Critical Design Report

Submitted to:
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Created by:
Team A: Rebels With a Cause

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Executive Summary

The AEV design project consisted of brief initial labs for the group to familiarize themselves with the AEV equipment and problem, followed by 4 main performance tests. The first of these tests was to test two different AEV bodies to find which elements work best to solve the MCR. The second test tested two different code body solutions for the same reason as test one. The goal of test three was to make small optimizations to both the best body from test one and the best code from test two to prepare the group for the final test. The final test produced the results that are the focus of this document and is what the final recommendations are based upon.

The model used in the final test was based on model 1 from test 1 and the code was based on code body 1 from test 2. The body was modified to have laser cut chassis in the same shape as the test one model, but removed unnecessary materials to remove weight and remove the need for brackets between parts. The code was modified to remove braking and reversing at the first trip to the gate, the trip to the caboose and the trip back to the start after the gate to reduce energy usage. This run used 231.5 J, 62.3 s and had an energy/mass ratio of .915 J/g. The group achieved third place in the class with a final weighted score of 73.66.

Based on these results and results from the previous tests the group recommends using this style of AEV to the rebellion. This model satisfies the goals of the MCR to be efficient, cheap and low maintenance. However, the group suggests more testing be done on the chosen model from test 1. Due to a calculation error, the group did not realize this model actually had a lower energy/mass ratio than the final design, and could possibly use less energy than the final design if proper optimizations were done to its code body.

Table of Contents

Introduction

The purpose of this project was to come up with design of an AEV that fulfill the requirement of environmental friendly, low cost and have maximized efficiency on the energy used as it completed a full trip around the track, pick up a the load and return to its original position while make a stop before the clearance gate on the way back and the way go. The team make sure this happen without having to assist or touch the AEV during the whole trip.

The desired result of the AEV is to design and assemble the interceptor aircraft with green, energy efficient, and cost effective system. This is important as the rebel alliance has very limited power and to ensure that this is covert operation to make sure the galatic empire is unaware of this. After a small-scale prototype of the aircraft is made, a full scale model will be used to perform this run for the upcoming war with the galatic empire.

Experimental Methodology

Performance test 1

The goal of this test was to create a body of code that would take an AEV to the first gate and stop there and then use this code on two different AEV models to The first model, seen in figure A.1, was designed to be evenly balanced to maintain stability in turns and to increase efficiency by keeping the motors far from the center so the propellers will not be blocked. The arduino was placed in the front following by the L shaped arm in the middle and the battery on the very back underside of the body. The wings were placed on each wing with the motors being in a pull configuration for the trip there and a push for the trip back.

The second design, seen in figure A.2, has the wing panels flipped vertically to bring the motors closer to the center of the AEV and also above the plane of the chassis. The arduino was placed across the chassis between the wings, with the battery at the front and the arm at the back. This AEV was designed to test different weight distributions to see if the place of the base of the arm or the part of the arm with the wheels would create better balance, and to see if better balance could be achieved by changing the position of the motors.

Propeller configuration was designed to allow optimal power efficiency during each part of the run. The data for propeller configuration was collected by the entire class using 4 wind tunnels with different propellers in different configurations. Based on this data, found in figures A.3-A.8, it was decided both models would have propellers with 30 degree pitch in a pull configuration going to the caboose to maximize efficiency since the propulsion efficiency increases linearly with advanced ratio, and a push configuration after attaching to the caboose to maximize thrust since it increases exponentially with arduino power

Performance Test 2

The goal of this lab was to take the better of the two AEV models from test 1 and test it using two different code solutions to complete a full run along the track. The group chose model 1 from the previous lab as it outperformed model 2 by using 66.71 J and traveling just passed the gate at 4.39 m compared to model 2's 68.67 J and only 1.71 m. Figure A.9 shows a plot of power usage vs. distance for these two models in test one.

The first code body solution the group went with used only time based commands and can be found in appendix B. The rationale behind using only time based commands was to eliminate the inconsistency factor of mark based commands as time commands are independent of external sensors and the ambient lighting in the room. However code using only time commands requires a lot of trial and error as a single mistake in the run means the entire run must be redone with new code as AEV does not know where it is at any point.

The second code body solution used only mark based commands and can also be found in appendix B. This code, while being vulnerable to light pollution to cause inconsistency, was designed to reduce energy usage by allowing the AEV to use its position to coast as long as possible and brake itself when needed.

Performance Test 3

The goal of this test was to optimize the chosen code from test 2 and the chosen model from test 1 by implementing smaller changes. Code solution one from test 2 was superior to solution two, using only 242.8 J and 62.7 s to complete a full run where solution 2 used 285.5 J and 68 s. Figure A.10 shows a plot of power vs. distance for both runs from test 2.

To optimize the code the group eliminated the brakes and reverse power portions as the AEV approached the gate, as it approached the caboose, and as it approached the end of the run. These sections previously resulted in large spikes to the power usage of the AEV and were able to drop the total power used significantly. Figure A.11 shows the plot of power vs. distance for each stage of optimizing code.

To optimize the model of the AEV the group opted to create a new laser cut chassis that had the same shape and dimensions as the built chassis of model 1 from test 1. This chassis would reduce weight by eliminating the need for brackets between pieces as well as having large rectangular holes in the chassis where material was not needed. Reducing the weight of the AEV would allow for cheaper construction as well as less energy consumed.

Performance Test 4

This test would be the final test the group would run and produced the data used later in this document as the results presented to the rebellion. The group spent the first 2 days of this test working on the code to create a consistent and efficient code body. During the final day of this test the group had two runs to be scored by the instructional staff, the better of which would be compared with the other groups in the class. Results and takeaways from these tests can be found in the following sections.

Results

The final AEV model can be seen as a photo in figure A.12, a solidworks assembly with bill of materials in figure A.13 and a dimensioned drawing in figure A.14. The first of the final two runs took 231.5 J and 62.3 seconds to complete, and the second run suffered a critical failure and did not complete its run. For the successful run, points were lost from the overall score as the AEV needed to be stopped by hand just before the gate both instances and also hit the caboose at a relatively high speed giving the run a score of 43 points out of 50. However, the energy/mass ratio of this run was .915 J/g, the second lowest in the class, giving the group a weighted score of 46.6 out of 50, and accounting for time the group had a final score of 73.66, which was third best in the class.

Figure A.15 shows a power vs. distance plot for the final run, the first pre-optimization run of the new chassis and model 1's run with the time based code from performance test 2.In figure A.16, a bar graph of energy used in these three runs, it is clear that as the project went on the group was successfully able to reduce the energy usage of the AEV.

Figure A.17 shows the time to complete a full run in each of the mentioned runs. From the test 2 run and the final run time is comparable at 62.7 seconds and 62.3 seconds respectively. However the pre-optimization run with the new chassis had a significantly worse time of 66.2 seconds. This is due to the decreased mass of the AEV causing problems with the code used for the test 2 run, thus after editing the code to account for the new mass the first successful run took longer. This was fixed through optimizations as the time of the final run shows.

Lastly, figure A.18 shows the energy/mass ratios of the three respective runs. The graph shows that the run from test 2 actually had a vastly superior energy/mass ratio of .883 J/g, compared to .930 J/g and .915 J/g respectively. This discrepancy is due to a miscalculation in energy/mass ratio that took place during test 3 and was not caught until after the final run. This error will be discussed more in the following section. Despite this, the group's final result was below 1 J/g and was the second lowest ratio in the class.

