AEV CDR Draft

Submitted to:
Inst. Richard Busick
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Created by:
Team R

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The Ohio State University
Columbus, OH
24 March 2018

Abstract

The purpose of this lab is to develop an Advanced Energy Vehicle (AEV) to fulfill the requirements outlined in the Mission Concept Review (MCR) so Smart City Columbus can potentially utilize our designs in creating a monorail that allows citizens to travel from Easton to Linden to Polaris and back. The objective of this lab is to design, prototype, and test AEVs to determine which designs best fulfill the purpose of the lab. Team R's main goal was to design and create an AEV that limits air resistance while also keeping weight low so as to maximize efficiency. To achieve this goal, Team R drafted four designs (one per team member), utilized screening and scoring matrices to decide on one design, and then ran that design through a number of tests. The design chosen was Max Doucette's vertical design, as it was the most stable design. Two variations of the design chosen in the Preliminary R&D labs were created and tested during Performance Test 1. In the Advanced R&D labs, Team R tested five propeller configurations utilizing 3030 propellers and 2510 propellers to determine the best propellers to use. Wind tunnel tests were also conducted on 3030 propellers to determine whether pushing or pulling provides more thrust using that propeller. Results from this test found that pulling configurations produced more thrust. Only 3030 propellers were tested in the wind tunnel due to time constraints and the set-up provided to the team. Tests using only the 2510 propellers failed to move the AEV, so we eliminated those from further testing. The best configuration had two 3030 propellers in a pulling configuration. The second-best configuration using two 3030 propellers with one pulling and one pushing the AEV was also later used in Performance Test 1. Performance Test 1 consisted of having the AEV travel to, stop at, and then pass through the timed gate representing stopping for passengers in Linden. In programming the AEV, the functions “motorSpeed” and “goFor” were used most often, as the “goToAbsolutePosition” and “goToRelativePosition” often sent the AEV much too far down the track or not nearly far enough. Power braking was also utilized in this performance test, as the team wanted precise braking without having to add weight through adding a servo. The one push, one pull motor configuration seemed to accelerate faster than the two motors pulling configuration during Performance Test 1 and is currently Team R's primary design in the interest of making the AEV more time efficient. In addition, the one push, one pull motor configuration allows for easier coupling to the payload at the end of the track. Though that motor configuration may not produce as much thrust as a motor configuration with two motors pulling, it handled better on the track and was more responsive to changes in the Arduino code for Performance Test 1.

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Introduction

Smart City Columbus tasked Koffolt Properties with creating an Advanced Energy Vehicle (AEV), an autonomous monorail vehicle, to alleviate the "urban deserts" that exist within the city of Columbus. The monorail will travel back and forth from Easton to Linden, and then from Linden to Polaris. The purpose of the lab is to create the most energy efficient and time efficient prototype AEV to not only travel this distance, but also to pick up another monorail car at the end of the track and bring it back to the starting point. In addition, this lab provides first year engineering students with experience in working with small teams that are part of a larger company.

Contained in this report is the experimental methodology for Performance Test 1, the results of Performance Test 1, an analysis of those results and discussion of what the results mean relative to the larger AEV project, and lastly what conclusions Team R has drawn from this testing and how Team R can reduce, mitigate, and prevent error in further testing.

Experimental Methodology

After the group decided on which two designs will be used, the designs had to be prepared for Performance Test 1 to further understand how well each design will work for the final test in comparison to the other. The task set for the first performance test was to develop a code for each AEV design that would simulate the AEV beginning at one place and getting to another while having to make a stop in between. The specified code had to start at the starting line of the track, travel approximately half the distance of the track and come to a stop at a gate for five seconds (until the gate opens up), and then start up again with enough power to go through the gate. A couple decisions that had to be made before code was made were deciding whether the AEV would use power braking or coasting to a stop at the gate, how much motor power was being used for the AEV, and whether the AEV would use time or position to determine when the AEV would stop. The use of power braking would be more time efficient and save time for the process of stopping, but it would also use more power during the process. The higher the motor power would be set in the code would correlate to higher max speed the AEV would have during the process, so the power would have to be set to some speed that would be fast enough for the AEV to efficiently move down the track, but also be a speed that is safe enough for the AEV to stop without crashing into the gate. After a few tests, we decided that a safe and efficient speed would be at 40% motor power. The group decided to use time as a variable for when the AEV would stop instead of position because it was a more consistent measurement for the AEV, and when using the position as a variable was unreliable because for some tests the reflective sensors would malfunction and the AEV would stop at random times, and in some cases, not stop at all. The equipment used for this lab included our two AEV designs that we had determined to use for testing, the Arduino app used to develop code, and the assigned test track to test our AEV's effectiveness on.

Results

Both of the team's designs consisted of a vertical deign structure with the battery holder and battery attached on one side and the Arduino board on the other side. The team used zip ties to secure the wires attaching the AEV components to each other to decrease drag on the AEV. The main difference in the design of the two AEV concepts was the propeller configuration used on each. Although two 3030 propellers were utilized in the run for both designs, the first design had both propellers pulling the AEV while the second design had the one propeller pushing and one pulling. The first design can be found in Figure 1 and the second design can be found in Figure 2 below.

