Critical Design Review Report

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Executive Summary

The Advance Energy Vehicle (AEV) was created in order to solve the problem presented in the Mission Concept Review (MCR). The goal, as contextualized within the Star Wars universe, was to use the AEV to transport R2-D2 units across a war-torn planet in order to aid the rebel alliance's reconstruction efforts. With energy and money being finite resources, the vehicle had to be created to be cost-effective to build, energy-efficient, and reliable enough to consistently carry out its mission. With this in mind, the team performed tasks ranging from the design, extensive testing, and redesign of the vehicle in order to meet these requirements. The project provided the group with valuable experience in coding, prototype development, and working in a team environment which will be useful in future engineering careers.

To begin the experimental process, initial designs were created by each team member during the first lab so that the group could analyze and select an AEV from a varied range of vehicle types. Out of the five designs, AEV Concept Sketch #4 was chosen. Not only did it fulfill the requirements of being cost effective and energy efficient but it also proved to be quite aesthetically pleasing. Several initial tests were then performed to optimize components of the vehicle- the external tracking sensors were calibrated, the most efficient propeller and propeller configuration was found, and the outline of an Arduino code was produced. During this phase of the project, it was found that the 3020 propeller in the pull configuration was the most energy efficient and therefore this orientation was used when hauling the R2-D2 cargo back to the starting point.

After that, the most comprehensive tests (Performance Tests 1, 2, and 3) were performed. Performance Test 1 was used to compare two different AEV designs against each other to determine which was a more suitable candidate in terms of energy efficiency and performance. Through this test, the team determined that a simpler, flat AEV design was more energy efficient and surprisingly outperformed the winged original design. During Performance Test 2, two different Arduino codes were tested using the newly chosen AEV to determine which commands expended the least energy and performed most consistently. Due to issues with the wheel sensors and time constraints, the team had to combine Performance Test 2 with Performance Test 3. Performance Test 3 was used to complete the full scenario with an energy efficient and consistent AEV. Two codes were written and tested against each other: a code using the "reverse()" and "celerate" commands to reverse thrust break before the gate and a code using a coasting method to slowly stop in front of the gate. The coast-heavy code was found to be more energy efficient simply because the motors weren't constantly in use, however this code had difficulty completing the tasks assigned due to inconsistent mark counting and stopping time. This resulted in the team deciding to use an Arduino code that utilized a combination of coasting and reverse thrust braking to ensure abrupt stops when necessary.

Most of the analysis completed during this project was accomplished through the use of the MATLAB GUI "AEV Analysis Application". For each phase of testing, the group would write their code, test their vehicle, and then proceed to examine the graphs and energy breakdown data provided by the software to make crucial design decisions. Using this advanced research method, the team was ultimately able to construct an AEV that successfully completed the bulk of the tasks outlined in the Mission Concept Review. The design and creation of the AEV demonstrated project management and teamwork, a mastery of the developmental process, and strong project documentation skills that could be applied to the outside world.

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Introduction

The objective of this lab was to complete the final Arduino code used in the AEV's run, make last minute adjustments to the vehicle, and ultimately undergo a final evaluation to see if the AEV successfully completed the Mission Concept Review. This being the last lab of the overall project, the final testing allowed the group to observe the results of their research and analysis over the past few months. This experience was quite valuable, for often in the engineering world professionals will work on a single project for an extended period of time. The culmination of their efforts will only be realized when the final product is completely finished, therefore this lab served as a preview of what the future has in store for the students. The following Critical Design Review Report was created to convey the results of the vehicle's final testing as well as serve as a reflection on the entire design and analysis process. First, the experimental methodology is described to the reader in addition to the specific materials used during the lab. After that, the results of the past few performance tests as well as the results of the final test are presented with their accompanying graphs. The individual conclusions and recommendations drawn by each team member are then presented along with an appendix of additional figures and tables and a list of references.

Experimental Methodology

This lab was conducted using a plethora of equipment including the team's final Advance Energy Vehicle, the aluminum overhead testing track, a micro USB cable, a scale, and a computer running the "AEV Analysis" MATLAB application as well as the Arduino program. On the first day of Lab 11, the team got together and discussed what needed to be completed for the AEV to accomplish the R2-D2 transport mission successfully. As previously discussed in the Preliminary Design Report and past two lab memos, at this stage in the design process the group had already decided upon the final AEV design (Figure A10) and final code (Figure A1) that would best fit the requirements of the objective as well as conserve energy. Therefore, the main goal was to perfect the intricacies of the code and to eradicate any potential issues that could arise during the final run.

The first step in this procedure was to upload the final Arduino code to the AEV. To do so, one student opened the Arduino program on their computer, connected the vehicle to the desktop using a micro USB cable, and subsequently pressed the "Run" button to transfer the user-written code from the computer to the Arduino board on the AEV (Figure 1).

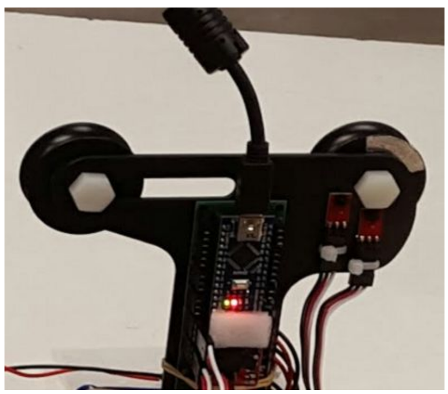


Figure 1: Arduino Program Transfer from Computer to AEV

After this, one group member carried the AEV to the start of the overhead testing track and initiated the run while two other members positioned themselves at strategic locations along the intended route in case of vehicle malfunction. The code was intended to make the AEV travel to the first gate and halt for seven seconds before advancing to the R2-D2 cargo. The vehicle was meant to then pick-up the cargo, return to the first gate, and again halt for seven seconds before returning to the start. A clearer visualization of this route can be seen in the diagram below (Figure 2).

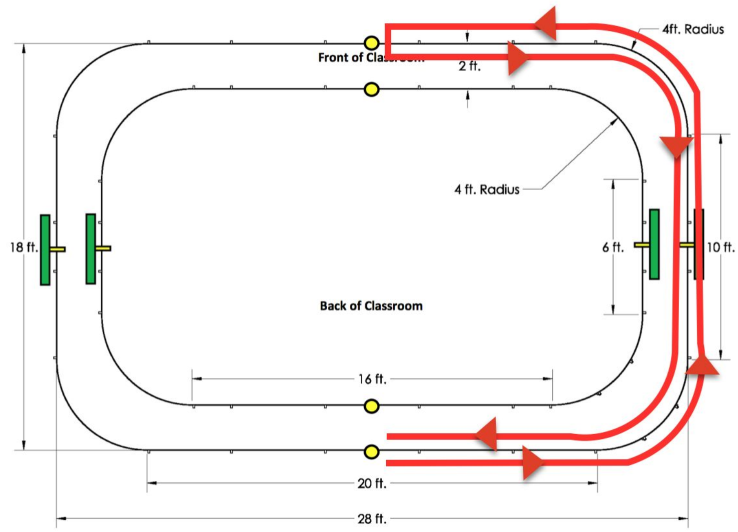


Figure 2: Diagram of Intended AEV Route

After the initial run, the AEV did not perform as intended. It ran into the gate during both phases and stopped too early at various points, therefore the team's next step was to tweak the mark values used in the "goToAbsolutePosition()" and "goToRelativePosition()" commands as well as the time values used in the "goFor()" commands. After the team discussed and agreed upon the changes, the new code was uploaded and the testing process started over again. This was done until the AEV performed all phases of its journey consistently.

On the second day of lab no further was testing was needed for the group had succeeded in perfecting the AEV's run during the previous lab. The third day of lab consisted solely of final testing. When the team was summoned by the teaching assistants, the AEV (equipped with the final code and correct mark/time values) was tested two times on the overhead track as an ultimate evaluation. The better of the two runs was recorded by the grader and then the AEV was once again plugged into the computer via micro USB cable. The EEPROM data collected during the mission was then uploaded into the "AEV Analysis Tool" MATLAB application in order to determine the overall energy usage of the vehicle. This value was recorded by the grader and the mass of the AEV was then found using a gram scale so that it could be factored into the team's final score. A more in-depth look at the scoring/grading requirements can be seen below (Figure 3).

		Run 1			Run 2		
Procedure		Yes	No	PTS Earned	Yes	No	PTS Earned
Team shows proper testing procedure (up to 10 points)				/10			/10
AEV starts and travels to first gate				/4			/4
Gate Routine	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
Gate Routine	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
Total Score = Total Pts Earned * Δt					Max Total Score		

Track Layout: ___________
(Inside or Outside)

Mass of AEV: ___________
(in kilograms)

Total Energy: ___________
(Joules)

Total Time Run1: _________
(seconds)

Total Time Run2: _________
(seconds)

Delta Time Run 1:

$$\Delta t1 = 1 + \frac{150 - \text{total time}}{150}$$

= ________________

Delta Time Run 2:

$$\Delta t2 = 1 + \frac{150 - \text{total time}}{150}$$

= ________________

Energy/Mass: __________
(Joules per kilogram)

Figure 3: AEV Final Test Run Scoring Guidelines

Results

As discussed in previous reports, the physical design of the AEV was tested, evaluated, and altered many times during the experimental process. The design phase began in Lab 1: Creative Design when the team members were tasked with each creating their own concept sketches of an AEV based on the criteria they thought to be most important (Figures A3-A7). From there, the merits of each design were compared and contrasted by the team in order to determine which design to proceed with. These concepts were then compared against one another in the concept scoring and screening matrixes created by the team (Tables 6 and 7). Three of the five concepts were far too ambitious or unreasonable to consider, therefore only concept sketches #2 and #4 were seriously considered. Both AEVs exhibited simple geometry, compact frames, and low masses however the group ultimately decided to proceed with concept #4 due to its aesthetically-pleasing wing features, lower cost, and aerodynamics. This AEV design performed so well in the following labs that the group did not alter it at all between the first lab and Lab 8: Performance Test 1. As a result, the AEV was one of the two prototypes used in PT1 to discern which design elements were most efficient. A picture of this “original” design can be seen below (Figure 4) and more detailed orthographic and bill of materials drawings can be found in Appendix A (Figures A8-A9).

