Critical Design Review

Submitted to:
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Created by:
Team P

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ENGR 1182.01
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Columbus, OH
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Abstract

This paper discusses the development of Group P’s Advanced Energy Vehicle (AEV) for the AEV project. The purpose of this project was developing a small, energy-efficient vehicle over the course of several months. The AEV design focused on minimizing energy usage while meeting design and operational constraints discussed in the Mission Concept Review for the project. This paper will discuss the methodology of testing the AEV, the development of an initial design, changes and improvements made to this design and the final AEV design. Then this paper will show that Groups P conclusions drawn from the AEV project.

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Executive Summary

The Advanced Energy Vehicle (AEV) design project focused on the design and creation of a lightweight energy-efficient vehicle which can transport cargo along a set monorail course. The goal, coming from the Mission Concept Review (MCR) of the project, was creating a lightweight energy-efficient vehicle which could successfully complete a test course in under two and a half minutes. The need for an AEV, and this project, stemmed from a need for an energy-efficient vehicle. The team was tasked to design a vehicle which could operate in a limited-energy environment. Based off this constraint, along with a mass limit of 500 grams, the team developed the AEV to meet these needs.

In preparation for designing the AEV, the team analysed the systems which made up the AEV. The two most significant of these were testing propellers in a wind tunnel, and energy usage analysis. Through wind tunnel testing, the team determined that larger propellers would be used on the AEV. The energy usage analysis provided the team with a valuable tool for analysing energy usage by the AEV which would be useful in creating the final coding solution. After these analyses, the team created an initial design which was tested over several weeks.

The AEV was tested and improved over several weeks during 3 performance tests. The first performance test, focusing on the design of the AEV, was not a focus of the team as the AEV designs were extremely similar. The team instead focused on creating an initial code. The second performance test, focused on coding, resulting in the creation of a consistent code which could complete the course. The third performance test, focused on energy usage, resulted in a decrease of energy usage, reducing from 320 Joules in the initial tests to 280 Joules in later tests.

The final design was a culmination of the knowledge gained from the performance tests. The physical design of the AEV was changed minimally while the code was heavily modified since its first iteration. The code was improved to be consistent and energy-efficient while also reducing the time needed to complete the course. Overall, the final design was much more energy-efficient and consistent than the initial design and met all the requirements stated in the MCR.

The team recommends that the AEV project incorporates more lab time for testing and development. The time allotted in class is barely enough to properly test and develop a final design. Additional time outside of class would result in better AEV designs and less stress on the design team.

Experimental Methodology

During each performance test the team was tasked with perfecting one aspect of the AEV design and tasks during four testing phases. These test were complete sequentially and helped improve on each design of the AEV.

During the first performance test the team was tasked with comparing two vehicle designs to see which to continue forward. The team only tested one design prototype since the designs' similarity would make the performance almost the same. Since the only difference between the teams AEV designs was a 3D printed V at the front, the team predicted that the performance between them would be extremely similar.

Performance test two was tasked with completing the code required to complete the mission. The team completed this testing through a trial and error process in the coding design process. At the start the team brainstormed idea on how to code the AEV to complete the mission. The team would then test the theorised code to see if it completes the tasks, if the AEV did not complete the tasks, then team would then amend the program with the viewed results to implement a new solution. For example if the AEV stopped short then the team would increase the motor speed or change the position of where the AEV stops the motors.

Figure 1: A picture of the overhead track and the gate

Performance test three was tasked with increasing the efficiency of the vehicle through any means possible. The team attacked this test through two vectors, the first was decreasing weight and the second was making improvements in the code. To decrease the weight the team tried to remove unnecessary parts from the AEV. In the team's case this could not be done as there was no unnecessary parts on the AEV. The second vector the team took to reduce energy usage was to remove or simplify unnecessary parts of the code. For example, in the code the team first developed used reverse thrust as a braking method but the team realized that they did not need to brake or speed up as much when going into the cargo area or drop off area due to the decreased precision needed in those areas.

Performance test four was task with test the vehicle to see if it completes the mission requirements. This testing was done by having a member of the instructional team to see if the AEV can complete the required tasks with or without assistance. This test is then completed twice to see if the code is repeatable or not.

Results and Discussion

Each member of the team came up with a design in Lab 4: Creative Design Thinking, the team used Concept Screening to abandon two designs with lower scores and kept comparing the two prototype AEV concepts left using Concept Scoring. The only difference between these two concepts is a 3D-printed tip of the AEV which is never printed out. The following figures and tables are the team's two prototype AEV concepts and the concept screening and concept scoring of the prototype concepts.

