Critical Design Review

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Executive Summary

As part of the Smart Columbus initiative, Team N has been commissioned by the city to create an efficient system of Advanced Energy Vehicles. The purpose of these vehicles is to transport passengers from Linden to Polaris via monorail system. Along with the AEV needing to be as energy efficient as possible, it also needs to be cheap and cost effective. The goal of this lab was to determine the best design for the AEV, to be as reliable as possible. The main purpose for the extensive research and redesigning of the AEV is to be able to effectively use it to pull passengers from Linden to Polaris on a monorail track cheaply and reliably.

Design wise, several different trends were found with Team N's particular design that will affect how the AEV will be coded in the future. The chosen AEV model features the arduino and wheel arm in the middle of a flat board, with two wings at the front, with outward facing motors attached to said wings. The first trend found with this design was that when the motors were facing toward the direction of motion, the AEV went much further on less power than in the reverse direction. It's also been found that the wheel arm must be centered so that the wheels are directly above the center of the AEV for maximum stability. Considering these trends in the final design will ensure peak performance.

Several different condition trends were also discovered about the AEV, allowing it to be more efficient if these conditions are accounted for. The first condition trend found was that the sensors of the AEV would be the most precise, consistently 18-20 marks short, when the reflectance tape that was used by the sensors was of the best quality possible. It was also found that when the reflectance wheel was screwed tightly against the wheel arm, sensor readings were also more precise. The final test was to determine what percentage of total distance moving was spent coasting based upon how much power was used. It was found that when the percentage of power was set to 30%, the AEV coasting percentage was the highest of all the other tested percentages. The further the AEV can move with its motors cut, the less the city will have to pay for powering the AEV.

With collection of this data, several recommendations can be made on designing the final AEV, as well as setting in the final codes. Design recommendations include ensuring that the wheels are securely placed above the middle of the AEV for maximum stability, as well as making sure that, when the passenger car is attached to the AEV, the motors are facing away from the passenger car for maximum strength. Coding recommendations include making sure that the reflectance tape has seen little wear and tear, as well as making sure that the reflectance wheel is tight against the wheel arm. Finally, the AEV should be run at 30% power often to ensure a large percentage of the AEV distance is made while the power is cut.

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Introduction

The city of Columbus aims to incorporate an Advanced Energy Vehicle (AEV) to transport people from Linden to Easton and Polaris to have a transportation system that improves safety, limits transportation pollution and provides a way for citizens to access basic services. Team N of Baker International has been tasked to design an AEV that is energy and time efficient. First, the experimental methodology will be explained including what equipment was used and the steps done for each section of the design process. Next, the results of the different research and development phases will be shown followed by the results of the different performance tests. Finally, the trends and how the results were used are explained in the discussion section. To conclude the report, the conclusion and recommendation section will include how the AEV can still be improved as well as repeat the major findings from the project.

Experimental Methodology

During the preliminary research and development, the team got accustomed to coding an arduino seen in Figure C.2, by writing a code that had the motors go for a certain amount of time and at different speeds on a stationary set-up without wheels similar to Figure C.1. Next the team built a sample AEV out of given supplies to use to determine what improvements could be made to the design. The given supplies consisted of a variety of parts including wheels, two arms, and several flat pieces of plastic that could be used as a board to hold the AEV together. Next, the reflectance sensor and wheels were added to the original design. The team ensured the reflectance sensors pictured in Figure 1 below on the left of the image were working properly by implementing a code onto the arduino software.

Figure 1. Reflectance Sensor and Wheel with Reflective Tape

During lab 3, the data extraction tool on Matlab was used to receive information about the power, distance and time of the code from the arduino and reflectance sensors. To finish the preliminary research and development, each team member brainstormed a prototype design based on the results from the previous labs.

The accuracy of the reflectance sensors and the distance the current prototype coasted at a specified voltage was tested for the advanced research and development. Using the tape measure on the straight track the correct distance traveled was recorded and using the data extraction tool, the measured distance traveled was obtained. By comparing the results of the tightness of the wheel to the arm of the vehicle and the quality of the tape, the best conditions were determined to lower the error as much as possible. After that, the Voltage-Distance test used the straight track to find the total distance traveled and the data extraction tool was used to determine how far the vehicle coasted when the power equaled zero. The distance coasted was tested from 20% power to 40% power in increments of 5% for 3 seconds on the track to compare how the voltage changes the coasted distance.

During the first two performance tests, the curved track was used to implement how the incline will affect the speed of the AEV. The first goal was to develop the code to get the AEV to stop between the sensors to open the gate and then proceed through after 7 seconds. The next step was to adjust the code in addition to the previous step, so the vehicle stops and returns to the starting point after obtaining the caboose.

Next, the third advanced research and development topic was addressed. For this topic, the goal was to determine the best way to minimize the total energy usage throughout the entire mission. Using the curved track the AEV was run for the entire mission and the incremental energy usage from the data analysis tool was collected. To minimize the energy usage the voltage and time intervals from parts of the code were adjusted.

Finally, the final performance tests were performed. These tests were a series of three trials that had the AEV complete its mission as explained for performance test two. However, this test focused on optimizing the energy and total time used to complete the mission. After each test, the code in the AEV was adjusted to observe the best results for the following test.

Results

The sample AEV from the preliminary research and development looked unstable on the track based on the configuration of its parts. From the distance vs power graph below in Figure 2, the vehicle also did not move as soon as the motors turned on and did not stop once the power turned off.

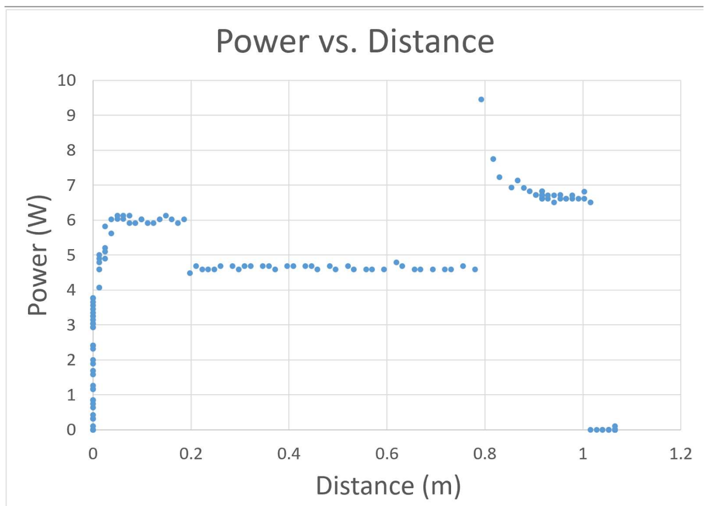


Figure 2. Distance vs Power Graph

These observations were used to brainstorm AEV designs.Figure D.1 included a plastic shell to make the AEV more aerodynamic to save energy and increase efficiency. Figure D.2 focused on safety and aimed to increase stability by having a symmetric design. The propellers were also positioned in opposite directions to limit the change when the direction was reversed. Similar to Design 1, Figure 3 had a round front to decrease air resistance. After comparing the designs, the team decided to combine the aerodynamic shell of Figure D.1 to the symmetric configuration of Figure D.2 to increase the stability and efficiency of the AEV which is shown as Figure D.4.

To move forward in the design process, the team determined which prototype was to move forward by developing a concept screening and scoring sheet shown below as Tables 1 and 2.

