# Configurable High-throughput Puncher for Microfluidic Devices

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ME 450 Design and Manufacturing III: Final Report
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# EXECUTIVE SUMMARY


This paper details work completed through April 21st, 2020, on the project of designing a configurable high-throughput puncher for microfluidic ports. This includes the definition of the project scope, information on the project background, research and development of the requirement and specifications, and multiple designs from the concept generation stage. Also included is the final design with the concept evaluation and selection matrices, verification, validation, and risk assessment plans, detailed engineering analyses, an eco-audit and ethics report, and a final discussion and conclusion section.

The Integrated Biosystems and Biomechanics Laboratory at the University of Michigan has developed a novel microfluidic device capable of developing structures that model post-implantation embryonic human development from stem cells. The UM Office of Technology Transfer has pushed for the commercialization of this device for human development research and drug toxicity screening. Commercialization is currently limited by the manufacturability of the device. Currently, the device needs to be punched with six ports consisting of four 8 mm ports and two 1.2 mm ports. The ports are created in the device manually, with medical grade, disposable punches. This process takes an experienced lab technician a minimum of about twenty minutes to punch 36 ports into six devices. Additionally, the device design is subject to change after the conclusion of the design project. Therefore, we have been asked to design a precise, high-throughput method to create ports in microfluidic devices which can be reconfigured to accommodate changes to the microfluidic device design.

From the research conducted, the requirements and engineering specifications were determined and tabulated (Table 2, pg. 9). The top priority requirements include configurability, reduced cycle time, positional precision, and reliability. The final concept is a multi-platform device which includes a custom SLA 3D-printed array that holds stainless steel punch tips, which lowers into the PDMS which is sitting atop an x, y, theta alignment table. Pneumatic cylinders are situated atop the punch array to supply the power necessary to punch up to thirty-six 8 mm ports at a time. More details and pictures of the final design can be found starting on page 17. Our validation approach includes testing our specifications via methods outlined on page 26. No validation results can be reported, as no physical artifact was manufactured due to the COVID-19 pandemic. We are supplying this deliverable replete with all the information a mechanical engineering undergraduate student would need to produce the device for the sponsor. As a result, we are analyzing our performance based on the clarity and completeness of this deliverable.

The only physical expenditure was for $7.65 on dowel pins. A budget of $392.35 with a $600 conditional budget remains.

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## PROBLEM DESCRIPTION

Professor Jianping Fu and Dr. Yi Zheng of the Integrated Biosystems and Biomechanics Laboratory have developed a novel stem-cell based microfluidic device to study human embryonic behavior. This technology has significant potential in high throughput pharmacology and toxicology screening as well as research into post-implantation human development. To model these cells, human pluripotent stem cells (hESCs and hiPSCs) are grown in conventional culture conditions in a laboratory setting. Dr. Zheng and his colleagues have engineered a microfluidic device to create the 3D environment in which these stem cells can develop into embryonic-like sac structures. This device contains three channels: a central channel for loading a matrix material, another for loading hESCs or hiPSCs, and a third containing flowing liquids carrying morphogen molecules that induce stem-cell differentiation. The microfluidic devices are lined with trapezium-shaped posts 80 micrometres apart that create evenly spaced matrix pouches where the stem cells can grow and differentiate. One of the major limitations to commercialization of the current device is that the ports through which the fluids are added must be punched manually in a tedious process that takes a minimum of twenty minutes to complete a sample of six devices. In order to circumvent the current limitations of the microfluidic device sample preparation, Professor Fu and Dr. Zheng are seeking an engineering solution that can reduce the time it takes to create the ports in the microfluidic device. The solution must be reconfigurable to accommodate changes in port location and port diameter to allow for design changes and preparation of other microfluidic devices. To correctly position the ports, the design must have high precision and positional accuracy.

## SUMMARY OF RELEVANT INFORMATION SOURCES

To gain a better understanding of the microfluidic devices, Professor Fu provided several online articles regarding the research on the device that has been conducted by the lab thus far. The current device contains three separate channels: a central channel for loading the gel matrix (Geltrex), a channel for loading hESCs or hiPSCs, and a channel for liquids that induce stem-cell differentiation. Figure 1, pg. 6, displays the three channel microfluidic device [1].

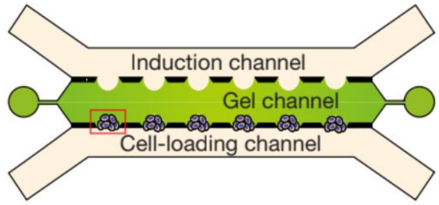


**Figure 1.** Schematic of the three channel microfluidic device used by Professor Fu's lab team [1]. The microfluidic device contains three channels: the induction channel, gel channel, and the cell-loading channel.

As shown in Figure 1, there are three distinct channels per device. Each channel needs two ports, with one on each end of the channel. The design changes that could affect the punch configuration include changing the sizes of the channels and the positions of the channel endpoints. Figure 2, below, displays cell growth occurring at 18 hours (t = 0h) after the introduction of hiPSCs and the formation of epiblast-like cysts at 54 hours (t = 36h) within the microfluidic device [1].

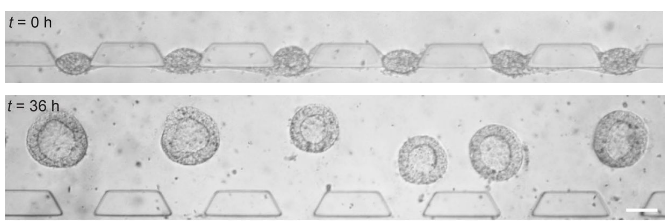


**Figure 2.** Cell growth in the microfluidic device over 36 hours in the lab [1]. At 18 hours (denoted t = 0h) after the introduction of hiPSCs into the microfluidic device, cell cultures are shown to be developing between the trapezoidal dividers of the microfluidic channel. At 54 hours (denoted t = 36h) after the introduction of hiPSCs into the microfluidic device, epiblast-like cysts begin developing within the gel matrix.

From Figure 2, one can see the growth that occurs after stem-cell differentiation is induced after 54 hours. This differentiation is triggered by the side channels in the microfluidic device which carry the hESCs, hPSCs, and other flowing liquids. These cell "nutrients" are then fed to the central channel which houses the gel matrix material in which the stem cells grow.

Additional sources were consulted to gain a better understanding of the current medical biopsy puncher used to create ports in the microfluidic device. Figure 3, Pg. 7, shows the Harris uni-core

8 mm diameter medical biopsy punch, which is one of the models currently used in the lab to create ports in the microfluidic device.

**Figure 3.** Harris Uni-core 8 mm diameter puncher provided by Professor Fu's lab team. The 8 mm model is used to create ports that connect to the cell loading and induction channel, as shown in Figure 1, pg. 6. The 1.2 mm puncher was not provided so no image is available.

The Harris Uni-Core 8 mm diameter, shown in Figure 3, is used to create ports at the ends of the cell loading channel and induction channel (Fig. 1 [1], pg. 6). Currently, a 1.2 mm Harris Uni-Core punch is used to create ports at both ends of the gel channel, however, Professor Fu's lab team was unable to provide the exact model they use for the microfluidic device, so currently no image is available. The typical punch sizes that need to be accommodated for in the puncher device range from 1.2 mm to 8 mm diameter.

Furthermore, the material used for the microfluidic device is polydimethylsiloxane (PDMS), which is a common polymer choice for modern biomedical microfluidic applications [2]. Table 1 summarizes important material properties [2] of PDMS samples that cured at 25 °C.

**Table 1.** Material Properties of PDMS samples cured at 25 °C [2].

| Property | Value (MPa) |
|---|---|
| Tensile Modulus | 1.32 ± 0.07 |
| Ultimate Tensile Strength | 5.13 ± 0.55 |
| Compressive Modulus | 186.9 ± 5.4 |
| Ultimate Compressive Strength | 51.7 ± 9.6 |
| Shear Modulus | 0.44 ± 0.02 |

The material properties reported in Table 1, pg. 7, were used to perform the necessary analysis to determine the minimum required force to puncture the PDMS. Additionally, it was found that punching the PDMS is the most viable subtractive manufacturing method at room temperature (~22 °C as measured in Professor Fu's lab) because the most efficient way to machine PDMS is to cryogenically cool it below -143 °C [3], which is not a feasible option for our design due to time constraints and budget limitations.