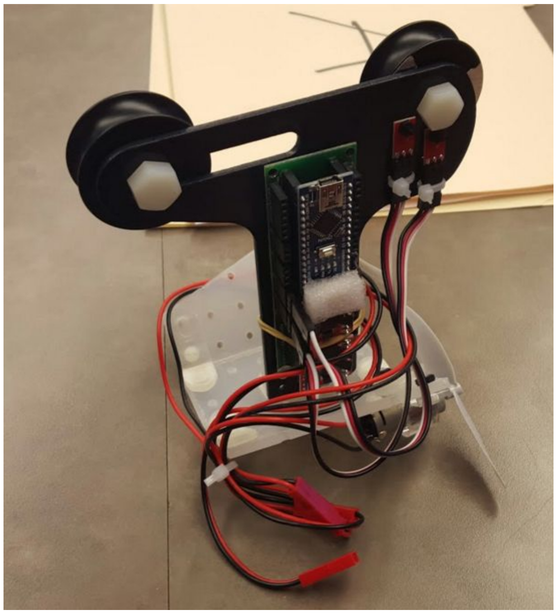


FIgure 4: Photo of Original AEV Design

When creating the design of the second AEV prototype, the team brainstormed areas in which the original concept could be improved. It was determined that although the trapezoidal wings of the vehicle “looked cool”, they simply added additional weight which in turn decreased efficiency. The group also decided to increase the lateral distance between the propellers on this new design to see if that aspect had any effect on efficiency. Consequently, the new AEV design's body consisted simply of a single horizontal rectangular piece. Due to a variety of reasons, this newer design was chosen for the final test run over the original design. Most of these reasons will be discussed below, however one of the main reasons for this decision was cost. The original design cost approximately $176, however the group realized that they could easily trim this cost using the newer design. The lack of wing pieces and additional brackets and screws needed to attach said pieces resulted in a reduced cost of $159, a much more attractive price range. A photo of the final design can be seen below (Figure 5) and more detailed orthographic and bill of materials drawings can be found in Appendix A (Figures A10-A11).

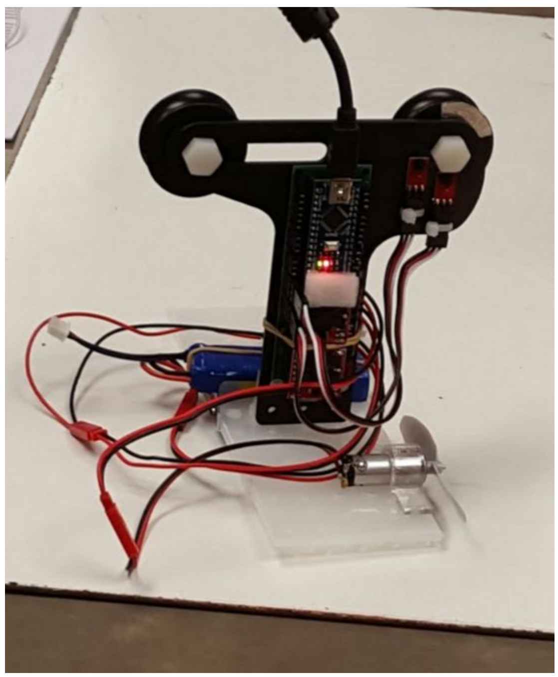


Figure 5: Photo of Final AEV Design

After completing Performance Test 1 in which two different designs were tested, it became clear that the simple, flat design was more efficient than the original design chosen by the team. Shown in Figure 6 and Tables 1 and 2 below, the simple AEV design used less energy than the original design (72.763 J compared to 73.732 J). In addition, the simple AEV design travelled a further distance than the original while using the same Arduino code. This was quite a surprise to the team, for they expected the original design's aerodynamics to give it a competitive edge. Nonetheless the data caused the team to reevaluate the design of the AEV,
who ultimately decided to proceed with the simple, flat design. This allowed the team to use less energy in order to complete the assigned tasks.

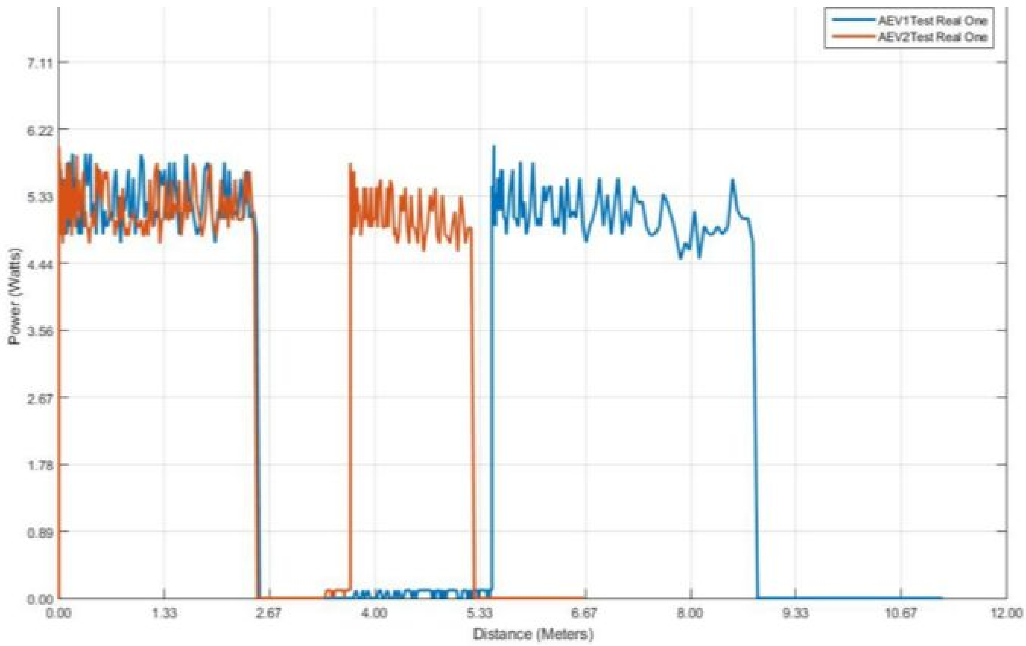


Figure 6: Plot of Power vs Distance for Two AEV Prototypes

Table 1: Phase Energy Breakdown Data for Newer (Final) AEV Design

Phase	Arduino Code	Distance (m)	Time (s)	Total Energy (J)
1	reverse(4)	0	0.2	5.29
2	motorSpeed(4,20)	2.52	10.33	35.245
3	reverse(4)	2.7	0.2	5.29
4	motorSpeed(4,20)	3.56	6.12	26.429
5	brake(4)	2.5	0.2	0.508
Total (J)	72.762			

Table 2: Phase Energy Breakdown Data for Original AEV Design

Phase	Arduino Code	Distance (m)	Time (s)	Total Energy (J)
1	reverse(4)	0	0.2	5.29
2	motorSpeed(4,20)	2.52	9.52	35.245
3	reverse(4)	1	0.2	5.29
4	motorSpeed(4,20)	1.4	6.04	27.445
5	brake(4)	2	0.2	0.462
Total (J)	73.732			

To determine the configuration of the propellers, the team participated in a lab in which different propeller sizes and orientations were tested. The wind tunnel data was collected from each group and sent out to the class and by analyzing the Excel spreadsheets the team determined that the 3020 Puller propeller configuration was the most efficient. The configuration data is included below (Figure 7). This knowledge was used in the design process as the team chose the 3020 propeller blade and decided to run the AEV with both propellers in push configuration on the way to the cargo. On the way back to the starting position the team thought the added efficiency of the puller configuration could help offset the added weight of towing the cargo.

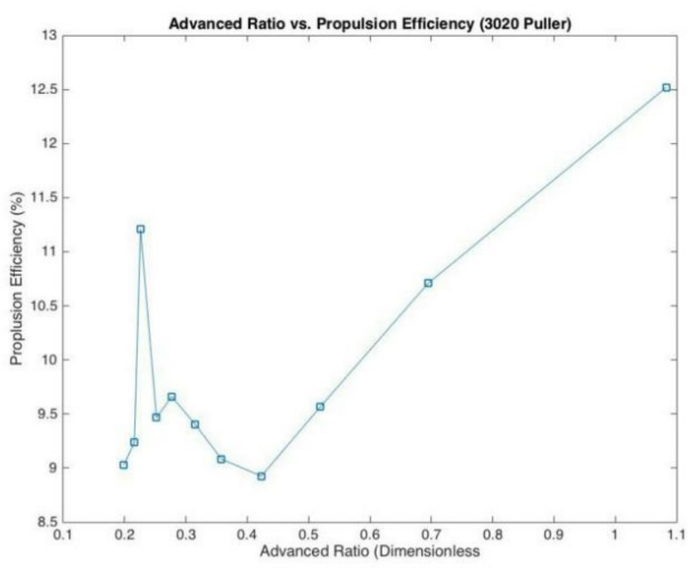


Figure 7: Propulsion Efficiency vs Advance Ratio for 3 Inch Puller Propeller

During Performance Test 2, the team encountered issues with the wheel sensors that caused a delay. For some unknown reason the mark readings that the wheels were producing were wildly inconsistent, causing the group to have to recalibrate them multiple times per lab. Because of this, Performance Tests 2 and 3 were combined into one test. In this lab, two competing Arduino codes were written in order to test the energy efficiency of different function calls. The first code (Figure A2) relied heavily on coasting to the gate and cargo in an attempt to use as little energy as possible by timing up when to break the AEV for a smooth, calculated approach. The second created code (Figure A3) heavily utilized the "reverse()" command in conjunction with the "celerate()" command in order to implement a sort of reverse-thrust braking system so that the AEV could stop more consistently. In code 1 there was a low total energy usage of 285 J as can be seen in Table 3. This value was much more appealing than the energy usage of 378 J in code 2, shown in Table 4 below.

