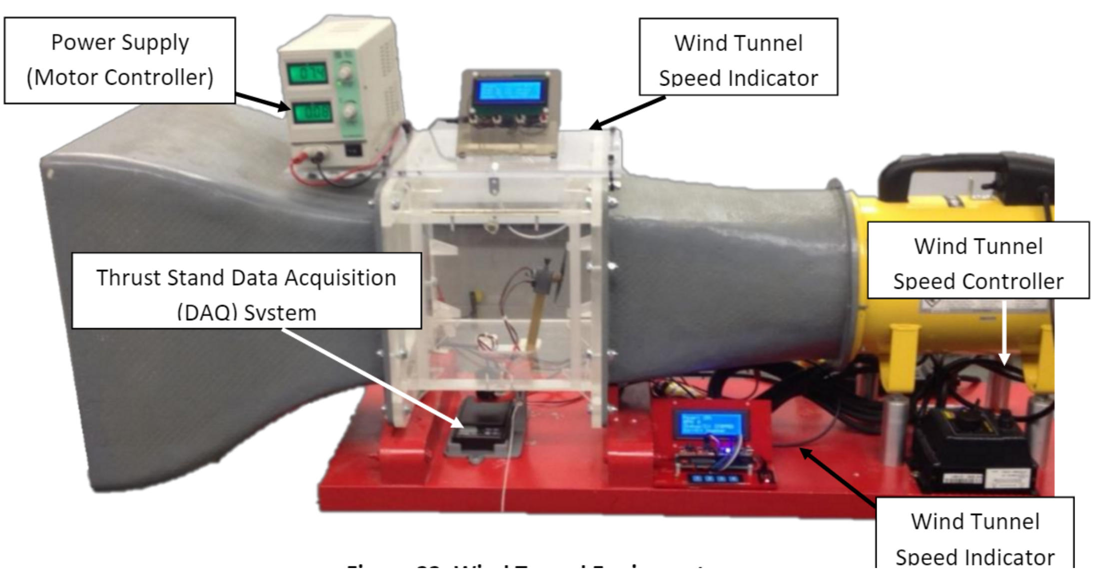


Figure 5: Wind Tunnel Components and Setup

The equipment was set up, and the pre-set values were adjusted to 7.4 Volts, and a wind speed of about 2.8 meters/sec. After recording the initial values, the Arduino power percent was decreased in increments of 5%(originally, it was at 60%). At each increment, percent power, current, thrust scale, and RPM was calculated. Based on the recorded values, the group calculated new values, such as advance ratio, propeller efficiency and calibrated thrust.

Next, the group started working towards a final AEV design. To start, each group member took approximately 10-15 minutes to create an individual design. After the design was created, the group came together and combined all their ideas into one AEV design. This AEV was to be evaluated at a later date.

Data analysis was an important aspect of the design cycle up to this point. The group developed a sample program to analyze the data of the AEV. After the AEV ran its program, the group opened the aevDataRecorder program in MATLAB. By connecting the AEV to a computer via mini-USB, the AEV's data was downloaded with the MATLAB program. Then, the group created a MATLAB file that would convert the EEPROM data to physical parameters. Equations of the conversions were given. The results were then plotted.

Proceeding onwards, the group downloaded the MATLAB Design Analysis Tool. After installing the app, the group used the analysis tool to perform all the calculations and graphs performed earlier. This Design Analysis Tool was used to analyze data from this point onwards. A picture of the AEV Design Analysis Tool is included below.

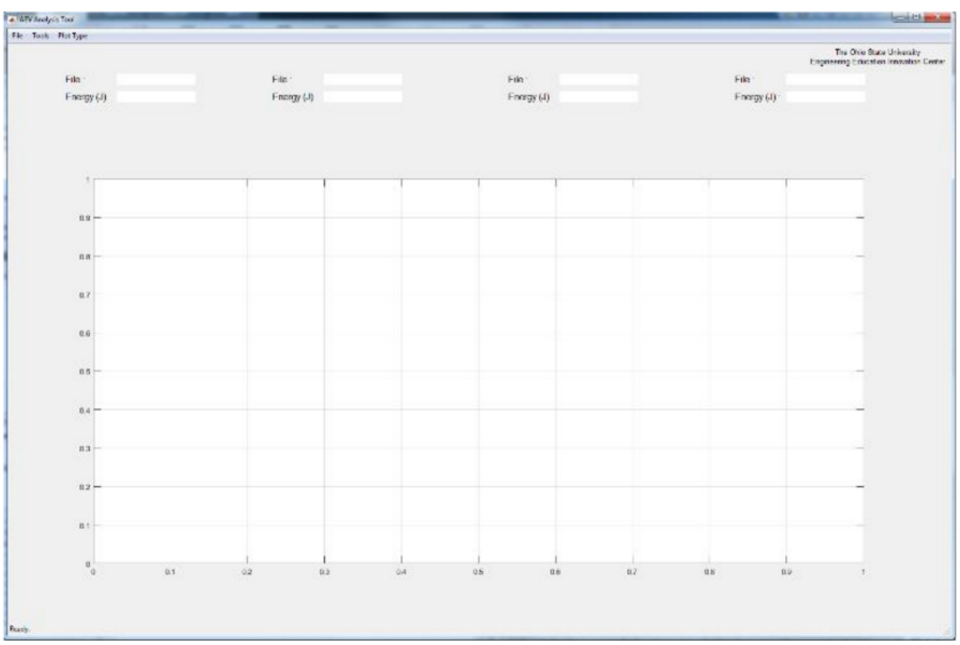


Figure 6: MATLAB Design Analysis Tool

After the group learned of data analysis, the group once again revisited their individual designs and team design created earlier. Using the methods of concept screening and concept scoring, the group evaluated both their individual and team designs based on several success criteria. This criteria included categories such as weight, durability, blockage and power consumption. For concept screening, the group used plus signs, minus signs and 0s, while actual numbers were used in concept scoring. Everything was compared to the sample AEV as a base design.

The group then checked the wheel count, attempting to see if there was any error. After running the program, the distance traveled was recorded. The marks were calculated based upon this measurement, and then labeled actual marks. Then, that value was compared to the value recorded through the Arduino, and compared. The difference between both values was meant to be 2 or under, but the group first experienced about 12 marks. The group troubleshooted the problem, counterboring screws, replacing reflective tape, and using a new sensor.

After this, the group proceeded to enter the main design cycle. To start the design cycle, the group's first goal was to design two AEVs, and create a program which would take the AEV up to the first gate, and then stop it between the two sensors right before the gate. Data of the two AEV's(which ran under the same code) was compared. To solve the problem, the group had the AEV run to a certain position, and then reversed the motors, slowing down the motors to an eventual stop.

