AEV Project Critical Design Review

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Executive Summary:

The primary objective of the Advanced Energy Vehicle (AEV) design project is to complete the MCR (Mission Concept Review). The MCR entails beginning at the starting position on a half circle track. The vehicle is to stop at the gate by tripping the first sensor without tripping the second sensor. The vehicle will then travel the remainder of the half circle to magnetically attach to the caboose. Following this, the vehicle will travel back to the gate, performing the same sequence as before, waiting 7 seconds for the gate to open after tripping the 1st sensor. Finally, the vehicle returns to its starting position, successfully transporting the precious cargo home. The second main objective of the AEV design project is to introduce engineering students to concepts of the design process but more precisely to develop teamwork skills, by expressing experimental observations and results, through professional documentation. Furthermore, from a scientific standpoint, the mission objective focuses on functional consistency, functional efficiency, and energy command of a relatively small autonomous vehicle. Team H primarily set the goal of achieving operational consistency. This involves successfully picking up and delivering the precious cargo stored on a caboose to the original starting spot, while maintaining gravitational balance, aerodynamics, and being lightweight, yet robust, stopping at a couple of sensors in between trips. The second main purpose behind the group's vehicle will be for the device to be energy efficient. These goals will be achieved by screen/score testing various variables of the AEV's design such as: the software code used, propeller type used, framework of the AVE's body, and mass/weight of the machine, etc. Data will be collected and observations will be made on the experiments of these previously stated different variables, to finalize a product that is consistent, yet energy efficient. The remainder of this report will discuss these topics and concepts in much greater detail, along with proper tables and figures to give readers a visualization of what is being discussed.

The need for Advanced Energy Vehicles is at an all-time high. In today's society, there is a huge push to convert to clean energy sources. Coal, oil, and natural gases, although these are fossil fuels, and may allow for machines and technology to run consistently, often lack in the category of energy efficiency. Therefore, introducing engineering students to these concepts early on in their educational careers, is vital to the scientific community. This experience, allows students to consider these aspects when taking higher level classes, and eventually when they enter their fields of interest. All of Team H is aware of the global conditions and with that in mind, have been treating this project like a real-world problem. Energy is a very valuable commodity in life, and is often taken for granted. Clean Energy is the way of the future, and that is the true purpose behind this project.

A major result is Team H successfully completed a code to complete the MCR mission objectives. The program meets all requirements under 2.5 minutes, and runs in precisely 53 seconds. The final performance test scored a 50/50 on the MCR operational run. The final vehicle used 251.473 Joules of Energy, which is relatively low for the weight of the vehicle being 262 grams, giving an Energy/Mass ratio of 0.97. When carrying the cargo home to the starting position, it has never fallen off the track in several successive test runs. The type of battery used per trial does not affect the result of completing the run thus far. Only when several successive test runs in a row due to drainage. Moving forward, Team H plans on applying teamwork skills and design process methodology in future Engineering experiences and applications. This is supported by the schedule (Appendix X)

Table of Contents:

Introduction

The AEV project has been completed by Team H. This report serves to highlight the results of the projects, along with walking through the process of how the results came to be. All important results are included, accompanied by the explanation of these results. Graphs, tables, and other visual aids are present to help provide an understanding of the project as a whole along with individual aspects of it. The goal of the project was to run a small, autonomous, electric-powered vehicle across a track suspended from the ceiling. To completed the mission, the vehicle had to fulfill a list of requirements during the run. In short, it had to go to the end of the track connect with a caboose and return to the start with the caboose. The vehicle was powered by a small battery provided by the instructional team and coded using an arduino controller that could be coded using a computer program. Team H was given all semester to complete this task, and did so with complete success.

Experimental Methodology

Over the course of the past 9 weeks Team H has been working on all aspects of the AEV project. In the beginning stages, all focus was on using predetermined code to become familiar with the Arduino, along with brainstorming and grading possible designs for the vehicle. After that, focus switched to building the actual vehicle and getting it on the track to test; gaining knowledge related to percentage of motor power usage and distance travelled. At this point, Team H gained an understanding of how the propellers work best and how minimizing mass along with compacting the AEV all contribute to running an efficient vehicle. The initial designs changed to reflect these finding and Team H narrowed to 2 designs. After further testing and the use of scoring matrices, Team H decided on a design to use and it is the current model at this point. Once a design was picked, the focus shifted again. At this point, coding the AEV to complete the entire task was the main objective. Team H wrote and tested a code that completed the task without error. Data was collected and approximately 270 J of energy was used.

After Team H successfully completed the mission at 270 J, focus switched to making adjustments to the code and design to lower the energy usage. New blades were bought and testing began. A design that accommodated for these blades was built, since they were much wider than the previous blades. After time spent working with these new blades, no progress was being made, so Team H switched back to the old blades and focused on making changes to the code. Longer periods of gliding without the motors were introduced, along with shorter, more powerful bursts of energy. At the final test, with changes to the design and code, Team H completed the run in 53 seconds and using just 251.473 J. For detailed descriptions and procedures of each lab period, refer to the lab manual, “The Ohio State University Advanced Energy Vehicle Design Project: Lab Manual” located on carmen.

Results and Discussion:

One of the first main results team H reached is that when testing the two different types of propellers, it became apparent that the 3020 propellers provided far more thrust than the 2510. This became apparent by looking at the data taken during the wind tunnel lab. The following two tables provide a comparison of the thrust of the 3020 and 2510 puller configurations.