Table 3: Energy Breakdown Test Code 1

Phase	Arduino Code	Time (s)	Total Energy (J)
1	celerate(4,0,23,2)	2	3.1178
2	motorSpeed(4,23)	5.52	32.9382
3	celerate(4,23,0,5)	5	28.4128
4	brake(4)	7	7.21
5	motorSpeed(4,23)	11.5	27.1768
6	brake(4)	10	0.0921
7	celerate(4,0,35,2)	2	6.194
8	motorSpeed(4,35)	7.4	68.4441
9	brake(4)	8	0.8979
10	celerate(4,0,35,2)	2	5.1353
11	motorSpeed(4,35)	9.06	83.9184
12	brake(4)	2.4	0
		Total Energy:	285.6431 J

Table 4: Energy Breakdown Test Code 2

Phase	Arduino Code	Time (s)	Total Energy (J)
1	celerate(4,0,30,2)	2	6.1266
2	motorSpeed(4,30)	6.2	46.3247
3	motorSpeed(4,30)	2.2	17.3141
4	brake(4)	9	1.1247
5	motorSpeed(4,30)	4.9	52.9853
6	motorSpeed(4,30)	2.1	39.6999
7	brake(4)	7	0.6785
8	celerate(4,0,45,2)	2	26.5853
9	motorSpeed(4,45)	2.7	41.4558
10	motorSpeed(4,45)	2	25.8743
11	brake(4)	8	0
12	celerate(4,0,45,2)	2	25.1071
13	motorSpeed(4,45)	2.8	45.66
14	motorSpeed(4,45)	2.7	49.0976
15	brake(4)	2	0
	Total Energy:		378.0339

Figure 8 below is a graphical representation of code one. By examining the plot and comparing it to the phase graph of code 2 (Figure 9), it can be seen that code one was quite consistent in energy usage with no dramatic spikes as opposed to code two which had four major spikes in energy usage. These spikes can be attributed to the use of the "reverse()" and "celerate()" commands to stop the AEV on its journey. This phenomenon can also be observed in lines 2,6,10, and 14 of Table 4. Another factor in the higher energy usage of code 2 can be attributed to a ten percent increase in the motor speed. These changes added up to a 100 J addition in energy usage compared to code one, however there was one important attribute of code 2 that code 1 did not possess: consistency. Due to the coast-heavy commands utilized in code 1, the stopping distances of the AEV would vary wildly between runs and therefore it was almost impossible to pinpoint what mark values to use in the program. Thanks to the abrupt halts present in code 2, the AEV stopped at the correct distance from the gate every time without issue. As a result, the group agreed to incorporate the pertinent parts of both codes into their final code.

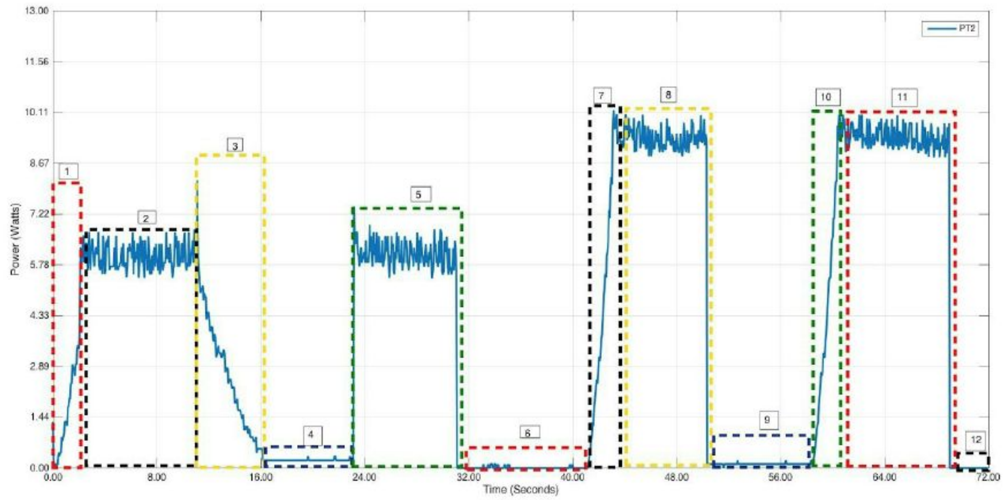


Figure 8: Graph of AEV Power vs. Time with Phase Divisions for Test Code #1

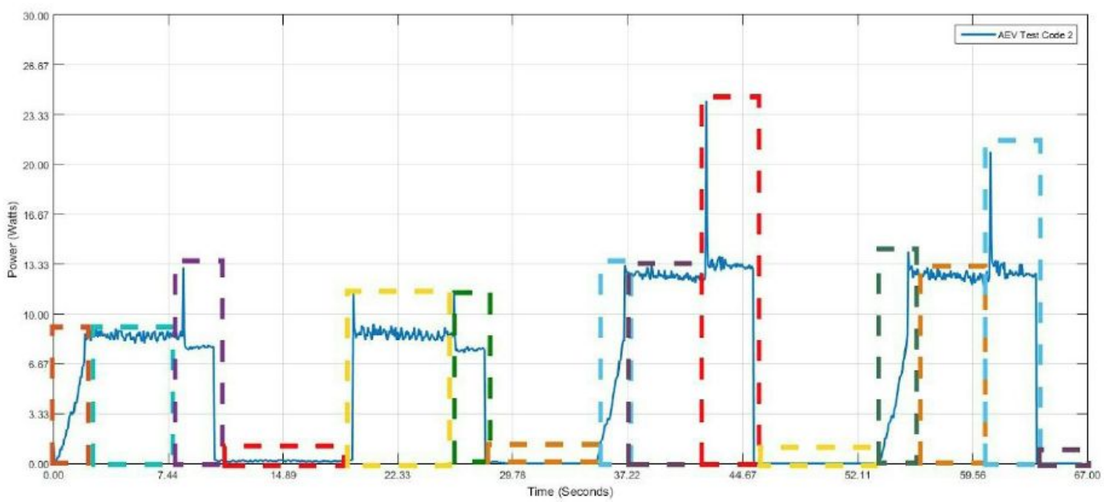


Figure 9: Graph of AEV Power vs. Time with Phase Divisions for Test Code #2

After examining the results of the previous labs, the team took pieces of each code to create the final code (Figure A2). This code was largely based off of code 1 but also implemented a motor reverse brake to provide greater stopping control of the AEV. Because this code still relied on coasting, it meant that a lot of daily mark value tweaking was required- something the final code was meant to cut down on. However, the increased efficiency of this method greatly outweighed the inconvenience. The reverse braking helped create a more consistently performing code, yet not a perfectly consistent one. The AEV was able to correctly proceed to the cargo, but was not able to stop at the gate in time on the return trip- therefore the team had to increase the acceleration of the strong reverse brake, consuming a massive amount of energy. This occurrence can be seen in the graph (Figure 10) and table (Table 5) below in phase nine. As one can see, the final test code was only 3 J more efficient than code 1 and took six seconds longer.

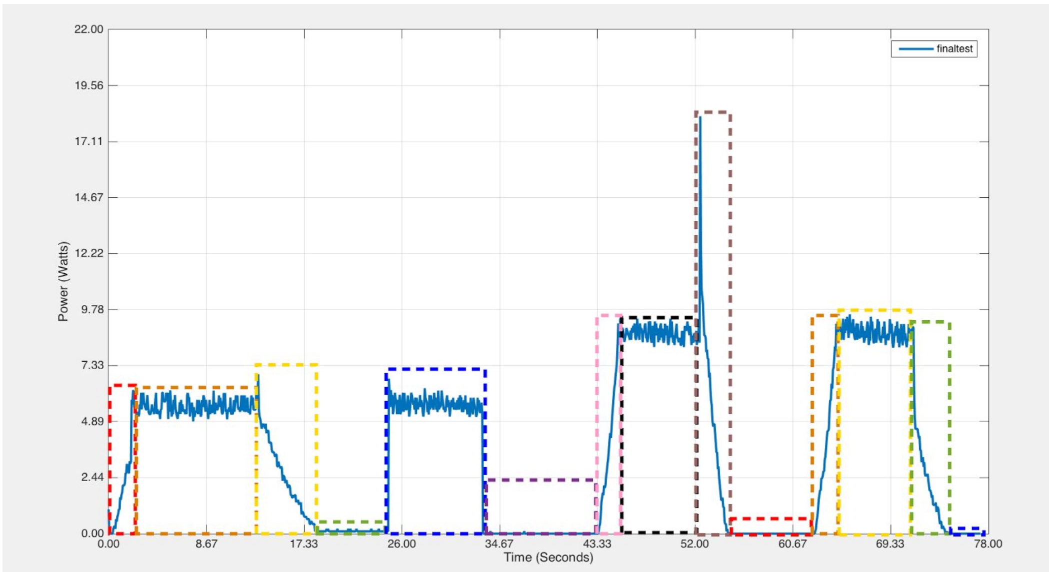


Figure 10: Graph of AEV Power vs. Time with Phase

Table 5: Energy Breakdown Final Code

Phase	Arduino Code	Time (s)	Total Energy (J)
1	celerate(4,0,23,2)	2	3.0162
2	motorSpeed(4,23)	11.2	60.873
3	celerate(4,23,0,5)	5	12.7934
4	brake(4)	6.5	0
5	motorSpeed(4,23)	8.6	46.9838
6	brake(4)	10	0
7	celerate(4,0,35,2)	2	8.8062
8	motorSpeed(4,35)	7	59.8448
9	celerate(4,40,0,2.5)	2.5	15.7188
10	brake(4)	7.5	0
11	celerate(4,0,40,2)	2	7.3809
12	motorSpeed(4,35)	6.8	59.9779
13	celerate(4,23,0,3)	3	6.606
14	brake(4)	3	0
		Total Energy (J):	282.001

