Subway Rail Car Filter Sampling Tool

Final Design Report
Submitted to the Faculty of the Department of Mechanical Engineering

By Team SLICE

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December 6, 2013

Mr. Erik Brown

Lawrence Livermore National Laboratory

Livermore, CA

Dear Mr. Erik Brown,

Attached is one copy of the Senior Project Final Design Report for the Subway Rail Car Filter Sampling Tool. We appreciate the feedback and advice you have given us throughout the past year. Thank you for support on this project!

Sincerely,
Julia Pollard

Distribution:

Professor Mohammad Noori: 1 Copy

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1. Abstract

The following design report has been prepared by Team Slice for both Cal Poly's Mechanical Engineering Department and Lawrence Livermore National Laboratory. This report provides an overview of the design ideation process of creating a subway rail car filter sampling tool. This cutting tool will take samples of HVAC filters from subway railcars in New York City, NY. These samples will then be used for processing in biological terror emergency response situations. This device will provide an easy, safe, and user friendly tool to cut filter samples. The current method of cutting is a pair of scissors or shears, which is not only difficult but also poses a safety hazard to the biohazard team. This tool can be transported easily to the emergency response site. It is constructed of materials that will withstand decontamination chemicals and will not attract anthrax particles. In the following pages, relevant background topics and engineering specifications are discussed. Preliminary designs, a weighted design matrix, testing results, and feedback from Lawrence Livermore National Laboratory are discussed. The final design, its components, and its cost also follow.

2. Introduction

Growing turmoil and hostility throughout the world has led to an increased threat of biological terrorist attacks. This has prompted the need for more assertive ways to protect the public in the event of a biological terror attack. Current research at Lawrence Livermore National Laboratory (LLNL) in conjunction with the United States Department of Homeland Security is being used to classify the severity of bioterror attacks and to improve and create national emergency response protocols. Because airborne toxins are a particularly effective dispersal method for bioterror agents, air filtration systems offer a unique look into the bio-toxin distribution. Specifically, the air filters are able to trap some of the bio-toxin particles. The contaminated filters can then be analyzed by researchers to better classify the severity of bio-toxin attacks. In order to further the research and create a standard in analyzing filter samples, LLNL has contacted California Polytechnic State University, San Luis Obispo's Mechanical Engineering Department in an attempt to create a standard for testing air filter samples.

A team of senior mechanical engineering undergraduates from Cal Poly has been tasked with a yearlong project to design a device that will cut uniform samples from air filters. The device may be used in both laboratory and emergency response situations. The scope for this project has been narrowed to deal with subway railcar air filters contaminated with the bio-toxin Bacillus anthracis (Anthrax) in order to keep the device requirements to an acceptable level. Successful completion of this project will lead to further research in classification of bioterror attacks as well as the development of a national standard in air filter sample testing.

Biohazard response teams are often caught in stressful situations in which information must be quickly processed to analyze the situation. In the event of airborne toxin attacks, teams must quickly process air filters to determine the extent and damage of the attack. Currently, teams must cut samples from air filters by using scissors, but this process is often slow and leads to a loss of toxin particles. A versatile device is needed to quickly cut square samples from air filters, without the loss of filtrate, to be transported for laboratory analysis.

3. Background

This section highlights some of the important aspects and research pertaining to the filter sampling tool project, including a description of anthrax, current bioterror emergency response protocols, current air filter design, and a discussion of current cutting methods.

3.1 Anthrax

Anthrax is a disease caused from the spores of the bacterium Bacillus anthracis. Currently, the Center for Disease Control and Prevention (CDC) has classified anthrax as a Category A bioterrorism agent [2]. This classification is reserved for the bio-agents that pose the greatest risk for the health and safety of the general public. Additionally, anthrax results in high mortality rates and leads to public panic and social disruption.

Anthrax was not always used as a biological weapon. Cases of anthrax date back for centuries, and some reports link anthrax back to the days of ancient Greece [8]. Anthrax spores are found naturally in soil and commonly infect livestock. Close contact with livestock led to many human reported cases. It was not until the beginning World War I that countries began researching anthrax as a biological weapon. Germany is credited with developing the first biological weapons program used to attack its enemies [4]. Further research led to Japan experimenting with anthrax on prisoners of war in World War II and attacking 11 Chinese cities with biological weapons. Development of anthrax continued throughout the years and currently 17 countries are suspected of having biological weapons programs despite a 1972 Geneva Biological Weapons Convention that banned production of such programs [5].

There are three modes for anthrax to infect an individual. They include cutaneous, in which a person is infected through a skin lesion; gastrointestinal, in which a person is infected through consuming anthrax contaminated food products; and pulmonary, in which a person is infected through inhalation of anthrax spores [1]. The scope of this project deals with pulmonary and, to a lesser extent, cutaneous infection; cutaneous and gastrointestinal infection will not be further discussed. Pulmonary anthrax infection is regarded as the most severe infection method and often leads to fatality. Symptoms start as cold or flu-like, but gradually worsen into more severe respiratory problems [1]. Pulmonary anthrax infection is the most common form of anthrax as a bioweapon because of the high fatality rate and effective dispersal method. Symptoms of pulmonary anthrax poisoning often go misdiagnosed until it is too late to use antibiotics. An attack of this nature over an urban population could lead to hundreds of thousands of deaths and a complete breakdown of infrastructure in government and medical care [8]. Additionally, an attack in a confined space, such as a subway railcar, could lead to an entire population of infected subjects.

In 2001, there were 22 reported cases of anthrax poisoning in humans. These were the result of a terrorist attack in which anthrax was mailed in envelops throughout the United States. There were 11 confirmed cases in which individuals suffered from pulmonary anthrax contamination. Ultimately, 5 people died due to pulmonary anthrax exposure in this attack [6]. While the death toll from these attacks is relatively low, the effects were felt throughout the country. An atmosphere of fear was created and led to additional anthrax hoaxes. Additionally, it is estimated that the attacks cost over 1

billion dollars in decontaminating infected buildings. As well as the ability to harm people an anthrax bioterror attack also has deep political, social, and economic impacts on society.

3.2 Emergency Response Protocols

Emergency response to a bioterrorist attack involves many different tasks that must be simultaneously completed in order to successfully asses and handle the situation. The CDC has developed protocols for response during the first 24 hours of a bioterrorist attack [10]. These first 24 hours are known as the acute phase and considered the most important hours because of how they can shape the outcome of a particular terrorist attack. Additionally, each situation presents itself with unique circumstances and all responders and equipment must be ready to adapt to the situation.

Within the first 24 hours, data analysis is a key component to properly implementing the correct emergency response. Quick and accurate analysis of data will allow for the proper containment and aid dispersal. Surviving anthrax contamination is highly dependent upon how quickly one can be diagnosed and the severity of the attack [10]. Knowing both of these factors quickly could be the difference in saving lives in the event of such a bioterror attack. It is in this area that the development of standardized air filter testing can quickly identify the severity of the bioterror attack. With this information appropriate medical response can be taken to help save lives from anthrax contamination.

Currently, specific standards in sampling do not exist for anthrax contamination. The current method is determined on a case by case basis, in which the investigator decides which method of sampling will be used. Usually, this results in a bulk sampling technique because it is necessary to get a full representation of contamination severity [3]. This leads to many surface and air samples which must all be analyzed at an approved laboratory. Additionally, there are often safety concerns for laboratory workers and often samples have unpredictable levels of spore contamination. Standardization of the sampling technique could lead to faster emergency response actions to combat the anthrax contamination. One potential method of standardization could come from sampling of the air filters within HVAC systems. Because air is constantly being circulated through the HVAC system, air filters stand to have a high chance to have a uniform amount of filtrate. Through subsequent protocol development for the handling and analysis of air filters, general standards can be developed in the event of an airborne bioweapon attack.

3.3 Air Filters

Air filters come in a multitude of shapes, sizes, and media, but they all are tasked with the process of creating clean air to breathe. All filters are designed upon standards developed by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE). Updated ASHRAE codes in 2007 (ASHRAE 52.2) determined that all filters must have an efficiency rating filter's ability to work on a particular particle size under a predetermined air flow rate [?]. The testing procedure and rating are available for all commercially sold air filters.

Pleated filters form the basis for the project scope and will be further discussed. In accordance with ASHRAE standards, pleated filters fall within a category 2 classification. This classification means the filters have relatively dense medium of poly cotton, fiberglass, or another synthetic material (ASHRAE

52.2). The addition of pleats to the filter allows for greater surface area to account for increased flow resistance. These filters are most effective on particle sizes in the range of 5 to 10 microns diameter [9]. High efficiency pleated air filters have an even greater operating range. To create the pleats it is necessary to have a sturdy frame to place the medium around. This is generally accomplished with the introduction of a wire mesh support frame.

Current pleated air filters can provide a level of protection against an airborne biological anthrax attack. Anthrax spores range in size from 1 to 1.5 microns in diameter and 4 to 10 microns in length, which is enough to get trapped in standard pleated air filters [7]. While this will not stop the spread of an airborne anthrax attack, it will allow for significant data to be collect from the air filters to classify the bioterrorist attack. The creating of standards in air filter analysis will make biological emergency response more effective.

Current processing methods for filters include significant manipulation of the filter by laboratory workers through the use of standard scissors. This has two effects: 1) Laboratory workers are exposed to dangerous conditions by cutting contaminated filters and sharp edges left by the wire frame. 2) There is a significant loss of filtrate because of the constant handling, moving, and shaking of the filter. The loss of filtrate will lead to misrepresented laboratory analysis. Better processing of the filters can be accomplished through a device that can eliminate these two points. With the introduction of a new device standards can be correctly derived and emergency protocols can be better implemented.

3.4 Current Cutting Methods

No current devices or standards exist for cutting samples for HVAC filters. The researchers at LLNL use a pair of scissors to take 5” x 2.5” samples from the air filters, but this can lead to dangerous conditions as their gloves may be punctured by the metal wire backing in the HVAC filters.

The scissors use the shearing method for cutting the filters. This method involves a moving blade that pushes the material to be cut against a fixed blade. The shearing process is also similar to the die cutting method that uses a punch to force the material to be cut against the stationary die. Because the level of cut has been deemed acceptable by LLNL the shearing method will further be explored as a viable cutting method for this device design.

Additional methods to be explored are crushing and laser cutting. Crushing consists of either a set of blades or a die and punch that will meet instead of moving past each other. This could be an effective method for cutting through the metal wire filter backing if it can also successfully cut through the filter material. Laser cutters may be explored depending on the level of power available at incident sites. Laser cutting would provide a high level of accuracy and a very clean cut edge.

Extensive testing of all viable cutting methods will need to be performed in order to select the optimal cutting method for integration into the overall device.

4. Objectives

The objective of this senior project is to design a cost-effective filter sampling tool for emergency response. Through the team's research and communication with LLNL, some specific requirements for this tool have been identified. Using a quality function deployment (QFD) system of weighing the significance of each requirement, the project tem was able to quantifiably determine the importance of each design aspect (see Appendix B).

1. Take 5"x5" or 5"x2.5" sample for any location on filter
2. Accommodate filters that may vary in size from 18" x 9"x ¾" up to 24"x24"x2"
3. Accommodate different filter materials and pleat spacing
4. Safe and easy to use by personnel in full SCBA protective gear
5. Minimize loss of filtrate, dispersion of and reaerosolization of contaminates
6. Can be decontaminated with Isopropyl Alcohol or bleach solution between samples
7. Consider incorporation of sample container with tool to minimize surface contamination of tool and to expedite sample handling
8. Consider ease of repair for parts that wear out
9. Consider effects of static electricity on effectiveness of tool to take a sample while minimizing filtrate loss

5. Problem Definition

Biohazard response teams are often caught in stressful situations in which information must be quickly processed to analyze the situation. In the event of airborne toxin attacks, response teams must quickly process air filters to determine the extent and damage of the attack. Currently, emergency responders must cut samples from air filters by using scissors, but this process is often slow and leads to a loss of toxin particles. A versatile device is needed to quickly cut rectangular samples from air filters, without the loss of filtrate, to be transported for laboratory analysis.

6. Concept Design Methodology

It was necessary to develop designs that fit the criteria stated in the QFD matrix. Extensive brainstorming and iteration sessions have led to the five designs that follow. One key criterion for the concepts was the use of non-violent cutting method. A violent cutting method can be dangerous because it poses a risk for the machine operator as well as the possibility of distributing the anthrax particles into the air. It should be noted that all designs have been created without a set blade pattern. Blades are only shown to project where they would be on the device. The concepts shown are only designed based on a cutting method and will be adapted to include the final blade design and cutting method. Blade design is discussed in the following section.

7. Concept Models

The following sections represent preliminary designs used to create the lead concept design of this project.

7.1 Preliminary Design: Lever Press

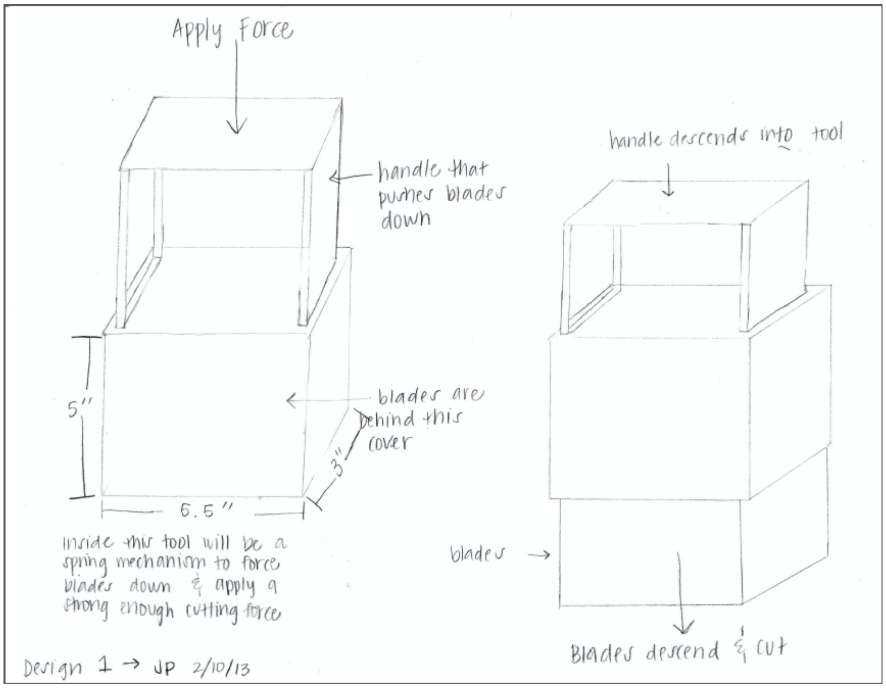


Figure 1. Level Press

7.1.1 How it Works

The lever press incorporates a push-down handle that presses a blade in a downward cutting motion to cut the filter samples in a uniform manner. The blade would be a standard 2.5" x 5.0" rectangle to cut the sample and it would be hidden under a protective cover when the lever was not engaged, which is an important design for safety.

7.1.2 Benefits of Design

This lever press would be beneficial for filter sampling in emergency response situations because it is simple to use, human-powered, portable, could be easy to manufacture and could be designed to incorporate a container for sampling.

7.1.3 Negatives of Design

The main problem with this design is its ability to be cleaned because of the protective cover. The cover over the blade presents an issue of spreading contaminates in hard-to-reach areas within the device. Other issues with this design are that it is not the cleanest filter cut because it might require a lot of human force that may crush the filter pleats. This is not ideal since crushing may lead to contaminate dispersion.

7.2 Preliminary Design: Lever Press Iteration

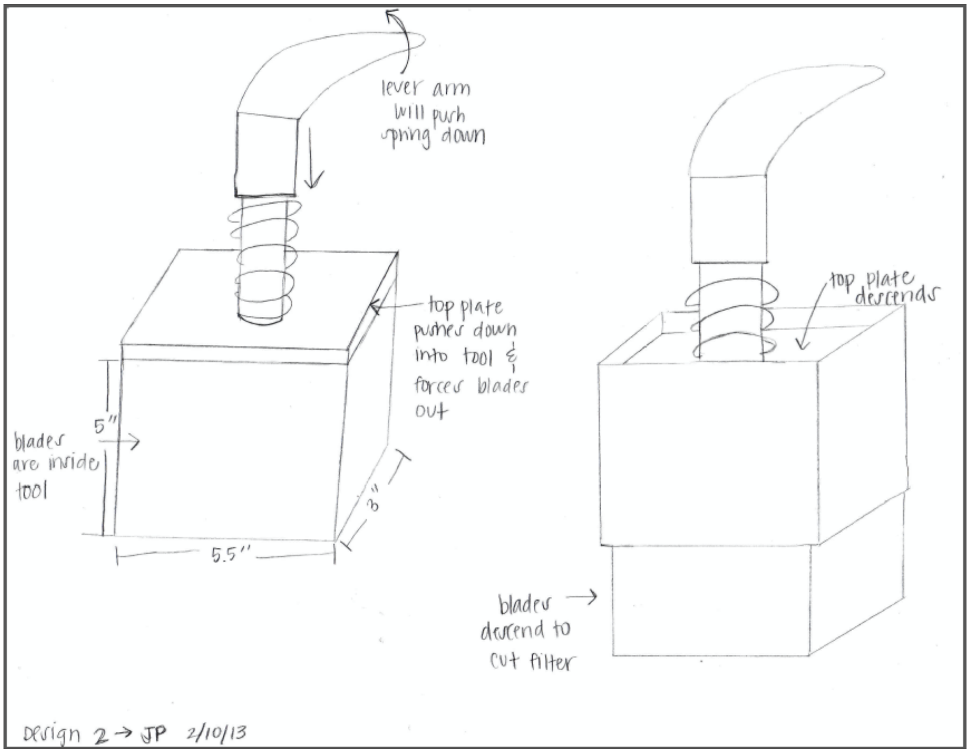


Figure 2. Lever Press Iteration

7.2.1 How it Works

This is similar in concept to the lever press design, but has an alternative press method. This incorporates a single hole-punch inspired lever press that allows the user to press with one hand. The blade and cutting method is the same as the other lever press idea, therefore the benefits and negatives of this design are the same.

7.3 Preliminary Design: Spring-Loaded Launcher

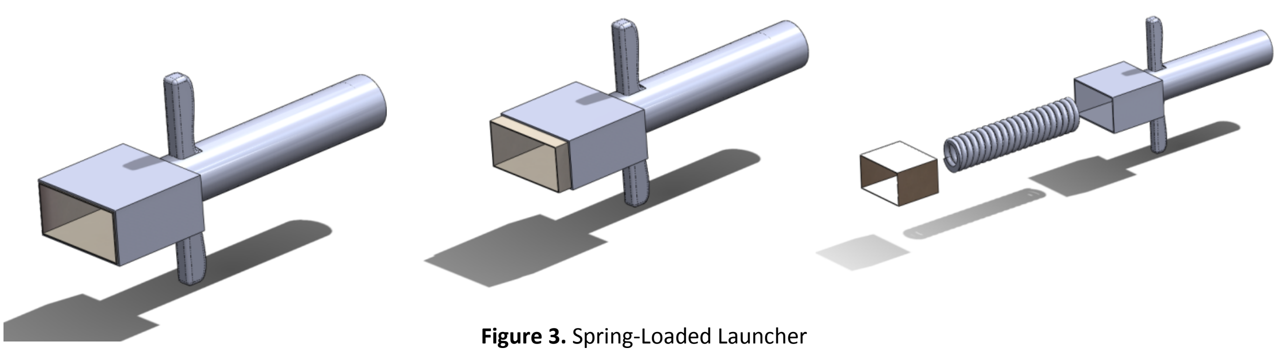


Figure 3. Spring-Loaded Launcher

7.3.1 How it Works
The spring-loaded launcher concept uses the force from a large spring to launch the rectangular cutting blade through the filter sample. The user would utilize the potential energy from a compressed spring to force the 2.5” x 5” cutting blade through the filter. The spring could be powered with an actuator that compresses the spring, which would be released using an electronic switch. The handles on the sides are for the user to maintain stability throughout the cutting process.

7.3.2 Benefits of Design
This design could be portable and easy to use for emergency crews.

7.3.3 Negatives of Design
This design may be “too violent of a cut” because it is a forceful blade cutting through the filter sample, which could disperse contaminates into the environment and poses a danger to the emergency crews. Similar to the lever press, the spring-launcher would be tough to clean because of the blade chamber that hides the blade before the launcher is initiated. Lastly, the pleats may be deformed from this cutting process because of the nature of the flat cutting blade.

7.4 Preliminary Design: Push-Through

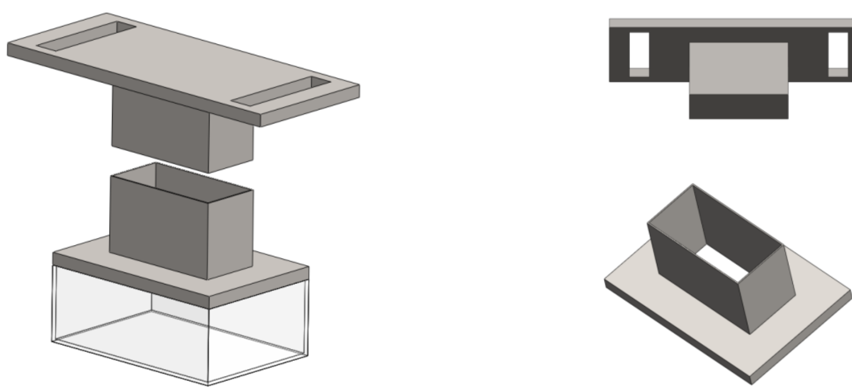


Figure 4. Push-Through

7.4.1 How it Works
The simple push-through design with an incorporated container utilizes a top plunger that pushes the filter through the bottom cutting blade. The bottom cutting blade has a through-hole for the filter sample to fall into the sampling container. There would not be any moving mechanical components to this design.

7.4.2 Benefits of Design
The design is very simple which would allow for easy manufacturability and little maintenance over the life of the product. The concept directly incorporates a container which would help with containing any contaminate dispersion.

7.4.3 Negatives of Design

The push-through concept does not lead to the cleanest filter cut because the pleats may be deformed from the flat cutting blades. Similarly, the plunger top may require a lot of force from the user in order to cut this blade. Lastly, there was no consideration as to the dispersion of contaminates from the excess filter material once the sample cut is made.

