

# Automated Battery Changer

A Major Qualifying Project

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by:

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Kyle Mercik, ME

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Jake Nutting, ME

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Professor Eben Cobb, ME Advisor

## **Abstract**

Multicopter autonomous helicopters (MRAH) are increasingly being used in academic, military, and commercial applications. Many of these MRAHs are limited to short autonomous flight times and distances because the discharged batteries need to be manually exchanged for charged batteries. One solution to this issue is to create an automated battery changer (ABC) that can replace the discharged batteries with a fresh set of batteries. We have designed and built a base station that passively orients the MRAH and exchanges the discharged batteries with a new set. The ABC uses a crank slider mechanism which inserts the new batteries while pushing out the old batteries on a rail system.

# Authorship

Abstract: Nutting

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# Chapter 1: Introduction

Across the world Unmanned Aerial Vehicles (UAVs) are becoming very popular in the academic, military, and business industry. For this project our focus is in multirotor helicopters, which typically use four, six, or eight rotors to create lift. The blades of the multirotor helicopter are in a formation where half of them are clockwise and the other half counter-clockwise which allows the helicopter to be controlled. For this project it would be used autonomously and the battery changer would be used as a means to allow the helicopter to travel farther distances without having to continuously move the charging station.

The main issue with these UAVs is that they have short flight times due to the amount of power they draw out of the batteries to run the motors. Using more batteries or larger batteries results in more power for the rotors but due to the fact that the UAV weighs more and the motors have to draw more power to compensate. Many UAVs have to always return to a point where humans can swap the batteries on it manually. This reduces the area that the UAV can cover as it has to return to a base point or human intervention is needed at another point to swap the batteries on the UAV.

The Automated Battery Changer (ABC) would be fully autonomous and would allow for helicopters to extend the time spent in the air and the area that it can cover. The helicopter aligns itself on the base and then the battery is swapped with a fresh battery. The used batteries are collected and can later be removed for charging. Charged batteries can then be inserted into the magazine on the base by human interaction. The ABC acts as a station that most any multirotor helicopter can use with some modifications to increase the amount of flight time for the UAVs.

There are solutions to this problem, but most tend to be expensive or will work on only certain models of multirotor helicopters. Some solutions involve wireless charging, which

although is starting to become more effective still has many issues to overcome. This is because wireless charging is not able to transmit large amounts of power, which increases charge times which decreases the amount of time a UAV can spend in the air. Some of these solutions also involve significant modifications to an existing UAV in order to make it compatible with the base. Size has also been a limiting factor for many bases as most were made to be compatible with smaller UAVs.

For this project the proposed solution looks to solve all of these issues. The ABC uses inexpensive materials and mechanisms in order to lower cost. The battery swapping process has also been made fast and efficient to allow it to minimize downtime to allow the helicopter to cover areas in a timely manner. The alignment rod has been mounted to a standard plate to allow it to mount of different makes and models of multirotor helicopters. With these solutions the ABC should be very effective at increasing the speed of the battery swapping process through a shorter amount of time necessary to align itself with the base.

Unfortunately our final system did not perform as it should have due to many issues in the assembly and manufacturing of the device. Many of the individual components of the project did work as intended however, leading to some minor successes throughout the project. With minor modifications to the project the system should perform as intended. If additional improvements are made to the ABC the system could be able to perform more efficiently and reliably. Therefore, despite some of the issues of the project, the ABC has created a path to be followed to find a fast and reliable solution to the autonomous battery exchange sequence.

# Chapter 2: Background

## 2.1 Introduction

### 2.1.1 Justification

The need for Unmanned Aerial Vehicles (UAVs) steadily increases as they see more use in the military, commercial, and academic industries. The need for a system to autonomously swap the batteries in these devices is important in these applications. In the military a report was published by the Department of Defense outlining the use of UAVs in the United States Military titled FY2009-2034 Unmanned Systems Integrated Roadmap. In this report they discuss the use of UAVs and how they are versatile and save a significant amount of fuel. The Department of Defense (DOD) also discusses moving systems to being autonomous to remove human inputs, improve reaction time, and also reduce mid-air collisions.

Using autonomous systems also reduces the need for humans to risk their lives in tasks needed of the military such as reconnaissance and surveillance, target identification and designation, counter-mine and explosive ordnance disposal, and chemical, biological, radiological, and nuclear reconnaissance.<sup>1</sup> Two of these tasks, reconnaissance and surveillance and target identification and designation, can be completed by smaller UAVs. In increasing the use of autonomous systems, the DOD also wants automated aircraft refueling for these UAVs to reduce the human inputs needed. With the military using many UAVs that are battery powered a system to swap these batteries would be a necessity for the United States Military. This necessity was also outlined in the FY2011-2036 Unmanned Systems Integrated Roadmap where Admiral

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<sup>1</sup> Department of Defense, 2009

Nevin Carr, Chief of Naval Operations, states two available options with one of them being “... We might start thinking about setting up drone refueling stations”.<sup>2</sup>

In the commercial industry, Amazon is currently looking into improving their delivery service with Amazon Prime Air.<sup>3</sup> This service uses a Multirotor Autonomous Helicopter (MRAH) which carries a package which can then be delivered to an individual’s home. Although the implementation of this service is still in progress, still needing approval from the FAA, the need to increase the distances traveled by these MRAHs is necessary. With the additional weight on the MRAH, flights will be shortened due to the power draw necessary for flight. If numerous autonomous battery exchanging stations were placed in an array in an area then the MRAH could go to each station when it needs new batteries and can increase travel time and reduce delivery time.

Lastly to aid in the military’s needs, many academic institutions are designing and building autonomous battery exchanging systems to interface with UAVs. Some institutions have already built systems, which will be further discussed later in this section. These systems use very different methods to swap the batteries in the MRAHs. Some of these systems focused on more critical parts such as charging methods more than the battery exchanging itself.

### **2.1.2 Multirotor Helicopter Frame**

The Automated Battery Changer (ABC) system is designed to be used with the Tarot 680PRO frame seen below in Figure 1.<sup>4</sup> This frame was chosen because of the competitive price, ease of assembly, and also because it is similar in size and weight of most multirotor helicopter frames, with the motor to motor distance being 27.36 inches (695 mm) and the weight of the

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<sup>2</sup> Department of Defense, 2009

<sup>3</sup> Amazon, 2013

<sup>4</sup> HobbyKing – Tarot 680PRO, 2015

frame being 1.72 pounds (780 grams). The most important measurement on our copter was the height from the ground to the lower rods of the 680PRO frame, which was 7.09 inches (180 mm).



*Figure 1: Tarot 680PRO Frame<sup>5</sup>*

Many multirotor frames use a similar design to the Tarot 680PRO frame. For comparison a custom frame built by a student at WPI was also examined for similar features. The custom frame shows many similar properties to the Tarot 680 PRO frame, as it uses the same landing skids and uses the six arms to mount the motors. Most importantly, the frame also includes a similar camera mount rails to the Tarot and other premade frames. The frame was primarily 3D printed using PLA that can also glow in the dark for increased visibility in nighttime flight. This frame can be seen below in Figure 2.



*Figure 2: Custom Multirotor Frame built by Zach Lovett a student at WPI.*

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<sup>5</sup> Hobbyking – Tarot 680PRO, 2015

## **2.2 Batteries**

### **2.2.1 General Information**

There are many different types of rechargeable batteries that are used in different applications such as Nickel Cadmium (NiCd), Nickel Metal Hydride (NiMH), Lithium Ion (Li Ion), and different variations of Sealed Lead Acid (SLA).<sup>6</sup> Many factors are considered when choosing a battery type, such as weight, cost, shape, and many more. To perform the best for providing power to the MRAHs a Lithium Polymer (LiPo) battery was chosen, which is a variation of a lithium ion battery. LiPo batteries are rechargeable and can be recharged hundreds of times before any significant performance decrease is seen.<sup>7</sup> They are also lightweight compared to the lithium ion batteries and can be made to have a low profile, which makes them ideal for being attached to a MRAH.<sup>8</sup> They are also more resistant to being overcharged and have a less likely chance of leaking making them very safe compared to lithium ion batteries.

### **2.2.2 Multirotor Helicopter Battery**

With these factors the Turnigy 5000 mAh 4S 20C LiPo Pack<sup>9</sup> was selected to be used for the battery on the MRAH due to the size and weight. Typically on most MRAHs two of these batteries are used to increase flight time. These batteries only weigh 1.18 lbs. (536 g) and are only 5.83 x 1.92 x 1.29 inches (148 x 49 x 33 mm) making them small and lightweight enough to be used on our frame. The battery can be seen below in Figure 3. These batteries are strapped to the bottom of the frame and currently the electrical connection is made by using the 4 mm bullet-connector on the battery and connecting to the opposite 4 mm bullet-connector on the MRAH.

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<sup>6</sup> BatteriesPlus, 2014

<sup>7</sup> Battery University, 2015

<sup>8</sup> Ibid

<sup>9</sup> HobbyKing – Turnigy 5000 mAh Lipo Pack, 2015



Figure 3: Turnigy 5000mAh LiPo Battery<sup>10</sup>

## 2.3 Existing Battery Swapping Devices

### 2.3.1 UAV Coverage and Economic Comparison

In 2010 a report was made by the Korea Advanced Institute of Technology to compare using either a battery exchanging or a battery charging station was more economical and increased the in-duty flight cycle.<sup>11</sup> Many factors were considered, including battery charging time, number of batteries, number of UAVs, and the cost of everything involved in the system. The results of this test determined that when either the UAV or UAVs want greater coverage of an area the battery exchanging system is cost effective. Similarly if more than 2.5 UAVs are used at a time on the same platform the battery exchanging becomes more cost effective. If less than 2.5 UAVs are being used at a time in a low coverage area than a recharging station proves to be more cost effective. Based on the data provided using a battery exchanging system has many clear advantages compared to a battery charging station, mainly with the significantly increase of

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<sup>10</sup> HobbyKing – Turnigy 5000 mAh Lipo Pack, 2015

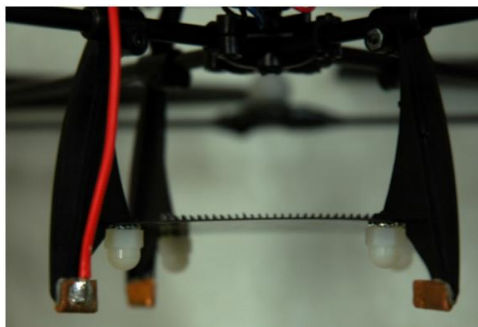
<sup>11</sup> Kemper, F. Paulo, 2010



the in-flight duty cycle. In the following section both types of stations are analyzed to look at the components of the overall design.

### **2.3.2 Autonomous Vehicle Battery Recharge System**

In 2007 at MIT a charging station was designed which would recharge battery-powered aerial vehicles autonomously during long duration missions. Another goal of the charging station was to have the base be able to be mounted on a vehicle so that the MRAHs could land and take off from the vehicle itself basically making a mobile charging station. The charging station was designed to work with COTS Quadrotor helicopters to work autonomously with the MRAH. The electrical connections on the COTS helicopter were made by using blocks of copper which were wired to the electrical inputs of the COTS helicopter which can be seen in Figure 4.



*Figure 4: COTS Frame with Copper Connections on the legs<sup>12</sup>*

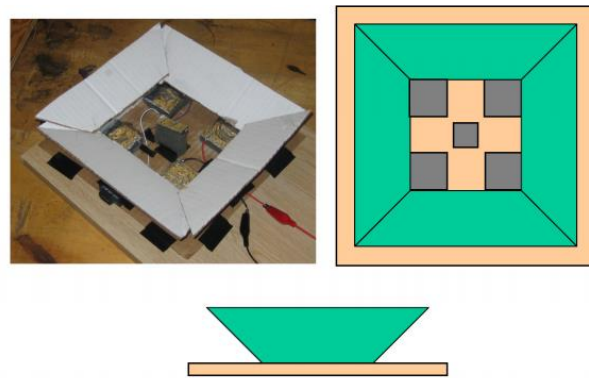
To align the COTS helicopter and make sure the legs make proper contact, the landing pad was designed to passively guide the COTS helicopter into place. The landing pad than had larger electrical connections in the corners of the station so the COTS helicopter could properly land and begin the charging process. The frame design and prototype can be seen in Figure 5.

The major problems outlined with the project were the significantly slow charging times, which

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<sup>12</sup> Dale, D.R., 2007

made the COTS helicopter spend more time charging than time in the air. Each charge was successful proving that the passive alignment worked well even with a simplistic design.



*Figure 5: Landing Pad Design with electrical connections in the corners that can be seen in gray. An additional contact was added to the center later for increased charging rate.<sup>13</sup>*

### **2.3.3 Automated Battery Swap and Recharge**

In 2011 another group at MIT designed and built an automated battery swapping and recharging station which stored, charged, and exchanged the batteries on the MRAH.<sup>14</sup> They found that recharging the battery on the MRAH took a significant amount of time. In addition powering down the MRAH and swapping the battery also used time that could be reduced. This system chose to keep the MRAH powered through the entire battery swapping process referring to it as a “hot” battery swap.<sup>15</sup> This system required many different sub-systems to complete the tasks, which included using two drums to store the batteries, a sloped landing pad to have the MRAH land on, a rail system to swap the batteries, and copper rails to charge the batteries while they are in the drum waiting to be fully charged and loaded into the MRAH. The full system can be seen below in Figure 6.

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<sup>13</sup> Dale, D.R., 2007

<sup>14</sup> Michini, Bernard, 2011

<sup>15</sup> Ibid

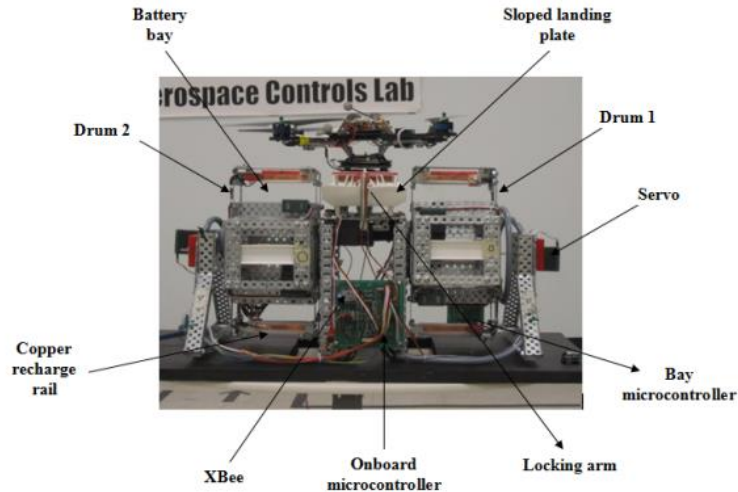


Figure 6: Automated Battery Swap and Recharge Station<sup>16</sup>

To keep the batteries aligned properly and reduce battery swapping times the design takes full advantage of a battery carriage and receiver seen in Figure 7 which uses a rail type design to slide the battery in and out of the receiver. The battery is mounted in the receiver and when it is ready to go into the MRAH the battery is pushed in by a rack and pinion system which can be seen in Figure 8. The battery carriage uses copper strips which apply the necessary pressure to keep a constant electrical connection. To keep the battery carriage and receiver lightweight they used 3D printing which also allowed the make complex designs.

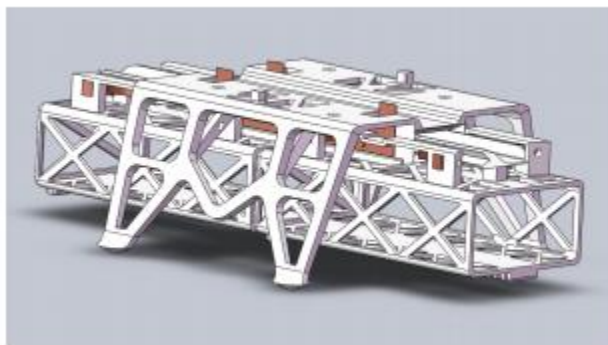
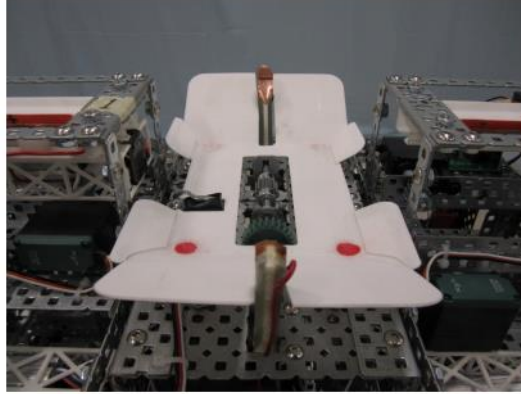


Figure 7: Battery Carriage and Receiver Model<sup>17</sup>

<sup>16</sup> Michini, Bernard, 2011

<sup>17</sup> Ibid



*Figure 8: Landing Pad with central pinion gear to move battery carriage<sup>18</sup>*

With this design they were able to perform well with an average swap time of 21.8 seconds, only needing to swap the battery seven times in over 60 minutes.<sup>19</sup> This increased the mission time significantly and only 4.2% of the time did the MRAH spend swapping batteries.<sup>20</sup> The only improvement that was being researched for the design was to keep track of the health of the MRAHs, so if they were draining too much power, motors were getting to hot, or the battery voltage was incorrect the station could inform the user. This designed proved successful and with eight battery bays with recharging capabilities the MRAHs could spend multiple hours performing missions with multiple MRAHs. For one MRAH they considered it could stay flying for an indefinite period of time.

### **2.3.4 Automatic Battery Replacement System for UAVs**

In 2011 another system was designed, analyzed, and built a ground station capable of swapping a UAV's batteries by the Korea Advanced Institute of Science and Technology

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<sup>18</sup> Michini, Bernard, 2011

<sup>19</sup> Ibid

<sup>20</sup> Ibid

(KAIST).<sup>21</sup> To find a solution to this problem, they created six key goals that needed to be accomplished by the ground station:

1. Guiding the UAV to the battery replacement site
2. Orienting the UAV in a desired position
3. Locking the UAV position on the station
4. UAV-battery connections: extracting and placing a battery in the UAV
5. Battery transportation
6. Battery array function

To orient the UAV properly, three key designs were created to find a solution. The first design focused on gravitational energy and used a cone shape to properly center the copter. The second design uses arm actuation and linkages to push the UAV towards the center, using a more active system compared to the first design using a passive alignment system. The third and final design they created uses pulleys and cables and when the motor is activated the pulleys slide towards the center of the platform moving the UAV to a central position. The designs can be seen below in Figure 9.

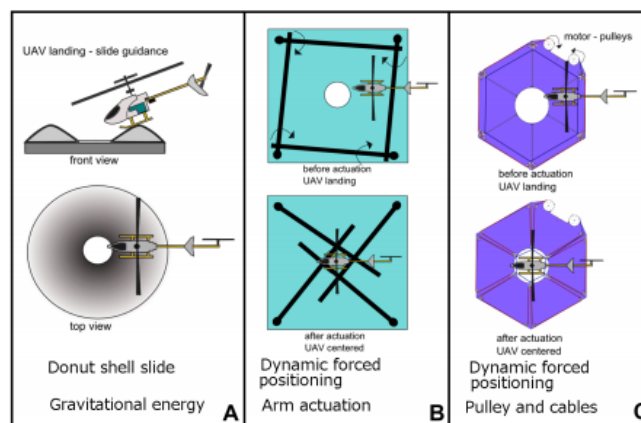


Figure 9: Alignment designs for a battery exchanging base for UAVs<sup>22</sup>

<sup>21</sup> Suzuki, Koji, 2012

To make the electrical connections between the battery and the UAV three main designs were created. The designs used mechanical and magnetic force to provide a reliable connection and hold the battery in place. In Figure 10A it can be seen that there is an upward force applied and the two arrows on the side represent spring assisted latches that would lock the battery in place. In Figure 10B neodymium magnets replace the spring assisted latches, which would provide the force necessary to hold the battery in place. In Figure 11 a leaf spring latch is used in the design where the battery is pushed upward and when it is inserted all the way the latches lock the battery in place. This would involve designing and building a battery case to match the leaf spring latch.

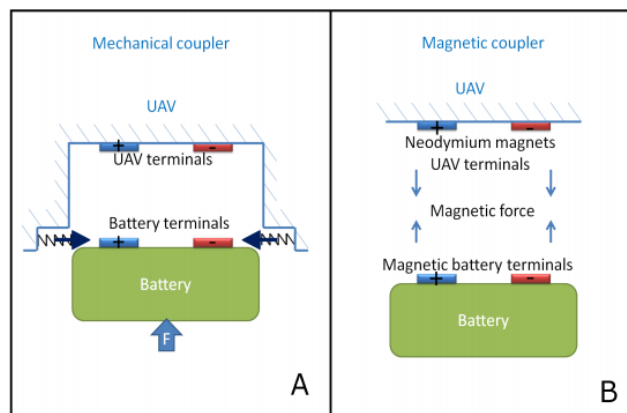


Figure 10: Design A uses spring assisted latches that provide a mechanical force. Design B uses magnetic force from neodymium magnets to hold the battery in place.<sup>23</sup>

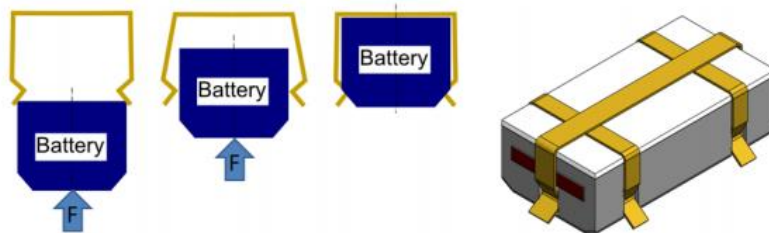


Figure 11: This design uses a leaf spring latch to hold the battery in place. A custom battery case is also needed for the design to work.<sup>24</sup>

<sup>22</sup> Suzuki, Koji, 2012

<sup>23</sup> Ibid

To store the batteries two major designs were considered. The first design seen in Figure 12 used a circular array to store the batteries. The UAV would land in the middle of the circular array and a rack and pinion would be used to push the batteries into the UAV. When the batteries are in the circular array they would be charging until they are needed for the next use. This design is very compact but if charging is also required would involve a significant amount of wiring and power to charge all of the batteries. The second design seen in Figure 13 involved a matrix array of batteries that would be picked and pulled out by a small crane. Each of these batteries would also be charging when not in use.

