Critical Design Review (CDR) Report

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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 and cost effective transportation system for R2D2 units. 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 first 7 labs as well as the four performance tests helped the team enhance its understanding of the iterative process of decision making and design.

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. During lab 02a, the team tested the external reflectance sensors and learned the functions associated with 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 creative design thinking. During the lab, each team member designed an AEV and later on the team decided on a final design. During lab 04a, team k learned how to download data from the automatic control system and convert EEPROM Arduino data to usable parameters. Lab 04b familiarized the team with the design analysis tool and how to use it to analyze collected data. Lab 05 introduced 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. 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 the reflectance sensors were working correctly. 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. Lab 09 was the second performance test, which allowed the team to finish writing the code that had been decided upon in lab 08. Lab 10 was the third performance test, which allowed the team to optimize the AEV's energy usage and make improvements. Lab 11 was the final testing period for the AEV, and the team was able to finalize a code that consistently allowed the vehicle to complete a full circuit on the track and to complete the entire mission.

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. The process of designing an AEV was thorough and detailed, and required the use of decision making techniques to make important choices between different prototypes. This Critical Design Review will describe the process that started several months ago with lab 01 and culminated in the final design for the AEV during lab 11.

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. Figure 2 shows the code used for lab 01.

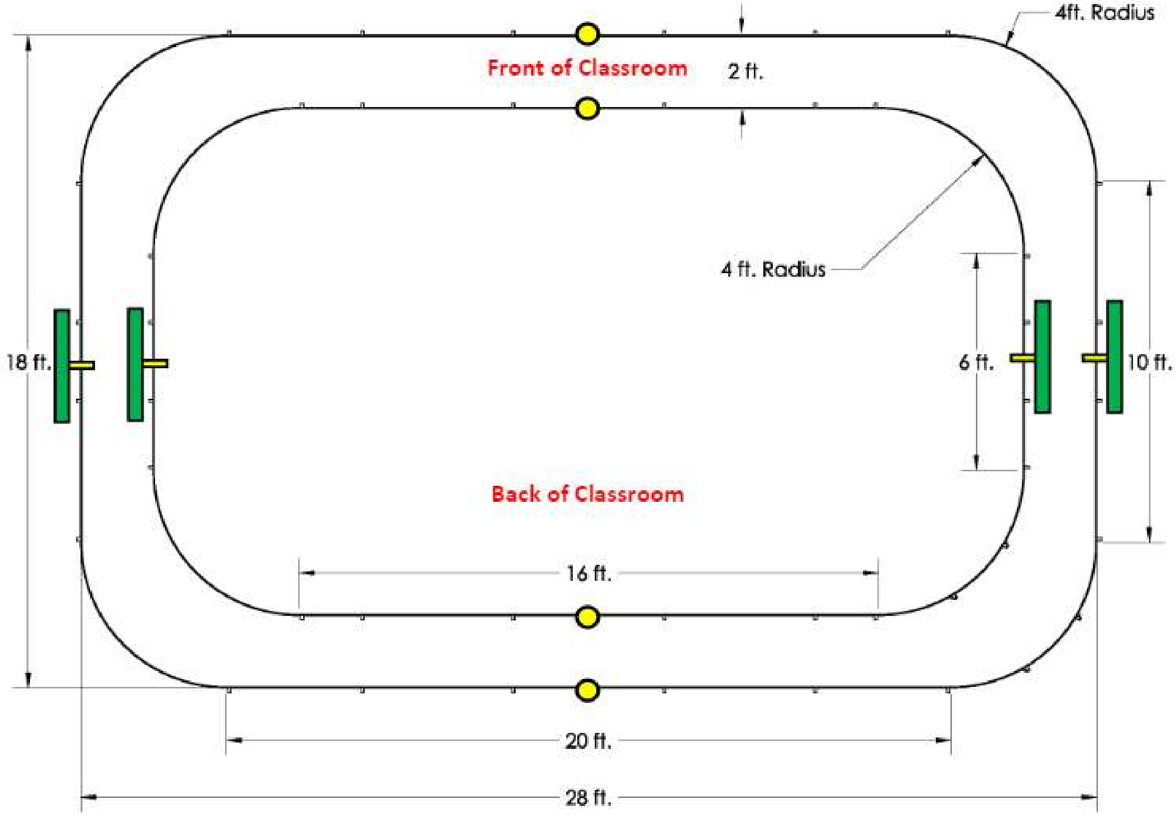
Figure 1: Properly Installing Propeller Onto Motor

Figure 2: Code Used in Lab 01

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

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 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, 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

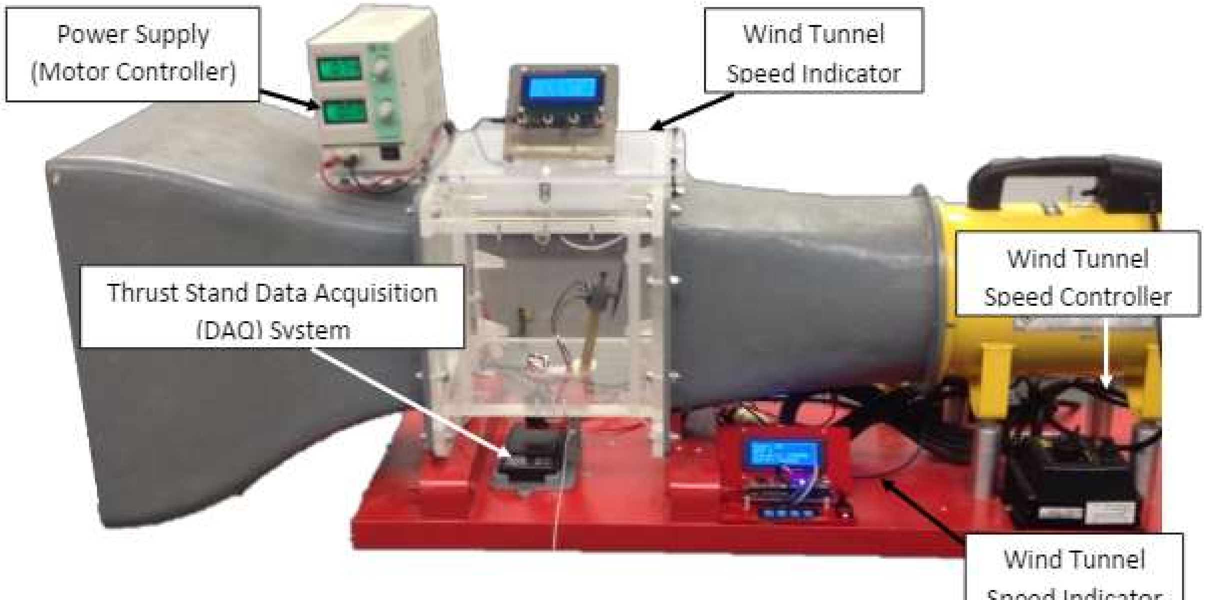


Figure 22: Wind Tunnel Equipment

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. The program used is shown in figure 5. 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.

