Critical Design Review (CDR) Report

Submitted to:

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Columbus, OH

21 April 2015

This report is the description of Group-A's progress towards development of energy efficient Advanced Energy Vehicle designed to perform the mission objective of Jurassic Park. This report summarizes the progress of the group right from Lab Session 1 to the final testing lab. Important landmarks and progress of the Group is discussed in the following pages. Relevant results and graphs are incorporated inside this report to make the necessary conclusions. Recommendations and required changes section explains the group's thoughts on changes required for the efficient AEV.

Contents

Executive Summary

The primary objective behind the course was the theme of Jurassic Park. The goal of the group was to come up with a way to transport visitors from the visitor center to the pick-up point where the baby dinosaurs are located and finally, bring the baby dinosaurs back to the original starting position. The group decided to design Advanced Energy Vehicle (AEV) to complete this task. The team members decided to make this vehicle cost efficient as well as energy efficient by modifying design and code at various stages. AEV is a mode of transport which can do multi task as compared to trivial automobiles which are designed to perform a specific task. The AEV which was designed by our group was a prototype for transportation of visitors (such as a bus or train) as well as it had the feature of attaching itself to the caboose and bringing it to the desired location.

Number of research methods were utilized by the group at various stages to obtain desired results. The following research methods were used for design and testing the AEV:

1. **Solidworks:** An online tool used for designing the AEV and understanding the structure and location of various components associated with it.
2. **Arduino:** This software was the foundation of the AEV. It was used to code the micro-controller to make AEV perform desired tasks.
3. **Screening and Scoring Matrices:** This method was adopted to finalize the design of the AEV. These matrices consisted of different contents and grading points were awarded based on each design.
4. **Sensor Tests:** This test was used at various stages to determine the proper functioning of the sensors used to make AEV travel specific distance.
5. **AEV Data Recorder:** This software involved MATLAB to record the data from the AEV with specific code and determine the efficiency.
6. **Wind Tunnel Testing:** This testing involved deciding the configuration and working of the propellers. Through this method, team A was able to decide the changes required (explained later) in order to obtain energy efficient AEV.
7. **Design Analysis Tool:** This was the highly used research method in order to determine the various parameters for the AEV. It was used in order to obtain various graphs and necessary data.

Three performance tests were conducted in order to determine the efficiency and functioning of the AEV. The first test analyzed the differences between two designs of the AEV. The team analyzed the energy differences between the two AEV's and finalized upon the design based on the results obtained (explained later). The second performance test concentrated on optimization of the Arduino code to complete the mission objectives (Arduino code present in the appendix). The final performance test was focused on making the AEV energy efficient. This was the most difficult lab session as it had numerous variables in addition to the energy data recordings (Ref. Discussion). For every minute change in code, the team had to record another set of energy data and graph it to understand the changes. Various graphs were generated in order to determine the most efficient code for running of the AEV.

Abstract

Background

The AEV designed by group A had to meet the mission objective. The goal as discussed earlier was the primary objective. The total distance to be covered by the AEV was 75.83 feet. The track involved taking four turns and stopping in front of the sensor for seven seconds each time. The AEV had to attach itself to the caboose using magnet. The entire process had to be unmanned. LiPo batteries were to be used in order to power the run. The entire process had to be completed within 150 seconds.

Results

After months of working, team A successfully met the mission objectives and designed an energy efficient AEV which performed the assigned tasks in 74 seconds. The energy used was 242 Joules for the entire journey. Detailed explanation of the results are shown in the results section.

Recommendation

The team designed energy efficient AEV but the current design can be modified further in order to obtain stable, cost efficient AEV. The cost of the current AEV is $168.00. The theoretical cost for the modified AEV is $159.30. The team recommends to develop an AEV with enough weight and properly aligned (towards the center) center of gravity to obtain stability on the turns. Further discussion is done in the following pages.

Introduction

The primary purpose of performance tests was to analyze the current status of the AEV and finalize the AEV design, code and data for the final test run.

In the Performance Test 1, concepts from previous labs that discussed AEV capabilities and ideal design components were used. Two designs were created and tested on the test track. Comparing the two designs for the AEV to determine a more efficient one was useful as it will help minimize errors and maximize the success at fulfilling the criteria listed in the Mission Concept Review, and at securing the best possible option of AEV for Jurassic Park's transit system that reduces energy waste by maximizing energy efficiency.

In performance test 2, primary emphasis was on finalizing the code for the final design. The team had to account for minor changes occurring due to changes in the tracks such as bumps, unsmooth turns and different mass of caboose each new lab.

Performance test 3 involved the team's focus on energy optimization by plotting graphs using various parameters and analyzing the data obtained by the run. The team utilized the resources such as Microsoft Excel and MATLAB to obtain necessary results.

Experimental Methodology

The Performance Test 1 was started by brainstorming ideas for two AEV designs, which culminated in Designs A and B, which can be seen in Figures 1 & 2. Grant and Yash were the leaders for the ongoing discussion. Once the two AEV designs were finalized, a code was written which was a common code used while testing both the designs. Design A was built using the AEV kit provided to the team, and can be seen in Figure 1. The code was then uploaded to the AEV. The AEV was then tested on the track and the data was obtained. The same process was followed for Design B where it was built using the AEV kit and tested on the track to receive the data. The data received from both the test runs was used to calculate the energy efficiency. The two AEV designs built were also tested for traits such as balance, ease of maintenance, durability, mass and propeller position using the concept scoring and screening methodology.

Similarly, performance test 2 was conducted in order to determine the code required for running the AEV. The code had to be flexible in order to account for minute changes occurring due to variables such as battery voltage, uneven track and improper attachment of the caboose. This test was also used to determine the physical parameters of the designed AEV such as cost, durability and maintenance. The team took a step further to obtain relevant data in order to guarantee the customer a period of time where AEV would require no maintenance cost. As seen from Figure 3, the team had to design AEV meant to function on the outer track. The layout shown in the figure demonstrates the coding requirement strategies adopted by the team.

Finally, the last performance test was conducted in order to determine the energy efficiency of the AEV. The team analyzed the data obtained and plotted graphs to ease the understanding of the information. Yoon and Donghoon were the leaders of discussion. Yoon optimized the design further in order to make the AEV more energy efficient.

