Critical Design Review

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Executive Summary

The galactic empire is working to rebuild their army after the destruction of the Death Star. To ensure that the galactic empire is not suspicious of any activity, the rebel alliance needs to prepare for war on remote planets, where power is limited. The alliance is searching for an efficient, effective monorail network system that can transport constructed R2D2 units from one side of the land to where the interceptor aircrafts are being assembled. Since the AEV mission takes place on a remote planet where power is a luxury, the mission emphasized energy management, operational efficiency, and operational consistency. The objective was to program an AEV to start at the drop-off area, travel to the gate to be checked in, activate a sensor, wait seven seconds to go through the gate, navigate to the cargo area, and then stop at the cargo area. The AEV then was required to pick up an R2D2, wait five seconds to make sure that the cargo was loaded, and then go back to the drop-off area. The monorail was expected to have slight variations over time due to the fact that the planet was unstable, so the AEV was not supposed to depend on only one track. As contractors, the team was asked to produce an operationally consistent AEV that had a minimal energy to mass ratio and could perform the Scenario. This final product will be presented to the rebel alliance.

The team began working on the mission by building a concept AEV and familiarizing themselves with the external sensor hardware components, troubleshooting techniques, and numerous function calls. Each member then exercised creative abilities by brainstorming initial designs for the AEV. These designs were shared with the rest of the team and were analyzed via Concept Screening and Scoring. The design that was unanimously decided to be the best was assembled and utilized in the following labs as the team learned how to utilize the design analysis tool in MATLAB for analyzing data the arduino collected during runs.

Three performance tests were executed to allow the team to make final adjustments in the design and code and thus optimize the AEV's consistency and efficiency. In Performance Test 1, two potential AEV designs were tested and analyzed. The first design featured a base that was perpendicular to the arm; the second design consisted of a base that was parallel to the arm. A test run for the first design needed only 67. 4137 joules of energy to travel the first quarter of the track, whereas the second design required 68.5575 joules. The first design was therefore concluded to be more efficient and was thus used in the next two performance tests. In Performance Test 2, two codes were developed and analyzed. One code employed a large power surge in the reverse direction whenever the AEV approached the gate or the R2D2, whereas the second code allowed the AEV to coast to a stop. Although the first code was more consistent, the second code was more energy efficient. Therefore, a combination of these two codes were used for the final code. In Performance Test 3, the behavior of the AEV was closely observed and necessary adjustments in the code were made so that the AEV could fulfill the objectives and requirements from the Mission Concept Review. Over the course of this final performance test, the required supplied energy for traversing the entire track was lowered from 313.058 joules to 291.826 joules, thus improving the energy efficiency of the AEV.

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Introduction

After the destruction of the Death Star, the galactic empire is rebuilding their army. To guarantee that the galactic empire is not aware of any operations, the rebel alliance must prepare for war on remote planets, where power is a luxury. The alliance is in need of an efficient monorail network system for transporting R2D2 units from one side of the land to where the interceptor aircrafts are being constructed. Because there is little power at the location where the AEV mission occurs, the AEV must focus on energy efficiency and operational consistency.

The team's objective was to produce an AEV that could begin at the drop-off area, go to the gate, activate a sensor, wait seven seconds to go through the gate, travel to the cargo area, and then stop at the cargo area. The AEV was then required to pick up an R2D2 unit, wait five seconds to make sure that the cargo was properly loaded, and then traverse back to the drop-off area. The monorail may have some variation over time due to the instability of the planet, so the AEV should not have depended on one specific track. As contractors, it was the team's responsibility to produce an effective, efficient AEV to execute the Scenario.

Experimental Methodology

The team started working on the mission by constructing a concept AEV, learning about the various hardware components, and learning the basics of how to develop a code. Next, each member brainstormed initial designs for the AEV and shared their ideas with the rest of the team. Concept screening and scoring was performed to outline the strengths and weaknesses of each design, and the team analyzed the results to determine a design that best met the objectives of the Mission Concept Review. The team evaluated the efficiency of this design by assembling it, programming it with a certain scenario, and testing it on the straight tracks. The team then familiarized themselves with the design analysis tool in MATLAB for extracting and analyzing data collected by the arduino during runs.

In Performance Test 1 (Labs 08A/B/C), two different AEV designs were assembled, tested on the outside track, and analyzed with the use of the design analysis tool in MATLAB. The results of a run with the first design was compared to the results of a run with the second design in order to determine which design was more energy efficient. In Performance Test 2 (Labs 09A/B/C), two different codes were developed and tested on the outside tracks. The data that the arduino collected during these test runs was extracted with the use of the design analysis tool and analyzed for determining which code was better suited for fulfilling the needs of the Mission Concept Review. In Performance Test 3 (Labs 10A/B/C), the behavior of the AEV on the track was observed and necessary improvements in the code were made for the AEV to stop at the appropriate times and places.

Results & Discussion

In Performance Test 1, two AEV designs were tested. The Vertical Design, shown in Figures 12 and 13, involved the entire AEV apparatus to be on the same plane, minimizing air resistance. The Parallel Design, shown in Figures 10 and 11, was derived from the team's initial design where the base of the AEV face flat to the ground.

The team's concept design developed in Lab 4 was minimally modified to produce the final AEV design. For Performance Test 1, the initial team design, now called the parallel design, was tested, but without the shield. This later design was reanalyzed using Concept Screen and Scoring methods as shown in Tables 8 and 9. The parallel design consistently performed above average, so the team decided to continue tests on that configuration. The initial concept design created by the team in Lab 4 was ultimately the design that underwent final testing, excluding the shield. The shield idea was removed to reduce the cost of the system. The shield would have been 3D printed, which would have also added more weight to the AEV. Overall, Performance Test 1 helped the team solidify the parallel AEV design as the most efficient.

The first lab of this entire project began with some design brainstorming to get a general idea of expectations for the build of the team AEV. The next lab to address the design of the AEV was lab two when tests were performed to determine which propeller size and configuration would prove to be most efficient. Based on the testing that was performed in this portion of lab, the team decided to use the puller configuration and 3in blade on both concept designs. When looking at the propulsion efficiency versus advance ratio, the 3030 setup (3in blade, Figure 1) had a steeper slope on the graph than the 2510 setup (2.5in blade, Figure 2), meaning it was more efficient. Also, the pusher configuration proved to be better than the puller configuration since it generated more thrust and had higher power output values, as seen in Tables 2, 3, and 4. The next step in the design process was having each team member create a set of orthographic drawings of a unique design to score and determine if the design should be considered using for the final AEV. After screening and scoring the four team members' and one original team designs, the team design finished the process with the best ratings and was therefore selected to continue developing.

The next step in the design process was Performance Test 1 which compared the energy efficiency of two different AEV designs which ran on actual code. In lab 8A, the team tested the first AEV design. This design included a body parallel to the ground with a perpendicular arm. This differed from the second design in that the second design was entirely vertical (testing in lab 8B) (Figures 10, 11, 12, and 13). The team developed a code that successfully stopped the AEV close to the gate and collected data from these runs (Figure 8 and Table 6). In lab 8B, the team tested the second design (Figures 12 and 13) in which the entire AEV was vertically oriented. Data wa collected after this run and graphed so it could be compared to the data from the first design test run (Figure 9 and Table 7). In comparison to the design tested in lab 8A, the two vehicles presented only minor energy differences. The energy consumption of the vehicle from this run was about 68.5 joules, which was about 1 joule higher than the first design. While the results were very similar, the first design was chosen to move forward with due to having slightly less energy consumption. Since only one quarter of the track was completed, the difference in energy would be cumulative as more segments of the track were added onto the journey. Therefore, the first design would end up being more energy efficient than the second design.

During Performance Test 2, two codes were put against each other to determine which was more energy efficient. The first code tested utilized a power surge to stop the AEV at each of the critical points on the track. The second code took out the power surges and instead allowed the AEV to coast to a stop at each of the critical points on the track. Since the team did not have enough time to complete a full run of code 2, only the first half of each run was used to compare the amounts of energy used. A comparison of the energy can be found in Figure 7 of the appendix. Even though code 2 used 102.2J and code 1 used over double at 221J, the team still decided to keep developing code 1 since it was nearly complete. The team also decided to incorporate more of the coasting from code 2 into the completion of code 1.

The final Performance Test in lab 10 allowed the team to fine tune the code from the previous lab to meet the objectives in the MCR and to improve energy efficiency. Since the code for the full track was basically complete from lab 9, the team was able to take this time to try out different variations of the code to see what changes would improve the energy consumption of the AEV. Figure 6 highlights four of the runs performed during this lab period, each code using less energy each time (Table 5).

The team was able to effectively use the entire design process and performance tests in order to discover what proved to be most energy efficient for the AEV. A total breakdown of energy consumption for each phase of the vehicle's motion can be found in Table 11 in the appendix.

The team's AEV performed 2 rounds of final testing as shown in Figure 21. For run 1, the AEV behaved unpredictably on the upstairs track. The first half of the track went well, but the AEV stopped approximately 6 inches before the second gate, making the team push it to the sensor. Then, when approaching the final stopping point, the AEV stopped approximately a foot short of where it was supposed to. Run 1 resulted in a score of 43/50 and consumed 364.8 J of energy.

Run 2, shown in Figure 21, was a substantial improvement. In this run, the AEV performed along the first half of the track perfectly. When it got to the second gate, however, it traveled further than expected and needed to be stopped. It proceeded through the gate towards the stopping point, and needed to be stopped again before it touched the foam. The penalties for stopping the AEV twice were only 2 points, resulting in a total score of 48/50. The amount of energy consumed was substantially lower at 278.7 J.

The team noticed previously that the AEV used considerably less energy on the downstairs track. This was true when comparing the energy consumption of the final tests. Run 1 on the upstairs track used 364.8 J of energy, while run 2 on the downstairs track used only 278.7 J of energy. This is a substantial difference in energy consumption that cannot be explained due to differences in code. The energy discrepancy must have been caused by differences in friction and length of the tracks.

In performance test 1 (lab 8), two designs were developed and tested in order to compare overall energy efficiency. The first design (Figures 10-11, 22-24) consisted of a base perpendicular to the arm that utilized a dual motor system to travel on the track. This design was tested from the starting position to the first gate and used approximately 67.44 joules of energy (Figure 8, Table 6). The second design (Figures 12-13, Figures 16, 17) differed from the first in that the base was parallel to the arm, creating a design that was entirely vertical. The second design was also tested from the starting position to the first gate, and was found to use approximately 68.5 joules (Figure 9 Table 7). While the difference in energy consumption was not drastic, by extrapolating the data to predict the outcome had the designs been tested on the full track, it was determined that design 1 would ultimately use far less energy. Based on this data, it was decided that design 1 would be continued and further developed.

In performance test 2 (lab 9), two unique codes were developed to compare the energy consumption of each. The first code used a reversal of the motors at a high energy percentage to stop the AEV at each location. While this code was found to be reliable, it consumed a large amount of energy. Since the motors had to run continuously up until each stopping location, this used up a large amount of energy. This code used 442 J of energy. A second code was developed that allowed the AEV to coast to a stop at each location. This code was found to be more efficient because the time the motor had to run continually was decreased and the reversal of the motors was excluded. This combination drastically reduced the energy consumption. The team did not have enough time to test a full run for this code, but a run for half the track was successfully completed. This half run used about 102.2 J of energy. In order to compare these two runs accurately, the first run's energy consumption was divided by two to compare both half-track runs (Figure 7). This resulted in an energy consumption of 221 J for the first code and 102.2 J for the second code. Based off these results, it was clear that the second code was far more efficient. However, this code was also more unreliable. Therefore, aspects of both codes were combined for future labs to maximize efficiency and reliability.

In performance test 3 (lab 10), final adjustments were made and overall energy efficiency was analyzed in order to maximize efficiency. The code was tested numerous time to check for consistency and to make minor adjustments that ultimately reduced energy consumption. The data collected from the test runs displayed a clear decrease in energy consumption (Figure 6, Table 5). After running several test runs, it became apparent that the largest amount of energy was consumed during the periods in which the AEV ran at a constant motor speed for an extended period of time. Upon this discovery, the code was adapted to minimize this time where the motors were used to run consistently at a constant power output. After making these adjustments, the energy consumption clearly declined. In order to minimize the time the motors were running, the AEV was programmed to cut the power at an earlier location and coast into each of the gates. Once the AEV neared the specific stopping location, a power surge and reversal of the motors was utilized to stop the vehicle completely. This ensured that the AEV stopped precisely where it was required. While this surge of energy did increase the energy consumption, this effect was minimal as the amount of energy used throughout the constant power output traveling between gates was far greater than the minimal power output during the stopping of the AEV.

