Critical Design Report

Submitted to:
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19 April 2017

Executive Summary

The purpose of the AEV (Advanced Energy Vehicle) labs was to develop a working model that will complete the objectives presented in the Mission Concept Review. The mission was to successfully make it around the track, to pick up the cargo and return it to the start with a vehicle that meets all design and operational constraints, while minimizing the energy to mass ratio. The overall objective for the labs was to acquire the skills necessary to program and create a unique AEV that could potentially fulfill the MCR. Over the course of the semester, the team has tested for various components including efficiency of the AEV, design and effectiveness of push vs. pull propellers, and the proper way to program the Arduino controller. The labs have helped the team to better understand and draw conclusions in the previously stated fields. The motivation behind the project itself is/was to encourage problem solving, critical thinking, and innovation in developing engineers.

The Mission Concept Review (MCR) in the AEV Lab Manual outlined the actual task to be completed by the AEV, along with any and all constraints. The necessity of the AEV was indicated in a scenario found at the beginning of the MCR. Essentially, there is a load that must be retrieved transported along a curved track with a gate bisecting the pathway. Within the MCR, it was explicitly stated that energy is a resource that must be conserved. The team's finalized AEV design will complete the task via the execution of a program by the Arduino controller.

In the initial labs, the team drafted several prototype concepts for the AEV. These designs were compared and the group then decided on a final design that implemented the best aspects from each individual's concept. The team also tested various propeller designs for efficiency, coming to the conclusion that the 3020 propeller is the most efficient propeller to use. The team learned how to utilize the Arduino's ability to collect data during its operation. This allowed the team to quantitatively observe and analyze the performance of the AEV.

The team recommends to any future teams constructing an AEV that it is far more important to use class time making adjustments to the code and not the design of the AEV. Most of the designs consisted of two propellers and minimal parts to reduce weight, the key determining factor in the success of an AEV was the ability of the program to complete all tasks as efficiently as possible. The most efficient method of travel was to supply the AEV with an initial burst of energy at the start of each phase, followed by a period of coasting to the end of the phase.

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Introduction

The general purpose of the AEV labs completed since the start of the semester was to develop a design of an AEV with the intended function of completing the overall mission of creating an AEV to pickup the cargo and return it to the start successfully.

The AEV must be programmed to traverse the track and return to its starting position with a load. In the center of the track, the AEV must stop for approximately 7 seconds to trigger the lowering of a gate that will allow the AEV to pass. This same gate must be lowered on the way to the load and on the way back to the initial position. The MCR also states that the AEV must conserve power, so resource efficiency is a large concern of the team. The AEV must complete its task within 2.5 minutes. In the team's experience through the lab, this is more than ample time; therefore, time complexity was not a noteworthy consideration to make.

Experimental Methodology

Overall, the lab procedures provided the team with instructions to adequately develop a working AEV model. The arc of the project began with an introduction to the Arduino controller, the Arduino programming environment, and the MCR. The team used the reference design (sample AEV) to learn what the project would entail. A wind turbine was used by the instructional staff to collect data on the two provided types of propellers (the "3030" and the "3020"). The team then proceeded forward by brainstorming prototype AEV designs and eventually choosing one to act as a working model. This choice was informed by using two different methods of concept evaluation, one being more quantifiable than the other. A specific algorithm was implemented and used by the team's new AEV to provide the opportunity to learn how to use the provided AEV Analysis Tool (a GUI and program written in MATLAB). After the aforementioned introductory lab material, the team began actually working directly on fulfilling the MCR.

For an entirely comprehensive coverage of the experimental methodology, refer to the source material in use by Engineering 1182 students: the *Advance [sic] Energy Vehicle Design Project Lab Manual*.

Results & Discussion

For Performance Test 1, the sample AEV (see AEV Lab Manual for visual) and the team's custom model (see figure 1 in Appendix A) chosen from the concept screening and scoring test were utilized. The team mainly focused on, in the concept screening and scoring sheet, weight of the AEV, stability while on a track and the efficiency. The team chose to focus on the mentioned criteria because the team felt those were the most critical areas to success with the AEV. The team's expectation for the two vehicles were to be similar to the sample AEV but slightly more efficient due to reduction in weight. The sample AEV consists of two motors supported by wings that extend from the main body of the vehicle. The team's custom model also consists of two motors, but they are supported by the vehicle's main T shaped body. The battery and arduino are positioned between the motors, the battery resting on top and the arduino suspended underneath. The four prototypes that the team rendered were all similar in design to each other and the sample AEV. After reviewing each design the team decided to focus on minimizing the weight of the vehicle and to utilize a compact design, leading to the final model. See Tables 1 and 2 in Appendix A for the *Concept Screening Scoresheet* and *Concept Scoring Matrix*, respectively.

During Performance Test 1, the team observed that the custom model behaved very similarly to the sample AEV. Both the first model and the sample AEV consumed comparable amounts of power as shown by Figure 2 below, being that they utilized the same Arduino program with the same power settings. (See Figure 3 and Tables 3 and 4 in Appendix A for a performance analysis for each AEV corresponding to each program phase.)