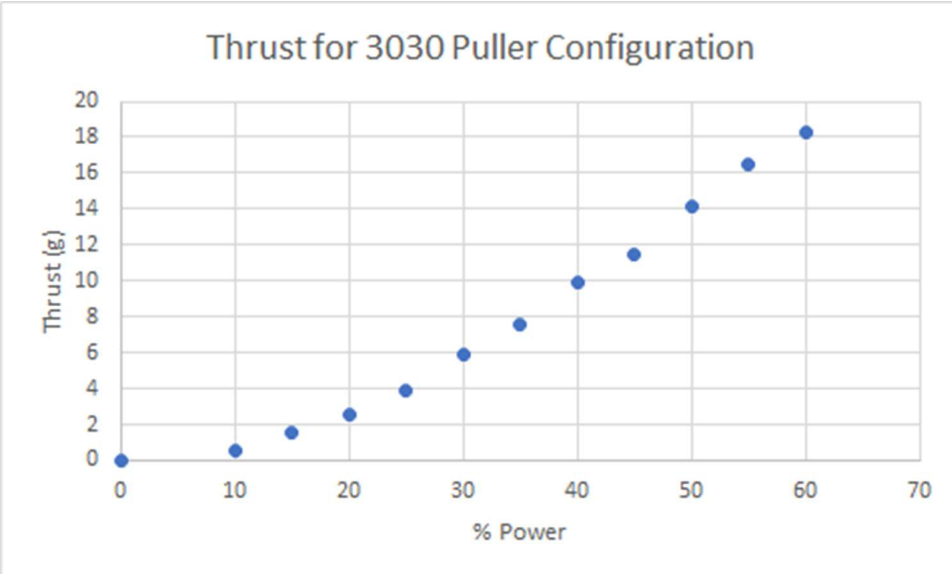


Figure 1: 3020 puller configuration thrust vs percent power

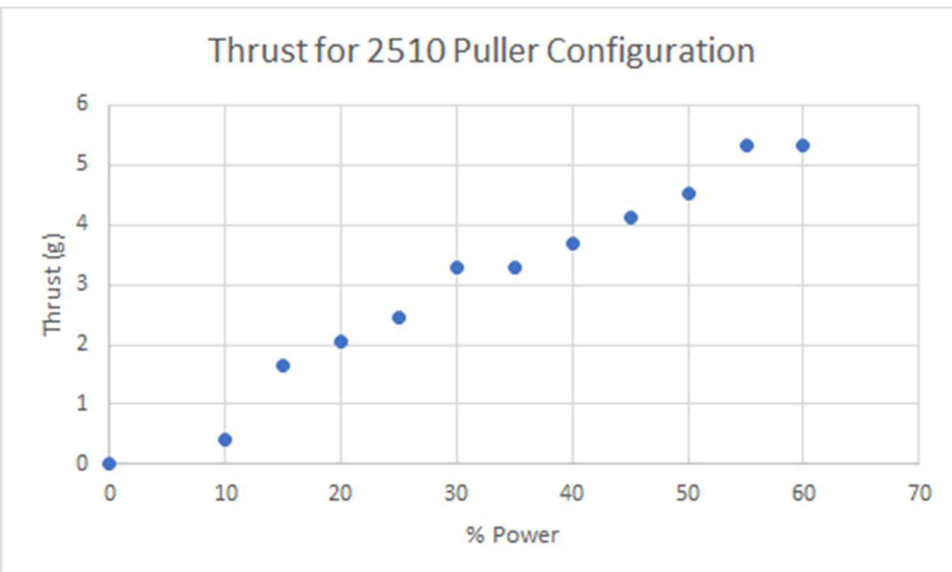


Figure 2: 2510 puller configuration thrust vs percent power

As one may see, the 3020 propellers provided over three times as much thrust on average. Team H also discovered that 3020 propellers worked much better by testing both the propellers on the same AEV with the same code. The test using the 3020 propellers worked fine, and the AEV rolled smoothly to the gate. However, when the team put the 2510 propellers on and ran it again, the AEV did not even begin to move.

Team H spent the first few weeks observing and brainstorming ideas for AEV designs. Each team member came up with a design, and the team met and discussed their options. Observing two of the designs presented (3 and 4), those two designs were very like the reference AEV provided to the team. Two of the designs presented by the team were replicas of the reference AEV design provided so the scoring was exactly the same as the reference. The team decided to continue with design one and two for testing, while comparing it to the reference AEV from before.

Screening Scoresheet					
Success Criteria	Reference	Jesse	Josh	Nate	Bret
Balance	0	0	+	0	0
Center of Gravity	0	0	+	0	0
Power Efficiency	0	0	0	0	0
Cost	0	+	0	0	0
Weight	0	+	0	0	0
Aerodynamics	0	0	+	0	0
Consistency	0	0	0	0	0
Sum +	0	2	3	0	0
Sum -	0	0	0	0	0
Sum 0	7	5	4	7	7
Net Score	0	2	3	0	0
Continue	Revise	Yes	Yes	Revise	Revise

Table 1: design concept screening sheet

Team H narrowed the testing down to seven different categories. These categories are seen in the scoring and screening matrix above. These seven categories were decided to be the most important factors for team H to test the AEV potential. Josh's AEV outperformed Jesse's AEV in balance and center of gravity, which is part of what Team H was looking for and its design was more aerodynamic than Jesse's. After reviewing the 4 designs presented by the team, it was concluded that Josh's design, which will now be referred to as design 1, would be moved forward with. After completing this lab, an alternative design, design 2, which was a modified version of Josh's design. Team H decided to test these two designs because they were balanced, and were aerodynamic. Design one had a larger rectangular base (2.5'' x 7.5'') and wings extended horizontally in the middle. It used the trapezoid plates for wings and utilized the L shaped arm. The Arduino was placed on top of the base and the battery was placed below the base using the battery supports provided. Design two had a smaller rectangular base (2'' x 6'') and the wings were placed in the back. The wings used the trapezoid bases and were angled out using the brackets. The motors supplied were attached underneath the wings. The arm utilized in design two was the L shaped arm. The base was attached to the arm sideways then the Arduino and battery were placed on opposite sides of the base. Finally, there was an angled bracket attached to the arm, that extends between the wings and motors provided, which connects to the caboose. Both designs used the black 3020 propellers. After the two designs were picked Team H moved on to testing them.

Scoring Matrix							
		Reference		1		2	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Balance	20%	2	0.40	3	0.60	5	1.00
Center of Gravity	5%	3	0.15	4	0.20	5	0.25
Power Efficiency	15%	3	0.45	3	0.45	3	0.45
Cost	10%	3	0.30	3	0.30	3	0.30
Weight	10%	3	0.30	3	0.30	4	0.40
Aerodynamics	15%	3	0.45	4	0.60	4	0.60
Consistency	25%	4	1.00	4	1.00	5	1.00
Total Score			3.05		3.45		4.00
Continue?		No		Revise		Develop	

Table 2: Design concept scoring matrix

After testing both designs, it was observed that design two was more balanced on the track, and it had more control. Because of this, design two was more consistent. The team was successfully able to stop design 2 inside the two markers before the gate six times in a row utilizing design two, however, when testing design 1, the results obtained were far more random. On multiple occasions the team noticed that design one would stop at significantly different spots than it had the run before. This called the consistency of design one into question. Since one of team H's main priorities for the AEV is consistency, this inconsistency factored in largely to our decision in picking the better design.

Other observations made testing these designs were that the energy consumption of both designs did not differ significantly. Design two completed one run in which it completed the MCR by making one full trip around the track, the energy vs. distance graph from this run can be found in figure 1. The total energy used in this run was 270 joules. Team H noticed spikes in energy as the AEV approached the gate. This corresponded to the codes brake function to stop the AEV. Then the energy dropped while it was at the gate. The smaller spikes in the energy corresponded to the changes in speed implemented in the code. The second half of the run used more energy than the first half due to the added weight of the caboose.

