Preliminary 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.

In the context of this class, the team worked with a scale model of the full project for the purpose of design and testing. Four tracks total were set up from the classroom ceiling, made up of two concentric ovals, each halved. At the halfway point of each track, a gate was put in place. A sensor at the front of the gate, when tripped, would lower the gate after seven seconds. A second sensor, however, placed further along would de-activate the previously activated gate. This in particular showcases the precision the team would have to employ with their AEV to successfully complete the Mission Concept Review. The team with the most successful design at the end will be given the contract for the full-scale AEV design.

Throughout the semester, the team completed several lab procedures in order to gain knowledge about the AEV construction process. These procedures introduced new tools and concepts for analyzing and creating AEV designs. Early labs introduced the key parts involved in AEV construction. Central to this was the Arduino-based controller, whose programming language and environment were also introduced through the labs. Programming the Arduino was revealed to be the primary method for controlling the AEV, with simple commands for powering the motors and taking input from sensors on the wheels. These reflectance sensors counted wheel rotations by counting occurrences of reflective sticky tape on the wheel. This measure was able to be converted to real-world units by accounting for the circumference of the wheel, giving the team the ability to control the distance the AEV travelled. Wind tunnel testing was also conducted in lab to give quantitative insight into the question of which propeller design was most efficient. The team was given even further precision for AEV analysis when introduced to the AEV Analysis Software. This allowed for the EEPROM data from the Arduino after an AEV run to be downloaded and analyzed. With direct access to the AEV's current, voltage, and position at any given time, the team had greater ability to refine the design.

Beyond the technical learning through the lab processes, creative design skills were learned as well. Team members were encouraged to think creatively while designing their own AEV concepts, and then working together with team members to combine useful ideas into one aggregate design. Throughout the course of the labs, the team was encouraged to continually incorporate new ideas from all team members into constant improvement of the AEV design. Tools were introduced to compare these potential designs, particularly the idea of Screening and Scoring. The screening process involved quick and general comparisons between a large quantity of designs, while scoring allowed for more precise comparisons of the specific attributes each design possessed.

Overall, the labs up to this point have allowed the team to develop their skills while working toward the task of completing the goals stated in the Mission Concept review. The labs have been heavily structured, providing detailed instructions for specific tasks in order to guide the process along. Now that the team has obtained this knowledge, the remaining labs will be much less structured. The team will have to use their own planning in order to complete more free-form goals with the ultimate task of fulfilling the Mission Concept Review and meeting all of its criteria by the end of the semester.

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.

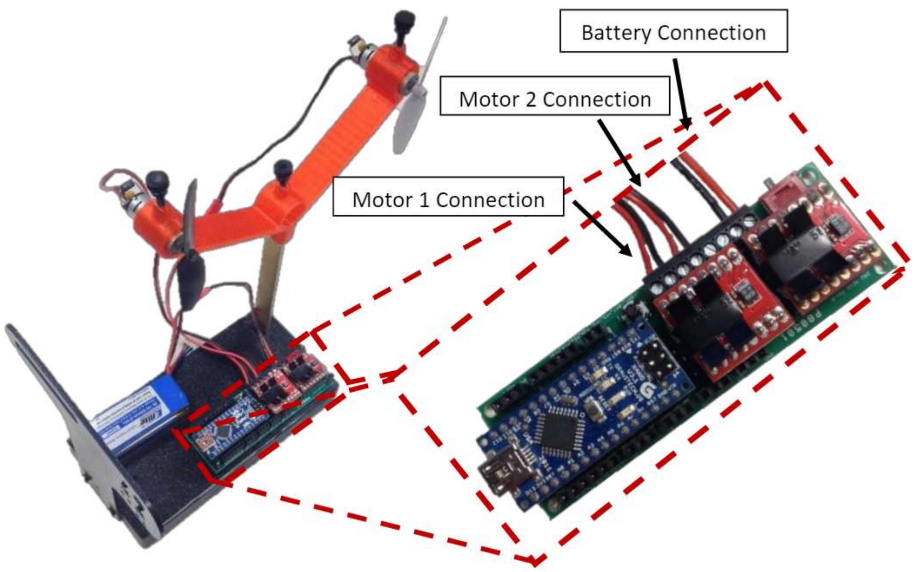

Figure 1:Motor and Arduino Connection

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.