Figure 2. First prototype AEV concept

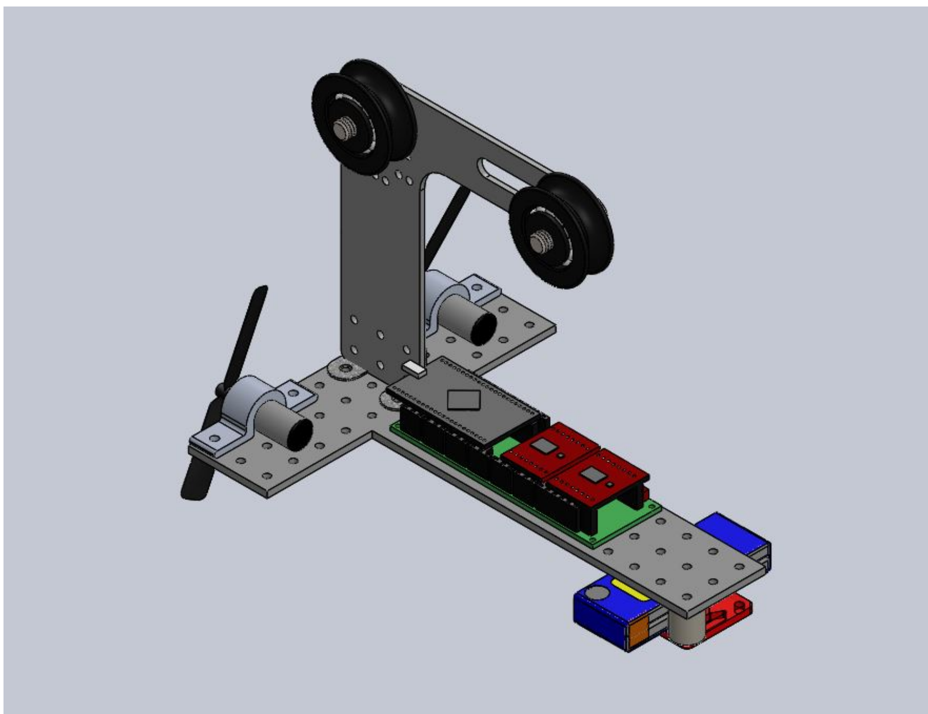


Figure 3. Second prototype AEV concept

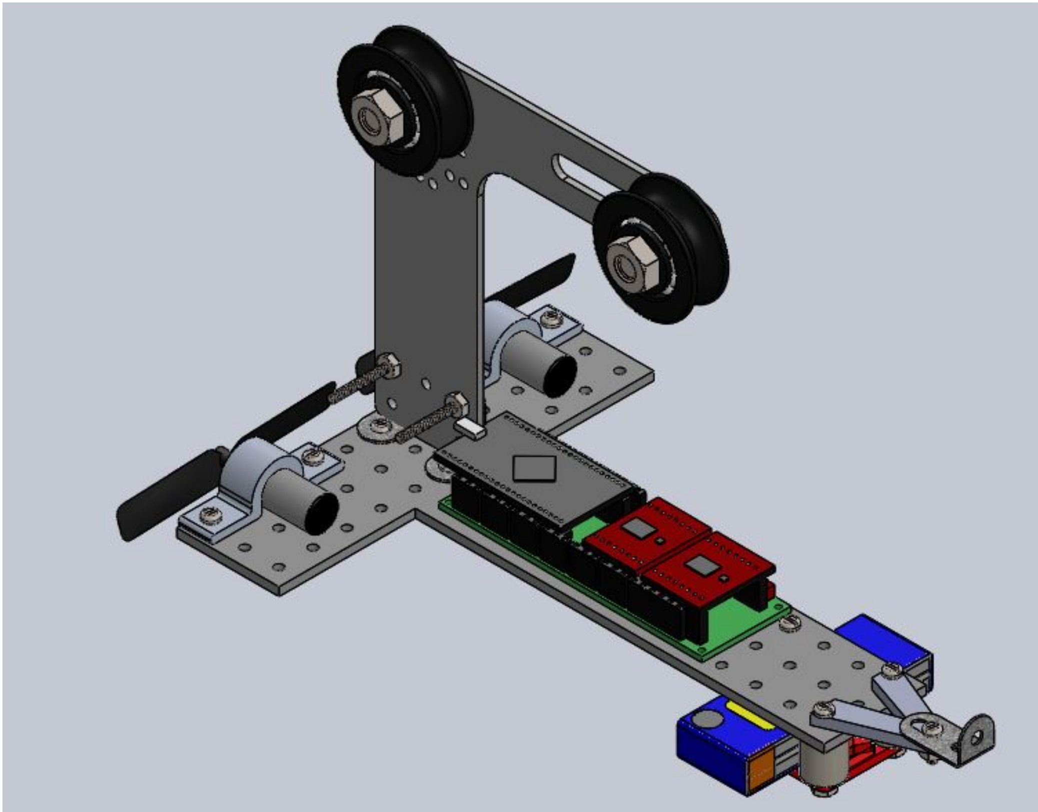


Table 1. Concept Screening of the Prototype AEV Concepts

Success Criteria	Reference	Kyle's Design (First prototype)	Jason's Design	Wenbo's Design	Ishan's Design (Second prototype)
Balanced in Turns	0	0	0	0	0
Minimal Blockage	0	+	0	0	+
Center of Gravity	0	+	0	+	+
Maintenance	0	0	0	0	0
Weight	0	+	+	-	+
Cost	0	+	-	-	+
Environmental	0	0	-	0	0
Sum +'s	0	4	1	1	4
Sum 0's	7	3	4	4	3
Sum -'s	0	0	2	2	0
Net Score	0	4	-1	-1	4
Continue?		Yes	No	No	Yes

Table 2. Concept Scoring of the Two Selected Prototype AEV Concepts

		Reference		Kyle's Design		Ishan's Design	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weight Score	Rating	Weighted Score
Balanced	15.00%	3	0.45	4	0.6	4	0.6
Minimal blockage	15.00%	3	0.45	5	0.75	5	0.75
center-of-gravit y	10.00%	3	0.3	4	0.4	4	0.4
maintenance	15.00%	3	0.45	4	0.6	4	0.6
Weight	15.00%	3	0.45	3	0.45	2	0.3
cost	20.00%	3	0.6	5	1	5	1
Environmental	10.00%	3	0.3	3	0.3	4	0.4
Total Score	100.00%		3		4.1		4.05
Continue			No		Combine		Combine

As seen from the Concept Screening, Jason's and Wenbo's design each only has one +'s but two -'s, so these two designs were filtered at the beginning. Again, because of the similarity of the other two concepts, they achieved same scores in Concept Screening. Both designs are cost effective relative to the reference, and weigh less. In addition, the two designs are symmetric from left to right and the parts are nicely placed from front to back, therefore gain points in center of gravity and minimal blockage. Finally the team used Concept Scoring to compare the two designs. Since the first design doesn't have the 3D-printed part, it gained more scores in Weight. And since the second design has a tip, it is more aerodynamic which makes it gain more scores in Environmental. However, based on the team's decision, Weight criteria is given more weight in the scoring than Environmental criteria, the team chose the design with slightly higher score, which is the first design. Then as observed in Performance Test 1 the first prototype was able to run smoothly and successfully, the team decided to abandon the second prototype design.
There are two ways to reduce the cost of the overall system, one is to reduce the cost of AEV and the other is to reduce the cost of energy.

