Critical Design Review

Submitted to:

Inst. Phillip Schlosser

GTA Amena Shermadou

Created By:

Group R

Maycee Hurd

Anna Goodge

Jack Bell

Chris Lipnicky

Engineering 1182

The Ohio State University

Columbus, Ohio

19 April 2018

Executive Summary

Linden, a neighborhood in Columbus, Ohio, is described as an "urban desert." This is due to specific factors prohibiting the convenience of travel for its citizens. Some of these factors being a nearby highway and inadequate public transportation which cut off residents from local public services. However, Smart City Columbus hopes to solve this problem and bridge the gap of opportunities between residents of Linden and other neighboring areas. The team of engineers at Koffolt Properties was asked to design an Advanced Energy Vehicle, or AEV, that would efficiently transport people from Linden to the commercial areas of Easton and Polaris.

To create a solution to this task, research had to be conducted on the fundamental components of an AEV. This started with preliminary research, where the team investigated how to use its parts such as the Arduino Nano board, motors, and reflective sensors. Here is when the team learned the important skill of programming with Arduino. During this time, the first designs for prototypes were created. Each team member individually drafted a model of the AEV to discuss. After that, two specific topics were researched in the advanced research and development stage. These two topics were motor configuration and the differences between coasting and power braking. Once these two areas were tested, the data found in the research was applied to the first performance test, in which the AEV would complete the first part of the final task. The performance test would prove to influence the design because of its constraints such as track variance and the specific positions of stopping for the vehicle.

During the motor configuration lab, two different orientations were tested. The first was both motors facing in the same direction and the second was each motor facing opposite directions. Under the same independent variables, the power used by the opposing motors was always higher than that of the motors facing the same way. Afterwards, the differences between the two were tested to determine the most effective method of stopping. Coasting proved to be a more consistent method of stopping and used less energy, however it took much a longer distance to stop than power braking. Based on the nature of the task, power braking was deemed the superior method of the two. Because the results were not particularly appealing, alternative methods of stopping will also be tested, one of these methods being the use of the Micro Servo as a contact brake to quick stopping. During the performance test stage, it was discovered that using distance instead of time as the independent variable in the Arduino programs proved to be a more consistent and efficient method.

The main reason that this research could be incomplete is the lack of variances in each area tested. In the future, more motor configurations should be tested, and coasting and power braking should be analyzed under additional scenarios. Even though some of these topics may not coincide directly, their research is conducted with the ultimate goal of reconnecting Columbus' "urban desert".

Table of Contents

Introduction

Residents of Columbus refer to the neighborhood of Linden as an "urban desert." This means that, despite being in a geographically urban area, its citizens are still generally cut off from basic public services that are otherwise easily accessible to other nearby areas. The I-71 highway runs straight through this area, limiting local travel routes. Using public transportation is not a convenient option for citizens either because of Linden's inadequate transportation system and bus stations. These are the problems that Smart City is trying to solve. Smart City is an organization that is working towards creating Smart solutions to problems in communities involving public services (City of Columbus, Ohio, 2018). The organization asked the team of engineers at Koffolt Properties to design and create an Advanced Energy Vehicle (AEV) to safely and efficiently transport Linden residents to the commercial areas of Easton and Polaris.

Experimental Methodology

To create an effective design for the AEV, the team first needed to conduct several stages of research that pointed to the factors of the design. The first of these stages being the preliminary research and development, where the team learned about the basic components of the AEV such as the Arduino Nano board, reflective sensors and the motors. To learn the basic commands used in the Arduino syntax, the team created a program that would accelerate the motors and run them individually for various times and speeds (see attached: Code A.i). After that, the reflective sensors were introduced to the models and the observed how the sensors responded to traveling a certain amount of "marks", or distance (one mark is equal to .487 inches). Members of the team would spin the wheels of the AEV to simulate movement, and the program would stop running after it read the required amount of marks (see attached: Code A.ii). The sensors attached to the arm of the vehicle are shown in Figure 1 (The Ohio State University, 2018).
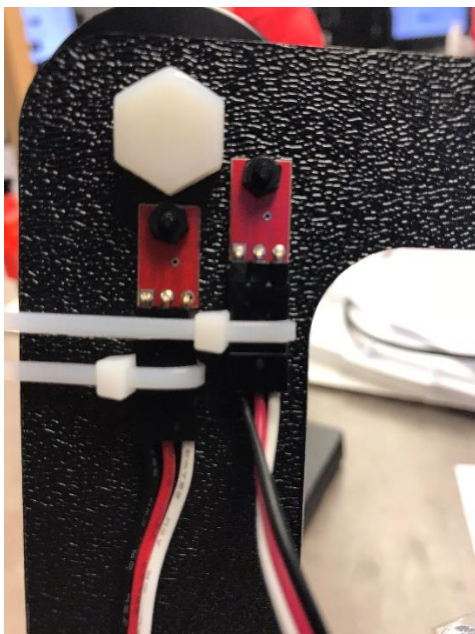

Figure 1: The reflective sensors attached correctly to the AEV

During this stage, each team member had hand drawn their own prototype design. Each design was discussed, and their strengths and weaknesses were recorded. After this, the team moved on to the advanced research and development stage, where they investigated to topics of choice. Those topics being motor configuration and coasting vs. power braking. Motor configuration refers to the orientation of the motors on an AEV model. To analyze this, two separate configurations, one with two motors facing in the same direction (Figure 2) and one with two motors in opposite directions (Figure 3), were programmed using identical codes and ran down the straight track. Energy consumption would be the dependent variable that was investigated.
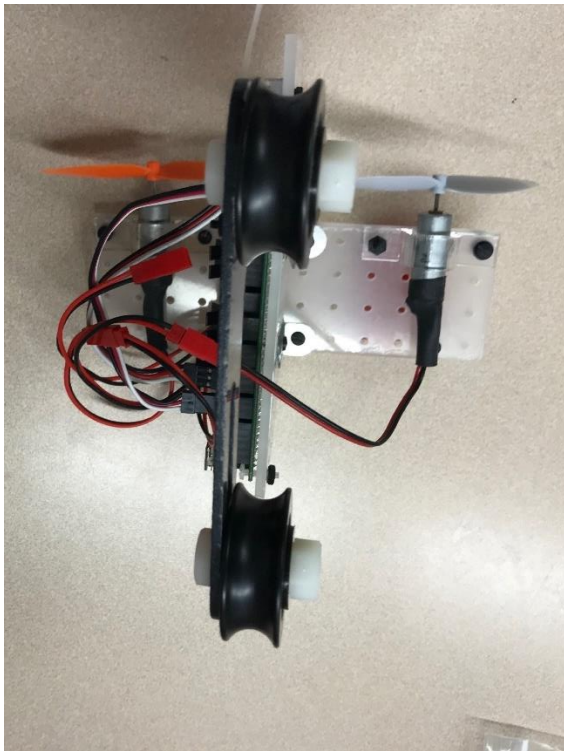