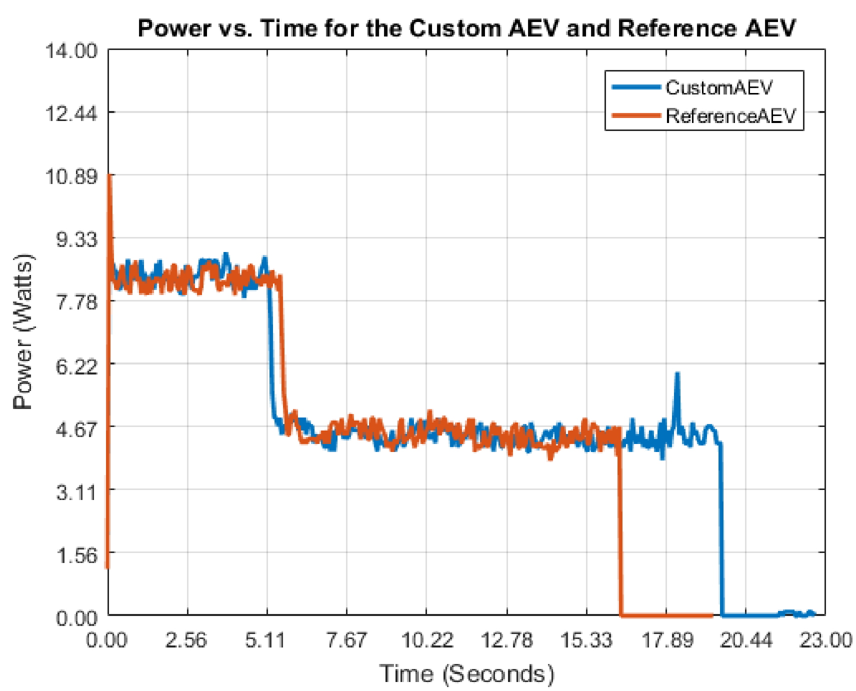


Figure 2: Power over Time Comparison for Performance Test 1

Both vehicles behaved in a manner similar to what the team had anticipated, which was producing similar results and energy consumption except for the team's design using slightly less overall energy. The performance test reinforced the team's belief that the team should further develop the concept for a direct drive vehicle. Using the data collected from System Analysis Tests 1 and 2, the team concluded that the 3020 propeller was a superior model as shown by Figures 4, 5, and 6 on the following pages.

Figure 4 shows a consistently high thrust output for the 3020 when used to push a load, reaching approximately 60 grams at a power setting of 10% and seeing little improvement as more power was given to the motor.

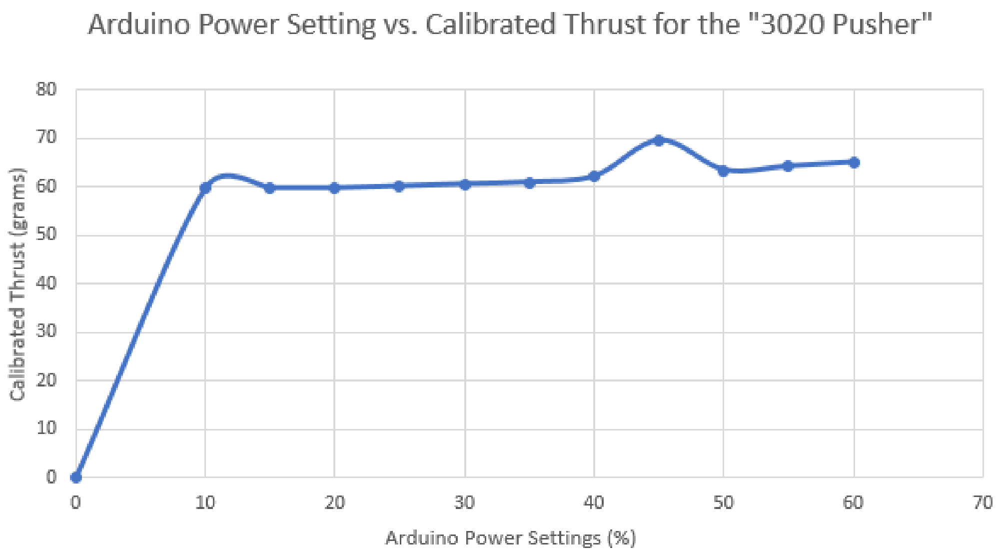


Figure 4: Arduino Power Setting vs. Calibrated Thrust for the 3020 when pushing a load

Figure 5 shows a gradual increase in thrust for the 3030 when used to pull a load, but only reaches a thrust output of 18 grams.