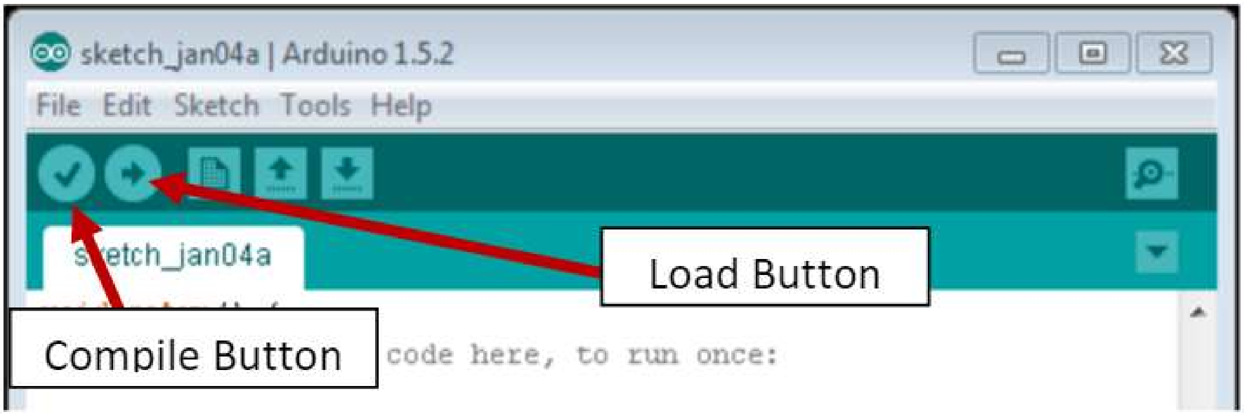

Figure 2: Compile and Load Button in Arduino

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.

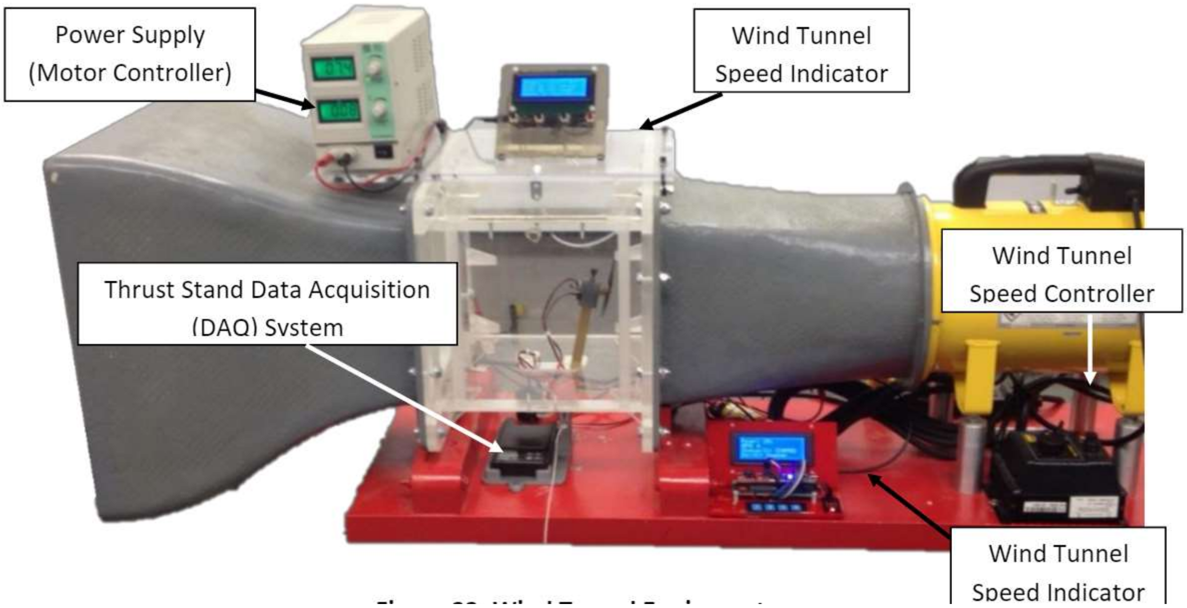

Figure 5: Wind Tunnel Components and Setup

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.