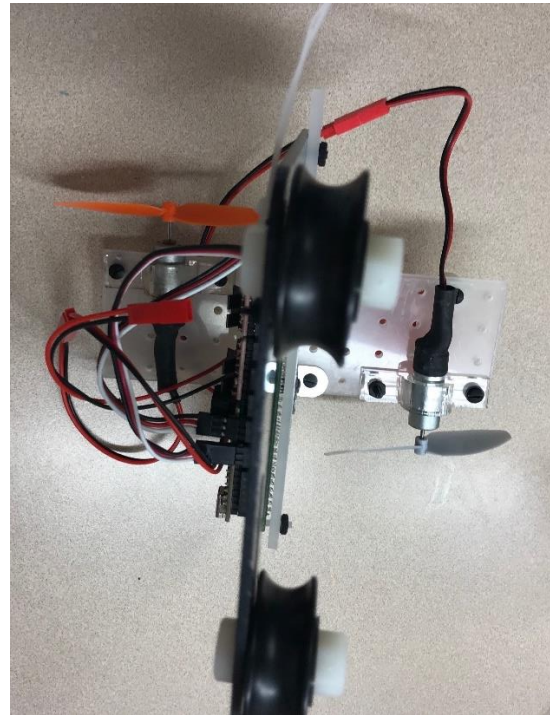Figure 2: Motor Configuration 1

Figure 3: Motor Configuration 3

Once motor configuration was tested, the team moved on to coasting vs. power braking. This lab was conducted by given the same AEV model (Figure 4) two different programs that only differed by their method of stopping. Both programs would have the AEV travel forward for the same amount of time at the same power percentage. After this forward motion ended, the first program cut power to the motors and let the vehicle stop on its own due to friction (see attached: Code CB.i). The second code however, made the motors run in reverse for a short amount of time (see attached: Code CB.ii). This was intended to create an opposing force and slow the AEV in a faster manner. Each of these programs were ran five times each. The stopping distance and energy consumption for each trial was recorded and then analyzed.
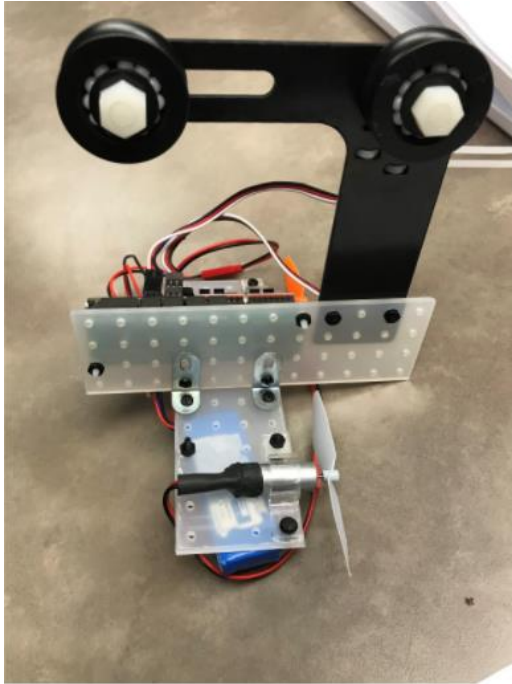
Figure 4: AEV Model used in the coasting v. power braking tests

After the data from these labs was analyzed, the team applied this newfound knowledge to their solution to performance test one. The first performance test included the first part of the final procedure. The test required the AEV to travel up the inclined track, stop in a specific range of distance (about 10 feet away from the starting point), trigger a motion activated sensor that would open a gate, and then finally proceed through the gate. Once this task was completed, the next step is to work on completing performance test two, which involves all of performance test one but also requires the test to travel backwards with the "passengers".

Results

The first stage of design was not so much centered around the idea of collecting data as much as it was about observing the components of the AEV and their properties. In the first lab, the team experimented with creating programs that would run the motors for specific amounts of time and at specific power percentages. It was noted that in order to run the motors at a constant speed, they first needed to be accelerated. Another observation made in this lab was that the propellers would not start spinning immediately, but only after the power exceeded approximately 25%. In the next lab, the reflective sensors were investigated. During this testing, the orientation of the external sensors proved to be a crucial factor in determining what direction the AEV traveled. If the sensors were attached backwards, all of the position commands would need to be switched in the opposite direction. Another observation was the difference between the absolute position command and relative position command. The absolute position command made the AEV travel a distance relative to its starting position, and the relative position command made the AEV travel to a position relative to its current position. The team used these commands to complete a scenario that involved spinning the wheels until they read a certain distance.

