Preliminary Design Report

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Abstract

The purpose of the AEV Lab was to, as a team, develop an AEV Controller that utilized an Arduino Nano and the Arduino software coding environment that successfully met certain guidelines set regarding the AEV's ability to move on an overhead track, stop when desired, and pick-up cargo, whilst remaining energy efficient, and of a low mass and cost. The design process of the AEV involved the completion of numerous labs that targeted specific aspects of the AEV Controller including the code needed to run it and the way in which the reflectance sensors on the AEV's arm functioned. Through a variety of trials and failures, the team concluded that their final AEV Controller design was to essentially consist of a T-shaped base, a T-shaped arm, 3030 puller propellers, the Arduino, the battery, and the reflectance sensors. Going forward, it is recommended for the team to strategically and carefully code their AEV's run on the overhead track. Additionally, it is recommended to practice the AEV run numerous times before the test run day to ensure the AEV will run successfully.

Executive Summary

In order to create an Advanced Energy Vehicle (AEV) that meets the demands of the rebel alliance by transporting cargo via a caboose while performing consistently regardless of the type of track the AEV is on, effectively transports cargo despite the type of cargo being transported, and uses the least amount of energy possible, a design process was followed. This design process included using, testing, and developing code for an Arduino Nano, reflectance sensors, propellers, an initial design, and a secondary design. By meeting the needs of the rebel alliance through the creation of such an AEV, the alliance will be able to discreetly prepare for battle against the galactic empire.

Overall, the design process allowed the team to discover flaws and inconsistencies in the original AEV design, causing the team to create a second design. The first step in the design process assisted the design team by allowing them to understand the importance of the syntax of the code, as spelling and placement of commands is of the utmost importance when writing a code. The second part of the design process was testing the different propeller types and configurations. Of the two propeller types, the 2150 and the 3030, the 3030 propeller was found to be more effective in its propulsion efficiency. Of the two configurations of the 3030 propeller, the pusher and the puller configuration, the puller configuration was chosen, as its propulsion efficiency was greater than the pusher configuration. After the discovery that the 3030 puller propeller should be used, the design team realized their initial design, which was the reference design provided in the lab manual, was not efficient enough. So, the team experimented with the physical parts of the AEV, leading to the creation of the second design.

Once the second design was created, the testing of the efficiency and consistency of the AEV continued. However, this was soon thwarted when the team discovered that the placement of the wheels in relationship to the track prevented the aluminum on the wheels from coming in contact with the reflectance sensors. This problem helped the team to redesign the AEV, resulting in the third and current design.

With the current design, performance testing began to finalize the design of the AEV. The current design consisted of two possible choices for arms, with all other aspects of the AEV remaining the same. Between a L-shaped arm design and a T-shaped arm design, the latter was chosen to be the final design, as it displayed better balance and stability on the track.

As the design process moves forward and concludes, the team must concentrate on the Arduino code and guarantee that the MCR requirements are met before presenting the AEV to the rebel alliance. Reflecting on previous issues with the code, the team must ensure accuracy with spelling, syntax, and placement of commands in the code. In regards to fulfilling the MCR requirements, the team must carefully review the requirements and prepare accordingly, in order to make sure mistakes like those made in the preliminary design process are not repeated.

Table of Contents

Introduction

In order to fulfill the requirements set in the Mission Concept Review, located in the lab manual, the team explored a design process that focused on an initial design of the AEV, a secondary design, the coding of the Arduino Nano, addressing which propeller configuration to use, and the use of reflectance sensors. By following this design process, the team was able to ensure that the team's AEV design was operationally efficient, operationally consistent, and utilizes the least amount of energy possible.

In order to fully explore the discoveries of the team during the preliminary steps of the design process of the AEV, the following sections will describe the team's methodology during their experimentation, the results obtained, and all notable conclusions and decisions reached after analyzing the results. In particular, these sections will examine the issues incurred during the design process, such as problems with the reflectance sensors and coding, how the team developed their current design, and their plans moving forward, which include fulfilling the MCR requirements by finalizing the AEV design and Arduino code and continually updating the project portfolio.

Experimental Methodology

The main equipment used in this lab included a USB cable, an Arduino Nano microcontroller, propellers, a Li-Po battery, electric motors, reflectance sensors, wheels with reflectance tape, an AEV support arm, and a PCB board. To control the Arduino, an Arduino Integrated Development Editor (IDE) software was utilized to call specific commands that the Arduino recognized. Some of these commands include *motorSpeed(), brake(), celerate(), reverse(), goToAbsolutePosition(), goToRelativePosition(),* and *goFor().*

Shown in Figure 1, an Arduino Nano, a microcontroller, was used to control the motors, record system data, and direct the movement of the AEV on the overhead track. This was done using a software program called the Arduino Integrated Development Editor (IDE), along with a USB cable which was used to uploaded the IDE to the Arduino. Along with the Arduino software, MATLAB and Excel were utilized to calculate and analyze data in the design process.

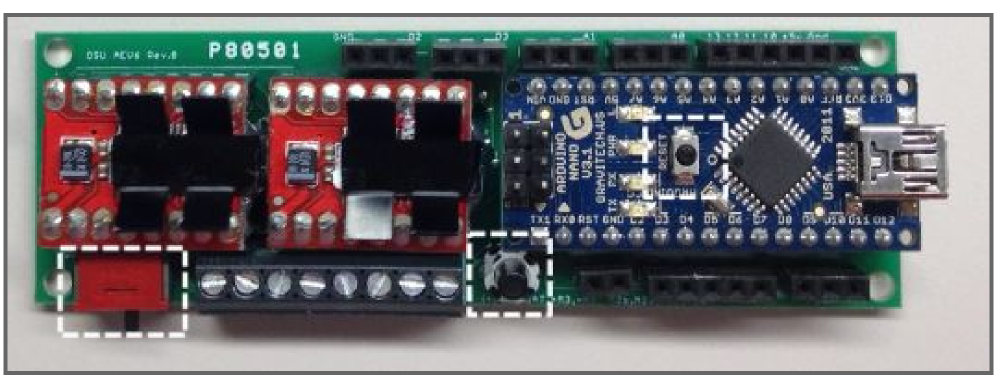

Figure 1: Arduino

The provided electric motors were used to transfer power from the Li-Po battery to the propellers, shown in Figure 2, which directed the direction and speed in which the AEV was moving on the overhead track. The wheels and the support arm provided mobility of the AEV on the overhead track. The wheels connected to the body of the AEV. Also connected to the body of the AEV was a magnetic bracket that allowed for attachment of the cargo caboose.

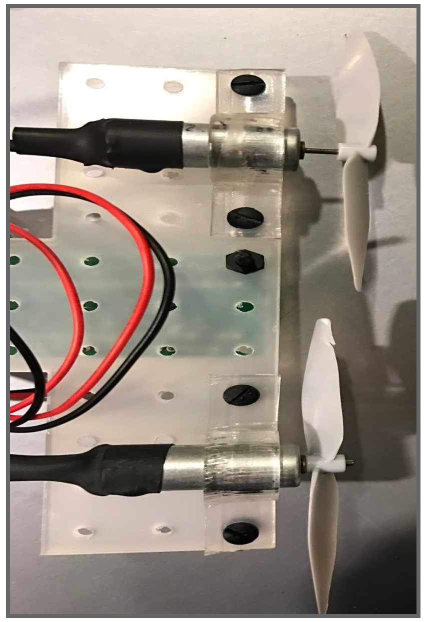

Figure 2: Propellers connected to PCB board and motors

Figure 3: Wheel with Reflective Tape

The reflectance sensors, shown in Figure 4, were used to allow the Arduino to keep track of the distance travelled by AEV on the overhead track. It collected "marks" as the wheel rotated a certain distance. For every rotation of the wheel, shown in Figure 3, the reflectance sensors picked up reflectance from reflective tape placed on the wheels and counted "marks." This allowed for the reflectance sensors to respond to specific command calls directing the AEV to travel a certain distance. Additionally, the reflectance sensors made the AEV capable of collecting vital data that would allow for the team to make vital conclusions.

Figure 4: Reflectance Sensors connected to Support Arm

In addition to assisting with the reflectance sensors, the wheels helped to move the AEV whilst on the track. The wheels connected to the AEV via the support arm, which connected to the body of the AEV consisting of a PCB Board. For more information on the individual parts used in the AEV lab, refer to the AEV Lab Manual.

Putting all the parts together, the lab manual provided instructions on how to make a sample AEV design, which was used in the first few labs. An image of the sample AEV design is shown below in Figure 5.

Figure 5: Sample AEV Design

As the sample AEV design clearly did not meet certain MCR requirements, the team created another design, shown in Figure 6 , utilizing the T-shape arm and T-shape base.

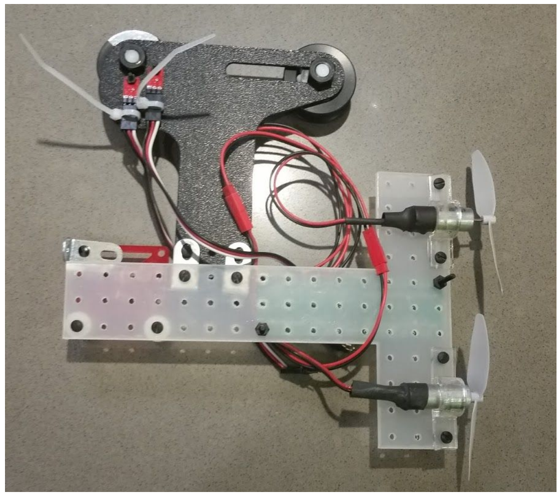

Figure 6: Current Team Design

The AEV Lab consisted of a total of ten labs. Each lab targeted a different aspect of the AEV design or functioning of the Arduino software. In lab one, Arduino Programming Basics, the team learned about the Arduino controller and how to work directly with the Arduino software using basic function calls. Also, it was introduced how to upload the code to the Arduino via a USB wire. Given a basic scenario, the team coded simple function calls that would allow for the AEV to move on the overhead track.

