Critical Design Review

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Engineering 1181
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Executive Summary

Throughout the semester, the team has been working on designing and optimizing an advanced energy vehicle (AEV). An AEV is a lightweight, autonomous vehicle that is designed to be as energy efficient as possible, with a minimal energy/mass ratio. Along with being as energy efficient as possible, the AEV also has to be able to consistently complete its task of bringing a load of cargo from one side of the track to the other, stopping at check in points in between. The development and research of AEV's is very important because these vehicles are designed to be used on a remote planet where power is very scarce. Due to this, no excess energy can be wasted. AEV's are not limited to remote planets where power is scarce, however. The development of these vehicles is also could also be very useful on Earth. Vehicles that use the least amount of power possible could save businesses great deals of money. These vehicles also have zero harmful emissions, so they do not harm our environment.

In order to ensure that the vehicle being designed was as energy efficient as possible, various research methods were used. Wind tunnels were used in order to find the most efficient propeller configuration. The team found that utilizing a propeller in a "puller" configuration was the most efficient. Data regarding current, voltage, position etc. was saved in the Arduino during runs was pulled and analyzed. This was done with the use of a program written in MATLAB by the team. Data from different vehicle designs, and different coding techniques were compared, and the most efficient ones were further developed. Different AEV design components, and overall design concepts, were put into tables and analyzed with concept screening and scoring techniques.

AEV designs and codes were tested/optimized in three different Performance Tests. The focus of Performance Test 1 was to test two different body designs, and carry on developing the more efficient option. The first design tested was constructed only with parts provided by the instructional staff. The second design was designed by the team, and laser cut. The second design proved to be more energy efficient, due to it being lighter than the first design. In Performance Test 2, the team developed and tested two different Arduino codes. One code used low power percentage that was sustained over a longer distance. The second code tested used high bursts of energy that were sustained for a short distance. Lab results show that short bursts use roughly half of the power than a lower power percentage that is sustained longer. During Performance Test 3, our code was further optimized to ensure that it would use the least amount of energy possible. This was done by coasting into the cargo, without using thrust from propellers to stop. Power percentages were also increased, while decreasing the time that they were sustained. All of these factors ultimately led to a highly efficient vehicle.

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Introduction

The overall purpose of this project was to introduce the team to the design process and to using problem solving methods. This project used individual lab days and lab series to help the team complete the mission. Every lab the team gained new information that would help the team complete the mission on time. Each lab had a special role in the final AEV design and code. The team used problem solving skills to figure out a way to make the AEV as efficient as possible. Performance Tests 1, 2 , and 3 all built on each other to help guide the team to complete the AEV and code. Performance Test 1 had the team construct two different AEV designs and test these designs with the same code to find the most efficient design. This Performance Test had the team utilize the design process skills acquired in previous labs. Performance Test 2 had the team use the better design from Performance Test 1 and create two different codes to complete the mission. The code that was more efficient, as well as more consistent, was considered over the latter code. Finally, Performance Test 3 was to take the AEV and code from the previous two Performance Tests and optimize the energy efficiency of both. All of these Performance Tests led the team to the ultimate product for the final testing. The purpose of the final testing was to give the team and compare the efficiency of the team's final AEV's two attempts to complete the mission, as well as compare individual run results with other teams in the class.

The group was given the mission to transport R2D2 units. After the collapse of the the Death Star, the galactic empire was rebuilding the empire's army. The rebel alliance had to rebuild the alliance's military on isolated planets to be sure that the galactic empire would not notice. The power was very limited on these distant planets. The transportation system that was given to the team to use was a monorail system to move the R2D2 units. The R2D2 units were constructed on one half of the planet, and the units had to be carried to the other side where the interceptor aircrafts were being built [1]. With scarce power the rebel alliance was in need of an energy efficient vehicle to save all power possible to transport the units.

Experimental Methodology

In the Advanced Energy vehicle labs, the team tested several designs and multiple variations of the arduino code to complete the mission stated in the Mission Concept Review. The first series of labs, weeks 1-6, consisted of the team becoming familiar with the equipment and gathering data to aid the design process. Weeks 8-11 were then used for performance testing, where the team ran test runs and collected data from the runs to improve the design and code of the AEV.