The equipment used for the Performance Test was the AEV kit provided to the team along with a battery which was used to build the AEV. The AEV kit provided contained an arduino, two propellers, two electric motors, two count sensors, two sensor wires, screws and nuts, and pieces for the body structure. A computer where the code to be tested was written and a USB cord to connect the computer to the arduino so that the code could be transferred was used. Finally, the AEV was tested on the pre-determined track.

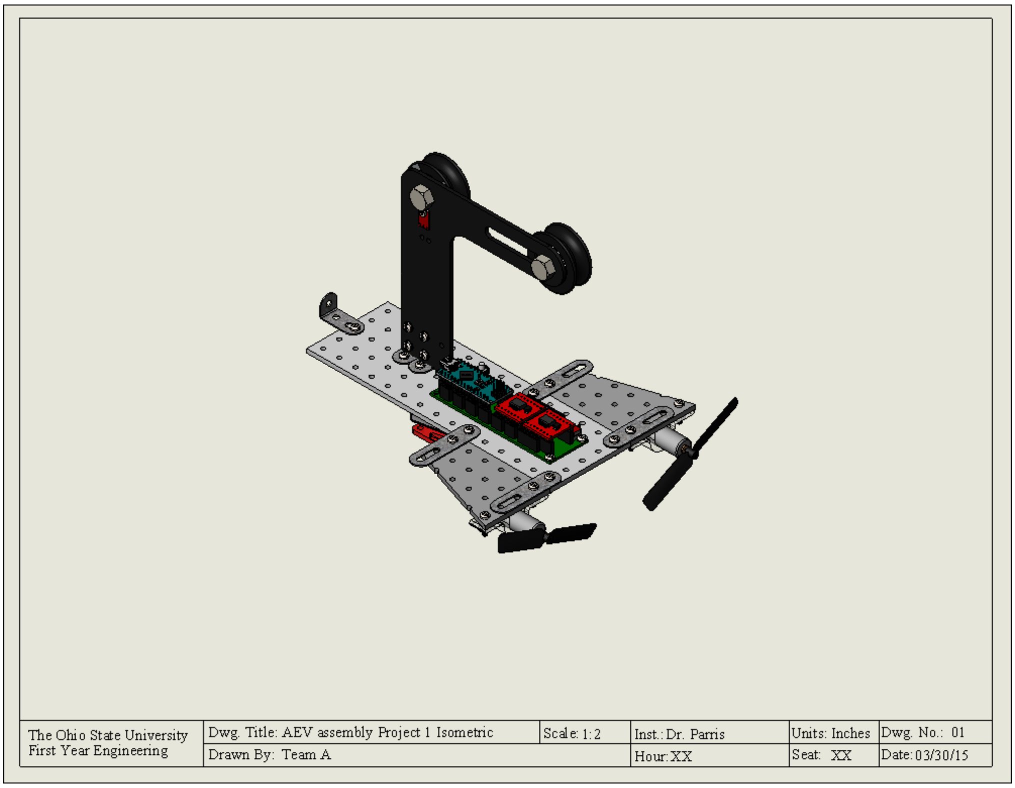


Figure 1. Design A (isometric)

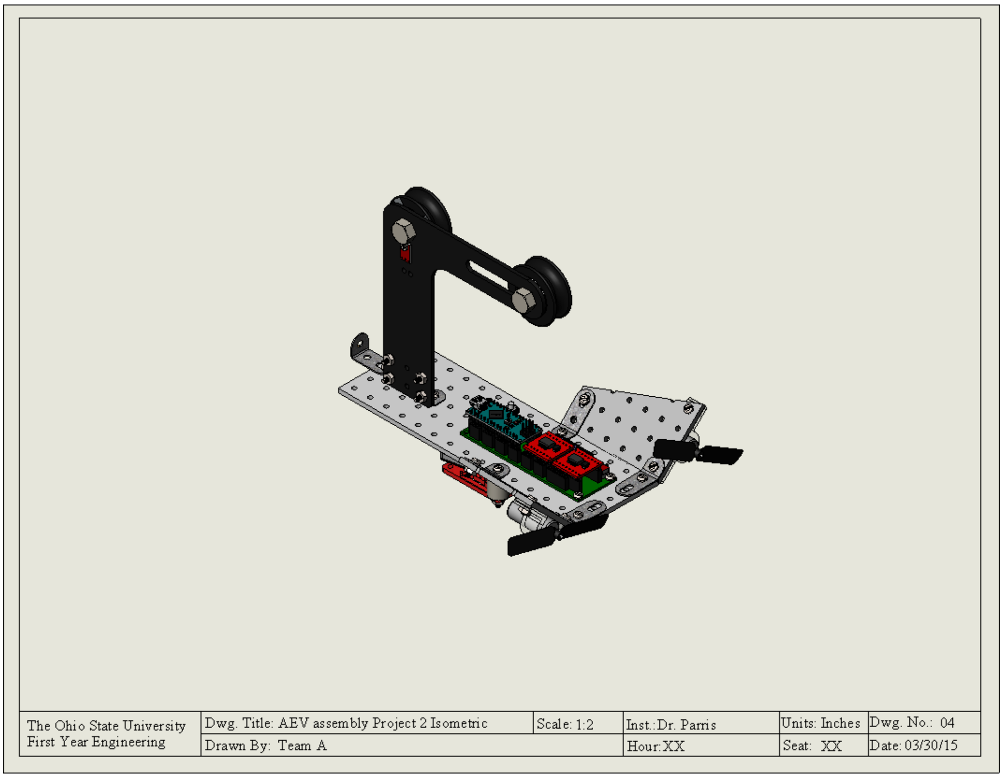


Figure 2. Design B (isometric)