For lab 11A, the team worked diligently to fine tune the code and ensure the AEV completed all the requirements in the MCR. However, due to slight variations in the upstairs track versus the downstairs track, a lot of adjustments had to be made to correct for the differences in location. Due to this troubleshooting, no final tests were conducted in lab 11 A. The AEV was found to consume 312.79 J of energy (Figure 5), which was slightly higher than tests run in previous labs. This difference in energy consumption was due to the differences in the upstairs versus the downstairs track. Because the positions were adjusted, the motors then had to run longer to travel the appropriate distance. Therefore, more energy was consumed upstairs than downstairs.

During the final testing in lab 11, the AEV consumed approximately 364.84 joules during the first run (Figure 18). The AEV successfully completed the first half of the track, stopping for 7 seconds at the first gate before continuing to the end of the track to pick up the R2 unit. It successfully attached the cargo and waited 5 seconds before starting back. Some trouble was run into on the way back at the gate as the AEV did not travel far enough to trigger the sensor. A team member pushed the AEV slightly to trip the sensor. After this, the AEV continued back to the start position but stopped slightly short of the actual location. Here again, a team member aided the AEV in successfully making it completely back to the start location. In comparison to the rest of the class's final runs, Team O performed about average, as shown in Table 12. With a mass of 0.243 g, the AEV's mass to energy ratio was 1147. The team earned 48/50 points with the run, and earned 72.6 points overall. For all sections of the test, mass, energy used, delts t, and energy to mass ratio, the AEV performed about average.

As seen in Figure 20, the AEV's performance improved over the course of the performance tests. Initially consuming 313.05 J of energy, after testing and improving the AEV, the final test run only consumed 278.73 J of energy (Table 10). These improvements in energy consumption were due to variations in the code. After it was discovered that it was more efficient to allow the AEV to coast to a stop rather than use a reversal of the propellers, the team implemented more coasting time. Additionally, throughout performance tests it was found that the power could be cut sooner for coasting, therefore requiring the engines to run for a shorter distance and use even less energy. One of the drastic differences in energy consumption arose due to the differences in the upstairs versus downstairs tracks. The upstairs track used far more energy than the downstairs track for reasons unable to be explained. These differences could be due to differing distances in the track length or friction due to the different surfaces of the two tracks. When the team switched from testing on the downstairs track to the upstairs track, this was where the spike in energy was located on the graph in Figure 20. Even though no adjustments were made to the code, the AEV consumed a far greater amount of energy upstairs compared to downstairs. As the final test was run on the downstairs track, less energy was consumed.

Conclusion and Recommendations

After thorough development, design, and testing, the team settled on a final design for the AEV that optimized the energy consumed based on the weight of the vehicle. The final design (Figure 10 and 11) featured two motors with 3in. propellers and a body parallel to the ground. All aspects of this design had been through rounds of testing and only the best, most efficient pieces of each design made it through each round to end up on the final AEV design.

Energy consumption for the AEV decreased from the start of the lab to the final test. The first full run of the AEV used 442J of energy and this value was decreased to 278.7J for the final run. The team made careful use of lab time to ensure as much time as possible could be dedicated to improving the performance of the AEV. Extra time was spent preparing for the performance test because during these lab periods, the team was able to gather a lot of data on how different versions of code would translate to energy consumption. The team was able interpret the results from the many performance tests and apply this knowledge to writing code that was able to make the final AEV much more efficient than the first full track run.

The final team's AEV design was meant to be both energy efficient, light, and durable. Figure 20 highlights how the energy consumption of the AEV would, on average, decrease with every run. This verified the team's' efforts in continually working to make the AEV more efficient. This AEV design was also very efficient in terms of the energy mass ratio. With an energy mass ratio of 1147, this put the team as the third lowest ratio out of the entire class (Figure 20). Finally, the durability of the AEV would outperform most other AEV when looking back to the requirements in the MCR. Having a durable vehicle was critical when going on long journeys across a barren planet.

One recommendation to improve the AEV project would be to give more time for open lab. This project was very dependant on the use of the track and the ability to test written code. Without access to the track to run, teams could be halted in their work process and may run out of time. Another recommendation to improve the AEV project would be to provide more guidance when saying the code needs to be made so it is consistent. The one problem was no one on the team had coded in C before, so each team member believed the commands provided in the lab manual were the only commands that could be used. When the team discovered using loops and if statements was a possibility, it was already too late to rewrite and test an entire new code.

Appendix

Table 1: Team Project Schedule

	ℹ	Task Mode	Task Name	Duration	Start	Finish	% Complete	Jennifer Bertrand	Melanie Gross	Katie Gonsoulin	Jessica Hudak
40	✓		Write Code for Testing	11 days	Thu 3/9/17	Thu 3/23/17	100%		1 hour		
41	✓		3D Printed Part Design	3 days	Wed 3/8/17	Fri 3/10/17	100%		1 hour		
42	✓		AEV Design 1 Build	11 days	Thu 3/9/17	Thu 3/23/17	100%	30 minutes	30 minutes		
43	✓		AEV Design 1 Test	1 day	Thu 3/23/17	Thu 3/23/17	100%	30 minutes	30 minutes	30 minutes	30 minutes
44	✓		AEV Design 2 Build	11 days	Thu 3/9/17	Thu 3/23/17	100%	15 minutes			
45	✓		AEV Design 2 Test	11 days	Thu 3/23/17	Thu 4/6/17	100%	30 minutes	30 minutes	30 minutes	30 minutes
46	✓		Write Code 1 for Testing	11 days	Thu 3/9/17	Thu 3/23/17	100%		30 minutes		
47	✓		AEV Final Design Completion	11 days	Thu 3/9/17	Thu 3/23/17	100%	15 minutes	15 minutes	15 minutes	15 minutes
48	✓		PDR	17 days	Sat 3/4/17	Mon 3/27/17	100%	1 hour	1 hour	1 hour	1 hour
49	✓		Write Code 2 for Testing	11 days	Thu 3/9/17	Thu 3/23/17	100%		30 minutes		
50	✓		Test Code 1 and 2	1 day	Thu 3/23/17	Thu 3/23/17	100%	1 hour	1 hour	1 hour	1 hour
51	✓		Progress Report Lab 10	3 days	Thu 3/23/17	Mon 3/27/17	100%		30 minutes		
52	✓		Performance Test 3 (test smaller portions of chosen code on chosen design)	1 day	Thu 3/30/17	Thu 3/30/17	100%	1 hour	1 hour	1 hour	1 hour
53	✓		Progress Report Lab 11	3 days	Thu 3/30/17	Mon 4/3/17	100%	1 hour	1 hour	1 hour	1 hour
54	✓		Final Testing	1 day	Thu 4/6/17	Thu 4/6/17	100%				
55	✓		Update Website	21 days	Thu 3/9/17	Thu 4/6/17	100%				
56	✓		Team Meeting Notes	21 days	Thu 3/9/17	Thu 4/6/17	100%	1.5 hours			
57	✓		Critical Design Review Report	6 days	Thu 4/6/17	Thu 4/13/17	100%	1.5 hours	1.5 hours	1.5 hours	1.5 hours
58	✓		CDR Oral Presentation	11 days	Thu 4/6/17	Thu 4/20/17	100%	1 hour	1 hour	1 hour	1 hour

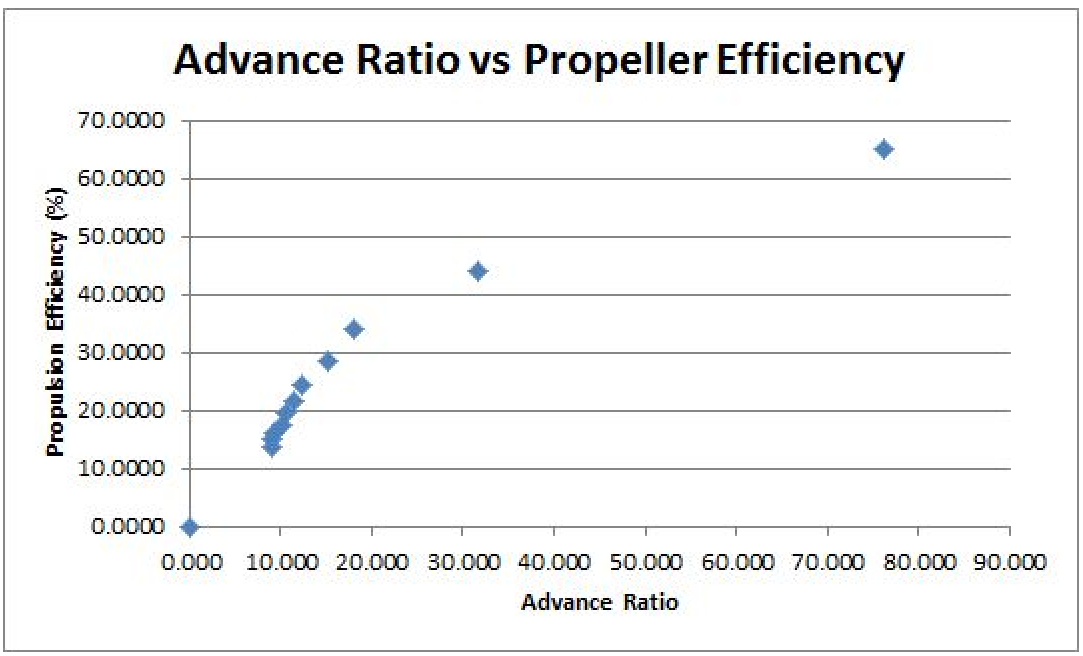


Figure 1: 3030 Second Pusher Propeller Advance Ratio vs Propulsion Efficiency Graph

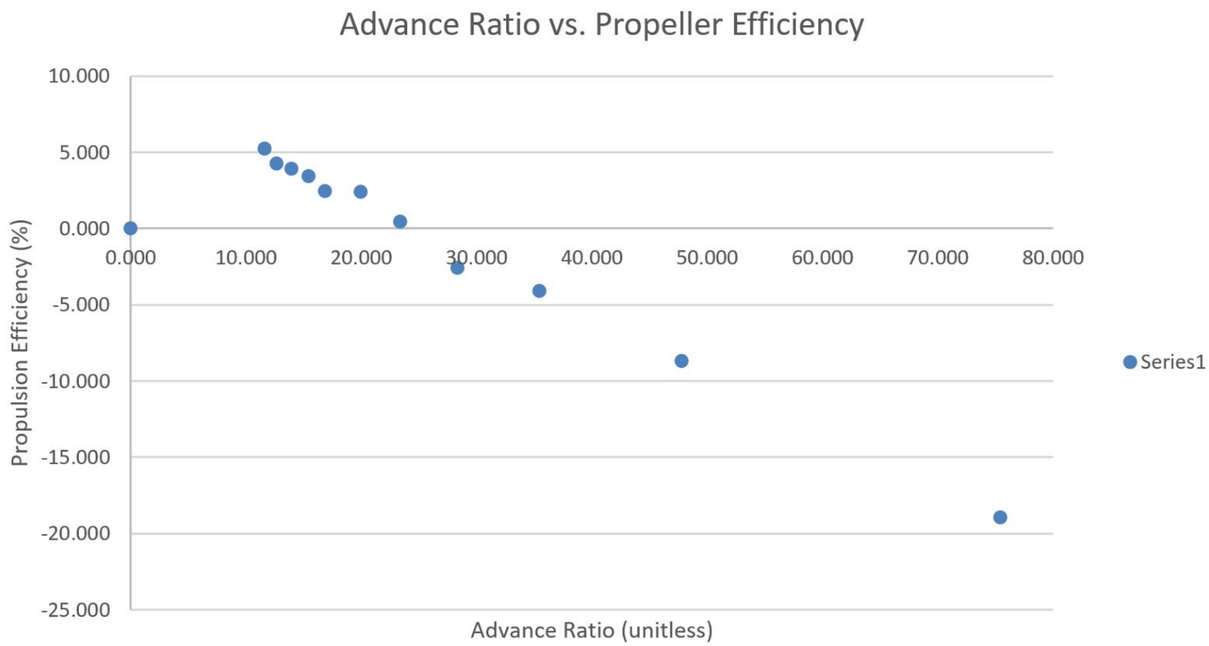


Figure 2: 2510 Puller Propeller Advance Ratio vs. Propeller Efficiency Graph

Table 2: Wind Tunnel Data Analysis First 3030 Pusher

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.0000	0.000	0.000	0.00000000	0.00000	0.000	0.0000
-0.1233	2035	0.000	-0.00000438	-0.00326	0.000	62.6826
-0.9453	3035	0.0999	-0.00003356	-0.02503	-25.053	42.0293
-1.7262	3892	0.2664	-0.00006129	-0.04570	-17.156	32.7747
-2.6304	4610	0.5180	-0.00009339	-0.06964	-13.444	27.6701
-3.9045	5449	0.8436	-0.00013863	-0.10337	-12.254	23.4096
-3.6168	6167	1.2432	-0.00012841	-0.09576	-7.702	20.6841
-3.3702	6826	1.7168	-0.00011966	-0.08923	-5.197	18.6872
-1.8495	7425	2.1978	-0.00006567	-0.04897	-2.228	17.1797
-0.2055	8043	2.8490	-0.00000730	-0.00544	-0.191	15.8596
1.3563	8682	3.5002	0.00004815	0.03591	1.026	14.6924
3.2058	9481	4.3068	0.00011382	0.08488	1.971	13.4542