Lab two, External Sensors & System Analysis 1, was divided into two parts. In the first part, the team worked with reflectance sensors and additional function calls. It was familiarized how the reflectance sensors work, utilizing the aluminum on the wheels, and how the function calls require a distance, in marks, to be noted. In the second part of lab two, the team used a wind tunnel to imitate the motion of an AEV to test two different propellor types of two different configurations. The team then chose the most efficient propeller type and configuration after looking at the the results including values for propeller advance ratio, propulsion efficiency, power input, and power output .

Lab three, Creative Design Thinking, consisted of two parts as well. In the first part, each member sketched an individual AEV design in orthographic view on an orthographic paper. Then, in the second part, the entire team created one team sketch of an AEV design. This aided the team in the design process, providing an outlet for the team to step away from the sample AEV design.

In lab four, System Analysis 2 and Design Analysis Tool, the team ran the AEV on the overhead track from the starting point to gate, and collected its EEPROM data. The EEPROM data recorded during the run was then downloaded from the Arduino into MATLAB, and then converted into physical parameters using Excel before being analyzed. To graph the data, Excel and the Design Analysis Tool, run by MATLAB, was used.Notable plots created included a power versus time graph and a power versus distance graph.

In lab five, Screening and Scoring, the team learned about concept screening and scoring. The team used a concept screening scoresheet and a concept scoring matrix to rate their own individual AEV designs along with the team AEV design by looking at each design's advantages and disadvantages in regards to certain set criteria. Organizing and identifying the positives and negatives of each design allowed for the team to assure their team design was the best of all of their designs.

Lab 6 acted as a Halfway Checkpoint for the team. During this lab, the team redesigned their AEV and finally manipulated the AEV sample design to create a new design. In lab seven, the team created and presented their Preliminary Design Review Oral Presentation. The team discussed their design process, short term and long term goals, and their next steps moving forward.

In lab 8, Performance Test 1, the team was instructed to create two different AEV designs and record observations after testing them. Specifically, the team chose to look at the balance, cargo attachment, and energy efficiency of both designs.

Going forward, the team has to complete Performance Test 2, 3, 4. Additionally, the team needs to continually update their project portfolio, an online blog focused on the team's progress, their CDR, and work on the extra credit video.

Results

As a total of eight labs have been completed thus far, a significant amount of useful data has been measured, calculated, and analyzed. Specific data has especially aided the team in creating their current AEV design. Lab 1, Arduino Programming Basics, allowed for the team to work with the provided Arduino command calls. Although no considerable numerical results were yielded from lab 1, the importance of familiarizing the function calls to the team is notable as the commands would be utilized in the majority of the following labs. For example, Lab 9, Performance Test 2, is solely focused on the code necessary to meet MCR set requirements regarding the AEV's performance on the overhead track.

Part 1 of lab 2, External Sensors & System Analysis 1, introduced additional command calls that can be called to work with the reflectance sensors. As the command calls require a distance that the AEV traveled (in marks) to be indicated, simple math has to be done to calculate the marks. It was vital to understand how the conversion factor worked as it would be utilized in the following labs, including PT2, to control the distance the AEV traveled on the track. For example, if the team wanted the AEV to travel 35 feet on the overhead track using the *goToAbsolutePosition(m)* function call, the following conversion factor would be done:

$$0.4875\ inches\ =\ 1\ mark$$
$$0.040625\ \ feet\ =\ 1\ mark$$
$$35\,feet\ = 862\ marks$$

Therefore, the function call would be *goToAbsolutePositon(862).* In part 2 of lab 2, data was collected for two different propellers of two different configurations using the wind tunnel. The data found was used to calculate additional values including the calibrated thrust, the power input, the power available, the propulsion efficiency, and the propeller advance ratio. All data calculated was completed using Excel. The data calculated for the 2050 pusher, 2050 puller, 3030 pusher, and 3030 puller propellers can be found in Appendix A (A1, A2, A3, A4). Analyzing the data, the team decided to specifically look at the propulsion efficiency of each propeller. To represent the data graphically, a graph was created for each propeller of each configuration representing the relationship between propulsion efficiency. The graph for the 3030 puller is found below in Figure 7, while the additional graphs are found in Appendix A (A5, A6, A7). It was evident that the 3030 puller propellers yielded the highest propulsion efficiency. As propulsion efficiency accounts for the energy yielded from the energy consumed, a higher propulsion efficiency would ensure energy is minimized. Since the 3030 puller propellers had the highest propulsion efficiency, the team decided that this propeller type and configuration would be used on their team AEV design.

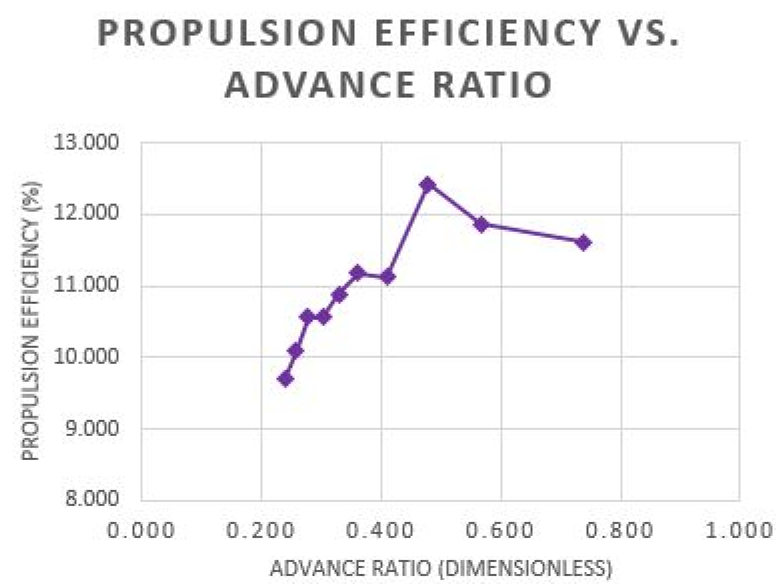

Figure 7: Propulsion Efficiency versus Advance Ratio (3030 Puller)

Lab 3, Creative Design Thinking, did not yield any concrete, numerical data. Instead, it allowed the team to, individually and as a team, design different AEV Controllers and identify the materials/costs needed to execute it. This allowed the team to observe exactly what the next stages of the design process would look like. For example, the team saw that redesigning the AEV from the original design could bring upon issues regarding the AEV's overall balance, durability, and ability to attach to the cargo. All individual designs drawn can be found in Appendix B (B1, B2, B3, B4). The final team design is shown below in Figure 8:

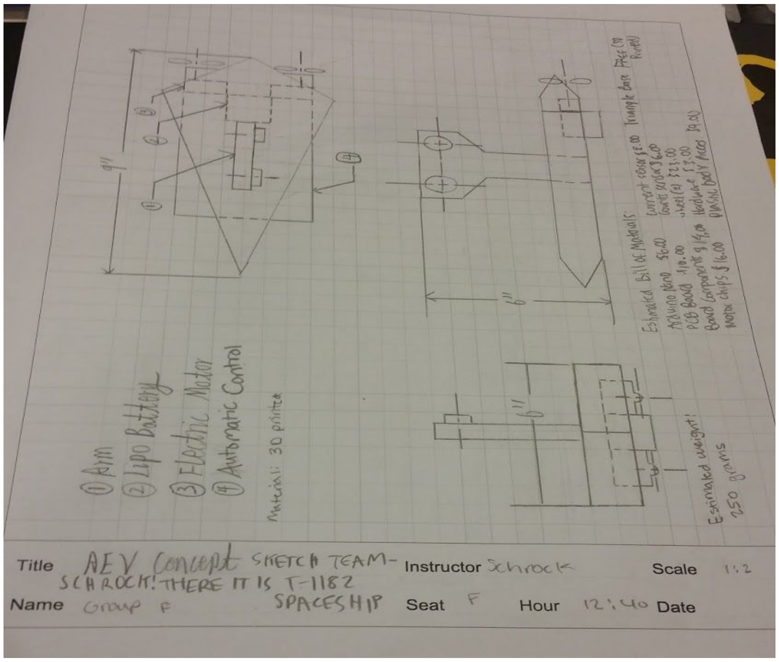

Figure 8: Team Design

All analysis done pertaining to the individual and team drawings is discussed in the Discussion.
Lab 4, System Analysis 2 & Design Analysis, collected and calculated data regarding the AEV's performance on the overhead track. From the performance, EEPROM data was measured. By importing the data into MATLAB, it was imported into an Excel document, which easily allowed for the team to analyze it. To have a clearer understanding of the data, the team converted it into physical parameters. Additionally, a graph representing the relationship between power versus time was created. To even further represent the data, the Design Analysis Tool was used to create another graph representing power versus and time and also power versus distance. Both graphs that were made using the Design Analysis Tool are shown below in Figure 9 and 10.

