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Electrathon Vehicle: Electrical Power

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By

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Electrathon Car – Optimization of Power

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Abstract

Title and Author: Electrathon Car – Optimization of Power by Samuel C. Johnson (Mechanical Engineering Technology)
As EV cars innovate, so must the minds of the people who don't yet understand the importance of renewable energies. No longer are gas combustion cars allowable with global warming becoming an "act now" issue. Renewable energies are thrusting their way into everyday conveniences and there must continually new uses being discovered. The issues comes down to awareness to a public eye. Major companies across the globe are fighting together to combat climate change but real change for the future comes from the youth.

A team of six students from Central Washington University are developing a smaller version of an EV car that could potentially reduce the carbon footprint. The Electrathon Race allows students to design, manufacture and compete with their vehicle in an effort to raise awareness of EV's potential. This proposal is the face first dive into the Electrathon potential.

The Electrathon Vehicle: Electrical Power proposal is an in depth dive into theorizing, constructing and testing the design of an electrical circuit. A breakdown of this report gives an extensive and thorough analysis of the problem. How do you efficiently deliver 1kw/hr of power to an electric motor? The methods used to face this challenge and the results seen after are laid out in this report.

The challenge of competing in the Electrathon Race is delivering power to an electric motor for an entire hour without exceeding 1kW/hr of power. The goal is to travel as much distance in the one hour as possible. This challenge has many different aspects to consider. These range from the type of batteries used, the skill of the driver and how to maximize power output. The most intuitive way to approach this problem is through rigorous testing. These tests will require the Ellensburg Airport to grant us access to their airfield. There, the car will be ran uninterruptedly for one hour while instruments record speed, distance traveled and power used. Ultimately, the overall weight of the vehicle and the aerodynamic of the body will have the largest impact.

After competing at Portland International Raceway, the EV traveled a total of 41 miles! This was a huge accomplishment for myself and LG Hernandez, Lathan Halaapiapi, Chris Clark and Ryan Shiner. The results are published here.

Introduction

Description and Motivation

In today's political and economic climates, global warming is a constant issue. In an effort to develop a more eco-friendly and short ranged vehicles, the Central Washington University has allocated resources into an Electrathon car. This project primary goal is so satisfy a complete manufacturing process. An ancillary benefit is exposing others to EV cars and renewable energies will influence the many involved in this project.

The primary problem with designing an electrical circuit for an Electrathon car is delivering as much power as possible to the motor for as long as possible. The Electrathon Society of America (ESA) has the race last one hour. There are many types of batteries, design parameters and efficiencies to consider and because of this the ESA limits the playing field of power delivery to 1 kWh. These restrictions lead to a handful of natural questions. How much power does the car need to be considered competitive for this race? How far can the initial design for the car to go? Can the weight be reduced to be more efficient? Is it possible to use this design and implement on a larger scale? While these questions are to be tested, the true goal here is to execute an engineering plan.

Function Statement

The purpose of designing an electrical circuit is to provide ample power to an hour long race. A series of batteries will be needed to deliver a 1 kWh of energy to a motor while maintaining basic instrument functions.

Design Requirements

For the Electrathon car to compete in the Electrathon of American race, there are standards relevant to engineering that must adhered to. The design instruments must follow the listed parameters below.

- The battery(s) are limited to an output of 1 kWh of power.
- There are different categories of battery, each have their own specific weight. For Lithium Ion batteries, the combined weight must not exceed 15lbs.
- For standard lead acid batteries, such as a Optima Red Top, there is no weight restrictions but limited in quantity to 2
- The entire electrical system must have adequate fuses per gauge of wire/amps
- There must be insulation between any component drawing powers from the battery and connection to frame, this prevents death to the driver
- There must be an electrical “kill switch” on both interior and exterior of the car, it must be located in the main positive power cable
- Vehicles can only be powered by electric motors

Scope

The scope of this project is to design an electrical circuit that will propel the EV vehicle to move. This will include the design of an electrical circuit as well as a thermal containment unit for the batteries.

Success

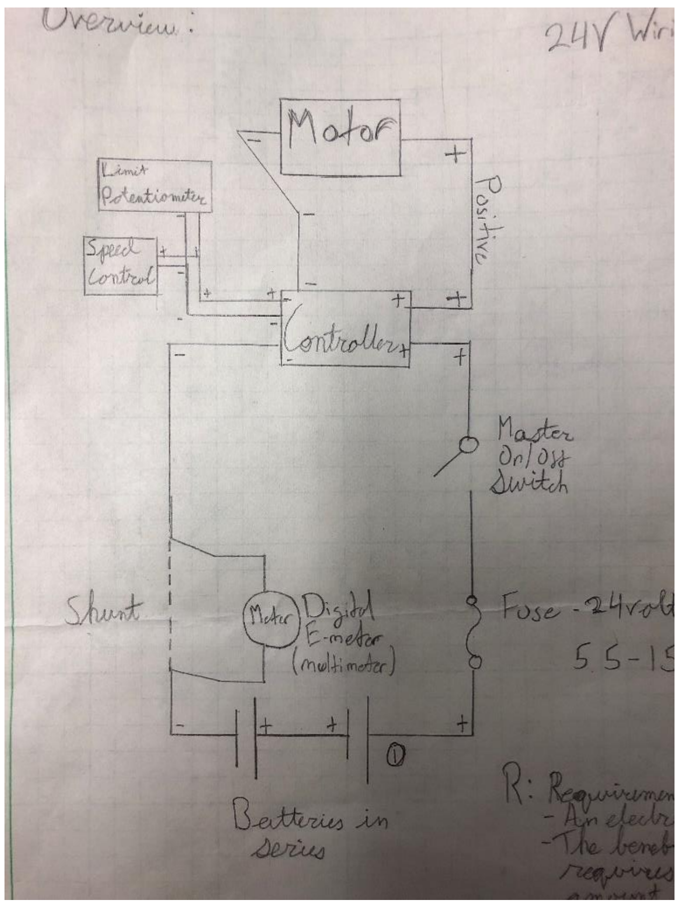
The simplest goal of success for this would be to finish the race while keeping all internal components intact. Assuming this is accomplished, finishing in any position but last would be a moral success. Based on rough estimates and the crossing of fingers for failure in competition cars, it’s realistic to achieve a top speed of 30 MPH. From an efficiency standpoint, keeping the cumulative weight of the circuit under 100 lbs., excluding the motor, would be a tip of the hat to the merit of anyone’s engineering prowess.

Design and Analyses

The approach: A Proposed Solution

There are many aspects of the circuit such as voltage, resistance, amplitude and weight that contribute to the efficiency of the EV vehicle. The initial design will feature two lead acid batteries and ergonomic components for monitoring. Proof of the usefulness for these add-ons can be achieved using standard measuring tools and basic electrical calculations. Thus to CWU implemented the RADD metric as a baseline for what one would consider decent engineering. The goal is to determine Requirements then to analyze them in a way to help develop Design parameters. This all should be documented for prosperity sake. To explain this process with this project in mind, an electrical circuit must be idealized with requirements set forth by both ESA and CWU. The basic satisfying both of this entities is outlined and can be seen below.

Design Description



Benchmark
Benchmarks are outlined in the Gantt chart by triangles and arrows. Also read milestones under the Proposed Schedule section.

Performance Predictions
The advantage of building an electrical circuit is there are fewer ambiguities in the design itself. A modest, yet blind, initial prediction is to turn the motor at a rate of 2000 rpm. However, as the circuit mounts onto the frame and other EV projects are completed, this RPM should drop significantly. Testing and gathering data raw data should prove this down the road. Equally, testing will improve on what is given in the original analyses.

Description of Analyses
The many different analyses that are listed in this proposal are there to show the breakdown of the EV's electrical circuit. Each analysis contributes directly to the construction, design and eventually optimization. These analyses range from which type of battery will be used, the gauge of wire used per component and the charging/discharging rate of the battery.

Appendix A1 and A2 show the specifications of two types of batteries considered to power the Electrathon vehicle. A1 describes two lead acid batteries wired in series. These two batteries are a significantly heavier option weighing in at 63.4lbs. The benefit of these types of batteries is they aren't restricted by weight but by quantity to two. Running them in series will produce a total potential of 0.6Kw/Hr. As of the end of fall quarter, this is the best option. A2 talks about the much more "hip" battery option, Lithium Ion. The biggest problem with these types' batteries is the expense and volume needed to house aboard the EV vehicle. The Lithium Ion battery also is limited by weight to only 15 lbs. Because of this hard cap of weight, the prices to make this a viable choice skyrocket. However, according to batteries within a "reasonable budget", the calculations show these types of batteries could only produce .29 kWh of energy.

Appendix A3 and A4 talk discuss the recharge rate of the batteries and the discharged energy through the motor. Both batteries charged to 60% capacity under 10 minutes which gives an approximate rate of 1.5Volts/min. If the batteries are left on the tenure for longer than 5 hours, they could reach 100%. With that said, it only took 8 minutes 2 seconds to charge battery #1 and 7 minutes 11 seconds to charge battery #2. This gives an approximate rate of 2.2 volts/minutes. The discharge discussed in appendix A4 ran the batteries attached directly to the motor for an hour, the full duration of race. Using a spectrometer to observe the RPM's of the motor, there was a decrease of 200 RPM over the 60 minutes. Converting the RPM's into rotational speed (ω) to determine the power through the motor. Power in = 12Voltes * 2 Batteries * 2 Amps = 48 Watts. The efficiency can be determined by, E = Power out / Power In. Rearranging this, Power out = Power in * E. Power is determined by Torque * ω. Ultimately, Torque = Efficiency * Watts / ω. Assuming there is 20% efficiency through the motor. Using this formula at both 30 seconds and a full hour yields 0.067Nm/s and 0.039Nm/s respectively. This results in a 41.8% loss of power. This is where a majority of improvements will be made.

Appendix A5 and A6 list the type of wire, gauge, fuse sizes, length of wire and weight of the wire. A5 references the wire used for the secondary components, the potentiometer and speed control. For this design, the team decided to use 14 gauge, copper wiring with a length of 20 feet which added a total of .248 lbs. A necessary fuse of 15 amps will be used as well. Overkill is necessary as protection to the driver. Appendix A6 shows the wiring used for the circuit directly dealing with the battery to the controller and then from the controller to motor and back to the batteries. Using 30 feet of 2 gauge copper wire adds on a hefty 6.03lbs. A necessary fuse of 200 Amps will be used as well and will be implemented in the return line back to the battery. The key pieces to understand is the ability for the current to run through the wire and to have sufficient fuses to prevent damage to the circuit or driver.

Appendix 7 talks about fasten the wiring using zip-ties to the frame of the EV vehicle. To start the calculations it was necessary to know that AWG wiring is sheathed with polyvinyl chloride, PVC. With that in mind, PVC has a compressive strength of approximately 7,500PSI. Taking just the thickness of the PVC coating, separating the inner copper wire from the calculation of the 14 gauge wire, and applying a basic force equation, $F = \tau_{max} / Area$. Calculating the max stress for the PVC to be 1,080,726 lbs. However, copper has a significantly smaller compressive strength of 6.527KSI. Implementing this value in the previous force equation yields a realistic compression of 168151 lbs of force. The max stress allowed to be applied is forced to be under that of copper yield. Some of these results are realistic but that math is what it is. There will be recalculations for this parameter later.

Appendix 8 is a simple summation of the overall resistance in the in circuit. Gathering the resistance of the shunt, master switch, and total length of both 2 gauge and 14 gauge wiring at the lengths needed, there will be a total of 0.156Ω!

Design Issues

Issues with these designs is the lack of hands on experience. It’s easy to solve for numbers but experience will prove how effective they are.

- Are there other types of batteries that are lighter than lead acid but cheaper than lithium ion?
- Can the motor be changed in any way for improvement purposes?

Best Practices

The best practice for designing a competitive vehicle to exhaust all possibilities. This will be achieved as more time is allocated towards this project.

Ergonomics

The driver will be in charge of how much power to pull from the battery at any given time. Assuming the speed controller is used at more than just max speed, there will be skilled involved when driving the EV car. However aggressively the driver can discharge the   mm batteries will come with real-time data as the team begins to understand discharge potential. This is precisely why it’s important to have an in-vehicle

Technical Risk Analysis, Failure Mode Analyses, Safety Factors, Operation Limits
The only technical risk is being shocked, in the Electrician world they call this person a “sparky”. Operation limits will be the 1 kWh of power. Safety factors are included by the ESA.