In the advanced research stage, the team studied topics that were believed to prevalent in creating a solution to the task. The first topic studied was motor configuration and how it affected the energy consumed by the AEV. Two different conditions would be tested by accelerating both models from 0 to 40% power in two seconds, and then running at that power percentage for 3 additional seconds. Figure 5 shows the data collected from the runs.
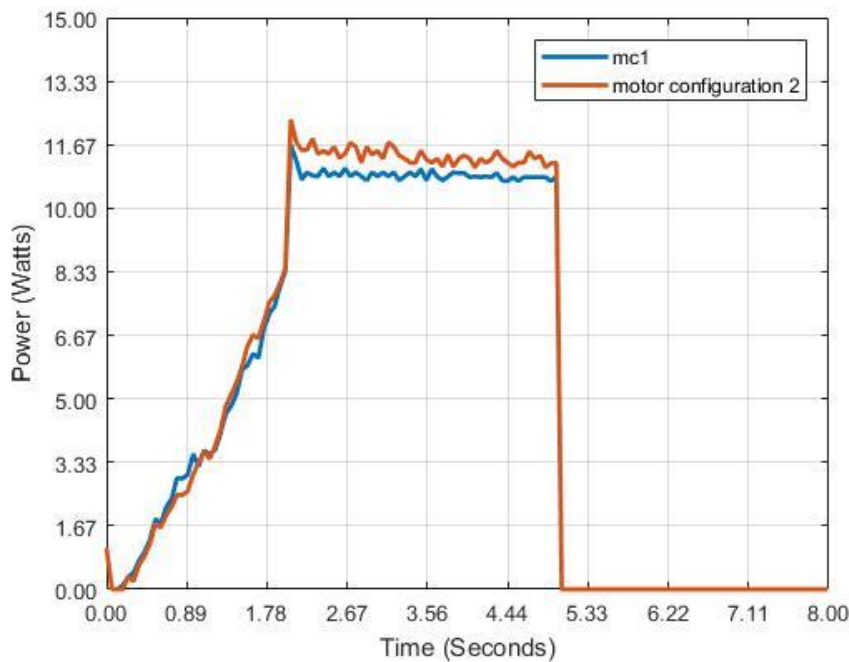

Figure 5: Energy v. Time plots for Configuration 1 (blue) and Configuration 2 (orange)

As seen in the graph, motor configuration one (both motors facing the same direction) used, on average, approximately 0.5 watts less than motor configuration two (motors facing in opposite direction). Because the only difference between these two programs was the one motor running in reverse used by configuration two, it can be inferred that running in reverse consumes more energy than running in a forward direction. This data suggested that the team should use a configuration similar to the first in the final design.

The next topic that was investigated was the differences between coasting and power braking. The experiment analyzed the two techniques and how they were able to effectively stop the AEV. The same vehicle model ran two different programs whose only difference was its stopping method. The coasting program stopped the AEV by cutting the motors and allowing the vehicle to roll along the track until friction stopped it. Oppositely, the power braking program stopped the vehicle by reversing the motors and running them in the backwards direction, thus creating an opposing force. Both of these programs were ran five times each (Table 1 and Table 2).

Coasting Lab			
Run #	Start Position	End Position	Stop Distance
1	324 in	76 in	144
2	324 in	87 in	133
3	324 in	84 in	136
4	324 in	84 in	136
5	324 in	84 in	136

Table 1: Data collected for coasting trials

Power Braking Lab				
Run#	Start Position	Stop Position	Forward Motor end Position	Brake Distance
1	324 in	190 in	220 in	30
2	324 in	191 in	216 in	25
3	324 in	185 in	228 in	43
4	324 in	187 in	220 in	33
5	324 in	185 in	224 in	39

Table 2: Data collected for the power braking trials

The tables above represent the distance required by each method to stop the AEV. For both programs, the motors stopped running in the forward position after it reached approximately the 220-inch position mark (or traveled about 104 inches); here is where the vehicle began its stop. The coasting method took a much larger distance to stop, with an average stopping distance of 137 inches opposed to that of the power braking method with 34 inches. However, based on the data collected, coasting proved to contain less variance. The standard deviation of stopping distance for coasting was 3.6 inches, whereas the standard deviation for power braking was 6.4 inches. To further compare these methods, the energy used needed to be analyzed as well. Figure 6 and Figure 7 show the energy v. time plots for select trials of coasting and power braking respectively. Coasting showed to use less energy, given that the maximum amount of energy used at any time was 10.2 watts. Power braking could use up to 18 watts during its runs. Power braking also uses the motors while they are running in the reverse direction, which was concluded earlier to use more energy.
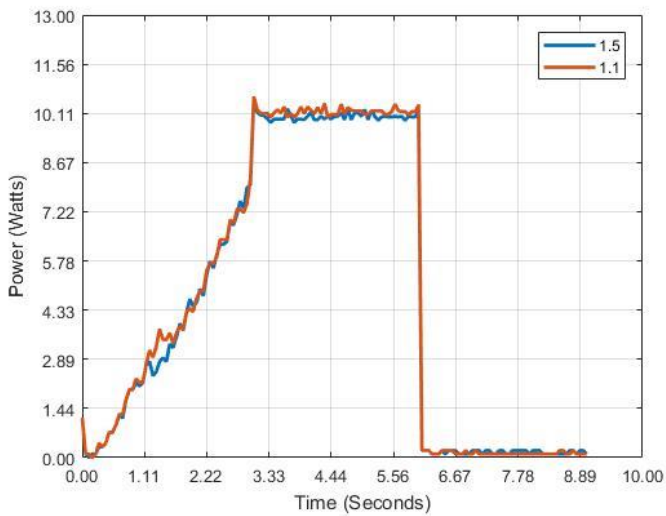
Figure 6: Energy v. Time plots for coasting
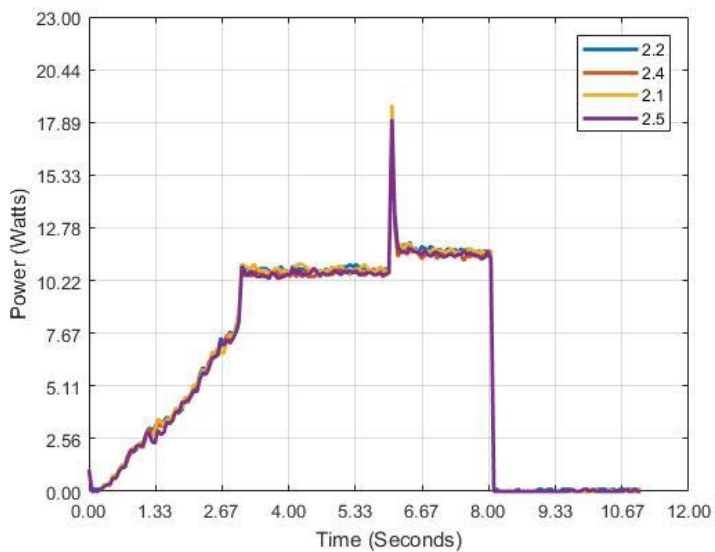
Figure 7: Energy v. Time for Power Braking

After the advanced research and development was conducted, the model had to be tested under the scenario of the first performance test. During the preparation for the performance tests, both coasting and power braking were tested to see which performed better under the conditions of the new track. Coasting was a much more difficult method to use because the change in elevation typically prevented the AEV from even reaching the intended distance before sliding back down the hill. Power braking tended to be more effective in completing the task however, it proved to be tedious to work with due to its high inconstancy.

