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03/27/2019
Critical Design Review

Abstract

The City of Columbus has requested an energy efficient and fully automated vehicle to provide rapid travel between Linden and either Polaris or Easton. The mission was to satisfy this request and provide the city with an energy efficient and cost effective vehicle for the smart Columbus initiative. A single company was divided into three groups to individually produce different prototypes of an Advanced Energy Vehicle (AEV). These groups were to work together and share information, while staying under a 500k budget per vehicle. These vehicles were created to foster sustainability and lead Columbus into "a future beyond what anyone has imagined" [1].

There was an initial provided model AEV that was utilized as a base configuration for the AEV designed by group E. The group was required to devise testing procedures to improve this initial AEV. The group decided to test motor configuration and coasting versus power braking in order to see how different motor setups and stopping scenarios affected overall costs. This was completed by testing each configuration three times at 20, 30, and 40 percent motor power. The first configuration was a Side by Side design and had both motors on the same end, pushing or pulling the AEV in the either direction. The second configuration featured a motor on each end of a rectangular shaped AEV. The group also compared power braking versus using a servo motor. This was done by running the AEV first with power braking and then with a servo and comparing the observational results, energy usage, and in turn cost. This testing was done with the final motor design which was a development of the Side by Side design.

The Side by Side motor configuration did not allow for the AEV to be as streamlined as the Double Ended configuration, however, the motor accelerated faster in the forward direction for the first graded test and braked more easily compared to the Double Ended design. The servo was more efficient in terms of braking and utilized less energy and put the AEV on a more exact path.

Based on the results, it was decided that the group would go with the Side by Side motor configuration with the servo motor attached. The design was oriented so that the AEV was pulled toward the caboose and then once attached, would push away with the caboose. There were some issues with balancing the AEV design and for performance test three, a singular piece was produced for the entire base of the AEV, that enhances balance, symmetry, and was lighter in weight. If there had been more time the group would likely not gone with this exact AEV design because it could have been better. The group recommends that using better securing techniques, instead of duct tape and zip ties, would have made the AEV more reliable. The overall design, however, worked very well for the task at hand.

Introduction

The City of Columbus has requested an energy efficient and fully automated vehicle to provide rapid travel between Linden and either Polaris or Easton. The mission was to satisfy this request and provide the city with an energy efficient and cost effective vehicle for the smart Columbus initiative. A single company was divided into three groups to individually produce different prototypes of an Advanced Energy Vehicle (AEV). These groups were to work together and share information, while staying under a 500k budget per vehicle. These vehicles were created to foster sustainability and lead Columbus into “a future beyond what anyone has imagined” [1].

The goal of this dilemma was to develop an Advanced Energy Vehicle that was more efficient, and cost effective than the model AEV. This was completed through testing and research. The group decided to test motor configuration and braking methods. The results of this testing were to be provided and the changes of the AEV design were to be made based on data.

Experimental Methodology

In order to design the AEV, it was necessary to model a prototype AEV, and the group created two models, see Appendix B and C. Along with these models, a track, see Appendix E, was used to model how these vehicles would traverse between their destinations. The group decided to initially test the orientation of the motors. From the results of that experiment the most cost effective model would be used for the next experiment to determine the difference in cost of coasting and power braking.

To test the difference in effectiveness of the motor orientations, the group created two different designs. The first of which was the Double Ended design, see Appendix B, which had one motor in front and one in back providing stability and uniform travel speeds. The second design, as seen in Appendix C, was a Side by Side design that could be oriented in either direction, creating either a push or pull effect by the motors. The group tested these designs by using increasing power levels three times for each percentage from 20 to 40 percent, incrementing by tens on the flat track. The code, as seen in Appendices F and G were used for this experiment. This experiment tests each design going both forwards and backwards which allows for comparisons in usefulness as the AEV was pulling a heavy caboose on its way back to the start. The data was collected after each trial and uploaded into MatLab to record and compare the cost efficiency

The group continued with the Side by Side design to test power braking versus coasting. Testing the cost effectiveness of coasting versus power braking was fairly similar to the previous test as it still uses the code from Appendix G for coasting and uses code from Appendix I for power braking. Once again, the tests used increasing power starting at 20 going to 40 in increments of 10 on the same flat track as the previous experiment. Traveling in each direction was again tested. The data was collected after each trial and uploaded into MatLab to record to compare the cost efficiency.

The group found that power braking was the more effective means of braking and after speaking with other members of the company, the group decided to continue to focus on different methods of braking. The final test the group decided upon was to test the difference in power braking and servo braking. The group tested the difference in cost efficiency on the main track, see Appendix E. The AEV was to travel and connect to the caboose while the group recorded the energy cost and time cost. Each method of braking was tested at the same speed, though, braking was adjusted to work with the differing methods. The code for each can be seen in Appendix I for the Power braking method and Appendix J for the servo brake. Once more, the data that was collected was recorded in MatLab and the price of each method was compared.

Results

There was lot of information gathered from the tests performed on the AEV. This included observable information. First, the Double Ended design did not travel as far as the Side by Side design. The Side by Side design was also more efficient in the forward direction compared to the reverse direction. That is, it traveled farther when it was being pushed rather than pulled. This was different from the Double Ended AEV motor configuration which had similar efficiency in both directions. Also, the higher the power placed upon the AEV, the longer the coast became. Coasting was also observed to be inconsistent when compared to power braking or servo braking in regard to stopping location. Servo braking was seen to be slightly more exact than power braking.

At 20% power, the Side by Side design traveled farther and used less energy on both the outgoing and incoming portions of the motor configuration tests. For the outgoing segment of the tests, the Side by Side design, on average, traveled 16.5 inches farther and used 1.2 less joules of energy than the Double Ended design. For the incoming segment of the tests, the Side by Side design traveled 30.3 inches farther while using 0.5 less joules of energy. The results of energy versus distance for both designs tested at 20% power can be seen in Figure 1 below and Figure 2 on the following page. In terms of dollars per inch, it was calculated that the Double Ended design costed $1,032.90/inch and the Side by Side design costed $243.36/inch.

