Preliminary Design Review (PDR) Report

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27 March 2017

Executive Summary

The purpose of the AEV (Advanced Energy Vehicle) project was to design a vehicle capable of completing the Mission Concept Review (MCR). The mission was introduced to the class with a Star Wars theme, and it emphasized the need for creating an energy efficient, green, and cost effective transportation system for R2D2 units. Several tasks were outlined in the Mission Concept Review that each team's vehicle needed to complete in order to be successful. First, the vehicle needed to travel along a curved track and stop at a gate, waiting for the gate to lower, and then it had to follow the rest of the track to pick up the cargo. The vehicle then had to return with the cargo to its starting position, once again stopping at the gate. The vehicle needed to accomplish this mission using as little energy as possible and for as cheap a price as possible. The AEV project up to this point consisted of 8 labs that followed a structured design process in order to introduce teams to engineering processes and concepts. During the first 8 labs, teams collected data and tested not only the components of the AEV, but also tested prototype versions of their AEVs.

During lab 01, each team became familiar with the hardware elements that make up the AEV as well as with basic features of the Arduino controller program. This was accomplished by calling and testing several different functions and by writing a simple Arduino control program. During lab 02a, the team tested the external reflectance sensors and learned not only how they work, but also how to correctly call functions essential to completing the mission utilizing them. The team also completed a basic program that moved the AEV from the starting point on the track to the gate. Lab 02b consisted of wind tunnel testing, an important step in the design process that would indicate which of the available propeller configurations, 3030 or 2510, each team should choose based on efficiency and advance ratio. The goal of lab 03 was to introduce two techniques for creative design thinking. During the lab activity, each team member designed an AEV individually and later on the team communicated to decide on a final design. During lab 04a, team k learned how to download data from the automatic control system and to convert EEPROM Arduino data to usable parameters. Lab 04b familiarized the team with the design analysis tool and how to use it to upload, plot, analyze and export data in the form of figures. Lab 05 introduced two decision making techniques, Design Screening and Design Scoring, and discussed the positives and negatives of each technique. The team then used these techniques to create concept scoring and screening matrices for each of the AEV designs and to decide which design was the best overall based on criteria decided upon by the team. Lab 06 was the halfway checkpoint between the introductory and background labs to the performance tests and design iterations. During lab 06, the team discussed necessary changes and began thinking of ways to improve the final design. Lab 07 consisted of testing the AEV on the straight track to ensure that the reflectance sensors and other components were working correctly. Next, the team used the provided code and the data collected to determine efficiency and to detect and reduce errors. Lab 08 was the first performance test, which allowed team k to decide not only which of the two final design options was better, but also which Arduino code was better out of the two that had been written. During the performance test, two designs and codes were tested in an attempt to complete the mission and it was quickly evident that the design utilizing a servo motor braking system was more energy efficient and more suited to completing the task

consistently. Out of the two program options, a program utilizing position rather than time was chosen because time was found to be an inconsistent parameter to base travel distances on.

The first 8 labs provided the necessary background and skills that will be helpful in optimizing and finalizing the design of the AEV in order to complete the mission. A few recommendations include scheduling lab 02a and lab 02b on separate dates so that all team members can witness both parts instead of being separated and having to explain them to each other. Additionally, before the first progress report was assigned, it would have benefited students to see an example of what was expected in a progress report so that students could've done it right on their first try.

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Introduction

The goal of the AEV project was for each team to design a vehicle and write a program to control the vehicle that would complete the tasks outlined in the Mission Concept Review as efficiently as possible. Each team had to design an Advanced Energy Vehicle using a kit containing a standardized set of parts, but many of the parts provided were optional and could be replaced or modified. The scenario for the mission was that the Rebel Alliance needed an energy efficient transportation system to prepare for war against the Galactic Empire. First, the vehicle needed to travel along a curved track and stop at a gate, waiting for the gate to lower, and then it had to follow the rest of the track to pick up the cargo containing an R2-D2 unit. The vehicle then had to return with the cargo to its starting position, once again stopping at the gate. The AEV project introduced the teams to many new and important engineering concepts such as iterative design processes and testing as well as prototyping. Throughout the first 8 labs, many important decisions were made regarding AEV and AEV program design that set the basis for the completion of the mission.

Experimental Methodology

All of the following labs were performed in accordance with the AEV lab manual, which is located on carmen. All pictures of lab equipment were taken directly from the lab manual.

The purpose of Lab 01 was to familiarize the team with the hardware elements of the AEV as well as with the basic features of the arduino controller program. First, two electric motors were clamped into a stand and, as instructed in the lab manual, two propellers were attached so that the dull side was facing away from the motor casing. Once the propellers were firmly attached to the stand in the correct direction, the Arduino, with the power switch set to "off," was connected to the motors and then to the battery. The next step was to open the Arduino programming environment to write a basic program to test the propellers. Once the Arduino IDE (Integrated Development Environment) was opened, the code was written inside a tab called "01_myCode." After the basic program was complete, the Arduino controller was connected to the computer via a USB cable. After connecting the USB, several changes were made in the "tools" tab in accordance with the lab manual. Next, the program was uploaded to the Arduino, the USB was detached, and the power was switched on. Finally, the program was executed by pressing the start button on the Arduino controller and the power was switched off after waiting 10 seconds. The code used is provided below.

Figure 1: Properly Installing Propeller Onto Motor

1. Accelerate motor one from start to 15% power in 2.5 seconds.
2. Run motor one at a constant speed (15% power) for 1 second.
3. Brake motor one.
4. Accelerate motor two from start to 27% power in 4 seconds.
5. Run motor two at a constant speed (27% power) for 2.7 seconds.
6. Decelerate motor two to 15% power in 1 second.
7. Brake motor two.
8. Reverse the direction of only motor 2.
9. Accelerate all motors from start to 31% power in 2 seconds.
10. Run all motors at a constant speed of 35% power for 1 second.
11. Brake motor two but keep motor one running at a constant speed (35% power) for 3 seconds.
12. Brake all motors for 1 second.
13. Reverse the direction of motor one.
14. Accelerate motor one from start to 19% power over 2 seconds.
15. Run motor two at 35% power while **simultaneously** running motor one at 19% power for 2 seconds.
16. Run both motors at a constant speed (19% power) for 2 seconds.
17. Decelerate both motors to 0% power in 3 seconds.
18. Brake all motors.
19. Save Program as (Save As:) PrgmBasics

Figure 2: Code Used in Lab 01

The purpose of lab 02a was for the team to become familiar with the reflectance sensors and the functions that utilize the reflectance sensors. First, the reflectance sensors were tested by calling the “reflectanceSensorTest();” function into the 01_myCode section of the sketchbook. This test was very important because the reflectance sensors are essential to the success of an AEV in order to control the position of the vehicle. After the sensors were verified to be working correctly, a short program was written to move the AEV along the inner track and stop before the gate. After the program finished running and it was confirmed that the wheel count sensors were working correctly, the sensors were zip tied in place and fixed to the arm. A picture of the inner track is provided below.