Discussion

Throughout the Research and Development process the group focused on maintaining the original mission but also creating a unique design. Each of the Advanced R and D labs provided in depth insights into the direction the team could go. The motor configuration lab allowed the team of engineers to realize that despite possibly some configurations that would look possibly more aesthetic, a basic concept of 2 "wings" with the motors on them would be the most effective method moving forward. Although, this lab was beneficial, the coasting vs power braking gave the team further ideas and details that will be crucial moving forward. Energy and time are expensive and for that reason the use of each should be minimized. After trying multiple methods, it was determined that power braking would be more accurate. However, moving forward the team is also exploring the servo as an alternative method.

The prototypes the team worked with are very similar. However, the one difference is the servo motor added. The addition of the motor would change the way braking occurs. It would also add cost. The team is currently trying both power braking and still possibility the use of the servo. For performance test 1, only power braking was used, and the test was completed. However, it took many runs that failed before the right code could be created. The model with the servo was also attempted. However, the interaction between the servo arm and the track was not what the team was hoping and thus, the use of that prototype was put on hold. The two porotypes that we were officially during the performance tests were the model used in the advanced research and development and one that was similar to it but with a few parts moved around. When the 2nd performance test was the next goal the team felt more adjustments needed to be made the overall design of the AEV. The team altered the current design further by moving the Arduino to the bottom. The Arduino was then attached to the base and the battery rested between the base and the Arduino. This model allowed the group to increase stability and balance and allow for easier access to the Arduino and the wires attached to it (Figure 8). After successfully completing the second performance test the team elected to stick with this as the model to be used in the final performance test.
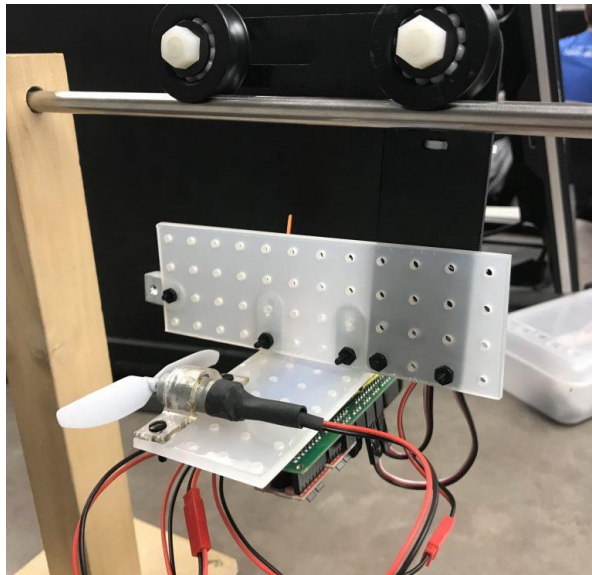

Figure 8: AEV model used in second and third performance tests

In the initial research and development process when deciding on designs to move forward with a concept screening and scoring process was completed (Figure 9 and Figure 10). There were two designs that scored highly.

Success Criteria	Reference	Design A	Desgin B	Desgin C	Design D
stability	0	+	+	+	-
durability	0	-	+	+	+
aerodynamic	0	-	+	+	-
mass	0	+	+	-	+
cost	0	+	-	-	+
sum +'s	0	3	4	3	3
Sum 0's	5	0	0	0	0
Sum -'s	0	2	1	2	2
Net score	0	1	3	1	1
Continue?	combine	combine	combine	no	yes

Figure 9: Concept Screening Matrix

Success Criteria	Weight	REFERENCE		DESIGN A		DESIGN B		DEISGN C		DESIGN D	
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
stability	20%	3	0.6	3	0.6	4	0.8	3	0.6	2	0.4
durability	15%	3	0.45	2	0.3	5	0.75	4	0.6	3	0.45
aerodynamic	10%	2	0.2	2	0.2	5	0.5	3	0.3	2	0.2
mass	30%	3	0.9	4	1.2	2	0.6	1	0.3	4	1.2
cost	25%	3	0.75	4	1	1	0.25	1	0.25	4	1
Total Score			2.9		3.3		2.9		2.05		3.25
Continue?		no		combine		no		no		yes	

Figure 10: Concept Scoring Matrix

Design A (Figure 11) was a model that looked like a fish but required a special 3D printed part. Design D (Figure 12) was a t-shape based that looked somewhat like the team's current design. The idea for the team's current design came from design D. The stability and balance that was displayed in that design is why the team decided to move forward with it. However, the team felt

space could be conserved and that's when the design was altered to put two rectangles perpendicular to create a smaller, more compact design.
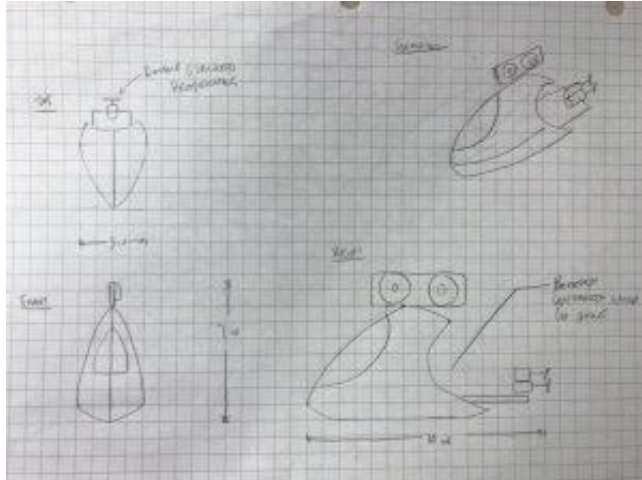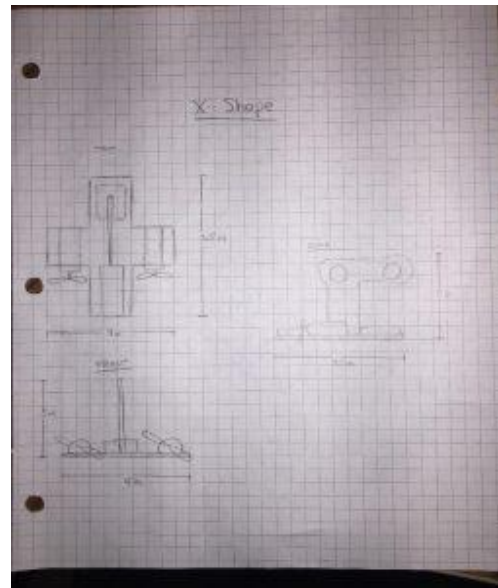