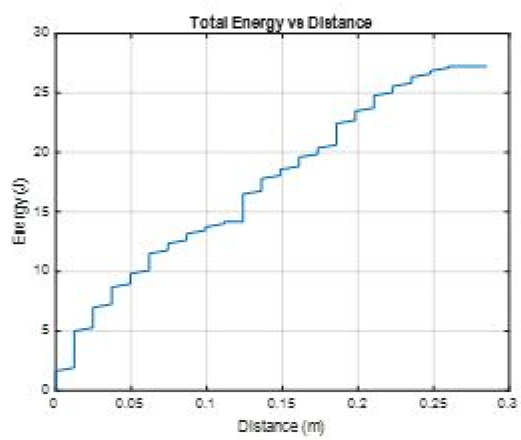

Figure 1: Energy vs Distance for Doubled Ended Design at 20% Power

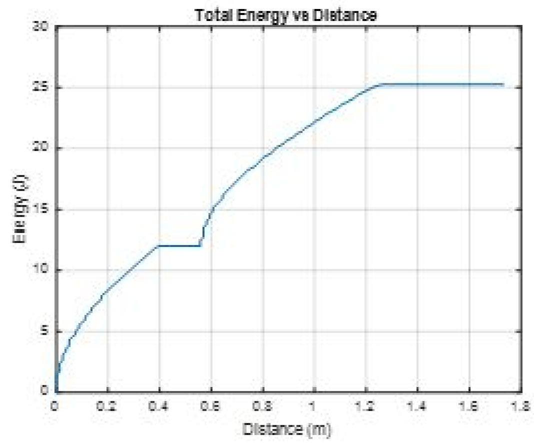

Figure 2: Energy vs Distance for Side by Side Design at 20% Power

At 30% power, the Side by Side design traveled 25.5 inches farther and used 2.1 less joules of energy on the outgoing segment of the test. On the return segment, the Side by Side design traveled 12.5 feet farther but used 2.3 more joules of energy than the Double Ended design. The incoming portion of the tests at 30% power was the first portion of all tests in which the Double Ended design used less power. The results of energy versus distance for both designs tested at 30% power can be seen in Figure 3 below and Figure 4 on the following page. In terms of dollars per inch, the Double Ended design costed $177.12/inch and the Side by Side design costed $92.84/inch.

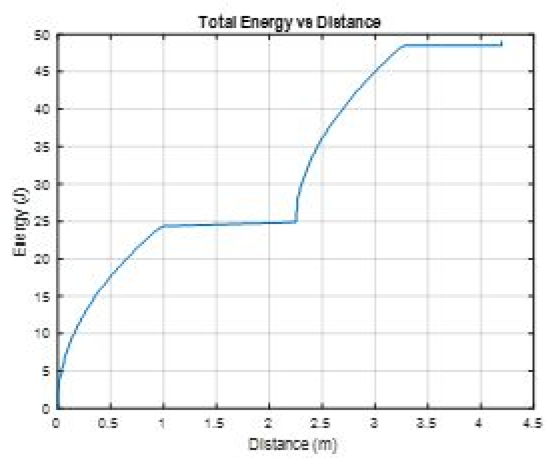

Figure 3: Energy vs Distance for Doubled Ended Design at 30% Power

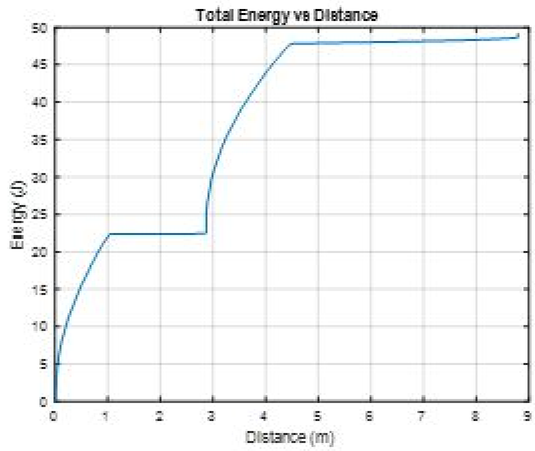

Figure 4: Energy vs Distance for Side by Side design at 30% Power

At 40% power the Double Ended design traveled farther on all outgoing portions of the tests. On average, the Double Ended design traveled 11.8 inches farther but used 3.5 more joules than the Side by Side design. On the incoming segment of the tests, the Side by Side design once again travelled farther but used more energy. It traveled 12.6 feet farther but used 2.5 more joules than the Double Ended design. The results of energy versus distance for both designs tested at 40% power can be seen in Figure 5 below and Figure 6 on the following page. In terms of dollars per inch, the Double Ended design costed \$92.35/inch and the Side by Side design costed \$83.19/inch.

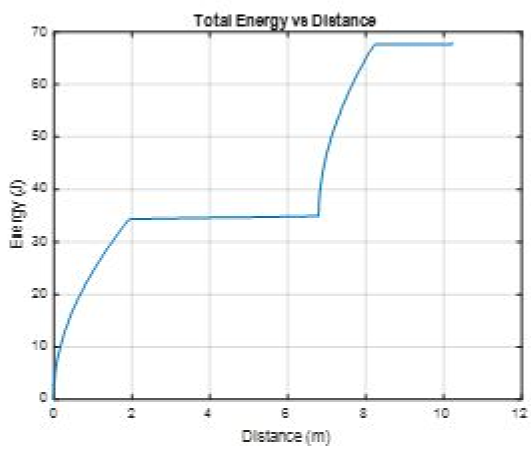

Figure 5: Energy vs Distance for Doubled Ended Design at 40% Power

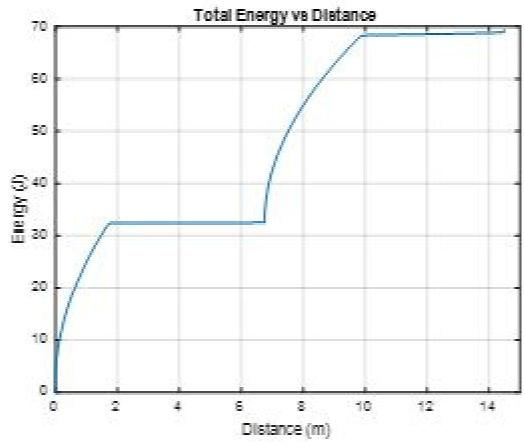

Figure 6: Energy vs Distance for Side by Side design at 40% Power

When coasting versus power braking was examined, it was found that coasting used significantly less energy than power braking. Figure 7 below shows results for the Side by Side design being power braked from 20% power. This figure can be compared to the first segment of Figure 2, which shows energy versus distance for the Side by Side design at 20% power. As seen in Figure 2, coasting allowed for there to be an instantaneous cutoff of energy. When stopped within three inches by being power braked, the reverse thrust resulted in 9.6 more joules being used.

