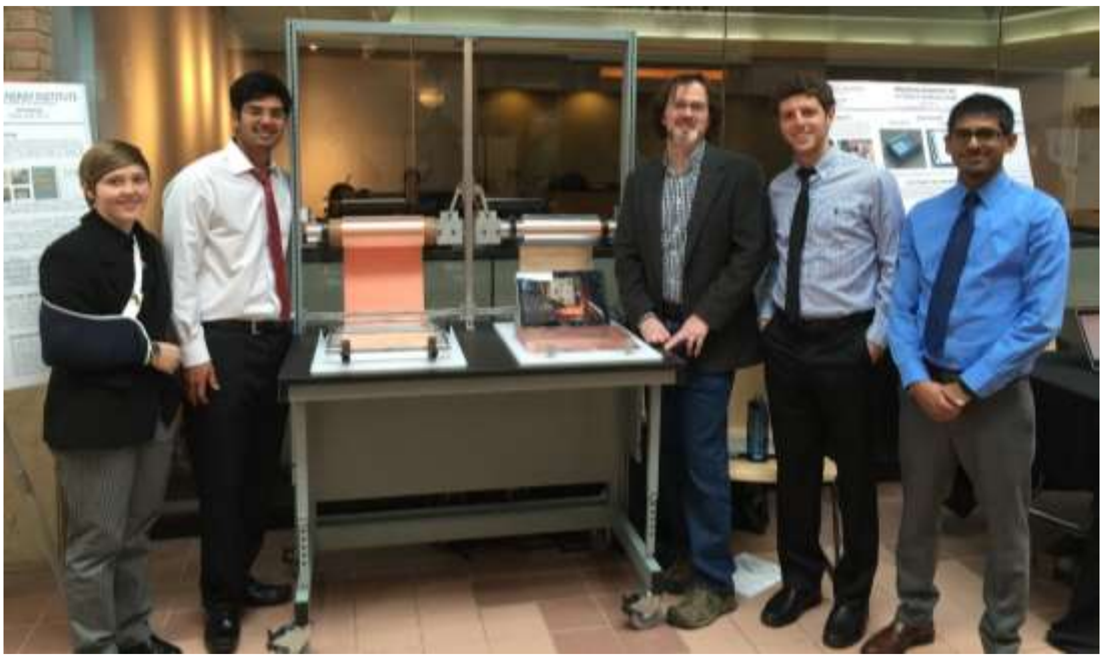
University of Michigan

Mechanical Engineering 450: Design and Manufacturing III

Project 19

April 22, 2015

Design and Fabrication of a Li-Ion Battery Electrode Coating Fixture



Aakash Agarwal

Daniel Gilden

Raji Kiridena

Kelsey Wiers

Executive Summary

We worked with the University of Michigan Energy Institute Battery Fabrication and Characterization User Facility, whose goal is to provide resources for researchers to fabricate batteries regardless of the experience level of the researcher in battery fabrication. The piece of equipment we worked with was the Mathis Labcoater, which evenly coats foil that will be used as the cathode and anode of a Li-Ion battery with electrochemical slurry, and cures it in an oven. A frame is used to hold the foil during the coating and curing process, and can be removed from the machine to load and unload foil. However, the process for loading foil into the frame was very difficult, and left the loaded foil with many undesirable wrinkles, which would create an uneven coating of slurry on the foil surface. This uneven layer would lead to a poorly performing battery which could explode under extreme conditions. Our goal was to create a process and equipment to simplify the loading process for the user, and decrease the number and significance of wrinkles created in the foil. On top of reducing created wrinkles and increasing usability, our other goals were to: have a high success rate in loaded foils, minimize the wasted foil on each loaded piece of foil, make our equipment compatible with the current lab setup, include a place to hold the roll of foil, make all pieces manufacturable using ME department facilities, minimize the cost of the system.

The design chosen to solve these problems was made up of five main sections: a pair of hinged bars to hold the rolls of foil, a guide system to feed the foil into the loading area, uprights to hold the frame in place, redesigned clamps to hold the foil, and a guide when cutting the foil off the roll. The design concepts were chosen by ranking from an idea pool for each subsystem. Most parts were fabricated in the ME machine shop, with the rest bought, then assembled in the ME X50 room over the course of a month. Our main costs were in ordering non-standard stock, and we were under budget.

Tests to validate the success of our system involved loading foil into the frame using both the previous and new systems, and recording important measurables, including number and severity of wrinkles created, loading time, and waste length. The tests showed that our system was a significant improvement on the previous system, with wrinkles and loading time being significantly decreased, and waste length falling within our specification. Our overall tested success rate jumped from 0% on the old system to 96% on the new system.

Improvements that could be made to the system include improving the clamp design to be more user friendly, and hold the foil more tightly, and improving the foil roll holders to reduce the friction between it and the rolls, and a guide to show where the foil roll is properly aligned with the frame. Overall, our new process and equipment made a previously un-usable piece of equipment very user-friendly to use, and we consider it a success.

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Background

This Li-Ion Battery Electrode Coating Fixture project was sponsored by the University of Michigan Energy Institute and the team worked in the Battery Fabrication and Characterization User Facility under the Senior Lab Manager, Dr. Greg Less. This lab is intended to be used to build prototype lithium-ion batteries by anyone who wants to test their research.

The process of manufacturing lithium-ion batteries (Fig. 1) begins by mixing electrochemical slurry composed of either a graphite compound for the anode [1] or a lithium-oxide compound for the cathode [2] which acts as electron collector during the ion flow within the battery cell. [3] This slurry is then spread evenly onto the electrodes, most commonly through a process called slot die coating.[4] The electrodes in lithium-ion batteries are made of copper (anode) [5] and aluminum (cathode) foil.[6] It is very important to achieving ideal battery performance that the slurry coat is uniform on the electrodes. If a part of the electrode has more or less slurry than the rest, there will be a difference in the lithium-ion concentration which creates hot spots in the battery. These hot spots lead to decreased battery life or performance and in extreme cases can lead to battery explosion.[7] Our project focuses on ensuring the lab has the capability to coat electrodes with slurry as uniform as possible.

After the electrode has been evenly coated with slurry, it is put into an oven to dry the slurry. Once both the anode and cathode have been coated, they are pressed together with a separator between them in a process called calendering.[8] The purpose of calendering is to lower the porosity of the electrodes thereby eliminating unnecessary volume from the battery.[9] If a flat cell battery is being produced, the electrodes get a slit cut into them for the terminal of the battery then several layers of electrode pairs are stacked and packaged together to form the battery. To produce a cylindrical cell, a long sheet of electrode material is rolled into a cylinder of the correct diameter and put into a battery casing.[10]

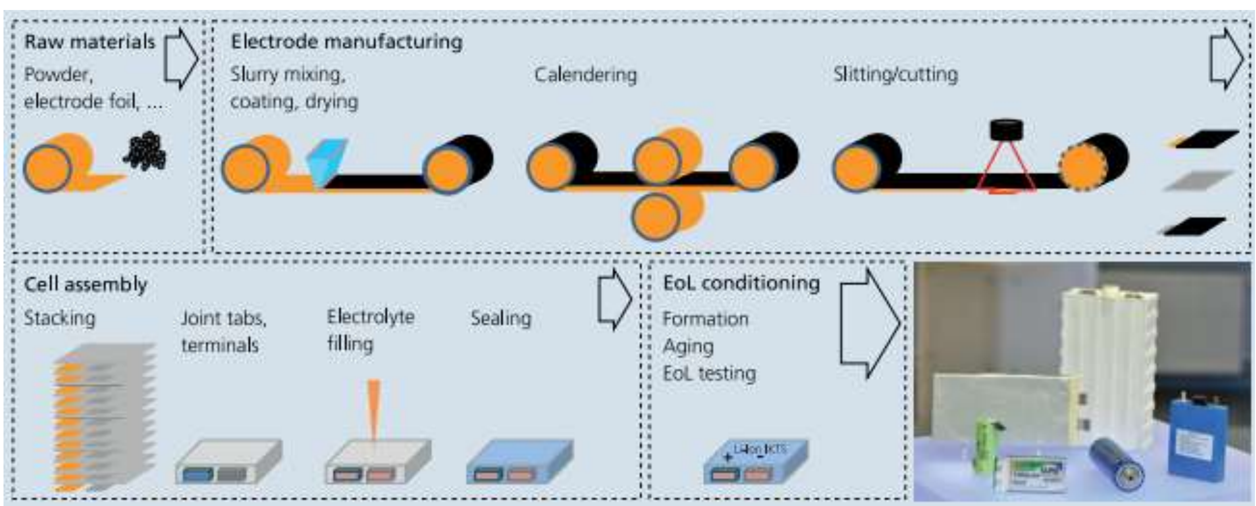

Figure 1: Lithium-ion batteries are produced by coating the foil electrodes with an electrochemical slurry, drying the slurry, pressing the electrodes together, cutting them, and packaging them.[7]

Problem Description

Our sponsors are facing problems working efficiently with the frame of the Swiss Mathis Labcoater Type <<LTE-S>> machine (Fig. 2) which was purchased only a few months prior to the introduction of this project and hasn't yet produced any acceptable products.[10] The machine can be used as a dryer and laboratory coating table.[11] The frame, which holds the electrode foil to be coated and dried, is of great importance in battery prototype production. The technique and success of loading foil into the frame depends on the amount of training and experience that the user has with the machine. The current process has not been efficient for the purposes of the Battery Lab. Since the lab is meant to be used by anyone looking to make a prototype of their research, it would be ideal to have a process that does not require too much training and is easy to learn. Loading the foil into the frame is very tedious, does not follow a fixed process, and requires a lot of human handling, which leads to too many wrinkles in the foil. In addition, the frame only works for foil which is the entire width of the frame because the holding clamps are warped and only hold on the edges, which causes non-uniform tension on the foil, adding to the winkles (Fig. 3).

Figure 2: Mathis Labcoater Type <<LTE-S>> coater and drier used in the Battery Lab [11]

Figure 3: Non-uniform tension causes additional wrinkles in the foil.

Wrinkles in the foil are detrimental to the battery performance because they lead to a non-uniform slurry application and too much rework and waste material, which is hoped to be avoided due to the high cost of foil and other materials.[7] We will measure the success of the project mainly by comparing the formation of wrinkles before and after a solution has been implemented. Our goals are to make this process easier and more efficient, which should lead to a decrease in wrinkling and a more uniform slurry coat. We believe we can achieve this by designing additions to the current frame and replacing the clamping and tensioning system in order to reduce the amount of times the foil is touched directly by hand.

Benchmarks

In order to compare our design and evaluate its effectiveness, we will look to four benchmark processes that are currently used for foil coating in battery production.

The first one, which is also the simplest process, is the "By Hand" process. It requires the user to cut the foil to the required dimensions by hand and place the foil on a flat glass surface. The right amount of slurry is added on top of the foil and, using a special knife, the user spreads the slurry uniformly over the surface. The foil with fresh slurry is then placed in a vacuum oven to dry the first coated side. Once the slurry is completely dried, the user repeats the same procedure for the other side of the foil. This process is not suitable for the Battery Lab because it requires a lot of practice and experience. It also requires the user to be extremely careful when handling the foil with the fresh slurry since it could easily rip and therefore takes a lot of time.[10]

The second process that we will compare our design to is the one that is currently being used at the Battery Lab with the Labcoater Type <<LTE-S>> machine. With this method, the electrode foil is loaded by hand into a frame which applies tension, the frame is put on the coating machine where a blade spreads the slurry evenly across the foil, and the frame is then pushed into the oven to dry. To coat the other side, the frame is pulled out, flipped over, coated, and dried again.[10]

The Labcoater Type <<LTE-S>> machine is designed to be used with metal foil, fabric and plastic. However, the University of Michigan Battery Lab and the Pennsylvania State University Battery Lab are the only two places that use this machine for battery production. The third benchmark comes from Pennsylvania State University, where our sponsor's colleague has been using the machine for a long time and after a lot of training he has gotten proficient at loading foil into the frame. The technique he uses follows the same pattern as the one that it is currently used at University of Michigan Battery Lab, but the experience he has allows him to do it very quickly and efficiently, therefore he does not experience wrinkling.[10] Even though this would be the cheapest solution for our problem, the purpose of the University of Michigan Battery lab is to be used by anyone that wants to test a new type of battery and does not have enough time to practice the process until they reach the necessary level of expertise.

The last benchmark process is that used in mass battery production. In this process, the machine automatically does the coating process in a continuous manner. The machine uncoils the foil roll, coats both sides of the foil at the same time, dries them, and cuts the final coated electrodes to the right dimensions.[12] The machine shown below (Fig. 4) will be available on the University of Michigan Battery Lab and it mocks a large scale production machine that will be available to prototyping.[13] The team decided to use this benchmark to capture some of the concepts of uncoiling the foil roll and placing the foil into the right position in order to be coated.

Figure 4: Industrial scale battery production machine: CIS Custom Multi Head Coater.[13]

The team also found some patents that could be used as starting points for solving our problem. One of them is the *Wrapping paper fixture,* which is a simple wrapping/unwrapping system patented in 1939 by Lawton Frank H (Fig. 5, pg. 4).[14] The mechanism designed by Frank allows its users to wrap/unwrap the roll without touching the roll with a combination of a spring system as well as cutting the foil with a mounted knife.

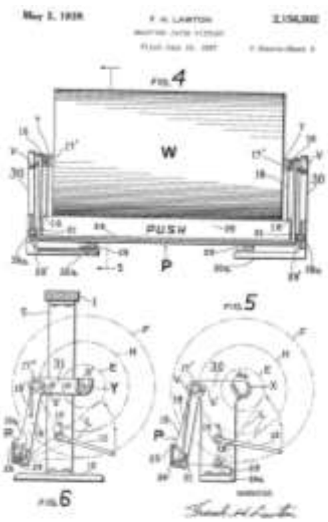

Figure 5: Patented unwrapping roll system [14]

The second patent found is a tensioning system created by Ricky Paul Bennett in 2013 called *Balanced stencil foil tensioning frame with foil alignment fixture* (Fig. 6).[15] In this invention the frame grips/locates the edge of the foil to stop it from moving laterally and then depresses the foil, resulting in a tensioning of the foil. In this mechanism a few of tension segments can move in a linear direction to create a uniform foil tension (Fig. 7). Once the required tension is achieved, the user places the top enclosure on top of the tensioning frame. The team analyzed the tensioning system and it would be a great starting point to our tensioning system design system it is simple and very effective.

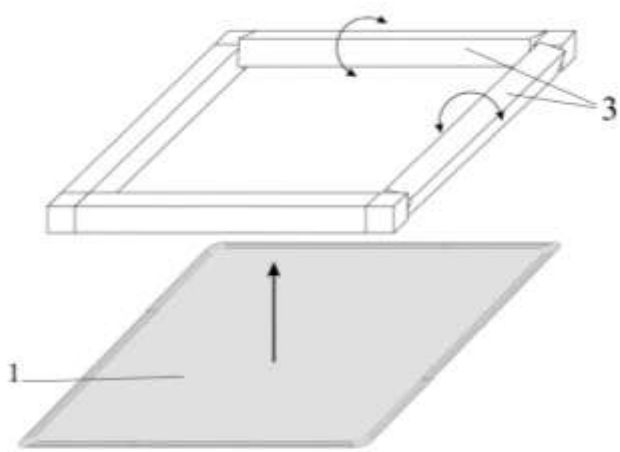

Fig. 6: Tension mechanism frame [15]

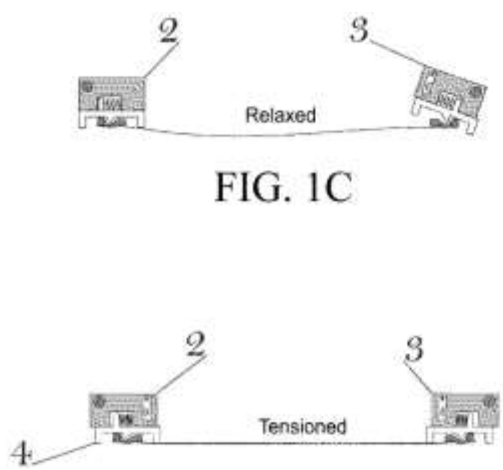

Fig. 7: Tension mechanism [15]

The team also looked at a patent mechanism that offers another solution to the the non-uniform tension applied to the foil. The name of the invention is *Paper tension control device for printing presses* and it was created in 1926 by Laycock Kenneth G.[16] It is meant to be used in newspaper press printing, but the main concept of it could also be used for solving our problem. It consists of a spring roller tension system that effectively eliminates problems related to under or over tensioning the paper (Fig. 8, pg. 5).

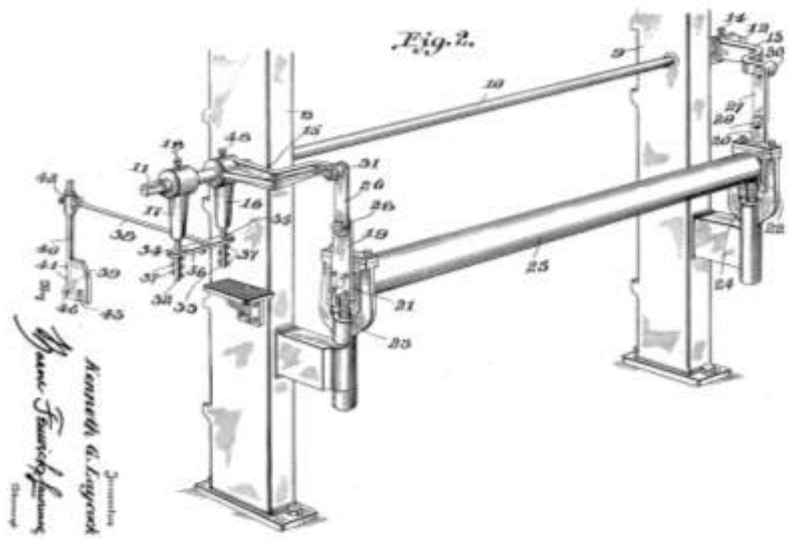

Figure 8: Newspaper press printing tensioning system [16]

User Requirements and Engineering Specifications

After speaking to our sponsors, examining the current process for loading foil into the coating machine, and looking at current benchmarks, we were able to create a list of user requirements and engineering specifications we would like to meet in order for our design to be considered a success. We have split these requirements and specifications into basic physical engineering requirements, usability requirements, and foil quality standards. We have further subdivided our requirements into “needs” - those which must be met - and “wants” - those which we would like met, but for which not meeting requirements does not result in the design being considered a failure.

1: Physical Engineering Requirements

Needs:

1.1: The new design must be able to aid in loading various sizes of foil into the Labcoater frame.

Based on measurements taken in the lab, the Labcoater frame currently can load foils with lengths between 143 and 365mm, and widths under 280mm. The dimensional standard set by the current design must be met. In addition, the aluminum and copper foils used in battery fabrication will be between 9 and 15 µm, so our design must be able to clamp foils of those thicknesses in place.[17][18]

1.2: Any design element holding a foil roll must fully support a roll up to 10kg in weight.

In the design process, it may be found that user error can be reduced by assigning a specific space for the foil roll. This may involve elevating the roll, in which case the design element supporting the roll must be able to support up to 10kg.[17][18]

1.3: The new design must be fully compatible with the current machine and frame.

While it would be possible to completely redesign the Labcoater frame, it is significantly more cost and time-effective to only make small, simple changes that do not significantly change the frame. It is also important that the final design is actually compatible with the unchanged portions of the frame and machine - while this seems glaringly obvious, it serves to highlight the fact that there are parts of the current design that do work well, which should not be modified.

2: Usability Requirements

Needs:

2.1: The battery loading process must be simple to use for anyone wanting use this lab.

Since the lab could be used not only by people very experienced in battery fabrication, but also by people who have never fabricated a battery before, the user experience must be as simple as possible. In order to measure this, the current process was analyzed, strengths and weaknesses identified, and benchmarks created that would imply an improvement in usability over the current process. It should take under 30 minutes for one training session, under 10 minutes for a piece of foil to go from the roll to being coated, the foil should be handled less than six times per load, and 90% of loads should be successful. The former two requirements meet benchmarks set by the current process, while the third reduces user error, and the fourth is a goal set forth by our sponsor.

2.2: All four high probability failure points in current setup must be eliminated.

After an analysis of the current loading process, four steps have shown to have nearly a 100% failure rate for foil in terms of severity of wrinkles, regardless of how well previous steps were carried out. In each of these steps, wrinkles are almost always created in the foil, leading to restarting the loading process. These four points are: loading foil into the first clamp, loading foil into the second clamp, tensioning the left side of the foil, and tensioning the right side of the foil. The reasons for these failures can be attributed to a very thin foil coupled with complicated clamps, for the former two failure points, and the difficulty of perfectly even tensioning on both sides, for the latter two. The number of high probability failure points must be reduced to zero.

Wants:

2.3: Decrease loading time and training time to under one minute and five minutes respectively.

These requirements are once again based on the current process, but now improve upon the current process rather than meet them as in the similar “need” requirement.

2.4: Include a foil cutting mechanism and storage rack for foil roll in our design.

In talking to our sponsor and analyzing the current process, it has been seen that the first mistakes a new user may make is in cutting the foil to size, currently done with scissors, and moving the roll of foil from its current storage area in a desk drawer to a workstation, where a user may accidentally bump the roll against an edge and tear the foil. A very simple way to remove these points of user error could be to include a standard cutting mechanism and storage rack for the foil in our design. These both reduce the number of decisions a user has to make, the former showing the user exactly where to cut foil, and the latter removing the chance that a user may tear the foil while moving it.

2.5: Decrease major failure points from nine to two.

There are nine major failure points in the current foil loading process. A major failure point is a point in the process where if something is done incorrectly, the user may need to completely restart the process. The nine major failure points are: moving the roll from its storage spot to its cutting area, cutting the foil, moving the foil from the cutting area to the loading area, placing the foil in the first clamp, placing the foil in the second clamp, tensioning the left side of the foil, tensioning the right side of the foil, moving the frame from the loading area to the machine, and using the coating knife. It would be ideal to reduce this number of major failure points to two, which would translate to removing three failure points past the four described in the similar "need" requirement.

2.6: Design a robust enough loading jig that maintenance is needed only once a year, or less frequently.

It would be ideal to build a robust enough loading jig that requires maintenance only once a year. However, this would be a long term goal, and not necessarily testable by this team in our 4 months with the project. Also, because of the difficulties in foil loading in the current process, the process has never been carried out on its intended scale, so it is impossible to know the reliability of the physical components of the current process.

3: Foil Quality Standards

Needs:

3.1: Waste less than 100mm of foil length per clamped side, or 200mm foil length total per loaded foil.

Every time foil is loaded into the frame, there is an amount of excess material at each clamped end. Since this foil is relatively expensive, the sponsor would like less than 100mm of waste length per side, or 200mm total per sheet.

3.2: Minimize foil wrinkling in loading process.

This is arguably the most important specification, and is the crux of our design. As explained in earlier sections, wrinkles cause a decrease in battery performance, and can even lead to battery explosions. We will use two methods to measure wrinkles then combine those measurements to determine the acceptability of each loaded foil. This specification will be used to determine whether a foil is a "pass", and the process has resulted in a good piece of foil, or a "fail".

Method 1: 2D image analysis

Similar to grain size analysis [19], this will involve using a black and white flat image of the foil (Fig. 9, pg. 8) to try to analyze wrinkle density for a standard foil sheet. This method will be able to accurately give a measure of how wrinkled a standard sheet is.

Figure 9: Black and white image of a wrinkle in the foil to be used for 2D image analysis.

Method 2: Characterization of wrinkles by type

All wrinkles created on a piece of foil can be characterized as Type 1-4 (Fig.10). Wrinkles of Types 1-3 are generally caused by foil handling, while type 4 wrinkles are caused by tensioning the foil. A piece of foil will pass this specification if for a standard 280mm x 365mm copper sheet, if there are under 20 Type 1 wrinkles, under five Type 2 wrinkles with under five intersection points, and no Type 3 or 4 wrinkles. This is somewhat qualitative and errors could come about when trying to characterize the wrinkles by type. For example, a small Type 3 wrinkle could potentially be mistaken for a Type 2 wrinkle, and a piece of foil could pass when it should not. This is why we used characterization in tandem with 2D image analysis.

Figure 10: Wrinkle types 1 (top left), 2 (top right), 3 (bottom left), and 4 (bottom right). Wrinkle types 1-3 are caused by handling, while type 4 wrinkles are caused by tensioning. The severity of the wrinkle increases with the value (e.g. type 1 wrinkles are less severe than type 3 wrinkles).

Wants:

3.3: Waste under 25mm of foil length per clamped side, or 50mm foil length total per loaded foil.

As explained in requirement 3.1, there is an amount of excess material at each clamped end of each foil piece. While the sponsors do not necessarily need this little excess, it would be advantageous to minimize was as much as possible. If it is possible to save over 75% of the waste from requirement 3.1, it could be possible to actually load the saved material as another full sheet.