Methods and Construction

Methodology

When approaching the physical construction of an electrical circuit, standards and methods from an electrical discipline must be adhered to. The mindset is simple, safety first. When adding a new component to the circuit, always ensure the circuit loop is open. Equally, it’s important to meticulous calculate all the different voltage potential, amps and resistances across the many components. Reusing components hinges upon correctly analyzing these fundamental properties. With that in mind, optimizing a component’s life expectancy is standard in any business mindset. This past week was frustrating for not only myself but the entire EV team. The EV team is still waiting for funds from CWU to go towards the EV club. We were expecting to receive funds no later than the 20th of January. Due to set backs, we still haven't received a green light for reimbursement. The team has been apprehensive spending their own money which has slowed down the manufacturing. To gain momentum and trust in the CWU system and select EV team members, the team went to the CWU office and checked if the club was recognized or not. As of 1/28/19, the club was officially chartered and funds would come soon. Manufacturing will be completed for a majority of the EV team by March 1st.

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t. This will reduce cost of replacement parts and increase efficiency of labor.

Another approach to designing an electrical circuit is using the Worst-Case Circuitry Analysis. WCCA is a technique that determines the various stresses under extreme external or internal conditions. Typically, WCAA tests both beginning and end of a component’s life but follows a specific step system. First and foremost, determining each piece that will be in the circuit. Then each piece will have a specific database, taking into account all potential unintentionally and predictable stresses and determining the components tolerances. Quantifying this approach uses formulas to determine the worst case minimum and maximum stress. A reference formula looks like this below.

$$\text{Worst Case Minimum} = \text{Nominal Value} - (\text{Nominal Value} \times \Sigma\,|\,\text{Negative Biases}\,|\,) - \left(\text{Nominal Value} \times \sqrt{\Sigma\,(\text{Random Effects})^2}\right)$$

$$\text{Worst Case Maximum} = \text{Nominal Value} + (\text{Nominal Value} \times \Sigma\,|\,\text{Positive Biases}\,|\,) + \left(\text{Nominal Value} \times \sqrt{\Sigma\,(\text{Random Effects})^2}\right)$$

With this methodical approach would guarantee minimal downtime of part replacement.

Construction

Building the electrical circuit for the Electrathon Car is rather straightforward. The biggest constraint, other than being safe, is designing around are the amps. Amps control the flow of power to any given component, the greater the amps the voltage that is allowed to flow. This is analogous with constant pressure through a fire truck hose and a garden hose, pressure being the amps. With that in mind, running 2 gauge wire from two lead acid batteries wired in series to a controller is how the power will be distributed throughout the vehicle. A shunt and Multi-meter will be place in between along this first path for monitoring purposes. A shunt's purpose is to create the path of least resistance, to ensure there isn't back flow of energy into the Multimeter as it "reads" the circuit. The purpose of the Multi-meter will be to displays quantified data of what's happening in the circuit for both testing and racing purposes. As the energy is divided through the controller, a majority will be given to the motor. There will be a small portion pulled away from the controlled to using the 14 gauge wire. These other loads are the Potentiometer (or Pot) and Speed Controller (throttle). Both of those two components function similarly, they control the flow of energy through the controller into the motor. However, the Pot creates a hard cap to how much can be released and the speed controller uses what isn't being restricted by the pot. These two components in conjunction can force the input of energy to the motor to stay under 1 kWh, assuming there is enough power being delivered. After the current passes through the motor, it will return to the battery via controller. This return path is where the master on/off switch will be implemented with a 200 Amp fuse.

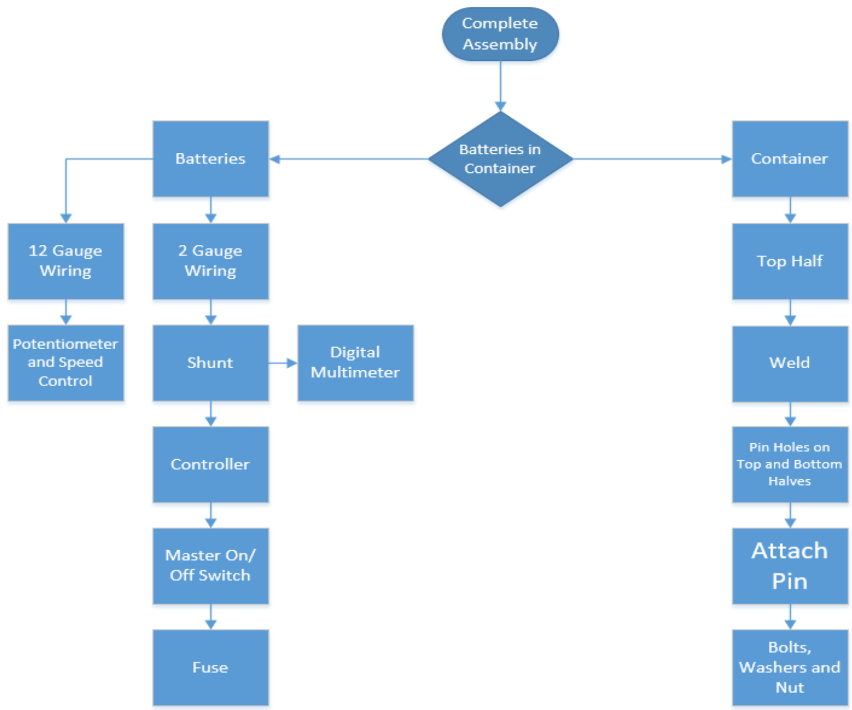
The batteries will be encased in a small steel box to ensure they stay warm to operate at a high level of efficiency. The goal is to keep the batteries at a constant 86 degrees Fahrenheit. This is the most optimal temperature for efficiency.

Current (I) = Voltage (V) / Resistance (R)
Voltage (V) * Current (I) = Watts (W)
Watts (W) / Time (T) = Energy Delivered
Rotational Speed (Omega) = RPM * 2pi / 60
Power $_{IN}$ (Pin) = Torque (T) * Rotational Speed (Omega)
Efficiency (E) = P_{OUT} / P_{IN}

With that said, for the proposed design the batteries will be wired in series. This type of power delivery maximizes the voltage output from the two batteries. Having a shunt and Digital Multimeter following in the circuit will allow up to second information about the circuit. This piece will be completed by the time this proposal has been submitted. The ordering of additional components will be follow shortly after. The list of components can be found in the parts list. Assuming the parts aren't faulty then the construction should be finished no later than February 1st. To compensate for unseen wiring or technical issues, I'll order multiple quantities for parts susceptible to breakage, i.e. fuses.

Building the thermal containment box for the batteries is a must. This project will be completed simultaneously as the circuit is completed. With the knowledge of knowing that batteries operate the most efficient at 25 degrees Celsius, or 77 degrees Fahrenheit. To begin manufacturing the container, it's important to note the existing EV vehicle's frame already has the bottom half of the box attached. Note appendix drawing B1. The top half of the battery containment will be attached via pin holes welded into place on both halves. The difficult part of the process is welding the pin holes concentrically to allow a pin to sit smooth. To ensure this happens, the pin will be placed inside the cylinders as the spot welding occurs. Equally, the welding must be strong enough to handle the force of the top half as it pivots. A cotter pin will hold the sliding pin in place during operation. The side plates will be cute out of a rectangle into two triangles and welded onto the sides. These welds aren't critical and can be rushed if need be. To ensure the entire containment box is secured to the frame, who rear tension blocks will be bolted together. This is necessary for America EV standards to be met as well as mitigating safety concerns. Drilling the holes for this will have to align with holes drilled into the rear sheet on the containment box.

Drawing Tree



All Drawings for battery container can be found in Appendix B.

Parts List and Labels

Battery Containment

Bottom Half of Container (Steel Mounting Box) ………….….Previously Completed
Top Half of Container (Steel Mounting Box)………..…………To Be Manufactured
Nuts…………………………………………………………..………Purchased
Bolts…………………………………………………………...…………Purchased
Washer……………………………………………………..……………Purchased

Electrical Circuit

2x Lead Acid Batteries………………………………...……....Donated from CWU
20ft 12 Gauge Wire ………..Purchased
30ft 2 Gauge Wire …………………………………………………….Purchased
Shunt ……………………………………………………………........Purchased
Digital Multimeter……………………….……………….Donated from CWU
Controller ……………………………………...…………..From Previous Project
Master On/Off Switch………………………………………..………......Purchased
15 Amp and 200 Amp Fuse……………………………..………..…Purchased

Manufacturing issues

Potential manufacturing issues come from both the circuit and battery containment. The biggest issue from the battery containment is ensuring a damn-near perfect seal to ensure minimal heat escaping. Also welding on pin holes onto both the top and bottom containment box will need to have high levels of tolerance to fit.

Issues that could arise with the electrical development are improper connections to each component. This may cause a short and burnout the component, increasing the cost of replacement parts.

Testing Method

Method/Approach

Determining the many different types of metrics will be a huge addition to the EV team. Testing will be the most important aspect of designing not only the electrical circuit but all of the major projects involved. Equipment first, testing the batteries will come with maximizing output. An electrical circuit has many different components to test for. The voltages, resistance and overall amps are the key pieces of information. Using a multimeter directly, these quantities will be quantified and used as benchmark standards towards optimization. How to utilize this data has yet to be determined, but will define a significant portion of what is the motor is capable of outputting. However once the data is collected about the current coming out of the batteries will be scrutinized under a fine microscope. The drop of current through the wires and the current through the controller will be measured after each change to the output of the batteries. Due to the variable RPM speed of the motor, measuring the electrical potential across the motor will be crucial. This will be done by using some pieces of tape and a spectrometer. Once a deeper understanding of how to manipulate the output RPM's of a motor, tests will also be performed to capitalize on this data.

All other components will have a GO or NO GO success mark. However, if it comes to light that these components could be more parasitic than useful, methods will be created to determine their usefulness.

Eventually, as the team's individual projects come to completion more components will be added onto the vehicle. Once this process begins, it will be necessary to measure everything over again. The additional weight will take a heavy toll on the efficiency of the motor.

Testing Procedures

First and foremost, charging and draining lead acid batteries in rapid succession will permanently damage the battery. Because of this, battery discharges will be limited as a precautionary measure. Before testing begins, the circuit must be complete with exception of the batteries. This will yield the purest data, especially the first 5 minutes as the battery has the most push into the circuit. Once the test has gone underway, collecting more data the better. There will be milestone testing as more of the EV team completes their add-ons. The ability to create trends and arguments will guide the team to a greater chance of success.

The testing of the EV vehicle will commence in phases after each team member's project is mounted to the frame. To do this properly, there's an order to which projects will be attached. Starting with the drive train (LG Hernandez), suspension (Chris Clark) and steering (Lathan Halaapiapi) will all be attached first and then tested simultaneously. These three projects are intertwined together and need to be completed before anything else is mounted. Placing a force over the top of the front two shocks will test the shocks themselves and the construction of suspension. The steering construction will commence after. The testing of this project will be implemented by resisting the steering column by placing an object into the path of steering. This will simulate the stress of racing pace onto both steering column and suspension system. The final phase of testing will be completed once the electrical system has been attached. The actual testing will be to see how efficient the car runs and how long the batteries can last. How far can the EV car go? These are the lingering questions that will determine the success of the vehicle.

Deliverables

With only the completion of only the batteries wired in series with the motor, limited data can be accounted for. However, there is proof that over the course of an hour long discharge, the batteries lost approximately 40% of their overall potential. Other data will be collected such as different potential charge across all components and after each time more project pieces are being added on, i.e. other team members finished products.

Testing issues have been bountiful. The largest problem so far has been getting power to the Digital Multi-meter. The wiring to power the DMM requires a direct feedback to the positive terminal on the battery as well as a negative connection on the shunt. To wire this correctly, the 18 gauge wire running from the DMM to the negative connection needed to be stripped and soldered together. Twisting the unsheathed copper wire around the negative connection bolt secured its placement onto the bolt. Once then was finished, running a long 18 gauge wire to the positive battery wire terminal to complete the circuit.

Budget/Schedule

Cost and Budget

The hardest part of any project is staying on time and this project will not be an exception. Not just from the electrical circuit being completed but from the entire team finishing on time. Coordinating college students to meet a deadline is like herding cats. The true risk here of incomplete projects will that they can prevent the EV vehicle from competing. Beyond the threat of a poor timeline of completion, the secondary problem will be budgeting. With exception of the batteries and motor, most of parts involved in this type of electrical circuit are cheap to replace. There will be a well thought-out budget to be put in place to ensure each team member’s project can become fully funded. Finally, the risk of electrical shock is always a constant when designing an electric circuit. This issue can be easily avoided because by having the electrical wiring housed inside of conduit. Also, the battery’s terminals will have rubber coverings to ensure no accidental discharge into the metallic frame.

Appendix C and D are parts and total project budget. In both appendices, the parts are assumed to be ordered and not donated. The motor and batteries alone drive up the cost of this project to a minimum of $500. However, due to the generosity of the MET department, the majority of cost driven parts will be donated. The batteries, motor and testing multimeter are the most notable donations. With that said, accruing the other pieces will happen on a shopping trip at Ace Hardware over the Christmas break. If there are any specialty items, they will be ordered on a need basis.