To control the behavior of the vehicle, the arduino coding program was used. Lab 1 was used for the team to become familiar with the arduino commands. A program of these commands was uploaded to the Arduino Board, which executes the code. The Arduino Board also stores information from each run, known as EEPROM data (Electrically Erasable Programmable Read-Only Memory), that can be extracted and used for data analysis. The Arduino Board is shown below in Figure 1.

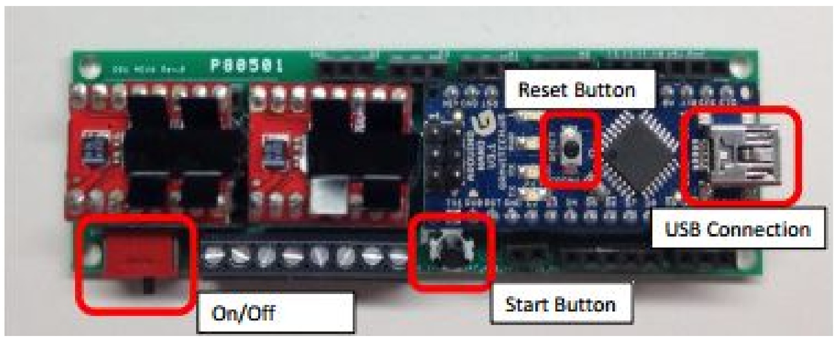

Figure 1: Arduino Board

In lab 2a, two team members implemented the reflectance sensors to complete some simple tasks with the vehicle. The reflectance sensors count the number of wheel rotations by sensing how many times the reflecting tape on the wheel passes by, in order to keep track of the distance traveled by the vehicle. Each sensor count, referred to as a mark, represented 0.4875 inches traveled on the track. The reflectance sensors are shown in figure 2 below.

Figure 2: Reflectance Sensor (Left) and reflected taped wheel(Right)

In lab 2b, the other two team members tested propeller types in a wind tunnel to calculate the propulsion efficiency and advance ratio of the propellers. The propeller was connected to an electric motor and positioned inside the wind tunnel. The data recorded was the RPM and power output of the propellers, and the wind velocity. This data, recorded with different amounts of supplied power to the wind tunnel, was used to calculate the propulsion efficiency and advance ratio, and helped the team make decisions on what propeller configuration to use for the AEV.