Discussion

The final design was based on our first model for the Preliminary Design Report (PDR), where the group decided to make it more lighter by laser cutting the chassis making it into one whole chassis. By using the laser cutting,the group cut the unnecessary material in the chassis - the three rectangular holes on the left and right wings and also the part underneath the arduino to further reduce the weight of the AEV. This chassis also save the time to assemble the AEV since it does not need any steel bracket to join the wings and the main body. However, the group forgot to account for the metal bracket that would attach to the magnet on the caboose, and thus was forced to place two L shaped brackets at the front of the AEV using the same holes as the arduino. A third flat bracket was placed in between the two brackets so that metal would be in the position of the magnet of the caboose.

Based on the previous code, the group come up the final code solution where breaking and reversing was eliminated before the AEV arrived at the gate and the before the run ends. This also lowered the energy usage at several slowdown points. The group used the momentum of the AEV to coast without using energy to have optimized energy usage with the lowest record of energy used (231.5 J) and shortest time taken (62.3s) to perform the MCR compare to our previous runs, models and codes.

The trends shown in figures A.16 and A.17 show that the group was able to improve on the AEV model and code for the final test to best satisfy the MCR. While not having a better energy/mass ratio, the new AEV uses less total energy and will be cheaper to manufacture as it uses less materials and brackets than the previous design, which were the group's and the project's main goals. Figures A.19 and A.20 show the concept screening and scoring matrices respectively, and show that in both the final AEV model scores higher than any of the previous designs and all designs that were actually tested on the track. The final design has a near identical screening as model 1 from performance test one, but has a + in maintenance as there are less brackets and construction to worry about. The final design also had a score of 3.45 in the concept scoring, putting it 0.15 higher than model 1 from performance test 1.

Error could have occurred during the final test at several points. The largest potential source of error is the wings of the laser cut chassis. Since the wings had large hollow portions in them they drooped significantly more than the assembled model 1 chassis. This could have led to less balance through turns during runs and also requiring more energy to move the same distance since the motors are no longer parallel to the chassis. Another source of error was the miscalculation of the energy/mass ratio of the model 1 AEV. The group realized this error too late into development of the code solution for the new AEV chassis and was unable to create new tests for the model 1 AEV, meaning that this AEV may actually have performed better than the laser cut chassis if the group had realized the actual energy/mass ratio and spent time optimizing code for this model.

Conclusion & Recommendations

The AEV design process started from the lab 3, Creating thinking design where each team member created orthographic drawing of the AEV. During the lab 3, the team has 5 design altogether and a best design was selected based on a screening and scoring matrices. During the performance test 1, the group's prototypes are basically based on the selected best design. Both of the prototypes can be seen in the figure A.1 and figure A.2 in the appendix A.The screening process showed that both of these prototypes have the same net score. In order to determine the best model, the two prototype designs were built and tested on the track with same coding to determine which model was more efficient. It appeared that model 1 was efficient than model 2. It travelled further and used less energy than model 2. Model 1 was chosen and the code for the full run was written for this model. In order to make the AEV more efficient, the team produced a new chassis with an idea that probably would reduce the total weight of the AEV. The final product of the AEV can be seen in the figure A.12 in appendix A. Throughout the whole process in the performance test lab, most of the time, the team modified the coding in order to produce the most efficient AEV. Finally, the team run the AEV on the track for the final testing and competed against the other team's design. On the final run, the AEV successfully managed to finish the first run.

The Team has the best AEV design than the rest of the class. The team is the only team using one whole chassis with some holes that helped to reduce the excessive weight.A lighter body weight allows for less required energy. This amazing design also caused it to perform better in any other ways such as good balancing during turns at the curves and less time consuming to assembly the AEV. Although the AEV run inconsistently, it was largely because of the coding and other factors.

The AEV project could be improved by giving teams the opportunity to test the AEV outside of class time. This is because, during the class time, about half of the class time is used to wait in line to test the AEV. The entire project would move faster if there is a way for the teams to work outside of the class. Another thing that could be improvise is the condition of the track for both lab. Both of the track should have good condition in terms of the lighting of the track, the departure gate of the AEV and the track.

Error from the lab could have been resolved by attaching additional supports to the wings to cause them to droop less and make the thrust more consistent. Also, calculations could have been checked more thoroughly to avoid simple mathematical errors and allow the group to work with the most efficient AEV design