Concept Generation

As the first step towards a design solution, the team came up with some design ideas that could bring efficient and feasible approaches for the final concept. We used two methods to generate the concepts: functional decomposition and brainstorming. The design was broken down into five different subparts: foil roll rack, foil loading mechanism, clamping system, tension system, and cutting mechanism (Fig. 11). Cutting was designed to be the last step because it can't cause additional wrinkles if the foil is already properly attached to the frame. For each sub-function, the team considered who the user is and the requirements of the project and of each subpart when generating possible design ideas. Samples of concepts are shown below and all generated concepts are described in Appendix A (pg.29).

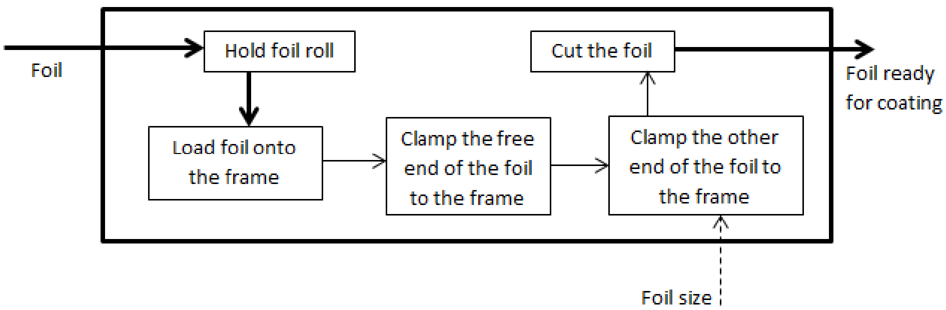

Figure 11: Functional decomposition

For the foil roll rack, the team assumed that the rack has to be able to withstand the weight of the roll as well as any other load generated by uncoiling the roll. The main concepts involved the availability to store two rolls (anode and cathode) on a rod, like the example in Figure 12.

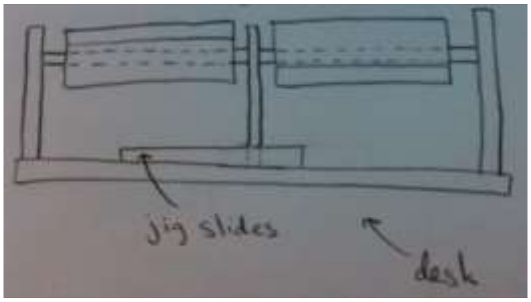

Figure 12: Side by side foil roll holders

The foil loading mechanism is of extreme importance and it should be carefully chosen in order to eliminate failure points. The main concepts for this function involved a bar the foil rolls under to keep it at the correct height and a mechanism to keep the foil attached to this bar so it doesn't flap around and get wrinkled (Fig. 13, Fig. 14).

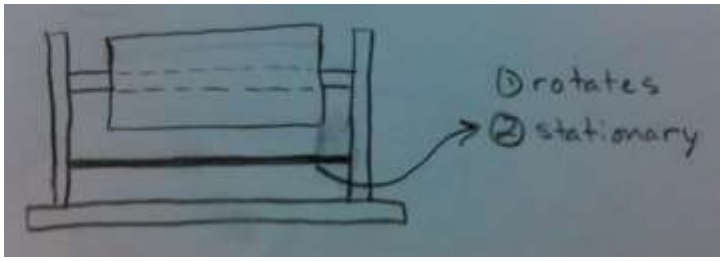

Figure 13: The foil rolls under the dark bar and is loaded onto the frame.

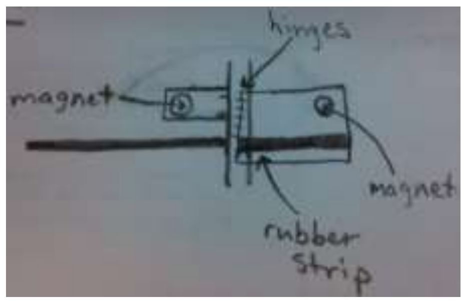

Figure 14: The foil can be held against the bar with a magnetic clip.

The third subpart analyzed by the team was the clamping system used to hold the foil in the frame. We generated concepts mainly that have a lever that rotates upward (Fig. 15), so the foil doesn't get wrinkled by fitting it into a slot, then the lever closes down on the foil to hold it in place and apply tension.

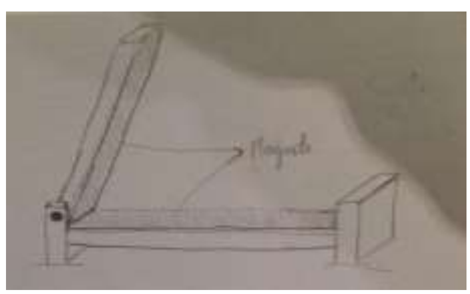

Figure 15: The clamp rotates up then is closed on top of the foil.

In order to provide enough tension to the foil for an easy and uniform coating process, the team came up with a variety of designs that interact with the clamping system. One idea comes from a similar mechanism to the patent shown in Figures 6 and 7 (pg.4) (Fig. 16).[15]

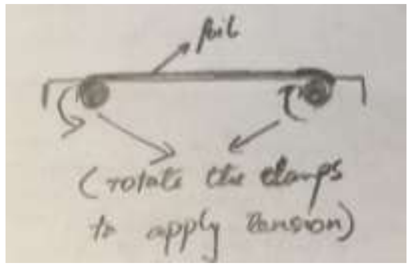

Figure 16: Tension mechanism with clamps that grip the foil and rotate outward.

The last sub-function is the cutting mechanism that allows the user to cut the foil from the roll once it is loaded into the frame at the right dimensions. We mostly came up with a variety of different blade designs that can be attached to our design, like a paper cutter style knife (Fig. 17).

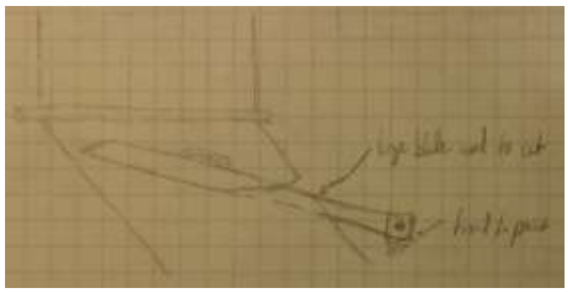

Figure 17: Cutting mechanism design concept utilizing an attached paper cutter blade.

<u>Concept Selection</u>

After discussing the needs and wants of the project with our sponsor, we chose key criteria for a Pugh cart to help us rank our concepts. The criteria were given weights ranging from 1 to 5 where a 5 indicates the highest priority. The criteria are as follows:

1. Reduction of wrinkles (with weight of 5) - The occurrence of wrinkles is the main problem our sponsor. Therefore, a selection of a concept that minimizes the wrinkles from the current process was our highest priority.

2. Loading time (with weight of 3) - It was important to the sponsor that our design be easy to use, which makes loading time a relatively high priority.

3. Foil handling amount (with weight of 3) - This ranks the amount of times a user would touch the foil while loading the frame, with less touches yielding a better score. Less foil handling means less wrinkle generation.

4. Number of failure points (with weight of 3) - The current process of loading the foil into the frame generates nine failure points. A decrease would automatically reduce the wrinkles.

5. Amount of waste (with weight of 2) - It would be ideal to minimize the area of metal foil wasted on each side of the clamp after the coating is performed on the foil. The sponsor did not show that waste was a huge concern.

6. Ease of maintenance (with weight of 2) - Our design should have low maintenance requirements i.e. once in a year.
7. Manufacturability (with weight of 1) - Our design needs to be something that we are able to build within our time and resource constraints.
8. Cost (with weight of 1) - The budget for our project is $400.

For each sub-function, we ranked each generated concept on a scale of 1 to 5 for each criterion, with a 5 being the best possible solution. We also discussed each generated concept with the sponsor and accounted for those discussions when choosing which design to further pursue.[21]

<u>Foil Roll Rack</u>

We generated five different concepts for designing the foil rack: Stacked, Side-By-Side, One On Each End, One-Holder and None (Fig. 18). The first three ideas would hold two foil rolls, the fourth would hold one, and the last would not hold any. We chose to move forward with the side by side foil holders (Fig.A.1.2, pg. #29) because this design shared the highest score with one holder on each end and it fits into the provided work surface better. The disadvantage of "Side-By-Side" concept is that there will have to either be two jigs for the frame to fit in (one in front of each foil roll), or one jig that slides back and forth between the two foil rolls.

Characteristic	Weight	Stacked	Side-By-Side	One On Each End	One-Holder	None
Reduction of wrinkles	5	4	5	5	3	1
Loading Time	3	5	4	4	3	1
Foil handling amount	3	5	5	5	3	1
Number of failure points	3	4	4	4	3	1
Amount of waste	2	5	5	5	5	5
Ease of maintenance	2	4	4	4	3	2
Manufacturability	1	3	3	3	4	5
Cost	1	3	3	3	4	5
Overall Score		86	88	88	66	38

Figure 18: Pugh chart to rank each foil roll rack concept (Fig. A.1.2, pg. 29). We chose the side by side holders, which shared the highest ranking.

<u>Foil Loading</u>

We generated two concepts for a bar to keep the foil at the correct height and two concepts to keep the foil attached to that bar when the frame isn't being loaded (Fig. 19, pg. 13). We choose the non-rolling bar (Fig. A.2.1, pg. 30), instead of the rolling bar, because it is easier to manufacture, has lower cost, and requires no maintenance. The disadvantage of the non-rolling bar is that the excess friction could lead to tearing or wrinkling of the foil if used aggressively. We chose the clip to hold the foil (Fig. A.2.2, pg. 30) over the magnetic bar because the foil isn't magnetic and wouldn't actually be attracted to a magnet.

Characteristic	Weight	Rolling bar	Non-Rolling Bar	Magnetic Bar	Clip-To-Hold-Foil
Reduction of wrinkles	5	4	4	4	5
Loading Time	3	5	5	5	4
Foil handling amount	3	4	4	4	3
Number of failure points	3	4	3	4	3
Amount of waste	2	5	5	5	5
Ease of maintenance	2	4	5	4	4
Manufacturability	1	3	5	3	3
Cost	1	3	5	2	4
Overall Score		83	86	82	80

Figure 19: Pugh chart to rank each foil loading concept. We chose the non-rolling bar combined with a clip to hold the foil (Fig.A.2.1, Fig.A.2.2, pg. 30).

<u>Clamping System</u>

Five clamping system concepts were generated and scored (Fig. 20).We selected the square rubber grip clamping system (Fig. A.3.3, pg. 32), instead of the round rubber grip, because it has larger area of contact and will provide better grip. The disadvantage of the larger contact area is that it leads to slightly more wasted foil. The current system is very close to round rubber grip and experimentally we see that it doesn't hold the foil well.

Characteristic	Weight	Magnets	Toggle Clamp	Square Rubber Grip	Round Rubber Grip	Keep Current
Reduction of wrinkles	5	5	5	5	5	2
Use time	3	5	5	5	5	2
Foil handling amount	3	5	5	5	5	1
Number of failure points	3	3	5	5	5	2
Amount of waste	2	4	4	4	5	5
Ease of maintenance	2	3	4	5	5	5
Manufacturability	1	3	4	4	4	5
Cost	1	2	3	4	4	5
Overall Score		83	93	96	98	55

Figure 20: Pugh chart to rank each clamping system concept. We chose the square rubber grip (Fig. A.3.3, pg. 32).

<u>Tension System</u>

Again, five concepts were generated to add tension to the loaded foil (Fig. 21).We decided to use a combination of two concepts. We plan to remove the springs from the current tension system and add the concept of additional tension provided by inertia of the foil while uncoiling (Fig.A.4.1, Fig.A.4.4, pg.32)

Characteristic	Weight	Keep Current	Remove Springs From Current Method	Patent From DR1	1 Long Spring (Low k)	Tension From Foil Roll
Reduction of wrinkles	5	2	4	5	4	4
Use time	3	2	4	1	5	5
Foil handling amount	3	1	5	1	5	5
Number of failure points	3	2	4	1	4	4
Amount of waste	2	5	5	4	5	5
Ease of maintenance	2	5	5	2	5	4
Manufacturability	1	5	3	1	5	4
Cost	1	5	4	1	4	4
Overall Score		55	86	48	91	88

Figure 21: Pugh chart to rank each tension system concept. We chose to remove the springs from the current method and utilize tension from the back-force in the foil roll (Fig.A.4.1, Fig.A.4.4, pg. 33,34).

Cutting Mechanism

Of the generated cutting mechanism concepts, we chose to use the V-groove (Fig. A.5.1, pg. 34) with an unattached X-acto knife (Fig.A.5.2, pg. 35), even though it got the lowest score on the Pugh chart (Fig. 22). The V-groove provides an accurate and precise guide of where to cut the foil. We chose to use the unattached X-acto knife based on conversations with the sponsor because it is very easily replaced, inexpensive for the lab, and is still very easy to use.[21]

Characteristic	Weight	V-groove	Unattached Exacto Knife	Attached Exacto Knife	Paper Cutter Blade	Pizza Cutter
Reduction of wrinkles	5	4	4	4	4	4
Use time	3	5	3	4	4	4
Foil handling amount	3	5	4	5	5	5
Number of failure points	3	5	4	4	5	5
Amount of waste	2	5	5	5	5	5
Ease of maintenance	2	4	4	4	4	4
Manufacturability	1	3	5	4	4	4
Cost	1	4	4	4	4	4
Overall Score		90	80	85	88	88

Figure 22: Pugh chart to rank each cutting mechanism. We chose to use the V-groove (Fig. A.5.1, pg. #34) with an unattached X-acto Knife (Fig. A.5.2, pg. 35).

Design Drivers and Challenges

There were three primary design drivers that we took into consideration when designing the system. The three drivers are:

1. Reduce the wrinkles in the foil while handling, or at minimum add no wrinkles to the foil.

2. Reduce the failure points as much as possible – failure points being points at which the foil could tear or had a high probability of wrinkling to a degree that it would be necessary to restart the foil coating process.

3. Reduce user time and increase user friendliness.

We designed every mechanism of the loading station by taking all the drivers into consideration. The new foil roll rack keeps the foil roll in a safe place to prevent its continuous handling and additionally, uncoiling the foil would be much easier and faster. The new foil loading mechanism will aid in foil alignment, increase in foil tension and reduce touching of the foil while loading it into the frame. The upgraded clamping system is more user friendly and doesn't require the foil to be put through a small gap that grips and wrinkles it. The removal of the springs from the current clamping system makes the frame less complicated to use. A systematic cutting process after the foil has been loaded into the frame has been introduced to reduce the cutting time, increase the accuracy of cutting the foil to the right size and make the process more user friendly. Previously, cutting was the first part of the process and left the foil very susceptible to wrinkles, which is why we have move it to the end when the foil is already in the frame.

Overall, the most challenging part of our model is the actual validation of foil acceptability. It is very hard to measure the severity of wrinkles in very thin foil, and set limits as to what is defined as "severe". For an explanation of how this was achieved, refer to the Validation Protocol (Appendix D, pg. 80) In terms of design, the biggest challenge we had was getting the new clamping system to provide enough frictional force to allow the foil to be tensioned, while still being user friendly and easy to operate.

To simplify our project, we essentially want to improve a current process using engineering design. Thus, a mathematical model of our system would not be as appropriate one that would model the inputs and outputs to each functional segment of our system. This model (Fig. 23) was then used to validate each of our design ideas.

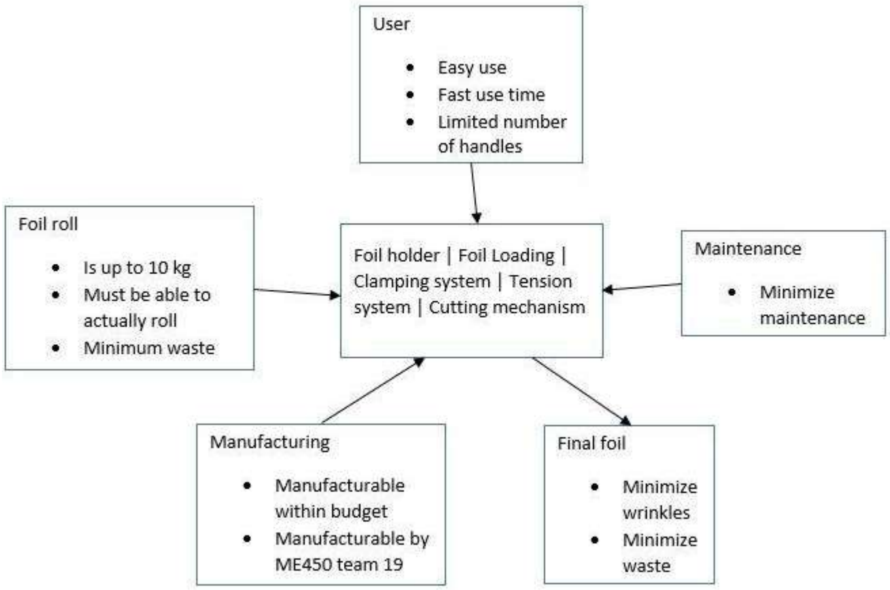

Figure 23: The simplest competent model of our design to optimize the foil loading process assesses inputs and outputs of each functional segment of the loading process.

Concept Description

After selecting the desired mechanism for each function (Fig. 11, pg. 9), we made a CAD model of our design. The assembled loading station is part of a rolling table which was provided by our sponsors. The black surface in the CAD model (Fig. 24, pg. 16) is the surface of the table which also comes with the two side posts and the top connecting bar shown in the model.

Figure 24: The Loading Station is part of a given table. The black plate, side posts, and top bar in the CAD model are the table.

Foil Holding Rack

Side-By-Side (Fig. 25) was selected because it could load two foil rolls at a time and because the two rolls don't interfere with each other. The only disadvantage of this rack is that the loading station requires more space than other designs, but the provided desk is large enough to accommodate this. Each roll holder rotates toward the user via a hinge system, allowing the user to replace and empty foil roll.

Figure 25: Side-By-Side foil roll rack.

Foil Loading System

We decided to use the Non-Rolling Bar design (Fig. 26, pg. 17) explained in concept selection (pg. 12). The CAD model can be seen in Fig. 4. The Non Rolling Bar aids in aligning the foil and provides sufficient tension so no wrinkles are generated while uncoiling.

Figure 26: Two non-rolling bars would be placed on top of each other to guide the foil between them and keep it at the correct height.

Clamping System

The clamping system (Fig. 27) was updated from the original design (Fig. 15, pg. 10) from rubber coated clamps to silicone coated clamps. The initial design of rubber clamps could possibly melt when placed in the oven at 150^{o}C, which prompted the switch to silicone. Silicone was used on the previous clamps which ensured us that would be a good material.

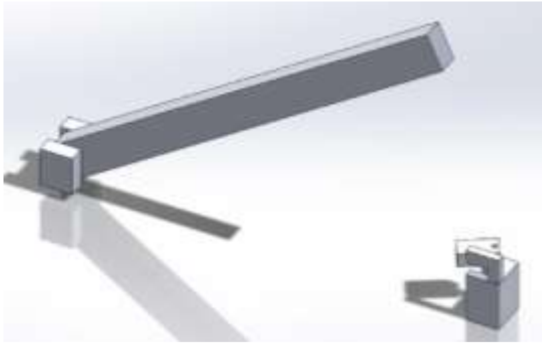

Fig 27: Silicone coated clamps.

Figure 28: V-groove cutting mechanism.

Cutting Mechanism

The V-groove system (Fig. 28) allows a very precise and accurate cut and it does not add any unnecessary complexity to the loading station. Moreover, the unattached X-acto knife allows the user to easily replace it whenever it breaks or gets dull. The only disadvantage of this design is that the unattached knife could be harmful if the user is not careful when handling it.

Frame Holder

In addition to the functions shown on the functional decomposition (Fig. 11, pg. 9), the team also designed jig for holding the frame while it is being loaded with foil (Fig. 29, pg. 18). This jig consists of several uprights with slots in which rods on the frame can easily slide into to hold it in place.

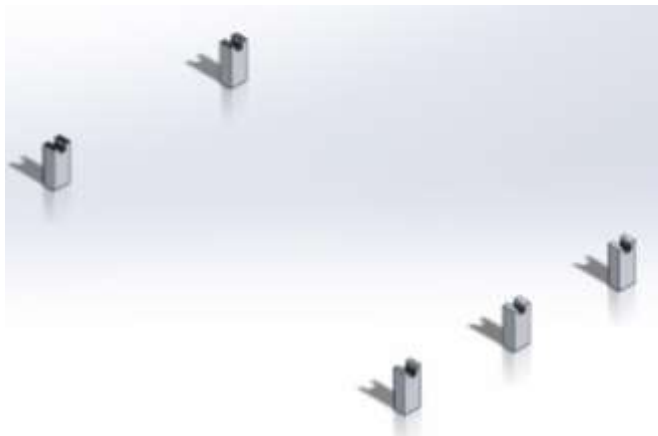

Figure 29: The original frame holder design was five uprights with slots to hold the frame at an exact position while loading the foil.

Engineering Analysis

Empirical testing

Our most important, and possibly most intensive engineering analysis, was experimentally measuring wrinkles in foil after loading foil into the frame. In order to do this, we used two methods: first, we characterized wrinkles by type and counted the number of wrinkles of each type, and secondly, we used 2D profilometry to measure wrinkle height and width. The characterizations of wrinkle by type are shown in Figure 10 (pg. 8).

By running tests on pieces of foil artificially wrinkled to have wrinkles that match type 1-3 wrinkles, we were able to further characterize the wrinkle types. The results are as follows:

- Type 1 wrinkle areas have amplitudes that range from 0.1 to 0.7 μm, and have an average roughness between 0.05 and 0.1. Type 1 wrinkles are generally caused by light handing, and are expected when pressure is put on the face of a piece of foil over a small area, such as picking up a piece of foil. There are generally areas covered by type 1 wrinkles – there will generally not be a single standalone wrinkle.
- Type 2 wrinkles have amplitudes between 0.6 and 2.0 μm, and average roughness values between 0.1 and 3.6. Type 2 wrinkles are generally standalone wrinkles, and can be created when too much pressure is placed on the face of a piece of foil, the edge of the foil is slightly compressed, or the foil is lightly folded down. These wrinkles can generally be reduced from the foil when tensioned, but still create a significantly uneven surface on the foil. The vast majority of wrinkles created using the previous loading process were type 2 wrinkles.
- Type 3 wrinkles will have wrinkle amplitudes 2.0 μm and higher, and an average roughness 3.0 and higher. Type 3 wrinkles are caused by large compressions of the side of the foil and heavy folding. They are permanent in the foil, and cannot be minimized by tensioning. Type 3 wrinkles are very similar to type 2 wrinkles in terms of depth, but the width of the wrinkle is smaller than that of a type 2. The creation of these wrinkles needs to be completely removed from the loading process.

Tests were run on four pieces of foil (two aluminum, two copper). All roughness parameters were found using high quality .tiff scans of each piece of foil, and the roughness tool in Gwyddion, which finds one dimensional roughness parameters for lines drawn on the foil, with a cutoff value of 0.0000 and sample line thickness of 50 pixels. Wrinkle amplitudes were found by adding maximum roughness valley depth and peak height values for each sample line. Average roughness was found by the software as “the average deviation of all points roughness profile from a mean line over the evaluation length” according to the software documentation. Figure 30 shows an example of one sample test, and the wrinkle type areas measured for one piece of foil. Approximately 10 samples were taken of each wrinkle type area from each piece of foil, for a total of 40 samples of each type of wrinkle. We found that the type of foil did not create any significant variation in the range of wrinkle amplitudes and average roughness’s for each wrinkle type.