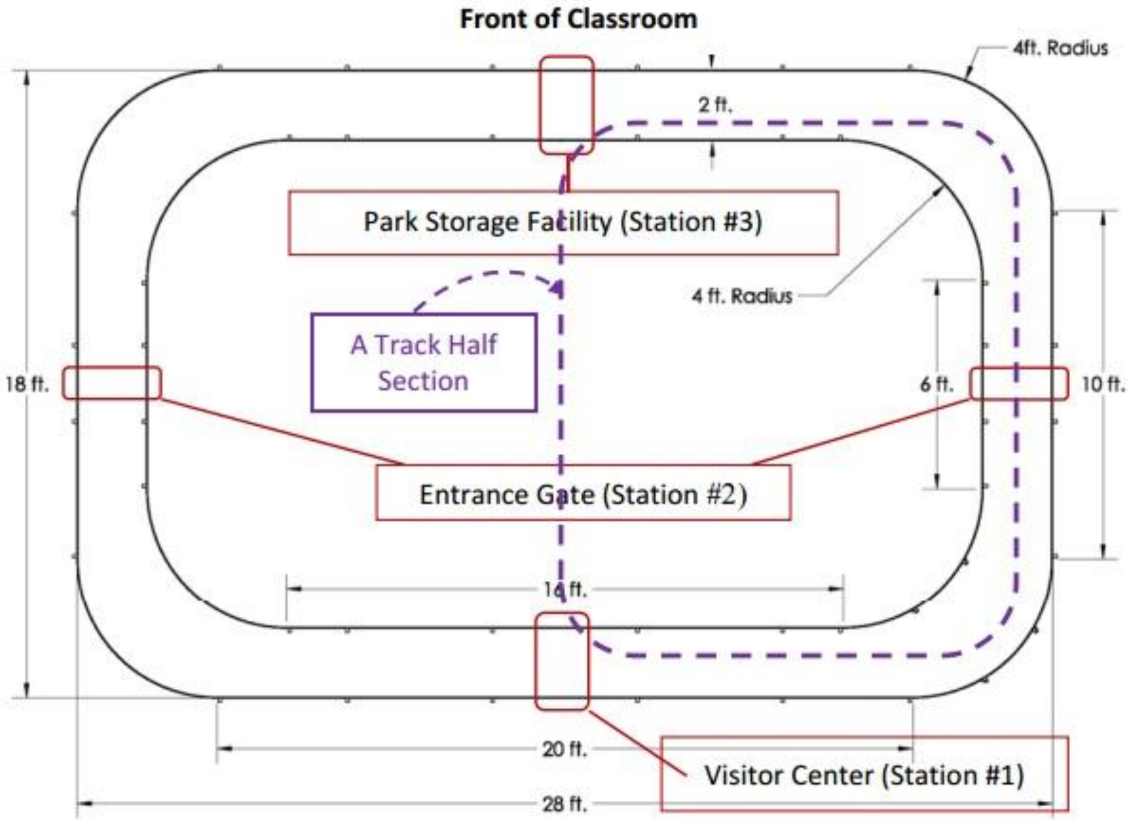


Figure 3: Track Layout

Results

System Efficiency is the percentage of power being used by the AEV out of all the power provided to the AEV via the battery. Advance Ratio, the velocity of the AEV versus the RPM, are displayed. A high system efficiency reflects that more and more of the provided power is used, indicating an energy efficient system. The higher the advance ratio, the less RPM are needed to achieve a higher velocity.

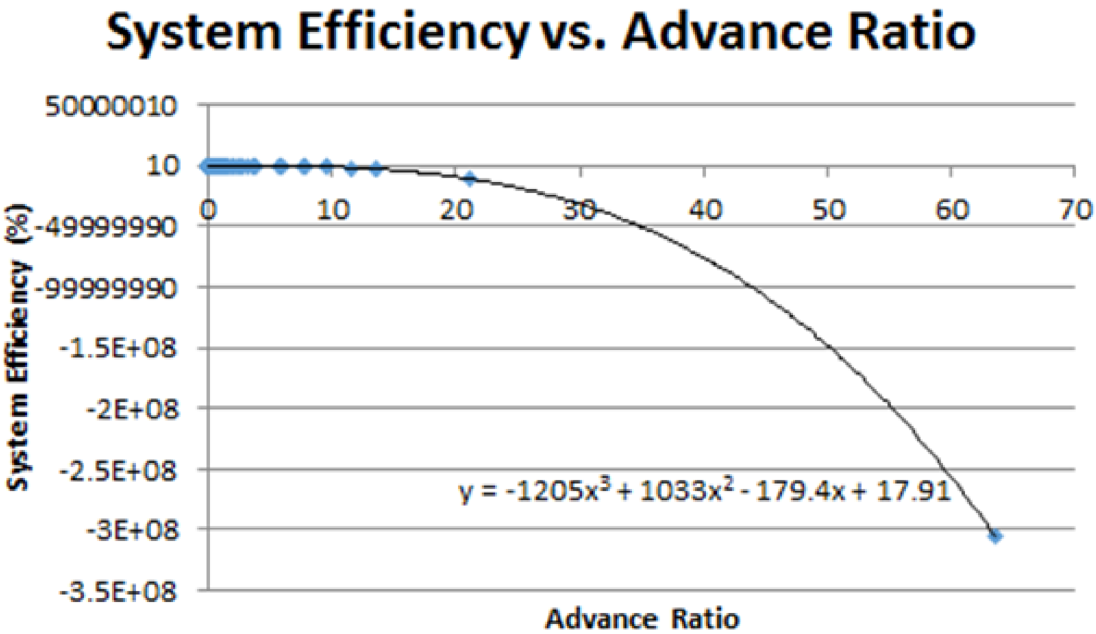


Figure 4. System Efficiency vs. Advance Ratio (Design A)

Figure 4 displays an uncharacteristic, according to our previous labs and tests, curves deeply into the fourth quadrant of the cartesian graph. The data points are characterized by a trendline that is a third order polynomial that crosses the x-axis. Given that it cross the x-axis in a gradually decreasing curve, it can be suggested that as advance ratio increases as efficiency decreases.

