Preliminary Design Review

Submitted to

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March 22nd, 2022

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Executive Summary:

The purpose of this lab is to learn about energy management, operational efficiency, and operational consistency while applying coding skills. To learn about these aspects, a situation was presented that required a small AEV to be created that would automatically hook up to a cart that can be transported to different stations along the track. The goal was to create one of these AEV's the most efficient and consistent way possible. The AEV will use absolute position tracking to acutely position itself in the required spots while being the most efficient as possible. In this certain situation, an energy efficient AEV is required because the park this would be built in is secluded and does not have much access to electricity. Because the vehicle has limited access to electricity, it must use as little energy as possible hence why it must be as efficient as possible. To produce a design for an energy efficient AEV, 2 different AEVs were built and tested, while various aspects were then inspected to determine which one was more efficient. The first AEV design, design 1, was based partly off of the original model given at the beginning of the lab. Design 1 was built and modified to use the 3-bladed propellers and as well was made for components to be attached on the bottom. Design 1 was then tested, and the data was taken from the EEPROM and converted into useful data using a MATLAB script coded by a lab member. Design 1 was then taken apart and Design 2 was constructed. Design 2 took the same energy efficient approach as Design 1 making sure to use the 3-bladed propellers as well as a bottom mounted Arduino. However, Design 2 was made for its looks partly using the X-Wing from *Star Wars* as well as its stability. Design 2 was then run, and the data was taken from the EEPROM and converted one again into useful information using the MATLAB script.

Introduction:

The purpose of the AEV project is to create an energy efficient and autonomous vehicle to transport people and cargo along a monorail inside a national park. The vehicle must conserve as much energy as possible since the power at the park is limited and stranding the tourists or cargo is not an option. The project is important because creating a model AEV allows for rapid prototyping and configurations that if otherwise started on a large scale would take months or even years to complete, however using small scale AEVs, major changes can be completed in days and smaller changes can be completed in hours. The AEV will focus on energy management, operation efficiency, and operational consistency. The AEV will go slow enough to allow for the passengers and cargo to have a comfortable ride ensuring that passengers do not fall off the cart. The AEV will have energy per kilogram minimized to prevent energy waste.

AEV Initial Concepts:

In Performance Test 1 two designs were compared to see which was better suited to the task explained above. Design 1 was inspired by the sample AEV given at the beginning of the lab, from there it was adapted for the highest energy efficiency and the lowest mass, as well improving the aerodynamic drag experienced by the model through the addition of a battery carrier which was 3-d printed. Design 2 attempted to further these improvements made through, attempting to further decrease drag by decreasing the width of the airframe used. This also attempted to lower the mass used and decrease the energy used per kilogram. Design 2 was made for its striking resemblance to the x-wing from *Star Wars* additionally it would be more stable. The designs originally created in lab 1 were all abandoned besides Design Model B

(Figure 12), this was because Design Model B incorporated the best features known at that time. However, since then experiments have improved the knowledge and better choices have been made. For instance, the choice to put the Arduino on the bottom to allow for an optimal center of gravity location. Or the incorporation of an aerodynamic battery carrier which decrease drag and optimizes C.G location. All changes were based off experience gained in experiments. The prototypes allowed for the AEV to have the best starting configuration possible that would then be edited to a more efficient model. For instance, the aerodynamic shield in Design Model B allowed for the thought of the aerodynamic shield on the battery carrier. Which will also be used to hold the servo that will hook onto the cart (shown at the start of the AEV in figures 9 and 10).

Results and Discussion:

Performance Test 1 was conducted last week and generated valuable information in determining the most energy efficient AEV (Advanced Energy Vehicle) design. Both designs (refer to figures #9 and #10 in the Appendix for design projections of 1 and 2 respectively) were similar in many aspects: monorail hangar attachment placement, hangar attachment used, Arduino assembly controller placement, and others. The differences between the vehicles were the number of wings, the central plastic base used for holding all the components, the motor placement, and the battery placement. In addition, a 3-D printed part was featured on design 1. This 3-D printed part was created to holster the battery on the front of the vehicle while allowing better aerodynamics it also functioned to hold the servo that would hook the AEV to the cart. Three designs were originally created by the group in experiment 1: Creative Design Thinking, (with the addition of a sample design for a total of 4) which encouraged creative thinking regarding combinations of parts for energy efficiency. These combinations in experiment 1 influenced the structures of designs 1 and 2 in several ways- most notably the need for a 3-D printed part (See figures #11, #12, and #13 for design concepts in experiment 1).

Design 1 was selected by judging other designs based off a design concept screening and scoring sheet (refer to tables 6 and 7 for concept screening and scoring sheets respectively). A design was created by each team member with the addition of the sample design (from experiment 1) for a total of 4 (refer to figures #11, #12, and #13 for orthographic projections of the 3 original designs). These designs were then judged on characteristics that were vital to the success of the AEV: balance, center-of-gravity location, durability, cost, environmental impact, look, etc. Design B from the concept screening and scoring was chosen to continue onto Performance Test 1 under the new name of “Design 1”. Design 2 in Performance test 1 was made to incorporate the fundamental qualities of design 1 based off the concept screening and scoring sheet, such as low energy usage and center of gravity location however it would also add stability and looks to the AEV. The goal with Design 2 was to create a better looking AEV more stable, as well as improving on the aerodynamic characteristics of the design by decreasing the width of the base section.

Ultimately the double wing structure of Design 2 led to an increase in weight as well as a decrease in the thrust experienced by the AEV because of an increase in drag between the propeller slipstream and wing structure, making Design 2 less efficient. While the graphs and data alone support this energy inefficiency hypothesis, Design 2 was unable to traverse the incline portions of the track with the code that Design 1 ran on. While Design 1 was able to traverse the entire half-track run. This comparison allowed a simple conclusion to be made about the energy usage of Design 2. However, subsequent tests were done to ensure this, the half-track run code used was then modified to allow Design 2 to complete the half-track run. Modifications consisted of increasing motor power percentages and changing the absolute position values where the AEV needed to stop. Design 1 consumed a total of 69.323J of energy completing the half-track run (Table #3), while Design 2 consumed a total of 114.18J on the same run (Table #3). This was a significant difference which the team didn't expect. The team made Designs 1 and 2 to be similar, however Design 2 performed poorly in comparison. This information contributed to the group decision of continuing with Design 1.