Figure 11: Concept Draft A

Figure 12: Concept Draft D

The coasting vs power braking lab was crucial for data and analyzing the process that goes into moving the vehicle down the track. The energy consumption in coasting was lower than that of power braking. However, in terms of time to stop, power breaking was much more effective. However, both showed inaccuracies with distance. As the team moved into performance tests, flaws were found in power braking. As the battery was changed the numbers in the previous code did not result in a successful attempt. Furthermore, power braking and coasting depending on the run and how the AEV starts can result in some distance error when stopping and accelerating. As the team moves toward the final tests, decreasing error will decrease cost, and increase efficiency. Whether, the code is altered to result in more accurate runs or the use of the servo, one or both will be necessary for the team's overall success.

The first and second performance tests were a large step. Going from learning about the components and the way each one worked in the research and development stage to making the vehicle perform was a big challenge. Although, the team could complete the first test it took many trial runs to finally get it right. One of the biggest changes the team made after performance test one, other than the Arduino switch that was mentioned previously, was moving to using marks and the sensors in our code. This allowed more precise braking and movement. Moving into performance test 2, the AEV was much more successful. Lastly, the Final Test was where everything needed to run smoothly. The first run was moving well until a propeller flew off. The team replaced the propeller for the 2nd test. However, after 2 runs another substantial change was made. The team received new reflective tape and set the screws connecting the

sensors into the arm, so they did not cause as much friction with the wheel. This allowed a much easier rotation for the wheel, and thus resulted in more accurate tests. The final run went perfect except for one error at the gate on the way back. This final run used 204 Joules of energy (Figure 13), took 49 seconds to run, and cost approximately $570,000 due to accuracy penalty (see attached: PT3).
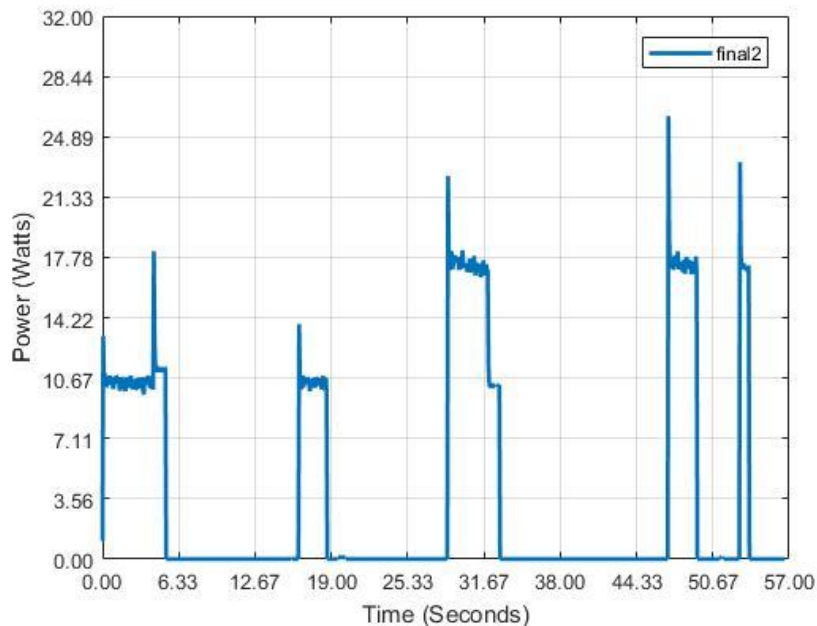

Figure 13: Time v Energy for the final test

Conclusion and Recommendations

Advanced energy vehicles (AEV) are small, electric motor-powered, propeller-driven vehicles that hang from a monorail track hung from the ceiling of the classroom. The AEV semester long project taught teamwork, project management, design processing, and documentation. The objective of the project was to design the most efficient AEV to run the set track and have that model complete the final performance test. The entire semester was built upon each other to design the best AEV. Through each step, revisions were made in the design of the vehicle. In the preliminary research and development, the designs of all teammates were scored and presented the best AEV with the highest score. This AEV was then used in the advanced research and development. Different motor configurations were tested and the most efficient one was chosen to move forward with. This AEV was used in performance test one. After performance test one, the AEV was rearranged so the Arduino was on top of the battery. This was the last part of the design that was altered. As discussed previously, the design has been changed multiple times. This is natural; as more tests are run, the more problems come about. In the preliminary research and development, brainstorming, initial designing and analyzing were used in creating the AEV.

The concept scoring was how each AEV was analyzed. In the advance research and development and performance tests, constraints were identified and the AEV was altered to fit these requirements. This design process and cycle lead to the final design for the AEV. The battery should be switched out after every ten runs to reduce the error of power. Since the power of the battery decreases every run, using the power percent and time causes inaccurate results. The wheel sensors were used along with the goToRelativePosition commands to provide more accurate results (see attached: Code PT2). The guidelines say the Arduino cannot be within two inches of the magnet. To solve this problem, the idea of moving the Arduino to the bottom of the AEV came about. The key to success on this project is to spend class out of time on majority of it. In class, test runs should be the main priority. Outside of class, discussion and analyzing of what happened in class should be done. Also, preparation for the next class needs to be done out of class. As soon as class starts, each team member should be working on their tasks. Lack of preparation is what lead to the incompleteness of some of the research. Therefore, there is not much data specifically for the motor configurations experiments. The team did not have a plan at the beginning of the research period so much time was wasted. As for the final testing, the AEV was very inconsistent up until the final performance test. It would run many perfect runs and then when it was time to test it fell short often. This was a major concern. Upon talking to an instructor, the realization that the screws holding the wheel sensors in place were causing friction on the wheel. This was fixed upon realization. The last day of performance testing, the AEV was extremely consistent however, the time constraint was what held the team back from getting a perfect run. Despite these challenges, the team was still able to complete the initial task of transporting residents from Linden to Easton and Polaris in a time and energy efficient manor while also remaining within the budget constraint of $600,00.