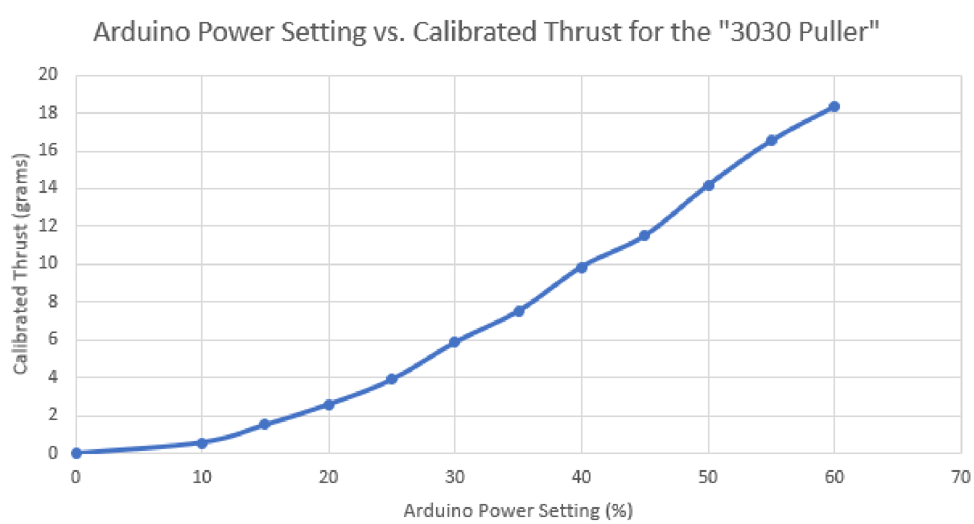


Figure 5: Arduino Power Setting vs. Calibrated Thrust the 3030 when pulling a load

Figure 6 shows that to maximize the efficiency of a propeller, the advance ratio should not exceed approximately 0.75. These results were replicated for both propeller types. (See Equation 1 in Appendix A for the components of the propeller advance ratio and a sample calculation.)

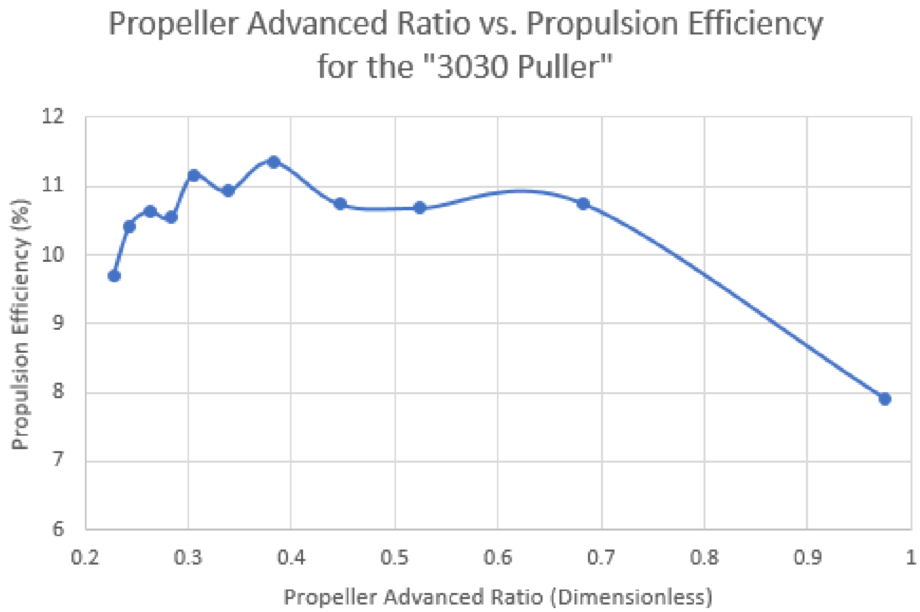


Figure 6: Propeller Advance Ratio vs. Propulsion Efficiency for the 3030 model when pulling a load

During the final testing the team made several observations and therefore adjustments based off of the observations. The AEV successfully made it through the first half of the course with little to no issues. However it appeared that the sensors accuracy became increasingly inconsistent the more distance the AEV traveled, because of this once the cargo was picked up the AEV struggled returning to the gate and therefore completing the rest of the mission. The efficiency of the vehicle differed significantly between the two final tests (see Appendix B AEV final testing scoresheet). The first test used approximately 305 Joules where the second test used 215 Joules. The team adjusted the code between the two trials to cut down on the energy consumption by implementing more coasting. The team's AEV did not perform to the level that the team had hoped, with a 38/50. The team devoted a large portion of time early in the semester to getting the direct drive model to work, and therefore did not give full attention to detail on the final design that was used. The team's sensors, even after troubleshooting, still had issues properly tracking distance after about 16 feet traveled. This caused a problem when the AEV approached the gate for the second time because the motors would cut off prematurely no matter what adjustment was made to the code.

Conclusion & Recommendations

The final result of the AEV was sub-optimal. Several factors impacted the final outcome of the AEV. The largest issue was that the group failed to produce a working direct drive model. Time constraints and crucial parts being delayed nearly a week were important factors in its failure. The design also had one large flaw. The use of a rubber band as a belt between the two grooved wheels, as seen in figure 4, failed. The group then tried to replace this critical aspect of the design. When no timely solution was found, the group was forced to abandon the design, and returned to the propellered AEV design.

Several important lessons were learned about the propellered AEV throughout the labs. For example, the direction of each propeller type greatly affects the efficiency of the propellers (as seen in the Results & Discussion section of this report). The issue was that, because the AEV will travel in both directions, a propeller will be inefficient when traveling in one direction. Another important lesson learned by the team was to have a solid backup plan in case the first plan goes wrong. The team was working on the direct drive model but while waiting for key parts also worked on a propeller based design as a backup. Therefore when the team decided to not move forward with the direct drive, due to too many complications and shortage of time, the team had a back up plan to quickly use for final testing.