Appendix A - Figure and Tables

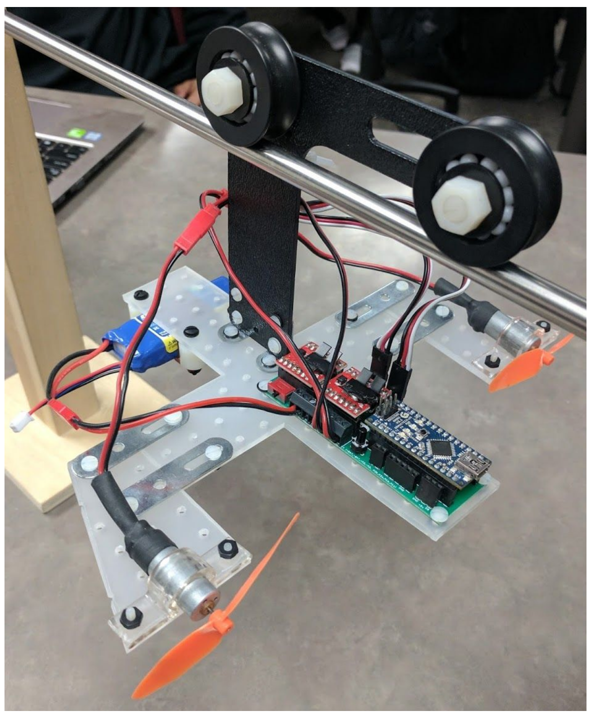


Figure A.1: AEV model 1

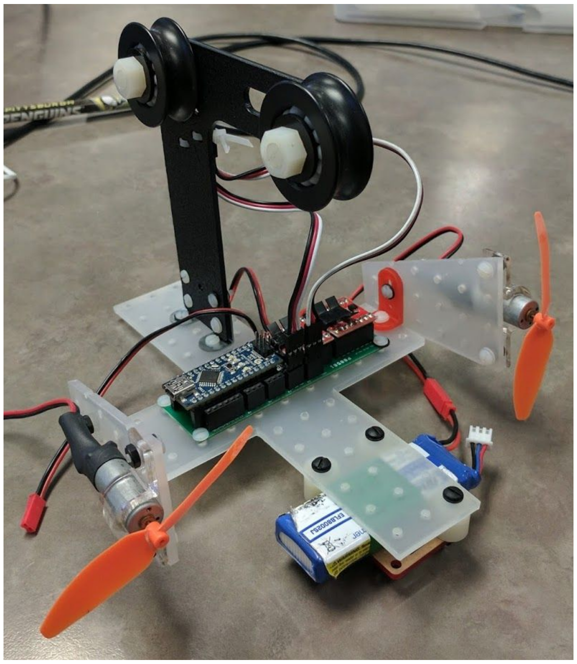


Figure A.2: AEV model 2

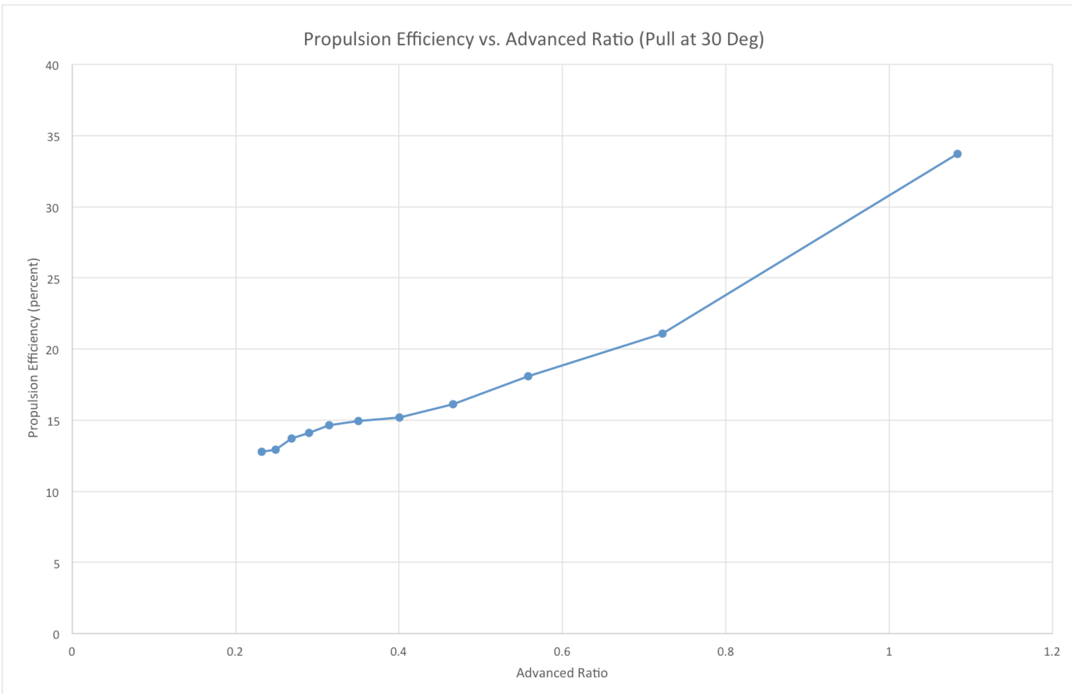


Figure A.3: Propulsion Efficiency vs. Advance Ratio of a pull configuration at 30 degree pitch.

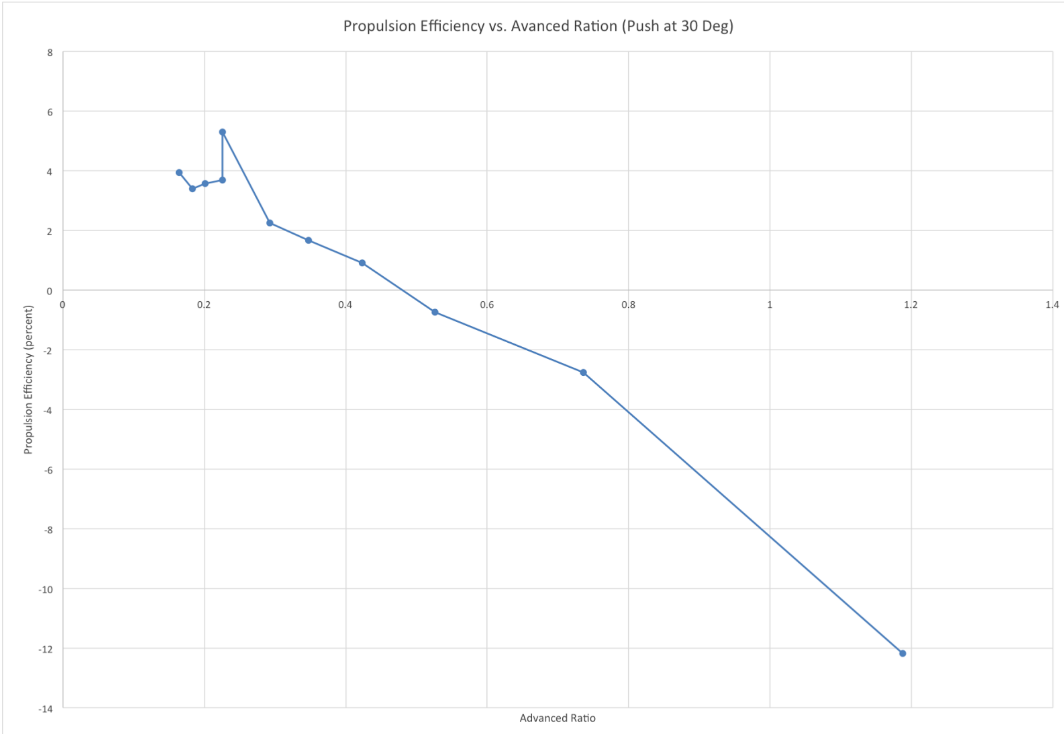


Figure A.4: Propulsion Efficiency vs. Advance Ratio of a pushl configuration at 30 degree pitch.

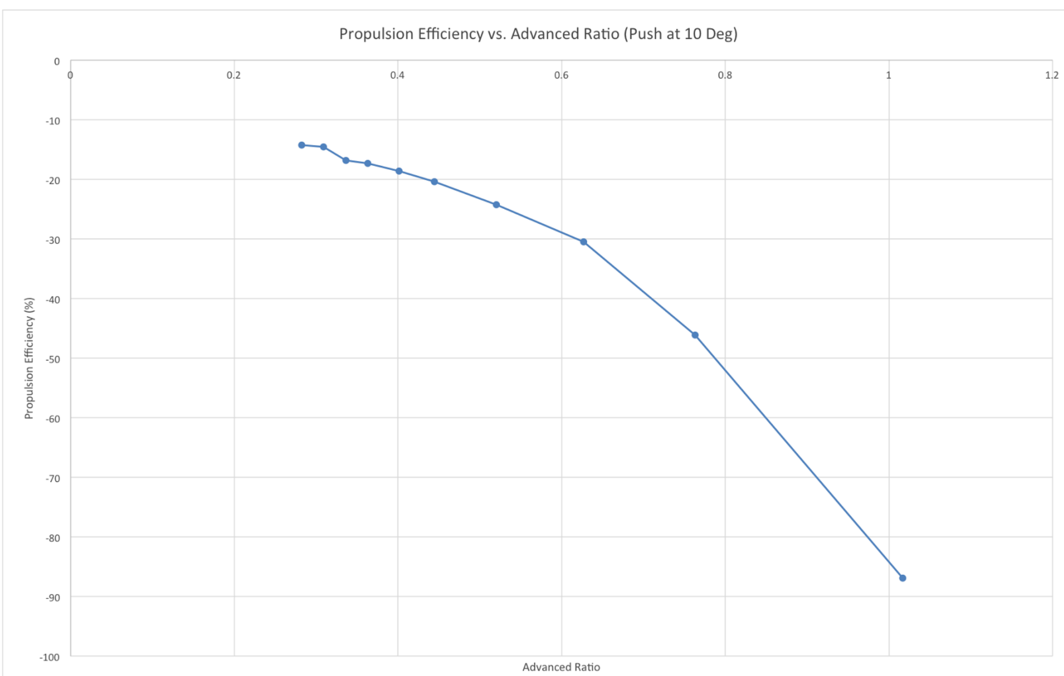


Figure A.5: Propulsion Efficiency vs. Advance Ratio of a push configuration at 10 degree pitch.