When the original proposal was purposed many of the original items that needed to be construction have changed. Starting with the original idea of how to mount and safely run 6 gauge electrical wire onto a metallic frame. This major safety concern sparked the following ideas. The batteries that rest on the interior side of the Battery Containment Unit must have thick rubber covers. This is to prevent electrical discharge into the metallic frame which has potential to draw current to the driver. A set of the terminal covers cost $5.00 for a pair. Another source of the increased budget is due to conduit. The conduit is to safety mount battery gauge wiring to the frame of car without hurting the driver. Conduit is sold at $1.06/ft. and is typically bought in 10 foot sections. This brings the total to $11.00 after tax. The ordering of parts isn't a crucial part of this project but doing the construction safely has become the most important priority.

The labor involved in this project will be extensive because of testing and potentially welding. The small area to be welded shouldn't take up too much time but will need to be accounted for. Once a full evaluation of the electrical circuit has been completed, the focus will turn to testing the EV vehicle sufficiently. A simple assumption of this writer's involvement might peak to 100 hours of total project involvement.

Milestones

Major milestones for this project are listed as such

- Finishing the electrical circuit
- Mounting the circuit to the EV car's frame
    - Testing with new weight of the frame
- Having other projects added on to frame
    - Testing with drivetrain, suspension and frame add separately

Human Resources

People who have directly influenced this project include Professional Charles Pringle, Dr. Johnson PE, and Dr. Choi PE. A shout out to both Matt Burvee and Eric from the machine shop.

Discussion

From the beginning of the scholastic year, the job of designing an electrical circuit from the group up seemed daunting. The design was simple and contained all necessary requirements from Electrathon America and the MET department. Yet the time frame to pull off a project of this magnitude seems challenging. Building upon the basics will largely be a choice of sensibility. Is it necessary? Will adding more increase efficiency? If more is added how much will it add to the weight of the car? For the early part of this project the trying drawing more power away from the motor appears to be a terrible idea. However, things could change if the batteries or motor improve. Trying to keep an open mind and changing the approach to solving problems will be vital to the growth of this project. Additionally, the coordinating the other members to be on the same timeframe will be a struggle.

Design Evolution

As the project has evolved away from the electrical circuit into a battery containment unit new challenges have surfaced. The biggest challenge has been negating the conductivity of the metal containment box. This obstacle has been met by insulating the interior side of the box with a thick layer of nonconductive plastic. The introduction of this thin layer of plastic into a finite space has been accounted for by using basic volume calculations, Base x Width x Height. Leaving with more than enough space for rubber terminal covers to be placed over the battery terminals, inside the box. Also, having a 6 gauge battery line running 24 volts of current rundown along the side of the frame will be troublesome. This was countered by having the wiring sheathed into conduit piping and zip tied onto the frame. As problem settled others arose such as what to do with the other parts other circuit. Where were we suppose to mount to electrical controller? How could we attach a shunt and multimeter to be visible for the driver? With all that said, other issues are still on the horizon as the programs gets into thick of construction.

Successful

From the initial phase of this project had struggles primarily due to direction. Designing an electrical circuit is not a core part of the curriculum at the MET department. Because of this establishing a foundation to be up to standards of CWU is difficult. Learning the basics of electricity while co-designing an EV car comes with challenges from all directions. By the time this project found its feet, the due date was weeks ahead. Looking forward, the true success of the fall quarter is project finding its purpose.

As winter quarter came to a close, the project found its center within 5 of its original members. The electrical circuit will be completed last because of the space needed for the suspension and steering. The mounting of the electrical circuit will be simple once all the other projects have bene completed. This is great for the electrical circuit because it'll require as much open volume. Once this is completed, the electrical circuit will come to an end and the racing will commence.

Next Phase

The next phase of this project is truly exciting! The goal is to pull as much energy out of the batteries as possible. How to go about this is the true challenge. Is it possible to unload a battery in an hour using some device that that forces current? Can the writer of this proposal figure out how to efficiently design a circuit with no prior knowledge? Ultimately, these questions will be answered and with a lot of hard work and a bit of luck, everything will come together.

Conclusion

The Electrathon Vehicle - Optimization of Power

The electrical circuit designed was conceived, analyzed and will be implemented in a team of 5 college students to compete in an Electrathon race. This project will satisfy the standards set by both ESA and MET department. In combination will produce a full vetted project that will require 12 analysis and 5 drawings while ensuring no electrical leakage can occur. Preventing any sort accidental electrical discharge into the frame will be accomplished to ensure driver safety. The approach for designing this will match any engineering merit and the feat will make any professional proud. The following three requirements will be met and accomplished to finish this senior project.

This project meets all the requirements for a successful senior project, including:

1. Having substantive engineering merit for both efficiency and optimization of an electrical circuit and motor combination while working in-tandem with other senior projects.
2. The size, weight and cost were all kept within the design parameter to give help to the team's ability to compete. The optimization of the vehicle will allow a highly agile project.
3. This design will efficiently allow 1kWh of energy to be delivered while moving the EV car at a minimum of 30MPH for the duration of the race for a complete hour.

Appendix – Analysis A1

Batteries | Senior project | 10/21/18

Allowable Batteries that will be analized... Maximum output may not exceed One KW

Low end batteries - Quantity allowance: 2, regardless of weight.

Optima Red top batteries specs, SC25H?

Voltage: 12 Volts

Model #: 25

Reserved Capacity: 100. This is super important as it measures the length of time (in minutes) a fully charged battery will discharge 25 Amps. After the battery will only produce 10.5 amps.

100 minutes

Physical Specs

Length: 10"
Width: 6 7/8"
Height: 8 7/8"
Weight: 31.7 lbs

One battery

41.8 Amp/hours.

Accounting for a second battery and some tolerance

Length: 21"
Width: 13" 6/8" ~ 14"
Height: 17 6/8 ~ 18"
Weight: 75.8 lbs ~ 76 lbs

Two batteries

Cost For $195.66 each

12 Volts x 2 batteries = 24 Volts
25 Amps x 2 batteries = 25 Amps

$$\boxed{\frac{600 \text{ Watts}}{1 \text{hr}} = \frac{0.6 \text{KW}}{\text{HR}}}$$ ✓

Internal resistance = 0.003 Ω

Less than allowed but not optimal ✓

Reserve Capacity @ 25 amps - 90 minutes

Lead acid batteries

Weight = 63.4 lbs

Appendix – Analysis A2

A2

Samuel C Johnson | MET 489 | Lithium Ion battery

Given:

The Electrathon of America only allows a total weight of 15lbs of Lithium Ion batteries. The other constraint is a maximum of 1kw/hr.

Q (mAh) - Electric flow in milliamp/hours

E (Wh) - Energy in Watt hours

V (V) - Voltage measured in volts

Find: Lithium Ion battery(s) that produces 1Kw/hr while staying under 15lbs.

Assume: cost isn't an issue.

Brand: Fire power Featherweight Lithium Battery

Dimensions:
- 4 3/4 in - Base
- 2 3/8 in - Width
- 3 5/8 in - Height
- 1.20lbs - Weight

Specs: 12Volt battery, 24WH, Watt hours

Finding amps: 24Wh/12Volts = 2.00 Ah

$I = \frac{V}{R}$

Resistance: $R = \frac{V}{I} = \frac{12\ \text{Volts}}{2.00\ \text{Ah}} = 6.00\Omega$

Cost per battery ~$100.

$\frac{24\ \text{Watts}}{1\ \text{hour}}$, assuming a perfect 24 watts being distributed,

$$\frac{1000\ \text{Watts}}{\frac{24\ \text{Watts}}{1\ \text{battery}}} = 41.6\ \text{batteries}$$

41.6 batteries · 1.20lbs = 50lbs

$$15\ \text{lbs} \Big/ \frac{1.20\ \text{lbs}}{1\ \text{battery}} = 12.5$$

12 batteries

Maximum output for 12 batteries = 12 batteries · 24 watts = 288 watts

Appendix – Analysis A3

Samuel C Johnson | MET481 | Recharging Batteries

Finding the rate which the batteries.
Given the starting battery charge is 6% and 9%. respectively.
Assume no loss due to resistance in either wire or battery. Also, the starting voltage to be "0."

Battery #1	Time	Voltage	Volts/min
Time to 20% -	1:27	2.4V	2.4/1.45m = $\boxed{1.65V/m}$
Time to 40% -	4:46	6.9V	6.9/4.76m = $\boxed{1.44V/m}$
Time to 60%	8:02	12.2V	12.2V/8.03m = $\boxed{1.52V/m}$
Time to 80%	NA	N/A	N/A
Time to 100%	NA	NA	N/A

Battery #2	Time	Voltage	Volts/min
Time to 20%	1:17	3.7	3.7/1.28 = $\boxed{2.89V/m}$
Time to 40%	3:55	7.1	7.1/3.92 = $\boxed{1.81V/m}$
Time to 60%	7:11	12.7	12.7/7.18 = $\boxed{1.77V/m}$
Time to 80%	NA	N/A	NA
Time to 100%	NA	NA	NA

Appendix – Analysis 4.1

Samuel C. Johnson | MET481 | Battery Discharge | A4.1

Finding the rate the batteries lose their charge by measuring the loss of rpms, converting to torque.

Given: The batteries are "fully" charged (see appendix A6) with 12.0Volts each.

Assume: - The batteries are ran in series with only a motor attached, no body weight of the car and perfect transfer of power from batteries. Assume motor has 20% efficiency.

Time	RPM	Rotational Speed (ω=rpm·2π/60)
0:30s	1350	141.3 rad/s
10:00m	1320	138.2 rad/s
20:00m	1280	133.9 rad/s
30:00m	1250	130.8 rad/s
40:00m	1220	127.7 rad/s
50:00m	1190	124.6 rad/s
60:00m	1150	120.4 rad/s

Assuming perfect power transfer, i.e. Power in = Power Out, referencing appendix 1F, Two batteries at full charge of 12V each being delivered at 2Amps.

Power in = 12Volts (2 batteries) · 2 Amps = 48 Watts

Finding Torque → $P_{out} = T * \omega$, $P_{in} = 48$ watts

$Efficiency = \frac{P_{out}}{P_{in}}$ → $P_{out} = E \cdot P_{in}$ → $0.2 \cdot 48$ watts

assumption

$P_{out} = T * \omega$, $T \cdot \omega = 0.2 \cdot 48$ Watts, $Torque = \frac{0.2(48)}{141.3\ rad/s}$

Appendix – Analysis A4.2

Samuel G Johnson | MET481 | Battery Discharge | A4.2

$$\text{Torque (30s)} = \frac{0.2(48\text{ Watts})}{141.3\text{ rads/s}} = 0.067\text{ Nm/s}$$

assumption

$$\text{Torque (60m)} = \frac{0.2(24\text{ Watts})}{120.4\text{ rads/s}} = 0.039\text{ Nm/s}$$

Loss of power over the hour

$$\frac{0.067\text{ Nm/s} - 0.039\text{ Nm/s}}{0.067\text{ Nm/s}} = \boxed{41.8\%\text{ loss of power}}$$

Appendix – Analysis A5.1

A5.1

Samuel C. Johnson Senior Project

The size of the wire and fuse

Types of wire: Copper or aluminum

Assuming a range of amps from batteries while considering the fuses needed...

American Wire Gauge

Wire Size AWG	Fuse or breaker size
20	5.5 amps
18	9 amps
16	12 amps
14	15 amps

Specs of Copper Wire...

AWG	Weight	Diameter	Resistance/Length	Cost/foot
20	0.00295lb/ft	0.0320in	10.15mΩ/ft	
18	0.00492lb/ft	0.0403in	6.385mΩ/ft	
16	0.00781lb/ft	0.0508in	4.016mΩ/ft	
14	0.01241bs/ft	0.0641in	2.525mΩ/ft	

Specs of Aluminum Wire

AWG	Weight	Diameter	Resistance/Length
20	0.000939lb/ft	0.0320in	16.6056mΩ/ft
18	0.00149lb/ft	0.0403in	10.4433mΩ/ft
16	0.00237lb/ft	0.508in	6.5679mΩ/ft
14	0.00378lb/ft	0.0641in	4.1306mΩ/ft

Appendix – Analysis A5.2

A5.2

Clearly, using copper wire is the better choice. Moving forward, calculating the full resistance of only the length of wire.

AWG	Length	OHMS per length	Total weight	Total Cost
20	16ft	162.4mΩ	0.0472lbs	
	18ft	182.7mΩ	0.0531lbs	
	20ft	203mΩ	0.059lbs	
18	16ft	102.16mΩ	0.07872lbs	
	18ft	114.93mΩ	0.08856lbs	
	20ft	127.7mΩ	0.0984lbs	
16	16ft	64.256mΩ	0.1249lbs	
	18ft	72.29mΩ	0.14058lbs	
	20ft	80.32mΩ	0.1562lbs	
14	16ft	40.4mΩ	0.1984lbs	
	18ft	45.45mΩ	0.2232lbs	
	20ft	50.5mΩ	0.248lbs	

To be used

Appendix – Analysis A6.1

Samuel C Johnson | Battery Wiring A6.1

The size of the wire and fuse for the battery circuit. Finding wire and fuse.