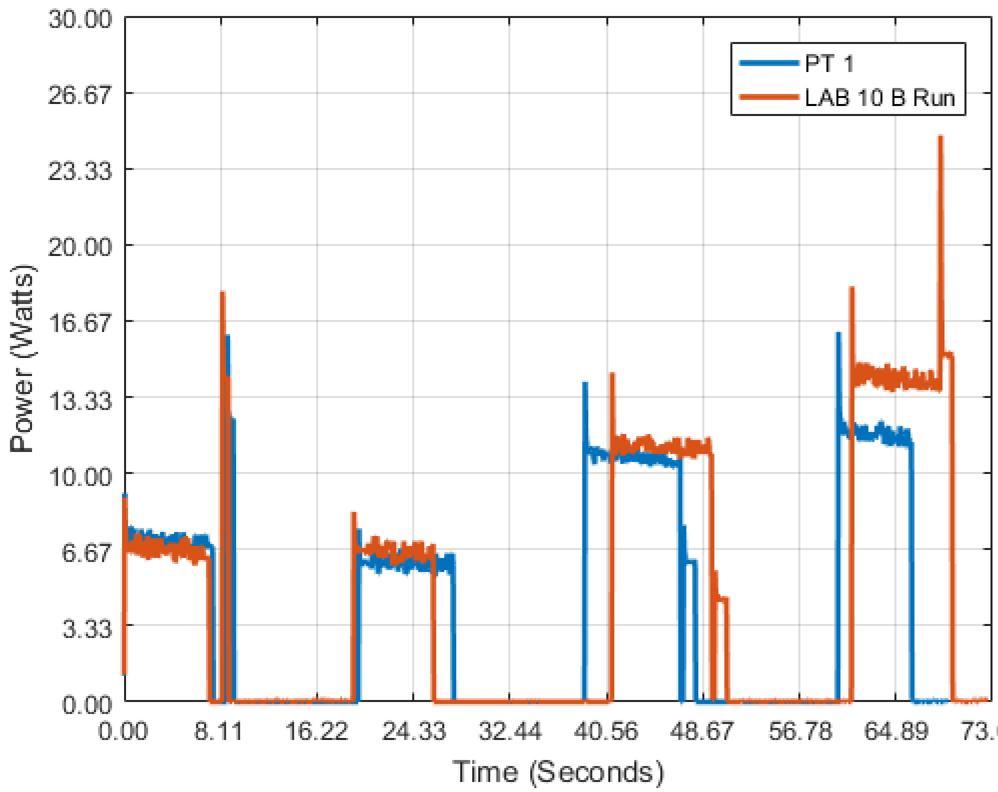
During the initial stages of the AEV development the team created an estimated total cost of the AEV of around 160 dollars. This total was done by adding up all the estimated part that were to be used in the AEV construction. Afterwards once the final design was completed the team added up all the used part to see what was used in the actual construction on the AEV. As seen in the bill of materials.

Table 3. Breakdown of AEV Unit Cost

Type	Part	Number	Cost-per unit	Total Unit Cost
Electronics	Arduino	1	100	100
Electronics	Electric Motors	2	10	20
Electronics	Sensors	2	4	8
Electronics	Propellers	2	0.45	0.9
Electronics	Sensor Connectors	2	2	4
Body	Motor Mounts	2	0.59	1.18
Body	T-Shape	1	2	2
Body	Angle Brackets	1	0.84	0.84
Body	L-Shaped Arm	1	3	3
Body	Wheeles	2	7.5	15
Body	Screws and Nuts	1	2.88	2.88
Body	Battery Supports	3	1	3
			Total Cost	160.80

To reduce the cost of the AEV the team tried to take away unnecessary parts of the AEV that did not have a specific function or task. However, due to the AEV's already simplistic design the team find no parts that deemed unnecessary. Since no parts could be removed the total above is the total per unit cost of the AEV in its current state. The light weight of the AEV resulted in reduction of both the cost and weight of the AEV. When the weight of the AEV is reduced, it makes the AEV more energy efficient. Later in Performance Test 3, the team collected data from each run and analyzed ways to make change to the code and reduce energy consumption. When the AEV approached both the cargo area and the drop-off area, it used a reverse motor command to slow down. The team decided to cut off these two commands and brake the motors earlier to make the AEV coast to the area, which reduced energy usage significantly. During this this testing the team had an managed to cause a 15% decrease in the total power used during each run. As seen in the figure below is the first code base the completed the MCR compare to the tested code base.