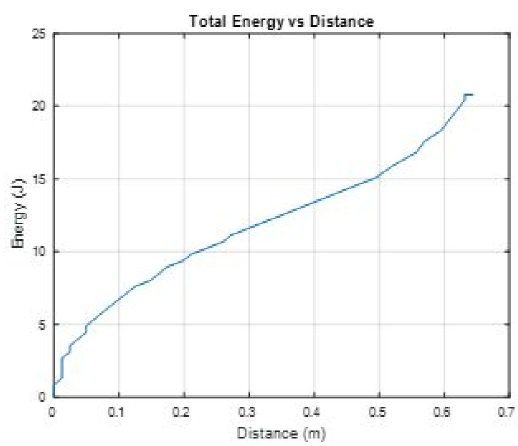

Figure 7: Power Braking the Side by Side Design From 20% Power

Three instances of braking were examined for both power braking and servo braking. Servo braking was found to use significantly less energy with an average energy use 0.45 J. Power Braking was found to use an average of 12.14 J of energy. Table 1 below shows these results.

Table 1: Average Energy Use of Servo and Power Braking

	Power Braking	Servo Braking
Energy	12.14 J	0.45 J

Discussion

The 20% power tests resulted in the least cost effective trial runs for both vehicles. When the dollars per inch of each design was taken into account, it showed that the Double Ended design had difficulties gathering momentum at this low power. This may have been due to either the overall mass of the Double Ended design or inadequate power being supplied for a push-pull thrust system. At 30% power, both vehicles became more efficient in terms of dollars per inch. The Double Ended design had an 83% decrease in dollars per inch, whereas the Side by Side design had a 28% decrease. The higher power resulted in both vehicles performing more efficiently. At 40% power, both vehicles saw the most efficient results for dollars per inch. At this power there was only a $9.35 difference, whereas the 20% power tests resulted in a $789.54 difference, both favoring the Side by Side design These results were not expected. There was an expectation that a lower power would result in lower energy costs when compared with distance traveled. The higher energy output resulted in a more energy efficient performance which led to a more time efficient performance as well.

The motor configuration tests also showed that the Side by Side design traveled farther than the Double Ended design in all portions of testing except the outgoing segment of the 40% power test. At this segment, the Double Ended design consumed an average of 3.5 joules more energy in order to travel 11.8 inches farther. These results led the team to believe that a mixed push-pull system was not as efficient as a strictly push or pull system. It was also shown from the results that the Side by Side design traveled farther when being pushed rather than being pulled. This trend was consistent at all different power outputs. This result was expected as a push system was assumed to be the most effective. This information also led the team to orient the AEV to be pulled towards the caboose, and pushed with the load.

The power braking tests showed that it required significantly more energy to come to a stop when compared with coasting. The tests at 20% power resulted in nearly twice the energy required to stop within three inches of each other. A higher energy consumption was expected due to the motors having to be ran in the reverse direction for a short period of time. While coasting was the more cost effective method, it did not provide reliable results in regard to stopping location. When Servo braking was examined, a lower energy consumption was expected, but not to the degree to which it was lower. Even with the extra capital cost of $5,950 for the servo motor, it saved an average of $6,047.50 for each instance of braking when compared to power braking. This led the team to a determination that servo braking was the optimal braking method.

Potential sources of error include differing design weights and varying battery power. The Double Ended design weighed 0.05 lbs more than the Side by Side design. This difference in weight may have led to the Double Ended design resulting in numbers that are not entirely indicative of a mixed push-pull system and would have been a systematic error. Different batteries were used on different days. These batteries may not have been supplying the same power from day to day. Also, runs completed earlier in lab time may have had a higher charged battery than runs at the end of lab time. This would also have resulted in systematic error. The braking results could also have error because multiple trials in the same conditions were not recorded, so the recorded trial could have had variance from the average behavior.

The screening matrix, as seen in Table 2 below, shows the two different AEV designs ranked in comparison to the model AEV provided by the engineering department. Both of the new designs were ranked against the model which was at zero for all criteria. A plus indicates a positive trait and a minus indicates a negative trait. It was found that the Side by Side design was better because it has advantages in the forward direction and the reverse direction, when the AEV was intended to pull the caboose behind it, unlike the Double Ended design which would require more power to pull the AEV. The Double Ended configuration was, however, more effective when it came to size in terms of balancing on the track. Overall, the Side by Side design scored higher, but modifications must continue to be made to account for the negative in the size category.

Table 2: Concept Screening Matrix for AEV Designs

Success Criteria	Provided Model	Double end	t-shaped
Energy Efficiency	0	0	0
Reverse	0	-	+
Forward	0	0	+
Cost	0	0	0
Size	0	+	-
Sum +'s	0	1	2
Sum 0's	5	4	2
Sum -'s	0	1	1
	0		
Net Score	0	0	1
Continue?	No	No	Yes

The scoring matrix, as seen in Table 3 below, provides a more in depth analysis of the AEV designs compared to the screening matrix. The results, however, were similar in that the Side by Side design also outweighed the Double Ended design and the provided model. The weight of how pertinent the success criteria were was provided and the score created based on this weight. Cost was one of the highest priorities, as well as, the reverse direction because when the AEV was in reverse it was required to carry the caboose with it. Overall, the Side by Side design scored slightly better than the Double Ended design, thus providing more evidence that the Side by Side configuration was the better choice in design.