Figure 5: Lab 05 Straight Track Code

STRAIGHT TRACK

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.

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.

The purpose of Lab 09 was for teams to test their AEV designs and continue the recursive, trial and error process of testing, making improvements, and testing again. Lab 09 consisted of the team writing an Arduino code that would successfully navigate the track and perform a complete run as outlined in the Mission Concept Review. The lab procedure for Lab 09 was not standardized as it had been in previous labs. Instead, each team was able to spend the lab period performing any tasks deemed necessary to improve their vehicles. For team K, Lab 09 was spent optimizing the two Arduino codes that had been written. The first task performed during Lab 09 was to make several calculations that would be necessary in writing the code. First, the distance from the starting point on the track to the gate was calculated in inches and converted to marks. Second, the distance from the gate to the caboose was calculated and converted to marks. Finally, these values were entered into a program skeleton created by team K and the vehicle was ready to be put on the track. After the vehicle was put on the track, changes were made to the code to improve performance, and this process was repeated for the remainder of the lab. Each time the AEV was put on the track, valuable information was collected regarding potential changes to both the code and the physical body of the vehicle. By the end of lab 09, a functional Arduino code had been written that successfully navigated the AEV through a complete run on the track. The team made sure to allow the Arduino to finish collecting data before turning off the vehicle and removing it from the track.

The purpose of Lab 10 was for teams to continue testing their AEV designs in order to make progress towards a vehicle capable of completing the tasks outlined in the MCR while using a minimal amount of energy. Although the Arduino code developed during lab 09 was functional and consistent in completing the Mission Concept Review, there was significant room for improvement when it came to energy efficiency. Lab 10 consisted of team K analyzing its Arduino code from lab 09 and deciding on how the code could be improved both in terms of consistency and energy efficiency. The entirety of Lab 10 was spent optimizing the code and testing the AEV on the track. The first order of business during lab 10 was to copy the existing, working Arduino code and save it so that if the new changes to the code caused problems, they could easily be reverted. Next, the team decided to make a small change to the physical vehicle that would increase performance overall and reduce energy usage. The change made was reversing the propellers so that the side with the text was facing outward rather than in the direction of travel. This change was predicted to greatly increase the energy efficiency when carrying the caboose because the propellers are much more efficient when travelling in the direction of the text. The next change made was a change in the approach to programming the AEV. The way the team had the code set up had the AEV's motors running at medium power settings for extended periods of time, which used a lot of energy. The team changed the code so that the AEV would power up its motors to high motor speeds for a very short period of time, giving it enough velocity to coast the remainder of the distance it needed to travel. This change was expected to reduce the total energy usage, as the propellers are more efficient at high motor speeds. The two changes to the from a programming and physical perspective were expected to improve the energy efficiency of the vehicle.

The purpose of lab 11 was for the team to demonstrate that their vehicle was capable of successfully completing the goals laid out in the Mission Concept Review. The beginning portion of the lab consisted of the team making its final changes to the code and ensuring that the AEV was capable of completing the full circuit on the track consistently. There was one primary change that was made to the code during the beginning of the lab to help ensure consistency on the track. The team had noticed a tendency of the vehicle to stop early, so several marks were added any time the vehicle stopped so that the vehicle would no longer stop too early. Once the team was confident that its vehicle was consistently capable of completing the required circuit, a teaching assistant was called over to score the team's vehicle during a full run. Although each team was allowed two trial runs, the team received a perfect score on the first run so the second run was unnecessary.

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 underwent a small delay (less than half a second) after the motor started before they would begin to spin. 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 meant that the AEV would continue moving until friction between the wheels and the track brought it to a stop after the call of the brake() command. One basic solution to this problem was reversing the motors to apply thrust in the direction opposite to the travelling vehicle 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 caused 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. The data collected can be seen below in figures 6, 7 8 and 9.