Performance Test 1 was important to the design process because it demonstrated the need for a light vehicle. Ideally, future changes made to the AEV should help make the vehicle lighter or stay the same weight and improve aerodynamic characteristics. Design 2 was less aerodynamic than design 1 for 1 reason, the double winged structure increased the drag between the wings and the propeller slipstream, which caused the AEV to benefit from less force than the motors were producing. Furthermore, one of design 2's motors were offset a couple degrees. While it was mostly unnoticeable to the eye, this error likely impacted the motors contribution to the overall thrust of the vehicle. However, this offset motor was an innate part of the vehicle based on the parts available, meaning it could not be fixed without an improvement in available building parts or manufacturing new building parts. This process would likely be a waste of time and possibly add more weight to the vehicle. The System Analysis tests 1 and 2 gave the team direction with how to code the designs for Performance Test 1. This experiment involved testing different coding functions which have the same outcome but different ways of getting there. Most notably, these tests compared using the celerate command and the motorSpeed command. Figures #14 and #15 show the celerate and motorSpeed performances during their respective flat track runs. The motorSpeed command uses less total energy in this run and as well takes less time. Additionally, a fatal error could occur when using the cellerate command, if the cellerate command were to be active (meaning the code is still increasing the power of the motors) and the AEV were to go past a position that was used in the next line of code to stop the AEV(in Arduino it would look like this: celerate(10,40,4,4);
goToAbsolutePosition(10*(8/3.901)), then the AEV would never stop and the safety of passengers would be at risk. This information showed the team that the motorSpeed command should be used primarily rather than celerate, however small time values for celerate could be used to reduce strain on motors. The half-track code was created using this style. Performance tests will help gauge AEV efficiency throughout the future of the design process.

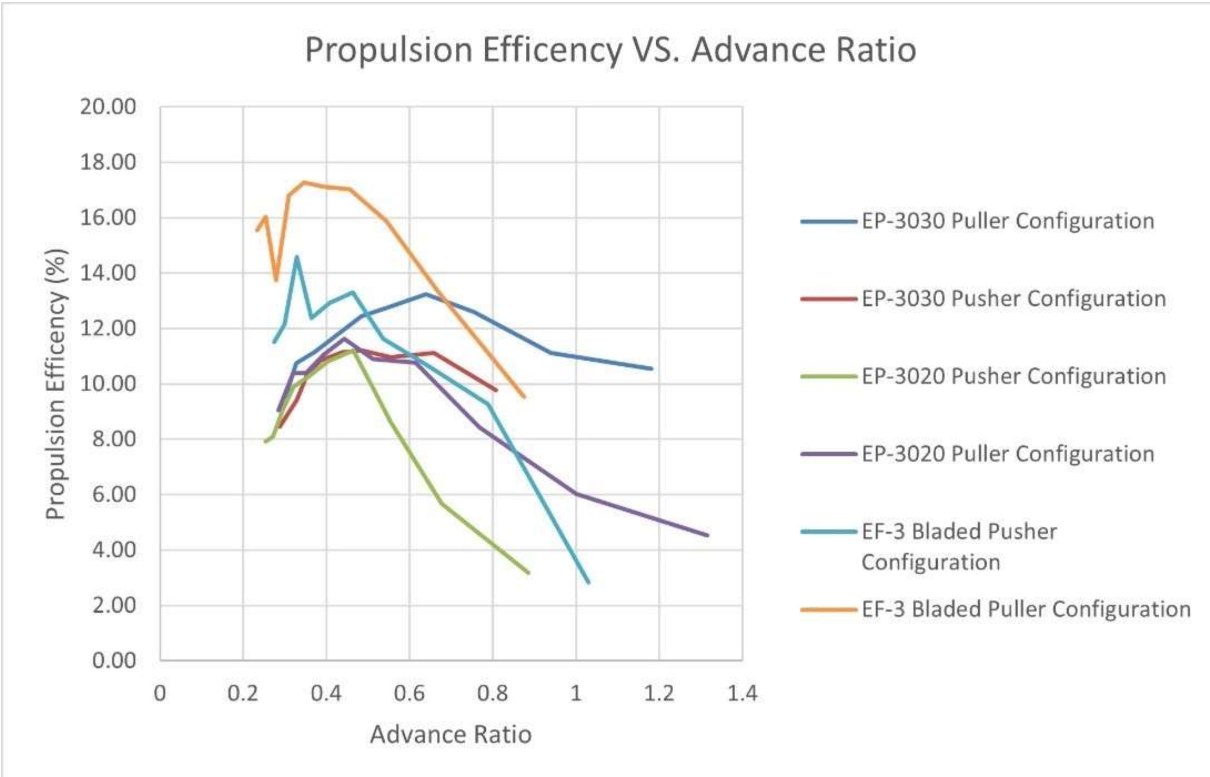

Figure #1. System Efficiency vs. Advance Ratio

Experiment 4 tested three different propellor types each in 2 different configurations. These two configurations were pusher and puller (tractor). As seen above in figure 1, EF-3 bladed puller configuration has the best propulsion efficiency for most of the advance ratio. In addition, the EF-3 blade pusher configuration comes second place until around 0.5 advance ratio. This shows that the EF-3 bladed propellors will give us highest efficiency at lower advance ratios (approximately 0.7 and below). These advance ratios tend to occur at motor power percentages around 30-40%. The code used had motor power percentages around 30-40% meaning EF-3 was the most suitable pick for the propellors.