Table 3: Wind Tunnel Data Analysis Second 3030 Pusher

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.0000	0.000	0.0000	0.00000000	0.00000	0.000	0.0000
0.2055	2035	0.0074	0.00000757	0.00564	76.247	65.0042
1.0275	2994	0.0888	0.00003783	0.02821	31.770	44.1829
1.8495	3892	0.2812	0.00006810	0.05078	18.058	33.9886
2.8770	4610	0.5180	0.00010593	0.07899	15.249	28.6949
3.9045	5389	0.8658	0.00014376	0.10720	12.382	24.5469
5.3430	6107	1.2691	0.00019673	0.14670	11.559	21.6610
6.7815	6766	1.7464	0.00024969	0.18619	10.662	19.5512
8.4255	7485	2.2644	0.00031022	0.23133	10.216	17.6731
9.8229	8143	2.8860	0.00036167	0.26970	9.345	16.2451
11.7135	8802	3.5816	0.00043129	0.32161	8.979	15.0288
15.0015	9760	4.5288	0.00055235	0.41189	9.095	13.5536

Table 4: Wind Tunnel Data Analysis 2510 Puller

Thrust Calibration	RPM	Power Input	Power Output	Power Output	Propulsion Efficiency	Advance Ratio
grams	*RPM*	*Watts*	*Horsepower*	*Watts*	*%*	*--*
0.000	0.000	0.000	0.00000000	0.000	0.000	0.000
-0.740	2180.000	0.111	-0.00002821	-0.021	-18.953	75.417
-0.781	3443.000	0.255	-0.00002978	-0.022	-8.698	47.752
-0.658	4640.000	0.459	-0.00002508	-0.019	-4.076	35.433
-0.658	5800.000	0.722	-0.00002508	-0.019	-2.592	28.346
0.164	7050.000	1.043	0.00000627	0.005	0.448	23.320
1.192	8263.000	1.399	0.00004545	0.034	2.423	19.897
1.397	9780.000	1.628	0.00005329	0.040	2.441	16.811
2.630	10650.000	2.165	0.00010031	0.075	3.456	15.438
3.452	11800.000	2.516	0.00013166	0.098	3.902	13.933
4.274	13000.000	2.849	0.00016300	0.122	4.266	12.647
5.918	14200.000	3.197	0.00022570	0.168	5.265	11.578