Based on input from our sponsor and products sold by microfluidics companies [4], the most widely used method to create holes in PDMS is via a single punch tool. This serves as our only benchmark, and confirms that there is no current solution for a configurable, high-throughput puncher for microfluidic device connection ports. Currently, the only information gap is potential input from other biomechanics labs at the University of Michigan who may find our reconfigurable punching device useful for their own lab experiments and research.

## REQUIREMENTS AND ENGINEERING SPECIFICATIONS

From our discussions with our sponsors, we developed engineering specifications for our device that would meet the user requirements for the punching device. Table 2, pg. 9, summarizes these requirements and specifications.

**Table 2.** User requirements and engineering specifications. Each specification is ordered based on priority, with “1” being the most important for the sponsor, and “3” being the least important

| User Requirements | Engineering Specifications | Priority |
|---|---|---|
| Reconfigurable | Punching device shall accommodate punches with diameter of 1mm, 1.2 mm, 1.5 mm, 2 mm, 2.5 mm, 3 mm, 3.5 mm, 4 mm, 5 mm, 6 mm, 7 mm, and 8mm | 1 |
| | Device shall be capable of punching 36 ports within a 10 cm x 10 cm area | |
| Precise | ⌀500 µm positional tolerance zone | 1 |
| Improved cycle time from current 20-30 minutes | <5 minutes process to punch 36-54 ports | 1 |
| Reliability | Punching device shall last two years at punching 10 cycles per week | 1 |
| | All parts are commercially available and/or machinable by a mechanical engineering undergraduate student | |
| Clean cut all the way through PDMS | Cut through 1 cm of PDMS with no destruction of the microfluidic channels (thus resulting in prevention of fluid flow into channels) | 2 |
| Create fixture for devices | Fixture must be able to securely hold the PDMS samples for accurate location of port positions | 2 |
| Material remover | Cut-out part must be removed from the original material without user effort | 2 |
| Low cost | <$1,000 | 3 |
| Weight | <22.7 kg according to OSHA standards [5] | 3 |
| Table dimensions | <0.2 m x 0.2 m x 0.3 m | 3 |

For each requirement specified by our sponsors, we created engineering specifications that were designed to meet those requirements, and assigned each a priority value, from 1 to 3, based on the importance to the user. As shown in Table 2, the requirements of “reconfigurable,” “precise,” and “improved cycle time” have a priority of 1, indicating that they are the most important user requirements to meet for the project.

## CONCEPT GENERATION

For the concept generation phase of our design process, we broke our device into two primary systems: the puncher and the alignment system. For each system, we created multiple designs that could meet the customer requirements and satisfy the engineering specifications of the device.

### Puncher

Our first concept for the punching mechanism is that of the open face hamburger. In this design, the PDMS is placed onto the puncher tips and a flat plate comes down in a vertical motion to apply equally distributed pressure to the PDMS. A schematic of this design layout is shown below in figure 4.

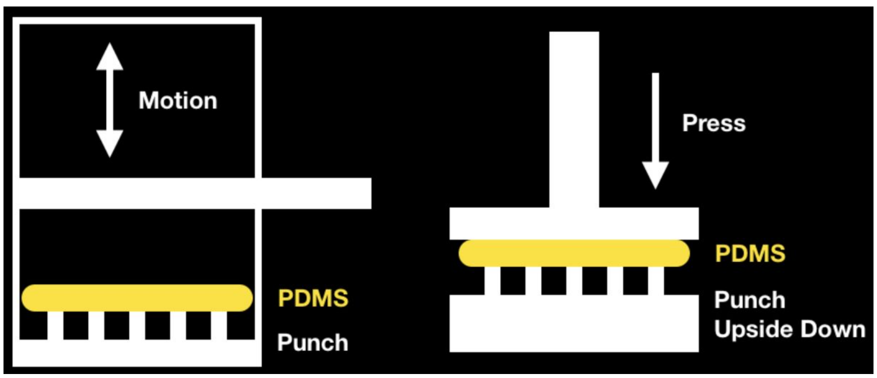


**Figure 4.** Concept #1: Open face hamburger. A press applies downward pressure on the PDMS, which is aligned on top of the punches, so that the PDMS is pushed into the punches and the ports are created.

This process would likely have issues with securing the PDMS to the punching fixture, potentially resulting in unwanted movement of the PDMS sample during the punching process which can lead to ports being punched in in the wrong locations.

The second design concept is that of the jaw, which consists of punches on a plate that is connected to a hinge. The punches come down at an angular motion to create the ports in the PDMS. This design is shown below in Figure 5, pg. 11.

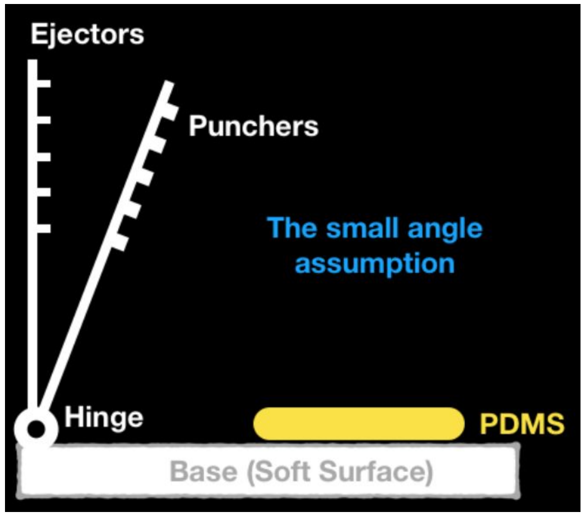


**Figure 5.** Concept #2: Jaws. A plate with the punch tips press-fit into is connected to a hinge attached to a rigid base. The punch plate comes down at an angle to create the ports in the aligned PDMS sample, with the excess material being ejected from a stationary ejector plate adjacent to the base.

When PDMS material is extracted, the excess material in the punch is removed by the ejectors. This design provides a high cycle time, but could also lead to poor cut quality due to the angular nature of the punching motion.

Our favored punching concept is that of the hamburger, shown below in Figure 6, pg. 12, which consists of multiple layers on top of one another.

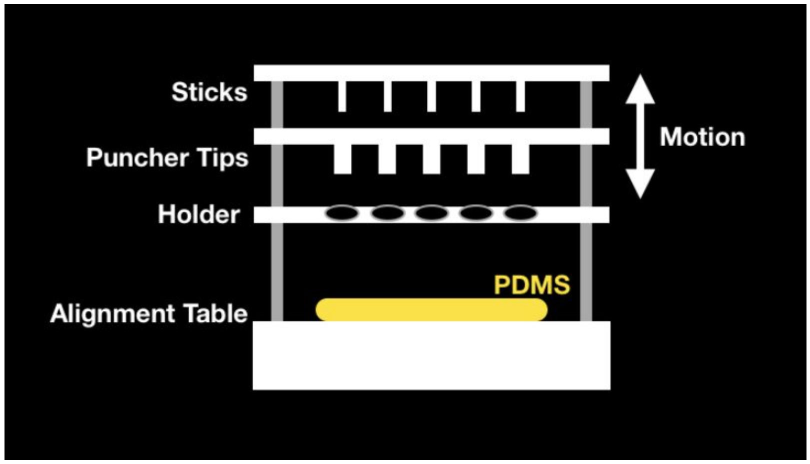


**Figure 6.** Concept #3: Hamburger. This design consists of multiple moving platforms. The PDMS rests on an alignment table that can be adjusted manually according to the port design. The puncher tips come down and create the ports in the PDMS, while the holder prevents the PDMS from coming off the table. The sticks then eject the extracted PDMS material from the punchers.

The PDMS sample is placed onto a fixed table, as shown, and the puncher tips then come down and punch the ports into the PDMS while the holder prevents the PDMS from moving during this punching process. Although this design provides good cycle time, the force required to punch 36 holes at a time using this design as well as the multiple moving parts associated with the design, were a concern. However, this design is both simple and robust.