Discussion

Over the course of the design process a few trends were noticed, one being that controlling the AEV to stop precisely and accurately was very difficult to do. This was the main problem with the team's first code, for the use of coasting made the AEV very inconsistent with any variance in battery level or track. While testing, the team experimented in using a brake to stop the AEV by reversing the motors and applying a burst for a short amount of time. This proved more effective in stopping, but was not as reliable as desired as it still relied upon the power level of the battery to apply the burst. This is a trend the team should have made note of early on in an effort to seek an alternate method of stopping, but did nothing to solve and elected to continue with the use of the motor brake. In hindsight, perhaps a servo motor braking method utilized by some other teams should have been implemented, yet the team justified continuing with the less reliable method because it conserved time. By the time these issues became glaringly apparent, the team had only two labs left- not enough time to dramatically overhaul the design of the AEV or to restructure the code.

Potential sources of error were heavily prevalent throughout the design and testing process, the biggest being the sheer lack of knowledge the team had going into the AEV project. This resulted in the team trying to put together designs that would be easy to draw and that looked cool rather than those that would logically be efficient and be able to complete the mission. As a result, potential error during the initial design selection was present as the team made up what factors were most important to them, putting no thought into which aspects may actually prove most important. Another source of error could be the propeller efficiency testing. During the oral presentation process the team noticed there was variance between groups in what propeller was more efficient. The team chose the 3020 propeller, but this decision could have been falsely assumed to be the most efficient design through incorrectly collected data or poor data analysis. Yet another potential source of error in this process was the performance tests. During the course of the testing process the team could have mixed up the two codes that were used as well as the final code. This could have resulted in the team using a code that was not intended to be used and the team could have analysed the efficiency of these codes improperly as well.

The team used screening and scoring matrices to ultimately decide which design to continue with, resulting in the simplistic, flat, final design being used. As one can see in the screening matrix below (Table 6), the final design received a net score of 3 which was greater than or equal to the 7 other designs considered and it excelled in form factor, low mass, and sleek aesthetics.

Table 6: Design Screening Matrix

Success Criteria	Reference	AEV Concept Sketch 0	AEV Concept Sketch 1	AEV Concept Sketch 2	AEV Concept Sketch 3	AEV Concept Sketch 4	Final Design	Competing Design
Form Factor	0	+	-	+	-	+	+	+
Mass	0	+	-	+	-	+	+	+
Aerodynamics	0	0	0	0	0	0	0	+
Durability	0	0	0	0	0	0	0	0
Center-of-gravity	0	-	+	+	+	+	+	+
Payload towing capacity	0	-	+	-	+	-	-	-
Aesthetics	0	-	0	0	+	+	+	0
Sum +'s	0	2	2	3	3	4	4	4
Sum 0's	7	2	3	3	2	2	2	2
Sum -'s	0	3	2	1	2	1	1	1
Net Score	0	-1	0	2	1	3	3	3
Continue?	No	No	No	No	No	No	Yes	No

The final design also scored the highest in the concept scoring matrix (Table 7) receiving a score of 3.9. The other prototype tested in Performance Test 1 received a score of 3.75 and the other concepts all scored much lower. Again, the vehicle's form factor, mass, and visual appeal helped to distinguish it from the others. The final design's dominance of these matrices helped the team decide to use it in their final testing.

Table 7: Design Scoring Matrix

		Reference		AEV Sketch 0		AEV Sketch 1		AEV Sketch 2		AEV Sketch 3		AEV Sketch 4		Final Design		Competing Design	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Form Factor	20%	2	0.4	3	0.6	1	0.2	4	0.8	1	0.2	5	1	5	1	5	1
Mass	20%	2	0.4	3	0.6	1	0.2	4	0.8	1	0.2	5	1	5	1	5	1
Aerodynamics	10%	3	0.3	3	0.3	3	0.3	3	0.3	3	0.3	3	0.3	3	0.4	4	0.3
Durability	5%	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15	3	0.15	3	0.2	4	0.15
Center-of-gravity	20%	3	0.6	2	0.4	4	0.8	4	0.8	4	0.8	4	0.8	4	0.8	4	0.8
Payload towing capacity	20%	3	0.6	2	0.4	4	0.8	2	0.4	4	0.8	2	0.4	2	0.4	2	0.4
Aesthetics	5%	2	0.1	2	0.1	2	0.1	2	0.1	3	0.15	2	0.1	2	0.1	2	0.1
Total Score			2.55		2.55		2.55		3.35		2.6		3.75		3.9		3.75
Continue?			No		No		No		No		No		No		Yes		No

Although the matrices suggested the team made the correct decision, upon reexamining the data there was not a reasonable amount of evidence or justification to have used the design the team chose as the final design. The design lacked a proper method of braking, resulting in a lot of lost time to tweaking the mark values of a code that could not do what the team wanted because of the limitations of the batteries and tracks. Instead, the team should have made a design that had a physical brake to stop consistently. The defense the team had for their design before these realizations however were that it was light, easy to build, used the more efficient puller configuration when towing, and that it was simple. As seen in the data collected during Performance Test 1 (Tables 1 and 2), the light and simple mentality of the design was effective in that this AEV traveled further than the AEV it competed against while still using less energy. Being easy to build cannot be backed up by any data, but having to transport the AEV in a tiny box meant that less time was spent on having to reassemble the AEV each lab which was a huge positive as the team could instantly jump into testing. Using the puller configuration for towing was not by itself a differentiating factor but the efficiency of the overall design (as seen in PT1) working together with the added efficiency of the puller design resulted in a harmonistic partnership.

During the final run the team made several notable observations about the AEV. One observation was that although the team did all they could to perfect their code, the AEV still could not fully complete the MCR. The vehicle would have crashed into the gate on the return trip and into the finish line had a team member not interfered. This was due to the inconsistent braking methods mentioned above as well as the time constraint in developing the code. Because of these issues, the group received a run score of 42/50. Another observation made during the run was that elapsed time factored into the calculation of the overall AEV score. Initially the team thought that time was a non-factor and that a low motor power level would be the most efficient way of completing the mission, however after testing the team learned this was not true. The AEV proved to be the slowest in the class with a time of 73.15 seconds- obviously hurting the group's score. Another observation the team made during final testing was that the methods it used for braking were poor and that it should have seeked out a more effective way of braking, such as using a servo motor brake. The reverse motor braking consumed high amounts of energy and yet still proved unreliable resulting in an energy usage of 282.011 J, one of the higher values in the class. The mass of the AEV was also a disappointment because the group's goal was to make the AEV as light as possible however it barely weighed less than other teams' at 237 g. Overall, the team received a total score of 63.52 which was less than stellar. The final scoring sheet in Appendix A (Figure A12) gives more details on the run.

Conclusion and Recommendations - Bryan

In this lab, the mark values used in the "goToAbsolutePosition()", "goToRelativePosition()", and "goFor()" commands of the Arduino code were tweaked in order to optimize the program for final testing. The code was then uploaded to the AEV and two runs were conducted in order for the team to receive a total score for their vehicle. The AEV did not perform nearly as well as expected, for it had to be helped along its path two separate times resulting in a loss of 8 points from the run score (Figure A12). The AEV also used a high amount of energy (282 J) and took 73 seconds to complete its run which proved to be quite mediocre in comparison to the other groups' values. In fact, the overall score of 63.52 was disappointingly the worst score of any AEV in the class. The team completed the run, however it would have been incomplete without user interference. The code frankly proved too inconsistent to be viable because it relied too heavily on coasting and not on a physical braking method. The team ran out of time too quickly to adequately address this issue, and therefore had to present an inferior product. If the team had sat down and truly thought out all phases of the design process and final requirements before beginning, the performance of the vehicle would likely have improved.

In hindsight, the potential errors mentioned in the discussion section of this report could have been resolved for the most part if the group had noticed them earlier. The first error, the fact that the team did not know what they were doing when creating initial designs, could have been resolved in a few separate ways. The group could have either asked the professor for help in getting started, researched similar vehicles online to gain ideas, or perhaps even questioned past students on their design strategies. To combat the issue of possible propeller configuration misinformation, the team should have gone back over the advanced ratio propeller data to ensure the 3020 puller orientation was indeed the most efficient. Finally, to resolve the error of mixing up the three codes, the team could have simply labeled the programs better or perhaps saved all three in separate locations so that it would be impossible to confuse them.

All in all, if this lab could be done over again it would be recommended that the team use a servo motor with a physical brake to ensure consistency. Nonetheless, this entire process provided the team with many valuable experiences. The extensive coding, technical writing, and cooperation that the AEV project required proved to be quite helpful in developing essential engineering skills. The prototype development and analysis were also a welcome break from the monotony of normal class and served as engaging ways to keep the team interested in the task at hand. Although the performance of the AEV was disappointing, the experience was not.