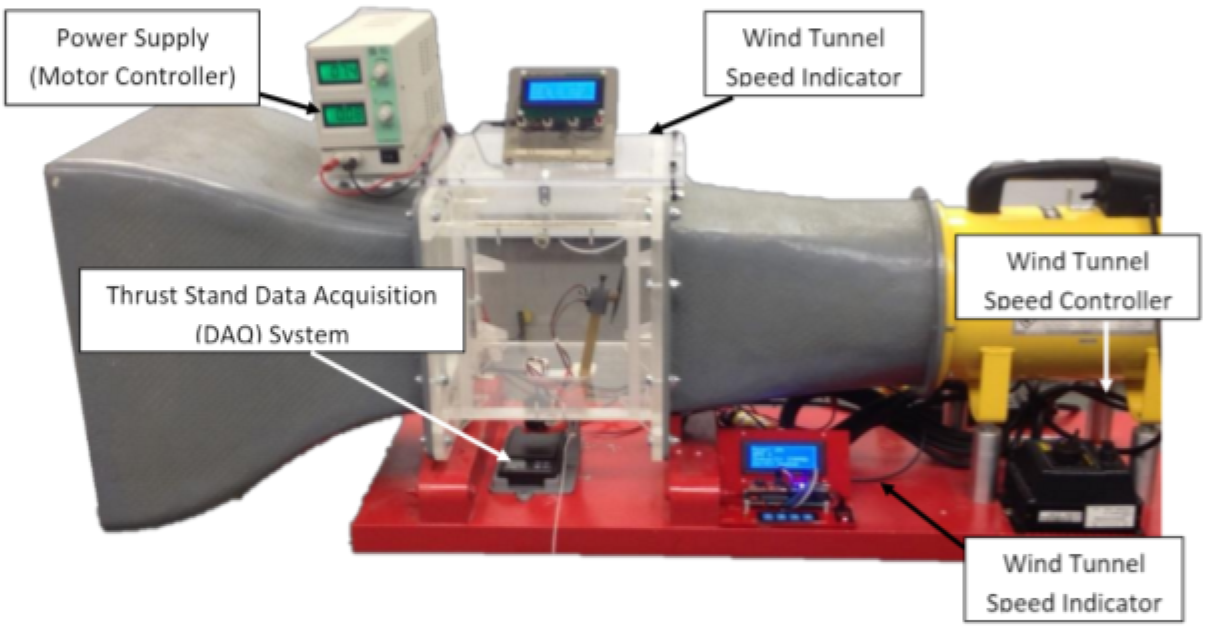

Figure 3: Wind Tunnel Equipment

Weeks 3-5 consisted of the essential labs for coming up with vehicle prototypes. In lab 3, each team member created a concept sketch of a potential AEV design. Later on in lab 5, the team created a screening and scoring matrix to logically decide which designs to move forward with and take ideas from. To do so, the team discussed which criteria was most important to the success of the project, and rated each concept sketch based on how each met the criteria. Lab 4 entailed creating a MatLab program that could take the EEPROM data from the Arduino nano and convert it to physical parameters for analysis of the data. The program output includes the energy used on the last run, and a graph of energy vs. time, both of which aided decision making in the design process.

The next steps toward completion of the AEV project were the performance tests. There were four performance tests; design, code, efficiency, and final testing. In Performance Test 1, the design test, two different vehicle prototypes were tested using the same code for each. The behavior of each design and efficiency data recorded from this test were used to make the decision of which design to move forward with. During Performance Test 2, the code test, the chosen vehicle design was tested using two different codes. Once again, the behavior and efficiency data, this time of the code, were used to aid in the decision of which variation of the code to move forward with. Performance Test 3 was used to make any extra design or code changes in order to maximize efficiency. Performance Test 4 was the final testing, where the team had two opportunities to perform a full run, completing all the criteria in the Mission Concept Review, in front of the instructors. The time and efficiency from these two runs were the final and official data for the AEV project.

Results

From lab 2b results, the team gathered that the most efficient propeller configuration was the 3030 puller. This information influenced the propeller configuration in the team's prototype and final designs. In Table 1 below, the results from this lab are shown. As was expected, as the wind tunnel power supply increased, the RPM and thrust scale readings increased as well.

Table 1 - Lab 2b Data Entry

Current	Thrust Scale Reading	RPM	Arduino Power Setting
amps	*grams*	*RPM*	*%*
0.16	9.6	0	0
0.29	12.4	1377	10
0.39	16	2155	15
0.51	20.3	2814	20
0.6	29.2	3413	25
0.72	27.8	4131	30
0.82	31.3	4850	35
0.92	35.1	5508	40
1.01	37.3	6107	45
1.11	41	6766	50
1.2	43.2	7365	55
1.3	48	8023	60

From the data above, the propulsion efficiency and advance ratio can be calculated. The advance ratio is a dimensional analysis tool used by combining the three variables of velocity, rotations per minute, and propeller diameter into one singular variable. The advance ratio (J) is calculated with the formula: $J = \frac{v}{(RPM/60) * D}$ where v = the wind velocity in m/s, and D = the propeller diameter. A plot of the calculated propulsion efficiency vs. advance ratio is shown in Figure 4 below. The two variables had a strong positive correlation.