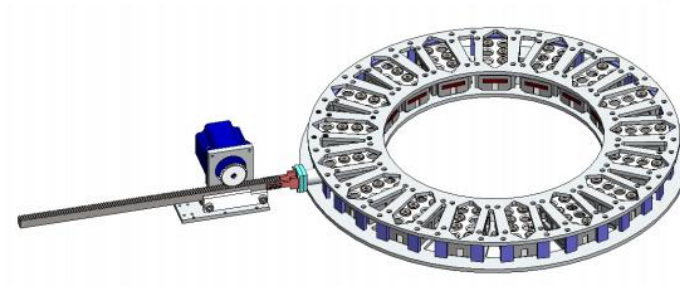


Figure 12: Circular Array for storage and charging of batteries. The batteries are inserted and removed using a rack and pinion.<sup>25</sup>

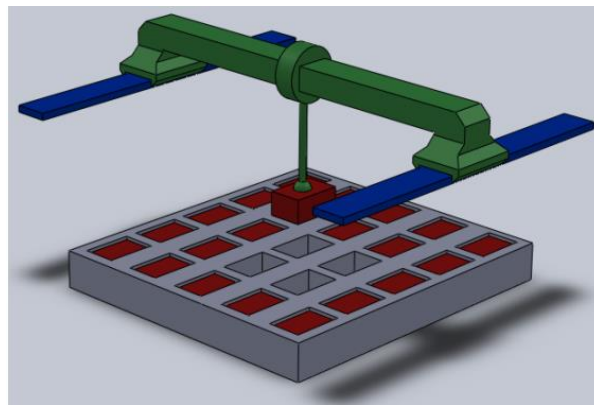


Figure 13: A matrix array of batteries that and stored and charged in each bay. The batteries are inserted and removed by a crane type device.<sup>26</sup>

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<sup>24</sup> Suzuki, Koji, 2012

<sup>25</sup> Ibid

<sup>26</sup> Ibid

The final prototype seen in Figure 14 created by the group involved the circular array of batteries and the active arm actuation to center the UAV. The batteries are pushed towards the center and a scissor-lift elevator pushes the battery into the UAV. They also used magnets in the battery case to hold the battery in place in the UAV. When the battery needs to be extracted the scissor lift uses an electromagnet in it which can overcome the force of the magnets in the battery case. The estimated time for this base to swap the batteries was 47.5 seconds.<sup>27</sup>

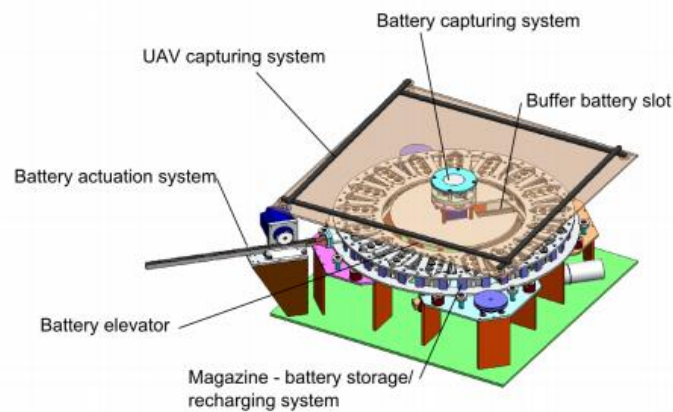


Figure 14: Model of Automatic Battery Replace System<sup>28</sup>

### 2.3.5 Automated Refueling for Hovering Robots

In 2012 a project was done at WPI to create a fully autonomous system to refuel small-scale UAVs.<sup>29</sup> They used an active alignment system consisting of two four bar linkages which pushed the UAV to the center of the landing platform which can be seen in Figure 9B. The electrical connections were made using a custom electrical connection designed to have a low weight and provide a reliable mechanical attachment. Touch latches were used with a custom pin that pushed into the latch and locked itself in place. These were mounted on a plate and

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<sup>27</sup> Suzuki, Koji, 2012

<sup>28</sup> Ibid

<sup>29</sup> Cochran, Nigel, 2012



positioned to not cause any electrical issues such as shorting. The design of the electrical connection can be seen below in Figure 15.



*Figure 15: Custom Electrical Connection using touch latches.<sup>30</sup>*

For the final design which is seen below in Figure 16 a scissor lift is used to bring the battery up the UAV to lock it in. This design however could only swap the battery in about five minutes, which was slower compared to the other designs that have been reviewed in this section.<sup>31</sup> The scissor lift spent 30 seconds moving from being retracted to being extended numerous times in the process which accounted for nearly 60% of the entire exchange process. The electrical connections also proved to be unreliable as contact between the battery pack and UAV sometimes did not occur, which was due to the battery pack not moving upward properly causing an arc-like motion which was bending the contacts.



*Figure 16: Automated Refueling Station<sup>32</sup>*

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<sup>30</sup> Cochran, Nigel, 2012

<sup>31</sup> Ibid

<sup>32</sup> Ibid

# **Chapter 3: Methodology**

## **3.1 Introduction**

The main requirement for this project was to design and build a device capable of exchanging the batteries in a MRAH. The design focused on creating a simple system on a low budget that could be manufactured and assembled easily. Another goal was to allow opportunities for the design to be improved on relatively easily if this project were to be continued upon. The following chapter discusses the decisions made in the final design of the Automated Battery Changer.

## **3.2 Goal Statement**

The following goal statement was created for the project at the beginning of the project: Design an automatic battery changing station for quadcopters/hexacopters. This goal statement helped guide us in creating our final device to automate the battery exchanging sequence. As time progressed throughout the project a new statement was created: Design an automated battery exchanging station for multirotor autonomous helicopters. This new statement allowed us to expand the different MRAHs that could land on our system. To continue guiding the project design specifications were created to narrow down our design selections.

## **3.3 Design Specifications**

The following are design specifications that were created to help guide the project in designing the Automated Battery Changer. These specifications have been organized into categories that focus on the entire system and others that govern the design of the subsystems of the ABC.

## Overall System

1. The cost of the entire system should be under \$500
  - This ensures that we stay by the budget set of \$350 given by WPI. If the necessity to go over budget rises there will be availability for additional funding.
2. Must last at least five years of operation with regular maintenance
  - As this system will be placed outdoors for large periods of times in many different climates the system needs to be reliable.
3. The time required to swap batteries must not take more than three minutes.
  - In order for our device to compete well against sending a human being to interact with the MRAH, the device needs to swap the batteries in a reasonable amount of time.
4. The system must allow the switching of batteries without human interaction.
  - The system must be autonomous to fulfill the goals of this project.
5. The system must be water resistant.
  - As the system will most likely be used in the outside environment the materials used must be able to resist water to prevent any failures.
6. The system must be able to withstand temperatures above 0°F and below 110°F.
  - The materials for the entire system must be able to withstand extreme temperatures.
7. Width of the system must not be greater than 32 inches.
  - To make the system easy to transport the entire system cannot be wider than a standard door frame of 32 inches.
8. The weight of the entire system must not exceed 50 pounds.

- To make the system easy to transport a weight restriction is needed to reduce the amount of people required to move the system.

### **Battery Package**

9. The battery package must not add more than 1 pound to the total weight of the MRAH excluding the weight of the battery.
  - This is to ensure there is not a significant decrease in the performance of the MRAH. If the MRAH is too heavy it will waste power which will reduce flight time.
10. The Battery Package should be compatible with the provided frame and easily modifiable to fit other frames.
  - The battery package needs to be able to be attached to the frame in order to provide power. To ensure it can attach to numerous frames the design needs to be simplistic to work with other MRAHs.
11. The Battery Package must be able to allow swelling of 10% of the battery volume.
  - As lithium polymer batteries heat up they swell on the sides. This occurs when power is being drawn or when they are charging. Our battery package needs to be designed to allow the swelling of the batteries to prevent any damage to the batteries.
12. The battery package must provide a reliable electrical connection that can be easily connected and disconnected.
  - To ensure that the system can swap the batteries in less than three minutes, a simple electrical connection is needed in order quickly connect and disconnect the battery package from the MRAH.

13. The battery package must be balanced in both the X and Y planes.

- This is to ensure that the MRAH does not lose any performance due to the battery box being offset.

14. The battery package must not adjust the center of gravity of the copter by more than two inches in the Z Axis.

- This is to ensure the MRAH does not lose performance because of the adjustment of the center of gravity.

### **Landing Platform and Alignment System**

15. The landing platform must accommodate landing gear that have an area of 15 inches by 13 inches.

- The landing platform must be able to accommodate the 680PRO Frame that was purchased and allow the MRAH to land properly on the platform.

16. The platform must be able to align the MRAH consistently.

- The platform must have an alignment system that can move the MRAH into place for the battery swapping process to occur.

### **Battery Storage**

17. The battery storage device must be capable of holding four battery packages and allow ease of replenishing.

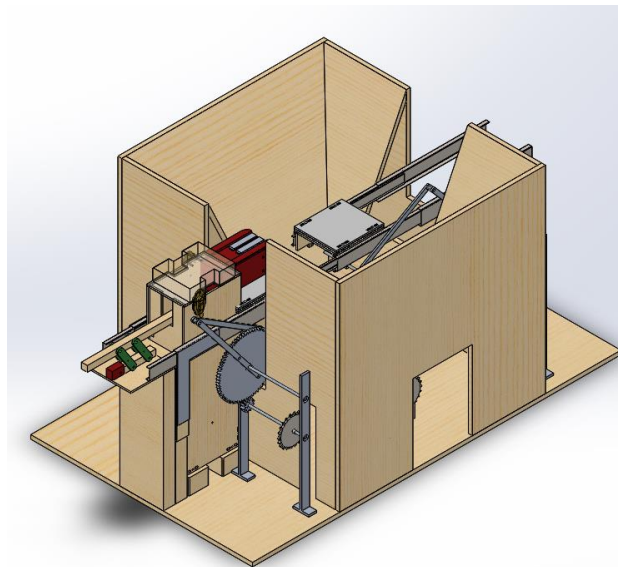
- This is to ensure that the MRAH can run for longer periods of time than needing to be reloaded every time the battery is swapped. The storage system also needs to be easily reloaded by the user by not requiring any tools and simple to access.

18. The battery storage device must reliably move the next battery into place to be loaded into the MRAH.

- The storage device needs to be able to move the battery into place for the battery swapping sequence to begin.

### 3.4 Design Overview

The final design can be seen below in Figure 17. The system consists of four major systems: Battery Package, Battery Storage, Battery Exchange System, and the Landing Platform and Alignment System. Each of these systems consists of many components which will be discussed in the following sections.



*Figure 17: Final Model of the Automated Battery Changer*

#### 3.4.1 Decision Matrix

To help in the design selection process four decision matrices to help select the best design. Each of the matrices has factors which are given different weights depending on how important they are and each design is given a rating on that factor of 1-5. The best design was selected by having the highest total score. For each major component of the project 8-12 of these factors were rated. In the following list each factor will be defined as to how a rating was given.

**Durability:** This factor refers to how well the component can handle constant usage without failure. This could include added stress on the component or weather factors.

**Ease of Assembly:** This factor refers to how easy the component is to assemble. This was mainly chosen based on the number of parts and hardware required to assemble the component.

**Ease of Installation:** This factor refers to how easy the component is to install onto the system.

**Ease of Manufacturing:** This factor refers to how easy the component is to manufacture. This is mainly defined by the amount operations required to machine the parts to create the component.

**Ease of Operation:** This factor refers to the amount of additional forces needed such as motors or mechanisms to operate the component. Less motors and mechanisms scored higher than additional forces to keep the design simplistic.

**Ease of Storage/Transportation:** These factors cover two topics, the storage of the component and transportation of the component. This factor was mainly chosen based on the components size and shape.

**Maintenance:** This factor refers to the difficulty of maintaining the component and the upkeep required to keep the component working properly.

**Manufacturing Cost:** This factor refers to the cost of creating the component. This may include purchasing parts and the actual manufacturing of the components.

**Material Cost:** This factor refers to the cost of the materials required for the manufacturing of the component.

**Performance:** This factor refers to the ability of the component to complete the task. This could include how much time it would take to complete the task or how well the component will complete the task.

**Reliability:** This factor refers to how consistent the component is or will be at completing the task required.

**Safety:** This factor refers to any safety concerns with the component. Although ideally no human interaction is needed but if the component has the possibility of failing or has exposed parts that could potentially cause injury safety does become a concern.

## **3.5 Landing Platform and Alignment System**

### **3.5.1 Initial Designs of the Landing Platform and Alignment System**

In designing the landing platform the first decision to be made was to how the MRAH was going to align itself upon the platform itself. In the research that was initially done the choice to be made was to either create an active or passive alignment system. The active systems used linkages or other mechanical systems to push the MRAH towards a central point to activate the battery exchanging system. Although this system can be very reliable, much of the time spent in the entire battery swapping process in previous projects was used in the active alignment system. If the process is too slow it will not prove effective in being used with numerous MRAHs.

Passive alignment systems provide a simple solution to the alignment problem. Using a sloped surface and a large area will allow the MRAH to easily land on the landing platform. Passive alignment systems are also very easy to build and will provide consistency in the MRAH landing in the same spot reliably. They are also easy to make universal as the only adjustments that may need to be made are reducing the length of the arms on the MRAH or creating smaller or larger sloped surfaces for different sizes of MRAHs. In the end a passive alignment system was chosen as it could be easily modified and built. The results of the decision matrix can be seen below in Table 1.



Safety Factors	Weighting	Passive System	Active System
Durability	10	5	3
Ease of Installation	5	5	3
Ease of Manufacturing	8	5	3
Ease of Operation	10	3	5
Ease of Storage/Transportation	10	3	3
Maintenance	7	5	2
Manufacturing Cost	10	5	3
Material Cost	8	4	3
Performance	15	4	5
Reliability	15	4	5
Safety	2	3	3
Total	100	84	75

Table 1: Decision Matrix for Alignment System.

The first design that was created used what we considered as a Square-V shape. This used four sloped sides to center the MRAH towards the middle of the platform. The first conceptual design is seen below in Figure 18. The interior bottom was defined by the profile of the landing gear, while the outer dimensions were defined by the landing tolerances of a copter. This resulted in an area within which the copter could land, and it would naturally fall into the predetermined position.

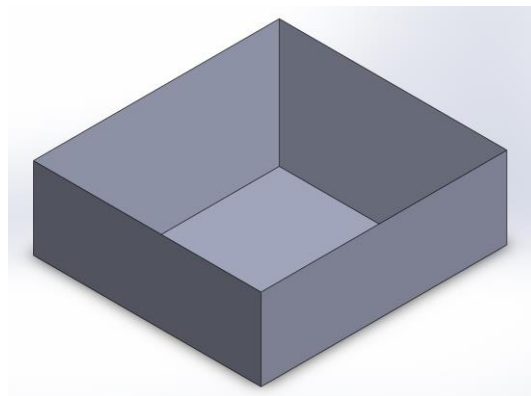
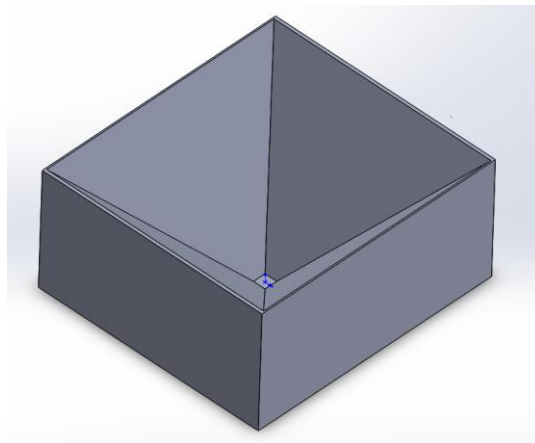


Figure 18: First Design of the Passive Alignment System

This overall design did not necessarily ensure the copter would not align correctly, and when the concept was tested, could potentially result in it the landing gear getting stuck on the

sides, or the MRAH settling at an angle. Although this design did not work, it provided us with new ideas as to how to revise the design. This was the origin of the passive alignment system.

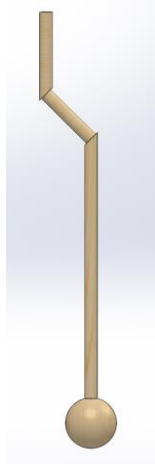
Solving the problems that this alignment system required continuing the sloped sides downwards, increasing the overall height of the box. This change meant that we would need to add to the geometry of the MRAH, a single point that would meet the bottom of the defined box. This design allows us to guide the copter into its intended resting place more reliably. The revision of the original design can be seen in Figure 19 below.



*Figure 19: Revision of the original design. This allowed the copter to land in the same spot more reliably.*

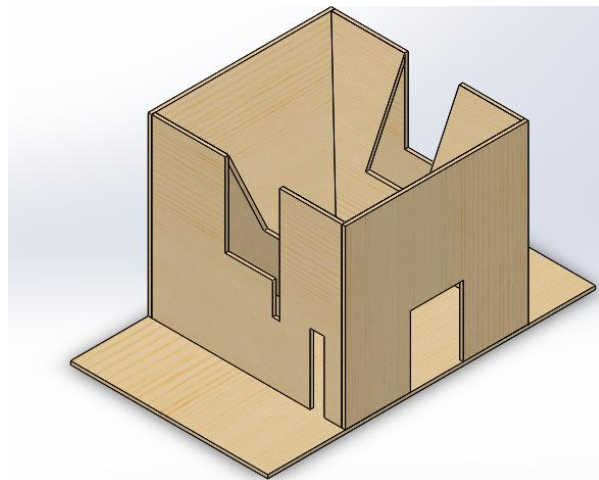
### **3.5.2 Final Design of the Landing Platform and Alignment System**

The final design was created with the intention of using an alignment rod seen in Figure 20 extending from the MRAH that had a ball shape on the bottom. This ball at the end of the rod would guide the MRAH towards the center of the passive alignment design. The size of the cone was made to be 27 inches by 28 inches to accommodate the design specifications to fit through doors but to also allow ample room for the MRAH to land in harsh conditions.



*Figure 20: Alignment Rod which extends from the MRAH*

The cone has numerous slots to allow for the other components of the system to interact with the MRAH once the landing process is complete. A switch is also placed in the bottom of the cone so when the MRAH has fully aligned the process begins to exchange the battery. Other slots were created to allow for the mechanisms to work properly, such as the slot to allow for the gear to rotate for the slide-crank mechanism. The platform and alignment cone were designed to be made out of plywood due to its rigidity, availability, and low cost. The final design of the cone can be seen below in Figure 21.



*Figure 21: Final Design of the passive alignment system.*

## **3.6 Battery Package**

### **3.6.1 Initial Designs of the Battery Package**

In order to make sure that the battery can be reliably exchanged into the MRAH two main systems were researched: horizontally or vertically loading the battery. In the research of the two methods power tool batteries were looked into, as they had similar designs and were examined at a local hardware store. The vertical power tool battery had large connections to transferring the electrical power and had a simple solution of only creating vertical motion. Gravity can also be taken advantage of when removing the battery from the MRAH. The drawback to a vertically loaded battery was that if gripping force from the MRAH was insufficient, the battery would fall straight downward potentially injuring someone below. The passive alignment cone design also interferes with using a vertically loaded battery as the alignment rod would be unable to fully center in the cone as a more complicated design would be necessary

The horizontal power tool battery had more points of electrical contact and more clips to provide a more reliable connection to the MRAH. As the battery would also be mounted horizontally it would be less likely to fall out of the MRAH in normal conditions. The only downside to using a horizontally loaded battery is that extra work on the motor is required to insert and remove the battery from the MRAH as there is no assistance from gravity.

Horizontally loading the battery was the choice that was made based on the decision matrix seen below in Table 2. Horizontally loading the battery ensured that the batteries would be held securely and the electrical connection would be maintained throughout all conditions of flight. If loaded vertically, the connection on the battery would be forced to withstand the force of gravity in addition to the forces already on the MRAH. This could prove problematic in rough conditions that the MRAH may need to handle.

Safety Factors	Weighting	Horizontal Loading	Vertical Loading
Durability	12	5	4
Ease of Assembly	15	4	3
Ease of Manufacturing	15	4	4
Maintenance	7	5	4
Manufacturing Cost	8	4	3
Material Cost	5	4	4
Performance	15	5	3
Reliability	15	5	3
Safety	8	5	3
Total	100	91	68

Table 2: Decision Matrix for Battery Package

With this decision made, we looked into what we could use in order to hang on to the batteries in this way. The initial idea involved stubs, which would be held onto on the copter on by an opposing profile. The round shape of the stub would aid in the grabbing process and allow for a reasonable margin of error of alignment. Copper was chosen as a material to both hold onto the MRAH and make the electrical connection. The initial design can be seen below in Figure 22.

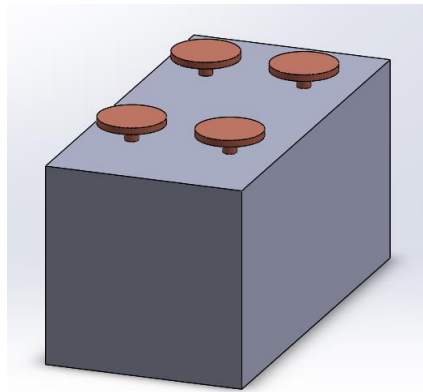
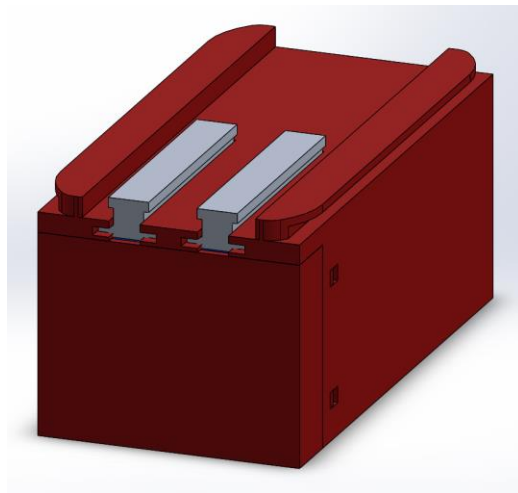


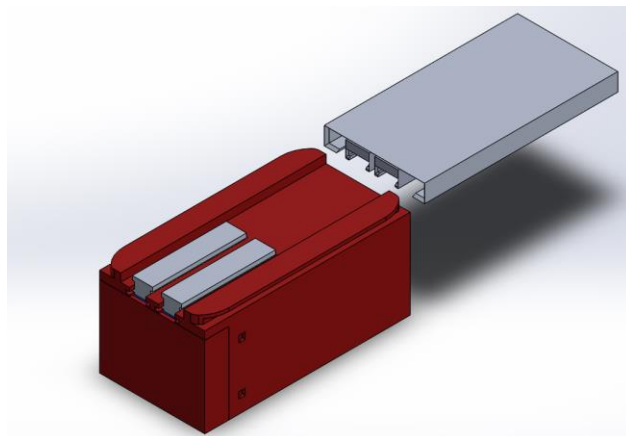
Figure 22: Initial Battery design with copper studs

As the project moved forward, it became clear that having the electrical connections and the means of hanging on to the batteries in a single element, the copper studs, would be a poor decision. The copper studs would not be able to keep the box steady while also maintaining the proper electrical connection. For this reason, the copper studs were divided into two components,

the electric contacts and the box holding tabs, which became integrated into the main section of the box. Through some of our background research, general knowledge, and the new idea for the battery exchange, the design that came out of the information provided turned out to be a rail system seen in Figure 23 below. The male rails would be attached to the battery box and the female rails would be installed onto the plate attached to the MRAH which can be seen in Figure 24. When the rails slide into each other a connection is made which makes a full circuit providing power to the MRAH.



*Figure 23; Battery Box with Rails and Tabs*



*Figure 24: The female rails on the MRAH slide into the rails on the battery box to make the electrical connection. The tabs on the plate connect to the sides of the battery box.*

As the rails could be very long or very short, a graph was made to compare the weight, resistance, and volume of different materials to find which material would be best used for our project. This graph can be seen in Figure 25.

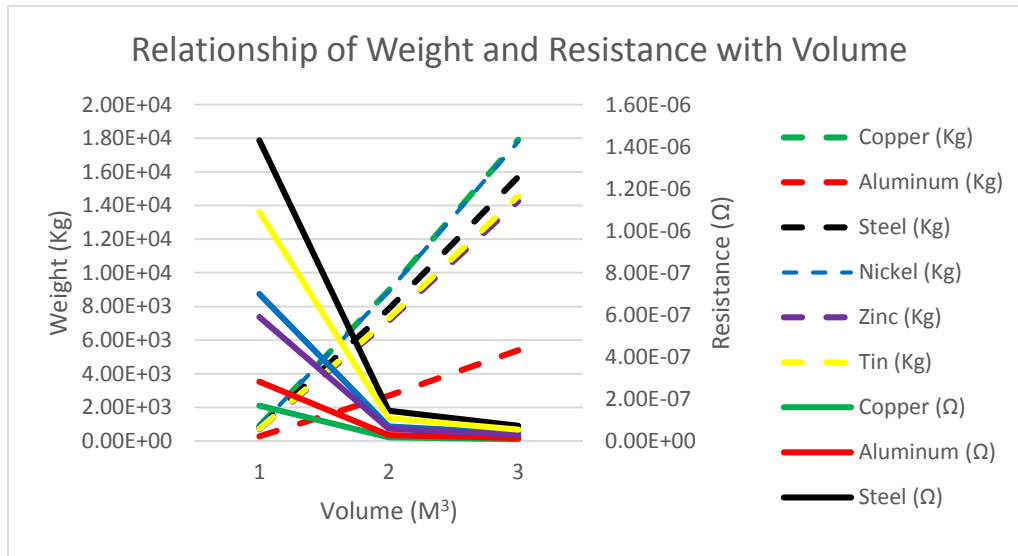


Figure 25: The relationship of different materials based on weight, resistance, and volume.