7.5 Preliminary Design: Vice Cutter

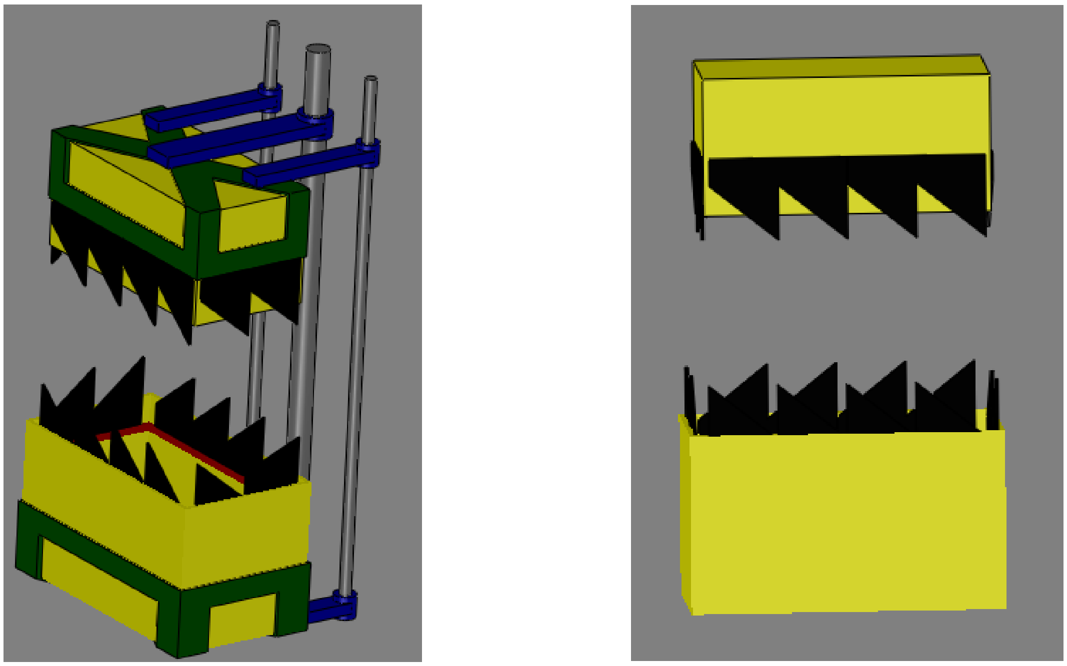


Figure 5. Vice Cutter

7.5.1 How it Works

This design is based on a simple vice design. The cutting blades are located on individual guides that create a sample size of 2.5” x 5”. The vice serves to keep the cutting guides in the proper alignment as well as the cutting force that drives the blades through the filter sample. The multiple teeth allow for more grip on the filter while the cutting begins which minimizes the deformation of the filter pleats. Once the cutting method has finished, the sample is already contained within the device which also eliminates sample dispersion. The blades could be removable to allow for easy cleaning and decontamination.

7.5.2 Benefits of Design

This design is ideal because it does the best job of addressing the issue of dispersion of contaminates since it incorporates a method of cutting that reduces pleat deformation and incorporates a container. The dual-cutting blades will also enhance the cutting ability and contaminate loss. The vice could be manually actuated or electronically motorized.

7.5.3 Negatives of Design

The only negative of the design is that it still has exposed blades which present a danger to the emergency crew member. This problem could be addressed with blade guards that could be easily decontaminated.

8. What Was Learned From Preliminary Designs

The most important design criterion is product safety. Safety includes both the device when in use and in storage/transport. This led to the development of a concept that minimizes the exposure of blades to the user which is essential for an emergency crew member operating around hazardous biochemicals. Since the emergency crews will be operating in SCBA protective gear, the device must minimize the chances of a crew member exposing their protective gear to the blades and being in risk of contamination.

The second important goal of the project is to create a device that is easy to clean in an alcohol or bleach solution. Several of the preliminary concept designs incorporated protective guards that shield the blades while not in use. However, it creates a problem of contaminate dispersion within the device itself. If a contaminated device is used to cut multiple filters, then the sampling data could potentially become flawed and unusable.

The final goal of the project is to create a device that does not deform the filter pleats and minimizes the dispersion of contaminates. The deforming and crushing of pleats could potentially lead to dispersing contaminates into the air. However, from the early cutting method tests, it has been determined that minimizing pleat deformation is incredibly difficult to design so a containment method will need to be created.

9. Blade Testing

The need to have an established cutting method and blade design has proven to be a key component of the conceptual design. Currently all designs are independent of a specified blade selection. Because the blade selection and design is being addressed separately, the current concept designs have been developed on the premise that they will be adaptable to the final blade orientation. The following sections detail the preliminary cut test. This initial cut test was conducted with three separate items: 4” hobby nippers, a utility knife, and a lever-arm paper cutter. Although rudimentary, this has led to some valuable initial conclusions about the blade design.

9.1 Subject #1— 4” Hobby Nippers – Ace Hardware

For this test, the 4” nippers, shown below, were used to cut the filter.

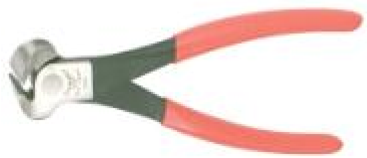


Figure 6. Nippers

The cut was clean and not very force intensive. The nippers were able to cut the metal, fiberglass, and synthetic materials to the same level with very clean edges. The material was not frayed in any way. Nippers are made from hardened steel blades, but use mostly an application of force to complete the cut. It is possible that the mechanical advantage led to the ease of cut. Figure 7 details the end result from the Nippers test.

Figure 7. Close Up of Cut from nippers

9.2 Subject #2—Utility Knife—Irwin

A utility knife, shown below, was used to cut the air filter in this test.

Figure 8. Irwin Utility Knife

The blade was not able to make a clean cut and it seemed to rip the material. It required considerable force to cut through the material and the metal. When a hard backing was used behind the pleat material it still required a large input of force to make the cut. Additionally the blade was pitted after cutting through the metal. Figure 9 shows the cut quality obtained with the Irwin Utility Knife. The utility knife blades are not durable enough for this application.

Figure 9. Result from Irwin Utility Knife Cut Test

9.3 Subject #3—Paper Cutter

A standard lever press paper cutter, shown below, was used to cut the air filter.

Figure 10. Paper Cutter Set-up

This test was conducted using a traditional lever-arm paper cutter. Because of the design of the paper cutter, it was necessary to cut through the beverage board frame. This gave the most trouble in the cut, which could be a result of trying to cut through all the material at once or because of the sturdiness of the beverage board frame. Two cuts were made with this device. Figures 11 and 12 detail the results for a cut parallel to the pleat axis. Figure 13 details the result of cutting perpendicular to the pleat axis. The blade on the paper cutter was not particularly sharp. Overall, it had a very clean cut edge. The only problem may arise from the crushing and bending of the pleats as shown in Figures 11 and 13.

Figure 11. Cut Parallel to Axis Showing Pleat Bending as Blade Passes

Figure 12. Parallel to Pleat Axis- Cut Result

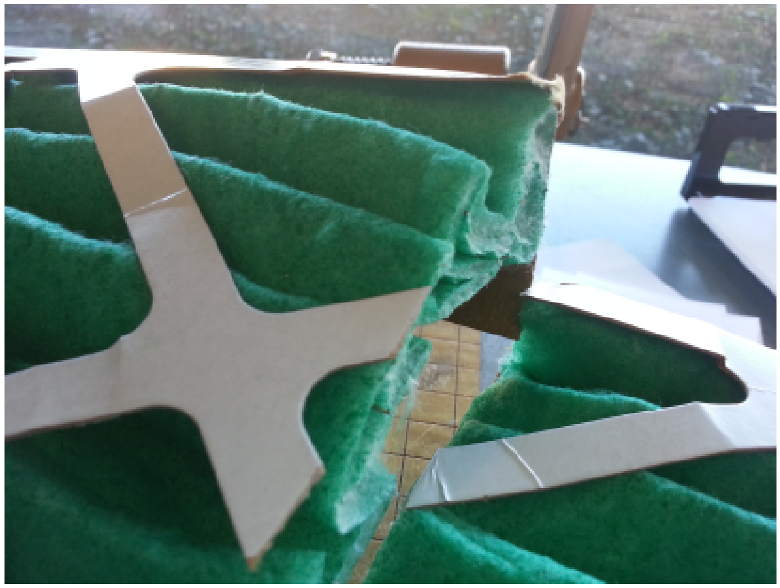


Figure 13. Perpendicular to Pleat Axis- Cut Result

10. Conclusion from Cutting Tests

Based on the results of these preliminary tests it is recommended that a thicker, stronger blade should be used for the final design. The sharpened utility knife blade is too fragile for cutting through the metal. The thicker blades found in the nippers and the paper cutter both gave clean cuts. The nippers utilized a cutting method where the two blades met at a point. The paper cutter utilized a shearing method. Both of these gave clean cut edges and should further be explored.

11. Lead Concept Design

From the initial design concepts and testing of various blades, a lead concept design was created. It was determined from testing that a thick blade should be used to cut the air filter. From design criteria it was also important that a container was included in the model, that the tool would be portable, and that it would be safe. On the following pages are design drawings of the lead concept model that incorporates all of the necessary design requirements.

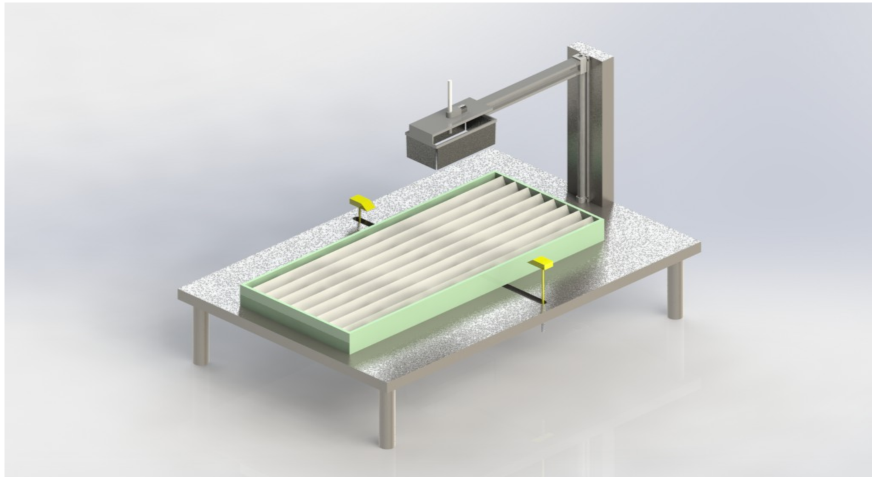
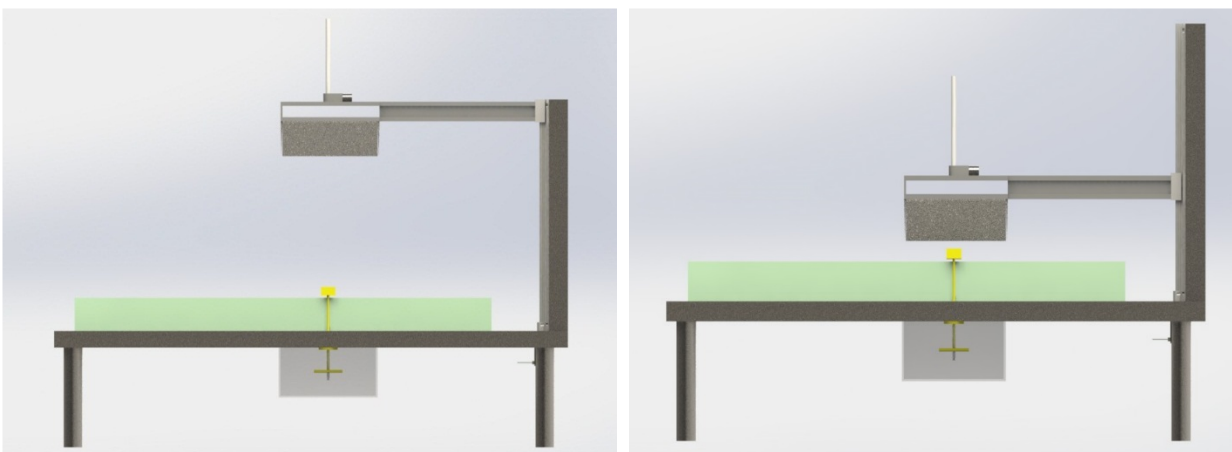


Figure 14. Lead concept design with square blade and linear actuator



Figures 15-16. Side views of concept design showing the movement of the blade as it cuts the filter

11.1 How it Works

This design incorporates a table top that holds the cutting device and a container to catch the filter sample. The cutting device is a rectangular blade. It will be controlled by a lead screw actuator that applies the correct amount of force required to cut the air filter. The lead screw will be controlled by an electric motor and powered by a battery, but, in the event of battery or motor failure, it can also be controlled manually with a crank. The blades will be rectangular in shape and will cut a 5” by 2.5” sample.

11.1.1 Lead Screw and Rail System

The current model utilizes a lead screw that has attached linear rails. This system allows for the transfer of controlled, linear motion through the use of an electric motor. Additionally, the lead screw can be adapted to use a hand crank in the event of electric motor failure. The railing system can also be

purchased in a design that is splash and dust proof. This would allow for easier decontamination of the system. The ideal lead screw system is one that is free of greases and lubricants because these could create problems with decontamination.

11.1.2 Motor

The ideal power system will utilize a DC stepper motor. These motors are allowed to rotate to any number of steps in the motor's rotation. This allows for precise control of the motor's rotation as defined by the control system. The control system will be researched in order to select the proper motor for the lead screw assembly. It may also be necessary to design the control system depending on complexity and time. However, the off-the-shelf option may fulfill the device's requirements. Depending on the company, the lead screw system can be purchased with a DC stepper motor and control system.

A standard DC electric motor is not an ideal design for the lead screw system because a gear train would be necessary to set the screw speed to its desired value. It spins at one speed for a given voltage input. This adds unnecessary components to the device, and a DC stepper motor should be selected instead of a standard DC electric motor.

11.1.3 Battery

The lead choice is a rechargeable lithium ion battery designed for power tools. This would allow for long hours of operation and with a properly sized motor could last for multiple days under continuous use. Research and calculations must be done in conjunction with motor selection to pick the most efficient combination.

11.1.4 Blades

The blades will be removable to allow for cleaning and sanitizing. There will be a quick release method to remove and reattach the blades so this will not take too much time away from taking samples. The exact shape and thickness of the blades will be determined through further testing next quarter.

11.1.5 Clamps

The table top will include clamps to accommodate different filter sizes. The clamps will sit in slots so they can be adjusted to hold narrow and wide air filters. Ideally, off the shelf clamps will be used for this purpose.

11.1.6 Incorporated Container

Underneath the table top will be a container to catch the filter sample after it has been cut. The filter will drop into the container once cut by the blade. It would be ideal to use a Tupperware container in the device because this is easily accessible and easy to transport.

11.1.7 Laser Guides

Laser guides will be used to draw the shape of the sample prior to cutting. This will allow for proper filter alignment in the device.

11.1.8 Plunger

A plunger may be incorporated above the blade to push the filter into the container. This will only be necessary if it is determined that the filter sample gets caught in the blades after cutting. The current plunger may require gearing and a rack and pinion based on a small DC motor that may be used.

11.2 Benefits of Design

This concept design incorporates all necessary requirements. It will accommodate all air filter sizes and pleat spacing. The blades can be easily cleaned with their simple detachment method. The table top design is portable and can be transported to an emergency site easily. It also provides a workspace when there wouldn't normally be a table to cut on. A container is incorporated into the table top design, and once cut, a lid can be placed on the container and it can be transported to the lab. Safety is also incorporated into this design because the lead screw and actuator prevents the user from having to force the blades down onto the filter. The long life of the battery should also allow the emergency response team to use the cutting tool for a full 8 hour day. The lead screw also offers a beneficial cutting method because it will allow minimal filtrate loss. The automation of the cutting process would reduce the chances any potential safety hazards occurring.

11.3 Negatives of Design

The removable blades, although beneficial to cleaning, will require some time to remove and reattach after each use. This time should be minimal, however. The blades will also be uncovered and could pose a potential safety hazard if the user ever reached under the blades. This risk could be prevented by simple blade coverings during transportation and a tool to attach and remove the blades.

12. Design Matrix

Using the design criteria for the filter sampling tool, the preliminary design concepts were evaluated and scored. The weight factor of each criterion was determined using a range of 1-5, with 5 being the most important. The designs were scored on a scale of 1-10 with 10 being the most able to fit the criteria. A weighted score was calculated for each design, and the results are in Table 1 below.

Table 1. Weighted Design Matrix for Vice Cutter Selection

Criteria	Weight	Lever Press	Spring-Loaded	Push Through	Vice Cutter	Lead Screw Cutter
Standard Sample Size	**5**	10	10	10	10	10
Container to Transport Sample	**1**	7	7	8	8	8
Easily Decontaminated after Each Use	**4**	3	3	6	5	5
Light Weight/ Portable	**4**	7	7	7	7	6
Minimal Filtrate Loss	**5**	5	3	6	8	8
Durable	**4**	TBD	TBD	TBD	TBD	TBD
Easily Repairable	**3**	TBD	TBD	TBD	TBD	TBD
Easily Manufacturable	**3**	TBD	TBD	TBD	TBD	TBD
Safe to Use	**5**	6	3	4	4	6
Easy to Use	**4**	8	8	8	8	8
	Total	184	159	192	198	204

13. Feedback from LLNL

The above concept designs were presented to LLNL in March 2013. The Lead Concept Design was Team Slice's ideal design, and based on the Design Matrix it also best matched met the criteria. After presenting the concept ideas to Lawrence Livermore, the sponsors and biohazard team had feedback for improving the final design.

The first feedback from the designs presented was to make the design more portable. Although the Lead Concept Design would not be very large, it was not handheld and it would be difficult to carry.

Another piece of feedback was to select off-the-shelf parts and materials whenever possible. This ties into the cost of the overall device, which should be as low as possible LLNL reminded the team. The LLNL representatives also suggested the possibility of incorporating the 1-Liter bottles they use in testing as the filter container in the design. But after much discussion, it was decided that using Tupperware would work better for filter transportation and cost.

Throughout the presentation of designs, the question of decontamination was brought up multiple times. It is very important that the device and material used can be decontaminated easily and without harm to the cutting tool.

The last feedback given to Team Slice was to include a blade cover or safety mechanism. It was determined that some type of cover is necessary for the device so the blades won't injure anyone while in transport.

14. Improved Lead Concept Design

Based on the feedback from Lawrence Livermore National Lab and the Bio Team, a more portable version of the Lead Concept Design was created.

14.1 How it Works

This design utilizes the same aspects of the Lead Concept Design explained in the previous pages. The only difference is the table. Instead of a solid table with a whole for the container, the table will only be a frame. The legs will be telescoping and folding to allow for a smaller size and easier transportation. The side rails will also be telescoping to allow the table to be compressed. These modifications to the Lead Concept Design allow the user to shrink the filter sampling tool and carry it more easily.

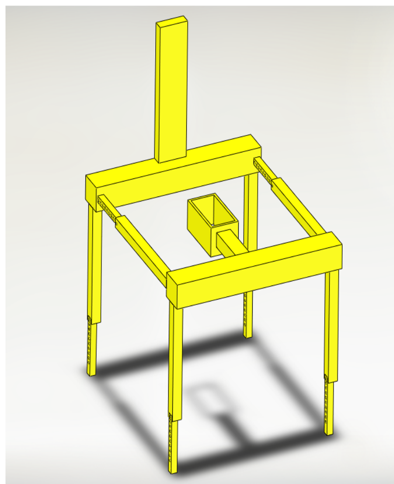


Figure 17. Table frame of the Improved Lead Concept Design

14.2 Benefits of Design

The table will be more light weight, smaller, and easier to carry. Because of these changes, it is more portable and users will have an easier time transporting it to and from the emergency site.

14.3 Negatives of Design

This design would allow particles and contaminates to fall underneath the table and onto the floor. This would make it very difficult to clean and decontaminate the site. Adding telescoping rails and telescoping and folding legs would also add more components to the overall design.

15. Portable Drill Press Design

Because the feedback from the Concept Design Presentation suggested a portable filter sampling tool, Team Slice created a completely hand-held design.

15.1 How it Works

A drill will power this design. The drill will be attached to a lead screw that pushes the top plate and top blades down. The top blades will meet the bottom blades and cut the filter, allowing the filter sample to

fall into the container below. There is a safety guard which also acts as a filter stabilizer (seen in Figure 18 below in yellow) that will hold the filter in place while also protecting the user's hands from hitting the blades. The drill can be used in reverse to move the top plate back up and to release the remaining filter.

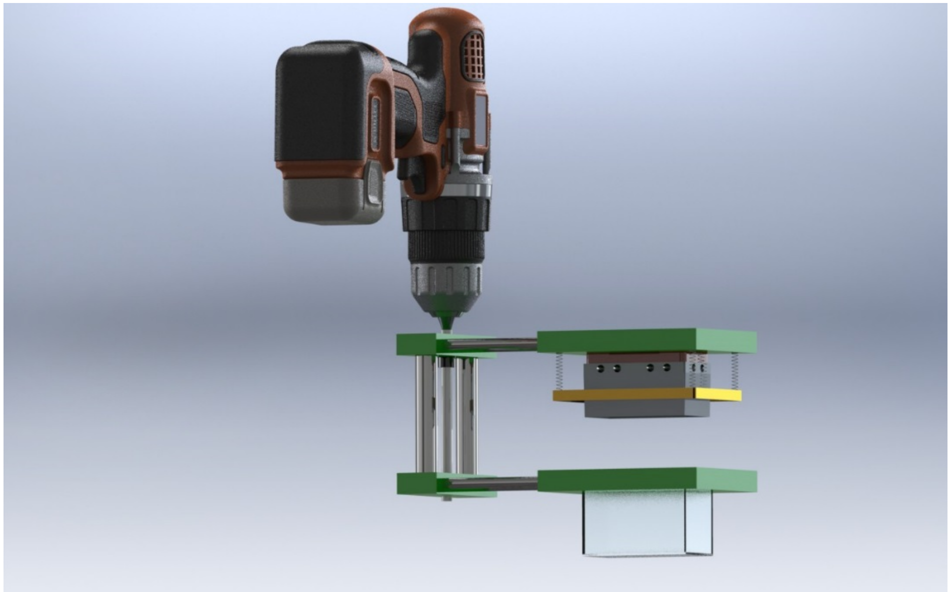


Figure 18. Drill Press Design

15.2 Benefits of Design

This design is completely portable and can be used at an emergency site or in a lab setting. It is light weight so it will be easy to transport. It should allow for all users because of its light weight. This design also incorporates a filter container than can catch and contain the filter and particulates. The battery of this drill can be interchanged quickly and easily when it runs out of power as well.

15.3 Negatives of Design

This design will require the use of two hands. One will hold the drill and the other will need to hold the opposite side of the device to maintain stability. Although two hands are needed, it shouldn't be too difficult to hold because it will be a relatively small device.

16. Design Selection-May 2013

Team Slice presented the Improved Lead Concept Design and the Portable Drill Press Design to Lawrence Livermore in April 2013. After discussing the possibilities, it was decided that the Portable Drill Press Design and the Lead Concept Design would be combined to create a final filter sampling tool. The idea of the more portable Lead Concept Design was not chosen because the open table top would cause contaminates to disperse into the air and on the floor.

Figure 19. Design Drawing

16.1 How it Works

The LLNL team decided that the final design would be the Drill Press Design that can be fitted into a table top support similar to the original Lead Concept Design. This will allow the design to be portable and light weight while also giving the user a stand if desired. The cutting blades, lead screw, and filter container will be connected in one device, just like the Drill Press Design. This will fit onto a support with legs that can be used to turn the cutting tool into a standing device.

16.2 Benefits of Design

This design will allow for ease of use of the biohazard team. The drill-powered device will not require any force from the user other than that of just holding the device and filter. This should ensure an ergonomic device. Its small size also provides a convenient and easily transportable tool. In the case of an emergency, this device can transported from the lab to a car to the site easily because it is lightweight and doesn't take up much room. Additional legs can be attached the device to provide a stand for the cutting tool as well so the user has flexibility. This allows the user to cut while holding the device and filter or while resting the device and filter on the stand. Opposing blades will ensure a solid, clean cut of the filters and will ensure the correct size and shape of the sample. The material of the device should provide a bleach-resistant surface to allow for decontamination between uses while also exhibiting low-static energy as to not attract anthrax particles.