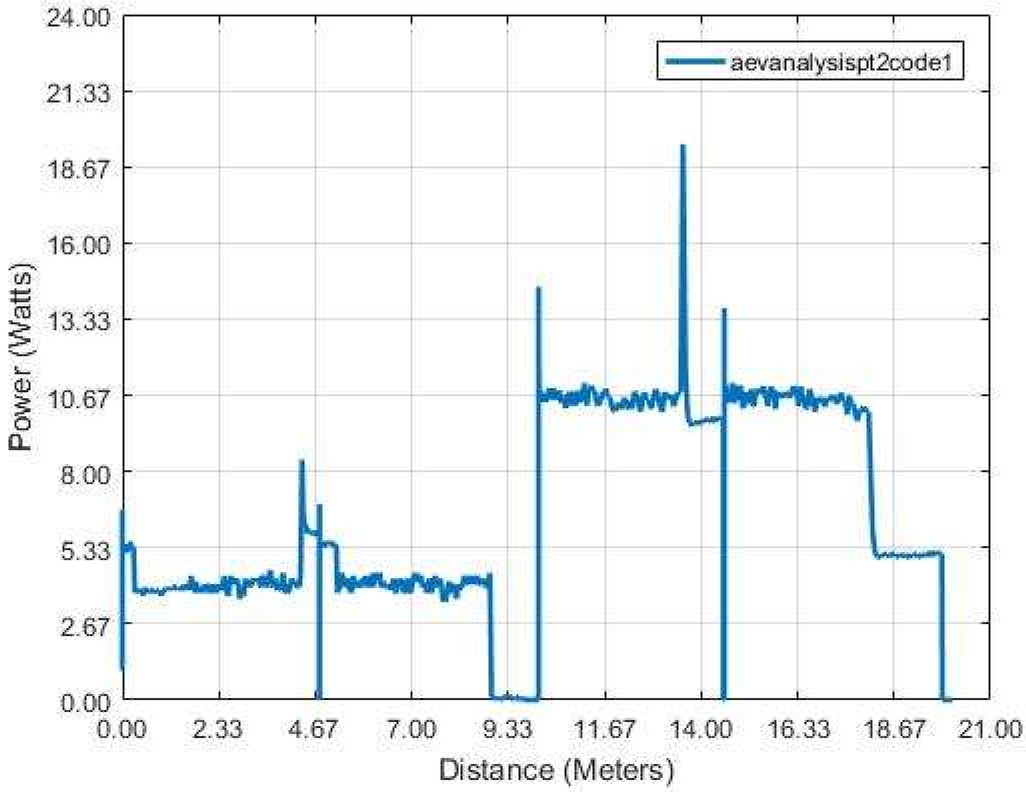


Figure 3: Design 2 power vs distance for one full run

Design one never completed one full test around the track. However, both designs ran from the start to the front of the gate. The following figure is a graph of Power vs. Time for design 1 for one trip from the start to the first gate.

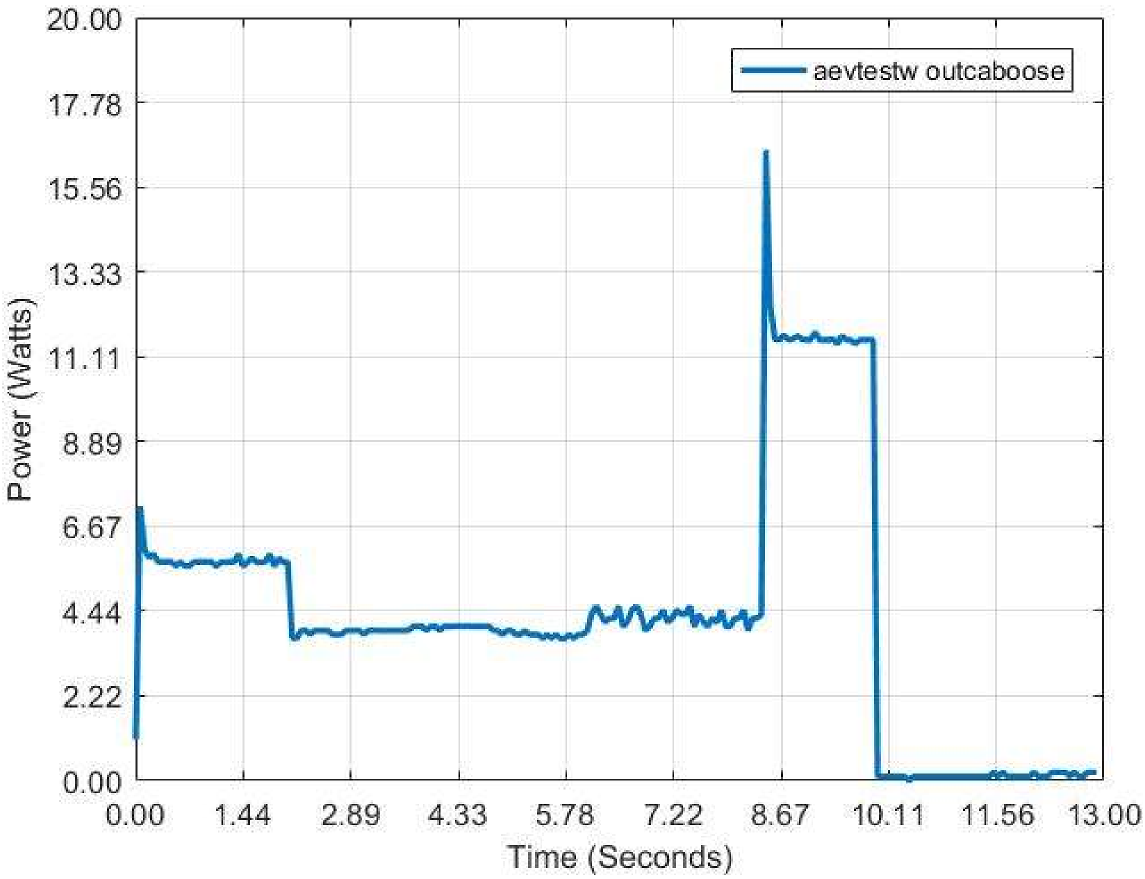


Figure 4: Design 1 power vs time for one trip to the first gate

This run used around 45 joules. Under the same conditions, design 2 also ran this and also consumed around 45 joules. This result was expected, because design 2 was not designed to improve upon the energy consumption of design 1, it was built to improve balance and control, which helps with the AEV's consistency which was Team H's goal. The lack of variation in the amount of energy used by the AEV's meant that energy consumption was a non-factor in deciding which AEV to move forward with. However, the team is not pleased with the amount of energy that the AEV is currently consuming.