Another punching device concept was that of creating a CNC punch mechanism. This setup is visualized below in Figure 7.

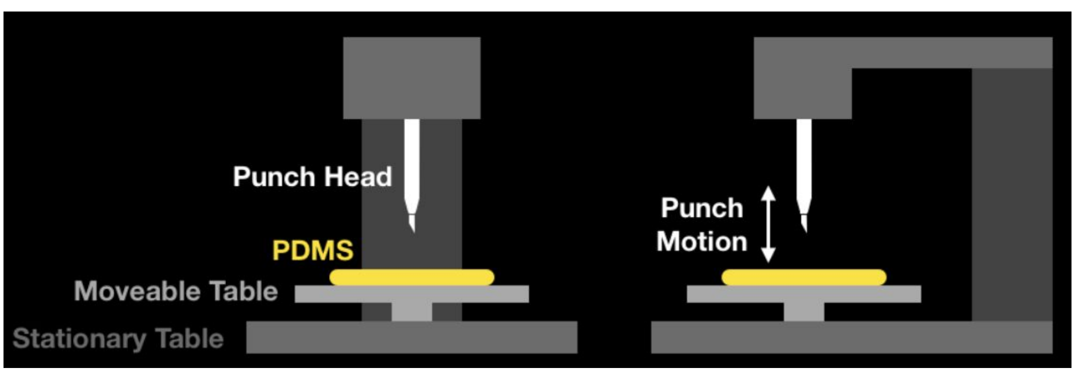


**Figure 7.** Concept #4: CNC. The PDMS sample is placed onto a moveable table that changes position based on computerized input from the user. The single punch head then punches the desired hole sizes in the required locations.

For the CNC design concept, a commercially bought biopsy punch would be placed into the device which would be able to locate holes based on user input. This allows for a high degree of reconfigurability. However, this design would also be difficult to implement since it relies heavily on computer control.

The final design concept is our "cavity" concept, shown below in Figure 8.

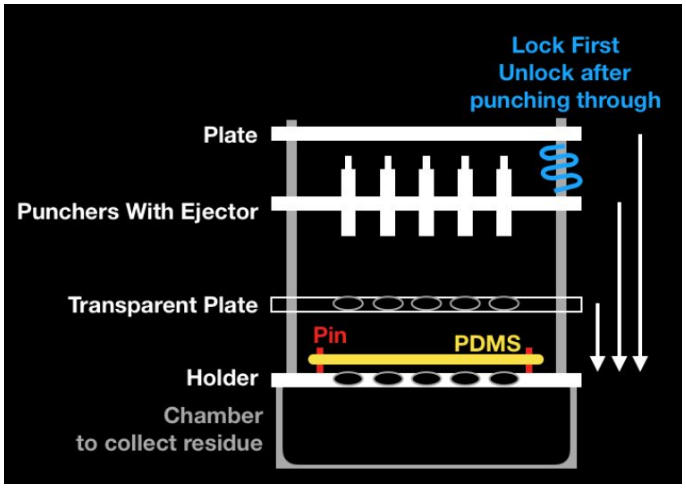


**Figure 8.** Concept #5: Cavity. This design is very similar to the hamburger design (Fig. 6, pg. 12), however, this design has a chamber below the PDMS to easily store extracted PDMS material. Additionally, this design uses commercially bought biopsy punches instead of separate steel punch tips.

In this design setup, the PDMS is placed onto the holder and the punches come down vertically and punch the ports through the material. The "punched" material would then be immediately ejected into a chamber below. This design allows for efficient material removal but the instability in the securement of the PDMS may lead to poor port quality.

**Alignment**

Our first concept for our alignment system is the laser alignment system, shown in Figure 9, pg. 14.

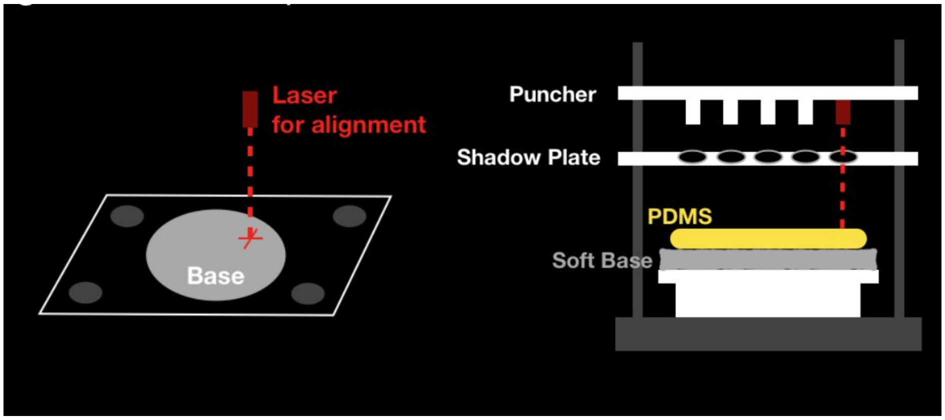


**Figure 9.** Concept #1: Laser. A laser is pointed directly downward from a rigid plate above the PDMS sample. The PDMS is aligned via an alignment marking on the PDMS itself.

The laser is positioned directly above the secured PDMS sample and projects a laser dot on each port location. The PDMS material is then positioned and aligned according to this projected pattern. This alignment method allows for high reconfigurability in puncher design as it can accommodate multiple different microfluidic channel designs. However, because the PDMS is clear and the laser resolution is not high, accurate alignment can be difficult.

The second alignment method is the groove for alignment, shown in Figure 10.

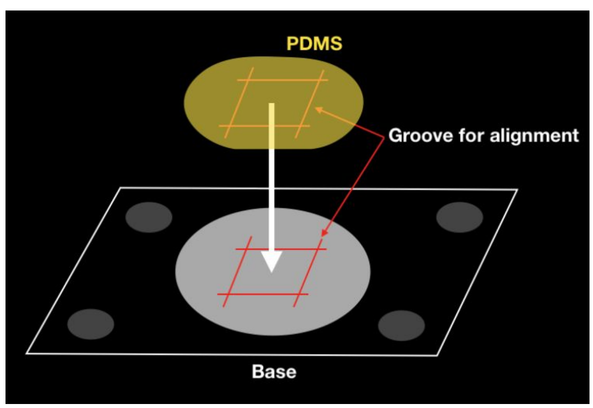


**Figure 10.** Concept #2: Groove. The PDMS material is made with grooves made during production. Rails on the base of the puncher then align the PDMS sample accordingly

The PDMS is placed and onto the base of the device and aligned via a groove pattern on the base itself, as shown in Figure 10. This allows for rapid placement and alignment of the PDMS. A drawback of this design, however, is that the grooves are very small and would be very difficult to manufacture. Not only this, but the silicon master wafer from which the PDMS samples are made from would need to be changed to allow for groove channels in the PDMS itself to be made, which would be costly for the client.

The third method for alignment is the moveable base, shown in Figure 11. This design is similar to the alignment method that is currently in use in the Integrated Biosystems and Biomechanics Laboratory.

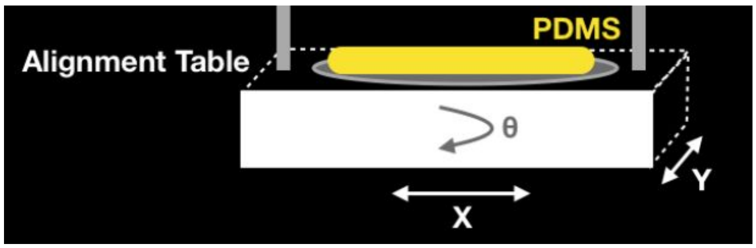


**Figure 11.** Concept #3: Moving Platform. The PDMS sample is placed onto a moveable x, y, theta stage, that allows for manual user alignment.

The PDMS sample is placed onto a moveable stage and secured to prevent unwanted movement in the PDMS sample. The table is then adjusted through manual user operation of dials that allow the table to rotate and move in the x- and y-axis shown. This manual positioning allows for accommodation of multiple different microfluidic design configurations. However, manual alignment can take a long time and commercially bought  alignment tables can be very expensive.