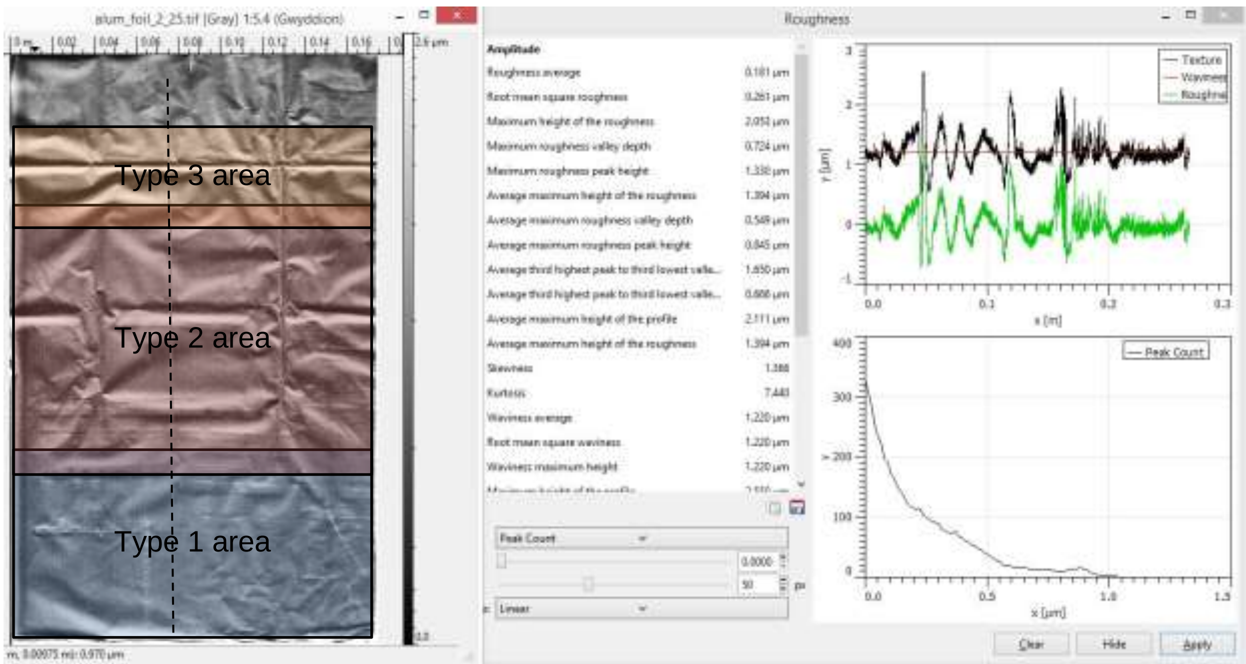

Figure 30: Using Gwyddion software, we were able to measure wrinkles on each foil sheet. On this sheet (left), we have marked the wrinkle area types, and highlighted the line used to measure roughness parameters. For this figure, we have drawn the line through the entire foil, whereas in a test we would draw the line only in each area type, and take multiple samples. On the right side of the figure we see the measured parameters, including maximum roughness valley depth and peak height and average roughness. The top right plot shows the peaks and valleys graphically, while the bottom right plot shows the frequency of each peak height.

<u>Mockup Construction</u>

In order to understand how the components would interact with each other, the team built a mockup representation of the loading station (Fig. 31). After designing each component, the next step was putting them together to allow the identification of any possible complication that could not be identified in the separate designs. The other purpose of this section is to discuss what was learned through assembling the mockup.

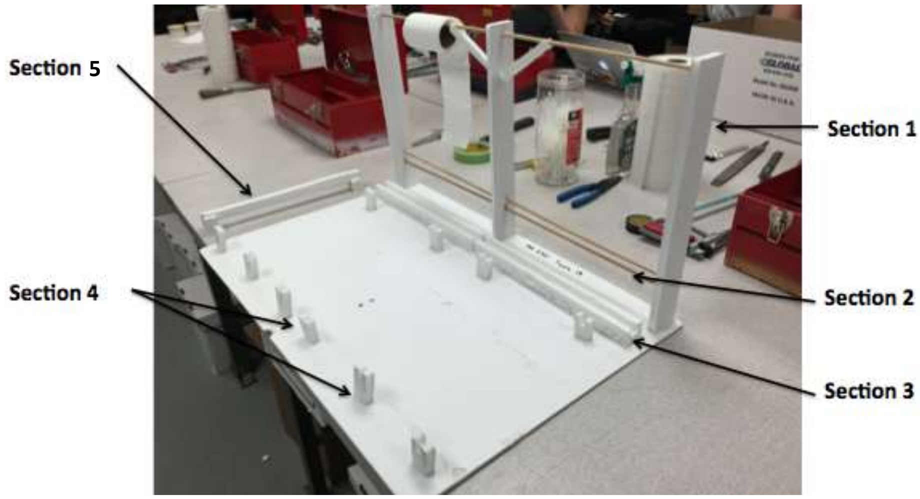

Figure 31: Isometric view of mockup where Section 1 represents the foil roll holder, Section 2 is the loading system, Section 3 is the V-groove cutting mechanism, Section 4 is the frame holder, and Section 5 is the new clamp design.

Firstly, we realized that the loading mechanism (Section 2 of Fig 31) could be attached to the same pillars as the foil roll holder. That would help us to save space and make manufacturing less complicated.

We also decided that it would be more reasonable to have two frame holders attached to the table instead of the having a sliding system to position the frame to the desired position. Creating a sliding system for such a simple set of supports was unnecessary and it was easier to just manufacture two sets of supports.

The last learning concerned how components would attach to the desktop. The team planned to attach all components directly to the desktop we were given. In looking at our mockup and the given desk, we realized it would be difficult to drill holes in the desktop accurately enough to align everything properly. Therefore, we designed a baseplate on which we would attach the frame holders and V-grooves that would then be attached to the table.

FMEA

The full failure modes effect analysis can be seen in Table 1 (pg. 21).

The highest-risk aspect of our design involves user error in wrinkling foil while loading into the frame. While we have tried to minimize this risk as much as possible, the foil will still need to be unconstrained from the time it is pulled out of the guiding bars to the time at least one clamp is engaged. We think that with a minimal amount of training, users will be able to understand that the foil needs to be handled gently in this stage of the loading process, so we have only given this a likelihood of “2”. We have given the severity of this risk a “2” as well, as we do not know how severe wrinkles caused by users could be. Wrinkles could be severe enough that they fail our wrinkle specification, or very small type 1 wrinkles - however, we believe that most wrinkles created will not cause the foil to fail our spec.

ID	Risk Item	Effect	Cause	L	S	I	Actions to Minimize Risk	Action to Remediate Owner
1	Foil roll is damaged between unpacking from shipping box to loading on to loading station	A number of layers of foil in roll are unusable - could range from one layer to all layer in roll	User drops roll, or bumps roll against something	1	3	3	Reduce distance that roll must move in its lifetime, and number of times it is moved.	Remove damaged sections from roll, or buy new roll
2	Clamping fails on one or both clamps in frame	Tensioning process fails	Clamps not fully engaged	1	1	1	Make clamps more simple	Re-clamp foil
3	Foil tears while tensioning	Foil tears	Too much tension on foil	1	3	3	Limit tension applied to foil	Remove damaged foil from frame, re-tension using less tension
4	Frame not properly fixed in frame holders	Tensioning process removes frame from holders, wrinkles or tears foil	Frame holding clamps not engaged	1	2	2	Simplify frame holding clamps	Remove damaged foil, if any, re-place frame on holders, engage clamps properly
5	Foil is wrinkled during loading into frame	Foil cannot be used for coating	Rough pulling of foil though guide bars	2	3	6	Minimize number of times foil must be handled	Remove wrinkled foil from frame, re-start process
6	Someone is cut with Xacto knife	Depends on severity of cut - could range from a small scratch to death	Misuse of Xacto knife	1	3	3	Make sure knives are stored in safe location and only removed from that location when used in cutting foil	Insurance
7	Foil is cut improperly	Uneven foil	Misuse of v-groove	1	1	1	Make sure foil is cut within v-groove	Cut foil until even

Table 1: Failure Modes Effect Analysis (FMEA). In this table, L, S, and I stand for Severity, Likelihood, and Impact, respectively. The highest risk is of wrinkling the foil while loading it into the frame as shown by line 5.

Design Changes

In order to improve the design and achieve more suitable results the team made changes to parts that were previously specified. Some changes were also made in order to fix design and manufacturing mistakes. The reasoning behind each change is described below and shown in Engineering Change Notices in Appendix B (pg. 37).

1) The position of the v-groove in relation to the frame was fixed and it gave no room for adjustments during the loading process. The team also considered that the amount of foil that was being wasted because of the gap between the frame and the v-groove was unnecessary. For these reasons the team changed the pair of holes in the baseplate where the v-groove is mounted to a pair of slots. The slots help the user to position the v-groove and allows for less material waste.

2) We realized that the design for the loading system was needlessly complicated. It would be very difficult to put a bar through the entire middle pole, and there was no need to use a round bar for the top guide while using a flat piece for the bottom piece. It was also nearly impossible to affix the ends of the top bar to the desk, place it close enough to the bottom bar to constrain the foil, and make the space between top and bottom bars even throughout the subsystem. The new design remedied these problems, and made both top and bottom bars the same material. It also made the subsystem more structurally robust by using ½'' round stock and machined aluminum blocks, and reduced the surface area touching the foil significantly, as a round bar touches much less of the foil than a flat bar would.

3) When designing the lock spacer, we assumed that the foil roll holder would sit centered on the upright on the side of the desk. However, when the foil roll holder was installed, we found that the back edge of the foil roll holder was behind the back edge of the desk upright. Because of this, one of the holes on the spacer would not be on the desk, and would not fasten to the desk properly. We redesigned the spacer so that both holes on one side of the lock would be connected to the desk, which would not impair the structural integrity of the lock.

4) The two bars connecting the top hinges with the bottom hinges were designed to have two holes with one being the same size as the holes in the hinges that were specified by the manufacturer. However, once we received the hinges, the holes were not as specified, so the team had to change the size of the hole in the connecting bars to match with the correct dimension of the holes in the hinges.

5) The team inserted a plug on the top of the middle pole because there was a mistake during manufacturing and the middle pole turned out to be smaller than expected. The leftovers of material of the middle pole was not enough to make a new middle pole and the price of another middle pole did not justify making a new one. With this in mind, the team designed a plug that goes on the top of the middle pole and extends the middle pole to the exact dimension. The fix was quick and financially beneficial for the budget of the project.

6) The L-brackets used to attach the middle pole to the top of the table were previously designed to be placed on the smaller edges of the middle pole (in the front and back of the pole). However, after taking more measurements and assembling some of the parts we realized that there was no room on the top of the table to attach the L-brackets. For this reason, the team decided to use the hole that was attaching the plug to the middle pole for the L-brackets also. This change also required a change to a longer bolt.

7) After adding the plug to the top of the middle pole the team needed to add spacers to extend the contact surface of the L-brackets with the top surface of the table. For this reason we decided to manufacture two small spacers that are almost unnoticeable but are very important for adding support to the middle pole and making it more stable.

8) The L-brackets that are used to support the free-end of the foil holders were previously designed to have two holes to mount them to the sides of the table. One of the holes was placed on one of the top corners and the second hole was on the bottom of the opposite side. In order to decrease unnecessary complexity the team changed the holes' position. Now they are aligned to each other. They are both in the middle of the surface and about the same distance from their respective sides. The team also added counter-bores to the holes to avoid interference of the bolts' heads with the foil holder.

Final Design

The finalized design of the loading station can be seen below in Figure 32 and the finalized design for new clamps on the frame is shown in Figure 33 (pg. 24). We made one major change to our design since Design Review 3, which was the addition of two base plates. We attached the components that hold the frame in place and the v-groove cutting component to this base plate and from there we are planning to attach this base plate to the given desktop via slots we machined in the base plate. Because the desktop can't be put onto the mill, it would've been difficult to drill holes accurately enough for the frame to fit well into its holders, but with the base plate, we can drill less accurate holes and still be able to move the components into the correct position.

Figure 32: Final design of loading station. Note the addition of base plates.

Figure 33: Final design of new frame clamps.

Discussion

The finished prototype, which can be seen in Figure 34 below, passed validation by testing against our engineering specifications and through discussion with the sponsors who were pleased with the results. There were some issues with the design and other aspects of the project and there is some work that could be done in the future to improve the loading station, but overall the loading station is a vast improvement over the current process and should be considered a success.

Figure 34: Final prototype at the April 2015 Engineering Design Expo.

Results

To validate our design and prototype, 15 loadings of a standardized foil length were done on each foil type using both loading systems, the old and the new loading process, for a total of 60 tests. Tests were done by team members and students without previous exposure to the system. Area of type 1 wrinkles, number of type 2-4 wrinkles, waste length, loading time, and acceptability to be coated were recorded for each loaded foil. A summary of the test results is shown in the Table 2. Based on our tests, our process is a significant improvement on the old process in all areas except waste, where the user specification is still met. The most significant improvement comes from wrinkle reduction from all the types. The success rate is a consequence of reducing wrinkles during the loading process.

Test focus	Old process (n=30)	New process (n=30)
Type I wrinkles (in^2)	49.2 ± 3.9	1.6 ± 0.2
Type II wrinkles (#)	8.0 ± 0.7	0.8 ± 0.1
Type III wrinkles (#)	3.3 ± 0.5	0.0 ± 0.0
Type IV wrinkles (#)	5.1 ± 0.6	0.7 ± 0.2
Waste length (in)	1.8 ± 0.1	2.8 ± 0.0
Loading time (s)	212.3 ± 13.8	30.6 ± 2.2
Success Rate	0%	96%

Table 2: For the new process there were less wrinkles of all types, loading time was significantly less, and success rate was substantially better. Waste length increased slightly, but was still within the user requirement and engineering specification.

Design Critique

The final design was successful on meeting the sponsor's requirements and expectations, but there is more room for improvements that would make the loading process even more efficient. The team was not completely satisfied with the final product of the roll holder. The roll holder's alignment with the frame is not precise enough to avoid some complications during the loading process. The copper and aluminum rolls come in with different inner cylinders. While one is made of cardboard (copper), the other is made of aluminum and the aluminum cylinder is not precisely cut. For this reason we had to use two stops, one on each side of the roll, that are used to stop the rolls from sliding sideways on the holder and putting them misaligned. We could have come up with a solution for this issue as well and facilitate the usage of the loading mechanism even more.

Another issue is the high friction coming from the aluminum cylinder rotating on the roll holder. This generates high resistance when uncoiling the foil roll. One quick solution could be the addition of grease in the interface between the roll holder and the foil roll cylinder. A more complex solution could be a redesign of the roll holder and a change from a non-rotating holder to a rotating holder in which the foil rolls are tightly attached to the roll holder and it is free to rotate. We would recommend the addition of grease in the interface between the aluminum roll and the roll holder as a quick solution. The user needs to ensure that there is enough grease every time the loading station is used. In addition, after removing the frame from the oven, we would recommend to let the frame and the silicon to cool down for a few minutes. This would avoid any problems with the clamping system being too hot and dangerous for the user.

Lastly, the new design for the frame clamps didn't turn out as user friendly as we had hoped. The clamps do close and hold the foil tightly enough for tension to be added. They serve they're functional purpose flawlessly. However, in providing enough frictional force to hold the foil, the lock on the clamps becomes very difficult to open and close. This can sometimes lead to the user's hand slipping and putting a hole in the foil or otherwise damaging it. This would ideally be fixed by either using a different type of locking mechanism or by switching back to the old clamping method.

On the other hand, there are many parts of our design which work very well such as the cutting mechanism and the hinge and lock system for changing the foil rolls. Manufacturing was a high point of the project and all parts were done with precision and, for this reason, the design is very robust. Overall, the final design offers a high efficiency of the loading process without too much complexity. The team wanted to deliver a simple and clever solution that would allow users to come in and learn how to use the machine quickly, which we believe we did.

Future Work

In addition to the current design of the prototype, two features geared toward usability could be added to increase performance. Addition of a measurement scale to the base-plate, would allow the user to measure foil length while loading and an alignment aid for changing the foil rolls would help the user to correctly line up a new foil roll on the roll holder.

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Appendix A: All Generated Design Concepts

1. Foil Roll Rack:

    1.1. Stacked – Both rolls, aluminum and copper, are placed on top of each other sustained by a cylindrical fixed bar mounted across two columns. The user has the option to manually switch them up and down or to use them as is firstly placed.

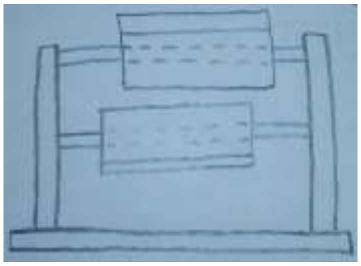


Figure A.1.1: Two foil roll holders stacked on top of each other.

    1.2. Side By Side – Both rolls, aluminum and copper, are placed next to each other at the same level. They are sustained by a cylindrical fixed bar mounted across three columns. One roll would be placed between the first and the second column and the second roll would go between the second and the third column.

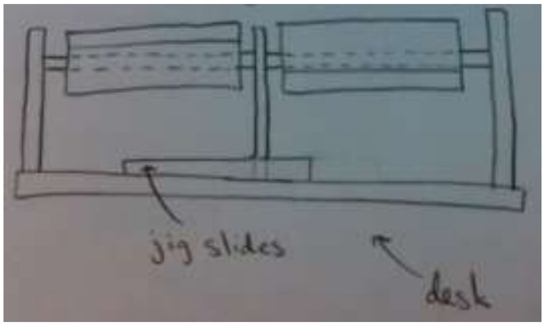


Figure A.1.2: Side by side foil roll holders.

    1.3. One On Each End – rolls, aluminum and copper, would be placed facing each other with a gap between them to place the coating frame. The rolls would be sustained by a cylindrical fixed bar mounted across two columns.

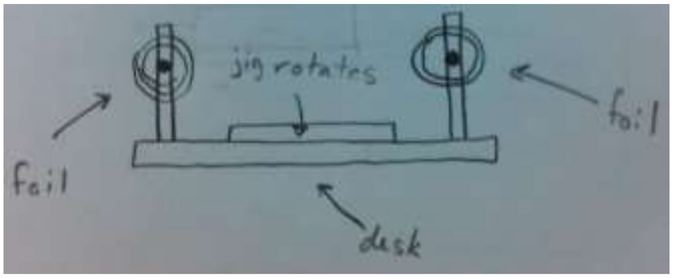


Figure A.1.3: One foil roll holder on each end with a rotating jig.

1.4. One-Holder – The roll, aluminum or copper, are sustained by a cylindrical fixed bar mounted across two columns. There is only space for one roll, which in this case would require the user to manually switch between the different rolls.

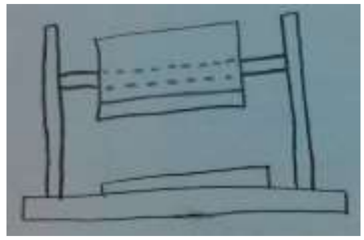


Figure A.1.4: One foil roll holder.

1.5. Current design – The current design provides no mechanism of rack to place the rolls and help with the coating process. The user is required to hold the roll by hand and uncoil it to the desired dimensions.

2. Foil Loading:

2.1. Rolling Bar – A cylindrical rolling bar will be placed at the same level of the coating frame. It would allow the foil to slide smoothly and in the correct direction into the frame. The rolling bar would also function as a method of holding the end of the foil for further use. The user would pull the foil end and load it into the frame to the desired length.

2.2. Non-Rolling Bar – A cylindrical fixed bar that would be placed at the same level of the coating frame. It would allow the foil to slide smoothly and in the correct direction into the frame. The rolling bar would also function as a method of holding the end of the foil for further use. The user would pull the foil end and load it into the frame to the desired length.

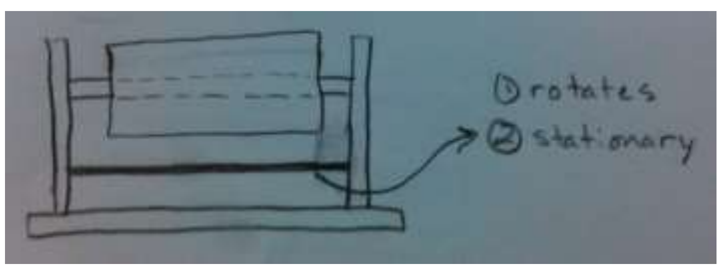


Figure A.2.1: The foil would roll under a bar that could either be rotating with the foil or stationary and could possibly be magnetic to hold the foil.

2.3. Magnetic Bar – A magnetic bar would be fixed and placed at the same level of the coating frame. It would help to guide the foil into the frame and use the magnetic field in order to hold the end of the foil for further use. The user would pull the foil end and load it into the frame to the desired length.

2.4. Clip-To-Hold-Foil – A clamping system would be placed at the same level of the coating frame. The foil would slide under the top bar and the desired length of the foil is place into the frame. The bottom bar should be clamped to hold the end of the foil in place when the desired foil length is loaded into the frame. The user would pull the foil end and load it into the frame to the desired length.

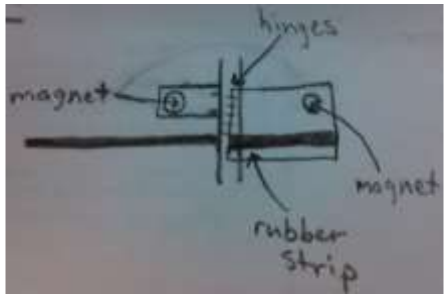


Figure A.2.2: Example of a clip that could hold the foil the bar it is rolling under.

2.5. Current design – The user is required to manually slide the foil between the clamping systems at both ends of the frame. The foil would be at the desired length before it is loaded.

3. Clamping System:

3.1. Magnets – This clamping system would allow the user to raise the top bar while loading the foil into the frame by one of the ends being pivoted. Both the top and bottom bars would have magnets with high magnetic field, which would allow the foil to be in place even when tension is applied to the foil.

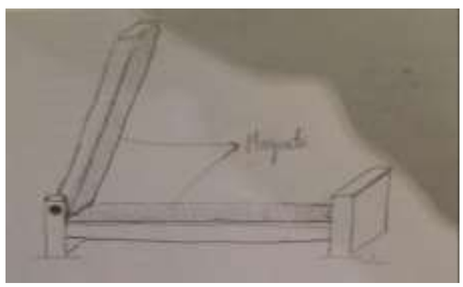


Figure A.3.1: Flip-up clamp with magnets to hold it closed on the foil.

3.2. Toggle Clamp – This clamping system would allow the user to raise the top bar while loading the foil into the frame by one of the ends being pivoted. Once the foil is place in the frame, the user lowers the top bar and uses a toggle clamp to push the top bar against the bottom bar, which would hold the foil in place.

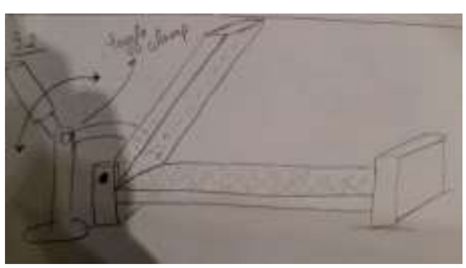


Figure A.3.2: Flip-up clamping system controlled by a toggle clamp.

3.3. Square-Rubber Grip - This clamping system would allow the user to raise the top bar while loading the foil into the frame by one of the ends being pivoted. Once the foil is place in the frame, the user lowers the top bar and uses a toggle clamp to push the top bar against the bottom bar, which would hold the foil in place. However, in this case a rubber material to increase the grip once tension is applied to the foil covers the inner face of the top and bottom bar.

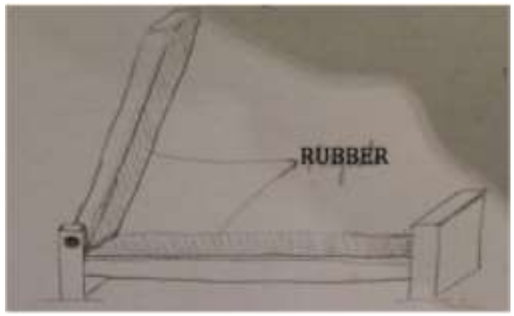


Figure A.3.3: Prismatic flip-up clamp with rubber grips.

3.4. Round-Rubber Grip - This clamping system would allow the user to raise the top bar while loading the foil into the frame by one of the ends being pivoted. Once the foil is place in the frame, the user lowers the top bar and uses a toggle clamp to push the top bar against the bottom bar, which would hold the foil in place. However, in this case the top bar has a cylindrical shape while the bottom is flat. A rubber material to increase the grip once tension is applied to the foil wraps the top cylindrical bar.

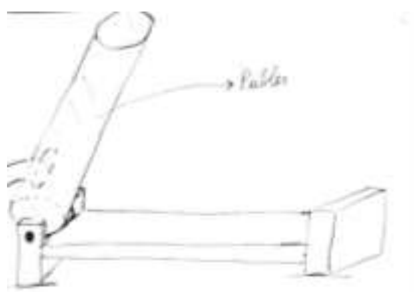


Figure A.3.4: Cylindrical flip-up clamp with rubber grips.

3.5. Current design – The current design requires the user to slide the foil through a small gap between the top cylindrical bar and the bottom flat bar. The top rubber cylindrical bar can be rotated around its axis in order to raise it and then rotated back to lower it.

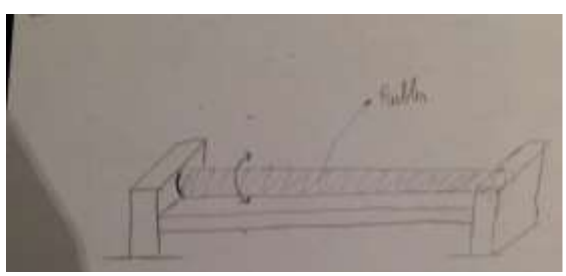


Figure A.3.5: Current clamping system with an off-axis roller with a rubber grip.

4. Tension Mechanism:

   4.1. Sliding Clamp – In addition to hold the foil in place, the far end clamp would also be free to slide back and forth. The user would manually pull the clamp closer or further from the first clamp in order to adjust the tension on the foil. The sliding mechanism already exists on the current design but it requires further improvement because it has too much resistance and it is unaligned with the frame.