Hardware seemed to be another issue for the group—the sensors which measure distance did not function properly. They worked inconsistently and did not properly count distance traveled. It was for this reason that the group attempted to use a code reliant on time. Consistency was again an issue. The most efficient method, which is to coast the majority of the way, was difficult given the inconsistencies of propellers mixed with long-run timing. The method the group attempted was to accelerate quickly then rapidly decelerate at the gate. The timing again needs precision, and was done by trial and error. The group failed to produce a program that made the AEV cross the gate. It was for this reason the group reviewed the issues with the sensors, and began coding using distance measurements. The group performed the sensor test and changed the arm used. This solved the sensor issue and thus allowed the implementation of absolute and relative positioning. It is highly recommended to not use strictly time based Arduino commands. Finding out a way to make the distance tracking sensors work with consistency was imperative to the success of the project.

The team's AEV design differs from other designs because of the 3D printed arm that provided additional stability over any given arms in the AEV kit. It is also compact and light providing easy acceleration. Another advantage of team F's AEV is the placement of the arduino and the battery. They are centered such that the AEV is balanced while on the straights and the curves.

An improvement that the team could have made with the AEV project could be budgeting our time better. When the team was working on the direct drive, all the necessary parts should have been ordered on the same day before spring break as to have everything to work on the design at once, as opposed to ordering parts at different times and thus being set back with the production of the design.

Appendix A

Tables & Figures

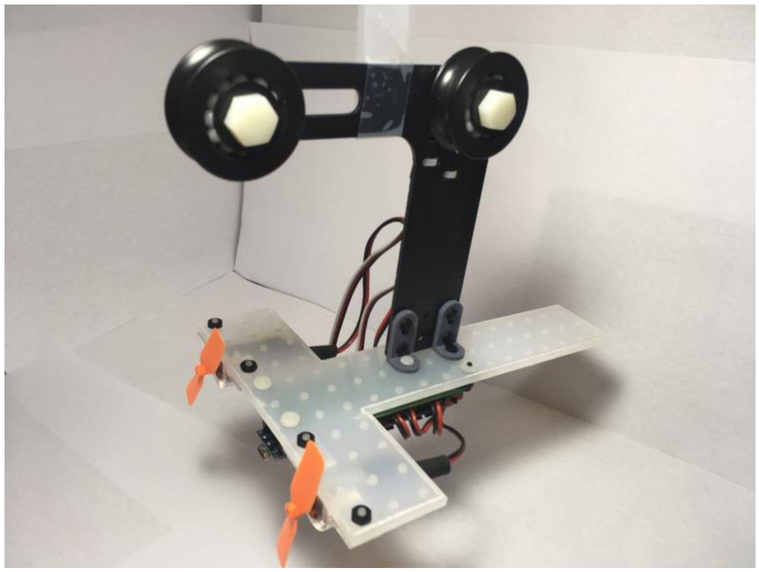


Figure 1: Sample Design Used in Testing for Group F

Table 1: Concept Screening Scoresheet

Success Criteria	Reference	Brian's Design	Zach's Design	Rafe's Design	Kenny's Design
Balanced in Turns	0	-	+	0	0
Minimal Blockage	0	-	-	0	0
Center-of-Gravity	0	+	+	+	+
Maintenance	0	0	-	0	0
Cost	0	0	0	0	0
Efficiency	0	0	+	-	-
Sum +'s	0	1	3	1	1
Sum 0's	6	3	1	4	4
Sum -'s	0	2	2	1	1
Net Score	0	-1	1	0	0
Continue?		no	yes	no	no

Table 2: Concept Scoring Matrix

		Reference		Brian's Design		Zach's Design		Rafe's Design		Kenny's Design	
Success Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Balanced in Turn	20%	3	0.6	2	0.4	5	1	3	0.6	3	0.6
Minimal Blockage	15%	3	0.45	2	0.3	1	0.15	3	0.45	3	0.45
Center-of-gravity	20%	3	0.6	4	0.8	5	1	4	0.8	5	1
Maintenance	10%	3	0.3	3	0.3	1	0.1	2	0.2	3	0.3
Cost	10%	3	0.3	3	0.3	3	0.3	3	0.3	3	0.3
Efficiency	25%	3	0.75	3	0.75	4	1	2	0.5	1	0.25
Total Score	**100%**		3		**2.85**		**3.55**		**2.85**		**2.9**
Continue?					**No**		**Develop**		**No**		**No**