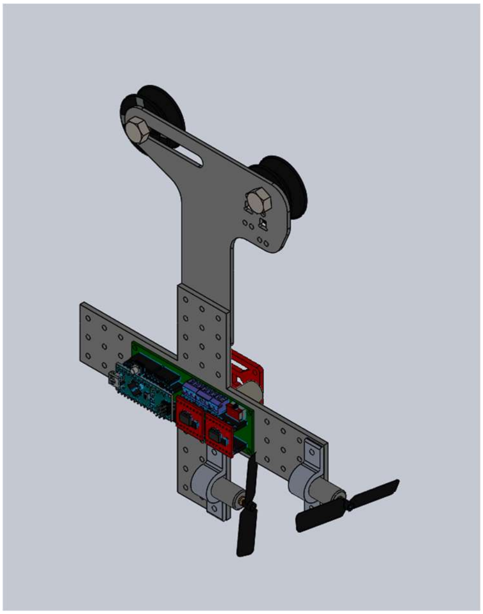


Figure 1: AEV Design Concept 1

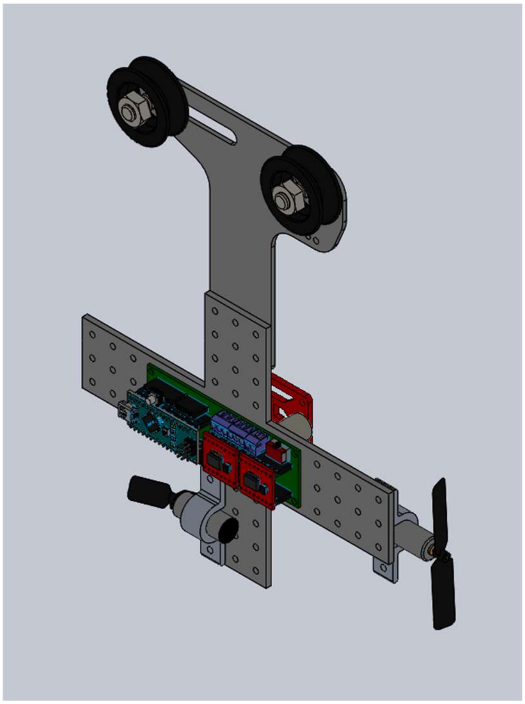


Figure 2: AEV Design Concept 2

The designs created by the team in the preliminary research and design phase of the project all had their own concepts that were more beneficial than others. However, weighing the pros and cons of each design, the team decided it would be most beneficial to move forward with Max

Doucette's design due to its lightweight design and aerodynamic features. The factors that led to this decision can be found on the screening and scoring matrices in appendix C. This original design had a two-push propeller configuration. The team designed this model in SolidWorks and then constructed it in the lab. The team tested the propeller configurations on the AEV as well as performed the wind tunnel test on the AEV. It was noted that a two pull propeller configuration was the most efficient. However, when testing the AEV during performance test one, it was observed that the one push one pull configuration was more efficient and also allowed for the team to construct a device on the open end of the AEV in the front to pick up the load used in Performance Test 2.

During the run used in Performance Test 1, it was noticed by the team that the AEV utilizing the-one-push-one-pull control program accelerated quicker than the two-pull concept. This was a surprise to the team. Following the wind tunnel testing as well as the propeller configuration tests, the data showed that a two-pull propeller configuration was the most efficient. Although both of the AEV designs used the same control program in the performance test, the one push one pull design concept used less energy when accelerating. Because of this, the design hit the gate instead of stopping between the two sensors on the track. This led the team to believe that the second design with the one push one pull propeller configuration was more efficient, so it was used in performance test two. The control program was altered to run the motors for a shorter amount of time in order to keep the AEV from hitting the gate again. After multiple trial and error runs by the team, the AEV successfully utilized a one-push-one-pull configuration to stop between the two gates for seven seconds and then continue when the gate opened.

Discussion

Throughout all of the pR&D labs and aR&D labs, the end goal was to determine two different prototypes to test for the performance tests based on the data collected throughout all of the labs. Originally there were four designs that would be tested for the project, each member getting to design their own prototype. In order to determine which prototype functioned the best, the group used screening and scoring matrices to develop a rating system for the lab.