Table 3: Concept Scoring Matrix for AEV Designs

		Provided Model		Double end		t-shaped	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Energy Efficiency	15%	2	0.3	2	0.3	2	0.3
Reverse	25%	2	0.5	2	0.5	4	1
Forward	15%	2	0.3	2	0.3	4	0.6
Cost	25%	2	0.5	3	0.75	3	0.75
Size	20%	2	0.4	4	0.8	2	0.4
Total Score			2		2.65		3.05
Continue?			No		No		Develop

The team's final model used a laser cut frame which allowed for a Side by Side motor configuration. The laser cut piece was created because the Side by Side frame did not allow for a simple towing setup if the AEV was to use a push method to tow the caboose. This piece was also $2,514.00 cheaper than the standard parts that would have been required. The team also installed a servo motor to take advantage of the minimal energy consumption when braking. Servo Braking was used in combination with as much coasting as possible to limit overall energy costs. The final design can be seen in Appendix D.

The team's final runs all went over the $500K budget. Table 4 below shows the results of the final three runs and Appendix K shows the code for the final runs. Run 1 suffered the highest accuracy penalty of 1.25. This was due to this run being conducted before the final code was completely finalized. This run also had the highest energy cost as it used the least amount of coasting. Runs 2 and 3 were both more accurate and less energy intensive, but still over budget. This was due to two primary reasons. The accuracy penalty was due to a poor implementation of the servo motor. The team used duct tape to fasten the servo motor to the frame. This method of fastening worked for several days of testing, but after numerous runs, the servo motor became loose. This was noticed too late and resulted in random stopping behavior and inconsistent stopping locations. To solve this, the team should have drilled holes into the laser cut frame in order to secure with screws. The high energy costs were due to increased consumption when the AEV towed the caboose. Significantly more energy was used during this portion of the test which was expected. This led the team to question whether a propeller system was the most efficient system. To solve this, the team should have conducted experimentation that compared propeller propulsion versus direct drive propulsion.

Table 4: Final Costs

	RUN 1	RUN 2	RUN 3
Capital Costs	$155,308	$155,308	$155,308
Energy Costs	$252,500	$240,500	$234,000
Time Costs	$183,000	$178,500	$177,000
Accuracy Penalty	1.25	1.111111111	1.176470588
R&D Costs	$ -	$ -	$ -
Safety Violations	$ -	$ -	$ -
TOTAL COST	**$699,683.00**	**$620,863.56**	**$638,837.41**

Conclusions and Recommendations

The experiments performed tested the AEV under multiple conditions to extract data about the cost efficiency of the AEV, which resulted in the conclusions that the Side by Side design was more cost efficient than the Double Ended design, and coasting was more cost efficient than power braking. The final AEV design was stable but completed the final performance with some errors.

The objective of the first experiment was to decide between two AEV configurations. This objective was successfully met as the Side by Side configuration was less costly relative to distance traveled. Additionally, cost information about power usage was gained. The pattern observed was that the cost per distance of either AEV design decreased as the power the motors are set to increases. The difference in cost between the designs also decreases as power increases, meaning design flaws are less impactful to cost at higher speeds. The objective of the second experiment was to determine if power braking or coasting the AEV was better. The conclusion of this experiment was that coasting was more power efficient. However, it was observed that the stopping distance of the AEV was significantly more variable while coasting than when using reverse thrust to power brake. The objective of the third experiment was to determine if power braking or using a servo to stop was more ideal for the final run in both cost and ability to write an accurate program. The result of experiment three was that the servo was more cost effective and made programming significantly easier and more consistent. The final run was for the AEV to autonomously reach a stop sign, pause and wait for it to move, then reach a load, attach to it, then return to the stop sign, wait and return to original starting place. Throughout this run the goal was to be as cost efficient as possible, by reducing time and energy usage. During the final runs, the AEV did not successfully stop on some occasions, however time and energy were conserved well and costs were not overly excessive.

In the first experiment the different masses could be fixed by performing the experiments with one base design, such as a large square, that was conducive to putting two motors on one side and putting the motors opposite of each other. In the second experiment the limited number of trials could be improved simply with more time to perform more trials. The variability in the battery for both experiments could be improved with a testing time long enough to complete all trials with the same battery, or using the Arduino Wifi or a wifi shield to wirelessly transmit data to reduce the time involved with extracting data. The battery voltage dropping could be improved by charging or changing the battery between each trial or whenever the voltage drops below a specific threshold. In the third experiment and final performance tests failure to stop was attributed to the attachment method for the servo motor. The servo being attached with screws would have made the AEV brake more consistently as trials progressed and would have made programming easier. It was also determined that adding a servo increased the amount the encoder wheel 'slipped' making it impossible for the AEV to accurately determine its position. There were also two different tracks so encoder position was less relevant. The solution would have been a sensor like an ultrasonic sensor, laser, or other proximity sensor, especially since all of the portions of the final run were dependant on physical landmarks which could be sensed in such a fashion.

Due to the results of the motor configuration testing, the AEV configuration was now a variation of the Side by Side because it was the more cost efficient design. Despite the lab results, the AEV code used power braking, this was because of the precision needed. However, coasting was more efficient, so while completing the early performance tests, power braking was reduced and the amount of a stop that was a coast was decreased to improve efficiency. The results of the third experiment were used for programming the final performance run because the servo was used and most of the code written for the third experiment was reused for the final performance. The results of the final performance run determined the final cost.

The results of the advanced research labs were incomplete in range of data, which was limited by the number of trials which were performed. The cause of the limited number of trials was lack of time, which was absorbed by technical difficulties. The team worked through many difficulties which were inconsistent, such as the Arduino programming software being deleted from computers overnight, the Arduino not working on the same USB port twice in a row, or the computer taking excessive time to compile a single program. The braking test was incomplete because it's result was binary, power braking or not power braking, whereas with more tests with varying power and duration more information could be gained about how to optimally power brake, since power braking was needed for consistent precision regardless of inefficiency. The information gained while testing power braking was limited to only one power level and gave no guidelines for code development (Figure 7, Results). The final code was incomplete because the tests were not completely successful leading to accuracy penalties (Table 4, Discussion). The final incompleteness was caused by limited resources in time as the trials were rushed, space, as multiple teams had to wait turns for the track , and energy, as the battery would drain without a chance to fully recharge.