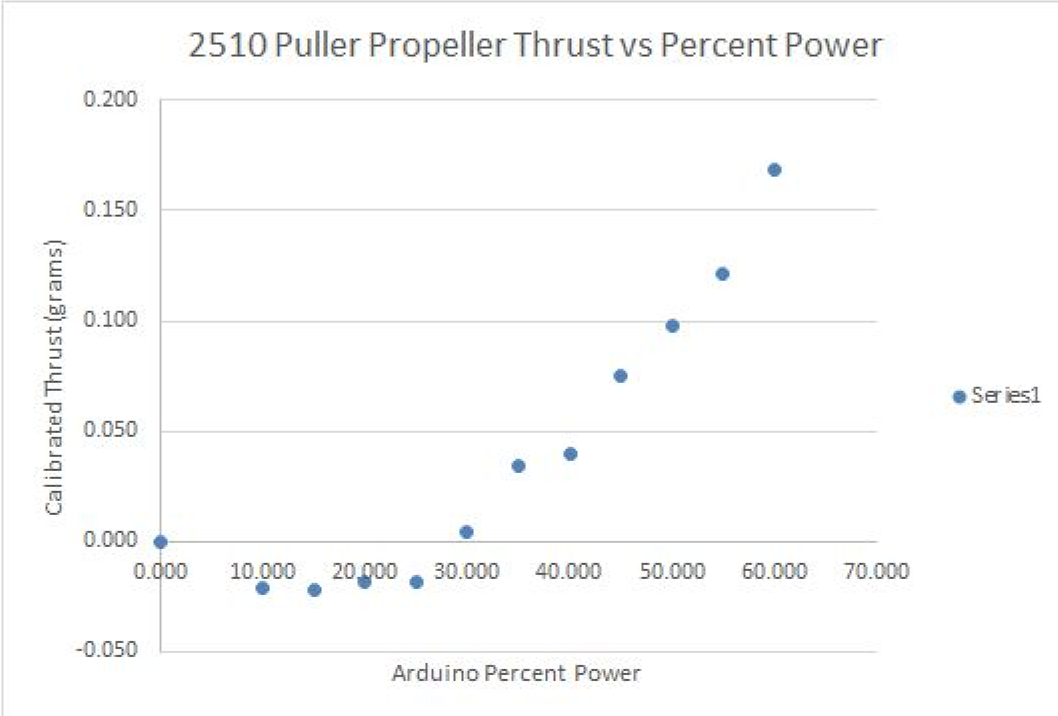


Figure 3: 2510 Propeller Thrust Vs Percent Power

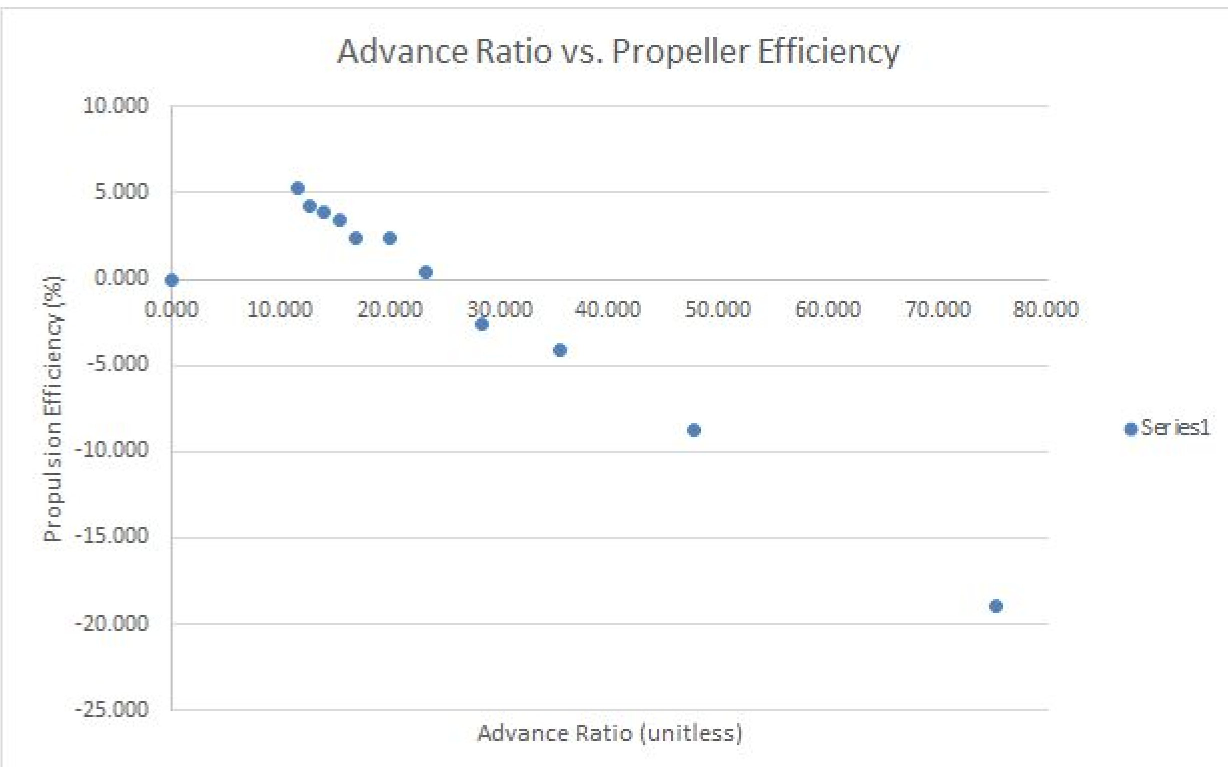


Figure 4: 2510 Advance Ratio vs Propeller Efficiency

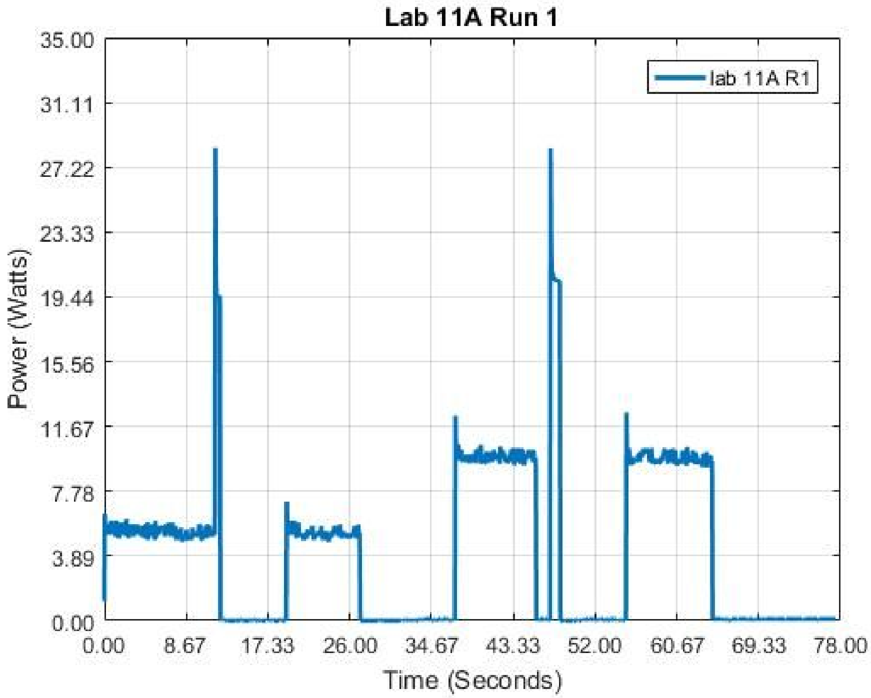


Figure 5: Lab 11A Run 1

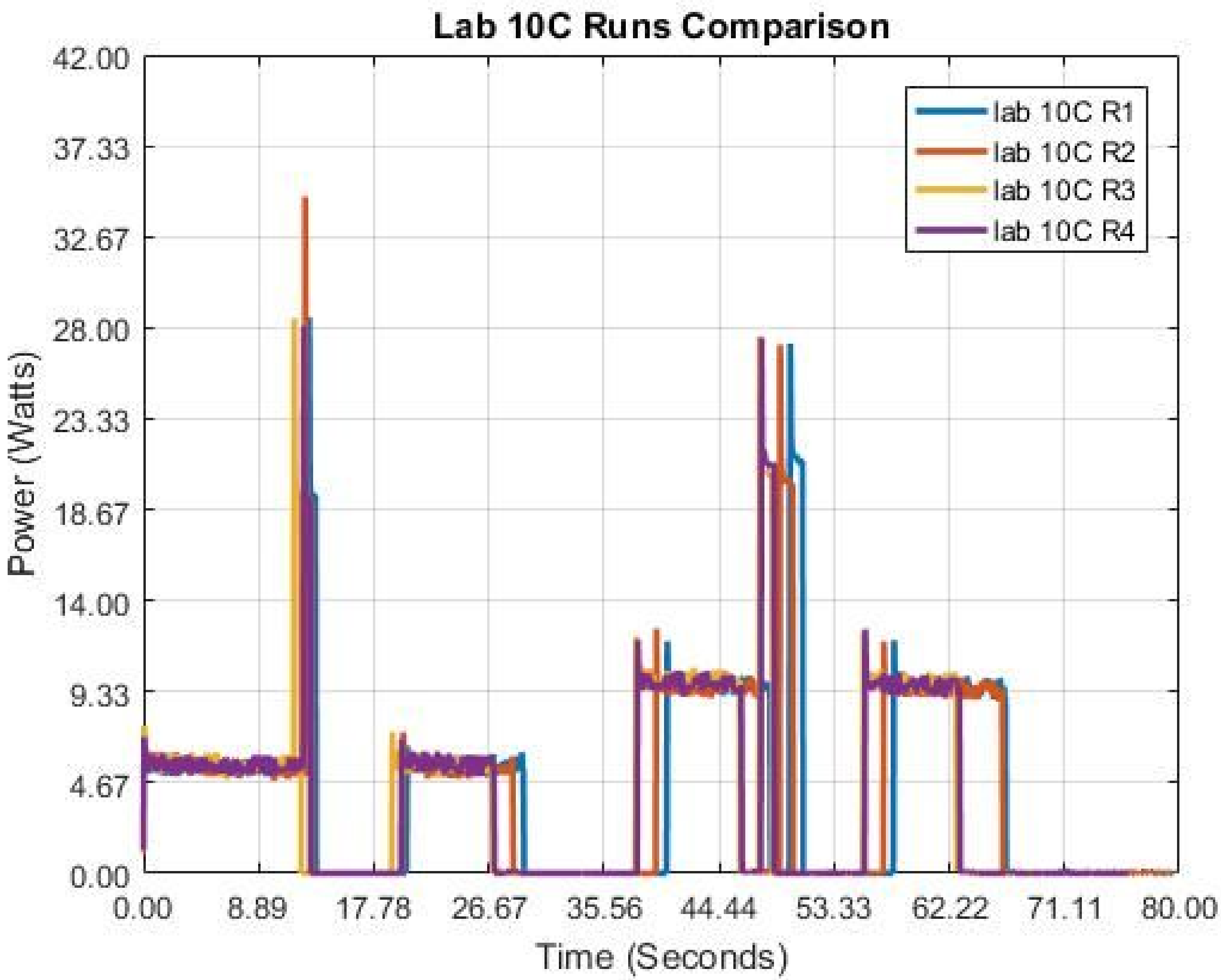


Figure 6: Lab 10C (Performance Test 3): Run Comparison

Table 5: Performance Test 3 Energy Comparison

Lab	Run	Energy Used (Joules)
10	1	313.058
	2	310.648
	3	291.548
	4	291.826

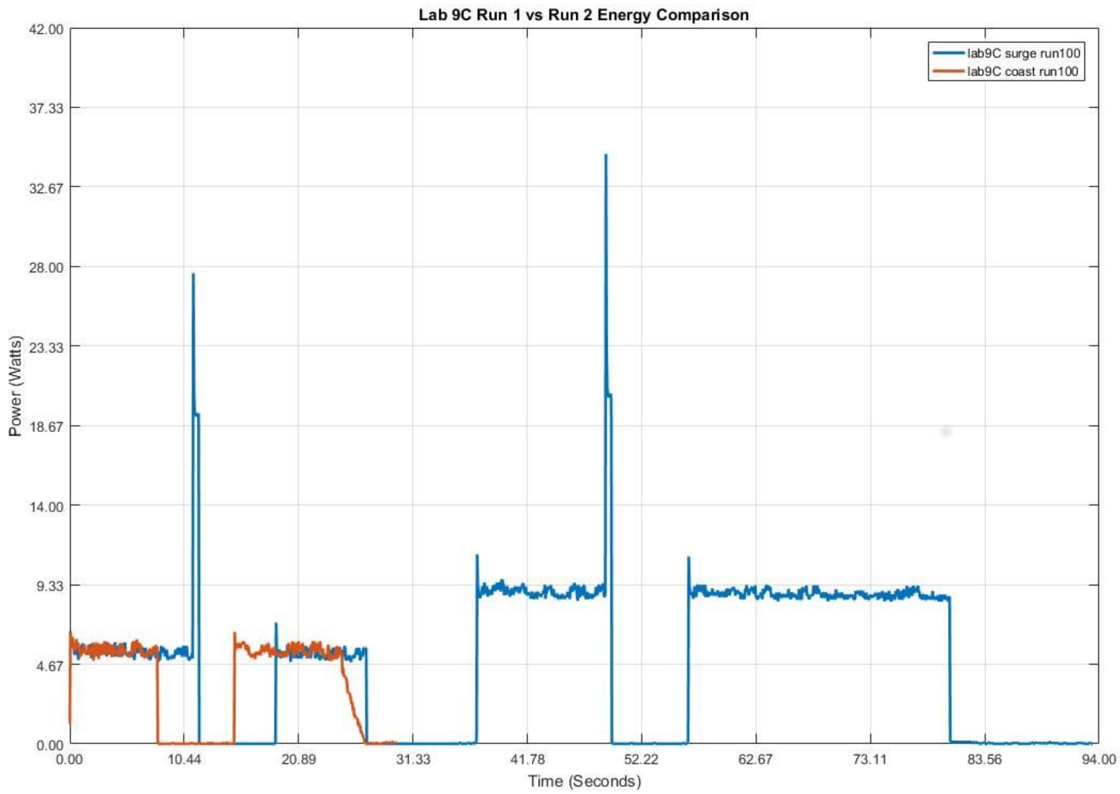


Figure 7: Lab 9C (Performance Test 2): Code Comparison

Test Run One: Start to Gate Lab 8A

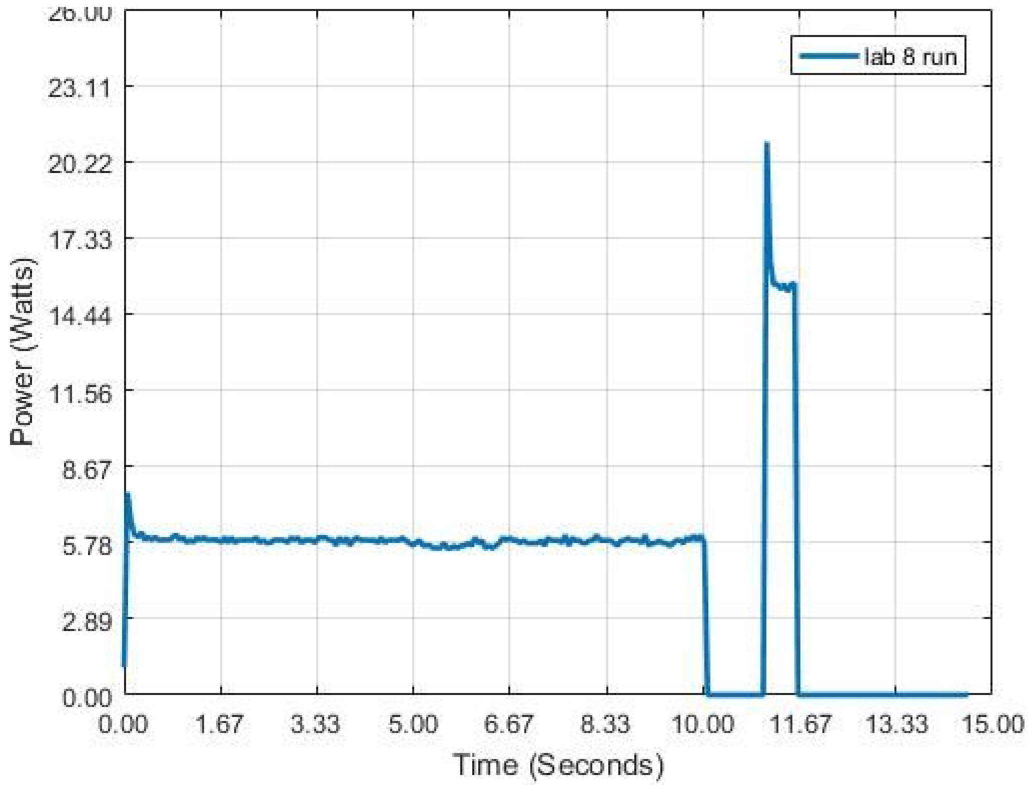


Figure 8: Lab 8A (Performance Test 1): Design Comparison

Table 6: Lab 8A Run 1 Phase Energy Breakdown

Phase	Arduino Code	Time(seconds)	Total Energy (joules)

1	reverse(4);
	motorSpeed(4,25);
	goFor(10);
		10	58.658

2	brake(4); goFor(1);	1	0

3	reverse(4);
	motorSpeed(4,60);
	goFor(.5);
		0.5	8.7557

4	brake(4);	4	0
		Total Energy:	67.4137

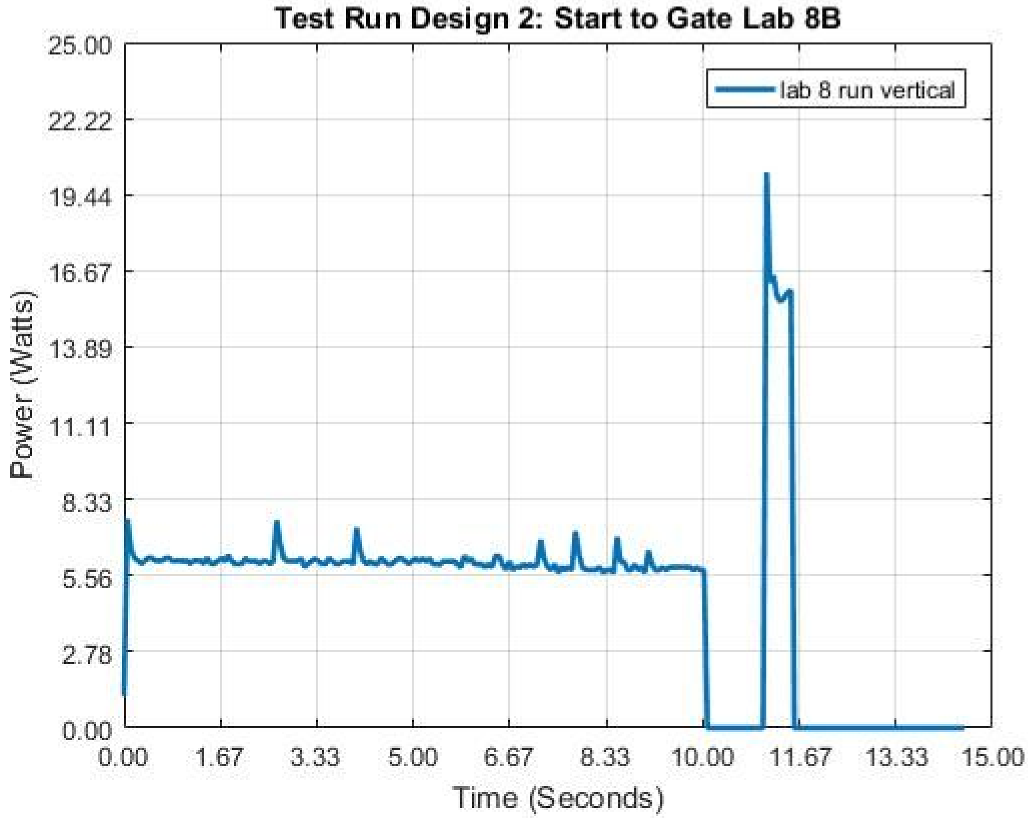


Figure 9: Lab 8A (Performance Test 1): Design Comparison

Table 7: Lab 8B Run 2 Phase Energy Breakdown

Phase	Arduino Code	Time(seconds)	Total Energy (joules)
1	reverse(4);	10	
	motorSpeed(4,25);		
	goFor(10);		60.6531
2	brake(4);	1	
	goFor(1);		0
3	reverse(4);	0.5	
	motorSpeed(4,60);		
	goFor(.5);		7.9044
4	brake(4);	4	0
		Total Energy:	68.5575