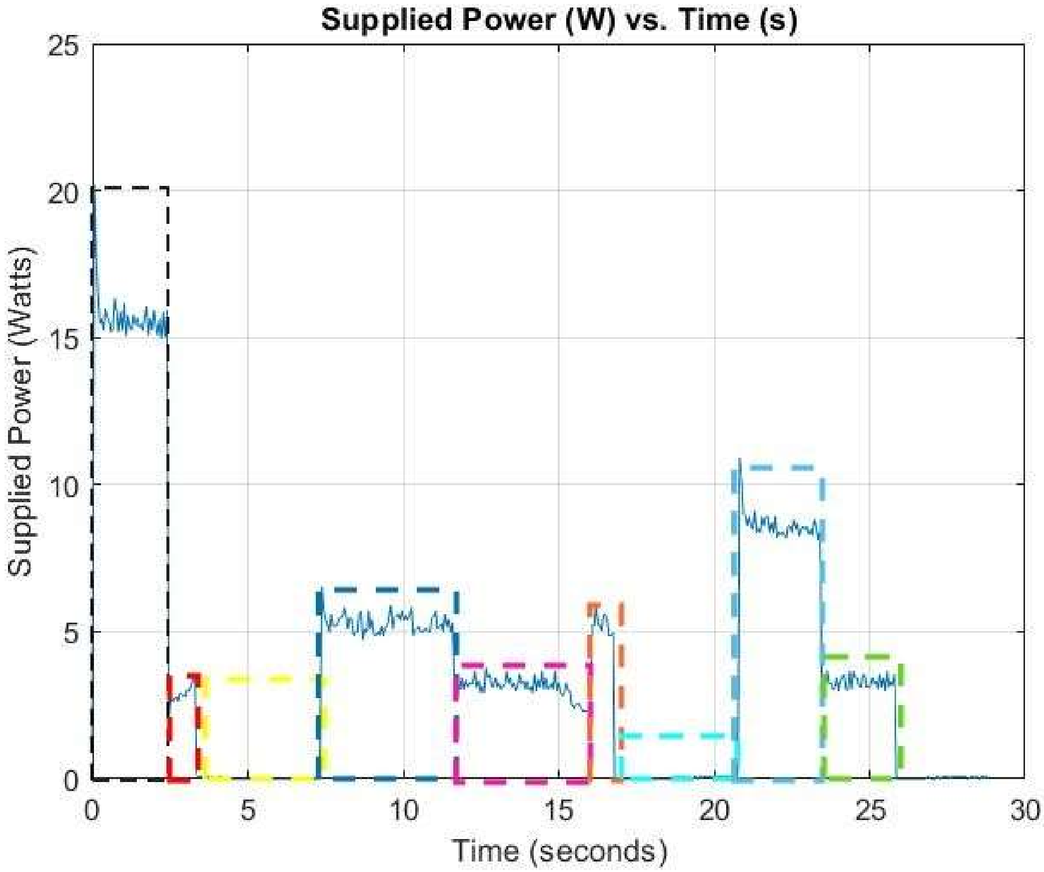

Figure #2. Supplied Power vs. Time (with phase breakdowns) for Design 1 Half-track run

Figure #2 shows the supplied power to the motors vs. time on the half-track run for design 1. The different color dashed boxes around the graph indicate different phases. Phase 1 was the highest energy phase because it shows the vehicle going up the first incline on the track in pusher configuration, which is the less optimal configuration. Phase 2 represents the vehicle traveling on the horizontal after the incline and getting over to the pickup station at a low speed. Phase 3 is where the vehicle stopped at the station for 4 seconds and then reversed. When the vehicle is braked, energy levels are approaching zero. Phase 4 is where the vehicle accelerated along the horizontal before going down the now decline. Phase 5 shown in magenta is where the vehicle reduced its power not only because it was going down a decline and thus had more speed but also because it was going around a turn near the end of the phase. Phase 6 in orange shows the power after the vehicle made it around the turn and needed more power. In Phase 7 power was cut to come to a stop at “the waves”, this lasted 4 seconds. In Phase 7 shown in a cyan dashed box is where the vehicle increase power to make it up the incline, note how its is significantly less power because it is in puller configuration. In Phase 8 the vehicle uses a small amount of power to traverse the horizontal for another 3 feet.

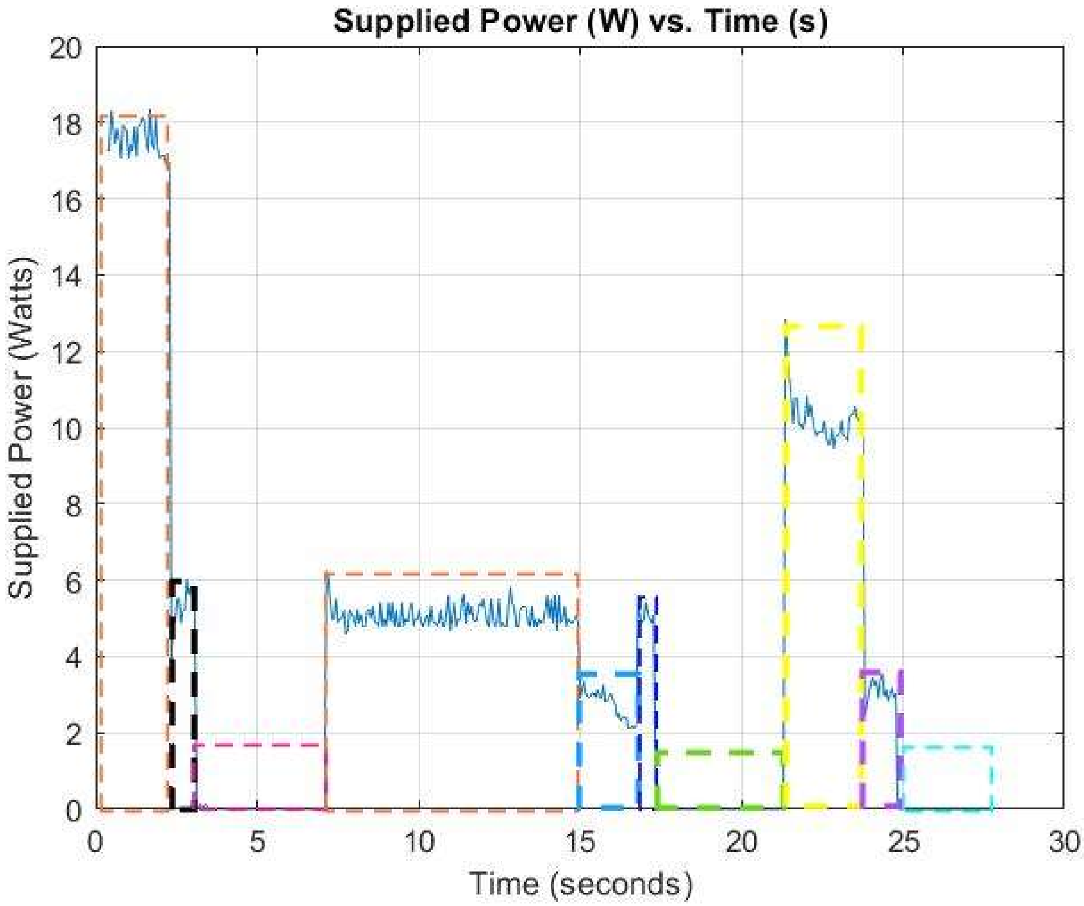

Figure #3. Supplied Power vs. Time (with phase breakdowns) for Design 2 Half-track run