Appendix A: Schedule

01/10/2019
Members Present: All members present.
Topics/Agenda: Familiarizing with Arduino coding and creation of the company website
Action Items:

- Website creation: Clark Godwin
- Sketchbook setup: Ben Bachmann
- Programming basics exercise: All members

Overview:
Lab 01 was the introduction to the AEV project. The website for Baker International Company was created and team members familiarized themselves with it. Exercise 1 was completed giving each team member exposure to the AEV, controller and basic programming commands.
Upcoming tasks:
Each team member was tasked with exploring the 1182 Carmen page and familiarizing themselves with the AEV documents within.

01/17/2019
Members Present: All members present.
Topics/Agenda: Completing the second exercise on the P R&D Manual, making the team working agreement, reviewing the AEV kit policy, label, and checklist.
Action Items:

- Website stuff: Ben, Grace
- Setting up AEV and paperwork: Ben, Clark
- Programming and the second exercise: Maddy
- Teamworking agreement: Grace

Overview:
Lab 02 tasked us with completing more work on the AEV project. The website for Baker International Company was edited and paperwork involving the AEV was completed. Exercise 2 was completed giving each team member more exposure to the AEV, controller and basic programming commands.
Upcoming tasks:
Each team member was tasked with exploring the 1182 Carmen page and familiarizing themselves with the AEV documents within.

01/31/2019
Members Present: All members Present

Topics/Agenda: Reflectance sensor test, run programmed code, data extraction tool
Actions Items:

- Building AEV: Clark, Ben
- Reflectance sensor test: Maddy, Ben
- Running programmed code: N/A
- Data extraction tool:N/A
- Website: Grace

Overview:
Lab 03 tasked us with completing more work on the AEV project. The reflectance sensor test was completed and the sensors work.
Upcoming Tasks:
Run the programmed code in order to use the data extraction tool. Figure out why the AEV was not working

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02/07/2019
Members Present: All members present
Topics/Agenda: Finish tests from Lab 03. Complete the fourth P R&D activity. Start P R&D activity five. Complete progress report and prepare for grant proposal and lab quiz.
Action Items:

- Lab 03 Tests: All members
- Website: Grace

Overview:
Finishing Lab 03 required us to run programmed code and utilize the data extraction tool. Lab 04 required us to discuss the individual AEV sketches and create progress report 1. Lab 05 required us to rate all of the individual sketches compared to the baseline sketch and design the finalized design of the AEV.
Upcoming Tasks:
Complete all unfinished lab work and prepare for grant proposal and lab quiz.

02/14/2019
Members Present: All members present
Topics/Agenda: Lab proficiency quiz, grant proposal presentation, grant proposal vote
Action Items:

- Lab proficiency quiz: All members

- Grant proposal: All members

Overview:
The first 30 minutes of lab were spent taking the lab proficiency quiz. The remainder of the time was spent presenting the design and watching other groups' presentations.
Upcoming Tasks:
Determine team roles and prepare for the committee meetings on the following lab day. Start brainstorming ideas for the advanced research and development portion of the project.

02/21/2019
Members Present: All members present
Topics/Agenda: Attend committee meeting, determine research and development topic(s), prepare for lab 07
Action Items:

- Committee Meeting: All members
- Determine research and development topics: All members
- Submit part for 3D printing: Maddy
- Website: Grace

Overview:
The first 10 minutes of lab were dedicated to the committee meeting. The remainder of the time was spent determining the research and development topics and discussing tasks that will be completed in upcoming labs.
Upcoming Tasks:
Prepare for lab 07.

02/28/2019
Members Present: All members present
Topics/Agenda: Begin testing and research on AEV (motor configuration).
Action Items:

- Reflectance Sensor Test: All
- Rebuilding AEV: Clark
- Testing on AEV: All
- Data Collection/Coding: Ben
- Website: Grace

Overview:

The reflectance test was performed and then individual group testing on the AEV was completed. The motor configuration 1 was tested at 20, 30, and 40 percent power. Work was done on the second progress report.

Upcoming Tasks:

Prepare for lab 08 and complete all unfinished tasks of lab 08.

03/04/2019

Members Present: All members present

Topics/Agenda: Analyze the data collected during lab 08.

Action Items:

- Data Analysis: Ben
- AEV: Clark
- Coding: Maddy
- Website: Grace

Overview:

The group determined that motor configuration on the AEV was going to be tested and testing was started.

Upcoming Tasks:

Prepare for lab 09 and complete all unfinished tasks of lab 08.

03/06/2019

Members Present: All members present

Topics/Agenda: Analyze the data collected during lab 08 and continue to collect data and analyze.

Action Items:

- Website: Grace
- Coding: Maddy, Ben, Clark
- Data Analysis: Everyone

Overview:

The first motor configuration test was finished and the second motor configuration was created for testing.

Upcoming Tasks:

Prepare for lab 10 and complete all unfinished tasks of lab 09.

03/07/2019

Members Present: All members present
Topics/Agenda: Analyze the data collected during lab 09 and continue to collect data and analyze.
Action Items:

- Website: Grace
- Data Analysis: Maddy
- AEV: Ben
- Testing: Everyone

Overview:
The second motor configuration was tested and the data collected and analyzed. Brake testing started.
Upcoming Tasks:
Prepare for lab 11 and complete all unfinished tasks of lab 10. Prepare for performance test 01 and finish progress report 02.

3/18/2019
Members Present: All members present
Topics/Agenda: Analyze data and prep for performance test 01.
Action Items:

- Website: Grace
- Prep: Maddy, Ben, Clark

Overview: The team analyzed data from the previous lab and began preparing for performance test 01.
Upcoming Tasks:
Prepare for performance test 01.

3/20/2019
Members Present: All members present
Topics/Agenda: Performance test 01.
Action Items:

- Website: Grace
- Performance Test: Maddy, Ben, Clark

Overview: The team spent the majority of the class making adjustments for the performance test and then the test was completed successfully.
Upcoming Tasks:
Prepare for performance test 02.