The final alignment method is via a series of pins located on the base of the punching device, shown in Figure 12, below.

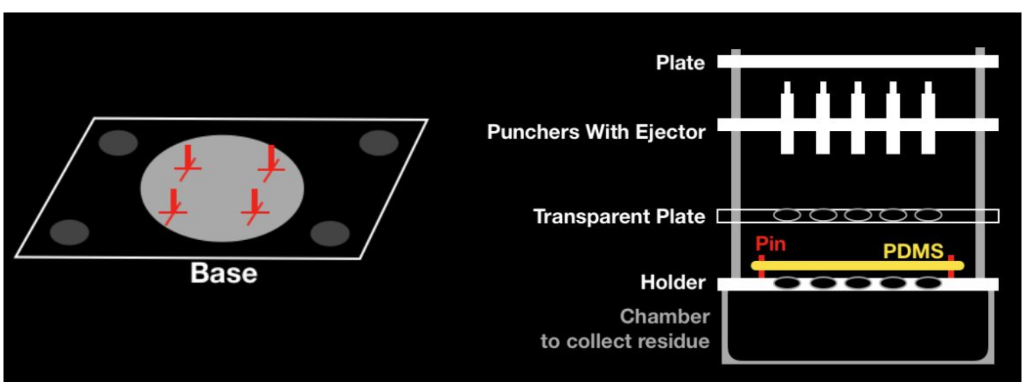


**Figure 12.** Concept #4: Pins. The PDMS is created with small slots and rigid pins on the base of the puncher to align the sample for accurate punching.

Four small holes are inscribed in the PDMS sample that allow for quick alignment using the pins in the punching device base. These pins are placed away from any of the microfluidic channels, allowing for multiple microfluidic design configurations to be used with this alignment method. Additionally, the pins are commercially available and are cheap, and implementation of these pins into the base is also very simple. However, this alignment method is very imprecise and can take the user some time to properly align the PDMS sample.

## CONCEPT EVALUATION AND SELECTION

To rate each design for both the punch system and the alignment system against one another, we created two decision matrices.  Each requirement, for both the punching system and the alignment system, were rated based on priority, with 1 being the worst and 5 being the best. The two design matrices were kept separated so that any of the alignment methods could be integrated with any of the punch systems. The first decision matrix is for the punch system, as shown in Figure 13, below.

| Punch System | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reconfigurability | Precise | cycle time | clean cut | securability | material removal | low cost | weight | table dimension | | Final Weight |
| Weight | 4 | 5 | 3 | 4 | 4 | 4 | 1 | 2 | 3 | | |
| | | | | | | | | | | | |
| CNC | 5 | 3 | 2 | 4 | 1 | 2 | 1 | 1 | 5 | | 87 |
| Hamburger | 4 | 4 | 4 | 5 | 5 | 4 | 3 | 3 | 5 | | 128 |
| Jaws | 4 | 1 | 4 | 1 | 2 | 3 | 3 | 4 | 3 | | 77 |
| open face hamburger | 4 | 2 | 4 | 5 | 1 | 4 | 3 | 3 | 5 | | 102 |
| Cavity | 4 | 3 | 4 | 3 | 5 | 5 | 3 | 3 | 5 | | 119 |
| 5 = good; 1 = bad | | | | | | | | | | | |

**Figure 13.** Decision matrix for punch system. The hamburger design is shown to be the optimal choice.

The winning system for the punching mechanism was that of the hamburger design, with a final weighted score of 128. This is the design that our team selected to be the final design concept.

The second decision matrix is for the alignment system (Fig. 14, pg. 17), which compares the laser, groove, moving platform, and pins alignment methods to one another.

| Alignment System | | | | | | |
|---|---|---|---|---|---|---|
| | Reconfigu rability | Precise | cycle time | low cost | | Final Weight |
| Weight | 3 | 5 | 4 | 1 | | |
| | | | | | | |
| Laser | 3 | 2 | 1 | 2 | | 25 |
| groove | 3 | 2 | 5 | 5 | | 44 |
| moving platform | 5 | 3 | 2 | 1 | | 39 |
| pins | 3 | 2 | 4 | 5 | | 40 |
| 5 = good; 1 = bad | | | | | | |

**Figure 14.** Decision matrix for alignment system. The groove alignment system is shown to be the optimal choice.

The highest scoring alignment system was that of the groove system, with a final weighted score of 44. However, although our team did preliminary testing to validate this design choice, we ultimately had to switch alignment systems due to the COVID-19 pandemic. Because we could no longer test, we decided to include the moving platform in our final design, instead, since we already had proof it works in Dr. Fu's lab.

## FINAL DESIGN SOLUTION

Through our concept selection process and the change in the resource availability due to the COVID-19 pandemic, we concluded that the hamburger concept with an alignment table is the best final design solution. The combined concept from ideation is in Figure 15, below, and described on Page 12 & 15.

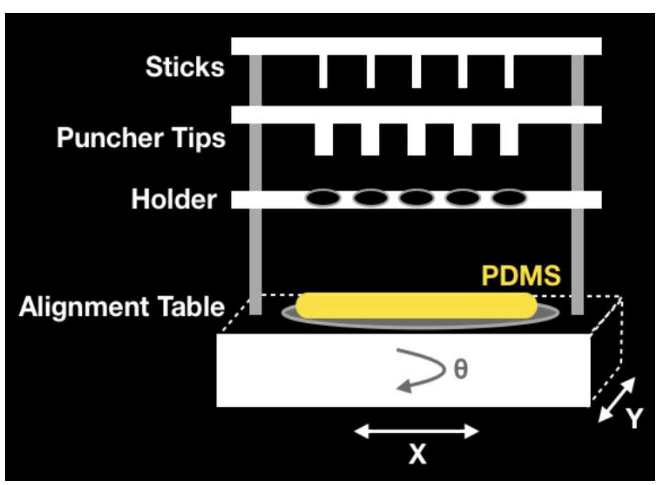


**Figure 15.** Combined design concept: Hamburger and moving platform for alignment.

The final design concept, shown as a CAD model in Figure 16, pg. 19, includes several key additions to the combined design concept. Among these is the inclusion of the pneumatic actuation system and a spring table force offloading system to protect the alignment table. The other key system included is the sliding plates of the 'hamburger.'

**Theory of Operation**

The first step in operating the puncher is aligning the PDMS to the puncher. The PDMS is placed on the spring table with a soft material such as a cutting mat or a stack of papers beneath. The shadow plate is then lowered to the PDMS and the micrometer handles are turned to align the markings on the PDMS to the markings on the shadow plate. Once the markings are aligned, the switch on the pneumatic system is flipped and the push plate/punch holder travels down and cuts through the material. Once the PDMS has been punched through, the switch is flipped and the push plate/punch holder retracts. Because the PDMS tends to stick to the punches, the PDMS and shadow plate will travel up as well. The dowel pins in the ejector plate will push the cut material from the punches when the push plate reaches the top. To remove the PDMS from the punches, the shadow plate would simply need to be pushed down and voila, there's a perfectly punched PDMS sample.

**Actuation System**

To move the plates containing the punchers up and down, we elected to use pneumatic cylinders. Pneumatic cylinders were chosen as a result of the large punch force required that is calculated in the *Engineering Analysis* section. The punch force of 3800 N meant that the lever we initially planned on using would be prohibitively large. The range of possible actuation methods was reduced based on decisions about punching time and complexity. The final design incorporates three pneumatic actuators each capable of producing 1400 N at 700 kPa input air pressure. Since the building air line pressure in GGBL averages about 110 psi, there will be more than enough force available to punch through the PDMS. The pneumatic actuators are mounted by threaded holders that match the 1-¼"-12 mounting threading on the pneumatic cylinders. There are two flow control devices: a double pole double throw switch and volume flow rate control valve. Flipping the switch will cause the pneumatic cylinder to travel up or down. Adjusting the volume flow rate control valve will adjust the speed at which the cylinders actuate. This prevents the pneumatic cylinders from slamming up or down into the plates during actuation.