With the main focus being on a lower resistance, the results of the graph showed that the aluminum and copper have the lowest resistances and as the volume increases the resistance of both materials approaches zero. The weight of the rails was also an important factor to not reduce the flight time of the MRAH. The results of the graph showed that aluminum had the lowest weight of all of the compared materials by far. With the lowest weight, second lowest resistance, and generally low cost aluminum became the chosen material.

In order to determine the size of the rails necessary to transfer the power from the batteries to the MRAH, the main goal was to reduce the resistance of the material. Having the resistance of the rails as low as possible will provide minimal voltage or current drop through the system. Having a low resistance also prevents any issues with burning, melting, voltage drop, current drop, or general damage to the system. With the wires currently used in the system being

10 AWG, which even at a foot long only have a resistance of approximately .001 ohms, the goal was to create two rails that when put together did not create a resistance greater than .001 ohms.

In order to perform the calculations the first assumption made was that both rails were making full contact with each other, so it could be assumed that the rails were one piece. Using the resistivity equation we assumed that the length of the block was 1 in. long which is L and the cross sectional area was .75 in. by .5 in. for the area to be .375 in<sup>2</sup> which is A. The resistivity of aluminum is  $1.043 \times 10^{-6}$  ohms-in which is  $\rho$ . Therefore the total resistance was:

$$R = \frac{\rho L}{A} = \frac{(1.043 * 10^{-6}) * (1)}{.375} = 2.781 * 10^{-6} \Omega = 2.781 \mu\Omega$$

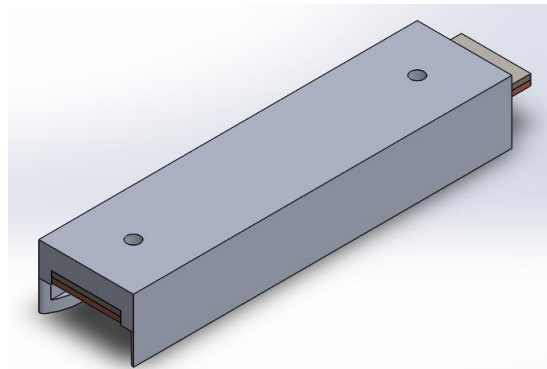
The result exceeded what we needed greatly only providing a total resistance of 2.781  $\mu\Omega$ . With these theoretical results the rails could be made even smaller and still provide a significantly small resistance if necessary. Even if the rails were making significantly less contact, such as only 50% contact between the rails, the resistance is still well below the requirement that was set.

### **3.6.2 Final Design of the Battery Package**

The final design for the rails only had one major difference which was that a spring force was added to the connection. Although it reduced some of the area for the electricity to travel, it was not significant enough to drop the voltage from the batteries to the MRAH. The spring force was a necessary addition as in order for the male rails to make a full connection and still have room to slide into the female rails a force would be needed to keep contact between the two rails as the MRAH flies. If the rails disconnected from one another during flight even for a short period of time could cause serious issues for the MRAH. As the amount of time to make this change was short, tests were done to see which material would be able to apply the force necessary to hold the rails in place. The best materials that were found were a strip of spring steel

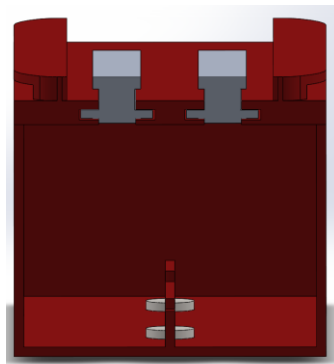


that backed a sheet of copper. The copper has a significantly higher conductivity and lower resistance than the spring steel, this was able to hold the rails together and allow the sliding to occur without too much friction or resistance from the spring steel allowing the rail in seen below in Figure 26.



*Figure 26: When the strips are bent into position they create a spring force against the rail causing it to stay in place. Above is with the strip of spring steel and copper not bent into position.*

The battery package also includes the steel discs on the bottom which are required for the electromagnets to hold the battery on the cart seen below in Figure 27. These small steel discs do not interfere with the sliding of the batteries as they are low enough in the battery package. A divider is also included in the center to reduce the amount of movement of the batteries while in the package.



*Figure 27: Inside of complete battery package. On the bottom are the steel discs for the electromagnets.*

Additionally chamfered edges were added to the rails to account for any error in the connection with the MRAH seen below in Figure 28.

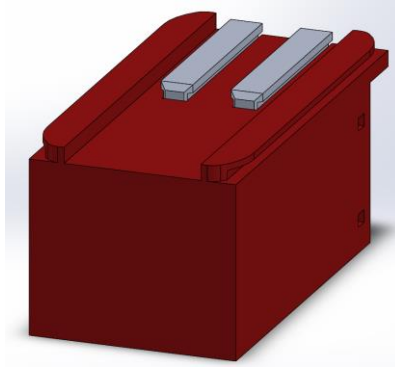


Figure 28: The rails have chamfered edges to allow for error in alignment.

## 3.7 Battery Exchange System

### 3.7.1 Initial Designs of Battery Exchange System

With the direction of delivery chosen, we needed a means that could accomplish this direction of motion. If a short travel distance was necessary, a simple four-bar would function. Given that our battery box was at least six inches long, we needed a mechanism that provided more horizontal travel. For this reason, we looked into eight-bar linkages and the potential that they might provide. One particular influence in this design was straight-line walking-beam eight bars seen below in Figure 29, of which similar designs are used in industry.

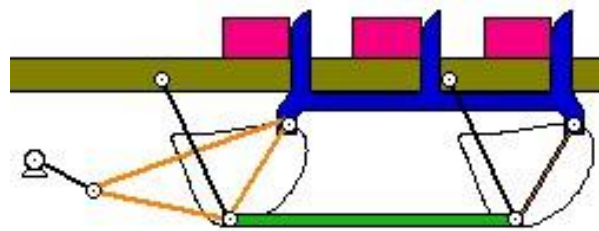
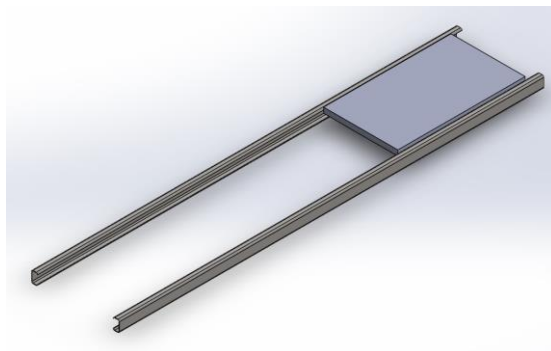


Figure 29: Straight-Line walking-beam eight bar linkage

A second design that was looked into was a combination between the battery exchange system and the battery storage system of using a rotary table. The rotary table would have arms that hold the batteries in place. The arm use either a pneumatic piston with grips activated by actuators to hold the battery in place or using a mechanism to drive an arm to push the battery

into place and remove the battery. After looking at this design further it involved using numerous motors and actuators which could increase the potential for failure. This would also spend more time loading the battery into the MRAH as it would have to extract the discharged battery, load the new battery into place, insert the new battery into the MRAH, and finally retract the arm so the MRAH could begin flight. The time required to perform these actions would not be able to meet the design specifications for the project. The benefit to the rotating design was that it would also become easier in the future to connect a charging station to, as in previous projects that were researched they were able to easily add charging capabilities to each bay.

In order to move through the design process a decision needed to be made as to how the battery package was going to move through the system. The decision was made to use a cart on rails to slide into the passive alignment system seen in Figure 30, which narrowed down the power mechanisms to a four bar and eight bar linkage. The idea was that this means was flexible, and could be modified to travel as far as needed. As the process was continued onto how to power the mechanism a crank slider was also suggested. This would allow horizontal motion from rotational motion and could reset after a full rotation.



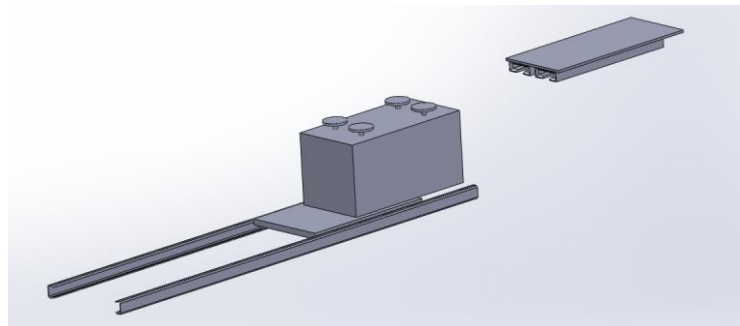
*Figure 30: Initial Cart Design. The cart would slide inside the outer rails.*

With the cart design being heavily favored a decision matrix was created with regards to how cart would be moved by a mechanism. The decision matrix can be seen below Table 3.

Safety Factors	Weighting	Eight Bar Linkage	Four Bar Linkage	Rotary Table	Crank Slider
Durability	10	3	4	3	4
Ease of Installation	12	2	3	3	4
Ease of Manufacturing	10	3	3	2	4
Ease of Operation	15	3	5	3	5
Ease of Storage/Transportation	7	3	4	3	4
Maintenance	8	2	4	3	4
Manufacturing Cost	6	2	3	2	4
Material Cost	6	3	4	2	4
Performance	12	4	4	5	4
Reliability	10	4	5	5	5
Safety	4	3	4	3	4
Total	100	59	79	64	82

*Table 3: Decision Matrix for Battery Exchange System*

Major changes made to this design later down the road were made due to differences in part geometry and alignment needs. The design in Figure 31 below presented a larger challenge in finding a solution to apply power to the system. For this a crank and slider was design and machined. The crank slider mechanism was designed to ensure that a full 360 degree rotation of the input crank was not possible, and we had a limited angle of functionality. This forced the design to be able to provide enough force at all parts of its cycle, rather than suffering from reduced force output at maximum and minimum extension. The battery cart, rails, and crank and slider components developed into a single subassembly, which we referred to as RailPower.



*Figure 31: Initial Battery Design on the cart. The copper studs slide into the rails on the MRAH.*

In implementing the slide crank mechanism, we needed to analyze it to ensure that the slide crank would be able to make the required movements necessary. In order to analyze the slide crank mechanism simulations were run to see how the slide crank was able to perform. In the graph below, the velocity of the output shaft of the crank slider was analyzed in four different programs: PMKS (Planar Mechanism Kinematic Simulation), MatLab, Working Model and Linkages. The acceleration plots can be seen in Figure 32. Working Model produced results significantly off from the other three, and so its results were considered inaccurate.

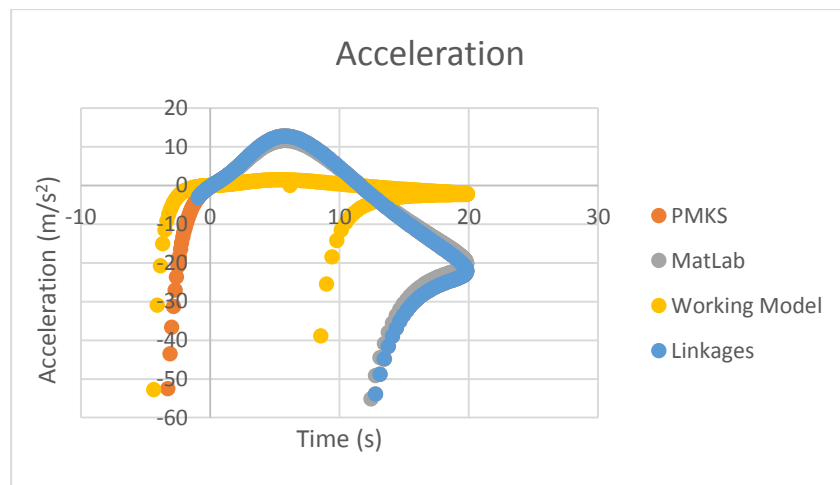


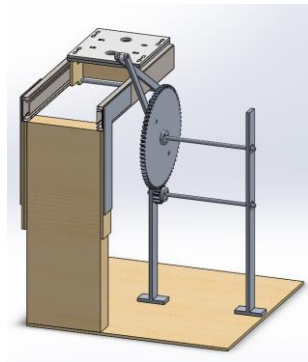
Figure 32: Simulation of the Crank Slider Mechanism

The plot above demonstrates positive acceleration up until the 11.5 second mark. After that, acceleration goes negative as the crank slider approaches its maximum extension. At the 20 second mark, the plot jumps backwards in time, indicating the confusion of the programs as we arrest motion.

### 3.7.2 Final Design of Battery Exchange System

The design of the cart needed to be able to hold the battery package from the loading from the magazine into the cart. The decision was made to use electromagnets as they could easily disconnect and connect to both the cart and MRAH as necessary with little modifications

to the cart. In order to move the battery into the MRAH a slide-crank mechanism was used to provide mechanical advantage and horizontal motion, along with gears to provide a larger mechanical advantage. This design also incorporated using an additional crank-slider on the back side of the alignment cone to extract the battery from the MRAH. These two crank-slider mechanisms were also operated on one motor to reduce additional points of failure. The mechanisms were then positioned to allow for the insertion and extraction of the battery through timing the slide crank mechanisms so the new battery pushed the old battery out and then the cart extracted the battery. One side of the Slide Crank can be seen below in Figure 33.



*Figure 33: Slide Crank Mechanism with gears for increase mechanical advantage*

## **3.8 Battery Storage**

### **3.8.1 Initial Designs for Battery Storage**

Three designs were created for the storage of the batteries. The first design involved using a rotary table as described in the battery exchange system, which would hold the batteries in the arms extending from the table. This design would involve placement inside the alignment cone and when the MRAH would land, the arm would extend and retrieve the battery, rotate, then insert the next battery. The rotary table also had the possibility of adding in additional charging in the future if necessary. Similar to the battery exchange system the arm would use too many motors and actuators which would become points of failure.

The second design involved using a magazine which would use a gravity feed to have the batteries move downward. Although the system would be reliable and not depend on any mechanical features other than the necessary rod to push the battery out of the magazine to be loaded, this would increase the general height of the entire system and would need a large amount of mounting hardware to hold the magazine in place.

The third and final design used the magazine but also incorporated a coil spring in order to provide mechanical force upward to load the batteries into place. This allowed for the magazine to be mounted directly to the base of the system. This design displayed the most promise and simplicity for the design. Springs are also easily available and low cost which provided an easy solution to the problem. The final decision matrix can be seen in Figure X below.

Safety Factors	Weighting	Rotary Table	Gravity Force	Spring Force
Durability	8	3	4	5
Ease of Installation	15	3	2	5
Ease of Manufacturing	10	3	5	4
Ease of Operation	10	3	5	4
Ease of Storage/Transportation	7	2	5	5
Maintenance	7	3	5	4
Manufacturing Cost	5	3	5	4
Material Cost	5	3	5	4
Performance	15	5	4	5
Reliability	15	5	4	5
Safety	3	4	5	5
Total	100	71	83	93

Table 4: Decision Matrix for Battery Storage

### 3.8.2 Final Design for the Battery Storage

The original designs for this did not change significantly over the course of the project. It was designed to be easily scalable, and changes that were necessary down the line only required sizing changes. The majority of parts were designed to be easily laser cut from quarter inch

plywood, making this subassembly easy to reproduce and remake. The block of wood and sheet of acrylic that are strapped to the rest of the box were added to provide a hard surface for the batteries to be stopped by. Otherwise, the spring force applied to the batteries could possibly eject the batteries from the magazine or cause misalignments. The final design of magazine can be seen below in Figure 34.



Figure 34: Final Magazine design

In order to determine the required spring to use in the magazine Hooke's Law was performed to calculate the spring constant necessary from the spring.

$$F = k(x - x_0)$$

$$x = \text{Height from bottom of magazine to cart level} = 16 \text{ inches}$$

$$x_0 = x \text{ minus total height of four battery pack} = 4 \text{ inches}$$

$$F = \text{Force needed to move four battery packs} = 12 \text{ pounds}$$

$$k = \frac{16 \text{ inches} - 4 \text{ inches}}{12 \text{ pounds}} = 1 \text{ lb/in}$$

In order to achieve the required constant spring rate McMaster-Carr sells cut to length springs which involves taking the rate constant divided by the final length when cut. With some



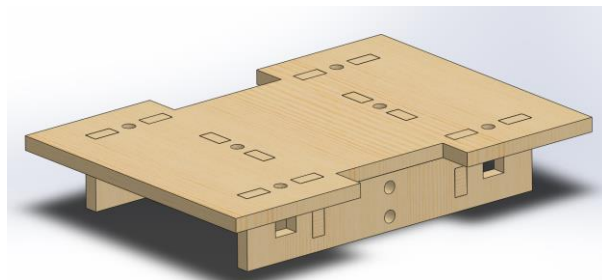
assistance from the sales division of McMaster-Carr they helped locate springs that were close to the required spring rate of 1 lb/in, which can be seen in Table 5 below.

Part Number	Rate Constant	Spring Rate (lbs/inch) When Cut to 16" length (rate constant/cut length = spring rate)	Price
9663K27	17.2	1.07 lbs/inch	\$5.66
9663K83	17.62	1.10 lbs/inch	\$5.62
9663K99	16.52	1.03 lbs/inch	\$8.70
9663K74	19.31	1.20 lbs/inch	\$5.40
9663K94	21.93	1.37 lbs/inch	\$9.12

*Table 5: Springs and Spring Rate Values when cut to the desired length of 16"*

With these values we chose the 9663K83 as the higher spring rate could compensate for any additional frictional forces that were unexpected and the with the magazine having a lid any additional force does not affect the alignment of the system.

For the purpose of applying the spring force evenly to the batteries, and allowing smooth operation, a simple cart was designed seen below in Figure 35. Collapsing rails, identical to the ones used in the rail assembly, were bolted inside the magazine, and the cart was attached to these.



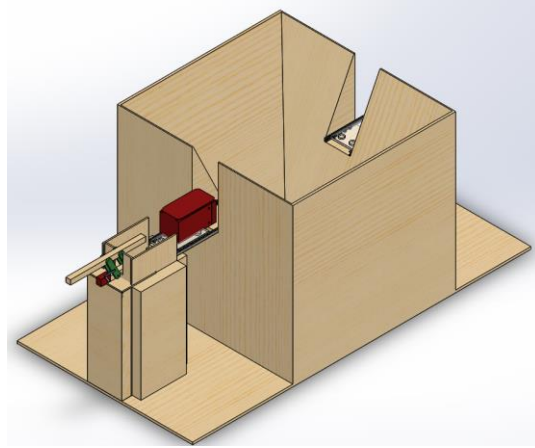
*Figure 35: Magazine Cart that holds the batteries in the magazine. The spring force applied to the cart forces the batteries upward.*

The design of the battery magazine originally called for a spring and spring guide to be included. Implementing this proved difficult, as the spring did not stay straight. Without the proper spring guide we were unable to keep the battery straight and a full length telescoping spring guide would be necessary. A simple alternative was to use extension rather than compression. A thin cord was tied to the magazine rails, and run to the outside of the magazine where it was tied to a bungee cord. This resulted in our spring force being external, allowing us to experiment with various extension lengths. Unfortunately, since we did not purchase and produce all 4 battery packs that the magazine would be able to hold, we did not test this method of spring force against the full weight of a fully loaded magazine.

## **3.9 Overall Design**

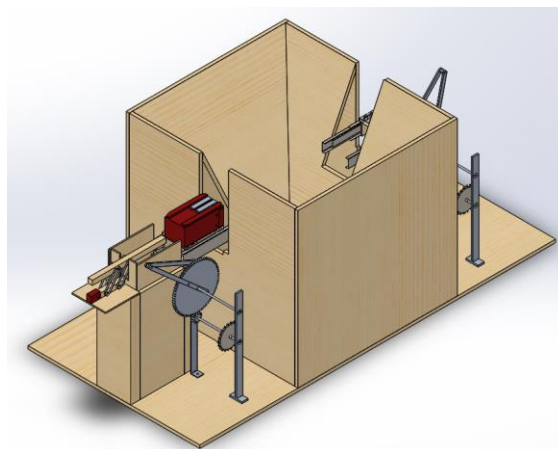
### **3.9.1 Initial Designs of Automated Battery Changer**

With all of the design choices made and modelled, the last step was to merge all of the parts together into a full assembly. Our preliminary design can be seen below which included many of the early concepts of components for the project. A majority of the project was built with wood, and wooden blocks were used as supports. In the first design seen below, no motors or mechanisms were included, as the decision making process was still being worked on as to how the slides should move back and forth. Below is the initial design in Figure 36.



*Figure 36: First design of the Automated Battery Changer*

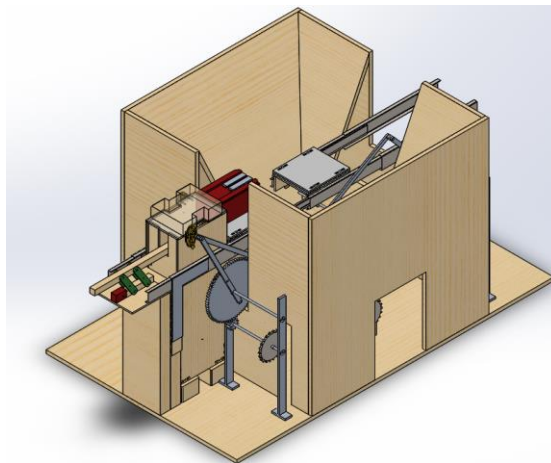
As progress was continued the second design was formed. This design incorporated the mechanisms required. The slots in the cone were adjusted for the new slides that were purchased and a gear ratio was included to increase the mechanical advantage of the slide crank mechanism. This design also included a rework of the battery package, which now included the rails and a well-defined cover for the batteries. The main component missing from this revised drawing was the motor positioning on the base, as the decision making process continued to decide on what motor to use, how to drive the motor, and how many motors total to use. The secondary design can be seen below in Figure 37.



*Figure 37: Second Design of the Automated Battery Changer*

### 3.9.2 Final Design of Automated Battery Changer

All of the designs that were created kept a similar framework and never had any significant changes, other than additional parts added in for clarification. In the final design seen below in Figure 38, a top has been added to the battery magazine to prevent the battery packages from leaving their intended positioning. The mounting of the slides has been updated with L and triangle shaped pieces mounted to the wooden block behind the magazine for additional support. The magazine placement has been moved from behind the rails to in between them, thus reducing the overall size of the platform. This also has the added benefit of reducing the distance the batteries needed to be moved. Blocks have been added underneath the magazine to bring it up to the necessary height. Slots have been cut in the passive alignment system to mount the motor, chain tensioner, and chains inside of the assembly. The cart itself was split into two identical cuts of acrylic, because it was easier to cut the thinner sheets of acrylic, and we needed to keep the required height of the cart.



*Figure 38: Final Design of the Automated Battery Changer*

### 3.10 Control Board and Software

In order to operate the system properly a circuit board capable of receiving inputs and producing outputs had to be chosen along with board to drive the motors. The selection process was shortened when an Intel Galileo Board and an ITEAD Dual Stepper motor driver shield were provided free of charge for the project. These boards when attached together allowed control of the stepper motor and also allowed control of the electromagnets on the cart to hold the battery package in place. In order to figure out the programming of the board a process flow diagram was created which is seen below in Figure 39. This goes through the steps for the programming needed to operate the Automated Battery Changer.