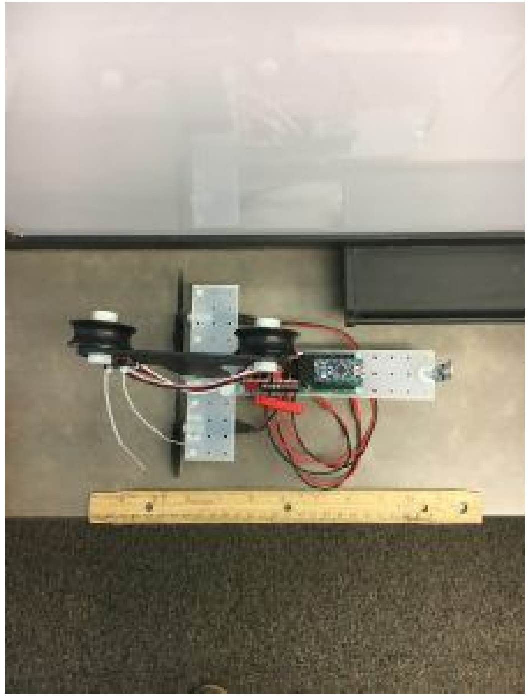


Figure 10: Final AEV Design Top View

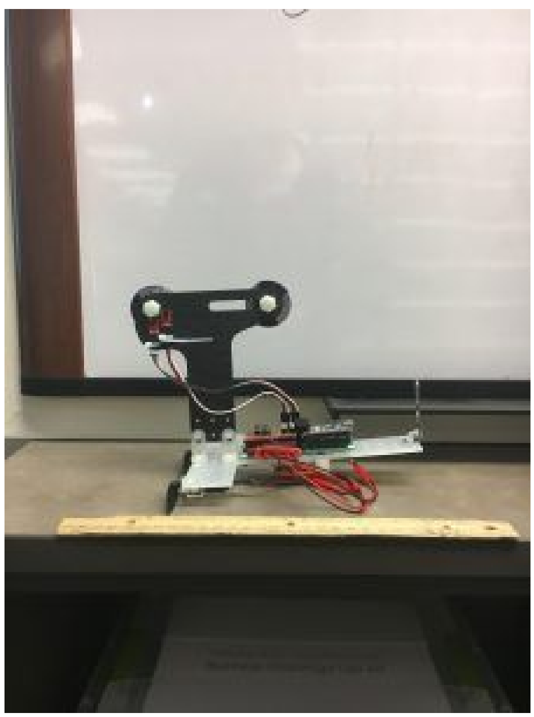


Figure 11: Final AEV Design Front View

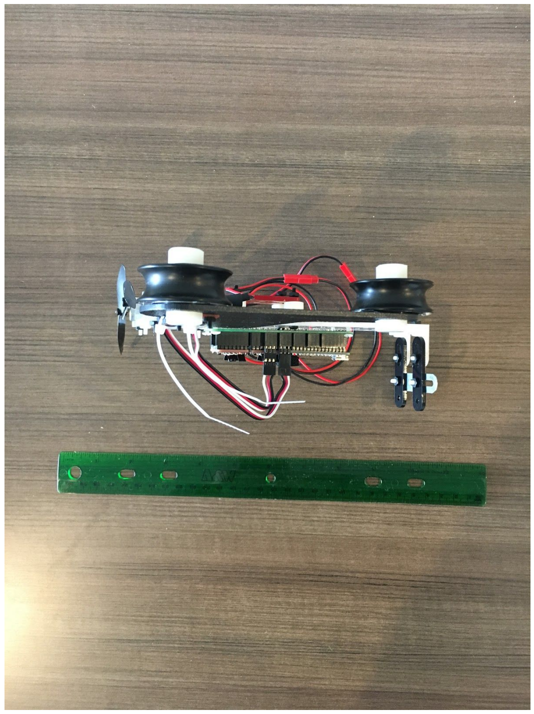


Figure 12: Vertical AEV Design Top View

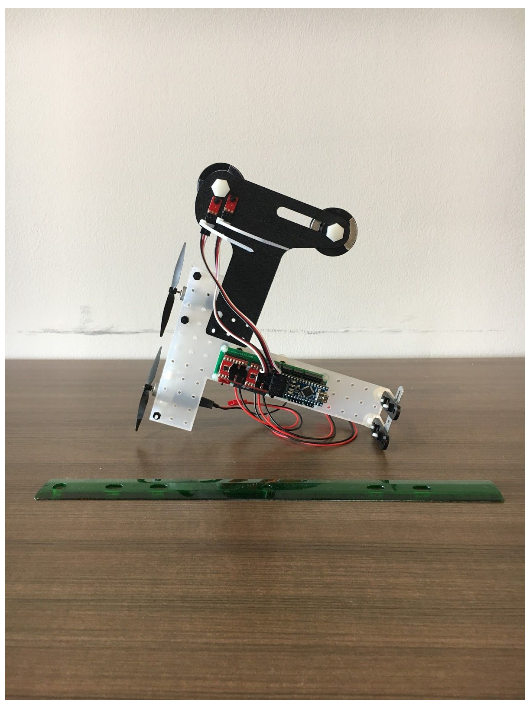


Figure 13: Vertical AEV Design Front View

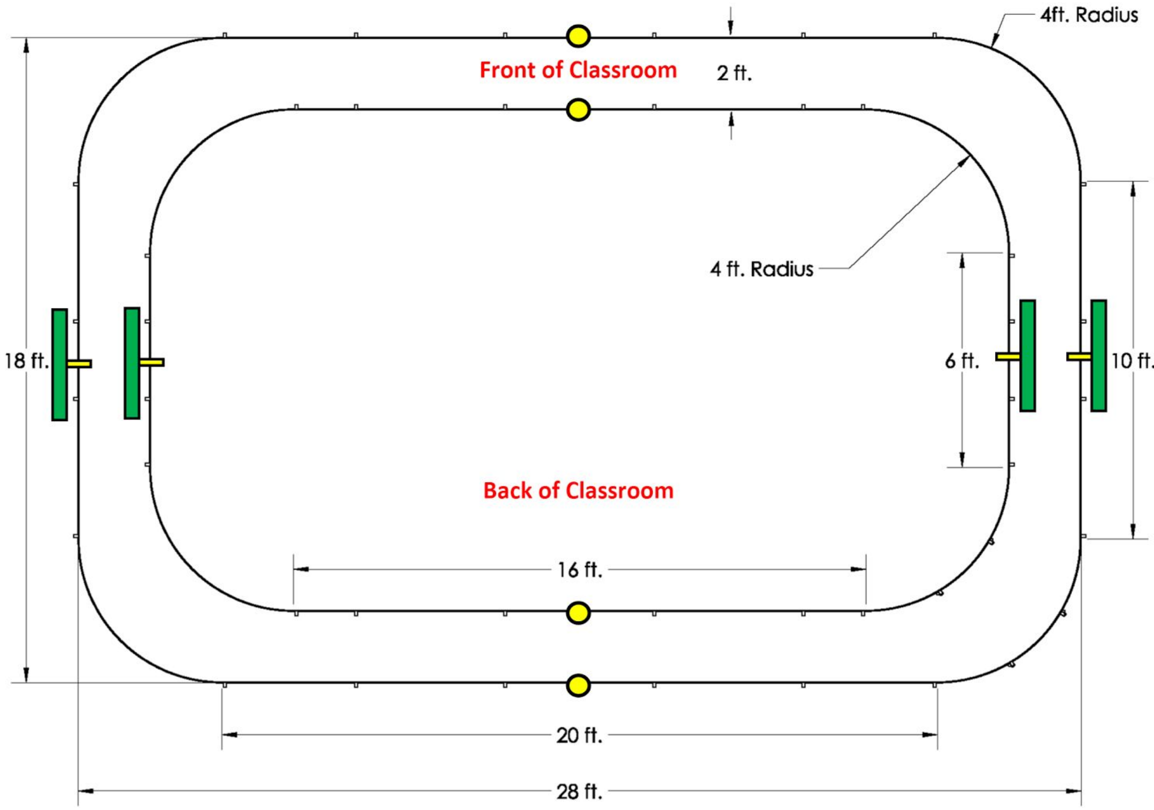


Figure 14: AEV Track Layout

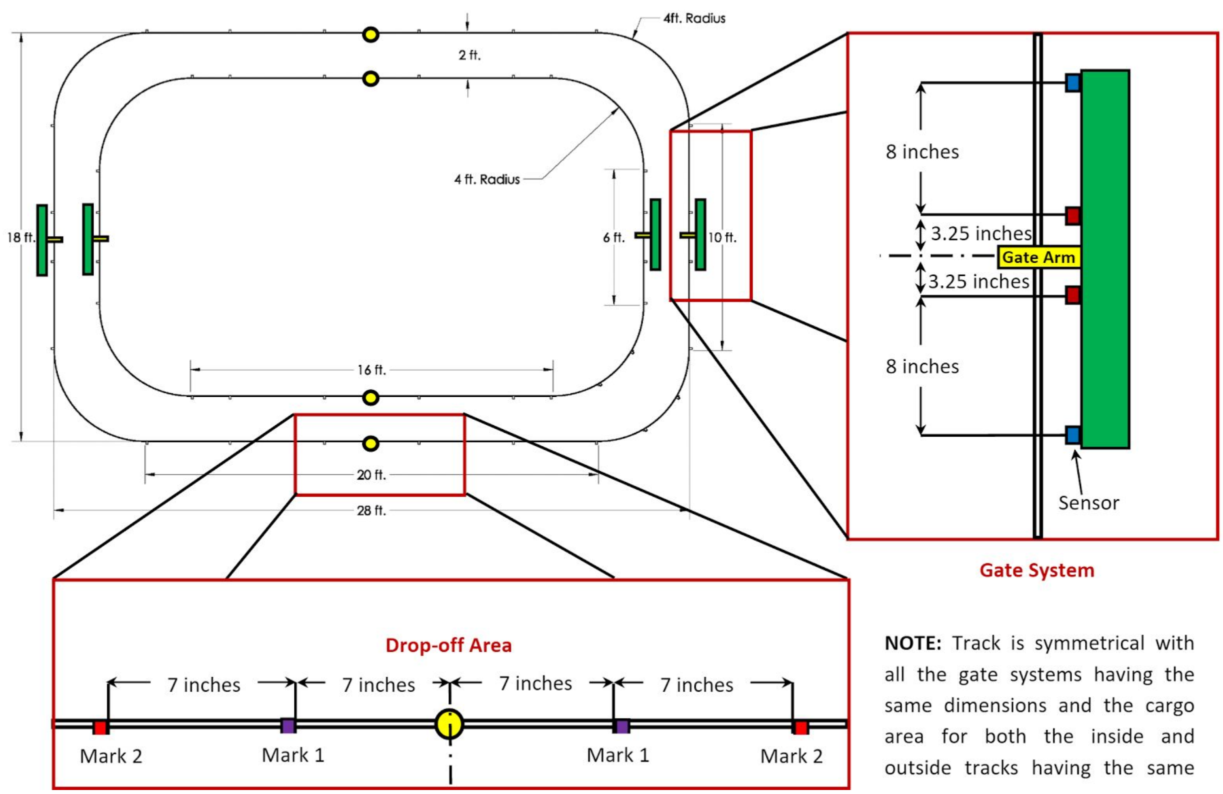


Figure 15: AEV Track Layout Beginning and Gate Specifics

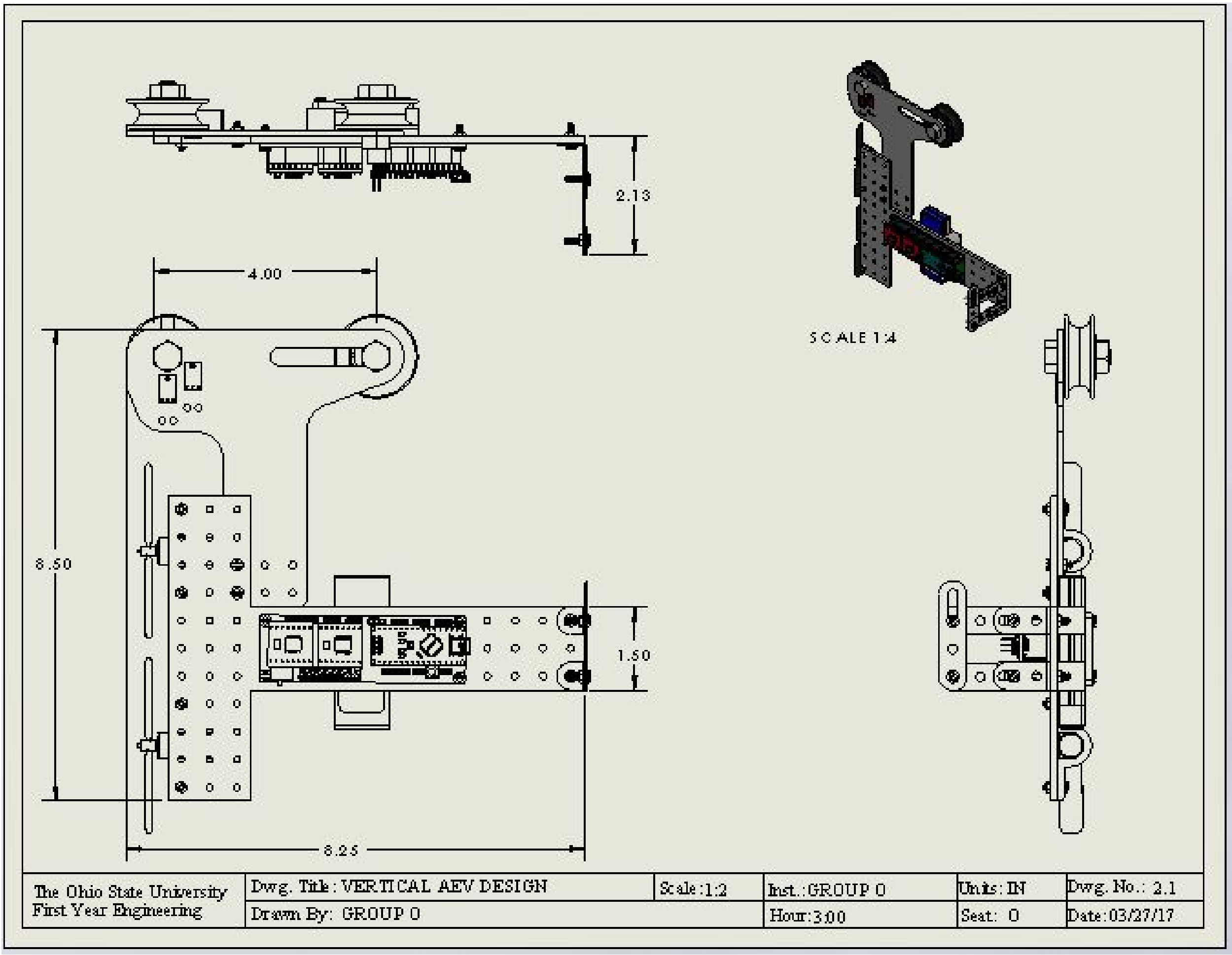
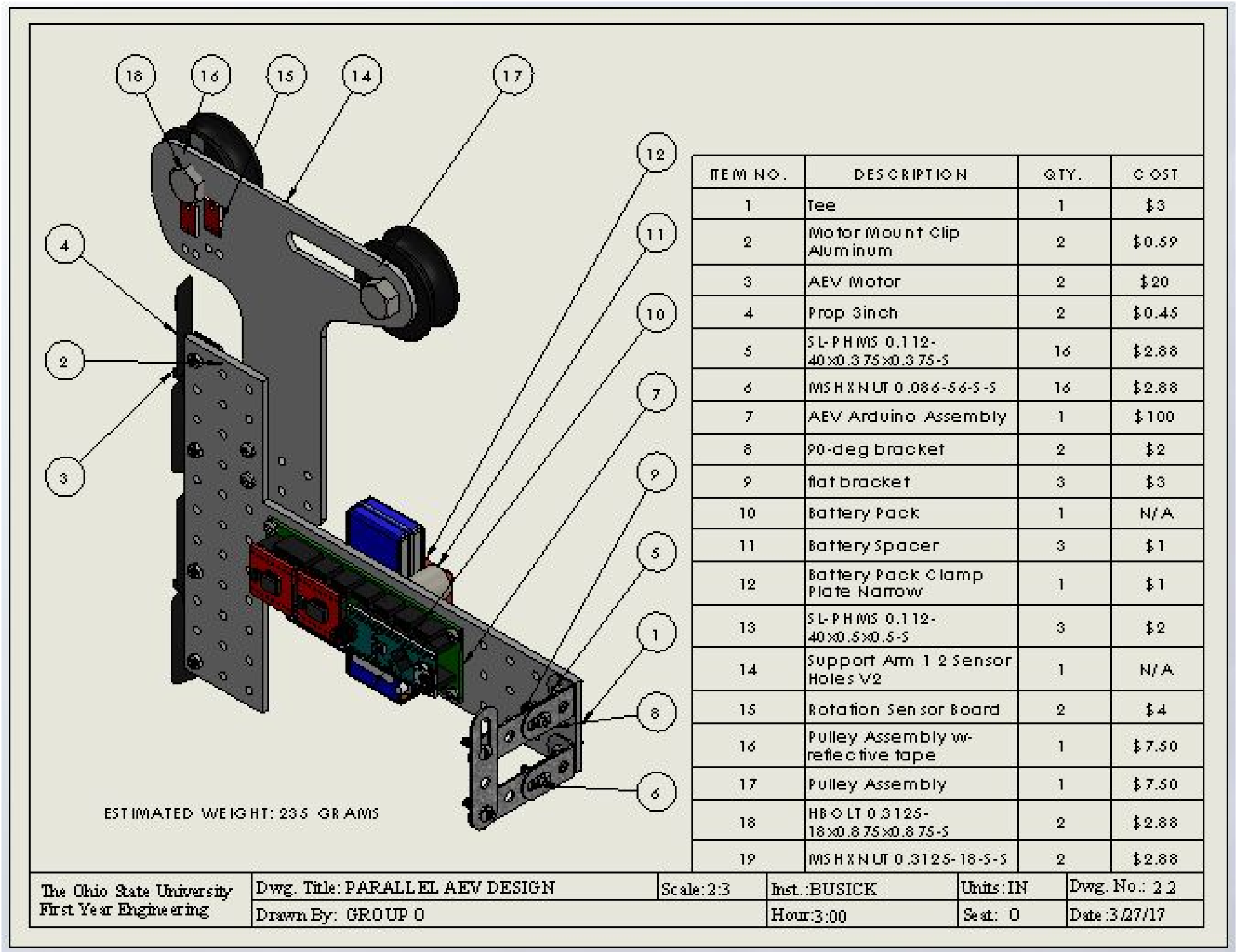


Figure 16: Primary Orthographic Views and Dimensions of Vertical AEV Design



ITEM NO.	DESCRIPTION	QTY.	COST
1	Tee	1	$3
2	Motor Mount Clip Aluminum	2	$0.59
3	AEV Motor	2	$20
4	Prop 3inch	2	$0.45
5	SL-PHMS 0.112-40x0.375x0.375-S	16	$2.88
6	MSHXNUT 0.086-56-S-S	16	$2.88
7	AEV Arduino Assembly	1	$100
8	90-deg bracket	2	$2
9	flat bracket	3	$3
10	Battery Pack	1	N/A
11	Battery Spacer	3	$1
12	Battery Pack Clamp Plate Narrow	1	$1
13	SL-PHMS 0.112-40x0.5x0.5-S	3	$2
14	Support Arm 1 2 Sensor Holes V2	1	N/A
15	Rotation Sensor Board	2	$4