Appendix

Figures

Figure 6: Energy usage of several trials using coasting as a stop method
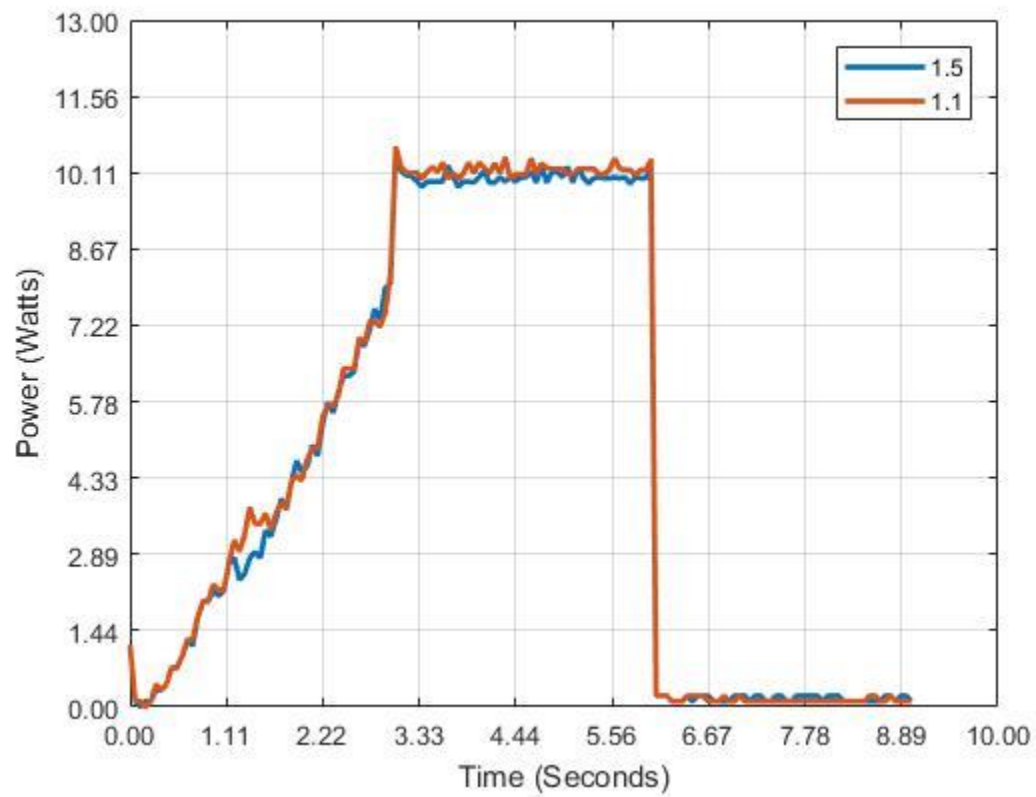
Figure 7: Energy usage of several trials using power braking as a stop method

Figure 9: Concept Screening matrix

Success Criteria	Reference	Design A	Desgin B	Desgin C	Design D
stability	0	+	+	+	-
durability	0	-	+	+	+
aerodynamic	0	-	+	+	-
mass	0	+	+	-	+
cost	0	+	-	-	+
sum +'s	0	3	4	3	3
Sum 0's	5	0	0	0	0
Sum -'s	0	2	1	2	2
Net score	0	1	3	1	1
Continue?	combine	combine	combine	no	yes

Figure 10: Concept Scoring Matrix

| Success Criteria | Weight | REFERENCE | | DESIGN A | | DESIGN B | | DEISGN C | | DESIGN D | |
		Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
stability	20%	3	0.6	3	0.6	4	0.8	3	0.6	2	0.4
durability	15%	3	0.45	2	0.3	5	0.75	4	0.6	3	0.45
aerodynamic	10%	2	0.2	2	0.2	5	0.5	3	0.3	2	0.2
mass	30%	3	0.9	4	1.2	2	0.6	1	0.3	4	1.2
cost	25%	3	0.75	4	1	1	0.25	1	0.25	4	1
Total Score			2.9		3.3		2.9		2.05		3.25
Continue?		no		combine		no		no		yes	

Figure 13: Energy v. Time usage of final test. Total of 204.84 Joules
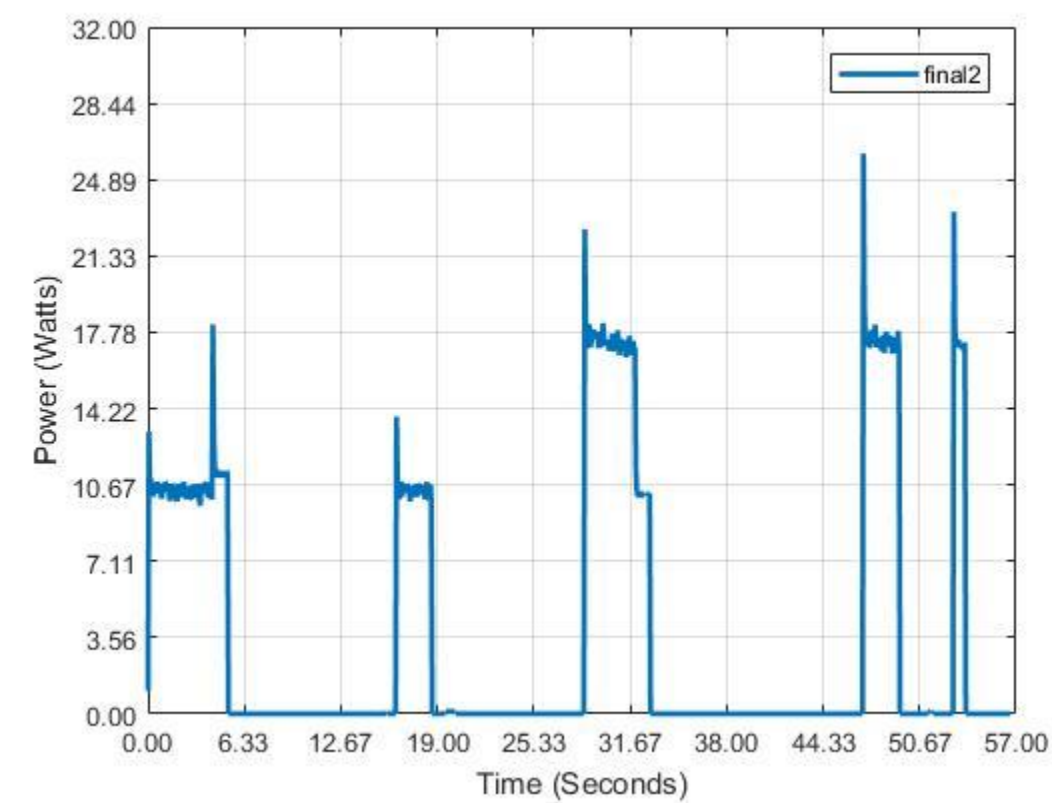
Schedule