Success Criteria	Reference	Design 1	Design 2	Design 3	Design 4
Price of Parts	0	0	+	-	+
Aerodynamics	0	+	0	0	+
Stability	0	+	+	0	+
Weight	0	-	+	0	+
Efficiency	0	0	0	0	+
Sum +	0	2	3	0	5
Sum 0	0	2	2	5	0
Sum -	0	-	0	1	0
Net Score	0	1	3	-1	5
Continue?	Combine	No	Yes	No	Yes

Table 1. Concept Screening Sheet

		Reference		Design 2		Design 4	
Success Criteria	Weight	Rating	Weighted Score	Ratin g	Weighted Score	Ratin g	Weighted Score
Price of Parts	25%	3	0.75	4	1	4	1
Aerodyna mics	20%	3	0.6	2	0.4	3	0.6
Stability	15%	2	0.3	2	0.3	2	0.3
Weight	15%	3	0.45	3	0.45	2	0.3
Efficiency	25%	3	0.75	3	0.75	3	0.75
Total Score			2.85		2.9		2.95
Continue?		No		No		Develop	

Table 2. Concept Scoring Sheet

Based on the concept scoring results, the team built the design shown as Figure 7 (page 7). This design is cheaper and more stable than the other designs because the weight of the AEV is dispersed from either side of the track. The team elected to not incorporate the shell because it would cost money to build and time, which is why Figure D.4 was not built.

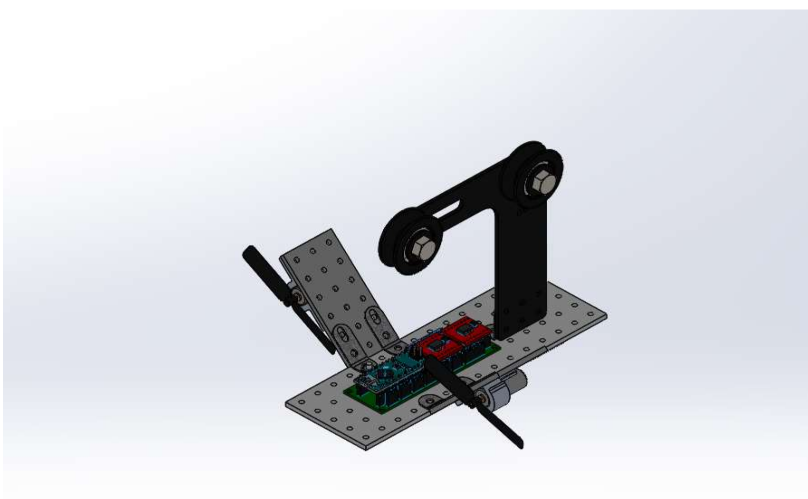


Figure 7. AEV Design

The reflectance sensors had a consistent error of about 10% when the wheel was tight against the arm of the vehicle. The error can be seen from the change in height of the blue and orange bars in Figure 8 below. When the wheel was moderately loosened, the percent error was erratic. Figure 9 (page 8) shows a change in the difference between both bars across all three trials. Figure 10 (page 8) supports that no data was collected when the wheel was loose because the reflectance sensor did not pick up on a signal so there is no orange bar.

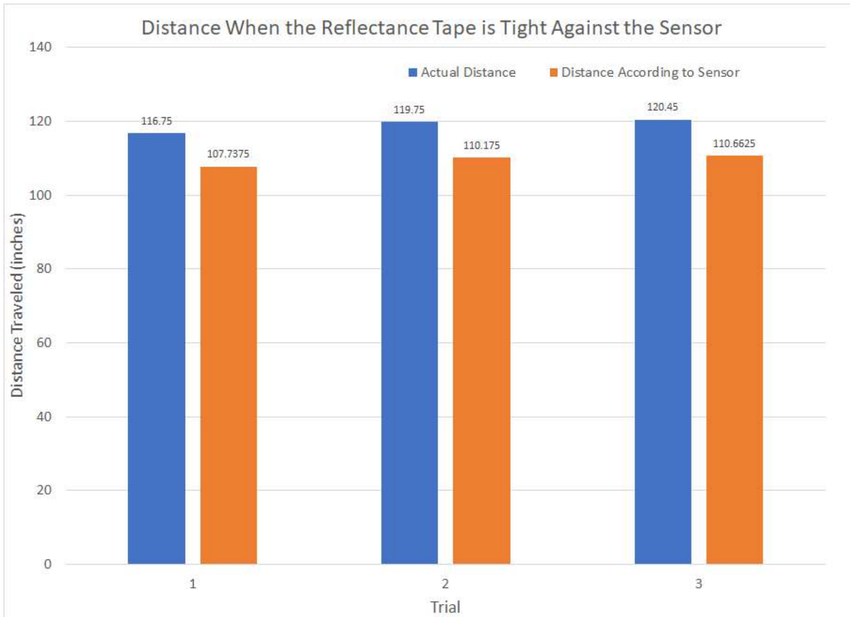


Figure 8. Sensor Test- Tight

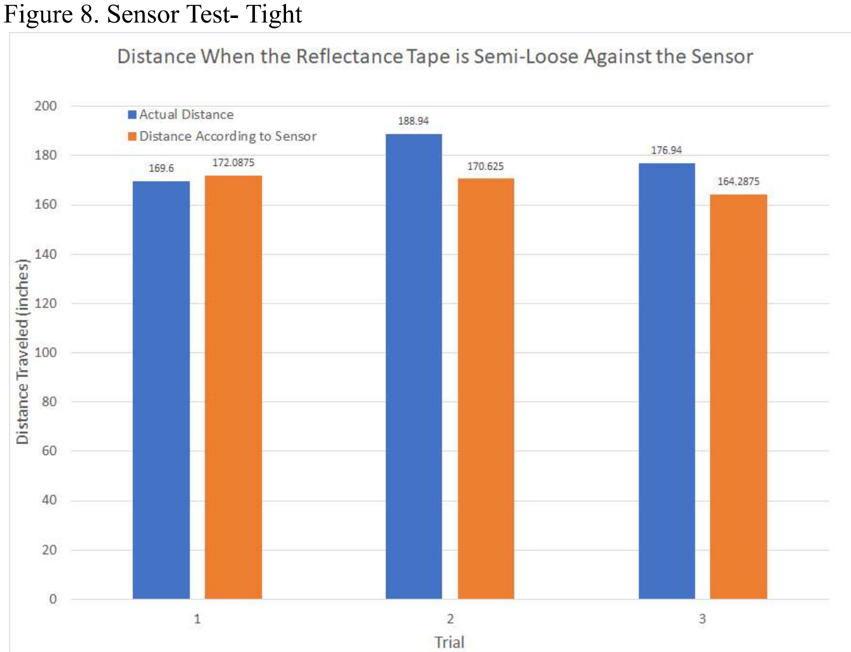


Figure 9. Sensor Test-Moderate

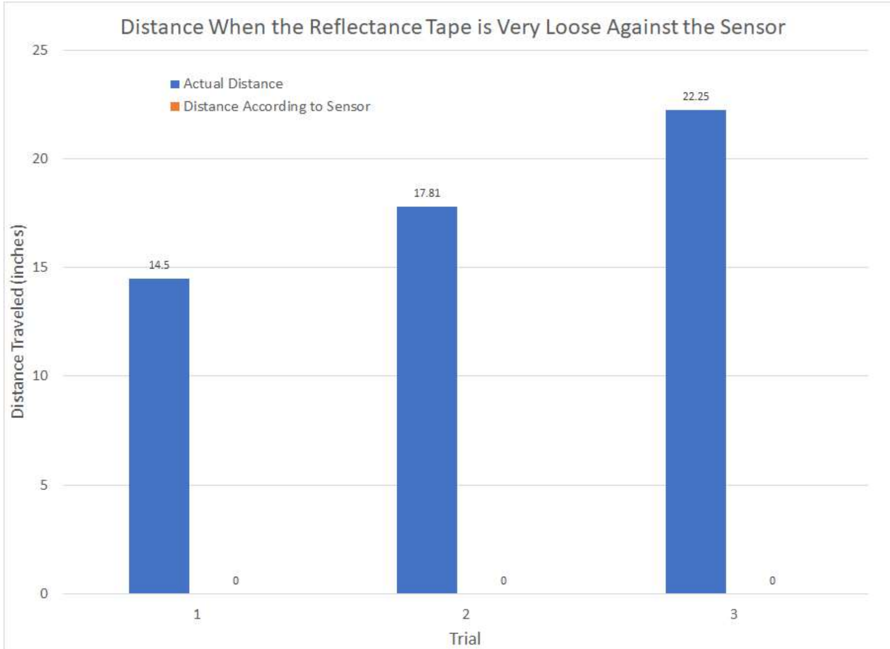


Figure 10. Sensor Test-Loose

When the wheel was tightly pressed, and the quality of the reflectance tape was good there was a 10% error as seen in Figure 11 (page 9), but the error increased to 20% when the quality of tape was poor as in Figure 12 (page 9). These results suggest that even in the optimal conditions the sensors are not completely accurate. These results will be used for the code for the performance test so that the code does not entirely depend on the accuracy of the sensors.