Once the group had tested both AEVs under one code, the group had settled on the final AEV design. This design is located in Figure 1 in the appendix. The group created two different sets of code that both completed the same objective. One set of code the group used involved the absolutePosition(); command, while the other code involved relativePosition();. Both codes performed the same, for the most part.

Finally, the group proceeded to look for ways to optimize energy. One idea considered was the usage of coasting instead of an immediate stop with the reverse() command. The group had planned to implement this, but was unable to due to time constraints. The group had the second half of the MCR to complete, and as such, placed the primary focus on that instead of on energy optimization, as the completion of the MCR had more precedence.

Results

As the propellers are the AEV's main source of propulsion, their design was analyzed in particular in order to obtain optimal AEV performance. This analysis was performed in System Analysis 1. In System Analysis 1, two possible propeller types were provided, numbered 2510 and 3030. Wind tunnel testing was performed with each propeller design to compare their efficiency. Various parameters were then measured and recorded, such as RPM and thrust, while other parameters were calculated, such as calibrated thrust, advance ratio and propeller efficiency. As a function of vehicle velocity, propeller RPM, and propeller diameter, a singular value for output power can be obtained through dimensional analysis using the non-dimensional unit of Propeller Advance Ratio. Below, graphs depicting propulsion efficiency for each propeller design are shown, with respect to propeller advance ratio. It is significantly clear that propeller 3030 is more efficient at almost any advance ratio, and therefore design 3030 was selected as the team's propeller of choice. System Analysis 1 had lead the group to this decision.

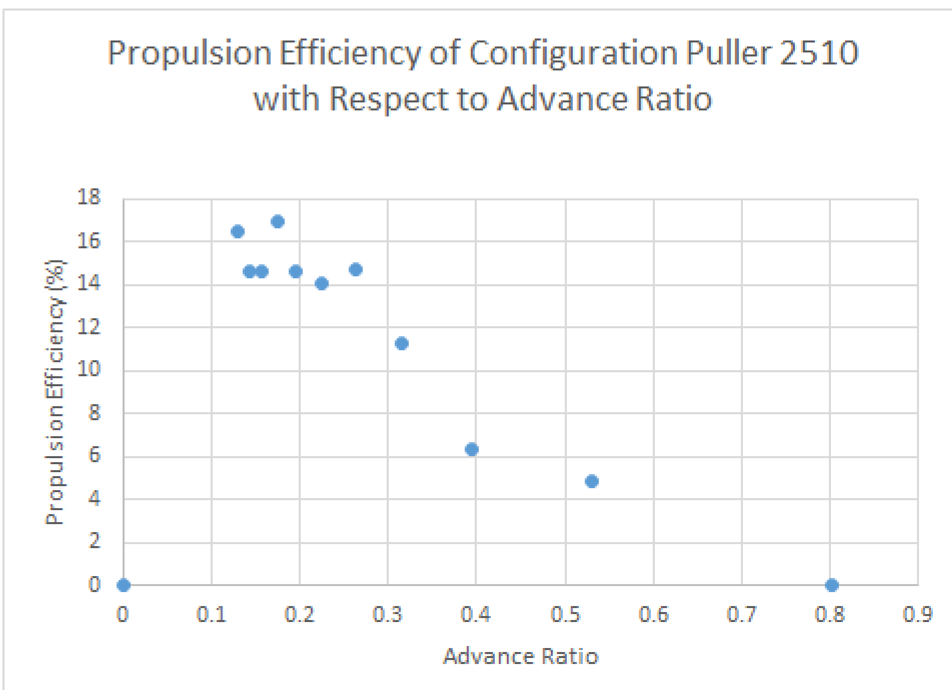


Figure 7: Propulsion Efficiency of Puller 2510 Configuration

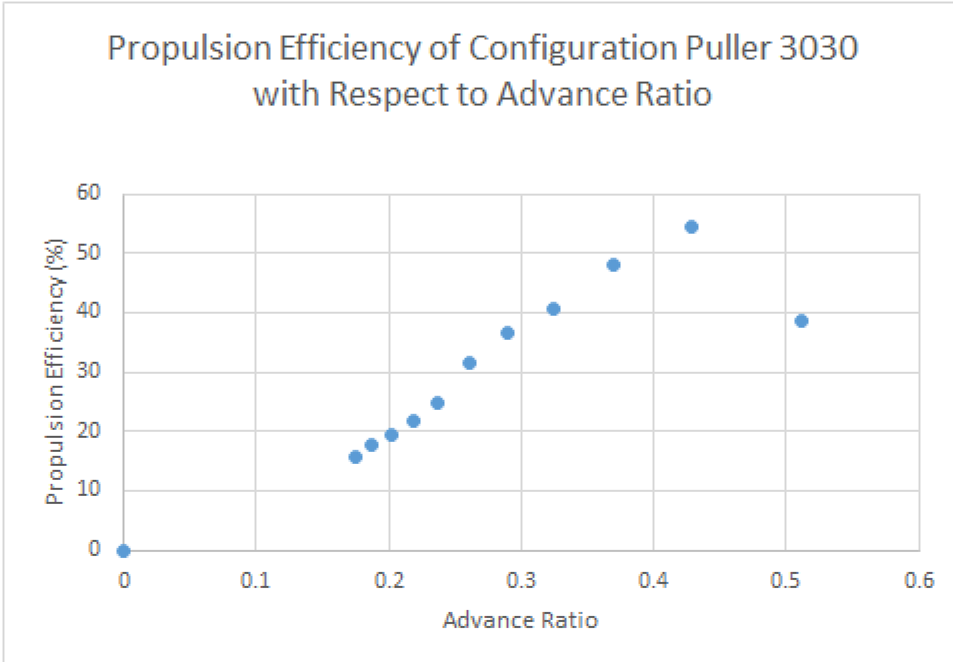


Figure 8: Propulsion Efficiency of Puller 3030 Configuration

System Analysis 2 familiarized the group with AEV data gathering, analysis, and calculation. In the main design cycle, the group will have to constantly observe data and adjust the AEV off that data. System Analysis 2 replicated this scenario, as the group had recorded, converted and calculated data. System Analysis 2 also presented the MATLAB Design Analysis Tool. Overall, System Analysis 2 had introduced and alleviated the data analysis portion of this lab.

Once the group had decided on their two prototypes, the team sought to use the Data Analysis tool to create Power vs. Time graphs for each AEV design. This would allow the team to analyze how the different AEVs utilize the energy provided in order to complete the task given to it in the code. After much tribulation, the team were able to obtain some data from a test run for one of the AEV prototype designs. The Power vs. Time plot for it is shown below, broken into distinct phases which showcase specific events corresponding to the Arduino code. A phase breakdown is provided to show energy use in each stage.