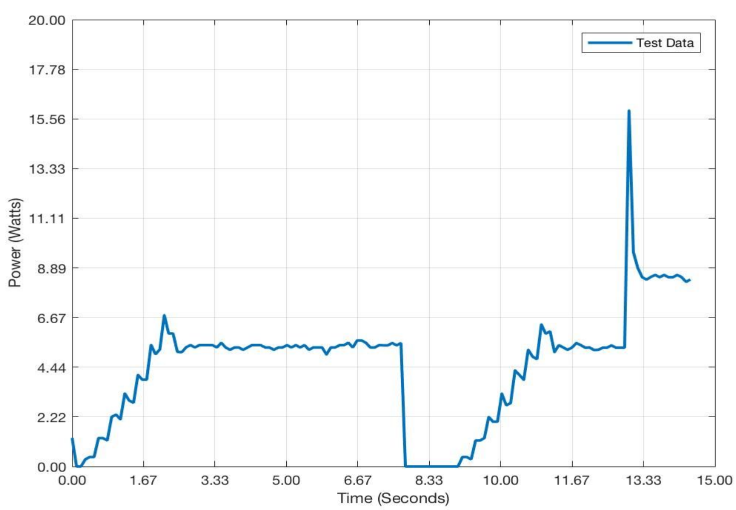

Figure 9: Power versus Time

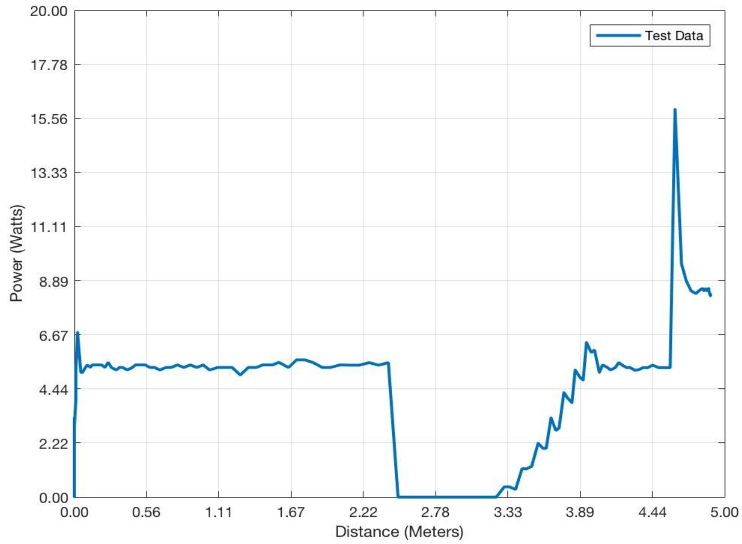

Figure 10: Power versus Distance

The graphs allow the team to observe how specific command calls that are imported into the Arduino have a direct impact on the supplied power and its fluctuations. As shown in the both graphs, the relationship between power and time, and power and distance is not consistently linear. The team analyzed this in way that associated individual command calls to its graphical representation. For example, as the line remains relatively flat from 0.01 to 2.5 seconds in Figure 2 above, it can be inferred that the *motorSpeed()* and *goFor()* commands were being utilized to allow for the AEV to simply move around the track, while not fluctuating in its power input or output. Additionally, the area under the power versus time graph is the energy. This allowed for the team to observe an estimation of the energy that the AEV would possess during its run. The methodology and results from Lab 4 were especially beneficial as they would be again applied again in the first performance test.

Lab 5, Screening and Scoring, yielded additional significant results. Using the screening and scoring methodology, the team was able to observe which design created had the most advantages and disadvantages in regards to each design's the balance, amount of blockage encountered on the rail system, center-of-gravity, maintenance, durability, cost efficiency, and environmentally friendliness. The concept screening scoresheet and the concept scoring matrix is shown in Appendix B (B5, B6). By evaluating the scores of both the concept scoring matrix and concept screening scoresheet, it is obvious that the team design would be the best to execute.

However, as a team, the team never was able to create the team design they drew and further scored. After discussing its functionality as a team, it was concluded that the design was too complicated. It was mutually felt, as a team, that the design would not turn out as hoped. This unclarity felt led the team to create their current AEV design. Taking in account all results found in labs 1 to 5, the team made a new team AEV design. This design was created by simply reconstructing the AEV a number of times until a desirable design was created. Therefore, no orthographic drawing was ever created of the current AEV design.

Throughout lab 6 and lab 7, the team created an executable plan for lab 8, Performance Test 1. Going into PT1, the team identified that their current AEV design had three major issues regarding the overall balance of the vehicle, its ability to attach to cargo, and its energy efficiency. PT1 allowed for all of issues to be tested by the team. By creating two different designs with different arms (further discussed in the Discussion), the team ran both different designs on the overhead track using the same code. Since the team specifically was looking at the AEV's balance, cargo attachment, and energy efficiency, when each AEV design was run on the overhead track, the team visually analyzed it, while also collecting its EEPROM data. Regarding the balance, the team was easily able to identify which arm balanced better simply by hanging each design on the overhead track. Regarding cargo attachment, the team ensured the magnet on both designs lined up with the cargo magnet. Regarding energy efficiency, the team, as stated previously, worked with the EEPROM data and Design Analysis Tool. The team ran the AEV with the T-shape arm and the L-shape arm on the overhead track using the same code. For both arms, graphs were created representing power versus time and power versus distance. The graphs created for both arms are shown in Appendix C (C1, C2, C3, C4). By analyzing the graph of power versus time for the T-shape arm and L-shape arm (C1 and C3) and looking specifically at the area under the graphs, it can be estimated that the T-shape arm uses less energy because it has less area under the graph. This would mean that the T-shape arm would allow for the AEV to overall be more energy efficient than if the L-shaped arm was used. As the T-shape arm was the best balanced and the most energy efficient, the team chose to use that arm for their AEV design rather than the L-shape arm, which the team initially thought would be the better arm. In addition to the arm, the AEV will also utilize the 3030 propellers. Both designs tested in PT1 applied the 3030 puller configuration as that was proven, as discussed earlier, the best for energy minimization.

Overall, PT1 incorporated techniques from System Analysis 1 and 2, including identifying the best propellers through the highest propulsion efficiency and using the Design Analysis Tool to create graphs that allowed for the team to make assumptions about the AEV's energy efficiency. After acquiring data from each lab and analyzing it, it can be assured that the AEV the team designed will satisfy the requirements set in the MCR regarding energy efficiency, low mass, ability to attach to the cargo, environmentally friendly, durable, and so on.

Discussion

Each lab individually allowed for new analyzations to be made that would ultimately aid in the successful completion of the AEV running on the overhead track and meeting all MCR requirements. Leading to the current team design, the team encountered a variety of complications. In lab 1, the team was able to utilize the provided Arduino command calls to complete a given scenario for the AEV to complete on the overhead track. Although the scenario completed was not the AEV code that would be developed in Performance Test 2 to meet the MCR requirements, it still applied the same command calls. Each team member familiarizing themselves with the function calls makes the coding simpler and understandable.

Lab 1, however, did present the team with their first complication. After developing the code, it was expected that the code would import successfully into the Arduino. Although, this was not case. The team encountered an error in their code. After analyzing the code very closely, the team identified that the *brake()* command was misspelled as *break().* Even though this was a small error, it taught the team the significance of calling the commands correctly. The Arduino software is very particular as to the commands it recognizes. When developing the code for PT2, the team is going to take into account that correct spelling and formatting of command calls is vital, and if done incorrectly may cause potential errors.

The team explored how the reflectance sensors functioned in Lab 2A. After working directly with the specific command calls to track the distance the AEV traveled using the reflectance sensors, *goToAbsolutePosition()* and *goToRelativePosition()*, the team gained a better understanding of how important the reflectance sensors are. In regards to the purpose of the lab, they would allow for the AEV to navigate its way around the track, stopping at the gate, the cargo, and the drop-off area. In addition, during the design process of the AEV, the team experienced some trouble in positioning the reflectance sensors correctly on the AEV arm. Before finalizing the current AEV design, which was done in Lab 6, the team noticed that when the AEV was ran, it never stopped, regardless if the motor speed was set to 0 or the *brake()* command was called. After looking closely at the AEV, it was noticed that the wheels were positioned backwards with the aluminum facing outwards, which would prevent the aluminum from ever being detected by the sensors. This simple, silly error taugh the team a lot. It was analyzed and noted exactly how the sensors and wheels must be placed to work properly. Since taking off the arm is frequently done for storage reasons, this was imperative to realize. Every time the arm is taken off and put back on and the AEV is not running properly, the team examines the reflectance sensors and their placement.

Working with the wind tunnel in Lab 2B led the team to identify that using the 3030 puller propellers would minimize the most energy. Specifically, the team looked at propulsion efficiency to make this conclusion. Essentially, this is a major identification as it will meet goals set in the MCR regarding the AEV's overall energy efficiency. From this, the team decided to consistently use the 3030 puller propellers on their AEV design.

The design process of the AEV has not been a simple one. The team failed to create a functional design until after Lab 6, which was the halfway checkpoint. Working with the AEV's EEPROM data collected from its performance on the overhead track in lab 5, and the screening and scoring of the numerous AEV designs in lab 5 left the team will a number of problems in front of them. The team fell behind in the creative design lab when they created their team design. The team design created was deemed too complicated to actually physically execute. Therefore, going forward, the team found the EEPROM data for the sample vehicle rather than their team design. Additionally, the team scored and screened the sample vehicle. Since the team worked with the sample vehicle rather than their team design, they were set back. After realizing how they had fallen behind, the team created their current team design. To do so, the team did not create an orthographic drawing, but rather physically manipulated the sample vehicle design until it looked satisfactory and as desired. This involved utilizing the T-base, the L-arm, and the 3030 puller propellers. The team felt after creating this design it did successfully meet certain

MCR requirements. For example, it weighed less than the sample AEV. It weighed 237.2 grams with the battery, while the sample AEV weighed 250 grams. This is about 5% lighter. A lighter mass will maintain a better mass-energy relationship. Additionally, it is better cost wise. The team design created in lab 3 required the purchasing of additional wings. By using only pieces provided, the team spends no additional cost. Along with mass and cost, the current AEV design is environmentally friendly, durable, and maintainable. In theory, the team predicted the AEV to run smoothly along corners of the track and through the gate as its width is relatively thin. Also, the team hypothesized that the design would be energy efficient as it utilized the 3030 puller propellers.