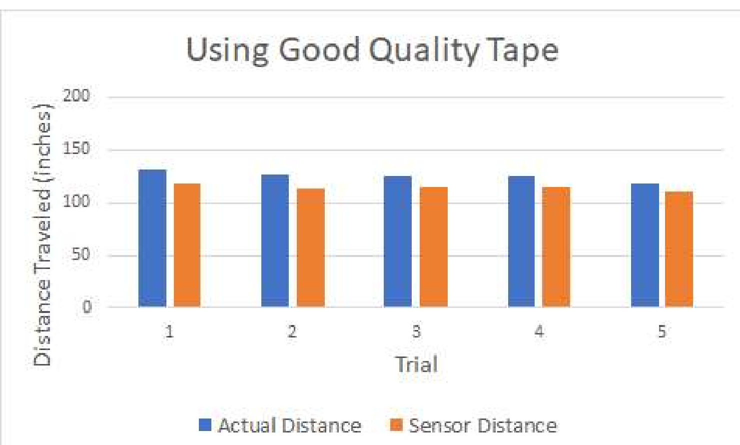


Figure 11. Sensor Test- Good Quality

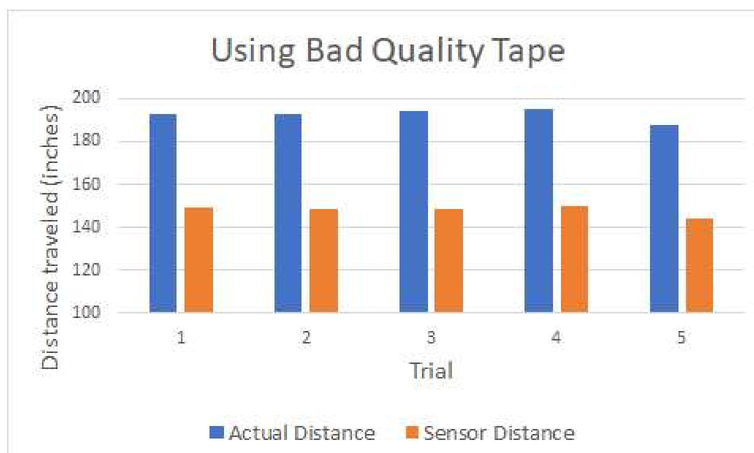


Figure 12. Sensor Test- Bad Quality

The voltage-distance test shows that the distance coasted increased exponentially until 30% power. Once the voltage was set to 30%, 35% and 40% power, the distance coasted was half of the total distance traveled as seen in Figure 13 below. This data was used for the initial code for the first performance test, to save time by having an idea of the total distance the AEV is expected to travel at a certain voltage and to determine the voltage that will have the AEV travel the farthest for maximum energy efficiency. From Team A of Baker International, their data shows that using a servo motor as a form to brake the vehicle, uses more power than simply coasting to a stop which supports the decision to focus on coasting to a stop.

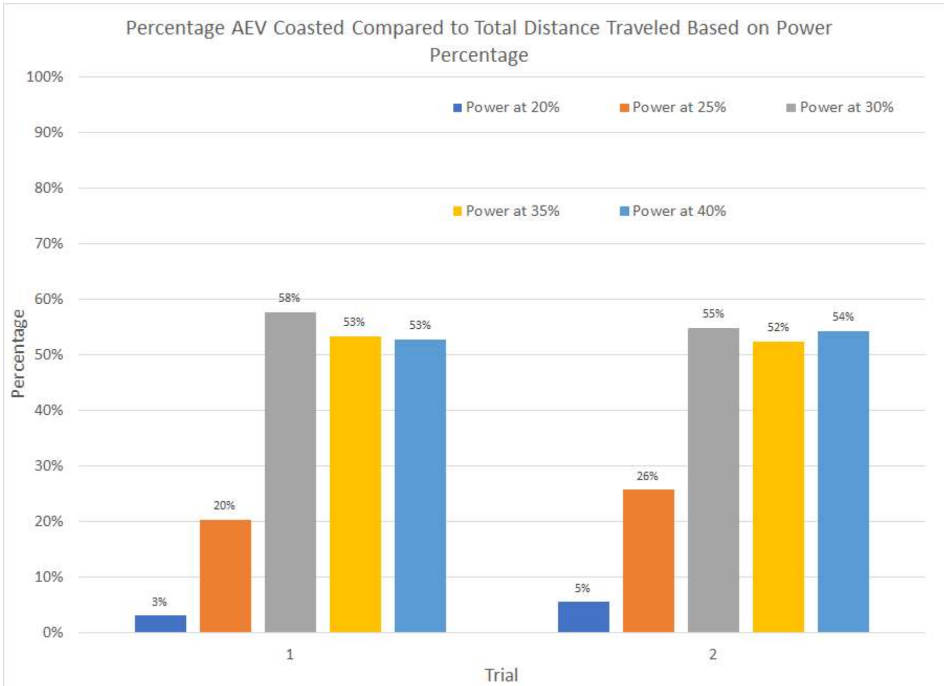


Figure 13. Voltage-Distance Test Results

During the performance test, the AEV did not end in the same location for every trial despite no change to the code as seen in Figure 14 below, showing three trials from performance test one using the same code. As seen from Figure 14, the blue trial 34 ended within an acceptable range for the gate, so the following trials were completed to ensure the vehicle would end in the same spot each time. However, from the difference in ending height from the figure it can be seen that neither of the following trials matched the same ending distance as the first one. Because of this, the team aims to incorporate a more advanced code where the accuracy of the stopping location is more precise.

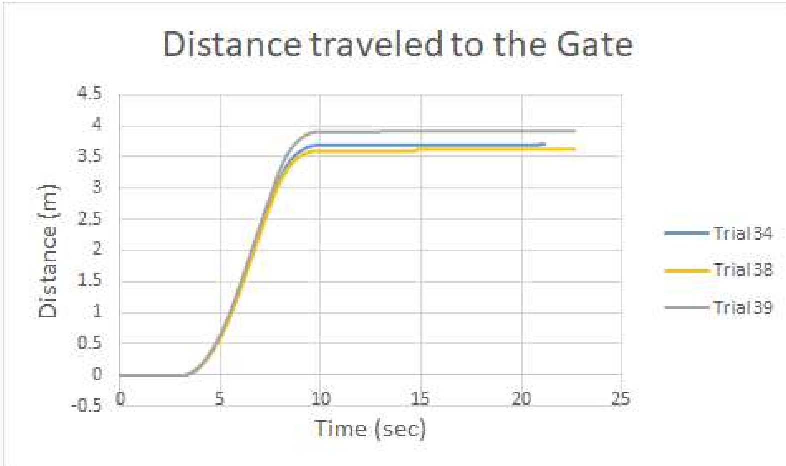


Figure 14. Performance Test 1 trial data

The starting code did not give enough power for the AEV to travel up the incline but stopped halfway up and slid back down. Because the power had to be increased to pass the incline the AEV went too fast to coast to a stop at the desired location before the gate. This information was used to make improvements to the AEV, so it can stop in a more consistent location. After discussing the second performance test the team realized the arduino would be too close to the magnet, so the configuration of the AEV has been changed to the below Figure 15 (page 12) where the location of the arduino has been flipped with the battery so the arduino is behind the motors. While determining this configuration it was found that the wheels needed to be in the center on the main board in order for the vehicle to remain horizontal and stable. The vehicle also moved easier when the motors were moving in the forward direction than in the reverse direction.