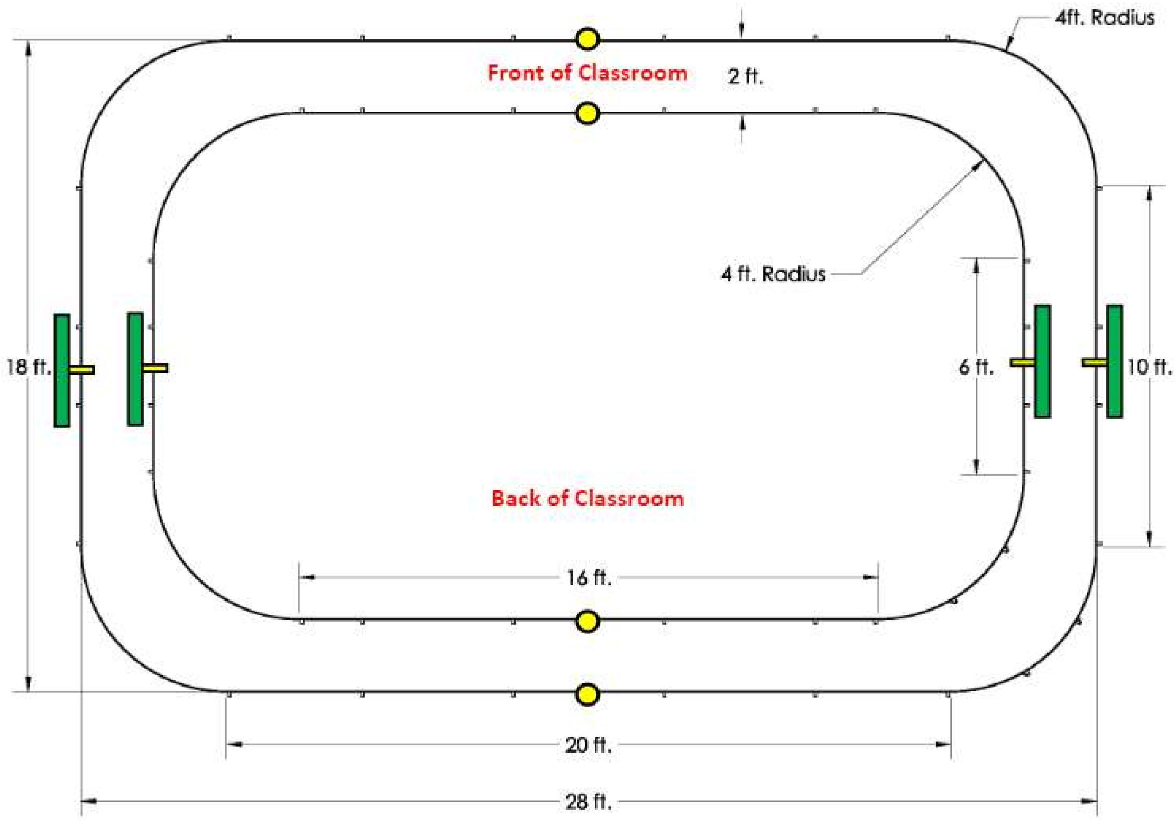


Figure 4: AEV Track Layout

Figure 3: Diagram of AEV Track

The purpose of Lab 02b was to familiarize the team with propulsion system efficiency and wind tunnel testing equipment. During lab 02b, wind tunnel testing techniques and equipment were employed to determine which propeller configuration out of puller 3030 or puller 2510 was more efficient and at what power settings the propeller performed the best. It was important to determine which power settings resulted in the highest efficiency because unlike other parts of the AEV, the electric motors that were provided are the only ones that may be used. During lab 02b, two wind tunnels were set up, one in each of the two configurations, and the potential was set to 7.4 volts, which is similar to what the fully charged lithium ion battery to be used in the AEV will provide. Data from the wind tunnels was collected and recorded and sent to the teams.

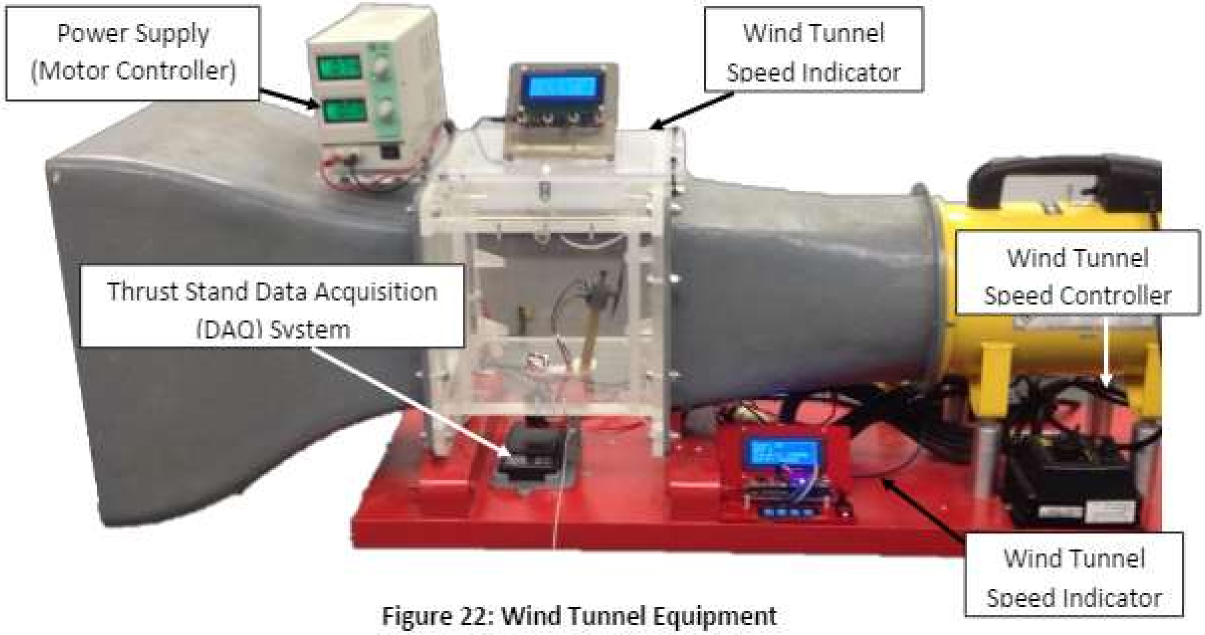


Figure 4: Wind Tunnel

The purpose of Lab 03 was to learn two techniques used for creative design thinking, to become familiar with obstacles to creativity, to become familiar with the components in the AEV kit, and to brainstorm individual AEV concept sketches. The setup for the Lab 03 activity was simple, requiring only the AEV kit and the AEV desktop stand. The lab equipment was to serve as a visual and cataloging aid when creating orthographic drawings. The activity consisted of two separate brainstorming periods. During the first brainstorming period, which lasted 15 minutes, each team member worked individually and developed an idea and a concept sketch of the AEV. During the second brainstorming period, which lasted 20 minutes, all team members worked together to choose a design. The goal of this period was to decide whether one of the individual member's designs should be adopted or whether the team members should come up with a new design together. Several design considerations listed in the lab manual needed to be accounted for when choosing an AEV design. After deciding on a design, each group member drew concept sketch in an orthographic view. The four designs created by the team members can be found in the appendix.

The purpose of lab 04a was to download data from the automatic control system, convert EEPROM Arduino data to physical parameters, and to calculate performance characteristics using the converted physical parameters. The equipment required to complete Lab 04a included a functional AEV with the battery attached, a USB connection cable, and an AEV test rail. The first task completed during the lab was writing a simple program that would move the AEV from the starting point to the first stop, just before the gate, when it was placed on the track. During its time on the track, the Arduino collected a significant amount of data. To ensure the data collection was finished, the team waited until the yellow light on the Arduino controller stopped flashing before switching the power off. Next, the Arduino was connected to the computer using the USB cable and the EEPROM data was uploaded to an excel spreadsheet using the provided AEV Data Recorder script file in MATLAB. The final task that was completed required that a MATLAB script be written to convert EEPROM data to usable metric data. Once the data was converted, the AEV's performance was analyzed through calculations and figures.

The purpose of Lab 04b was to become familiar with the design analysis tool and how to use it to upload, analyze, plot and export data in the form of figures. Lab 04b required no physical equipment other than the computer on which the analysis was performed. Lab 04b consisted of installing and using the AEV Analysis tool to visualize and relate the data collected during the AEV's run on the track. Using the analysis tool, the data saved from Lab 04a was used to create plots of Power vs Time and Power vs Distance so that the team could see how the AEV performed throughout the whole run. Using this data, the team will be able to make changes to both the Arduino code and the AEV itself to decrease the amount of power necessary to perform all required tasks.

The purpose of Lab 04b was to become familiar with the design analysis tool and how to use it to upload, analyze, plot and export data in the form of figures. Lab 04b required no physical equipment other than the computer on which the analysis was performed. Lab 04b consisted of installing and using the AEV Analysis tool to visualize and relate the data collected during the AEV's run on the track. Using the analysis tool, the data saved from Lab 04a was used to create plots of Power vs Time and Power vs Distance so that the team could see how the AEV performed throughout the whole run.

The purpose of lab 05 was to become familiar with techniques for design decision making and to become familiar with design screening and scoring concepts to use when observing the strengths and weaknesses of each AEV design. The setup for lab 05 was simple, requiring only a completed AEV design, a USB cable, the Li-PO battery and the desktop stand. The first step in the lab activity was to complete a basic AEV design, but this had been finished prior to class. Next, a simple AEV program was written using the Arduino software that ordered the AEV to move back and forth on the straight track.. After the program was written, the AEV was put on the track and the code was executed. After the run, the next task was to develop the success criteria that would be used to evaluate the performance of the team's AEV designs. The success criteria decided upon by the team for this lab were balance, compactness, center of gravity, maintenance, durability and cost. The weight assigned to these criteria were 25%, 15%, 25%, 15%, 15%, and 5%, respectively. Finally, the team used a concept screening and concept scoring matrix for each of its designs using the criteria that had been decided upon.