Figure 4: Final Test Code Compare to Performance Test Two Code

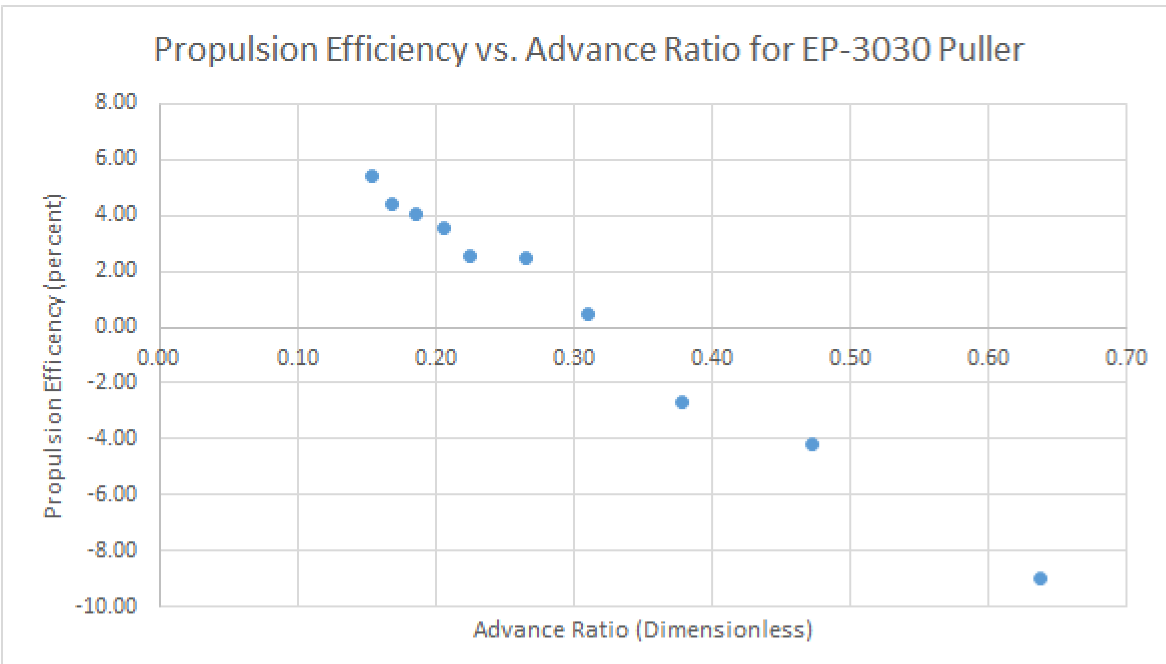


At this point, the team has completed the AEV Project Objective, Initial Concepts, and Experimental Research part of the design process. Following is the design cycle where the team use four performance tests to achieve the best design solution. In Performance Test 1, the team tested the only design since they decided to abort the idea of 3D printing. And the design was able to function successfully. In Performance Test 2, the team developed two sets of code that are mostly similar with minor differences like the way to stop the AEV at the gate. One set of the code used coasting to make the AEV stop at the gate. However, this approach is relatively inconsistent in where the AEV stops. The other set of code used a motor reverse to slow down the AEV and this stopping method is more accurate. So the team decided to adopt the set of code that uses a reverse method to brake the AEV. In Performance Test 3, the team did minor changes to the code to reduce the energy consumption. The team used to use a reverse command to slow down the AEV at the cargo area and drop-off area. Seeing that this command was redundant and cost more energy, the team took off these commands and increase the distance for the AEV to coast and managed to reduce energy consumption for dozens of joules.

Finally in the last Performance Test, the team showed the final run to the instructional team. In the final testing, the AEV was able to complete nearly all of the requirements successfully, except that it did not reach the first gate and had to be manually moved forward by a team member. The final run took 69 seconds and 273 joules of energy. The final AEV weighs 238 grams, so after calculation, the Energy-Mass ratio was 0.872 joules/gram.

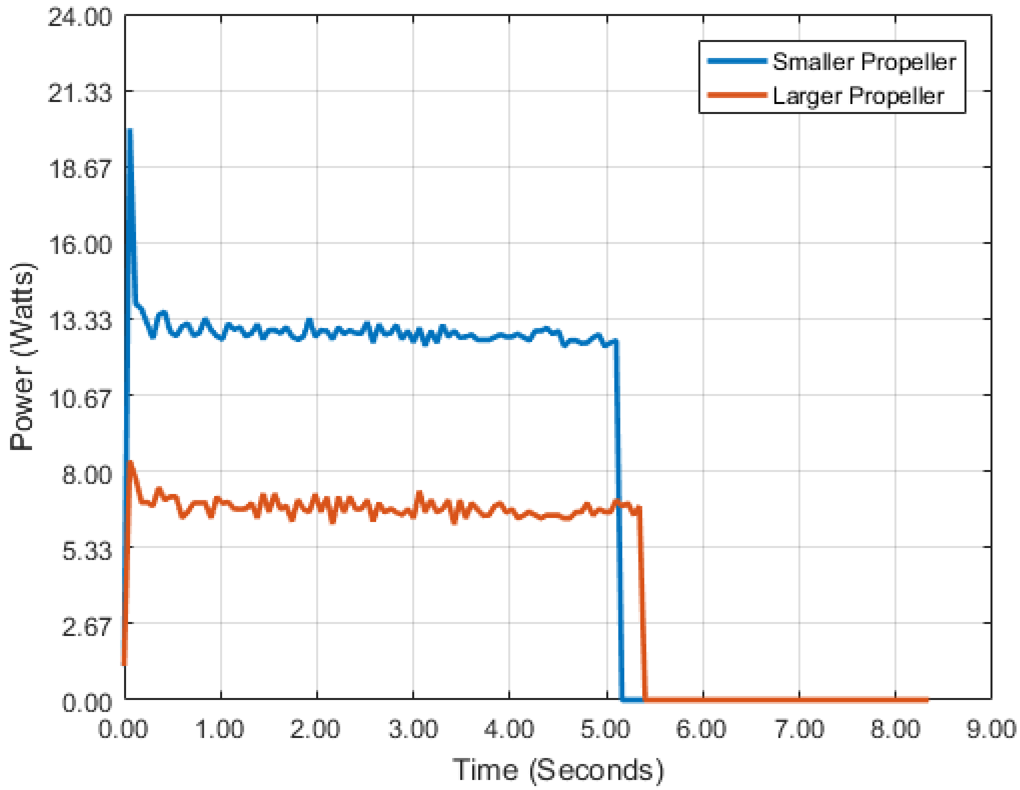
During the process to pick a propeller the team did two test to determine the most energy efficient one. This first test was running the propeller in a wind tunnel to test the advance ratio and trust. This testing was inconclusive though due to operator error during the test. As seen with the graph below the data as extremely inconsistent.

Figure 5: Propulsion Efficiency vs. Advance Ratio for EP-3030 Puller



Due to this the tested the motors in in a different manor. The team had the AEV run at a similar speed with each propeller to determine which is more efficient. This was done by having the AEV go to the same position on the straight track while keeping the AEV velocity similar. During this test, the smaller propeller used 64 joules while the larger propeller used 34 joules. As seen with the graph below, the smaller propeller used almost twice as much power as the larger one while moving the AEV at the same velocity.

Figure 6: Energy Usage of Large Propeller Compare to Smaller Propeller



This data shows that there is a statistical significant difference between the two propellers. From this data the team decided to use the larger propeller since it used less power.

Below is the phase breakdown for the final performance test run. This is the graph of the energy usage over time. This graph has each phase labeled on it.