Figure 6: Thrust vs Power for Puller 2510

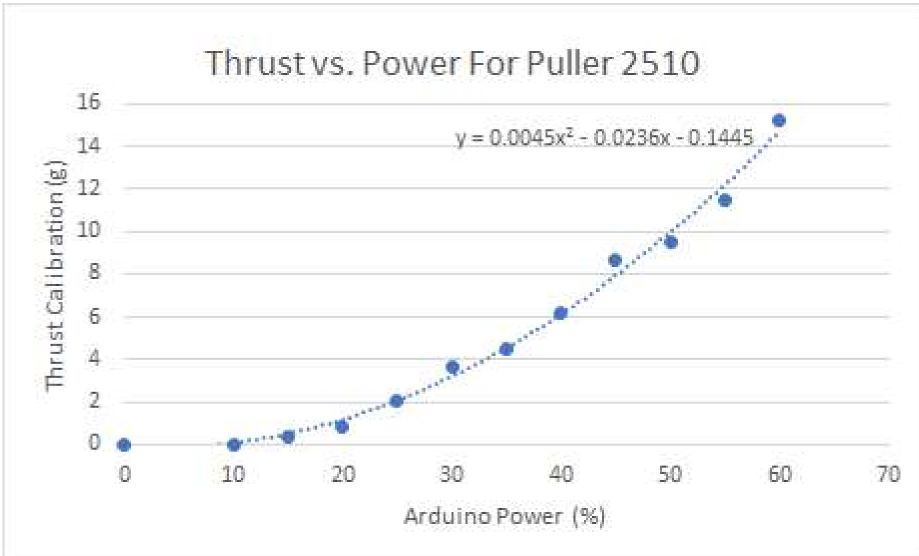


Figure 7: Efficiency vs Advance Ratio for Puller 2510

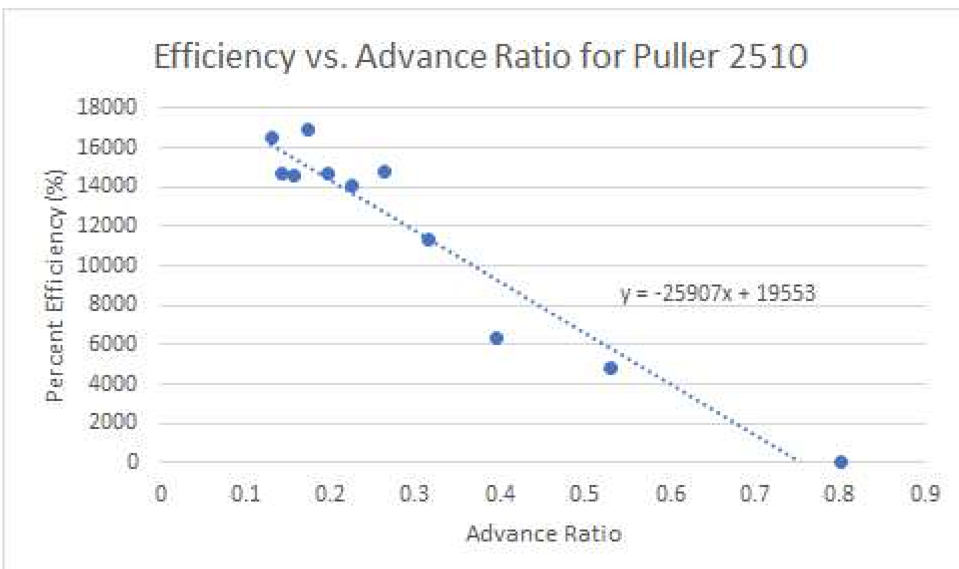


Figure 8: Thrust vs Power for Puller 3030

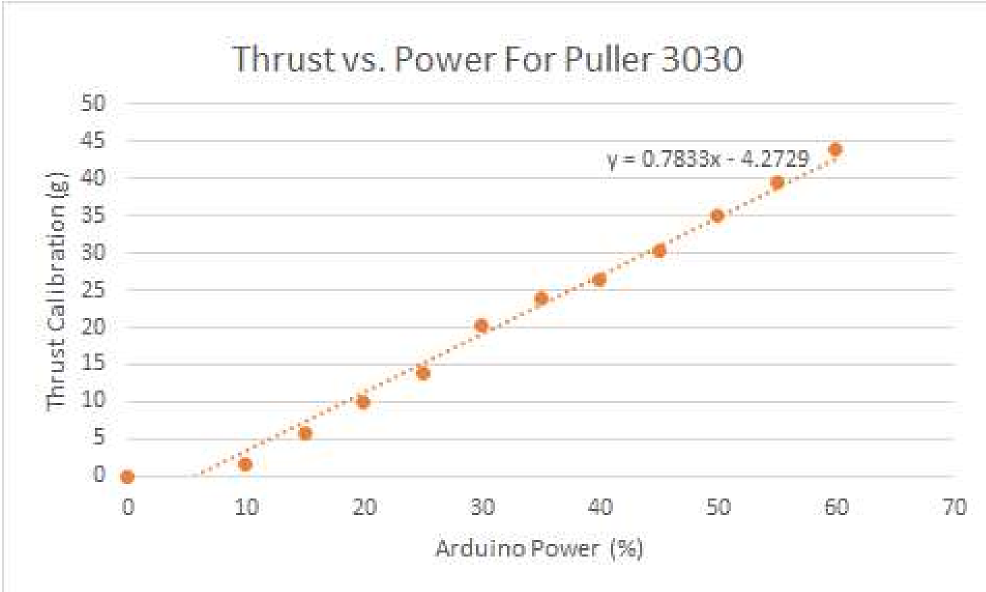
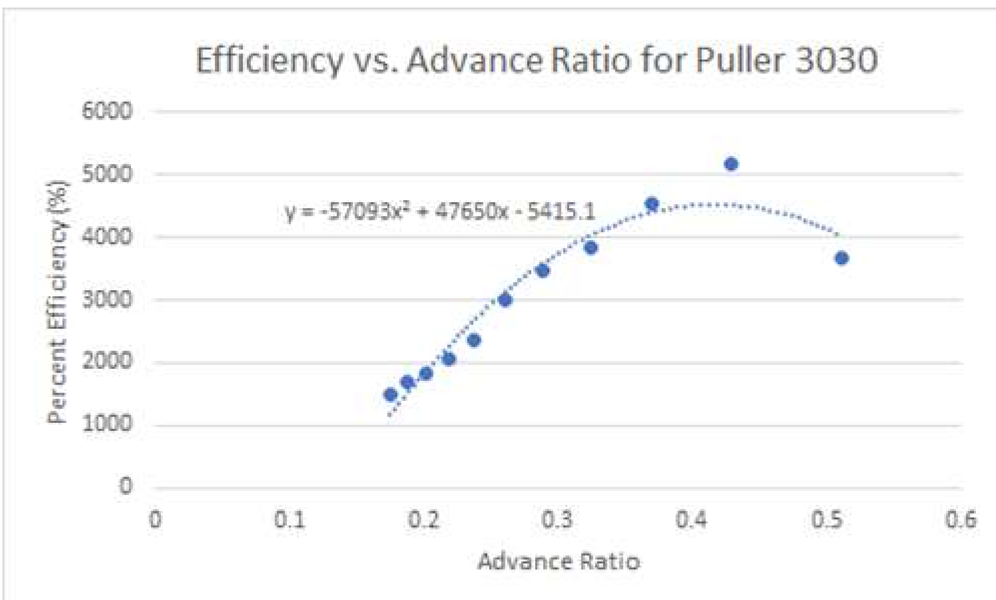


Figure 9: Efficiency vs Advance Ratio for Puller 3030



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.