<u>STRAIGHT TRACK</u>

1. Accelerate all motors from start to 25% in 3 seconds.
2. Run all motors at a constant speed (25% power) for 1 second.
3. Run all motors at 20% power for 2 seconds.
4. Reverse all motors.
5. Run all motors at a constant speed (25% power) for 2 second.
6. Brake all motors.
7. Save the program as CSS1.

Figure 5: Lab 05 Straight Track Code

The purpose of Lab 06 was for the team to assess the situation and decide upon various changes to the AEV as well as gathering data on the track and beginning to design the control program. The team spent much of lab 06 applying a new braking system to the AEV using the servo motor. To apply the brake, two holes were drilled near the slot in the top of the arm and the servo motor was zip tied on through those holes in a position where its arm could contact a wheel to slow the vehicle. The team spent the remainder of the lab experimenting with the servoWrite(); function and trying to understand how the servo motor works on a more detailed level.

The purpose of Lab 07 was for teams to test their AEV designs using a standardized arduino code and use the data collected to develop an energy model. Lab 07 consisted of the team performing three tasks to collect data and model the energy consumption of the AEV. The first step in the lab procedure was to weigh the AEV on an electronic scale and enter its mass in grams into the data spreadsheet for use later in the lab. Next, the AEV was programmed (the code used can be found in the Appendix) to perform a simple run on the straight track. The code called for the Arduino controller to run all motors at 30% power for 4 seconds and then to reduce the motor speed to 0 and allow the AEV to coast until it either came to a stop or failed to stop and hit the end of the track. When team K's code was run, the vehicle behaved as expected, accelerating for 4 seconds and then coasting to a stop before the end of the track. The starting and stopping points of the wheel containing the reflectance sensor were noted using the measurement system on the track and those values were also entered into the data sheet for later use. Finally, the team made sure to allow the AEV time to finish recording data before switching off the power and removing it from the track. For the second task, the data collected by the Arduino during the straight track run in task 1 was loaded into the AEV data recorder application and saved as an excel sheet displaying the EEPROM data. The team then used the spreadsheet to compare the hand measured value for marks travelled vs the Arduino-recorded value for marks travelled in order to determine if the Arduino was recording accurate data. For the third task, all the data collected in tasks 1 and 2 was used to perform calculations of the propeller force, friction force, and net force on the AEV.

The purpose of Lab 08 was to test two different AEV designs and two different programs on those AEVs to determine which AEV and which program was better. Four runs were completed in order to make a final decision. First, the AEV design without the added brake was run with a program using time instead of marks. Second, the AEV design without the added brake was run with a program using marks instead of time. Third, the AEV design with the added brake was run with a program using time instead of marks. Finally, the AEV design with the added brake was run with the program using marks instead of time. After all the tests were finished, it was determined that the AEV design with the added brake and with a program using marks instead of time was the best option.

Results

As a result of lab 1, the team completed a basic Arduino program and became more familiar with both the hardware and the software that will be used in the AEV design. During the lab, it was discovered that both propellers undergo a small delay (less than half a second) after the motor is started before they begin to spin. This delay will certainly need to come into consideration when designing the control program. It was also discovered that the brake() command does not apply an actual braking force to the AEV, but instead simply cuts power to the motors. This means that the AEV will continue moving until friction between the wheels and the track brings it to a stop after the brake() command is called. One basic solution to this problem is reversing the motors to apply thrust in the opposite direction that the vehicle is travelling to slow it down. Only a few errors were encountered when completing lab 1. The only mechanical error that was encountered was the friction in the motor that causes a delay when the propellers are commanded to start from rest. Most of the error that occurred during the lab was human error, including spelling mistakes and syntax errors. These errors were corrected by proof-reading the code before attempting to compile it. Many of these small problems may have been prevented if the proper syntax was shared with the class beforehand. After finishing the first scenario, scenario two was attempted but not completed due to an unexplainable error that could not be fixed before the end of the lab.

Lab 02a provided the team with a good understanding of how the reflectance sensors work physically and can be utilized in the Arduino software to locate and position the AEV. Additionally, the team became familiar with reflectance sensor related functions such as goToRelativePosition and goToAbsolutePosition. Before the AEV was tested on the track, the team noticed that the thrust from the propellers was pushing the vehicle in the opposite direction that it was intended to travel. This was fixed by calling the reverse(4) function to spin the propellers the other direction. After this problem was fixed, the program worked and the AEV performed well on the track and made it to the gate and stopped with only one noteworthy issue. This issue was that the vehicle lost all stability and began to wobble when rounding corners. The results of Lab 02b demonstrated which propeller configuration would be the optimal choice when designing the AEV. Out of the available propeller configurations, the 3030 puller was the most efficient for both propulsion efficiency and advance ratio. At every power setting, the 3030 puller configuration required fewer rotations per minute and achieved greater thrust scale readings. The tables used in the lab can be found in the appendix.