16.3 Negatives of Design

Because of the small size of this design, the filter could potentially fall to the floor and disperse some contaminates into the environment after it is cut. But because users of this device will be wearing protective gear, this shouldn't be harmful to them. Any contaminates that do reach the floor should be cleaned easily with a bleach and water solution.

17. Deflection Calculations of Horizontal Plates

To ensure that the force exerted on the blades during cutting would not affect the horizontal plates, deflection calculations were performed. To complete these calculations, free body diagrams (FBD) were constructed for all components. Material selection for the horizontal top and bottom plates were chosen as Aluminum, and using the material properties in the SolidWorks 3D model, the mass of these components were found. Relating each component of the device to one of the below loadings, the maximum deflection was calculated.

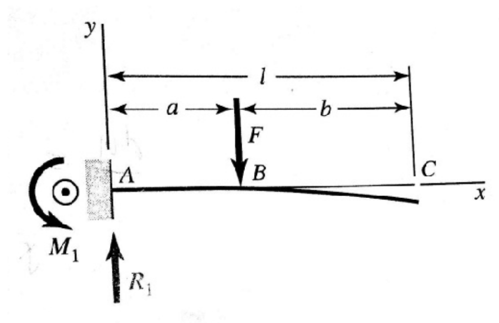


Figure 21. Loading of a Cantilevered Beam

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

Equation 1. Loading of a Cantilevered Beam Deflection Formula

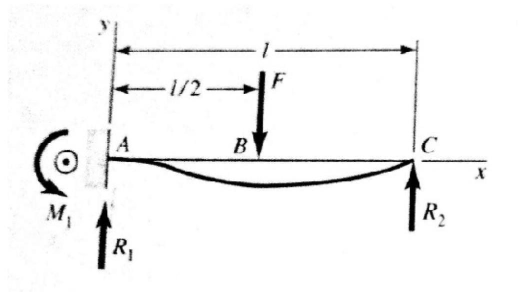


Figure 22. Loading of a Fixed and Simply Supported Beam

$$y_{max} = \frac{F(l-x)}{96EI}(5x^2 + 2l^2 - 10lx)$$

Equation 2. Loading of a Cantilevered Beam Deflection Formula

From the calculations, all components had negligible deflections between $2.9\text{x}10^{-5}$ inches and $1.8\text{x}10^{-3}$ inches. Because these values are so small, it is reasonable to assume that these will not affect the accuracy or strength of the cutting tool. Detailed calculations are shown in Appendix D.

18. Buckling Calculations of Lead Screw

To ensure that the lead screw would be able to withstand the applied force and torque of the drill, a buckling calculation was performed. The equation shown below was used to calculate this. P_{cr} represents the force that would cause buckling, so as long as the applied force of 100 pounds is less than P_{cr}, the lead screw will hold.

$$P_{cr} = \frac{C\pi^2 EI}{l^2}$$

Equation 3. Buckling Equation used to find Critical Load

Results gave a critical force, P_{cr} of 923.9 pounds. This is higher than the applied load of 100 pounds. Therefore, no buckling will occur.

19. Feedback from LLNL after Final Design Concept Presentation

Team Slice presented this final design concept to LLNL in May 2013. Although the overall design was agreed upon, a few changes were suggested. The first change was the type of powering device. The original design incorporated a power drill, but since the cutting tool will be used in a bio safety cabinet it would be very difficult to reach in and use the drill in a vertical position. It was decided that a motor will need to be used instead of a drill. Although this might be a little more difficult to design and a little more expensive, it will allow the LLNL Bio Team to use this device in the field and in the lab.

A second change to the cutting tool design was to eliminate the extendable rods that would allow the design to be compacted for travel and extended for use. The use of extendable rods would make the design less sturdy and it would be more prone to deflection. The design would be more complicated and include more components, also increasing the cost. It was decided by the LLNL team that the device did not need to be compactable for travel because it would be small enough in size already.

Other than these two changes, the LLNL team and Team Slice agreed on the other design aspects. Team Slice will finish calculations based on these changes and will begin to order components and construct the device in Fall 2013.

20. New Final Design

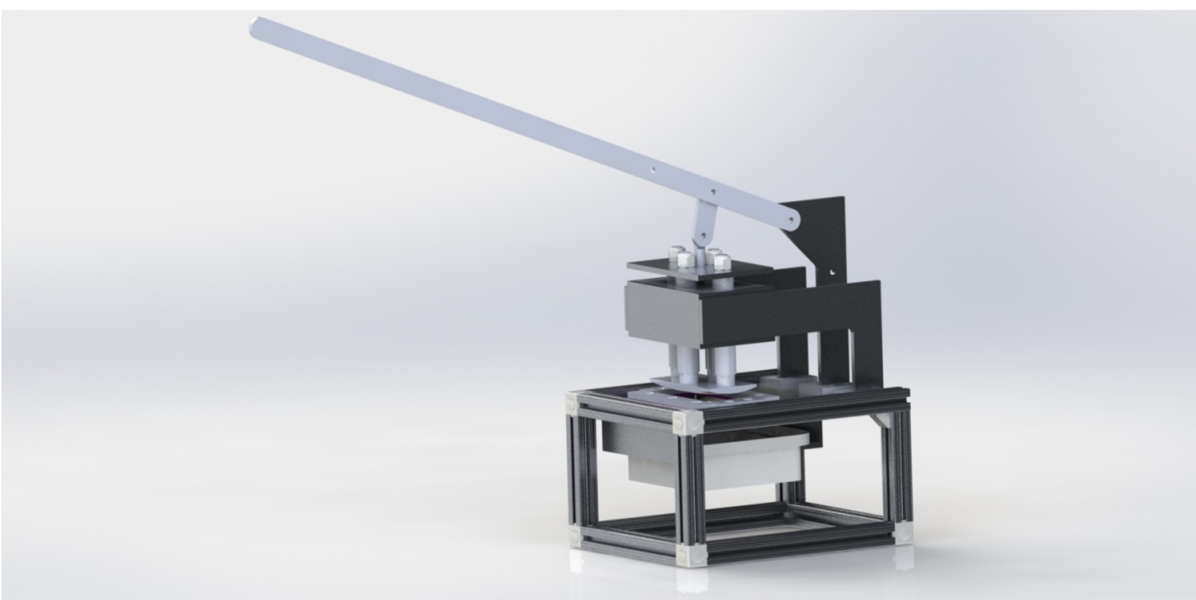


Figure 23. New Final Design

Over summer, the previous design that incorporated the lead screw was altered. Upon further thought and investigation, Team SLICE realized the cost and machining time of the design would be very extensive. A new design idea was created, which will not only lower the cost but also reduce the labor required to manufacture the prototype.

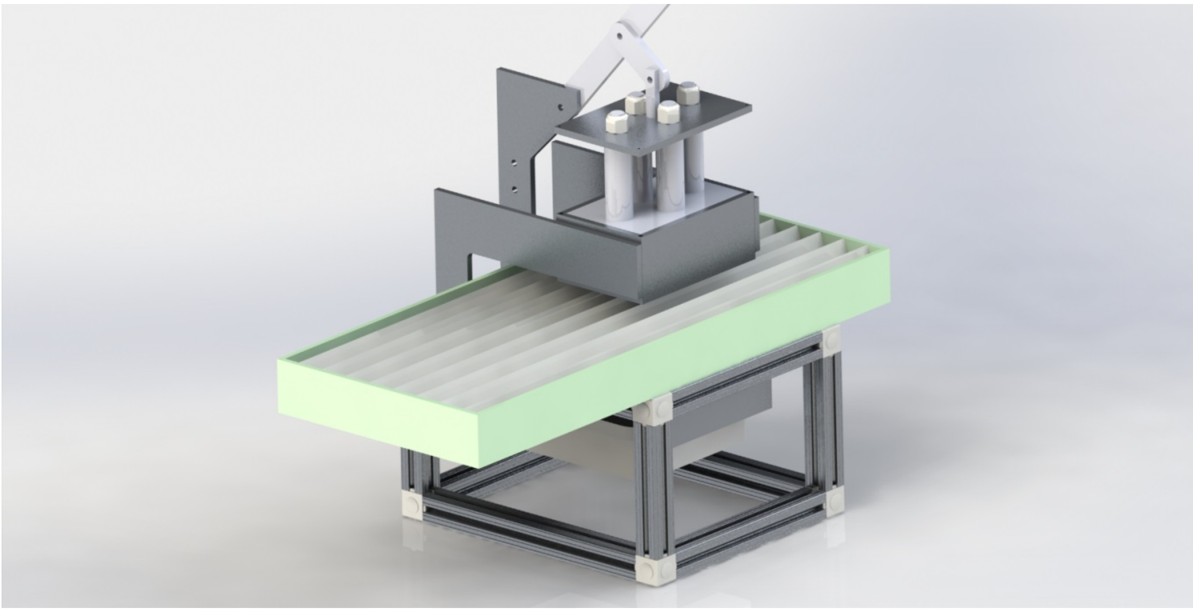


Figure 24. New Final Design With Sample Filter

20.1 How it Works

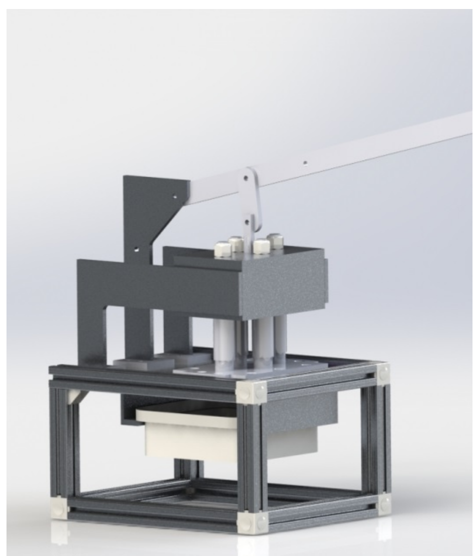


Figure 25. New Final Design: Disengaged (Left) and engaged (Right)

This new design replaces the drill and lead screw with a mechanical arm. This arm uses a lever action to force the die down, which will in turn cut the HVAC filter. The design will include a steel die that will cut the filter as it is pressed down. The die will come in contact with steel bars that will act as a shearing force. The final design will no longer include a tripod, as the device will be used on a table top or floor. It

will still include a holder for Tupperware to catch the filter piece. The material will be mostly aluminum, except for the steel cutting components.

20.2 Benefits of Design

This design will be lightweight and resistant to the bleach decontamination solution. The hardened steel die should withstand a lot of force and will be able to cut through the filters easily. The lever arm should make it safe and easy to use by anyone, even personnel in SCBA gear. The device can be transported and used in almost any environment including a biohazard cabinet. The device should prevent contaminate dispersal into the air as much as possible which adds to its safety. The material selection is discussed later in this report.

20.3 Negatives of Design

The lever arm does require force by the user, which might get tiresome if cutting hundreds of filters. Also, the alignment of the die and top plate when descending is not completely vertical which does not allow for a perfect cut each time. This will be fixed by the use of linear bearings.

21. Deflection Calculations

To ensure that the force exerted on the blades during cutting would not affect the components, deflection calculations were performed. To complete these calculations, free body diagrams (FBD) were constructed for all components. Material selection for the components was chosen as Aluminum, and using the material properties in the SolidWorks 3D model, the mass of these components were found. Relating each component of the device to one of the below loadings, the maximum deflection was calculated.

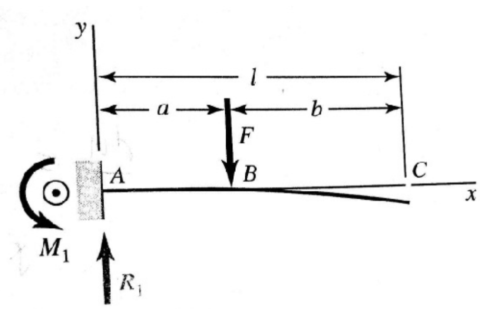


Figure 26. Loading of a Cantilevered Beam

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

Equation 4. Loading of a Cantilevered Beam Deflection Formula

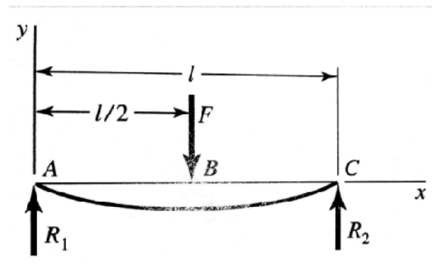


Figure 24. Loading of Simply Supported Beam

$$y_{max} = -\frac{Fl^3}{48EI}$$

Equation 5. Loading of a Simply Supported Beam Deflection Formula

22. Shear Calculations for Pins

To ensure that the shear force from the pins in the linkage exerted during cutting would not affect the components, shear calculations were performed. To complete these calculations, free body diagrams (FBD) were constructed for all components. Material selection was chosen as Aluminum. Using the equation below, shear stress was calculated and compared to the yield strength of a steel pin.

$$\tau = \frac{F}{A}$$

Equation 6. Shear Stress Equation

23. Cut Force Testing

Testing of sample blades was performed with the Cal Poly Instron machine in order to quantify the performance of the cutting blade. The minimum force required to cut the filters was determined through this testing. The durability of the blades, seen by repeated cutting, was also explored and analyzed.

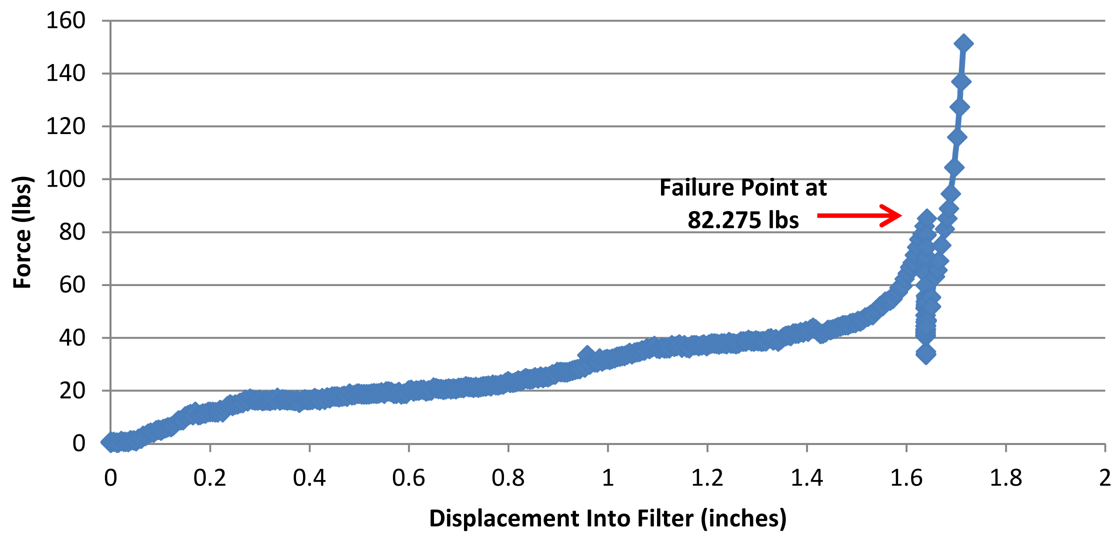


Figure 27. Instron Filter Cut Test Data of Standard Filter Sample

Instron testing was completed for a standard sample filter material in order to determine the failure point force of the filter. This test utilized a single blade that was forced down vertically in order to cut the filter. An opposing blade was not used in this test. It was determined from the testing that the failure point occurred at approximately 83 lbs. of force. As seen in Figure 19, there is a reduction in force of the Instron testing at 82.275 pounds, which indicates material failure because the material could no longer support the load applied. This is the minimum force required to cut the filter using a single blade. The final design will utilize a dual blade or a cut and die method which should lower the required force to cut the filter. In following calculations, a force of 100 pounds will be used, which is slightly larger than the required force found in testing. Although the actual force required in the final design will be lower than this estimated force, it will allow for a factor of safety and will ensure that the final design will cut all filters effectively.

24. Material Selection

The entire device, except for the blades which still have to be selected, will be made of anodized aluminum. This coating should protect the aluminum from corrosion when being decontaminated in the bleach solution. Although aluminum is typically corrosive and affected greatly by bleach, anodizing it should prevent most negative effects. Fatigue testing will be performed once the final design has been constructed that will analyze the effects of the bleach on the anodized aluminum. If any negative results are found, this material selection will be reconsidered.

Because the material used in this cutting tool needed to be strong, lightweight, and resistant to bleach, very few materials could even be considered. After researching Delrin, which was a considered material at one point in this design, it was determined that it would not be appropriate. Delrin reacts very poorly to bleach and even in just a five percent bleach solution, it would not withstand more than two weeks of cutting and decontamination if the desired 100 samples a day were taken. At this point, anodized

aluminum is the best choice for the device material and will be verified with fatigue testing when the device is completed.

25. Corrosion

Testing was performed to determine the corrosion effects on the materials used.

Background

The device is required to undergo decontamination after each use. The standard decontamination procedure is to place the device in a 10 percent bleach solution for 30 minutes and then to follow up with an alcohol bath to remove excess bleach. Bleach is a highly corrosive chemical to most metals because of the chlorine content. Bleach is a common name for the chemical compound sodium hypochlorite (NaClO). Because this chemical is highly corrosive to metals, it is necessary to know the type of corrosion and how many decontamination cycles the device can handle. Team Slice has conducted research to classify the types of corrosion that may be seen. However, it was determined that there does not exist any easy models for classifying corrosion to tensile strength reduction. Each study that has been conducted was specific to a particular case involved. Furthermore, Cal Poly's corrosion expert, Professor David Gibbs, was consulted on this matter. He has suggested that the exposure time in bleach should be minimal and that corrosion may not be a problem. For this reason, he has suggested that standard aluminum and steel may be ok for this project. Team slice will conduct a set of empirical testing to determine, if possible, a rough estimate on how many decontamination cycles the device can survive. With this determination, there will be a way to provide LLNL with an approximate unit life estimate. From literature searches it has been determined that there are extensive coatings that are immune to bleach corrosion. These will also be discussed among the team. Right now, the leading materials are anodized aluminum and passivised stainless steel. Hopefully, the treatments on these two materials will allow for better corrosion resistance.

Test

A study on the corrosive effects of a 10 percent bleach solution on 1020 steel, 304 stainless steel, and 6061 aluminum was conducted. This was developed in two phases. First, the samples were cycled for 30 minutes in the bleach solution followed by 10-15 minutes in a 91 percent isopropyl alcohol solution. This was done for 100 cycles. The second phase consisted of the samples continuously submerged for 50 hours in the 10 percent bleach solution.

The 1020 steel performed poorly and showed visible signs of rust after just 10 cycles. The condition of the steel continued to decrease as the experiment continued. The 304 stainless steel showed better resistance to the rust formation, but was also susceptible along the cut edge to discoloration and rust. The 6061 showed very few visible signs of corrosion. This was limited to darkening along one edge of the sample. It is recommended that aluminum be used for the bulk of this device design because it is lightweight, cost effective, and the least susceptible to corrosion. A better quality of stainless steel may also yield desired corrosion results, but would not outperform aluminum in terms of weight and cost. Stainless steel could be used for the blade, but there are concerns over rusting on the machined blade

edge. Titanium, known for great corrosion resistance against bleach, is better recommended for the blade.

A two part corrosive study was developed for testing purposes. Three different types of metals were tested: type 1020 steel, type 304 stainless steel, and type 6061 aluminum. Each piece selected was a square tube because a visual inspection could be made of both the inner and outer surfaces. The first test consisted of 100 cycles in, first, 30 minutes in a 10 percent bleach solution followed by 10 to 15 minutes in a 91percent isopropyl alcohol solution. The 10 percent bleach solution was a 10 percent Clorox solution which results in about 0.6% sodium hypochlorite dilution. After 100 cycles the samples would have spent a total of 50 hours submerged in the bleach solution.

The second part of the corrosion study consisted of a 50 hour submergence in a 10 percent bleach solution with the same samples previously tested. This was followed by 3 hours in a 91 percent isopropyl alcohol solution. The total time in the 10 percent bleach solution was 100 hours.

All samples were exposed to room temperature conditions during the experiment.

The samples of 1020 steel, 304 stainless steel, and 6061 aluminum were initially weighed to be 82, 92, and 68 grams respectively. The following images detail the transformation of the samples through 100 cycles in a 10 percent bleach solution.

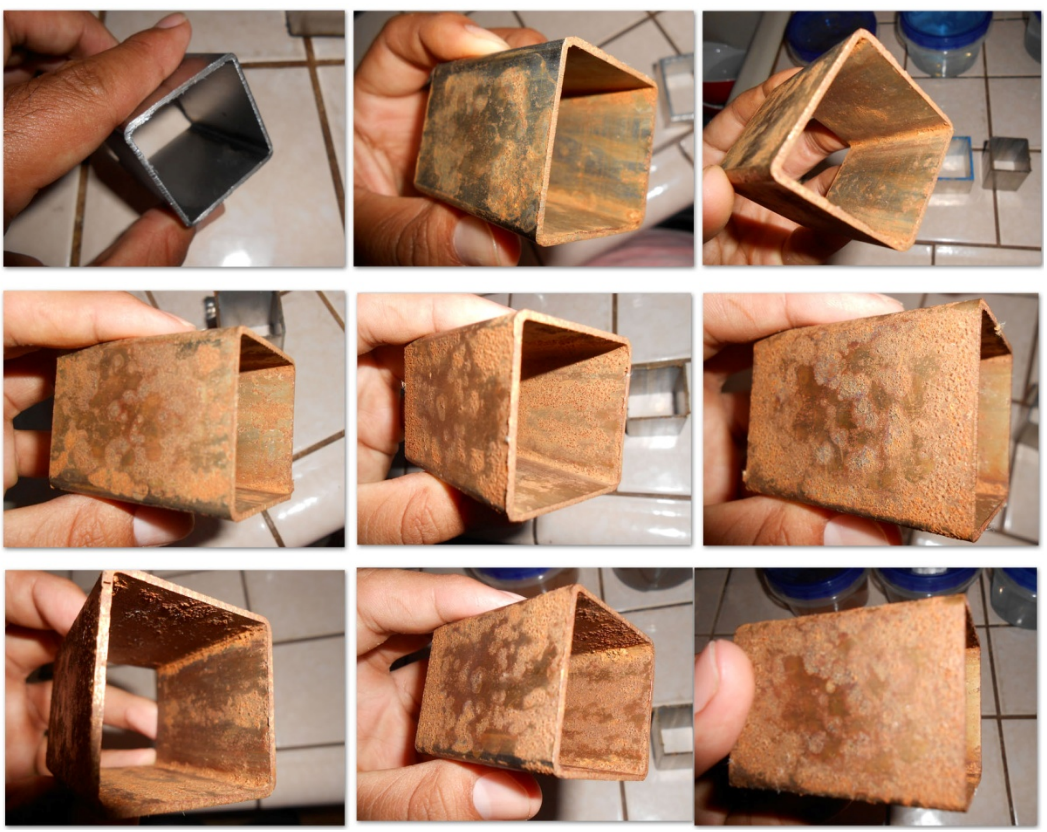


Figure 28. Progression of 1020 Steel through 100 Cycles. *TOP ROW*; Left: Initial Condition; Middle: After 10th Cycle; Right: After 20th Cycle; *MIDDLE ROW*; Left: 30th Cycle; Middle: After 40th Cycle; Right: After 60th Cycle; *BOTTOM ROW*; Left: After 70th Cycle; Middle: After 85th Cycle; Right: After 100th Cycle.