The team did identify certain flaws in the design though. Without testing, the team was unsure how well the design would be evenly balanced, attach to cargo, and positively minimize energy. To address these problems, the team developed a plan of execution for Performance Test 1 in Lab 8. The team created two different prototype AEV designs to test in PT1. The designs did not evolved in any way from the four individual prototype designs created in the creative design lab. As discussed before, the team failed to use the individual and team design from that lab as the execution of all the designs would have been too complex. Both designs created for PT1 were essentially the same; however, one utilized the T-shape arm, shown below in Figure 5, while the other used the L-shape arm, Figure 6. The team felt as if the rest of the AEV worked sufficiently and was interested in exploring the difference between the arms. To identify the advantages and disadvantages between the PT1 prototype designs, the 4 individual designs, and the sample AEV design, the team utilized the concept screening and scoring charts again. The figures are shown below in Figures 11 and 12.

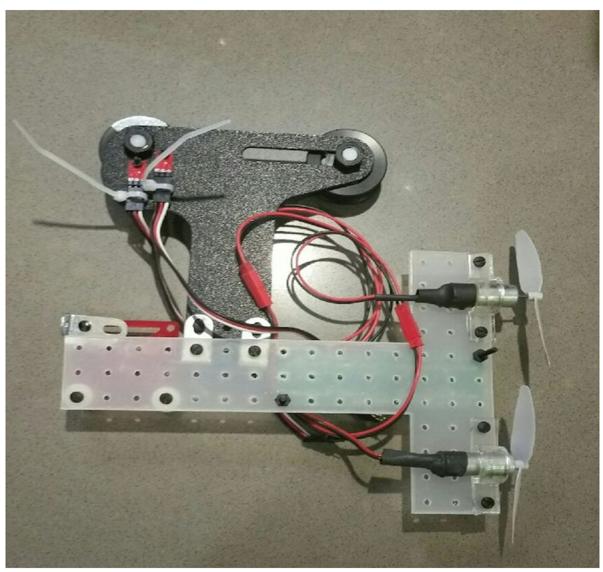

Figure 11: T-Shaped Arm AEV

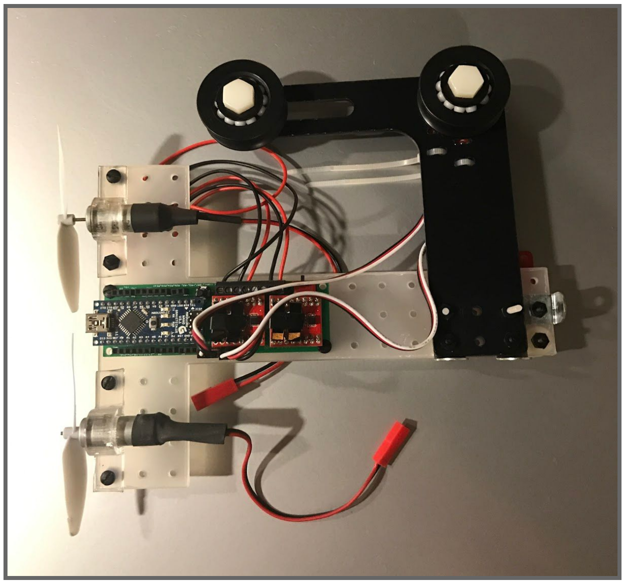

Figure 12: L-Shaped Arm AEV

Table 1: Concept Screening Scoresheet (Prototypes Included)

Success Criteria	**Reference**	**Design A - McKenzie**	**Design B - Abbey**	**Design C - Xinjie**	**Design D - Merveille**	**Prototype - L-shape Arm**	**Prototype - T-shape Arm**
Balanced in Turns	0	0	0	0	0	+	0
Minimal blockage	0	-	0	0	0	+	+
Center-of-gr avity	0	-	0	+	+	+	+
Maintenance	0	0	+	-	0	+	+
Durability	0	+	0	0	+	+	+
Cost	0	0	-	-	-	+	+
Environment al	0	0	0	0	0	+	+
Sum +'s Sum 0's	0 7	1 4	1 5	1 4	2 4	6 1	7 0

Sum -'s	0	2	1	2	1	0	0
Net Score	0	-1	0	-1	+1	+7	+6
Continue	Combine	No	No	No	No	Maybe - more testing	Maybe - more testing

Table 2: Concept Scoring Matrix (Prototypes Included)

		A Reference		Design W - McKenzie		Design X - Abbey		Design Y - Xinjie		Design Z - Merveille		Prototype - L-shape Arm		Prototype - T-shape Arm	
Success Criteria	Weight	Rating (0-5)	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Balanced in Turns	5%	3	0.15	4	0.2	3	0.15	3	0.15	3	0.15	4	0.2	3	0.15
Minimal blockage	15 %	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45	3	0.45
Center-of-gravity	10 %	2	0.20	3	0.3	2	0.20	4	0.4	4	0.40	3	.3	3	.3
Maintenance	25 %	3	0.75	3	0.75	4	1.00	2	0.5	3	0.75	3	.75	4	1.00
Durability	15 %	2	0.30	4	0.6	2	0.30	3	0.45	4	0.45	3	.45	3	.45
Cost	20 %	3	0.60	2	0.4	3	0.60	1	0.2	3	0.40	2	.40	2	.40
Environmental	10 %	3	0.30	3	0.3	3	0.30	3	0.3	2	0.3	2	.20	2	.20

Total Score		2.75		**3.00**		**3.00**		**2.45**		**2.6**		**2.8**		**2.8**
Continue	No		No		No		No		No		Maybe - more testing		Maybe - more testing	

Initially, the team thought the L-shape arm would work better on the AEV as shown by the scores in the concept scoring matrix and the concept screening scoresheet. However, the scoring found in the scoresheet and matrix were solely based off of assumptions and inferences. Testing was required to ensure that the results found were accurate. To test balance, the team used the desktop track. First, the team put the design with the L-shape arm on the track and next did the design with the T-shape arm. Solely by visual analyzation, the team saw a better balance of the AEV when the T-shape arm was used. When the L-shape arm was used, the AEV tilted slightly more to one side. To test cargo attachment, the team worked with the actual cargo piece. The team ensured that the magnet on their design was placed properly so that it would line up with the cargo magnet. Regardless of the arm used, the cargo attachment would function the same. The last test done in PT1 was done to understand whether the T-shape or L-shape arm minimized more energy. To do this, the EEPROM data was collected for a run using each arm on the overhead track. The EEPROM data was then graphed using the Design Analysis Tool to display the relationship between power and time, and power and distance. Analyzing the graphs, specifically the power versus time, allowed for the team to identify which arm minimized energy the best. The T-arm was concluded to have the best energy efficiency as the area under was smaller, so the AEV consumed less energy.

To represent the direct relationship between the code and the data collected from each AEV's run on the track, a phase diagram for each AEV design was made. The phases represent different command calls and their impact on the AEV's power. For example, the *motorSpeed()* command keeps the power relatively linear and constant. The phase breakdown graph and table for each arm is found in Figures 13 and 14 and Tables 3 and 4.

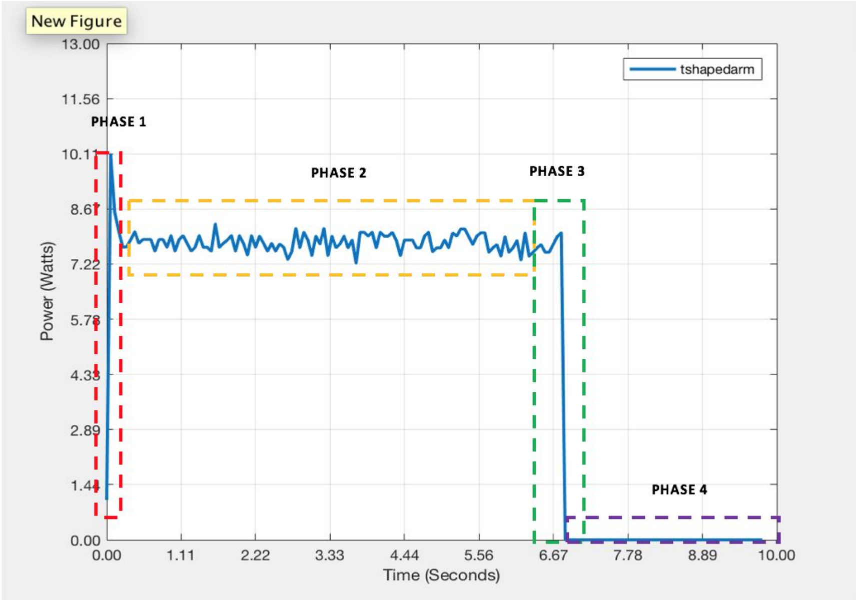

Figure 13: Phase Breakdown (T-shape arm)

Table 3: Table of Phase Breakdown (T-shape arm)

Phase	Arduino Code
1	reverse(4);
2	motorSpeed(4, 30);
3	goToAbsolutePosition(322);
4	motorSpeed(4, 0);