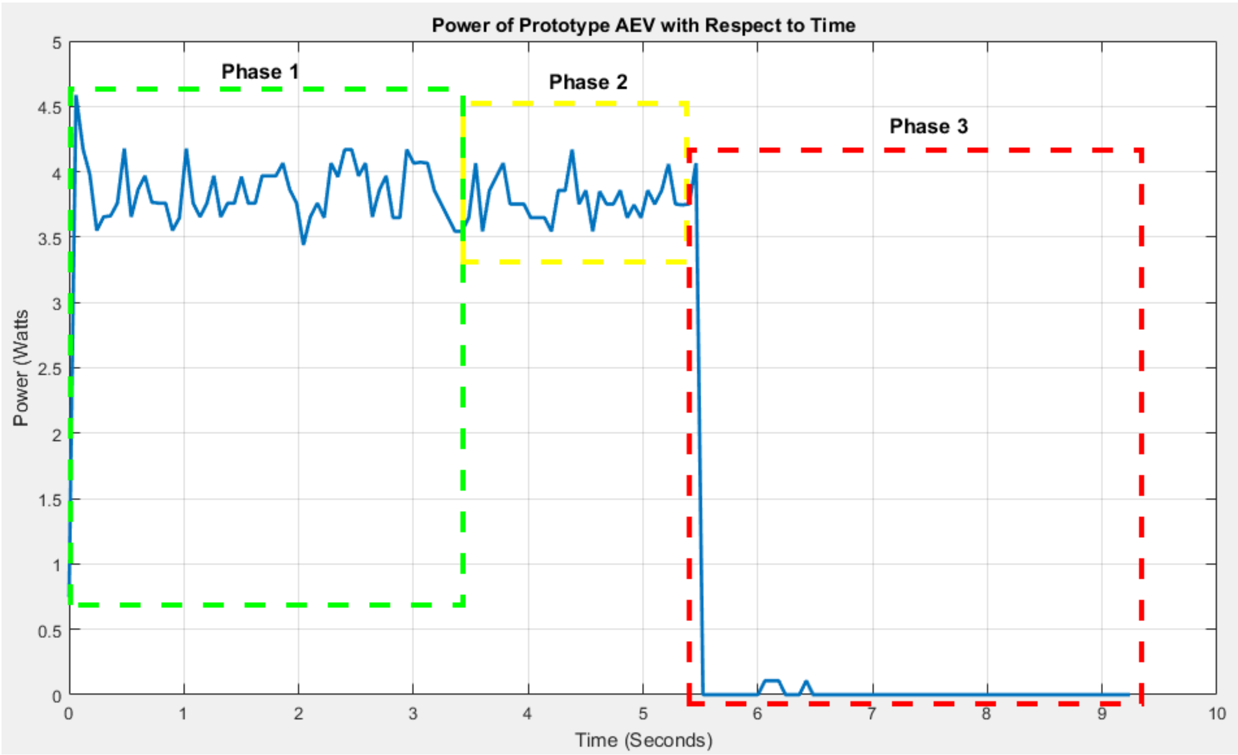


Figure 9: Power vs. Time Phase Analysis of AEV Prototype Design 2

Table 1: Phase Breakdown of AEV Prototype Design 2

Phase	Arduino Code	Time (seconds)	Total Energy (Joules)

1	reverse(4);
	motorSpeed(4, 25);
	goToAbsolutePosition(-280);
		0 - 3.4220	7.344

2	reverse(4); goToAbsolutePosition(-380);	3.4220 - 5.4620	7.762
3	brake(4);	5.4620 - 9.2420	0
		Total Energy Used:	15.106 J

Unfortunately, as the team was not able to run a test on the other AEV design within the time provided for the lab, no data was able to be collected from the other prototype. However, as previous tests had been run on a similar design in the past System Analysis lab, worthwhile data exists from these tests which could, to an extent, be used to draw worthwhile comparisons between the two designs. The phase breakdown of this AEV is shown below.

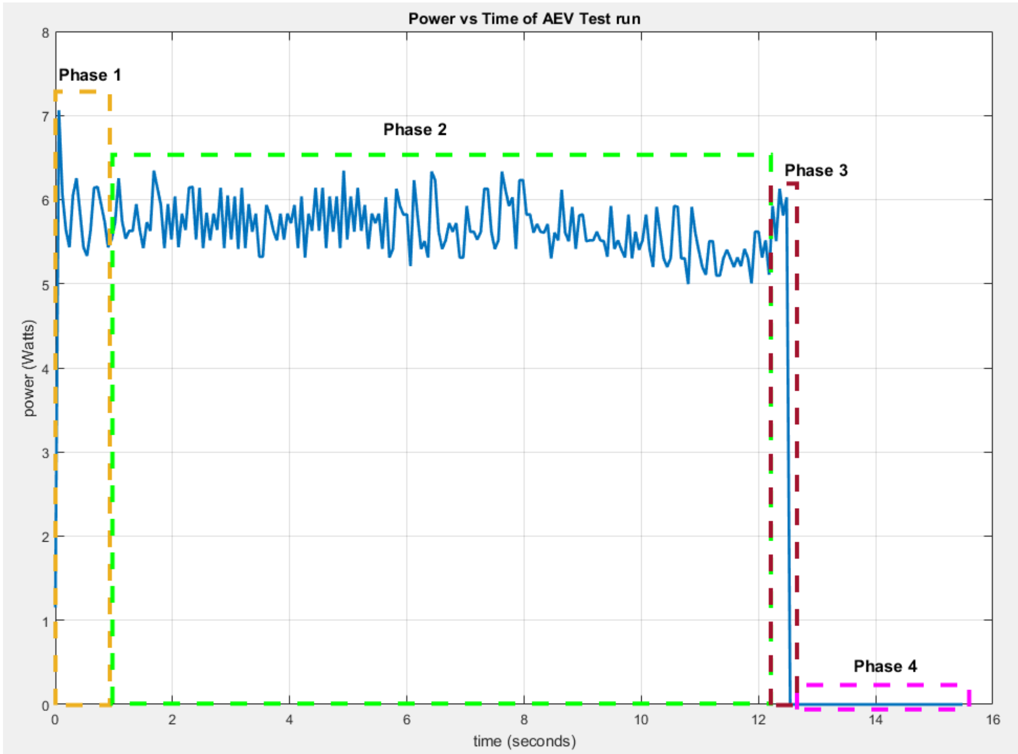


Figure 10: Power vs. Time Phase Analysis of Prior Test Run of Prototype Design 1

Table 2: Phase Breakdown of Prior Test Run of AEV Prototype 1

Phase	Arduino Code	Time (seconds)	Total Energy (Joules)
1	reverse(4); motorSpeed(4, 25);	0 - 0.96	5.4901
2	goToAbsolutePosition(380);	0.96 - 12.121	63.1831
3	reverse(4);	12.121 - 12.48	2.055
4	brake(4);	12.121-15.48	0.1808
		<u>Total Energy Used:</u>	70.9090 J