16	Pulley Assembly w-reflective tape	1	$7.50
17	Pulley Assembly	1	$7.50
18	HBOLT 0.3125-18x0.875x0.875-S	2	$2.88
19	MSHXNUT 0.3125-18-S-S	2	$2.88

Figure 17: Bill of Materials for Vertical AEV Design

Table 8: Concept Screening Scoresheet

Success Criteria	Reference	Design Team	Design Melanie	Design Jennifer	Design Katie	Design Jessica
Balanced in turns	0	0	0	0	0	0
aerodynamics	0	+	+	+	+	+
center of gravity	0	+	0	0	0	0
maintenance	0	-	-	-	-	0
durability	0	0	0	0	0	0
cost	0	0	0	0	0	0
thrust/power	0	+	-	0	0	0
environmental	0	0	0	0	0	0
sum +s	0	3	1	1	1	1
sum 0s	8	4	5	6	6	7
sum -s	0	1	2	1	1	0
Net score	0	2	-1	0	0	1
Continue?	no	yes	no	combine	combine	yes

Table 9: Concept Scoring Matrix

		Team Reference		Jennifer/Katie		Jessica	
Success Criteria	weight	rating	weighted score	rating	weighted score	rating	weighted score
Balanced in turns	15	4	0.6	3	0.45	4	0.6
aerodynamics	25	3	0.75	4	1	4	1
center of gravity	15	4	0.6	3	0.45	3	0.45
maintenance	5	3	0.15	3	0.15	3	0.15
durability	10	3	0.3	4	0.4	3	0.3
cost	5	5	0.25	5	0.25	5	0.25
thrust/power	20	4	0.8	3	0.6	3	0.6
environmental	5	3	0.15	3	0.15	3	0.15
Total Score			3.6		3.45		3.5
Continue?		Develop		No		No	