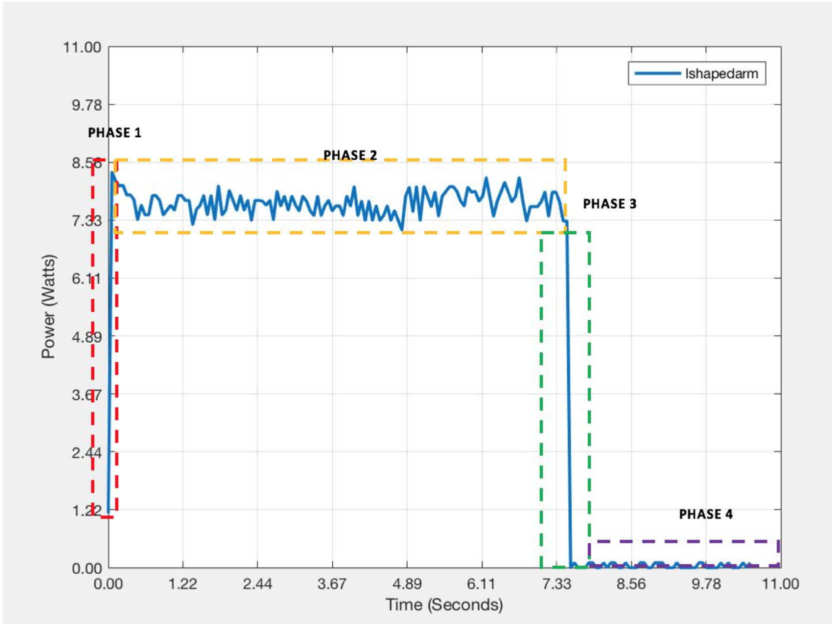

Figure 14: Phase Breakdown (L-shape arm)

Table 4: Table of Phase Breakdown (L-shape arm)

Phase	Arduino Code
1	reverse(4);
2	motorSpeed(4, 30);
3	goToAbsolutePosition(322);
4	motorSpeed(4, 0);

The phase breakdown ensures that the code is just as significant as design when it comes to energy efficiency. All in all, PT1 allowed for the team to be confident in their AEV design. Although not all theory was met in the ways expected, the team was able to understand why certain aspects of the AEV Controller function in the way that they do. Additionally, the team was able to identify potential errors from their previous errors. This made it easier for the team to correct problems when they arise as they most likely already encountered a similar problem. To summarize, the team's design process was not perfect; however, with modifications and by gaining a better understanding of each lab, the team was able to create a satisfactory AEV.

Conclusions & Recommendations

In the AEV lab, the team was required to management a project, work as a team, design and code an Advanced Energy Vehicle Controller, and document all important information including important takeaways and goals throughout the design process. The AEV is a small, autonomous, electric motor-powered, propeller driven vehicle that is required, stated in the Mission Concept Review, by the galactic empire to transport their R202 units between the land and their interceptor aircrafts. Since the AEV is working on remote planets and power is limited, it should maintain a low mass-energy ratio, be durable, environmentally friendly, maintainable, and balanced. After completing a total of eight labs, the team finally constructed the final team AEV Controller design based on all the data measurements, calculations, and analyses done in each lab. Lab 1 allowed team to become familiarized with Arduino command calls, which are simple codes that allow for the team to have control over the AEV and its movement. In lab 2, the two command calls, *goToAbsolutePositon() and goToRelativePosition()* were introduced to team. Specifically working with these two command calls and the reflectance sensors, the team could successfully move the AEV a desired distance. Additionally, lab 2 worked with a wind tunnel to test two different types of propellers that had two different configurations - 2050 pusher, 2050 puller, 3030 pusher, and 3030 puller propellers. With the data found from the test and additional values, calculated with Excel, including calibrated thrust, power input, power available, propulsion efficiency, and propeller advance ratio, the team concluded that the 3030 puller propellers would be the best to choose for their AEV team design. To draw this conclusion, the team identified that the 3030 pullers yielded the highest propulsion efficiency; therefore, the energy was minimized. In lab 3, each team member made an AEV design. As a team, a team AEV design was also created. This was done using the creative design thinking strategies that were laid out in the lab manual. In lab 4, the AEV was run halfway around the track. The EEPROM data was then measured, imported into MATLAB, and converted into physical parameters. Data was graphed and analyzed by the team using Excel and the Design Analysis Tool. In lab 4, the team learned how specific command calls that are imported into the Arduino have a direct impact on the supplied power and its fluctuations. In the lab 5, all the previous AEV designs were required to be evaluated by concept screening and concept scoring methods. After evaluating the designs, the team realized the previous designs were too complicated to fully develop. A new, simpler design was created.The current AEV controller is developed from this new AEV design. The current AEV Controller design reduced weight from 250 grams to 237.2 grams with the Li-Po battery included, making it about 5% lighter than the previous design. Because it only uses parts provided, with no other requirements, the current design is more effective. The team spends no additional cost because of this. Team was prepared for Performance Test 1 though lab 6 and lab 7. Several adjustments were made to ensure that all MCR requirements were fulfilled.

In performance test 1, the L-shaped arm and T-shaped arm were tested for the team's current AEV design. The conclusion found by testing the two support arms was that the T-shaped arm would proved to have better balance for the AEV whilst on the track. EEPROM data collected during these trials ensured that the T-shaped support arm was more energy efficiency than its counterpart design. The team believes the current design with the T-shaped arm, one 3030 pusher propeller, and on 3030 puller propeller is environmentally friendly, durable, maintainable, of a smaller mass, and cost effective. While the 3030 puller propeller appears to be ineffective upon looking at the AEV, it will actually be used as a pusher configuration, as it will only be utilized as the AEV is travelling backwards from the cargo port to the starting point.

Several issues were incurred throughout the preliminary design process. However, team corrected all the errors as they arose. In lab 1, the command call *brake()* was misspelled as *break(*). While the team found the spelling mistakes and corrected it in time, this error highlighted the importance of correctly coding the Arduino. In lab 2, the AEV did not move on the first three tests performed on the track, as the code was programmed incorrectly. To solve this, the function call reverse (4) was added to the first line of the code, so both motors were not able to function to allow the AEV to move in the correct direction. This lab also allowed the team to understand the importance of increasing motor power in the code, as originally the power was too low for the AEV to move at a reasonable rate to fulfill
the MCR. While the team was unable to develop the team design created prior to lab 5, they scored this design, as all previous designs were too complicated to fully develop. However, after scoring this design, a new AEV design was created based on all information and knowledge gained from lab 1 to 5. The current AEV controller was developed with major components included from the new AEV design. Three major issues were resolved during lab 6 and lab 7, including the overall balance of the vehicle, the ability of the AEV to attach to the caboose carrying the cargo, and the energy efficiency of the design. The team moved the support arm closer to the center of mass of the AEV, in order to solve the issue of the AEV tilting on the track due to the vehicle being unbalanced. The team also adjusted the placement of the bracket used for attachment of the caboose magnet, so the AEV attached to the caboose correctly. Finally, team decided to use one 3030 pusher and 3030 puller propeller. This choice in propeller type was based on the analyzation of the EEPROM data from lab 4, in order to optimize energy efficiency. The puller configuration will be used when the AEV is travelling backwards from the cargo port to the starting point.

For the upcoming performance test, team will prepare two codes. Each code will be tested on the overhead track a minimum of two times. EEPROM data will be collected for every test to analyze the consistency between the runs. Between these two codes, the code which operates with better consistency will be the chosen as the final code. For performance test 3, team will run the code chosen from PT2, and EEPROM data will be collected again. However, team will focus on the power supplied and total energy used by AEV. The values found will be analyzed to ensure that the design optimizes energy efficiency. All feedback from colleagues and superiors throughout the upcoming process will be taken into consideration by the team as to allow for new improvements and ideas to be developed.

Appendix A

(A1)

Table A1: 2050 Pusher Propellers Wind Tunnel Data

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.000	0	0.000	0.00000	0.000	0.000	---
-0.411	2950	0.244	-0.00002	-0.012	-4.786	0.929
-0.411	4100	0.474	-0.00002	-0.012	-2.468	0.668
0.000	4875	0.814	0.00000	0.000	0.000	0.562
0.000	6300	1.110	0.00000	0.000	0.000	0.435
0.822	7325	1.502	0.00003	0.023	1.556	0.374
1.644	8650	1.924	0.00006	0.047	2.430	0.317
2.466	9760	2.231	0.00009	0.070	3.143	0.281
4.110	10900	2.812	0.00016	0.117	4.157	0.251
4.932	12050	3.215	0.00019	0.140	4.362	0.227
5.754	13233	3.685	0.00022	0.164	4.440	0.207

(A2)

Table A2: 2050 Puller Propellers Wind Tunnel Data

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.00	0	0.00	0.00000	0.00	0.00	---
-0.82	3400	0.26	-0.00004	-0.03	-10.42	0.92
-0.41	4670	0.47	-0.00002	-0.01	-2.81	0.67
-0.41	5750	0.74	-0.00002	-0.01	-1.80	0.54
0.00	6900	1.07	0.00000	0.00	0.00	0.45
0.82	8200	1.42	0.00004	0.03	1.87	0.38
1.64	9400	1.81	0.00007	0.05	2.95	0.33
2.06	10500	2.20	0.00009	0.07	3.03	0.30
3.29	11700	2.59	0.00014	0.11	4.11	0.27
4.52	12800	2.97	0.00020	0.15	4.92	0.24
5.75	14011	3.33	0.00025	0.19	5.59	0.22

(A3)

Table A3: 3030 Pusher Propellers Wind Tunnel Data

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.000	0	0.000	0.00000	0.000	0.000	---
-3.699	2500	0.089	-0.00015	-0.109	-122.550	0.945
-4.932	3400	0.266	-0.00019	-0.145	-54.467	0.695
-6.987	4150	0.518	-0.00028	-0.206	-39.683	0.569
-8.631	5000	0.844	-0.00034	-0.254	-30.100	0.472
-10.686	5850	1.243	-0.00042	-0.314	-25.288	0.404
-13.152	6600	1.717	-0.00052	-0.387	-22.538	0.358
-14.385	7450	2.231	-0.00057	-0.423	-18.968	0.317
-16.851	8200	2.775	-0.00066	-0.496	-17.865	0.288
-19.317	9000	3.378	-0.00076	-0.568	-16.823	0.262
-23.427	9600	4.085	-0.00092	-0.689	-16.873	0.246