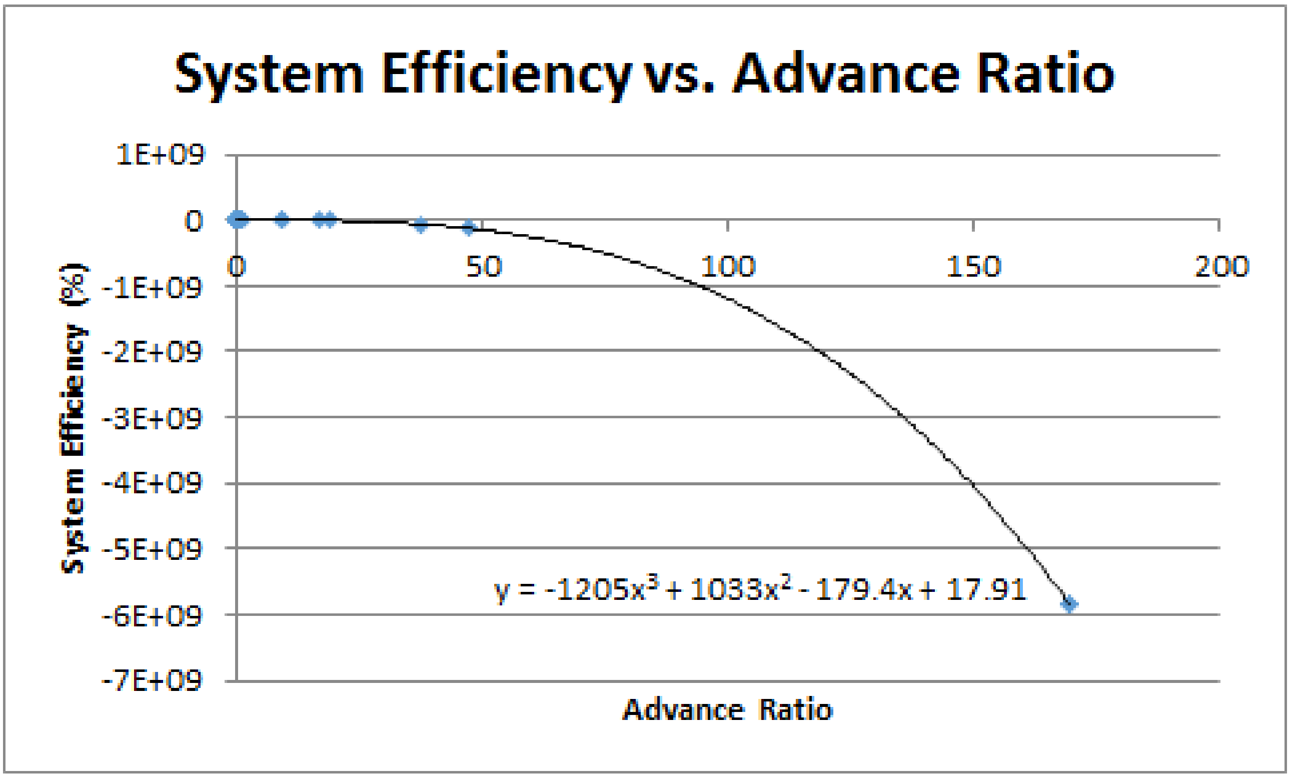


Figure 5. System Efficiency vs. Advance Ratio (Design B)

Figure 5, just as Figure 4, maps the advance ratio to a related system efficiency value but for Design B. The third order polynomial trendline is the same as that in Figure 4, though the range of advanced ratio values is greater in Figure 5 than in Figure 4, likely due to the difference in the amount of code that was run with each design. Just as in the previous figure, the more advanced ratio increases, efficiency seems to decrease.

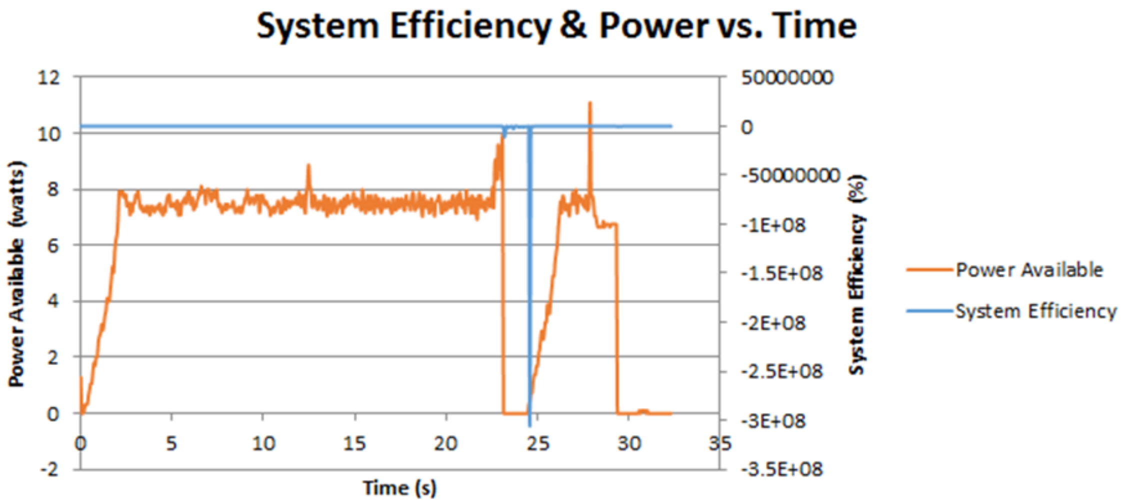


Figure 6. System Efficiency and Power vs. Time (Design A)

In Figure 6, power output and efficiency are compared over time for Design A. The power available to the Arduino increases, remains at a relatively similar rate for several seconds with constant system efficiency around 10%. Around 25 seconds, the efficiency drops, likely indicating a brake, and the power available drops with it. After 25 seconds, there is a swift increase, a sudden peak of power available to the AEV, and then a sudden drop between 25-30 seconds.