3/21/2019
Members Present: All members present
Topics/Agenda: R&D Oral Presentation.
Action Items:

- Presentation: Maddy, Ben, Clark, Grace

Overview: The team presented results gathered up until this point.
Upcoming Tasks:
Prepare for performance test 02.

3/27/2019
Members Present: All members present
Topics/Agenda: Performance test 02.
Action Items:

- Website: Grace
- Performance Test: Maddy, Ben, Clark

Overview: The team spent the class fine tuning the code and the test was completed successfully.
Upcoming Tasks:
Prepare for performance test 03 and committee meeting 02.

3/28/2019
Members Present: All members present
Topics/Agenda: Committee meeting 02.
Action Items:

- Meeting: Maddy, Ben, Clark, Grace

Overview: Heads of HR, PR, and R&D participated in relevant committee meetings at the beginning of lab. The team spent the rest of class preparing for AR&D 3.
Upcoming Tasks:
Prepare for performance test 03.

3/1,3,4/2019 (Multiple Days where team did same thing)
Members Present: All members present

Topics/Agenda: AR&D 03..
Action Items:

- Website: Grace
- AR&D: Maddy, Ben, Clark

Overview: The team tested the new AEV and prepared for performance test 03.
Upcoming Tasks:
Prepare for performance test 03.

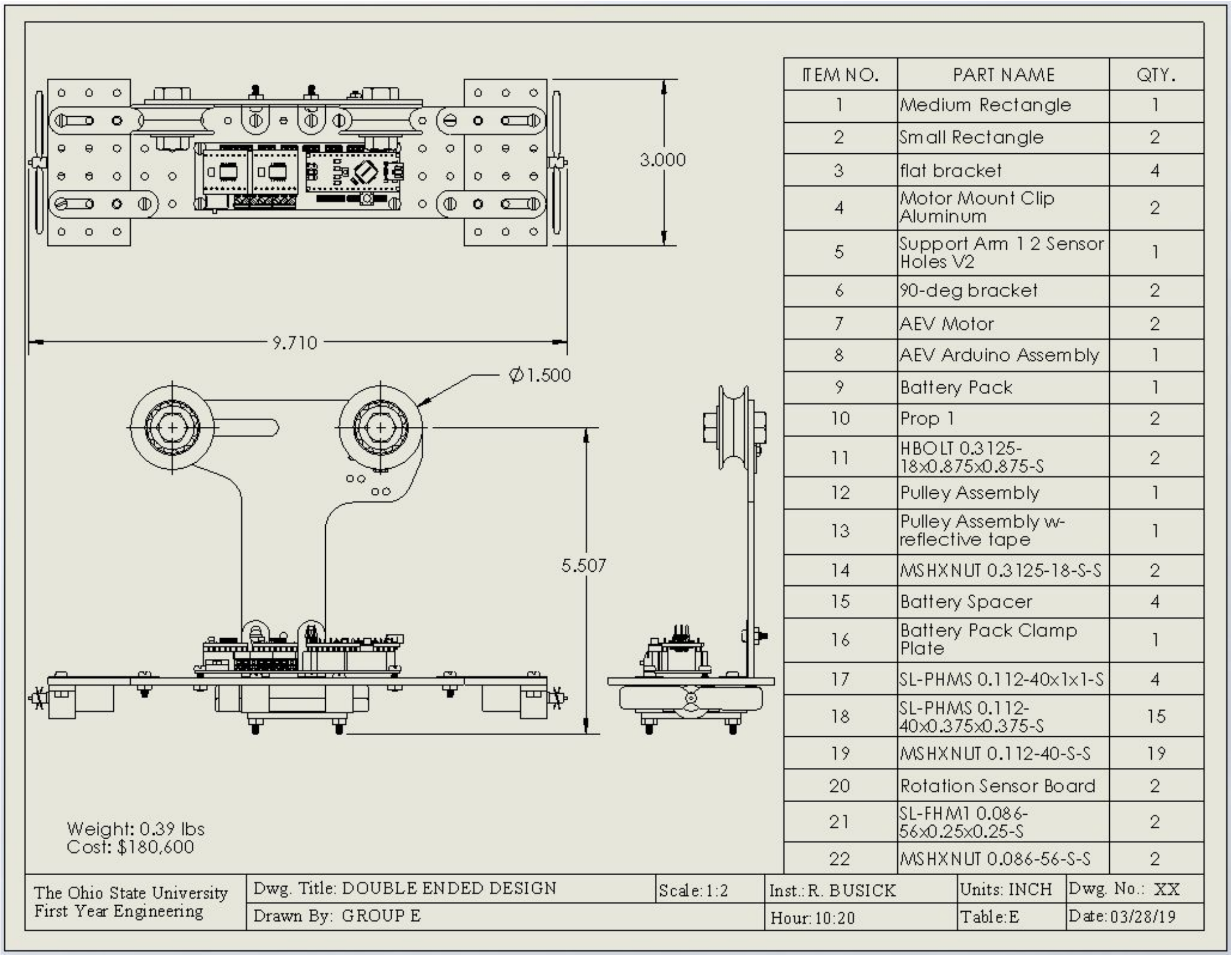
3/15,16/2019 (multiple days of same thing)
Members Present: All members present
Topics/Agenda: Final deliverables.
Action Items:

- Website: Grace
- Final deliverables: Maddy, Ben, Clark, Grace

Overview: Final AEV checklist and final deliverables.
Upcoming Tasks:
Prepare for final presentation.