- Initial design: all team members, Jan 15- Jan 22, first AEV design was complete to be tested
- Preliminary R&D: all team members, Jan 25- Feb 5, PR&D is completed
- Advanced R&D: all team members, Feb 6- Feb 22, advanced research is completed and analyzed
- Performance Test 1: all members, Mar 8- Mar 20, PT1 is completed and servo is tested
- Performance Test 2: all members, Mar 21- Mar 27, PT2 is completed and design has been changed to make room for magnet at the front
- Performance Test 3: all members, Mar 27- April 12, Final test is completed
- Final oral presentation: all, April 17th, team gives their presentation over the project and their solution
- Final website: all, April 18th, website is completed for the course and is turned in
- AEV showcase: all, April 23rd, website will be judged at showcase and is very close to being completed for presentation

Codes

Code A.1

//Program between here

//Accelerate motor one from start to 15% power in 2.5 seconds.
celerate(1,0,15,2.5);
//Run motor one at a constant speed (15% power) for 1 second.
motorSpeed(1,15);
goFor(1);
//Brake motor one
brake(1);
// Accelerate motor two from start to 27% power in 4 seconds.
celerate(2,0,27,4);
// Run motor two at a constant speed (27% power) for 2.7 seconds.
motorSpeed(2,27);
goFor(2.7);
// Decelerate motor two to 15% power in 1 second.
celerate(2,27,15,1);
//brake motor two
brake(2);
//reverse the direction of only motor 2
reverse(2);
//Accelerate all motors from start to 31% power in 2 seconds.
celerate(4,0,31,2);
// Run all motors at a constant speed of 35% power for 1 second.
motorSpeed(4,35);
goFor(1);
// Brake motor two but keep motor one running at a constant speed (35% power) for 3 seconds
brake(2);
motorSpeed(1,35);
goFor(3);
//brake all motors for 1 second
brake(4);
goFor(1);
//reverse the direction of motor one
reverse(1);
//Accelerate motor one from start to 19% power over 2 seconds.
celerate(1,0,19,2);
//Run motor two at 35% power while simultaneously running motor one at 19% power for 2 seconds.
motorSpeed(2,35);
motorSpeed(1,19);
goFor(2);
// Run both motors at a constant speed (19% power) for 2 seconds
motorSpeed(4,19);

```
goFor(2);
// Decelerate both motors to 0% power in 3 seconds
celerate(4,19,0,3);
//brake all motors
brake(4);
```

Code A.ii

```
 // run all motors for 2 sec at 25%
 motorSpeed(4,25);
 goFor(2);
 // run all motors for 12ft at 20%
motorSpeed(4,20);
goToAbsolutePosition(123);
//reverse all motors
reverse(4);
//run all motors for 1.5 sec at 30%
motorSpeed(4,30);
goFor(1.5);
// brake all motors
brake(4);
```

Code CB.i – *Coasting Program*

```
celerate(4,0,40,3);

motorSpeed(4,40);
goFor(3);

brake(4);
```

Code CB. ii – *Power braking program*

```
celerate(4,0,40,3);

motorSpeed(4,40);
goFor(3);

brake(4);

reverse(4);
motorSpeed(4,40);
goFor(2);
```

Code PT1- *Code used in performance test one*

```
//reverse both motors
reverse(4);

//Accelerate both motors to 40% in 3 seconds
celerate(4,0,40,3);

//keep going for one second
motorSpeed(4,40);
goFor(1.75);

//brake both motors
brake(4);

//reverse
reverse(4);
celerate(4,0,60,1.25);
motorSpeed(4,60);
goFor(1.0);

//brake at the gate
brake(4);
goFor(9);

//accelerate
reverse(4);
celerate(4,0,60,2);
```

Code PT2- *Program used to complete performance test two*

```
go to 20 marks
motorSpeed(4,40);
goToRelativePosition(-210);

//brake
brake(4);

reverse(4);
celerate(4,0,30,2);
```

```
motorSpeed(4,30);
goFor(.65);

brake(4);
goFor(7);

reverse(4);
motorSpeed(4,45);
goToRelativePosition(-110);
brake(4);
goFor(12);
reverse(4);
motorSpeed(4,50);
goFor(2);
brake(4);
```