Conclusion and Recommendations - Nick

The Advanced Energy Vehicle project required many numerous testing phases and redesigns in order to successfully complete the goals laid out in the MCR. Many of the performance tests that were done in the process of getting to the final run showed gradual improvement over time, such as with the changes made in the redesign (Figure 6). In the end, the improvements, while great, still didn't quite reached the level of efficiency and dependability that was hoped for initially at the start of this project. On top of the code itself having questionable reliability, the results of the final test run (with 282 J used over 73 seconds) was less than stellar compared to many other vehicles doing the same task.

The final design of the AEV did not initially appear to be the most ideal design of the two main designs created, and despite having numerous problems with using it in the final run, the straight base design still proved to be the most energy efficient and more reliable one to work with. It still, however, had its faults, from the lack of a proper braking mechanism to still not being the most efficient design when compared to many of the other vehicles that were created for this lab. Other non-design related factors, such as the unreliability of the batteries used to the constricting way the code itself was written, resulted in further hurdles that had to be overcome in order to see this project to the end. Despite its faults in performance, the team's AEV design still has an edge on many other designs in terms of weight and cost of the components used, so it can definitely be considered as a cheaper alternative to other vehicles performing the same task.

It is recommended, then, that future teams looking to tackle this project perhaps take into consideration aspects such as the variety of designs and code they will create to the quality of components that they will use. The team's final run could have proved more successful if the vehicle itself could have gone through a few more design iterations to find the right balance of control to efficiency. This goes the same for the code, where a rigorous performance test of the code as well as more versions of the code to experiment with reversing motors to brake versus allowing the vehicle to cost would have led to a more satisfactory final run. The quality of the parts used also has a big impact on the results of the runs. In particular, problems with the batteries losing charge and thus causing inconsistent runs was one of the bigger challenges faced with completing this project. If teams have the means to use higher capacity batteries for their vehicles, it is strongly recommended that they do so for that reason.

Conclusion and Recommendations - Tyler

The AEV design process began with the creation of five individual AEV concept drawings proposed by each the team members. A series of design matrices were used to evaluate the strengths and weaknesses of each design compared to one another. After the final design was chosen it was then tested against the second runner up AEV design. The best of the two AEVs would be used to test two different codes. Using the same AEV, two different codes were designed and used to complete the MCR. The AEV ran several trial with either code and then using analysis software the the energy efficiency of the codes was compared and used for the final run of the AEV.

The important takeaways from the AEV design project were the skills of basic prototyping. From design concept to a physical prototype there were many challenges met and lessons learned. The use of matrices to compare designs as well as the multiple performance tests gave insight to the real world applications of prototyping and design selection. One of the most important takeaways in terms of strictly AEV designs is that the puller configuration of the 3020 prop was by far the most efficient. Another important discovery was that the use of a servo based brake would dramatically increase the level of accuracy of the AEV’s trial runs. Finally the size of the AEV was to some extent irrelevant as the parts required for most designs were extremely close to one another in terms of mass.

Final analysis of the final AEV run data show that the teams AEV was not among the top in terms of efficiency. The design was lightweight, compact, and utilized some methods for efficiency, however the time of the runs was far longer than most other AEVs. This is due to the coasting approach and low motor power. The time element was not included as a large factor in the design process and it was reasoned that the lower the motor power the more efficient the design would become. This hypothesis was incorrect and it has shown that even a high motor power burst over a very short amount of time proved more efficient.

The obstacles faced in the AEV project could have been better met with a more accurately coordinated approach as opposed to the test and observe approach that was adopted. Because of time constraints and crowded lab testing space, the methodical design approach was hindered by rushed deadlines and requirements for completing the various lab assignments. A recommendation for future sections would be to utilize more time during the SolidWorks section of class. This would allow more meaningful development time and reduce the likelihood of a guess and go approach when producing the final aspects of the AEV.

Conclusion and Recommendations - Jordan

The team began the process of designing an AEV by sketching potential designs. After this the designs were scored against one another and a final design candidate was chosen. This design was perfected over the following labs and then ultimately pitted against another design in PT1. After PT1 a new design was chosen, and the team then worked on two competing codes. A final code was decided upon and then the team performed the final test.

Through completion of this lab the team gained valuable knowledge on the process of designing and testing several different designs. The team learned screening and scoring matrices, how to analyze data, how to efficiently analyze data, and how to be critical of even the seemingly best design. An important takeaway from this process were the 3020 puller configuration being the most efficient motor design. Another important concept was that AEVs need a physical brake to stop effectively as coasting and reverse motor braking are not reliable methods of stopping.

Upon completing final testing and receiving the data from each group, the team's AEV is in no way the best design in the class. In fact it was actually the worst in the class. This is because of the slow run speed, resulting in a long run time and low efficiency. Good aspects of the design however are the simplicity of the design as many groups had designs with unnecessary components. The simplicity of the team's AEV meant no time was spent reconstructing every class, it was easy to transport, and had a low component cost.

The team could have resolved these sources of error by putting in more effort towards the project as a whole. With regards to the code problem, there could have been better naming conventions and organization. The interpretation of data is a problem that could be fixed by developing a better understanding of the data.

In the future implementations of this class, there should be a weighing of the importance and time of each lab. This is because there were many early lab days that saw the team working for about ten minutes and then being done, but towards the end the team did not have enough time with testing on the track. Perhaps some of the shorter labs could be combined in an effort to give more time later for testing on the track. Also maybe there could be a lab dedicated to stopping because most teams had no ability to reliably stop. This lab could highlight the importance of such a feature.

The team was not able to complete the final run without touching the vehicle once at the gate because it had not come up with a reliable stopping method, causing the AEV to either roll through the second gate sensor or come up short to the gate.

Conclusion and Recommendations - Brad

The objective of the AEV design project was to develop an Advance Energy Vehicle that would complete the tasks outlined in the MCR. The project consisted of extensive designing, testing, and analysis. The team began by developing several design concepts, and testing and analyzing each to determine one concept to proceed with. Then extensive testing was done to determine whether the design chosen was energy efficient and performed consistently. This was done through Performance Tests 1, 2, and 3. During these tests, the team decided to change our design and proceed with a much simpler design. The final design consisted of a flat, simple base that was lightweight and energy efficient. This design proved to be cost efficient, easy to build, and energy efficient. These attributes are very important when designing a vehicle with limited resources and on a budget. While there were many positive traits to the team's AEV, there were things that could've been done in order to improve the AEV further. A servo brake could have been used to more accurately stop when needed. Also, a more efficient would have been developed if given more time to test. Ultimately, however, the team developed many important skills through this project, including project management and teamwork, using the design process, and project documentation.