Appendix B: Double Ended Design

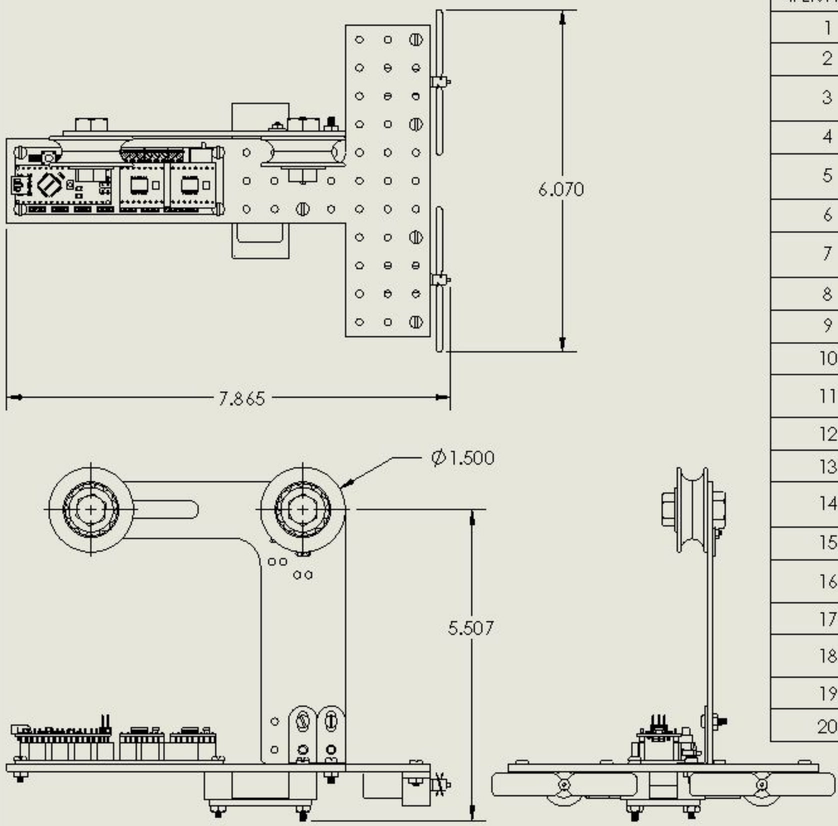
-Streamlined design, one motor in front, one in back



ITEM NO.	PART NAME	QTY.
1	Medium Rectangle	1
2	Small Rectangle	2
3	flat bracket	4
4	Motor Mount Clip Aluminum	2
5	Support Arm 1 2 Sensor Holes V2	1
6	90-deg bracket	2
7	AEV Motor	2
8	AEV Arduino Assembly	1
9	Battery Pack	1
10	Prop 1	2
11	HBOLT 0.3125-18x0.875x0.875-S	2
12	Pulley Assembly	1
13	Pulley Assembly w-reflective tape	1
14	MSHXNUT 0.3125-18-S-S	2
15	Battery Spacer	4
16	Battery Pack Clamp Plate	1
17	SL-PHMS 0.112-40x1x1-S	4
18	SL-PHMS 0.112-40x0.375x0.375-S	15
19	MSHXNUT 0.112-40-S-S	19
20	Rotation Sensor Board	2
21	SL-FHM1 0.086-56x0.25x0.25-S	2
22	MSHXNUT 0.086-56-S-S	2

Appendix C: Side by Side Design

-Two motors in the back



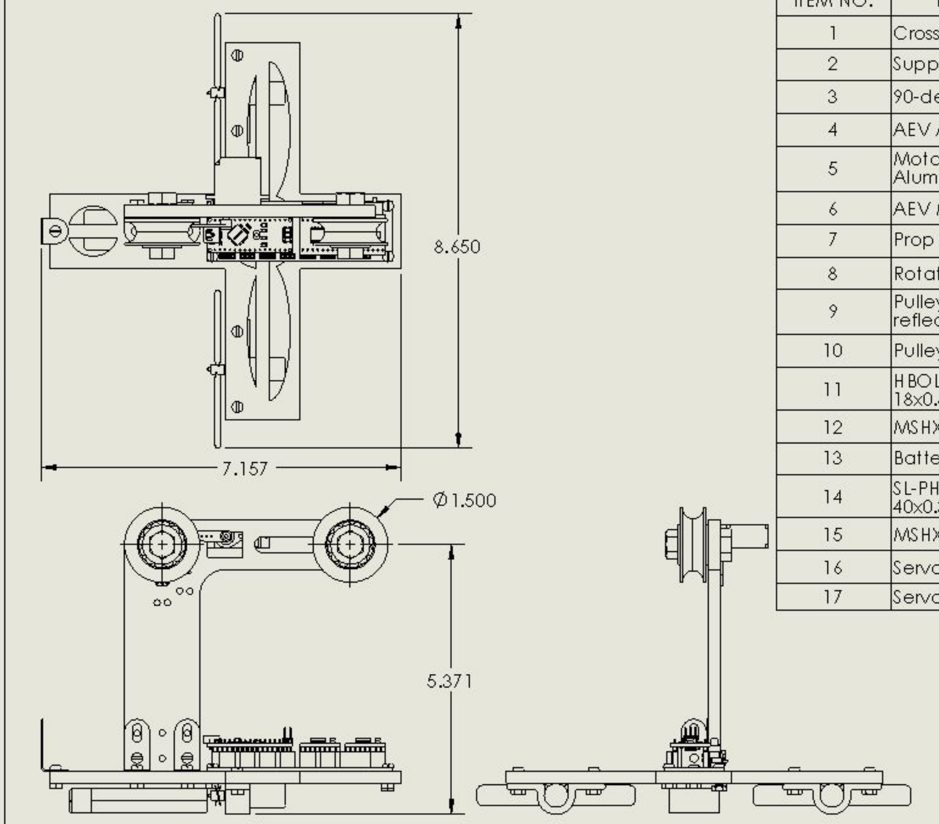
ITEM NO.	PART NAME	QTY.
1	Tee	1
2	AEV Arduino Assembly	1
3	Support Arm 2 2 Sensor Holes	1
4	90-deg bracket	2
5	Battery Pack Clamp Plate Narrow	1
6	Battery Spacer	4
7	Motor Mount Clip Aluminum	2
8	AEV Motor	2
9	Prop 1	2
10	Battery Pack	1
11	SL-FHM1 0.086-56x0.25x0.25-S	2
12	MSHXNUT 0.086-56-S-S	2
13	Rotation Sensor Board	2
14	Pulley Assembly w-reflective tape	1
15	Pulley Assembly	1
16	HBOLT 0.3125-18x0.875x0.875-S	2
17	MSHXNUT 0.3125-18-S-S	2
18	SL-PHMS 0.112-40x0.375x0.375-S	9
19	SL-PHMS 0.112-40x1x1-S	4
20	MSHXNUT 0.112-40-S-S	13