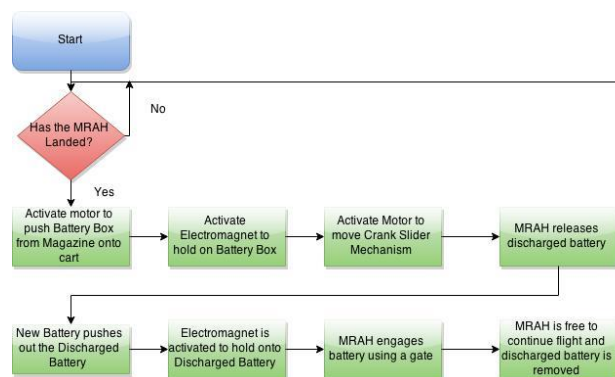


Figure 39: Process Flow Diagram of Automated Battery Changer

The Intel Galileo board is a microcontroller board similar to many readily available Arduino boards. The most convenient part of the Galileo board is that it is able to interface with many of the Arduino shields and other components, and with the Arduino having such a large market this was extremely convenient. The Galileo board has 13 digital pins, 5 analog pins, and is able to provide 5 volts to the input and output pins. This allowed for easy inputs and outputs in the system and could have additional components added for additional feedback from the MRAH.



Figure 40: Intel Galileo Board<sup>33</sup>

In addition to the Galileo board in order to drive the stepper motor and dual stepper motor shield was provided which can be seen in Figure 41. This stepper motor shield is able to provide 5-30 V based on the power input and approximately 750 mA to power the stepper motor. This stepper motor driver shield is able to directly interface with the Galileo board and using the standard Arduino programming a program can be written to operate the Automated Battery Changer.



Figure 41: ITEAD Dual Step Motor Driver Shield<sup>34</sup>

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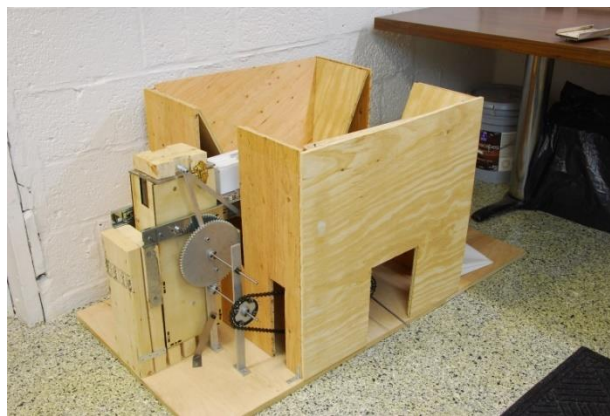
<sup>33</sup> Arduino, 2014

<sup>34</sup> ITEAD, 2012

## Chapter 4: Results

Due to time and budget constraints the full Automated Battery Changer was not able to perform the battery exchange sequence. This was mainly due to unforeseen manufacturing and assembly issues that setback the project at a crucial time not leaving enough time to make the necessary modifications needed to get the system fully up and running. Even with the system not fully working, some of the components did succeed in operation which will be outlined in the section.

Figure 42 below shows what was able to be completed on the Automated Battery Changer before numerous issues were encountered. As can be seen about half of the system is fully built with the back crank slider removed seen in Figure 43 as some incorrect alignment caused the back half to have to be readjusted.



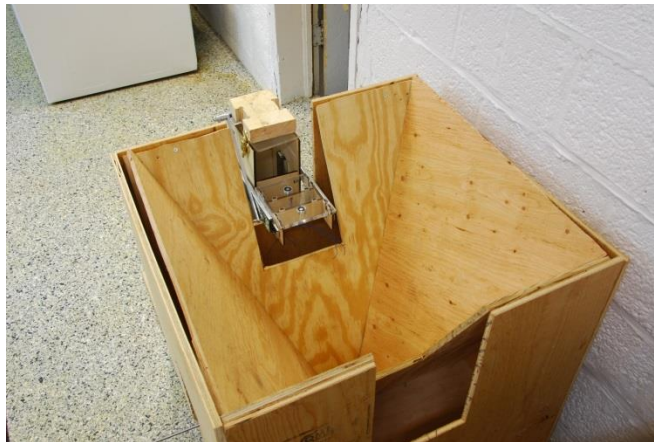
*Figure 42: Actual assembly of the Automated Battery Changer*





*Figure 43: The back crank slider was not installed due to issues in the assembly phase.*

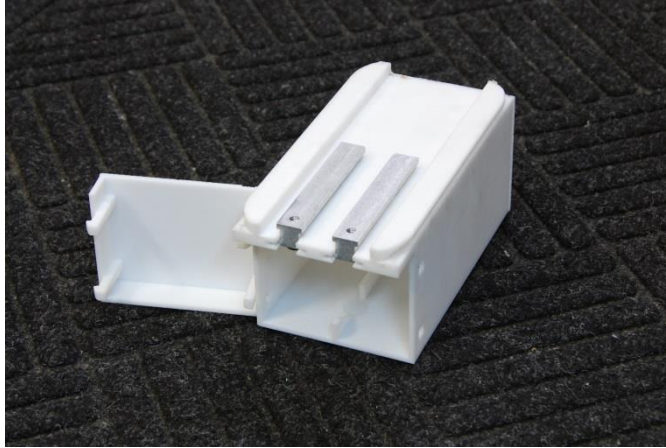
In Figure 44 below the cone and slide can be seen. The slide was able to move back and forth with the motor hooked up properly, even with the battery package placed on the cart which can be seen farther down. The cone itself was able to hold the MRAH in place as designed.



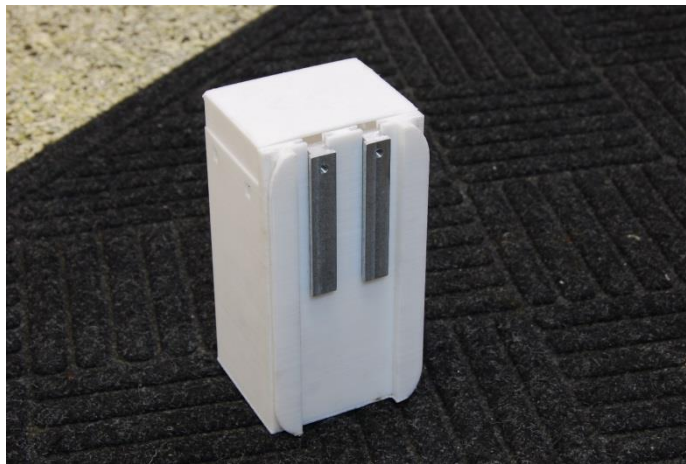
*Figure 44: Final cone assembly with slide in the starting position.*

The battery box was able to slide into the frame of the MRAH, but due to some dimensioning issues was unable to also attach with the rails. The rails were also able to slide onto the battery box separately. Two of the figures below, Figure 45 and Figure 46, show the battery box with the rails with the cover off and on. Figure 47 shows the battery box with the screws protruding from the rails, where the batteries would make connection to the rails using ring terminals.

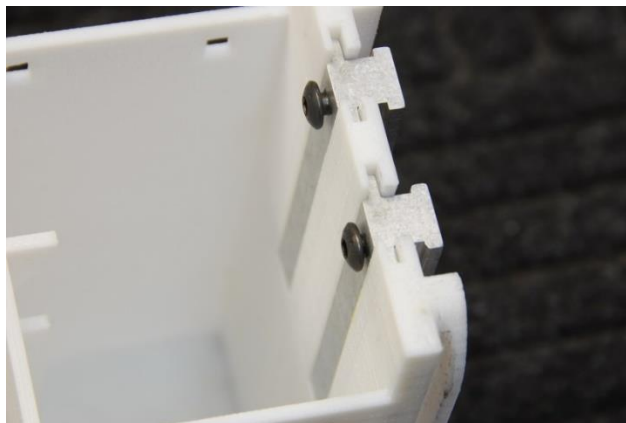




*Figure 45: Battery Package with installed rails. The cover is to the left.*

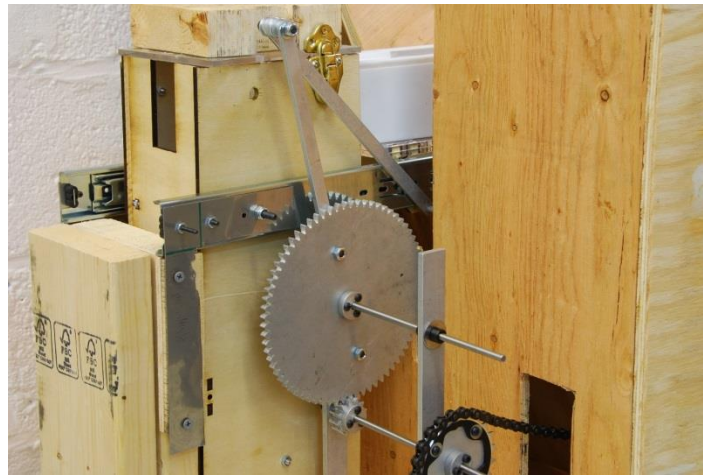


*Figure 46: Battery Package with cover attached*



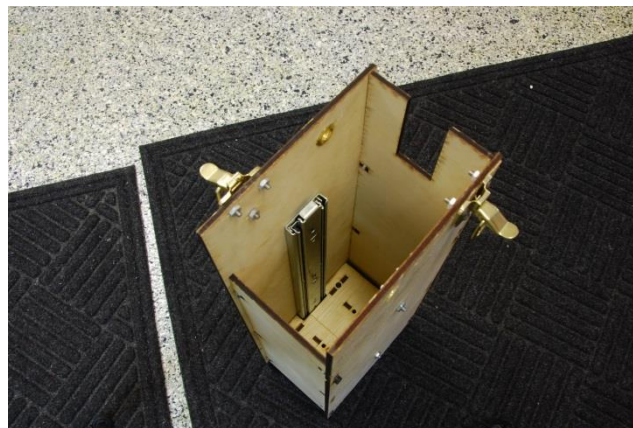
*Figure 47: The installed rails have a screw connection to attach the battery leads to the rails*

The motor with chain and chain tensioner also worked as intended. The motor was able to turn the gears and operate the slide crank mechanism. Figure 48 shows the slide crank mechanism with the attached chain going to the motor. The hubs can also be seen which connected the gears to the D-profile shaft.



*Figure 48: Slide Crank Mechanism*

The magazine worked as intended minus a few minor flaws in the system. The magazine can be seen in Figure 49 which shows the slide which the cart attaches to. The latches are also on the sides which allows the lid to connect to the magazine.



*Figure 49: Magazine with slides on the inside. The cart is attached to the slides.*

## **Chapter 5: Discussion**

This design has shown promise in numerous different areas of the system, but unfortunately in the final construction was not able to succeed. Based on the models and simulation of the components with more time dedicated to assembly, the ABC will be able to function as designed. Some of the wood components might need to be remade due to poor workmanship, while other parts might need some minor modification to allow proper clearance. Many of the design specifications were met such as the overall size and weight, but unfortunately some of the specifications were unable to be determined, such as the time to perform the exchange, as some parts of the system did not perform as expected and new parts would be needed to replace them.

### **5.1 Landing Platform and Alignment System**

The landing platform and alignment system have shown through some preliminary testing that it should work as intended. The alignment rod extending from the MRAH was able to move towards the center of the cone as designed. The only issue that was found was that the MRAH would not always settle parallel to the ground, due to tolerances between the cone and the rod. While this did not happen every time, it did occur enough that it would present an issue during the battery exchange sequence. Therefore, refinement of the alignment system would definitely be necessary.

### **5.2 Battery Exchange System**

Most of the battery exchange system worked as intended. The motor was able to move the slide crank mechanism as expected and overcame any frictional forces that were unexpected. This was able to extend and retract the cart on the slides and was able to move the battery on the

cart. The major issue was that the electromagnets were not able to hold the battery in place due to a lower magnetic force than expected and due to time constraints we were unable to purchase the necessary replacements in time to finish this mechanism. The software was able to also perform successfully, activating the motor and electromagnets when needed. The battery exchange system can be considered a success with some minor flaws.

### **5.3 Battery Package**

The battery package can be considered a success. After many attempts of 3D printing the outside box itself a final product was produced that was able to hold the rails. Many of the early prints suffered from material expansion, causing the slots for the rails to be smaller than intended. Sample slots were printed to compare the tolerances between machined parts and the 3D printed parts. Testing determined that thin-wall prints can produce material bleed in excess of 0.02 inches, and made the appropriate adjustments in the design. This adjustment proved successful in allowing proper assembly. The batteries fit within the box, with extra room allotted for expansion of the battery with increased usage cycles. In addition, the slots in the box for the steel disks to settle in, from which they would be attracted to the electromagnets, worked well. The connection to the battery and the rails was only incomplete to avoid cutting the wires extending from the battery, such that we would not ruin their ability to be charged. Charging the batteries in their custom housing would require a dedicated charging station. If the wires had been cut and the ring terminals attached to the battery the connections would have worked as intended. The male rails on the battery and the female rails on the MRAH also were able to slide together well although the chamfers were not able to be put on either side of the rails due to the lack of time.

## **5.4 Battery Storage**

The magazine worked as expected with a few minor issues. The main issue was that even with a spring guide the spring still tried to bend outward causing the magazine tray to not go as high as expected meaning that the battery could not be moved out of the magazine. This issue could be easily fixed which will be discussed later in this section. As for our ram rod that was supposed to push the battery out of the magazine this did not work as expected at all. The ram rod did not produce enough power to push the battery out of the magazine onto the cart. A new solution was created for this but due to time constraints unable to be implemented.

## **5.5 Automated Battery Changer**

Unfortunately due to time constraints, budget constraints, manufacturing issues, and assembly problems the final system did not come together as expected. The major issues came from the placement of components of the project. Working with plywood proved to be extremely difficult as the cutting of the material would provide poor dimensions and was not as precise as imagined. The cutting of the plywood also ruined the edges leaving an inconsistent surface which led to tolerance issues and some slots not being as large as expected. This led to components of the project being placed in incorrect locations and not being held together as first expected. Although the weight of the plywood was ideal for the project the material turned out to be very poor to use.

Many components on the board had to be repositioned numerous time in order to get some of them working. Aligning the gears from the motor to the slide crank mechanism with the chain tensioner and chain proved to be more of a challenge than originally expected. There was still some rubbing between the slide crank and the cone even when testing began of getting the cart to move back and forth as the slot was not made large enough. The full design for the

Automated Battery Changer needs some improvements to fix some of the tolerance issues and material issues.

## **5.6 Recommendations for Future Work**

With the Automated Battery Changer not being completed and working many improvements could be made to get the Automated Battery Changer into the final intended form. These improvements would include using different materials for the base and to replace some parts that did not function as expected. Further enhancements can be made to decrease the battery exchanging time and improve the alignment of the system. This would include some redesign of the system in addition to adding onto previous existing ideas to improve the system as a whole.

### **5.6.1 Landing Platform and Alignment System**

Currently the passive alignment system works as intended. Many improvements could be made to this system to increase the effectiveness of the alignment and make it more consistent and reliable. A recommendation was given towards the end of our project to add an additional alignment system on the end of the cart on the slides. This would correct any issue we had with the landing not being parallel to the ground and allow for a second alignment to occur in the process. As it stands now if the MRAH does not land properly this can create issues during the battery exchange process, so adding in a second alignment step could provide the solution we were looking for.

In addition to that, another suggestion that was given was to not have a flat bottom at the middle of the cone. This would restrict what MRAHs could land in the cone without either modifying the legs or the length of the alignment rod. The suggestion was to use a hole in the bottom such as a PVC tube and have the alignment rod extend into the PVC tube. This would

allow for a range of alignment rods to be used and the legs would be the only adjustment needed for the battery exchange sequence to occur.

The alignment rod also had one improvement that although is not entirely necessary would increase the performance of the MRAH. Although we were unable to finish the design of the rod we wanted to have it be retractable so if the MRAH had to land on the ground it would be able to perform that. The alignment rod could either fold into the MRAH or having a telescoping rod to extend and retract when necessary. This would have to run on a motor which would add additional weight to the MRAH but in order to not affect the center of gravity on the MRAH this would be a necessary addition.

Lastly the plate under the MRAH which is attached to the alignment rod and connects to the battery needs some adjustments. The plate was made using sheet metal and a layer of acrylic to act as insulation to the rails. Numerous modifications were needed to get the plate to connect to the battery and the rails were unable to connect to the plate without interfering with the connection to the MRAH. To fix this the rail spacing needs to be changed on the battery package and the plate would need to be professionally manufactured. Due to the inexperience of manufacturing sheet metal parts when attempting the bending the final dimensions did not come out as anticipated. This caused many hours of adjustments to get the correct dimensions to fit the battery box.

### **5.6.3 Battery Exchange System**

The battery exchange system worked minus the few minor flaws. The main flaw in the system was the incorrect electromagnet to be used on the cart. The electromagnet was supposed to be able to have 5.5 pounds (2.5 kg) of attraction force, but it was unable to hold the battery box while pushing into the MRAH. This could be due to many issues such as the precision

needed to push the battery box into the MRAH causing additional force on the battery box, the steel plate in the battery box not being close enough to the electromagnet, or the electromagnet not putting out as much force as expected. A more powerful magnet would not affect the operation of the system and with looser tolerances on the battery box and battery receiver on the MRAH the system should work as expected.

Using two slide crank mechanisms in order to operate the battery exchange process worked, with a large concern about the amount of moving parts. With the system sitting out in the environment the mechanisms could lock up or fail easily compared to simpler designs using less moving parts. Although simpler designs were examined and not chosen due to additional motors being needed, the designs had the added benefit of using fewer parts. One system we examined would use a rack and pinion to push the battery out of the magazine, into the MRAH, and out of the MRAH. A rack and pinion could also be used on the opposite side that would operate the cart back and forth in order to move the battery box out of the MRAH. A similar system could be used such as a linear actuator, which accomplishes the same task but are more standardized and readily available.

#### **5.6.4 Battery Storage**

The magazine worked well with the system with the exception of the spring having some minor issues. The easiest fix for this would be to make a telescoping sleeve on the outside of the spring to prevent any deflection of the spring towards the side of the mechanism. Another solution would be to use a stronger spring that will not deflect as much under the load, but this could potentially damage the lid of the magazine. Otherwise the lock on top of the magazine was able to hold the battery box in place to be pushed onto the cart. As we were unable to obtain more batteries and 3D print more boxes for testing we are unable to know if the spring and



magazine could support the weight of four battery boxes, but initially testing and calculations show that it should be able to withstand the force.

Removing the battery out of the MRAH still needs work as well as the project focused on improving the process of getting the battery in and out of the MRAH and not much on what to do after the battery was removed. A design would need to be created as to how to collect the discharged batteries for them to be removed and charged. Some possibilities could include an additional magazine that catches them or some sort of bin to collect the battery boxes as they are removed from the MRAH

Given the female end of the electric rails, a dedicated charging station for the battery boxes would also need to be designed. Our designs call for the bullet connectors that the batteries come with be cut off, and connected directly to the electric rails. Thus, having a dedicated means of charging would be beneficial, and relatively easy to create given our existing designs.

### **5.6.5 Automated Battery Changer**

The entire system itself was unable to perform the goal of automating the battery exchanging sequence. Most of this was due to the difficulty of positioning parts onto the landing platform itself and insecure mounting. One of the easiest solutions to this problem would be using a material other than plywood and wood for the mounting of the components. The reasoning for this solution is that the plywood and wood blocks were cut and screwed down using manual saws and drills. Because of this error occurred during the mounting of the components. The main reason plywood and other wood blocks were used was because of the cost and weight of the material. The end product produced was not within expected tolerances, even given our loose expectations. With proper tools plywood may have been able to provide the

results we were looking for but unfortunately with what we were available to use here on campus we were unable to get the size, chamfers, and holes we were looking for.

In order to find a suitable material to use, it must have a similar density to plywood to keep the overall weight as low as possible. Most plywood has a density of about 0.023 pounds/in<sup>3</sup>. A material that could be used would be a plastic, such as Delrin which has a density of .051 pounds/in<sup>3</sup>. Although this would more than double the weight of the system, in a CNC machine holes could be drilled and tapped to provide better positioning of components and the cone would go together better as machining Delrin is significantly easier than machining plywood. Another option would also be ABS that has a lower density at .036 pounds/in<sup>3</sup>. ABS also has a lower cost, but unfortunately there are some difficulties in machining ABS as it tends to stick to the tools. The last option would be using a material such as aluminum, which although significantly is significantly heavier and a higher price point, is very easy to keep within tolerance and is easily available in larger sizes.

## Chapter 6: Conclusion

This project was a minor success as the intended purpose was to design an automated battery exchanging station for multirotor autonomous helicopters. The major weakness in our project comes from the manufacturing and assembly aspect of the project, where due to budget and time constraints the full prototype was unable to function as planned. With some modifications to the current design the system will perform to the design specifications that were created. The solution created allows for a fast and easy battery exchanging system and with added improvements can make the process rapid by decreasing the time spent aligning.

The full system was not a success, but many of the components of the project solved many of the issues and did work as intended. The passive alignment cone provides a simple and inexpensive solution to aligning the MRAH and can accommodate numerous sizes of MRAHs currently with a small amount of modifications. The cone also provides a wide area to land allowing for the MRAH to land in poor conditions such as high winds. The rails on the battery pack were able to slide into one another and the spring force was able to secure the rails together. The battery pack was also able to slide into the MRAH when manually pushed together. The slide crank mechanism was able to move the battery back and forth as required. Lastly the magazine was able to push the battery up with the coil spring purchased. Overall the components of the system have demonstrated that when properly assembled and manufactured the system will perform a complete battery exchange in a rapid and reliable operation.

With the current state of this project a basis has been provided for future work to improve on the design with many suggestions provided in the discussion section. In Appendix C - E below the current designs have been made into drawings that can be used to work with in future

work of the project. The final product produced by this project did not work as intended but with minor modifications this system will work as originally designed.