Figure 28, shows how the 1020 steel reacted to the bleach solution. After just 10 cycles the steel showed a fair amount of rust and color change. There was also some dust build up on the surface. By the 30th cycle there was a particulate build-up on the outer surface of the steel tube. The 70th cycle shows the build-up along the inner corners of the dust/particulate matter. After 100 cycles the color has completely changed to deep rust and there was a heavy particulate build-up on all surfaces of the steel tube. The ending weight of the 1020 steel sample was 80 grams. This was a decrease in weight by 2 grams.

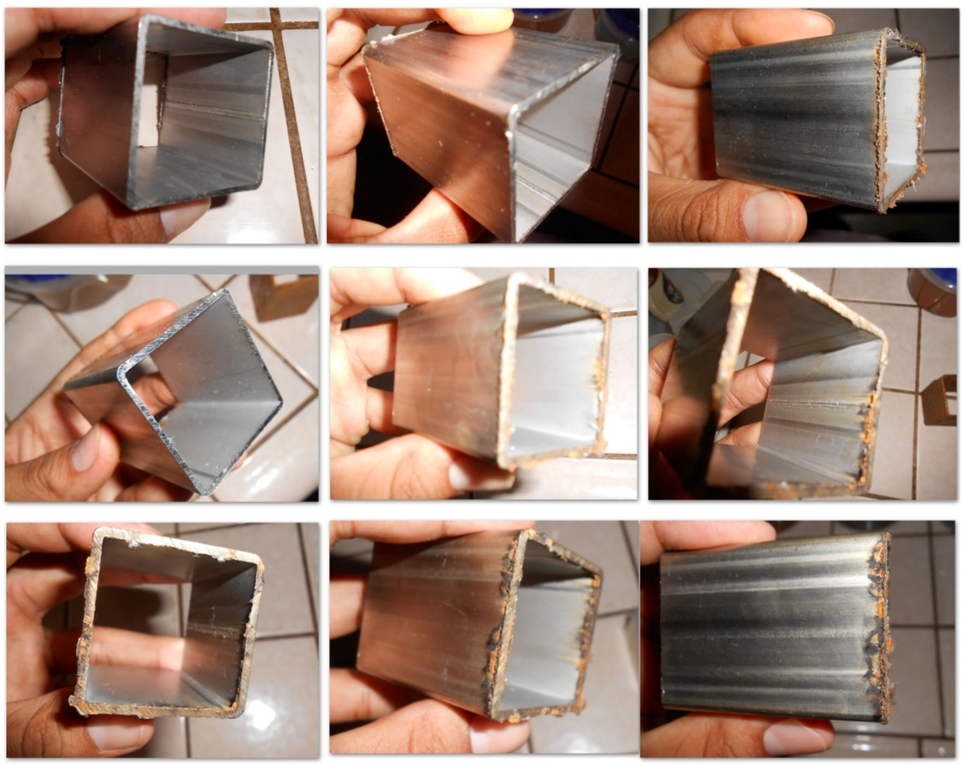


Figure 19. Progression of 304 Stainless Steel through 100 Cycles. *TOP ROW*; Left: Initial Condition; Middle: After 10th Cycle; Right: After 20th Cycle; *MIDDLE ROW*; Left: 30th Cycle; Middle: After 40th Cycle; Right: After 60th Cycle; *BOTTOM ROW*; Left: After 70th Cycle; Middle: After 85th Cycle; Right: After 100th Cycle.

Figure 29 details the progression of the 304 stainless steel sample through 100 cycles in a 10 percent bleach solution. The rust coloration seen in the final cycle was preceded by a black discoloration around the edge that was cut with a chop saw. In the later stages the black discolorations was followed by the rust. The heavy particle buildup described in the 1020 steel experiment was not present for the duration of the stainless steel experiment. While most of the discoloration appeared on the cut edge, there were slight rust spots on the outer and inner surfaces. They did not appear to have any pattern associated with their formation. The beginning and ending weight stayed at a constant 92 grams.

Figure 20. Progression of 6061 Aluminum through 100 Cycles. *TOP ROW*; Left: Initial Condition; Middle: After 10th Cycle; Right: After 20th Cycle; *MIDDLE ROW*; Left: 30th Cycle; Middle: After 40th Cycle; Right: After 60th Cycle; *BOTTOM ROW*; Left: After 70th Cycle; Middle: After 85th Cycle; Right: After 100th Cycle.

The sample of 6061 aluminum showed very little signs of visible corrosion for the duration of the 100 cycles. There were some slight dark spots and streaks that seemed to develop, but as a whole they were relatively small. The development of these spots was also along one edge of the sample. It is assumed that this was the edge of a previous cut, but cannot be confirmed. This dark spot formation is best shown on the right edge of the after 60th cycle image of figure 3. The weight stayed a constant 68 grams throughout the testing.

Figure 31. Images After Additional 50 Continuous Hours in a 10 Percent Bleach Solution; LEFT: 304 Stainless Steel; MIDDLE: 1020 Steel; RIGHT: 6061 Aluminum.

The results of the second phase of testing, 50 continuous hours in the 10 percent bleach solution, is shown in figure 31. The burred edge of the stainless steel sample had nearly completely dissolved and there were more rust spots around the same cut edge. The rusting has begun to creep away from this edge and down the outer wall of the sample. Despite the loss of the burred edge, the weight remained at 92 grams. The 1020 steel sample had more discoloration and more particle buildup. This buildup

could then be wiped away in a sort of dust. It was not fully cleared of the dust, particle buildup for the photo. It may be possible to scrape most of the buildup off of the surface. The weight did not change. The 6061 aluminum sample again showed very little discernible change. There may have been a slight increase in the area of the dark spots around the edge, but noting concerning or alarming. The weight of the aluminum piece did not change.

Heat Treatment

Figure 32. Heat treated 440C stainless steel.

Although not tested in the corrosion study, type 440C stainless steel was selected to be used as the punch and die components. This is due to the grain structure of this particular stainless steel (martensite) that has increased corrosive properties to chlorides. As has been earlier discussed, the decontamination process use sodium hypochlorite which is more commonly known as bleach. Additionally, stainless steels are softer than tool steels, which are commonly used for dies and blades. However, 440C allows for heat treating to increase this hardness up to Rockwell C60. This is close to D2 tool steel which has a hardness of Rockwell C62. Furthermore, 440C can be purchased in an annealed state which makes the material softer for machining purposes. This material was first recommended by Professor David Gibbs of Cal Poly.

An increase in material hardness and corrosive resistance was necessary, particularly for the chosen die cutting material, 440C stainless steel. Typically with stainless steel heat treatment, oxidation occurs in the metal causing a dark black appearance, which is essentially a form of rust. Rust results in a slightly accelerated corrosion process, which was to be avoided. A heat treatment method was necessary to increase the hardness, but an anti-oxidizing method was needed.

San Luis Obispo local and machinist Terry Boyer of *Boyer Built Machines* recommended a specific heat treating process, including using stainless steel foil to wrap the 440C. This reduces the oxygen content

surrounding the heat treated parts, thus reducing- but not eliminating- the oxidation. Thanks to Terry Boyer, Team Slice was provided with stainless steel foil to use for heat treatment.

The heat treatment process of the 440C was as follows:

1) Parts treated for 35-45 minutes in 1900°F furnace, with 440C wrapped in stainless steel foil
2) Remove foil and continue with 60 minutes of oil quenching in moderately hot oil
3) 60 minutes of tempering parts at 325°F

The heat treatment was conducted at the Cal Poly Hanger furnace and tempering using a standard kitchen oven.

Unfortunately some sacrifices were made due to the available resources. Hot oil-quenching was not available; air cooling was used as a substitute. Additionally, instead of using stainless steel foil, it would have been ideal to use a vacuum chambered-furnace to completely eliminate oxidation. However, due to cost and resource constraints, Team Slice was unable to conduct that method of heat treatment.

25.1 Materials Selection Quick Guide

Plastics

Not all plastics are acceptable for use with bleach. This is because some chemical compounds, such as the popular Delrin and Acetal, break down in a bleach environment. The following 15 plastics were determined to survive in bleach environments without excessive decomposition.

1) Acrylic
2) ECTFE (HALAR)
3) Flurosint
4) HDPE
5) PEEK
6) PET
7) Polycarbonate
8) Polypropylene
9) Polysulfone
10) PVC, Type 1
11) PVC, Type 2
12) PVDF
13) PTFE
14) Tecator/Torlon
15) UHMW

Each plastic has unique attributes that better suit it for particular jobs. For example, Team SLICE chose UHMW to use as a linear bearing. This is because the low friction of this material finds itself useful in corrosive environments where bearings/bushings need to be used. To use these plastics in this corrosive environment, one must also be cognizant of the operation temperature. While the 15 plastics

listed above all have acceptable performance in bleach environments, use at an elevated temperature will adversely affect some of their performances. When considering any plastic material thorough research must be conducted to ensure it will meet all standards of operation.

Metals

As the corrosion study found, aluminum is acceptable for this particular decontamination procedure at room temperature. The nature of metal corrosion is one that must be studied under the specific corrosive environment at hand. For this particular application, the following list has been ordered in terms of cost from cheapest to most expensive.

1) Aluminum
2) Low Grade Stainless Steel
3) Martensitic Stainless Steel (440 Series and other select 400 Series Stainless Steels)
4) Titanium

The industry standard is Titanium because many tests have showed that this material is inert in sodium hypochlorite under a wide variation of operating temperatures and condition. This would be the best choice, but it is also the most expensive material to purchase and difficult to machine. Aluminum was chosen because, at room temperature, it also possesses good corrosion resistance to bleach. This would not be the case at elevated temperatures. Martensitic Stainless Steel was selected for the die and die lips to provide needed corrosion resistance and toughness. Low grade stainless steels, as shown in the corrosive study, perform better than high carbon steels, but are not as strong performers as aluminum, titanium, and high grade stainless steel.

The recommendations found in this section are intended to make material selection easier for future groups to design devices for this particular decontamination procedure.

26. Cutting Selection

The final cutting device was a top die that descended and sheared against four lower blades placed in a rectangular shape. This design should mimic the shearing force of scissors and paper cutters. The die and the flat blades were constructed of 440C stainless steel that was heat treated. This heat treatment hardened the steel to ensure it would be able to withstand the repetitive cutting force and would also resist corrosion. The die has not been sharpened because of the tight tolerances expected between the die and die lips. This is expected to be tight enough to create the shearing effect without needing to be sharpened. This method was adapted from the earlier paper cutter test that did not use a sharpened blade. The same results are expected.

27. Cost Analysis

The table on the following page represents the cost of the materials used for the device as well as the cost of labor and CNC parts required.

Table 3. Expenses

Expense Description	Amount
Sample Tools for Cutting-nippers, blades	$28.06
Travel to LLNL 4/13	$246.00
Travel to LLNL 5/13	$246.00
Paper Cutter	$38.00
Summer Expenses	$51.93
Order from McMaster (Brian) Bottle Jack Bottom Table Rails	$192.26
Order from McMaster (Julia) Aluminum Sheet Hollow Rectangle Plastic Rod for Dowels Solid Aluminum Block	$164.91
Order from McMaster (Julia) CNC Part Aluminum rod	$54.46
Labor/ Parts for CNC	$998.00
Poster/Glue Expo	$26.45
Order from McMaster (Philip) 440C Stainless Steel Bar	$216.45
Order from McMaster (Brian) Aluminum Rod	$65.64
Order from McMaster (Philip) Assorted Alum, bolts, nuts, clevis pin, plastic	$97.25
Home Depot Nuts and Bolts	$15.13
Order from McMaster (Brian) Plastic for Bearing, Plastic Washers	$58.85
Total Spent	**$2,499.39**
Total Left	**$2,280.61**

28. Testing of Device

After the device was first completed and tested, it was determined that the alignment of the cutting die and the rods was not correct. The guide rods that were intended to keep the die aligned were too small in diameter and allowed the die and top plate to move back and forth. Because of this, the die did not descend straight and could not cut accurately each time. To fix this problem, larger guide rods replaced the initial ones. These were also ineffective at keeping the die aligned. Finally, while researching linear bearings, it was discovered the UMHW is used in corrosive situations. This is a plastic with a very low coefficient of friction. A full rectangular block of UMHW was selected to fill the void between the hollow, rectangular aluminum piece and the aluminum rods sleeves holding the die. This did not completely solve the problem, however. The device was still unable to cut the HVAC filter because of

alignment issues and blade and die issues. The blades were not sharp enough to cut the filter, and they couldn't descend vertically. Unfortunately, the device proved to be faulty and ineffectual.

Again, corrosion restraints have not allowed for a normal linear bearing to be selected. This is because the casing of corrosion resistant linear bearings is made from acetal, a material with terrible resistance to bleach. The ball bearings of these corrosion linear bearings are designed from 440C stainless steel. This gives further validation to the material selection for the die.

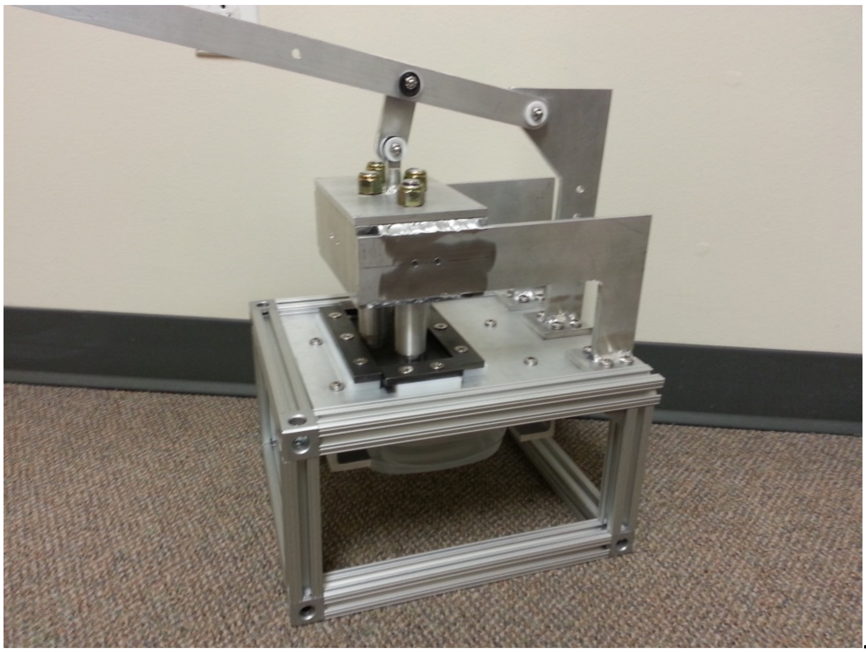

.

Figure 33. Final prototype assembly.

29. Recommendations for Future Improvements

It may be possible to still sharpen the die and die lips despite having already hardened. This could give a better cutting of the air filters. A sharpened die and die lips would have to be tested side-by-side with the current die. This was not done because of constraints with machining time and material. Hopefully this change in the design would allow for the device to function properly.

Another crucial recommendation is the use of D2 tool steel instead of 440C stainless steel. While the direct material costs of 440C is cheaper, the hardening process might be expensive. This is because a vacuum chamber would give the best hardening results against oxidation. Oil quenching will also give better results for corrosion resistance. Team SLICE was quoted a price of around $500 dollars for hardening the 440C in a vacuum chamber. Then, as discussed earlier, it was hardened in the machine shop furnace using stainless steel foil to keep oxidation low.

D2 tool steel does not need to undergo a hardening process. This material is also still capable of being machined. A direct corrosion comparison should be conducted between D2 and 440C. This will give definitive results on which will be cheaper in the long run. Either the D2 has good enough corrosion resistance to offset the hardening costs of 440C or it does not.

In the initial design, it was determined that the aluminum should be anodized to prevent corrosion. Unfortunately there was not time to have the aluminum anodized. A last recommendation would be to complete this process to ensure a long life of the device. A cheaper version would be to powder coat the aluminum. However, this is susceptible to scratching.

In terms of machining, the base plate should be manufactured using a water jet. This will be more precise than the CNC and much faster. The extensive number of holes in this plate made machining them accurately difficult. This is apparent in the alignment issues that the device has.

Overall, the decision not to go with more expensive alternatives was fueled by keeping the cost to minimum. This is because, as stated earlier, the competition is a pair of scissors. It is possible to get titanium coated scissors for very, very cheap. In this sense, the device designed in this report does not seem to make sense in terms of mass production numbers. This is especially true if decontamination must happen after each sample is cut. As was demonstrated in the corrosion study, the decontamination time takes away from the actual device usage time. If it will spend most of a work day in a bleach bath, it would be necessary to have multiple devices on hand. Again, something like the titanium coated scissors make more sense because of cost and durability.

30. References

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[10] United States. US Department of Health and Human Services. Centers for Disease Control and Prevention. *Public Health Emergency Response Guide for State, Local, and Tribal Public Health Directors*. Version 2.0 ed. Apr. 2011. Web. 6 Feb. 2013. <http://www.bt.cdc.gov/planning/pdf/cdcresponseguide.pdf>.

31. Acknowledgments

Team Slice would like to thank the following individuals for their support in this project.

Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory has provided Cal Poly's Team Slice the opportunity to complete this project. They have financially sponsored the project as well, which includes components, materials, and travel expenses.

Erik Brown, Lawrence Livermore National Laboratory

Erik is the LLNL project sponsor. He has provided excellent design criteria, project insight, and feedback on potential design concepts. He is available every week for teleconferences to answer any questions for Team Slice.

Professor Mohammad Noori, Cal Poly, SLO

Professor Noori is the project advisor and meets with Team Slice each week to ensure that they are on schedule with the project. He oversees the project and assists in any way necessary.

Professor Peter Schuster, Cal Poly, SLO

Professor Schuster taught the Senior Project lecture and organized the project, sponsor, grant, and funding for this project.

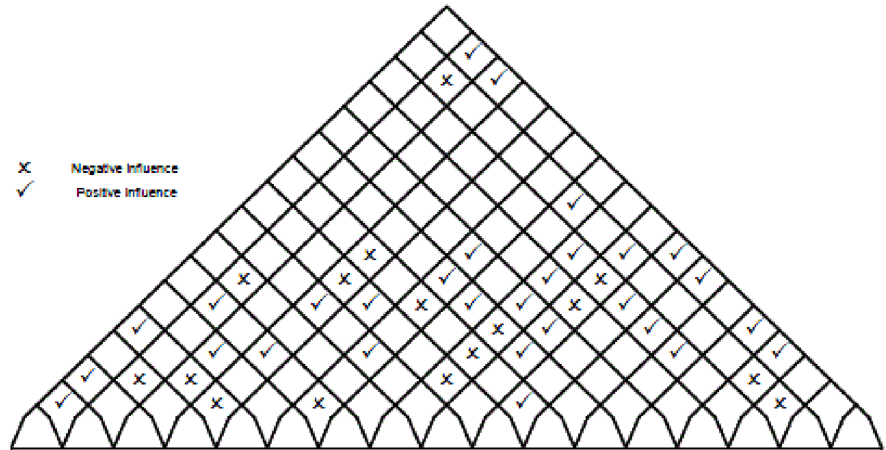
Professor David Gibbs, Cal Poly, SLO

Professor Gibbs is Cal Poly's resident corrosion expert in the materials engineering department. His advice was essential to conducting the corrosion report and final material selection.

Max Sluiter, Cal Poly, SLO

Max is a composites lab technician and assisted Team Slice in the filter Instron testing.