Figure #3 shows the supplied power to the motors vs time with the different phases being indicated by dashed boxes (same as figure #2). As seen above, design 2 reached a maximum of 18 Watts of supplied power whereas in Figure #2 design 1 reached a maximum of only 15 Watts (both maximums being in phase 1). This trend of design 2 using more power was consistent throughout the entire comparison of the two runs. Like design 1, phase 1 was the highest energy phase because it involved the AEV going from stopped to ascending an incline. This required a significant amount of power and design 2 was both heavier and less aerodynamic. There two reasons most likely account for the increase in supplied power in design 2 compared to design 1. Phase 2 shows the AEV using a lower motor speed to glide to the pickup station. Phase 3 is the AEV breaking at the pickup station. Phase 4 is the largest difference between Figures #2 and #3 because it omits phases 5 from Figure #2 and merges it into one phase. This change happened because design 2 couldn't make the half-track run on the lower power of phase 5 from design 1's code. This meant the power needed to be increased during that time interval of the run for design 2. Ultimately the team just continued the phase 4 code, and this worked. Phase 5 shows the deceleration around the bend on the half-track run. Phase 6 is where design 2 needed a little more power after going through the bend. Phase 7 is the AEV stopping at the waves location along the half-track run. Then for phase 8, the second most energy-intensive phase, the vehicle went up the second incline in puller configuration.

Phase 9 shows the vehicle being at the top of the incline and inching toward the stop. Phase 10 shows the vehicle stopping.

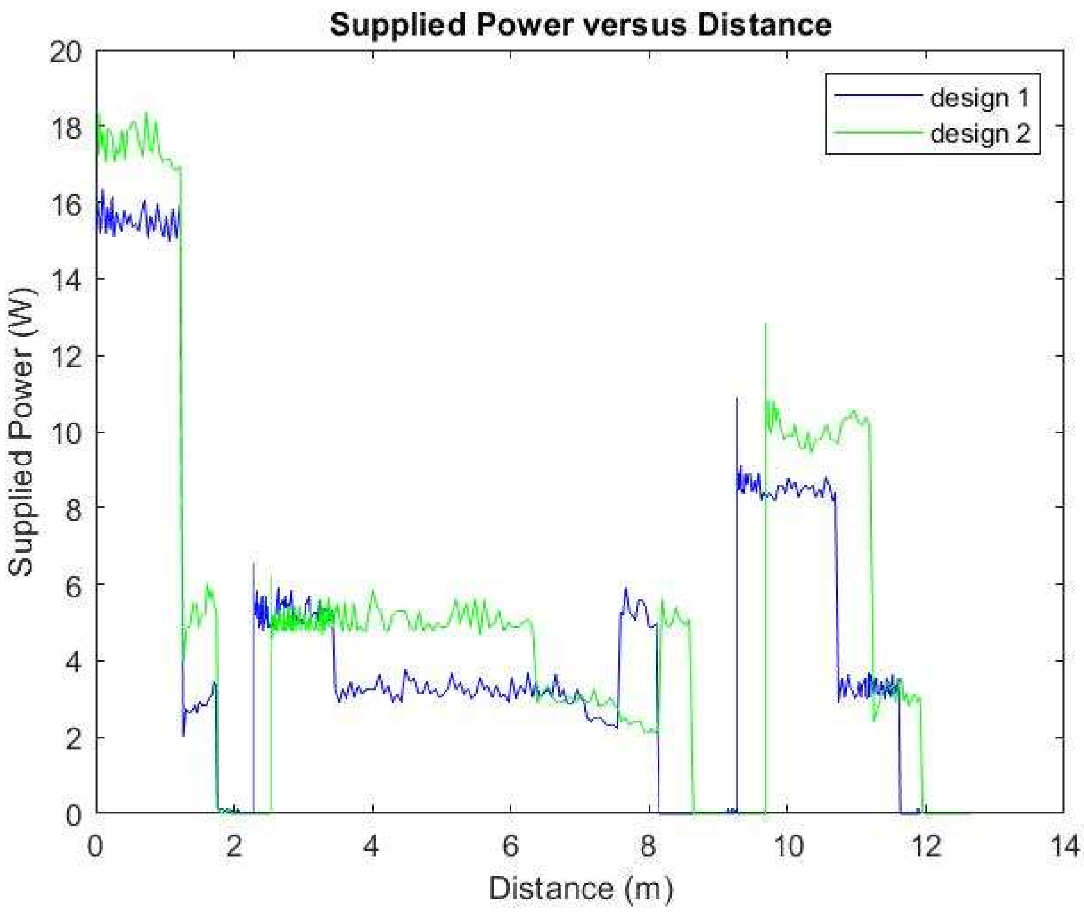

Figure #4 Supplied Power vs. Distance (both designs plotted together)

As mentioned above, design 2 clearly used more energy than design 1. Figure #4 above shows the supplied power to the motors in designs 1 and 2 vs the distance they traveled. Figure #4 agrees with the observation that design 2 used more energy. Interestingly, they show the same levels of supplied power in some places. However, This happened because they are coasting at those points. Around the 2-8 meters mark, the graphs looks somewhat the same because the designs are both coming down from the first incline and already have potential energy just from the height. This means less energy was needed to travel further and they cruised up until they stopped around 8-9 meters.

Phase	Arduino Code	Energy per Phase (J)
1	motorSpeed(4,45)	37.86
2	motorSpeed(4,14)	3.0633
3	brake(4) goFor(4)	0.949
4	motorSpeed(4,22)	22.47
5	motorSpeed(4,16)	13.92
6	celerate(4,15,12,1) motor Speed(4,22)	3.64
7	brake(4) goFor(4)	0.492
8	motorSpeed(4,30)	23.115
9	motorSpeed(4,16)	30.894
		Total energy per kilogram 507.07

Table #1. Supplied Energy for each line of code for design 1

Figure #2 visualized the supplied power vs time with phase breakdowns graphically for design 1. Table #1 above shows the same concept in the form of total joules per phase and the code executed at the phase. As mentioned before, phase 1 required the most energy for designs 1 and 2. This is because the motors need to be ran at higher powers to get the designs from stopped to moving up an incline. As seen above in Table #1, the AEV starts off with the motorSpeed function to start the motors. The First parameter represents both motors being activated and the second represents the power percentage the motors are to be ran at. 45% is the highest motor power percentage the team used for design 1. The energies per phase where the AEV was braked equaled around 0 which was expected. The AEV motors were only ran at 30% for the second incline because it was in puller configuration which is the optimal configuration to be in.