Figure 7: Energy Usage of Final Run with Phase Breakdown

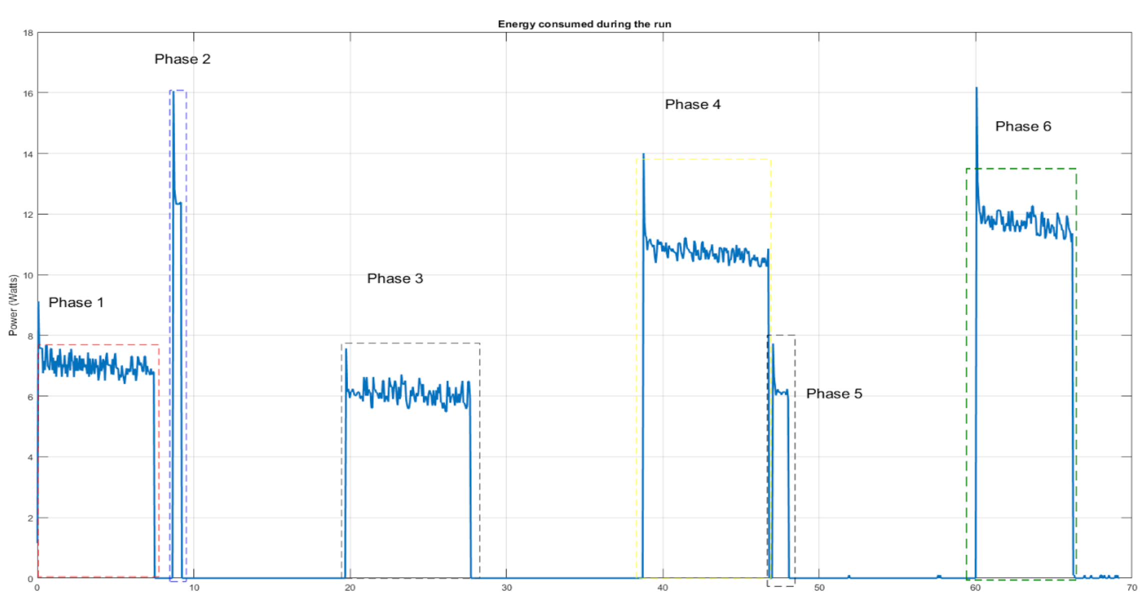


Table 4: Breakdown of each Phase Energy Usage

Phase	Arduino Code	Time (seconds)	Distance (meters)	Total Energy (Joules)
1	motorSpeed(4,25)	8.6	4.359	82.27
2	motorSpeed(4,48)	.5	.3	16.4
3	motorSpeed(4,25)	11	4.4	0
4	motorSpeed(4,42)	10	4.2	86.49
5	motorSpeed(4,26)	1.8	.6	16.37
6	motorSpeed(4,47)	6.6	2.3	72.65
			Total Energy used:	274.6

Using the phase breakdown was an important part of the team in determine how to reduce the energy usage of the vehicle. This data allowed the team to understand where large amounts of energy was being used and how to improve it.

Conclusion and Recommendation

In conclusion the Group P's AEV project was a success. The team completed all the tasks of the mission, made major improvement on the vehicle's energy usage, and designed a simple and easy-to-use AEV. As see above the team in the final tested managed to complete every task of the project during the test. This testing showed the collimation of weeks worth of testing and gradual improvements made to the AEV. These improvement were shown in the 16% overall decrease in energy usage and increased reliability in the code. The testing gave the data on the AEV design showing it's easy of use through the AEV's simplest nature. All of these improvement and design were based on fact and data gathered through repeatable experiment. Group P project was a success due to successful collection of data and the successful revisions of error the team had.

In the testing phase the team determine a large amount of important data that can be simplified down. The team found that the larger propellers are more efficient than the smaller propellers. To run the AEV at a constant speed, the smaller propellers need to spin twice as fast as the larger propellers do. This resulted in the smaller propellers requiring nearly double the amount of power as the large propeller. This lead to the next result. The team discovered that the propellers are more efficient at a lower speed than a higher speed. From these discoveries the team managed decreasing the amount of energy used by 16 percent due to changes in the main code base. This decrease was based solely on the changes to the code base and not on the propeller choice or speed the team chosen. While data collecting was important to the team, making sure the team resolved any errors in the project was also important.

During the lab sessions, the team have had several errors in the development of the AEV. First when building the AEV, the team put the the arm in the opposite direction and attached the sensor. When they first tested the AEV on the track, they realized that the AEV couldn't move forward because the arm was blocked by the track. So the team had to disassemble the sensor and the arm and put it in the right direction. The next time the team tested the AEV on the track, it ran towards the opposite direction. Without having to move the motors, the team added a reverse command at the beginning of the Arduino code to make the AEV travel to the correct direction. However, then the team found that the AEV couldn't stop at the designated spot. The team then ran the reflective sensor test to find out that one of the reflective sensor was broken and asked to change one. Continuing on, when the AEV arrived at the cargo area, the team found out that because of the weight of the battery, the front of the AEV was dragged down and resulted in the magnetic mount being too low to be attached to the magnet of the cargo. To solve the error, the team changed the position of the magnet mount from horizontal into vertical position so that it was high enough to reach the magnet of the cargo. Then when improving the Arduino code, the error was that the AEV couldn't stop at the gate consistently. Each time the team made minor changes to the Arduino code, the AEV failed to stop at the first gate in the next run. The team couldn't find a certain explanation to the phenomenon, but they came up with two possible reasons. The first being that the battery is dying each time the team ran the AEV, so that the AEV couldn't reach the percent power it was expected to in the next run, resulting in failing to stop at the gate. The second reason was that the slight swinging may also cause inconsistency because the forward momentum was distributed to the side of the AEV when it sways.

The team's AEV was not the most efficient AEV in the class, nor was it the best engineered design either. The team's AEV was suppose to be a simple and easy to operate design that allowed its user to complete the required mission with a low initial investment. In that regards the team managed to excel. The team created an AEV that can reliably complete the coded mission while having an extremely simple design. The team believes that their AEV is the simplest design for two reasons. First, it can be assembled in under 15 minutes and taken apart in under ten minutes. Second, system controls can easily be accessed on the Arduino which allows for easy troubleshooting and uploading new codes.