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# Chapter 8: Appendix

## Appendix A: Tarot 680PRO Datasheets

**IRON MAN 6800 ASSEMBLY SECTION 组装说明 TAROT**

**半圆头内六角螺丝M3x6mm**  
Socket button head screw

**内六角螺丝 (M3x6mm) x6**  
button head screw

**六角螺丝 (M2.5x20mm) x6**  
screws

**电池碳纤维底板 1.6mm**  
Battery carbon fiber base

**圆柱头内六角螺丝M2.5x20mm**  
Socket screws

**半圆头内六角螺丝M3x6mm**  
Socket button head screw

**内六角螺丝 (M3x6mm) x4**  
button head screw

**FORNT 前**

**M6 M1 M2 M3 M4 M5**

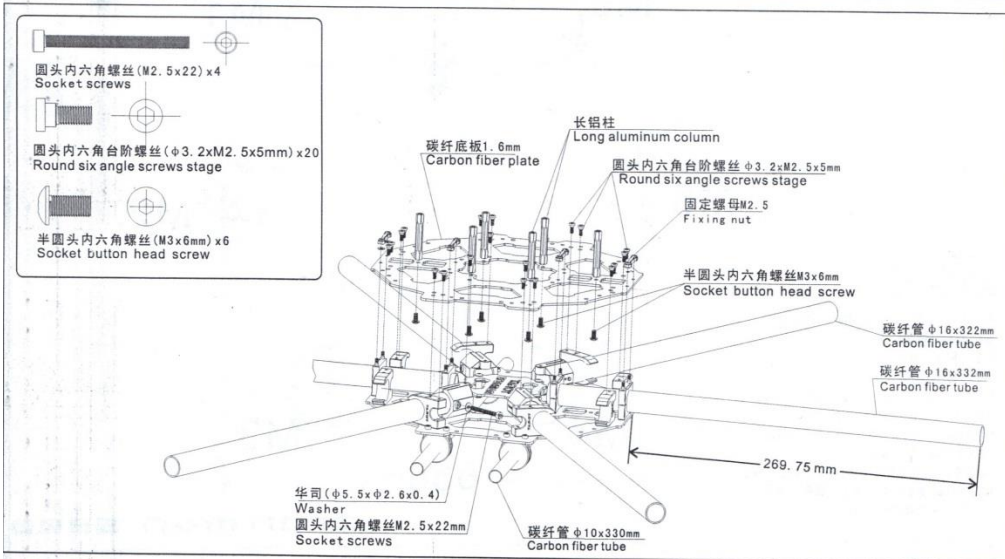
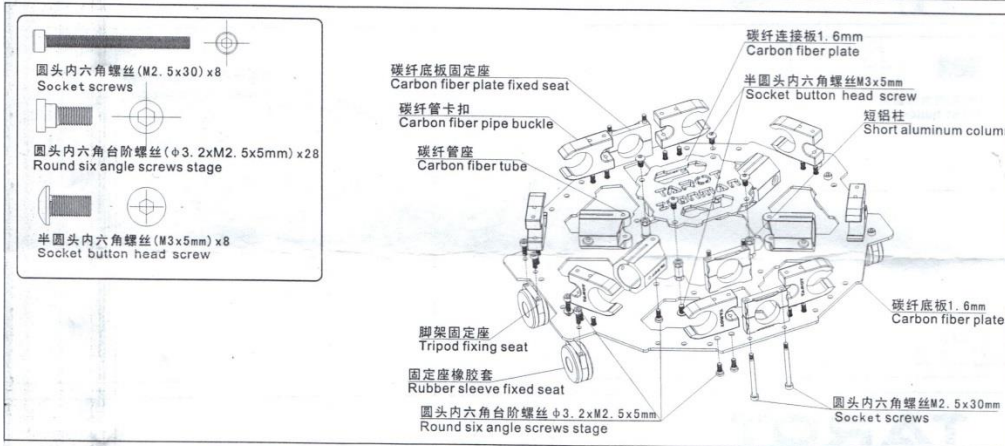
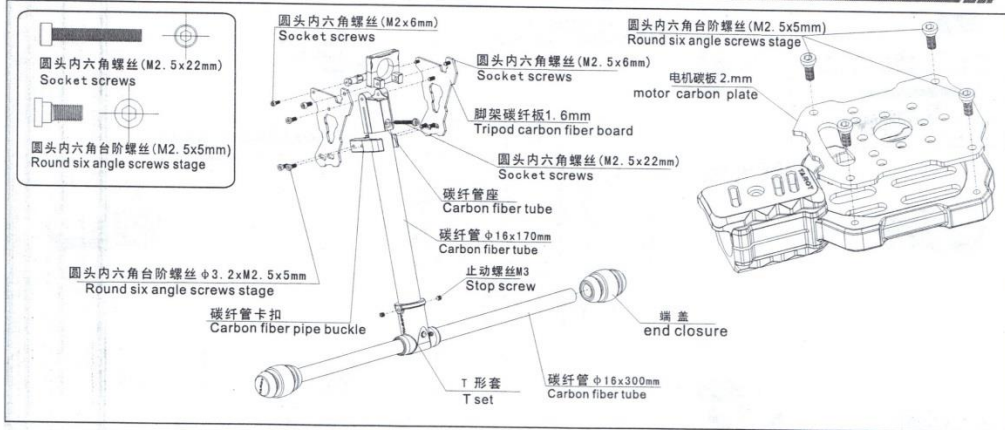
**680mm**

**IRON MAN 6800**

**注意**

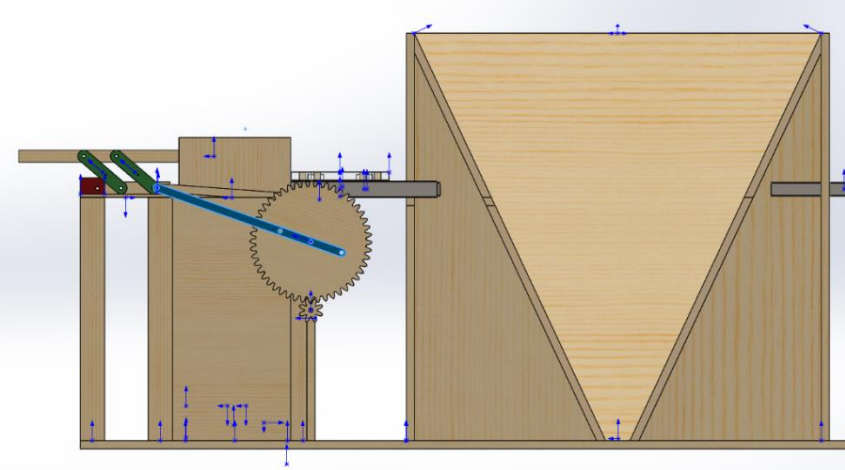
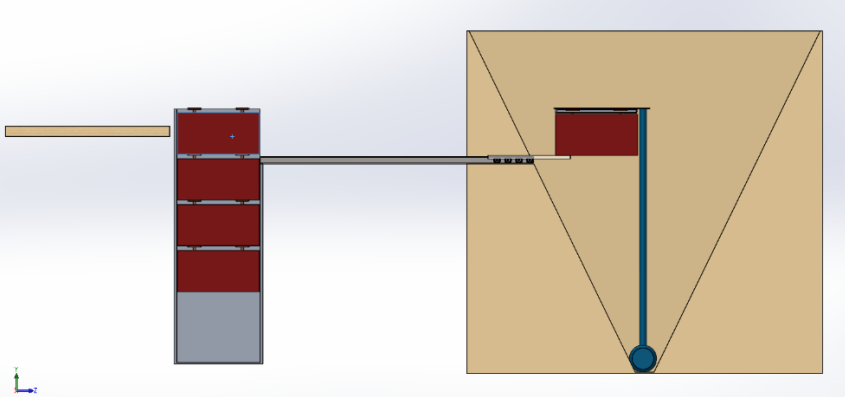
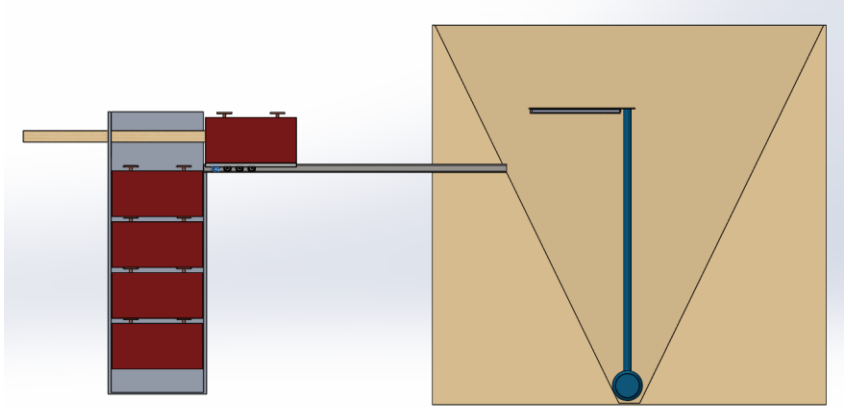
有正反之分，安装  
仔细辨认！  
M1、M5相同，M2、  
M3、M4相同。  
M1、M3、M5  
有区别，请仔细辨认，  
M2、M4、M6  
是相同的。

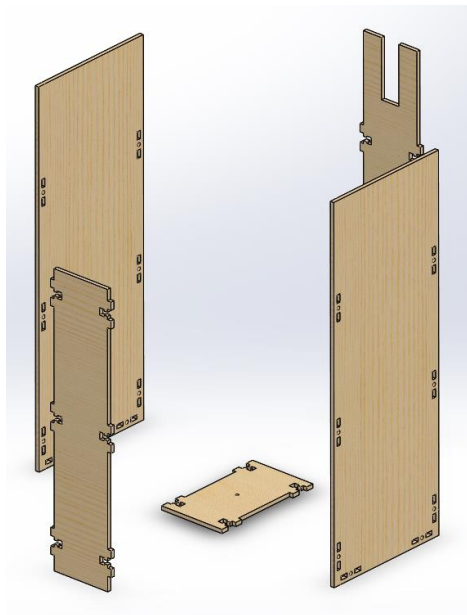
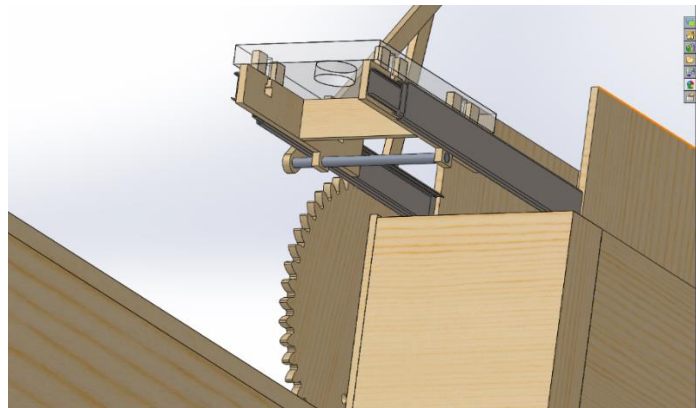
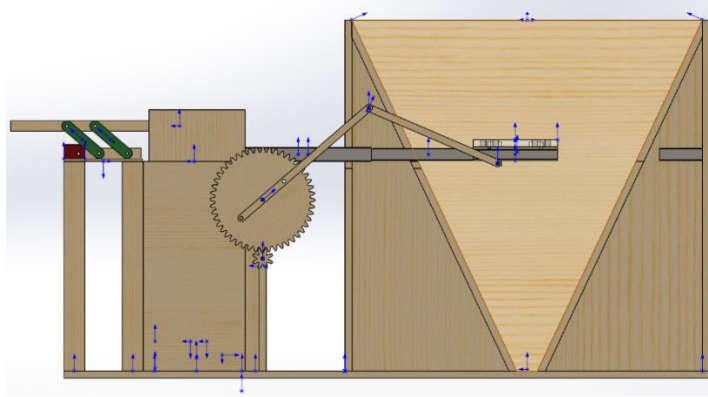
There are difference of  
M1, M3, M5  
and cons in the  
M2, M4, M6  
are the same too.

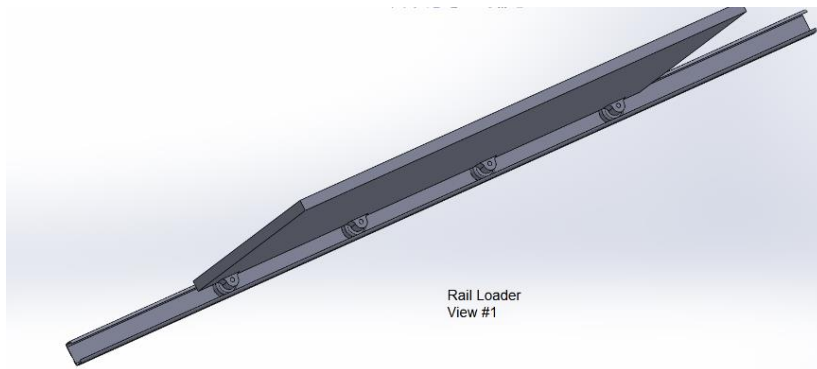
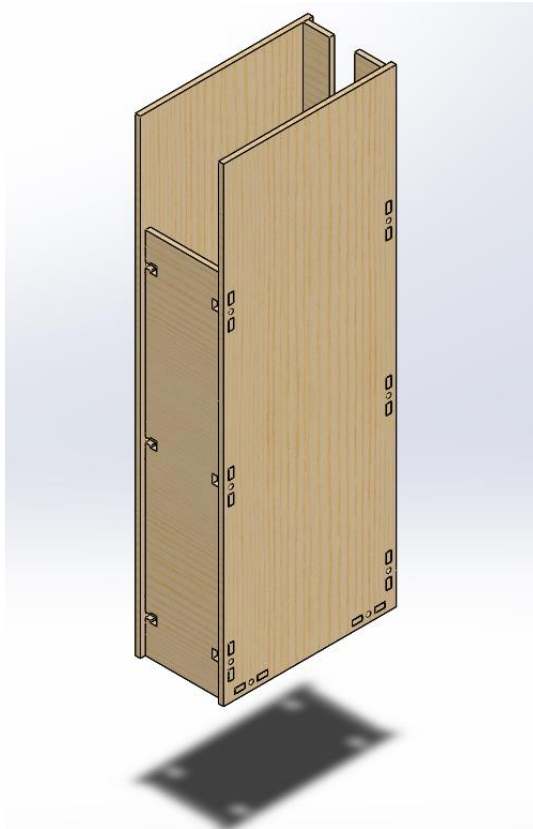