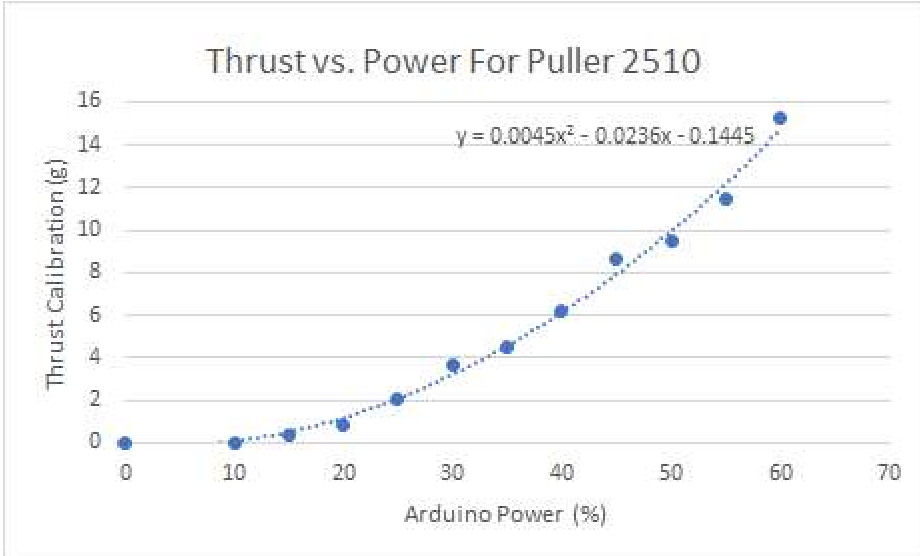


Figure 6: Thrust vs Power for Puller 2510

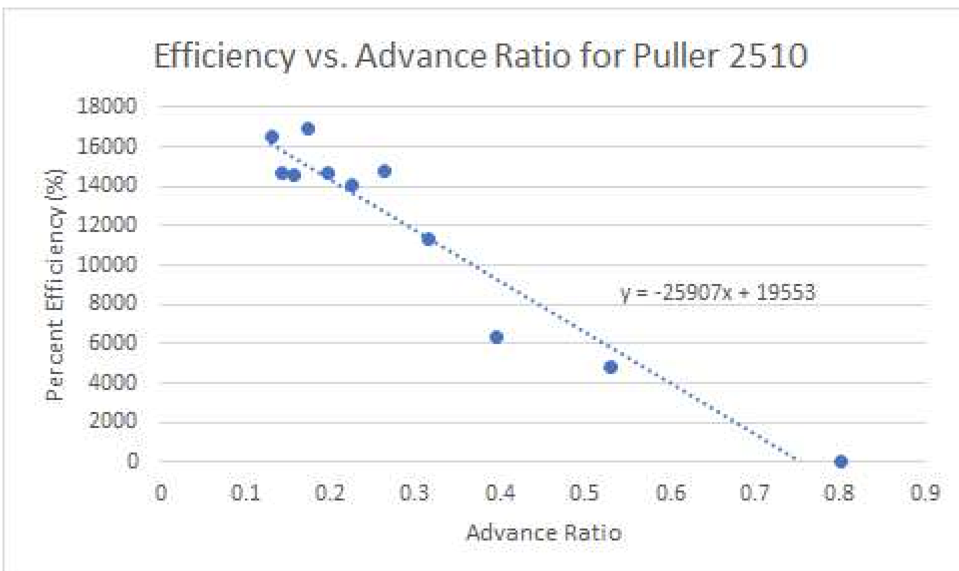


Figure 7: Efficiency vs Advance Ratio for Puller 2510

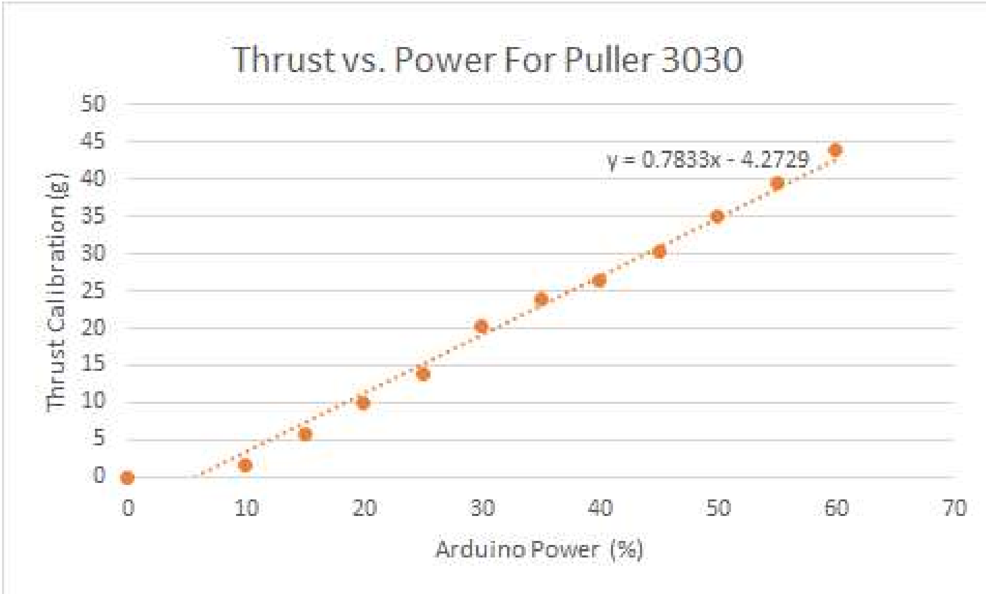


Figure 8: Thrust vs Power for Puller 3030

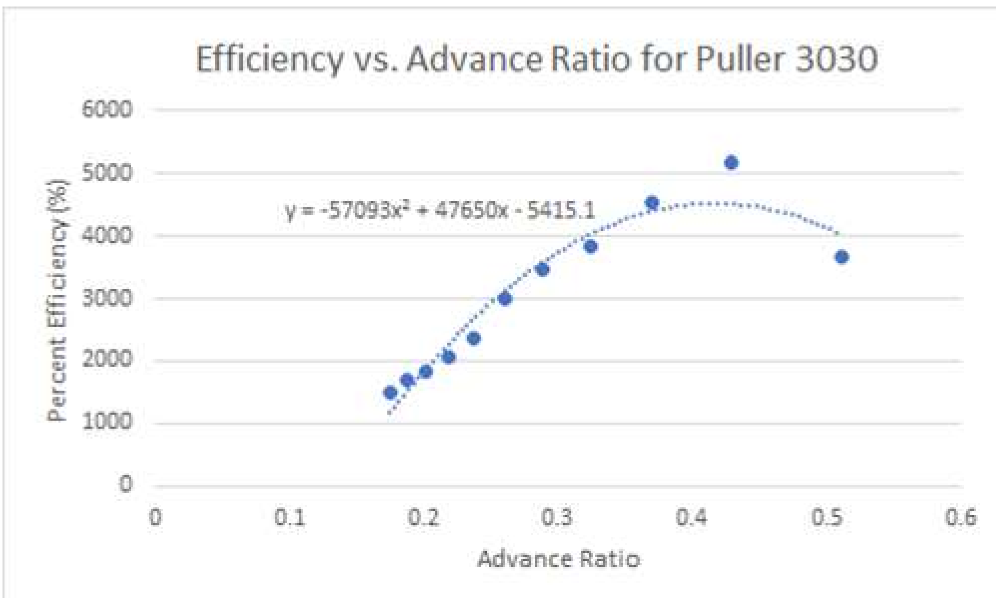


Figure 9: Efficiency vs Advance Ratio for Puller 3030

Lab 03 resulted in several interesting designs being introduced from members of team K. However, several obstacles were encountered by team members throughout the lab. First, some difficulty was experienced when trying to create orthographic drawings with oddly shaped parts such as the propellers and the vertical support arm. Second, some team members did not have time to complete their individual designs because they were busy finishing the AEV track testing component of Lab 02. Finally, during both phases of brainstorming a lack of instruments to measure AEV component dimensions and weight made it difficult to create accurate orthographic drawings. Many of these problems could have been prevented if the teams were provided with a list containing the dimensions and weight of the AEV components or if the tools necessary to make such measurements were available. Additionally, a better understanding of SolidWorks and 3-D printing prior to Lab 03 could have helped the team design the AEV by knowing the possibilities and limitations involved when designing new parts. Despite the problems encountered, four individual concept sketches were created and can be found in the appendix.

Lab 04 resulted in collection of a significant amount of data that was used to create a phase breakdown of the AEV run.During phase 1, three commands were issued. The first command, reverse(4), was used to reverse the motors. This was a necessary step because the motors were providing thrust opposite the desired direction before this command was added. Next, the motorSpeed(4,22) command was issued, powering all motors to 22 percent power. Finally, the goToAbsolutePosition(344) command was added, which directed the AEV to travel with the motors at 22 percent power until it had reached a position 344 marks away from the starting position, which was calculated to be just before the gate. According to table 1, Phase 1 of the code used the most energy, 49 Joules. However, this was due to the fact that it lasted the longest (8.94 seconds) and traveled the longest distance compared to the other two phases. According to figure 1, phase 1 of the code consistently used just under 6 Watts of power. During phase 2, three commands were used to slow down the AEV. First, reverse(4) reversed all motors to apply thrust opposite the direction of the AEV's travel. Second, motorSpeed(4,30) powered all motors to 30 percent their maximum power in order to quickly slow down the vehicle. Finally, the goFor(1) command was issued to make the motorSpeed(4,30) command stop after 1 second. According to table 1, phase 2 used the second most energy but as seen in figure 1 consumed energy at a much faster rate than any other phase due to the motorSpeed(4,30) command. During phase 3, only the brake(4) command was used to cut power to the motors after the vehicle had slowed down. For this reason, both the energy used and the energy consumption rate for this phase were very low. Only .0785 out of the 57.7219 Joules used during the run were used during phase 3. Analyzing the figures, it was clear that the power used during the run directly corresponded with the AEV commands being called. The general trend on each of figures 6 and 7 was correct despite an error in calculation causing the percentages of efficiency to be very high and unrealistic.

Phase Breakdown

Phase	Arduino Code	Time (seconds)	Distance (marks)	Total Energy (J)
1	motorSpeed(4,22)	8.94	344	49.1419
2	motorSpeed(4,30)	1	8	8.5015
3	brake(4)	2.82	2	0.0785
			Total Energy Used (J) :	57.7219