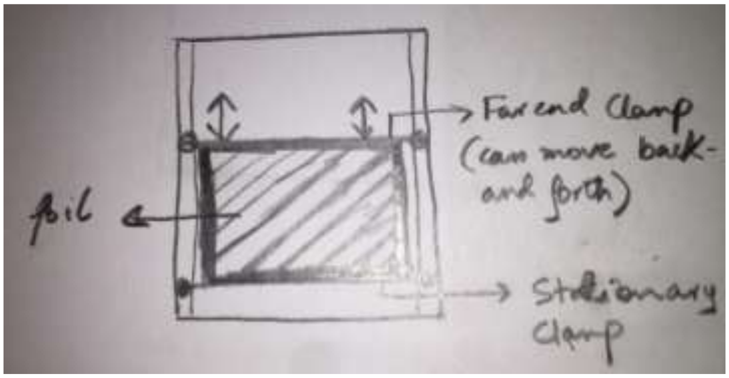


Figure A.4.1: Tension system that fixes the movable clamp on the frame and relies on the friction of the clamping system for added tension.

   4.2. Tension-Edge [15] – In this design, the clamps would be able to grab the two ends of the foil and rotate around their axis in order to pull the ends apart and apply the necessary tension. The clamps would grab the foil by having a slot where the user inserts the end of the foil.

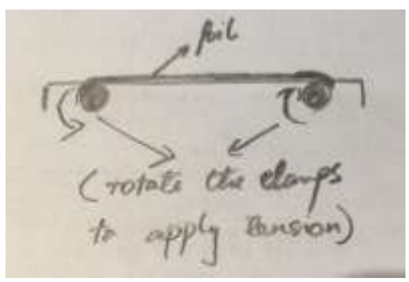


Figure A.4.2: Tension mechanism which grips the foil and rotates outward.

   4.3. Spring-Sliding Clamp – The current system look close to the Spring-Sliding Clamp system. The team would replace the current springs by longer ones that would allow the user to apply tension at any given point and the far end clamp would be able to slide in order to adjust to the right dimensions of the foil. The user would manually pull the clamp closer or further from the first clamp in order to adjust the tension on the foil. The sliding mechanism already exists on the current design but it requires further improvement because it has too much resistance and it is unaligned with the frame.

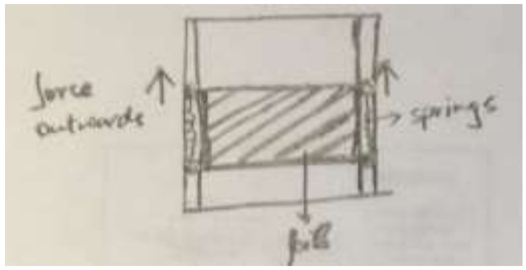


Figure A.4.3: Spring tension system provided by one long spring.

4.4. Roll Foil Tension – This mechanism would use the benefits of a sliding clamp coupled (same as 4.1) with the back force applied by the foil roll placed on the rack.

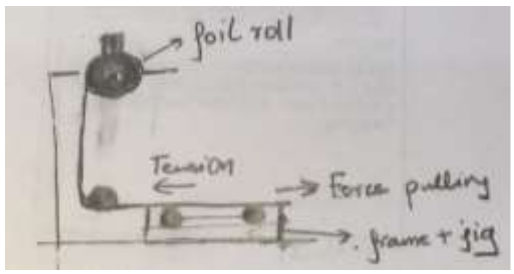


Figure A.4.4: Additional tension provided by inertia and back-force of the foil roll.

4.5. Current design – The current design allows the user to slide both the far end clamp and a spring system. The user can slide the spring closer to the clamp in order to obtain a spring force on the opposite direction, generating a tension force on the foil. The spring slides through the same mechanism as the clamp but it also has one screw on each end that it is used to fix the spring in place, so it will not move back once tension is applied.

Figure A.4.5: The current tension system fixes the movable clamp on the frame and uses short springs to apply additional tension.

5. Cutting Mechanism:

5.1. V-Groove – This idea would allow the user to slide a cutting blade through a V-Groove. The V-Groove would be place between the first clamp and the loading bar (discussed in section 2). The V-Groove allows a straight and smooth cut and does not require additional cutting force.

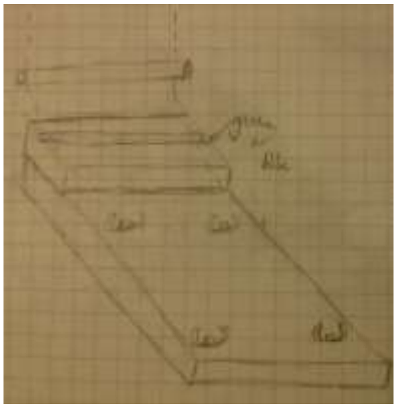


Figure A.5.1: A v-groove would guide the path of a cutting blade.

5.2. Unattached X-acto Knife – The X-acto knife would be coupled with a V-Groove. The knife would be place on a hanger at the roll rack with a protection on the sharp end. The user would need to slide the knife through the V-Groove. After cutting is finished, he/she would place the knife back on the rack.

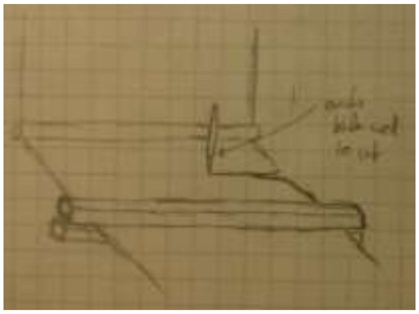


Figure A.5.2: Unattached X-acto knife to cut the foil.

5.3. Attached X-acto knife – The X-acto knife would be attached to the same surface as the V-Groove. Once the user is ready to cut the foil, he/she slides the blade through the V-Groove and then slides it back to the initial position. This allows the cutting knife to be attached to the system at all times, which decreases the chance of breaking if user drops it or loses it.

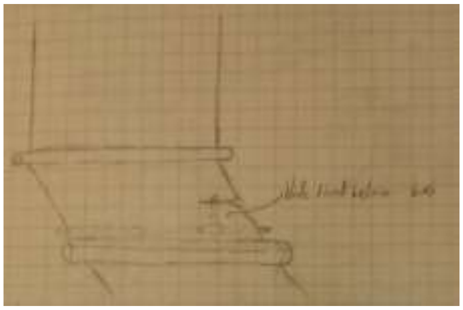


Figure A.5.3: Attached X-acto knife to cut the foil.

5.4. Paper-Cutter Blade – This concept allows user to lift the blade pivoted at one of the ends while loading the foil. Once loading is finished, the user lowers the blade that would cut the foil along a straight edge.

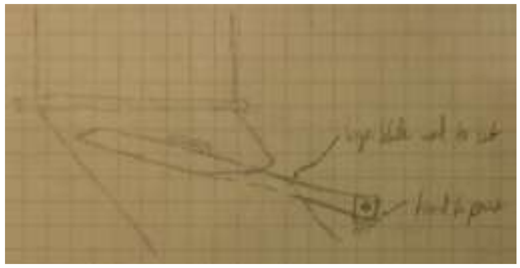


Figure A.5.4: Paper cutter style blade to cut the foil.

5.5. Pizza-Cutter – The Pizza-Cutter knife would be coupled with a V-Groove. The cutter would be place on a hanger at the roll rack with a protection on the sharp edge. The user would need to slide the cutter through the V-Groove. After cutting is finished, he/she would place the knife back on the rack.

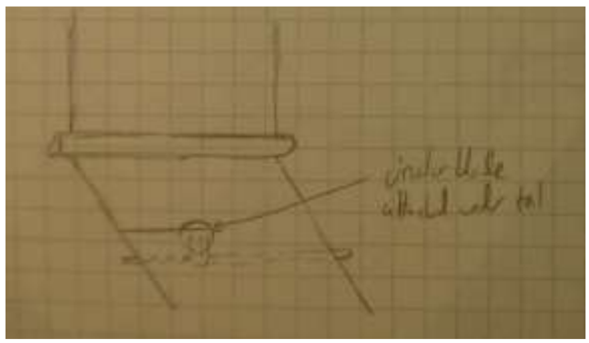
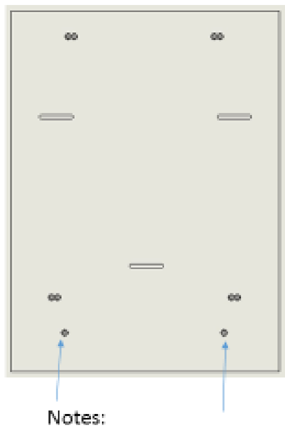


Figure A.5.5: Pizza cutter styled blade to cut the foil.

Appendix B: Engineering Change Notices

1)

WAS:



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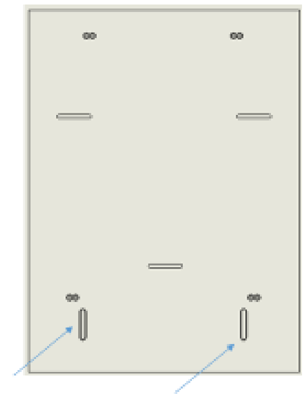
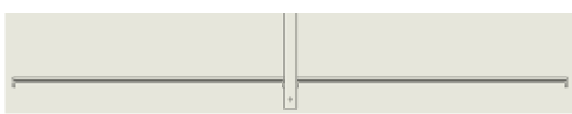


Notes:
The holes for ¼ - 20 bolts that mounts the v-groove to the base plate were changed into slots for ¼ - 20 bolts to increase adjustability and decrease material waste.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Base Plate
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

2)

WAS:



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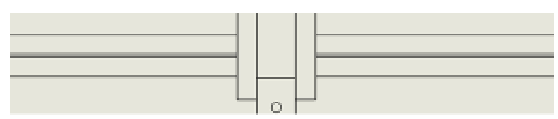
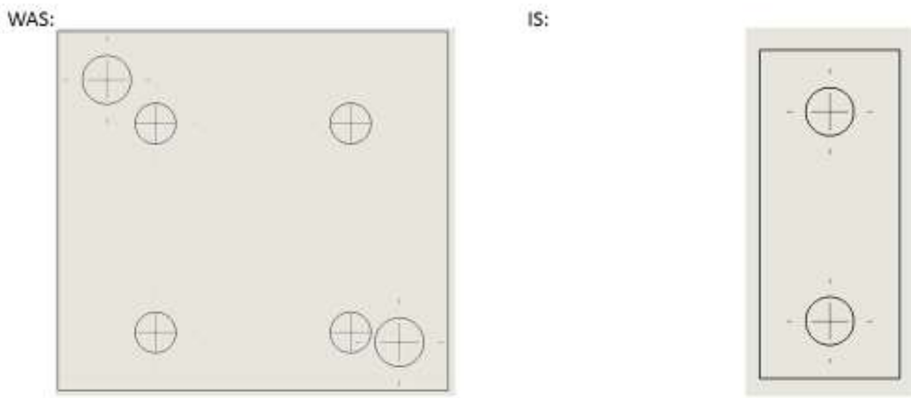


Notes:
Subsystem was overcomplicated and hard to manufacture. Redesign simplified design, reduced manufacturing time, and made subsystem more structurally robust. Had exact same functions as old design, and affected no other parts or processes.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Guide Subsystem
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

3)



Notes:
One hole of spacer would be hanging off the desk, so spacer was redesigned so both holes could be bolted to desk. This also resulted in us cutting off one side of the base of the barrel slide bolt lock.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Locking Spacer
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

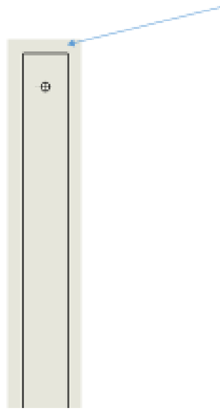
4)

Notes:
The smaller hole was changed to correctly match with the holes in the hinges.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Connecting Bar
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

5)

WAS:



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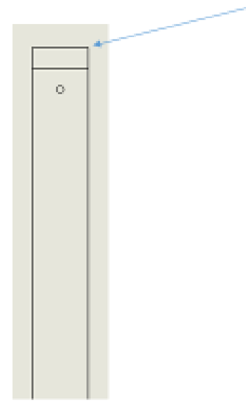
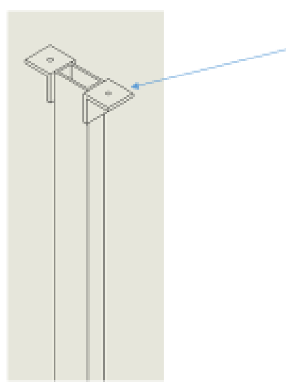


Notes:
A plug was manufactured and inserted on the top of the middle bar to correct a mistake during manufacturing and increase stability of the middle pole.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Top of Middle Pole
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

6)

WAS:



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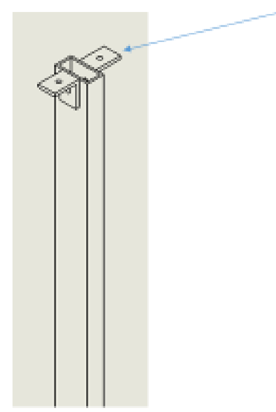
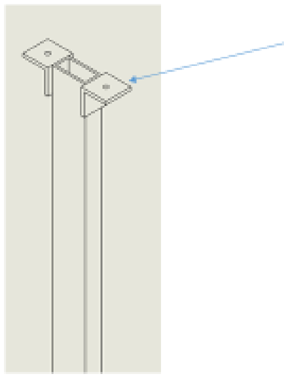


Notes:
When assembling the middle pole the team noticed that there was no space to attach the L-bracket of the top of the middle pole to the top surface of the table. The team decided to move them to the longer sides of the middle pole.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Position of L-Bracket of Middle Pole
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

7)

WAS:



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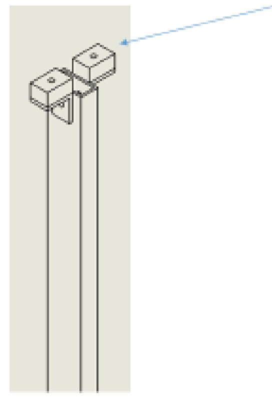
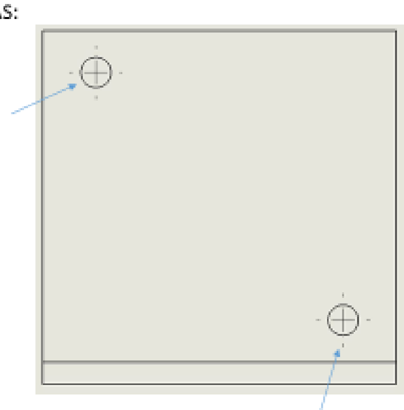


Notes:
Spacers were added to the top of the middle pole to extend the contact surface of the L-Bracket with the top surface of the table and to add more stability to the design.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Middle Pole Spacers
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

8)

WAS:



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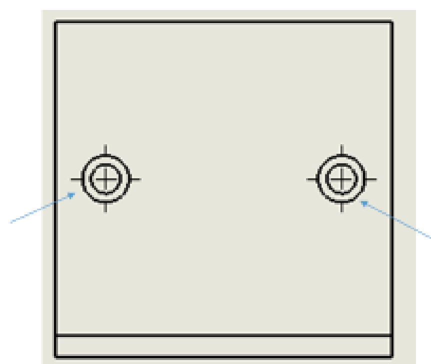


Notes:
The holes' placement was modified to minimize unnecessary complexity in manufacturing and design and counter-bores were added to each hole to avoid interference between the bolts' head with the foil roll holder.

ME 450 – Lithium-Ion Battery Coating Project
Ref. Drawing: Foil Roll Holder Clamp
Changes Made by: Team 19
Approved by Sponsor: Dr. Greg Less
04/02/2015

Appendix C: Bill of Materials, Manufacturing Plans, and Part Drawings

This appendix contains the bill of materials followed by manufacturing plans and drawings for each manufactured part.

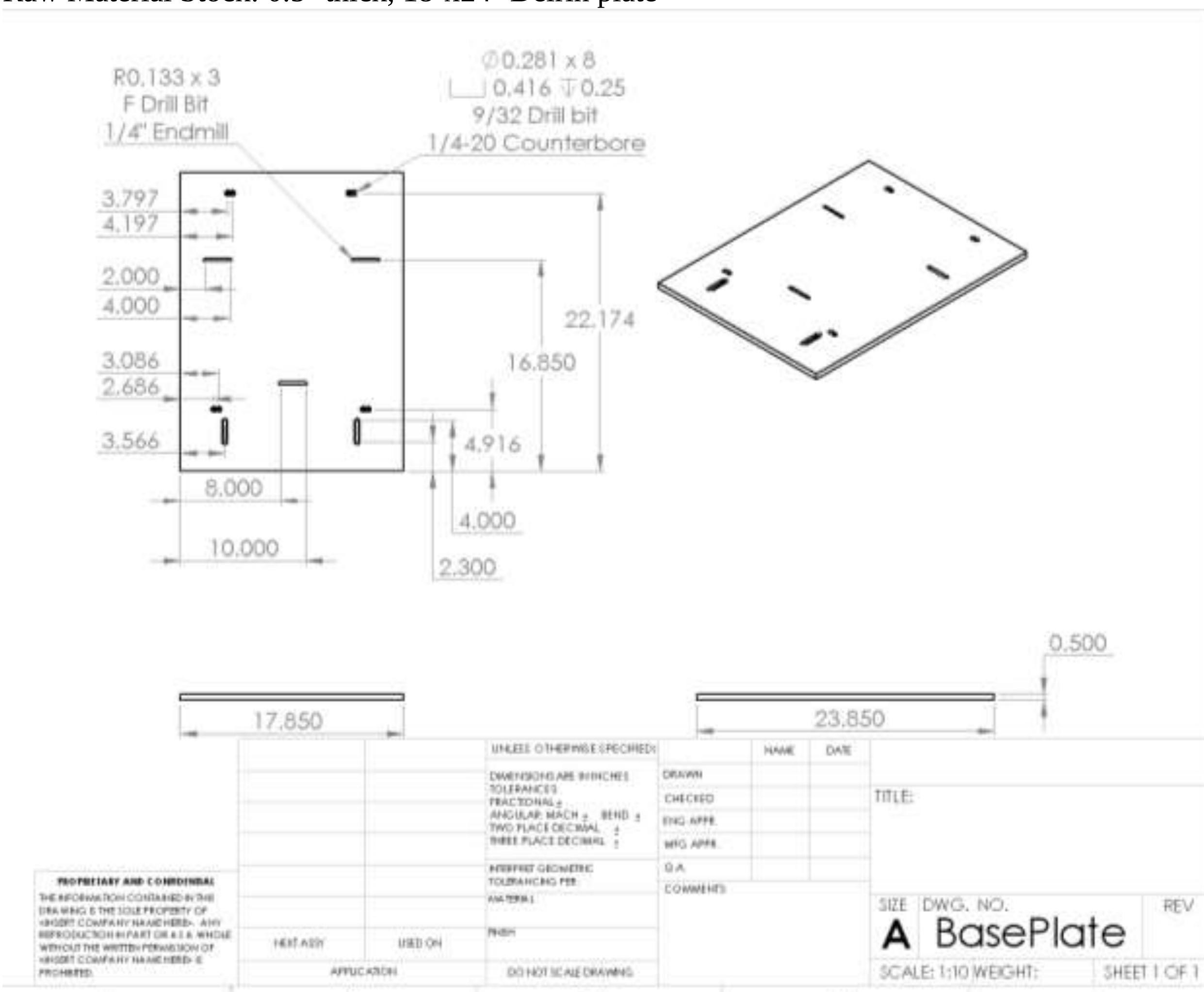
Bill of Materials

Material (multipurpose 6061 Aluminum)	Part Number	Qty	Price ($)	Associated Parts
Strap Hinge, Zinc-Plated Steel, 3-16/16" Door Leaf Length	1530A51	4	3.54	Foil Roll Holder Hinges
Surface-Mount Hinge: Bright Brass, Nonremovable Pin, 3/4" High, 5/8" Wide	1603A2	2	1.43	Frame Clamp Hinges
Tube 3" OD, .125" Wall Thickness, 2' long	9056K41	2	37.92	Foil Roll Holders
Rectangular Bar, 1/4" x 1"	8975K596	1	3.13	Foil Roll Holder Supports
90 Degree Angle, 1/4" Thick, 4" x 4" Legs	8982K63	1	47.49	C-clamps, Vertical Support Brackets
Rectangular Tube; 1/8" Wall Thickness, 1" x 2"	6546K39	1	44.17	Middle Support Post
One-Piece Clamp-on Shaft Collar for 3" Diameter, Black-Oxide Steel	6435K77	4	19.11	Foil Roll Clamps
Extereme-Temperature Silicone Rubber 1/8" Thick, 1/2" Width, 3' Long, Adhesive Back, Orange/Red	93755K51	3	5.82	Frame Clamp Grips
Steel Barrel Slide Bolt, Zinc-Plated	1441A32	2	2.44	Foil Roll Lock
Draw Latch, Nonlocking, 302 Stainless Steel, 1-1/16" Latch Distance	1590A43	2	4.83	Frame Clamp Locks
Surface-Mount Hinge: Zinc-plated steel, Nonremovable Pin, 1" High	Carpenter Bros. Hardware Store	1	3.49	New Frame Hinges
M4 x 0.7 screws	Ace Hardware	8	0.25	Screws to attach clamps to frame
1/2" Diameter, 3' Long, Turn ground & Polished Steel	Alro	2	11.38	Top Guide Bars
Teflon Tape	Jack's Hardware	1	1.37	Frame Clamps
Shipping and Tax			46.66	
		Total	372.37	

Manufacturing Plans and Drawings

Part Number: ME450-W15-19-01 Revision Date: 4/2/2015
Part Name: Base Plate
Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 0.5" thick, 18"x24" Delrin plate



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Fix the base plate to the mill	Mill	Toe Clamps		
2	Find corner of part	Mill	Toe Clamps	Drill chuck and edge finder	1200
3	Center drill and drill the holes on the end of the base plate with the v-groove	Mill	Toe Clamps	Drill chuck, center drill, F drill bit	1200
4	Pilot drill and Counter bore the holes	Mill	Toe Clamps	9/32 drill bit, 1/4-20 counterbore (socket cap screw)	1200
5	Drill holes at the ends of the v-groove slots and the middle desk attachment slot	Mill	Toe Clamps	Drill chuck and drill size F	1200
6	Mill slots (.05" passes)	Mill	Toe Clamps	Collet and 1/4" endmill	1200
7	Mill a counterbore into the v-groove slots	Mill	Toe Clamps	7/16" endmill, collet	1000
8	Turn the base plate around on the mill (move the v-groove end nearest to the operator)	Mill	Toe Clamps		
9	Find corner of part	Mill	Toe Clamps	Drill chuck and edge finder	1200
10	Center drill and drill the holes on the non-v-groove end of the base plate	Mill	Toe Clamps	Drill chuck, center drill, F drill bit	1200
11	Pilot drill and Counter bore the holes	Mill	Toe Clamps	9/32 drill bit, 1/4-20 counterbore (socket cap screw)	1200
12	Drill holes at the ends of the 2 remaining desk attachment slots	Mill	Toe Clamps	Drill chuck and drill size F	1200
13	Mill slots (.05" passes)	Mill	Toe Clamps	Collet and 1/4" endmill	1200