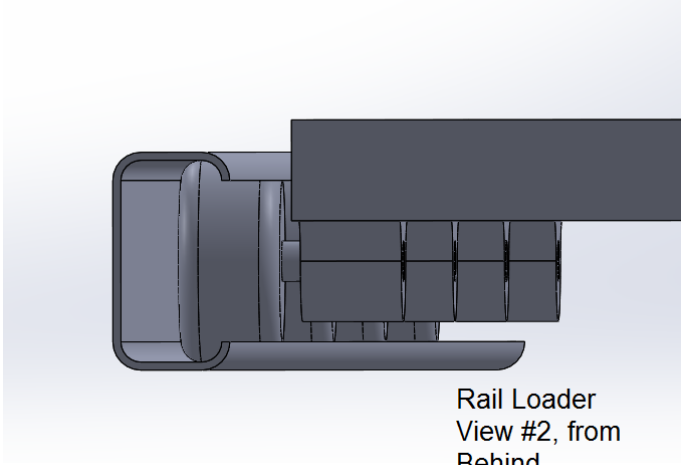


**Appendix B: Additional Early Concept Figures**

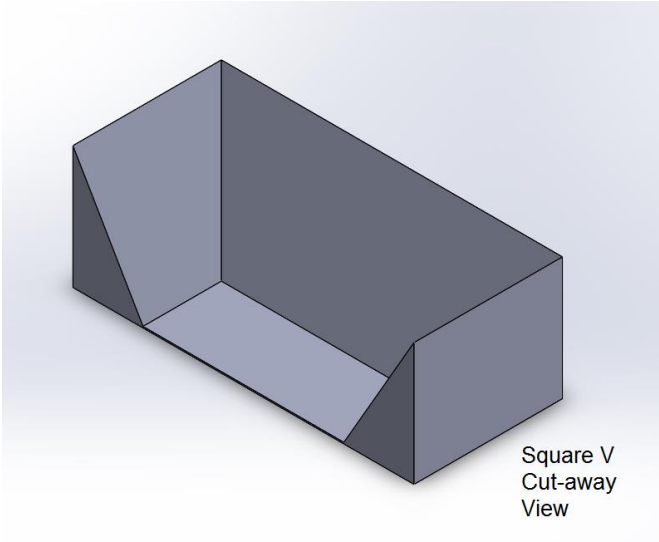




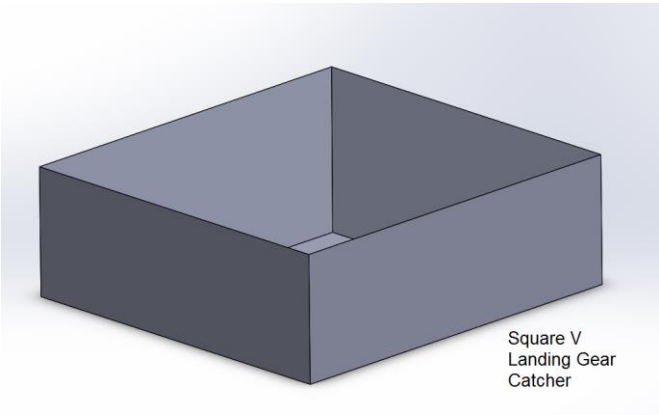




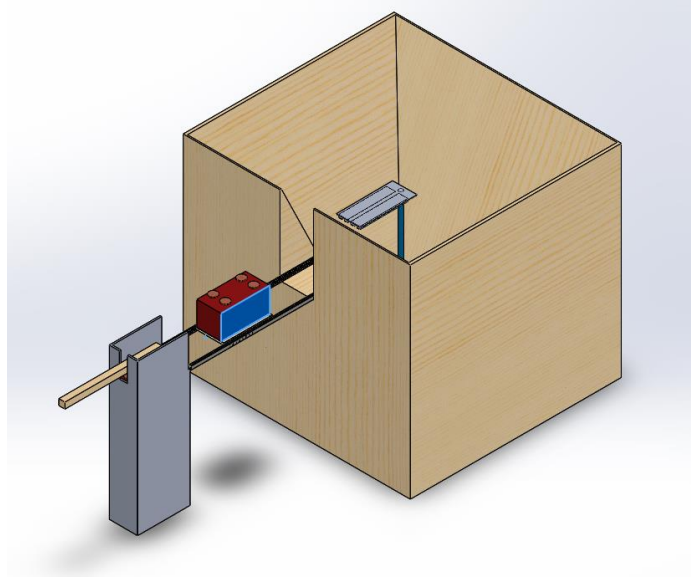
Rail Loader  
View #2, from  
Behind



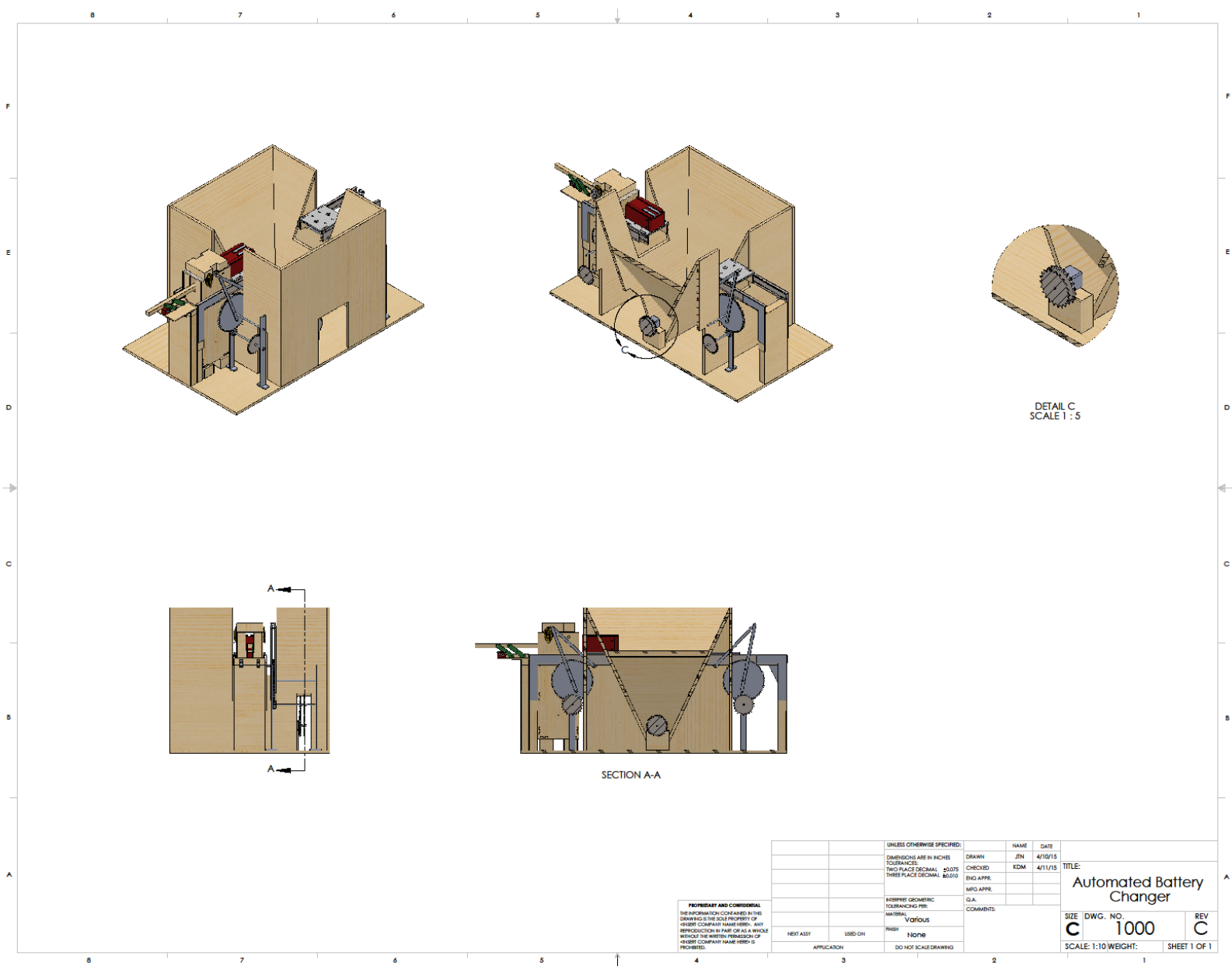
Square V  
Cut-away  
View



Square V  
Landing Gear  
Catcher



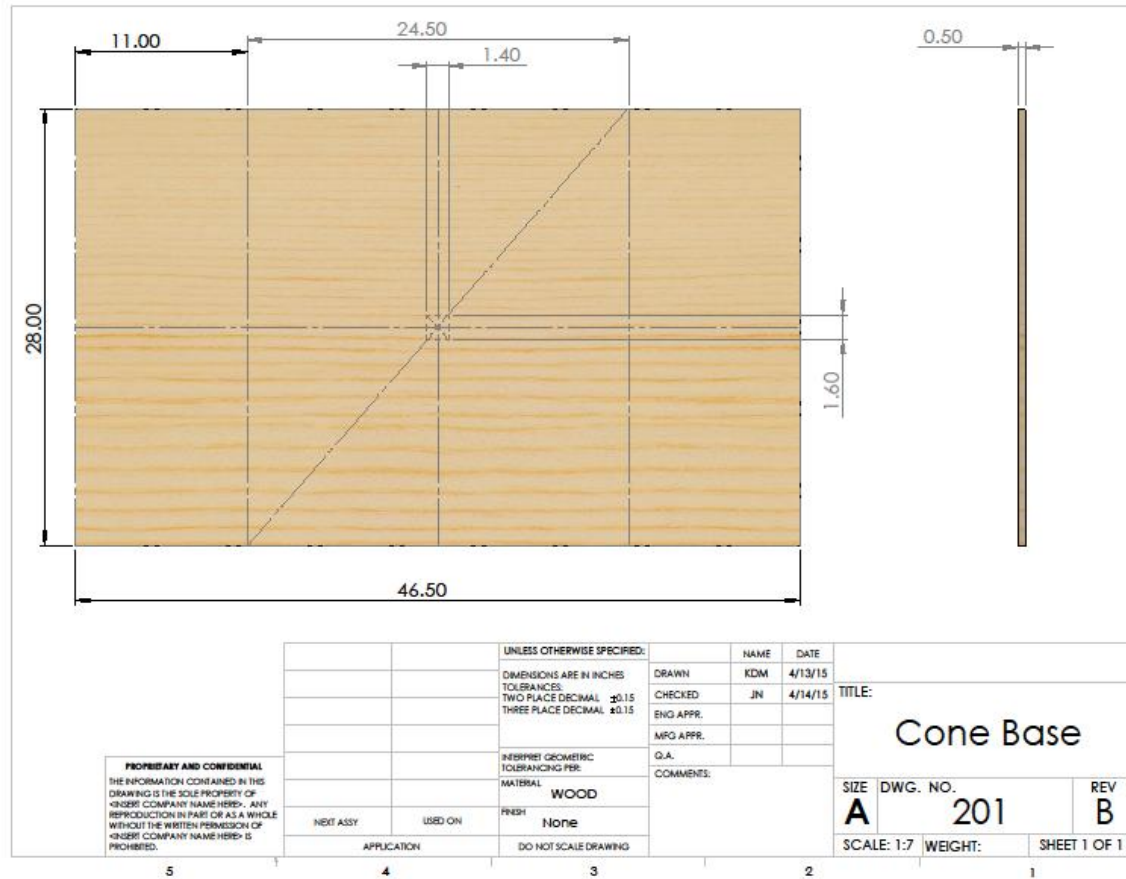




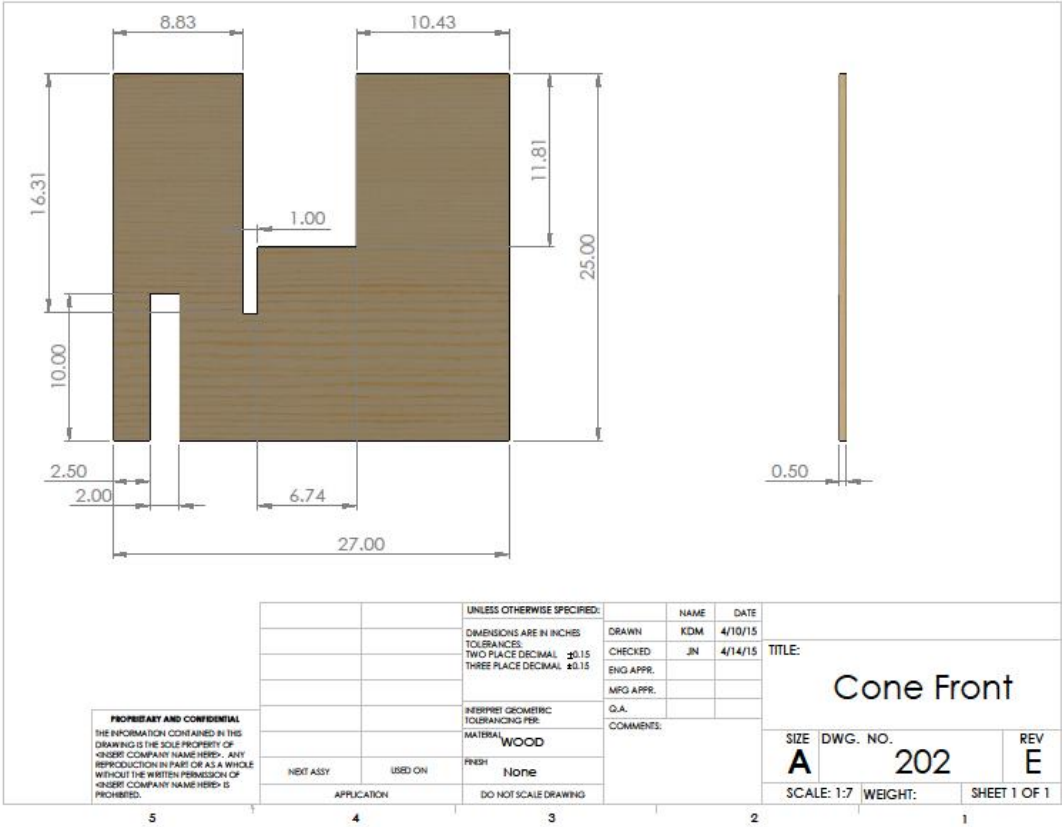
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UNLESS OTHERWISE SPECIFIED:		NAME	DATE	TITLE: <b>Automated Battery Changer</b>
DIMENSIONS ARE IN INCHES	DRAWN	JTN	4/10/15	
TOLERANCES	CHECKED	KDM	4/11/15	
TWO PLACE DECIMAL .0005	ENG APPR.			
THREE PLACE DECIMAL .0010	MFG APPR.			SIZE DWG. NO. REV
	Q.A.			<b>C 1000 C</b>
	COMMENTS:			SCALE: 1:10 WEIGHT: SHEET 1 OF 1
	MATERIAL:			
	Various			
	FINISH:			
	None			
NEXT ASSY	USED ON			
APPLICATION	DO NOT SCALE DRAWING			

## Appendix D: Drawings of the Cone Alignment and Base







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 WITHOUT THE WRITTEN PERMISSION OF  
 <INSERT COMPANY NAME HERE> IS  
 PROHIBITED.

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
		DIMENSIONS ARE IN INCHES TOLERANCES: ±0.15		DRAWN	KDM	4/13/15	TITLE:  <b>Cone Side 1</b>
				CHECKED	JN	4/13/15	
				ENG APPR.			
				MFG APPR.			
				G.A.			
		INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS:			
		MATERIAL		WOOD		SIZE DWG. NO. REV	
NEXT ASSY		USED ON		FINISH		A 203 A	
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:7 WEIGHT: SHEET 1 OF 1	

5

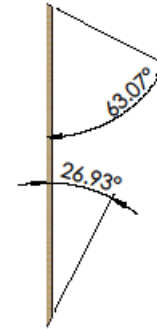
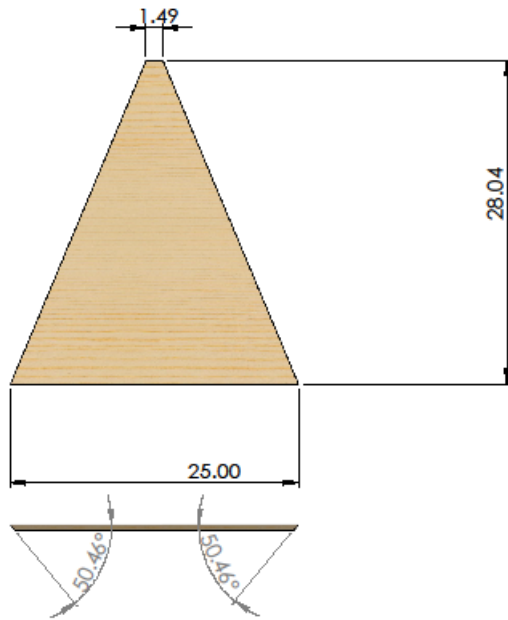
4

3

2

1





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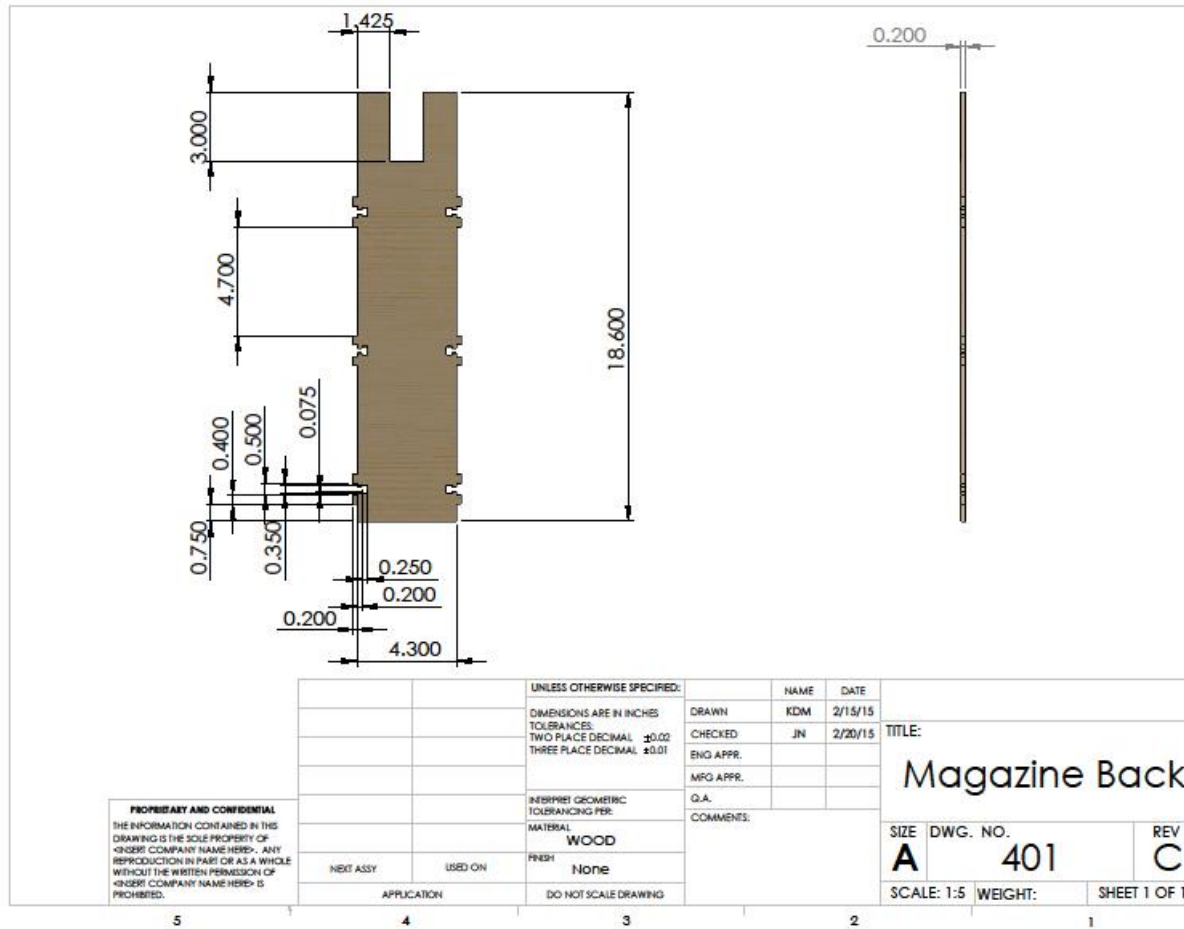
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE		
		DIMENSIONS ARE IN INCHES		DRAWN	KDM	3/22/15	
		TOLERANCES:		CHECKED	JN	4/14/15	
		ANGULAR: MACH ±0.5		ENG APPR.			
		TWO PLACE DECIMAL ±0.15		MFG APPR.			
		THREE PLACE DECIMAL ±0.15		Q.A.			
		INTERPRET GEOMETRIC TOLERANCING PER:		COMMENTS:			
		MATERIAL					
		WOOD					
		FINISH					
		None					
NEXT ASSY		USED ON					
APPLICATION		DO NOT SCALE DRAWING					
				TITLE:		Triangle Alignment	
				SIZE	DWG. NO.	REV	
				A	205	B	
				SCALE: 1:10 WEIGHT:		SHEET 1 OF 1	

5 4 3 2 1



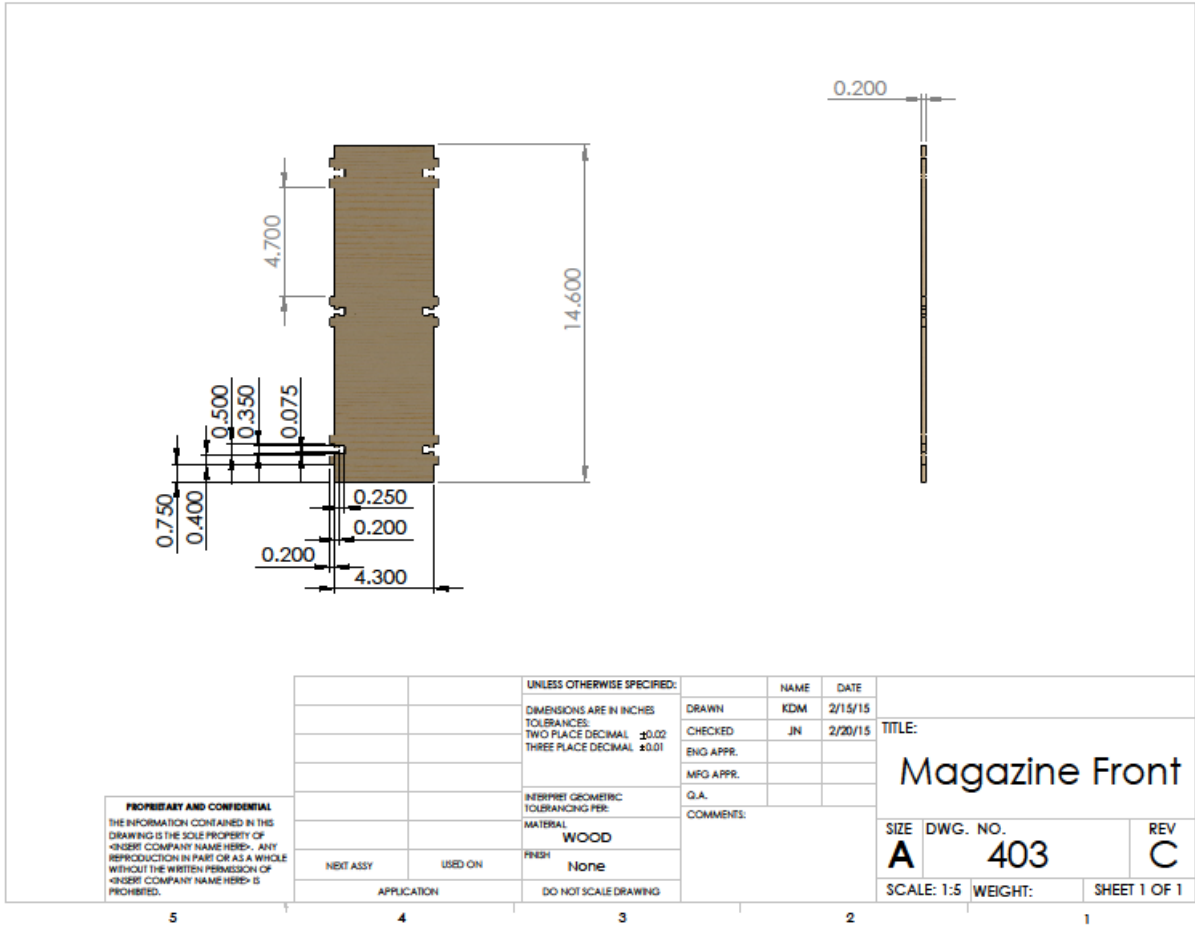


# Appendix D: Drawings of the Battery Magazine





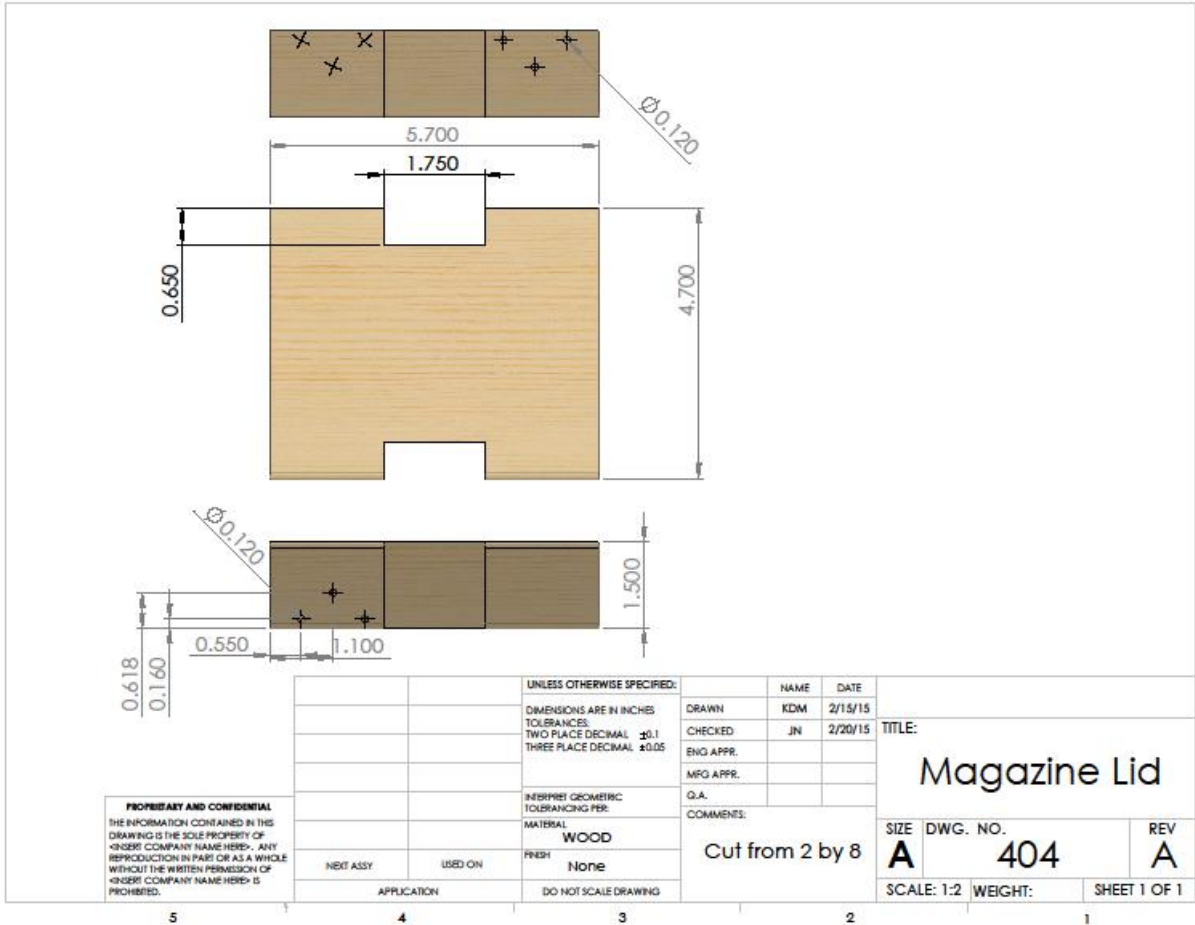


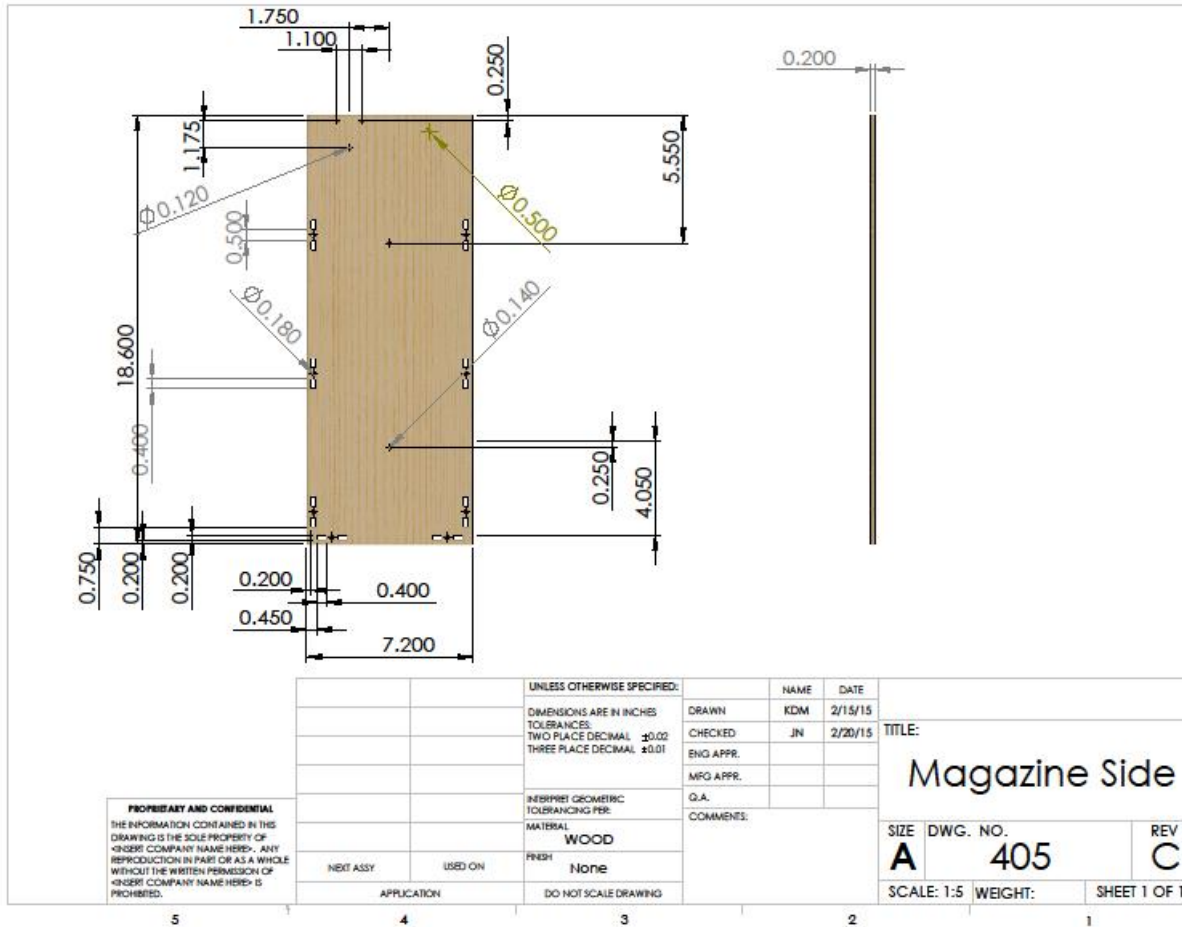


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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES		DRAWN	KDM 2/15/15
		TOLERANCES		CHECKED	JN 2/20/15
		TWO PLACE DECIMAL ±0.02		ENG APPR.	
		THREE PLACE DECIMAL ±0.01		MFG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.	
		MATERIAL		COMMENTS:	
		WOOD			
NEXT ASSY		USED ON			
		FINISH			
		None			
APPLICATION		DO NOT SCALE DRAWING			
TITLE: Magazine Front					
SIZE		DWG. NO.		REV	
A		403		C	
SCALE: 1:5		WEIGHT:		SHEET 1 OF 1	