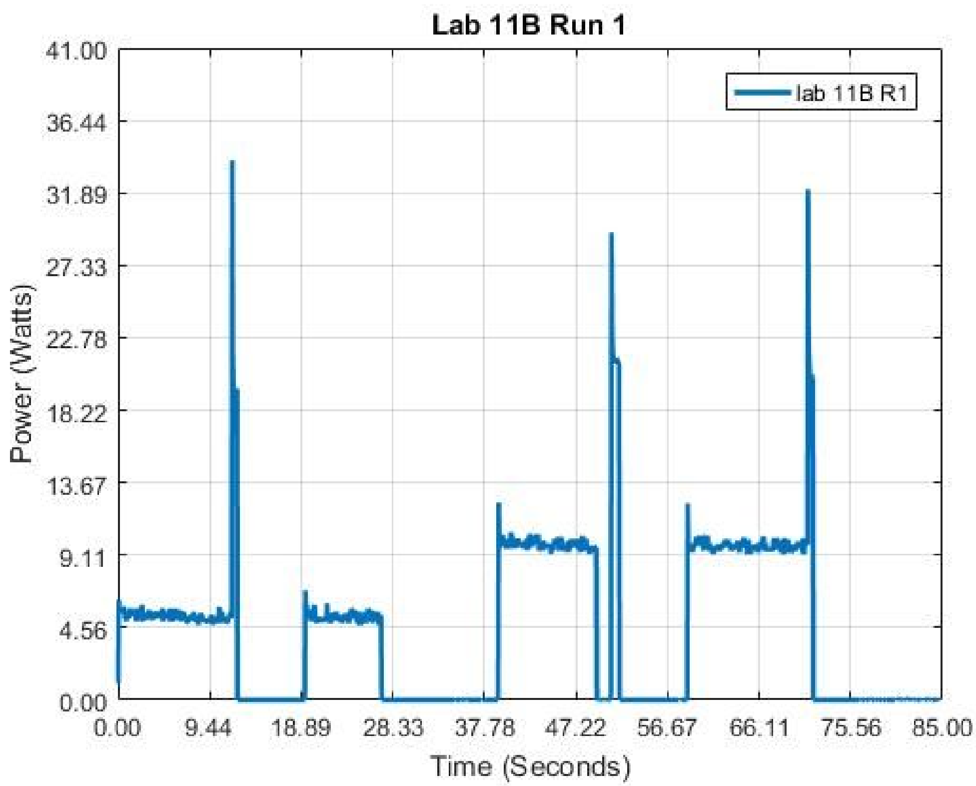


Figure 18: Lab 11B Run 1

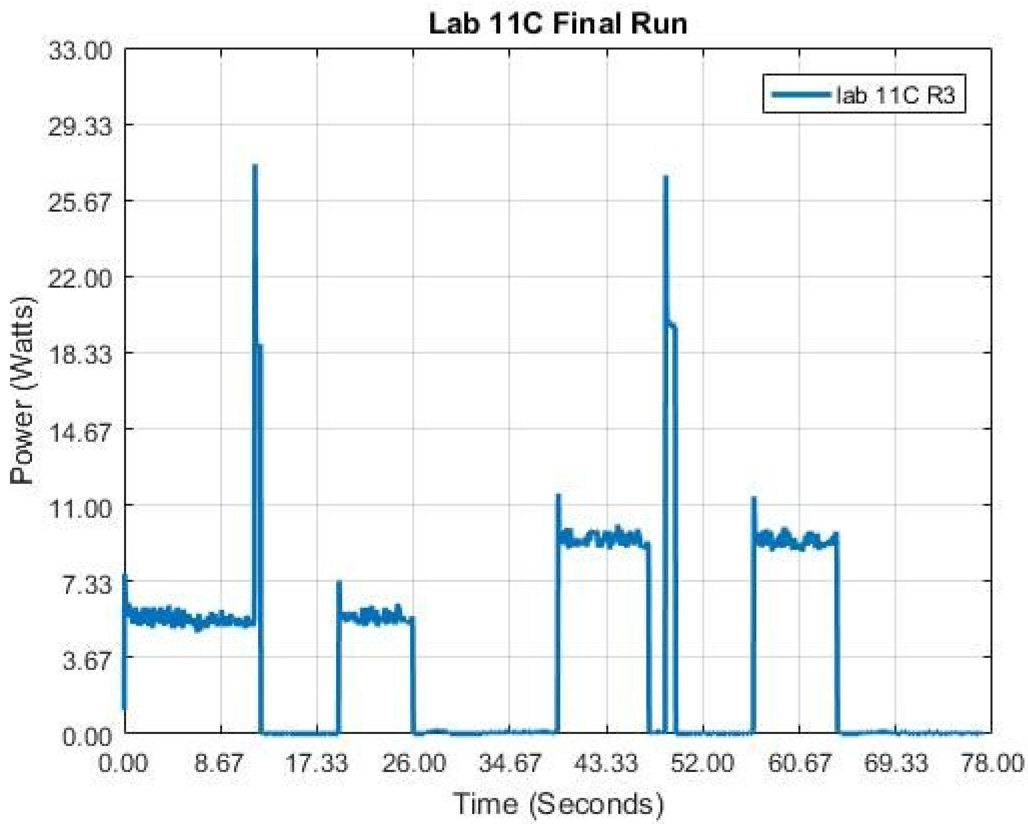


Figure 19: Lab 11C Final Test

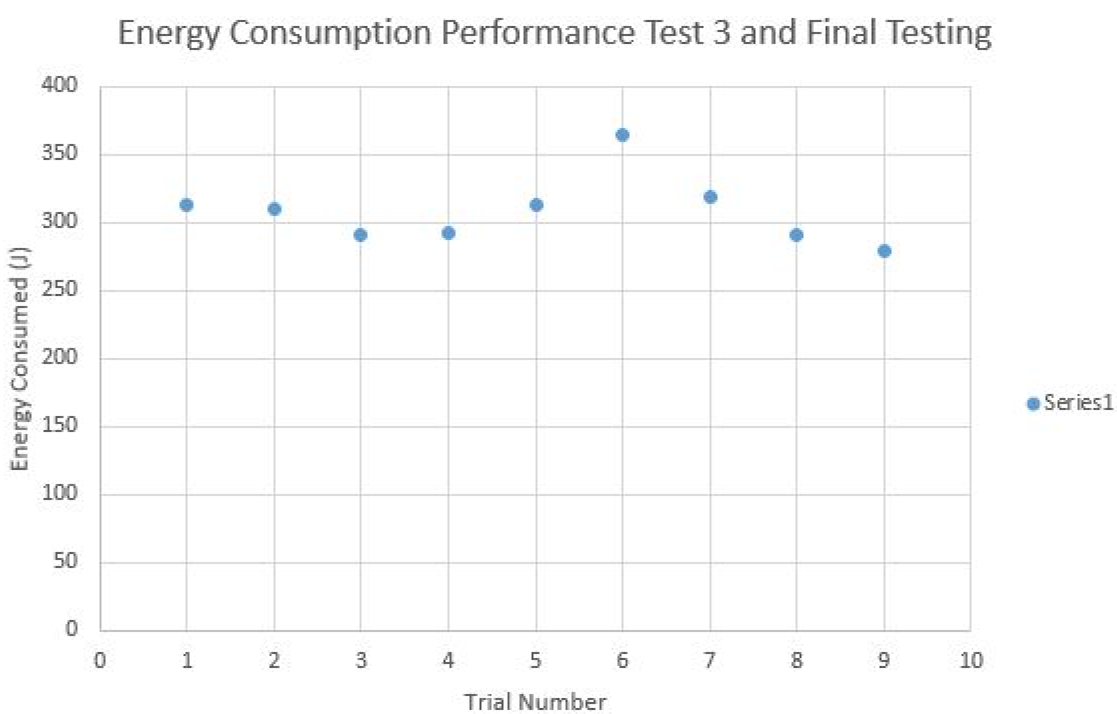


Figure 20: Energy Consumption over Performance Tests One and Two

Table 10: Energy Consumption for Performance Test 3 and Final Testing

Lab	Run	Energy Used (Joules)
10	1	313.058
	2	310.648
	3	291.548
	4	291.826
11	1	312.796
	2	364.84
	3	318.641
	4	291.528
	5	278.731

Table 11: Final Run Breakdown of Supplied Energy

Phase	Arduino Code	Time (sec)	Total Energy (Joules)

1	reverse(4);
	motorSpeed(4,23);
	goToRelativePosition(459);
		11.702	64.5302

2	reverse(4);
	motorSpeed(4,71);
	goFor(.5);
		0.6	10.7932

3	brake(4); goFor(7);	6.96	0.0372

4	reverse(4);
	motorSpeed(4,23);
	goToRelativePosition(244);
		6.72	37.3278

5	brake(4);
	goFor(6);
	goFor(7);
		12.96	0.7967

6	reverse(4);
	motorSpeed(4,37);
	goToRelativePosition(-325);
		8.22	76.5302

7	brake(4); goFor(1.5);	1.44	0.1178

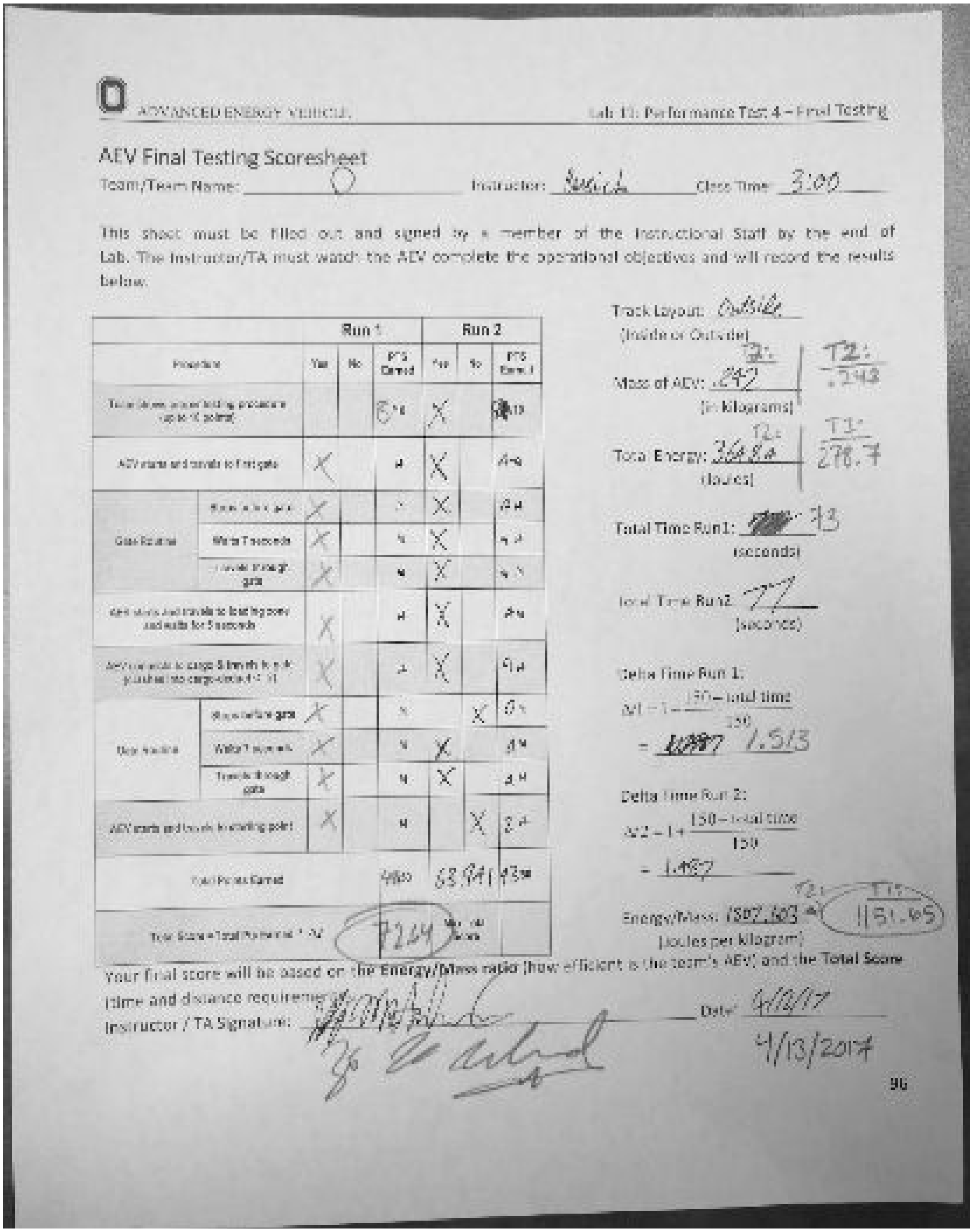
8	reverse(4);
	motorSpeed(4,71);
	goFor(.9);
		0.96	18.191

9	brake(4); goFor(7);	6.84	0.0868

10	reverse(4);
	motorSpeed(4,37);
	goToRelativePosition(-295);
		8.04	69.8255

11	brake(4);
	goFor(5);
	goFor(5);
		12.66	0.4991

	Total:	77.102	278.7355



ADVANCED ENERGY VEHICLE — Lab 13: Performance Test 4 – Final Testing

AEV Final Testing Scoresheet

Team/Team Name: O   Instructor: [illegible]   Class Time: 3:00

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.

Track Layout: Outside (Inside or Outside)

Mass of AEV: .242 (in kilograms) T2: .242

Total Energy: 364.8 (Joules) T1: 278.7

Total Time Run1: 73 (seconds)

Total Time Run2: 77 (seconds)

Delta Time Run 1: $\Delta t1 = 1 + \frac{150 - \text{total time}}{150}$ = 1.513

Delta Time Run 2: $\Delta t2 = 1 + \frac{150 - \text{total time}}{150}$ = 1.487

Energy/Mass: 1507.603 (Joules per kilogram) T1: 1151.65

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: [illegible]   Date: 4/12/17   4/13/2017

96

Figure 21: Final Testing Scoresheet

ENGR 1182 - AEV Final Test Results

Section 7219

Enter scores in blue fields

Team	Inside / Outside	AEV Mass (kg)	Total Energy (J)	Run Time (s)	Delta t	Energy / Mass (J/kg)	Points Earned (out of 50)	Total Score = Points Earned * Delta t	AEV Kit Turned In	Team
A	Outside	0.235	373.4	57.0	1.62	1589	48	77.8	Yes	A
B	Outside	0.212	301.5	72.1	1.52	1422	46	69.9		B
C	Outside	0.257	436.4	62.0	1.59	1698	50	79.3		C
D	Outside	0.215	408.0	54.0	1.64	1898	48	78.7		D
E	Inside	0.238	392.2	66.0	1.56	1648	40	62.4		E
F	Inside	0.230	367.2	84.3	1.44	1596	46	66.2		F
G	Inside	0.229	414.0	54.4	1.64	1808	48	78.6	Yes	G
H	Inside	0.315	412.8	80.5	1.46	1310	50	73.2	Yes	H
I	Inside	0.261	368.0	62.0	1.59	1410	44	69.8		I
J	Inside	0.243	207.9	53.6	1.64	856	50	82.1	Yes	J
K	Inside	0.209	295.2	51.0	1.66	1413	50	83.0		K
L	Inside	0.234	342.0	55.0	1.63	1462	48	78.4		L
M	Inside	0.167	333.9	66.0	1.56	2000	48	74.9		M
N	Inside	0.272	220.0	55.0	1.63	809	49	80.0		N
O	Outside	0.243	278.7	73.0	1.51	1147	48	72.6		O
P	Outside	0.275	431.0	59.0	1.61	1567	48	77.1		P
Q	Outside	0.235	354.0	60.0	1.60	1506	49	78.4		Q
R	Outside	0.253	355.1	69.0	1.54	1403	47	72.4		R