Table 1: Phase Breakdown

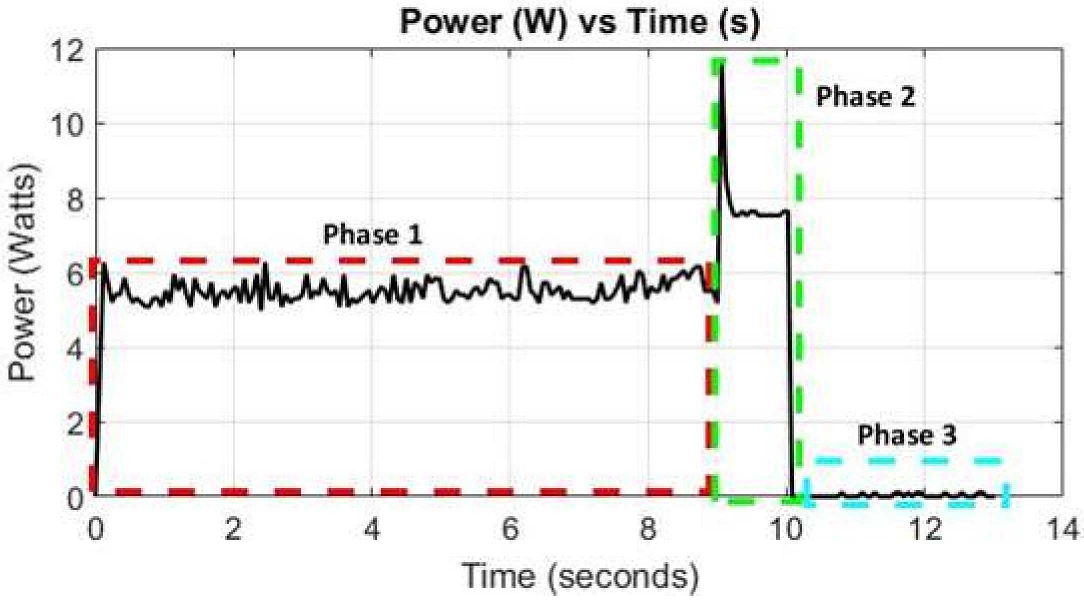


Figure 10: Phase Breakdown of Power vs Time

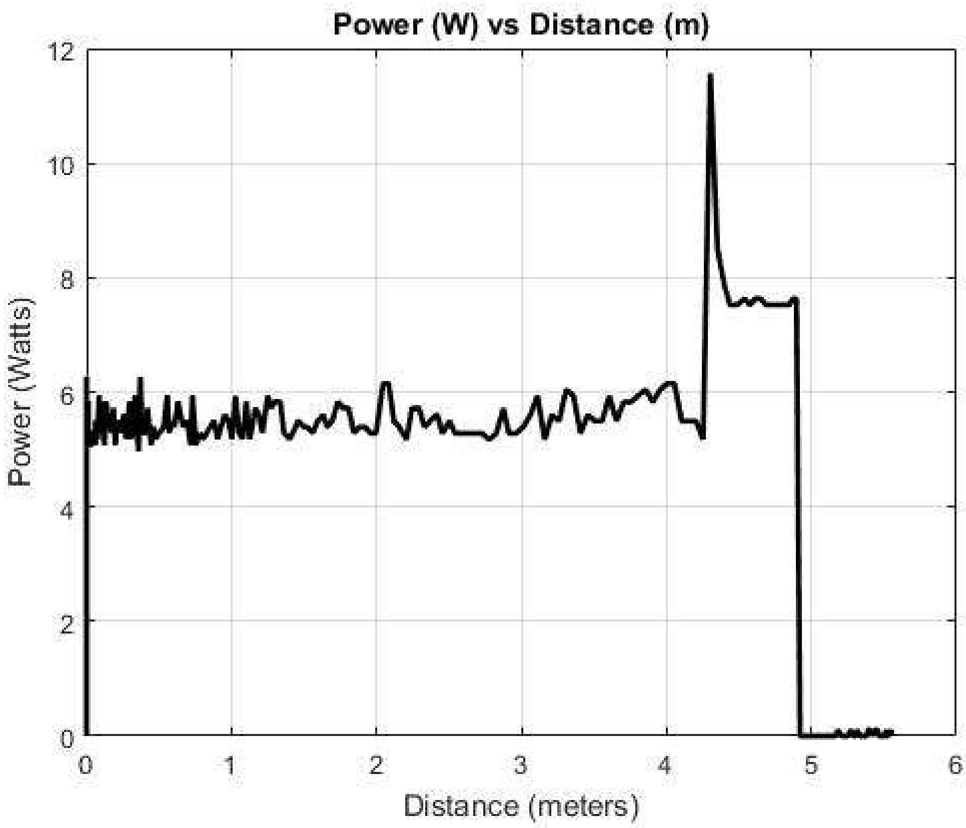


Figure 11: Power vs Distance

The data collected during the run on the straight track for System Analysis 2 was divided into three distinct phases in the run: moving forward at 22% power (motorSpeed(4, 22)), moving at 30% power (motorSpeed(4, 30)), and cutting off the power to the motors (brake(4)). Figure 1 provides the duration and distance of the phases as well as energy in joules, and figure 2 provides the graphical relationship between power and time broken down into the 3 phases. Phase 1 ran for about 9 seconds for 344 marks, consuming about 49 joules of energy. Phase 2 consumed 8.5 joules of energy during its 1-second, 8-mark run. Phase 3 consumed .0785 joules of energy for 2.82 seconds and 2 marks. In total, 57.7 joules were consumed by the AEV. Overall, phase 2 of this run used a higher rate of energy and power, leading to the idea of using a servo to conserve both quantities.

The results of lab 05 helped team K determine which vehicle design to adopt out of the choices available. The first time that the code was run, the AEV only moved a few inches and it moved in the wrong direction, likely due to the heavy weight and imbalance of the design in addition to forgetting to reverse the motors. The program was quickly modified by doubling the power applied to the motors, reversing the motors, and taking care to watch the AEV closely in case it flew off the track. During the run, the AEV moved at a desired speed and performed all the tasks fairly well. However, the vehicle was extremely imbalanced and swayed slightly from left to right the entire time, which is a major problem that was fixed when the team completed its final design. Using the sample AEV's run as a baseline, the team was able to rate each of the designs created in Lab 03. The scoring and screening matrices created during the lab can be found below.

		Sample AEV		Design A	(TIE Fighter)	Design B	(Zalo's Design)	Design C	(Khalid's Design)	Design D	(Ryan's Design)
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Balanced	25%	3	0.75	4	1	4	1	4	1	5	1.25
Minimal blockage	15%	3	0.15	2	0.3	5	0.75	3	0.15	4	0.6
Center-of -gravity	25%	3	0.75	5	1.25	4	1	3	0.75	4	1
Main-tenance	15%	3	0.45	3	0.45	3	0.45	4	0.6	5	0.75
Durability	15%	3	0.45	4	0.6	2	0.3	4	0.6	4	0.6
Cost	5%	3	0.45	1	0.05	4	0.2	2	0.1	1	0.05
Total Score:			3		3.65		3.7		3.15		4.25
Continue:			Combine		No		Combine		No		Combine

Table 2: Concept Scoring Matrix

Success Criteria	Reference	A	B	C	D
Balanced	0	+	+	+	+
Compactness	0	-	+	0	+
Center-of-gravity	0	+	0	+	+
Maintenance	0	0	0	+	+
Durability	0	+	-	+	+
Cost	0	-	+	-	-
Sum +'s	0	3	3	4	5
Sum 0's	6	1	2	1	0
Sum -'s	0	2	1	1	1
Net Score	0	1	2	3	4
Continue?	Combine	No	Combine	Combine	Combine

Table 3: Concept Screening Matrix

During lab 06, the team discussed the current state of the vehicle's design and decided upon ways to improve it and this resulted in the idea for using the servo motor as a braking system. During the lab period, an efficient braking system using the servo motor was devised and Dr. Schlosser quickly modified the support arm to accommodate the change.

Lab 07 provided the team with a mass measurement for the AEV as well as with calculations for the propeller force, friction force, net force, and marks error that were used to compare the performance of team k's AEV against other teams' AEVs. Overall, team K's AEV ranked 6th in propeller force, 8th in friction force, 6th in net force, and tied for first in marks error.

During lab 08, the team began with two prototype AEV designs. Each design was tested using two different codes and the results were analyzed. One prototype employed the standard method for braking, which was reversing the motors, while the other prototype used a servo motor brake to slow down. The four designs that the team came up with in lab 4 ended up evolving into the final two designs after using design screening and scoring matrices to determine which features were best from each design and then combine them into two designs. When the prototype employing the standard braking method ran on the track, it took noticeably longer to stop and consumed much more energy in the process. When the prototype employing the servo motor brake ran on the track, it stopped very quickly and precisely and used very little energy in the process. These results matched the team's expectations that a servo motor brake was more energy efficient and more effective than reversing the motors to slow down. Using the same control program, the design with the servo brake was consistently able to perform the task without errors, while the design without the servo brake stopped at different places each time. This performance test confirmed that the design with the servo brake was much better and affected the design process by making the AEV with the servo brake the obvious choice for the team's final design. The knowledge gained in System Analysis 1-2 enhanced the team's understanding of which actions use the most energy to perform and also gave an idea of the efficiency of the propellers at various power settings.

Discussion

During the wind tunnel testing, the puller 2510 and puller 3030 propeller configurations were tested under various conditions to determine how each propeller performed at different power settings. The results showed that System Efficiency vs. Advance Ratio (shown in figures 6,7,8,9) better for the 3030 configuration than the 2510. The 3030 propeller configuration was much more efficient both in energy usage and power output and was therefore a better choice.