During the testing process the team came up with two recommendations to improve the AEV design process. The first improvement that can be made is letting more testing time be available. This allows for more ideas and concepts to be experimented and improved on. During most lab days, the team was only focused on collecting data for the weekly lab report and never experimented on anything outside of recommended bounds. The second recommendation is that the Critical Design Review and Preliminary Design Review descriptions are not entirely accurate on what needs to be accomplished. This can be seen by the rubric having parts that the description never mentions. This causes confusion about what needs to be accomplished by these documents and results in difficulty in completing the assignment.

Appendix

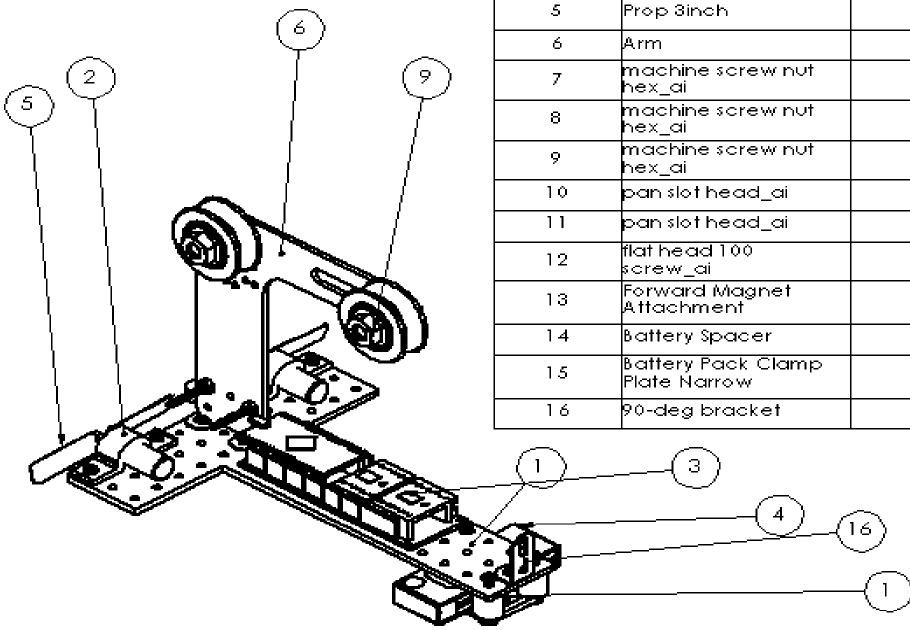
Table A1: Estimated Prototype Cost for Both Units

Type	Part	Number	Cost-per unit($)	Total Unit Cost($)
Electronics	Arduino	1	100	100
Electronics	Electric Motors	2	10	20
Electronics	Sensors	2	4	8
Electronics	Propellers	2	0.45	0.9
Electronics	Sensor Connectors	2	2	4
Body	Motor Mounts	2	0.59	1.18
Body	T-Shape	1	2	2
Body	Angle Brackets	1	0.84	0.84
Body	L-Shaped Arm	1	3	3
Body	Wheeles	2	7.5	15
Body	Screws and Nuts	1	2.88	2.88
Body	Battery Supports	3	1	3
			Total Cost	160.80

Figure A1: Figure of Dimensioned Final AEV

Figure A2: Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tee		1
2	Motor With Mount		2
3	Arduino		1
4	Battery Pack		1
5	Prop 3inch		2
6	Arm		1
7	machine screw nut hex_ai		12
8	machine screw nut hex_ai		2
9	machine screw nut hex_ai		2
10	pan slot head_ai		5
11	pan slot head_ai		8
12	flat head 100 screw_ai		2
13	Forward Magnet Attachment		1
14	Battery Spacer		3
15	Battery Pack Clamp Plate Narrow		1
16	90-deg bracket		2



The Ohio State University First Year Engineering	Dwg. Title: Prototype Two Bill of Material	Scale: 1:2	Inst.:Dr. Parris	Units: IPS	Dwg. No.: 4
	Drawn By: Group P		Hour:12:40	Seat: P	Date: 03/25/17

Table A2: Schedule for Entire Project

No.	Task	Start Date	Finish Date	Due Date	Jason Hahn	Kyle Fathauer	Ishan Taparia	Wenbo Nan	% Complete
1	AEV 1 Construction	January 20	January 26	January 27				x	100.00%
2	AEV 1 Testing	February 10	February 24	February 24	x	x	x	x	100.00%
3	AEV 2 Construction	February 14	February 17	February 17			x		100.00%
4	AEV 2 Testing	February 17	February 24	February 24	x	x	x	x	100.00%
5	SolidWorks Models	February 17	February 24	February 24	x	x			100.00%
6	Progress Reports	January 20	March 10	March 10	x	x	x	x	100.00%

PDR Tasks									
7	Presentation Worksheet	February 14	February 24	February 24	x	x	x	x	100.00%
8	Oral Presentation Draft	February 17	February 24	February 24	x	x	x	x	100.00%
9	Oral Presentation	February 24	March 3	March 3	x	x	x	x	100.00%
10	PDR	March 6	March 27	March 27	x	x	x	x	100.00%
Performance Testing									
No.	Task	Start Date	Finish Date	Due Date	Jason Hahn	Kyle Fathauer	Ishan Taparia	Wenbo Nan	% Complete
1	Develop Code	3/20	3/25	3/25	x	x	x	x	100.00%
2	Finalize Code	3/27	3/31	3/31	x	x	x	x	100.00%
3	Energy Optimization	4/3	4/7	4/7	x	x	x	x	100.00%
4	Final Testing	4/10	4/15	4/15	x	x	x	x	100.00%
CDR Task									
No.	Task	Start Date	Finish Date	Due Date	Jason Hahn	Kyle Fathauer	Ishan Taparia	Wenbo Nan	% Complete
1	Presentation Draft	3/25	4/7	4/7	x	x	x	x	100.00%
2	Presentation	3/25	4/15	4/15	x	x	x	x	100.00%
3	CDR	3/25	4/15	4/21	x	x	x	x	100.00%