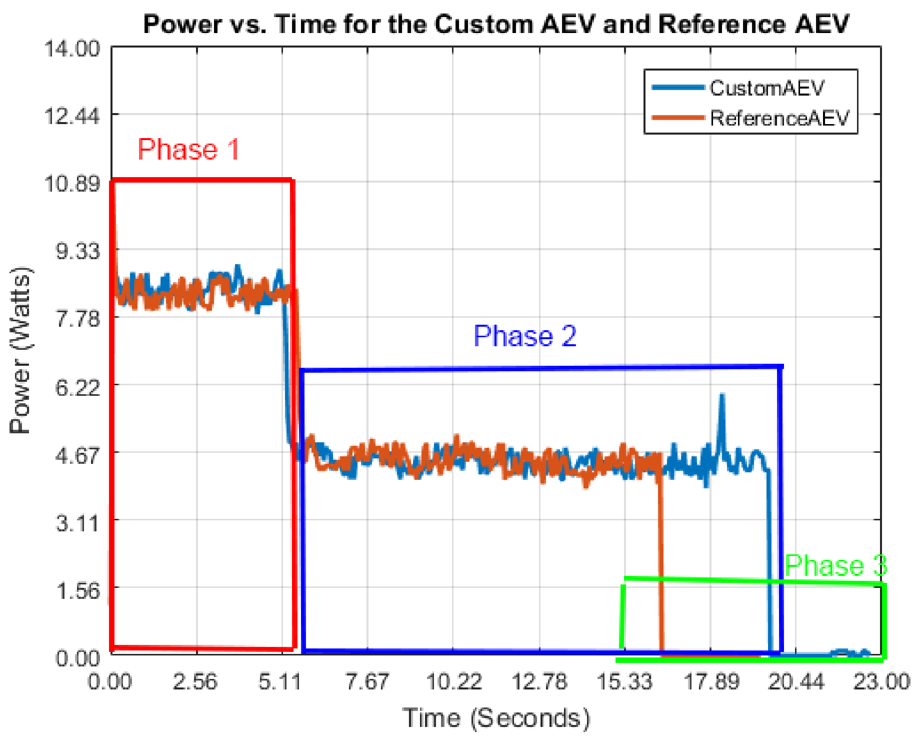


Figure 2: Power over Time Comparison for Performance Test 1 with Phase Breakdown

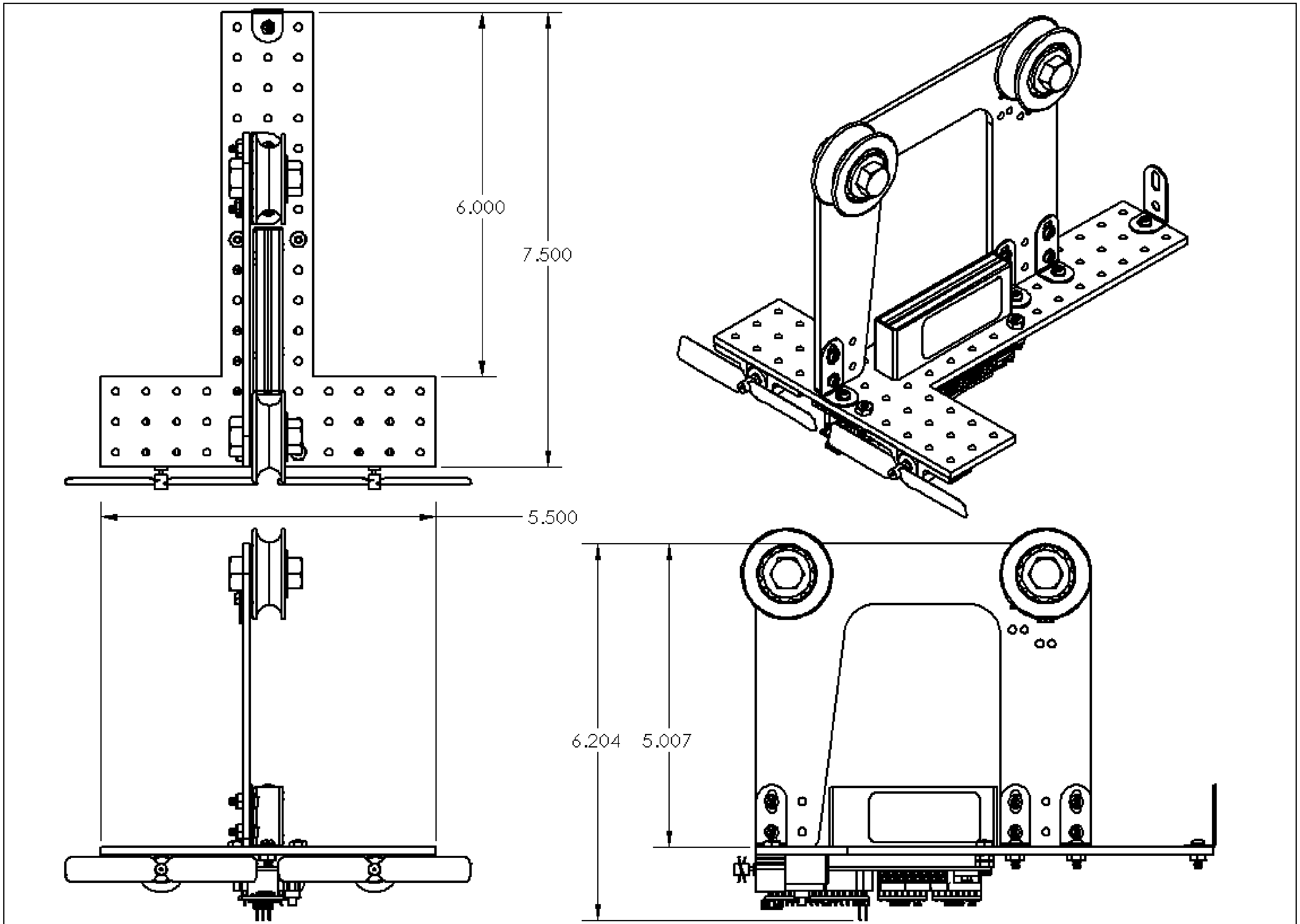
Table 3: Data Corresponding to Program Phases (Performance Test 1 for the Custom AEV)