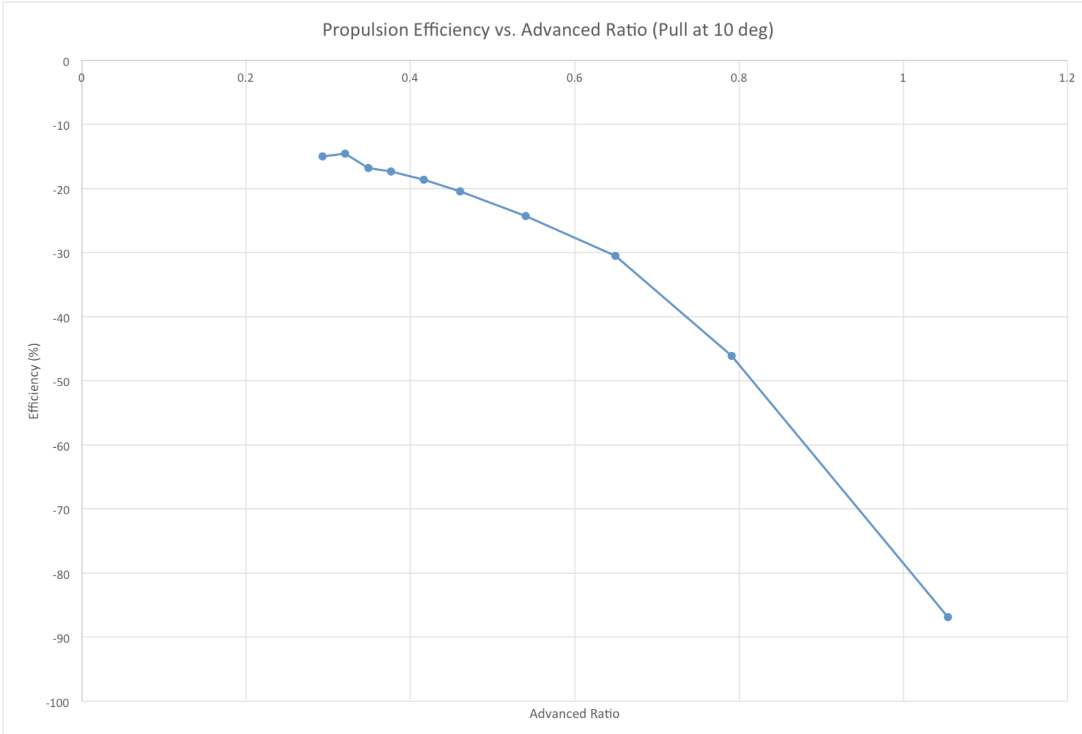


Figure A.6: Propulsion Efficiency vs. Advance Ratio of a pull configuration at 10 degree pitch.

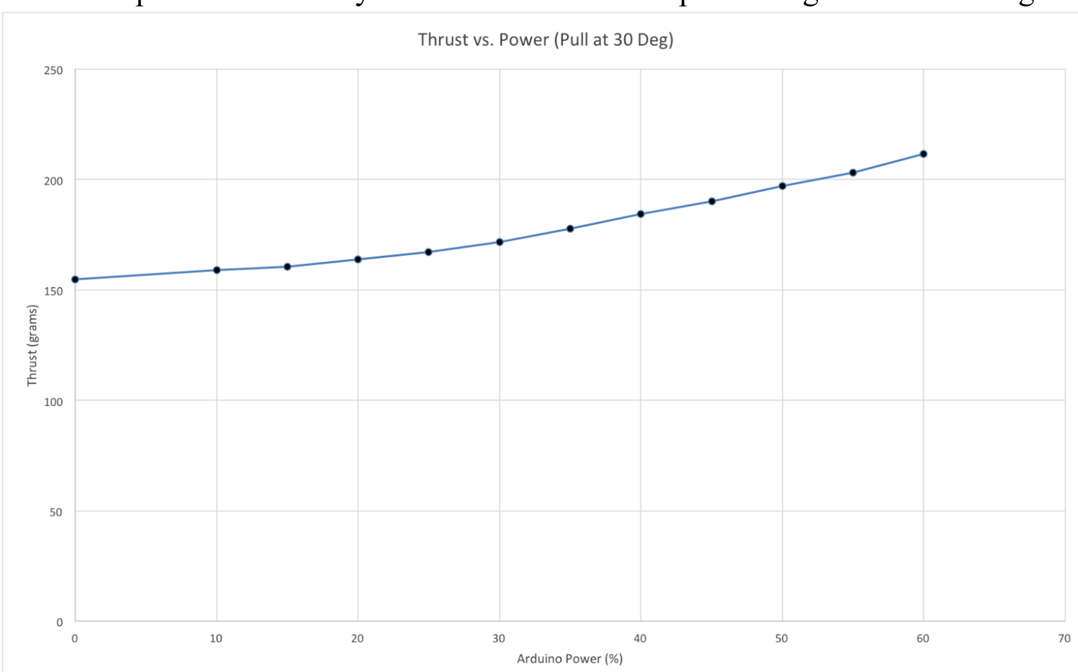


Figure A.7: Thrust vs. Power of a pull configuration at 30 degree pitch.

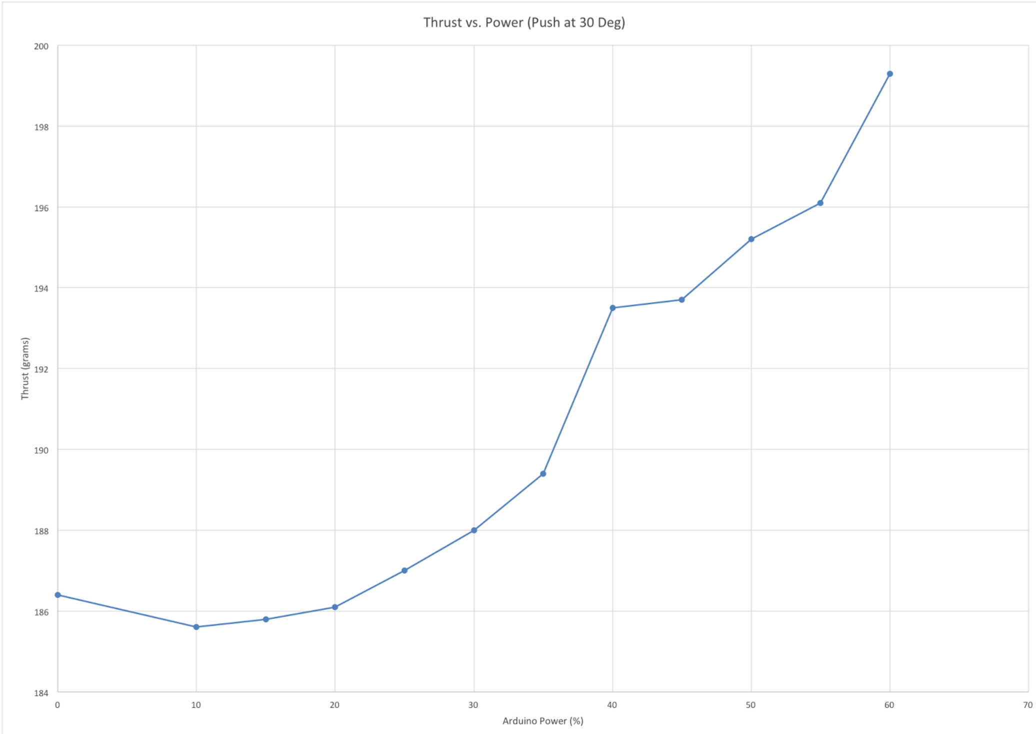


Figure A.8: Thrust vs. Power of a push configuration at 30 degree pitch.