Discussion

In Performance Test 1, the group evaluated two different AEV prototypes; one design focused on stability, while another was based around being highly condensed. The first design was derived from the design of the Sample AEV, with wings located at the front of the vehicle instead of the back. The SolidWorks assembly of this design is designated in Figure 1 of the appendix. The second design focused primarily on one specific aspect - size. The core of the design included a small rectangular piece, with two small trapezoidal pieces on either side. The propellers and motors were attached to the bottom of the trapezoidal pieces, while the arduino controller was placed on the top. The battery was taped to the base. An assembly of this design is located in Figure 2 of the appendix. Also, orthographic drawings for both prototypes are located in Figures 3 & 4 in the appendix.

The two prototype designs being worked with ultimately stem from the four concepts created by the team members in the Creative Design Thinking lab. All team members created something unique, but common goals were identified. A design that was efficient, quick, and effective was desired by all team members, and reflected in their own designs. These principles were synthesized along with some design cues from the Sample AEV to create the group's first prototype design. By utilizing some tried and true elements of the sample AEV while adding the group's creativity, a solid performer was created which could consistently and stably move about the track. When creating the second prototype, some of the team member's design ideas were taken to more extreme extents. By moving further from the provided sample AEV design, this prototype provided a weight advantage while sacrificing on stability and ease of use.

The group decided to use Prototype Design 2 as the final product. When the group compared all the prototypes and individual concepts to each other, Prototype Design 2 stood out. The group was particularly fond of its dense design. When the group sought to improve upon Prototype 2's compactness, it was quickly found that there was not much room for improvement upon the basic idea. As such, the group decided to proceed with Prototype Design 2, and ultimately made this design the final product.

The final design was included in the concept screening and scoring tables listed below. For brevity purposes, the final design was notated as Design F. Designs A-D referred to the individual ideas, and Design E represented the first prototype. It should be noted that Design F also represented the second prototype - the second prototype and the final design were one and the same.

Table 3: Concept Screening of Individual Designs and Both Prototypes

				Concept Screening			
Success Criteria	**Reference**	**Design A**	**Design B**	**Design C**	**Design D**	**Design E**	**Design F**
Weight	0	0	0	-	-	+	+
Cost	0	0	0	0	0	0	+
Environmental	0	0	0	-	-	+	+
Power Consumption	0	0	0	0	0	0	+
Durability	0	+	+	+	+	+	-
Center-of-Gravity	0	0	0	0	+	0	0
Turning	0	+	+	0	-	+	0
Blockage	0	-	-	0	0	0	-
Sum +'s	0	2	2	1	2	4	4
Sum 0's	8	5	5	5	3	4	2
Sum -'s	0	1	1	2	3	0	2
Net Score	0	1	1	-1	-1	4	2
Continue?	No	Yes	Yes	No	No	Yes	Yes

Table 4: Concept Scoring of Two Individual Designs and Both Prototypes

				Concept Scoring					
		E Reference		**Design A**		**Design B**		**Design F**	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Weight	20%	4	0.8	3	0.6	3	0.6	4.5	0.9
Cost	5%	3	0.15	3	0.15	3	0.15	4	0.2
Environmental	10%	3	0.3	3	0.3	3	0.3	4	0.4
Power Consumption	10%	3	0.3	2	0.2	2	0.2	4	0.4
Durabillity	10%	3	0.3	3	0.3	3	0.3	2	0.2
Center-Of-Gravity	15%	2	0.3	3	0.45	3	0.45	2	0.3
Turning	10%	3	0.3	3	0.3	3	0.3	3	0.3
Blockage	20%	3	0.6	1	0.2	3	0.6	2	0.4
Total Score			3.05		2.5		2.9		3.1
Continue?		Yes		No		No		Yes	

When compared to all previous models, the final design proved to be, overall, better than the others. While the final design was lacking in terms of categories such as blockage and durability, the design's excellence in other categories propelled it above the other designs. With a score of 3.1, the final design beat out the other prototype, Design E, which had a score of 3.05. In the concept scoring matrix, Designs A and B were also evaluated as well, and they both fell short of the final design - Design F.

As mentioned before, the final design placed a special emphasis on compactness. As such, the base only consisted of three plastic parts. Alongside those parts is the support arm, the sensors, wheels, battery, and arduino. The design was as minimal as possible, and as such costs were minimized. The estimated cost of the final design, otherwise known as Prototype Design 2, was about $143.64, which, when compared to the other Prototype Design, is $16.77 cheaper. Prototype Design 1 was estimated to be around $160.41. In the case of mass production, $16.77 will inevitably add up to become great savings. The bill of materials for both prototypes are located in Table 2 & 3 in the appendix.

The goal of Performance Test 10 was to optimize the AEV's energy usage. However, at the time, the group had only about half of the MCR completed. The AEV was able to successfully travel to the first gate, but could not go any further. As such, the group had decided to, at first, forego energy optimization in lieu of focusing on completing the MCR. The group made this decision when the available time was assessed, and the group determined that they had to focus solely on the MCR. The group had planned to implement more coasting within the code in order to lessen energy use, but the group was not able to get around to it. If the group was allotted more time, then that time would have been devoted towards the optimization of energy.

During final testing, the group's AEV performed flawlessly. The AEV traversed to the first gate, and made a stop within the two gate sensors. After waiting seven seconds, it then advanced to the other side of the track and slowed to pick up the caboose gently. When the caboose was picked up, the AEV did not ram it into the foam barrier, but rather connected with the caboose and immediately stopped. After the caboose was picked up, the AEV traveled back to the gate and stopped, waiting seven seconds before moving again. The AEV finally made its way to the beginning of the track, stopping perfectly between the foam barrier and the first hanger. Overall, the group's AEV had scored a perfect 50 out of 50. The scoring sheet can be found in Table 5, in the appendix.

Despite the perfect score, the AEV's energy usage was on the high side. The AEV used approximately 390 Joules. To stop the AEV, the group used the reverse command to first slow down the AEV. The reverse command is most likely the cause of the excess energy usage. With the caboose in tow, a high motor power was required to slow down the entire assembly. Specifically, 80% power was used to stop the AEV and caboose. This was done twice, and thus, the AEV consumed a considerable amount of energy. As mentioned earlier, the group did not have ample time to include more energy-efficient methods.