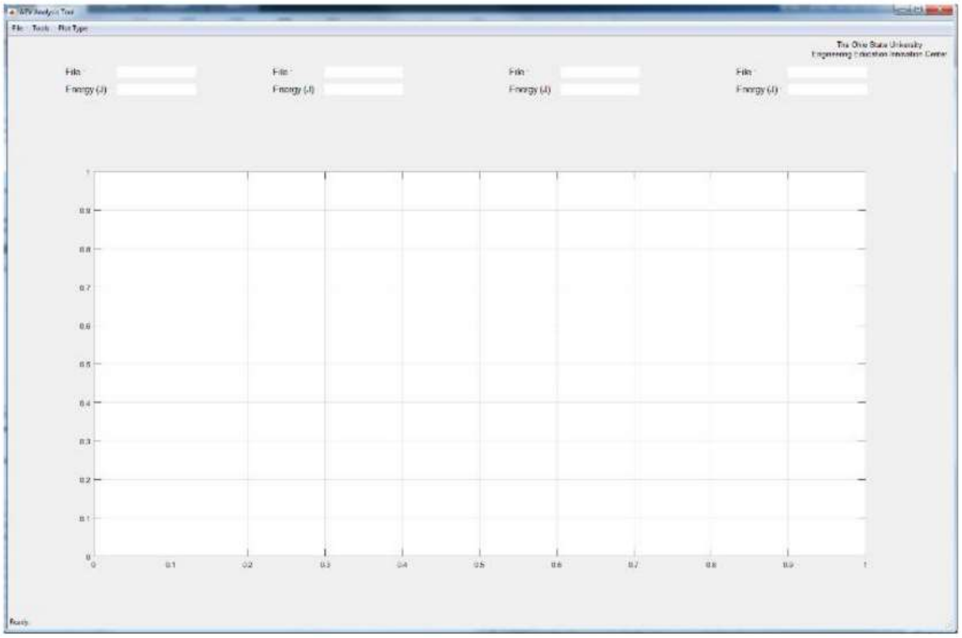

Figure 6: MATLAB Design Analysis Tool

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.

Results

Of the two concepts tested, one design is based around stability and simplicity, while the other focuses primarily on the idea of being as compact as possible. The first design drew inspiration from the sample AEV, but rather than having trapezoidal wings in the back, the wings were moved toward the front of the vehicle, in hopes of improving the overall dynamics of the design. A SolidWorks assembly of this design is located in Figure 1 in the appendix. The second aforementioned design took a brand new approach to the problem - size. The base of the AEV featured one small rectangular piece, which was surrounded by two trapezoidal pieces on both sides. The propellers were mounted on the bottom of the vehicle, while the arduino controller was placed on top. The battery was then taped to the L-shaped support arm, as there was admittedly a noticeable lack of space. This design can be found in Figure 2 in the appendix. Orthographic drawings of both prototypes can be found 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.

Both prototype designs went through the process of concept screening and concept scoring. After being tested with success criteria such as weight, blockage, power consumption and durability, both prototype designs proved to be effective designs, in comparison to both the sample AEV(the reference) and each team member's individual design created for Lab 03, the creative design lab. The concept screening and concept scoring matrices are located below. The first prototype was referred to as Design E, while the second prototype was referred to as Design F.

Table 1: 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 2: 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	

As seen above, the first prototype design was consistent in all assessed categories, while the second prototype design excelled in various categories but suffered in others. Due to its compact nature, the second prototype shone in the weight, cost and power consumption, but did poorly in the durability and blockage category, whereas the first prototype performed neutrally in all the mentioned categories. To further this point, the first prototype had six threes(the middle value) in the concept scoring, while the second prototype had only one. However, both prototypes still scored higher than any of the individual designs, as they both aimed to combine valuable aspects of each design presented. This can be seen in Table 2, where the best two individual designs obtained scores of 2.5 and 2.9, while the first prototype achieved a score of 3.05 and the second a score of 3.1.