Phase	Arduino Code	Distance (m)	Time (s)	Total Energy (J)
1	// Set initial motor speed of 20% for all motors reverse(4); motorSpeed(4, 30); // Use conversion of 24.62 marks per foot for 18 feet (the approximate distance to the gate) goToAbsolutePosition(24.62 * 18);	5.708	5.160	43.175
2	// Reverse all motors and set motor speed to 20% brake(4); reverse(4); motorSpeed(4, 20); // Return to starting position goToAbsolutePosition(0);	17.645	19.620	107.933
3	[motors cut, coast to stop]	17.732	22.620	108.127

Table 4: Data Corresponding to Program Phases (Performance Test 1 for the Reference AEV)

Phase	Arduino Code	Distance (m)	Time (s)	Total Energy (J)
1	// Set initial motor speed of 20% for all motors reverse(4); motorSpeed(4, 30); // Use conversion of 24.62 marks per foot for 18 feet (the approximate distance to the gate) goToAbsolutePosition(24.62 * 18);	5.609	5.581	46.220
2	// Reverse all motors and set motor speed to 20% brake(4); reverse(4); motorSpeed(4, 20); // Return to starting position goToAbsolutePosition(0);	15.949	16.381	94.683

3	[motors cut, coast to stop]	16.803	19.381	94.822



The Ohio State University First Year Engineering	Dwg. Title: AEV FINAL DESIGN	Scale: 1:2	Inst.:PROF. SHROCK	Units: INCH	Dwg. No.: 01
	Drawn By: GROUP F, SECTION 7221		Hour:1:50	Seat: 21-24	Date:4/18/17

Drawing

Table 5: Final AEV Design Bill of Materials

ITEM NO.	PART NUMBER	QTY.
1	Tee Base	1
2	AEV Custom Arm	1
3	90-deg Bracket	3
4	AEV Arduino Assembly	1
5	Pulley Assembly	1
6	Pulley Assembly w-reflective tape	1
7	Motor Mount Clip	2
8	AEV Motor	2
9	Prop 3inch	2
10	Rotation Sensor Board	2
11	SL-FHM1 0.086-56x0.25x0.25-S	2
12	HBOLT 0.3125-18x0.875x0.875-S	2
13	MSHXNUT 0.112-40-S-S	23
14	SL-PHMS 0.112-40x0.375x0.375-S	13
15	Battery	1
16	Magnetic 90-deg bracket	1