Type of wire, copper

The 4 wire sizes are suitable choices based on specs.

Assume a 2% or less voltage drop at 12 Volts, less than 50 amps will be applied.

AWG	Cost/ft	Weight	Allowable Amps	Diameter	Resistance / length
6	\$0.57/ft	0.07946	75A	0.1620in	0.3951mΩ/ft
4	\$0.81/ft	0.1264	95A	0.2043in	0.2485mΩ/ft
2	\$1.29/ft	0.2009	130A	0.2576in	0.1563mΩ/ft
0	\$1.84/ft	0.3195	150A	0.3249in	0.09827mΩ/ft

Calculating full resistance, and weight using various distances.

Wire size	Length	Total Ω	Total Weight	Total Cost
6	20ft	7.9mΩ	1.59lbs	\$11.40
	25ft	9.875mΩ	1.98lbs	\$14.25
	30ft	11.85mΩ	2.38lbs	\$17.10
4	20ft	4.97mΩ	2.53lbs	\$16.20
	25ft	6.21mΩ	3.16lbs	\$20.25
	30ft	7.45mΩ	3.79lbs	\$24.30
2	20ft	3.13mΩ	4.018lbs	\$25.80
	25ft	3.91mΩ	5.02lbs	\$32.25
	30ft	4.69mΩ	6.03lbs	\$38.70

This to be used.

Appendix – Analysis A6.2

A6.2

Wire size	length	Ω/ft	Total Weight	Total Cost
0	20 ft	1.97 mΩ/ft	6.39 lbs	$37.80
	25 ft	2.46 mΩ/ft	7.99 lbs	$47.25
	30 ft	2.95 mΩ/ft	9.59 lbs	$56.70

Fuse that is needed is..

Fuse rating recommended - 200 amps for 2AWG.

Appendix – Analysis A7

Samuel C. Johnson | Ziptie Compression A7

Find the maximum stress polyvinychloride can handle from a ziptie.

Given 14 gauge AWM wire, material is copper

Assume: homogeneous material

According to Pandvit.com 14 gauge wiring has a diameter of 0.111in with insulation. Uninsulated has a diameter 0.064. The coating is approximately 0.047in thick.

Assuming, when under compression only the PVC will deform and not the copper wiring, the force to fasten without fracturing the coating can be determined by the equation...

$$\sigma_{max} = Force / \pi (D_{outer} - D_{inner})^2$$

$$Force = \frac{\sigma_{max}}{\pi (D_{out} - D_{in})^2} \qquad \sigma_{max}, PVC_{Rigid} = 7{,}500 PSI$$

$$Force = \frac{7500\,PSI}{\pi (0.111in - 0.064in)^2} = \boxed{1080726 lbs}$$

Not realistic

$\sigma_{min} Cu = 6.5267\,KSI$

Assuming copper breaks internally first

$$Force = \frac{6.5267\,KSI}{\pi (0.111in)^2} = \boxed{168615 lbs}$$

Its pretty easy to not apply this much force to a ziptie.

Appendix - Analysis A8

Samuel C. Johnson | MET 481 | Overall resistance | A8

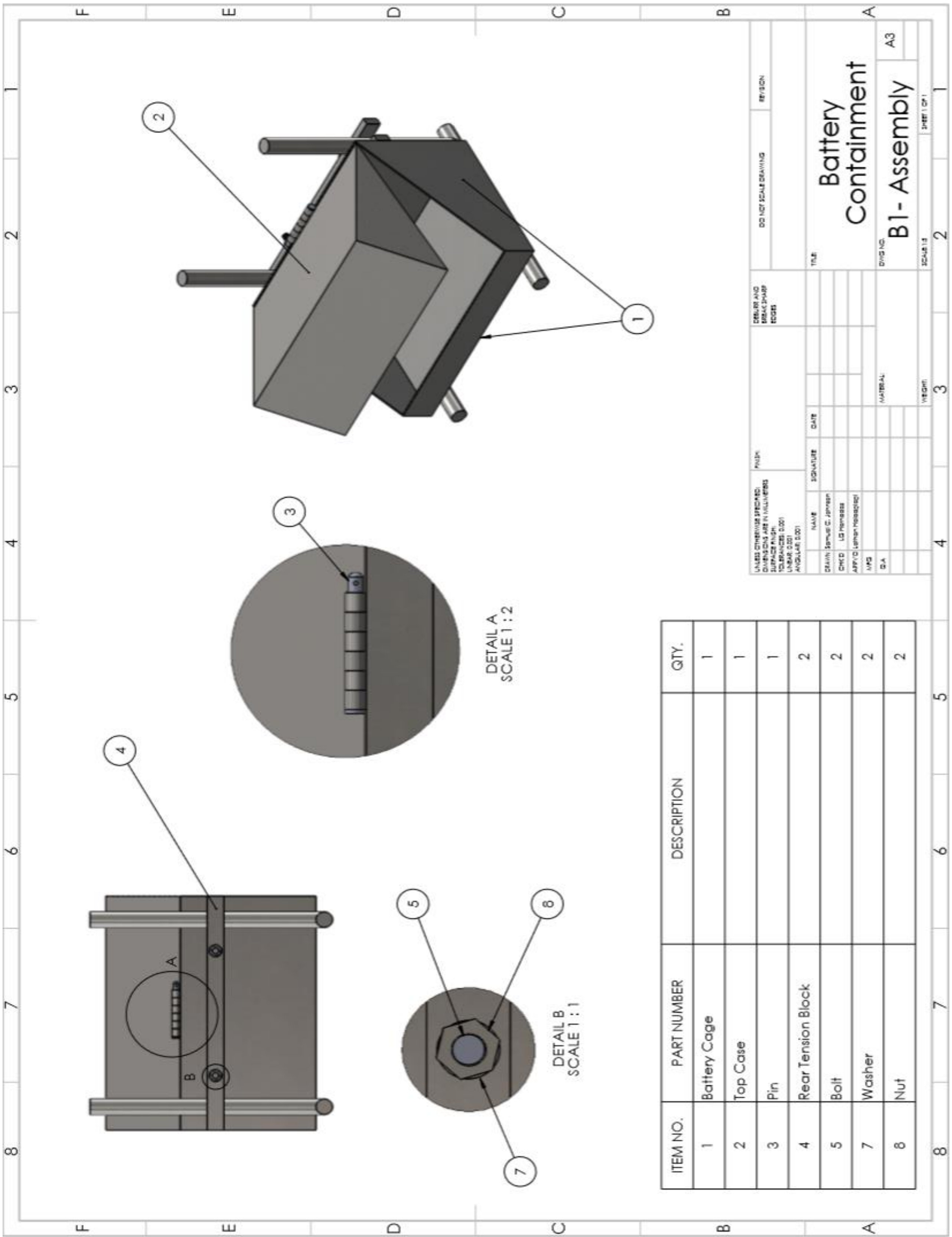
Find: The cumulative resistance in this circuit.
Given: The various components
Assume: A fixed length of wire

The resistance of a shunt, 0.001 Ohms or 1mΩ
The resistance of a controller, whatever
The resistance of a master on/off switch - 0.1Ω
The resistance of the total length of wiring, assuming 20ft is 50.5mΩ - For comonents
The resistance of the total length of wiring for the battery, assuming 2 AWG wire at 30ft, 4.69mΩ

Shunt - 0.001Ω
Master switch - 0.1Ω
Small Wire - 0.050Ω
Large Wire - 0.00469Ω

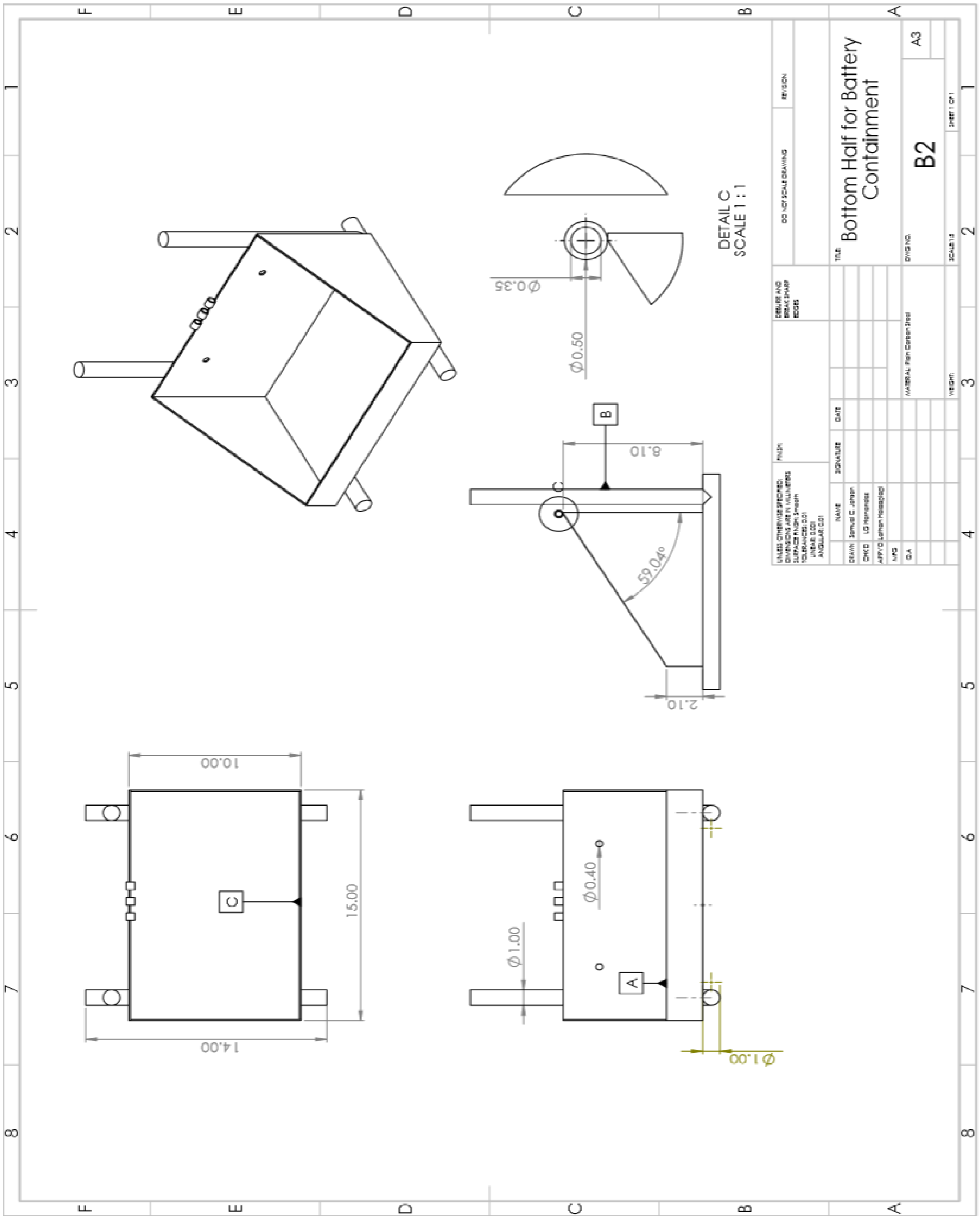
$\boxed{0.15569\Omega}$!!