Weight: 0.34 lbs
Cost: $173,560

The Ohio State University First Year Engineering	Dwg. Title: SIDE BY SIDE DESIGN	Scale: 1:2	Inst.: R. BUSICK	Units: INCH	Dwg. No.: XX
	Drawn By: GROUP E		Hour: 10:20	Table:E	Date: 03/28/19

Appendix D: Final Design

-Side by Side motor configuration with laser cut frame

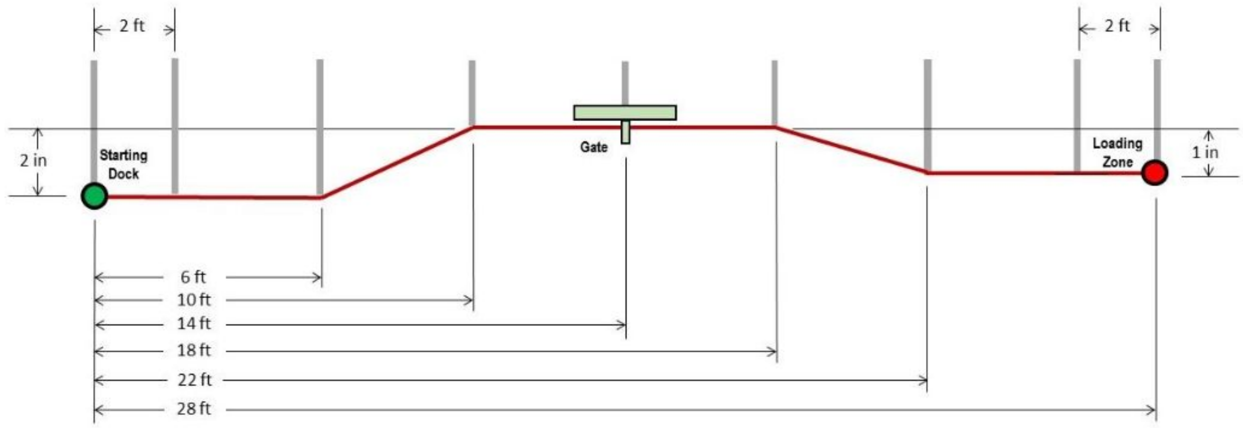


ITEM NO.	PART NUMBER	QTY.
1	Cross2	1
2	Support_2	1
3	90-deg bracket	3
4	AEV Arduino Assembly	1
5	Motor Mount Clip Aluminum	2
6	AEV Motor	2
7	Prop 3inch	2
8	Rotation Sensor Board	2
9	Pulley Assembly w-reflective tape	1
10	Pulley Assembly	1
11	HBOLT 0.3125-18x0.875x0.875-S	2
12	MSHXNUT 0.3125-18-S-S	2
13	Battery Pack	1
14	SL-PHMS 0.112-40x0.375x0.375-S	13
15	MSHXNUT 0.112-40-S-S	13
16	Servo Motor	1
17	Servo Arm	1

Weight: 0.44 lbs
Cost: $155,308

The Ohio State University First Year Engineering	Dwg. Title: FINAL DESIGN	Scale: 1:2.25	Inst.: R. BUSICK	Units: INCH	Dwg. No.: XX
	Drawn By: GROUP E		Hour: 10:20	Table: E	Date: 04/17/19

Appendix E: Track Model



Appendix F: Arduino Code for Double Ended Design Coasting

```
reverse(1);
motorSpeed(4,20);
goFor(3);
brake(4);
goFor(10);
reverse(4);
motorSpeed(4,20);
goFor(3);
brake(4);
goFor(10);
```

Appendix G: Arduino Code for Side by Side Design Coasting

```
motorSpeed(4,20);
goFor(3);
brake(4);
goFor(10);
reverse(4);
motorSpeed(4,20);
goFor(3);
brake(4);
goFor(10);
```

Appendix H: Arduino Code for Side by Side Design Power Braking

```
motorSpeed(4,20);
goFor(3);
reverse(4);
motorSpeed(4,28);
```

```
goFor(1.2);
brake(4);
```

Appendix I: Arduino Code for Power Braking

```
//to gate
celerate(4,0,28,1.5);
goToAbsolutePosition(270);
reverse(4);
motorSpeed(4,28);
goFor(1.2);
brake(4);
goFor(8);

//to caboose
reverse(4);
celerate(4,0,25,1.5);
goToAbsolutePosition(528);
reverse(4);
motorSpeed(4,30);
goFor(1.2);
brake(4);
goFor(5);
```

Appendix J: Arduino Code for Servo Braking

```
//to gate
celerate(4,0,40,1.5);
goToAbsolutePosition(200);
brake(4);
goToAbsolutePosition(288);
rotateServo(45);
goFor(2);
rotateServo(0);
goFor(5.5);

//gate to caboose
celerate(4,0,38,1.5);
goToAbsolutePosition(410);
brake(4);
goToAbsolutePosition(631);
rotateServo(45);
goFor(2);
rotateServo(0);
goFor(5);
```

Appendix K: Arduino Code for Final Run

```
//to gate
celerate(4,0,40,1.5);
goToAbsolutePosition(200);
brake(4);
goToAbsolutePosition(288);
rotateServo(45);
goFor(2);
rotateServo(0);
goFor(5.5);

//gate to caboose
celerate(4,0,38,1.5);
goToAbsolutePosition(410);
brake(4);
goToAbsolutePosition(631);
rotateServo(45);
goFor(2);
rotateServo(0);
goFor(5);

//caboose to gate
reverse(4);
celerate(4,0,49,2);
goToAbsolutePosition(395);
brake(4);
goToAbsolutePosition(383);
rotateServo(45);
goFor(2);
rotateServo(0);
goFor(7);

//gate to end
celerate(4,50,40,1);
goToAbsolutePosition(215);
brake(4);
goToAbsolutePosition(48);
rotateServo(45);
goFor(2);
rotateServo(0);
```

Works Cited

[1] The Ohio State University Engineering Department, MISSION CONCEPT REVIEW (MCR) AND DELIVERABLES