Final Arduino Code

```
void myCode()
{
  //----------------------------------------------------------------------------------------
  // myCode();
  //
  // This is the tab where the programming of your vehicle operation is done.
  // Tab _00_AEV_key_words contains a compiled list of functions/subroutines used for vehicle
  // operation.
  //
  // Note:
  // (1) After running your AEV do not turn the AEV off, connect the AEV to a computer, or
  //     push the reset button on the Arduino. There is a 13 second processing period. In
  //     post processing, data is stored and battery recuperation takes place.
  // (2) Time, current, voltage, total marks, position traveled are recorded approximately
  //     every 60 milliseconds. This may vary depending on the vehicles operational tasks.
  //     It takes approximately 35-40 milliseconds for each recording. Thus when programming,
  //     code complexity may not be beneficial.
  // (3) Always comment your code. Debugging will be quicker and easier to do and will
  //     especially aid the instructional team in helping you.
  //----------------------------------------------------------------------------------------

  // Program between here------------------------------------------------------------------

  int firstGateThrust = 48;

  int secondGateThrust = 26;

  reverse(4);

  // Move forward at 25% power
  motorSpeed(4, 27);

  // Stops moving after going around curve
  goToAbsolutePosition(350);

  // Stop the motors
  brake(4);

  // Coast until near first sensors
  goToAbsolutePosition(430);

  // Run motors backwards
  reverse(4);

  // Run the motors at 55% power backwards to stop the AEV
  motorSpeed(4, firstGateThrust);

  // Run the motors for 1.5 seconds
  goFor(0.5);

  // Stop the motors
  brake(4);

  // Wait for the gate to raise
  goFor(10.5);

  // Motors back to forward
```

```
    reverse(4);

    // Motors at 25% power
    motorSpeed(4, 25);

    // Temporary goFor to test the gate stop portion
    goFor(1);

    // Go to 5ft before the cargo
    goToAbsolutePosition(830);

    // Stop motors
    brake(4);

    goFor(11);

    reverse(4);

    // Run the motors at 40% to get back to gate
    motorSpeed(4,42);

    // Run until near first sensor
    goToAbsolutePosition(665);

    // Reverse the motors for stopping procedure
    brake(4);

    goFor(0.25);

    reverse(4);

    //Short burst of motor power to stop AEV at gate sensor
    motorSpeed(4, secondGateThrust);

    // Run the motors for 2 seconds as there is more weight with the cargo
    goFor(1);

    // Stop motors
    brake(4);

    // Wait for gate to go up
    goFor(12);

    // Gets motors back in the right direction
    reverse(4);

    // Set power to 45%
    motorSpeed(4, 47);

    //Go to right before drop off area
    goToAbsolutePosition(260);

    brake(4);


    // And here-------------------------------------------------------------------------------

  } // DO NOT REMOVE. end of void myCode()
```

Matlab Code used for Phase Break Down

```
%=======================================================================
% Name: Wenbo Nan, Kyle Fathauer, Jason Hahn, Ishan Taparia
% Date: 02/14/2017
% Class: 12:40-1:35 PM  Instructor: Kadri Parris
%
% Program title: Performance Analysis
%
% Program description: The Matlab program loads the EEPROM data, converts
% it into physical parameters and plot the power consumed by the AEV during
% the run. Then the program divides the plot into three phases and
% calculate the incremental and total energy of each phase.
%=======================================================================

clc
clear all

% Load EEPROM data into Matlab workspace
load('PT1.mat');
te = a(7:280,1); % EEPROM time
ie = a(7:280,2); % EEPROM current
ve = a(7:280,3); % EEPROM voltage
marks = a(7:280,4); % EEPROM marks
pos = a(7:280,5); % EEPROM positions

% convert EEPROM data into physical parameters
t = te / 1000; % physical parameters of time
i = ie / 1024 .* 2.46 / 0.185; % physical parameters of current
v = 15 .* ve / 1024; % physical parameters of voltage
d = 0.0124 .* marks; % physical parameters of distance
s = 0.0124 .* pos; % physical parameters of position

% calculate the power consumed
p = v .* i;

% plot power vs. time
plot(t,p,'LineWidth',2)
xlabel('Time (seconds)') % add x label to the plot
ylabel('Power (Watts)') % add y label to the plot
title('Energy consumed during the run') % add title to the plot
grid on % add grid to the plot
box on % add box to the plot

% Phase 1
xR = 7.44; % Right x-coordinate
xL = 0; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P1 = p(iL:iR); % Power values of Phase 1
t1 = t(iL:iR); % Time values of Phase 1

% Compute incremental energy of Phase 1
for j = iL:iR
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 1
e1 = sum(ej(iL:iR));

% Phase 2
```

```
xR = 9.241; % Right x-coordinate
xL = 8.7; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P2 = p(iL:iR); % Power values of Phase 2
t2 = t(iL:iR); % Time values of Phase 2

% Compute incremental energy of Phase 2
for j = iL:iR
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 2
e2 = sum(ej(iL:iR));

% Phase 3
xR = 16.38; % Right x-coordinate
xL = 27.72; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P3 = p(iL:iR); % Power values of Phase 3
t3 = t(iL:iR); % Time values of Phase 3

% Compute incremental energy of Phase 3
for j = iL:iR-1
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 3
e3 = sum(ej(iL:iR-1));

% Phase 4
xR = 46.8; % Right x-coordinate
xL = 38.7; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P4 = p(iL:iR); % Power values of Phase 3
t4 = t(iL:iR); % Time values of Phase 3

% Compute incremental energy of Phase 4
for j = iL:iR-1
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 4
e4 = sum(ej(iL:iR-1));

% Phase 5
xR = 48.6; % Right x-coordinate
xL = 46.8; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P5 = p(iL:iR); % Power values of Phase 5
t5 = t(iL:iR); % Time values of Phase 5

% Compute incremental energy of Phase 5
for j = iL:iR-1
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 5
e5 = sum(ej(iL:iR-1));

% Phase 6
xR = 66.6; % Right x-coordinate
```

```
xL = 59.94; % Left x-coordinate
iL = knnsearch(t,xL); % Element index of left point
iR = knnsearch(t,xR); % Element index of right point
P6 = p(iL:iR); % Power values of Phase 6
t6 = t(iL:iR); % Time values of Phase 6

% Compute incremental energy of Phase 6
for j = iL:iR-1
ej(j) = (p(j) + p(j+1)) / 2 * (t(j+1)-t(j));
end
% Compute total energy of Phase 6
e6 = sum(ej(iL:iR-1));
```