Conclusion & Recommendations

When the recorded data was analyzed, it was found that Prototype Design 2 had used less energy than Prototype Design 1. As seen above, Prototype 2 used a total of 15.106 Joules, whereas Prototype 1 had used 70.909 Joules. As mentioned earlier, the team did not have the time to run both prototypes on the same code. While the results above are based on different code, the code was similar in some manner. Both designs traveled at 25% power, while also attempting to reach a final destination of 380 marks. Even with the differences in code, Prototype 2 proved to be vastly more efficient than Prototype 1, with a difference of 55.803 Joules between their respective energy consumption. As such, the team will proceed with Prototype 2's design. Less energy consumption means that in the long term, Prototype 2 will place less of a burden on the environment, while also being more efficient than Prototype 1. Prototype 2 will also cost less to create in the future, as its total estimated cost is approximately $143.64 per unit, whereas Prototype 1 will cost about $160.41 per unit. In the appendix, the bill of materials with cost can be found for both Prototype 1 and Prototype 2, in both Tables 1 and 2 respectively. The group proceeded to make Prototype 2 the final design. After the group had decided on the design, they moved onto creating two sets of code, and then optimizing the energy usage of the AEV, and then finally testing the AEV's ability to complete the MCR.

The team had experienced many issues in past labs, ultimately leading to a failure of completing the first performance test. Various complications involved count sensor failures and motor polarity. The primary problems the group faced regarded the sensors. In several labs of the past, the AEV's sensors would fail to function properly, repeatedly failing the reflectance test. In one instance, many solutions were attempted to correct the issue, such as adjusting the reflecting tape on the wheels or counterboring the screws in the support arm, but to no avail. Finally, the group, with help of the GTA, had discovered that the sensor being used was faulty, and it was immediately replaced. Other times, the sensors were counting marks in the undesired direction. For example, the AEV would have been moving forward, yet the sensor would be counting marks backwards. This would lead the AEV to indefinitely travel forward, causing the group confusion as to why the AEV's motors would never stop at the desired location. After multiple failed runs and an eventual analysis, the group finally realized the counting of the sensors, and adjusted the code accordingly. However, this situation did not happen only once. Since certain parts of the AEV have to be broken down and reconstructed each lab, there is sometimes a mismatch of wires. This occurred, most notably, in Lab 08B. In Lab 08B, the AEV was traveling in one direction, but the sensors were counting marks in the opposite direction. Thus, based on the AEV's code, the AEV would have never reached the position where it was coded to stop. The group was oblivious to this issue for a good amount of Lab 08B, and kept trying to solve the problem in other fashions, thus wasting a crucial amount of time. This was one of the primary issues that prohibited the group from completing the objective of the first performance test.

Up to this point, the team has made many observations and collected numerous pieces of data regarding the AEV. Through the lab procedures, the team has used this information in order to continually improve and refine the design process. However, the team has also encountered many mishaps and mistakes which have held back the success of the design process considerably. As these issues happen continually, it becomes more clear that when serious problems occur, it is more likely to be some sort of hardware problem than an incorrect interpretation and utilization of the known data. The group has gained valuable experiences throughout the course of the AEV lab, such as teamwork, communication and documentation skills, and will incorporate the gained knowledge in future endeavors.

Appendix

Table 1: Team J Task Schedule for the Entire AEV Project

No.	Task	Start	Finish	Due Date	Est Time	Matthew Caldwell	Tarun Pilli	Jacob Phillips	John Kim	Percent Done
1	Progress Report for Lab 2	18-January	23-January	24-January	3.0 h	3.0 h	3.0 h	3.0 h	3.0 h	100
2	Sample AEV Construction	23-January	23-January	24-January	1.0 h		1.0 h		1.0 h	100
3	Progress Report for Lab 3	26-January	2-February	3-February	3.0 h	03.0 h	3.0 h	3.0 h	3.0 h	100
4	Revision of the Progress Report for Lab 2	3-February	3-February	7-February	1.0 h	1.0 h	1.0 h	1.0 h	1.0 h	100
5	Progress Report for Lab 4	3-February	6-February	7-February	3.0 h	3.0 h	3.0 h	3.0 h		100
6	Progress Report for Lab 5	7-February	13-February	14-February	4.0 h	4.0 h	4.0 h	4.0 h	4.0 h	100
7	Progress Report for Lab 6	14-February	20-February	21-February	4.0 h	4.0 h	4.0 h	4.0 h	4.0 h	100
8	Preliminary Check of the Project Portfolio	13-February	20-February	21-February	1.0 h	1.0 h	1.0 h	1.0 h	1.0 h	100
9	Executive Summary for New Lab	28-February	6-March	7-March	3.0 h	3.0 h	3.0 h	3.0 h	3.0 h	100
10	Progress Report for Lab 8	7-March	9-March	10-March	2.0 h	2.0 h	2.0 h	2.0 h	2.0 h	100
11	AEV 1 Construction	7-March	20-March	27-March	1.0 h	1.0 h	1.0 h	1.0 h	1.0 h	100
12	AEV 1 Testing	20-March	21-March	27-March	0.5 h	0.5 h	0.5 h	0.5 h	0.5 h	100
13	AEV 2 Construction	21-March	24-March	27-March	0.5 h	0.5 h	0.5 h	0.5 h	0.5 h	100

14	AEV 2 Testing	24-March	24-March	27-March	0.5 h	0.5 h	0.5 h	0.5 h	0.5 h	100
15	AEV Solid Works Models	21-March	25-March	27-March	2.0 h		2.0 h			100
16	Preliminary Design Report	21-March	26-March	27-March	7.0 h	6.0 h	6.0 h	1.0 h		100
17	Progress Report for Lab 10	31-March	3-April	4-April	3.0 h	3.0 h	3.0 h	3.0 h	3.0 h	100
18	Oral Presentation Draft	3-April	6-April	7-April	2.0 h	2.0 h	2.0 h			100
19	Progress Report for Lab 11	7-April	9-April	10-April	2.0 h	2.0 h	2.0 h	2.0 h	2.0	100
20	Oral Presentation	3-April	17-April	18-April	3.0 h	3.0 h	3.0 h	3.0 h	3.0 h	100
21	Critical Design Report	10-April	20-April	21-April	6.0 h	6.0 h	6.0 h	2.0 h	1.0 h	100
22	Project Portfolio	13-February	20-April	21-April	3.0 h	3.0 h	3.0	3.0 h	3.0	100