Table 12: Final Test Class Results

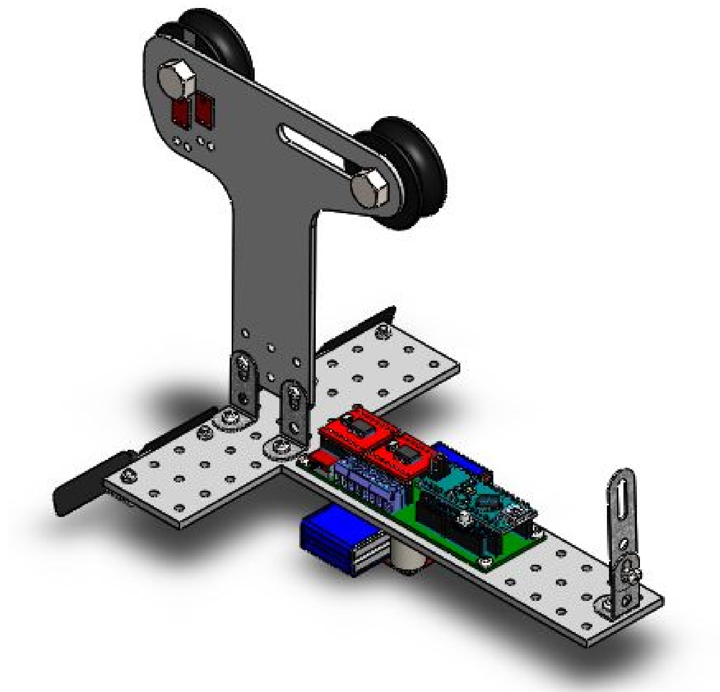
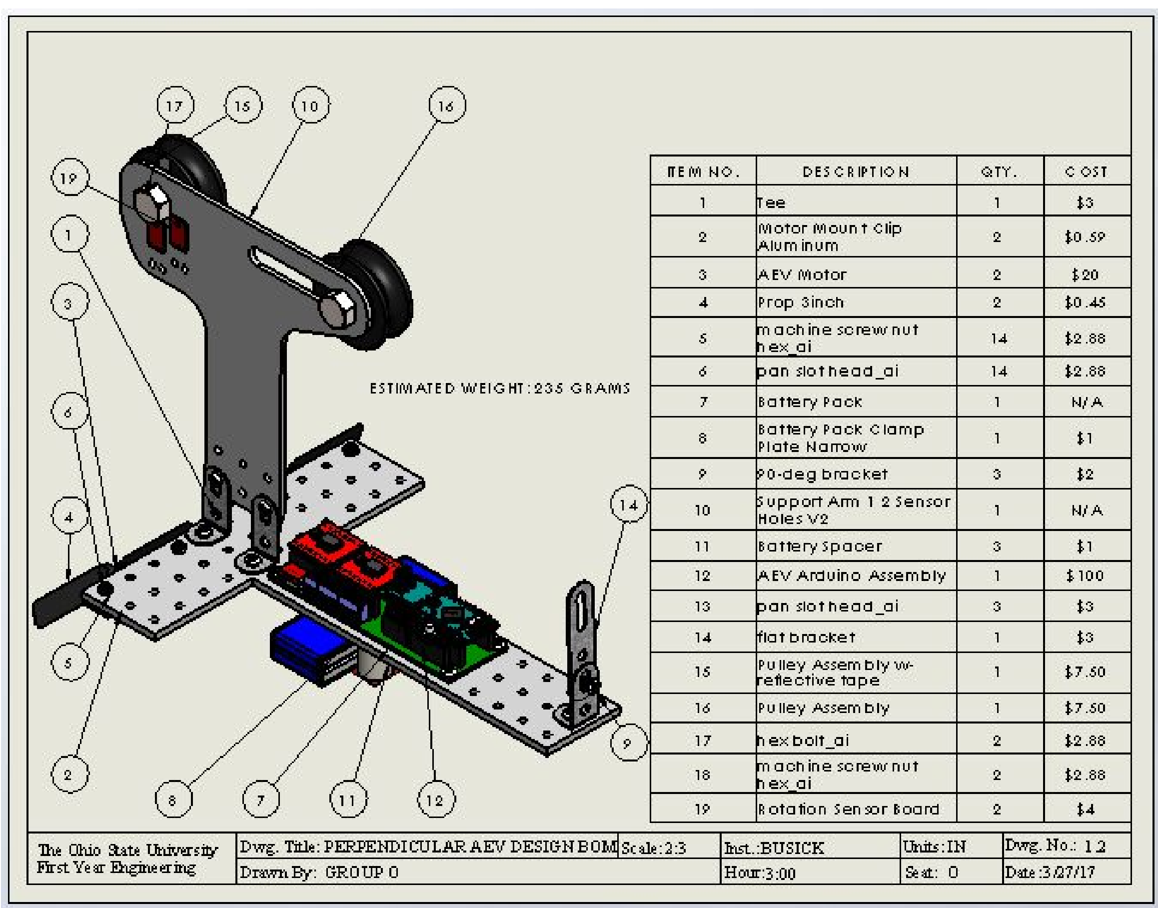


Figure 22: Final AEV Design



ITEM NO.	DESCRIPTION	QTY.	COST
1	Tee	1	$3
2	Motor Mount Clip Aluminum	2	$0.59
3	AEV Motor	2	$20
4	Prop 3inch	2	$0.45
5	machine screw nut hex_ai	14	$2.88
6	pan slothead_ai	14	$2.88
7	Battery Pack	1	N/A
8	Battery Pack Clamp Plate Narrow	1	$1
9	90-deg bracket	3	$2
10	Support Arm 1 2 Sensor Holes V2	1	N/A
11	Battery Spacer	3	$1
12	AEV Arduino Assembly	1	$100
13	pan slothead_ai	3	$3
14	flat bracket	1	$3
15	Pulley Assembly w-reflective tape	1	$7.50
16	Pulley Assembly	1	$7.50
17	hex bolt_ai	2	$2.88
18	machine screw nut hex_ai	2	$2.88
19	Rotation Sensor Board	2	$4

Figure 23: Final AEV Design Bill of Materials

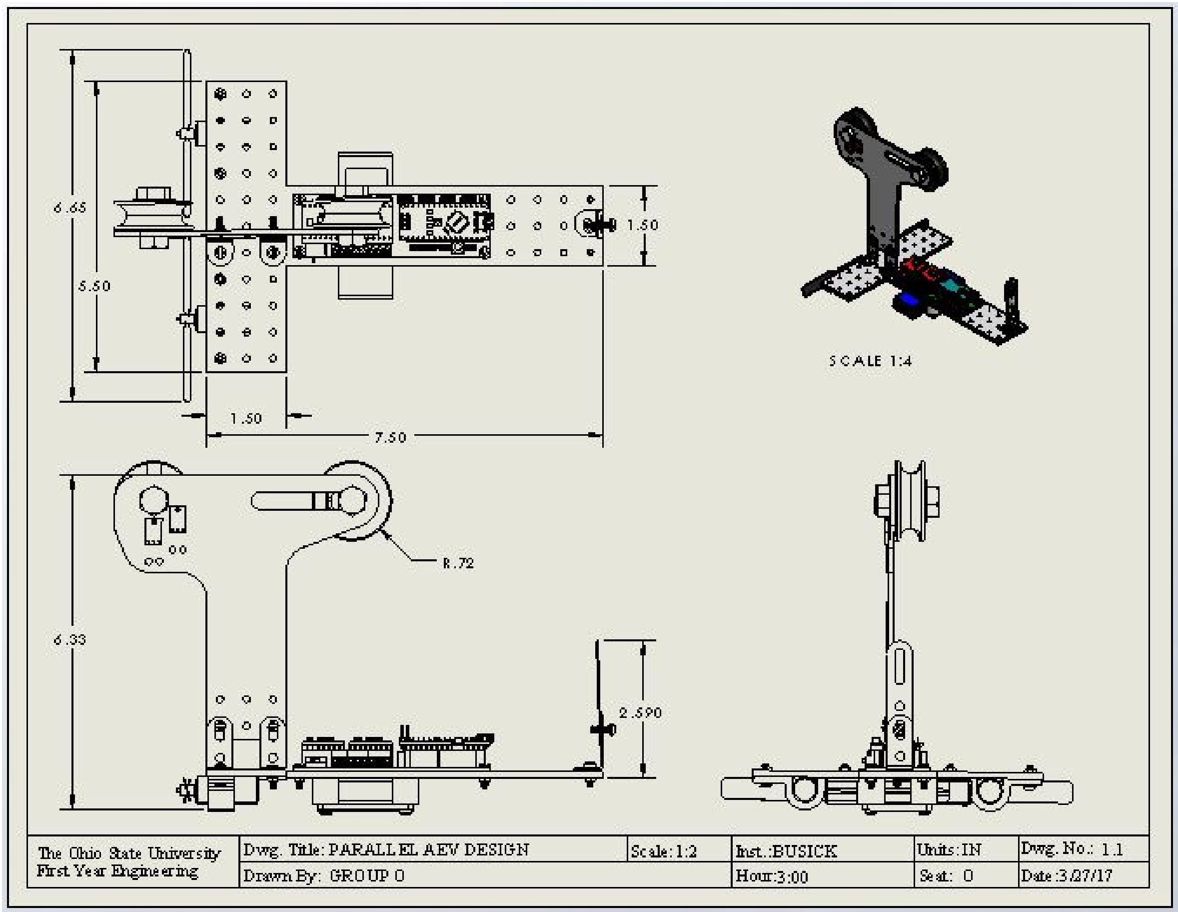


Figure 24: Final AEV Design Orthographic Views

Arduino Codes

Performance Test 1 Code 1

```
reverse(4);
motorSpeed(4,25);
goFor(10);
brake(4);
goFor(1);
reverse(4);
```

Performance Test 2 Code 1

```
//Positions are for upstairs track
//First quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(463);
reverse(4);
motorSpeed(4,71);
goFor(.5);
```

```
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(318);
brake(4);
goFor(5);
goFor(5);

//3rd quarter
//start back with r2 unit
reverse(4);
motorSpeed(4,35);
goToRelativePosition(-415);differently
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
reverse(4);
motorSpeed(4,35);
goToRelativePosition(-310);
brake(4);
goFor(5);
goFor(5);
```

Performance Test 2 Code 2

```
//Positions are for upstairs track
//First quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(230);
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
motorSpeed(4,22);
goToRelativePosition(318);
celerate(4,20,0,2); //or just do brake(4)
```

Performance Test 3 Code 1

```
//Positions are for upstairs track
//First quarter
reverse(4);
```

```
motorSpeed(4,22);
goToRelativePosition(460);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(314);
brake(4);
goFor(6);
goFor(5);

//3rd quarter
//start back with r2 unit
reverse(4); //don't do this if servo design
motorSpeed(4,37);
goToRelativePosition(-340); //go further? because heavier=accelerate differently
goFor(1);
reverse(4);
motorSpeed(4,73);
goFor(.5);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
reverse(4);
motorSpeed(4,37);
goToRelativePosition(-310);
brake(4);
goFor(5);
goFor(5);
```

Performance Test 3 Code 2

```
//Positions are for upstairs track
//First quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(460);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //stop at gate for 7 seconds
```

```
//2nd quarter
reverse(4);
motorSpeed(4,22);
goToRelativePosition(312);
brake(4);
goFor(6);
goFor(5);

//3rd quarter
//start back with r2 unit
reverse(4); //don't do this if servo design
motorSpeed(4,37);
goToRelativePosition(-335); //go further? because heavier=accelerate differently
goFor(1);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
reverse(4);
motorSpeed(4,37);
goToRelativePosition(-334);
brake(4);
goFor(5);
goFor(5);
```

Performance Test 3 Code 3

```
reverse(4);
motorSpeed(4,23);
goToRelativePosition(460);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
reverse(4);
motorSpeed(4,23);
goToRelativePosition(325);
brake(4);
goFor(6);
goFor(5);
```

```
//3rd quarter
//start back with r2 unit
reverse(4); //don't do this if servo design
motorSpeed(4,37);
goToRelativePosition(-301); //go further? because heavier=accelerate differently
brake(4);
goFor(1.5);
reverse(4);
motorSpeed(4,71);
goFor(1);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
reverse(4);
motorSpeed(4,37);
goToRelativePosition(-265);
brake(4);
goFor(5);
goFor(5);
```

Performance Test 3 Code 4

```
//Positions are for downstairs track
//First quarter
reverse(4);
motorSpeed(4,23);
goToRelativePosition(460);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
reverse(4);
motorSpeed(4,23);
goToRelativePosition(275);
brake(4);
goFor(6);
goFor(5);

//3rd quarter
//start back with r2 unit
reverse(4); //don't do this if servo design
motorSpeed(4,37);
goToRelativePosition(-303); //go further? because heavier=accelerate differently
brake(4);
```

```
goFor(1.5);
reverse(4);
motorSpeed(4,71);
goFor(1);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
reverse(4);
motorSpeed(4,37);
goToRelativePosition(-271);
brake(4);
goFor(5);
goFor(5);
```

Final Code

```
//First quarter
reverse(4);
motorSpeed(4,23);
goToRelativePosition(459);
reverse(4);
motorSpeed(4,71);
goFor(.5);
brake(4);
goFor(7); //stop at gate for 7 seconds

//2nd quarter
reverse(4);
motorSpeed(4,23);
goToRelativePosition(244);
brake(4);
goFor(6);
goFor(7);

//3rd quarter
//start back with r2 unit
reverse(4); //don't do this if servo design
motorSpeed(4,37);
goToRelativePosition(-325); //go further? because heavier=accelerate differently
brake(4);
goFor(1.5);
reverse(4);
motorSpeed(4,71);
goFor(.9);
brake(4);
goFor(7); //brake at gate for 7 seconds

//4th quarter
```

```
reverse(4);
motorSpeed(4,37);
goToRelativePosition(-295);
brake(4);
goFor(5);
goFor(5);
```