Part Number: ME450-W15-19-02

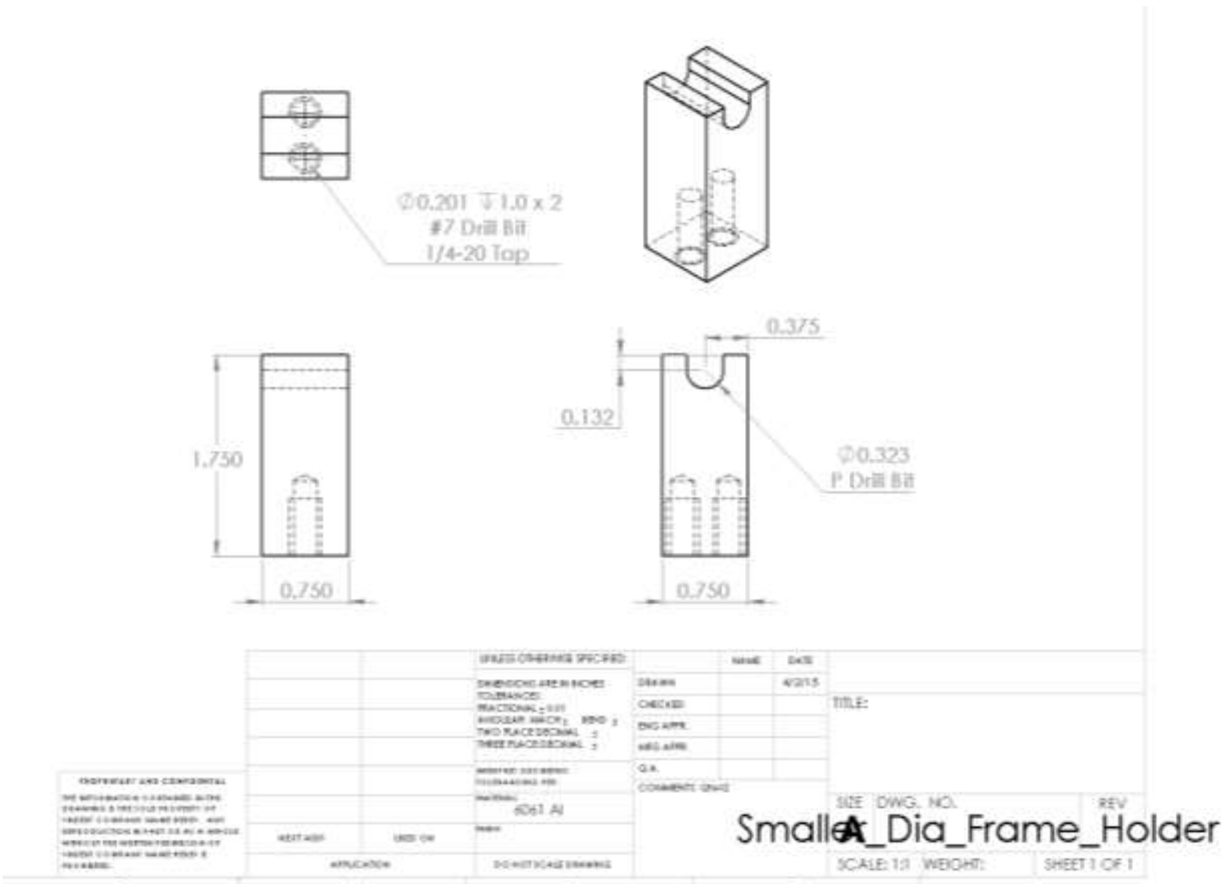
<u>Part Name: Frame Holder - Small</u>

Team Name: ME450-19

Revision Date: 4/2/2015

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 3/4" x 3/4"



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end to smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	Mill to height(.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
4	File machined edges			file	
5	Drill slot hole	Mill	Vice	P drill bit, collet, parallels	1100
6	Mill slot edges	Mill	Vice	1/8" endmill, collet, parallels	1600
7	File machined edges			file	
8	Find corner of part	Mill	Vice	edge finder, drill chuck	1200
9	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, #7 drill bit, chamfer	1200
	Chamfer Holes	Mill	Vice	drill chuck, chamfer	200
10	Tap Holes	Mill	vice	Center, drill chuck, 1/4-20 tap and handle	

Part Number: ME450-W15-19-03

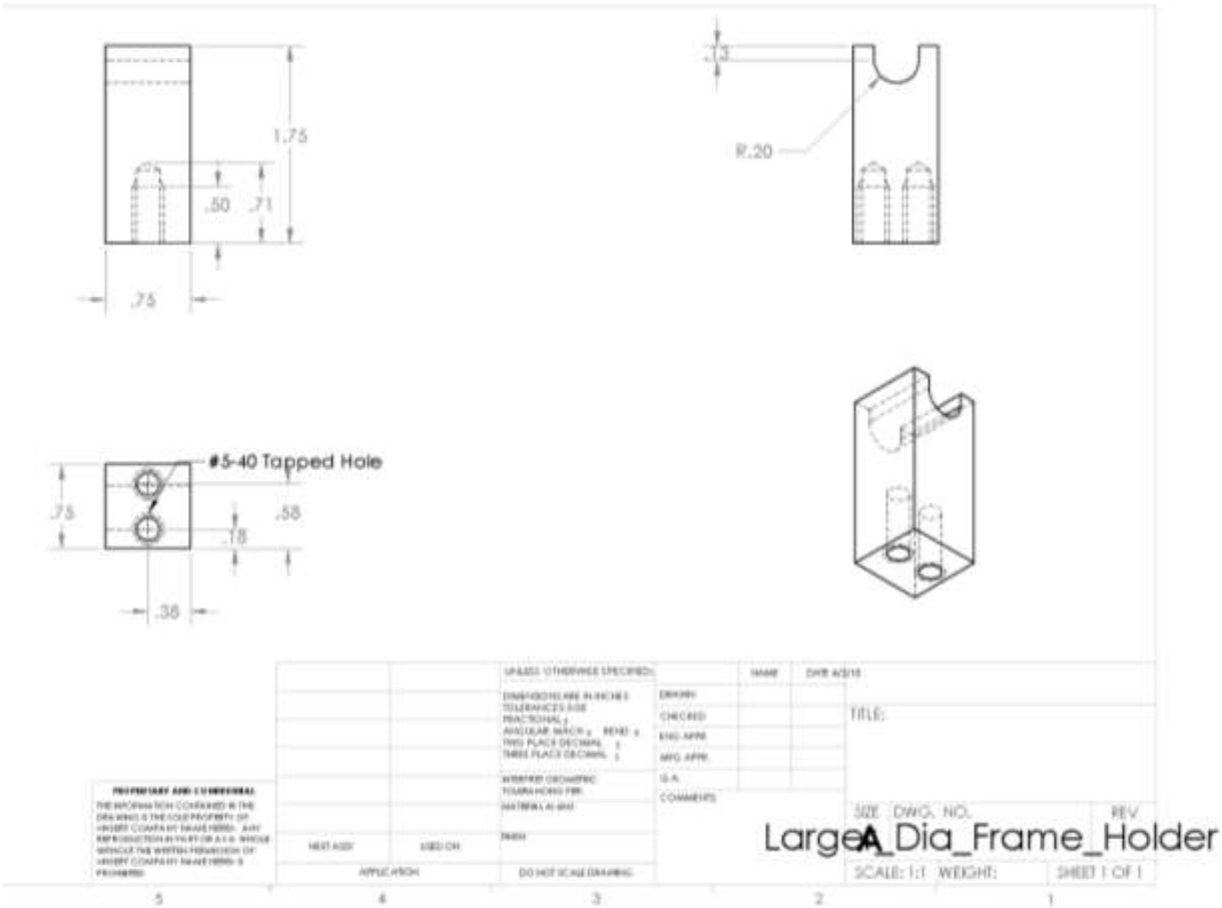
Part Name: Frame Holder - Large

Team Name: ME450-19

Revision Date: 4/2/2015

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 3/4" x 3/4"



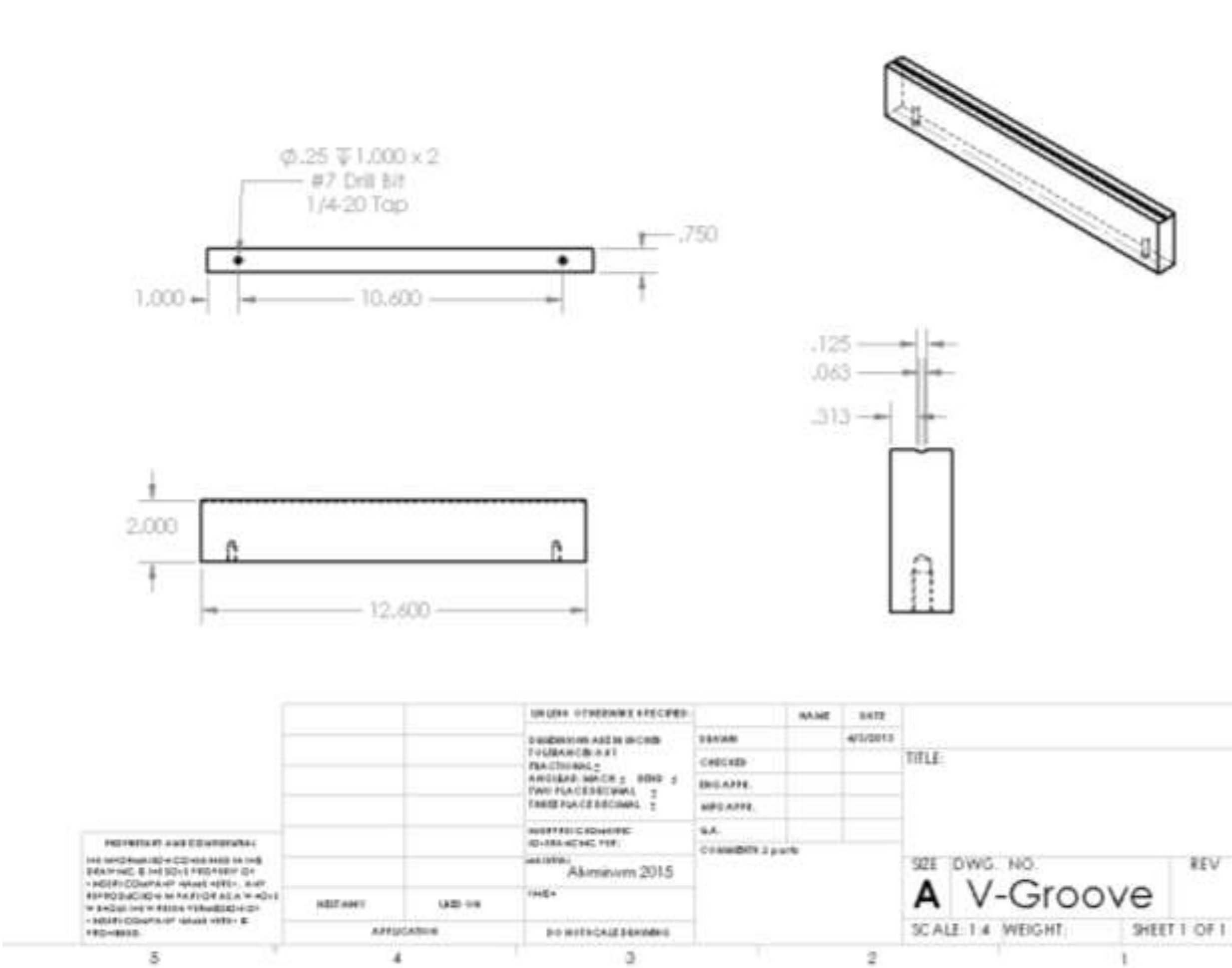
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end to smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	Mill to height(.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
4	File machined edges			file	
5	Drill slot hole	Mill	Vice	X drill bit, collet, parallels	1100
6	Mill slot edges	Mill	Vice	1/8" endmill, collet, parallels	1600
7	File machined edges			file	
8	Find corner of part	Mill	Vice	edge finder, drill chuck	1200
9	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, #7 drill bit, chamfer	1200
	Chamfer Holes	Mill	Vice	drill chuck, chamfer	200
10	Tap Holes	Mill	vice	Center, drill chuck, 1/4-20 tap and handle	

Part Number: ME450-W15-19-04 Revision Date: 4/2/2015

Part Name: V-groove

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, .75" x 2" bar



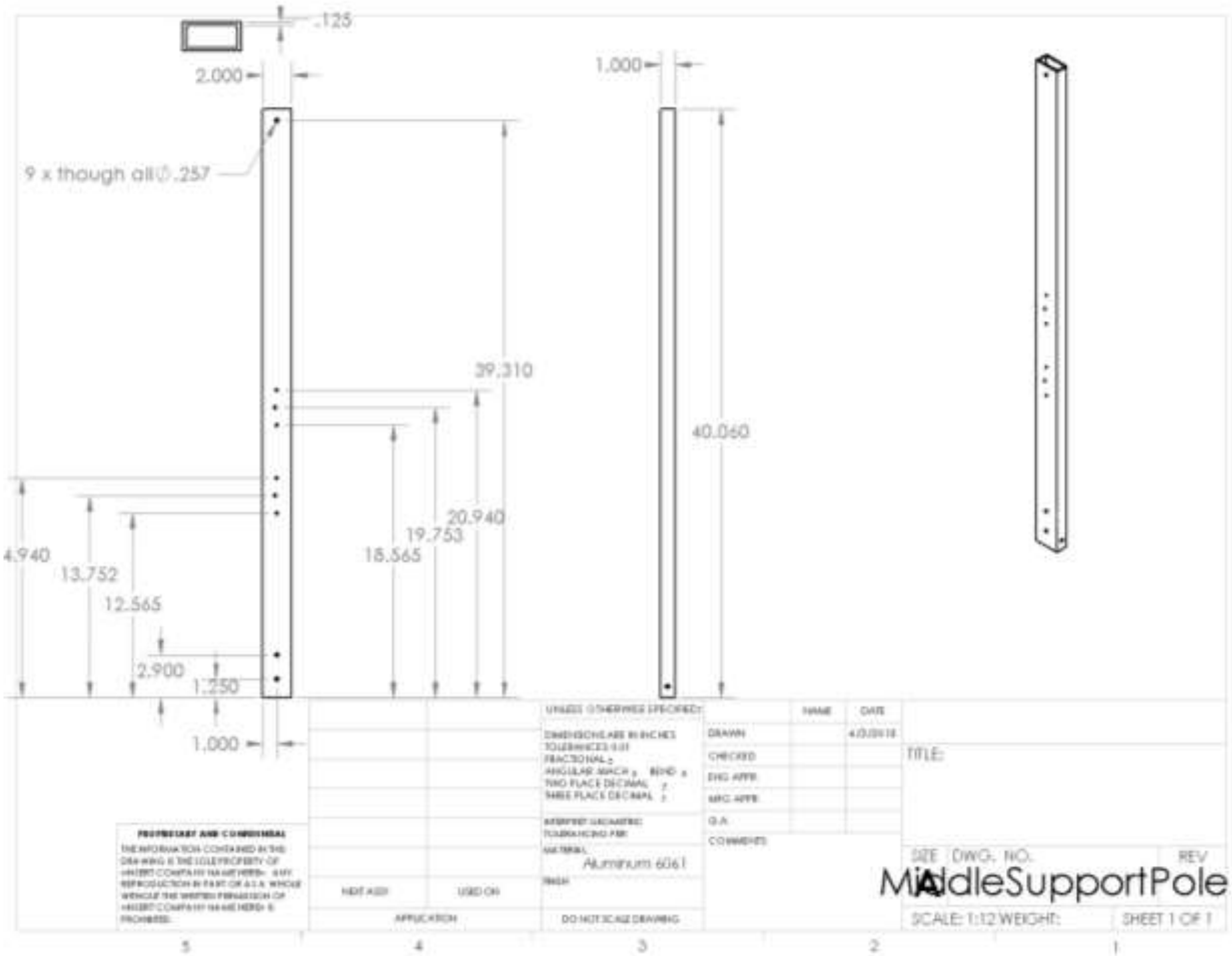
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	800
3	File machined edges			file	
4	Mill other end to length	Mill	Vice	3/4" endmill, collet, 1" parallels	800
5	File machined edges			file	
6	Mill 1/8" wide square groove in top face (0.125" depth passes)	Mill	Vice	1/8" endmill, collet, 1" parallels	1800
7	Mill 1/16" wide groove in top face (0.02" depth passes)	Mill	Vice	1/16" ballnose endmill, collet, 1" parallels	2000
8	Clean machined edges			file, pressure hose	
10	Center drill and drill holes in bottom face	Mill	Vice	drill chuck, centerdrill, #7 drill bit	1200
	Chamfer holes	Mill	Vice	drill chuck, chamfer	300
11	Tap Holes	Mill	vice	Center, drill chuck, 1/4-20 tap and handle	

Part Number: ME450-W15-19-05 Revision Date: 4/2/2015

Part Name: Middle Pole

Team Name: ME450-19 Quantity Needed: 1

Raw Material Stock: 6061-T6 Aluminum, 2" x 1", 1/8" thick Square Tube stock



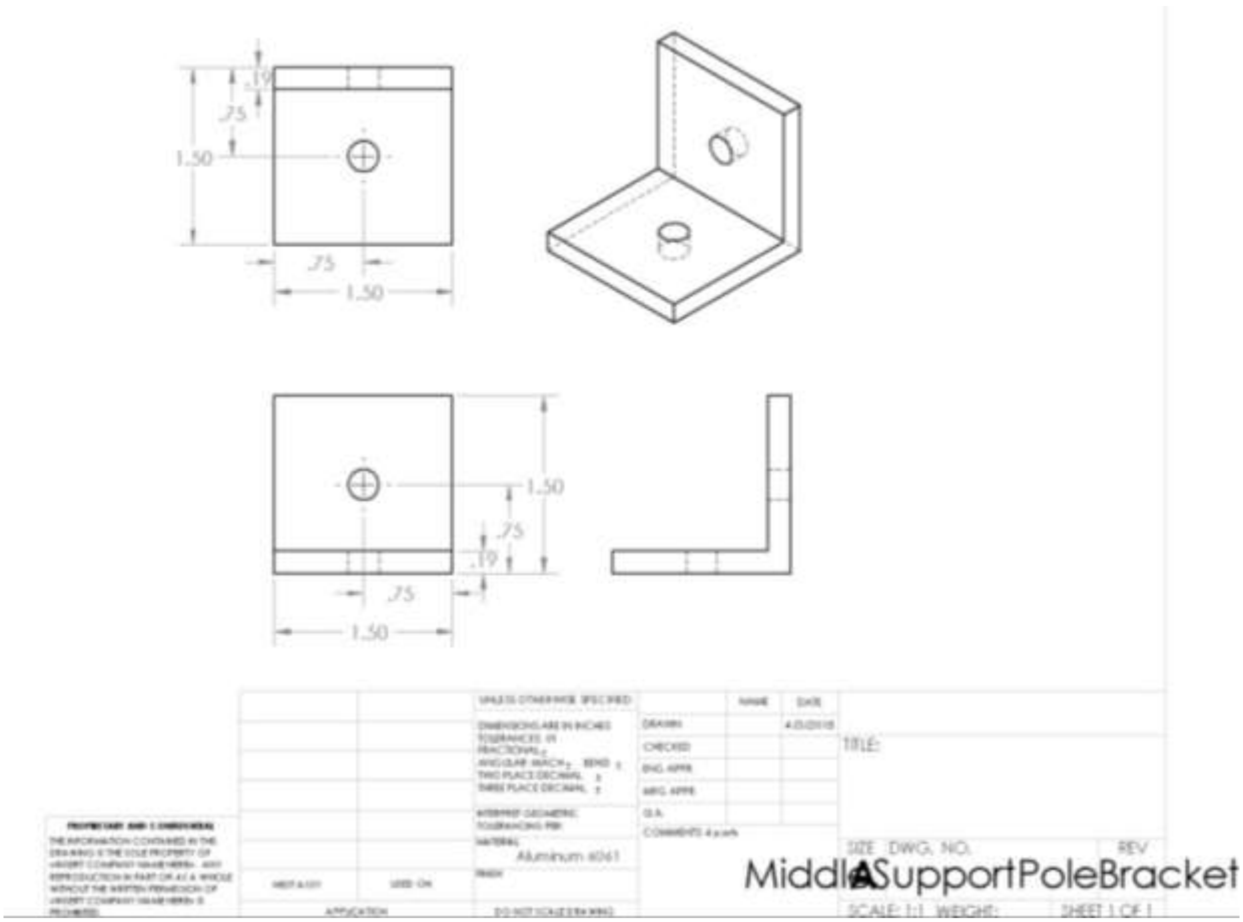
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			1000 ft/min
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Find corner of part	Mill	Vice	edge finder, drill chuck	1000
7	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
8	File hole edges			deburrer	

Part Number: ME450-W15-19-06 Revision Date: 4/2/2015

Part Name: Middle Pole Bracket

Team Name: ME450-19 Quantity Needed: 4

Raw Material Stock: 6061-T6 Aluminum, 1.5", 3/16" thick Angle stock



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Find corner of part	Mill	Vice	edge finder, drill chuck	
7	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
8	File hole edges			deburrer	

Part Number: ME450-W15-19-07

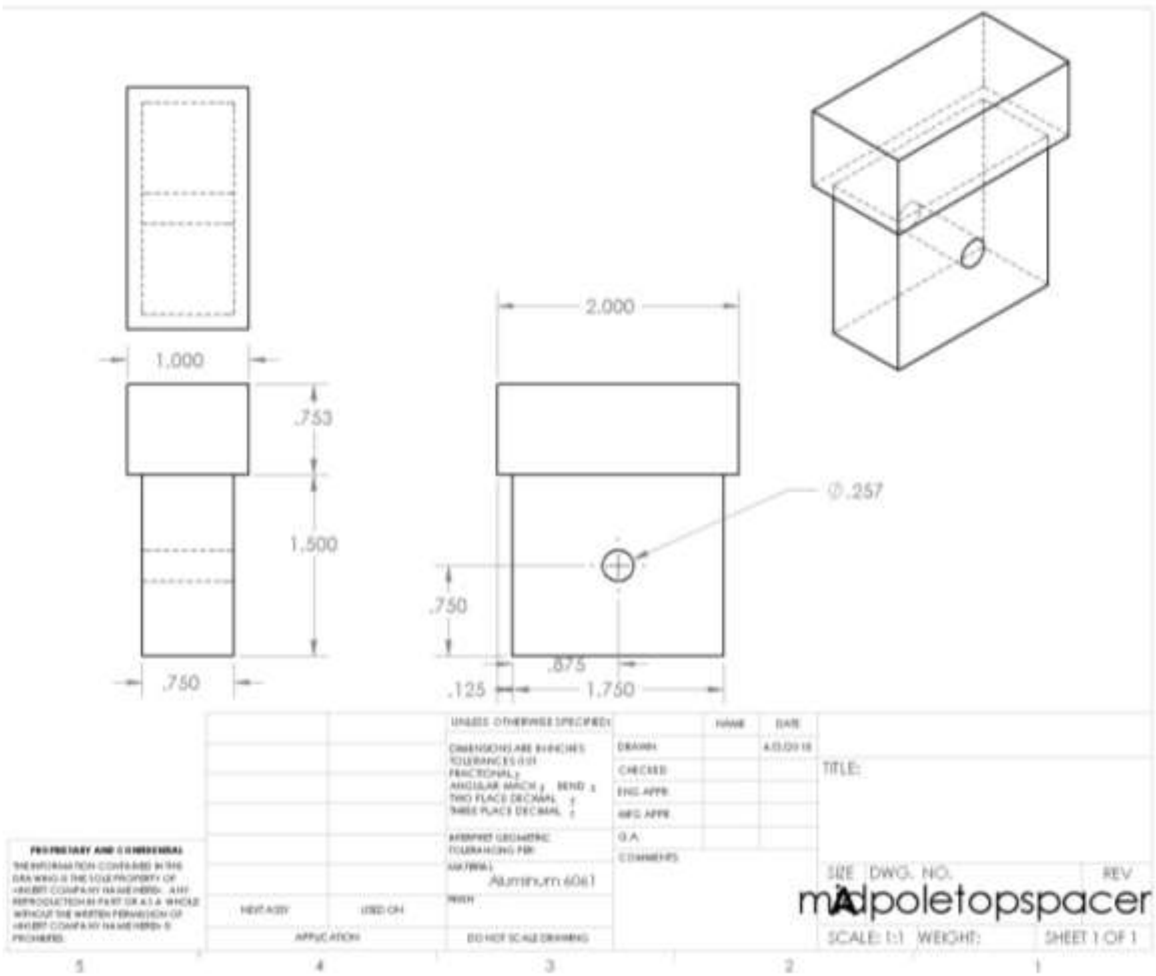
Revision Date: 4/2/2015

Part Name: Middle Pole Plug

Team Name: ME450-19

Quantity Needed: 1

Raw Material Stock: 6061-T6 Aluminum, 1" thick plate



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill top of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill to height	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Mill one side and front for smooth surface (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
7	File machined edges			file	
8	Mill to width and depth	Mill	Vice	3/4" endmill, collet, 1" parallels	840
9	Mill plug notch (1/8" horizontally, 1.5" vertically)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
10	File machined edges			file	
11	Find corner of part	Mill	Vice	edge finder, drill chuck	1000
12	Center drill and drill hole	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
13	File hole edges			deburrer	