Phase	Arduino Code	Energy per phase (J)
1	motorSpeed(4,50)	34.303
2	motorSpeed(4,20)	4.6043
3	brake(4) goFor(4)	0.022
4	motorSpeed(4,22)	39.727
5	motorSpeed(4,16)	5.8493
6	celerate(4,15,12,1)	2.435
7	motorSpeed(4,22)	2.281
8	brake(4) goFor(4)	24.14
9	motorSpeed(4,35)	3.4416
10	brake(4)	0.09102
		326.232 Total energy per kilogram

Table #2. Supplied Energy for each line of code for design 2.

Figure #3 visualized the supplied power vs time with phase breakdown graphically for design 2. Table #2 above shows the same concept in the form of total joules per phase and the code executed at the phase. Table #1 and #2 show practically the same code. However, design 1 in Table #1 tends to use less joules per phase than design 2 with a few exceptions. In addition, the code in Table #2 for design 2 generally has larger power percentages for the motors. This is due to design 2 being less aerodynamic and heavier (thus needing more power to move).

Design	Energy (J)	Weight (kg)	Energy per kilogram (J/kg)
1	69.323	0.269	257.7
2	114.18	0.35	326.2

Table #3. Energy per kilogram for each design

Table #3 shows the total energy of both designs on the half-track run, the weight of each design, and the energy per kilogram of each design. As seen above, design 1 uses roughly 45 less total joules than design 2 making it a clear winner in terms of total energy cost. As mentioned earlier in the discussion, design 2 weighed more which likely contributed to the high energy consumption. Also, the energy per kilogram of design 1 is a clear winner as seen above with its energy per kilogram being 257.7 J/kg compared to design 2's 326.2 J/kg.

Conclusion and Recommendations:

From the nearly 2x increase in energy usage from Design 1 to Design 2 (Figure #), the increase in cost from Design 1 to Design 2 of 3.3 percent (Tables 4 and 5) and comparing those results with the current mission critical goals discussed in the Executive Summary, Design 1 will be used in the ongoing experiments for the Advanced Energy Vehicle (AEV). Further goals of the AEV will be to minimize the energy used per kilogram from its current value (Table 1), this will be accomplished by decreasing the mass of the AEV. The team must check their perception of mass of certain parts such as the metal brackets since in Design 2 mass was significantly affected because of the amount of metal brackets used. Other important goals for the AEV are decreasing the drag between the airframe and the propeller slipstream that was found to be a fatal error with respect to energy consumption in Design 2.

Appendix:

Part	# of parts	Price per part	Total cost per part
Arduino	1	100	100
Electric motor	2	9.99	19.98
Servo motor	1	5.95	5.95
Count sensor	2	2	4
Propeller	2	0.45	0.9
Wheels	2	7.5	15
2.5" x 7.5" Rectangle	1	2	2
Trapizoids	2	1	2
T-Shape Arm	1	3	3
Angle Brackets	6	0.84	5.04

Motor clamps	2	0.59	1.18
Bulk screws and nuts	1	2.88	2.88
Battery Carrier	1	.84	.84
			Total 162.77

Table #4: Price Breakdown for AEV Design 1

Part	# of parts	Price per part	Total cost per part
Arduino	1	100	100
Electric motor	2	9.99	19.98
Servo motor	1	5.95	5.95
Count sensor	2	2	4
Propeller	2	0.45	0.9
Wheels	2	7.5	15
T-Shape	1	2	2
Trapizoids	4	1	4
T-Shape Arm	1	3	3
Angle Brackets	10	0.84	8.4
Motor clamps	2	0.59	1.18
Bulk screws and nuts	1	2.88	2.88
Battery Carrier	1	.84	.84
			total 168.13

Table #5: Price Breakdown for AEV Design 2

No.	Task	Start	Finish	Due Date	Ben	Matthew	Nick	% complete
1	AEV 1 Construction	2/2/2022	2/2/2022	2/2/2022	x	x	x	100
2	AEV 1 Wind Tunnel Testing	2/9/2022	2/9/2022	2/9/2022	x	x	x	100
3	Wind Tunnel Data Analysis	2/9/2022	2/16/2022	2/16/2022	x	x	x	100
4	Progress Report	2/9/2022	2/16/2022	2/16/2022	x	x	x	100

Figure #5: System Analysis 1 Schedule

No.	Task	Start	Finish	Due Date	Ben	Matthe w	Nick	% complete
1	Code Flat Track Run	2/16/202 2	2/23/202 2	3/8/2022	x		x	100
2	Matlab Code for Flat Track Run	2/16/202 2	2/23/202 2	3/8/2022		x		100
3	Code Half Track Run	2/23/202 2	3/2/2022	3/8/2022	x		x	100
4	Matlab Code for Half Track Run	2/23/202 2	3/2/2022	3/8/2022		x		100
5	Progress Report	2/16/202 2	3/8/2022	3/8/2022	x	x	x	100

Figure #6: System Analysis 2 Schedule

No.	Task	Start	Finish	Due Date	Ben	Matthew	Nick	% complete
1	AEV 2 Construction	3/22/22	3/24/22	3/31/22	x	x	x	100
2	AEV 2 Testing	3/22/22	3/24/22	3/31/22	x	x		100
3	PDR	2/16/22	3/31/22	3/31/22	x	x	x	100
3a	Title page, Table of contents, & List of Figures	3/28/22	3/28/22	3/31/22	x	x	x	100
3b	Executive Summary	3/29/22	3/30/22	3/31/22	x			100
3c	Introduction	3/28/22	3/28/22	3/31/22		x		100
3d	AEV Initial Concepts	3/28/22	3/29/22	3/31/22		x		100
3e	Results and Discussion	3/28/22	3/28/22	3/31/22			x	100
3f	Conclusion and Recomendation	3/29/22	3/30/22	3/31/22		x		100
3g	Appendix	3/21/22	3/31/22	3/31/22	x			100