Success Criteria	Reference	Short A	Short B	Glowacki A	Glowacki B	Doucette A	Doucette B	Beachy A	Beachy B
Stability	0	0	-	-	0	-	0	0	-
Aerodynamics	0	+	0	0	0	+	0	-	-
Weight	0	-	+	0	+	0	-	-	+
Durability	0	+	-	+	-	0	+	+	0
Safety	0	+	-	-	-	+	-	+	0
Sum +		3	1	1	1	2	1	2	1
Sum 0	5	1	1	2	2	2	2	1	2
Sum -		1	3	2	2	1	2	2	2
Net Score	0	2	-2	-1	-1	1	-1	0	-1
Continue?	Combine	Combine	No	No	No	Revise	No	No	No

Table 1: Screening Matrix

		Reference		Design 1 - Short		Design 2 - Glowacki		Design 3 - Beachy		Design 4 - Doucette	
Success Criteria	Weight	Rating	Wighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Stability	20%	3	0.6	3	0.6	3	0.6	2	0.4	2	0.4
Aerodynamics	25%	3	0.75	4	1	3	0.75	2	0.5	4	1
Weight	25%	2	0.5	2	0.5	3	0.75	2	0.5	3	0.75
Durability	15%	3	0.45	2	0.3	2	0.3	3	0.45	3	0.45
Safety	15%	3	0.45	3	0.45	2	0.3	3	0.45	2	0.3
Total Score		2.75		2.85		2.7		2.3		2.9	
Continue?		No		Develop		No		No		Develop	

Table 2: Scoring Matrix

The difference between screening and scoring matrices is that scoring can be more specific than screening. In a screening matrix, the criteria is weighted equally and the final score of each design is determined by adding up the success/fail rate of each category. The scoring matrix is determined the same way, except the scoring matrix goes more in depth because it weights the criteria based on how important each criterion is based on the group's priorities. Based on the matrices, both rated Alex Short and Max Doucette's as the most efficient and effective designs for the lab scoring a 2 and a 1 respectively in the screening, and a 2.85 and 2.9 respectively in the scoring. From that point on, we decided to test those two prototypes because of their high efficiency and effectiveness.

In the two Advanced R&D labs, the group decided to test the propeller configuration and use the wind tunnel as the two topics. We felt that these were two appropriate topics to do since both of the labs had similar processes because each compared how different propeller types acted in comparison to one another. In the first week, we primarily focused on the propeller configuration lab, and tested 5 different propeller sets: two push (one 3030, one 2510), two push (two 3030), two push, one pull (two 3030), two push (two 2510), and two pull (two 3030).