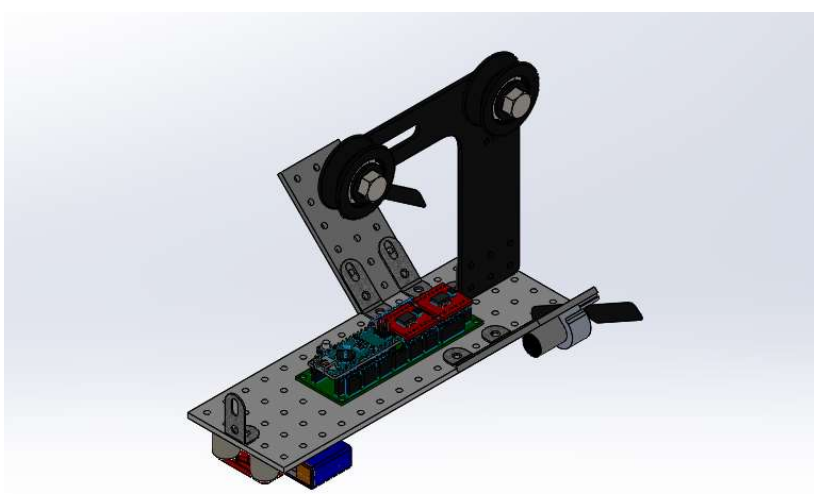


Figure 15. New AEV Design

For the third advanced research and development topic, the goal was to minimize the total energy usage used by the AEV while it completed the entire mission. From the data collected from the arduino, the sections with the most energy usage were observed, as seen from the peaks in Figure 16, comparing the energy usage from Trial 14 and Trial 17. The main tactic was to maximize the time the AEV was coasting so the energy needed to brake the AEV decreased. For this AEV to stop its momentum it reverses the motors, so by reversing the motors sooner with less power, allows the AEV to coast to a stop as seen by the different heights of the peaks in Figure 16 below.

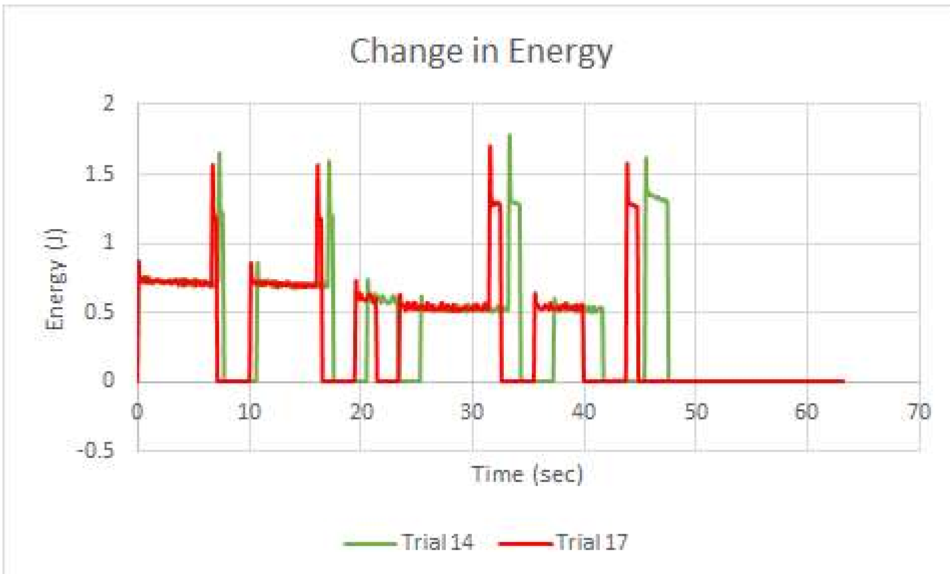


Figure 16. Record of the energy (Joules) used by the AEV during trials 14 and 17

For the final performance tests, the AEV completed the goals of the mission. However, points were deducted for not ending with all 4 wheels in the starting dock for the first test run. In the second run, the AEV went too far past the gate returning with the caboose, thus resulting in the AEV having too much speed and ended going too far in the starting dock. The third run had no major issues and completed the mission successfully. Despite changing the code and having the run before the test run perfectly, there was still error and the AEV did not accomplish what was expected. As seen in Figure E.1, of the data from the final performance tests, the most successful runs were on the second day of testing. The average time for all three runs was 57.52 seconds and the average total energy used was 340.41 joules. Based on the time and energy used, as well as the parts for the AEV the entire cost was determined to $630,989.83.

Discussion

From the concept screening and scoring figures it was decided that the fourth design would continue to be our new design. In the concept screening sheet, Table 2 (page 8), each criteria of the design was ranked on whether the design increased the part or had a negative impact. If the criteria of the design did not have an influence it was ranked with a zero. At the end, the points were added together to determine the best design. The success criteria was determined by what could be changed in the design of the AEV. The goal is to make the AEV energy efficient while remaining under the budget, so the total cost of the AEV, efficiency and aerodynamics were all criteria. Safety is also an important issue, so the stability and weight distribution were considered. The success of the AEV design for each criteria was mainly determined by how it was designed relative to the other designs. For example, Design 2, had less parts so the price and weight were listed as better than Design 3. By combining Design 1 and Design 2 into Design 4, the team was able to combine the successes of the original designs to make a more successful design. Out of all of the designs created, Design 4 succeeded in the criteria. As seen from the Concept Scoring Figure 8 (page 8) , the total score of Design 4 was only 0.05 points higher than Design 2. Since the weighted score was close in each design, the team decided to continue with Design 2, because the shell would have added more weight to the AEV and cost more time to build and create.

For the reflectance sensor test, the team anticipated the percent error to be 0%-3% when the wheel was tightly compressed against the arm and the tape was the better quality rather than seeing a result of 10% error. The reason behind this unexpected percent error could be due to the light of the room that hits the reflective tape. A systematic error for this lab was if the starting location was not the same as the measured starting point on the arduino. Determining how accurate the reflectance sensors are will help determine how to change the code so that the AEV will travel to the correct location, such as collecting the caboose or stopping before the gate. The team expected the distance coasted per the total distance traveled to remain a constant ratio. However, the results were not consistent as seen by the sudden leveling out of the bar graphs after the voltage was set to 30% as seen from Figure 13 (page 9). These results could be from the battery being drained after the tested trials or an additional air current going against the AEV creating an extra force at the end of the lab rather than at the beginning. These results help determine the optimal voltage to travel at that will result in the greatest distance coasted to use the minimum amount of energy.