Figure #7: Performance Test 1 Schedule

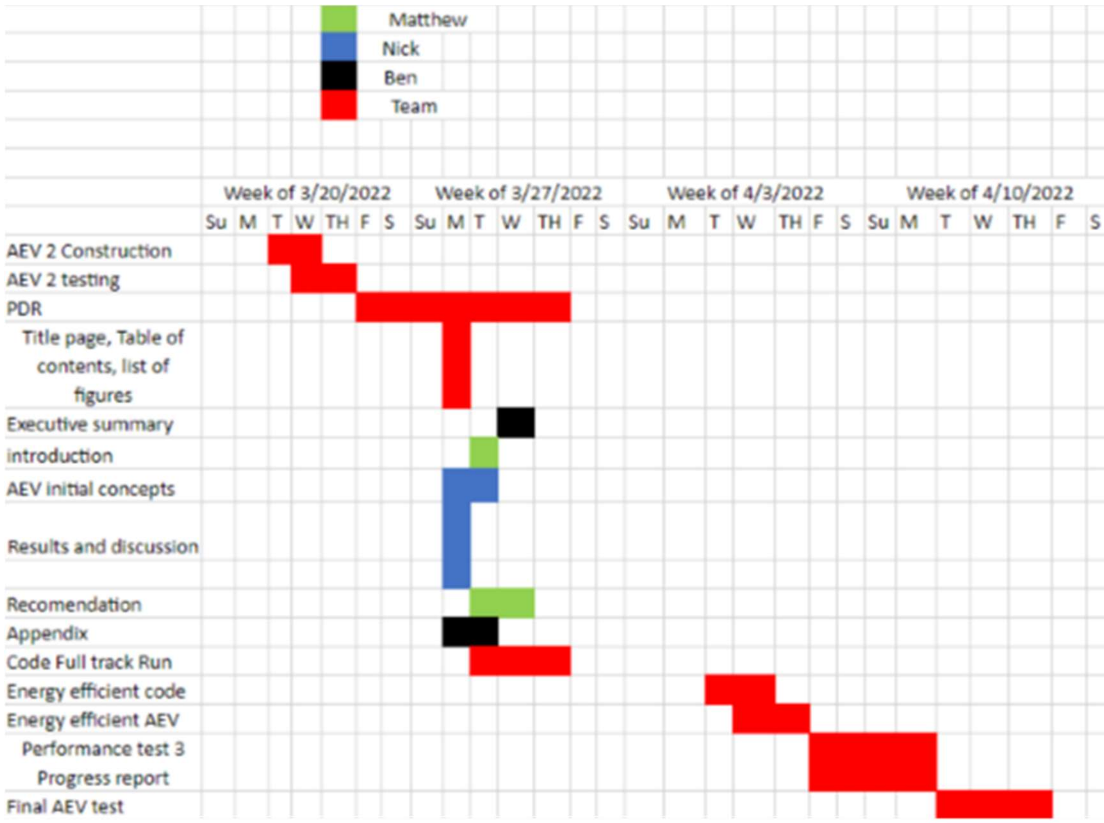

Figure #8: Daily Schedule for Performances 1,2,3, and 4

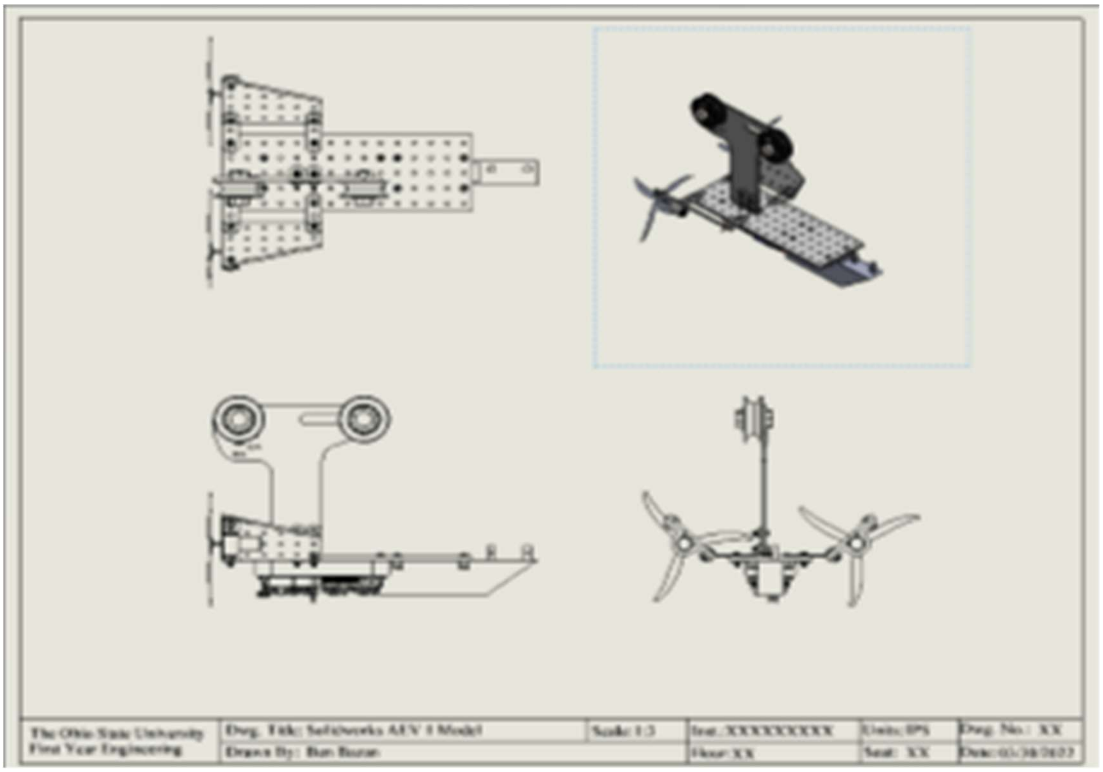

Figure #9: AEV Design 1 Solidworks model

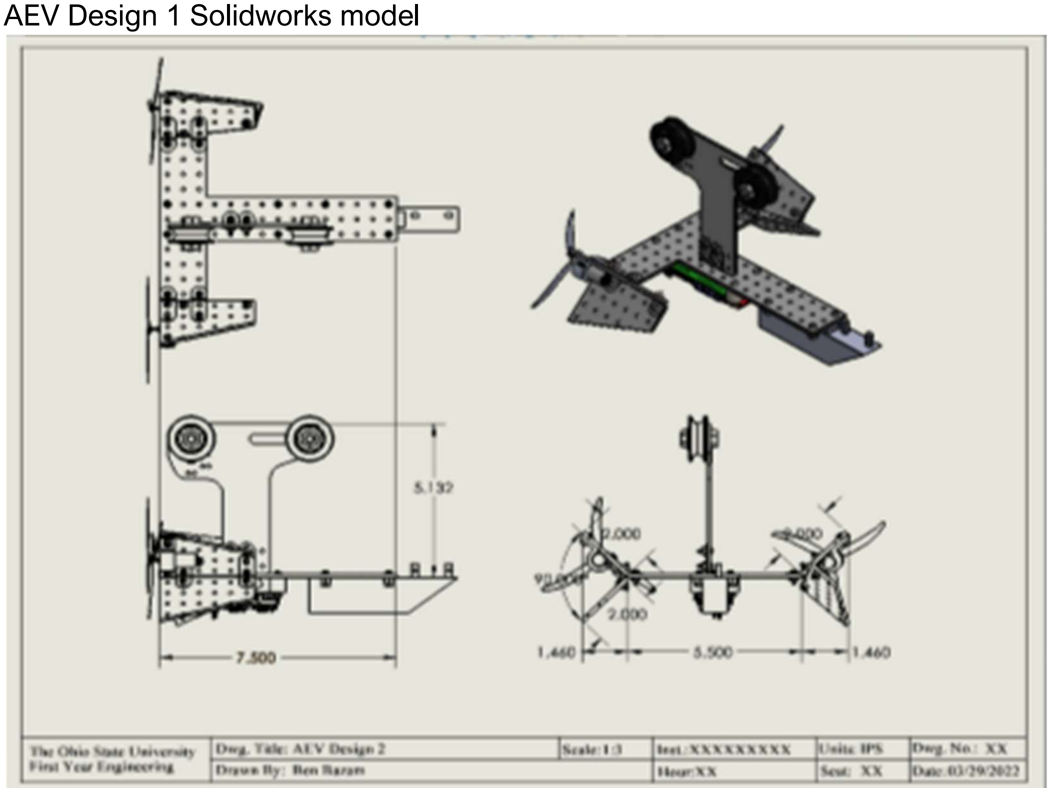