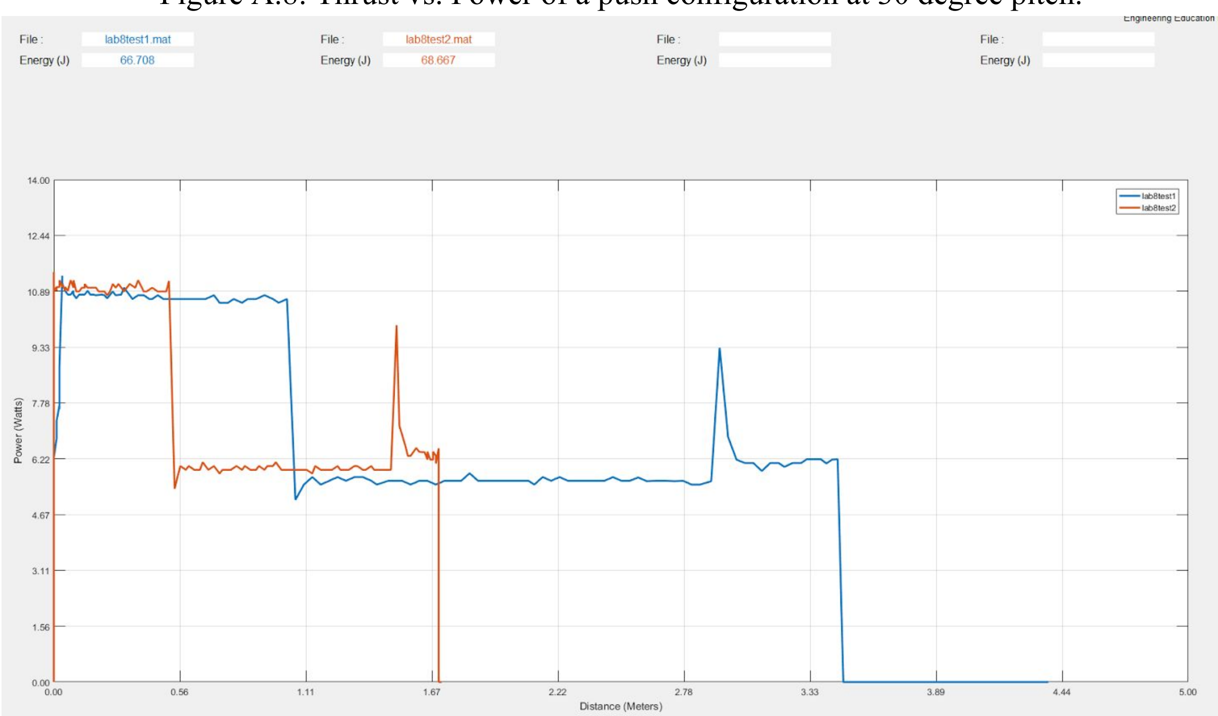


Figure A.9: Power vs. Distance of both AEV models from performance test 1. Energy usage of each model is a the top. Model 1 is file one and model 2 is file 2.

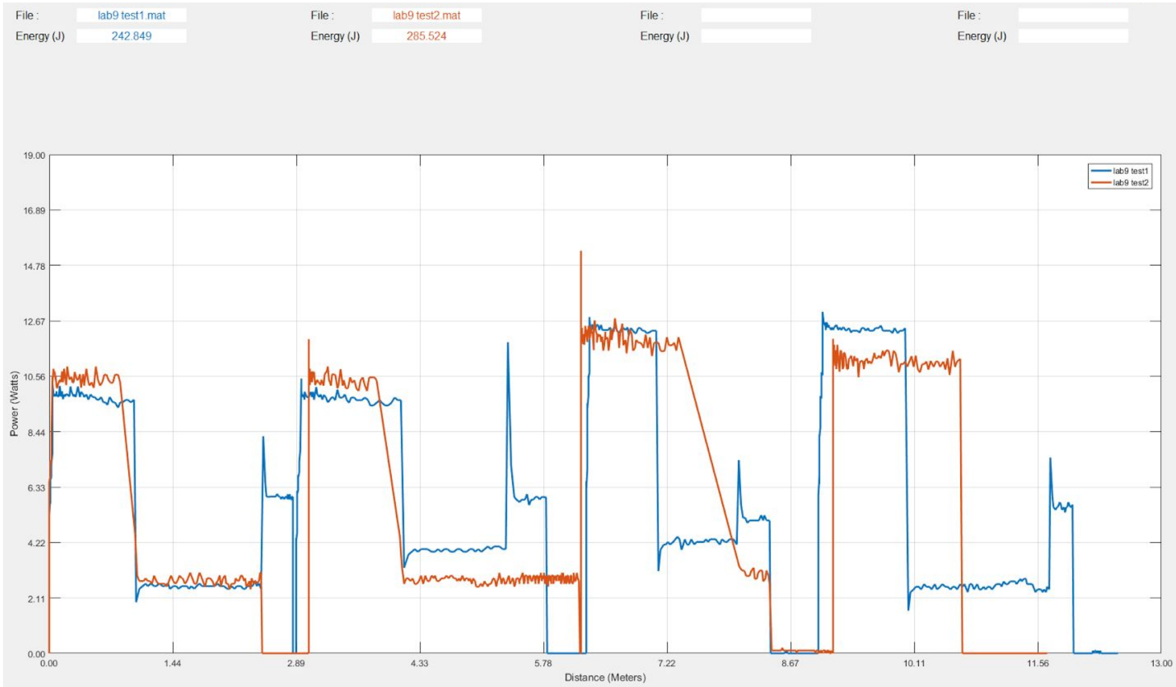


Figure A.10: Power vs. distance for both performance test 2 runs. Blue is time based code and orange is mark based code.

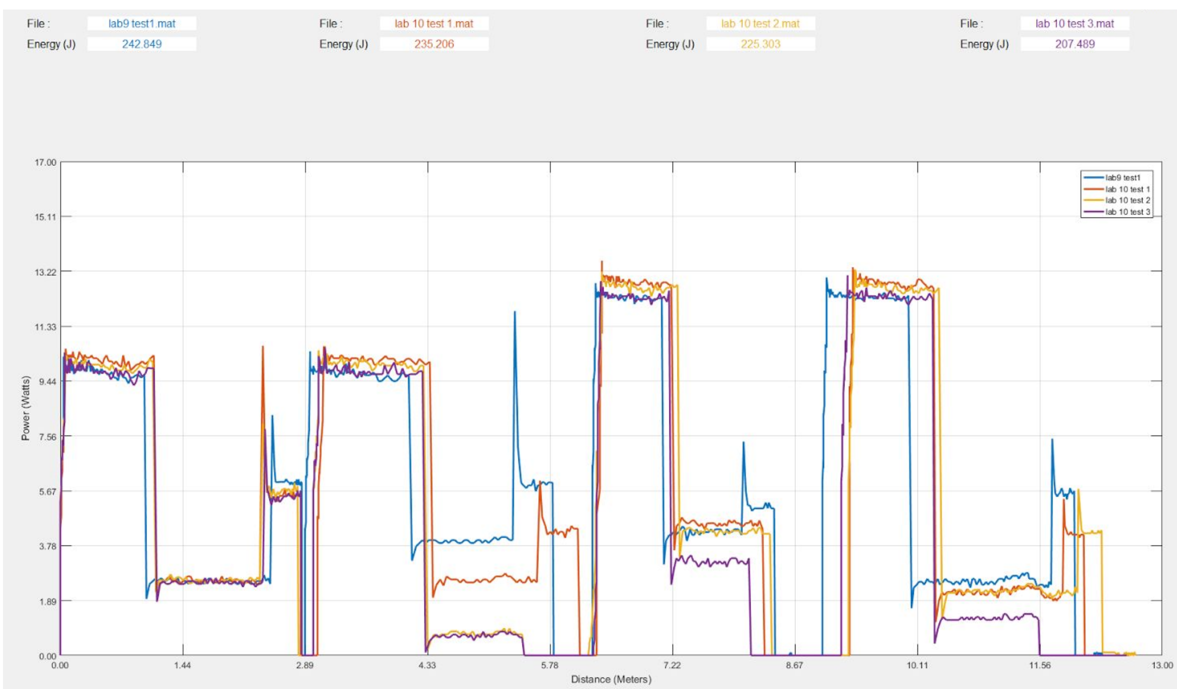


Figure A.11: Power vs. Distance for each of the optimization runs. The original run from test 2 is in blue and each subsequent optimization run is the color of each file at the top in order.