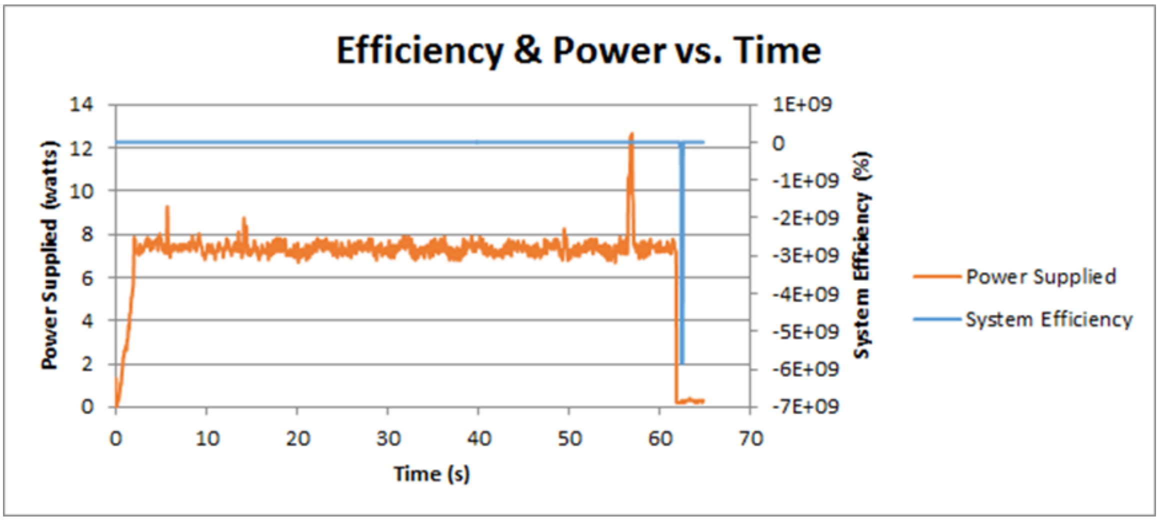


Figure 7. System Efficiency and Power vs. Time (Design B)

Figure 7 displays, just like Figure 6, the relationship of power supplied to and the efficiency of the AEV with time. Over time, the power available increases to a steady rate around 10 watts with the power efficiency leveling out around 10%. There is a sharp decline in both values at around 60 seconds at which point efficiency completely falls and power supplied slows to 0, likely signifying a break.

The team decided to conduct Energy analysis test of the two prototypes based on a
In Table 2, Design A's executed code is mapped to the energy supplied in designated phase of action. In totally, the supplied energy throughout the process as approximately 448 Joules.

Phase #	Supplied Energy (J)	Arduino Code	Total Supplied Energy (J)
1	26.50458387	celerate(4,0,30,2);	26.50458387
2	420.5132907	motorSpeed(4,30); goToAbsolutePosition(48);	447.0178745
3	1.434691506	brake(4);	448.452566

Table 1. Energy-Arduino Code Correspondence Chart (Design A)

In Table 2, despite having more code to execute, the amount of supplied energy reduced by 200% as compared to that of Design A's code.

Phase 2 in the table below represents the greatest amount of supplied energy, and the associated action is that of a motorSpeed() and goToAbsolutePosition() command. The segment with the least supplied energy occurred during phase 4, during which a brake() command was followed.

Phase #	Supplied Energy (J)	Arduino Code	Total Supplied Energy (J)
1	6.003163333	reverse(4); celerate(4,0,30,2);	6.003163333
2	158.9401252	motorSpeed(4,30); goToAbsolutePosition(197);	164.9432885

3	28.51606443	brake(4);
		goFor(1);
		celerate(4,0,30,2);
			193.459353

4	0.240863367	motorSpeed(4,30); goFor(1.5);	193.7002163

Table 2. Energy-Arduino Code Correspondence Chart (Design B)

It is to be noted that the tables above represent testing of the two prototypes of the AEV for a certain task. The task was that the AEV has to start from a starting position and reach the entrance gate. The task was small to facilitate time and conduct more tests in order to optimize the code and finalize the design.

Final Design Analysis

The final testing was performed during performance test 3 which involved the finalized code and design of the AEV. The full energy analysis was conducted and proper graphs were generated in order to obtain the final data recording.

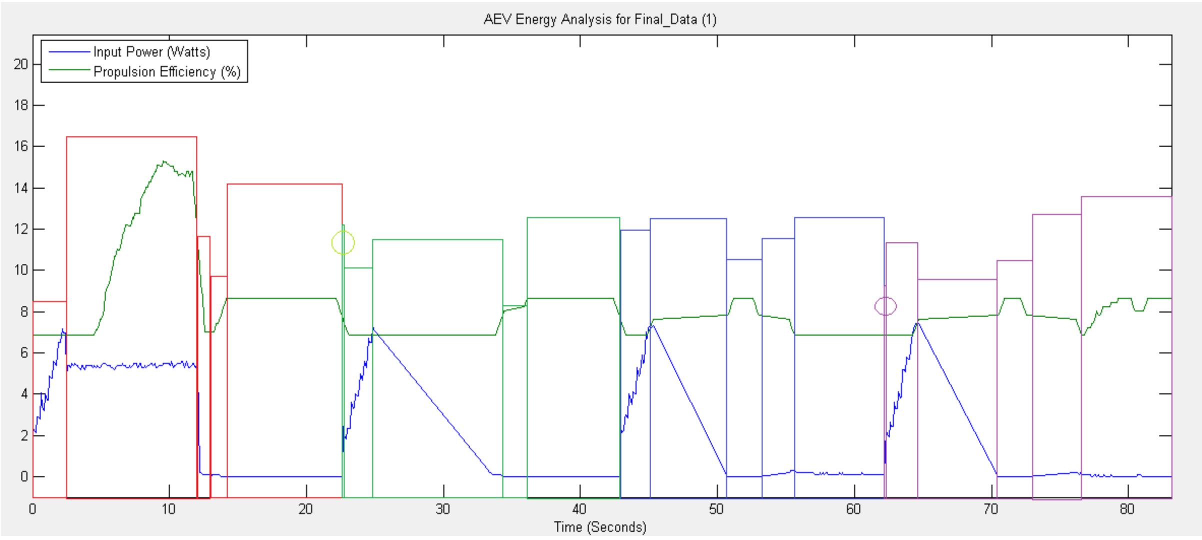


Figure 8: Final AEV testing data

The graph plotted above shows the final analysis of the AEV run on April 15, 2015. The phases represent various stages of the AEV. The AEV failed to position itself to the final location by about 1.5 feet. Other than that, the AEV had the following advantages:

1. Smooth turns
2. Proper attachment of the caboose
3. Stoppage at the desired location in front of the sensors
4. Efficiency for the bumps present on the tracks