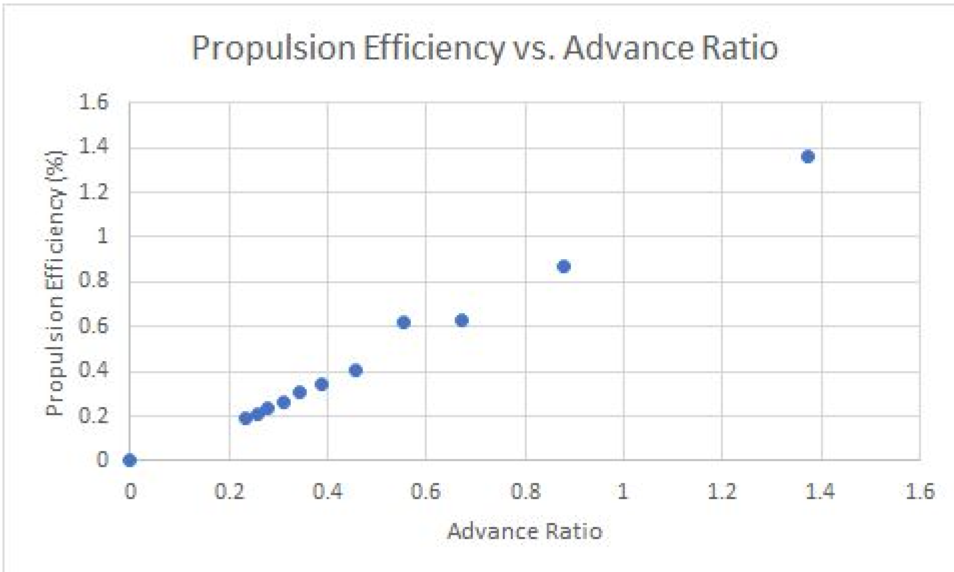

Figure 4: Propulsion Efficiency vs. Advance Ratio

In Lab 5, the team came up with the success criteria used for screening and scoring. There were five different criteria used; weight, balance, coast distance, propeller placement, and simplicity. All five criteria were weighted equally in the decision making process. The designs the team used for the following performance tests were based off these criteria. The team continued to use this criteria through Performance Test 3 to develop the final design. A representation of the final design is shown in Figure 8 in the appendix.

Though the goal of Performance Test 1 was to test two designs with the same code, the team was behind schedule at this point due to issues with the reflectance sensors. The team did not yet have a working code to get the vehicle past the first gate, so this lab was used to develop the working code further. Because the team was still behind schedule going into Performance test 2, instead of completing the goal of testing the chosen design with two separate codes the time in this lab was used to finish the working code to the point where the vehicle could complete a full run.

With a working code entering Performance Test 3, the team used this lab to test different acceleration powers and times to find the most efficient way to move the AEV. The key takeaway from this week was that a short burst of acceleration at a high power uses less energy than a slower acceleration at a lower power. Shown side-by-side in Figure 5 below are two test runs where the vehicle traveled to the first gate.

Slow Build-Up Acceleration | Short Acceleration Burst

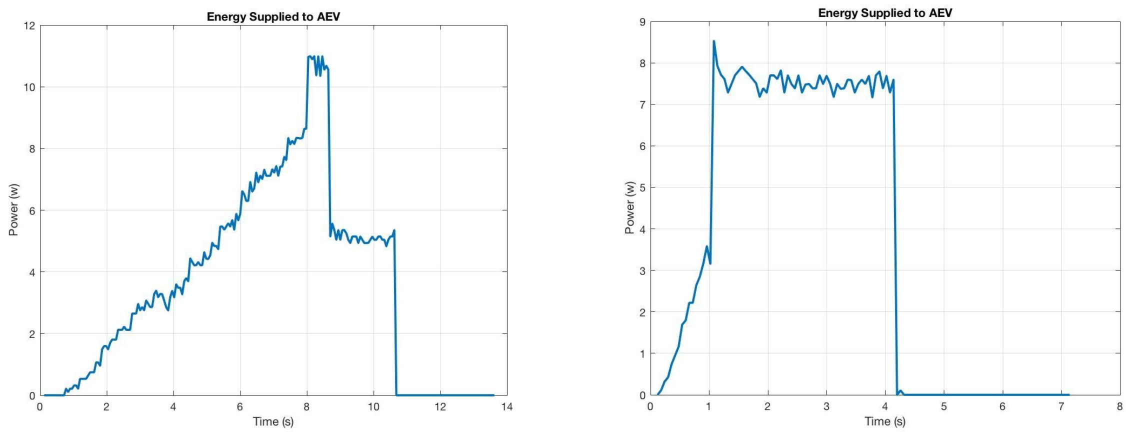

Figure 5: Slow Acceleration vs. Acceleration Burst

In Figure 5, the left graph shows the Energy vs. Time plot of a slow acceleration, while the graph on the right shows a short acceleration burst. The slow build-up used 47.4 Joules, while the short burst used 25.2 Joules. This data factored into the code used for final testing, as the team used short bursts to move the vehicle from rest to optimize efficiency.