Analyzing the phase breakdown for the AEV run, phase two, the braking phase, consumed energy at the highest rate, and this was a major issue that needed addressed (See figures 10 & 11). Throughout the project, the team noticed that the go-to solution used by most teams for braking the vehicle was calling the reverse function and powering up the motors to high percentages to slow the vehicle. Analyzing the phase breakdown for the AEV run, phase two, the braking phase, consumed energy at the highest rate, and this was a major issue that needed addressed (See figures 10 & 11). However, the team quickly noticed that this action used a significant amount of energy and set out to devise a solution to braking without using significant amounts of energy in the process. During lab 05, the team realized that the servo motor could be used effectively as a friction brake to the wheel that does not contain the reflective tape. This was accomplished by modifying the support arm to hold the servo motor in place near the wheel so that its arm could rotate and contact the wheel when necessary to slow the AEV without having to call the reverse() function.

The main source of error for team k in each lab was human error caused by lack of focus, miscalculation or inexperience with using the Arduino and all the associated programs. An example was in lab 08 the code for the track run had to be written several times due to miscalculations of the distance between the starting point and the gate. To resolve human error, team K assigned pairs to each task so that each person could check the other's calculations for accuracy and similarity. Another source of error was friction, which could be reduced primarily by reducing the normal force on the wheels and therefore the friction force, as they are directly related. To resolve this error, the team 3-D printed a lighter body for the vehicle that will be applied in the final design. Another potential source of error during the project included error with the instruments attached to the vehicle, particularly the reflectance sensors. This error was reduced by testing the reflectance sensors to ensure they were measuring within two marks of accuracy. One final source of potential error was failing to balance the vehicle properly, resulting in the AEV swaying and potentially causing a number of problems, including the catastrophic problem of falling off the track. This issue was fixed by using the desktop stand to see how the vehicle rested on the track and balancing it from there.

Conclusion and Recommendations

In the end, the tests and data analyses performed have led to promising prototypes and modifications that may have increased the AEV's ability to complete the Mission on time as well as save significant amounts of energy. The team has made connections between various technical concepts and utilized designing basics to further bring the AEV closer to these goals. With that being said, the team has decided to continue implementing on its current AEV design that included the energy-saving servo, as it recently stopped the AEV smoothly without having to waste valuable energy.

The group decided to go with the design that contained the servo mechanism as a break given multiple, promising tests. Among said tests, the most promising was when the group ran the AEV on the straight track. When the servo finally engaged and the propellers stopped spinning, the AEV stopped within a few inches, which was much, much faster than the other AEV, which had the propellers spinning in reverse. The group also discovered that their current AEV used less power than the AEV that used the reverse command to brake through looking at the EEProm data from the previous AEV, and comparing it to the energy usage of the AEV with the servo as the braking mechanism. Through these two observations, the group decided to continue with the AEV design that used the servo.

The group figured out that they should divide up their efforts better, and ahead of time for the next lab, as there were situations where the group would be sitting around trying to figure out what would be the best course of action. The group also realized that they should have been more diligent with their calculations and observations, as their first run on the track was cut short since they did not take into account an extra turn. Due to this miscalculation, the group discovered that it would be best to assign tasks in pairs in order to give each other a hand, and to double check every calculation in order to be the most effective, and efficient group possible. With these changes, the group felt comfortable, and prepared for the next lab. Additionally, the time it took to achieve a successful test on the track used nearly the entire class period, so the team was unable to download the data from the AEV to provide the figures that were supposed to be provided in the lab 08 results.

Appendix

Current	Thrust Scale Reading	RPM	Arduino Power Setting
amps	*grams*	*RPM*	*%*
0	187	0	0
0.18	187	3298	10
0.21	188	4993	15
0.24	189	6688	20
0.27	192	8383	25
0.31	196	10078	30
0.34	198	11773	35
0.39	202	13468	40
0.42	208	15163	45
0.48	210	16858	50
0.53	215	18553	55
0.57	224	20248	60

Table 4: Puller 2510 Data

Wind Tunnel Aerodynamics Data - Puller 2510

Thrust Calibration	RPM	Power In	Power out	Power Out	Propulsion Effciency	Advance Ratio
g		*Watt*	*HP*	*Watt*	*%*	.
0	0	0	0	0	0	0
0	3298	0.1332	0	0	0	0.802204151
0.411	4993	0.2331	0.01513926	11.289348	4843.135135	0.529875684
0.822	6688	0.3552	0.03027852	22.578696	6356.614865	0.395584523
2.055	8383	0.4995	0.07569631	56.44674	11300.64865	0.315599343
3.699	10078	0.6882	0.13625336	101.604132	14763.75065	0.262519279
4.521	11773	0.8806	0.16653189	124.182828	14102.06995	0.22472346
6.165	13468	1.1544	0.22708894	169.34022	14669.11123	0.196441141
8.631	15163	1.3986	0.31792451	237.076308	16950.97297	0.174481916
9.453	16858	1.776	0.34820304	259.655004	14620.21419	0.156938503
11.508	18553	2.1571	0.42389935	316.101744	14654.01437	0.142600619
15.207	20248	2.5308	0.56015271	417.705876	16504.89474	0.13066324

Table 5: Puller 2510 Data with calculations

Current	Thrust Scale Reading	RPM	Arduino Power Setting
amps	*grams*	*RPM*	*%*
0	206	0	0
0.17	210	4307	10
0.28	220	5136	15
0.41	230	5965	20
0.55	240	6794	25
0.73	255	7623	30
0.86	264	8452	35
1.05	270	9281	40
1.23	280	10109	45
1.44	291	10938	50
1.6	302	11767	55
1.86	313	12596	60

Table 6: Puller 3030 Data

Wind Tunnel Aerodynamics Data - Puller 3030

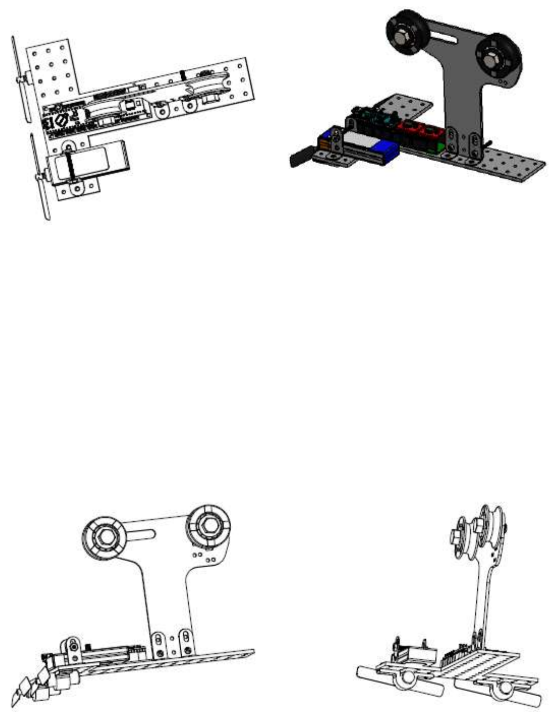
Thrust Calibration	RPM	Power In	Power out	Power Out	Propulsion Effciency	Advance Ratio
g		*Watts*	*HP*	*Watts*	*%*	.
0	0	0	0	0	0	0
1.644	4307	0.1258	0.006172992	4.6032	3659.141494	0.511893292
5.754	5136	0.3108	0.021605471	16.1112	5183.783784	0.429268771
9.864	5965	0.6068	0.037037951	27.6192	4551.61503	0.369610127
13.974	6794	1.0175	0.05247043	39.1272	3845.425061	0.324510511
20.139	7623	1.6206	0.07561915	56.3892	3479.526101	0.289220046
23.838	8452	2.2274	0.089508381	66.7464	2996.605908	0.260852391
26.304	9281	3.108	0.098767869	73.6512	2369.72973	0.237552463
30.414	10109	4.0959	0.114200349	85.1592	2079.132791	0.218095203
34.935	10938	5.328	0.131176076	97.818	1835.923423	0.201565589
39.456	11767	6.512	0.148151804	110.4768	1696.511057	0.187365039
43.977	12596	8.2584	0.165127531	123.1356	1491.034583	0.175033694