While testing the performance test, the location that the AEV came to a stop after each trial with the same code was expected to remain the same. Because of the variance of the end location as seen in Figure 14 (page 10), the team implemented a code to make up for this issue during the second performance test. However, it cannot be a precise code because the Reflectance sensors are not accurate. The variance in stopping location is an example of a random error because the AEV fell too short or too long at different times due to outside forces during that specific run. In order to stop the momentum of the AEV after it climbed the incline to ensure that it would stop before the gate, the team reversed the motors to add an additional force against the momentum of the AEV. This code proved successful in slowing the AEV down before the gate on the track. At the beginning of performance test 2, the team realized that the arduino was less than 2 inches from the magnet which is against the rules, so the team reconfigured the AEV. This design is similar to the previous design and appears just as stable. Because the vehicle travels more efficiently in the forward direction, more power will need to be used when the motors are going in the reverse direction. Thus, the direction of the propellers were also flipped so that when the AEV is traveling with the caboose it will be easier to move the extra weight, rather than before, when the AEV struggled to move itself in the reverse direction.

Team A within the company, tested the motor configuration and the effect of adding a servo. This data was not used to change the design, but the results do confirm the theory that using a servo uses more energy than coasting to a stop. From observation during the performance test two, Team A's results for motor configuration verified that the AEV would travel farther using two push motors rather than two pull ones. Team C in the company division tested the power of the battery and its effect on the efficiency of the motors, but their results suggest there was no effect. Team C also tested different configurations of the propellers and found that the results were different when the motors were facing opposite directions. These results were not used during testing, but it confirms that the AEV moves farther when the propellers are facing the same direction.

By reducing the energy usage the AEV will be more environmentally friendly as well as decrease the cost needed for fuel. The goal for the third advanced research and development topic was to reduce the energy usage by 50% by changing the code so the places with the most energy usage would decrease. However, the first trial had a total energy of 497.86 Joules, whereas the last trial had a total energy of 344.01 Joules. This was only a 30.9% reduction on the total energy used which was 20% short of the goal. The total energy usage is not an exact measurement because the value was only taken from one trial rather than multiple from the same code. As shown above in Figure 14 (page 10), the energy usage will not be the same because the results change with each run. However, the change in the data will be around the same range, so the results would show the same thing. The best way to decrease the energy usage was to focus on having the AEV coast to a stop more rather than having the motors stop the AEV without any movement afterwards.

In the end, the total cost of the AEV was $130,989.83 over the budget. This amount factored in the average time and energy used in the final performance tests as well as factored in the price of each part. Despite using the third advanced R&D topic to decrease the energy usage it was not enough to get the AEV to be under the budget amount. The most successful run was the last one where it ended with all four wheels in the starting dock and stopped in the correct range for the gates as seen from the calculations in Figure E.1. The runs prior were not as successful; the first run had the most energy and time and did not have all four wheels in the starting dock. The next run, decreased the time and energy, but overshot the gate with the caboose and the starting dock. In the endl, each run improved from the one before.

Conclusions & Recommendations

The goal of this process was to create a functioning AEV to transport passengers from Linden to Polaris. Several designs were created, but the first prototype AEV was a combination of the initial designs. During the advanced research and development phase, the reflectance sensors and distance coasted were tested. The reflectance sensors were proven to be precise in their readings when tightly attached to the arm as seen in Figure 8 (page 7), however the reflectance sensors were never accurate. This led to the reflectance sensors not being used in the first performance test, causing for a lack of precision and accuracy during the test. The distance coasted tests revealed that after reaching a certain speed, the AEV would coast for the same amount of distance as seen in Figure 13 (page 9). This information was used in performance test one, as the distance coasted remained the same despite the ending location of the AEV. For the second performance test, the precision of the reflectance sensors was used to determine a stopping location, and the difference in accuracy was accounted for in the code. As well as remodeling the code, a new prototype of the AEV was created for use during the future performance tests due to the discovered difference in push and pull on the motors. This AEV was used in the final performance test, which ran the entirety of the track. There were small accuracy problems with the first two trials of the final performance test, but by the third run everything ran according to plan. Many errors occurred during the process of the AEV project. The most notable error was the inconsistency of the AEV no matter which code was used. This issue was initially solved by having the AEV stop short of the target area and inch forwards, but in order to save time and money, this was cut and more accurate stopping locations were added. Another crucial error was in the propellers. Since the motors were run at 100% during aR&D 3, the propellers became loose on the motors and occasionally flew off the AEV. This was solved by lowering the power used and purchasing new propellers with a stronger connection to the motor. Through all the errors, the third trial of the final performance test was successful. However, the first two runs of the final performance test did not achieve perfect accuracy scores. This is due to an unknown error that caused a functioning code to stop working on the day of the performance test. This problem was resolved by inserting new speeds and stopping points for the AEV, but unfortunately this information was not found before the third trial. Some recommendations for the AEV include making a way for the AEV to be more consistent. Many trials running the same code produced different results, and when the performance tests were run it was difficult to know whether the AEV would overperform or underperform. Research could be done to find ways to make the AEV more precise, allowing for more time to be focused on aR&D in the future. If more time was allotted this research could have been done during the design process. The final recommendation is to use more complicated commands to create a smart code for detecting whether or not the AEV has completed its mission. This wasn't accomplished due to the lack of a code glossary for these commands, but having a Smartcode would be crucial in ensuring that the AEV ran as successfully as possible.

References

[1] Ohio State Fundamentals of Engineering Program, “Mission Concept Review and Deliverables.”[Engineering 1182 Course Documentation]. Available: carmen.osu.edu for ENGR 1182. [Accessed Mar. 26, 2019].

[2] Ohio State Fundamentals of Engineering Program, “Lab Manual Preliminary Research Design.” [The Ohio State University]. Available: carmen.osu.edu for ENGR 1182. [Accessed Mar. 26, 2019].

[3] Ohio State Fundamentals of Engineering Program, “User Manual – Reflectance Sensors.” [The Ohio State University]. Available: carmen.osu.edu for ENGR 1182. [Accessed Mar. 26, 2019].

[4] Ohio State Fundamentals of Engineering Program, “Lab Manual Advanced Research Design.” [The Ohio State University]. Available: carmen.osu.edu for ENGR 1182. [Accessed Mar. 26, 2019].

[5] Ohio State Fundamentals of Engineering Program, “Technical Communications Guide.” [The Ohio State University]. Available: carmen.osu.edu for ENGR 1182. [Accessed Mar. 26, 2019].

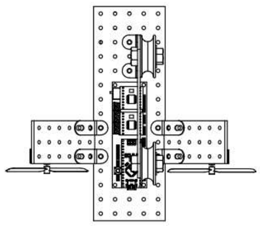
Appendix A: Project Schedule

Tasks	Start Date	End Date	Due Date	% Work Completed M. Fortner	L. Shimoda	M. Stitt	Main Tasks	% Completed
Team Meeting Minutes	15-Jan	17-Jan	18-Jan	10%	80%	10%	MF-Look over LS-Complete MS-Look over	100%
Website Update 1	15-Jan	17-Jan	18-Jan	20%	55%	25%	MF-Look over LS-Team Information MS-Approach to MCR	100%
Website Update 2	4-Feb	7-Feb	8-Feb	30%	40%	30%	MS- Add code used LS-Evolution of Design MS-Answer questions in MCR	100%
Grant Proposal	12-Feb	14-Feb	15-Feb	40%	10%	50%	MF- Gather information LS-Look Over MS-Make the slide	100%
Progress Report 1	10-Feb	14-Feb	15-Feb	25%	45%	30%	MF-Future LS-Analysis MS-Situation	100%
Committee Meeting 1	15-Feb	22-Feb	22-Feb	31%	31%	38%	MF- Public Relation LS- HR MS-R&D	100%
Progress Report 2	12-Mar	17-Mar	19-Mar	30%	35%	35%	MF-Future LS-Analysis MS-Situation	100%
Website Update 3	14-Mar	18-Mar	19-Mar	25%	45%	30%	MF-Add Codes LS-Adv R&D MS-Score Sheet	100%
Performance Test 1	7-Mar	19-Mar	19-Mar	75%	5%	20%	MF-Create Code LS-Record data MS-Run AEV	100%