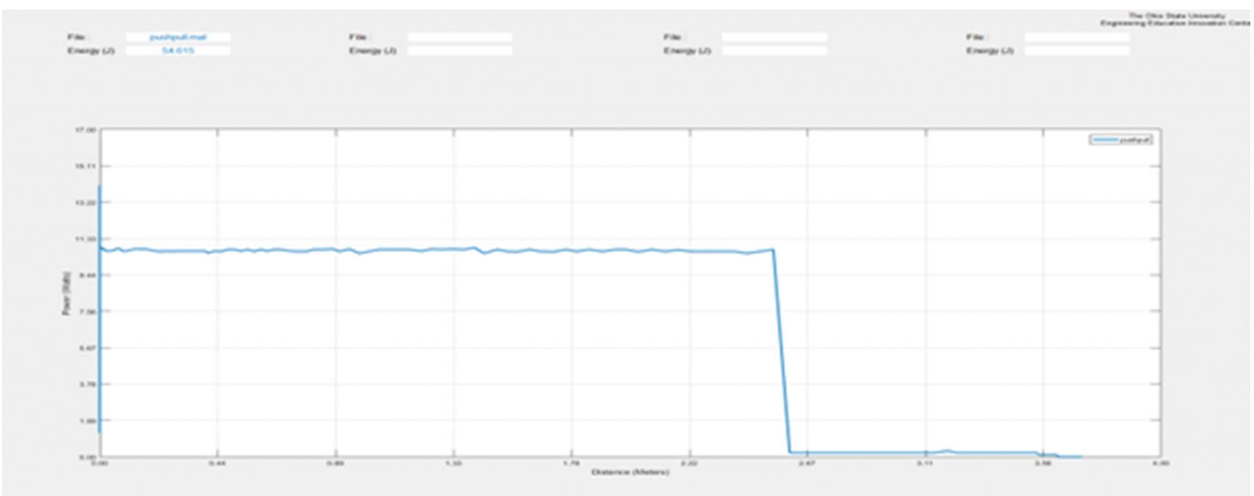


Figure 3: 2 3030 Push/Pull Power v. Distance Graph

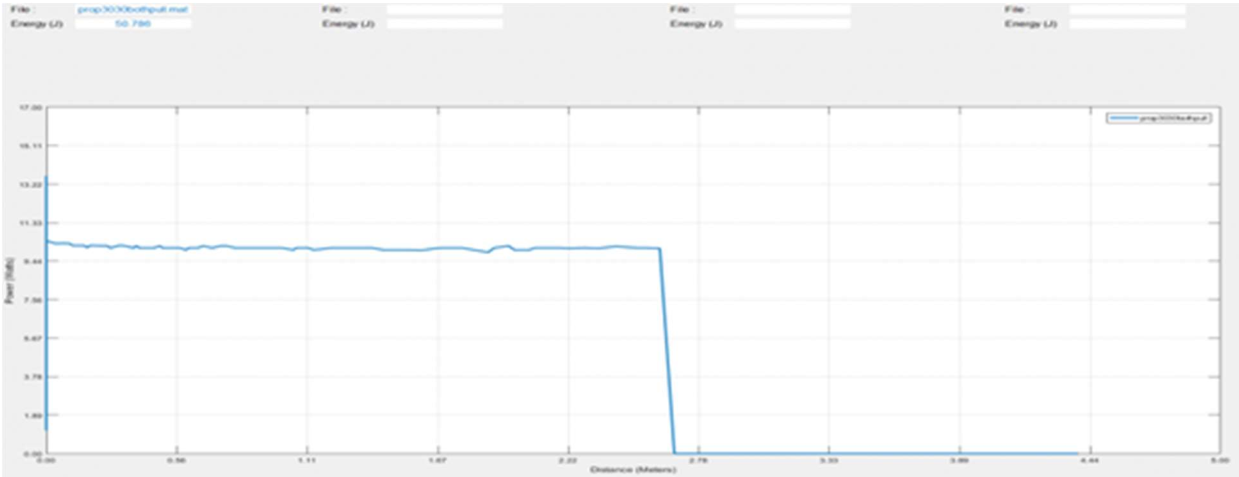


Figure 4: 2 3030 Pull Power v. Distance Graph

Using our results from the propeller configuration, the group decided that the two propeller configurations that worked best were the two 3030 propellers that had one push propeller and one pull motor, and two 3030 propellers that had both motors pulling. What we inferred from this was that having the motors pull would be more effective than having the motors push because the two best working configurations were also the only two configurations that included at least one pulling motor. A push and a pull motor were also tested in the wind tunnel lab to determine which is more powerful.

Thrust Calibration (grams)	RPM	Power Input (Watts)	Power Output (Horsepower)	Power Output (Watts)	Propulsion Efficiency (%)	Advance Ratio (--)
0	0	0	0	0	0	0
-0.0411	1916	0.2442	-1.40533E-06	-0.001047955	-0.4291381	0.95116383
0.6987	2874	0.4329	2.38906E-05	0.01781524	4.1153245	0.63410922
1.6851	3772	0.7252	5.76186E-05	0.042966167	5.92473339	0.48314685
3.1236	4550	1.0915	0.000106805	0.079644601	7.29680269	0.40053405
4.8909	5389	1.5318	0.000167234	0.124706678	8.14118543	0.3381759
6.9048	6107	2.0461	0.000236096	0.176056487	8.60449085	0.29841656
8.5899	6766	2.6048	0.000293714	0.219022654	8.40842497	0.26935115
10.7271	7365	3.1968	0.000366791	0.273516328	8.5559412	0.24744466
13.152	7964	3.885	0.000449706	0.33534569	8.63180669	0.22883349

15.7824	8622	4.5584	0.000539647	0.402414828	8.82798411	0.21136974
18.7827	9161	5.328	0.000642236	0.478915563	8.98865547	0.19893351

Table 3: Wind Tunnel: 3030 Pull Propeller

Thrust Calibration (grams)	RPM	Power Input (Watts)	Power Output (Horsepower)	Power Output (Watts)	Propulsion Efficiency (%)	Advance Ratio (--)
0	0	0	0	0	0	0
1.2741	1976	0.0592	5.36188E-05	0.039983525	67.5397374	1.13511673
2.0139	2934	0.1887	8.47523E-05	0.063199765	33.4921911	0.76448216
3.0003	3632	0.3996	0.000126264	0.094154751	23.5622501	0.61756351
3.9456	4550	0.7326	0.000166045	0.123819947	16.9014397	0.49296498
5.0553	5269	1.0212	0.000212745	0.158644307	15.5350869	0.4256957
6.7815	6047	1.4763	0.00028539	0.212815534	14.4154666	0.37092619
5.0553	6706	1.9832	0.000212745	0.158644307	7.9994104	0.33447519
9.9462	7305	2.5641	0.000418572	0.31212945	12.1730607	0.30704869
11.6313	8023	3.219	0.000489488	0.365010886	11.3392633	0.27957007
13.3575	8742	3.9072	0.000562132	0.419182112	10.7284529	0.25657637
15.3714	9281	4.7508	0.000646885	0.482381877	10.1536978	0.24167554

Table 4: Wind Tunnel: 3030 Push Propeller

After the wind tunnel lab and looking at the data calculated, the group determined what was the more efficient type of propeller. One of the most important columns to look at is the Propulsion Efficiency column. As you can see, the pull propeller has a lower percentage than the push propeller, but it also is a lot more stable than the push propeller which seems to be exponentially decaying as the Arduino power is constantly increased. We decided that this may be due to some sort of error when getting the readings for the push propeller during the lab, and there may have been an error for part of the pull propeller's wind tunnel lab based on the fact that the thrust calibration is negative for one of the power settings which does not make much sense. As a result, we decided that the pull propeller would be more efficient because it has a more stable propulsion efficiency making it more reliable even though it is less.

As a result, after the pR&D and aR&D labs, the groups have decided to move forward using Max Doucette's design with one design using two pulling 3030 propellers, and the other using one pushing 3030 propeller and one pulling 3030 propeller.