Table 7: Puller 3030 data with calculations

Estimated Weight: 275 grams

Estimated Price: $118

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	hex bolt_ai		2
2	machine screw nut hex_ai		4
3	pan slot head_ai		2
4	pan slot head_ai		1
5	90-deg bracket		4
6	AEV Arduino Assembly		1
7	Battery Sleeve		1
8	Battery		2
9	Kapton Tape		1
10	Prop 3inch		2
11	Tee		1
12	AEV Motor		2
13	Ball Retainer Inner Sleeve		2
14	Ball Retainer Outer Sleeve		2
15	Ball		48
16	Housing w-reflective tape		2
17	Motor Mount Clip Aluminum		2
18	Support Arm 1 2 Sensor Holes V2		1



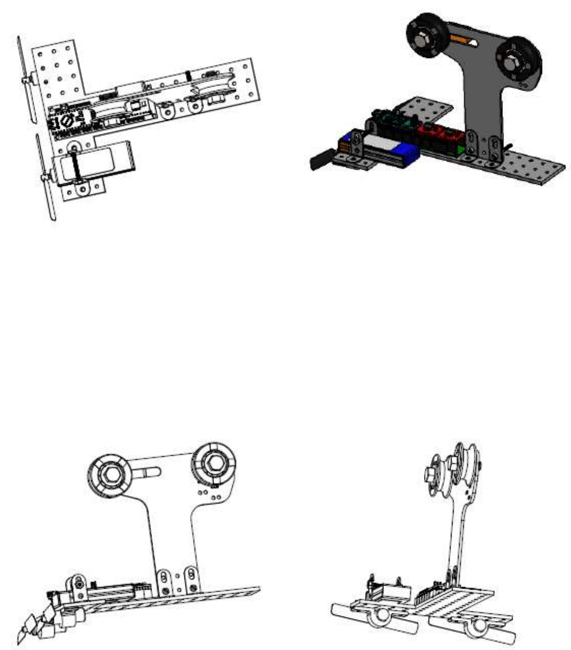
The Ohio State University First Year Engineering	Dwg. Title: Model 1	Scale: 1:2	Inst.:Dr. Phil Schlosser	Units: XXXX	Dwg. No.: XX
	Drawn By: Group K		Hour: 10:20	Seat: N/A	Date: 03/25/2017

Figure 12: AEV Prototype model 1

Estimated Weight: 300 grams

Estimated Cost: $128

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	hex bolt_ai		2
2	machine screw nut hex_ai		4
3	pan slot head_ai		2
4	pan slot head_ai		1
5	90-deg bracket		4
6	AEV Arduino Assembly		1
7	Battery Sleeve		1
8	Battery		2
9	Arduino Servo		1
10	Prop 3inch		2
11	Tee		1
12	AEV Motor		2
13	Ball Retainer Inner Sleeve		2
14	Ball Retainer Outer Sleeve		2
15	Ball		48
16	Housing w-reflective tape		2
17	Motor Mount Clip Aluminum		2
18	Support Arm 1 2 Sensor Holes V2		1
19	Rotation Sensor Board		2



The Ohio State University First Year Engineering	Dwg. Title: Model 2	Scale: 1:2	Inst.:Dr. Phil Schlosser	Units: XXXX	Dwg. No.: XX
	Drawn By: Group K		Hour: 10:20	Seat: N/A	Date: 03/25/2017

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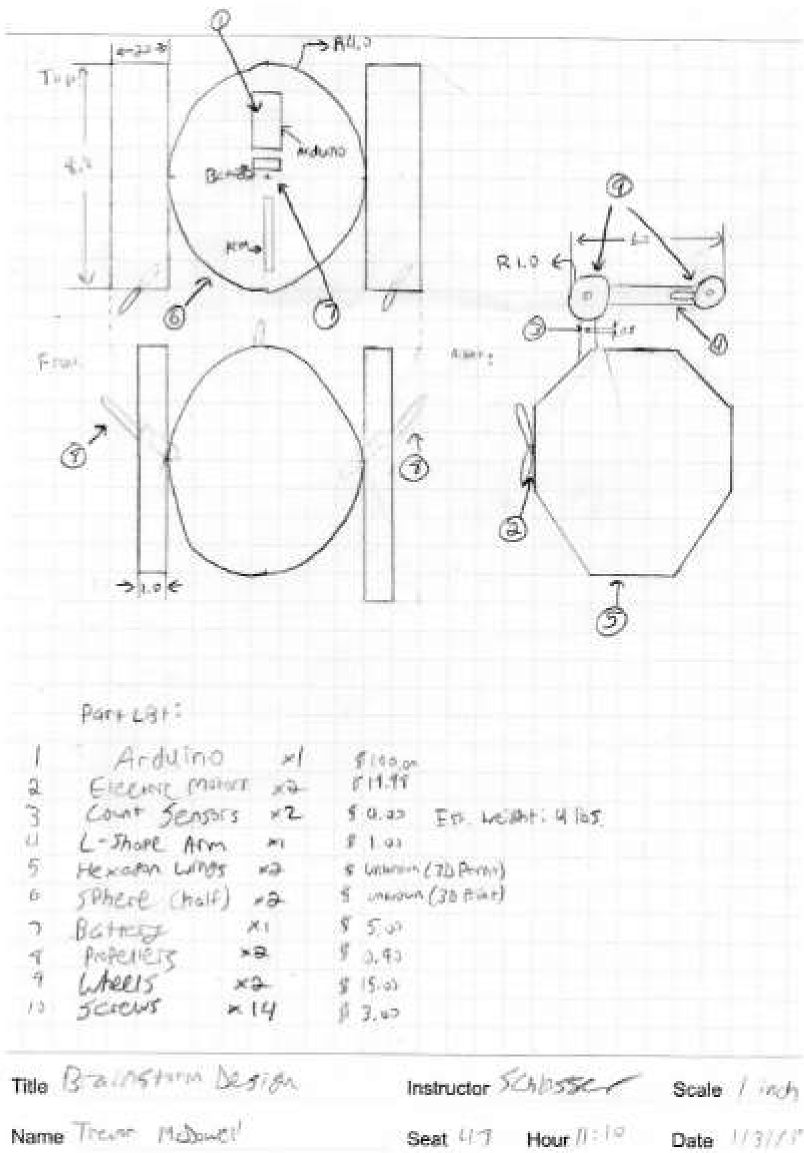
Figure 13: AEV prototype model 2

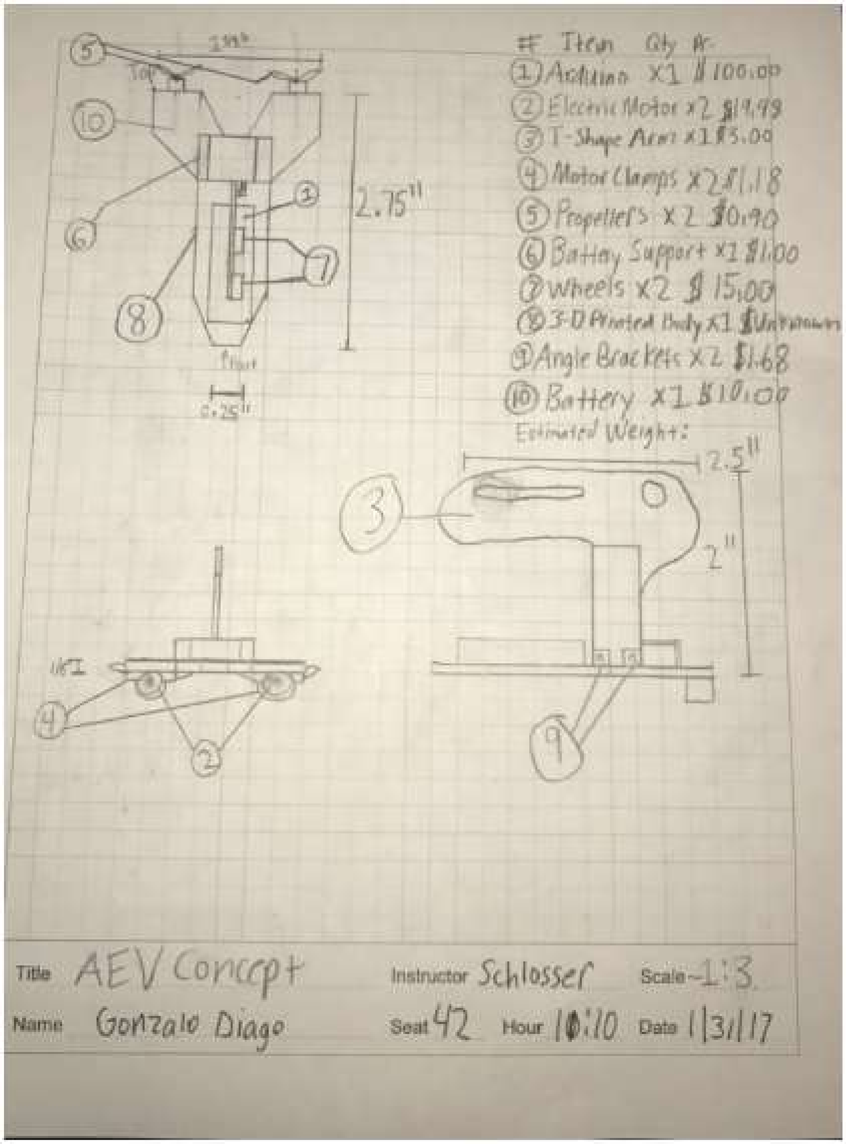
No.	Task	Start	Finish	Due Date	Gonzalo Diago	Khalid Musa	Trevor McDowell	Ryan Born	Percent Finished
1	PDR	24-March	26-March	27 - March	x	x	x	x	100%
2	Performance Test 2: Code	25-March	31 - March	31-March		x	x		90%
3	Performance Test 2: Design	25-March	31 - March	31-March	x			x	50%
4	Lab 10	26 -	2 - April	3 - April	x	x	x	x	35%