**Spring Table Offloading System**

In the technical specifications for the XY Theta Stage, it says that the load capacity of the stage is 6.61 lbf (29.4 N). This means that the stage would not be able to support the entire punching force, so to offload the force of the punch, a spring table was introduced. As the punches load the PDMS, the force is transmitted into the springs which compress. After a set compression distance based on the effective spring constant with the stage load capacity and calculated in the

*Engineering Analysis* section, the spring table on which the PDMS rests would contact another plate supported from the base plate to offload the additional punching force. A section view of this system can be seen in Figure 18, pg. 20.

**Figure 16.** Final design concept: CAD model.

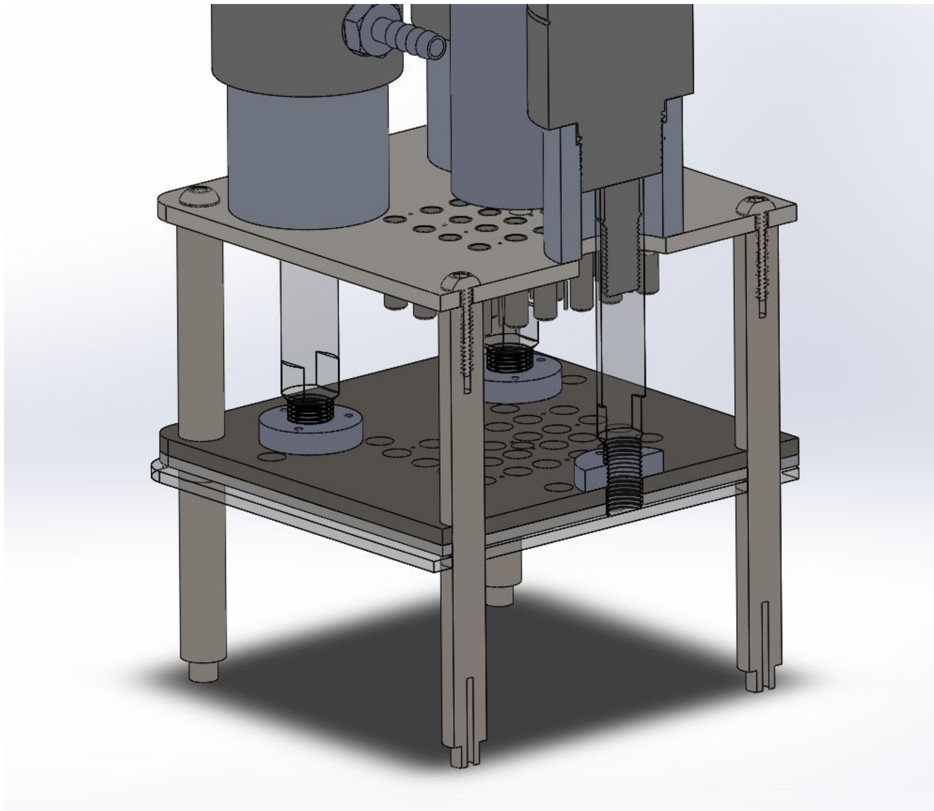

**Figure 17.** A partial section view of the upper portion of the assembly to show pneumatic system

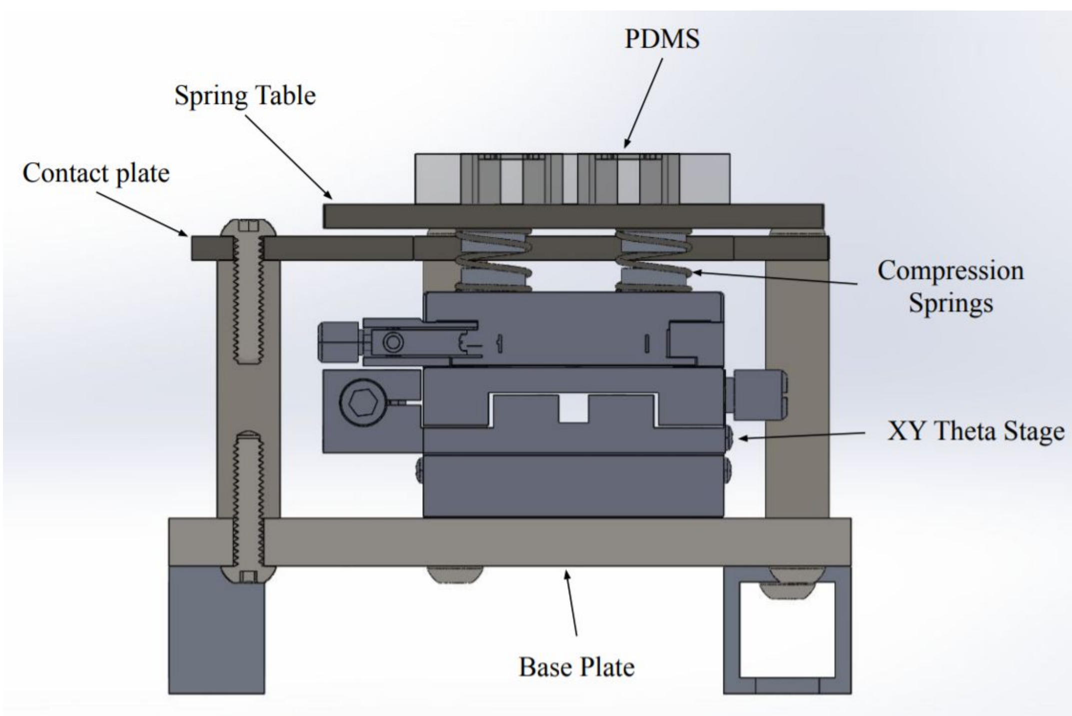


**Figure 18.** Section view showing the spring table offloading system

**Hamburger System**
The hamburger system is a reference to the layered plates that make up the design. The final design has five different plates connected by guide rails: the base plate, the shadow plate, the punch holder, the push plate, and the ejector plate. These plates are indicated in Figure 19, below.

The base plate supports the entire system. The guide rails on which the plates slide are pressed into the base plate and held in place by screws. The alignment table and spring table offloading system are also grounded to the base plate.

The shadow plate is a clear acrylic plate that is cut such that the punching tips can pass through it. The shadow plate should be engraved with alignment markings such that the markings on the shadow plate match new alignment markings on the PDMS. The PDMS can then be aligned using the alignment table so that the alignment markings on the PDMS align with the shadow plate. The shadow plate slides along the guide rails so that by aligning the PDMS to the shadow plate, you align the PDMS to the punchers as well.