Research and Development Presentation	19-Mar	20-Mar	21-Mar	33%	34%	33%	MF-Future LS-Voltage Test MS-Sensor Test	100%
Critical Design Review	22-Mar	27-Mar	28-Mar	20%	45%	35%	MF-Conclusions LS-Results MS-Overview	100%
Performance Test 2	22-Mar	26-Mar	26-Mar	70%	10%	20%	MF-Create Code LS-Offer suggestions MS-Run AEV	100%
Committee Meeting 2	28-Mar	28-Mar	28-Mar	33%	34%	33%	MF- Public Relation LS- HR MS-R&D	100%
Progress Report 3	3-Apr	7-Apr	7-Apr	30%	40%	30%	MF-Future LS-Analysis MS-Situation	100%
Final Performance Test	9-Apr	11-Apr	11-Apr	70%	5%	25%	MF-Create Code LS-Record Data MS-Run AEV	100%
Final Presentation Draft	3-Apr	7-Apr	7-Apr	30%	30%	40%	MF-Codes LS-Organization MS-Design	100%
Final Presentation	12-Apr	14-Apr	15-Apr	30%	40%	30%	MF-Codes LS-Organization MS-Design	100%
CDR Final Report	12-Apr	17-Apr	18-Apr	20%	50%	30%	MF-Conclusions LS-Results MS-Overview	100%
Final Website Update	15-Apr	17-Apr	18-Apr	30%	40%	30%	MF-Add Codes LS-Descriptions MS-Graphs	100%

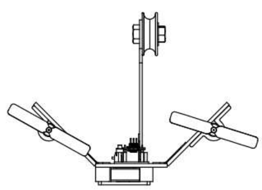
A.1 Project Schedule

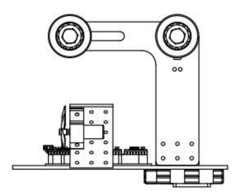
Appendix B: Solidworks Models



Length	7.5 in
Depth	2.5 in
Height	5.75 in
Weight	0.40 lbs
Cost	$151,842

ITEM NO.	PART NUMBER	QTY.
1	Small Rectangle	2
2	45-deg bracket	4
3	Support Arm 2 ABS	1
4	90-deg bracket	2
5	Motor Mount Clip Aluminum	2
6	AEV Motor	2
7	Prop 3inch	2
8	AEV Arduino Assembly	1
9	Pulley Assembly	2
10	MSHXNUT 0.3125-18-S-S	2
11	HBOLT 0.3125-18x0.875x0.875-S	2
12	test	1
13	Battery Pack	1
14	Battery Spacer	4
15	Battery Pack Clamp Plate Narrow	1



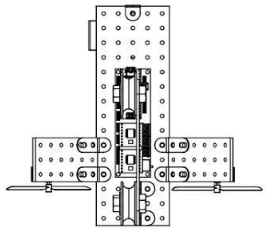


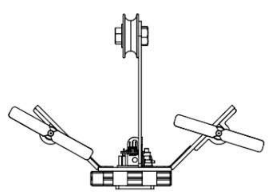
The Ohio State University First Year Engineering	Dwg. Title: AEV Prototype 1	Scale: 1:4	Inst.: Cohen	Units: IN	Dwg. No.:1
	Drawn By: Matthew Fortner		Hour: 9:10	Group:N	Date: 3/26/19

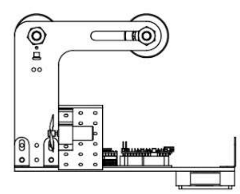
B.1 Design 2

Length	7.5 in
Depth	2.5 in
Height	5.75 in
Weight	0.40 lbs
Cost	$151,863

ITEM NO.	PART NUMBER	QTY.
1	Small Rectangle	2
2	45-deg bracket	4
3	Support Arm 2 ABS	1
4	90-deg bracket	3
5	Motor Mount Clip Aluminum	2
6	AEV Motor	2
7	Prop 3inch	2
8	AEV Arduino Assembly	1
9	Pulley Assembly	2
10	MSHXNUT 0.3125-18-S-S	2
11	HBOLT 0.3125-18x0.875x0.875-S	2
12	test	1
13	Battery Pack	1
14	Battery Spacer	4
15	Battery Pack Clamp Plate Narrow	1



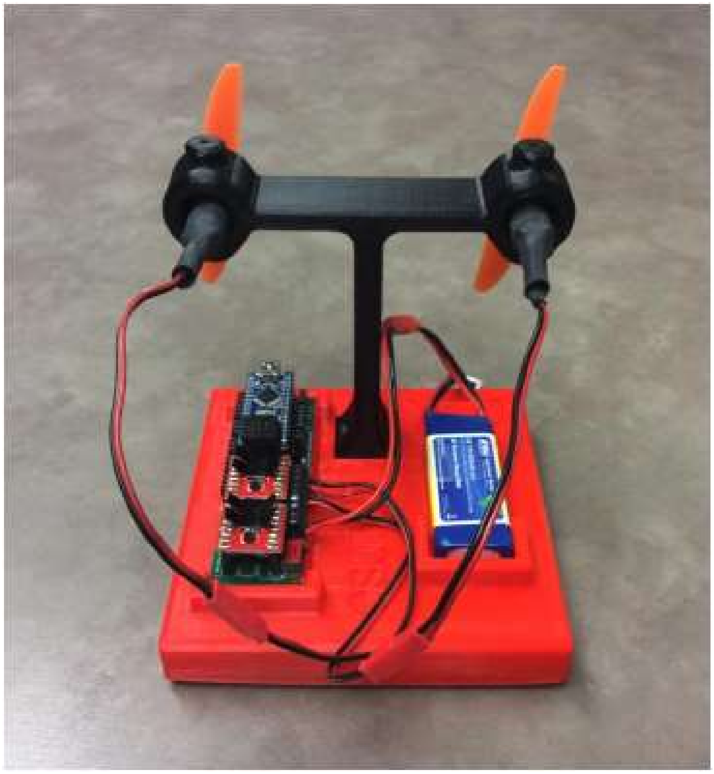




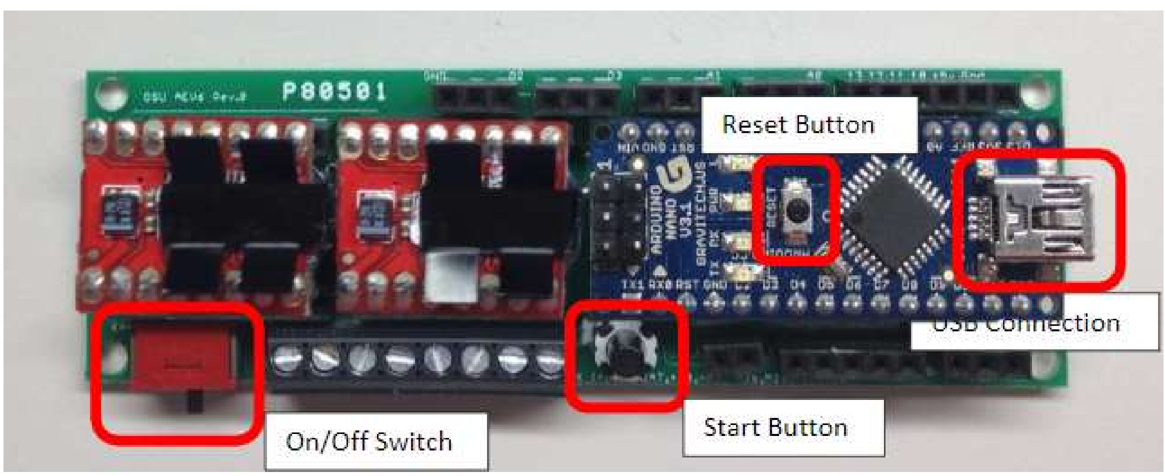
The Ohio State University First Year Engineering	Dwg. Title: AEV Prototype 2	Scale: 1:4	Inst.: Cohen	Units: IN	Dwg. No.:2
	Drawn By: Matthew Fortner		Hour: 9:10	Group: N	Date: 3/26/19