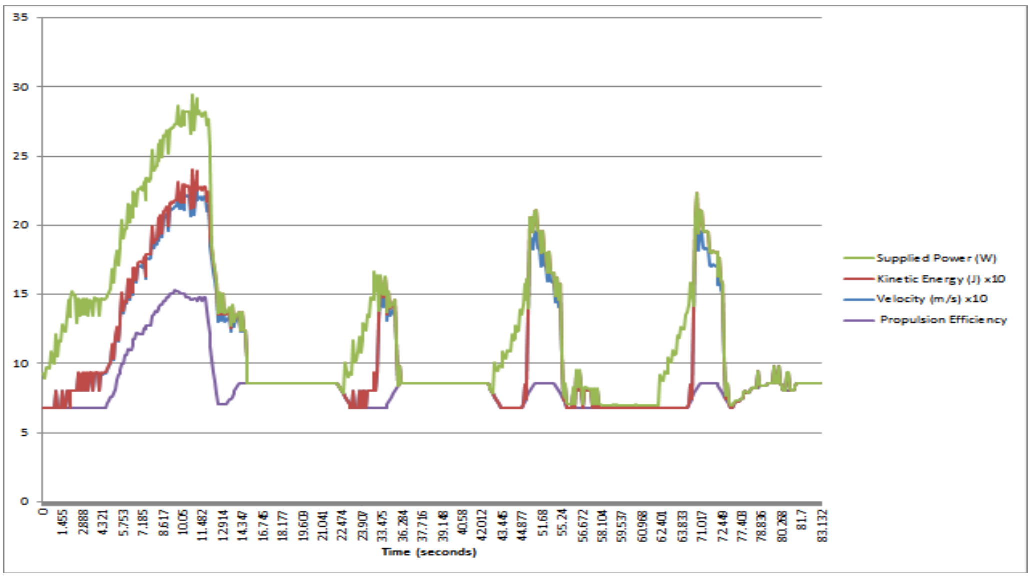


Figure 9: Full Energy Analysis

The figure above represents the complete energy analysis of the AEV. Various parameters such as Supplied Power, Kinetic Energy, Velocity and Propulsion Efficiency can be observed. The results are consistent with the findings from performance analysis tests conducted previously.

One of the main problems the team encountered was the change in battery power during the runs. Code was changed to work with AEV position and direction rather than time. Battery voltage regulation code was also included to adjust motor speeds as changes in battery power occurred. It was also noticed that reversing the motors used a significant amount of power, therefore it was decided to use reverse command as little as possible.

While changing the design of the AEV it was noticed that results were better when the weight of the parts was centered and as close to the rail as possible. The lowest weight that was achieved was of the final design, 0.271 kilograms.

During the final testing, the AEV did not function as expected (Ref. Score-sheet in appendix). The team was able to complete only 1 test run due to shortage of time. After the initial test run, the team performed reflectance sensor test where the team found out that the battery which was utilized had low voltage which resulted in improper functioning of the AEV. The AEV started from the initial position but did not stop in front of the sensor. The AEV did not attach to the caboose as it stopped before. Overcoming these obstacles, the team had proof of proper functioning of the AEV in form of the video which was approved by the instructor in order to determine the final run parameters.

Discussion

It was agreed upon, due to wind tunnel testing in Lab 7, that the ideal propeller configuration was the pusher configuration with the three inch EP-3030 styled propellers. From there Team A determined that it wanted to explore what would happen with a variation on the wing and propellers' orientation.

The initial design tested in Performance Test 1 (parts A & B) (PT1), Design A which involved a flat wing design, level with the main body, which would position the motors, and also the propellers, above the main body. It can be seen in the appendix as Figure A1. This required that the Arduino microcontroller was moved forward from where it was in the sample AEV. The battery was then moved slightly backward, along with the V-body, to compensate for the change in weight and to improve balance.

The second design which turned out to be our final design tested in PT1 (parts B & C), Design B, was a close relative to the initial design and the sample design. It was made with the flat wings and lowered motors and propellers but different orientation of components on the body, and can be seen in Figure A2, located in the appendix. What changed was that the orientation of the wings to the main body. The V-shape was returned to near its initial position, the battery likewise, and the Arduino Microcontroller positioned towards the end of the main body.

The four designs created by Group A in lab 1 primarily using different body shapes but with largely the same wing and motor position as the sample AEV. It would be fair to say that our focus completely shifted during the course of the eight exploratory labs and it shifted from body and to wings/motors/propellers position. In Lab 3 concept and scoring screening was undertaken with only the sample AEV, and as such, not all concept were scored and screened in lab 3.

The criteria we determined were of note in developing our AEV in lab 3 were as follows: balance of the AEV on the track, the ease of doing maintenance on the AEV, durability of the AEV, placement of propellers and mass of the AEV.

In Table 3, Team A listed the success criteria of an AEV determined in Lab 3 in a new concept scoring table. Rated against the sample AEV which was the only AEV analyzed in Lab 3, each design tested in PT1 exceeded the score of the sample across all criteria, and Final Design rated best of all.

Success Criteria	**Reference**	**Sample Design**	**Design A**	**Final Design**
Balance	0	0	+	0
Maintenance	0	-	-	+
Durability	0	0	+	+
Placement of Propellers	0	+	+	+

Mass	0	+	+	+
Sum of +'s	0	2	4	4
Sum of 0's	5	2	0	1
Sum of -'s	0	1	1	0
Net Score	0	1	3	4

Table 3. Concept Screening

In Table 4, building off the concept screening sheet from Lab 3, Group A developed a new sheet that compares the rated scoring of the sample AEV and two designs using the same criteria listed in Table 3.

Across all categories, the two designs tested in PT1 overpower the sample AEV overall, and Final Design is shown to be decisively a better design within Group A.

Success Criteria	**Weight**	**Reference & Sample AEV**		**Design A**		**Final Design**	
		Rating	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Balanced	15%	3	0.45	4	0.6	3	0.45
Maintenance	50%	3	1.5	3	1.5	4	2
Durability	15%	2	0.3	5	0.75	5	0.75
Placement of Propellers	10%	3	0.3	5	0.5	5	0.5
Mass	10%	2	0.2	3	0.3	3	0.3
Total Score			2.75		3.65		4
Continue?			No		Develop		Yes

Table 4. Concept Scoring

Efficiency is the ratio of work input to the work output. As it can be seen from the graphs above the work output steadily increases as the current increases. However taking into account the first 30 seconds of both the graphs, Since negligible weight is added or removed in the two designs it is seen that there is only a mere design change. The difference being the pushing in of the propellers and the change in orientation of the L-holder, change in efficiency however applying practical logic it can be believed that since the propellers are closer to the body the efficiency will increase and the data complements this belief that was shared by the group. Also the graph shows that design A takes more time to power up and hence more time to move and this result in loss of valuable time while transporting precious cargo.