Appendix B1 – Battery Containment Assembly w/ Bill of Materials

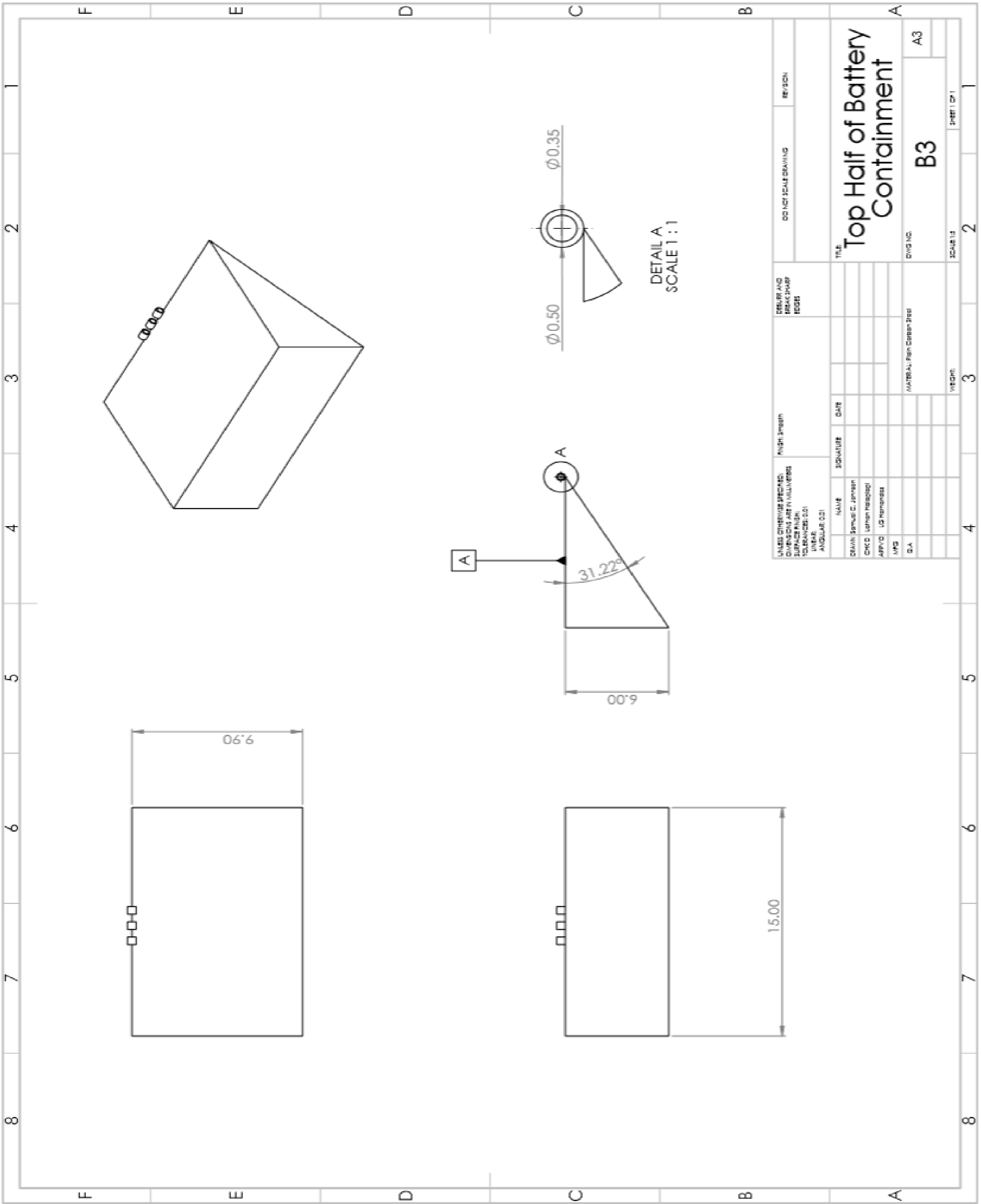


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Battery Cage		1
2	Top Case		1
3	Pin		1
4	Rear Tension Block		2
5	Bolt		2
7	Washer		2
8	Nut		2

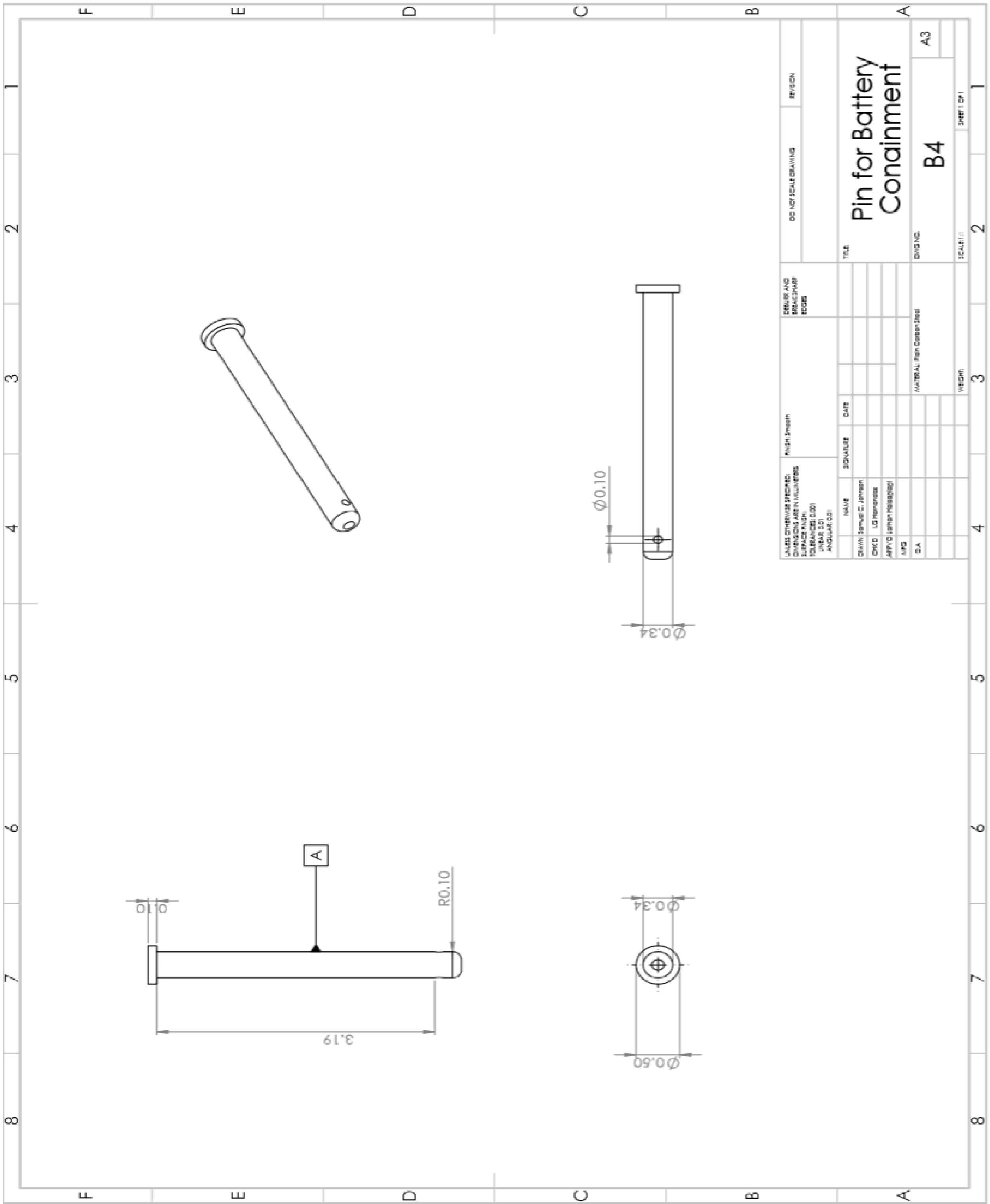
Appendix B2 – Bottom Half for Battery Containment



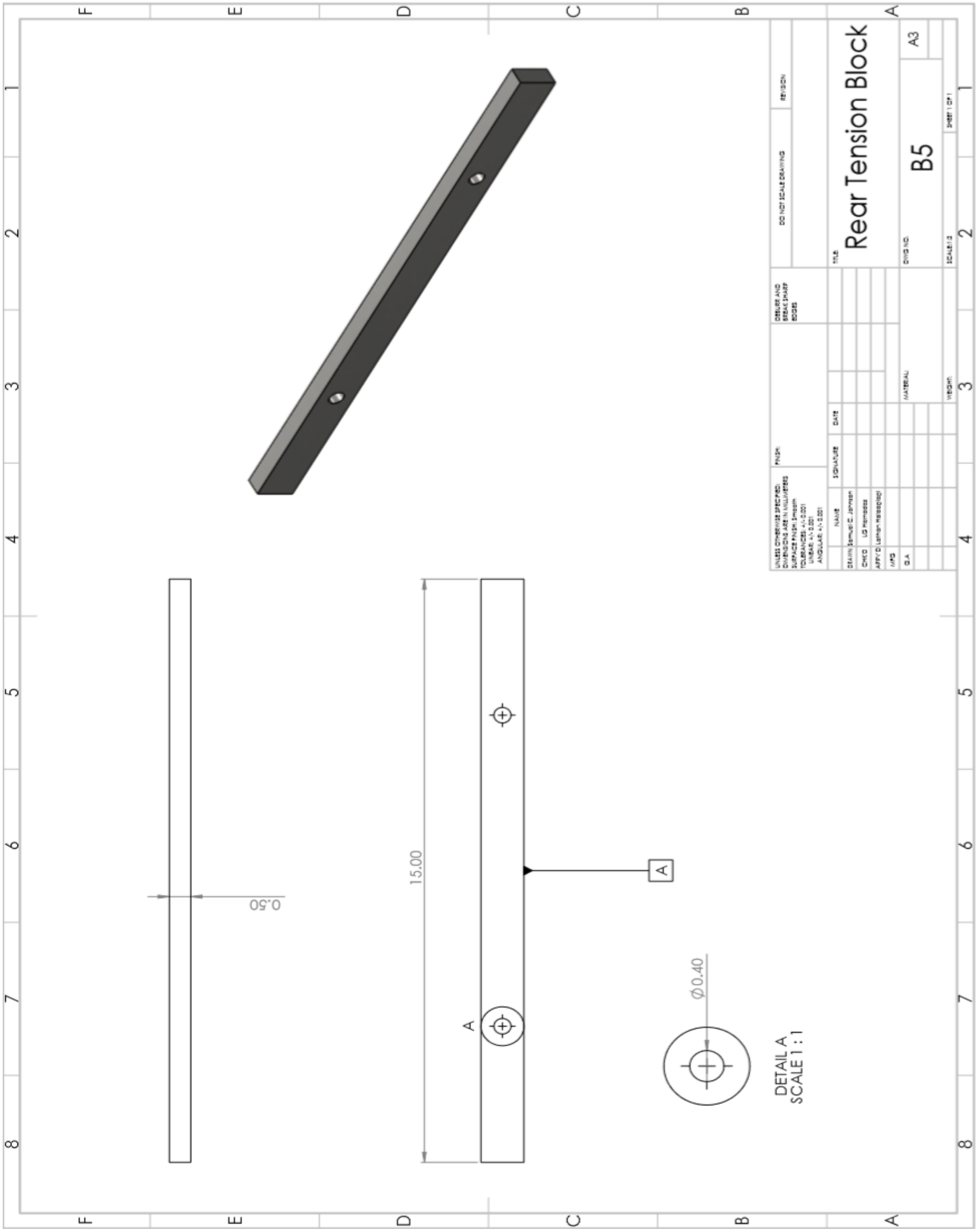
Appendix B3 – Top Half of Battery Containment



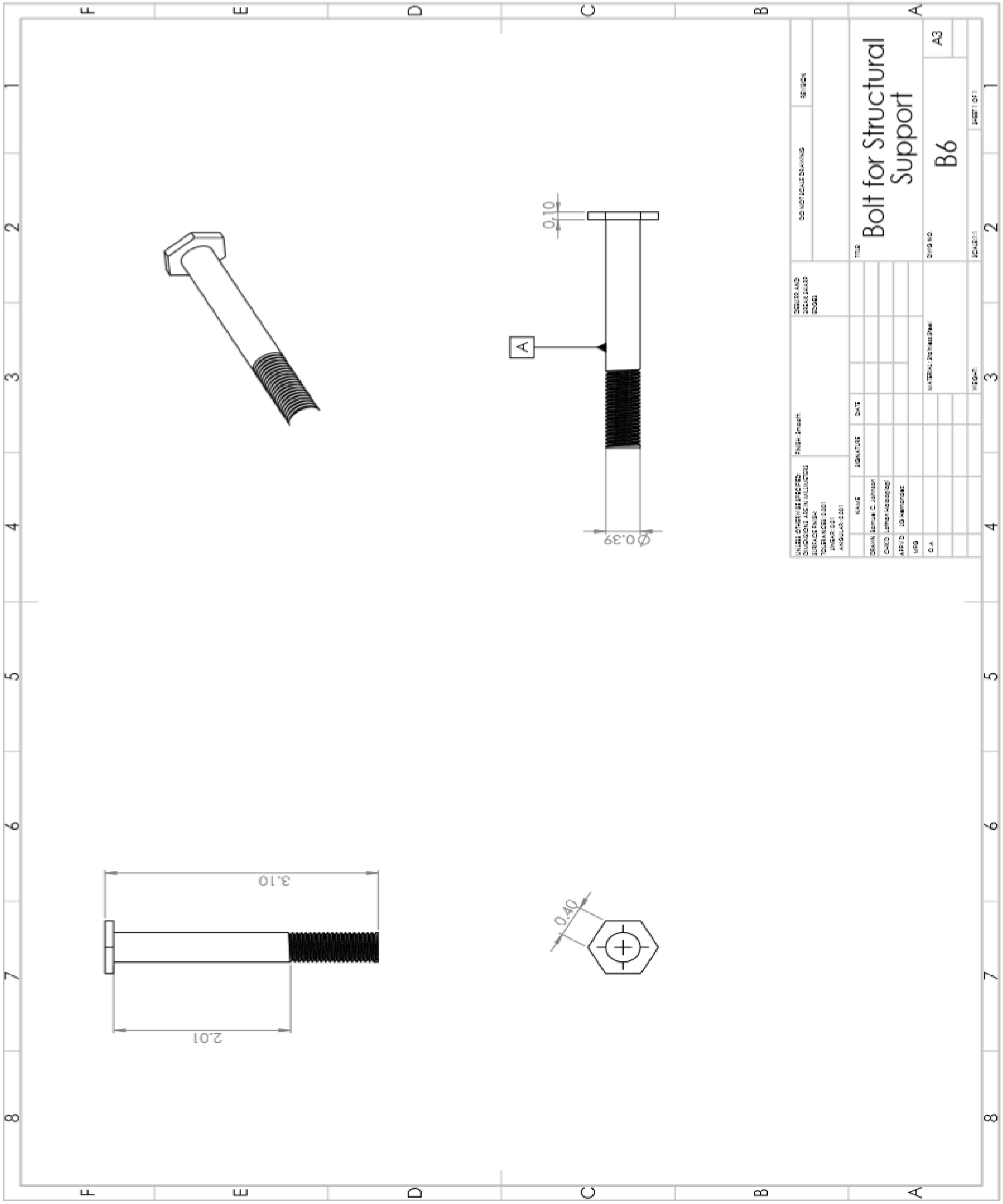
Drawing B4 – Bolt for Structural Support