For the final testing, the team was allowed two runs. In the first official attempt, the vehicle approached the first gate slightly faster than anticipated and bumped into the gate. This resulted in a failed run. To ensure a successful second run, a team member was stationed at the gate to tap the AEV to stop in the necessary space if needed. The vehicle on this run needed a slight tap approaching the gate for the first time as well as on the way back, to keep from hitting the gate. Other than this extra help, the vehicle performed as expected on the second official test run, which was a success. After extracting the EEPROM data from this run, it was observed that the 151.2 Joules used was slightly more efficient than the previous test runs using the same track, design, and code; all of which were within the range of 159-163 Joules.

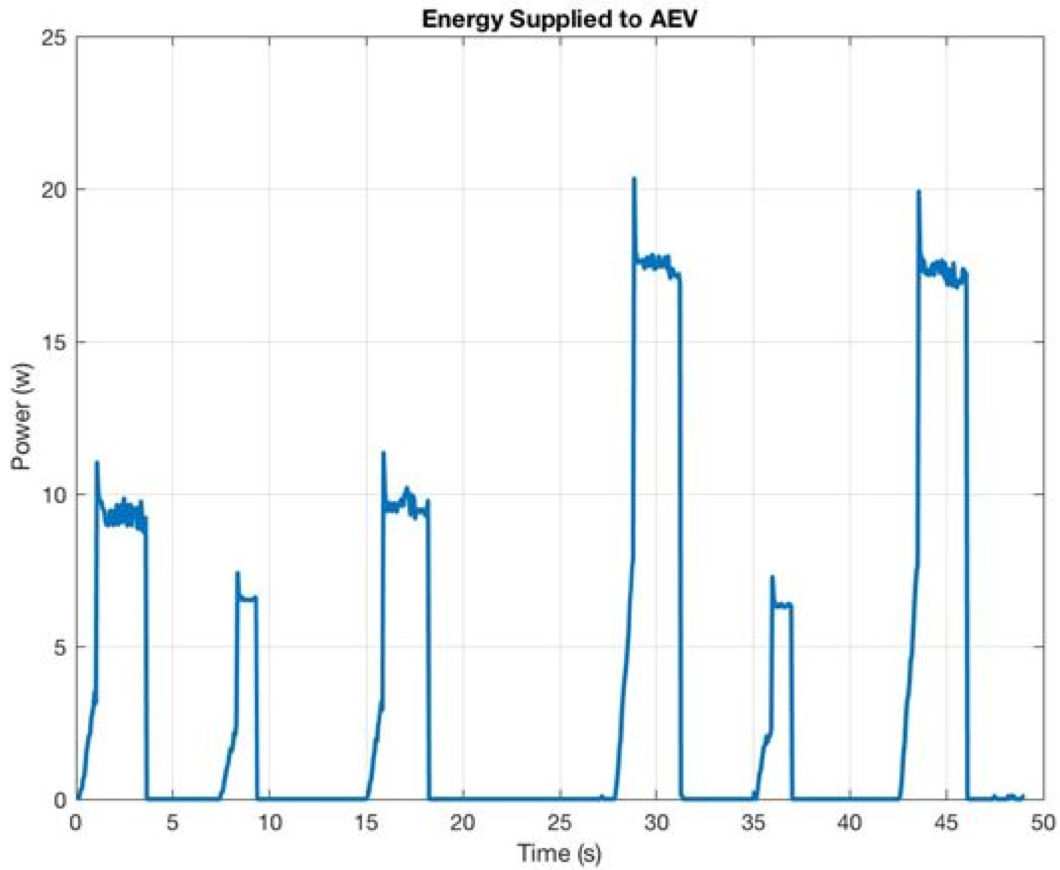

Figure 6: Supplied Power vs. Time (Final Run)

Figure 6 displays the supplied power vs. time plot of the final run. The four longest spikes in the graph represent the short acceleration bursts used to move the vehicle from rest. The two shortest spikes represent the motor brake used to attempt to stop the vehicle approaching the gate.

Discussion

In order to reduce costs, the team kept the material as thin as possible and cut out all of the unnecessary sections we could without compromising structural integrity. Most of the costs incurred were unavoidable due to the necessity of many components including both fans to maintain maximum efficiency.