The group conducted numerous test runs on Prototype Design 2 with the goal of completing the task of arriving at, and stopping at, the gate. Key to the group's learning was that the AEV will not stop on its own; as the brake command can only cut power to the propeller motors, the AEV simply continues to coast along. The group sought to control this using knowledge gained in previous labs of braking techniques. Slowing the AEV to a stop quickly was possible by reversing the direction of the motors; the force generated in the opposite direction of the AEV's movement caused it to halt. By repeatedly alternating between modifying code slightly and running another test, the team were able to get a better understanding of nature of the real-world effects of the Arduino code. This allowed progressive code optimization which continually improved on the result. As the team were only able to conduct test runs on Prototype Design 2 due to time constraints, direct comparisons between the two designs running the same code cannot be made. However, conclusions can be drawn by examining the results of the tests against previously made observations of the performance of the other design in past labs. One of the most significant differences was to do with the weight difference between the designs. As Prototype 2 was lighter than Prototype 1, it was able to run faster on less energy input. This was noted to be more conducive to the goal stated in the Mission Concept Review of using minimal power. A smaller design also made Prototype 2 more agile at turning corners. The lightness of Prototype 2 also allowed it to build up speed quickly, allowing for it to coast on no power further than Prototype 1 could.

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.

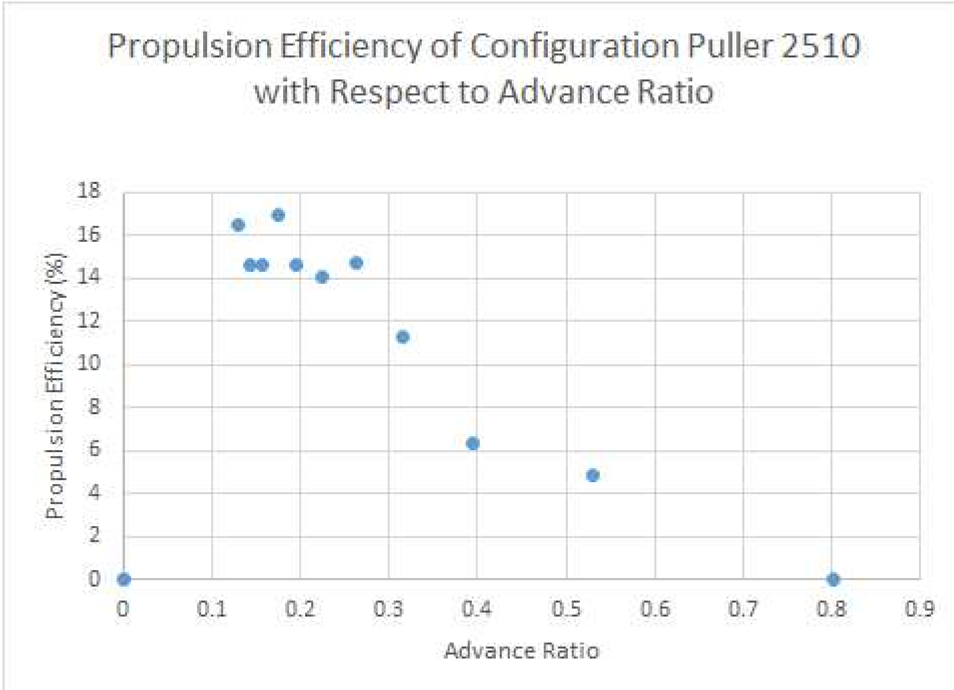

Figure 7: Propulsion Efficiency of Puller 2510 Configuration

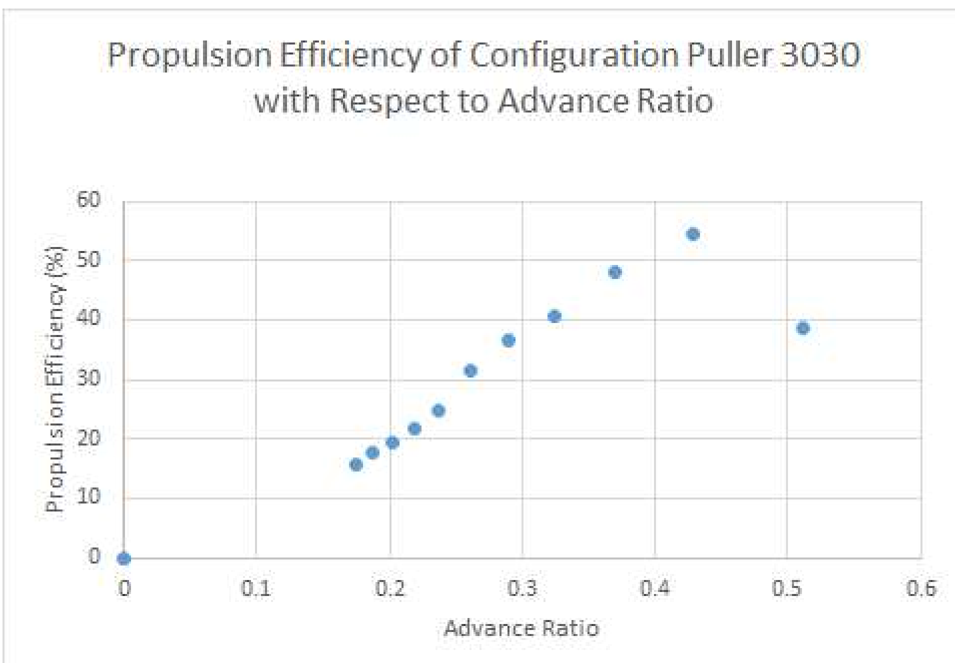

Figure 8: Propulsion Efficiency of Puller 3030 Configuration

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.

Using these skills for data analysis of the two prototype designs, 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.

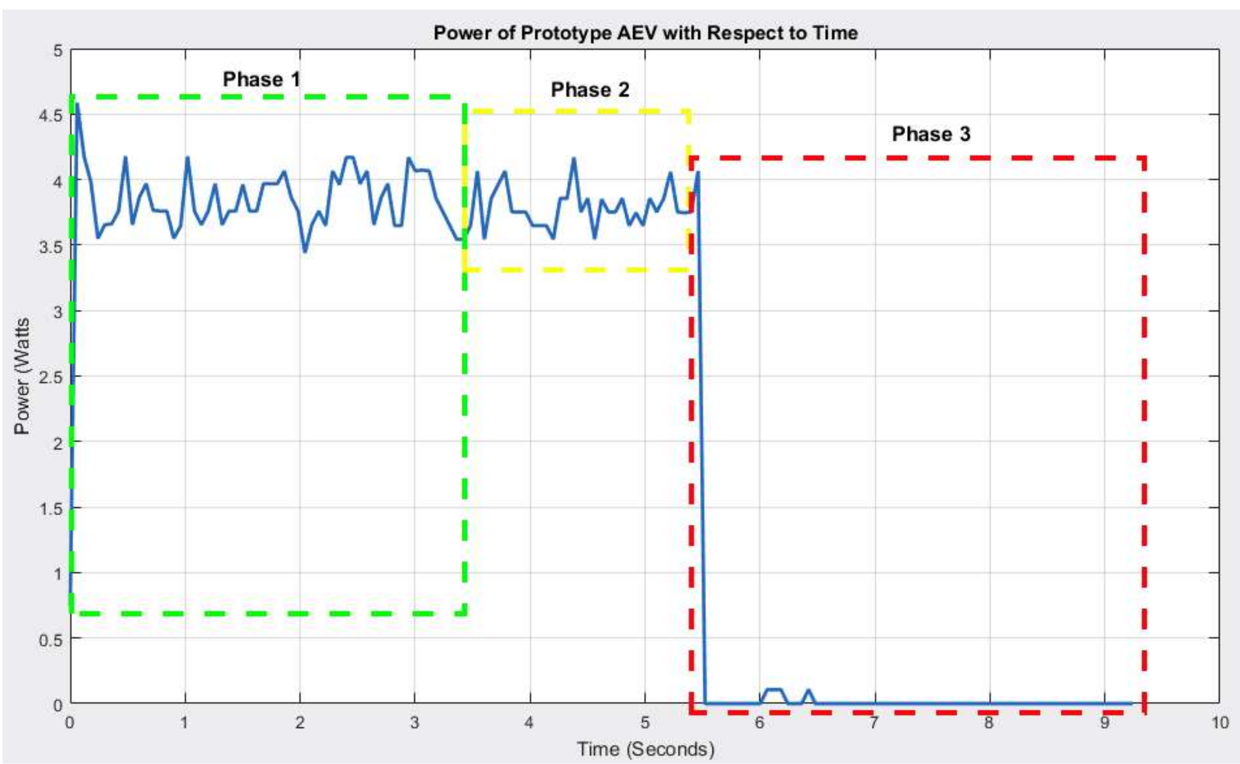

Figure 9: Power vs. Time Phase Analysis of AEV Prototype Design 2

Table 3: 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
		<u>Total Energy Used:</u>	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.