Part Number: ME450-W15-19-08

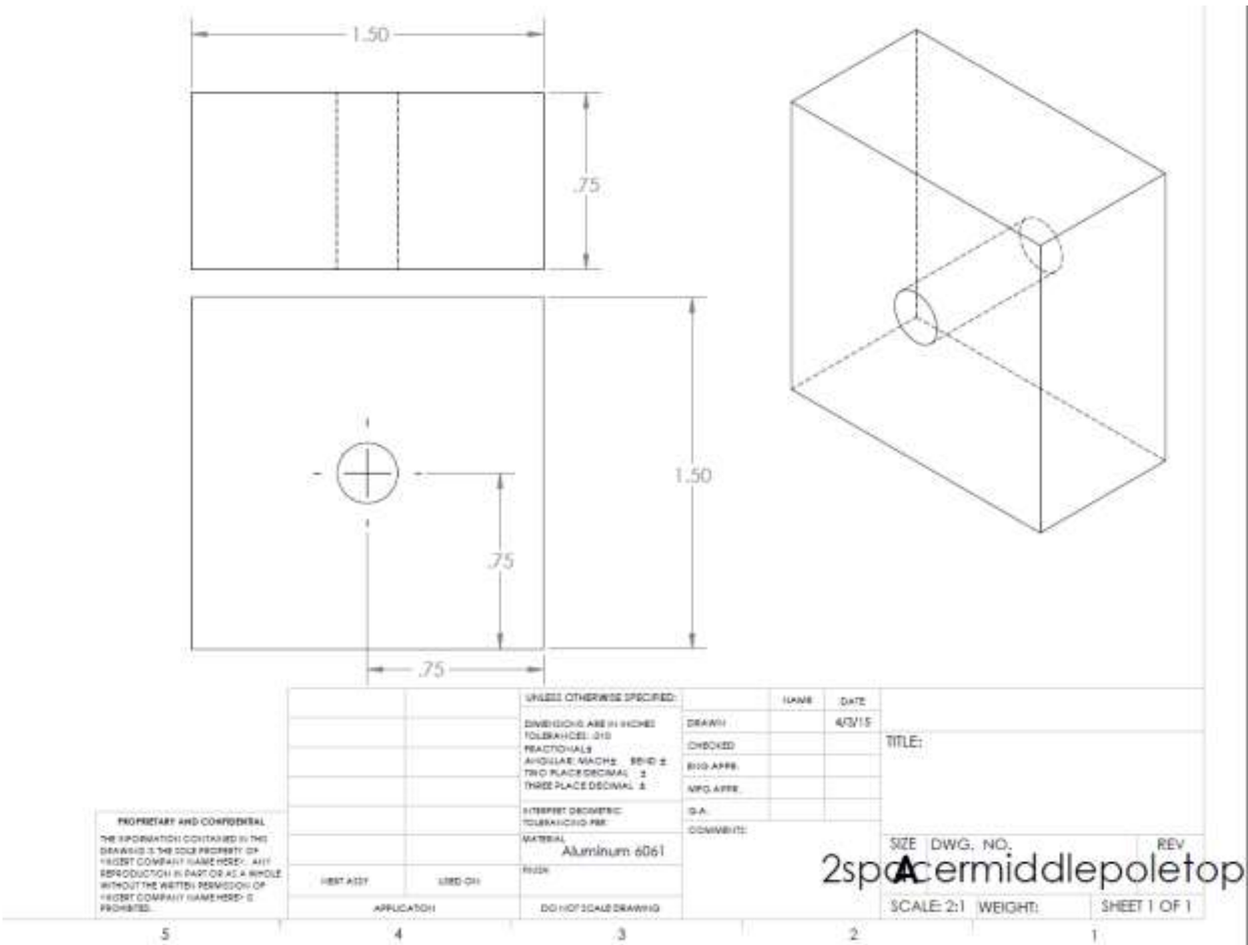
Revision Date: 4/2/2015

Part Name: Middle Pole Attachment Spacer

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 1" plate



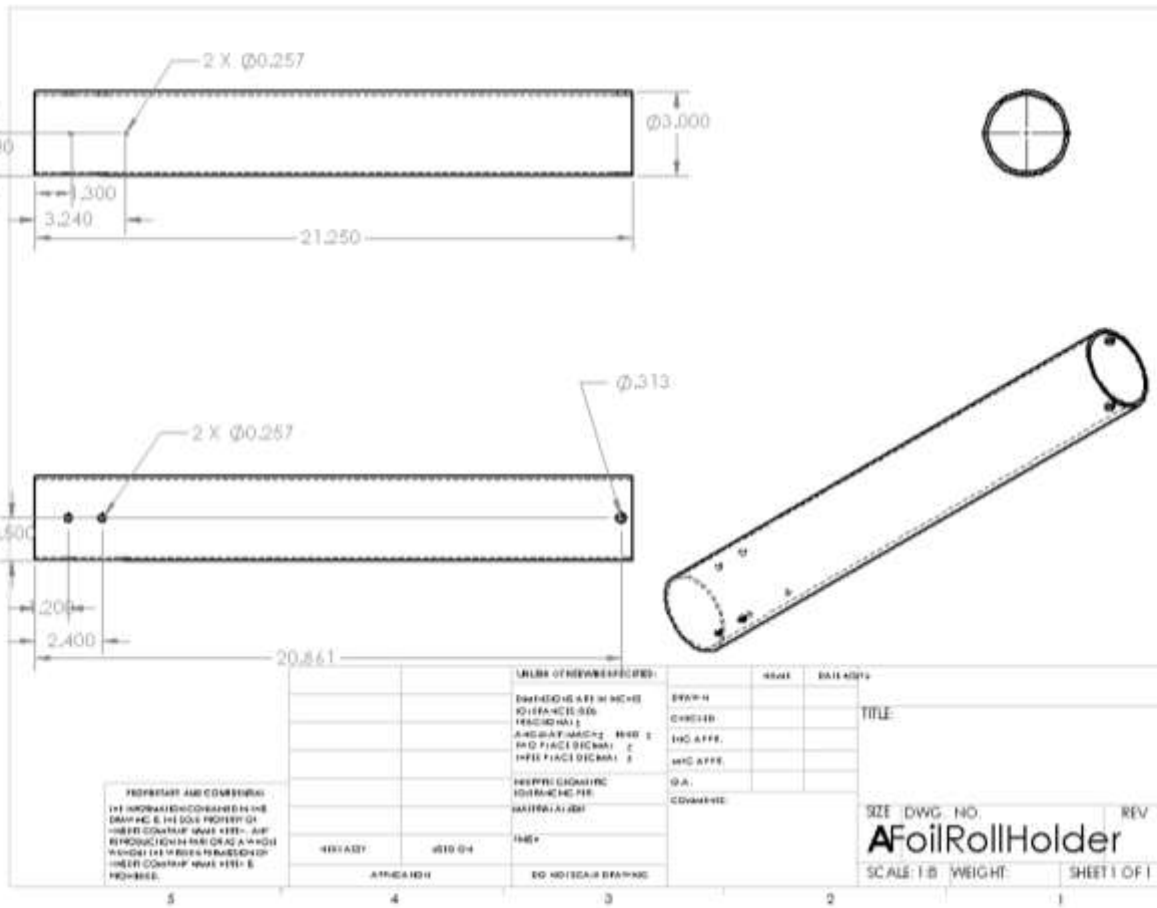
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Mill one side of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
7	File machined edges			file	
8	Mill other side to width	Mill	Vice	3/4" endmill, collet, 1" parallels	840
9	File machined edges			file	
10	Mill top of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
11	File machined edges			file	
12	Mill bottom to height	Mill	Vice	3/4" endmill, collet, 1" parallels	840
13	File machined edges			file	
14	Find corner of part	Mill	Vice	edge finder, drill chuck	1000
15	Center drill and drill hole	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
16	File hole edges			deburrer	

Part Number: ME450-W15-19-09 Revision Date: 4/2/2015

Part Name: Foil Roll Holder

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 3" OD Tube Stock, 1/8" thickness



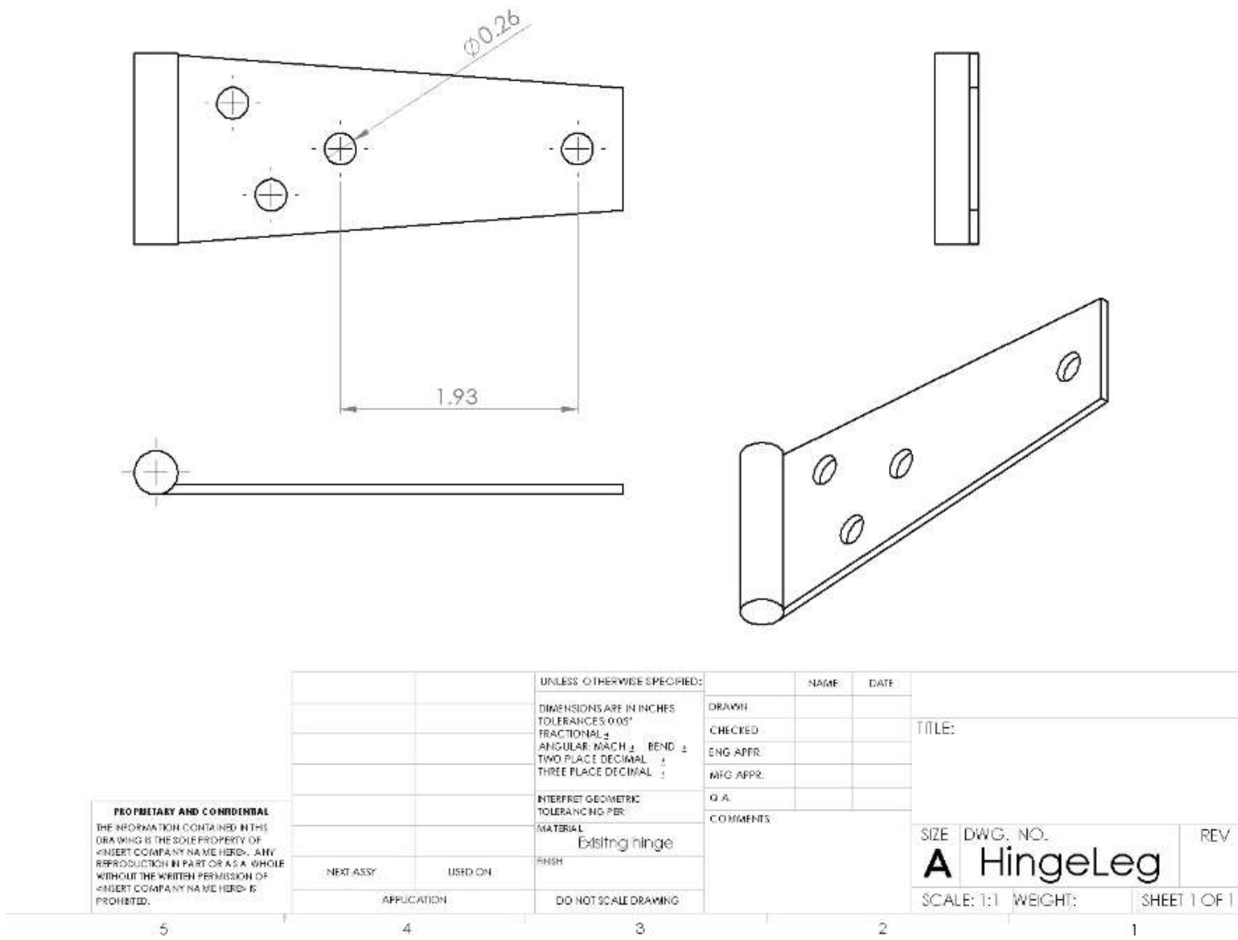
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Make plug to insert into one end of the tube for a center	Lathe	Chuck	facing tool	200
2	Lathe to correct diameter	Lathe	Chuck	facing tool	200
3	Lathe plugged end to smooth surface	Lathe	Chuck	facing tool	200
4	File machined edges			file	
5	Rough cut length	Band Saw			300 ft/min
6	File machined edges			file	
7	Bring part to length	Lathe	Chuck	facing tool	200
8	File machined edges			file	
9	Move part to mill, find zeroes	Mill	Vice, end supports (vertical)	drill chuck, edge finder	1200
10	Center drill and drill holes	Mill	Vice, Collet	drill chuck, center drill, F drill bit	1200
11	Turn part 90 degrees, center drill, and drill holes	Mill	Vice, Collet	drill chuck, center drill, F drill bit, N drill bit	1200
12	File machined edges			deburrer	

Part Number: ME450-W15-19-10 Revision Date: 4/2/2015

<u>Part Name: Foil Roll Hinge</u>

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: Strap Hinge, Zinc-Plated Steel



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Find corner of part	Mill	Vice	edge finder, drill chuck	
2	Center drill and drill hole	Mill	Vice	drill chuck, centerdrill, F drill bit	800
3	File hole edges			deburrer	

Part Number: ME450-W15-19-11/12

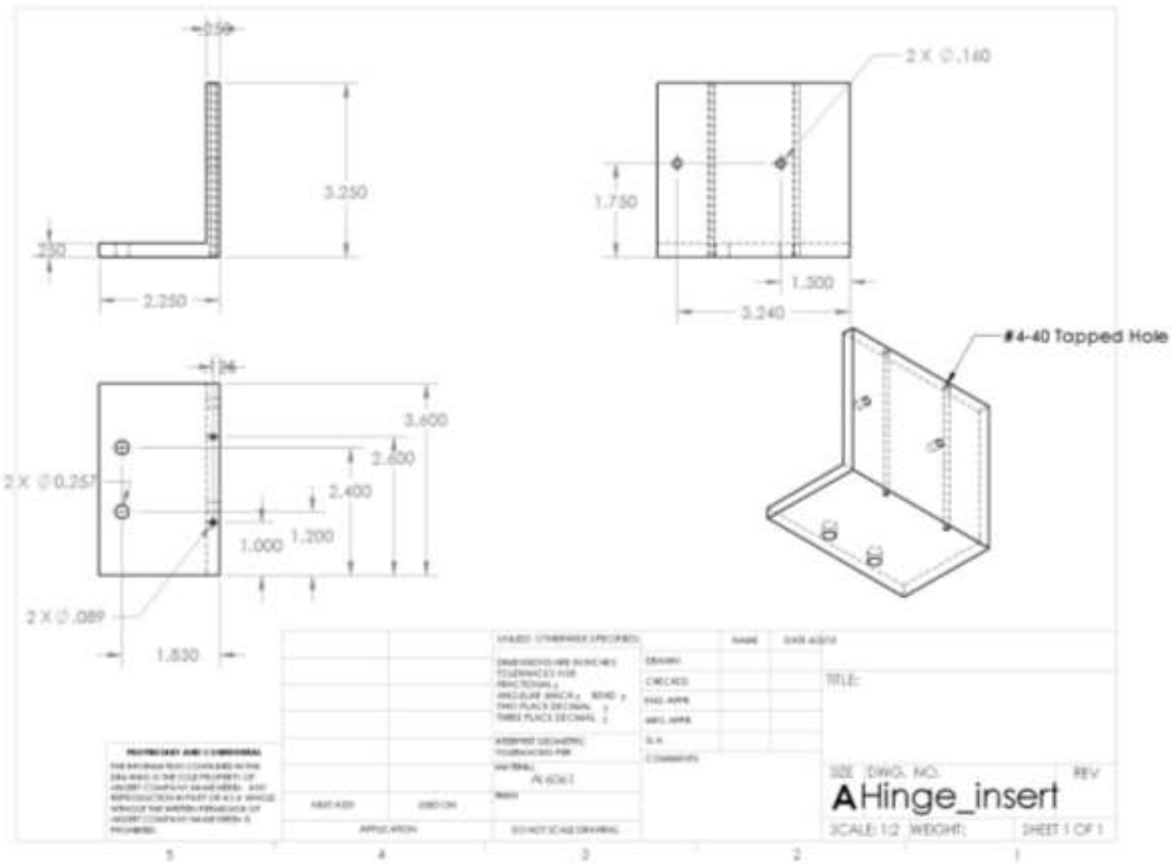
Part Name: C Clamp

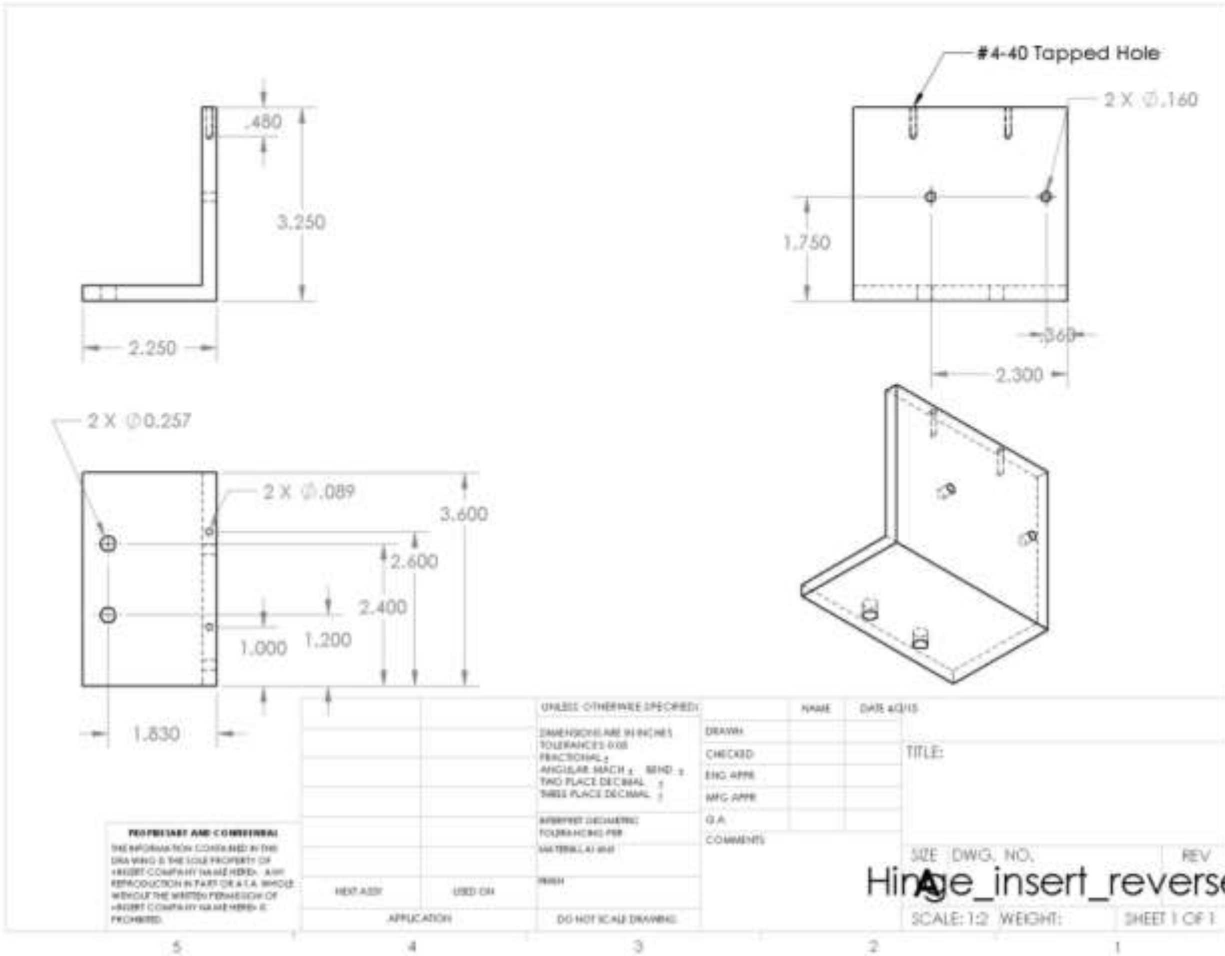
Team Name: ME450-19

Revision Date: 4/2/2015

Quantity Needed: 1 Left, 1 Right

Raw Material Stock: 6061-T6 Aluminum, 1/4" thick, 4" flange angle stock




#4-40 Tapped Hole
2 X ∅.160
.480
3.250
2.250
1.750
.360
2.300
2 X ∅0.257
2 X ∅.089
3.600
2.600
2.400
1.000
1.200
1.830
UNLESS OTHERWISE SPECIFIED:
NAME
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE DWG. NO.
REV
A
Hinge_insert_reverse
SCALE: 1:2 WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
5
4
3
2
1

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			300 ft/min
2	Mill one face to smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	800
3	File machined edges			file	
4	Mill one end smooth	Mill	Vice	3/4" endmill, collet, 1" parallels	800
5	File machined edges			file	
6	Mill to length	Mill	Vice	3/4" endmill, collet, 1" parallels	800
7	File machined edges			file	
8	Mill flanges to correct heights	Mill	Vice	3/4" endmill, collet, 1" parallels	800
9	File machined edges			file	
10	Center drill and drill 1/4-20 clearance holes	Mill	Vice	drill chuck, center drill, F drill bit	1200
11	File hole edges			deburrer	
12	Center drill and drill holes in top edge	Mill	Vice	drill chuck, center drill, #43 drill bit	1500
13	chamfer holes in top edge	Mill	Vice	drill chuck, chamfer	200
14	Tap holes in top edge	Mill	Vice	4-40 tap, handle, center, drill chuck	

Part Number: ME450-W15-19-13

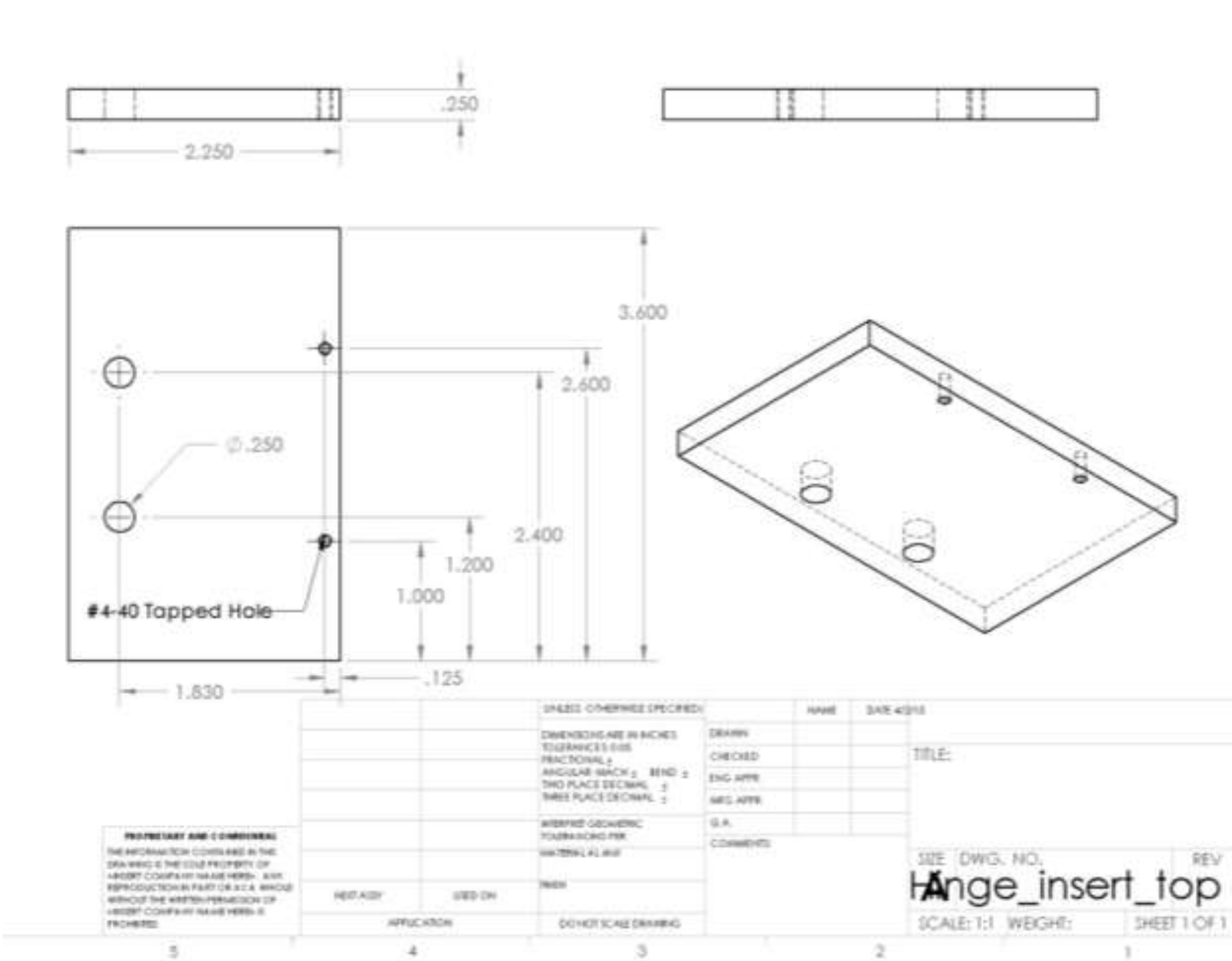
Revision Date: 4/2/2015

Part Name: C Clamp Top

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 1/4" plate



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Mill one side of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
7	File machined edges			file	
8	Mill other end to width (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
9	File machined edges			file	
10	Find corner of part	Mill	Vice	edge finder, drill chuck	1000
11	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
12	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, #30 drill bit	1600
14	File hole edges			deburrer	