As for the evolution of the project, the team started with a simple square design with the props set in a push-pull configuration. This provided the optimal prop placement for the team's push-pull configuration to propel the AEV forwards or backwards. However, too much weight was located in one spot and this hindered coasting. It was later redesigned to have low hanging chassis that maximized torque and minimized power consumption. The props were kept in the same push-pull configuration but the new body reduced the weight and the higher torque allowed for increased coasting distances. When the team conducted the screening the two options for the AEV that were compared were the chosen final design and which arm would be utilized.

	With Modded Arm	Without Modded Arm
Weight	4/5	4/5
Balance	5/5	2/5
Coast Distance	5/5	4/5
Simplicity	4/5	4/5
Propeler Placement	5/5	5/5
Total Score	22/25	19/25

Figure 7: Screening

In the final testing observations, the AEV did not behave entirely as the team had expected. Although it maximized efficiency, the runs could have been made more consistent with time.

Conclusion & Recommendations

During this experiment a vehicle was constructed to be as energy efficient as possible. The vehicle was programmed through the use of an arduino mini-controller. This vehicle was tested on a track a multitude of times in order to refine the code to produce the most energy efficient run possible. Each time the code was refined the vehicle was consistently made more efficient. During the final testing the AEV did not complete its first run, but after modification to the code the AEV completed all parts of the mission with the use of only 151.2 joules of energy. In all the AEV created by team J met all requirements set for the vehicle, it completed the mission with success while still staying as energy efficient as possible.

In conclusion to Performance Test 1 the team learned how to utilize the design process in order to design the AEV. The team cut the energy output down by utilizing the design with a longer vertical body, acquiring more torque on the wheels, and in turn more force with less power. Problem solving skills were utilized during Performance Tests 2 and 3, by designing and refining the code used to program the AEV. Improvement was also seen between Performance Test 3 and the final testing because the team utilized a high power burst of energy from the starting point to the gate, as well as from the gate to the payload. This burst of energy was more energy efficient than using low power for an extended period of time. Overall the AEV used 151.2 joules of energy, while completing the run in 47 seconds. This made for an energy to mass ratio of 703.3 joules per kilogram

Some error encountered during the lab can be accounted for by human mistake while others cannot. This was fixed by testing the AEV and finding where the human error occured in the calculation or coding. Human error from this experiment came from wrong commands being entered into the code such as power and absolute position. This was fixed by testing the AEV and finding where the human error occured in the calculation or coding. Non human error from this lab can be attributed to the nature of the reflectance sensors. The team encountered errors due to faulty sensors as well as ambient light affecting the effectiveness of the sensors. The former was solved by replacing the faulty sensors. Other errors was due to balance of the vehicle. This was solved by redistributing the weight through design and placement of components on the vehicle, as well as use of the T-shaped arm rather than the L-shaped arm.

The team would recommend a few concepts to further help the overall success of this project. The team would recommend that all classes are held in the same room to avoid error encountered by using two different tracks. The team would also recommend that the each lab series gets a scheduled lab day(1 hour 20 minute) to increase the amount of time the team has to complete the tasks at hand. The last thing that the team would recommend for this AEV project would be that all groups test on a similar length of track to better compare the results from each team.

The team completed all tasks on time except for testing two different designs in Performance Test 3 and the second code in Performance Test 2. The team ran out of time to complete both of these task because of setbacks due to reflectance sensors. The team completed the overall project with good results in efficiency and consistency of the AEV.