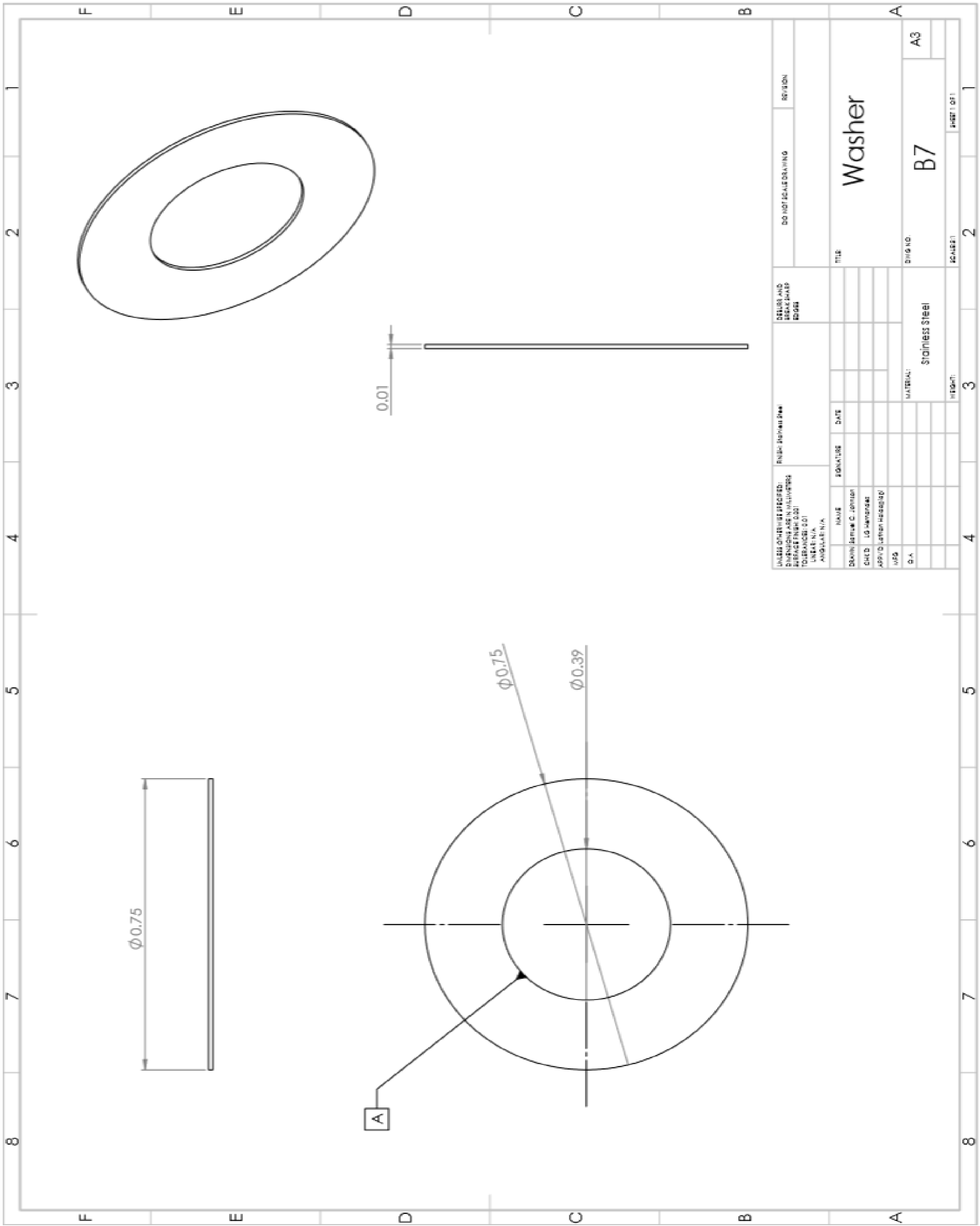
Drawing 5 – Rear Tension Support Block



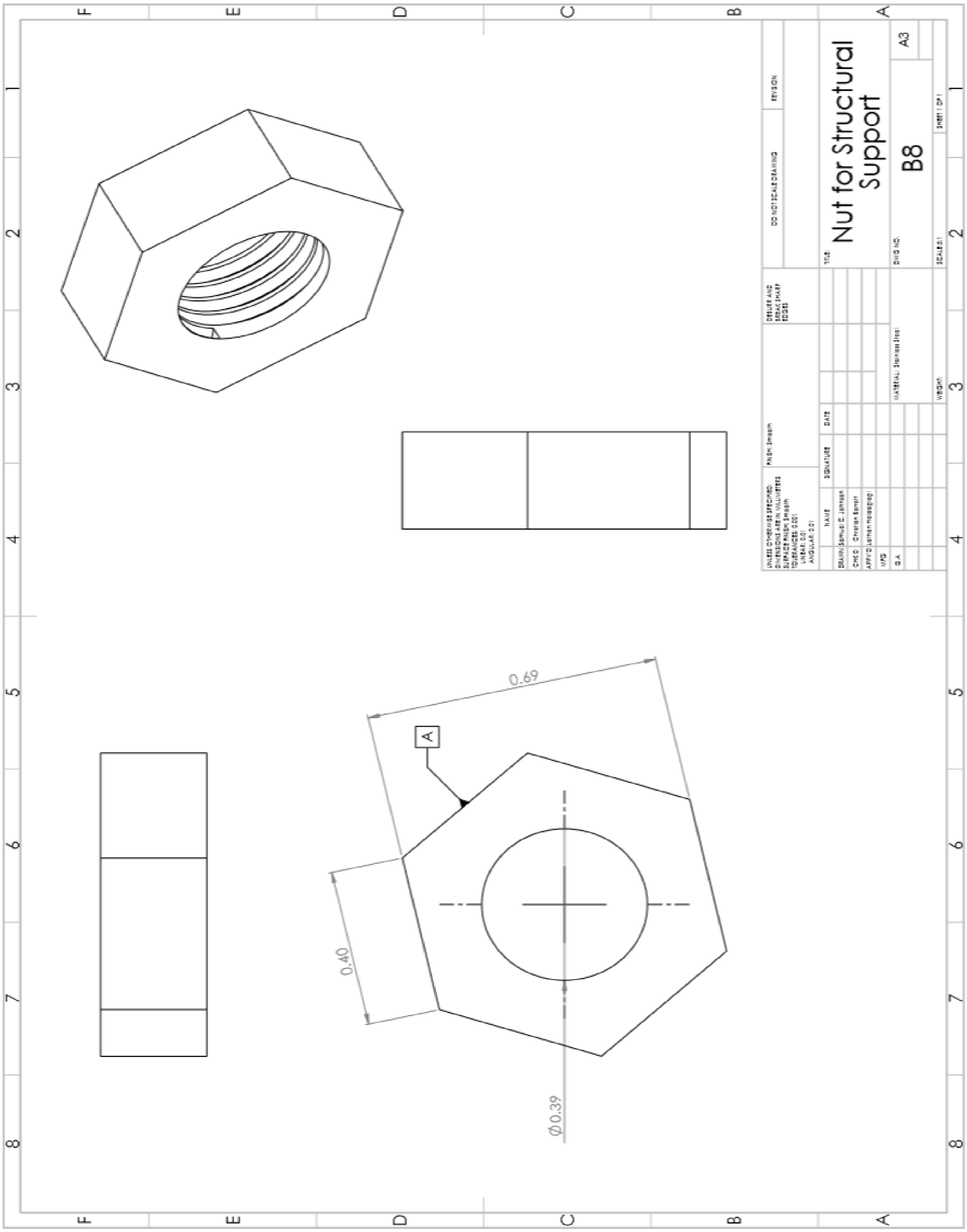
Drawing B6 – Bolt for Structural Support