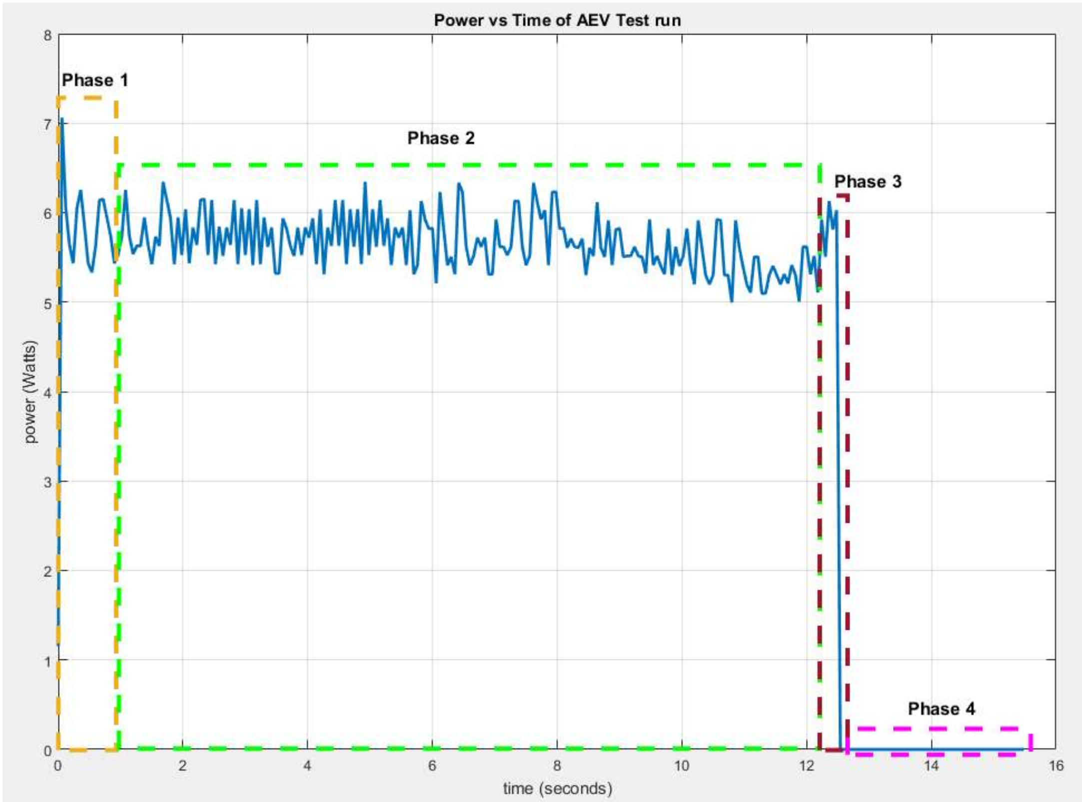

Figure 10: Power vs. Time Phase Analysis of Prior Test Run of Prototype Design 1

Table 4: 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

Conclusion and 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. Overall, Prototype 2's compactness, price, and energy consumption excel in comparison to Prototype 1, and therefore Team J will further develop Prototype 2.

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. Going forward, the primary conclusion the team will draw from this will be to trust the data and consider other faults when the results appear to be drastically different from what the data/code would suggest. In the event of such failures in the future, the team will rely on their knowledge of possible issues obtained through the past lab periods in order to troubleshoot more quickly and move on to completing the actual goal.

Appendix

Table 1: Team J Task Schedule for Performance Test 1

No.	Task	Start	Finish	Due Date	Est Time	Matthew Caldwell	Tarun Pilli	Jacob Phillips	John Kim	Percent Completed
1	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
2	AEV 1 Testing	20-March	21-March	27-March	0.5 h	0.5 h	0.5 h	0.5 h	0.5 h	33
3	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
4	AEV 2 Testing	24-March	24-March	27-March	0.5 h	0.5 h	0.5 h	0.5 h	0.5 h	33
5	Weekly Progress Report for Lab 8	7-March	9-March	10-March	2.0 h	2.0 h	2.0 h	1.0 h		100
6	Solid Works Models	21-March	25-March	27-March	2.0 h		2.0 h			100