Grading Rubric – Critical Design Review (CDR)

Instructor:____________________ GTA:____________________ Group:_____

Content

	Background		Results		Recommendation		Total
Abstract	3	Purpose Identified	4	Clear & concise	3	Direct & justified	
	2	Purpose not clear	2	Wordy and/or unclear	2	Unclear and/or weak	
	0	Poor / missing	0	Poor / missing	0	Poor / missing	___ 10

	Purpose		Background		Total
Introduction	4	Good / restated	4	Complete	
	2	Poor / copied	2	Incomplete / not specific	
	0	Missing	0	Missing	__ 8

	Procedure		Equipment		Total
Experimental Methodology	3	Could replicate experiment	3	Thorough description w/ pictures or diagram of setup	
	2	Some details missing	2	Setup unclear or equipment left out	
	1	Missing several important steps	1	Missing pictures/diagrams	
	0	Exceedingly poor	0	Exceedingly poor	___ 6

	Objectivity		Observations		Data Placement		Total
Results	2	Objective results	2	Objective observations	4	Easy to find	
	1	Some subjectivity	1	Some subjectivity	2	Some difficulty	
	0	Mostly subjective	0	Missing	0	Mostly hidden	__ 8

	Data Analysis		Tables & Figures		Total
Results	4	Logical steps / thoroughly explained	16	Good use of tables and figures	
	2	Difficult to follow or missing critical steps (i.e. sample calculations)	8	Needs more/fewer tables/figures	
	0	Exceedingly poor	0	Exceedingly poor	__ 20

Discussion	Analysis		Potential Error		
	4	Clear trends identified & relate to purpose	3	Reasonable / well justified	
	2	Trends unrelated to purpose / some missing	2	Unreasonable / poorly justified	
	0	Exceedingly poor / missing	0	Exceedingly poor / missing	__ 7
	Comparison to Theory		**Defense of Final AEV Model**		
	4	Quantitative and logical	5	Justified w/ data & theory of matrices	
	3	Qualitative or illogical	3	Justified w/o data or theory of matrices	
	2	Poor / Lacking critical details	2	Not fully reasoned / verified	
	0	Exceedingly poor / missing	0	Exceedingly poor / missing	__ 9
	Screen AND Scoring Matrices		**Observations from Final Run**		
	3	Justified w/ data & theory	3	Justified w/ data & theory	
	2	Justified w/o data or theory	2	Justified w/o data or theory	
	1	Not fully reasoned / verified	1	Not fully reasoned / verified	
	0	Exceedingly poor / missing	0	Exceedingly poor / missing	__ 6

Conclusion & Recommendations	Summary		Conclusions		Resolving Error		
	7	Summarized experiment, results, & discussion	7	Supported by data & relevant to purpose	6	Addresses error / reasonable	
	5	Summary lacking in parts or missing critical part	5	No link to results / discussion	4	Unaddressed or unreasonable	
	3	Poor / missing two parts	3	Lacking critical thinking	2	Poor / Lacking thought	
	0	Exceedingly poor / missing	0	Very poor / missing	0	Missing	__ 20
	Recommendations		**Reasons for Incompleteness**		**Format & Language**		
	7	Well thought out / reasoned	7	Justified w/ data, theory, & suitable references	6	< 2 mistakes in format < 2 mistakes in language	
	5	Not fully reasoned	5	Justified w/o data or theory or references	3	4-6 mistakes in total	
	3	Very poor	3	Not reasoned / verified	0	> 6 mistakes	
	0	Missing	0	Very poor / missing			__ 20

Appendix	Schedule		SolidWorks Models		
	18	Has completed/start/end dates, group members, percentage completed, roles, tasks, and estimated hours. Formatted Correctly	18	Has final model with bill of materials, overall dimensions, weight, cost and 3 views	
	12	Lacking a few of components from above	12	Lacking a few of components from above	
	9	Has very basic information, formatting issues	9	Missing prototype / has very basic information	
	5	Lacking or exceedingly poor	5	Exceedingly poor	
	0	Missing	0	Missing / Hand drawn	__ 36

Format & Language

Total

Content Placement	Body Content		Appendix Content		
	4	All in correct sections	4	Appropriately placed	
	2	Minor misplaced content	2	Minor misplaced content	
	0	Large sections of misplaced content	0	Too much content in appendix	__ 8

Labels & References	Labels & Placement		Referencing		
	4	All present w/descriptions & placement	4	Well referenced & described in body	
	2	Some missing or poor descriptions	2	Poor descriptions and/or references	
	0	Missing or no description	0	Missing references	__ 8

General Format	Errors		Citations		
	4	Fewer than 2 mistakes	3	Proper citations	
	2	2-5 mistakes	2	Few citation mistakes	
	0	More than 5 mistakes	0	Poor / missing citations	__ 7

Structure1	Brevity		Clarity		Flow		
	4	Concise	4	Clear	4	Smooth	
	3	Some wordy areas	3	Few parts confusing	3	Few disjointed parts	
	1	Very wordy	1	Many parts confusing	1	Many disjointed parts	
	0	Exceedingly Poor	0	Confusing overall	0	Very disjointed	__ 12

Wording	Professionalism		Tense / Person		
	5	No slang, jargon, etc.	5	No slips in tense/person	
	4	Some slips in professionalism	4	1-3 slips in tense/person	
	2	Distracting / poor	2	4-8 slips in tense/person	
	0	Exceedingly poor	0	More than 8 errors	__ 10

General	Spelling / Grammar / Punctuation		
	5	Minor errors	
	3	Few errors, but not distracting	
	1	Distracts from readability	_
	0	Complete lack of proofreading	5

Writing Total / 50

Content Total / 150

Total / 200

Instructor / GTA End-of-Lab Signoff

CDR: ___________________________________