Appendix A. QFD



Customer Needs/ Requirements	Weight Factor	5" x 2.5" sample size	Minimal effect of static electricity from material	Able to be submerged in bleach or alcohol mixture	Weighs up to 5 lbs and is handheld	Minimize vibration, reciprocation and rotation	Low-cost	No use of lead	Off-the-shelf products/materials	Minimum 100 cuts for an 8 hour use	Cutting guides	Safety mechanism around cutting device	Less than 2 hours of training	Minimal maintanence over time	Made of strong, fatigue resistant material	Possibly made of silicon or plastics	Accommodate different filter materials and pleat spacing	Easy to use in SCBA protective gear	Now: Scissors
Standard sample size	5	9									3						9		1
Container to transport the sample	1	9	9	9	9		9										3		1
Easily decontaminated after each use	4			9					1	3		3			3	3		3	4
Light weight/Portable	4	3			9		3		1	9					3	3		9	5
Minimal filtrate loss	5		9			9		9	3	3					3	9			2
Durable	4		3		3		3		3	9				9	9	3		3	4
Easily repairable	3				3		9		9	9				9					1
Easily manufacturable	3				3		9		9						1	3			5
Safe to use	5							3				9						9	2
Easy to use	4				3					9	3		9	1			4	9	3
Difficulty		5	3	2	4	3	3	1	3	4	2	3	1	3	2	4	4	4	
Absolute Importance Factor		66	66	45	87	45	87	60	89	162	27	57	36	67	78	90	64	141	
Relative Importance Factor (%)		5	5	4	7	4	7	5	7	13	2	4	3	5	6	7	5	11	
Ranking		5	5	6	3	6	3	5	3	1	8	6	7	5	4	3	5	2	

Figure A1. QFD

Appendix B. Design, Build, and Test Flow Chart

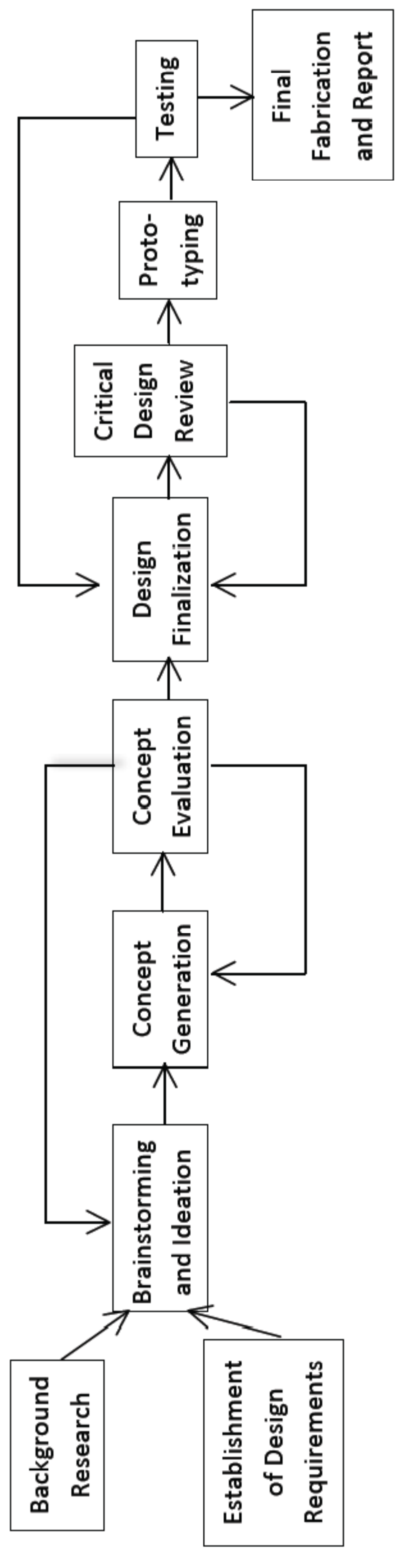


Figure B1. Design Process and Overview

Appendix C. Gantt Chart

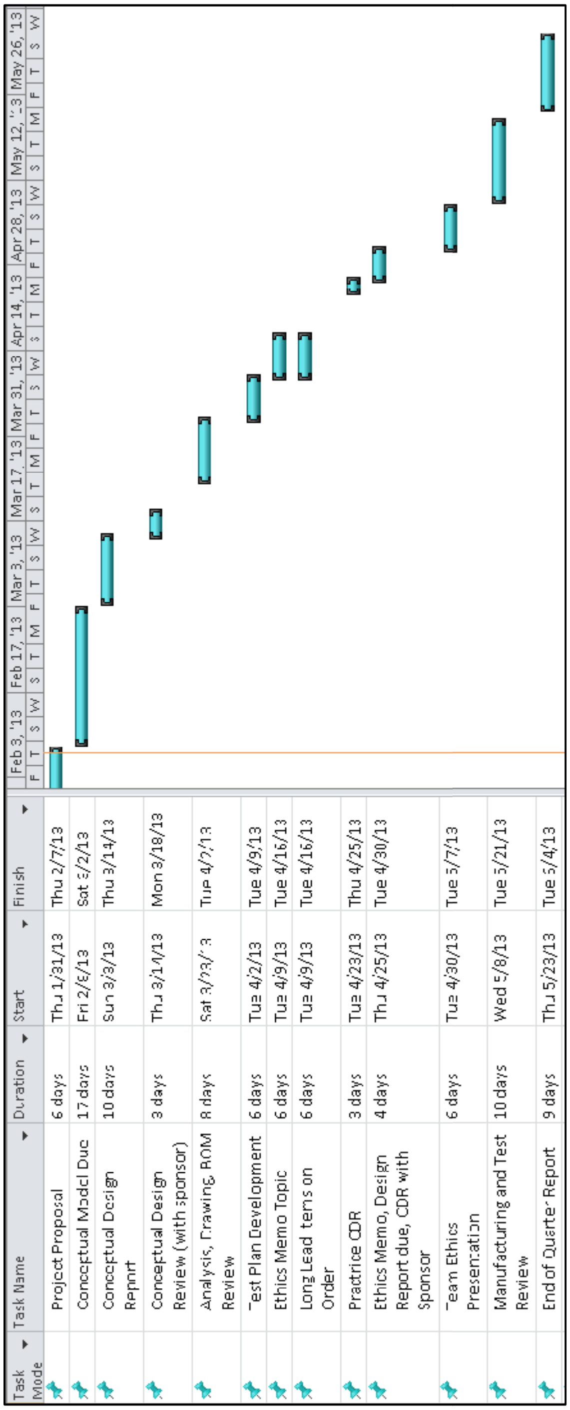


Figure C1. Schedule for February through June 2013

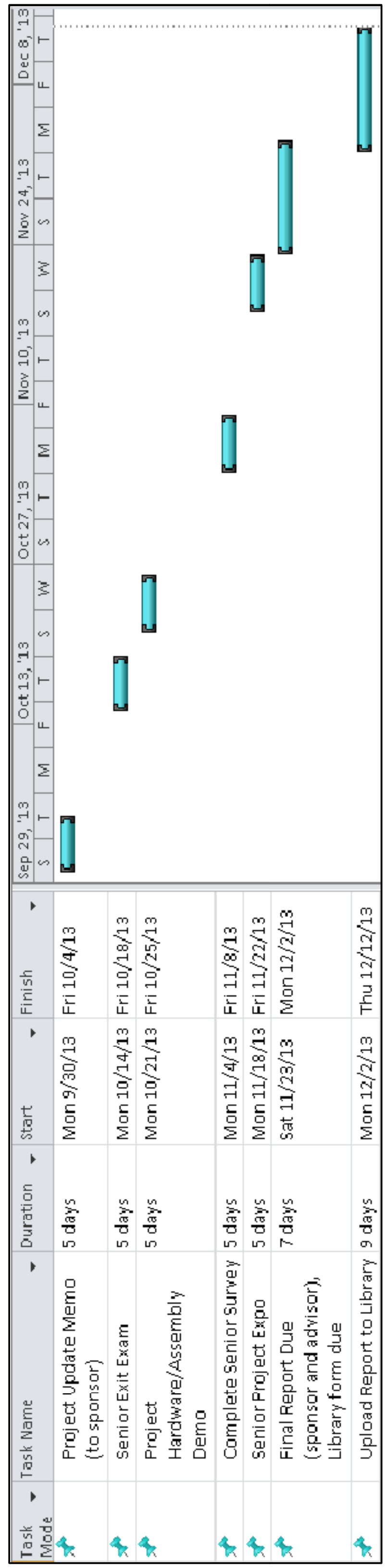


Figure C2. Schedule for September through December 2013

Appendix D. Deflection Calculations-First Design

For the top and bottom plates that hold the blades and filter container, SolidWorks was utilized to find the maximum deflection. The material selection and force load of 100 pounds was added, and the deflection tool allowed the maximum deflection to be viewed. The figures below show the deflection ranges for both plates, in millimeters. The maximum defection was about 0.00044 inches for the top plate and 0.0018 inches for the bottom plate.

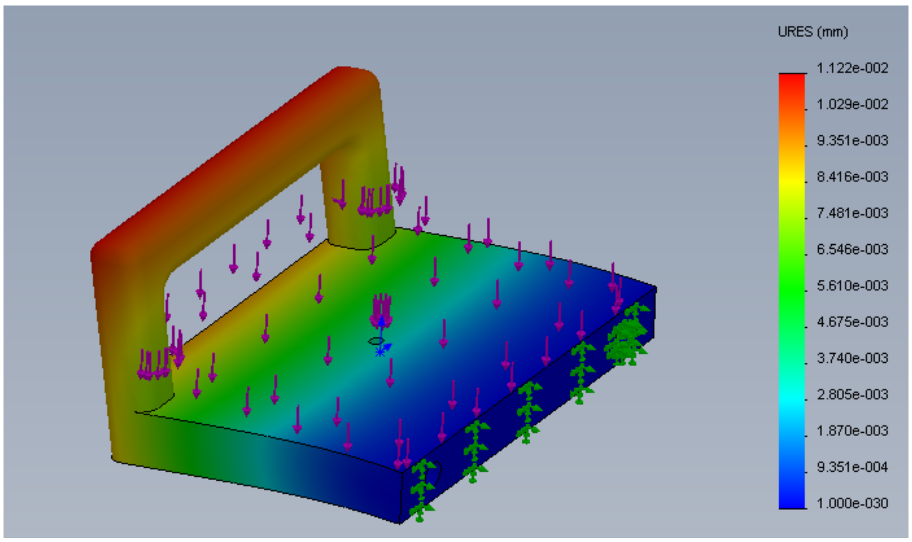


Figure D1. Top Plate Deflection

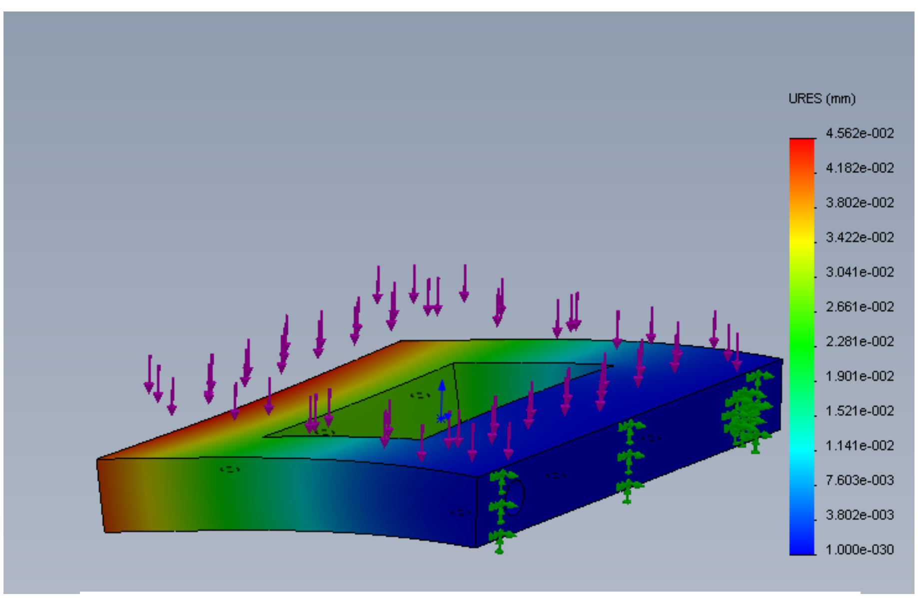


Figure D2. Bottom Plate Deflection

For the other components of the filter sampling tool, the loading diagrams and respective equations were used. To solve these equations, the weights and inertias were all calculated.

Top and Bottom Horizontal Outer Rod

The top and bottom outer horizontal rods will be made of anodized aluminum. The pipe's characteristics are listed below. Because neither rod has an applied force in the middle of the pipe, except for its own weight, the deflection is the same for both components.

$m = .05lb$
$Weight = F = 1.61lb$
$l = 3.5"$
$D = .5"$
$d = .370"$
$E = 10x10^6$
$x = {}^{l}/_{2} = 1.75"$

$$I_x = \frac{\pi(D^4 - d^4)}{64}$$
$$I_x = \frac{\pi(.5^4 - .37)}{64}$$
$$I_x = .002147985\ in^4$$

$$y_{max} = \frac{F(l - x)}{96EI}(5x^2 + 2l^2 - 10lx)$$
$$y_{max} = \frac{1.61(3.75 - 1.75)}{96(10x10^6)(.002147985)}(5(1.75)^2 + 2(3.5)^2 - 10(3.5)(1.75))$$
$$y_{max} = -.000029\ in$$

∴ Deflection is negligible

And Bottom Inner Horizontal Rod

The top and bottom inner horizontal rods will be made of anodized aluminum. The pipe's characteristics are listed below. Because neither rod has an applied force in the middle of the pipe, except for its own weight, the deflection is the same for both components.

$m = .01\ lb$
$Weight = F = .322\ lb$
$l = 3.5"$
$D = .25"$
$d = .120"$
$E = 10x10^6$
$x = {}^{l}/_{2} = 1.75"$

$$I_x = \frac{\pi(D^4 - d^4)}{64}$$
$$I_x = \frac{\pi(.25^4 - .12)}{64}$$
$$I_x = .000181569\ in^4$$

$$y_{max} = \frac{F(l-x)}{96EI}(5x^2 + 2l^2 - 10lx)$$
$$y_{max} = \frac{.322(3.75 - 1.75)}{96(10x10^6)(.000181569)}(5(1.75)^2 + 2(3.5)^2 - 10(3.5)(1.75))$$
$$y_{max} = -.000069\ in$$

∴ Deflection is negligible

Thin Top Plate

The thin top plate will be made of anodized aluminum just as the rods will be. The force applied to this plate includes its own weight, the weight of the drill, and the weight of the two vertical supporting rods as well as an opposing force from the reaction of the lead screw. The deflection from both forces were calculated separately and added together for the total deflection of the plate. The characteristics of the plate are listed below.

Using Weight as Force:

$Weight = F = 67.324\ lb$
$l = 2"$
$b = 8"$
$E = 10x10^6$
$a = {}^{l}/_{2} = 1"$

$$I_x = \frac{bh^3}{12}$$
$$I_x = \frac{(8)(1)^3}{12}$$
$$I_x = .666666667\ in^4$$

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

$$y_{max} = \frac{(67.324)(1)^2}{6(10x10^6)(.666666667)}(1 - 6)$$

$$y_{max} = -.000084\ in$$

Using Reaction as Force:

$F = 100\ lb$
$l = 2"$
$b = 8"$
$E = 10x10^6$
$a = {}^{l}/_{2} = 1"$
$I_x = \frac{bh^3}{12}$
$I_x = \frac{(8)(1)^3}{12}$
$I_x = .666666667\ in^4$

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

$$y_{max} = \frac{(100)(1)^2}{6(10x10^6)(.666666667)}(1 - 6)$$

$$y_{max} = .0000125\ in$$

$y_{total} = -.000084\ in + .0000125\ in$
$y_{total} = -.0000715\ in$

∴ Deflection is negligible

Thin Bottom Plate

The thin bottom plate will also be constructed of anodized aluminum. The weight on this plate include its self-weight, weight of the drill, the weight of the vertical rods, the weight of the lead screw, the weight of the top outer horizontal rod, the weight of the top inner horizontal rod, and the weight of the top plate. Deflection and plate properties are below.

$Weight = F = 255.05\ lb$
$l = 2"$
$b = 8"$
$E = 10x10^6$
$a = {}^{l}/_{2} = 1"$

$$I_x = \frac{bh^3}{12}$$
$$I_x = \frac{(8)(1)^3}{12}$$
$$I_x = .666666667\ in^4$$

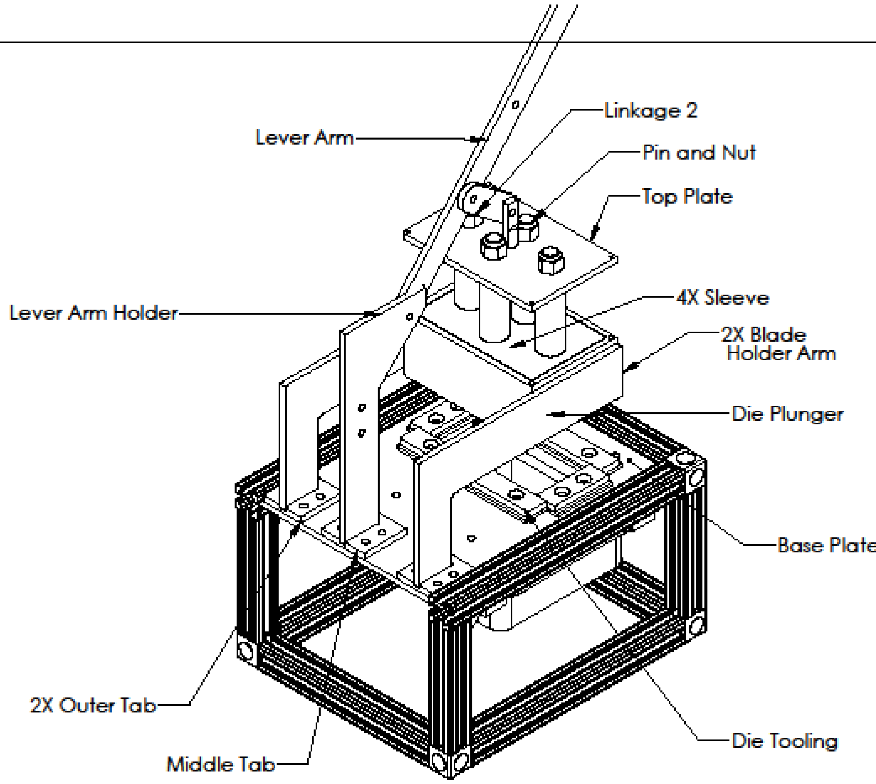
$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

$$y_{max} = \frac{(255.05)(1)^2}{6(10x10^6)(.666666667)}(1 - 6)$$

$$y_{max} = -.00003189\ in$$

$\therefore$ Deflection is negligible

Appendix E. Design Drawings-Final Design



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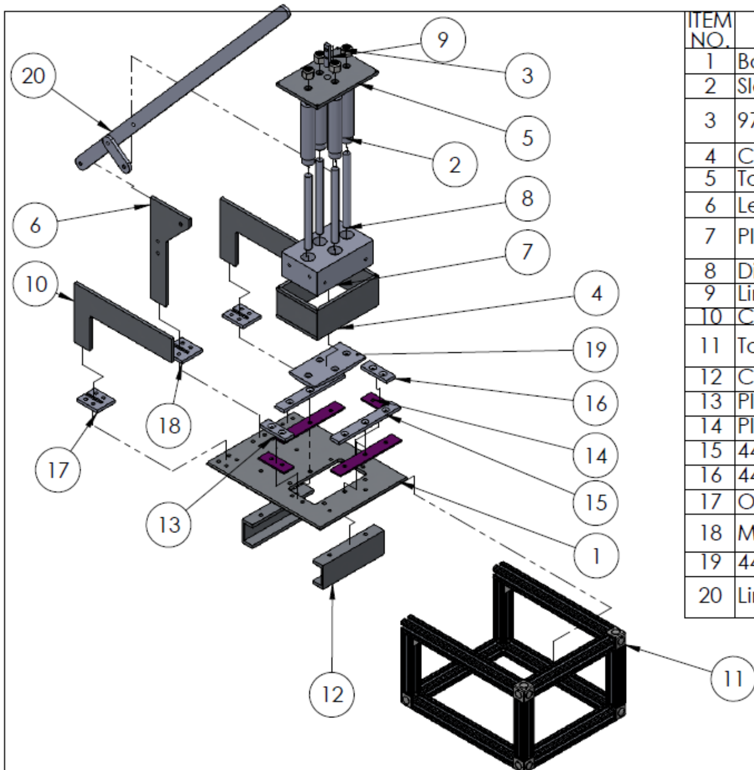
		NEXT ASSY:	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

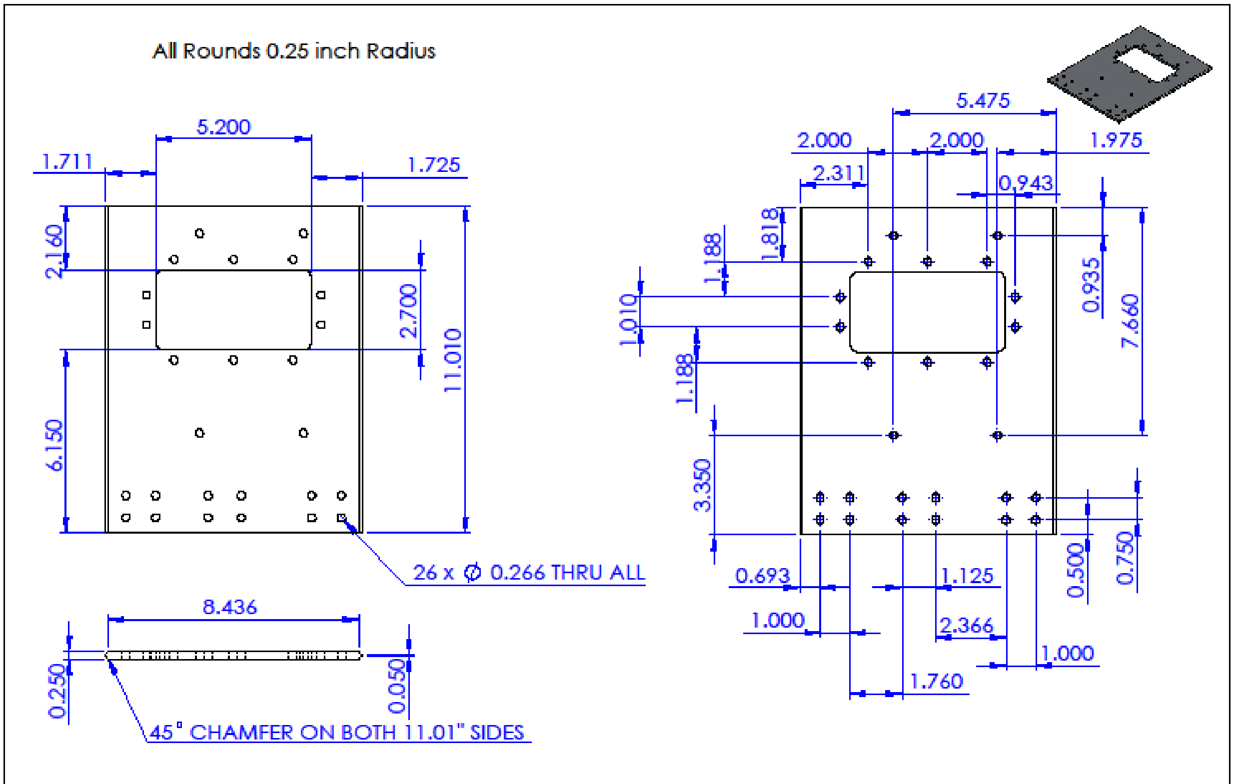
Figure E1. Final Assembly



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Plate	Device Base	1
2	Sleeve	Die Pin Sleeve	4
3	97135A255	Die Pin Lock Nut	4
4	Cover	Die Cover	1
5	Top Plate	Die Top Plate	1
6	Lever Arm Holder	Lever Arm Pivot	1
7	Plastic Bearing	Plastic Guide Insert	1
8	Die Pin	Threaded Pin	4
9	Linkage Tab	Top Plate Tab	1
10	Cover Arms	Die Cover Arms	2
11	Table Base	Aluminum T-Slot Table	1
12	Container Slots	U-Tubing	2
13	Plastic Long Spacer	Die Lip Spacer	2
14	Plastic Short Spacer	Die Lip Spacer	2
15	440C Long Die Lip	440C Die Lip	2
16	440C Short Die Lip	440C Die Lip	2
17	Outside Tab	Cover Arm Tab	2
18	Middle Tab	Lever Arm Holder Tab	1
19	440C Die	Die Plunger	1
20	Linkage Assembly	Lever Arm and Linkage	1