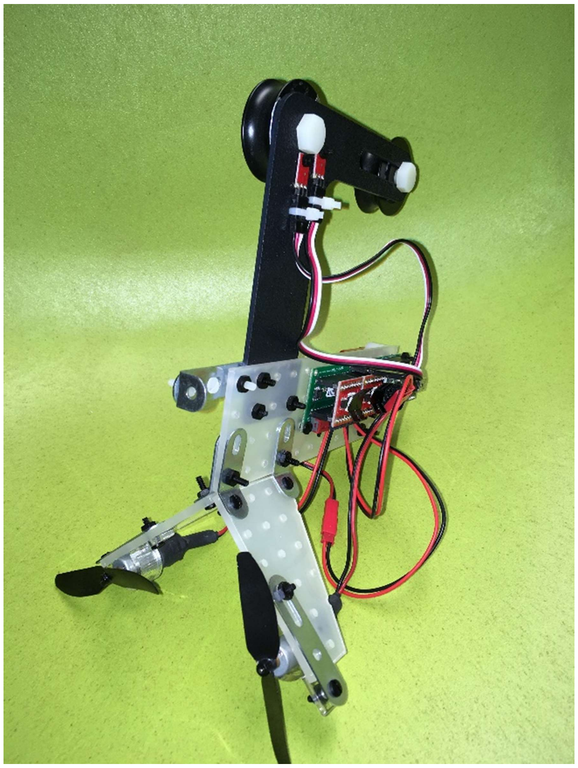


Figure 5: Image of design 2

After selecting design two over design one, Team H had two ideas to improve the design. The first idea was to increase the friction between the rail and the wheels on the AEV. This would increase the stopping consistency of the AEV. To accomplish that, Team H cut a rubber glove and wrapped it around the wheels. The rubber did make the AEV stop more quickly, however it made it more difficult for the AEV to move on the track. Since the motors had to run at a much higher power to move on the track with the rubber on the wheels, Team H decided to not implement the rubber to the design. The second idea involved changing the propellers. A member of Team H brought up a lab from the first engineering class that involved working with propellers and a wind turbine. The point he made was how propellers with three blades operated more efficiently than those with two blades. Team H has a solid works design of the three blade propellers, however the team thought it would be more beneficial to buy them since they lacked the experience in Solidworks to fully define it. Team H invested four dollars and bought two pairs of three blade propellers to test on the AEV.

After considering the design of the AEV, Team H shifted its focus to the code that would run the AEV. Team H split the code into four parts, which consisted of making it to the gate, picking up the caboose, returning to the gate, then returning to the starting position. The team split the code up into sections because it allowed them to find errors and test the code more efficiently. The code that Team H currently implemented with the AEV runs consistently. The code constantly used the motor and utilized the reverse functions to stop at the gates. As seen in appendix E. Then, Team H set their mind to building a second code that is still a work in progress. Team H plans to have another code that uses the motor less to reduce the amount of energy used. The code will cut the power to the motor with the Brake function and let the AEV coast up to the gate and stop. This will take time and testing to work, but the team believes it can be done and would be vital in reducing the energy consumption.

Shortly after performance test 1, team H began experiencing technical difficulties with the AEV. First off, the new set of propellers did not correctly fit on the motor. This was a disappointment for the team, as the Team was counting on the new motors to help increase efficiency. Also, the AEV stopped working on the track. Under the exact same conditions and motor speed, the AEV failed to move at all. The exact source of this error is still unclear; however it was clear that something changed. Team H trouble-shooted for around a week, however no progress was made. This led the team to create a slightly different design as pictured below.