(A4)

Table A4: 3030 Puller Propellers Wind Tunnel Data

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	--
0.000	0	0.000	0.00000	0.000	0.000	---
1.644	2994	0.389	0.00006	0.045	11.620	0.736
2.877	3892	0.666	0.00011	0.079	11.862	0.566
4.521	4610	0.999	0.00017	0.124	12.426	0.478
5.754	5389	1.421	0.00021	0.158	11.120	0.409
7.809	6107	1.917	0.00029	0.214	11.188	0.361
9.864	6706	2.486	0.00036	0.271	10.893	0.329
11.919	7305	3.097	0.00044	0.327	10.568	0.302
14.385	7964	3.737	0.00053	0.395	10.570	0.277
16.440	8562	4.477	0.00061	0.451	10.083	0.258
18.495	9221	5.239	0.00068	0.508	9.693	0.239

(A5)

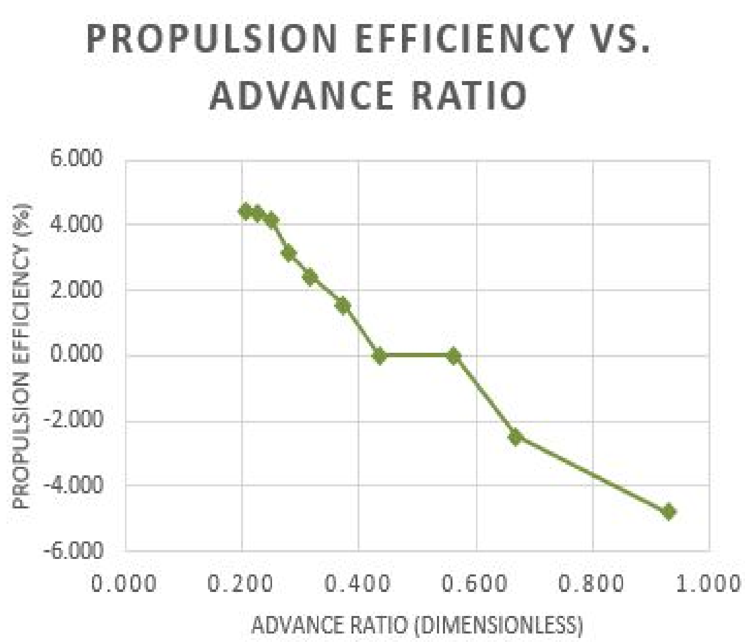

Figure A5: Propulsion Efficiency versus Advance Ratio (2050 Pusher)

(A6)

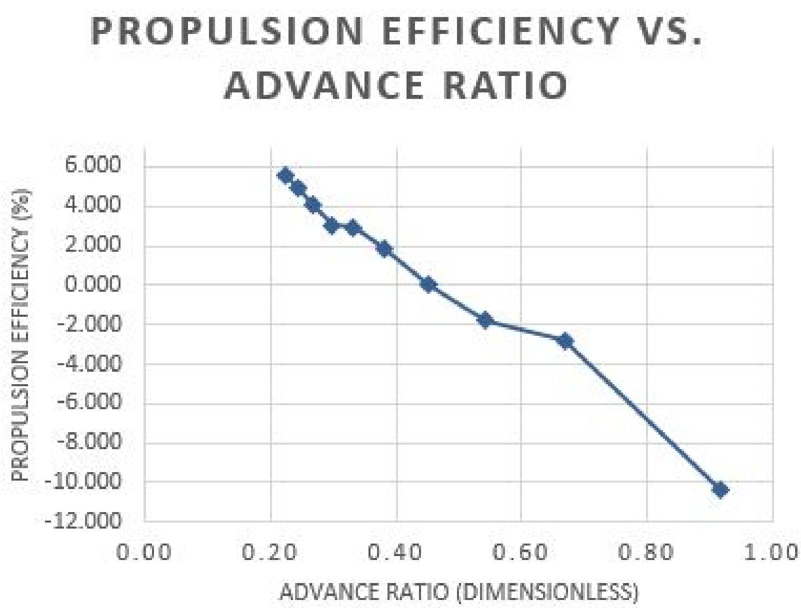

Figure A6: Propulsion Efficiency versus Advance Ratio (2050 Puller)

(A7)

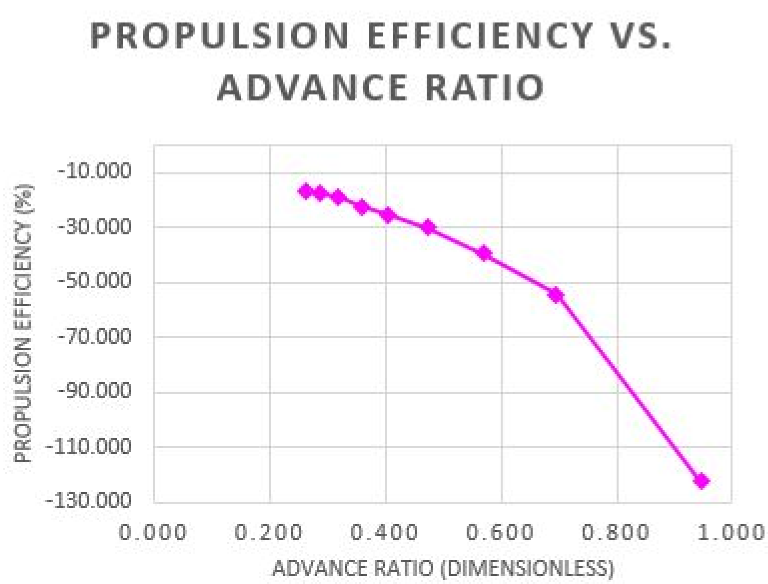

Figure A7: Propulsion Efficiency versus Advance Ratio (3030 Pusher)

Appendix B

(B1)

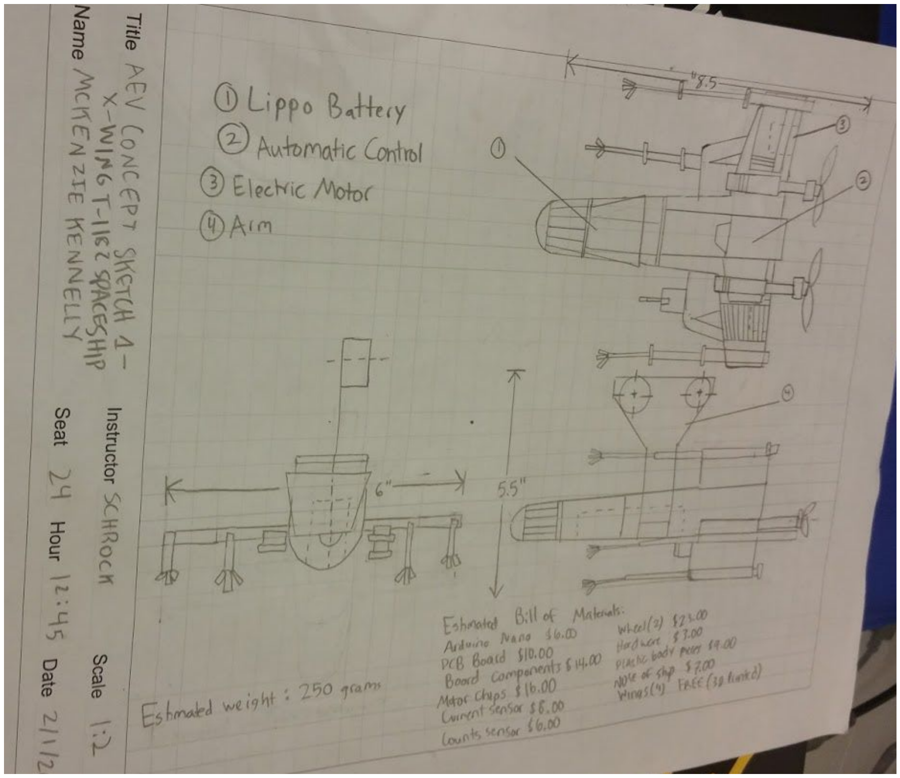

Figure B1: McKenzie Kennelly Individual Design

(B2)

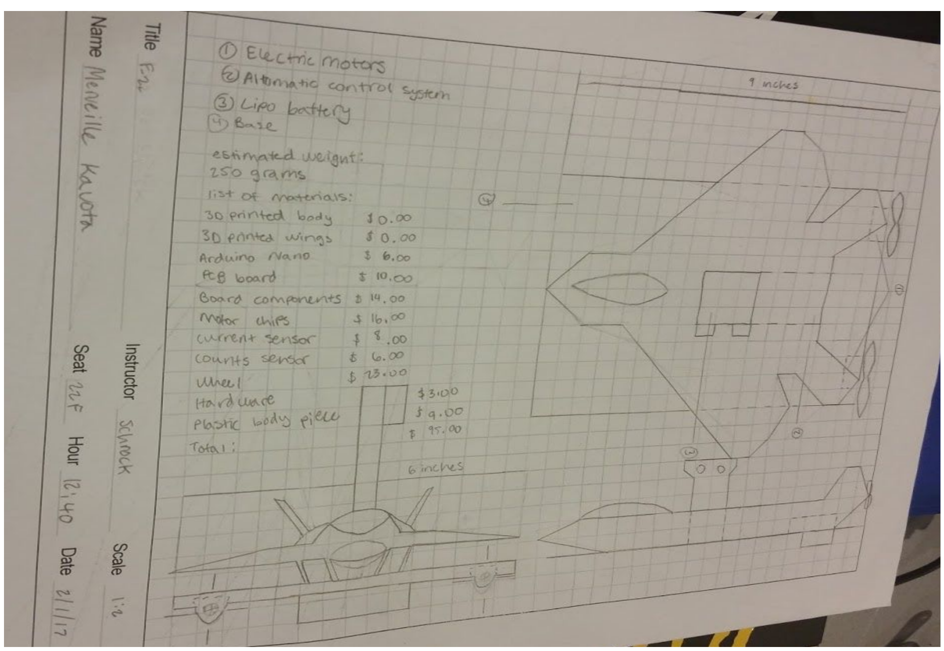

Figure B2: Merveille Kavota Individual Design

(B3)