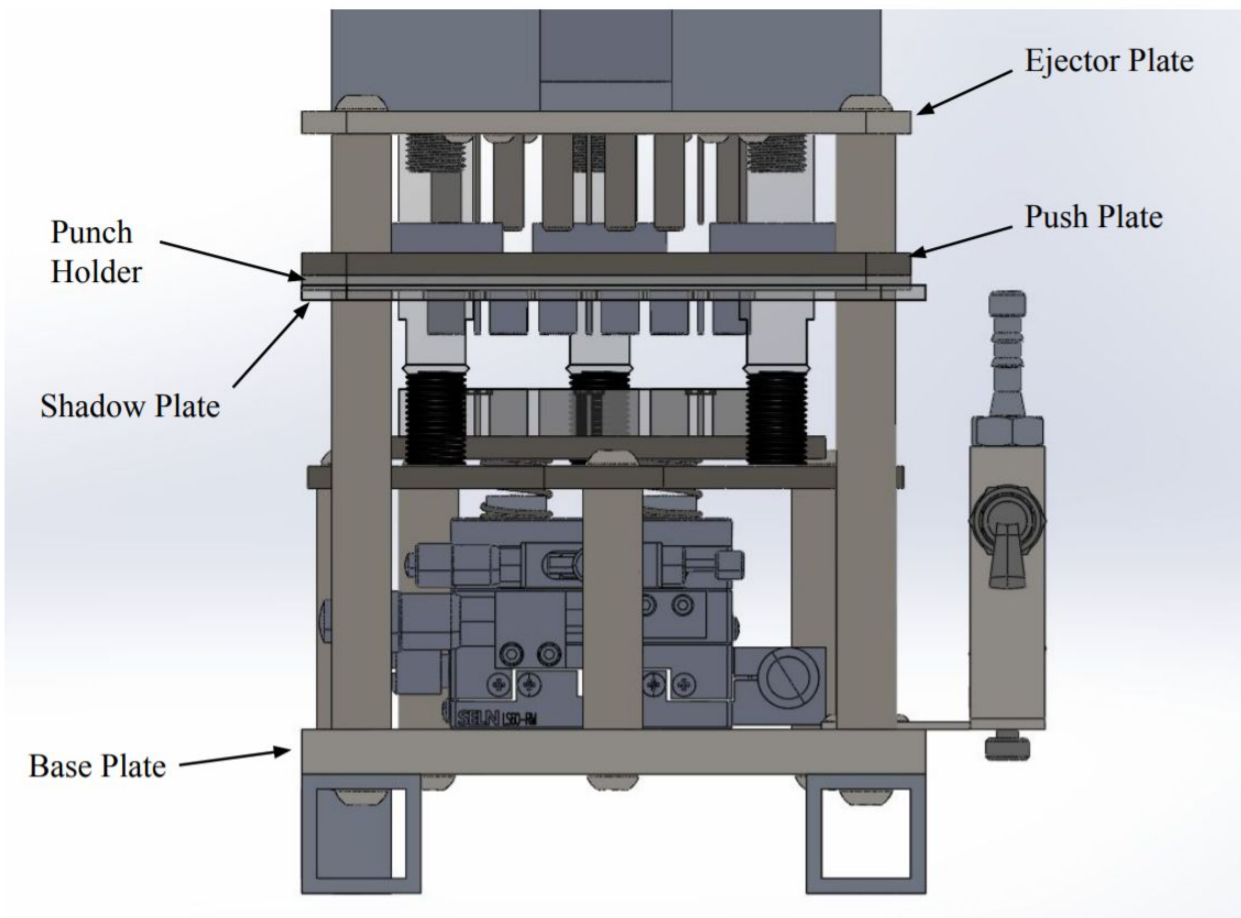

**Figure 19.** Front view of the final CAD model annotated with the names of the plates in the hamburger system.

The punch holder and push plate slide together along the rail. The punch holder is a high precision 3D printed SLA part that is designed to constrain the puncher tips radially. The puncher tips will be bonded into the 3D print. The push plate is a steel plate that transfers the punch force to the puncher tips. The pneumatic actuators are connected to the push plate through the input washer. The push plate has a hole pattern matching the punch tips so that the ejector pins can pass through to clear the punch of cut material.

The ejector plate has several purposes. It bolts directly to the top of the guide rails to constraint their movement. It also has dowel pins pushed into it that match the hole pattern of the punch tip so that the pins push out the cut material. The pneumatic cylinders are also mounted to the ejector plate.

The engineering drawings and manufacturing plans for each machinable component of the punching device can be found in *Appendices A* and *B*, respectively. Additionally, the bill of materials for the device can be found in *Appendix C*.

## ENGINEERING ANALYSIS

To validate the success of our engineering design, analysis was performed on several of its systems. These include the force required to punch ports through the PDMS, the capability of the springs in the punching device to withstand load, and bolt and bearing calculations.

### Punch Force

To analyze the required force for punching the ports into the PDMS, a Chatillon Load Cell was utilized. The load cell was placed on top of an 8 mm puncher and was used to punch 3 ports into a PDMS sample. This setup is shown below in Figure 20, pg. 23. Of these three trials, the average force was calculated to be about 10.4 kg to punch one port. For a sample of thirty-six 8 mm ports, this equates to a required force of 3800 N, defining the maximum necessary load force. The load cell was also used to find the force to remove the punch from the PDMS, which averaged to be 0.4 kg for each port.

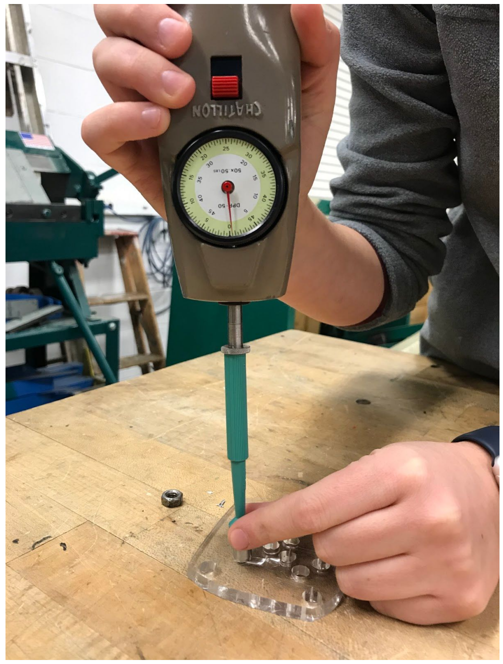

**Figure 20.** Force gauge used to test force required to punch port using 8mm puncher tip.

Though the original intent was to use a lever system in the design, the force requirement was much higher than our initial estimates, and the lever became infeasible as a result. Designs involving motors and a gear transmission were discussed, as well as using hydraulics, but to uphold the main priorities of our sponsors, convenience and reliability, we turned to pneumatics. Pneumatic cylinder considerations included bore diameter, stroke length, and acting direction as these parameters all affect the power factor of the cylinder. As is detailed in the *Final Design Solution* section of this report, our final design includes three, double-acting, 2 inch bore diameter cylinders, each with a 2.5 in stroke length and a power factor of 3.1 lb/psi.

**Alignment**

Before the COVID-19 pandemic, our team developed a test plan for comparing the alignment methods described in the *Concept Generation* section of this report. The plan was to machine a plate with thin, raised, features to test groove alignment, and dowels to test pin alignment. The engineering drawing and manufacturing plan for this plate can be found in *Appendix A.15* and *Appendix B.15*, respectively. The dowels were purchased and comprise the only expenditures made during this project.

Because we were never able to machine the testing plate, we chose an alignment system that is already used on a different apparatus in the Integrated Biosystems and Biomechanics Laboratory.

This system uses a high powered electronic microscope and an x, y, θ stage to align two layers of PDMS with one another. In our system, the microscope and stage is used to align an origin marking on the PDMS to a matching marking on the shadow plate (more details can be found in the *Final Design Solution* section of this report). Choosing this alignment system guarantees successful alignment when performed by a trained lab technician.

**Punch Tip**

The punch tip was another system impinged by the COVID-19 pandemic, as we had no way of verifying success through physical testing. Currently, lab technicians in the Integrated Biosystems and Biomechanics Laboratory use disposable biopsy punches which were designed for one time use retrieval of tissue samples in the medical field. An example of the punches used can be seen in Figure 3, pg. 7, of this report. The punches generally consist of a stainless steel tip situated in a plastic housing, sometimes with or without an extractor button on the top of the housing. Depending on the brand of puncher, the plastic housing is subject to change shape. Therefore, we decided that we'd integrate just the stainless steel tips into the design. The stainless steel tips are specially designed to taper at the end, which made purchasing raw material in the form of thin tubing less plausible. For our final design solution, we assumed that we'd be able to cannibalize the disposable punches, harvesting the specialized tips, and fixing those into the reconfigurable punch holder.

The punch holder is designed to be 3D-printed using an SLA 3D printer. Printing the punch holder, as well as making the device reconfigurable, allows us to use uncured resin and a UV light to glue the tips into the punch holder. This would be the recommended method after attempting a simple press-fit, which we could not test due to the COVID-19 pandemic.

**Spring Table**

As is well detailed in the *Final Design Solution* section of this report, a spring table was necessary to offload the force from the alignment stage, as its maximum load is 29.4 N. The compression distance was calculated using the chosen spring's rate, $k_s$, at 4.06 kN/m. The effective spring rate, $k_{eff}$, was calculated by multiplying the spring's rate times the number of springs used, which can be seen in Equation 1, below.

$$k_{eff} = 4 * k_s = 16.24 \text{ kN/m} \quad [1]$$

The load limit of the alignment stage was then divided by the effective spring rate of the system to find the maximum compression distance of the springs, as can be seen below in Equation 2.

$$\frac{29.4N}{16.24\ kN/m} = .001810\ m = 1.81\ mm \quad [2]$$

Therefore, there must be less than 1.81 mm between the spring table and the contact table. With the inclusion of a safety factor, we designed the distance to be 1.59 mm (1/16 in).