For Performance Test 1, the group tested the same design except one had two pulling propellers and the other had one pushing and one pulling propeller. What the group noticed between the two propeller sets was that when the motor speed was at 40%, the AEV with one push and one pull propeller still moved and accelerated at a faster rate. Keeping that in mind, it was also able to slow down and change directions at a quicker pace because the propellers were facing opposite directions. With the results we received from the first performance test, the group has decided the design with one push and one pull propeller is currently the front runner as the lead AEV design.

Conclusions and Recommendations

Week 9 was dedicated to completing Performance Test 1. The objective of the Performance Test 1 experiment was to develop a design and code for the AEV to travel from one end of a rail to the other end of the rail with a 7 second stop in between in the most efficient manner. Performance Test 1 focused on comparing different designs using a similar code, to complete an unbiased test that would reveal which design is best for the AEV to travel from one end of the rail to the other end. This test compared two designs, both similar to each other in their vertical body configuration, which was decided upon in the Preliminary R&D labs, that different in terms of their propeller configuration. The first design utilized two 3030 propellers in a pulling configuration, as shown in Figure 1, and the second design utilized one pulling 3030 propeller and one pushing 3030 propeller as shown in Figure 2. The test ultimately revealed that the one push, one pull propeller configuration was more efficient than the pulling configuration. The pulling configuration was tested first, and the code was adjusted using trial and error tests to maximize the efficiency and performance of the AEV to the point where the AEV stopped perfectly within the stop gates and also travelled to the end of the rail after having stopped. The one push, one pull configuration was tested using the same code, and travelled further on the first half of the rail, hitting the stop gate. This ultimately proved that the AEV travels faster and more efficiently with the one push, one pull configuration. The code was adjusted to allow for the AEV to stop within the gates at the stop sign using trial and error tests, and this design was used when conducting the final Performance Test 1, and successfully travelled to the stop sign, stopped within the gates, and proceeded through the gate to the end of the rail during the test.

The one push, one pull propeller configuration design successfully completed Performance Test 1 and will be the chosen design for Team R's AEV moving forward in the Performance Tests, based on the successes in this design's performances. Despite the aforementioned successes of this design, there are adjustments that will have to be made moving forward to maximize the efficiency and performance of the AEV for future testing. The most notable error that was present in Performance Test 1 was the lack of precision and repeatability in the performance of the AEV with the one push, one pull propeller configuration design. Many trial and error runs were completed for the AEV, with small alterations being made in the code to ensure the AEV stopped in the correct spot within the gates at the stop sign. However, there were minor inconsistencies in the performance of the AEV while completing these runs. For example, there were occasions in which the code for only the travel after stopping at the gate was changed, but the AEV would stop in inconsistent locations at the stop sign, even though the code for that section of the travel remained unchanged. This ultimately resulted in the AEV not stopping fully within the gates during Performance Test 1. The body of the AEV was within the gates, and triggered the stop sign to open, but the back end of the AEV sat parallel with the back gate during the official Performance Test 1 run. This error will be addressed before completing the Performance Test 2 and further testing. The code will be adjusted to allow for the AEV to travel an inch further, and the initial run of the AEV will be perfected before the code is made for the last half of the AEV run in which the AEV carries the payload. While this error was encountered, the Performance Test 1 was still completed, and showed a high level of success for the one push, one pull propeller configuration design. As shown in Figure 3 and 4, the power of the one push/pull design did not exceed that of the two pull propeller configuration, yet it travelled a further distance. This result was consistent with the results of the Performance Test 1, and it was confirmed that the one push, one pull propeller configuration design was the more efficient design for the AEV. Performance Test 1 was completed despite errors that had been encountered earlier in the design process. Barriers in the progression of the design included Arduino wires disconnecting, upload errors, and physical AEV pieces being broken or not functioning properly. However, none of these barriers affected the Performance Test 1 being completed on time and successfully, and there were no reasons for incompletion of the Performance Test 1.

Through the results of Performance Test 1 and the other tests discussed, it is evident that the one push, one pull propeller configuration maximizes the efficiency and performance of the AEV. The performance of the AEV is a product of this design, as well as the matching code that allows for the AEV to run efficiently. This design and code allows for the AEV to travel to the gate in the least amount of time, and stops within the gates for the stop sign quickly and precisely. Team R recommends the one push, one pull propeller configuration to be the propeller configuration of choice for all AEV models. This conclusion was initially drawn in the aR&D Propeller Configuration lab, and was further confirmed in the Performance Test 1. Team R also recommends the vertical orientation of the AEV body that is included in the final design of the AEV for Team R. This design makes the AEV aerodynamic, and allows for the best weight distribution across the body as possible. The weight also is distributed directly under the rail in this design, as opposed to being distributed perpendicularly, which would be the case in a horizontal design. This allows for maximum and ideal stability and balance in the AEV, which allows for the least energy and highest speed in the AEV's performance. This conclusion was initially drawn in the preliminary R&D labs, and was further confirmed in the Performance Test 1.