The group believed that there was scope for improvement in the stability of design A and improved in the areas related to area coverage and balance and hence decided to push in the wings and make adjustments so that the design was more compact. As the data and the graphs point out the new design was more successful in converting the energy input into the work done.

From the final run the AEV was able to complete the mission objective taking smooth turns as the team ensured configuration which involved center of gravity to be directly at the middle point of the AEV directly beneath the track. The only problem which occurred during the run was that the AEV did not stop at the final position and stopped 1.5 feet before.

Conclusion and Recommendations

In conclusion, throughout the design and testing process the group was able to analyze the data and produce an extremely efficient AEV design. This was achieved by optimizing the physical design, propulsion and programming. The entire task was completed successfully in order to complete the mission statement.

First, from a physical design standpoint, it was determined that the best approach would be to keep the mass as low as possible. This resulted in the very small, light and compact design. As few part were used as possible to keep the AEV weight minimal. Due to the lightweight design the AEV had an excellent weight to thrust ratio.

Next group optimized propulsion by analyzing the thrust of the motors in different configurations. It was concluded, through experimentation and data collection, that the motors produced the most thrust while set in a pusher configuration. Due to this discovery the AEV was designed so that the motors would be in the pusher configuration while it was pulling the load to give the maximum amount of thrust and best efficiency during the most energy intensive portions of the trip.

Last the group increased the overall efficiency by improving the AEV programming. The reliability between runs was increased by removing time based instructions and basing instruction execution on the AEV's current position and direction. The group then was able to decrease the energy used by allowing the AEV to coast at time and take advantage of the kinetic energy that the AEV developed during the run.
The above mentioned were the errors team observed and the necessary steps taken in order to resolve it.

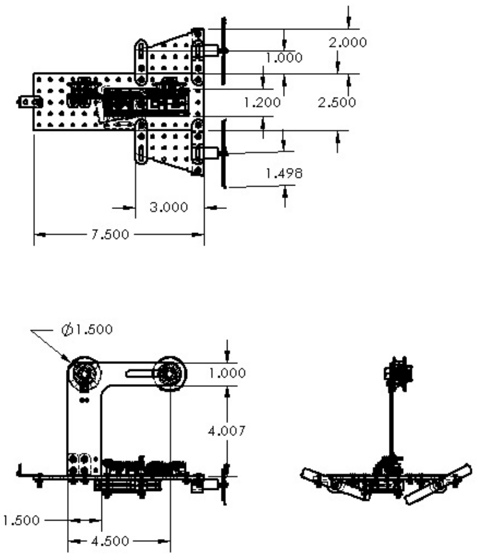
The team would like to recommend a few things for the future AEV projects. A command which would incorporate voltage of the battery required in order to function efficiently. The command should be merged with velocity or celerate in order to determine constant speed of the AEV. The battery was constantly dying and the team had to change the code blindly in order to achieve desired result. Another thing which the team would like to recommend is improving the resolution of the sensor present in the wheel. Currently, the code accepts just whole numbers as the argument. If decimal parameters could be passed as function arguments, it would make the AEV even more efficient.

Appendix

Schedule

Task and Roles	**Start date**	**Due date**	**Progress**	**Estimated Hours**	**Yash**	**Grant**	**Yoon Jae**	**Donghoon**
Wind Tunnel Testing	Already done	Already done	100	X	V	V	V	V
Program Design-Code for Comparing	Already done	Already done	100	X	V	V	V	V
AEV Design Adjustment	22-Mar	30-Mar	100	X	V	V	V	V
Construct the AEV	22-Mar	30-Mar	100	X	V	V	V	V
Performance Analysis (Matlab)	01-Apr	05-Apr	100	X	V	V	V	V
Develop programming strategy	05-Apr	08-Apr	100	X	V	V	V	V
Program Design-Code for Full Track	05-Apr	08-Apr	100	X	V	V	V	V
Program Design-Edit for Full Track	08-Apr	12-Apr	100	X	V	V	V	V

Prototype 1(A1)

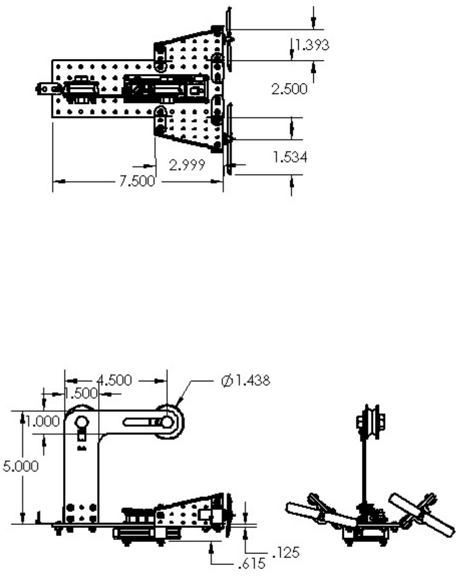


ITEM NO.	PART NUMBER	QTY.
1	Large Rectangle	1
2	90-deg bracket	3
3	Support Arm 2 ABS	1
4	Pulley Assembly w-reflective tape	1
5	Pulley Assembly	1
6	Magnet Cube	1
7	Battery Pack	1
8	Rotation Sensor Board	1
9	SL-PHMS 0.112-40x0.375x0.375-S	9
10	SL-PHMS 0.112-40x0.5x0.5-S	9
11	SL-PHMS 0.112-40x1x1-S	2
12	MSHXNUT 0.112-40-S-S	20
13	MSHXNUT 0.3125-18-S-S	2
14	MSHXNUT 0.086-56-S-N	1
15	Preferred Narrow FW 0.094	4
16	HBOLT 0.3125-18x0.875x0.875-S	2
17	SL-FHM1 0.086-56x0.25x0.25-S	1
18	AEV Arduino Assembly	1
19	Battery Spacer	2
20	Battery Pack Clamp Plate	1
21	Battery Sleeve	1
22	Kapton Tape	1
23	Battery	2
24	Right Trapezoid	2
25	flat bracket	4
26	Motor Mount Clip	2
27	AEV Motor	2
28	Prop 3inch	2

Weight : 268 Cost: $182

The Ohio State University First Year Engineering	Dwg. Title: AEV assembly Project 1	Scale: 1:4	Inst.: Dr. Parris	Units: Inches	Dwg. No.: 01
	Drawn By: Team A		Hour: XX	Seat: XX	Date: 03/30/15