B.1 New Design

Appendix C: Equipment

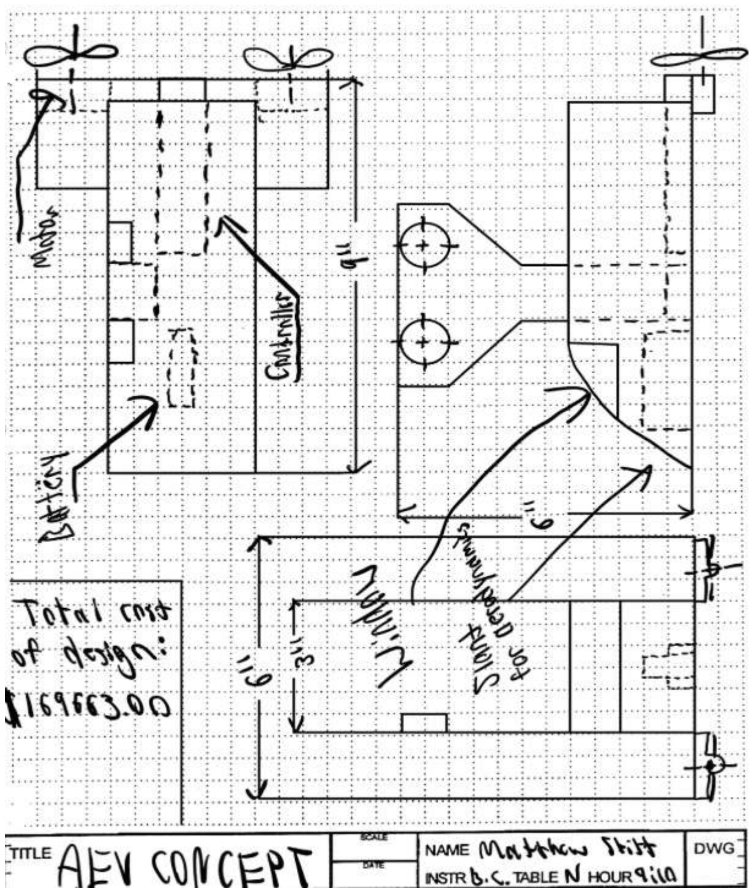


C.1 Motor stand with Lab 1 required equipment [2]

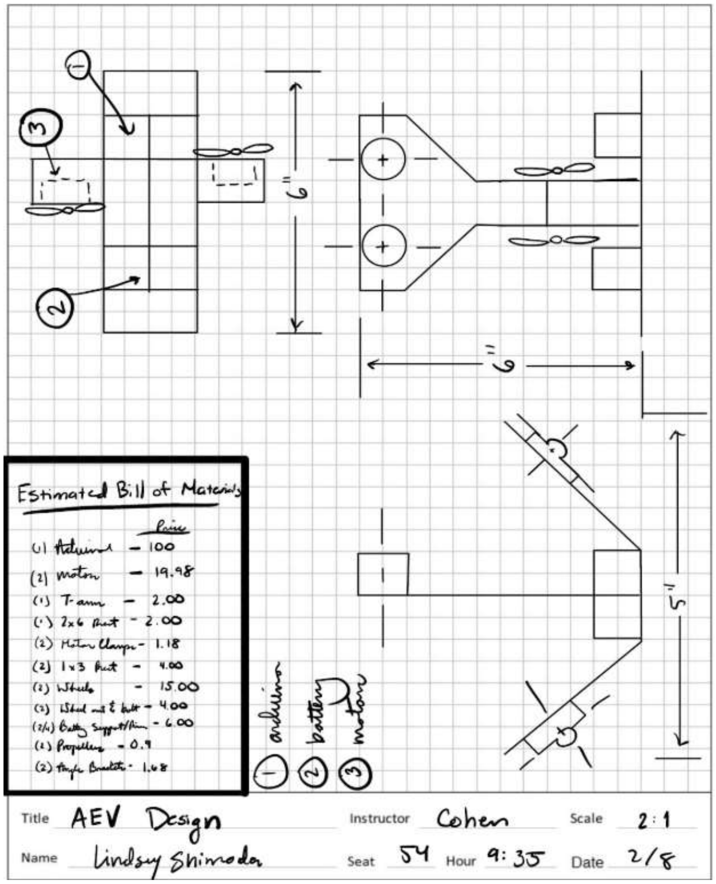


C.2 The AEV controller with an Arduino Nano [2]