References

"LM_MCR&Deliverables_18AUG2017.Pdf." Ohio State College of Engineering, Aug. 2017.

"LM_PreliminaryR&D_18AUG2017.Pdf." Ohio State College of Engineering, Aug. 2017.

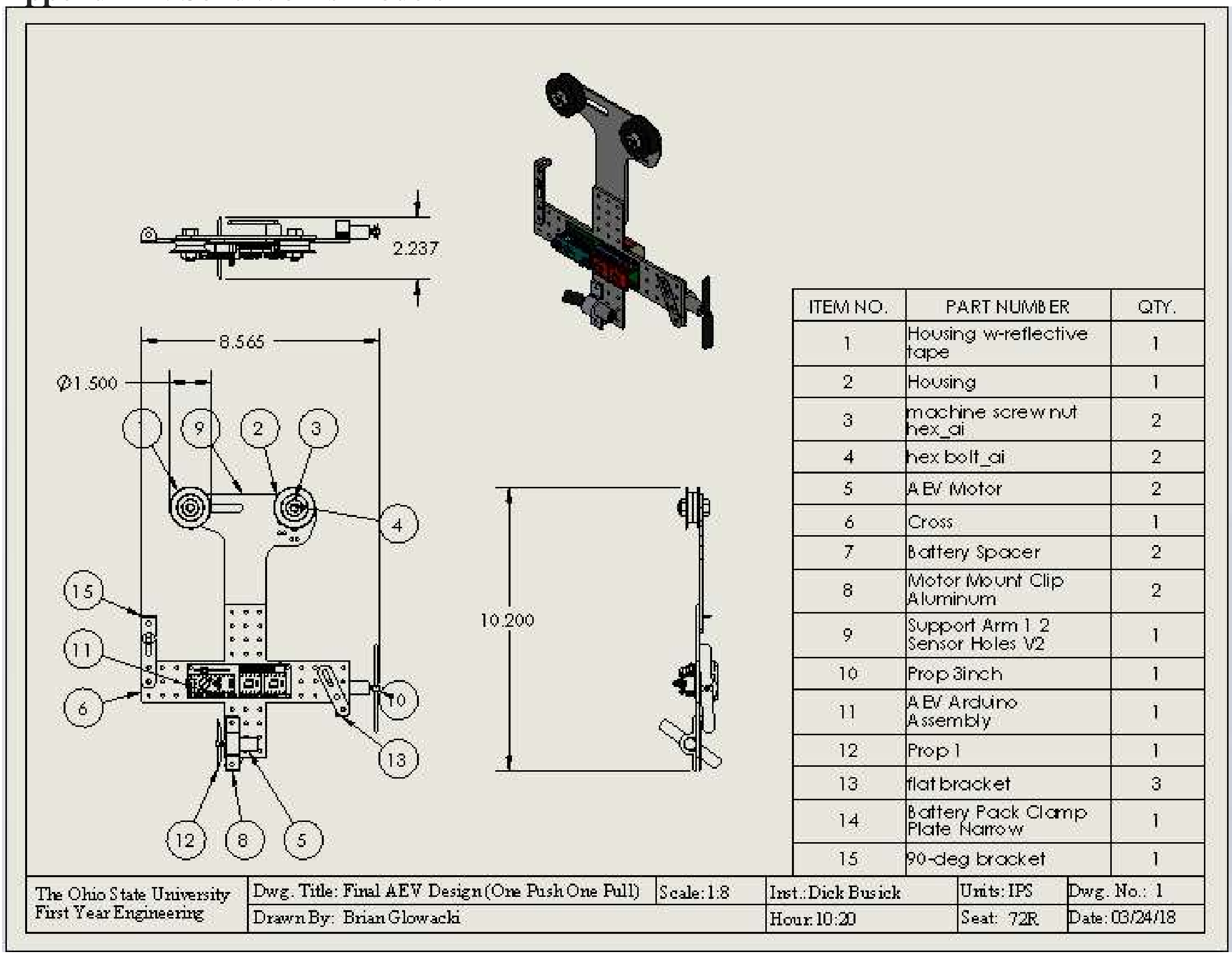
"LM_Advanced_R&D_PerfTests_18Aug2017.Pdf." Ohio State College of Engineering, 18 Aug. 2017.