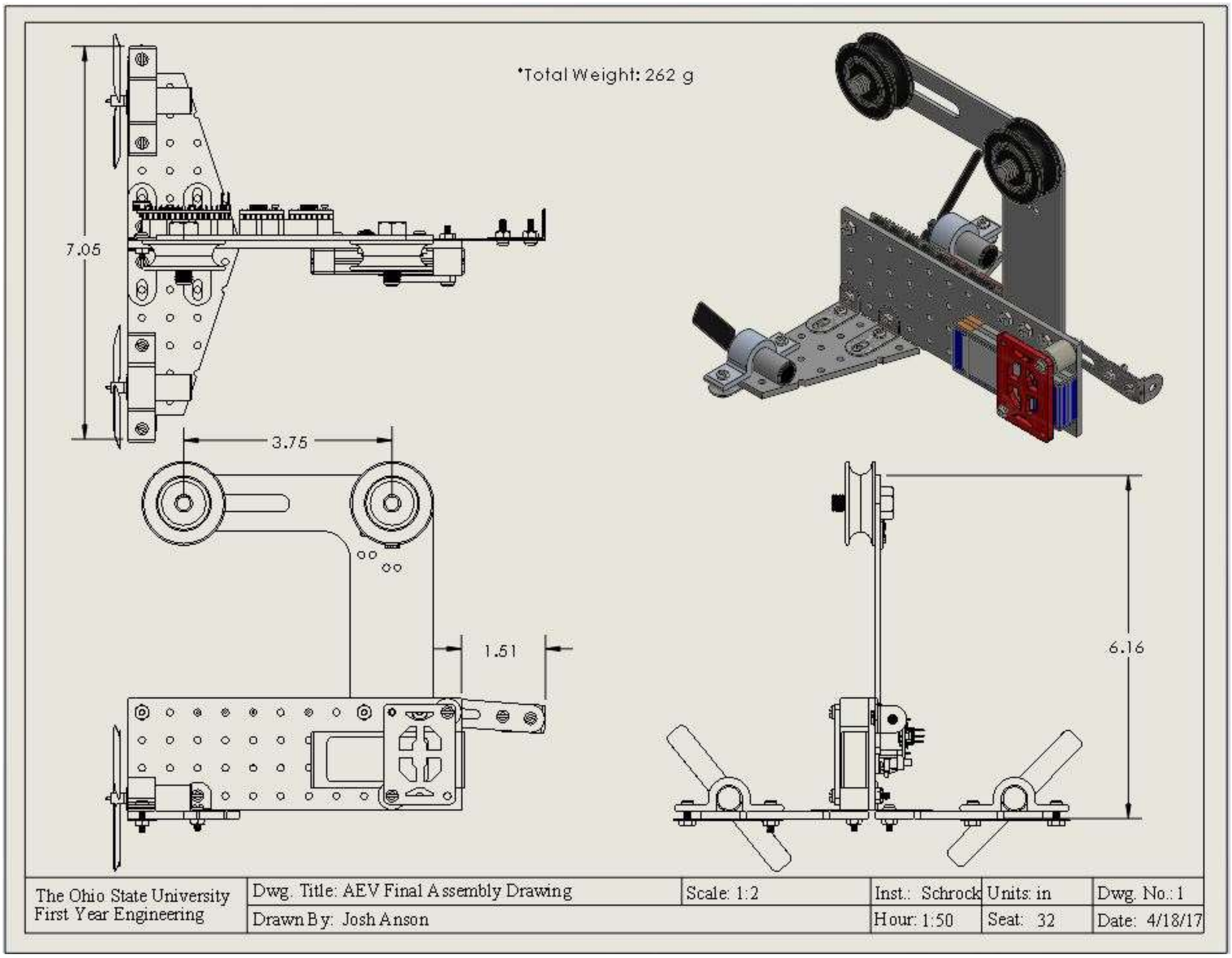


Figure 6: Final solid works assembly drawing of the final design

In this design, which would end up becoming the team's final design, the team changed the wings so that they extend from the body at 90 degree angles rather than the 45 degree angles that the AEV previously had. Also, in this design, the battery was moved up the side of the AEV, closer to the front, so the weight became more evenly distributed to reduce the friction on the wheels. These adjustments, along with a slight increase in motor speed, cause the AEV to begin performing again normally. This design was scored using the same scoring matrix as before, and it received the same score as design two, this scoring matrix can be found in appendix E. However, because of the slight increase in motor speed, the AEV was using approximately 270 joules to complete one trip around the track. Team H wanted the AEV to use less energy than this so we looked at the code to begin trimming energy used.

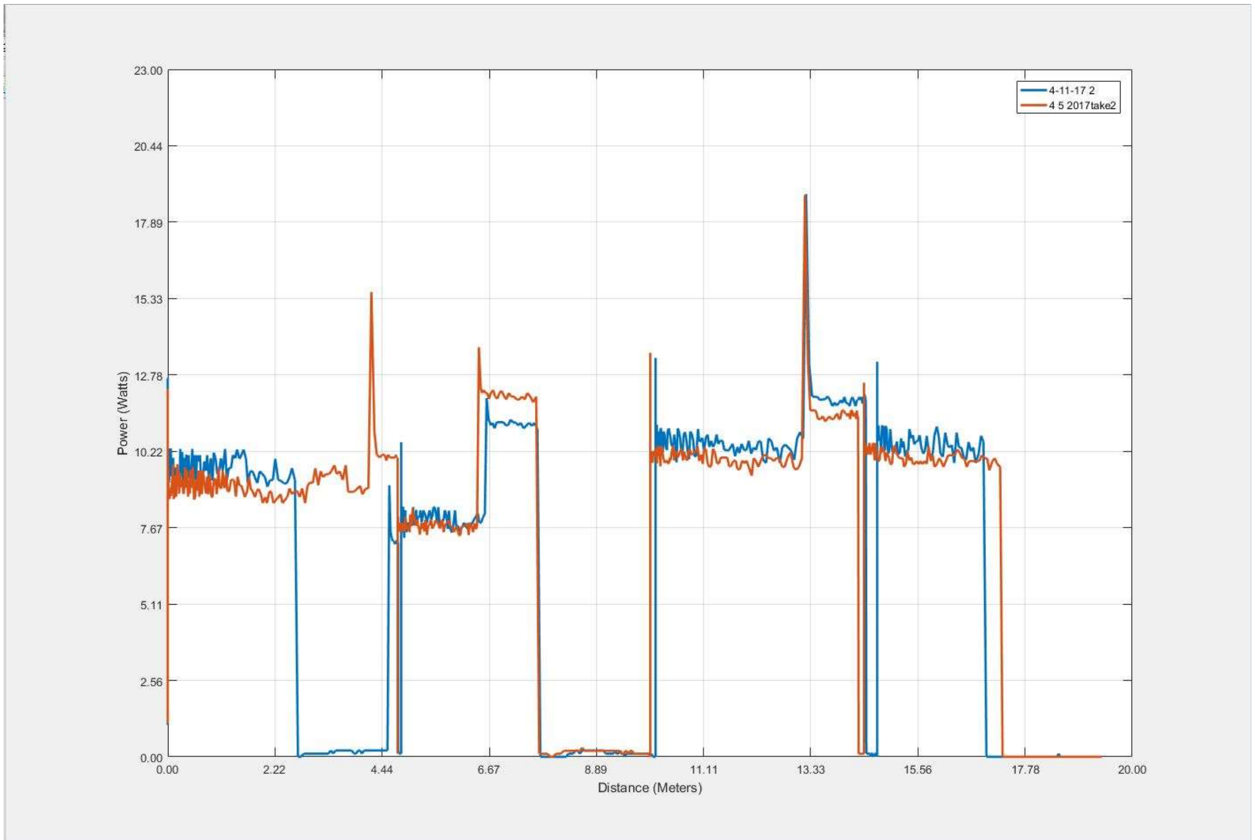


Figure 7: Energy usage of code 1 (orange) compared to the final code (blue)

Team H developed a code that involved longer streaks of coasting, to save energy. The power used by the AEV over distance for the two codes is pictured above. The plot in orange is the original code. One can observe that this code ran the motor at slightly lower powers, however, it also ran the motor for longer amounts of time. This run used 270 joules. The blue plot shows the power vs distance for our final run, in which only 250 joules of energy was used. This code used slightly more power however the power was used over shorter distances and the AEV was allowed to coast for longer distances. The team also had to decide whether we wanted to cut more energy, but sacrifice control. This would have been done by cutting the reverse sections out of the code, and allowing the AEV to coast gradually to a slow stop. This idea was not implemented however because control and consistency was a larger goal than efficiency, and in the end, team H did not want to sacrifice control, to cut energy use.

The team successfully completed performance test 4, final testing. The final results was that our AEV successfully completed the MCR, and received a 50 out of 50 for our performance on the track. On top of that, the final AEV weighed 262 g, and used only 251.47 joules. This gave us an energy to mass ratio of .95982 J/gram. This inflated our final score to 52.1.

One potential source of error is that one of the 3020 propellers the team has been using has become slightly misshapen because of the difficulties we have had putting it on and taking it off the motor. It is believed that one of the motors is slightly larger than it should be, because it is incredibly challenging to put the propellers onto, and take them off that motor. One of the propellers has been placed on that motor facing the wrong way (the less efficient orientation), however, because of the difficulties of the motor, the team has not been able to remove that propeller and switch its orientation. One other issue team H has run into during the testing process is the battery drainage after successive runs. Team H feels most comfortable utilizing a trial and error method, so the team runs the AEV many times during lab, and it has been noticed that after many times running, the motors will begin to become slow and less responsive. This causes significant error in the stopping speed and location of the AEV. Team H worked extensively to create an AEV that was very consistent, which would minimize our error the most. The team took many measures to mitigate the error through code that would increase control on the track. One specific example of this is in the final code, the code is designed to have the AEV move slowly around the corner after the gate, and only after it gets around the corner, it speeds up to coast to the gate. This was done to reduce the error from the AEV swaying on the track. Steps such as these ensured that Team H's AEV had as little error as possible.