**Future Analysis**
As was mentioned throughout the section, there is some analysis that would be done if we were able to make a physical artifact. These include testing the different alignment systems as planned, ensuring success when cannibalizing the stainless steel tips from the disposable punchers, and using a load to cell to double check the math on the spring table as to avoid damaging the alignment stage.

## RISK ASSESSMENT

As discussed previously in the *Engineering Analysis* section of this report, the punch force required to punch 36 holes per punch, a top priority requirement for the device, is as high as 3800 N. To achieve this force, as described in the *Final Design Solution* section of this report, we make use of three pneumatic cylinders, each of which contributing 1400 N. This force serves as the highest safety threat to the user, as it is capable of causing serious injury. To mitigate this catastrophic risk, along with limiting usage to trained lab staff, we recommend installing a switch guard over the actuation switch and adding a mesh wire cage with a small access door around the build. With this safety risk mitigated, there are no other pressing risks associated with the device.

Because it has no dependency on any electronic components, there are no electricity safety warnings. Also, the artifact was designed to specification, and weighs in under 9 kg, raising no safety risk for a user moving the device, as it falls under the NIOSH standard that is detailed in the *Engineering Standards* section in this report.

Because this device relies on shop air, there are potential safety risks involved, but the Integrated Biosystems and Biomechanics Laboratory already takes on any risk associated with powering pneumatics using shop air.

Furthermore, we have also prepared an FMEA report for our punching device, shown in Figure 21, pg. 26. The calculated RPN values are relatively low, which indicates that we have a fairly sound design. However, physical testing is required for product verification.

## FMEA

Process/Product Name: Reconfigurable Puncher

Responsible: ME450 Team 12

| Process Step/Input | Potential Failure Mode | Potential Failure Effects | SEVERITY (1 - 10) | Potential Causes | OCCURRENCE (1 - 10) | Current Controls | DETECTION (1 - 10) | RPN |
|---|---|---|---|---|---|---|---|---|
| What is the process step, change or feature under investigation? | In what ways could the step, change or feature go wrong? | What is the impact on the customer if this failure is not prevented or corrected? | | What causes the step, change or feature to go wrong? (how could it occur?) | | What controls exist that either prevent or detect the failure? | | |
| Push Plate | Cannot withstand punch force | Puncher not effective | 9 | poor material | 2 | Analysis to ensure stability | 1 | 18 |
| Base Plate | Not sturdy enough | poor port quality | 8 | poor material | 2 | Analysis to ensure stability | 1 | 16 |
| Switch Mount | Not sturdy enough | switch not held properly | 4 | poor manufacturing | 2 | Analysis to ensure stability | 2 | 16 |
| Ejector Plate | Loose fittings and misalignment | Extracted material can't be removed | 6 | Poor manufacturing | 2 | Test the finished part to make sure pins don't loosen during operation | 2 | 24 |
| Guide Rail | Misalignment | Plates can't move freely along rails | 8 | Poor material and poor manufacuring | 2 | Machine the part according to specifications | 1 | 16 |
| Spring Table | Can't withstand punch force | Plate not effective | 8 | Poor material | 2 | Analysis to ensure stability | 1 | 16 |
| Spring Holder | Loose fittings | Spring won't sit securely within spring holder | 7 | Poor manufacturing | 2 | Machine the part according to specifications | 1 | 14 |
| Punch Holder | Loose fittings | Puncher tip cannot be held upright | 9 | Poor material and poor manufacuring | 4 | Increase precision of 3D printing | 2 | 72 |
| Contact Plate | Cannot withstand punch force | Puncher not effective | 9 | Poor material | 1 | Analysis to ensure stability; increase size of holder | 1 | 9 |
| Pneumatic Holder | Cannot withstand punch force | Puncher not effective | 8 | Poor material | 1 | Increase contact surface area | 2 | 16 |
| Input Washer | Loose fitting | Puncher not effective | 8 | Poor material | 1 | Machine part according to | 1 | 8 |
| Risers | Not sturdy enough | Puncher not effective | 8 | Poor manufacturing | 1 | Machine part according to specifications | 1 | 8 |
| Table Support | Cannot withstand punch force | Alignment stage damage | 8 | Poor material | 1 | Machine part according to specifications | 1 | 8 |
| Shadow Plate | Misalignment | Puncher not effective | 8 | Low resolution laser cutting | 4 | Increase resolution of laser cutter | 1 | 32 |

**Figure 21.** FMEA report for punching device.

From Figure 21, the most at risk components of the device are the shadow plate, punch holder, ejector plate, and push plate, as these systems are critical for the creation of the ports in the microfluidic device, they must be able to align properly, handle the punch force, and be machined correctly.

## VALIDATION PLANS

As no physical prototype was constructed for this project, validation and verification for this project are limited. The requirements, with their respective validation strategies, are listed in Table 3, below, along with "Pass" or "NTC (Not Testable due to COVID-19)".

**Table 3:** Validation plans and results. For each engineering specification, a plan is developed and tested to validate that each user requirement is met for the device.

| User Requirements | Validation Plans | Results |
|---|---|---|
| Reconfigurable | Print an array to accommodate 1mm, 1.2 mm, 1.5 mm, 2 mm, 2.5 mm, 3 mm, 3.5 mm, 4 mm, 5 mm, 6 mm, 7 mm, and 8 mm punch tips | Pass |
| | Attach x36 8 mm punches within a 10 cm x 10 cm area | |
| Precise | Achieve ⌀500 µm positional tolerance while aligning using electronic microscope | Pass |
| Improved cycle time from current 20-30 minutes | Punch 36 ports in <5 minutes | NTC |
| Reliability | Calculated component life cycle calculations are greater or equal to 1,040 cycles | NTC |
| | BOM includes only commercially available and/or machinable by a mechanical engineering undergraduate student parts | |
| Clean cut all the way through PDMS | 1 cm of PDMS cut through with no destruction of the microfluidic channels; fluid is inserted into ports and verified to fill the channels | NTC |
| Create fixture for devices | PDMS sample is securely held while punched to prevent movement | NTC |
| Material remover | Cut-out part is removed from the original material without user effort | Pass |
| Low cost | <$1,000 total spent to manufacture artifact | Pass |
| Weight | Weigh device on a scale (to be <22.7 kg) | Pass |
| Table dimensions | Measure outer dimensions of artifact (to be <0.2 m x 0.2 m x 0.3 m) | Pass |

As can be observed in Table 3, many requirements were non-testable due to the quarantine in response to the COVID-19 pandemic, and therefore no conclusion on validation can be made. However, some passing requirements, such as material remover and reconfigurability, are passed as they are addressed during design consideration. They are very likely to pass based on the assumption that the parts are machined to the design specifications.

The precision requirement is a tentative pass, as our alignment method, which is the alignment table, is very similar to that of a machine that's already used in the Integrated Biosystems and

Biomechanics Laboratory, where high precision is required to align two PDMS layers. By directly purchasing the alignment system, the precision requirement is able to be met. The validation plan also offers the testing method, if the device is manufactured in the future, by measuring against a precise measuring device, such as a millimeter ruler.

The cost requirement was passed based on the Bill of Materials (*Appendix C*) and estimated prices, which totaled to <$900, about $100 under budget, shown in.

The weight and table dimension requirements were checked against the CAD, as all parts were detailed with material type and exact sizes. With the material weights function on SolidWorks, we were able to verify the weight as less than 8 kg and that the dimensions of the device were within 0.2 m x 0.2 m x 0.3 m.

## DISCUSSION AND RECOMMENDATIONS

Overall, we have created an effective and efficient design for a rapid punching system. The pneumatic aspect of the puncher will allow for minimum user input and is more ergonomic than a lever. Our "hamburger" base design, in which the PDMS sample is placed onto a fixed table and the puncher tips then come down and punch the ports into the PDMS while the holder prevents the PDMS from moving during this punching process, is our chosen final design for punching. This helps to ensure a clean, reliable, and repeatable punch process. As for alignment, the decision to use the moving platform is sound in that it has already been used by Dr. Fu's lab, which helps validate its success. The moving platform allows for manual positioning which will help accommodate multiple different microfluidic design configurations.