Appendix

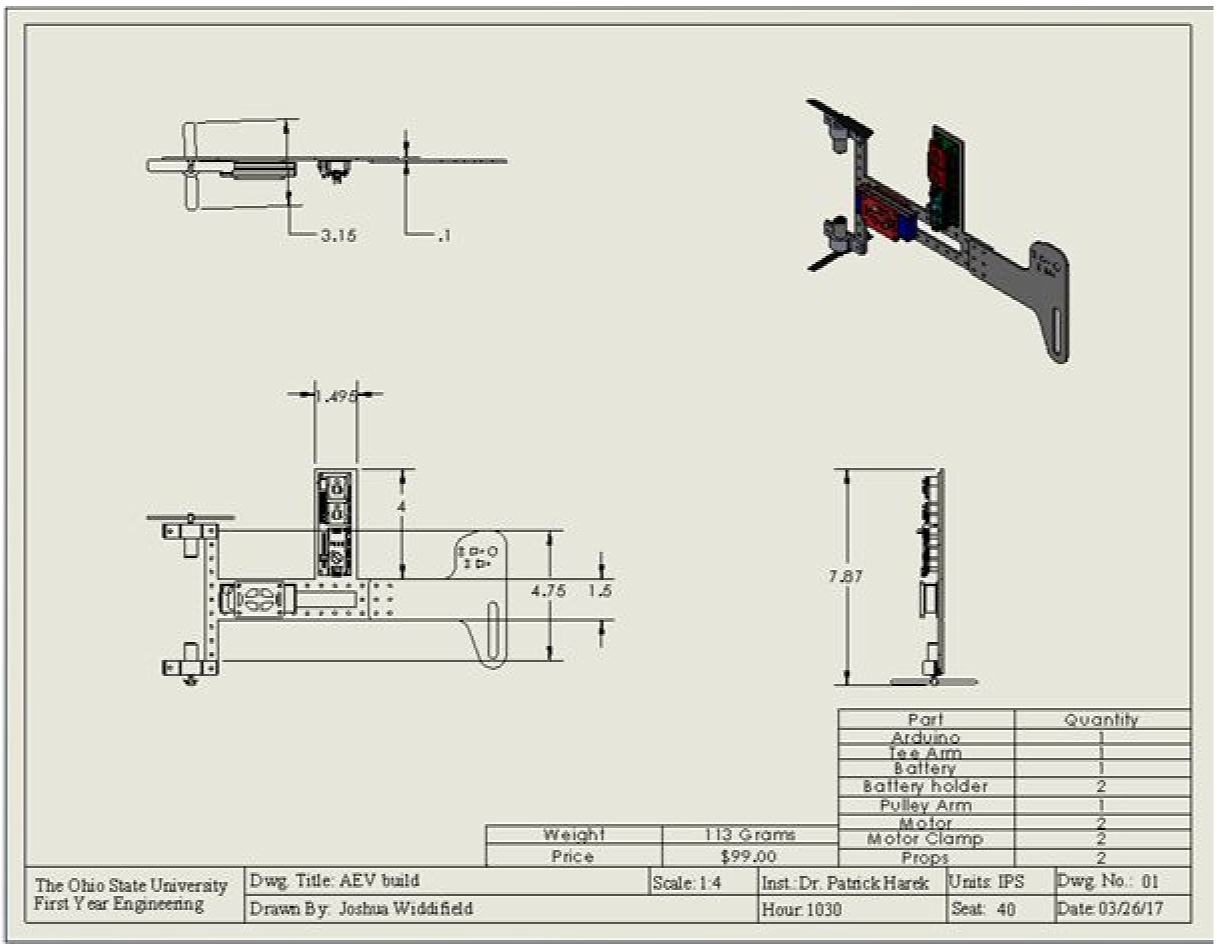

Figure 8: Three Drawing and Orthographic Views of Final Design

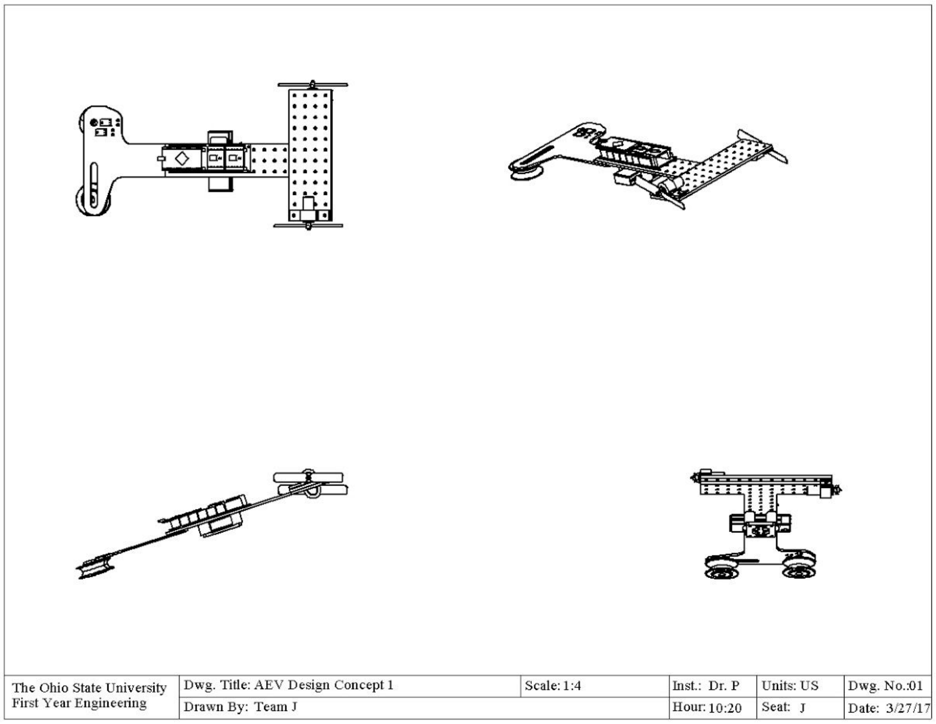

Figure 9: Three Drawing and Orthographic Views of Prototype

Team Schedule:

Task	**Teammate(s)**	**Start Date**	**Due Date**	**Time Needed**
Lab 2	All	26 Jan 2017	26 Jan 2017	2hrs
Progress Report 2	All	26 Jan 2017	2 Feb 2017	2hrs
Lab 3	All	2 Feb 2017	2 Feb 2017	1hr 20min
Progress Report 3	All	2 Feb 2017	9 Feb 2017	2hrs
Lab 4	All	9 Feb 2017	9 Feb 2017	1hr 20min
Progress Report 4	Josh and Ryan	9 Feb 2017	16 Feb 2017	2hrs
Lab 5	All	16 Feb 2017	16 Feb 2017	1hr 20min
Progress Report 5	Kenny and Zach	16 Feb 2017	23 Feb 2017	2hrs
Lab 6	All	23 Feb 2017	23 Feb 2017	1hr 20mins
Progress Report 6	All	24 Feb 2017	2 Mar 2017	2 hrs
Update Project Portfolio	All	26 Jan 2017	23 Feb 2017 (Checkpoint 1)	Indefinite

Task	Teammate(s)	Start Date	Due Date	Time Needed
Lab 7 Oral Presentation	All	23 Feb 2017	2 Mar 2017	2 hrs
Lab 8 A-C	All	9 Mar 2017	23 Mar 2017	1 hr 20 mins (each)
Lab 8 Progress Report	All	9 Mar 2017	23 Mar 2017	2 hrs
Lab 9 A-C	All	23 Mar 2017	29 Mar 2017	1 hr 20 mins (each)
Lab 9 Progress Report	All	23 Mar 2017	3 Apr 2017	2 hrs