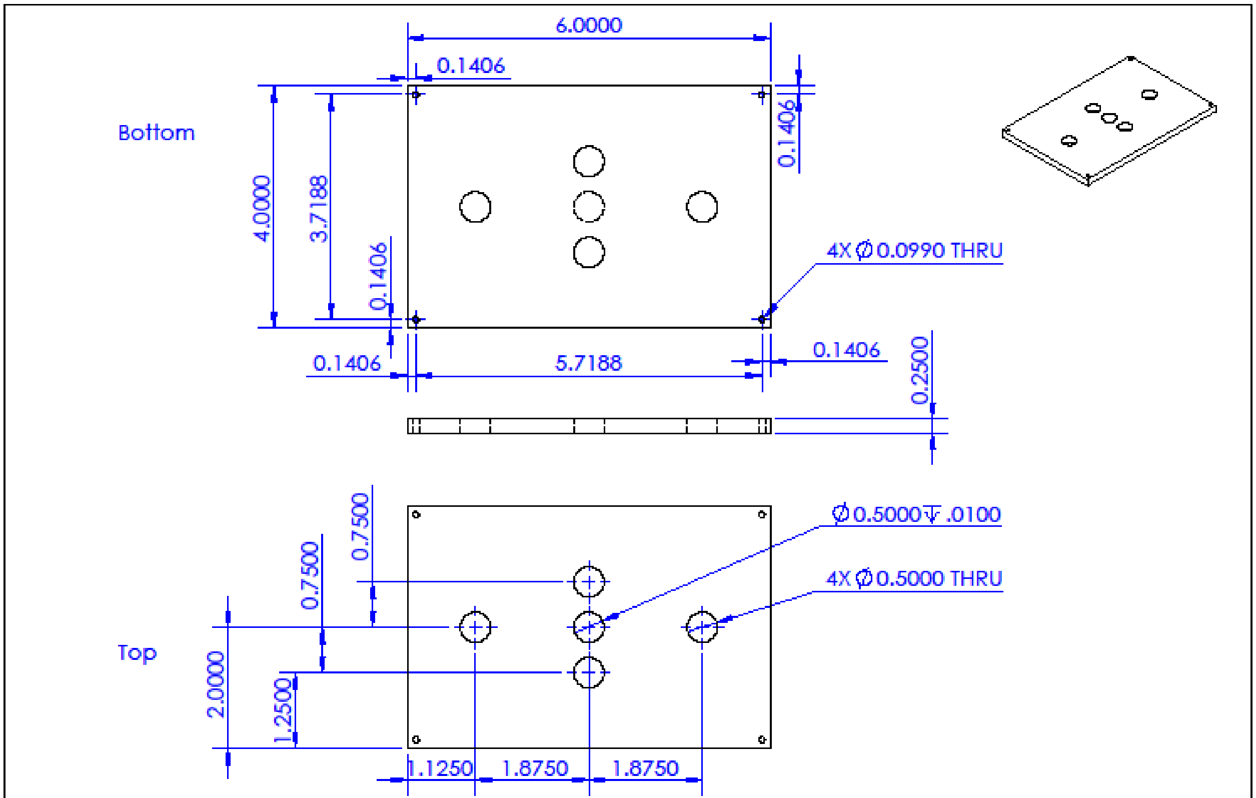
	DATE: 10/14/13	UNITS: INCHES	MATERIAL:
	TOLERANCE:	SCALE: 1:4	TITLE: EXPLODED VIEW
		NEXT ASSY:	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E2. Bill of Materials



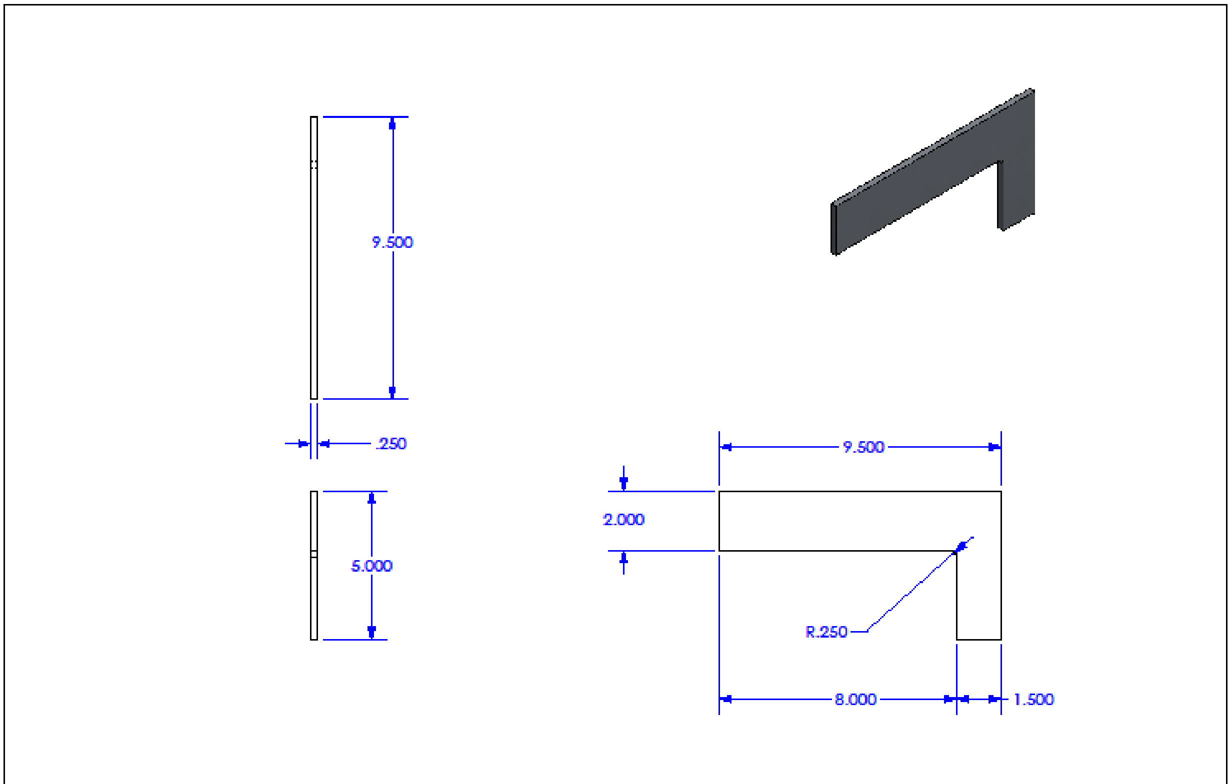
	DATE: 11/6/13	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: ±0.005	SCALE: 1:4	TITLE: BASE PLATE
		QUANTITY: 1	NAME: TEAM SLICE
		DRAWING #: 2	SIGNATURE: BRIAN HONG

Figure E3. Base Plate



	DATE: 11/07/13	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE:	SCALE: 1:2	TITLE: Top Plate
		QUANTITY: 1	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E4. Top Plate



	DATE: 11/6/13	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: ±0.005	SCALE: 1:4	TITLE: BLADE COVER HOLDER ARMS
		QUANTITY: 2	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E5. Cover Holder

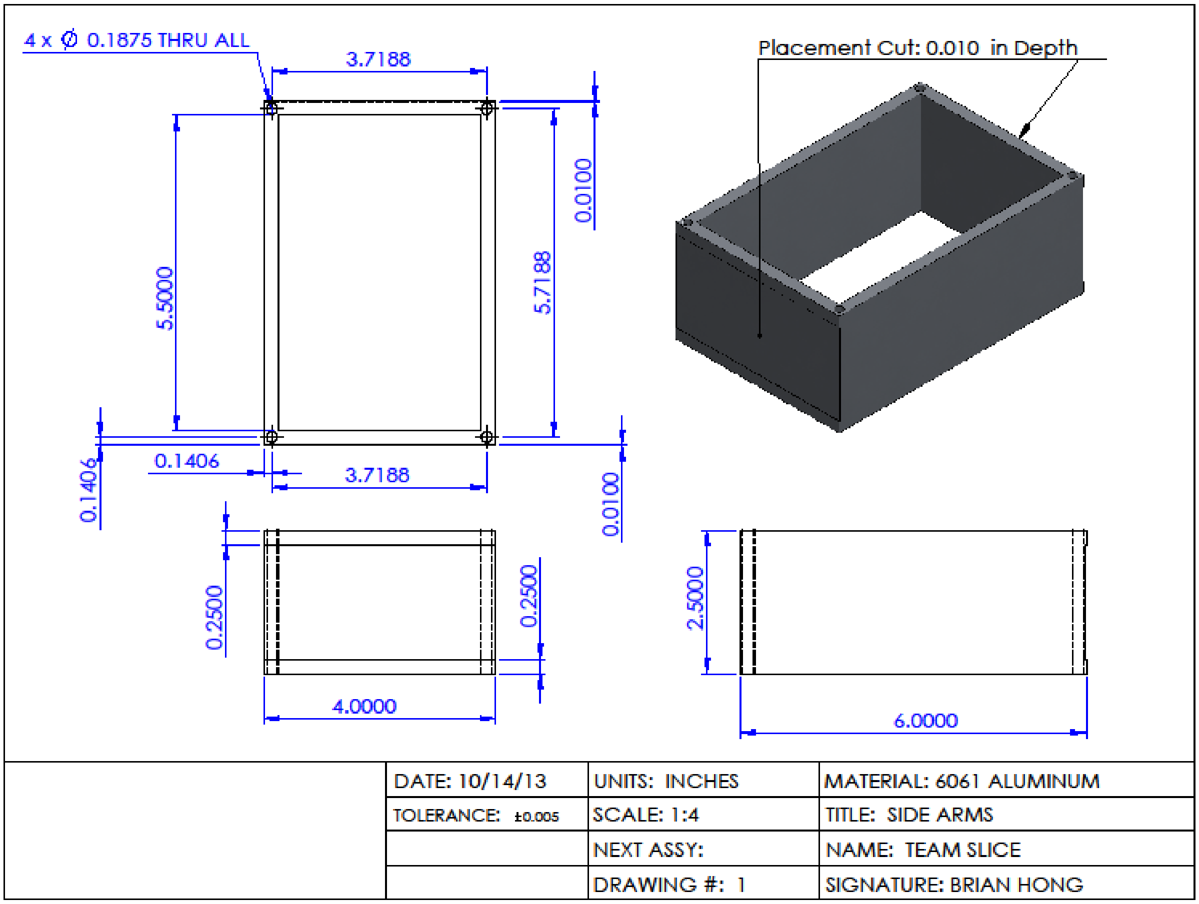
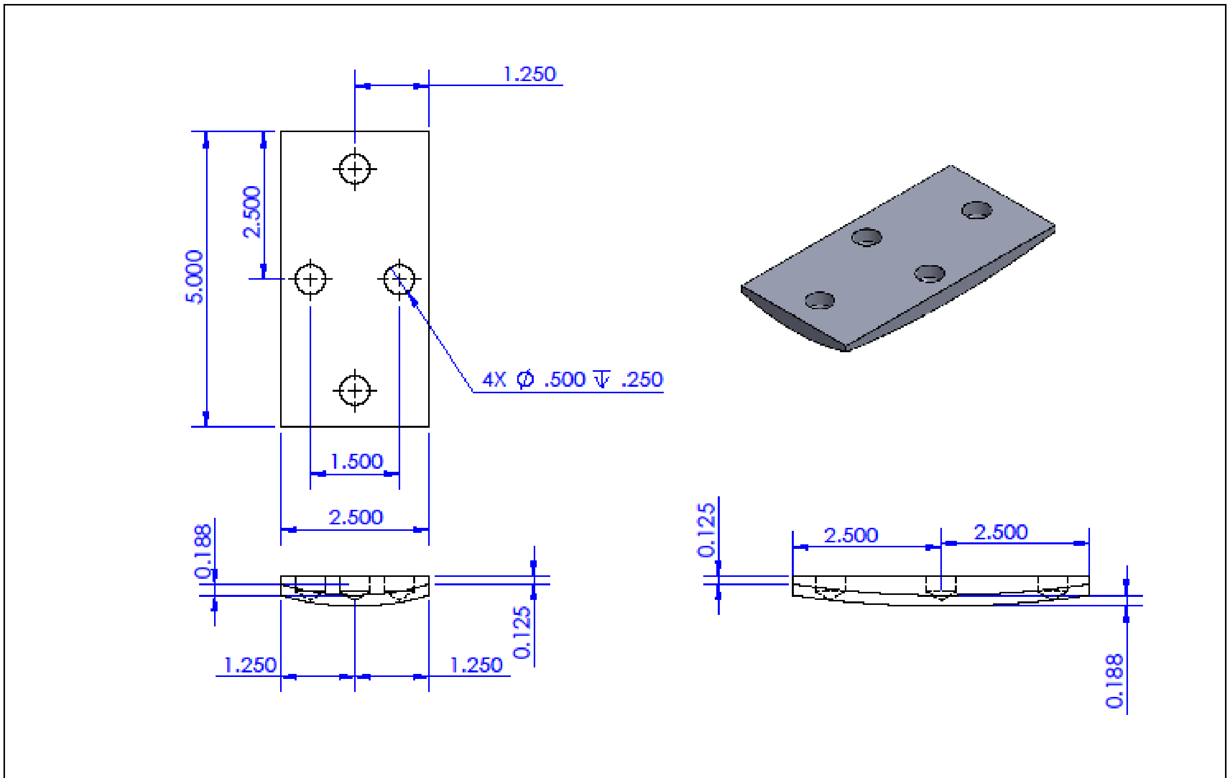
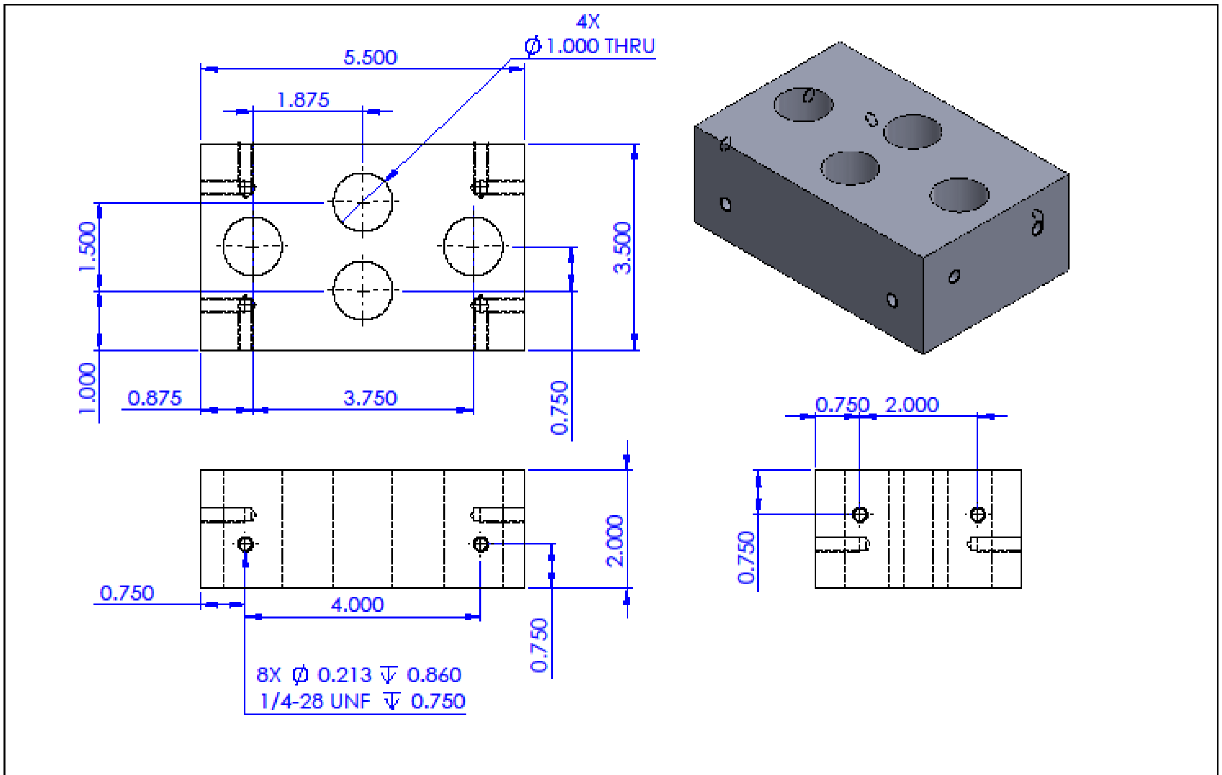


Figure E6. Cover



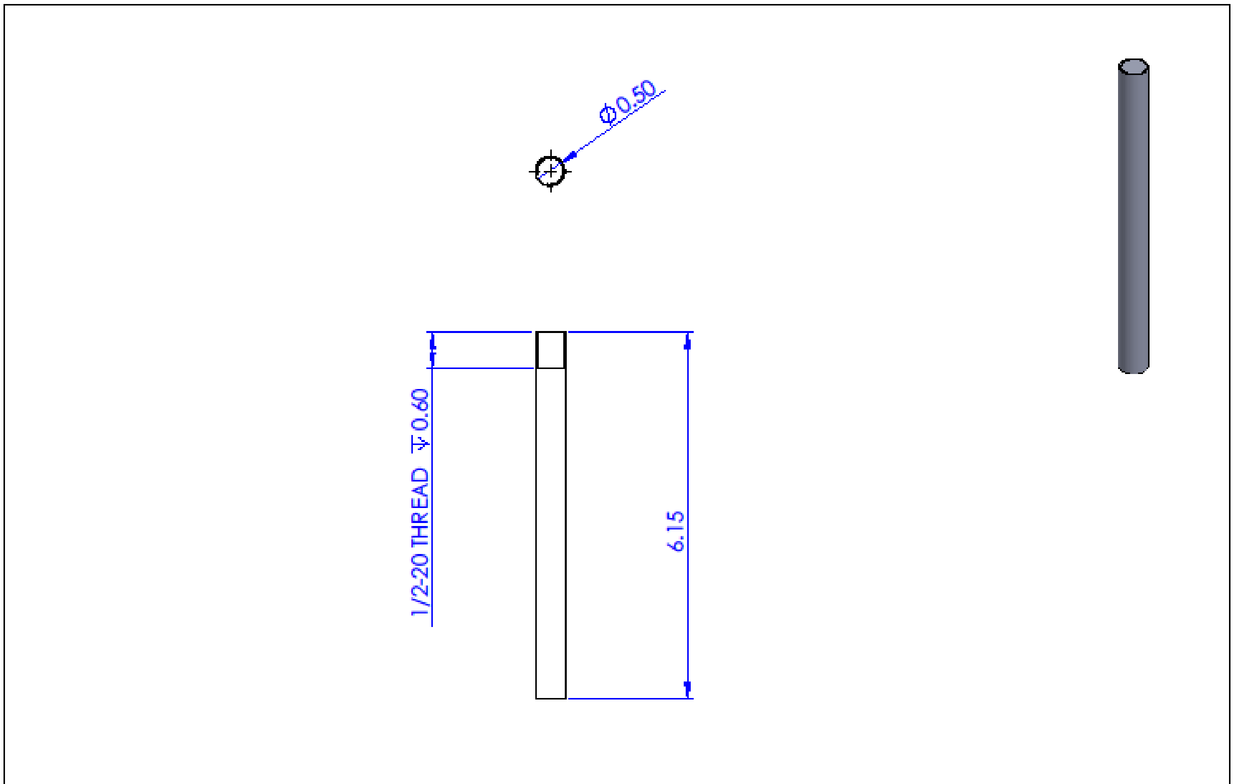
	DATE: 10/14/13	UNITS: INCHES	MATERIAL: 440C Stainless Steel
	TOLERANCE: ±0.005	SCALE: 1:4	TITLE: SIDE ARMS
		NEXT ASSY:	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E7. Die Plunger



	DATE: 12/02/13	UNITS: INCHES	MATERIAL: UMWH
	TOLERANCE: ±0.005	SCALE: 1:2	TITLE: PLASTIC BEARING
		NEXT ASSY:	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E8. Plastic Bearing Insert



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		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E9. Die Pin