Conclusion and Recommendations

The purpose of the AEV project is to design a vehicle that successfully completes the mission concept review while incorporating energy efficiency and design enhancements. This is done through a semester long project filled with labs all building up until the final testing. Team H has tested many different items, from propeller advance ratios, to the effect of changing the shape of our AEV to increase balance. Over the many weeks, the team has gone through many steps of the design process, and has now fully completed, and tested the final AEV design.

One of the first major results the team received was that comparing the 3020 propellers to the 2510, it was clear that the 3020 propellers were best. Through rigorous testing, team H has a design to move forward with. This was done through screening and scoring matrices, testing a multitude of times on the track, and using those two things to both quantitatively and qualitatively pick the superior AEV. It was decided that the team could work on cutting down energy with either design since there was no large discrepancies in the energy efficiency of the two. The team compared two different designs, but in the end, the final design used turned out to be neither of them. This was because of technical difficulties experienced. However, in the end, Team H believes that we met many of our design goals, and built one of the most consistent, and balanced AEV's in the class. This can be seen through our final testing.

Upon the final testing of the AEV, team H received a perfect score for the AEV completing the mission flawlessly. In addition, the team calculated an energy to mass ratio of .95982 J/gram. This meant the final score received ended up being 52.1.

Team H struggled early on with connecting the reflectance sensors from lab 2, but they caught up quickly in the next lab. Another problematic area for Team H was performance test 2 and 3. At that time their AEV stopped working so they spent most of their time troubleshooting and adjusting the code. This set the team back but they did manage to catch up and complete the labs once they solved the problem. To fix the problem, the team readjusted the battery and they increased the speed used in the code. One of our main ideas failed. This idea was to increase the AEV's grip on the track by placing rubber strips on the wheels. However, after testing, it was observed that the amount of energy used would be too high with the rubber. Team H encountered problems with one of the motors in that the propellers do not fit on the motor easily. However, this error was finally able to be resolved and the propeller was finally able to fit well on the motor.

Over the course of this project, and throughout the semester, Team H partook in many different labs pertaining to the AEV project. Some recommendations to improve the project would be to spend less time working on random Solidworks assignments, and instead, do solid works assignments that have to do with the AEV. For example, there was only one mandatory assignment all semester where a team member had to design a part for the AEV using Solidworks. Why not have more assignments like these? It might make kids realize the full potential of solidworks more and allow team members to become more creative with the AEV design.