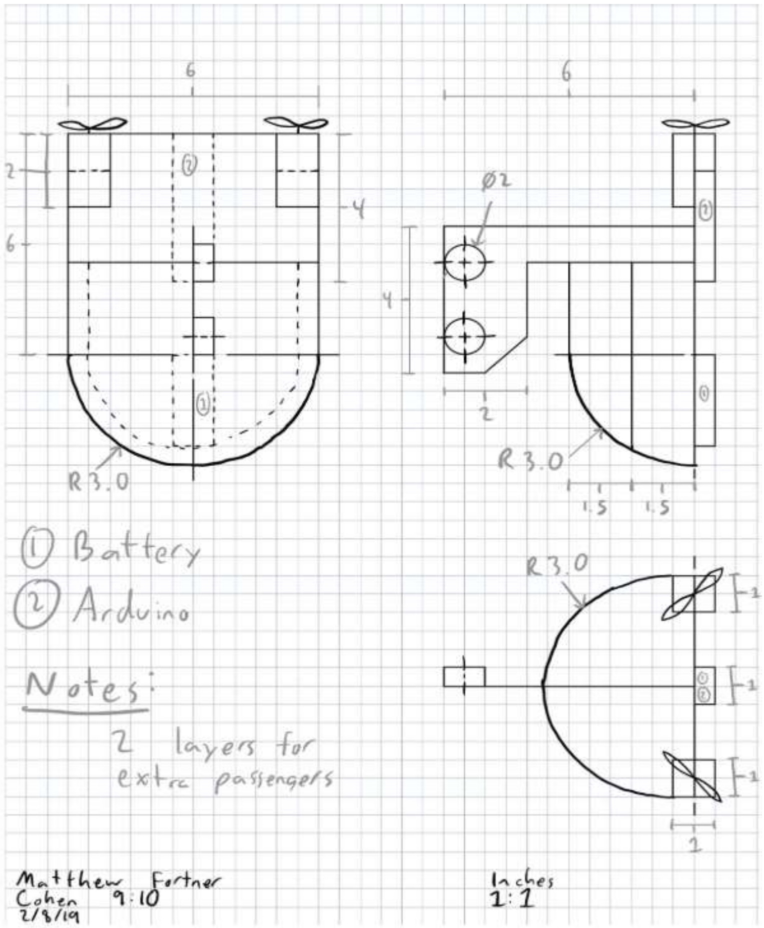
Appendix D: Prototype Designs



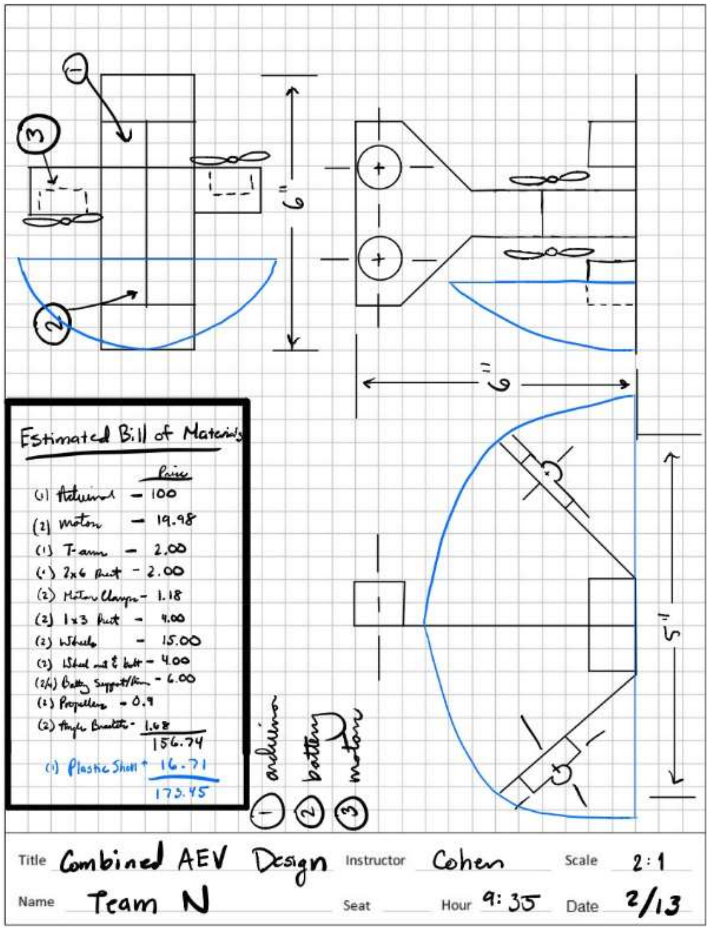
D.1 Design 1 Aerodynamic



D.2 Design 2 Maximum Stability



D.3 Design 3 Aerodynamic Front



D.4 Design 4 Combination

Appendix E: Final Performance Test

modify hilighted cells

RUN #1

ACCURACY PENALTY	
TOTAL SCORE (out of 40)	38
ACCURACY PENALTY	1.052631579

ENERGY COSTS: *baseline fee + $500/Joule*	
Baseline Fee:	$ 125,000.00
Total Joules from PT:	352.69
Cost from Joules used	$ 176,345.00
Total Energy Cost:	**$ 301,345.00**

TIME COSTS: *baseline fee + $1.5K/second*	
Baseline Fee:	$ 90,000.00
Total run time in seconds:	59.52
Cost from time used	$ 89,280.00
Total Time Cost:	**$ 179,280.00**

RUN #2

ACCURACY PENALTY	
TOTAL SCORE (out of 40)	36
ACCURACY PENALTY	1.111111111

ENERGY COSTS: *baseline fee + $500/Joule*	
Baseline Fee:	$ 125,000.00
Total Joules from PT:	335.46
Cost from Joules used	$ 167,730.00
Total Energy Cost:	**$ 292,730.00**

TIME COSTS: *baseline fee + $1.5K/second*	
Baseline Fee:	$ 90,000.00
Total run time in seconds:	55.86
Cost from time used	$ 83,790.00
Total Time Cost:	**$ 173,790.00**

RUN #3

ACCURACY PENALTY	
TOTAL SCORE (out of 40)	40
ACCURACY PENALTY	1

ENERGY COSTS: *baseline fee + $500/Joule*	
Baseline Fee:	$ 125,000.00
Total Joules from PT:	333.07
Cost from Joules used	$ 166,535.00
Total Energy Cost:	**$ 291,535.00**

TIME COSTS: *baseline fee + $1.5K/second*	
Baseline Fee:	$ 90,000.00
Total run time in seconds:	57.18
Cost from time used	$ 85,770.00
Total Time Cost:	**$ 175,770.00**

E.1 Final Performance Test Accuracy and Energy/Time Data

TOTAL AEV CAPITAL COSTS:	$ 144,377
Standard AEV Parts Total Costs:	$ 144,377
Custom Items for AEV Total Costs:	$ -
Other Items used for AEV Total Cost:	$ -

modify hilighted cells

STANDARD AEV PARTS						
		mass (g)	cost ($/g)	NEW Calculated Cost	*# Used*	*Cost*
Propulsion System	Arduino			$ 100,000.00	1	$ 100,000
	Electric Motors			$ 9,900.00	2	$ 19,800
	Servo Motors			$ 5,950.00	0	$ -
	Count Sensor			$ 2,000.00	0	$ -
	Count Sensor Connector			$ 2,000.00	0	$ -
	Propellers			$ 450.00	4	$ 1,800
Body Structure	T- Shape	30.240	$ 70.00	$ 2,328.48	0	$ -
	X- Shape	30.240	$ 70.00	$ 2,328.48	0	$ -
	2" x 6" Rectangle	21.033	$ 70.00	$ 1,619.54	1	$ 1,620
	2.5" x 7.5" Rectangle	32.868	$ 70.00	$ 2,530.84	0	$ -
	1" x 3" Rectangle	5.256	$ 70.00	$ 404.71	2	$ 809
	1.5" x 3" Rectangle	7.893	$ 70.00	$ 607.76	0	$ -
	Trapezoids (right angle)	7.893	$ 70.00	$ 607.76	0	$ -
	L-Shape Arm	15.374	$ 20.00	$ 338.23	0	$ -
	T-Shape Arm	17.976	$ 20.00	$ 395.47	1	$ 395
	Wheels			$ 7,500.00	2	$ 15,000
	Battery Clamp Narrow	3.981	$ 70.00	$ 306.54	1	$ 307
	Battery Clamp Wide	4.821	$ 70.00	$ 371.22	0	$ -
Brackets & Tools	Angle Brackets	0.268	70	$ 20.65	7	$ 145
	Screw Driver			$ 2,000.00	1	$ 2,000
	1/4" Wrench			$ 2,000.00	1	$ 2,000
	Motor Clamps (1/8 acrylic?)	3.255	70	$ 250.64	2	$ 501
	#55 A Slotted Strip, 2"	0.3708	70	$ 28.55	0	$ -
					TOTAL:	$ 144,377

*(polypropylene density assumed 0.90 g/cm3)

CUSTOM PARTS				
Item	*Type of material*	*Unit Cost*	*Grams*	*Cost*
				$ -
				$ -
				$ -
				$ -
				$ -
				$ -
				$ -
				$ -
				$ -
			TOTAL:	$ -

Custom part information			
	Type	Unit cost	
Laser Cut	PE	$70/g	+10% custom
	ABS	$20/g	+10% custom
	Wood	$50/g	+10% custom
	1/8"	$70/g	+10% custom
	1/4"	$90/g	+10% custom
	3D-printing	$20/g	+10% custom

*ask CFO for more information

OTHER PARTS			
Item	*Unit Cost*	*#*	*Cost*
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
			$ -
		TOTAL:	$ -

*ask CFO for more information / prices

E.2 List of AEV Parts and Part Costs

$$Total\ Budget\ (\$) = Capital\ Costs + \frac{Run_a + Run_b}{2} + R\&D\ Costs + Safety\ Violations$$

where:

$$Run_N = (Energy\ Costs_N + Time\ Costs_N) * Accuracy\ Penalty_N$$

and

Run_a *and* Run_b *are the lowest of Runs 1, 2, and 3*

instructions: fill out the other sheets in the excel, and your cost will be generated below

Capital Costs	$ 144,377
R&D Costs	$ -
Safety Violations	$ -

	RUN 1	RUN 2	RUN 3
Energy Costs	$ 301,345	$ 292,730	$ 291,535
Time Costs	$ 179,280	$ 173,790	$ 175,770
Accuracy Penalty	1.052631579	1.111111111	1
Run Costs	$ 505,921.05	$ 518,355.56	$ 467,305.00

TOTAL COST	$ 630,989.83

E.3 Final Overall AEV Budget