Lab 10 A-C	All	3 Apr 2017	6 Apr 2017	1 hr 20 min (each)
Lab 10 Progress Report	All	3 Apr 2017	10 Apr 2017	2 hrs
Lab 11 A-C	All	10 Apr 2017	13 Apr 2017	1 hr 20 min (each)
Oral Presentation	All	3 Apr 2017	20 Apr 2017	2 hrs
CDR	All	3 Apr 2017	20 Apr 2017	4 hrs
Project Portfolio	All	26 Jan 2016	20 Apr 2017	Indefinite

Note: All progress reports were split up as follows

Lab Situation- Kenny McCartney
Results & Analysis- Josh Widdifield
Future Situation- Zach Mount
Team Schedule- Ryan Baker

PDR was split up as follows:

Executive Summary - Kenny McCartney
Results- Joshua Widdifield
Discussion - Ryan Baker
Conclusions & Recommendations - Zach Mount

CDR was split up as follows:

Executive Summary - Kenny McCartney
Experimental Methodology & Results - Ryan Baker
Discussion- Joshua Widdifield
Conclusion & Recommendations - Zach Mount

References:

1. Whitfield, C., West, D., & Allenstein, J. (2016, December 12). THE OHIO STATE UNIVERSITY ADVANCE ENERGY VEHICLE DESIGN PROJECT LAB MANUAL. Retrieved April 18, 2017, from https://app.box.com//embed/s/2gaj9nkdkxyhjwcntvh9ga9elwwzuurn/?view=list&sortColumn=name&sortDirection=ASC&showItemFeedActions=true&showParentPath=true