Appendix

Appendix A: Wind Tunnel Data

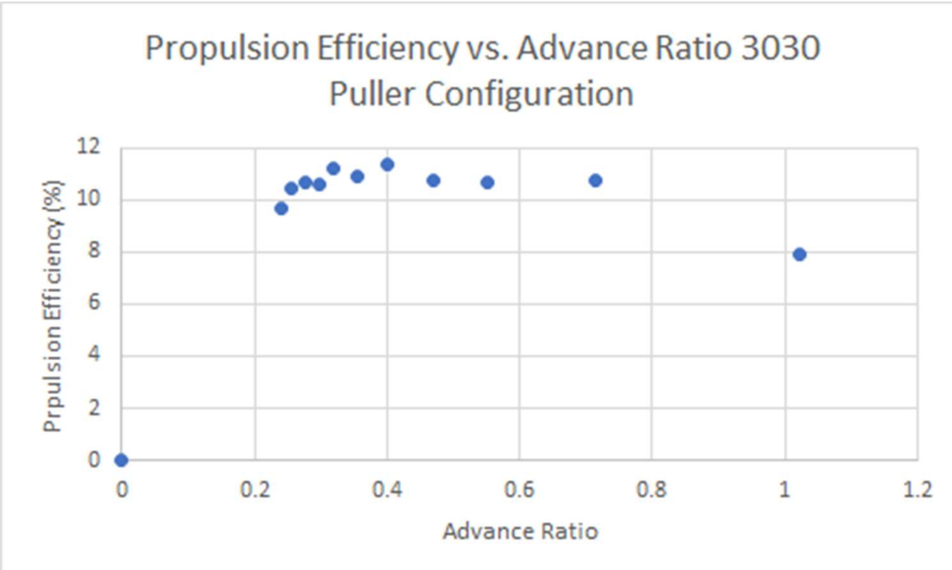


Figure 1: Propulsion efficiency vs advance ratio for 3030 puller configuration

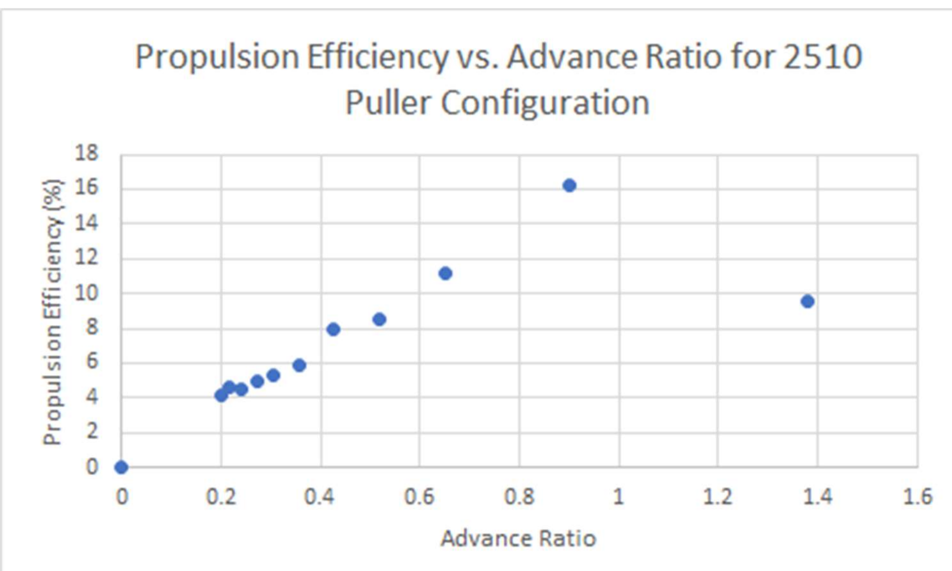


Figure 2: Propulsion efficiency vs advance ratio for 2510 puller configuration

Appendix B: Design Images

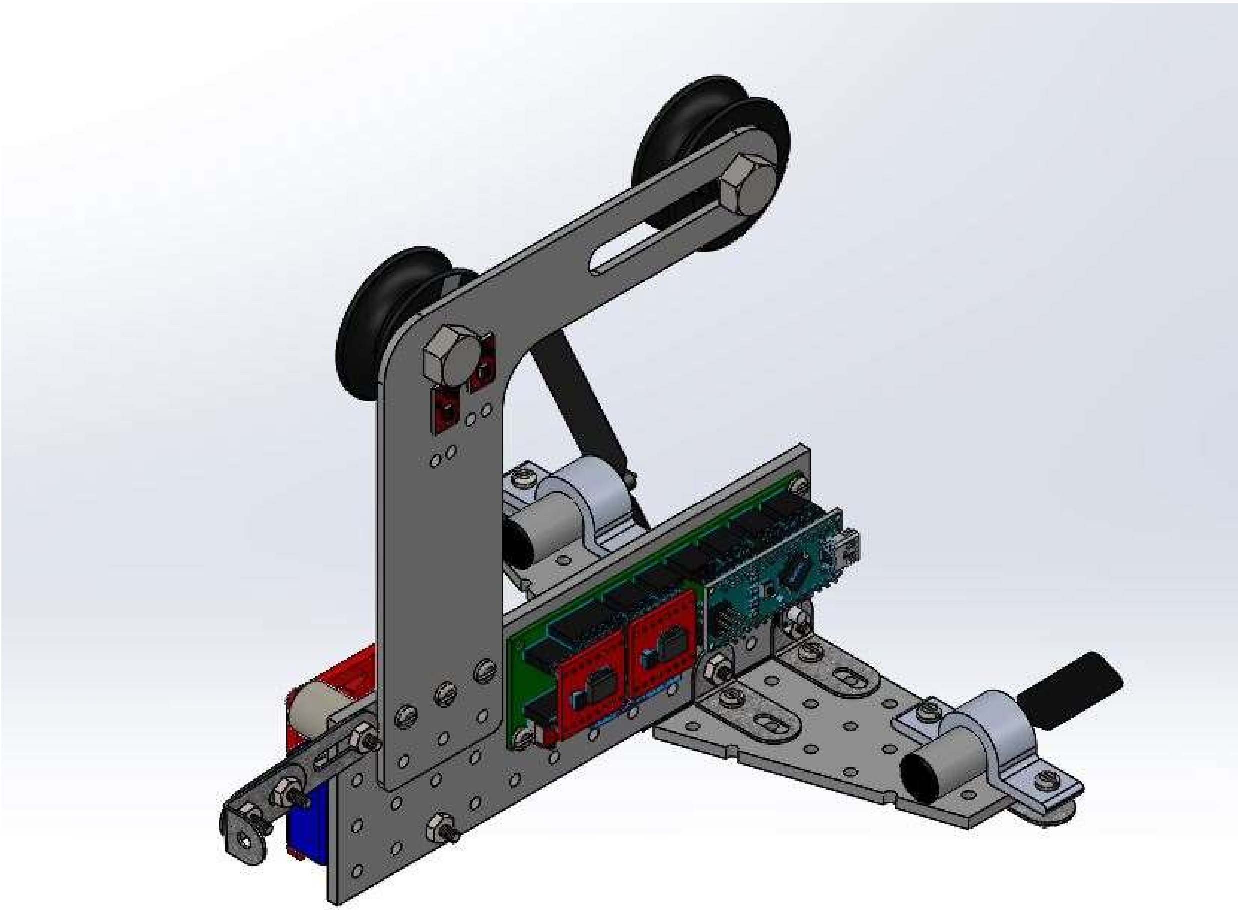
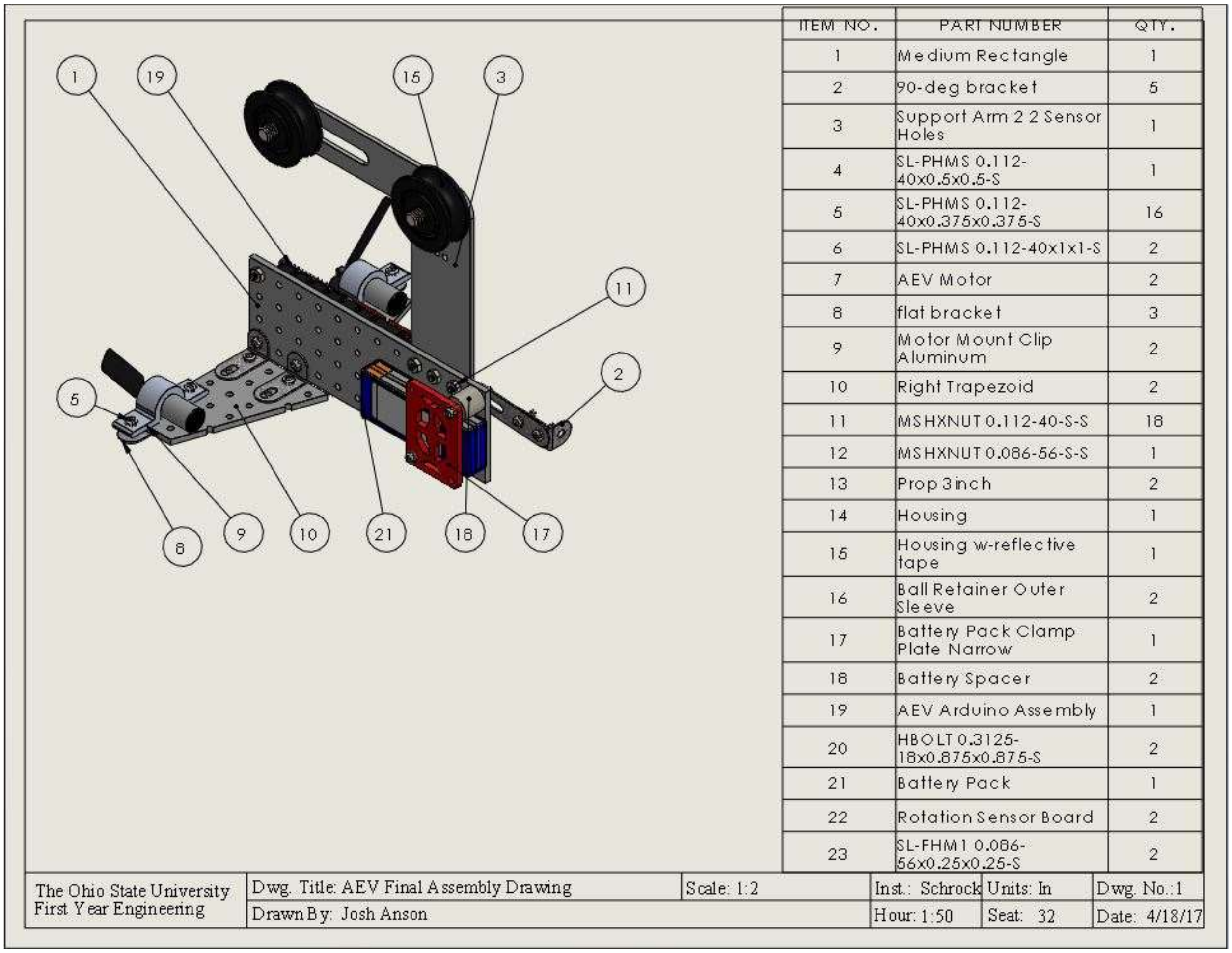