Appendix A

Table A1: Group A Complete AEV Project Schedule

Task	Start Date	Due Date	Nick B Responsibility	Bryan C Responsibility	Tyler S Responsibility	Jordan S Responsibility	Brad S Responsibility	Time (hours)	% Completed
Executive Summary 1	9/8/2015	9/15/2015	20%, write intro	20%, write body paragraph	20%, write body paragraph	20%, conclusion	20%, appendix/references	3	100%
Executive Summary 2	9/15/2015	9/22/2015	20%, write body paragraph	20%, write intro	20%, write body paragraph	20%, appendix/references	20%, conclusion	2	100%
Executive Summary 3	9/22/2015	9/29/2015	20%, write body paragraph	20%, conclusion	20%, write intro	20%, write body paragraph	20%, appendix/references	3.5	100%
Executive Summary 4	9/29/2015	10/6/2015	20%, conclusion	20%, write body paragraph	20%, write body paragraph	20%, write intro	20%, appendix/references	2.5	100%
Executive Summary 5	10/6/2015	10/13/2015	20%, conclusion	20%, write body paragraph	20%, appendix/references	20%, write body paragraph	20%, write intro	2	100%
Executive Summary 6	10/13/2015	10/20/2015	20%, write intro	20%, conclusion	20%, appendix/references	20%, write body paragraph	20%, write body paragraph	3	100%
AEV 1 Design/Construction	9/8/2015	10/27/2015	20%, brainstorm ideas	20%, brainstorm ideas	20%, brainstorm ideas	20%, construct AEV	20%, brainstorm ideas	2	100%
AEV 1 Test	10/27/2015	10/27/2015	0%	50%, test AEV on track	50%, catch AEV at gate	0%	0%	3	100%
AEV 2 Design/Construction	10/27/2015	10/27/2015	20%, brainstorm ideas	20%, brainstorm ideas	20%, brainstorm ideas	20%, construct AEV	20%, brainstorm ideas	2	100%
AEV 2 Test	10/27/2015	10/27/2015	33%, test AEV on track	0%	0%	33%, catch AEV at gate	33%, film test	3.5	100%
Write Outline for Oral Presentatio	10/30/2015	11/2/2015	0%	0%	50%, write half of outline	50%, write half of outline	0%	1	100%
Make 3-D Printed Part	11/5/2015	11/23/2015	100%, create part	0%	0%	0%	0%	1	100%
Write Code to Accomplish MCR	10/27/2015	11/9/2015	20%, brainstorm efficient code	20%, brainstorm efficient code	20%, brainstorm efficient code	20%, brainstorm efficient code	20%, brainstorm efficient code	4	100%
Make AEV in SolidWorks	10/30/2015	11/9/2015	0%	50%, create AEV 1	0%	0%	50%, create AEV 2	3	100%
Write PDR	10/30/2015	11/9/2015	20%, write exec sum and intro	20%, create graphs, tables, appendix	20%, write results section	20%, write exp meth section	20%, write discussion section	6	100%
Performance Test 2 Memo	11/9/2015	11/16/2015	50%, write half of memo	50%, write half of memo	0%	0%	0%	4	100%
Draft of Oral Presentation	11/9/2015	11/17/2015	20%, create 3 slides	20%, create 3 slides	20%, create 3 slides	20%, create 3 slides	20%, create 3 slides	2	100%
Performance Test 3 Memo	11/15/2015	11/23/2015	0%	0%	33%, write a third of memo	33%, write a third of memo	33%, write a third of memo	4	100%
Conduct Final Run	11/24/2015	11/24/2015	20%, do final check of AEV	20%, test AEV on track	20%, spotter for AEV	20%, spotter for AEV	20%, spotter for AEV	0.5	100%
Write CDR	11/24/2015	12/4/2015	20%, write 1/5 of report	20%, write 1/5 of report	20%, write 1/5 of report	20%, write 1/5 of report	20%, write 1/5 of report	7	100%
Give Oral Presentation	12/1/2015	12/1/2015	20%, present 3 slides	20%, present 3 slides	20%, present 3 slides	20%, present 3 slides	20%, present 3 slides	0.25	100%
Update Project Portfolio	10/5/2015	12/4/2015	0%	33%, create exec sum pages	0%	33%, create title page	33%, upload meeting notes	4	100%

```
reverse(4);                          //Reverse all motors.
celerate(4,0,23,2);                  //Accelerate all motors from 0 power to 23 in 2
seconds.
motorSpeed(4,23);                    //Run all motors at 23% power.
goToAbsolutePosition(-394);          //Go to an absolute position of -394 marks.

reverse(4);                          //Reverse all motors.
celerate(4,23,0,5);                  //Accelerate all motors from 23 to 0% power in 5
seconds.

brake(4);                            //Brake all motors.
goFor(6.5);                          //Go for 6.5 seconds.
//Stopped at Gate First Time

reverse(4);                          //Reverse all motors.
motorSpeed(4,23);                    //Run all motors at 23 % power.
goToRelativePosition(-317);          //Go to a relative position of of -317 marks.

brake(4);                            //Brake all motors.
goFor(10);                           //Go for 10 seconds
```

```
//Pick-Up Cargo

reverse(4);                          //Reverse all motors.
celerate(4,0,35,2);                  //Accelerate all motors from 0 to 35 power in 2 seconds.
motorSpeed(4,35);                    //Run all motors at 35% power.
goToRelativePosition(336);           //Go to a relative position of 336 marks.

reverse(4);                          //Reverse all motors.
celerate(4,40,0,2.5);                //Accelerate all motors from 40 to 0% power in 2.5 seconds.
brake(4);                            //Brake all motors.
goFor(7.5);                          //Go for 7.5 seconds.
//Stopped at Gate Second Time

reverse(4);                          //Reverse all motors.
celerate(4,0,40,2);                  //Accelerate all motors from 0 to 40% power in 2 seconds.
motorSpeed(4,35);                    //Run all motors at 35% power.
goToRelativePosition(330);           //Go to a relative position of 330 marks.

reverse(4);                          //Reverse all motors
celerate(4,23,0,3);                  //Accelerate all motors from 23 to 0% power in 3 seconds
brake(4);                            //Brake all motors.
//Run Finished
```

Figure A1: Arduino Code #1 Used to Complete MCR (Final Code)

```
reverse(4);                          //Reverse all motors.
celerate(4,0,30,2);                  //Accelerate all motors from 0 to 30% in 2 sec

motorSpeed(4,30);                    //Run all motors at 30% power
goToAbsolutePosition(-368);          //Go to an absolute position of -240

//Brake for gate.
reverse(4);                          //Reverse all motors
motorSpeed(4,30);                    //Run all motors from 30 power for 2 seconds
goFor(2);

//Stop at Gate First Time
brake(4);                            //Brake all motors
```

```
goForr(9);                          //Go for 9 seconds

reverse(4);                         //Reverse all motors
motorSpeed(4,30);                   //Run all motors at 30 % power
goToRelativePosition(-390);         //Go to a relative position of of -350

//Brake for Cargo.
reverse(4);                         //Reverse all motors
motorSpeed(4,30);                   //Run all motors at 30 power for 2 seconds
goFor(2);

brake(4);                           //Brake all motors for 7 seconds.
goFor(7);
//Pick Up Cargo

celerate(4,0,45,2);                 //Accelerate all motors from 0 to 45 % in 2 sec
motorSpeed(4,45);                   //Run all motors at 45% power
goToRelativePosition(330);          //Go to a relative position of 355


//Brake for gate second time
reverse(4);                         //Reverse all motors.
motorSpeed(4,45);                   //Set all motors to run at 45% power for 3 sec
goFor(3);

brake(4);                           //Brake all motors for 8 seconds
goFor(8);
//Stopped at gate second time.

reverse(4);
celerate(4,0,45,2);                 //Accelerate all motors from 0 to 45% in 2 sec
motorSpeed(4,45);                   //Run all motors at 45% power
goToRelativePosition(345);          //Go to a relative position of 360.

//Brake for final stop.
reverse(4);                         //Reverse all motors
motorSpeed(4,45);                   //Run all motors at 45% power for 3 sec
goFor(3);

brake(4);                           //Brake all motors.
//Run Finished
```

Figure A2: Arduino Code #2 Used to Complete Mission (Not Used in Final Run)