Appendix A - Schedule

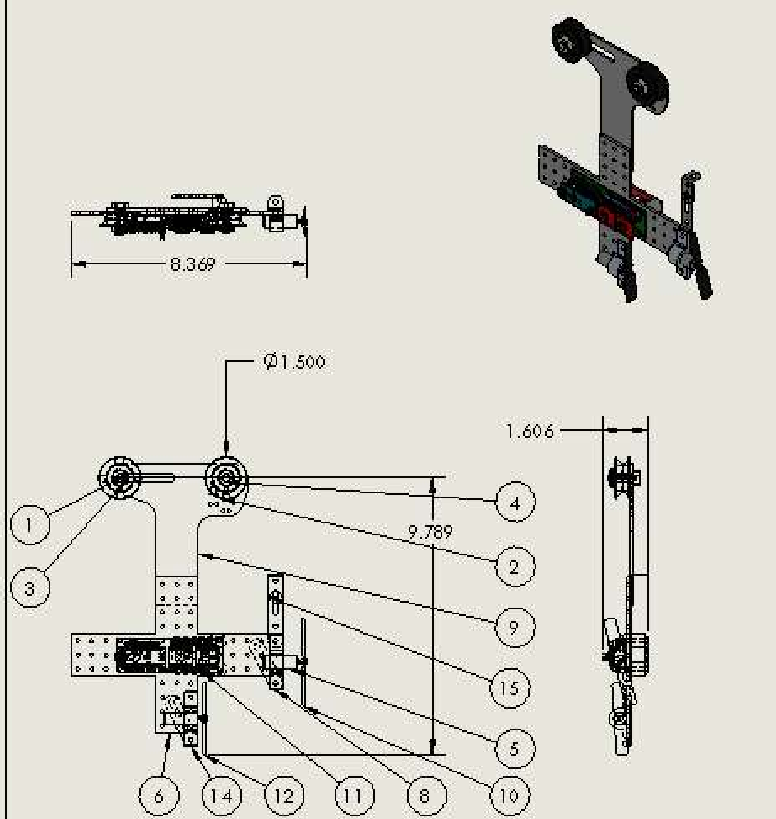
- Lab Week 10
  - 10A (3/22)
    - Team: Turn in CDR draft.
    - ALL MEMBERS: Begin Performance Test 2: Operational Objectives
    - ALL MEMBERS: Come to a conclusion about the conditions of the AEV's trip that are most important: energy efficiency, environment, consistency, track path, etc.
    - Brian: As head of programming, write code for the different scenarios decided upon by team for testing
    - ALL MEMBERS: Begin conducting tests on the different codes for each scenario to determine the conditions under which the AEV maximizes energy efficiency and performance.
  - 10B (3/26)
    - ALL MEMBERS: Continue Performance Test 2 testing
    - ALL MEMBERS: Prepare for Committee Meeting 2
  - 10C (3/28)
    - ALL MEMBERS: Complete Performance Test 2
    - ALL MEMBERS: Analyze Performance Test 2 and come to a conclusion about the conditions in which the AEV can perform best and confirm the code that will be used for the final testing
    - ALL MEMBERS: Finish preparation for Committee Meeting 2
- Lab Week 11
  - 11A (3/29)
    - ALL MEMBERS: Conduct Committee Meeting 2
    - ALL MEMBERS: Begin Performance Test 3: Energy Optimization
    - Alex and Brian: Focus on the code and decide what coding commands could be further tested against each other in order to maximize energy efficiency.
    - Max and Justin: Focus on the body and design and decide what design factors could be further tested against each other in order to maximize energy efficiency.
    - ALL MEMBERS: Once scope is narrowed, begin testing on specific elements (time permitting).
  - 11B (4/2)
    - ALL MEMBERS: If testing has not begun, begin testing. Otherwise continue testing.
    - ALL MEMBERS: Assign roles for completing Progress Report 3 (due 4/4) and Oral Presentation draft (due 4/9)
  - 11C (4/4)
    - ALL MEMBERS: Ensure Progress Report 3 is complete and turned in.
    - ALL MEMBERS: Complete testing. Come to concise conclusions about design and code and ensure that these results are solidified for the final testing.
- Lab Week 12
  - 12A (4/9)

        - ALL MEMBERS: Turn in Oral Presentation draft.
        - ALL MEMBERS: Perform Final Test Run #1
        - ALL MEMBERS: Make necessary adjustments if needed. If no adjustments are needed, complete the next testing runs.
    - 12B (4/11)
        - ALL MEMBERS: Continue Final Testing
        - ALL MEMBERS: Complete Final Test Run #2
        - ALL MEMBERS: Make necessary adjustments if needed. If no adjustments are needed, complete the next testing run.
    - 12C (4/12)
        - ALL MEMBERS: Continue Final Testing
        - ALL MEMBERS: Complete Final Test Run #3
- Lab Week 13
    - 13A (4/16)
        - ALL MEMBERS: Make efficient use of work day.
        - ALL MEMBERS: Assign roles for completion of Final Oral Presentation (due either 4/18 or 4/19), CDR (due 4/19) and Final Website (due 4/19)
        - ALL MEMBERS: Work diligently to complete all necessary assignments.
    - 13B (4/18)
        - ALL MEMBERS: If presentation is this day, turn in Final Oral Presentation by midnight before presentation, and complete Final Oral Presentation.
    - 13C (4/19)
        - ALL MEMBERS: Turn in CDR.
        - ALL MEMBERS: Turn in Final Website update.
        - ALL MEMBERS: If presentation is this day, turn in Final Oral Presentation by midnight before presentation, and complete Final Oral Presentation.