Weight: 235 g

Estimated Cost: $172.30

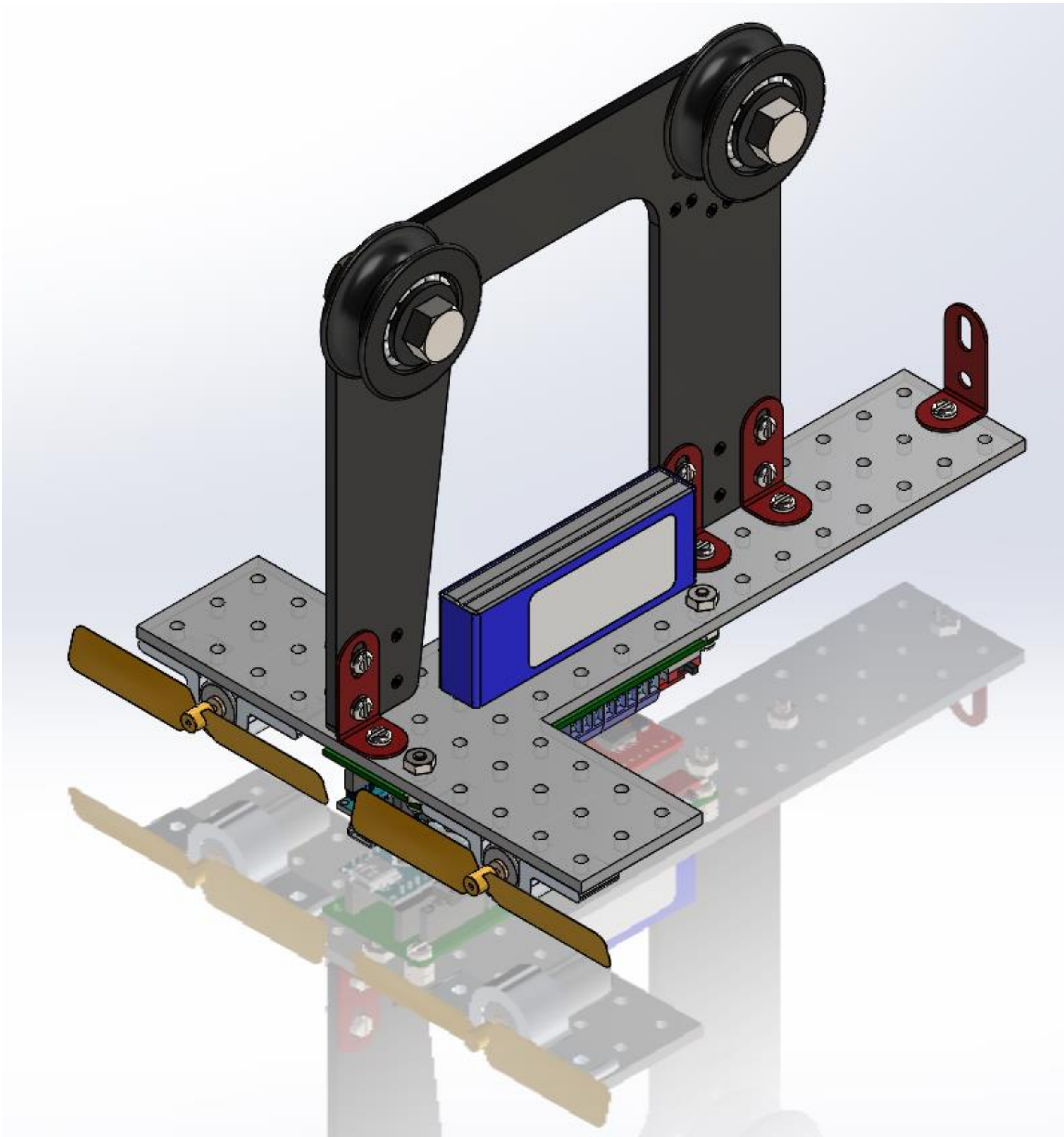


Figure 3: Final AEV Design Render

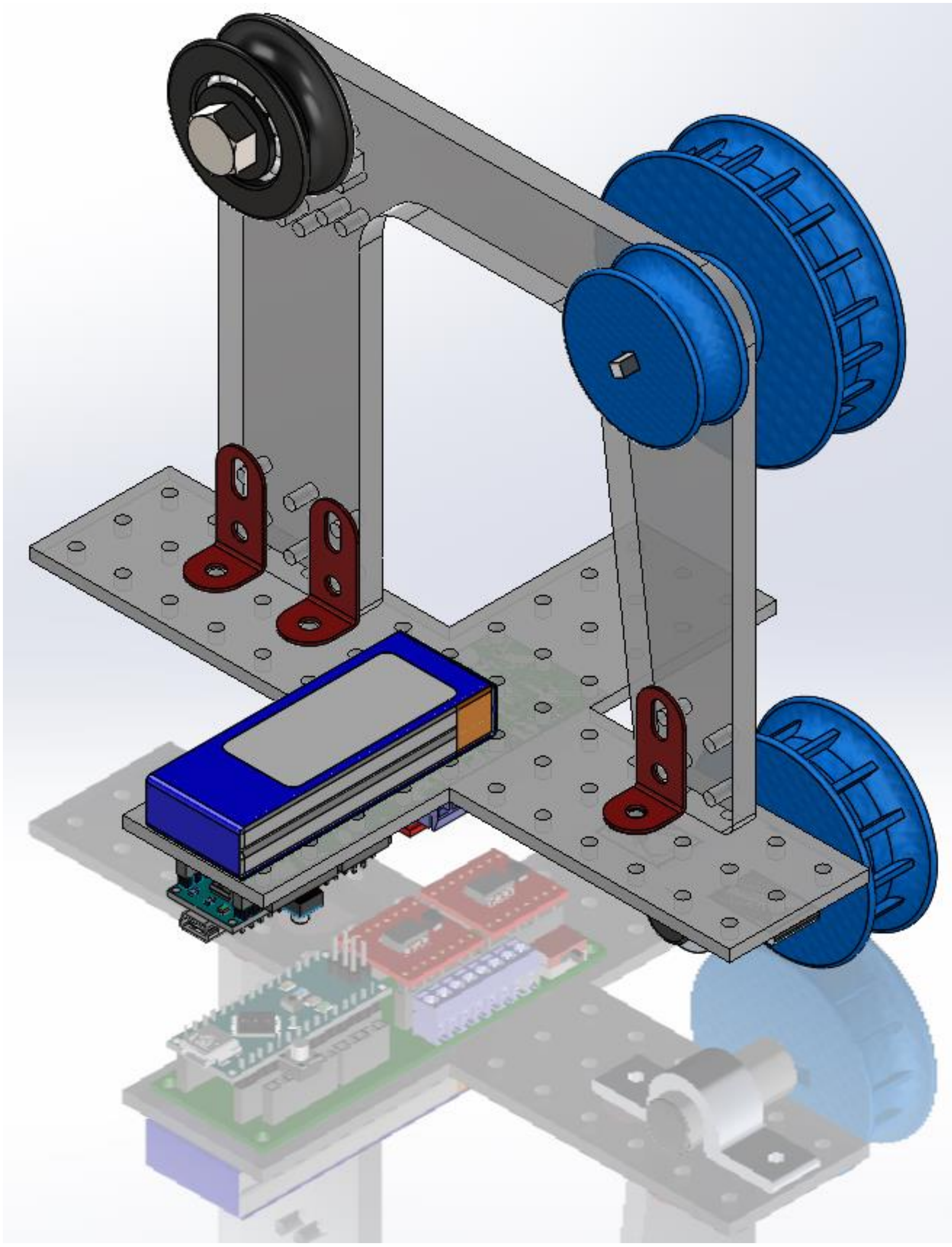


Figure 4: Direct Drive Design Render

Sample Calculations

Equation 1:

$$\text{Propeller Advance Ratio}$$
$$= (velocity(m/s) \div ((RPM \div 60) \times Diameter\ (m))) \times 100$$
$$= ((2.8) \div ((3000 \div 60) \times .08)) \times 100 = 0.7$$