Part Number: ME450-W15-19-14

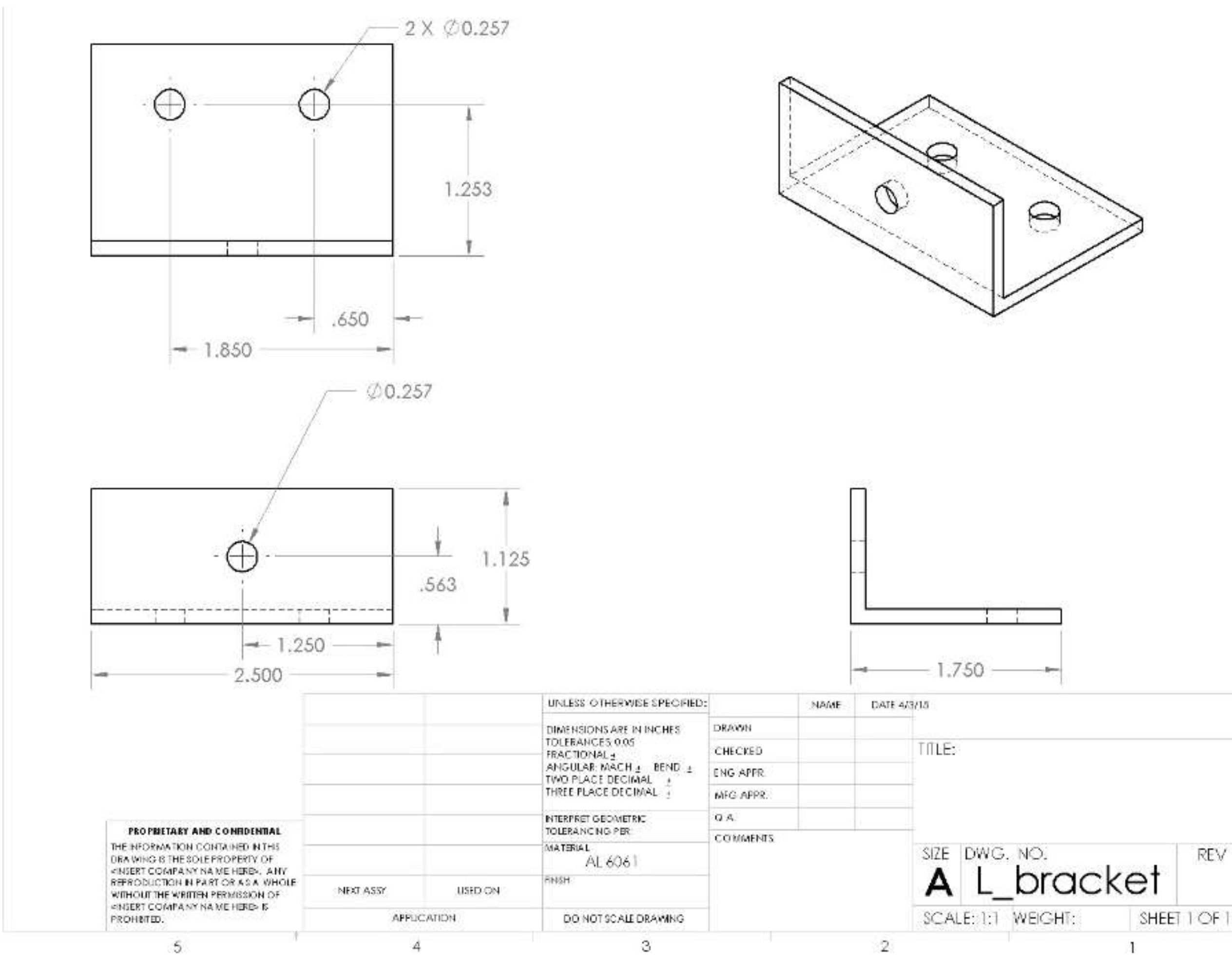
Revision Date: 4/202015

Part Name: Foil Roll Support Attachment Bracket

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 4" x 4", 1/4" thick Angle stock



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			300 ft/min
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Mill Flanges to length	Mill	Vice	3/4" endmill, collet, 1" parallels	840
7	File machined edges			file	
8	Find corner of part	Mill	Vice	edge finder, drill chuck	
9	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
10	File hole edges			deburrer	

Part Number: ME450-W15-19-15/16

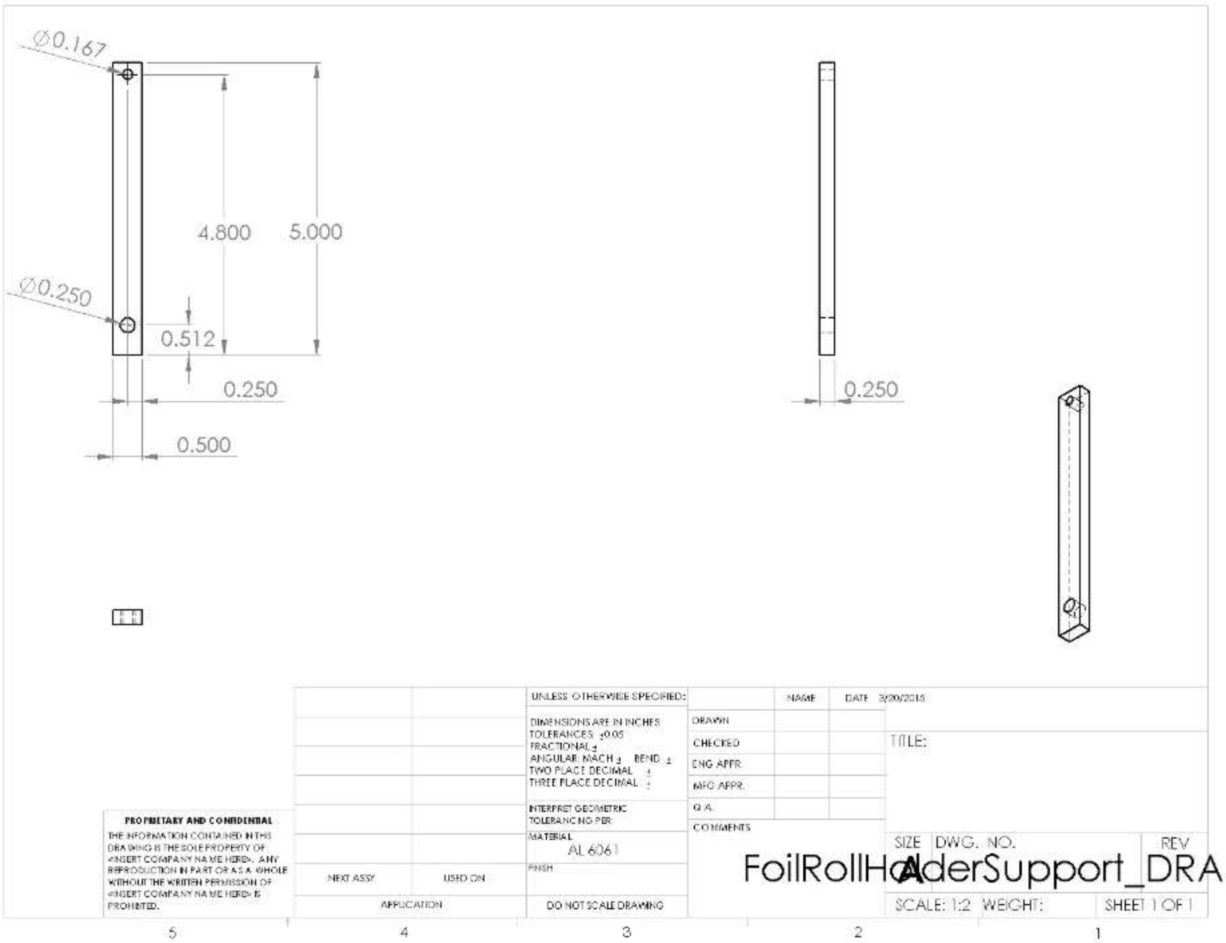
Part Name: Foil Roll Support

Team Name: ME450-19

Revision Date: 4/2/2015

Quantity Needed: 1 Left, 1 Right

Raw Material Stock: 6061-T6 Aluminum, 1/4" x 1/2" bar



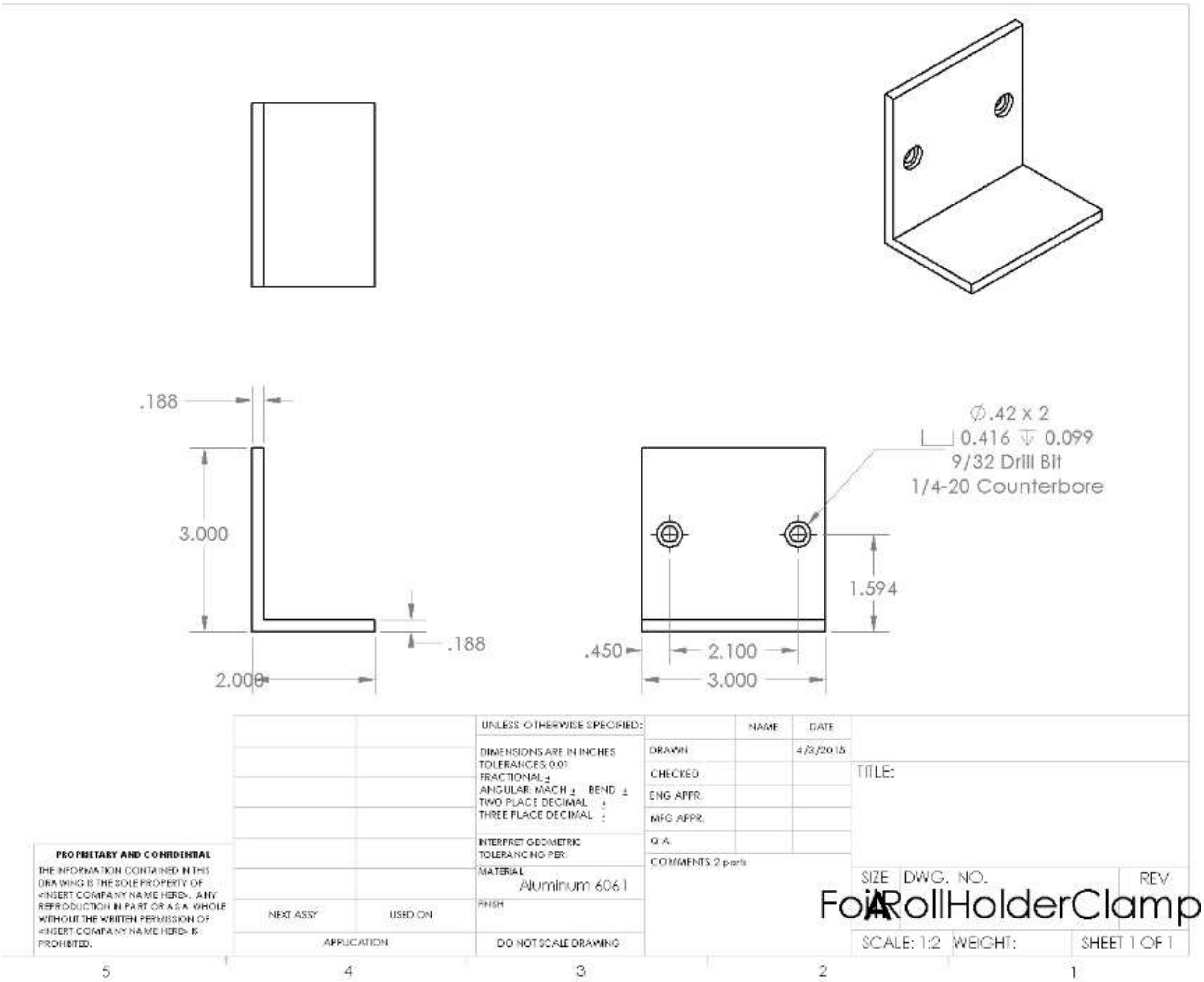
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut	Band Saw			300 ft/min
2	Mill one end to smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	800
3	File machined edges			file	
4	Mill other end to length	Mill	Vice	3/4" endmill, collet, 1" parallels	800
5	File machined edges			file	
6	Find corner of part	Mill	Vice	edge finder, drill chuck	1200
7	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
8	File hole edges			deburrer	

Part Number: ME450-W15-19-18 Revision Date: 4/2/2015

Part Name: Foil Roll Support Bracket

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 4", 3/16" thick Angle stock



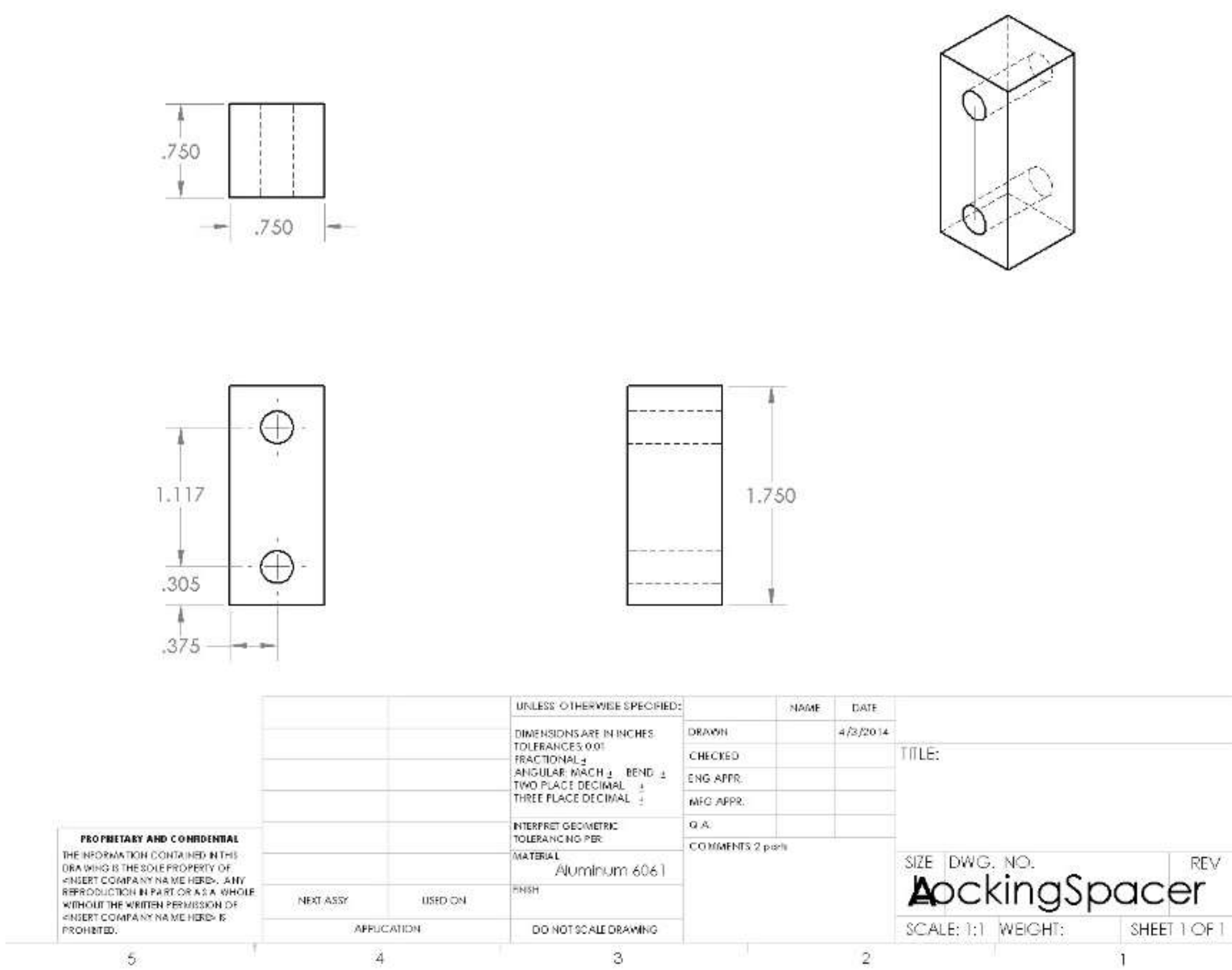
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut Length	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Rough cut flanges	Band Saw			
7	Mill flanges to length	Mill	Vice	3/4" endmill, collet, 1" parallels	840
8	Find corner of part	Mill	Vice	edge finder, drill chuck	
9	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
10	File hole edges			deburrer	

Part Number: ME450-W15-19-20 Revision Date: 4/2/2015

Part Name: Lock Spacer

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 3/4" x 3/4" bar



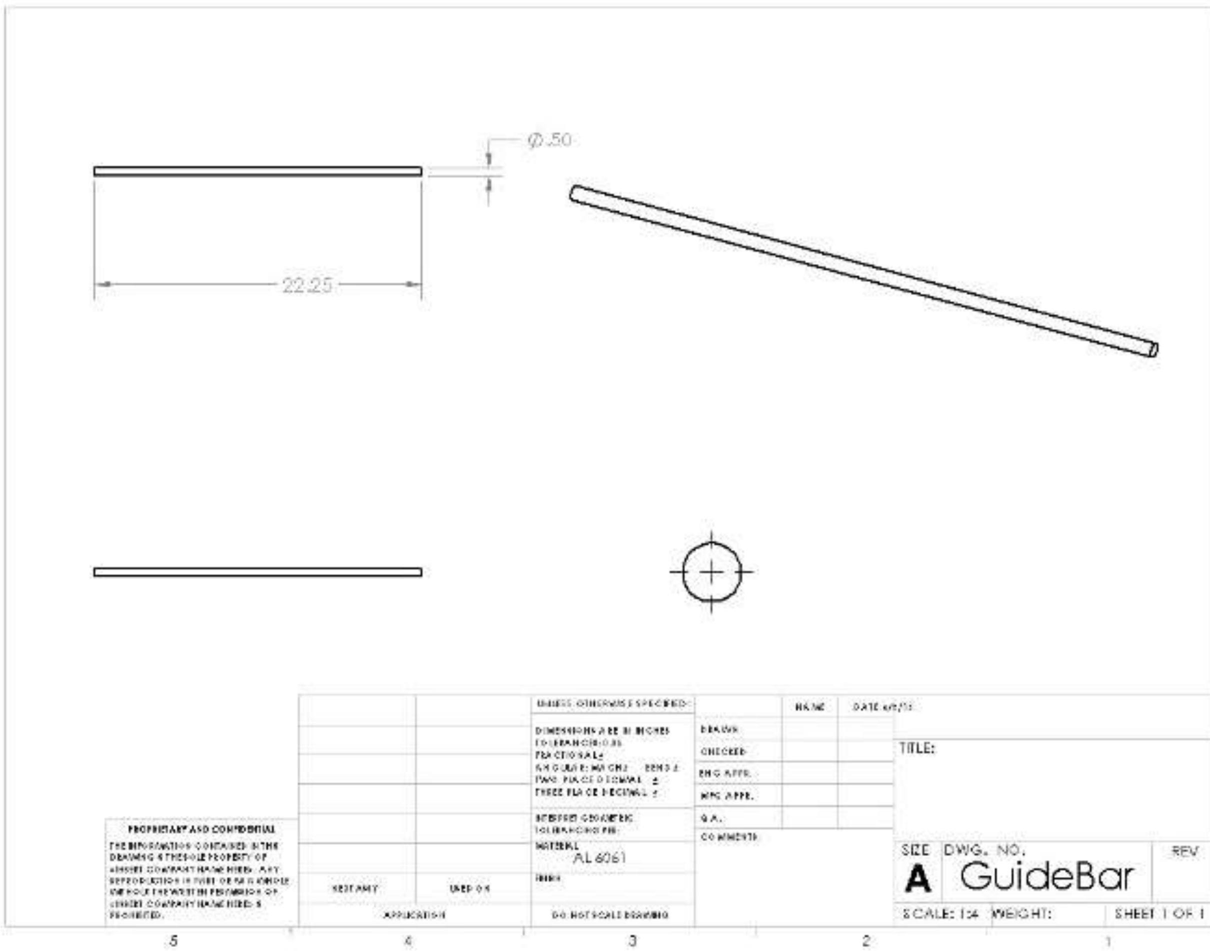
Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough Cut length	Band Saw			
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill other end to length (.05" passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Find corner of part	Mill	Vice	edge finder, drill chuck	
7	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit	1200
8	File hole edges			deburrer	

Part Number: ME450-W15-19-21 Revision Date: 4/2/2015

Part Name: Guide Bar

Team Name: ME450-19 Quantity Needed: 2

Raw Material Stock: 1/2" Diameter Steel



Step #	*Process Description*	*Machine*	*Fixtures*	*Tool(s)*	*Speed (RPM)*
1	Rough Cut	Band Saw			
2	File machined edges			file	
3	Drill live center	Lathe	Chuck	drill chuck, center drill	1000
4	Polish	Lathe	Chuck	emery cloth	1000

Part Number: ME450-W15-19-22

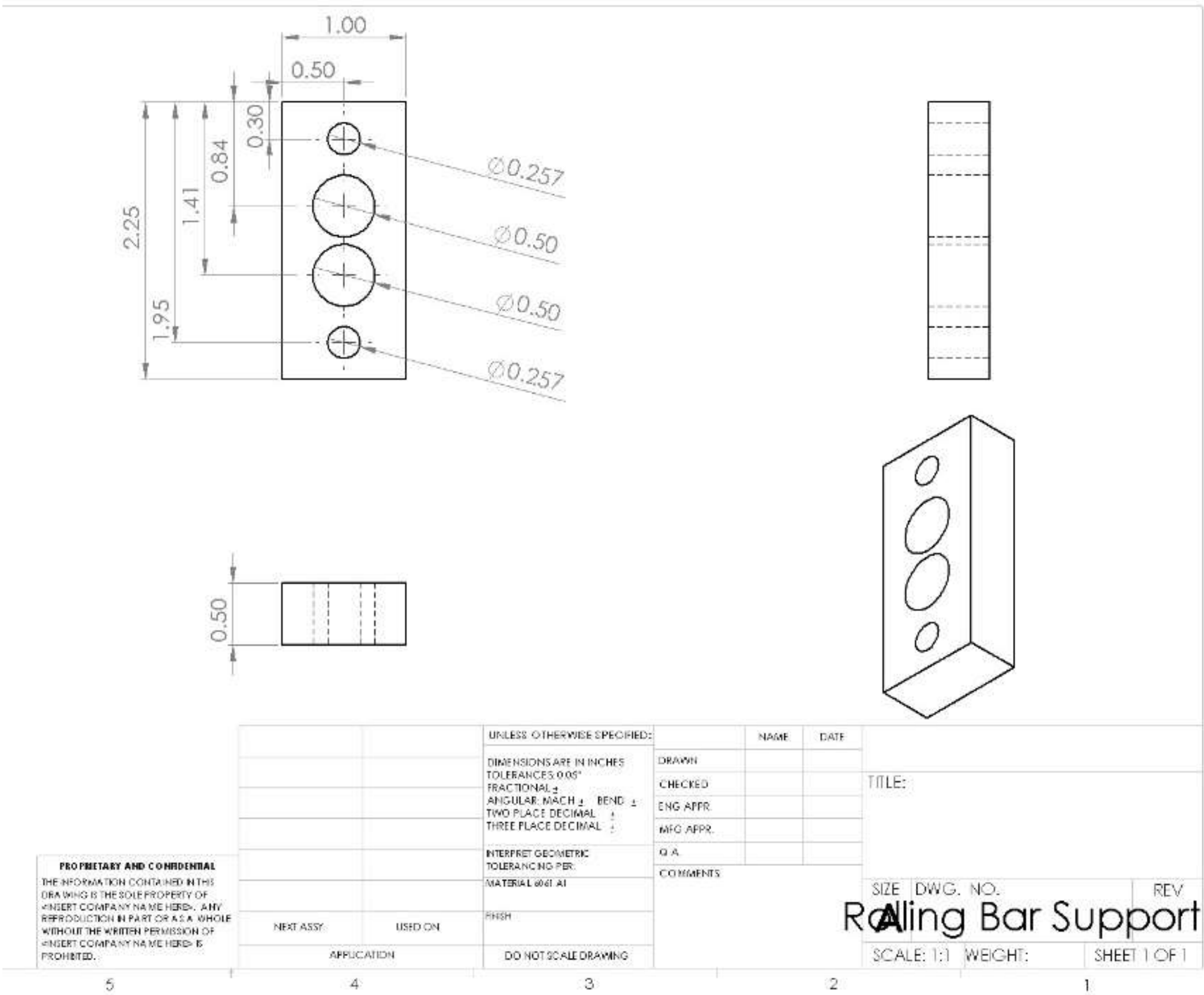
Revision Date: 4/2/2015

Part Name: Guide Bar Attachment

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 1" x 1/2" bar



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough cut	Band Saw			300 ft/min
2	Mill to size	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Find corner of part	Mill	Vice	edge finder, drill chuck	
5	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, F drill bit, 1/2" drill bit	1000
6	File holes			deburrer	