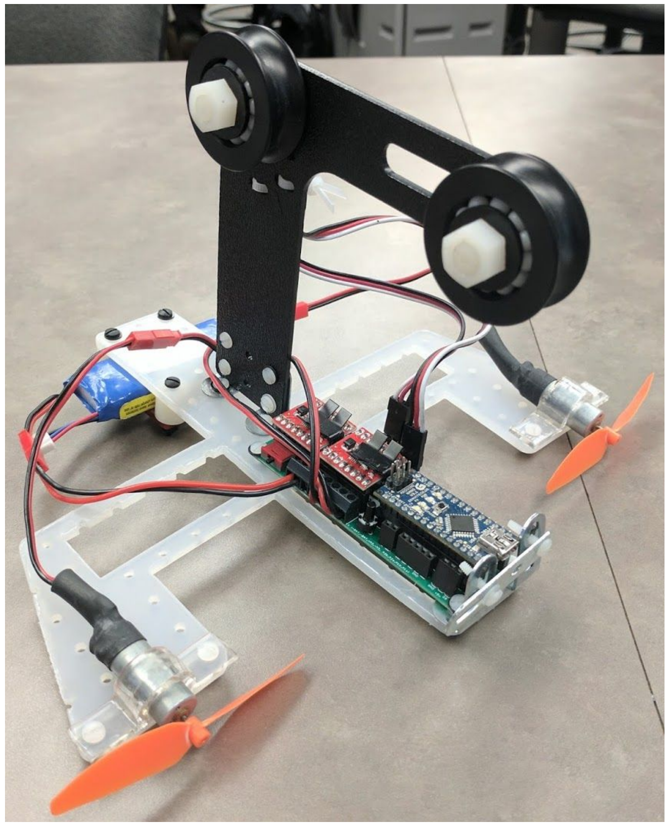
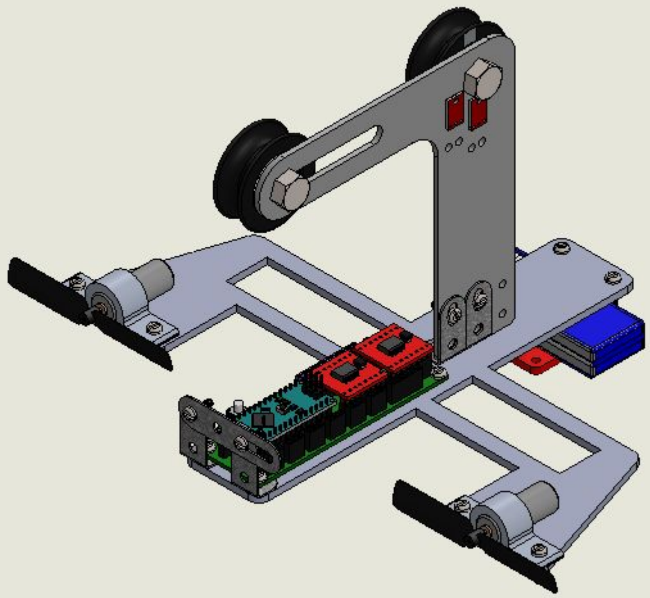


Figure A.12: Photo of the final AEV model.



ITEM NO.	PART NUMBER	QTY.
1	Laser Cut Chassis	1
2	Support Arm 2 2 Sensor Holes	1
3	90-deg bracket	4
4	AEV Arduino Assembly	1
5	Motor Mount Clip Aluminum	2
6	AEV Motor	2
7	Prop 3inch	2
8	SL-PHMS 0.112-40x0.5x0.5-S	4
9	SL-PHMS 0.112-40x0.375x0.375-S	10
10	SL-PHMS 0.112-40x1x1-S	3
11	Battery Pack	1
12	Battery Pack Clamp Plate Narrow	1
13	MSHXNUT 0.112-40-S-S	17
14	MSHXNUT 0.3125-18-S-S	2
15	Rotation Sensor Board	2
16	Pulley Assembly w-reflective tape	1
17	Pulley Assembly	1
18	HBOLT 0.3125-18x0.875x0.875-S	2
19	flat bracket	1

The Ohio State University First Year Engineering	Dwg. Title: Final AEV with bill of materials	Scale: 2:3	Inst.:Prof. Busick	Units: INCH	Dwg. No.: 1
	Drawn By: Drake Pocsatko		Hour: 1:50 p.m.	Seat: A/2	Date: 3/1/2017

Figure A.13: Solidworks assembly of final AEV model with bill of materials.

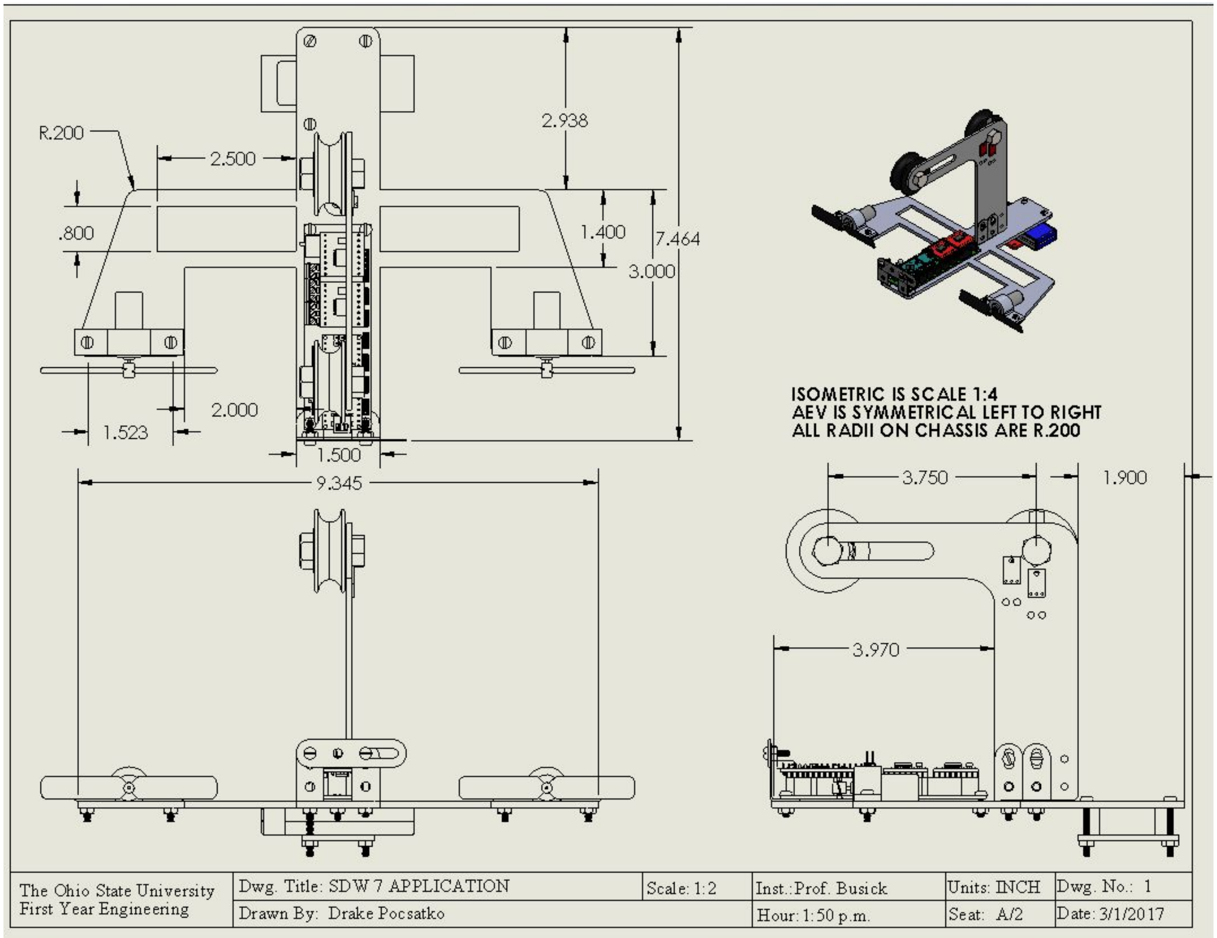


Figure A.14: Solidworks assembly 3-view drawing with dimensions.