Appendix B: SolidWorks Models



ITEM NO.	PART NUMBER	QTY.
1	Housing w-reflective tape	1
2	Housing	1
3	machine screw nut hex_ai	2
4	hex bolt_ai	2
5	AEV Motor	2
6	Cross	1
7	Battery Spacer	2
8	Motor Mount Clip Aluminum	2
9	Support Arm 1 2 Sensor Holes V2	1
10	Prop 3inch	1
11	AEV Arduino Assembly	1
12	Prop 1	1
13	flat bracket	3
14	Battery Pack Clamp Plate Narrow	1
15	90-deg bracket	1



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12	Prop 1	1
13	Battery Pack Clamp Plate Narrow	1
14	flat bracket	3
15	90-deg bracket	1

The Ohio State University First Year Engineering	Dwg. Title: Final AEV Design (Both Pull)	Scale: 1:4	Inst.: Dick Busick	Units: IPS	Dwg. No.: 2
	Drawn By: Brian Glowacki		Hour: 10:20	Seat: 72R	Date: 03/24/18

Appendix C: Figures and Tables

		Reference		Design 1 - Short		Design 2 - Glowacki		Design 3 - Beachy		Design 4 - Doucette	
Success Criteria	Weight	Rating	Wighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Stability	20%	3	0.6	3	0.6	3	0.6	2	0.4	2	0.4
Aerodynamics	25%	3	0.75	4	1	3	0.75	2	0.5	4	1
Weight	25%	2	0.5	2	0.5	3	0.75	2	0.5	3	0.75
Durability	15%	3	0.45	2	0.3	2	0.3	3	0.45	3	0.45
Safety	15%	3	0.45	3	0.45	2	0.3	3	0.45	2	0.3
Total Score		2.75		2.85		2.7		2.3		2.9	
Continue?		No		Develop		No		No		Develop	

Success Criteria	Reference	Short A	Short B	Glowacki A	Glowacki B	Doucette A	Doucette B	Beachy A	Beachy B
Stability	0	0	-	-	0	-	0	0	-
Aerodynamics	0	+	0	0	0	+	0	-	-
Weight	0	-	+	0	+	0	-	-	+
Durability	0	+	-	+	-	0	+	+	0
Safety	0	+	-	-	-	+	-	+	0
Sum +		3	1	1	1	2	1	2	1
Sum 0	5	1	1	2	2	2	2	1	2
Sum -		1	3	2	2	1	2	2	2
Net Score	0	2	-2	-1	-1	1	-1	0	-1
Continue?	Combine	Combine	No	No	No	Revise	No	No	No

Screening and Scoring Matrices

aR&D 1 Power v. Distance Graphs

Thrust Calibration (grams)	RPM	Power Input (Watts)	Power Output (Horsepower)	Power Output (Watts)	Propulsion Efficiency (%)	Advance Ratio (--)
0	0	0	0	0	0	0
-0.0411	1916	0.2442	-1.40533E-06	-0.001047955	-0.4291381	0.95116383
0.6987	2874	0.4329	2.38906E-05	0.01781524	4.1153245	0.63410922
1.6851	3772	0.7252	5.76186E-05	0.042966167	5.92473339	0.48314685
3.1236	4550	1.0915	0.000106805	0.079644601	7.29680269	0.40053405
4.8909	5389	1.5318	0.000167234	0.124706678	8.14118543	0.3381759
6.9048	6107	2.0461	0.000236096	0.176056487	8.60449085	0.29841656
8.5899	6766	2.6048	0.000293714	0.219022654	8.40842497	0.26935115

10.7271	7365	3.1968	0.000366791	0.273516328	8.5559412	0.24744466
13.152	7964	3.885	0.000449706	0.33534569	8.63180669	0.22883349
15.7824	8622	4.5584	0.000539647	0.402414828	8.82798411	0.21136974
18.7827	9161	5.328	0.000642236	0.478915563	8.98865547	0.19893351

Thrust Calibration (grams)	RPM	Power Input (Watts)	Power Output (Horsepower)	Power Output (Watts)	Propulsion Efficiency (%)	Advance Ratio (--)
0	0	0	0	0	0	0
1.2741	1976	0.0592	5.36188E-05	0.039983525	67.5397374	1.13511673
2.0139	2934	0.1887	8.47523E-05	0.063199765	33.4921911	0.76448216
3.0003	3632	0.3996	0.000126264	0.094154751	23.5622501	0.61756351
3.9456	4550	0.7326	0.000166045	0.123819947	16.9014397	0.49296498
5.0553	5269	1.0212	0.000212745	0.158644307	15.5350869	0.4256957
6.7815	6047	1.4763	0.00028539	0.212815534	14.4154666	0.37092619
5.0553	6706	1.9832	0.000212745	0.158644307	7.9994104	0.33447519
9.9462	7305	2.5641	0.000418572	0.31212945	12.1730607	0.30704869
11.6313	8023	3.219	0.000489488	0.365010886	11.3392633	0.27957007
13.3575	8742	3.9072	0.000562132	0.419182112	10.7284529	0.25657637
15.3714	9281	4.7508	0.000646885	0.482381877	10.1536978	0.24167554

Wind Tunnel Lab Results