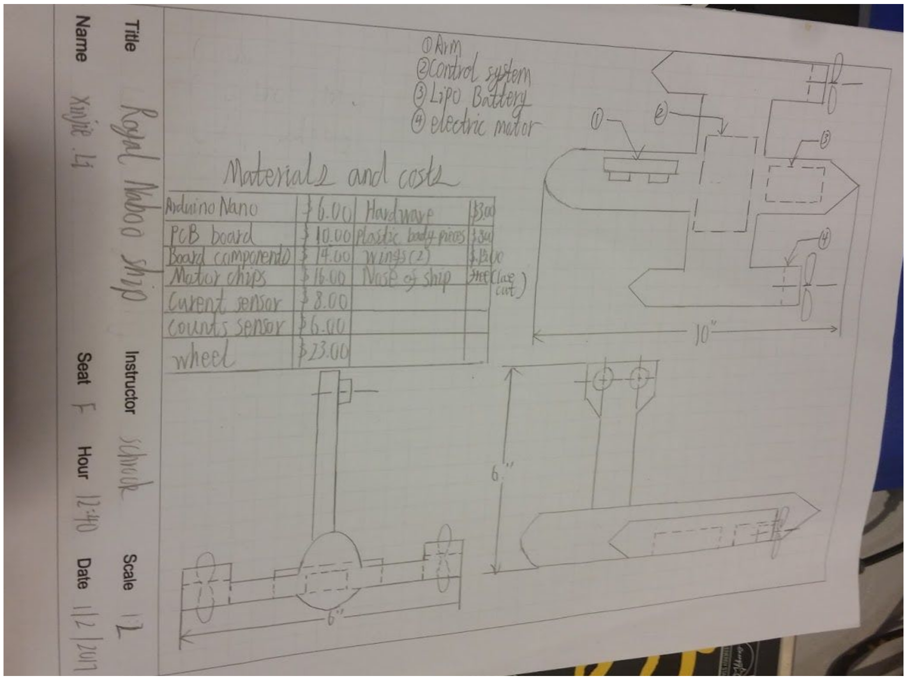

Figure B3: Vincent Li Individual Design

(B4)

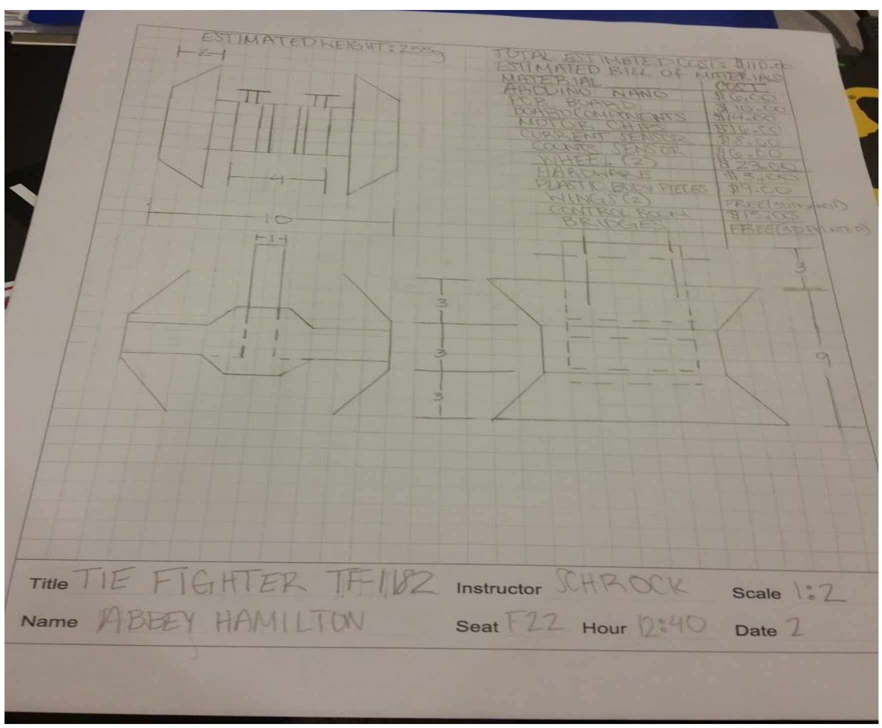

Figure B4: Abbey Hamilton Individual Design

(B5)

Table B5: Concept Screening Scoresheet

Success Criteria	Reference	Design A - Team Design	Design B - McKenzie	Design C - Abbey	Design D - Xinjie	Design E - Merveille
Balanced in Turns	0	0	0	0	0	0
Minimal blockage	0	+	-	0	0	0
Center-of-gravity	0	+	-	0	+	+
Maintenance	0	+	0	+	-	0
Durability	0	+	+	0	0	+
Cost	0	+	0	-	-	-
Environment	0	-	0	0	0	0
Sum +'s Sum 0's Sum -'s	0 7 0	5 1 1	1 4 2	1 5 1	1 4 2	2 4 1
Net Score	0	4	-1	0	-1	+1
Continue	Combine	Revise	No	No	No	Yes

(B6)

Table B6: Concept Scoring Matrix

		A Reference		Design V - Team Design		Design W - McKenzie		Design X - Abbey		Design Y - Xinjie		Design Z - Merveille	
Success Criteria	**Weight**	**Rating (0-5)**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Balanced in Turns	5%	3	0.15	3	0.15	4	0.2	3	0.15	3	0.15	3	0.15
Minimal blockage	15%	3	0.45	4	.6	3	0.45	3	0.45	3	0.45	3	0.45
Center-of-gravity	10%	2	0.20	4	0.40	3	0.3	2	0.20	4	0.4	4	0.40
Maintenance	25%	3	0.75	3	.75	3	0.75	4	1.00	2	0.5	3	0.75
Durability	15%	2	0.30	4	0.6	4	0.6	2	0.30	3	0.45	4	0.45
Cost	20%	3	0.60	2	0.40	2	0.4	3	0.60	1	0.2	3	0.40
Environmental	10%	3	0.30	3	0.3	3	0.3	3	0.30	3	0.3	2	0.3
Total Score			2.75		**3.20**		**3.00**		**3.00**		**2.45**		**2.6**
Continue		No		Yes		No		No		No		No	

Appendix C

(C1)

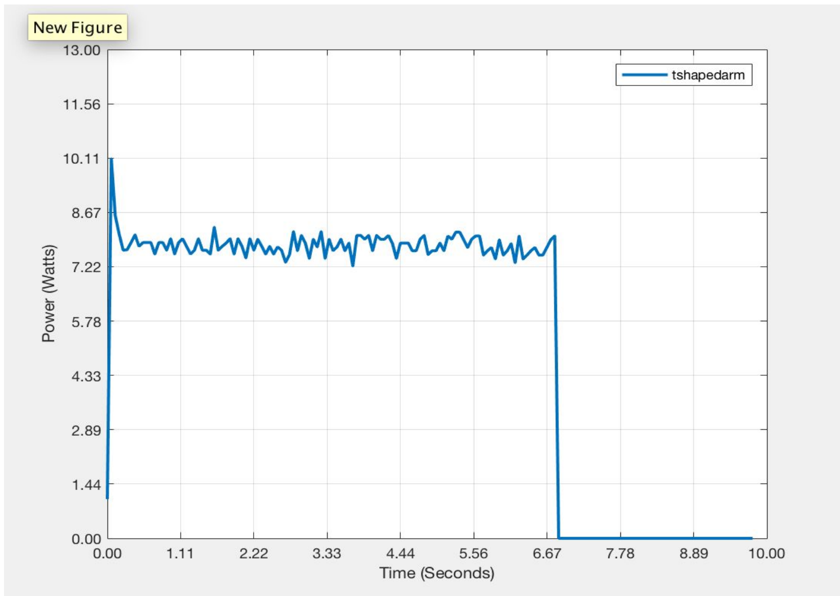

Figure C1: Power versus Time (T-Shaped Arm)

(C2)

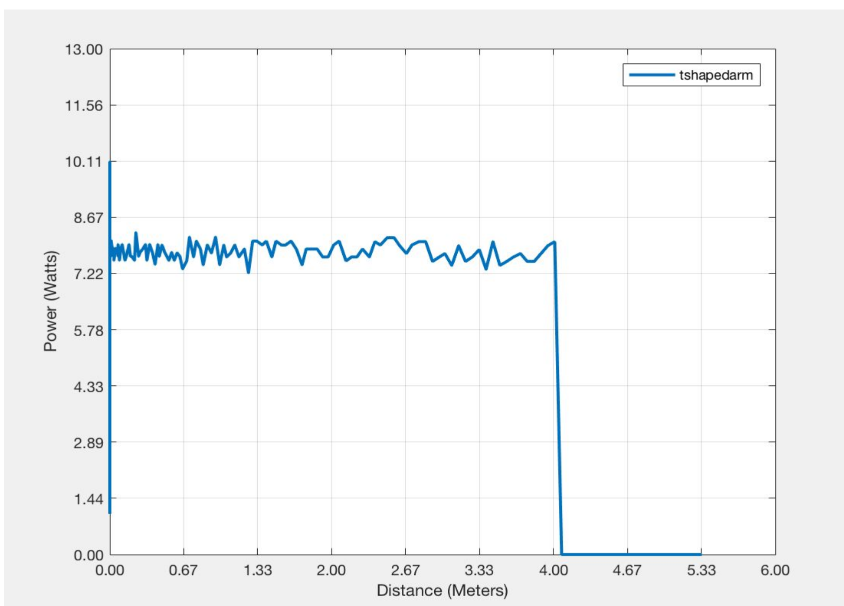

Figure C2: Power versus Distance (T-Shaped Arm)