Prototype 2(A2)



ITEM NO.	PART NUMBER	QTY.
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4	45-deg bracket	4
5	Motor Mount Clip	2
6	AEV Motor	2
7	Support Arm 2 ABS	1
8	Pulley Assembly w-reflective tape	1
9	Pulley Assembly	1
10	Magnet Cube	1
11	Battery Pack	1
12	Rotation Sensor Board	1
13	SL-PHMS 0.112-40x0.375x0.375-S	17
14	SL-PHMS 0.112-40x0.5x0.5-S	1
15	SL-PHMS 0.112-40x1x1-S	2
16	Preferred Narrow FW 0.094	4
17	MSHXNUT 0.112-40-S-S	20
18	MSHXNUT 0.3125-18-S-S	2
19	MSHXNUT 0.086-56-S-N	1
20	HBOLT 0.3125-18x0.875x0.875-S	2
21	SL-FHM1 0.086-56x0.25x0.25-S	1
22	AEV Arduino Assembly	1
23	Battery Spacer	2
24	Battery Pack Clamp Plate	1
25	Battery Sleeve	1
26	Kapton Tape	1
27	Battery	2
28	Prop 3inch	2

Weight : 265 Cost: $168

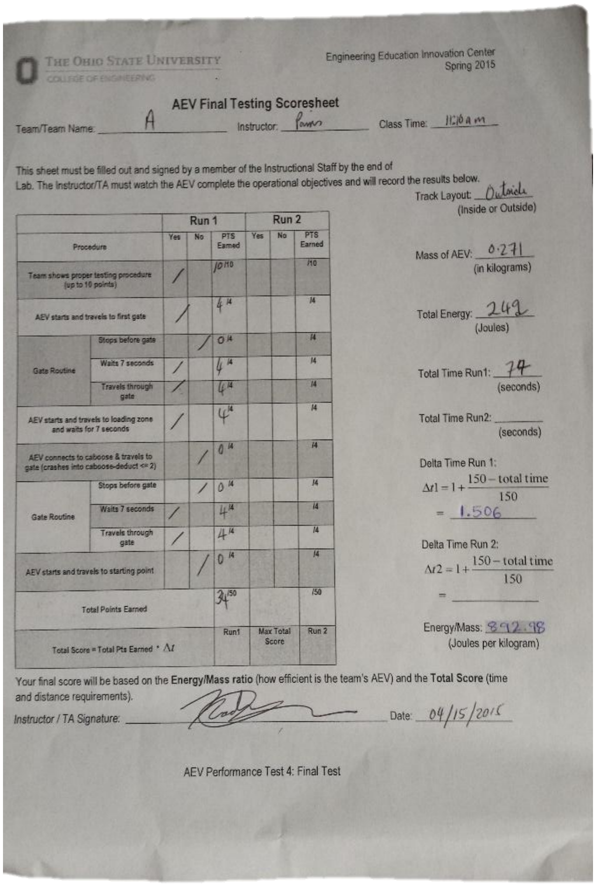
The Ohio State University First Year Engineering	Dwg. Title: AEV assembly Project 2	Scale: 1:4	Inst.: Dr. Parris	Units: Inches	Dwg. No.: 01
	Drawn By: Team A		Hour: XX	Seat: XX	Date: 03/30/15

Final Code

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

/*
*   Created By-Yashvardhan Gusani
*/

//Going from Visitor Center to Entrance Gate
reverse(4);
motorSpeed(4,20);
goToAbsolutePosition(-363);
brake(4);
goFor(1);
reverse(4);
motorSpeed(4,15);
goFor(3);
brake(4);
goFor(6);

//Going from Entrance Gate to Park Storage Facility
reverse(4);
motorSpeed(4,20);
goToRelativePosition(-385);
brake(4);
goFor(1);
reverse(4);
motorSpeed(4,15);
goFor(3);
brake(4);
goFor(11);

// Going from Park Storage Facility to Entrance Gate
motorSpeed(4,26);
goToRelativePosition(341);
brake(4);
goFor(1);
reverse(4);
motorSpeed(4,18);
goFor(2);
brake(4);
goFor(8);

// Going to the Visitor Centre
reverse(4);
motorSpeed(4,25);
goToRelativePosition(337);
```

```
brake(4);
goFor(10);
reverse(4);
motorSpeed(4,18);
goFor(2);



/*
*   End of Program
*/
```

Score Sheet (A3)



THE OHIO STATE UNIVERSITY
COLLEGE OF ENGINEERING

Engineering Education Innovation Center
Spring 2015

AEV Final Testing Scoresheet

Team/Team Name: A   Instructor: Powers   Class Time: 11:10 a m

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)

Procedure		Run 1 Yes	Run 1 No	Run 1 PTS Earned	Run 2 Yes	Run 2 No	Run 2 PTS Earned
Team shows proper testing procedure (up to 10 points)		/		10 /10			/10
AEV starts and travels to first gate		/		4 /4			/4
Gate Routine	Stops before gate		/	0 /4			/4
	Waits 7 seconds	/		4 /4			/4
	Travels through gate	/		4 /4			/4
AEV starts and travels to loading zone and waits for 7 seconds		/		4 /4			/4
AEV connects to caboose & travels to gate (crashes into caboose-deduct <= 2)			/	0 /4			/4
Gate Routine	Stops before gate		/	0 /4			/4
	Waits 7 seconds	/		4 /4			/4
	Travels through gate	/		4 /4			/4
AEV starts and travels to starting point			/	0 /4			/4
Total Points Earned				34 /50			/50
Total Score = Total Pts Earned * Δt				Run1	Max Total Score		Run 2

Mass of AEV: 0.271
(in kilograms)

Total Energy: 249
(Joules)

Total Time Run1: 74
(seconds)

Total Time Run2: ______
(seconds)

Delta Time Run 1:

$$\Delta t1 = 1 + \frac{150 - \text{total time}}{150}$$

= 1.506

Delta Time Run 2:

$$\Delta t2 = 1 + \frac{150 - \text{total time}}{150}$$

= ______

Energy/Mass: 892.98
(Joules per kilogram)

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: ______   Date: 04/15/2015

AEV Performance Test 4: Final Test