Arduino Program

```
// Initialize useful constants...
double pi = 3.14159265359;
double marksPerFoot = 24.61538462;
double maxSpeed = 25;
double allMotors = 4;

// Designate positioning values for a single point of control and clarity...
double stopOne = 8 + pi - 1; // point to start decelerating before the gate on the initial trip
double stopTwo = 8 + 2 * pi + 6 + 2 * pi; // point to start decelerating before reaching the cart
double stopThree = 8 + 2 * pi + 1; // point to start decelerating before the gate on the return trip
double stopFour = 2; // point to start decelerating before the AEV's starting position on the return trip.

// Initially reverse motors so that the AEV will move forward.
reverse(allMotors);

// Set motors to maxSpeed. Go at maxSpeed until just before the gate. Cut power to motors.
motorSpeed(allMotors, maxSpeed);
goToAbsolutePosition(marksPerFoot * stopOne);
motorSpeed(allMotors, 0);

// Reverse motors and do thrust for stop at gate.
goToAbsolutePosition(marksPerFoot * 16.3);
reverse(allMotors);
motorSpeed(allMotors, 32);
goFor(0.5);
motorSpeed(allMotors, 0);

// Reverse motors back to forward.
reverse(allMotors);

// Hold for 7 seconds to trigger the gate.
goFor(7);

// Set motors to maxSpeed. Go at maxSpeed until the AEV is close to the cart to be retrieved. Cut
power to motors.
motorSpeed(allMotors, maxSpeed);
goToAbsolutePosition(marksPerFoot * stopTwo);
motorSpeed(allMotors, 0);
```

```
  // Coast for 10 seconds.
  goFor(10);
```
Arduino Program (cont.)

```
  // Reverse the motors for the return trip.
  reverse(allMotors);

  // Set motors to maxSpeed. Go at maxSpeed until before the gate. Cut power to motors.
  motorSpeed(allMotors, 40);
  goToRelativePosition(-1 * (marksPerFoot * 8 + 2 * pi));
  motorSpeed(allMotors, 0);

  // Reverse motors and do thrust for stop at gate.
  reverse(allMotors);
  motorSpeed(allMotors, 40);
  goFor(0.5);
  motorSpeed(allMotors, 0);

  // Reverse motors back to forward.
  reverse(allMotors);

  // Hold for 7 seconds to trigger the gate.
  goFor(7);

  // Set motors to maxSpeed. Go at maxSpeed until just before the AEV's starting position. Cut power to
motors and coast.
  motorSpeed(allMotors, 40);
  goToRelativePosition(-1 * (6 + 2 * pi + 6));
  motorSpeed(allMotors, 0);
```

Appendix B

<u>Final Team Schedule</u>

No.	Task	Start	Finish	Estimated Time	Zach Ahern	Brian Cekada	Kenny Kelley	Rafe Sanders	% Complete
1	Custom AEV Construction	3/7/17	3/8/17	0.5 h		0.25 h		0.25 h	100
2	Custom AEV Testing	3/7/17	3/8/17	1.0 h	0.25 h		0.25 h		100
3	Sample AEV Construction	3/7/17	3/21/17	0.5 h		0.25 h		0.25 h	100
4	Sample AEV Testing	3/7/17	3/21/17	1.0 h	0.25 h		0.25 h		100
5	Direct Drive AEV Construction	3/28/17	3/28/17	1.0 h	0.5 h	0.5 h			100
6	Direct Drive AEV Testing	3/28/17	3/31/17	2.0 h	1.0 h		1.0 h		100
7	Final AEV Construction	3/31/17	3/31/17	0.5 h		0.25 h		0.25 h	100
9	Develop Arduino Program A	3/22/17	3/28/17	1.5 h			1.5 h		100
10	Develop Arduino Program B	3/22/17	3/28/17	1.5 h			1.5 h		100
11	Testing and Refinement	3/31/17	4/11/17	6 h	1.5 h	1.5 h	1.5 h	1.5 h	100
12	Final Test	4/12/17	4/12/17	2.0 h	0.5 h	0.5 h	0.5 h	0.5 h	100

AEV Final Testing Scoresheet

ADVANCED ENERGY VEHICLE — Lab 11: Performance Test 4 – Final Testing

AEV Final Testing Scoresheet

Team/Team Name: F Instructor: Schrock Class Time: 2:20pm (7221)

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.

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
AEV starts and travels to first gate		✓		/4	✓		/4
Gate Routine	Stops before gate		X	/4	✓		/4
	Waits 7 seconds	✓		/4	✓		/4
	Travels through gate	✓		/4	✓		/4
AEV starts and travels to loading zone and waits for 5 seconds		✓ 2		/4	✓		/4
AEV connects to cargo & travels to gate (crashes into cargo-deduct <= 2)		2		/4	✓		/4
Gate Routine	Stops before gate		X	/4		2	/4
	Waits 7 seconds	✓		/4		2	/4
	Travels through gate	✓		/4		X	/4
AEV starts and travels to starting point			X	/4		X	/4
Total Points Earned		36		/50	38		/50
Total Score = Total Pts Earned * Δt		3		Max Total Score	34.8		

Track Layout: ____________ (Inside or Outside)

Mass of AEV: .235 (in kilograms) .235

Total Energy: 305.471 (Joules) 215.79

Total Time Run1: 67.8 (seconds) 56.34

Total Time Run2: ________ (seconds)

Delta Time Run 1:

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

= ______________

Delta Time Run 2:

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

= ______________

Energy/Mass: __________ (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: [signature] Date: ______________