Table 1: Phase Breakdown

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

Figure 10: Phase Breakdown of Power vs Time

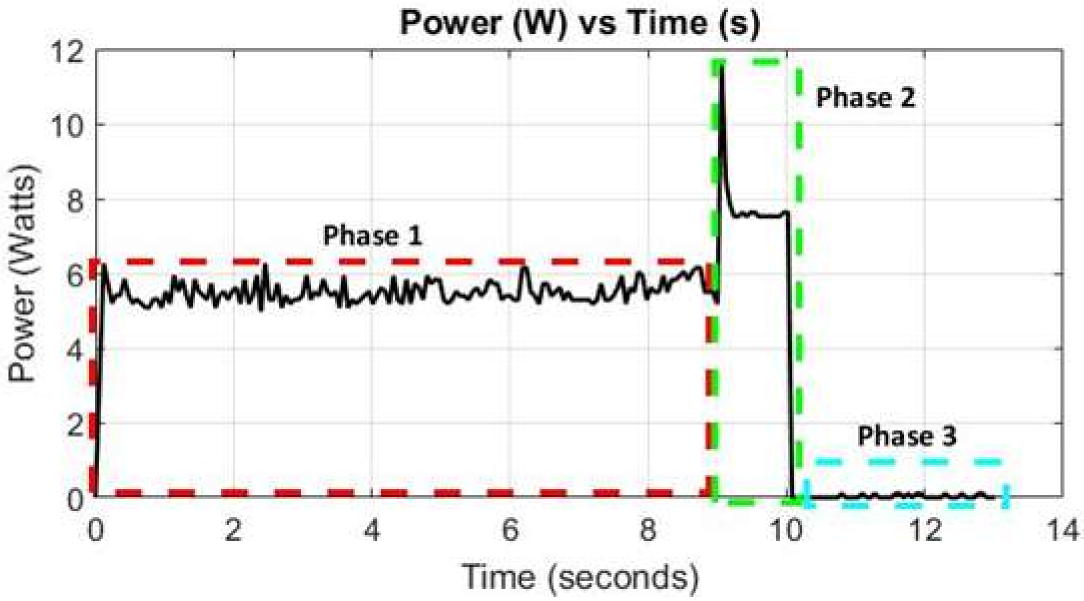
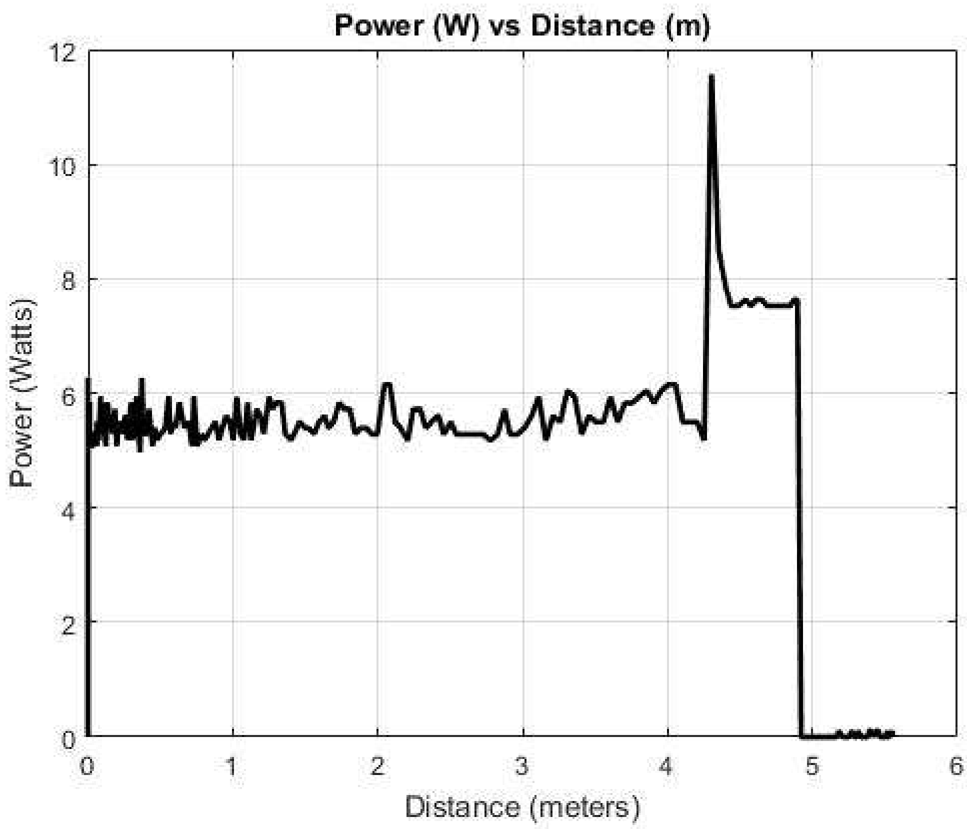


Figure 11: Power vs Distance



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.

Table 2: Concept Scoring Matrix

		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 3: Concept Screening 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

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.

During lab 09, team k made significant progress towards its goal of completing the mission described in the Mission Concept Review. One important decision was made within only a few minutes of the lab beginning. The decision made had to do with a highly distinguishable difference in effectiveness from one Arduino code to another. After running the AEV on the track using both the Arduino codes, it quickly became clear which code was more consistent and predictable. The first code written used absolute position as a means of determining how far the vehicle should move before it needed to stop, and this technique was effective. The position code was consistent, with little difference between each run. Meanwhile, the second code written used time as a means of determining how long the vehicle should travel before stopping at a certain point, and this technique was highly inconsistent and unpredictable. Code 2 was was decided against in favor of code 1. After determining which code would be used moving forward, the team spent the remainder of the lab focusing on improving the code. The first time the vehicle was run on the track using the chosen code, it successfully travelled to the gate, stopped, and moved past the gate once it lowered. Next, it managed to pick up the caboose and begin moving back towards the gate. Unfortunately, the vehicle failed to stop in front of the sensor (it stopped too early) that triggers the countdown for the gate to lower on the way back. The team figured that the solution to the problem discovered during the first run was to increase the number of marks travelled by the vehicle before applying the brake by 10. The next time the vehicle was put on the track, the change made successfully allowed it to stop inside the sensor and move past the gate with the caboose. Despite this success, the vehicle failed to stop at the end of the track on its way back and collided with the foam block. In order to fix this problem, the number of marks before applying the brake was reduced by 20. During the next run, the vehicle nearly completed the entire mission, but stopped too early. To fix this problem, 5 more marks were added before applying the brake. During its final run on the track of Lab 09, team K's AEV successfully completed one full circuit.

During lab 10, the team made several changes that turned out to be highly effective in improving the energy efficiency of the AEV. The first change made, reversing the propellers, required the team to perform several trial and error runs on the track before adequately updating the code to complete a full circuit without any errors. Despite the time spent modifying the code to function with reversed propellers, the team felt the modification was worth the effort. After reversing the propellers, the AEV was able to move fairly quickly at lower motor speeds when carrying the caboose. This was important because prior to reversing the propellers, the AEV struggled when carrying the caboose and required a large amount of energy and high motor speeds in order to move. The AEV was able to complete the full circuit almost 10 seconds earlier than before, and used less energy in the process when analyzed using the AEV data analysis tool (Refer to figures 14 and 15 below for plots of energy vs time before and after reversing the propellers). The next change made was for the team to take a different approach to the programming of the vehicle in order to reduce energy usage. Instead of running the motors constantly at low to medium speeds, the motors were run at high speeds for short periods of time, and this change led to reduced energy usage as well. After the change, there was a noticeable difference in the way the vehicle performed on the track. The vehicle was more stable when cornering and braking, and did not shift side to side as it had using the previous code. Additionally, the AEV was able to stop much faster because it had already started slowing down before the brake was applied. The two changes made to the AEV during lab 10 improved energy efficiency and performance by allowing the AEV to complete the entire run in less time, using less energy. Before the propellers were reversed, the AEV used over 300 joules of energy during the complete run. After the change was made, the vehicle used around 260, which was over a 10% improvement in efficiency.