7	Preliminary Design Report	21-March	26-March	27-March	7.0 h	6.0 h	6.0 h	1.0 h		100

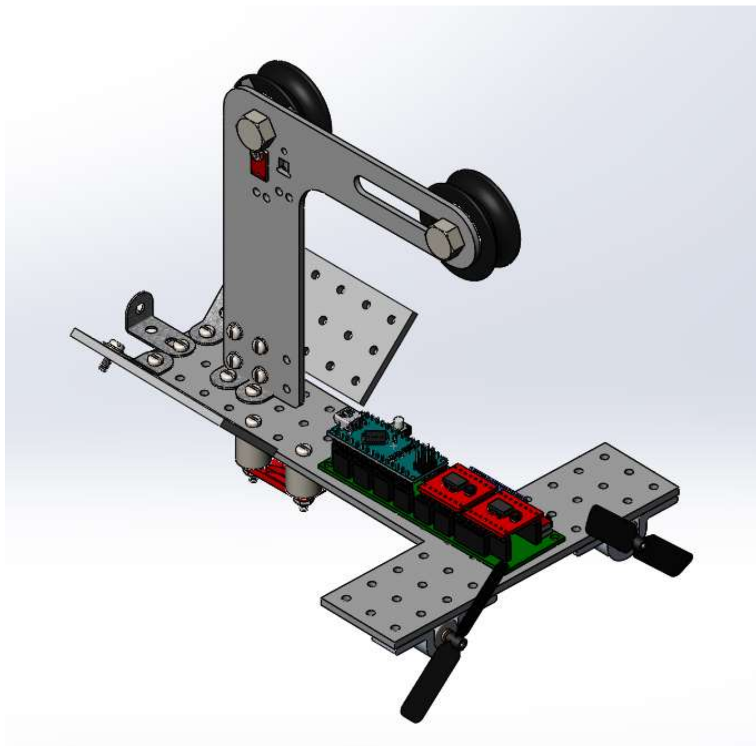

Figure 1: Team J's Prototype Design 1

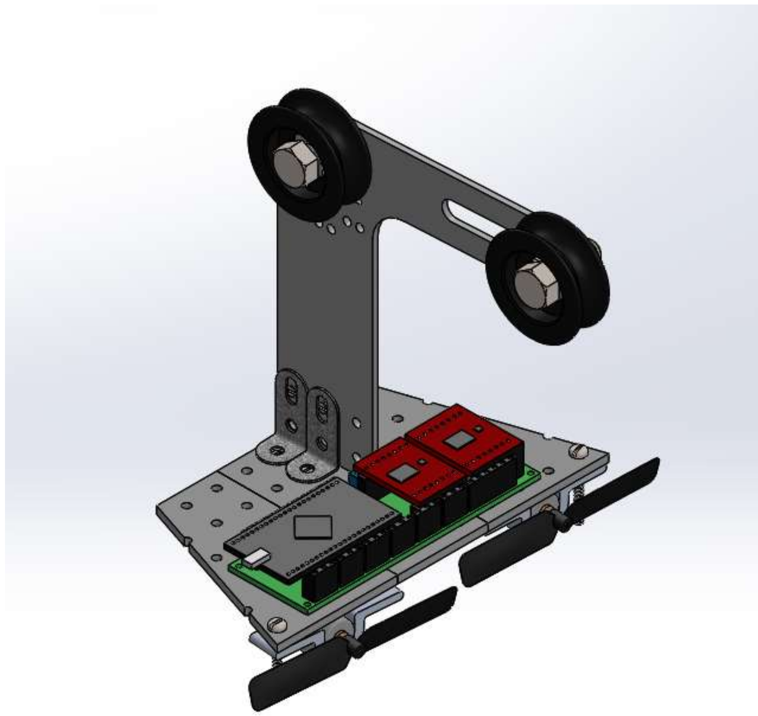

Figure 2: Team J's Prototype Design 2

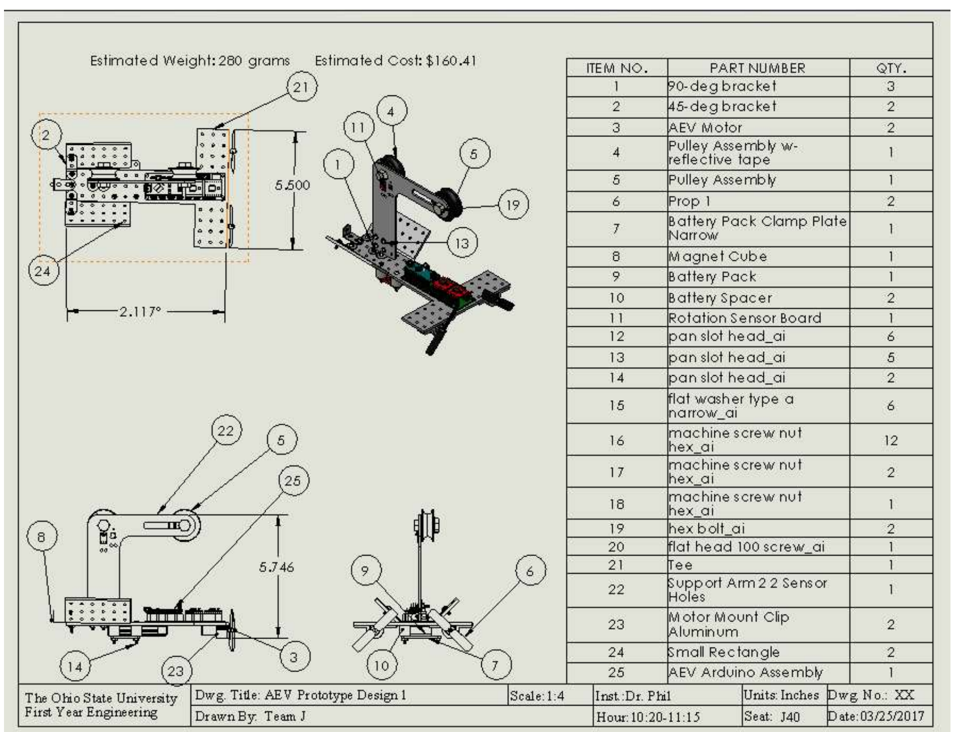

Figure 3: Team J's Prototype Design 1 Drawing

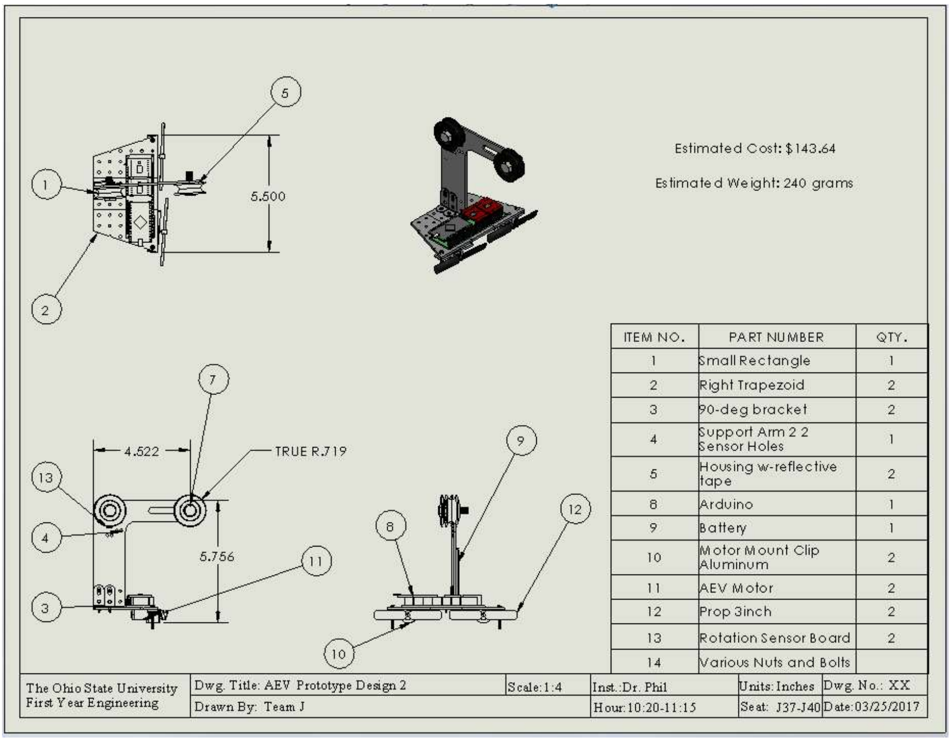

Figure 4: Team J's Prototype Design 2 Drawing

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

ITEM NO.	PART NUMBER	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 2 2 Sensor Holes	$3.00	1	$3.00
24	Motor Mount Clip Aluminum	$.59	2	$1.18
25	Small Rectangle	$1.00	2	$2.00
26	AEV Arduino Assembly	$100.00	1	$100.00

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

ITEM NO.	PART NUMBER	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