5 4 3 2 1

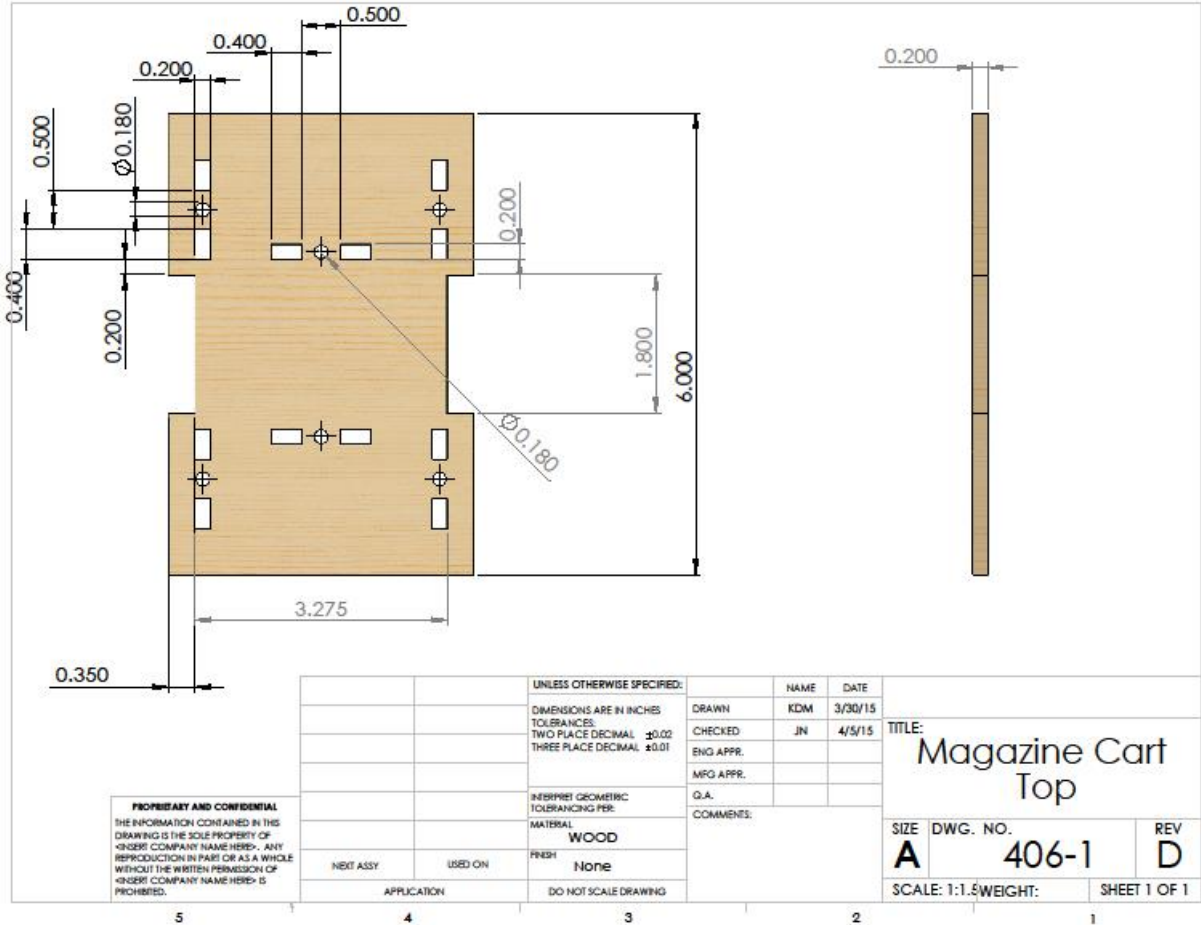


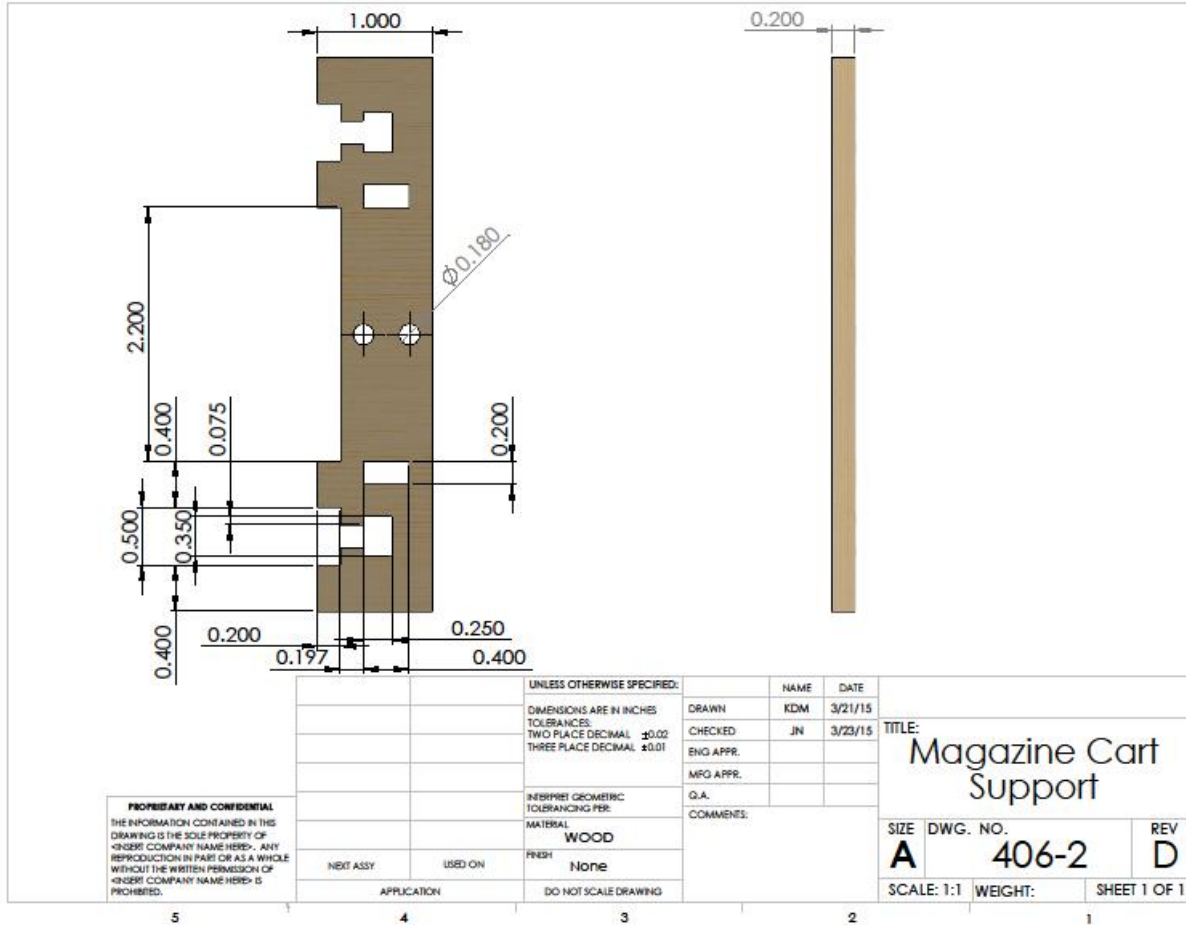


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UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES		DRAWN	KDM 2/15/15
TOLERANCES		CHECKED	JN 2/20/15
TWO PLACE DECIMAL ±0.02		ENG APPR.	
THREE PLACE DECIMAL ±0.01		MPG APPR.	
		G.A.	
		COMMENTS:	
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL			
WOOD			
FINISH			
None			
NEXT ASSY	USED ON		
APPLICATION			
DO NOT SCALE DRAWING			

TITLE: <b>Magazine Side</b>		
SIZE <b>A</b>	DWG. NO. <b>405</b>	REV <b>C</b>
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1



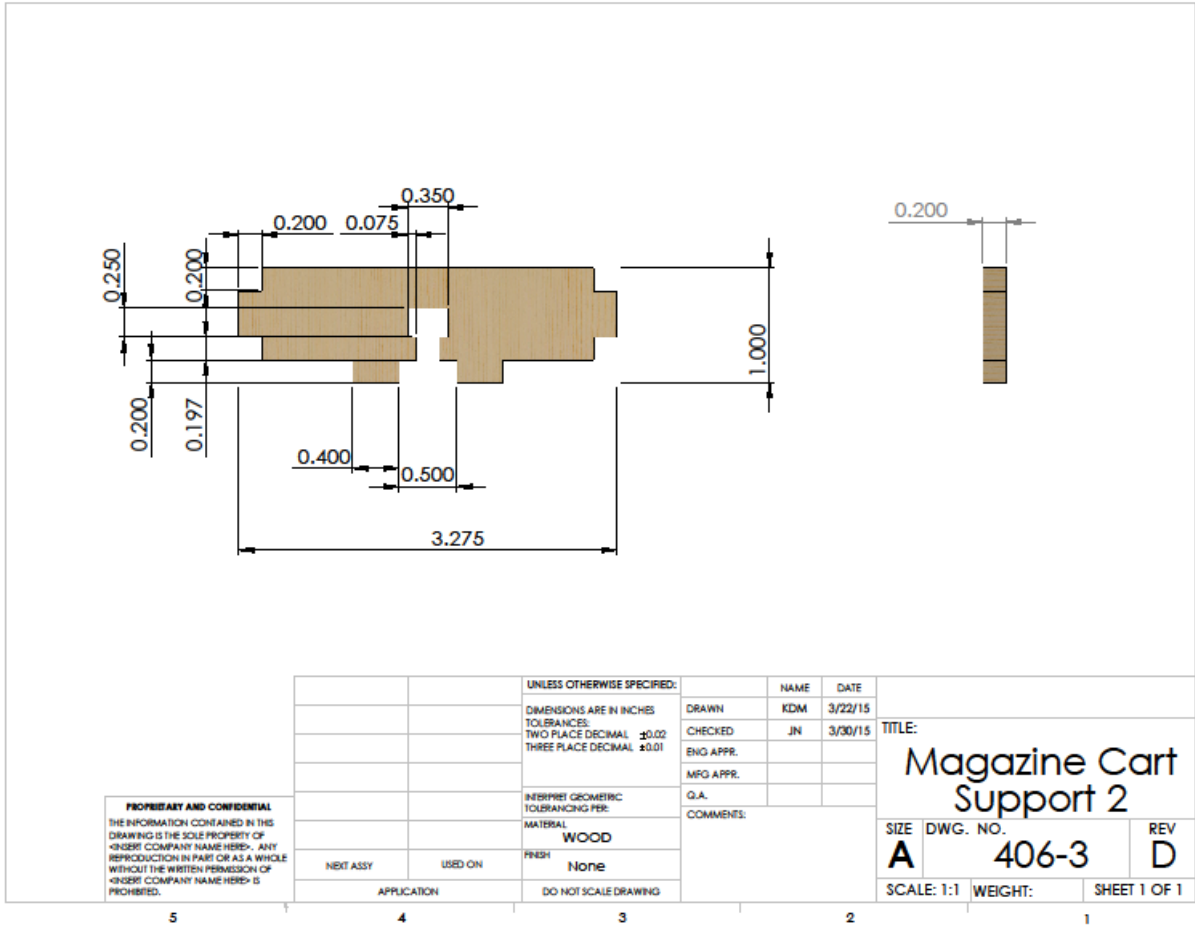


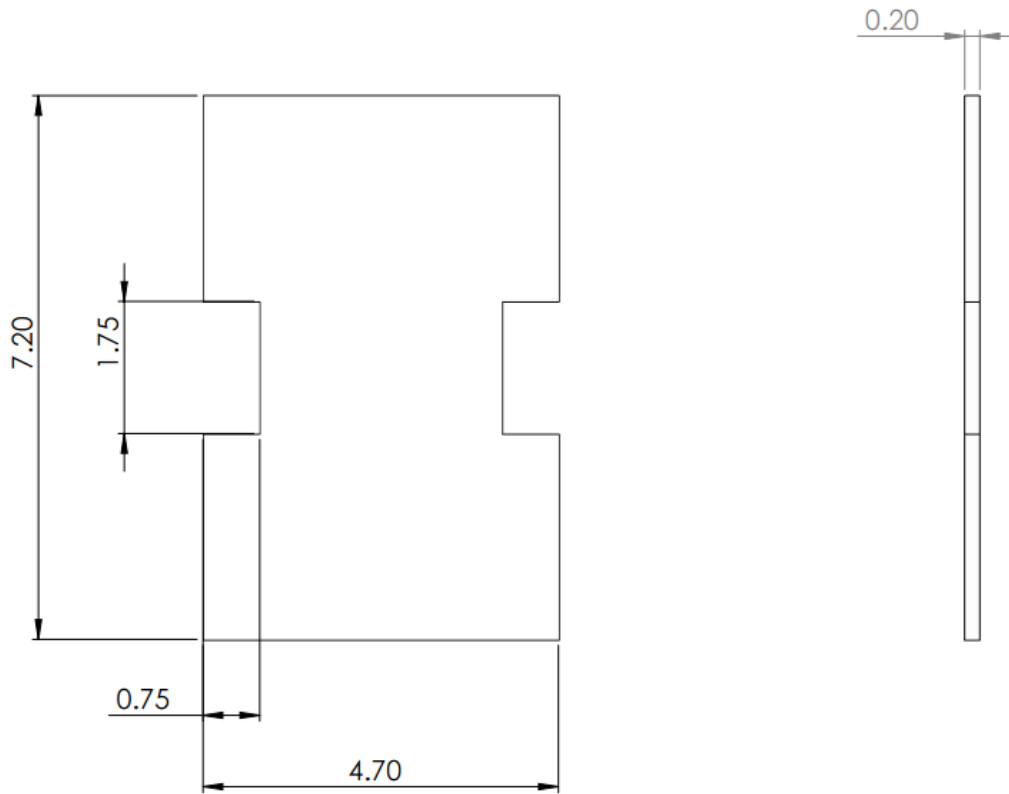
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**TITLE:**  
 Magazine Cart Support

**SIZE** DWG. NO. **REV**  
**A** 406-2 **D**

SCALE: 1:1 WEIGHT: SHEET 1 OF 1





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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE				
		DIMENSIONS ARE IN INCHES		DRAWN	KDM	2/15/15	TITLE: <b>Magazine Lid Stop</b>		
		TOLERANCES:		CHECKED	JN	2/20/15			
		TWO PLACE DECIMAL ±0.02		ENG APPR.					
		THREE PLACE DECIMAL ±0.01		MFG APPR.					
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.					
		MATERIAL		COMMENTS:					
		ACRYLIC				SIZE	DWG. NO.	REV	
NEXT ASSY		USED ON				<b>A</b>	<b>407</b>	<b>A</b>	
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2		WEIGHT:	SHEET 1 OF 1

5

4

3

2

1

# Appendix E: Drawings of the Battery Box

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	501	Battery Box Shell	1
2	502	Battery Box Cover	1
3	503	Turnigy 5000 mAh LiPo Battery	2
4	504	Male Electric Rails	2
5	505	Steel Discs	2

		UNLESS OTHERWISE SPECIFIED:	NAME	DATE
		DIMENSIONS ARE IN INCHES	DRAWN	JTN 4/15/15
		TOLERANCES:	CHECKED	KDM 4/16/15
		TWO PLACE DECIMAL ±0.075	ENG APPR.	
		THREE PLACE DECIMAL ±0.010	MFG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	
		MATERIAL	COMMENTS:	
		FINISH	None	
NEXT ASSY	USED ON			
APPLICATION	DO NOT SCALE DRAWING			

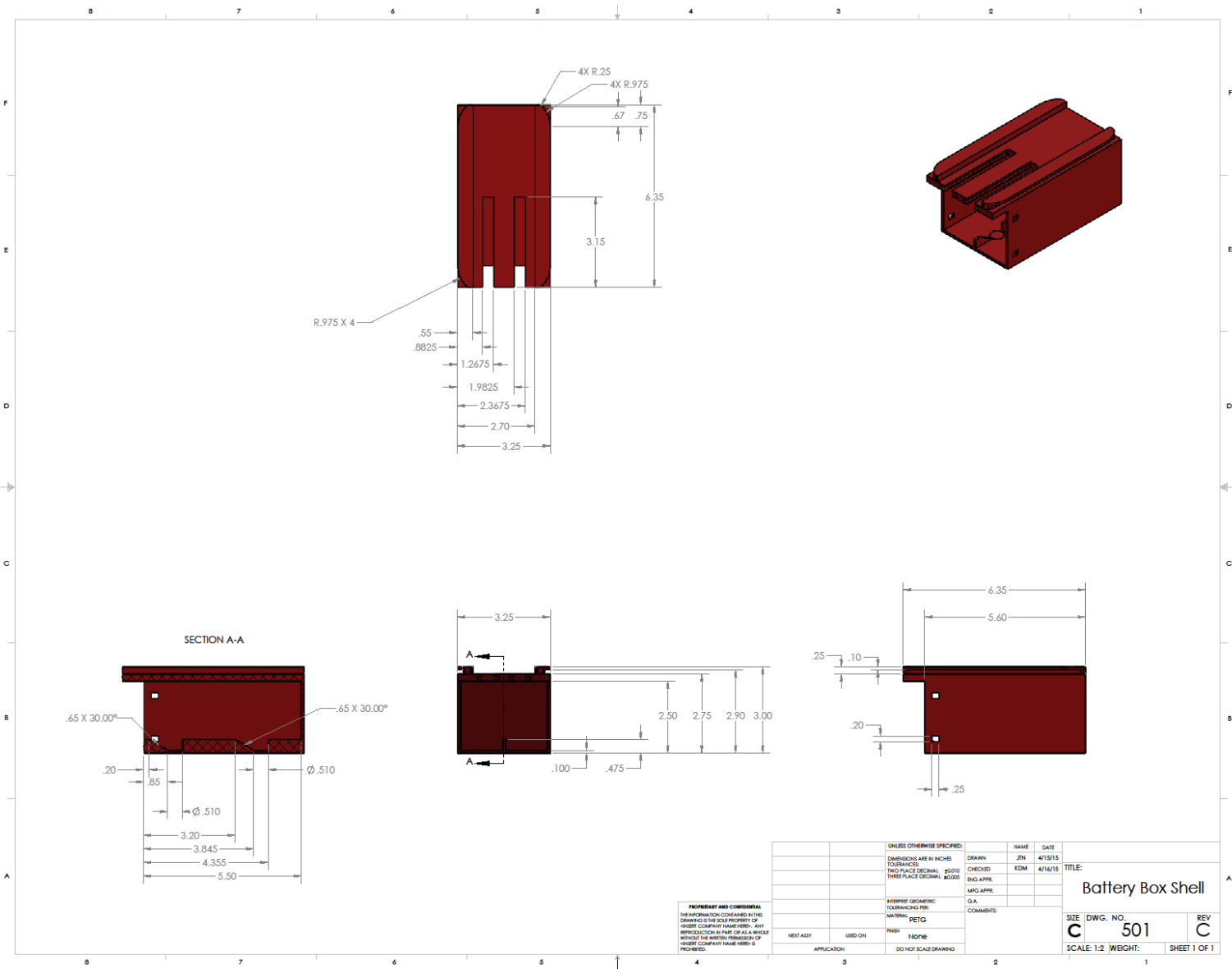
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TITLE: **Battery Box**

SIZE **A** DWG. NO. **500** REV **C**

SCALE: 1:5 WEIGHT: SHEET 1 OF 1





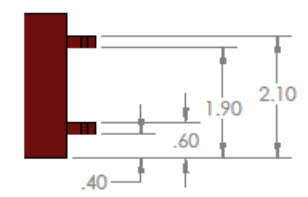
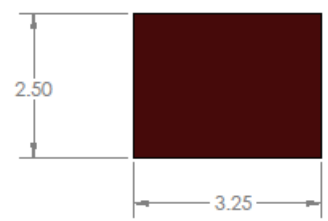
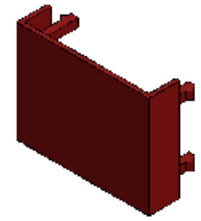
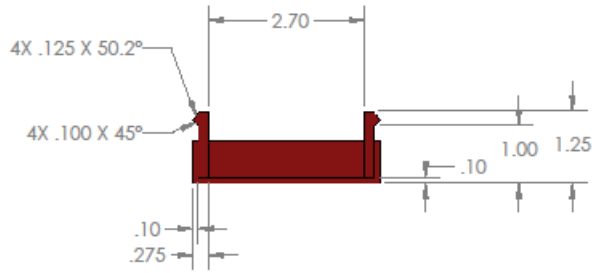
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UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	TOLERANCES	DRAWN: JFN	4/15/15
TWO PLACE DECIMAL	±.0015	CHECKED: KDM	4/16/15
THREE PLACE DECIMAL	±.0030	ENG APPR:	
		MSG APPR:	
HERTZ GEOMETRIC TOLERANCING PER: MATRISYS PCTC	G.A. COMMENTS:		
HERTZ ASST	USED ON:		
APPLICATION:	DO NOT SCALE DRAWING		

**Battery Box Shell**

SIZE DWG. NO. REV  
**C** 501 **C**

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



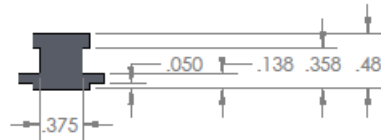
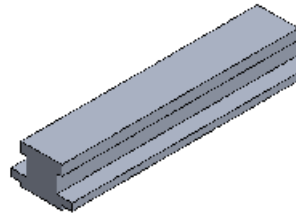
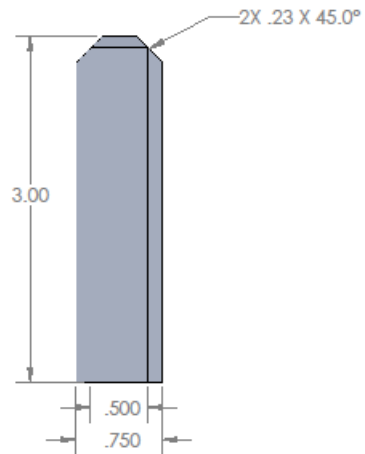
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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES		DRAWN	JTN 4/15/15
		TOLERANCES		CHECKED	KDM 4/16/15
		TWO PLACE DECIMAL ±0.010		ENG APPR.	
		THREE PLACE DECIMAL ±0.005		MPG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.	
		MATERIAL		COMMENTS:	
		PETG			
		FINISH			
		None			
NEXT ASSY	USED ON				
APPLICATION		DO NOT SCALE DRAWING			