Figure #10: AEV Design 2 Solidworks model

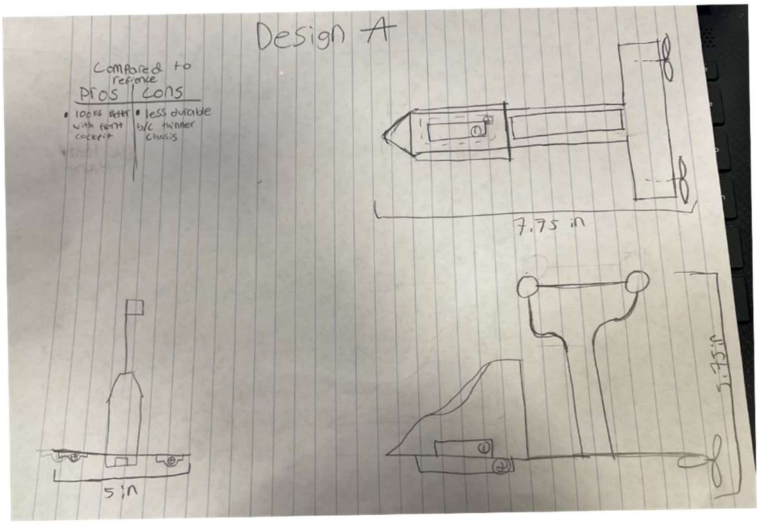

Figure #11: Orthographic projection of design model A (Ben Bazan's design)

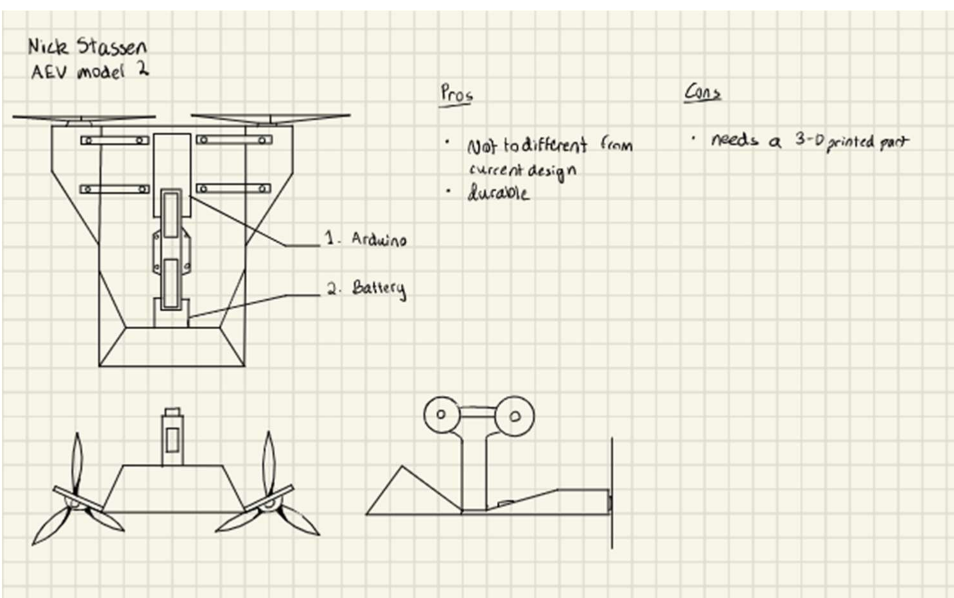

Figure #12: Orthographic projection of design model B (Nick Stassen's design)