(C3)

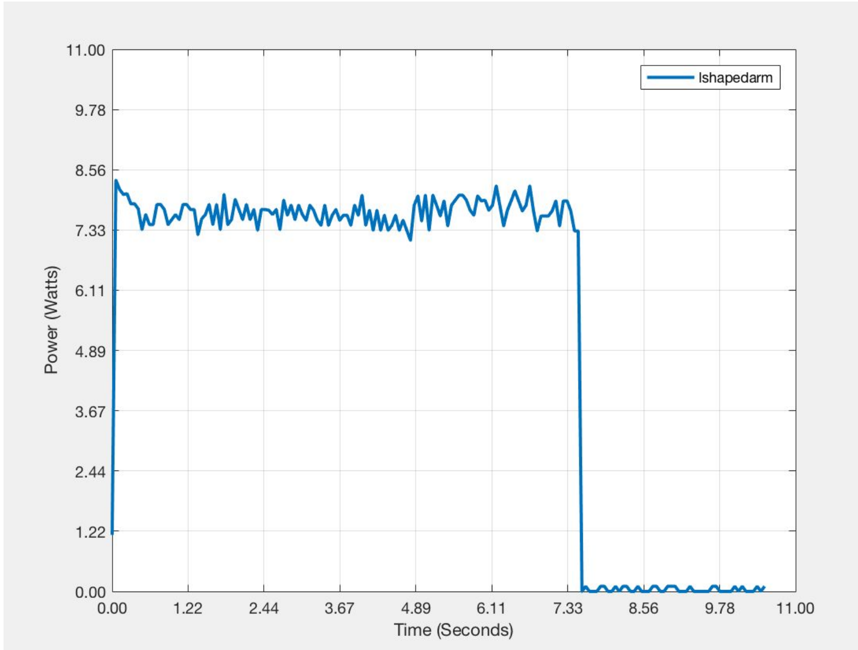

Figure C3: Power versus Time (L-Shaped Arm)

(C4)

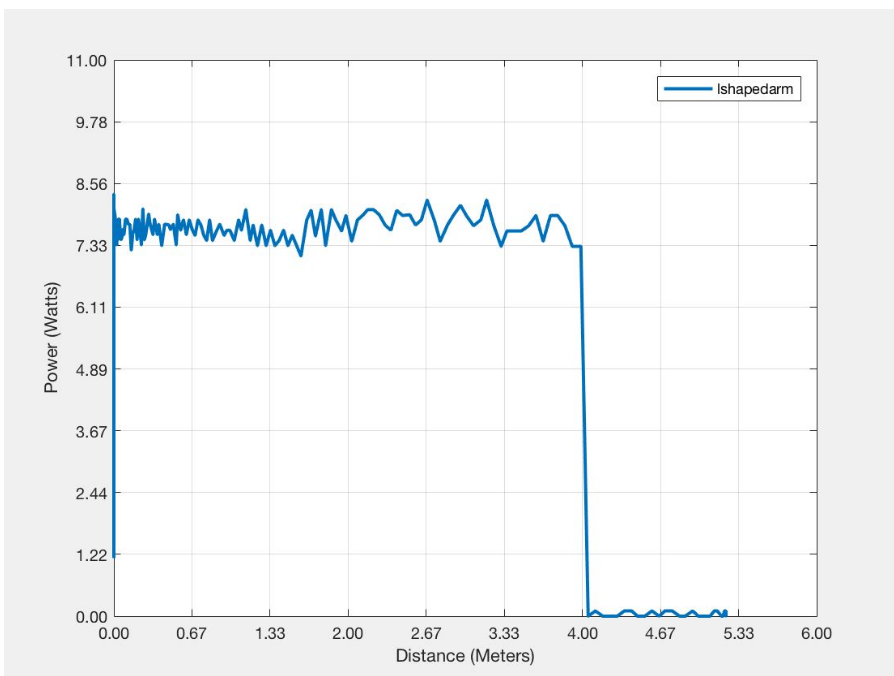

Figure C4: Power versus Distance (L-Shaped Arm)

Appendix D

Team Schedule

	No.	Task	Start	Finish	Due Date	Est Time	Abbey Hamilton	Merveille Kavota	McKenzie Kennelly	Xinjie Li	% Complete
Performance Test 2	1	AEV Design 1 Construction	1-February	21-March	21-March	8 h	0.5 h	1 h	0.5 h	1 h	100
	2	AEV Design Testing	15-February	21-March	21-March	2 h	0.5h	0.5h	0.5h	0.5h	100
	3	AEV Design Data Analysis	15-February	21-March	21-March	2 h	1h	1h	3h	1h	100
	4	AEV Design 2 Construction	15-February	21-March	21-March	2h	1h	1h	1h	1h	100
	5	Lab 9 Progress Report	7-March	21-March	22-March	5h	2h	2h	2h	2h	100
	6	Performance Test 1	7-March	21-March	21-March	8 h	4h	4h	4h	4h	100
	7	Lab 10 Progress Report	21-March	Before 31-March	31-March	5h					0
	8	Performance Test 2	22-March	Before 28-March	28-March	8h					0
	9	Preliminary Design Report	21-February	Before 24-March	24-March	10h	9h	5h	15h	6h	100
	10	Project Portfolio	18-Januaty	Before 21-April	21-April	20 h	0h	0h	6h	0h	45
	11	Extra Credit Video	15-February	Before 28-February	21-April	20 h	0h	3h	0h	3h	25

Appendix E

```
//  celerate(1,0,15,2.5); // Accelerate motor 1 from 0% to 15% in 2.5 seconds
//  motorSpeed(1,15); // Set the speed of motor 1 to 15% for 1 second
//  goFor(1);
//  brake(1); // Brake motor 1
//  celerate(2,0,27,4); // Accelerate motor 2 from 0% to 27% in 4 seconds
//  motorSpeed(2,27); //  Set the speed of motor 2 to 27% for 2.7 seconds
//  goFor(2.7);
//  celerate(2,27,15,1); // Accelerate motor 2 from 27% to 15% in 1 second
//  brake(2); // Brake motor 2
//  reverse(2); // Reverse motor 2
//  celerate(4,15,31,2); // Accelerate both motors from 15% to 31% in 2 seconds
//  motorSpeed(4,35); //  Set the speed of both motors to 35% for 1 second
//  goFor(1);
//  brake(2); // Brake motor 2 for 3 seconds
//  goFor(3);
//  motorSpeed(1,35); //  Set the speed of motor 1 to 35% for 3 seconds
//  goFor(3);
//  brake(4); // Brake both motors for 1 second
//  goFor(1);
//  reverse(1); // Reverse motor 1
//  celerate(1,35,19,2); // Accelerate motor 1 from 35% to 19% in 2 seconds
//  motorSpeed(2,35); //  Set the speed of motor 2 to 35% for 2 seconds
//  goFor(2);
//  motorSpeed(1,19); //  Set the speed of motor 1 to 19% for 2 seconds
//  goFor(2);
//  motorSpeed(4,19); //  Set the speed of both motors to 19% for 2 seconds
//  goFor(2);
//  celerate(1,19,0,3); // Accelerate motor 1 from 19% to 0% in 3 seconds
//  celerate(2,35,0,3); // Accelerate motor 2 from 35% to 0% in 3 seconds
//  brake(4); // Brake both motors



//  Run motor one at a constant speed (23% power) for 2.5 second.
//  motorSpeed(1,23);
//  goFor(2.5);+
//
//
//  // Brake motor one.
//  brake(1);
```

```
  // Outside Track
//  motorSpeed(4, 25);
//  goFor(2);
//  motorSpeed(4, 20);
//  goToAbsolutePosition(394);
//  reverse(4);
//  motorSpeed(4, 30)
//  goFor(1.5);
//  brake(4);

//  //Inside Track
  reverse(4);
  motorSpeed(4, 30);
  goToAbsolutePosition(322);
  motorSpeed(4,0);


//reverse(4);
//celerate(4,0,35,2);
//motorSpeed(4, 20.5);
//goToAbsolutePosition(332);
//brake(4);

//reverse(4);
//celerate(4,0,25,3);
//motorSpeed(4,20);
//goFor(1);
//reverse(4);
//motorSpeed(4,25);
//goFor(2);
//brake(4);

//reverse(4);
//motorSpeed(4,45);    //both motors move at a speed of 45%
//goToRelativePosition(295); //the AEV moves to a position of 295 marks
//brake(4);      // both motors stop
//goFor(9);
//motorSpeed(4,45);    //both motors move at a speed of 45%
//goToRelativePosition(172); //the AEV moves to a position of 172 marks
//brake(4);      // both motors stop
//goFor(7);
//reverse (4);      //both motors reverse direction
```

```
//motorSpeed(4,45);    //both motors move at a speed of 45%
//goToRelativePosition(172); //the AEV moves to a position of 172 marks
//brake(4);      // both motors stop
//goFor(9);
//motorSpeed(4,45);    //both motors move at a speed of 45%
//goToRelativePosition(295); //the AEV moves to a position of 295 marks
//brake(4);      // both motors stop
```