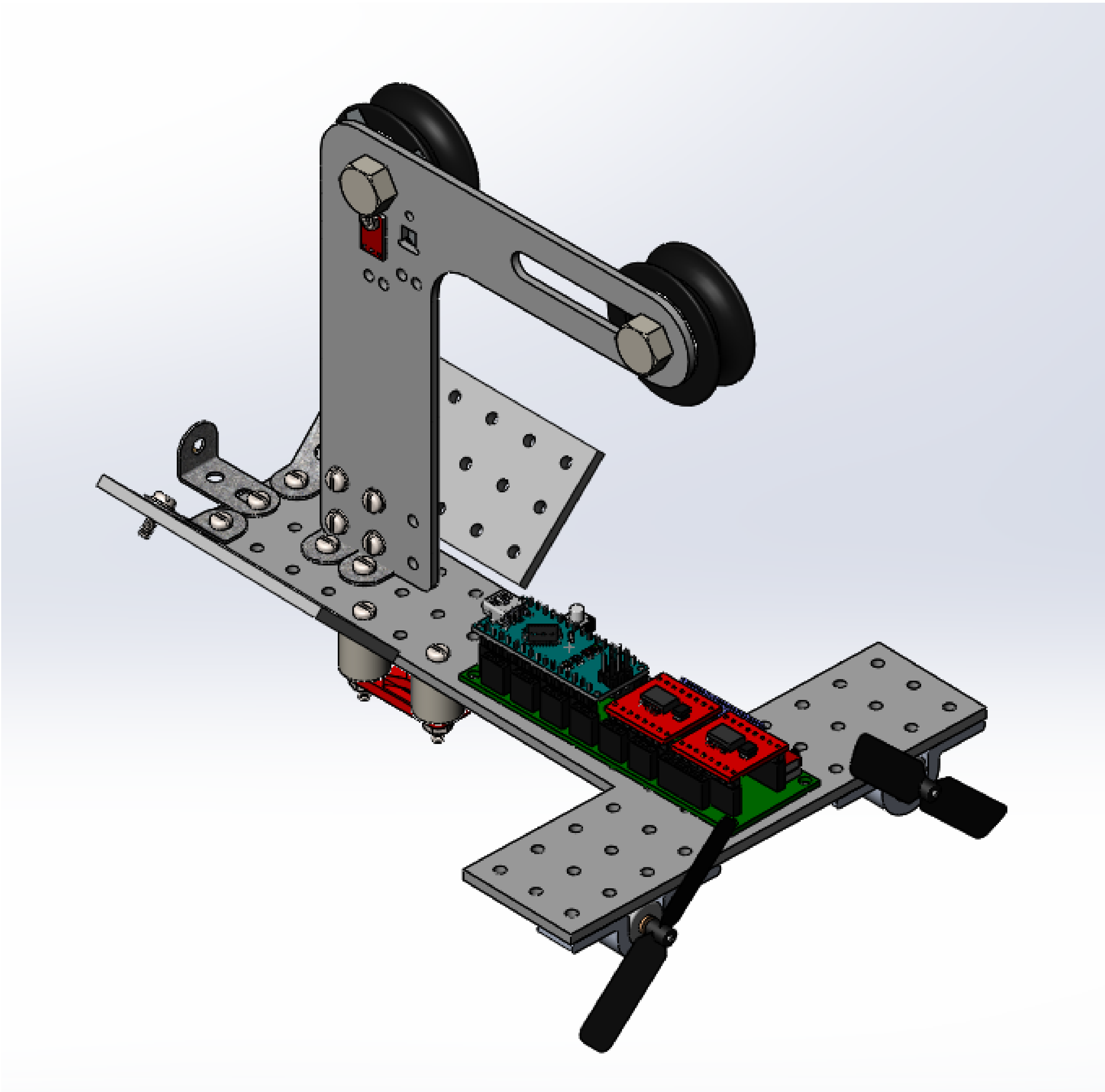


Figure 1: Team J's Prototype Design 1