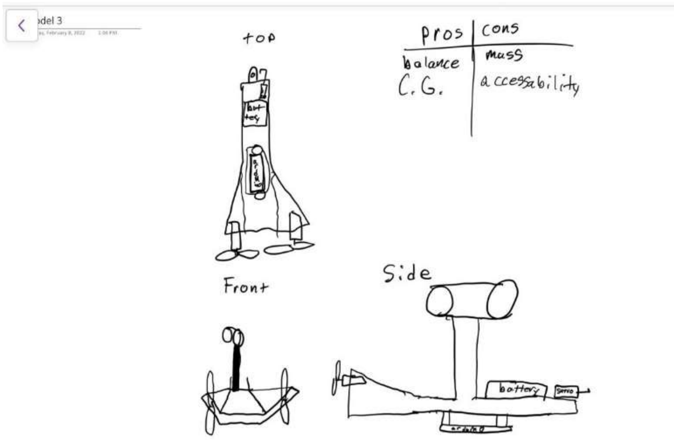

Figure #13: Orthographic projection of design model C (Matthew Geiger's design)

	Concept Screening and Scoring			
Success Criteria	**Refrence**	**Design A**	**Design B**	**Design C**
Stability	0	0	+	+
Eco-fuel	0	0	0	0
Look	0	+	+	0
Maintenance	0	0	0	0
Durability	0	-	+	0
Cost	0	-	-	0
Environmental	0	0	0	0
Sum +'s	0	1	3	1
Sum 0's	7	4	3	6
Sum -'s	0	2	1	0
Net Score	0	-1	2	1
Continue?	Combine	No	Yes	No

Table #6: Concept screening for designs A, B, & C

		Refrence		Design A		Design B		Design C	
Success Criteria	Weight	Rating	Weighted score	Rating2	Weighted score	Rating3	Weighted Score4	Rating5	Weighted Score6
Balance	5%	3	0.15	4	0.6	4	0.6	4	0.6
Minimal blockage	15%	3	0.45	3	1.35	3	1.35	3	1.35
Center-of-gravity location	10%	2	0.2	4	0.8	4	0.8	4	0.8
Maintenance	25%	3	0.75	3	2.25	3	2.25	3	2.25
Durability	15%	2	0.3	2	0.6	4	1.2	4	1.2
Cost	20%	3	0.6	2	1.2	2	1.2	3	1.8
Evironmental	10%	3	0.3	3	0.9	3	0.9	3	0.9
Total Score			2.75		7.7		8.3		8.9
Continue?			No		no		yes		no

Table #7: Concept scoring for designs A, B, & C

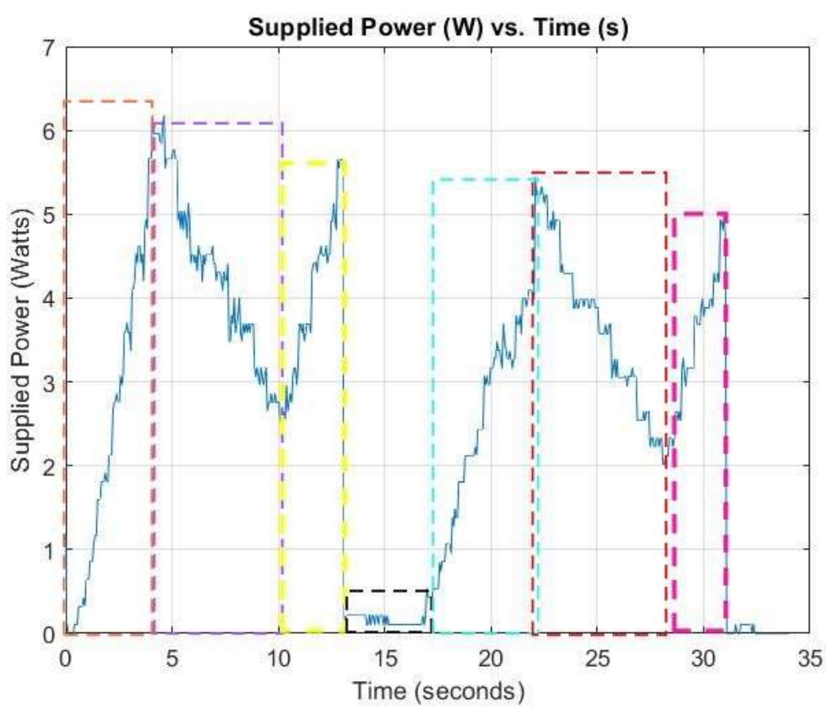

Figure #14: describes the AEV flat track run, supplied power versus time, using celerate commands, along with a phase breakdown.

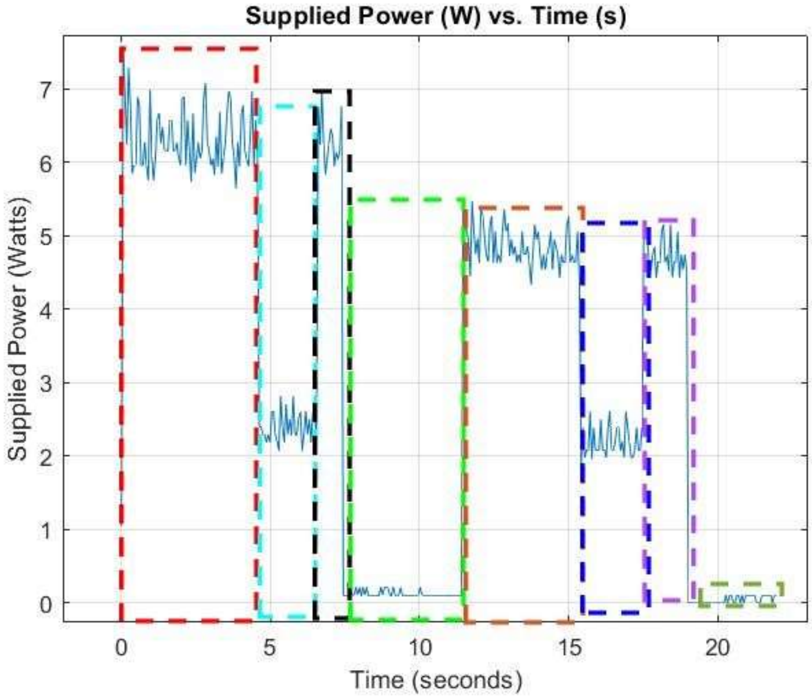

Figure #15: describes the AEV flat track run, with supplied power versus time, using motorSpeed commands. Along with a phase break down.

Division of work statement

Ben Bazan completed Appendix and Executive Summary components. Matthew Geiger completed the Introduction, AEV initial Concepts and the Conclusion and Recommendations. Nick Stassen completed the Results and Discussion.