TITLE:  
**Battery Box Cover**

SIZE	DWG. NO.	REV
<b>A</b>	<b>502</b>	<b>C</b>
SCALE: 1:2		WEIGHT:
		SHEET 1 OF 1

5 4 3 2 1

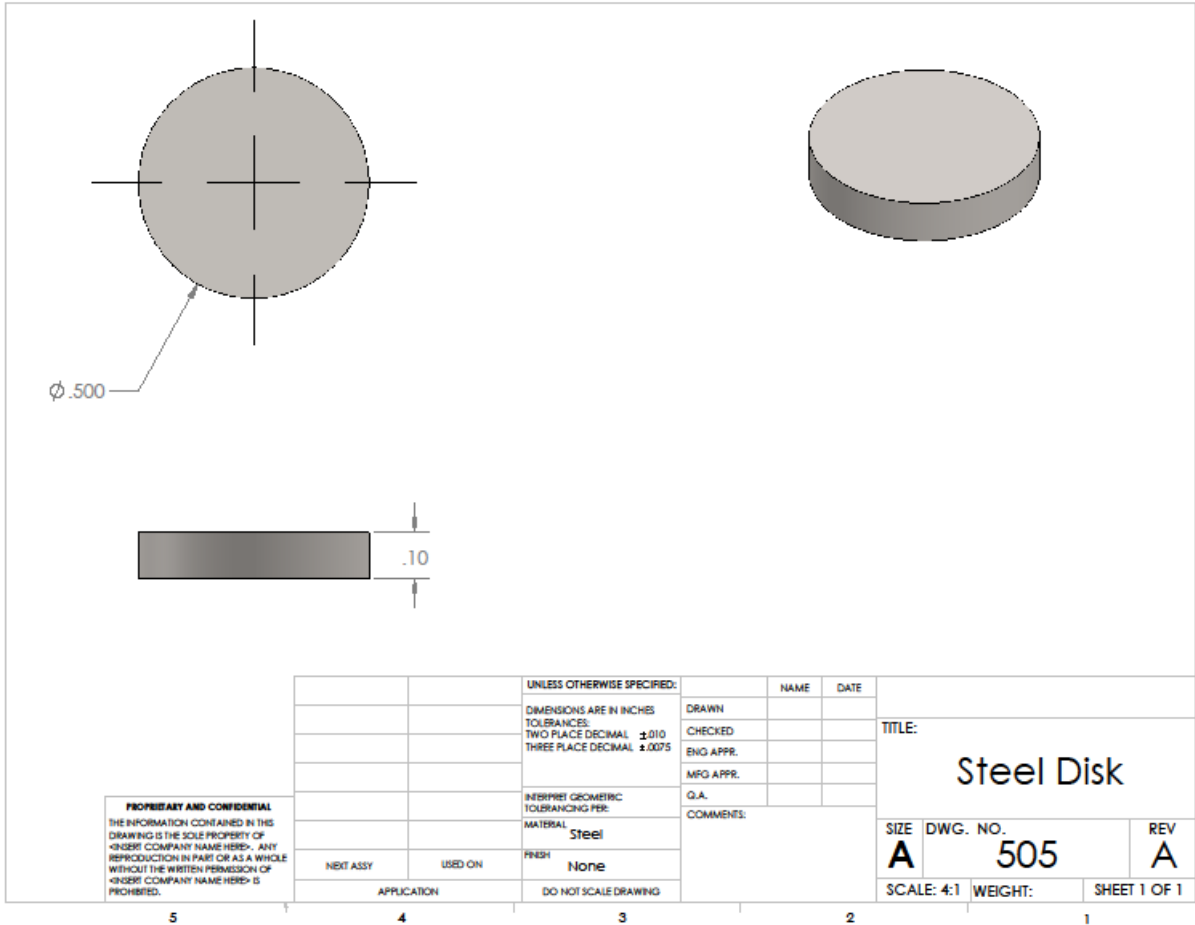


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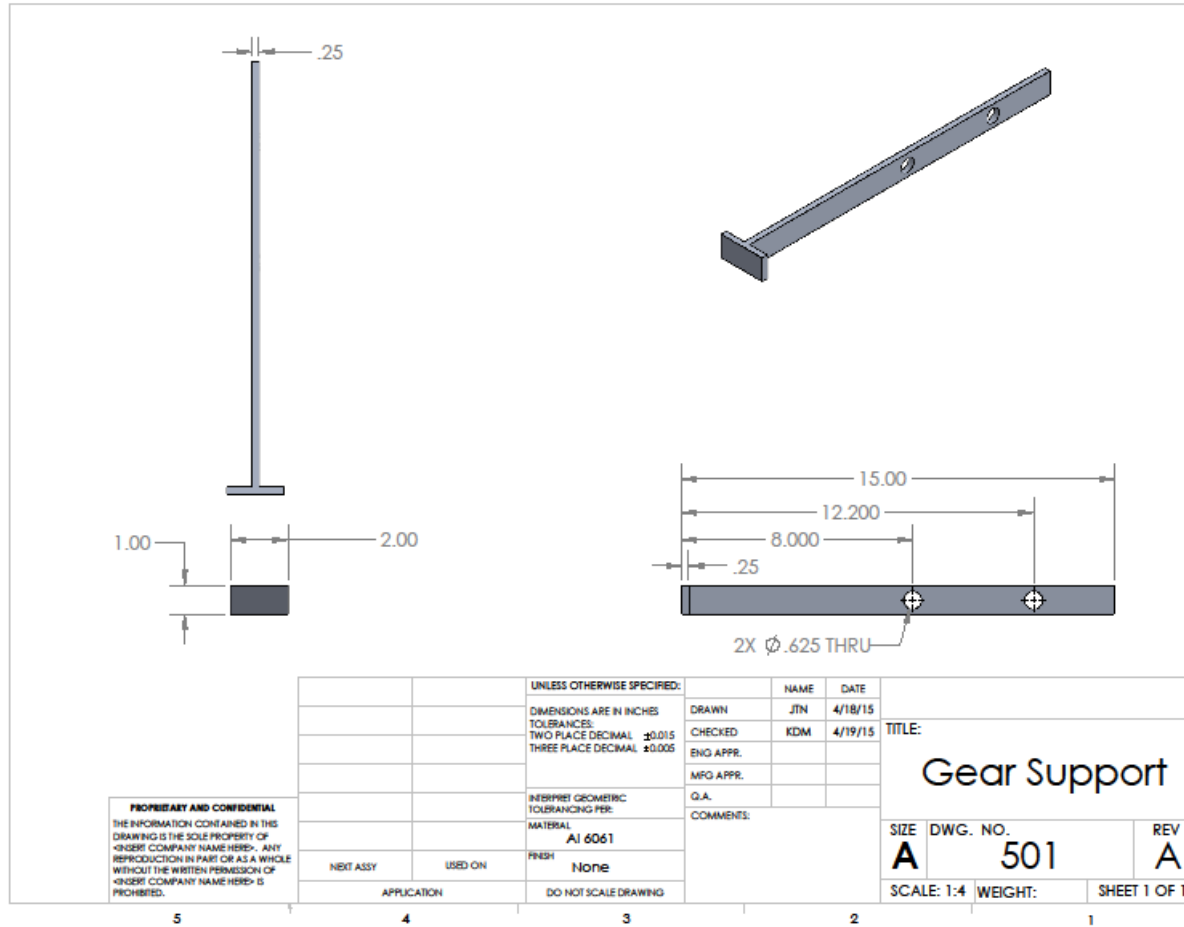
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		TOLERANCES	CHECKED	KDM 4/16/15
		TWO PLACE DECIMAL ±0.010	ENG APPR.	
		THREE PLACE DECIMAL ±0.002	MFG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.	
		MATERIAL	COMMENTS:	
		Aluminum		
NEXT ASSY	USED ON	FINISH		
		None		
APPLICATION		DO NOT SCALE DRAWING		

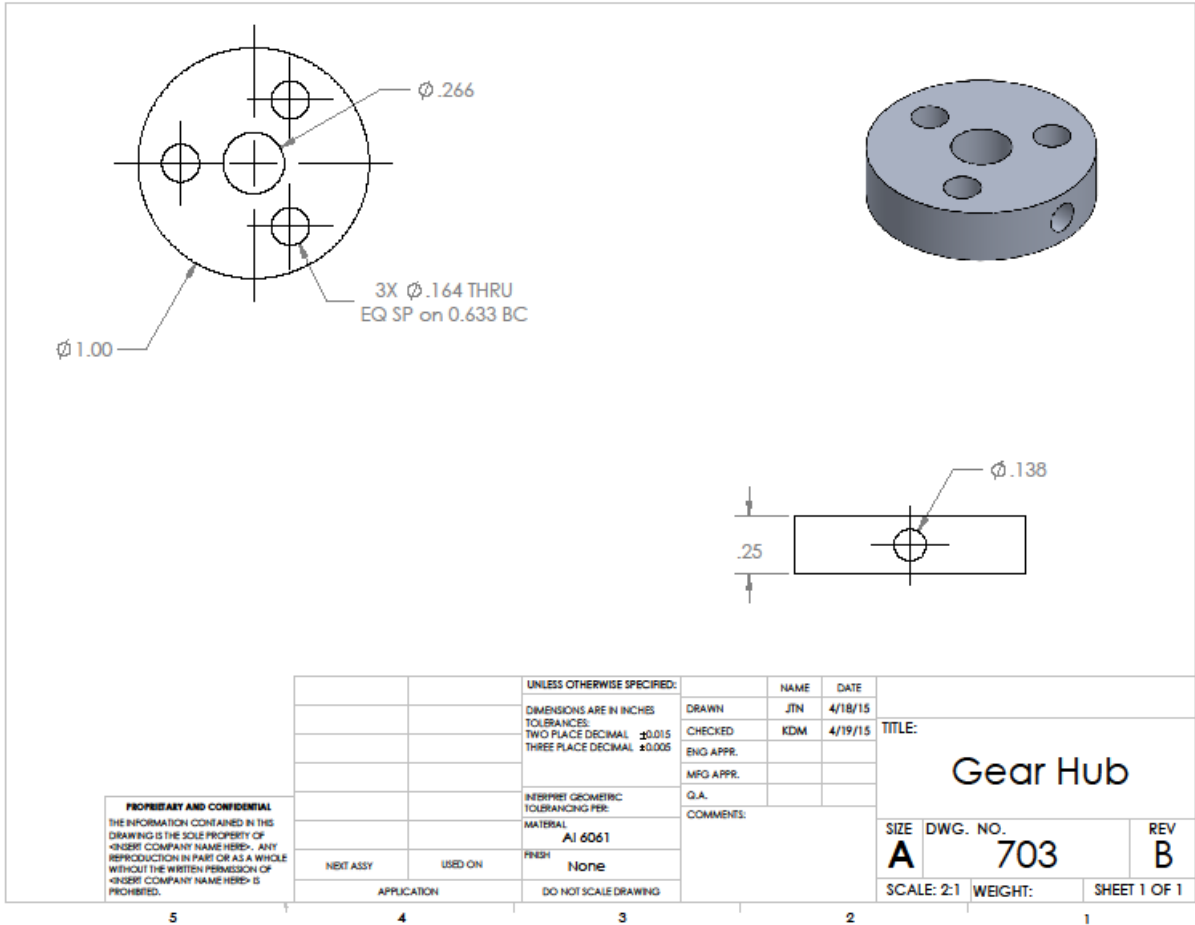
TITLE:		
Male Electric Rails		
SIZE	DWG. NO.	REV
A	504	D
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



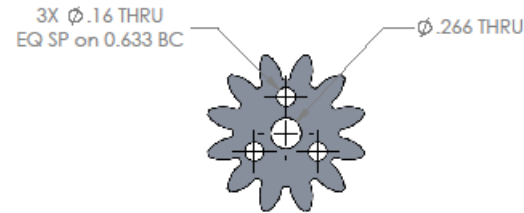
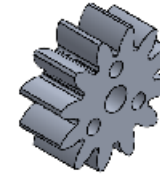
# Appendix E: Drawings of the Battery Rail Assembly







Gear Specifications	
Module	0.1
Number of Teeth	12
Pitch Diameter	1.200 inches
Teeth Height	0.240 inches
Root Diameter	1.16 inches
Pressure Angle	32°



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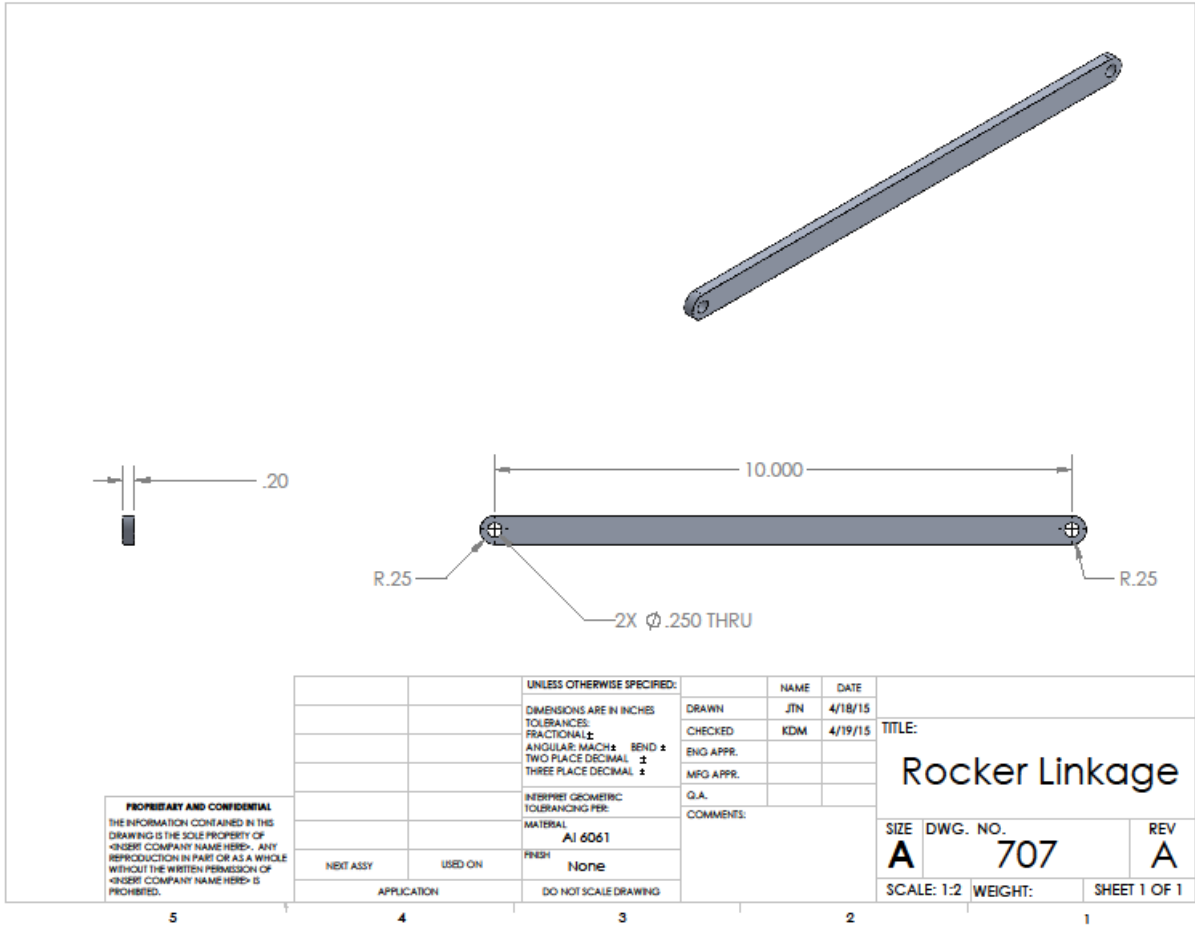
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		DIMENSIONS ARE IN INCHES		DRAWN	JTN 4/18/15
		TOLERANCES		CHECKED	KDM 4/19/15
		TWO PLACE DECIMAL ±0.015		ENG APPR.	
		THREE PLACE DECIMAL ±0.005		MPG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.	
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NEXT ASSY	USED ON				
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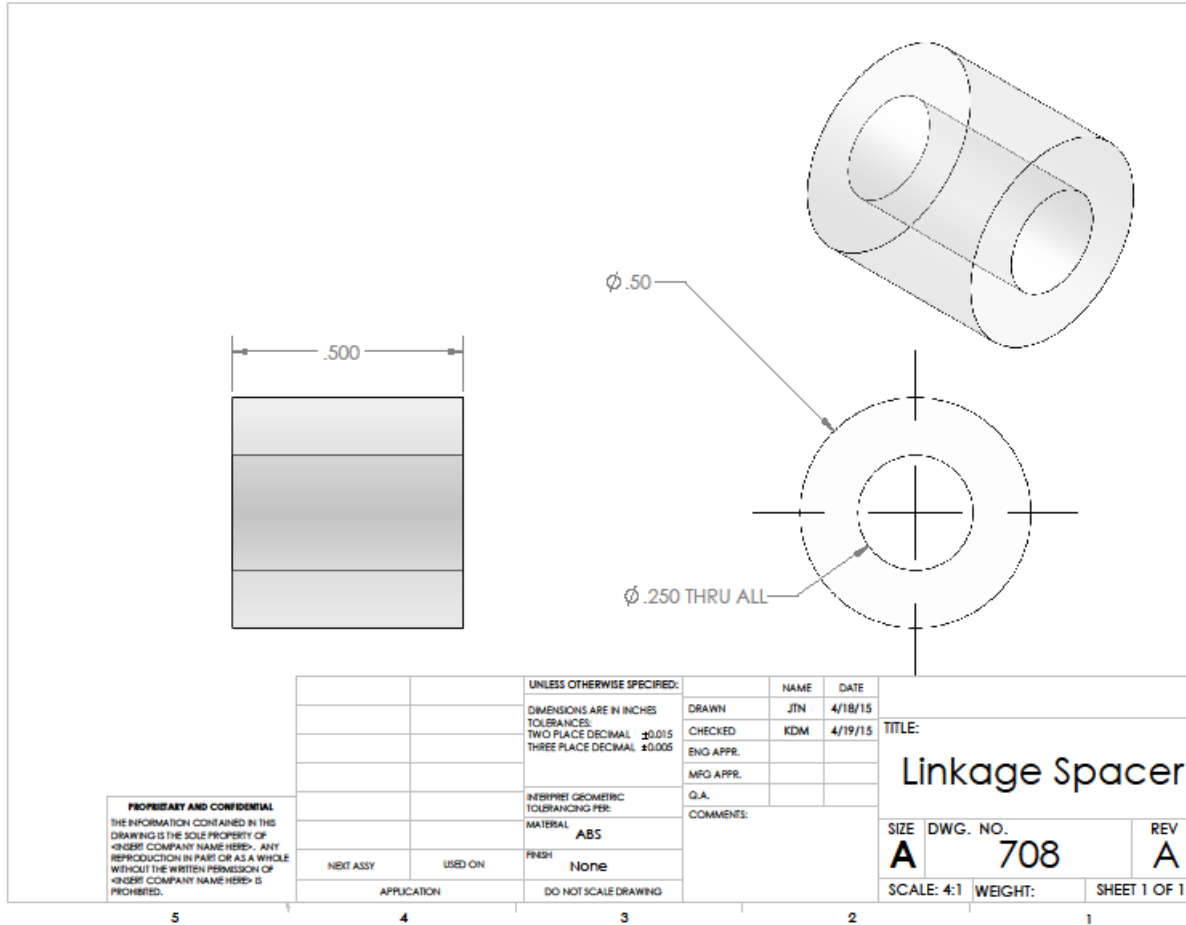
TITLE:		
Drive Gear		
SIZE	DWG. NO.	REV
A	705	A
SCALE: 1:1	WEIGHT:	SHEET 1 OF 1

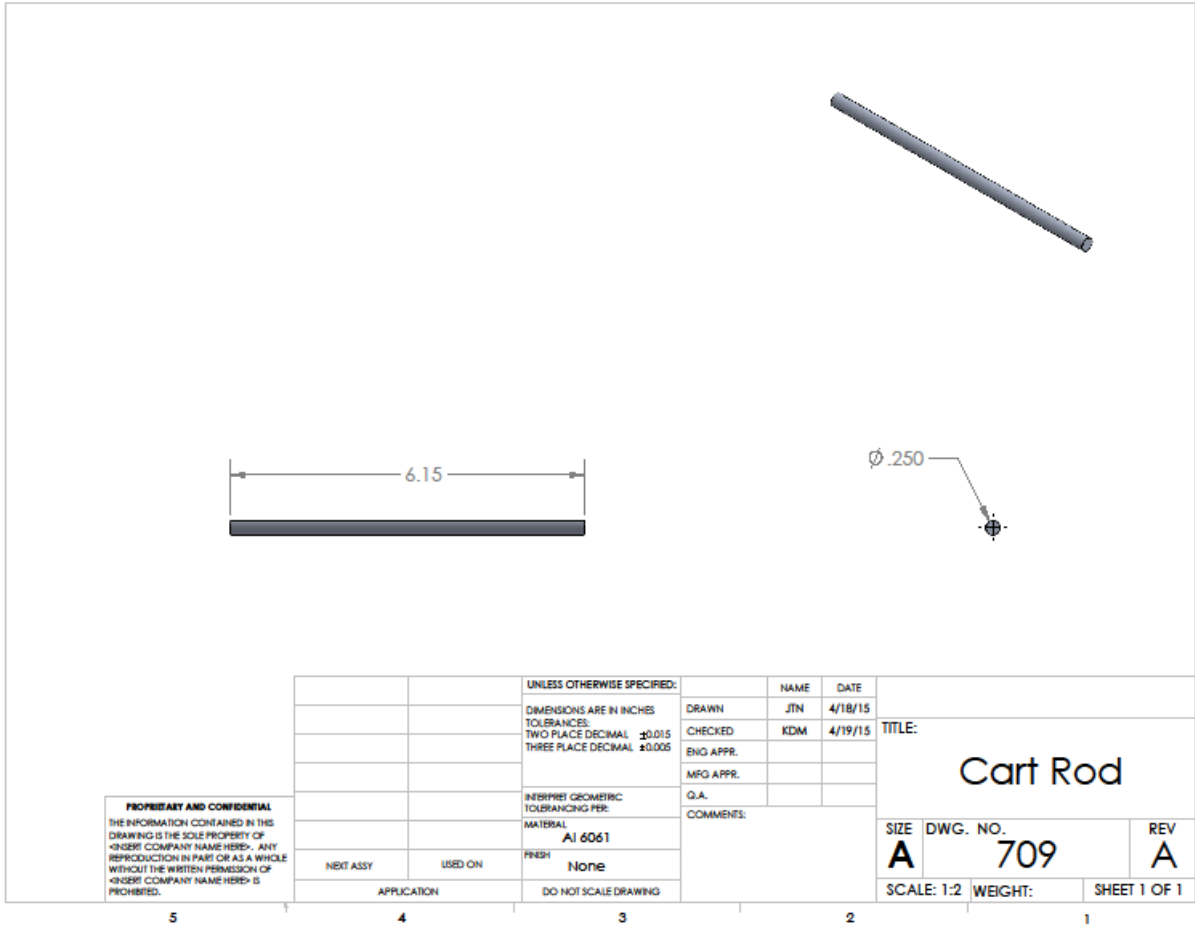
5 4 3 2 1

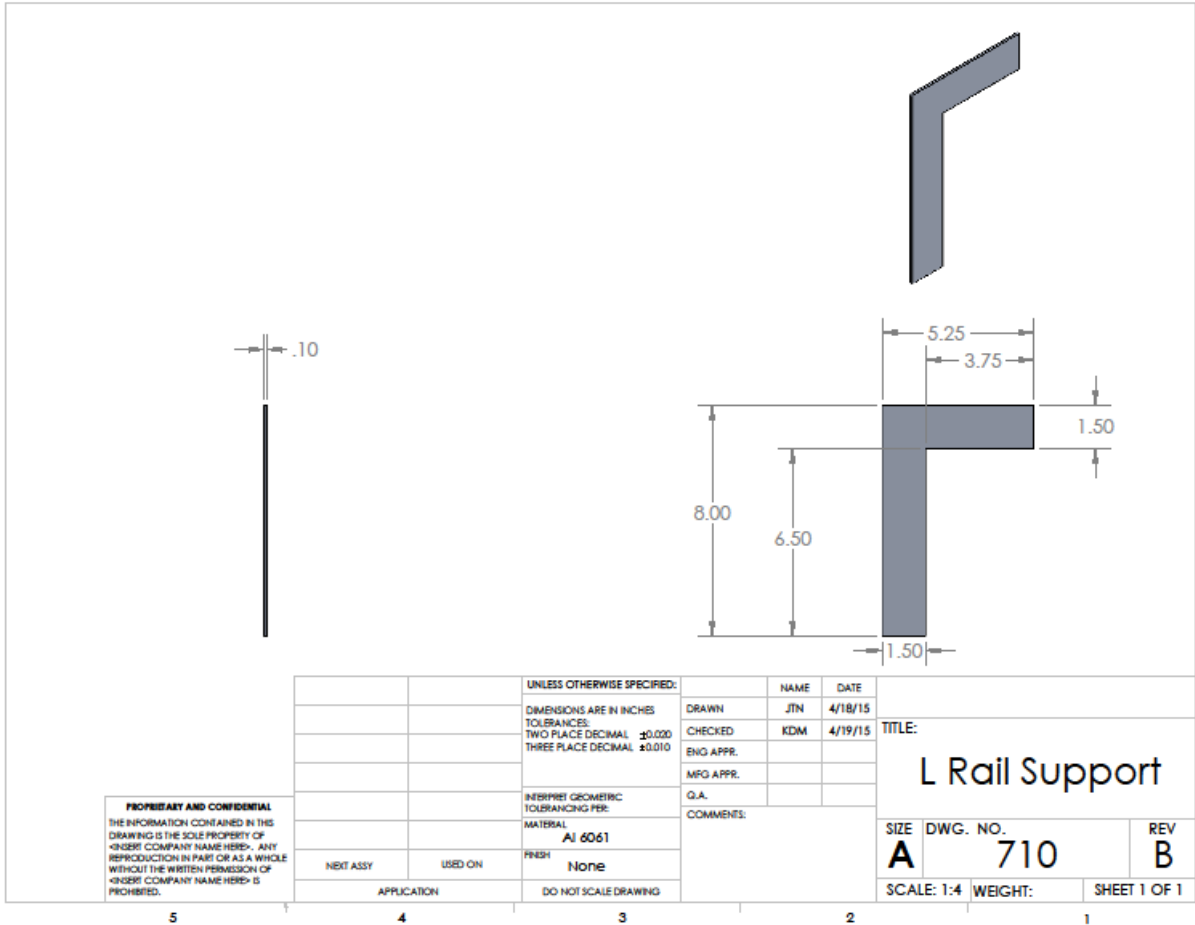






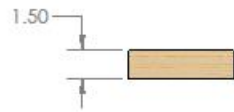






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		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES		DRAWN	JTN 4/18/15
		TOLERANCES		CHECKED	KDM 4/19/15
		TWO PLACE DECIMAL ±.020		ENG APPR.	
		THREE PLACE DECIMAL ±.010		MPG APPR.	
		INTERPRET GEOMETRIC TOLERANCING PER:		Q.A.	
		MATERIAL		COMMENTS:	
		Wood			
NEXT ASSY	USED ON	FINISH			
		None			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:		
Rail Mounting Block		
SIZE	DWG. NO.	REV
<b>A</b>	<b>712</b>	<b>A</b>
SCALE: 1:6	WEIGHT:	SHEET 1 OF 1

5

4

3

2

1