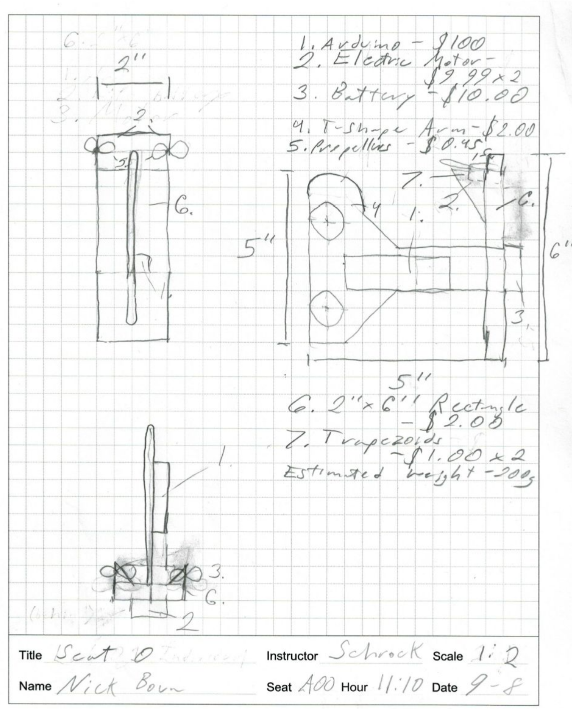


Figure A3: AEV Concept Sketch #0

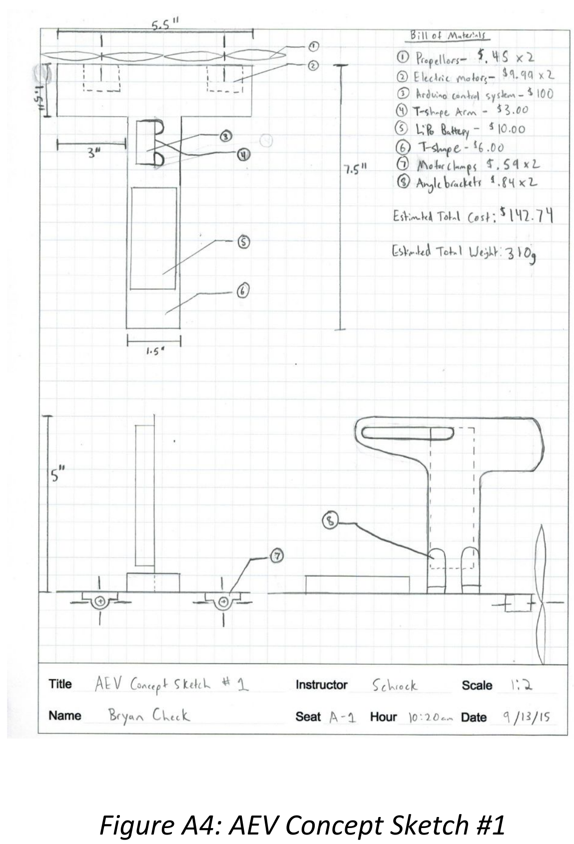


Figure A4: AEV Concept Sketch #1

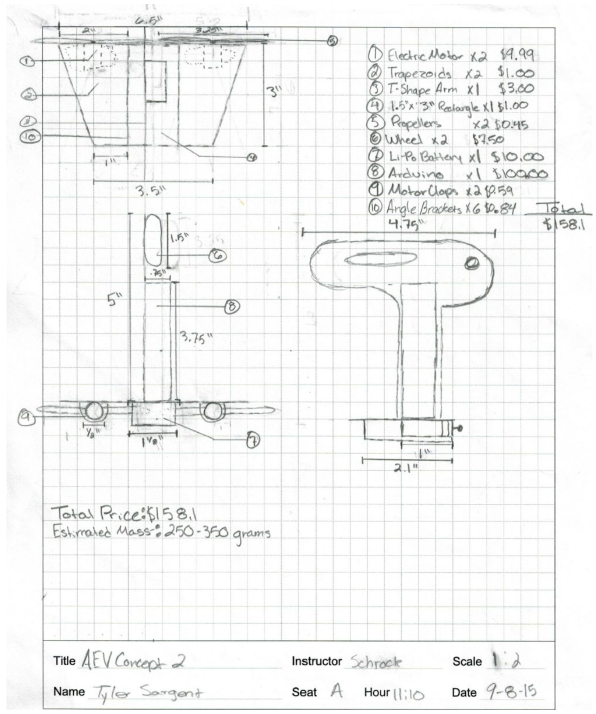


Figure A5: AEV Concept Sketch #2

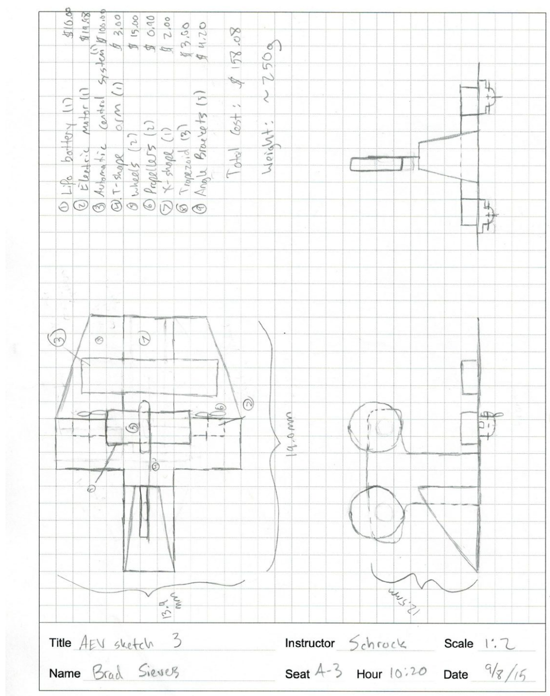


Figure A6: AEV Concept Sketch #3

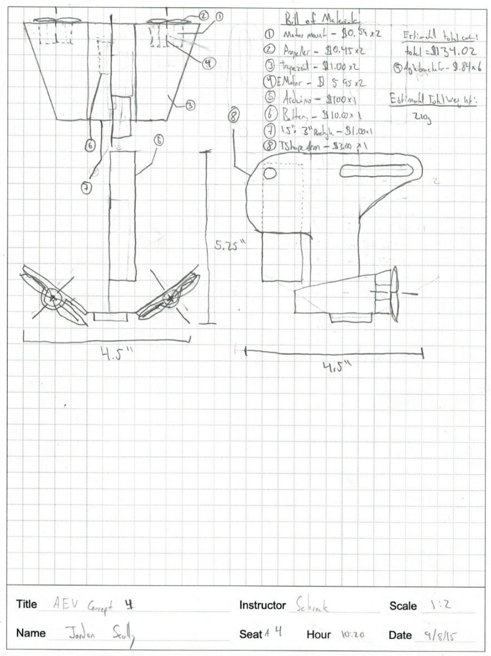


Figure A7: AEV Concept Sketch #4

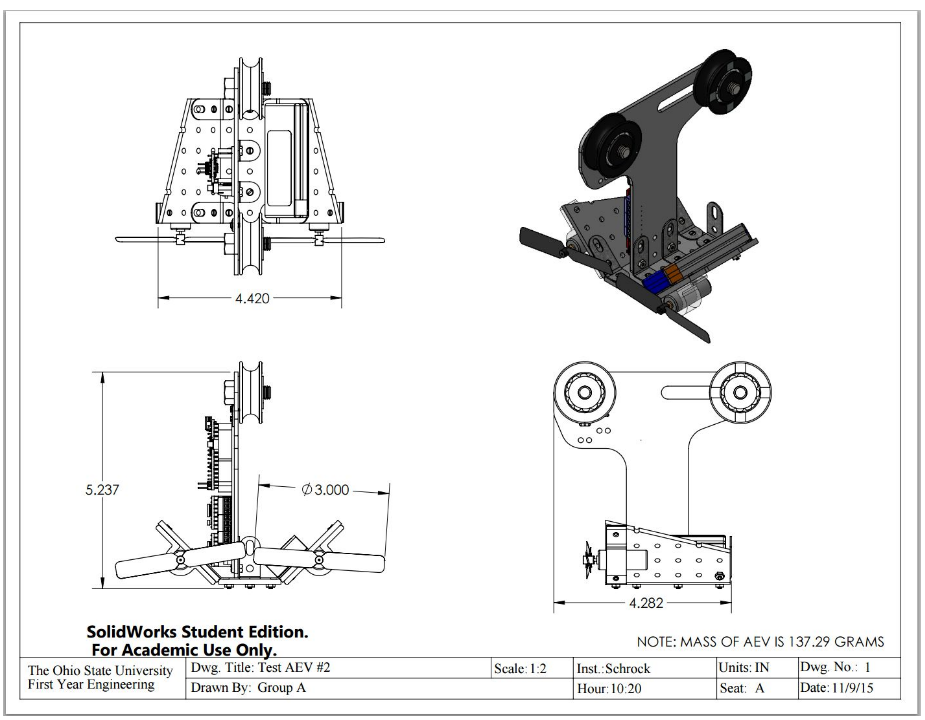


Figure A8: Original AEV (Not Used in Final Test) Orthographic Views

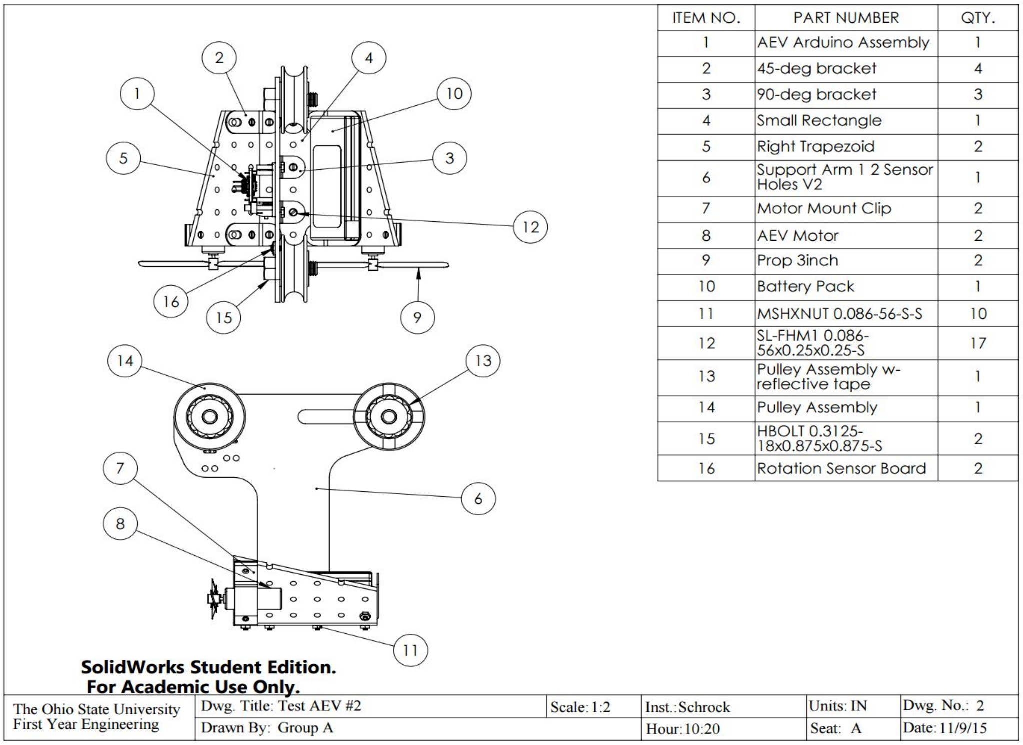


Figure A9: Original AEV (Not Used in Final Test) Bill of Materials Diagram

Table A2: Original AEV (Not Used in Final Test) Bill of Materials

Item Number	Part Identification	Quantity	Cost	Total Cost
1	Arduino	1	$100	$100
2	45-deg bracket	4	$0.84	$3.36
3	90-deg bracket	3	$0.84	$2.52
4	Small rectangle	1	$2.00	$2.00
5	Right trapezoid	2	$1.00	$2.00
6	Support Arm 2 ABS	1	$3.00	$3.00
7	Motor mount clip	2	$0.59	$1.18
8	AEV motor	2	$9.99	$19.98
9	Propeller (3 inch)	2	$0.45	$0.90
10	Battery	1	$15.00	$15.00
Various	Nuts, bolts, screws	1	$2.88	$2.88
13-14	Wheel	2	$7.50	$15.00
16	Rotation sensor board	2	$4	$8
Total Cost:	$176			