Figure 1: Final Design orthographic view of left side



ITEM NO.	PART NUMBER	QTY.
1	Medium Rectangle	1
2	90-deg bracket	5
3	Support Arm 2 2 Sensor Holes	1
4	SL-PHMS 0.112-40x0.5x0.5-S	1
5	SL-PHMS 0.112-40x0.375x0.375-S	16
6	SL-PHMS 0.112-40x1x1-S	2
7	AEV Motor	2
8	flat bracket	3
9	Motor Mount Clip Aluminum	2
10	Right Trapezoid	2
11	MSHXNUT 0.112-40-S-S	18
12	MSHXNUT 0.086-56-S-S	1
13	Prop 3inch	2
14	Housing	1
15	Housing w-reflective tape	1
16	Ball Retainer Outer Sleeve	2
17	Battery Pack Clamp Plate Narrow	1
18	Battery Spacer	2
19	AEV Arduino Assembly	1
20	HBOLT 0.3125-18x0.875x0.875-S	2
21	Battery Pack	1
22	Rotation Sensor Board	2
23	SL-FHM1 0.086-56x0.25x0.25-S	2

Figure 2: Final design orthographic view of left side with bill of materials

Appendix C: AEV Code

**********Code 1:**********

```
motorSpeed(4,25);
goFor(2);
motorSpeed(4,20);
goFor(4);
goToAbsolutePosition(346)
; reverse(4);
motorSpeed(4,25);
goFor(1.5);
brake(4);
//getting to the gate
```

```
reverse(4);
goFor(7);
motorSpeed(4,25);
goFor(2);
motorSpeed(4,20);
goToAbsolutePosition(715)
; reverse(4); brake(4);
goFor(5);
// connect to the caboose
motorSpeed(4,40);
goToRelativePosition(-
280); brake(4); reverse(4);
motorSpeed(4,40);
goFor(2);
brake(4);
//getting to the gate second time
goFor(7); reverse(4);
motorSpeed(4,40);
goToRelativePosition(-
280); brake(4); reverse(4);
motorSpeed(4,25);
goFor(3); brake(4);

//bringing her home
```

****

********Final Code********

```
reverse(4);

motorSpeed(4,35);

goToAbsolutePosition(215);
brake(4);

goToAbsolutePosition(368);
reverse(4);
motorSpeed(4,30);
goFor(1);
brake(4);

reverse(4);
goFor(7);
motorSpeed(4,30);
goToAbsolutePosition(520);
motorSpeed(4,40);
goFor(1.3);
brake(4);
```

```
reverse(4);
brake(4);
goFor(10);

// connect to the caboose
motorSpeed(4,40);

goToRelativePosition(-245);
brake(4);
reverse(4);
motorSpeed(4,43);
goFor(2);
brake(4);

goFor(7);
reverse(4);
motorSpeed(4,40);
goToRelativePosition(-180);
brake(4);

********************
```

Appendix D: Project Schedule

Lab Number/Role	Task	Start	Finish	Due Date	Josh	Nate	Jesse	Bret	% Complete
1	Arduino Programming Basics	18-Jan	24-Jan	25-Jan	x	x	x	x	100
2	External Sensor+ System Analysis 1	25-Jan	31-Jan	1-Feb	x	x	x	x	100
3	Critical Thinking/Brainstorming	1-Feb	7-Jan	8-Jan	x	x	x	x	100
4	System Alysis 2 +Data Tool	8-Feb	14-Feb	15-Feb	x	x	x	x	100
5	AVE design concepts	15-Feb	21-Feb	22-Feb	x	x	x	x	100
6	Halfway Check Point	22-Feb	28-Feb	1-Mar	x	x	x	x	100
7	PRD Oral Presentations	1-Mar	1-Mar	1-Mar	x	x	x	x	100
8A	PT1	7-Mar	7-Mar	7-Mar	x	x	x	x	100
8B	Coding-Work Session	8-Mar	8-Mar	8-Mar	x	x	x	x	100
8C	PT1-Code	21-Mar	21-Mar	21-Mar	x	x	x	x	100
9A	PT2	22-Mar	22-Mar	22-Mar	x	x	x	x	100
9B	PT2-Code-Work Session	24-Mar	24-Mar	24-Mar	x	x	x	x	100
Programing					x			x	100
Documentation					x	x	x	x	100
Design					x	x	x	x	100
Data Analysis					x				100
9C	PT2-Code-Lab	28-Mar	28-Mar	28-Mar	x	x	x	x	100
10A	PT3-Energy Optimization	31-Mar	31-Mar	31-Mar	x	x	x	x	100
10B	PT3-Energy Optimization-Work	4-Apr	4-Apr	4-Apr	x	x	x	x	100
10C	PT3-Energy Optimization-Lab	5-Apr	5-Apr	5-Apr	x	x	x	x	100
11A	PT4-Final Testing	7-Apr	7-Apr	7-Apr	x	x	x	x	100
11B	PT4-Final Testing-Work Session	11-Apr	11-Apr	11-Apr	x	x	x	x	100
11C	PT4-Final Testing-Lab	12-Apr	12-Apr	12-Apr	x	x	x	x	100
12A	Final project Report	14-Apr	14-Apr	14-Apr	x	x	x	x	100
12B	Finish CDR + Return AEV	18-Apr	18-Apr	18-Apr	x	x	x	x	100
12C	Final Oral Presentation	19-Apr	19-Apr	19-Apr	x	x	x	x	75

Appendix E: Scoring Matrices

Scoring Matrix					
		Reference		B (Final Design)	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score
Balance	20%	2	0.40	5	1.00
Center of Gravity	5%	3	0.15	5	0.25
Power Efficiency	15%	3	0.45	3	0.45
Cost	10%	3	0.30	3	0.30
Weight	10%	3	0.30	4	0.40
Aerodynamics	15%	3	0.45	4	0.60
Consistency	25%	4	1.00	5	1.00
Total Score			3.05		4.00
Continue?		No		Yes	

Table 1: Scoring matrix for the final design to show that there is no difference in score of design 2 and final design