Figure 12: Power vs Time for Propellers Facing Forward

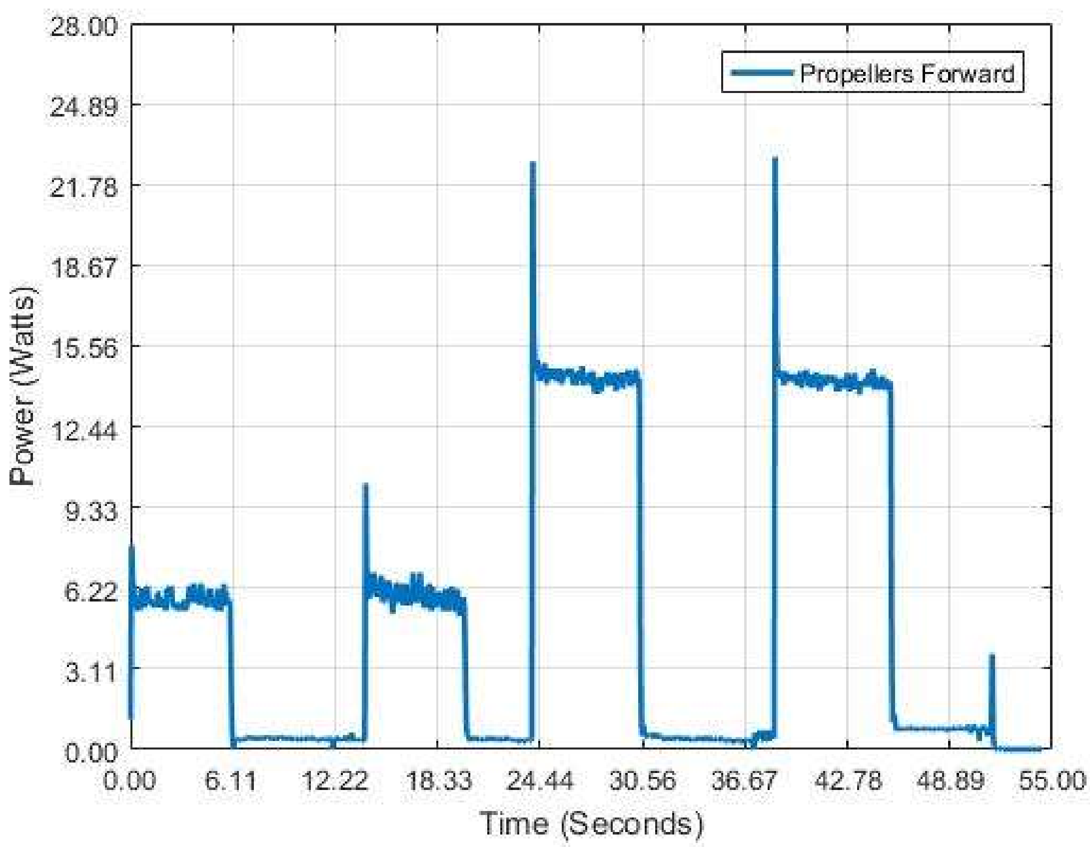
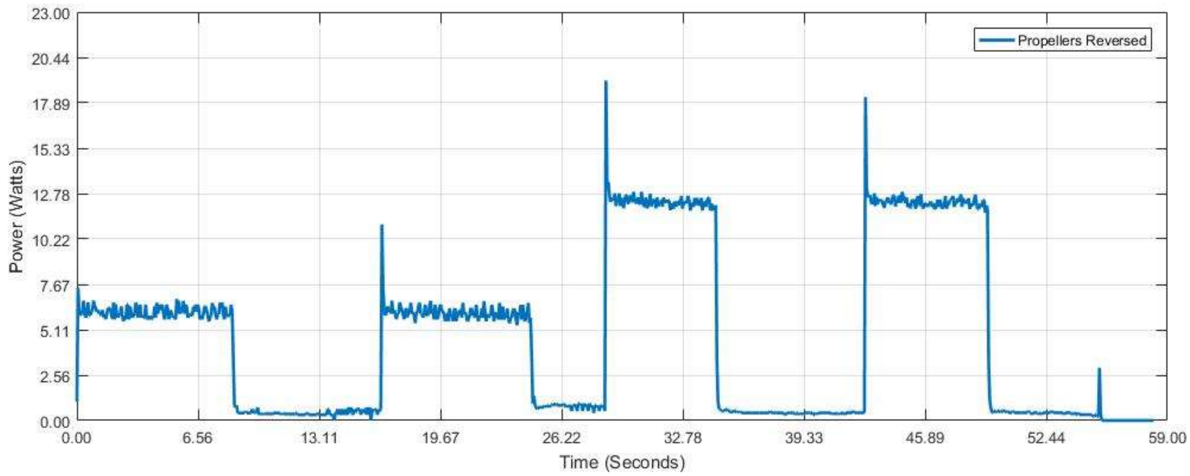


Figure 13: Power vs Time for Propellers Reversed



During lab 11, team k made a few small changes to the code that had allowed the AEV to complete several successful runs during lab 10. First, the team noticed that the vehicle had a tendency to stop a few marks before the first gate on certain occasions, so 4 marks were added to the position of the vehicle before calling the brake command and activating the servo motor brake. Next, the team noticed that the AEV was sometimes stopping too early in front of the caboose and therefore not picking up the cargo. To address this, 3 marks were added before the servo motor brake was activated in order to ensure that the AEV would always connect with the cargo. Finally, the AEV had a tendency to stop too late on its return run and collide with the green foam block at the end of the track. To address this, the team modified the code so that the AEV would apply its brake 6 marks earlier and this fixed the problem. After all of these changes were made, the team called over a grader and demonstrated a run, receiving a perfect score of fifty out of fifty. The score sheet for the final run is located under the appendix.

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.

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. From that point on, the team was left with two prototypes, one using a servo motor brake and one without it. These two designs were nearly identical and were based upon the design introduced by Ryan Born during lab 04. The two prototype designs were highly cost effective, using only parts provided with the AEV kit and minimizing the number of parts used. Prototype 1, the vehicle without the brake, was at an estimated cost of $118, while prototype 2 was at an estimated cost of $128. Although prototype 2 was more expensive, team k predicted that the added functionality of the servo motor brake would be worth the additional cost. The first performance test allowed team k to make its final decision regarding which of the two prototypes was better. The scoring and screening matrices that helped the team defend its final design against all the concepts can be found in the appendix.

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. To fix the balance issue, the battery was mounted on the opposite side of the servo motor.