Figure A.15: Power vs. Distance for each of key complete runs of the project. Yellow is the chosen code body from performance test 2, red is the pre-optimization run from performance test 3, and blue is the final run.

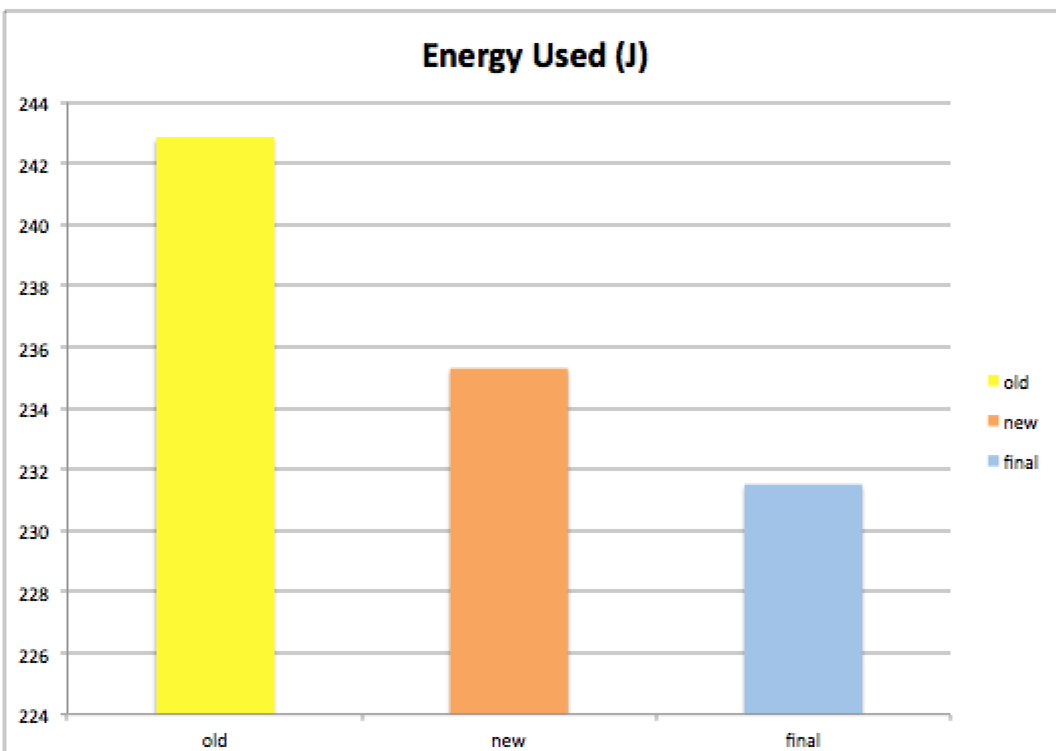


Figure A.16: Energy used by each of the runs in figure A.15.

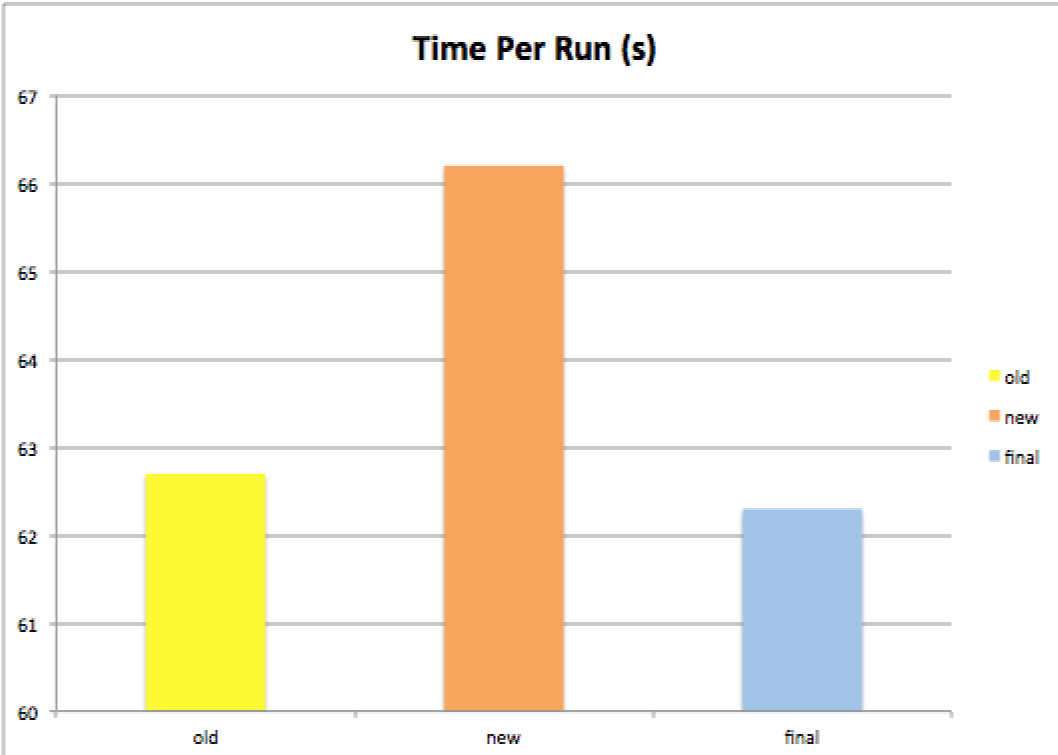


Figure A.17: Time used by each of the runs in figure A.15.

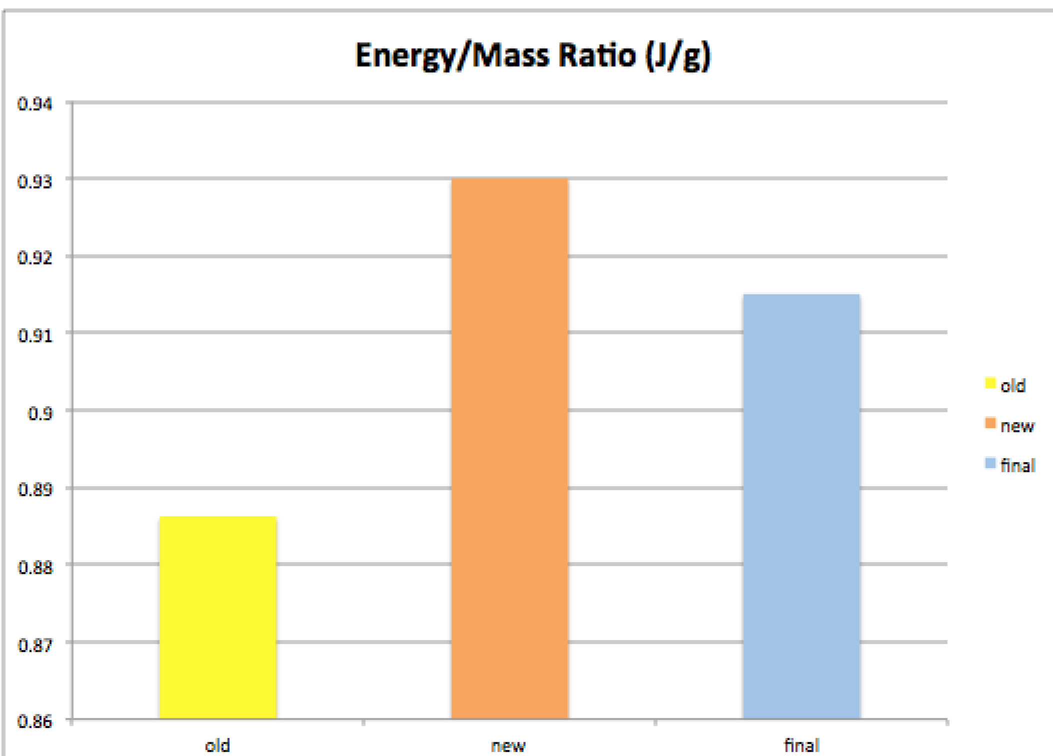


Figure A.18: Energy/mass ratio of each of the runs in figure A.15.