	Progress Report	March							
5	Lab 10 Energy Optimization	26 - March	3 - April	3 - April	x			x	20%

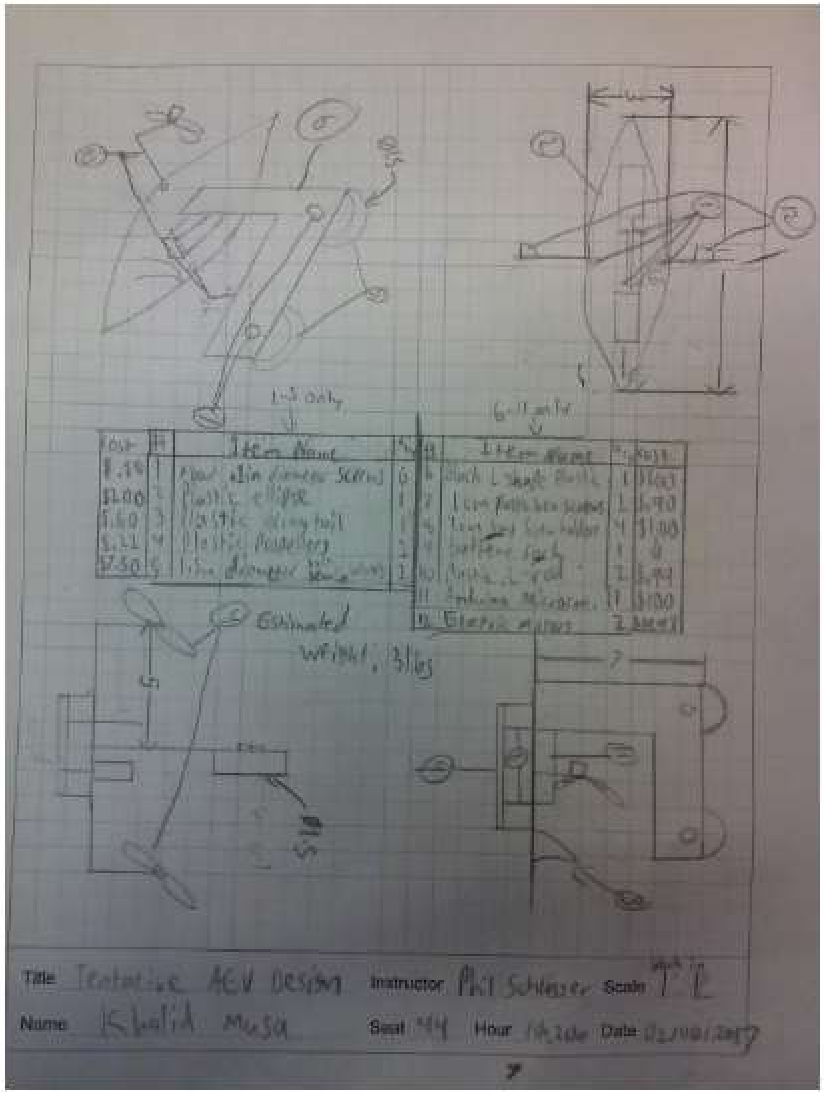
Table 8: Team Schedule



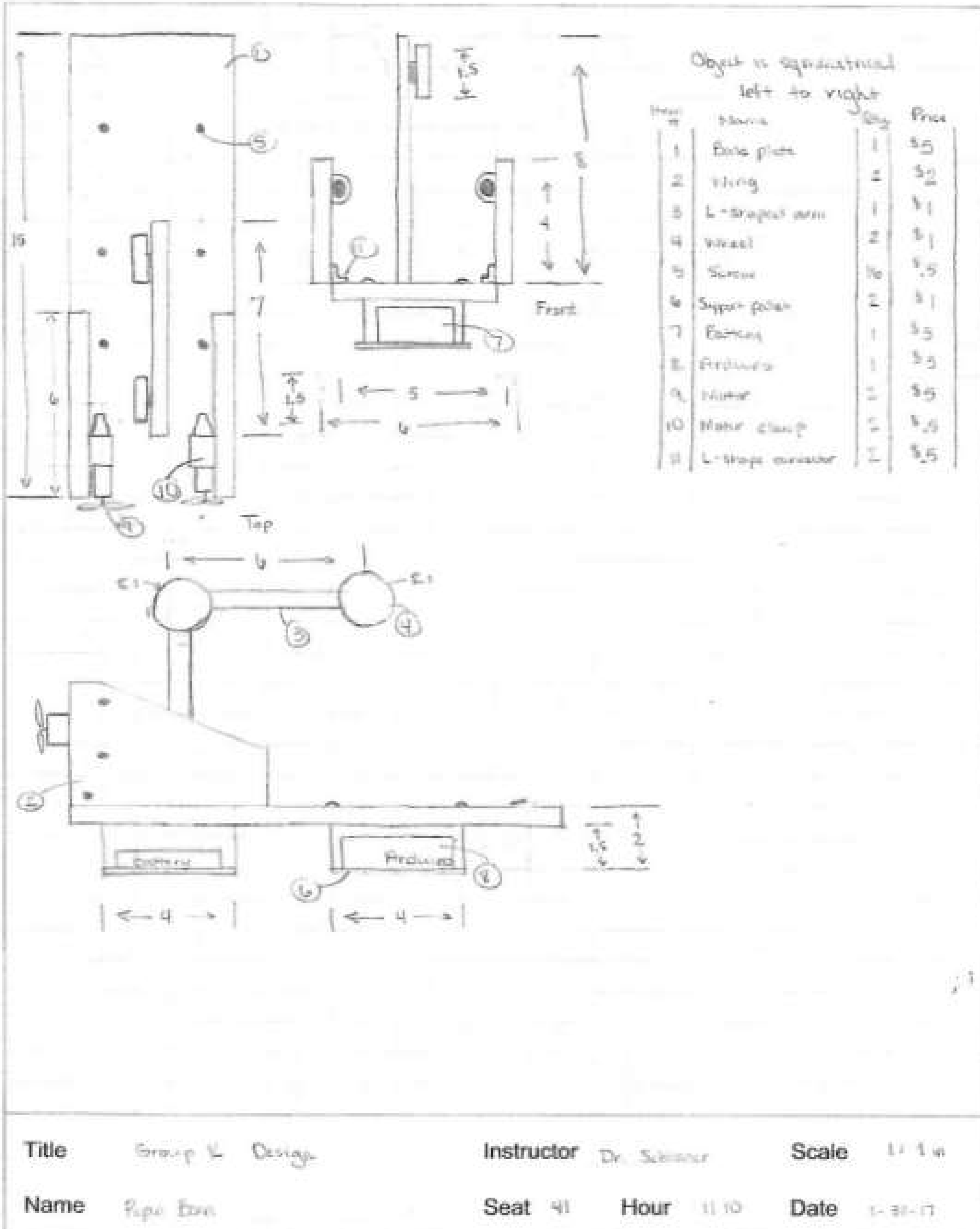
Design 1: Trevor McDowell



Design 2: Gonzalo Diago



Design 3: Khalid Musa



Design 4: Ryan Born - Also voted to be the Group AEV Design