Conclusion and Recommendations

In the end, the tests and data analyses performed led to promising prototypes and modifications that increased the AEV's ability to complete the Mission on time as well as save significant amounts of energy. Following the first seven labs and the first performance test, the team had made its final decision regarding which design would be used for the AEV. The final design for the AEV included a servo motor brake that served two important functions. First, it provided consistency. Second, it saved energy.
This final decision was made after several promising tests during the first performance test. Among the tasks performed, 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 faster than the other AEV, which had the propellers spinning in reverse. The group also discovered that the servo motor brake 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.

Fortunately, the team encountered only a few serious errors that were solved by the end of the design process. The most significant error was that the AEV was unbalanced and would sway side to side, particularly when cornering. This issue was solved by relocating the battery from the bottom center of the AEV to the left rear. Another issue that the team experienced was inconsistency that was caused by depletion of the battery. After four to five tests, the AEV would begin to perform differently due to the battery losing its charge, and as a result it would sometimes stop too early or too late. This issue was fixed by maintaining a battery that was freshly charged and by adapting the code to account for charged and uncharged batteries. Ultimately, very few errors were encountered.

For the future, team K recommends changing the order in which the labs were performed as well as changing some of the lab periods. First, the team believes it would benefit students to split lab 2 into two separate lab days so that each student on the team could witness the wind tunnel testing as well as the reflectance sensor setup. Additionally, it is recommended that the decision making techniques of concept scoring and concept screening are introduced before the students create prototype drawings of the AEV, so that ranking the choices is easier and more immediate.

By the end of lab 11, team k had an AEV that was able to consistently complete the full mission described in the Mission Concept Review and received a perfect score on the first run. The final design for the AEV was a sturdy and relatively cheap design, coming in at $128. Additionally, the usage of a servo motor brake allowed the vehicle to stop quickly whenever stopping was necessary and saved the team a lot of time that would've been spent attempting to create a code that reversed the motors to slow the vehicle. The lengthy design process culminated in an AEV design that led to success for team k during the final testing.

Appendix

Final Arduino Code

```
//  //**Downstairs track** Propellers Reversed
//  //Running and stopping at the first sensor
//  reverse(4);
//  motorSpeed(4,25);
//  goToAbsolutePosition(-356); //Was 390
//  brake(4);
//  rotateServo(25);
//  goFor(8);
//  rotateServo(0);
//
//  //Total Marks: 421.95 + 390 = 811.95
//
//  //Continuing after the gate is open
//  motorSpeed(4,25);
//  goToAbsolutePosition(-762); //Was 765
//  brake(4);
//  rotateServo(25);
//  goFor(4);
//  rotateServo(0);
//
//  //Run Back
//  reverse(4);
//  motorSpeed(4,45);
//  goToAbsolutePosition(-524); //was 535, 528
//  brake(4);
//  rotateServo(25);
//  goFor(8);
//  rotateServo(0);
//
//  //After the gate stop
//  motorSpeed(4,45);
//  goToAbsolutePosition(-145); //Small buffer, was 125
//  brake(4);
//  rotateServo(25);
//  goFor(6);
//  rotateServo(0);

//  //**Upstairs track** Propellers Reversed
//  //Running and stopping at the first sensor
```

```
//   reverse(4);
//   motorSpeed(4,25);
//   goToAbsolutePosition(-348); //Was 356
//   brake(4);
//   rotateServo(25);
//   goFor(8);
//   rotateServo(0);
//
//   //Total Marks: 421.95 + 390 = 811.95
//
//   //Continuing after the gate is open
//   motorSpeed(4,25);
//   goToAbsolutePosition(-758); //Was 762
//   brake(4);
//   rotateServo(25);
//   goFor(4);
//   rotateServo(0);
//
//   //Run Back
//   reverse(4);
//   motorSpeed(4,45);
//   goToAbsolutePosition(-520); //was 524
//   brake(4);
//   rotateServo(25);
//   goFor(8);
//   rotateServo(0);
//
//   //After the gate stop
//   motorSpeed(4,45);
//   goToAbsolutePosition(-155); //Small buffer, was 145
//   brake(4);
//   rotateServo(25);
//   goFor(6);
//   rotateServo(0);
```

Table 4: Puller 2510 Data

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 5: Puller 2510 Data with calculations

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 6: Puller 3030 Data

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 7: Puller 3030 data with calculations

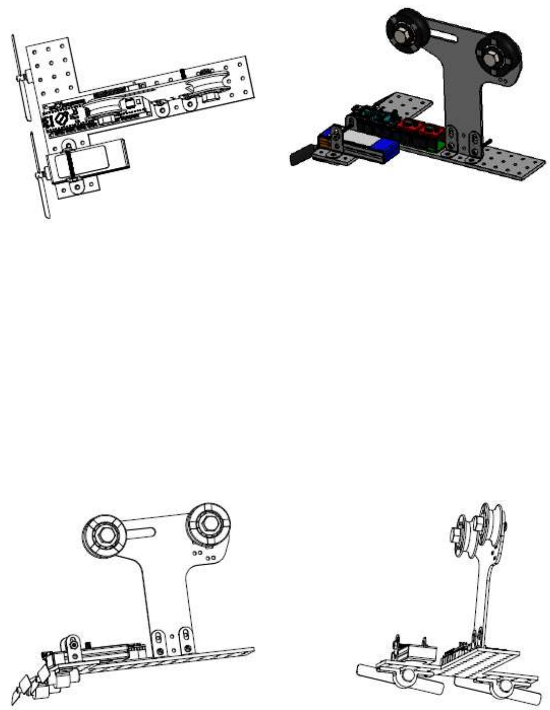
Wind Tunnel Aerodynamics Data - Puller 3030

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

Figure 14: AEV Prototype model 1

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

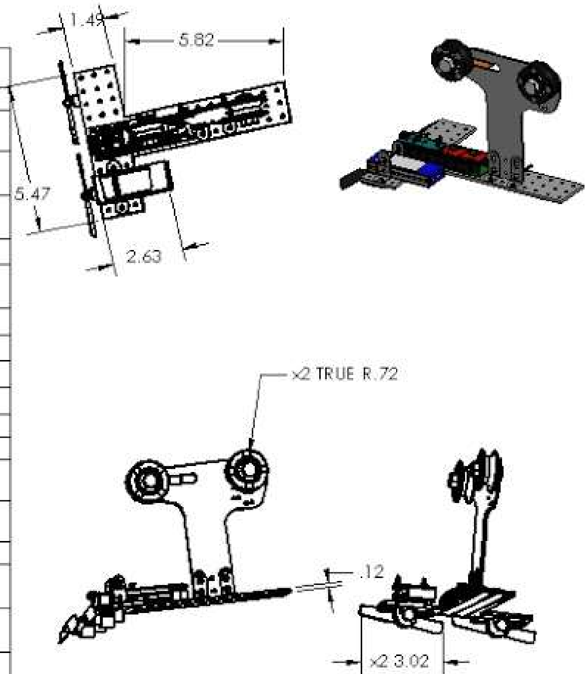
The Ohio State University First Year Engineering	Dwg. Title: Model 1	Scale: 1:2	Inst.:Dr. Phil Schlosser	Units: XXXX	Dwg. No.: XX
	Drawn By: Group K		Hour: 10:20	Seat: N/A	Date: 03/25/2017

Figure 15: AEV prototype model 2 (Final Design)

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

Figure 16: Team scoring sheet

Data Entered 7219

ADVANCED ENERGY VEHICLE — Lab 11: Performance Test 4 – Final Testing

AEV Final Testing Scoresheet

Team/Team Name: k Instructor: Dr. Phil Class Time: 10:20

This sheet must be filled out and signed by a member of the Instructional Staff by the end of Lab. The Instructor/TA must watch the AEV complete the operational objectives and will record the results below.