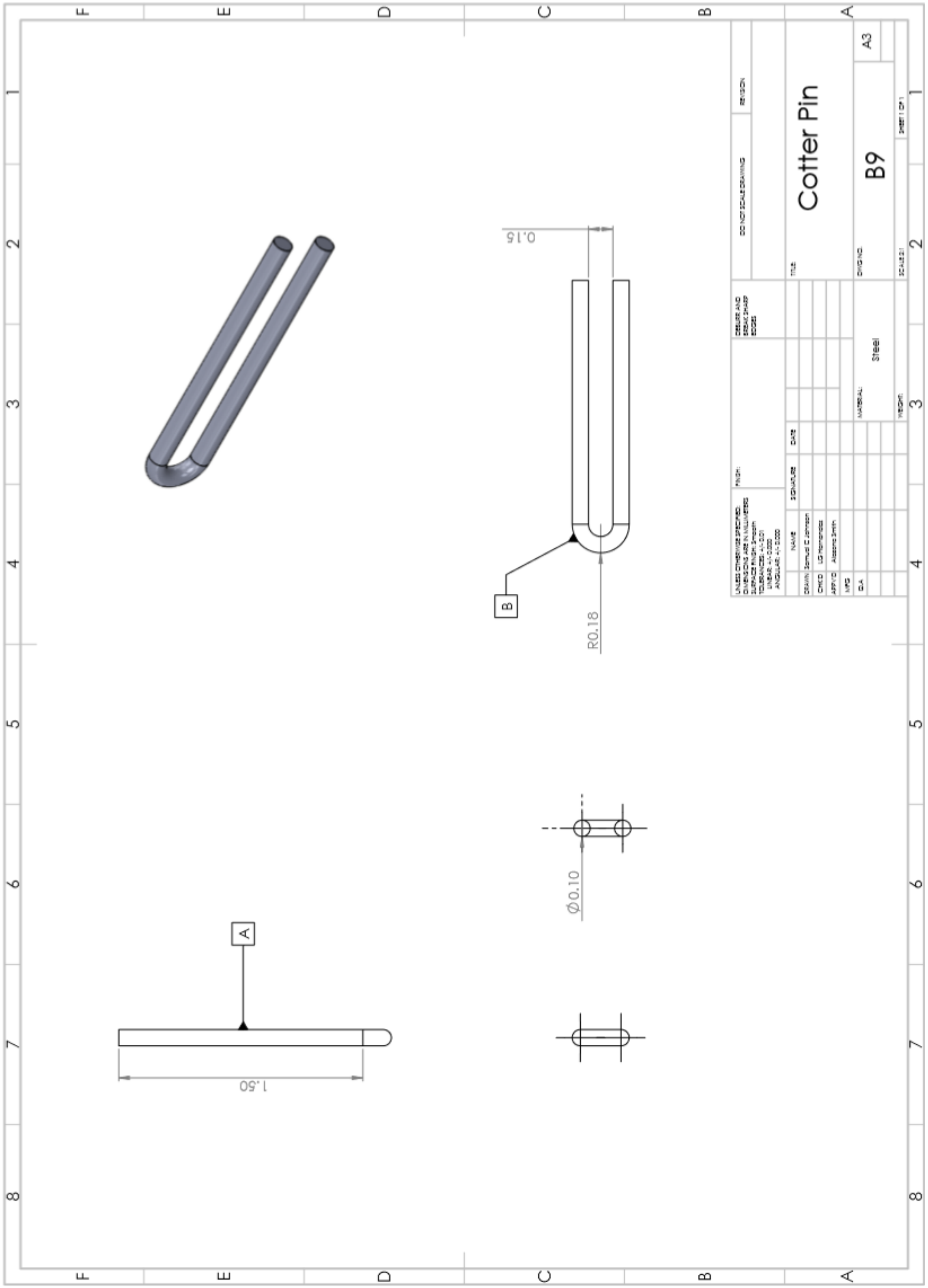
Drawing B7- Washer



Drawing B8 – Bolt



Drawing B9 – Cotter Pin



Appendix C – Part List / Budget

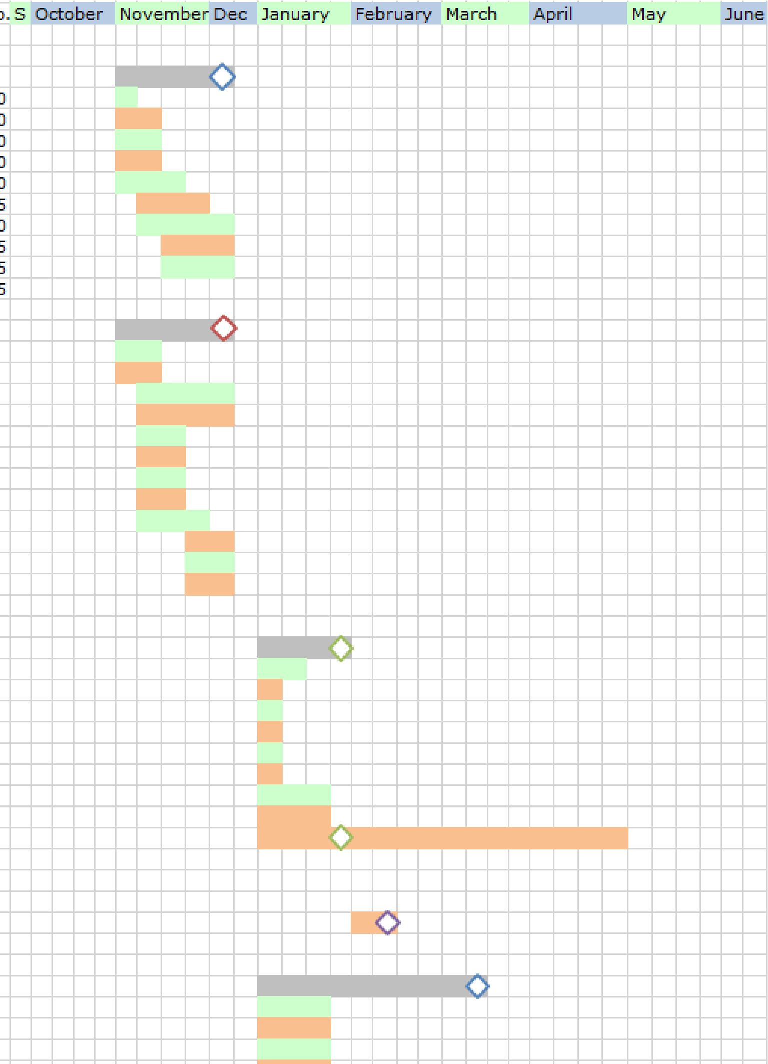
Item ID	Item Description	Item Source	Brand Info	Model/SN	Price/Cost	Quantity	Cost:	Actual
1	Motor	CWU	CWU	TBD	$300	1	$300	Donated
2	Controller	Internet	Curtis	AC F2A	Not Listed	Not Listed	Not Listed	
3	Master Switch	Zoro		G4683235	$5.41	2	$10.82	
4	Fuse	Internet?	AllFuses	TRS30R	$5.98	3	$17.94	
5	Battery(s)	Real Good	Lead Acid	RB75	$209.99	2	$419.98	
6	Shunt	Internet?	Ram Meter	A15A50	$35.59	1	$35.59	
7	Digital E-Meter	Internet	GearBest	57021	$16.70	1	$16.70	
8	Speed Control	Amazon	RioRand	RRPDMSCSGSPC	$12.99	1	$12.99	
9	Limit Potentiometer	CWU	Flute	Flute	$0.00	1	$0.00	
10	Battery Terminal Covers	Online	Crimp Supply	UL94 Flame Class V-2	$5.00	1	$5.00	
11	Conduit	Ace Hardware	??	??	$1.06/ft	10	$11.00	
							$530.02	

Appendix D – Budget

Item ID	Item Description	Item Source	Brand Info	Model/SN	Price/Cost	Quantity	Sub Totals	Actual
1	Motor	Internet	Electric Motor Sport	ME0909	$ 385.00	1	$ 385.00	$ 385.00
2	Lead Acid Batteries	Advance Auto Parts	Optima Red Top	75	$ 209.00	2	$ 418.00	$ 418.00
3	Shunt and Digital Mutli.	Internet	Banggood.com		$ 15.93	1	$ 15.93	$ 15.93
4	Controller	Internet	Walker Industrial	KBMD-240D	$ 129.50	1	$ 129.50	$ 129.50
5	Speed Control	Internet	RCPW	59080	$ 92.86	1	$ 98.26	$ 98.26
6	Potentiometer	Internet	Honeywell	53C21500	$ 17.73	1	$ 17.73	$ 17.73
7	Master Switch	Internet	Newark	PV6F240SS-341	$ 10.20	1	$ 10.20	$ 10.20
8	Small Fuse	Internet	Zoro	G2857145	$ 2.94	3	$ 8.82	$ 8.82
9	Large Fuse	Internet	Zoro	G0814274	$ 48.82	2	$ 97.64	$ 97.64
10	Bolts	Ace Hardware	N/A	N/A	$ 0.56	2	$ 1.12	$ 1.12
11	Washers	Ace Hardware	N/A	N/A	$ 0.11	2	$ 0.22	$ 0.22
12	Nuts	Ace Hardware	N/A	N/A	$ 0.12	2	$ 0.24	$ 0.24
								$1,182.66
				Labor	Type	Hours	Cost/Hr	Total
					College Student		$ 7.50	
				Breakdown				
					Analyses	40	$ 7.50	$ 300.00
					Testing	50	$ 7.50	$ 375.00
					Assembly	30	$ 7.50	$ 225.00
					Welding	10	$ 7.50	$ 75.00
								$ 975.00
				Indirect Costs	10%			$2,373.43

Appendix E – Gantt Chart

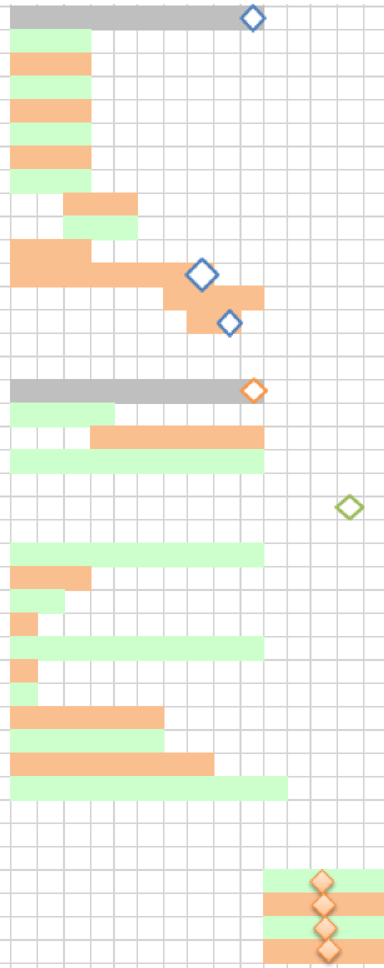
TASK ID	Description	Est. (hrs)	Actual (hrs)	%Comp.
1	Proposal*			
1a	Outline	2	1	100
1b	Intro	1	2	100
1c	Methods	0.5	2.5	100
1d	Analysis	10	12	100
1e	Discussion	2	1.5	50
1f	Parts and Budget	2	2.5	75
1g	Drawings	10	17	100
1h	Schedule	2	3	75
1i	Summary & Appx	1	2	75
	subtotal:	30.5	43.5	85
2	Analyses			
A1	Lead Acid battery	1	1.5	
A2	Lithium Ion Battery	1	1	
A3	Battery Charging Time	1	6	
A4	Battery Discharge	1	2	
A5	Small Gauge Wiring	1	1	
A5	Small Fuses	0.1	0.1	
A5	Resistance - Small Wiring	0.5	0.5	
A6	Large Gauge Wiring	1	1	
A6	Large Fuses	0.5	0.5	
A6	Resistance - Large Wiring	1	5	
A7	Zip-Tie Compression	2	2.5	
A8	Total Resistance	1	1	
	subtotal:	11.1	22.1	
3	Documentation			
3a	Lead Acid Battery	2	1	
3b	Master On/Off Switch	2		
3c	Gauge of Wire	2		
3d	Fuse	2		
3e	Shunt	1		
3f	Digital Multimeter	2		
3g	Speed Controller	2		
3h	Limit Potentiometer	1		
3i	10 Week Timeline			
	subtotal:	14	1	
4	Proposal Mods			
4a	Senate Meetings	5	7	
	subtotal:	5	7	
7	Part Construction			
7a	Motor	0.5	0.5	
7b	Controller	0	0	
7c	Master Switch	1		
7d	Large Fuse	1		



Appendix E Cont.

7	Part Construction		
7a	Motor	0.5	0.5
7b	Controller	0	0
7c	Master Switch	1	
7d	Large Fues	1	
7e	Battery(s)	0.5	0.5
7f	Shunt	1	
7g	Digital E-Meter	1.5	
7h	Speed Control	2	
7i	Limit Potentiometer	2	
7j	Small Fuse	1	1
7k	Sheet Metal for Box	5	6
7L	Welding pin support	5	2
7M	LG's Mounting Bracket	5	1.5
	subtotal:	25.5	11.5
9			
9a	Device Construct		
9b	Electrical Circuit	17	12
9c	Thermal Containment	10	2
	Update Website	10	7
	subtotal:	37	21
10			
10a	Device Evaluation		
10b	Motor	5	4
10c	Controller	3	0
10d	Master Switch	2	0
10e	Fuse	1	0
10f	Battery(s)	5	2
10g	Shunt	1	0
10h	Digital E-Meter	0	0
10i	Speed Control	2	0
10j	Limit Potentiometer	2	0
10k	Thermal Efficiency Ctmen	5	0
	Update Website	26	0
	subtotal:		
11			
11a	495 Deliverables		
11b	Batteries Efficiency	3	3
11c	Motor Efficiency	3	4
11d	Total Resistance	1	1
11e	Thermal Efficiency of Batt	4	0
	Project CD*	11	8
	subtotal:		
		108.6	114.1
Labor:	Total Est. Hours=	600	234.2
	100		

=Total Actual Hrs



Appendix G: Testing Data

Time (Minutes)	Volts (V)	Current (Amps)	Resistance (R)	Power (W)	W/Hr
0	12.12	7.62	1.5906	92.5	0
5	12.13	7.2	1.6847	85.7	6
10	12.08	8.88	1.3604	105.7	15
15	12.09	7.26	1.6653	88.7	25
20	12.09	6.8	1.7779	83.9	31
25	12.09	6.31	1.9160	76.9	38
30	12.07	6.26	1.9281	74.9	44
35	12.05	6.2	1.9435	73.2	51
40	12.03	6.19	1.9435	73.6	57
45	12.02	6.08	1.9770	72.9	64
50	12	5.97	2.0101	72.2	71
55	11.98	5.95	2.0134	71.7	79
60	11.96	5.88	2.0340	72.2	85
65	11.94	6.1	1.9574	73.7	91
70	11.92	6.05	1.9702	72.5	98

Time (Minutes)	Volts (V)	Current (Amps)	Resistance (R)	Power (W)	W/Hr
0	12.03	7.19	1.6732	86.4	0
5	12.03	6.9	1.7435	81.1	10
10	12.01	6.83	1.7584	81.5	17
15	11.99	6.8	1.7632	79.2	24
20	11.97	6.63	1.8054	77.2	31
25	11.95	6.43	1.8585	76.4	39
30	11.92	6.52	1.8282	77.9	45
35	11.9	6.36	1.8711	75.9	52
40	11.88	6.38	1.8621	75.9	59
45	11.86	6.53	1.8162	76.2	65
50	11.83	6.37	1.8571	75.5	71
55	11.82	6.38	1.8527	74.4	78
60	11.79	6.28	1.8774	74.7	85
65	11.77	6.24	1.8862	74	91
60	11.74	6.24	1.8814	73.6	96

Appendix I:

Introduction:

The goal of this experiment was test how efficient two nickel-plated batteries are at delivering power to an electric motor. This task comes with tangible limitations of producing no more than 1kw/hr of energy to the motor. This power cap is set by the Electrathon of America association. The batteries will have a DMM (Digitial Multi-meter) directly inline before the electric motor. Using this method for data collection will give insight on volts, amperage, power consumed and power produced over the hour. An initial assumption for battery output is to be .2kW/hr for one battery and .5kw/hr for two batteries. This assumption is based on efficiency of electricity as more energy is wired in a DC fashion to the motor. The following report will produce evidence for both maximum energy output of two batteries wired in series as well the power output by the motor.