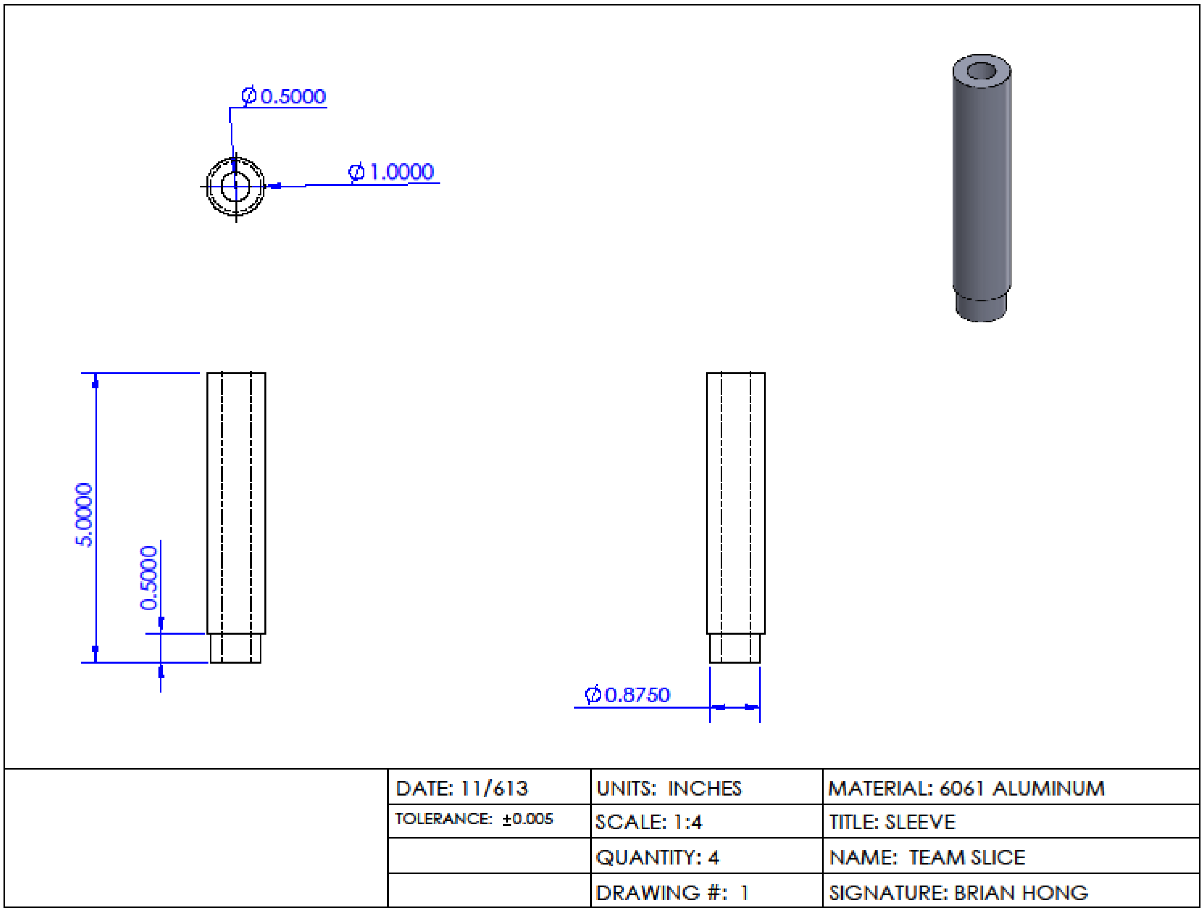


Figure E10. Die Pin Sleeve

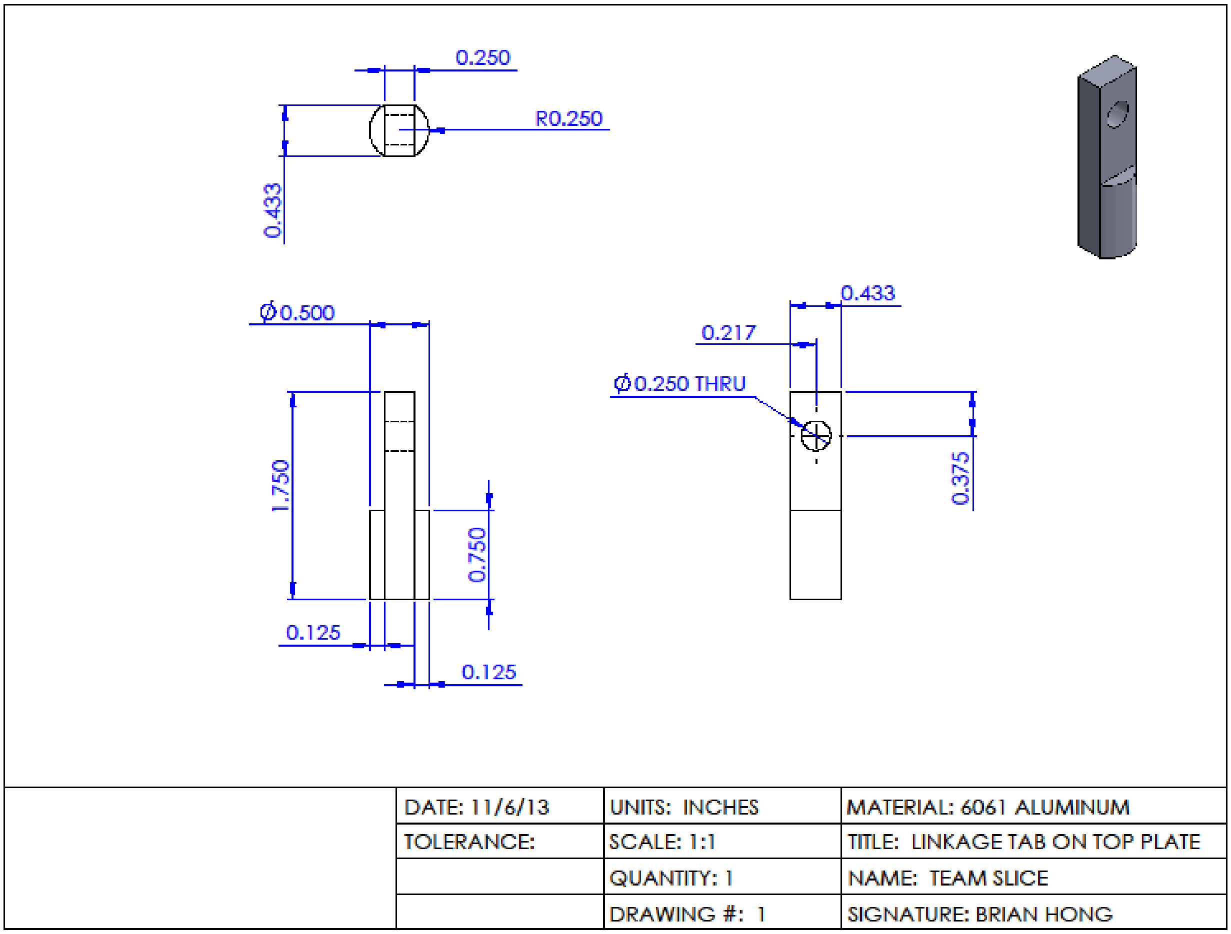


Figure E11. Top Plate Tab

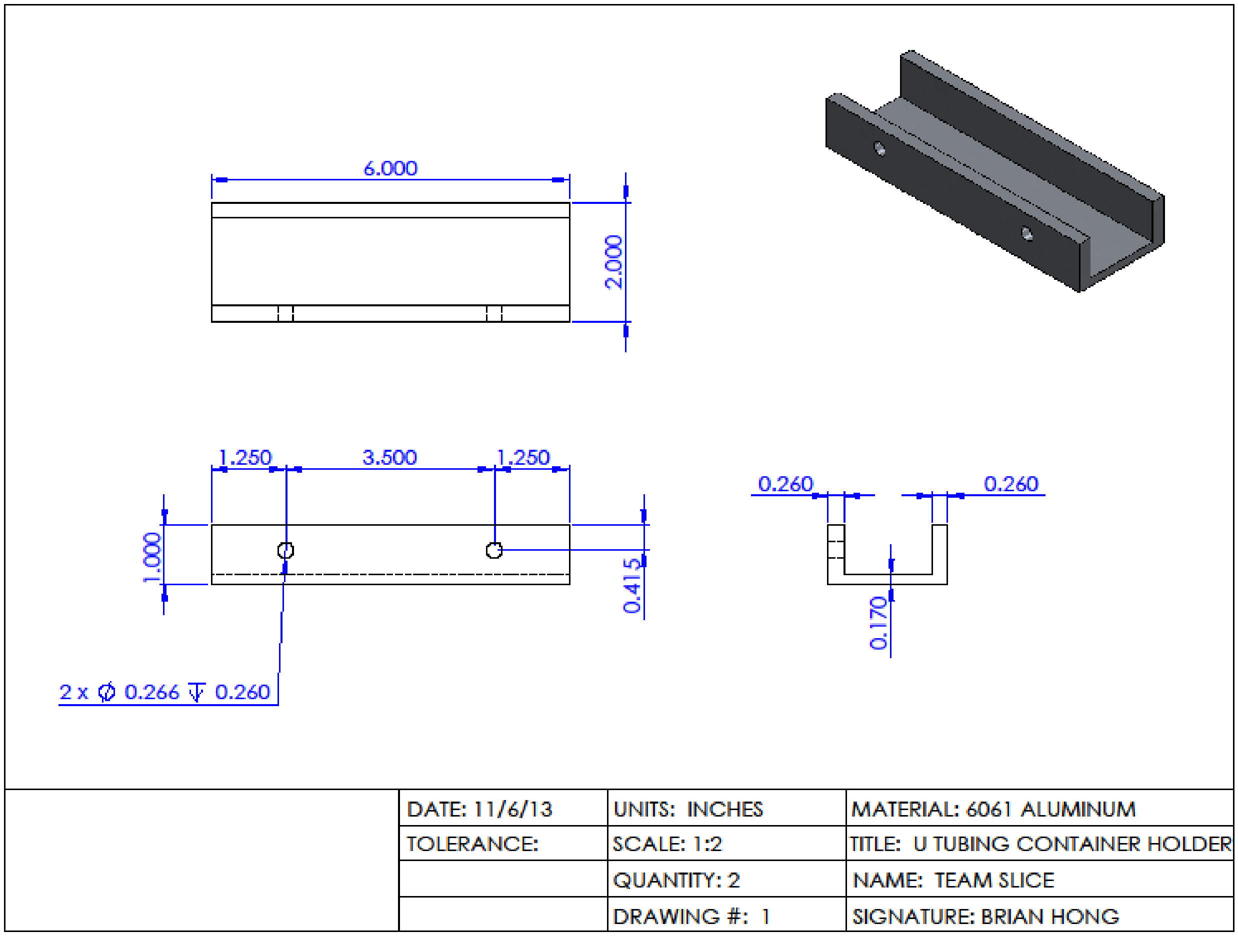
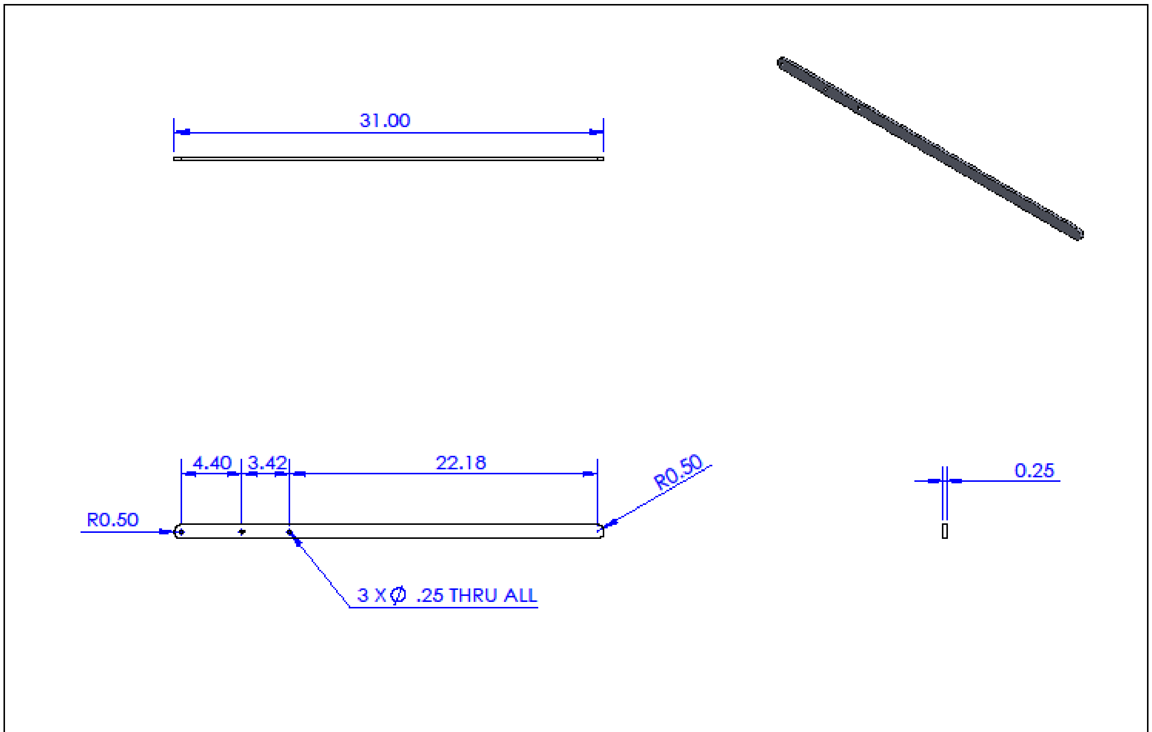


Figure E12. Container U-Tube Slot



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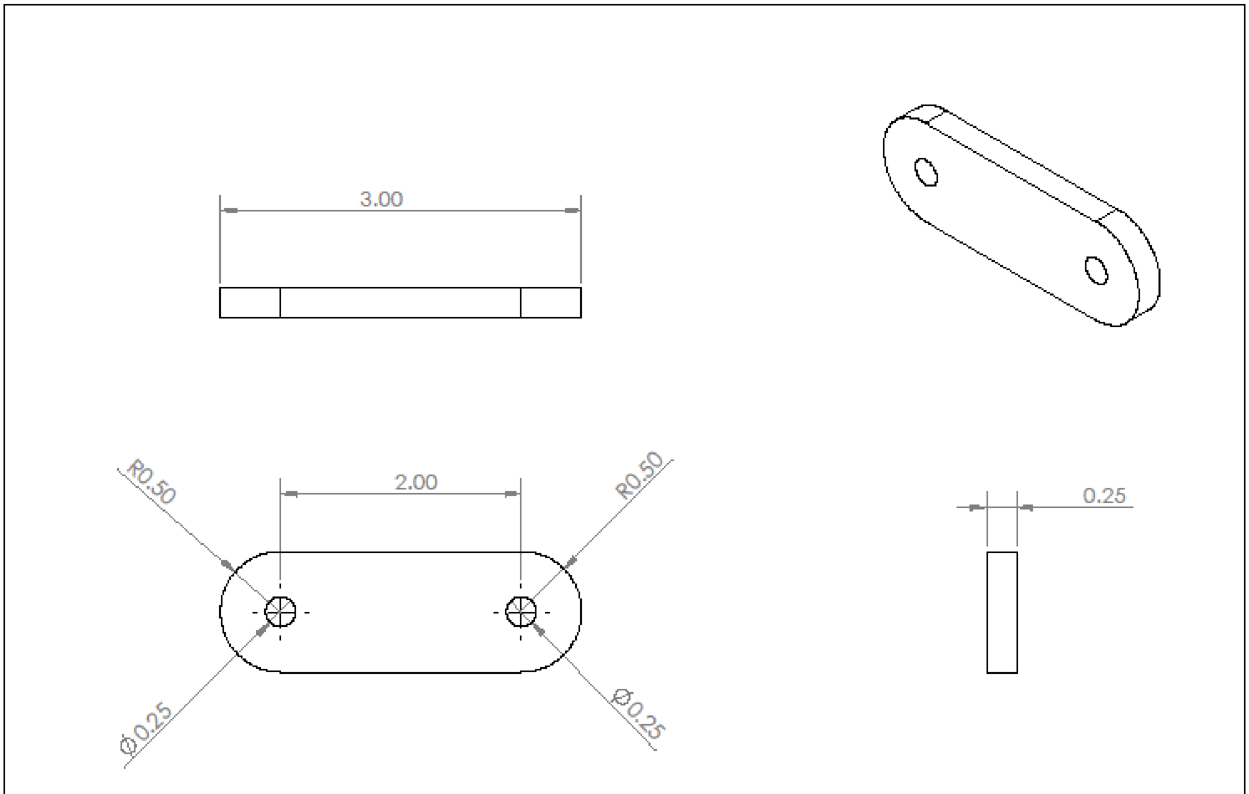
		QUANTITY: 1	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E13. Lever Arm



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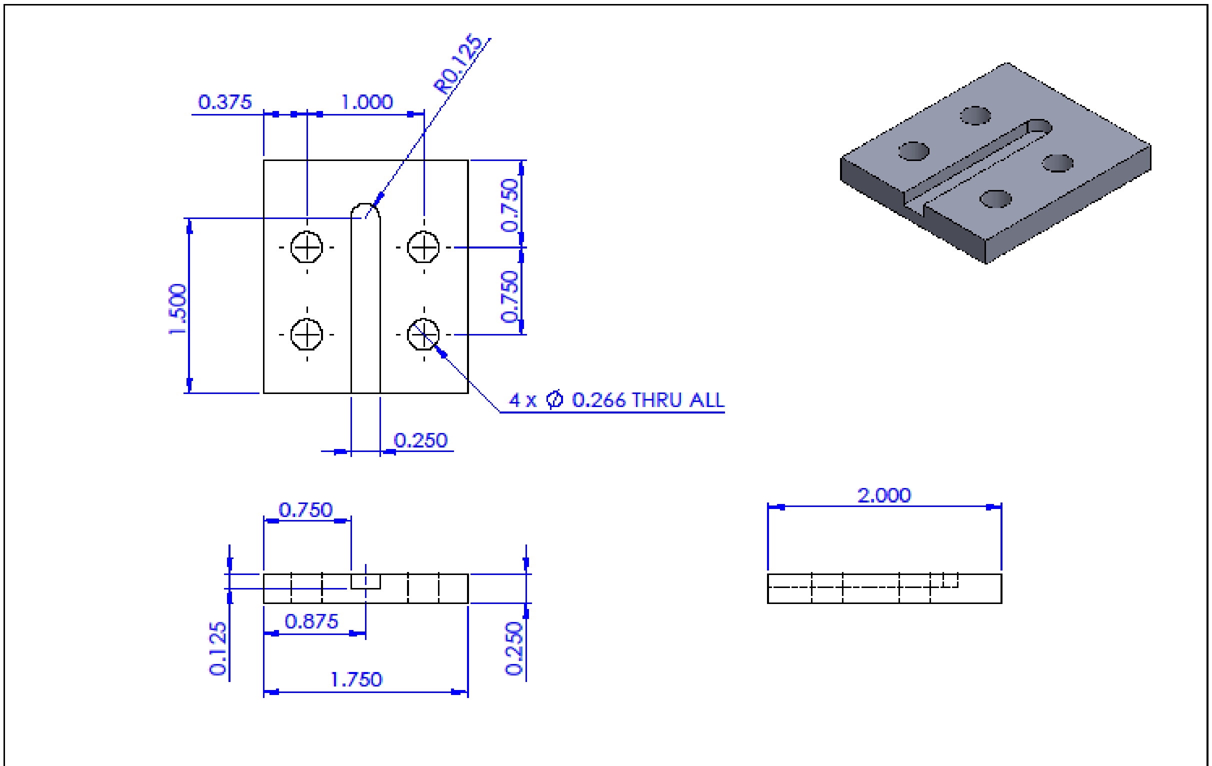
		NEXT ASSY:	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E14. Lever Arm Linkage



	DATE: 11/6/13	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE:	SCALE: 1:1	TITLE: OUTER TABS (FOR ARMS)
		QUANTITY: 2	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E15. Outer Arm Tabs