Code PT3 – *Final code used to complete the final performance test*

```
//go to 20 marks
motorSpeed(4,40);
goToRelativePosition(-262);

//brake
brake(4);

reverse(4);
motorSpeed(4,45);
goFor(1);

//going through the gate
brake(4);
goFor(9);

reverse(4);
motorSpeed(4,40);
goToRelativePosition(-90);
brake(4);

//stopping in the loading zone
goFor(10);
reverse(4);
motorSpeed(4,60);
goToRelativePosition(150);
brake(4);
```
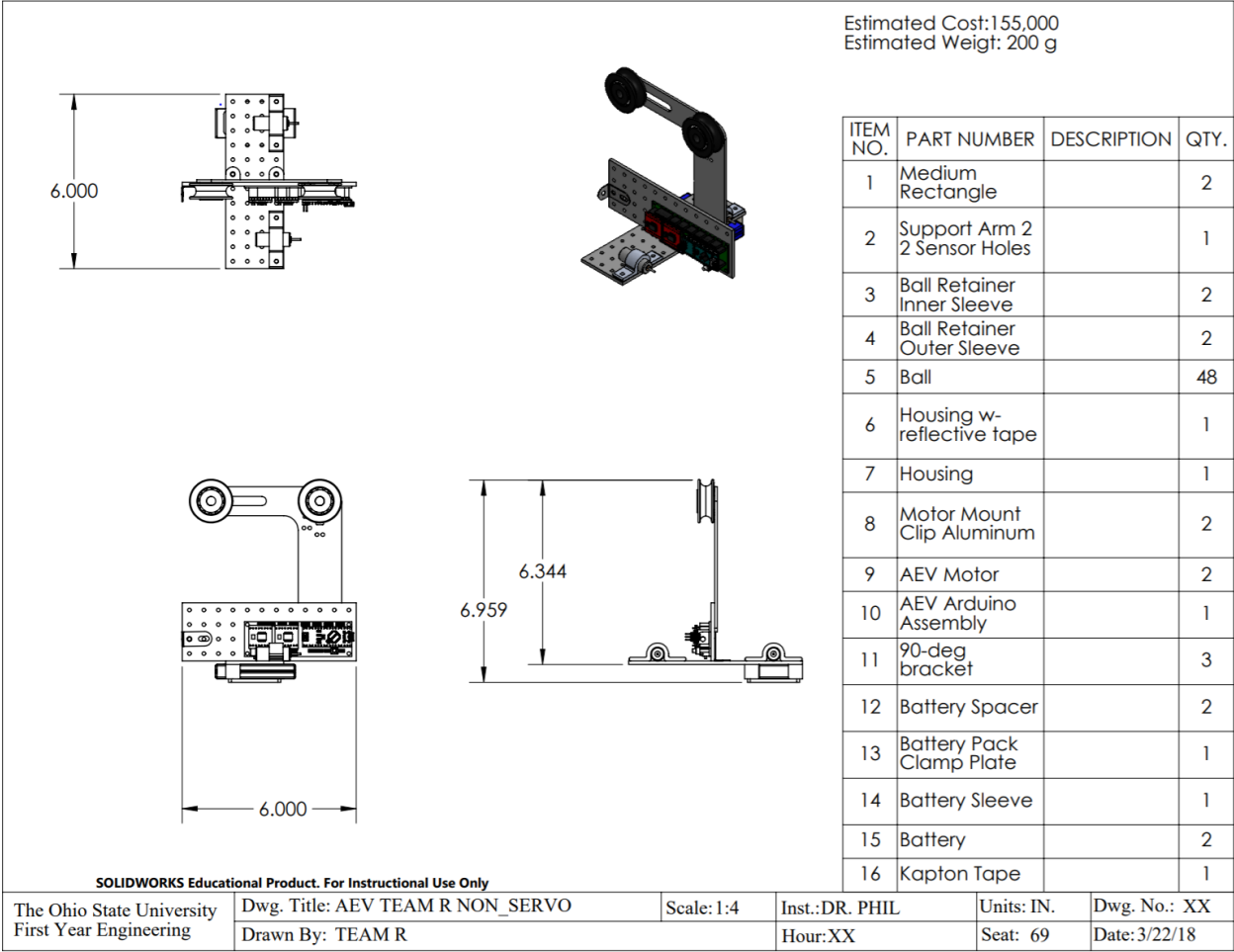
```
goFor(1);
reverse(4);
motorSpeed(4,65);
goFor(1);
brake(4);
goFor(10);

//going through gate
reverse(4);
motorSpeed(4,60);
goToRelativePosition(85);
brake(4);
goFor(2.5);
reverse(4);
motorSpeed(4,60);
goFor(.75);
```

SolidWorks Models

Model 1: AEV used for first performance test

Estimated Cost:155,000
Estimated Weigt: 200 g

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Medium Rectangle		2
2	Support Arm 2 2 Sensor Holes		1
3	Ball Retainer Inner Sleeve		2
4	Ball Retainer Outer Sleeve		2
5	Ball		48
6	Housing w-reflective tape		1
7	Housing		1
8	Motor Mount Clip Aluminum		2
9	AEV Motor		2
10	AEV Arduino Assembly		1
11	90-deg bracket		3
12	Battery Spacer		2
13	Battery Pack Clamp Plate		1
14	Battery Sleeve		1
15	Battery		2
16	Kapton Tape		1

SOLIDWORKS Educational Product. For Instructional Use Only

The Ohio State University First Year Engineering	Dwg. Title: AEV TEAM R NON_SERVO		Scale:1:4	Inst.:DR. PHIL		Units: IN.	Dwg. No.: XX
	Drawn By: TEAM R			Hour:XX		Seat: 69	Date:3/22/18

6.000
6.344
6.959
6.000

Model 2: AEV model used for second and third performance tests

7.044

6.575

6.701

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Medium Rectangle		2
2	90-deg bracket		3
3	Support Arm 2 2 Sensor Holes		1
4	AEV Motor		2
5	Motor Mount Clip Aluminum		2
6	Prop 3inch		2
7	Pulley Assembly w-reflective tape		1
8	Pulley Assembly		1
9	Battery Pack		1
10	AEV Arduino Assembly		1

The Ohio State University First Year Engineering	Dwg. Title: Final AEV drawing		Scale: 1:4	Inst.: Dr Phil	Units: IPS	Dwg. No.: 1:1
	Drawn By: Group R			Hour: 8:00	Seat: R	Date: 04/18/2018

Works Cited

City of Columbus, Ohio. (2018). *Smart Columbus Projects.* Retrieved from
https://www.columbus.gov/smartcolumbus/projects/

The Ohio State University, College of Engineering. (2018). *The Ohio State University Advanced Energy Vehicle Design Project: Mission Concept Review (MCR) and Deliverables.* Columbus, Ohio.

The Ohio State University, College of Engineering. (2018). *The Ohio State University Advanced Energy Vehicle Design Project: Lab Manual Preliminary Research and Design.* Columbus, Ohio.