		Run 1			Run 2		
Procedure		Yes	No	PTS Earned	Yes	No	PTS Earned
Team shows proper testing procedure (up to 10 points)		/		/10			/10
AEV starts and travels to first gate		/		/4			/4
Gate Routine	Stops before gate	/		/4			/4
	Waits 7 seconds	/		/4			/4
	Travels through gate	/		/4			/4
AEV starts and travels to loading zone and waits for 5 seconds		/		/4			/4
AEV connects to cargo & travels to gate (crashes into cargo-deduct <= 2)		/		/4			/4
Gate Routine	Stops before gate	/		/4			/4
	Waits 7 seconds	/		/4			/4
	Travels through gate	/		/4			/4
AEV starts and travels to starting point		/		/4			/4
Total Points Earned				80 /50			/50
Total Score = Total Pts Earned * Δt					Max Total Score		

Track Layout: ____________
(Inside or Outside)

Mass of AEV: ~~0.2769~~ 0.256
(in kilograms)

Total Energy: 302.826
(Joules)

Total Time Run1: 89.76
(seconds)

Total Time Run2: ________
(seconds)

Delta Time Run 1:

$$\Delta t1 = 1 + \frac{150 - \text{total time}}{150}$$

= ____________

Delta Time Run 2:

$$\Delta t2 = 1 + \frac{150 - \text{total time}}{150}$$

= ____________

Energy/Mass: ~~1164.87~~ 1183.07
(Joules per kilogram)

Your final score will be based on the **Energy/Mass ratio** (how efficient is the team's AEV) and the **Total Score** (time and distance requirements).

Instructor / TA Signature: Clinton Date: 4/10/2017

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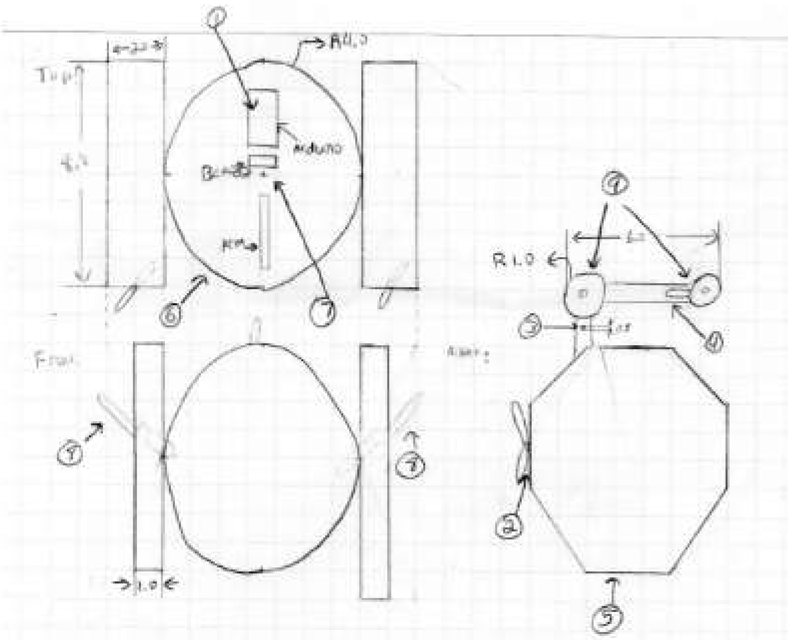
Table 8: Team Schedule

No.	Task	Start	Finish	Due Date	Gonzalo Diago	Khalid Musa	Trevor McDowell	Ryan Born	Percent Finished
1	Lab 1	17-January	17-January	N/A	x	x	x	x	100%
2	Progress Report 2	17 - January	23 - January	24 - January	x	x	x	x	100%
3	Lab 2	24-January	24 - January	N/A	x	x	x	x	100%
4	Progress Report 3	24-January	30 - January	31 - January	x	x	x	x	100%
5	Lab 3	31-January	31 - January	N/A	x	x	x	x	100%
6	Progress Report 4	31 - January	6 - February	7 - February	x	x	x	x	100%
7	Lab 4	7 - February	7 - February	N/A	x	x	x	x	100%
8	Progress Report 5	7 - February	13 - February	14 - February	x	x	x	x	100%
9	Lab 5	14 - February	14 - February	N/A	x	x	x	x	100%
10	Progress Report 6	14 - February	20 - February	21 - February	x	x	x	x	100%
11	Lab 6	21 - February	21 - February	N/A	x	x	x	x	100%
12	Lab 7 Executive Summary	21 - February	27 - February	28 - February	x	x	x	x	100%
13	Lab 7	28 - February	28 - February	N/A	x	x	x	x	100%
14	Progress Report 8	28 - February	5 - March	10 - March	x	x	x	x	100%
15	Lab 8	10 - March	21 - March	N/A	x	x	x	x	100%
16	Lab 9	24 - March	31 - March	N/A	x	x	x	x	100%

17	PDR	24 - March	26 - March	27 - March	x	x	x	x	100%
18	Lab 10	3 - April	7 - April	7 - April	x	x	x	x	100%
19	Progress Report 11	3 - April	8 - April	10 - April	x	x	x	x	100%
20	Final Test	10 - April	10 - April	14 - April	x	x	x	x	100%
21	CDR	10 - April	19 - April	20 - April	x	x	x	x	100%