Part Number: ME450-W15-19-23

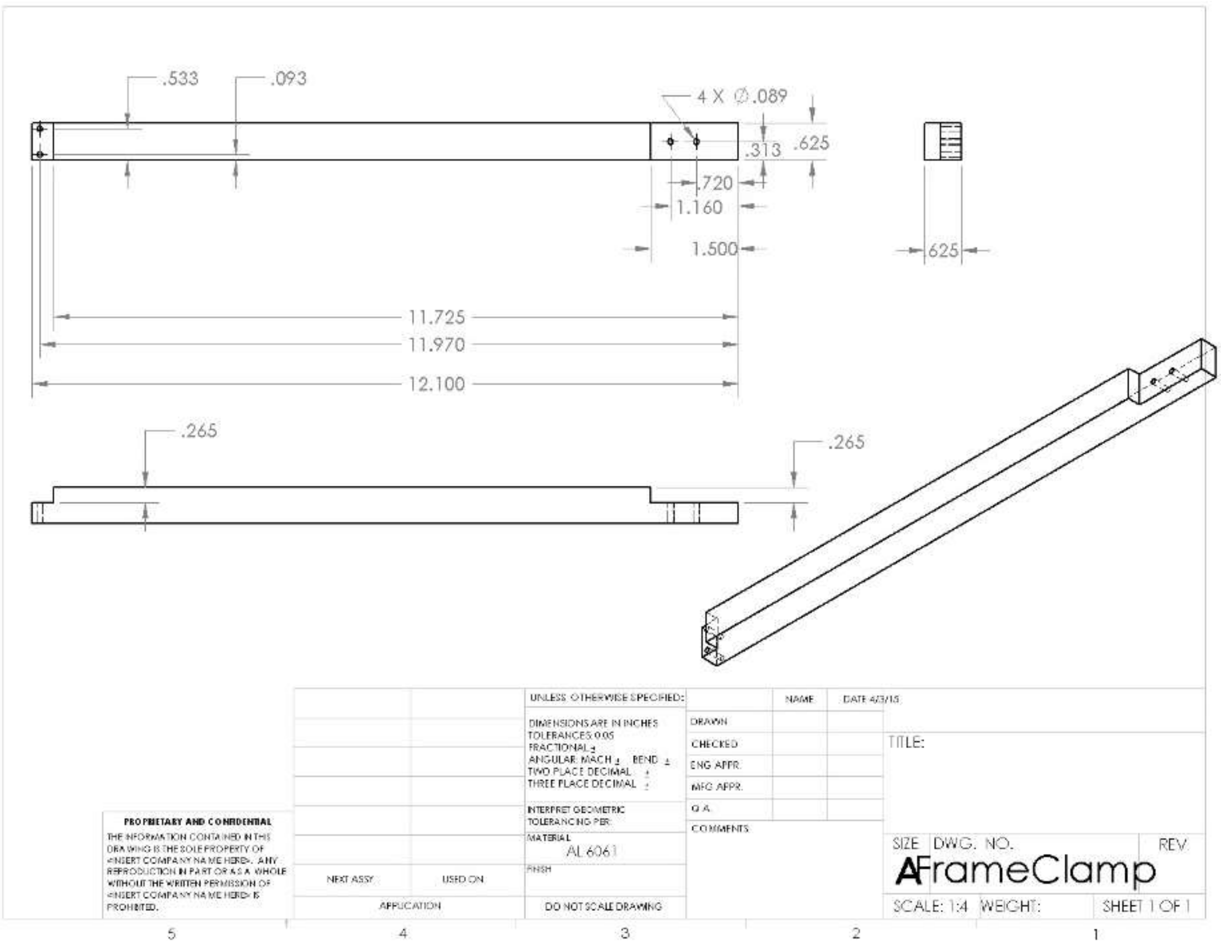
Revision Date: 4/2/2015

Part Name: Frame Clamp

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: 6061-T6 Aluminum, 5/8" x 5/8" bar



Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Rough cut	Band Saw			300 ft/min
2	Mill one end of part for smooth surface	Mill	Vice	3/4" endmill, collet, 1" parallels	840
3	File machined edges			file	
4	Mill to length (.05" passes)	Mill	Vice, stop	3/4" endmill, collet, 1" parallels	840
5	File machined edges			file	
6	Mill to notches (.05 passes)	Mill	Vice	3/4" endmill, collet, 1" parallels	840
7	Find corner of part	Mill	Vice	edge finder, drill chuck	1000
8	Center drill and drill holes	Mill	Vice	drill chuck, centerdrill, #43 drill bit	1600
	Chamfer holes (top and bottom)	Mill	Vice	drill chuck, chamfer	300
9	Tap Holes	Mill	vice	Center, drill chuck, 4-40 tap and handle	

Part Number: ME450-W15-19-24

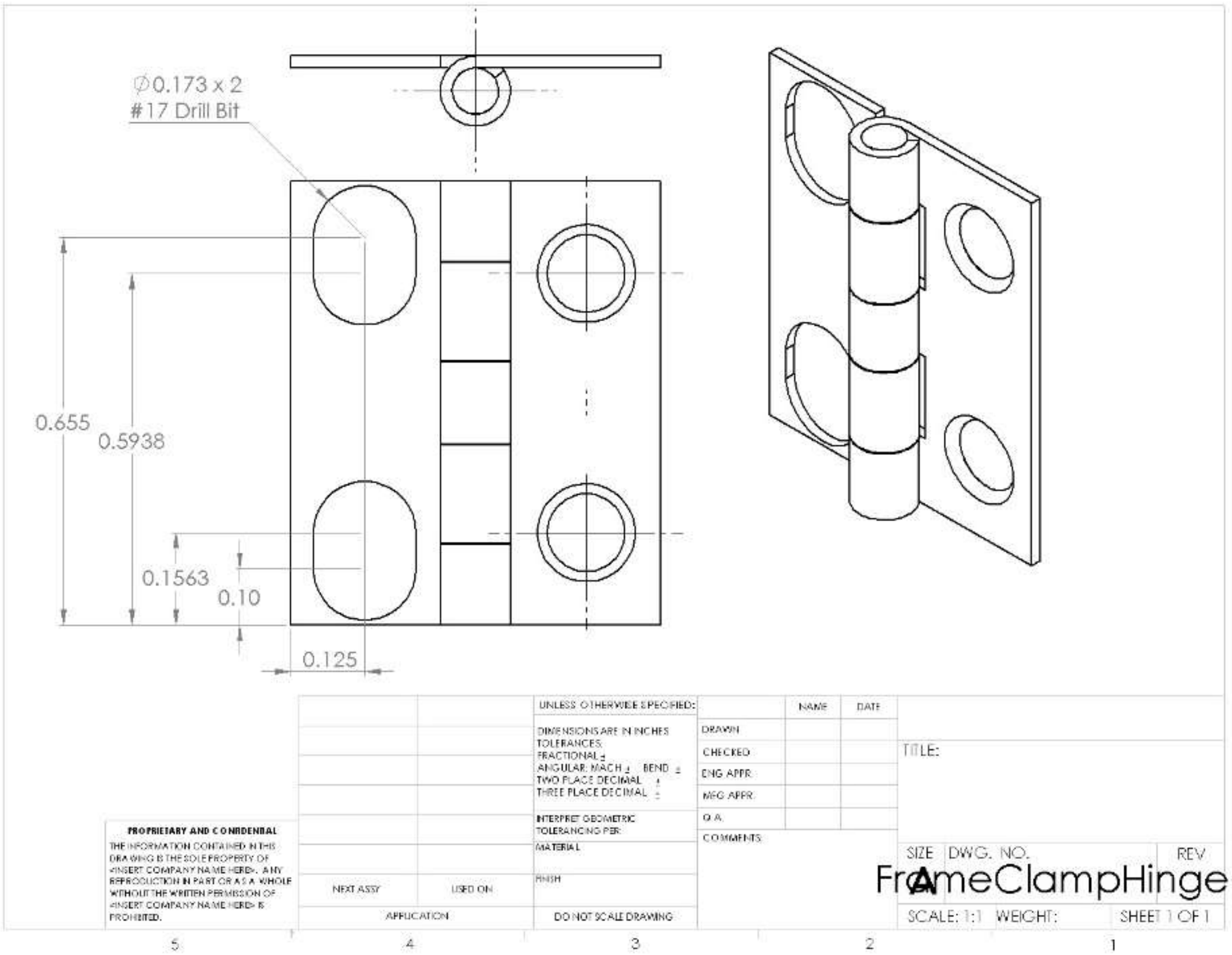
Revision Date: 4/2/2015

Part Name: Frame Clamp Hinge

Team Name: ME450-19

Quantity Needed: 2

Raw Material Stock: Hinge



Step #	*Process Description*	*Machine*	*Fixtures*	*Tool(s)*	*Speed (RPM)*
1	Find corner of part	Mill	Vice	edge finder, drill chuck	
2	Mill Slots	Mill	Vice	1/8" endmill and collet	1400
3	File hole edges			deburrer	

Appendix D: Validation Protocol

There are four main things that need to be tested empirically, and two tests that will cover the validation of these things. The four things to be tested are:

- Wrinkle reduction (Does the system reduce wrinkles on loading?)
- Waste reduction (Does the system reduce foil waste on loading?)
- Ease of use (Is the system easier to use than the original system?
- System robustness (Does the system work the way we intended it to?)

The first test we have performed uses only the aluminum and copper foil rolls, the unaltered frame, a flat surface to cut on, a marker, and a sharp knife. We loaded foil into the frame, recording the total time to load the frame and number of type 4 wrinkles created at the end of the loading process. Using a marker, we marked the amount of waste area on the loaded piece of foil. The foil was removed from the frame, and the number of type 1-3 wrinkles were counted. Tests were done on both aluminum and copper foil, and done by members of our team, our sponsor, and other ME 450 students. All tests were done using a standardized length of foil.

The second test we performed uses the new loading system we built, aluminum and copper foil rolls, a marker, and a sharp knife. We, again, load foil into the frame, this time using the method we have created. We, again, record total time to load the foil and type 4 wrinkles created, and mark the waste area with a marker. The foil will then be removed, and the number of type 1-3 wrinkles were recorded. Tests were done on both aluminum and copper foil, and done by members of our team, our sponsor, and other ME 450 students. All tests were done using a standardized length of foil.

To see if our system reduced wrinkles, we verified that fewer type 1-4 wrinkles were created in tests using our system, compared to the tests using the old method. To see if our system reduced waste, we verified that less waste was created in tests using our system, compared to the tests using the old method. To see if our system was easier to use than the old method, we verified that tests using our system took less time and created fewer wrinkles than tests using the old method. Testing system robustness was qualitative, and the system was adjusted until we were satisfied with its functionality.

Appendix E: Ethical Design Statements

Aakash Agarwal:

Each member of the team followed ethical engineering practice required under the guidance of ASME. The final design was chosen based on the code of ethics mentioned in the ASME Constitution, Article C2.1.1.

Firstly, our team increased the competence and prestige of the engineering profession by being the first team to design a jig for the frame of the Labcoater <LTS> machine. The machine is only used at one another place in USA for battery fabrication. Earlier, the frame of the machine was only suitable for coating active electrochemically slurry on fabrics. But we redesigned the frame with the jig to make it fully functional with thin metal foils (aluminum for cathode and copper for anode) of different desired dimensions.

Our design also takes user safety into consideration. The only unsafe part is an exacto knife used for cutting the metal foil for as less than five seconds. To increase the user safety we designed and manufactured a proper cutting mechanism which includes a V-groove.

While manufacturing, we followed proper manufacturing techniques under the supervision of the experts in the mechanical machine shop and took their advice immediately when we were doubtful about our manufacturing plans. This not only ensured our safety but also of our fellow engineers.

To be environmentally friendly and economical, our project used a lot of scrap materials that were not used by past ME450 teams. We designed our project to be simple, rigid and be sustainable for at least five years.

<u>Daniel Gildin:</u>

Nowadays, information can be exchanged very quickly and there is a large demand for fast engineering decisions and production. For this reason, engineers are constantly being challenged to deliver quick results while guarantying the safety, health and welfare of anyone that interacts with their designs. During our design generation and manufacturing we have addressed this issue by analyzing possible points in our design that could be hazardous to the users. The team identified that the foil cutting process can be dangerous to the users if the cutting knife is not handled properly. The team came up with a storage system that decreases the users' exposure to the cutting knife as much as possible.

During technical and engineering analysis and manufacturing of our design, we have limited ourselves to make decisions that are within our areas of expertise. For any decision outside our areas of expertise we sought help from experts. We encountered some challenges during manufacturing and the team consulted with machines shop specialist to make sure that we were doing everything correctly. We also had weekly meetings with our sponsor to address any questions regarding the design requirements. Even though we have been working on this project for a considerably amount of time, the sponsor can always provide more information about the Battery Lab users and some technical specifications.

Moreover, the team has been very professional and respectful with everyone that was or is involved with the project. We think that mutual respect is the key to guarantee a good working environment, which improves the final outcome of the project and opens space to healthy and productive discussions. We have been trying to keep our sponsor updated about any changes and decisions the team makes as well as constantly asking for his feedback about the project. Whenever our sponsor disagrees with something, the team listens to his point and tries to do the best to meet his expectations.

<u>Raji Kiridena:</u>

There were a number of ways our team addressed ethical design in designing and building our system. Firstly, we strived to make our system as safe as possible. One of our main user requirements was user friendliness, a part of which included safe design. We tried to minimize sharp edges, pinch points, and any other parts that could potentially injure the user while using the system. While we do have a knife as part of our system, we will make sure that the knife is placed in a contained place, and only removed during use.

We have also only performed services in our areas of competence. If there was anything that we needed to do engineering-wise that no one on the team had experience with, we would try to find someone who did have experience with our problem, and use them as a resource to solve our problem. If we could not find anyone that could help us with something we did not have knowledge of, we would have to find a way to work around the problem, or remove it from our scope. This was very important in machining, where we received a lot of help from Charlie and John in the ME shop, and in trying to find a specification for wrinkles, where we used our sponsor, Dr. Less to help us develop an appropriate specification.

We also made to act professionally with everyone we interacted with during the course of the project. We understood that we are representing ourselves, our team, ME 450, and to some degree the ME department and all mechanical engineers. We held ourselves to high standards in terms of professional communication, whether it was with our sponsor, faculty, other ME 450 students, and people we will talk to at the expo in the future.

We have also considered the environmental impact of our project when designing. We made sure that we wasted as little material as possible, and tried to recycle most of the stock we used from stock left by other ME teams in the machine shop and assembly room.

Kelsey Wiers:

This project doesn't have a heavy load of ethical concerns attached to it, but there are some general guidelines we followed while designing the loading station and documenting the project. First and foremost, in all of our reports, presentations, meetings, and other correspondences, we have been completely truthful in our expectations for the project and its design and level of success. It is especially important that we not lie, or deceivingly present, the results of our validation testing considering the possible damages incurred from defects caused by the loading station. Wrinkles in the foil can lead to a few results: (1) the wrinkles are detected, the material is thrown away, and the process is started over, (2) the wrinkled foil is made into batteries, which will be sub-optimal, or (3) if the wrinkle is severe enough, the battery can explode during use. The first result (wrinkles are detected), causes extra waste and will be discussed further in my environmental impact statement (pg. 84).

The second result (suboptimal batteries), is undesirable for the obvious reasons of not producing an optimal product, but also, it is the goal of our team to facilitate production of optimal batteries in order to help the evolution of battery technology. The Battery Fabrication and Characterization User Facility, this project's sponsor, is used mostly for research on new lithium ion battery technology. If we can provide a successful loading station for this lab, we are helping to impact the future of battery technology and possibly battery use in the general public and elsewhere.

The third result (battery explosion), is the worst possible case because of the possible injuries and damages that would be caused. It is clearly the goal of this team not to cause any injuries or other damages, directly or indirectly, because of our design of the loading station. In summary, if the loading station is unsuccessful in eliminating wrinkles, it is important that we disclose that.

The last important ethical aspect of our project is that we admit where mistakes were made and not try to cover them up with false justification. We did make a couple manufacturing mistakes that slightly affected our design and they are reflected in Appendix B (pg. 37).

Appendix F: Environmental Impact Statements

Aakash Agarwal:

The project we designed is very environment friendly because it does not require any energy and/or water. The process of loading and cutting the foil is easily performed by an adult human being.

To be environmentally friendly and economical, our project used a lot of scrap materials that were not used by past ME450 teams. We designed our project to be simple, rigid and be sustainable for at least five years.

In order to save the environment, we could have redesigned a system which had two foil holders on top of each other. This would have helped to save a lot of materials and machine time as we would only need one base plate instead of having two base plates in our current design. Secondly, we could have also removed the base plate and have the V-groove and frame supports directly attached to the table. Lastly, we could have also designed a sliding mechanism for the base plate that would linearly move back and forth to align perfectly with the two foil support holders.

Every part of the system is being used extensively and it is either made by aluminum and plastic that is recyclable. Therefore, its parts can be used for other purposes or future ME 450 teams when our product is not required by the user.

Daniel Gildin:

The environmental impact of our mechanism is very minimal. The team designed a system that does not require any electrical input to work and is able to deliver very good results. The first idea was to have a vacuum table in our design but we concluded that the benefits of this mechanism as well as the electrical power necessary to run the system did not justify the use of it.

When designing the system the team made a list of materials that were left in the machine shop and the assembly room from previous semester to minimize the material waste and reuse those that were already available to us. The reuse of materials from previous semesters was also very important to keep the project within budget. The team also analyzed the best options when buying materials by only ordering the amount that was necessary to guarantee that the project was going to be completed in a timely manner.

The team made an effort to come up with a design that minimizes the amount of material being use as well as any type of material replacement during the system's lifetime. Maintenance was also a concern and we came up with a design that would not require constant cleaning, which decreases the amount of cleaning chemicals and water usage.

The team was able to minimize the environmental impact of the design and the project as a whole.

Raji Kiridena:

There were a number of ways our team addressed the environmental impact of building and the use of our system. Firstly, we made sure to minimize the materials we bought, and tried to use as much material as possible from the ME shop or X50 assembly room. Much of the stock we used was material left behind by other ME 450 teams, and any stock we had to buy was either too large to find in old supplies, or specialized enough that it had to be special ordered. Much of the material we used was simple stock, such as aluminum plate stock, aluminum square stock, and aluminum angle stock, that we machined into what we needed to use.

We also designed our system to be very robust, and made reinforced as many mechanical failure points in the system as possible. We believe that the system could be used for ~5 years, and requires very little maintenance to keep working. The parts that we have used in the system are relatively simple, ad most could be machined in the ME shop by one person in under an hour. If something does break, we believe that our system is robust enough that a non-engineer could fix the part.

By trying to reduce foil waste, we will be able to make more batteries from each roll of foil, which will save environmental shipping costs over the long run, as fewer rolls will need to be bought per the same number of batteries fabricated. In reducing wrinkles, we also reduce foil waste, as in the old system, many wrinkles were made and each wrinkled piece of foil was waste. In making more successful foils, we can again fabricate more batteries per roll.

At the end of the life of the system, we believe that the parts of the system are fully recyclable. The base plates we used are made from delrin, and as a thermoplastic, is recyclable. Most of the other parts of the system are made from aluminum, and are again recyclable at the end of the lifetime of the system. The desk that we built on was not significantly changed by our modifications, and apart from a few holes in the desk, is fully usable as a desk after our system is taken off it.

Kelsey Wiers:

The environmental impact of our project exists in three categories: (1) the actual prototype, (2) the use of the prototype, and (3) the impact of the prototype on technology. The first category (prototype) includes the materials used to make the prototype and energy used to machine and assemble them. Most of our prototype is made of aluminum and there are a couple steel parts. Aluminum requires a relatively large amount of energy to produce compared to other metals, and an extremely large amount when compared to steel. We chose to use mostly aluminum despite these drawbacks because it is cheaper and lighter and we are only making one prototype of this design. If this were a product intended for mass manufacturing, more consideration of what material to use would've been necessary. Delivery of the materials we used is another way our materials impact the environment, but options for getting aluminum stock are limited, so we didn't have much control over this aspect of our design. There was also energy used in machining our parts, which was mostly done on the mill. Again, options for machining were limited and all require the use of at least some amount of generated power. The last aspect of the environmental impact of our prototype is its end of life disposal. It is the goal that our prototype will be in use for at least 5 years, hopefully much more, and at the end of its use, it should be disassembled and recycled as much as possible to mitigate the energy costs of producing the aluminum.

The environmental impact of the use of our prototype is relatively low, including only the materials and manufacturing of the foil rolls. The foils used with our prototype are aluminum and copper which are pretty energy costly to manufacture. However, these materials were out of the scope of our project and would be used regardless of our loading station design. The rolls of foil also come on a tube made of cardboard for the copper roll and aluminum for the aluminum roll. These tubes should also be recycled, but this was again out of the scope of our project. It was also one of our goals in designing the loading station to waste as little foil as possible. We took this into account when designing the new clamping system for the frame and in designing where the v-groove cutting mechanism should be located.

Even though all the environmental impacts discussed thus far have been negative, it is our hope that with successful use of our prototype, defect free lithium ion battery electrodes will be produced and contribute to the advancement of battery technology in the future with the end goal of more energy efficient and more powerful battery capabilities.

Authors

Aakash Agarwal: Aakash Agarwal was born in a small village in India, Sirsaganj. He has moved from city to city for better education opportunities. He did elementary and middle school in the capital city of India, New Delhi and high school in the educational hub of India, Kota. Then, he moved to Dubai, UAE for undergraduate studies and transferred to University of Michigan, USA as a sophomore. He is currently a senior in Mechanical Engineering with a minor in Computer Science. His favorite classes at U of M have been ME 305 - Finite Element Analysis (he loves to do force, pressure, stress and strain analysis on different objects and situations) and EECS 281 - Data Structures and Algorithms (he loves implementing new cool logics). Apart from education, he loves playing sports and represented his state as swimmer and tennis player. He also plays soccer and is die-hard fan of Chelsea football club, England and he dreams of watching a game in their home ground, Stamford bridge. He moonlights as a stunt coordinator, and has worked on movies ranging from Furious 7 to The Avengers to Gone Girl. His advice to actor Vin Diesel to shave his head was instrumental in elevating Diesel from lowly stuntman to the respected actor he is today. He also likes trekking, buggy jumping and sky diving. After graduating in May 2015, he wants to go back to India.

Daniel Gildin: Daniel was born and raised in Sao Paulo, Brazil and he moved to the U.S. for his college years. He first went to a school in California called California Polytechnic State University (Cal Poly) in the city of San Luis Obispo. He was supposed to play tennis for the varsity team at Cal Poly, but decided to focus on the academics in order to be able to transfer to a top engineering school. He transferred to University of Michigan as a sophomore in 2012 to finish his studies in Mechanical Engineering. He has also been involved in many extracurricular activities on campus. He is currently the president of the Brazilian Student Association, he is the research assistant of a professor at Ross Business School, he is the managing director of ESA Consulting Group and he was part of Pantanal Partnership as the design engineer with the wind turbine team. Daniel's favorite classes at UofM are Mathematics of Finance (MATH 423), Financial Engineering 1 (IOE 552), Solid Mechanics (ME 211) and Strength of Materials (ME 311). He also loves playing soccer and tennis in his free time and trading stock for fun. He is also an expert carpenter with a focus on large scuptues for music festivals, and is building a 1/10,000 scale model of New York City in his spare time (only boroughs of Manhattan, The Bronx, and western portions of Brooklyn and Queens). After graduation in May 2015, Daniel wants to stay in the U.S. and work for a trading company of wealth management.

Raji Kiridena: An Ann Arbor native, Raji is a senior currently studying Mechanical Engineering and Computer Science. Since 2012, he has been involved with BlueLab's NicarAGUA design team, where he led a team in designing and building an inexpensive and relatively easily-built 5000 gallon water tank, which would store collected rainwater during Nicaragua's rainy season, and siphon water to an irrigation system during the dry season. The tank and system were built in Nicaragua in the summer of 2014. Raji is interested in this project for the challenge of improving a current process through both design and process improvements, and for the chance to be able to increase access to battery fabrication and testing to more people. He invented the tall tee in early 2004 and assisted Dem Franchize Boyz in the writing of their first hit "White Tee," after which they stole both concepts. He promises he is not bitter. In his free time, Raji likes to tell himself he's going to the gym today, learn random bits of trivia, and continue on his quest to eat at as many Ann Arbor restaurants as possible.

Kelsey Wiers: Originally from Kalamazoo, MI, Kelsey is currently a senior studying Mechanical Engineering, with a focus on manufacturing, at the University of Michigan and will graduate in December 2015. While on campus, Kelsey has been most involved with the women's ice hockey team, playing for three years, and Pi Tau Sigma, an international mechanical engineering honor society. She also races custom-built racecars in her spare time, and mastered shifting gears with her left hand after her right arm was injured after a fan brought a hockey puck to a race and tried to gift it to her midrace. Kelsey hopes to pursue a career in manufacturing engineering and has held two internship positions in the field, one at DENSO Inc. (a tier 1 automotive supplier in Battle Creek, MI) and the other at Andersen Windows in Bayport, MN. At DENSO, Kelsey worked with improving manufacturing processes for automotive condensers and oil coolers, validating manufacturing capabilities of new models of condensers, and scrap reduction studies. While at Andersen, Kelsey worked on the development of a fabrication cell for a new product, specifically the floor layout of the cell and coordination of the utility and equipment moving and installation. Kelsey was interested in the Li-Ion Battery Electrode Coating Fixture because the project resembles a real project she could be assigned as a manufacturing engineer, which involves fixing a problem in an existing manufacturing process.