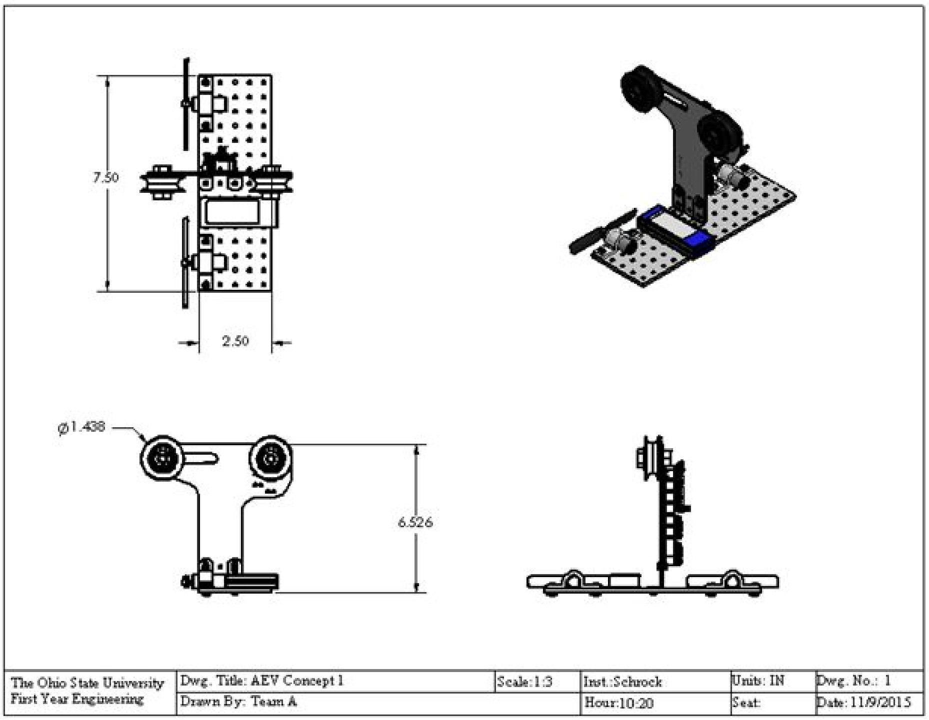


Figure A10: Final AEV Orthographic Views

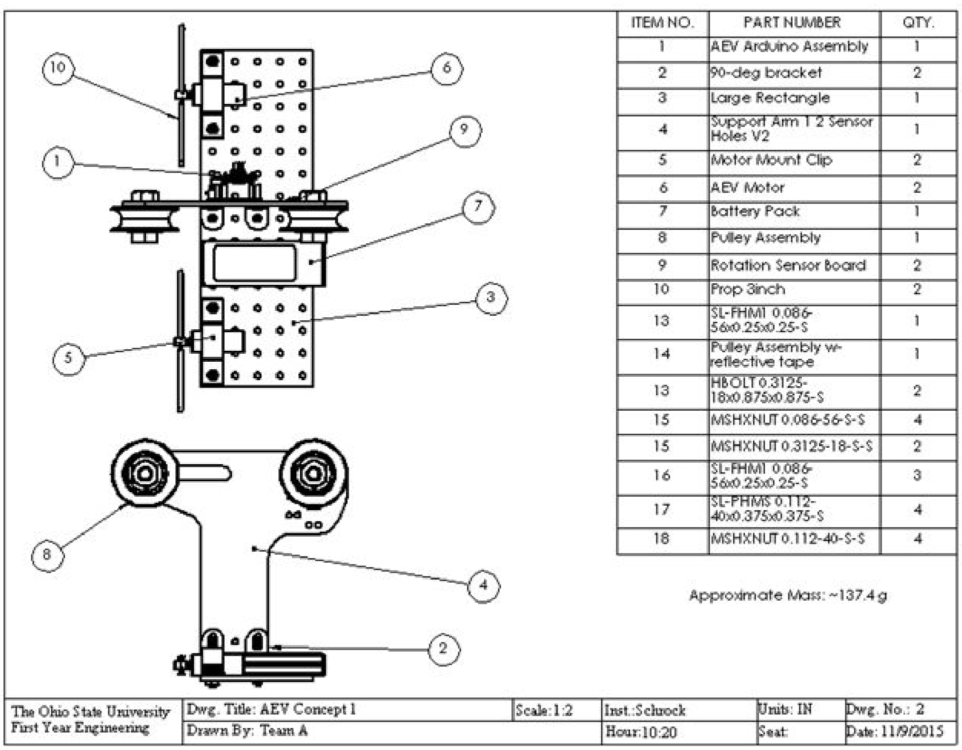
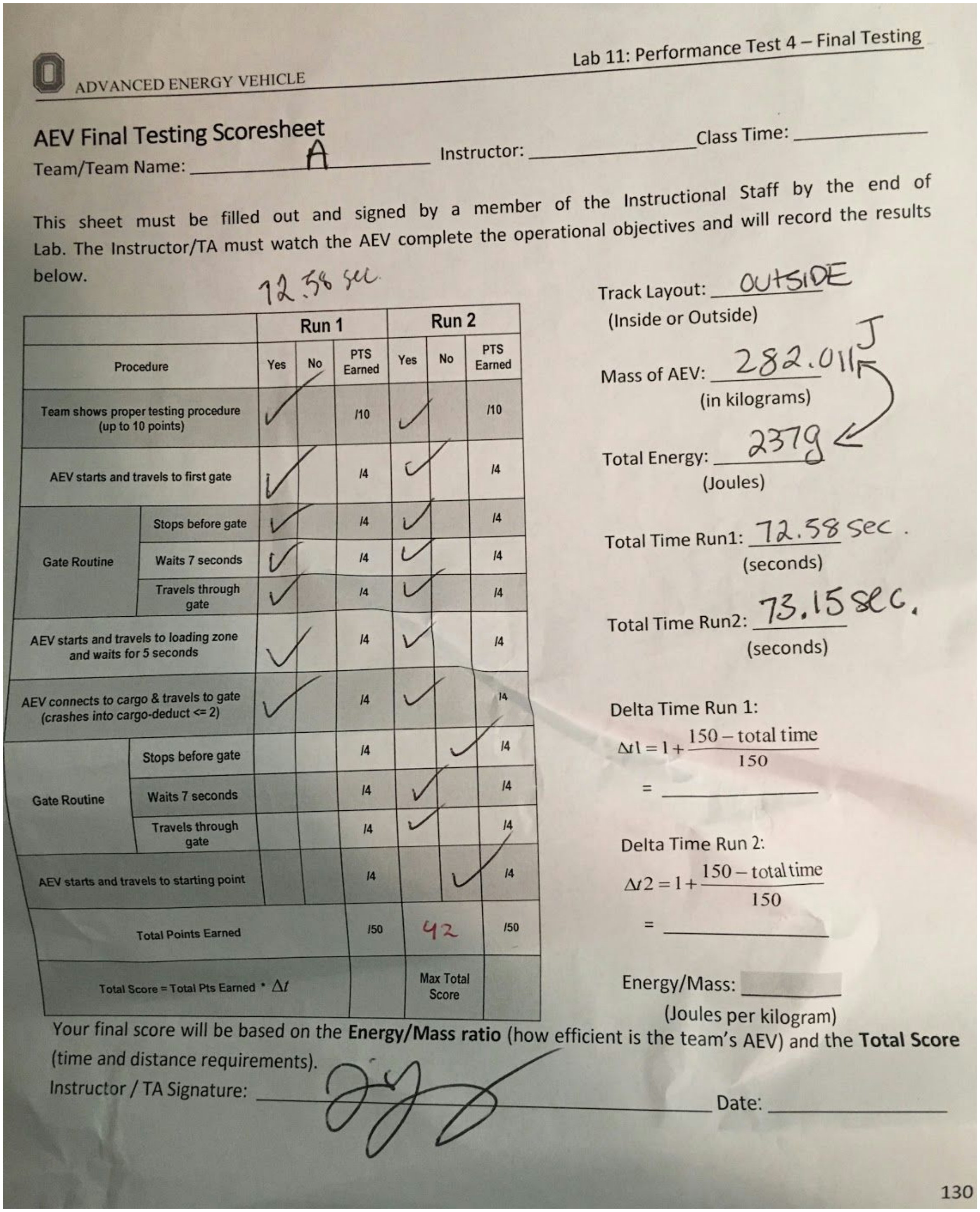


Figure A11: Final AEV Bill of Materials Diagram

Table A3: Final AEV Bill of Materials

Item Number	Part Identification	Quantity	Cost	Total Cost
1	Arduino	1	$100	$100
2	90-degree bracket	2	$0.84	$1.68
3	Large rectangle	1	$2.00	$2.00
4	Support Arm 2 ABS	1	$3.00	$3.00
5	Motor mount clip	2	$0.59	$1.18
6	AEV motor	1	$9.99	$9.99
7	Battery	1	$15.00	$15.00
8	Wheel	2	$7.50	$15.00
9	Rotation sensor board	2	$4.00	$8.00
10	Propeller (3-Inch)	2	$0.45	$0.90
Various	Screws, nuts, bolts	1	$2.88	$2.88
Total Cost:	$159.63			



ADVANCED ENERGY VEHICLE — Lab 11: Performance Test 4 – Final Testing

AEV Final Testing Scoresheet

Team/Team Name: A Instructor: ______ Class Time: ______

This sheet must be filled out and signed by a member of the Instructional Staff by the end of Lab. The Instructor/TA must watch the AEV complete the operational objectives and will record the results below.

72.58 sec

	Run 1			Run 2		
Procedure	Yes	No	PTS Earned	Yes	No	PTS Earned
Team shows proper testing procedure (up to 10 points)	✓		/10	✓		/10
AEV starts and travels to first gate	✓		/4	✓		/4
Gate Routine: Stops before gate	✓		/4	✓		/4
Gate Routine: Waits 7 seconds	✓		/4	✓		/4
Gate Routine: 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
Gate Routine: Stops before gate			/4		✓	/4
Gate Routine: Waits 7 seconds			/4	✓		/4
Gate Routine: Travels through gate			/4	✓		/4
AEV starts and travels to starting point			/4		✓	/4
Total Points Earned			/50	42		/50
Total Score = Total Pts Earned * Δt				Max Total Score		

Track Layout: OUTSIDE (Inside or Outside)

Mass of AEV: 282.011 (in kilograms)

Total Energy: 2379 J (Joules)

Total Time Run1: 72.58 sec. (seconds)

Total Time Run2: 73.15 sec. (seconds)

Delta Time Run 1:

$$\Delta t1 = 1 + \frac{150 - \text{total time}}{150}$$

= ______

Delta Time Run 2:

$$\Delta t2 = 1 + \frac{150 - \text{total time}}{150}$$

= ______

Energy/Mass: ______ (Joules per kilogram)

Your final score will be based on the **Energy/Mass ratio** (how efficient is the team's AEV) and the **Total Score** (time and distance requirements).

Instructor / TA Signature: ______ Date: ______

130

Figure A12: Final Run Scoring Sheet

References

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