Methods:
The construction of an electrical circuit isn't too difficult of a task but does require funding. An overcautious budget for this type of project should run $1000 before any breakage. See Appendix for budget breakdown. Components to reduce electrical leakage into the metallica frame will be 3D printed. The material used for 3D printing, PLA, has a much lower conductivity than metal and should provide good insulation. The only two components needed to be printed are Shunt Box and Electrical Power Switch. Dimensions and drawings are in appendix.

Data Capture:
Using the DMM directly inline with the electric motor will give data for all the key measurables. The usable collection of volts from the battery, ampere current and power consumed and produced are the pieces critical information. Reading from the DMM, you can collect data and present it in meaningful ways such as kW/hr. Using simple conversions, see appendix for example, you can determine a variety of none measured values such as resistance.

Testing Procedure:
The testing procedure for collecting data goes as follows:
Step 1: Cut 9' feet of 4 gauge wire from both positive and negative wire. This will be used to run the power from the batteries to the motor.

Step 2: Cut the negative line at 7' in and another two feet into 1' foot sections. These added splices in the line will be where the power switch, shunt and lead back to the motor will be wired.

Step 3: On one end of the negative 7' line, place a battery terminal connector and crimp a bare copper eyelet lug to the other end. Ensure there isn't any copper strands from the wiring sticking out, if so remove the excess copper. Don't attach the battery terminal to the battery yet, keep the circuit closed.

Step 4: On the other two 1’ sections, crimp one copper eyelet lug to both sides of the short wires. These sections will be used to connect the power switch to the shunt and the shunt to the electric motor.

Step 5: Slide the negative terminal lines into the power switch box and fasten the nuts down tight. Repeat this process with the other two 1’ foot sections as well. After both eyelet lugs have been attached, close the back of the power box using two screws in the designated areas. See drawings for details in appendix.

Step 6: Before placing the shunt in it’s box, the DMM needs to be wired for power. You’ll need a short 1’ foot 14 gauge wire and a long 7’ wire of the same gauge. It’s helpful to have the short wire be colored black and the long wire to be red, for convention of power direction. With the short black wire, cut 2” of the sheathing off, exposing the bare wire. With the exposed wire, separate the strands into equal bunches and wrap them around one of the shunts bolts. This result should create an “eye” in the wiring. Carefully slide the wiring off the bolt and solder the loop closed. Finish wiring the negative line by sliding the exposed wiring eye over the bolt and then slide the bolt into the shunt. Have the free black line end fastened into the DMM into the correct terminal. This will complete the connection. Finally, attach the long red wire to the battery terminal. Have the 14 gauge red wire run along the positive battery line and tape at various locations to keep things orderly. With the free end of the red wire, fasten it into the correct DMM terminal. This completes the circuit and allows the DMM to receive power while reading data passing through the shunt during activity.

Step 7: Place the shunt in box, see drawing for details. Wire the opposite end of the 1’ foot line to the shunt through the holes cut in the short side of the box. Wire the remaining 1’ section into the shunt box and fasten both nuts tightly down onto the shunt. Put two screws into the designated areas on the shunt lid and close the box shut.

Step 8: Wire the remaining 1’ lead line to the motor. Double check all connections throughout all the negative battery line. Turn the power switch to off so when you complete the circuit, current doesn’t flow. Attach both positive and negative terminals to the batteries. Turn on the circuit using the power switch.

Step 9: Run the batteries for 70 minutes and record volts, ampere, watts and kW/hr every 5 minutes.

Operational Limitations:
Due to the restrictions set by Electrathon of America the race only lasts 1 hour or by producing 1 kW/hr of energy, whichever comes first. Because of this limitation, the testing can only last 1 hour or if 1 kW/hr of energy is delivered to the motor.

Precision and Accuracy:
There is a natural ambiguity to measuring electric motors. Their design requires two copper coils to spin which causes measurements to be sporadic. Throughout the first test there was an

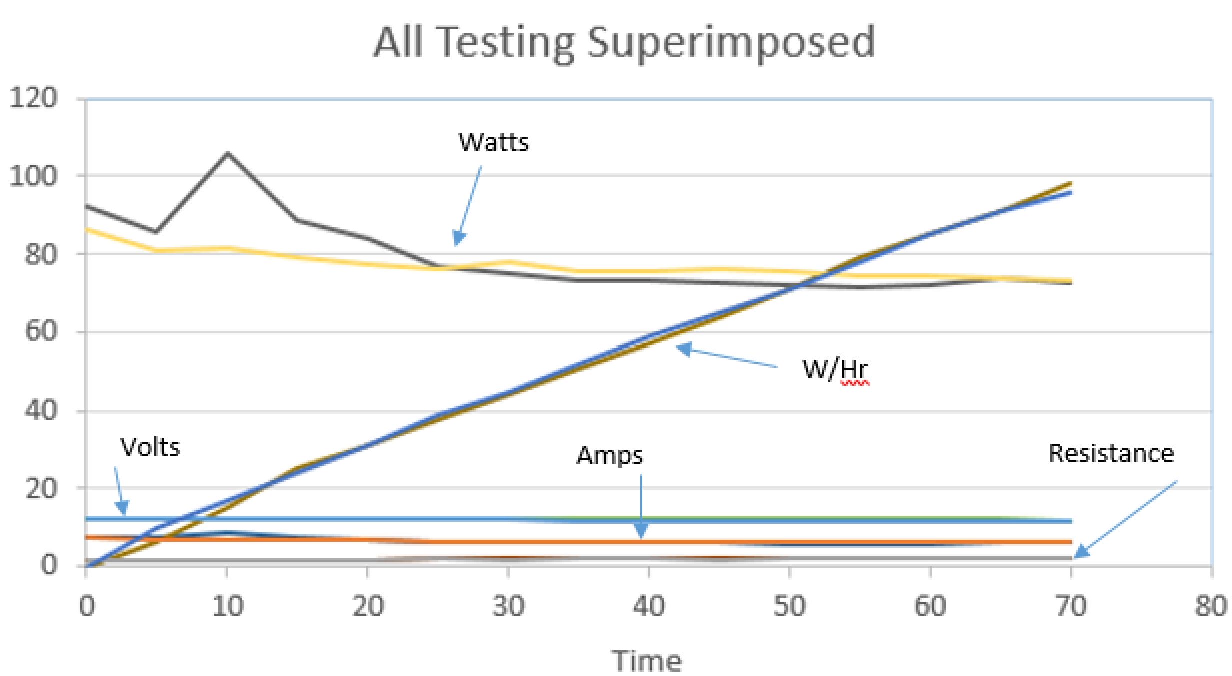
approximate +/- 0.50 Amps and energy per data recording. This is expect and normal for measuring an electric motor. With the current motor, it would be impossible to improve upon this accuracy. If the test required a much higher precision of measurements a better motor would need to be purchased.

Data Storage/Data manipulation/Analysis:
The data presented in this testing report is on the basic level of rigor. There is an example calculation in the appendix.

Raw Data:
Raw Data for One Battery

Time (Minutes)	Volts (V)	Current (Amps)	Resistance (R)	Power (W)	kW/Hr
0	12.12	7.62	1.5906	92.5	5
5	12.13	7.2	1.6847	85.7	11
10	12.08	8.88	1.3604	105.7	20
15	12.09	7.26	1.6653	88.7	30
20	12.09	6.8	1.7779	83.9	36
25	12.09	6.31	1.9160	76.9	43
30	12.07	6.26	1.9281	74.9	49
35	12.05	6.2	1.9435	73.2	56
40	12.03	6.19	1.9435	73.6	62
45	12.02	6.08	1.9770	72.9	69
50	12	5.97	2.0101	72.2	76
55	11.98	5.95	2.0134	71.7	84
60	11.96	5.88	2.0340	72.2	90
65	11.94	6.1	1.9574	73.7	96
70	11.92	6.05	1.9702	72.5	103

Time (Minutes)	Volts (V)	Current (Amps)	Resistance (R)	Power (W)	W/Hr
0	12.03	7.19	1.6732	86.4	0
5	12.03	6.9	1.7435	81.1	10
10	12.01	6.83	1.7584	81.5	17
15	11.99	6.8	1.7632	79.2	24
20	11.97	6.63	1.8054	77.2	31
25	11.95	6.43	1.8585	76.4	39
30	11.92	6.52	1.8282	77.9	45
35	11.9	6.36	1.8711	75.9	52
40	11.88	6.38	1.8621	75.9	59
45	11.86	6.53	1.8162	76.2	65
50	11.83	6.37	1.8571	75.5	71
55	11.82	6.38	1.8527	74.4	78
60	11.79	6.28	1.8774	74.7	85
65	11.77	6.24	1.8862	74	91
60	11.74	6.24	1.8814	73.6	96



Discussion:

The spreadsheets to the right represent the collected data from both experiments. The top spreadsheet is the testing a single battery and the bottom spreadsheet shows the batteries in parallel. This data leads to shocking some conclusions about not only basic circuitry but also load management. The first conclusion to be made is overall energy output. For the testing of only 70 minutes, how the batteries are wired had zero impact on the total energy output. (See final column for energy output) This result originally came across as a surprise. However it makes sense when you consider the only source drawing energy from the batteries is the electric motor. The motor can only draw so much power. With that said, wiring the batteries in parallel allows for a higher amperage flow over a longer period of time. If you compare the 3rd column in both spreadsheets, you'll see the Amps started lower than the single battery but ended on a high value as well. This effect was predictable but doesn't improve the overall output of energy. You can interpret this data as if the car were to race in the Electrathon, it wouldn't see a faster top speed but more sustainable MPH over the course of the race. However, this sustainability came with a slightly higher voltage drop, a 31% increase usage from the parallel circuit. Another key thing to note is the overall power delivered was less than .1kW/hr. A much smaller than estimated amount.

The biggest conclusion to see here is the batteries weren't tested long enough to see a substantial difference. The hour of testing wasn't long enough to see the effects of single battery vs parallel battery. The graph below is both testing superimposed over each other. Notice the near image of each testing.

Appendix J.

Engineering Technologies, Safety, and Construction Department

JOB HAZARD ANALYSIS
{Insert description of work task here}

Prepared by: Samuel Johnson	Reviewed by: Lathan Halaapiapi Approved by: LG Hernadez

Location of Task:	Central Washington University
Required Equipment / Training for Task:	Properly wiring an electrical circuit
Reference Materials as appropriate:	Electrathon American Handbook and National Electrical Code (NEC) as well as CWU MET department codes

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☐	☐	☒	☐	☐
Use of any respiratory protective device beyond a filtering face piece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	Wiring a circuit	**Shocking myself**	**Wiring the battery last, grounded the wire, wearing rubber gloves**

Appendix K – Resume

Samuel C. Johnson

602 N Pine St Apt 5 - Ellensburg, WA - (425) 301-8851

Samuel.Christopher.Johnson@gmail.com

Professional Summary

I'm a goal-oriented achiever looking for career and personal growth. I pride myself as someone who learns new concepts quickly while communicating ideas clearly. I believe in being reliable and am exceptional with time management. I demonstrate these qualities daily and choose to lead by example.

Education - Central Washington University & Bellevue College

Senior, Mechanical Engineer Technology, 3.5 GPA Grad Date - March 2020

Career History & Experiences

Big 5 Sporting Goods, Relief Manager - Factoria Wa, 98006 (January 17' - September 17')

• Supervised operations of business while coordinating employee's specific skills to monitor and care for departments and customers' needs

• Performed crucial operations such as EOD balancing store ledger and deposits, GARDA (money truck), and setting store alarm

• Cooperated with other stores to fill scheduling voids within the district

Pogacha's Restaurant, Server/Banquet Host/Bar-back - Issaquah Wa, 98027 (March 15' - August 16')

• Greeted customers at tables, took orders, suggested menu items, upsell food when possible

• Followed a routine checklist for both opening and closing procedures while keeping the restaurant clean and orderly

• Adapted to any front-of-house position when asked, assisted back-of-house when in a pinch

• Arranged presentation set up for Easter, Mother's Day, Christmas ect.

ChemPoint, Research & Development Internship - Bellevue, WA 98027 (November 12' – January 14')

• Research & Development for specific markets and chemical campaigns, honed in on our specific demographic

• Collaborated with Data Analysis teams for consumer pricing, both tiered and one-touch

• Updated and maintained CRM accounts with sale timelines future sale opportunities

• Created new leads, cold called and kept up-to-date needs on existing clients

• Trained all new-hire Interns in using CRM, day-to-day activities and

Affiliations, Interests & Skills

• Member of the ASME/SME Engineering Club at CWU

• Scored 100% on CSWA Exam (SolidWorks Exam)

• Built an antenna to watch NOAA (weather) Satellites