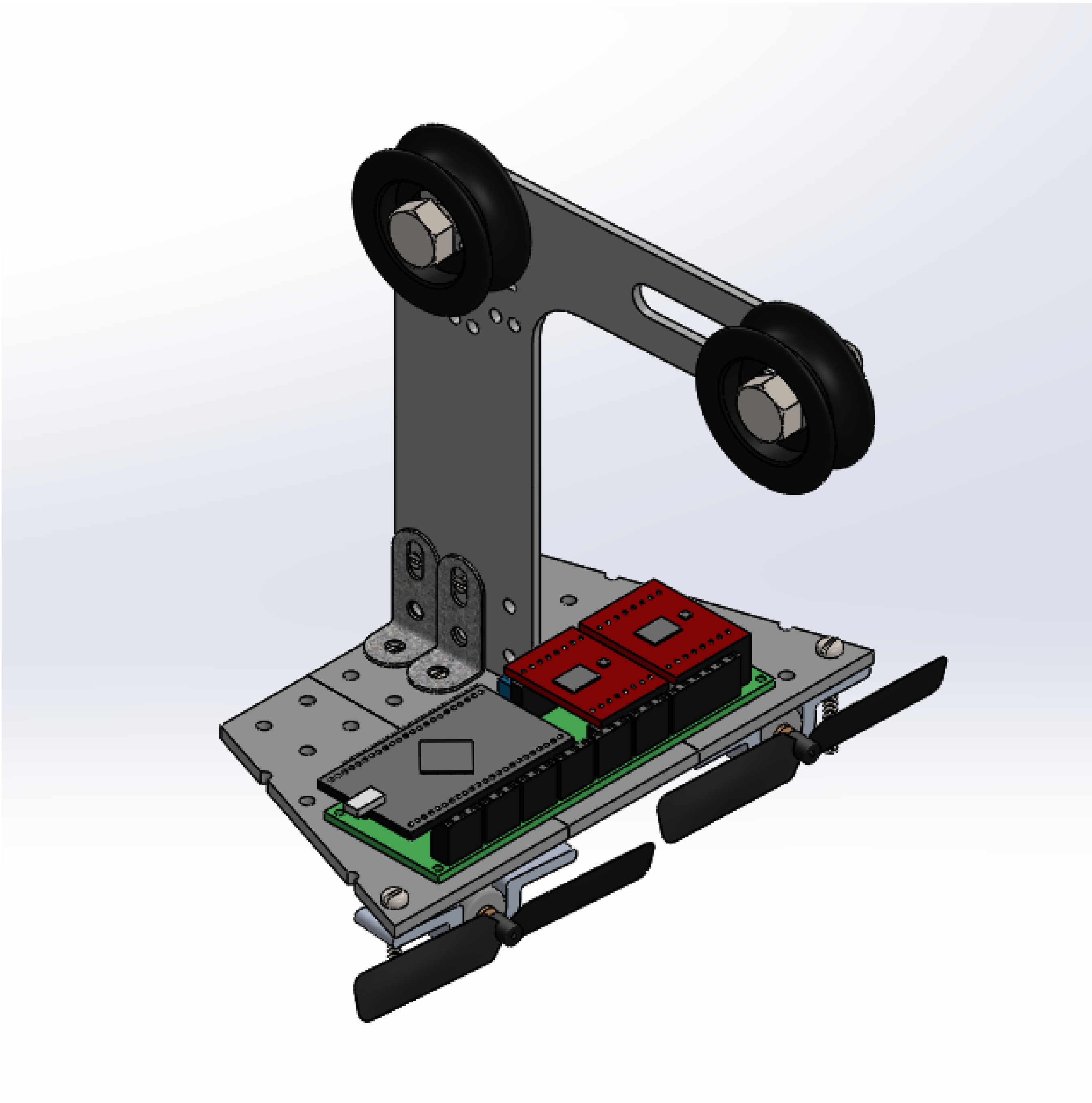
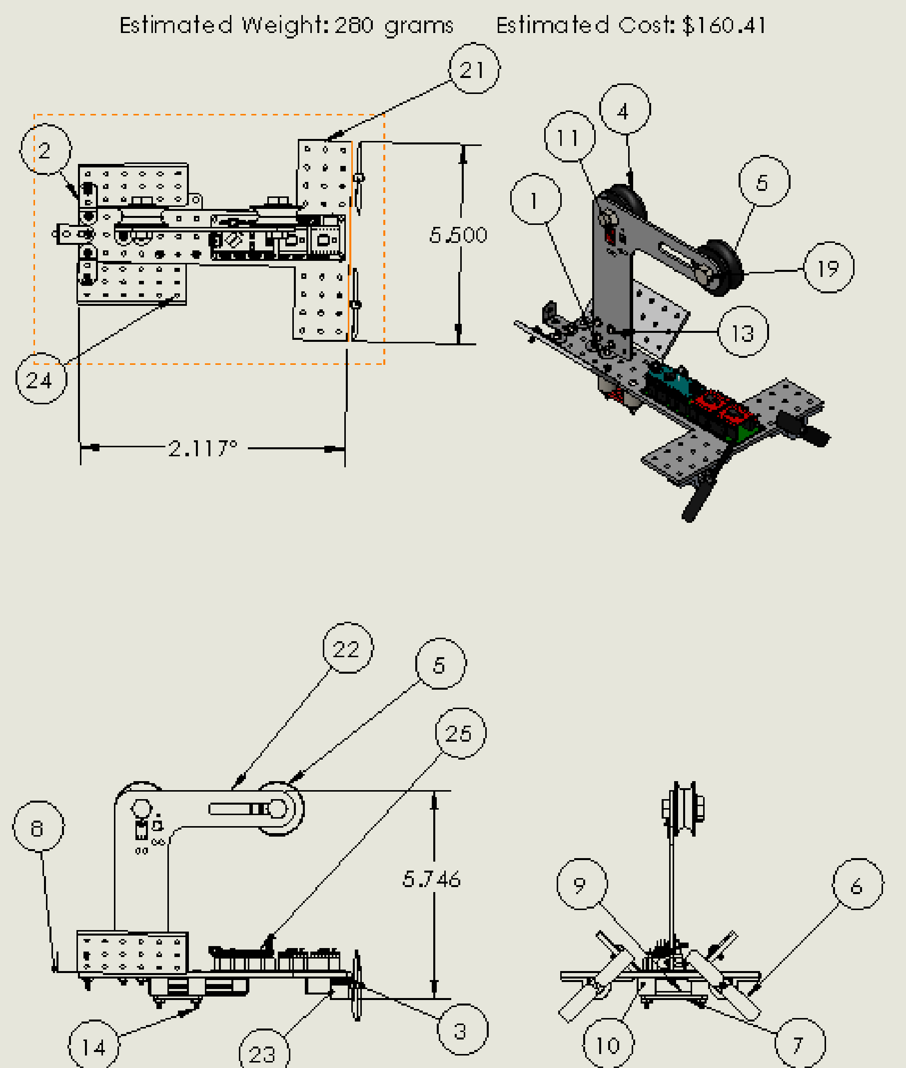