Success Criteria	Reference	Final	Model 1	Model 2	Design A	Design B	Design C	Design D	Design E
Balance In Turns	0	+	+	+	+	+	-	-	+
Minimal Blockage	0	+	+	0	0	-	+	+	+
Center of Gravity	0	+	+	+	0	0	0	0	-
Maintenance	0	+	0	0	-	-	+	+	0
Durability	0	0	0	+	-	+	-	.	0
Cost	0	0	0	0	+	-	+	+	+
Environmental	0	+	+	+	+	-	+	+	+
Sum +'s	0	5	4	4	3	2	4	4	4
Sum 0's	7	2	3	3	2	1	1	2	2
Sum -'s	0	0	0	0	2	4	2	1	1
Net Score	0	5	4	4	1	-2	2	3	3
Continue?	No	Yes	Test	Test	Combine	No	Combine	Combine	Yes

Figure A.19: Concept screening of previous designs compared to the final design.

Success Criteria	Weight	Reference	Final	Model 1	Model 2	Design E
Balance In Turns	25%	2	4	4	0	2
Minimal Blockage	5%	4	4	4	1	4
Center of Gravity	10%	3	4	4	4	2
Maintenance	10%	3	3	2	2	3
Durability	10%	3	1	2	4	3
Cost	15%	3	3	2	2	3
Environmental	25%	1	4	4	1	3
Total	100%	2.3	3.45	3.3	1.6	2.7
Continue?		No	Yes	Yes	No	No

Figure A.20: Concept scoring of all models that were built and tested.

Appendix B - Arduino Code

Performance Test 1 code:

```
celerate(4, 0, 40, 3);
goFor(3);
motorSpeed(4, 20);
goFor(3);
reverse(4);
motorSpeed(4, 25);
goFor(1);
brake(4);
```

Performance Test 2 code solution 1 (code reads top left, lower left, top right lower right):

```
celerate(4, 0, 39, 3);
goFor(3);
motorSpeed(4, 15);
goFor(3);
reverse(4);
motorSpeed(4, 25);
goFor(1.5);

brake(4);
goFor(10);
```

```
reverse(4);
celerate(4, 0, 39, 3);
goFor(3);
motorSpeed(4, 20);
goFor(2);
reverse(4);
motorSpeed(4, 25);
goFor(1);

brake(4);
goFor(2);
```

```
celerate(4, 0, 45, 3);
goFor(3);
motorSpeed(4, 20);
goFor(2);
reverse(4);
motorSpeed(4, 23);
goFor(1);

brake(4);
goFor(10);
```

```
reverse(4);
celerate(4, 0, 45, 3);
goFor(3);
motorSpeed(4, 15);
goFor(4);
reverse(4);
motorSpeed(4, 25);
goFor(1);

brake(4);
goFor(2);
```

Performance Test 2 code solution 2 (code reads top left, lower left, top right lower right):

```
celerate(4, 0, 39, 3);
goToAbsolutePosition(67);
brake(4);
int j = getVehiclePostion();
while(j < 80)
{
 j = getVehiclePostion();
if(j >= 80)
{
    motorSpeed(4, 15);
    goToAbsolutePosition(200);
    brake(4);
    goFor(10);
}
}

celerate(4, 0, 39, 1);
goToRelativePosition(65);
brake(4);
j = getVehiclePostion();
while(j < 330)
{
 j = getVehiclePostion();
if(j >= 330)
{
    motorSpeed(4, 15);
    goToAbsolutePosition(500);
    reverse(4);
    motorSpeed(4, 15);
    brake(4);
    goFor(2);
}
}
```

```
motorSpeed(4, 42);
goToRelativePosition(95);
brake(4);
j = getTotalMarks();
while(j < 650)
{
 j = getVehiclePostion();
if(j >= 650)
{
    motorSpeed(4, 15);
    goToRelativePosition(30);
    reverse(4);
    motorSpeed(4, 25);
    brake(4);
    goFor(10);
}
}

reverse(4);
celerate(4, 0, 39, 3);
goToRelativePosition(120);
brake(4);
j = getVehiclePostion();
while(j < 800)
{
   j = getVehiclePostion();
if(j >= 800)
{
      motorSpeed(4, 15);
      goToRelativePosition(50);
      reverse(4);
      motorSpeed(4, 25);
      brake(4);
      goFor(8);
}}
```

Optimized Performance Test 3 and Final Test code:

```
celerate(4, 0, 39, 3);
goFor(3.3);
brake(4);
goFor(2);
motorSpeed(4, 10);
goFor(1);
brake(4);
goFor(9);

celerate(4, 0, 39, 3);
goFor(3.2);
brake(4);
goFor(9);

reverse(4);
celerate(4, 0, 45, 3);
goFor(4);
brake(4);
goFor(1);
reverse(4);
motorSpeed(4, 30);
goFor(1);
reverse(4);
brake(4);
goFor(10);

celerate(4, 0, 45, 3);
goFor(3.5);
brake(4);
```

Appendix C - Team Schedule

Task		Start	Finish	Due	Drake	Mo	Hakam	Al	Mohammad	% Complete
PT 1	Code for test	3/16/2017	3/16/2017	3/18/2017	X					100%
	AEV 1 Construction	3/16/2017	3/16/2017	3/19/2017			X	X		100%
	AEV 1 Test	3/16/2017	3/16/2017	3/20/2017		X	X	X		100%
	AEV 2 Constructoin	3/20/2017	3/20/2017	3/21/2017			X	X		100%
	AEV 2 Test	3/20/2017	3/20/2017	3/22/2017	X		X	X		100%
	Progress Report	3/22/2017	3/22/2017	3/23/2017	X	X	X	X	X	100%
PDR Report		3/22/2017	3/22/2017	3/27/2017	X	X	X	X	X	100%
PT 2	Create Code 1	3/23/2017	3/23/2017	3/30/2017	X					100%
	Test Code 1	3/23/2017	3/23/2017	3/30/2017			X	X	X	100%
	Create Code 2	3/27/2017	3/27/2017	3/30/2017	X	X				100%
	Test Code 2	3/27/2017	3/29/2017	3/30/2017			X	X	X	100%
	Progress Report	3/27/2017	3/30/2017	3/30/2017	X	X				100%
PT3	Optimize Code	3/30/2017	3/30/2017	4/6/2017			X	X		100%
	Optimize Body	3/30/2017	3/30/2017	4/6/2017	X	X	X	X		100%
	Progress Report	3/31/2017	4/6/2017	4/6/2017			X	X		100%
PT 4	Run Test 1	4/6/2017	4/13/2017	4/13/2017		X	X	X		100%
	Run Test 2	4/6/2017	4/13/2017	4/13/2017	X	X	X	X	X	100%
CDR Report		4/13/2017	4/20/2017	4/20/2017	X	X	X	X	X	100%
CDR Presentation		4/13/2017	4/20/2017	4/20/2017	X	X	X	X	X	100%
Complete Project Portfolio		3/2/2017	4/20/2017	4/20/2017	X	X	X	X	X	100%