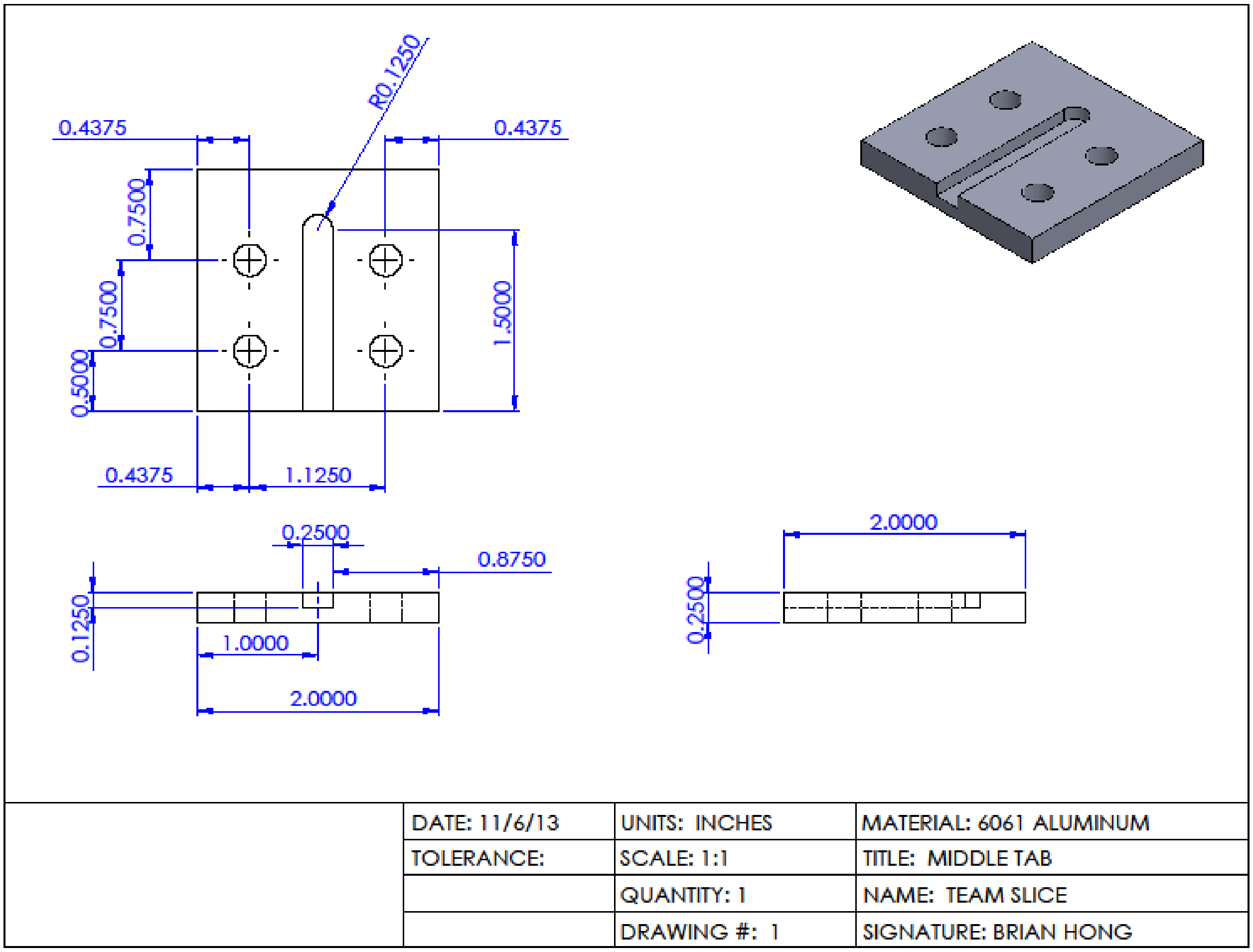


Figure E16. Middle Lever Arm Tab

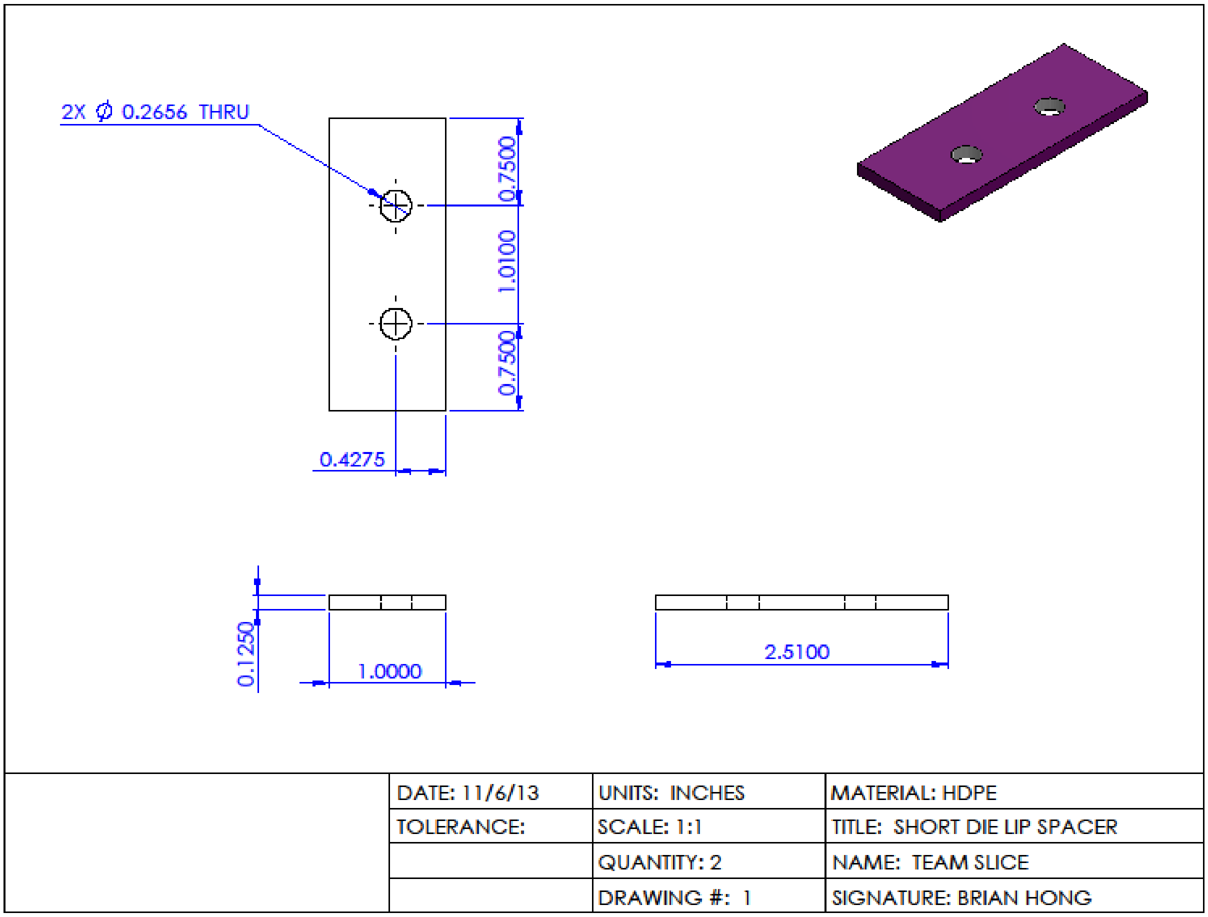


Figure E17. Plastic Short Die Lip Spacer

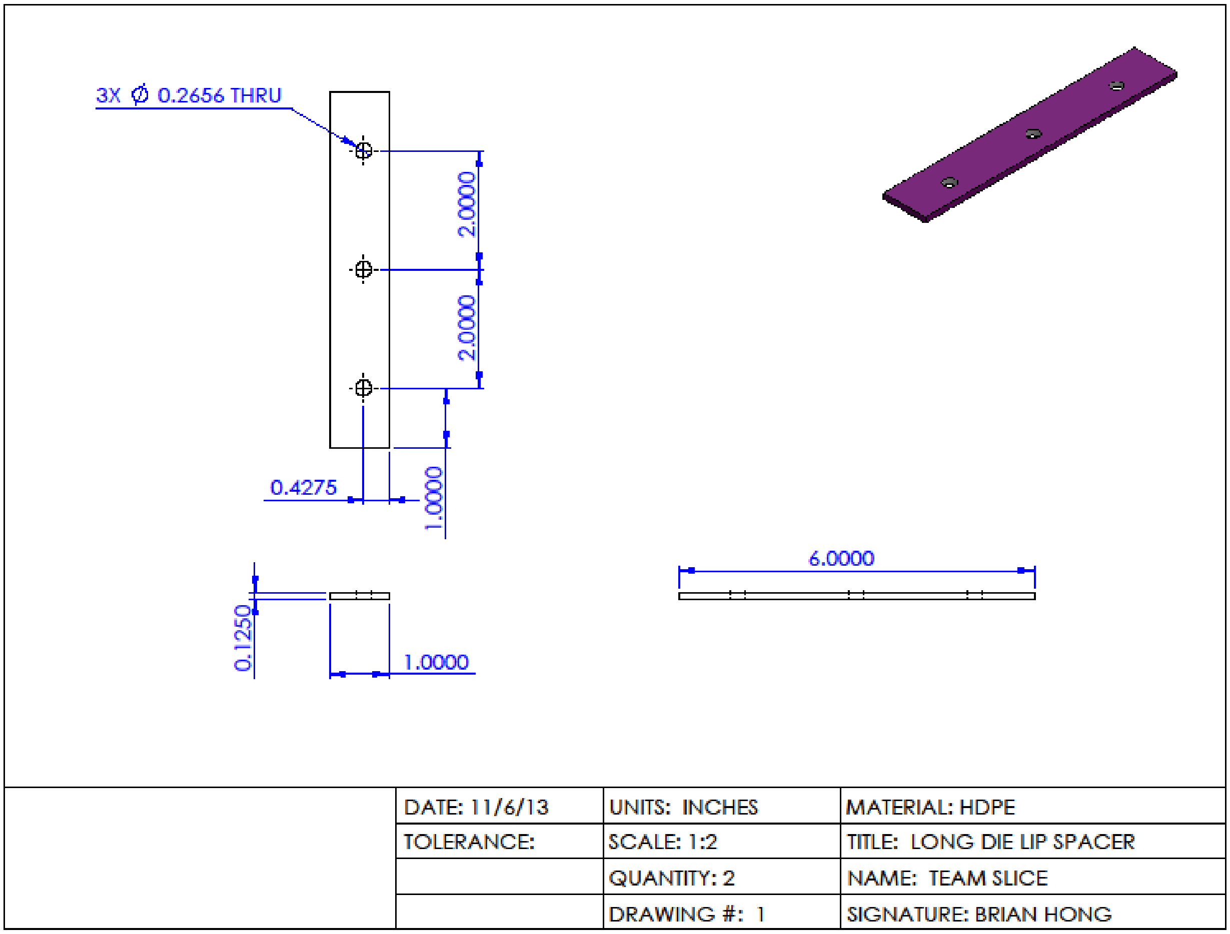
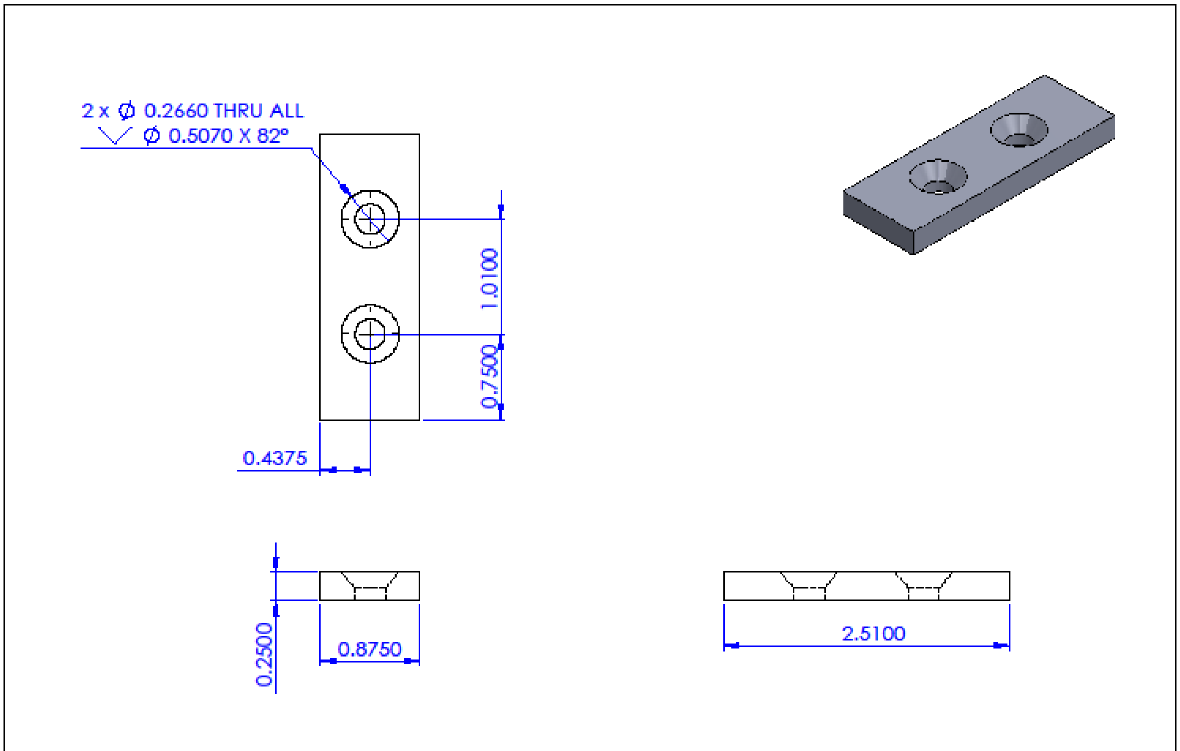
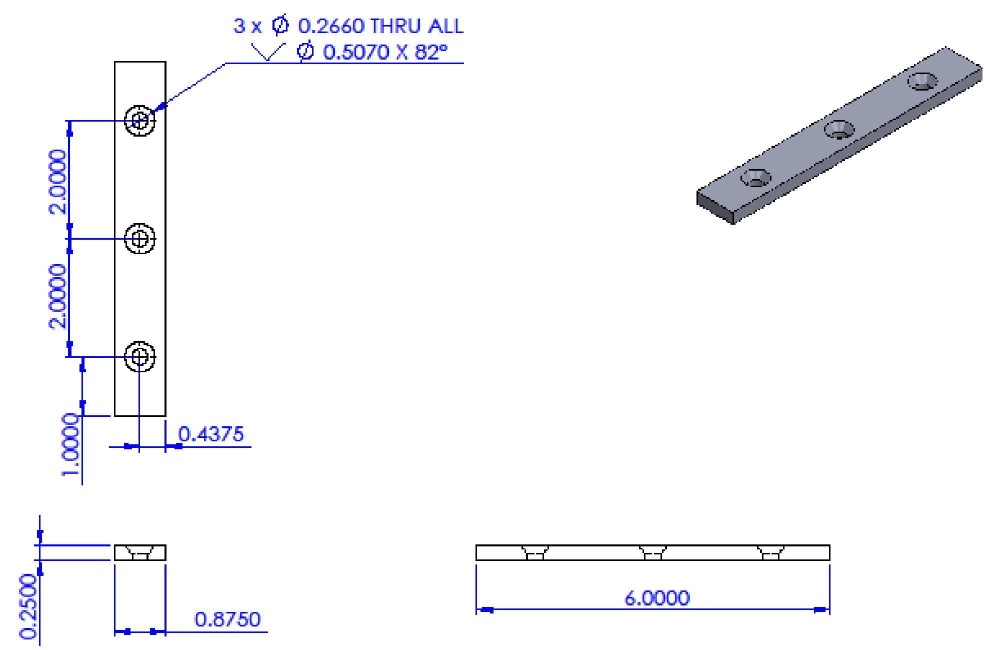


Figure E18. Plastic Long Die Lip Spacer



	DATE: 11/6/13	UNITS: INCHES	MATERIAL: 440C STAINLESS STEEL
	TOLERANCE:	SCALE: 1:1	TITLE: SHORT SIDE OF DIE LIP
		QUANTITY: 2	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E19. 440C Stainless Steel Short Die Lip



	DATE: 11/6/13	UNITS: INCHES	MATERIAL: 440C STAINLESS STEEL
	TOLERANCE:	SCALE: 1:2	TITLE: LONG SIDE OF DIE LIP
		QUANTITY: 2	NAME: TEAM SLICE
		DRAWING #: 1	SIGNATURE: BRIAN HONG

Figure E20. 440C Stainless Steel Long Die Lip

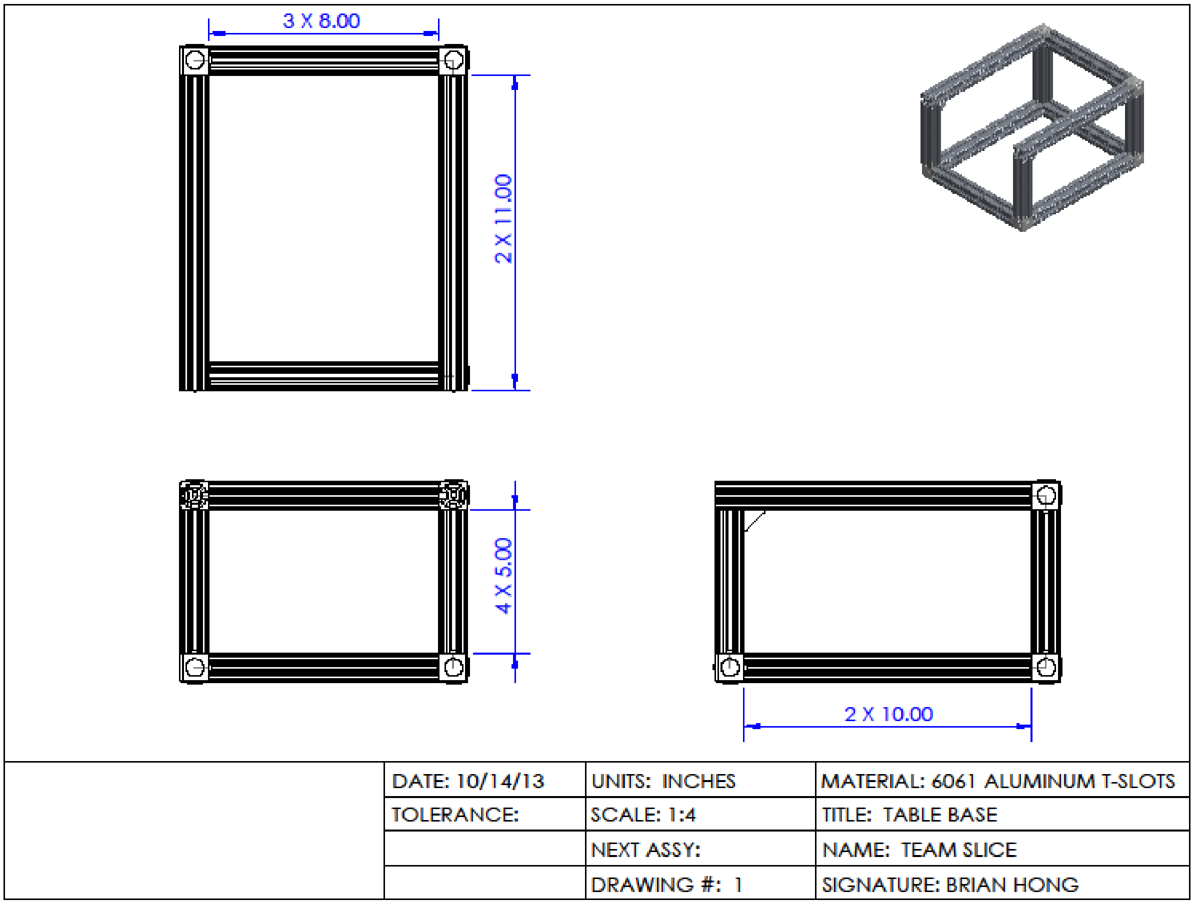
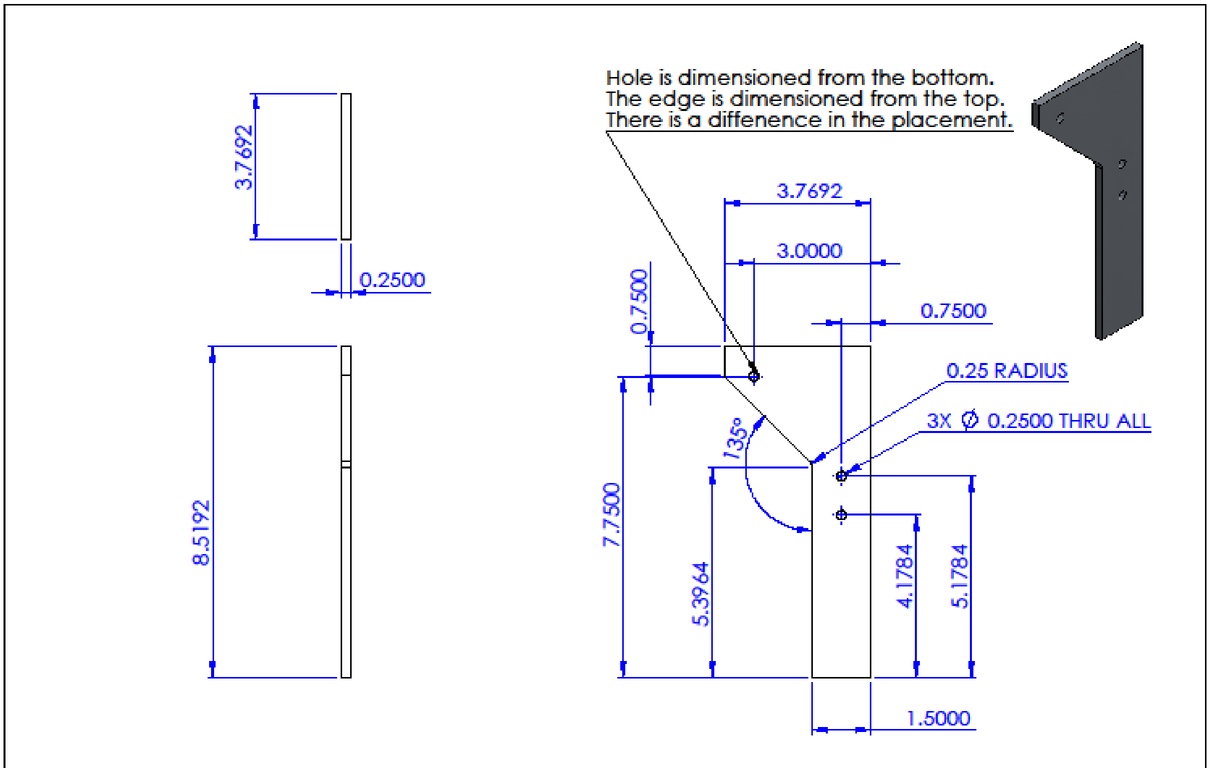


Figure E21. Aluminum T-Slot Tubing Table Base



	DATE: 11/07/13	UNITS: INCHES	MATERIAL: 6061 ALUMINUM
	TOLERANCE: ±0.005	SCALE: 1:3	TITLE: LEVER ARM HOLDER
		QUANTITY: 1	NAME: TEAM SLICE
		DRAWING #: 3	SIGNATURE: BRIAN HONG

Figure E22. Lever Arm Holder

Appendix F. Bill of Materials

ITEM NO.	PART NAME	DESCRIPTION	MATERIAL	VENDOR	PART NUMBER	QTY.
1	Base Plate	Device Base	6061 Aluminum Alloy, 1/4" Thick, 12" Width, 3' Length	McMaster	9246K44	1
2	Top Plate	Die Top Place				
3	Lever Arm Holder	Lever Arm Pivot				
4	Linkage Assembly	Lever Arm and Linkage				
5	Outside Tab	Cover Arm Tab				
6	Middle Tab	Lever Arm Holder Tab				
7	Cover Arm	Die Cover Arms				
8	Sleeve	Die Pin Sleeve	6061 Aluminum Tube, 1" OD, 1/2" ID, 0.25" Wall Thickness, 3' Length	McMaster	9056K282	1
9	Die Pin	Threaded Pin	6061 Aluminum, Precision Ground, 1/2" Diameter, 3' Length	McMaster	9062K313	1
10	Linkage Tab	Top Plate Tab				
11	Plastic Bearing	Plastic Guid Insert	UHMW Polyethylene Rectangle Bar, 2" Thick, 4" Width, 1' Length	McMaster	8702K147	1
12	Cover	Die Cover	6063 Aluminum Rectangular Tube, 4"x6", 1/4" Wall Thickness, 1' Length	McMaster	8975K314	1
13	Die	Die Plunger	440C Stainless Steel Bar, 1/2" Thick, 3" Wide, 1' Long	McMaster	88585K285	1
14	Die Lips	Die Lips	440C Stainless Steel Bar, 1/4" Thick, 1" Wide, 1' Long	McMaster	88585K225	1
15	Die Spacers	Plastic Spacers	Rigid HDPE Polyethylene Rectangular Bar, 3/8" Thick, 1" Width	McMaster	8671K13	1
16	Container Slots	U-Channel	6061 Aluminum, U-Channel, 2" Base x 1-1/4" Legs, 1' Length	McMaster	1630T473	1
17	Table Base	T-Slot Table	1"x1"x10' Extrusion T-Slotted Framing	McMaster	47065T101	1
18	T-Slot Brace	Right-Angle Brace	Aluminum Inch T-Slotted Framing System, 90 Degree Brace, Single, 2 Hole, for 1" Extrusion	McMaster	47065T216	2
19	T-Slot Corner Brace	3-Way Brace	Aluminum Inch T-Slotted Framing System, Corner Connector, 3-Way, for 1" Extrusion	McMaster	47065T244	6
20	Die Pin Nuts	Lock Nuts	Steel Nylon-Insert Hex Locknut, 1/2"-20 Thread Size, 3/4" Width, 19/32" Height	McMaster	97135A255	1 Pack
21	Linkage Screws	Shoulder Screws	18-8 Stainless Steel Shoulder Screw, 1/4" Diameter x 3/4" Long Shoulder, 10-24 Thread	McMaster	90298A540	6
22	Linkage Nuts	Lock Nuts	18-8 Stainless Steel Nylon-Insert Thin Hex Locknut, 10-24 Thread Size, 3/8" Width, 11/64" Height	McMaster	90101A011	2 Packs
23	Linkage Washers	Plastic Washers	Low-Friction PTFE Flat Washer, 1/4" Screw Size, 0.74" OD, 0.057"-0.067" Thick	McMaster	95630A475	1 Pack
24	Die Lip Screws	Flathead Screws	18-8 Stainless Steel Flat Head Phillips Machine Screw, 1/4"-28 Thread, 1" Length	McMaster	91771A561	1 Pack
25	Table Base Nuts	Lock Nuts	18-8 Stainless Steel Nylon-Insert Hex Locknut, 1/4"-28 Thread Size, 7/16" Width, 5/16" Height	McMaster	91831A120	1 Pack
26	Long Table Base Screws	Pan Machine Screws	18-8 Stainless Steel Pan Head Phillips Machine Screw, 1/4"-28 Thread, 1" Length	McMaster	91772A561	1 Pack

Appendix G. Deflection Calculations- Final Design

Small Link

$F = .024\ lb$
$l = 3"$
$b = .25"$
$E = 10x10^6$
$I_x = \frac{bh^3}{12}$
$I_x = \frac{(.25)(3)^3}{12}$
$I_x = .5625\ in^4$

$y_{max} = -\frac{Fl^3}{48EI}$

$y_{max} = -2.4E - 9$ inches
∴ Deflection is negligible

Large Link

$F = .406\ lb$
$l = 31"$
$b = .25"$
$E = 10x10^6$
$I_x = \frac{bh^3}{12}$
$I_x = \frac{(.25)(31)^3}{12}$
$I_x = 620.65\ in^4$

$y_{max} = -\frac{Fl^3}{48EI}$

$y_{max} = -4.06E - 8\ inches$

∴ Deflection is negligible

Horizontal Support

For Weight of Cutter:

$F = 2.5\ lb$
$l = 9.5"$
$b = .25"$
$E = 10x10^6$
$a = 7.5"$
$I_x = \frac{bh^3}{12}$
$I_x = \frac{(.25)(5)^3}{12}$
$I_x = 2.604\ in^4$

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

$$y_{max} = \frac{(2.5)(7.5)^2}{6(10x10^6)(2.604)}(7.5 - 28.5)$$

$$y_{max} = -7.762E - 5\ inches$$

For Weight of Rod:

$F = .62\ lb$
$l = 9.5"$
$b = .25"$
$E = 10x10^6$
$a = 4.75"$
$I_x = \frac{bh^3}{12}$
$I_x = \frac{(.25)(5)^3}{12}$
$I_x = 6.604\ in^4$

$$y_{max} = \frac{Fa^2}{6EI}(a - 3l)$$

$$y_{max} = \frac{(.62)(4.75)^2}{6(10x10^6)(2.604)}(4.75 - 28.5)$$

$$y_{max} = -2.126\ E - 5\ inches$$

$y_{total} = -.000076in + -.0000212in$
$y_{total} = -0.882E - 5\ in$
$\therefore$ Deflection is negligible

Appendix H. Shear Calculations- Final Design

Small Link Hole

$F = 93.476\ lb$
$r = .25"$
$\tau_y = 35{,}000\ psi$

$$\tau = \frac{F}{A} = \frac{F}{\pi r^2}$$

$$\tau = \frac{93.476}{.19635}$$

$$\tau = 476.06\ psi$$

$\tau < \tau_y, therefore\ shear\ stress\ is\ negligible$

Large Link Hole

$F = 93.882\ lb$
$r = .25"$
$\tau_y = 35{,}000\ psi$

$$\tau = \frac{F}{A} = \frac{F}{\pi r^2}$$

$$\tau = \frac{93.882}{.19635}$$

$$\tau = 478.1371\ psi$$

$\tau < \tau_y, therefore\ shear\ stress\ is\ negligible$

Appendix I. Buckling Calculations- Final Design

$E = 10{,}100\ psi$
$l = 3.5"$
$D = .5"$
$d = .25"$
$C = 4$

$$I_{x1} = \frac{\pi(D^4 - d^4)}{64}$$
$$I_{x1} = \frac{\pi(.5^4 - .25^4)}{64}$$
$$I_{x1} = .0028762\ in^4$$

$$I_{x2} = \frac{\pi(D^4)}{64}$$
$$I_{x2} = \frac{\pi(.5^4)}{64}$$
$$I_{x2} = .0030679616\ in^4$$

$$I_{total} = .0088203816\ in^4$$

$$P_{cr} = \frac{C\pi^2 EI}{l^2}$$

$$P_{cr} = \frac{4\pi^2(10{,}100).0088203816)}{3.5^2}$$

$$P_{cr} = 287.099\ lb\ total$$

$$P_{cr,per\ dowel} = \frac{287.099}{4}$$

$$P_{cr,per\ dowel} = 77.7745\ lb$$