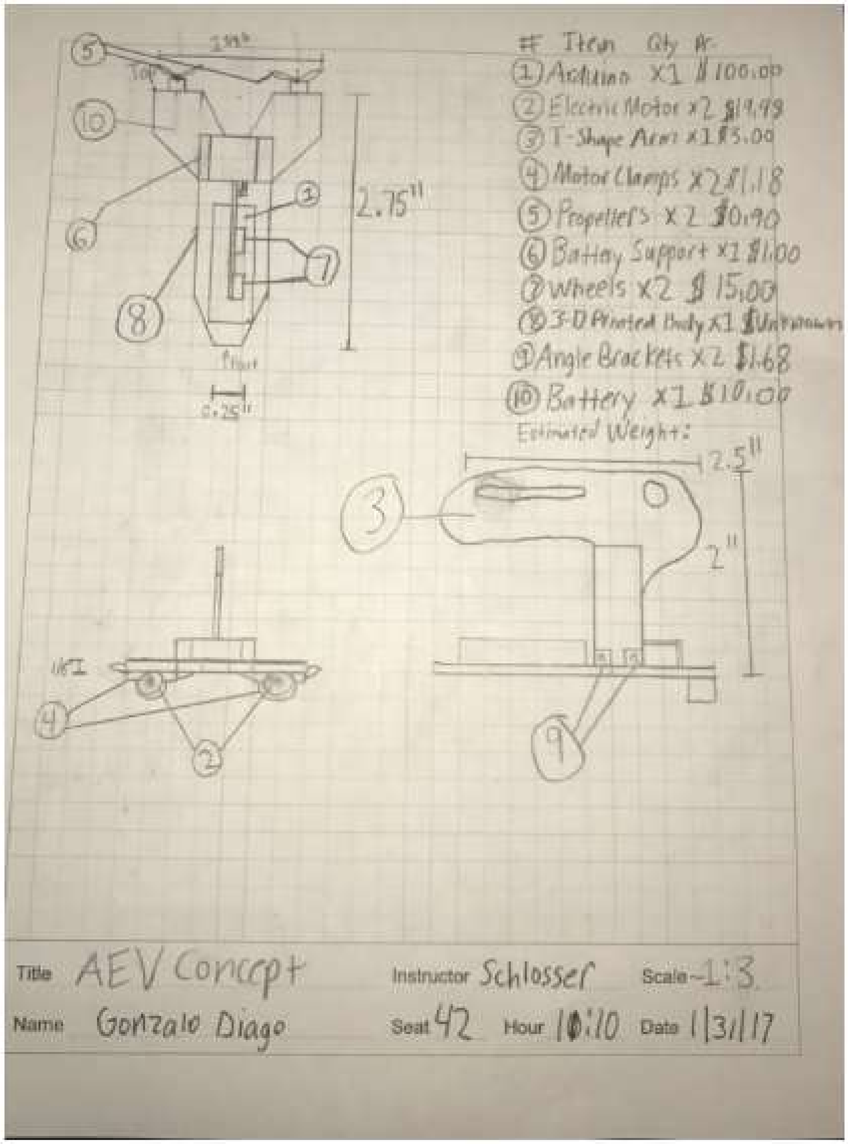
Part List:

1	Arduino	x1	$100.00	
2	Electric motors	x2	$19.99	
3	Count Sensors	x2	$0.20	Est. weight: 4 lbs
4	L-Shape Arm	x1	$1.00	
5	Hexagon Wings	x2	$ unknown (3D Print)	
6	Sphere (half)	x2	$ unknown (3D Print)	
7	Battery	x1	$5.00	
8	Propellers	x2	$0.90	
9	Wheels	x2	$15.00	
10	Screws	x14	$3.00	

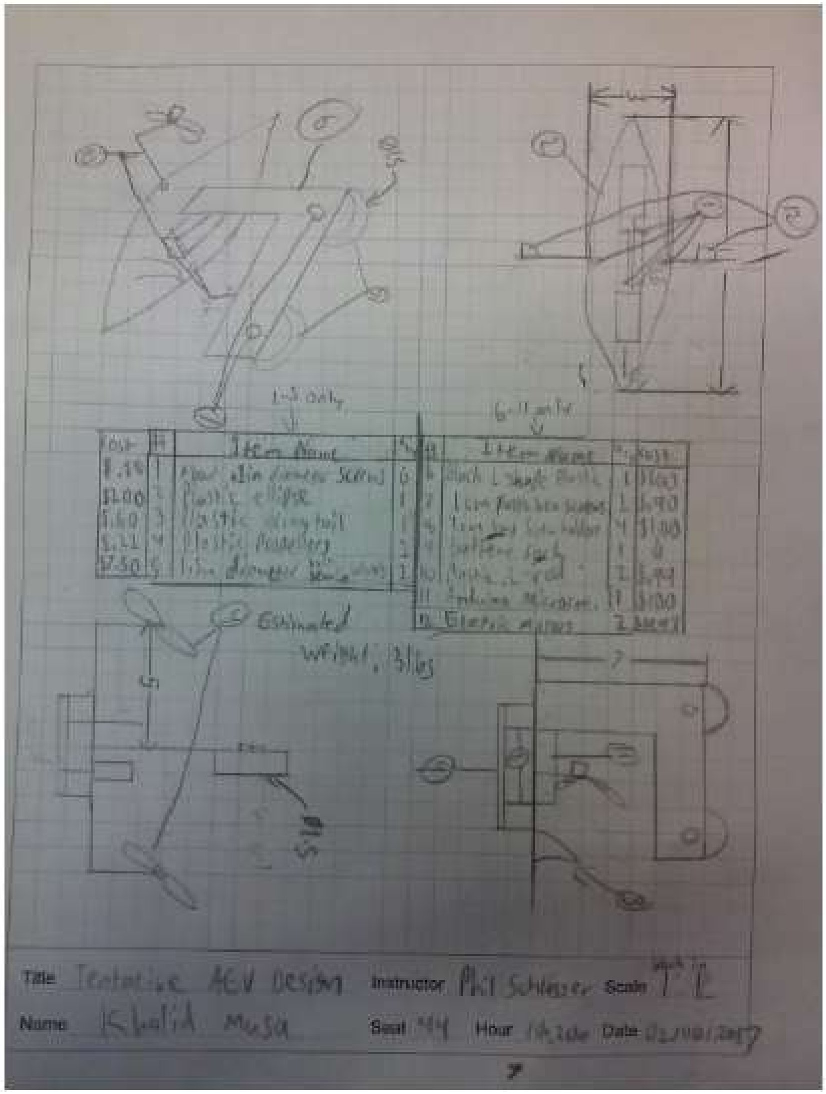
Title Brainstorm Design Instructor Schlosser Scale 1 inch

Name Trevor McDowell Seat 47 Hour 11:10 Date 1/3/18

Design 2: Gonzalo Diago



Design 3: Khalid Musa


Title
Instructor
Scale
Name
Seat
Hour
Date
Tentative AEV Design
Phil Schlosser
Khalid Musa

Design 4: Ryan Born - Also voted as the team’s final design