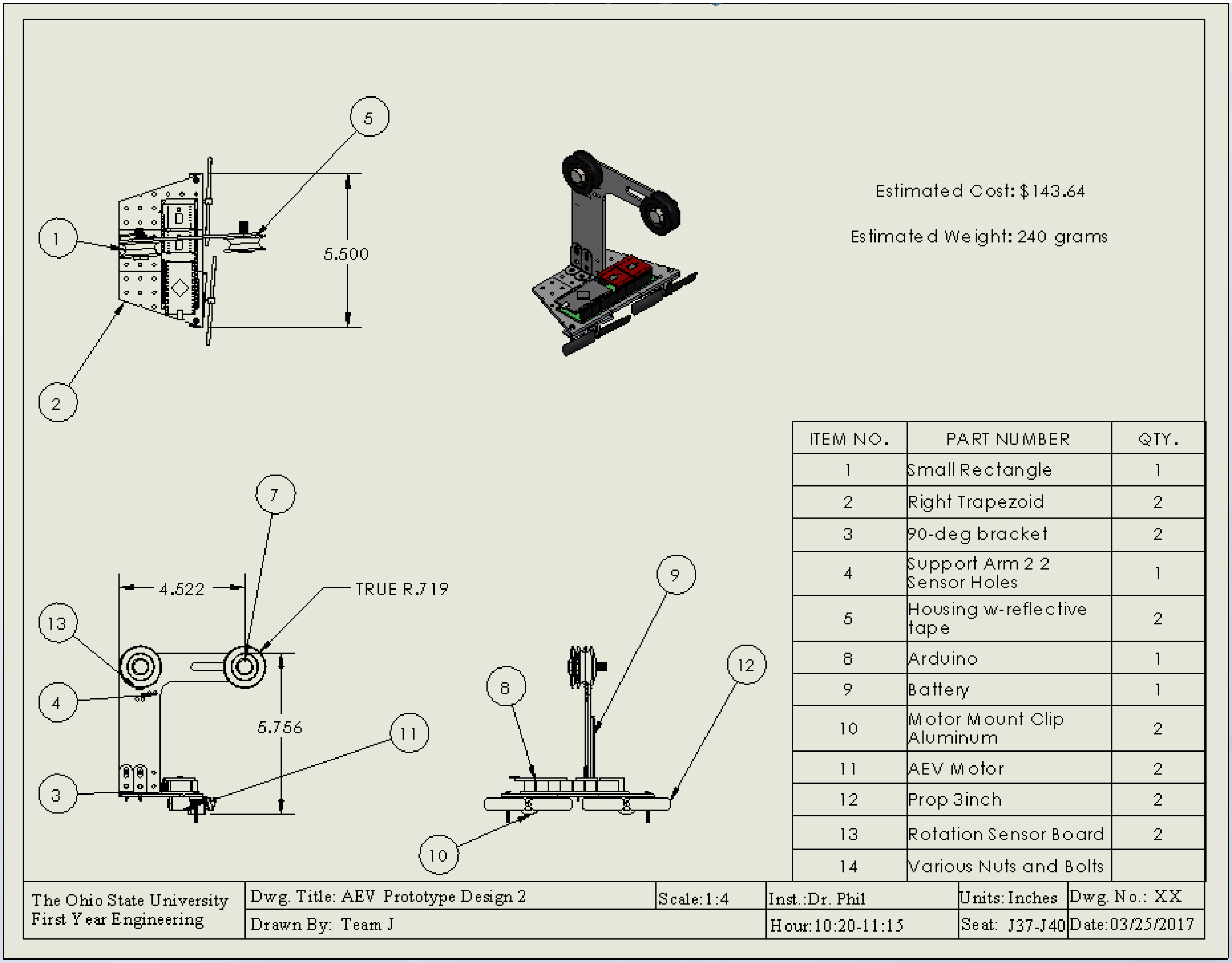
Figure 2: Team J's Prototype Design 2



ITEM NO.	PART NUMBER	QTY.
1	90-deg bracket	3
2	45-deg bracket	2
3	AEV Motor	2
4	Pulley Assembly w-reflective tape	1
5	Pulley Assembly	1
6	Prop 1	2
7	Battery Pack Clamp Plate Narrow	1
8	Magnet Cube	1
9	Battery Pack	1
10	Battery Spacer	2
11	Rotation Sensor Board	1
12	pan slot head_ai	6
13	pan slot head_ai	5
14	pan slot head_ai	2
15	flat washer type a narrow_ai	6
16	machine screw nut hex_ai	12
17	machine screw nut hex_ai	2
18	machine screw nut hex_ai	1
19	hex bolt_ai	2
20	flat head 100 screw_ai	1
21	Tee	1
22	Support Arm 2 2 Sensor Holes	1
23	Motor Mount Clip Aluminum	2
24	Small Rectangle	2
25	AEV Arduino Assembly	1

The Ohio State University First Year Engineering	Dwg. Title: AEV Prototype Design 1	Scale: 1:4	Inst.: Dr. Phil	Units: Inches	Dwg. No.: XX
	Drawn By: Team J		Hour: 10:20-11:15	Seat: J40	Date: 03/25/2017

Figure 3: Team J's Prototype Design Drawing 1



ITEM NO.	PART NUMBER	QTY.
1	Small Rectangle	1
2	Right Trapezoid	2
3	90-deg bracket	2
4	Support Arm 2 2 Sensor Holes	1
5	Housing w-reflective tape	2
8	Arduino	1
9	Battery	1
10	Motor Mount Clip Aluminum	2
11	AEV Motor	2
12	Prop 3inch	2
13	Rotation Sensor Board	2
14	Various Nuts and Bolts	

The Ohio State University First Year Engineering	Dwg. Title: AEV Prototype Design 2	Scale:1:4	Inst.:Dr. Phil	Units: Inches	Dwg. No.: XX
	Drawn By: Team J		Hour:10:20-11:15	Seat: J37-J40	Date:03/25/2017

Figure 4: Team J's Prototype Design 2 Drawing

Table 2: Bill of Materials With Cost For Prototype Design 1

Item No.	Part	Cost	QTY.	Total
1	90-deg bracket	$0.84	3	$2.52
2	45-deg bracket	$0.84	2	$1.68
3	AEV Motor	$10.00	2	$20.00
4	Pulley Assembly w-reflective tape	$7.50	1	$7.50
5	Pulley Assembly	$7.50	1	$7.50
6	Prop 1	$0.45	2	$0.90
7	Battery Pack Clamp Plate Narrow	$0.75	1	$0.75
8	Magnet Cube	$0.50	1	$0.50
9	Battery Pack	$2.00	1	$2.00
10	Battery Spacer	$2.00	2	$4.00
11	Rotation Sensor Board	$2.00	1	$2.00
12	Various Nuts and Bolts	$2.88	1	$2.88
22	Tee	$2.00	1	$2.00
23	Support Arm 22 Sensor Holes	$3.00	1	$3.00
24	Motor Mount Clip Aluminum	$0.59	2	$1.18
25	Small Rectangle	$1.00	2	$2.00
26	AEV Arduino Assembly	$100.00	1	$100.00
TOTAL COST	ALL			$160.41

Table 3: Bill of Materials With Cost For Prototype Design 2

Item No.	Part	Cost	QTY.	Total
1	Small Rectangle	$1.00	1	$1.00
2	Right Trapezoid	$1.00	2	$2.00
3	90-deg bracket	$0.84	2	$1.68
4	Support Arm 2 2 Sensor Holes	$3.00	1	$3.00
5	Housing w-reflective tape	$7.50	2	$15.00
8	Arduino	$100.00	1	$100.00
9	Battery	$2.00	1	$2.00
10	Motor Mount Clip Aluminum	$0.59	2	$1.18
11	AEV Motor	$10.00	2	$10.00
12	Prop 3inch	$0.45	2	$0.90
13	Rotation Sensor Board	$2.00	2	$4.00
14	Various Nuts and Bolts	$2.88	1	$2.88
TOTAL COST	ALL	$140.64		$140.64

Table 4: AEV Statistics

AEV Mass	Total Energy	Total Run Time
0.228 kg	391.791 J	61.59 s

Table 5: AEV Scores during Final Testing Run 1

Procedure	Yes	No	Pts Earned
Team shows proper testing procedure	✓		10/10
AEV starts and travels to the first gate	✓		4/4
Stops before gate	✓		4/4
Waits 7 seconds	✓		4/4
Travels through gate	✓		4/4
AEV starts and travels to loading zone and waits for 5 seconds	✓		4/4
AEV connects to cargo & travels to gate (crashes into cargo-deduct <= 2)	✓		4/4
Stops before gate	✓		4/4
Waits 7 seconds	✓		4/4
Travels through gate	✓		4/4
AEV starts and travels to starting point	✓		4/4
Total Points Earned			50/50