In all, we have created an efficient design which is very user friendly. However, a future consideration would be the reconfigurability aspect of our design since we chose to create our push plate from a metal plate, which requires machining, as opposed to a 3D printed medium. However, using metal opposed to a 3D printed medium was necessary for our particular design setup to ensure that the structure of the punching mechanism could withstand the forces applied to it. Another future consideration for our punching device design is the inclusion of a microscope camera with a zoom function to help further align the punching system. This would be used in conjunction with the moving platform to help ensure the accuracy of alignment.

## ETHICS AND PROFESSIONAL RESPONSIBILITY

The consideration of ethics and professional responsibility was of utmost importance in our engineering design. Since our puncher is to be used for critical stem cell research, we created our punching device to be reliable and safe. The National Society of Professional Engineer's code of ethics was kept in mind throughout our design process and in doing so we did not face any ethical dilemmas.

Sustainability was considered and designed into our project with the guidance of Professor Steven Skerlos of the University of Michigan and the University's Center for Socially Engaged Design. An assessment of sustainability can be found in the following section.

## SUSTAINABLE DESIGN ASSESSMENT

As mentioned in the *Ethics and Professional Responsibility* section of this report, in order to uphold our professional responsibility as engineers, we considered and assessed the sustainability of our design.

There are four necessary conditions that must be met favorably in order to designate a design as sustainable [8]. Addressing the first question, "does the system make significant progress toward an unmet and important environmental or social challenge?", our design progresses high-throughput manufacturing of a device that does meet an important social challenge, which in this case is stem cell research. Addressing the second question, "is there potential for the system to lead to undesirable consequences in its lifecycle that overshadow the environmental/social benefits?", our design has very little use-phase impact, as it only relies on pre-existing infrastructure in the Integrated Systems and Biomechanics Laboratory in which it will be installed. More specifically, it requires hook-up to shop air, as previously described in the *Final Design Solution* section. As for the production and end-of-life phase impacts, an eco-audit report was done and the details can be found below. Addressing the third question, "is the system likely to be adopted and self-sustaining in the market?", our design solves a direct need, ensuring adoption. Also, as this is currently a one-off artifact, and was designed as such, we did not take the market into account during design. With that, if multiple devices were manufactured, the impact would still remain low. Finally, addressing the fourth question, "is the system so likely to succeed economically that planetary or social systems will be worse off?", our device simply does not have a large enough negative planetary impact to make the Earth worse off for having it, and only positively impacts social systems.

We have not included a full eco-audit in this report, but using estimated material weights from the SolidWorks file, and data from Michael Ashby's Materials and the Environment [9], we were able to estimate a total global warming potential, or GWP, of about 30 kg $CO_2$ eq/kg and energy contribution of about 470 MJ/kg during the material processing, manufacturing, and end of life phases of this artifact.

With this data, and after meeting the four conditions of sustainable design, we conclude that this project is sustainable.

## ENGINEERING STANDARDS

Our team did not design our device to meet any specific engineering standards as our project is for a very specialized lab purpose. However, we did follow the NIOSH recommendation for the maximum weight our punching device could be to ensure its portability. Furthermore, we utilized ASME Y14 dimensioning and ANSI B4.1-1967(R2009) fit standards in the CAD portion of our design. Utilizing these standards ensures that the punching device can be accurately and reliably manufactured and assembled.

## CONCLUSION

In conclusion, the design problem is to reduce the microfluidic device production time by developing a solution to decrease the time it takes to punch ports into the device via the current punching method. After compiling research and benchmarks from relevant information sources and outlining our requirements and specifications, we have generated a few possible design concepts for punching and alignment. During the concept generation phase, we visited the Integrated Biosystems and Biomechanics Laboratory and observed the work done by Dr. Zheng to gain a better understanding of the current punching method and ways in which it can be improved. After a few meetings with our sponsors, we finalized the engineering specifications and decided on the final design solution, which is able to meet all the user requirements. Due to COVID-19, we did not get into manufacturing and validation phases, but we have presented our engineering drawings, manufacturing plans, and validation plans in this report. In addition, we focused more on ethics and sustainability for the design. We have followed the National Society of Professional Engineer's code of ethics and our design has been accessed to meet the four conditions in the guidance of Professor Steven Skerlos of the University of Michigan and the University's Center for Socially Engaged Design. In the end, we will deliver a full manufacturable package to our sponsor and an ME undergraduate student should be able to build up and test the device following instructions in the package.

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## AUTHOR BIOS

**Dingkun Guo**
Hometown: Chengdu, China
Mechanical Engineering motivation: Interested in mechanics and moving parts
Plans for after graduation: Studying robotics in graduate school
Fun Facts: Although my grandparents' home is very close to the protection area of pandas, I have only seen real pandas once.

**Maggie Kohler**
Hometown: Farmington, MI
Mechanical Engineering motivation: Consumer product design development
Plans for after graduation: Internship position as a mechanical engineering intern at Formlabs in Boston, MA
Fun Facts: I like to boat, drive, cook, and travel!

**Sarah Sober**
Hometown: Dexter, Michigan.
Mechanical Engineering motivation: I'm a big fan of the show "How It's Made"
Plans for after graduation: Full-time position as a rocket engine manufacturing engineer at Blue Origin in Seattle.
Fun Facts: I met Drew Feustel who was the commander of the ISS during expedition 56.

**David Stanton**
Hometown: Barrington, IL
Mechanical Engineering motivation: To create something that will have an impact on the world
Plans for after graduation: SUGS Master's program
Fun Facts: I'm difficult to find on the internet and that's because there are four members of my family named David Stanton

**Ian Tackett**
Hometown: Ann Arbor, Michigan
Mechanical Engineering motivation: I enjoy science, design, and hands-on work
Plans for after graduation: Work in the aerospace or healthcare industry
Fun Facts: I love mountain biking and biking in general

# APPENDICES

## Appendix A - Engineering Drawings

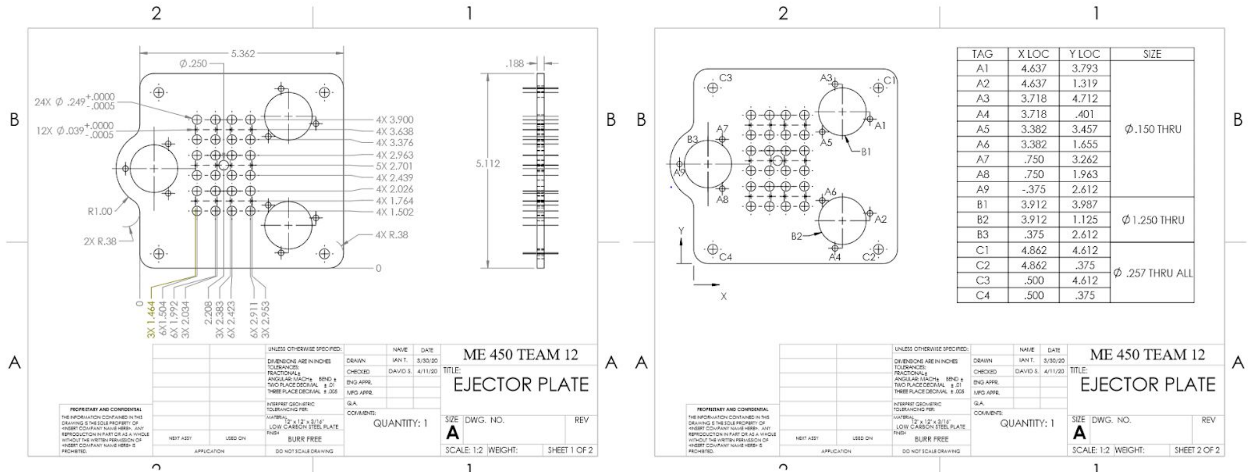


**Figure A.1.** Ejector plate engineering drawing.

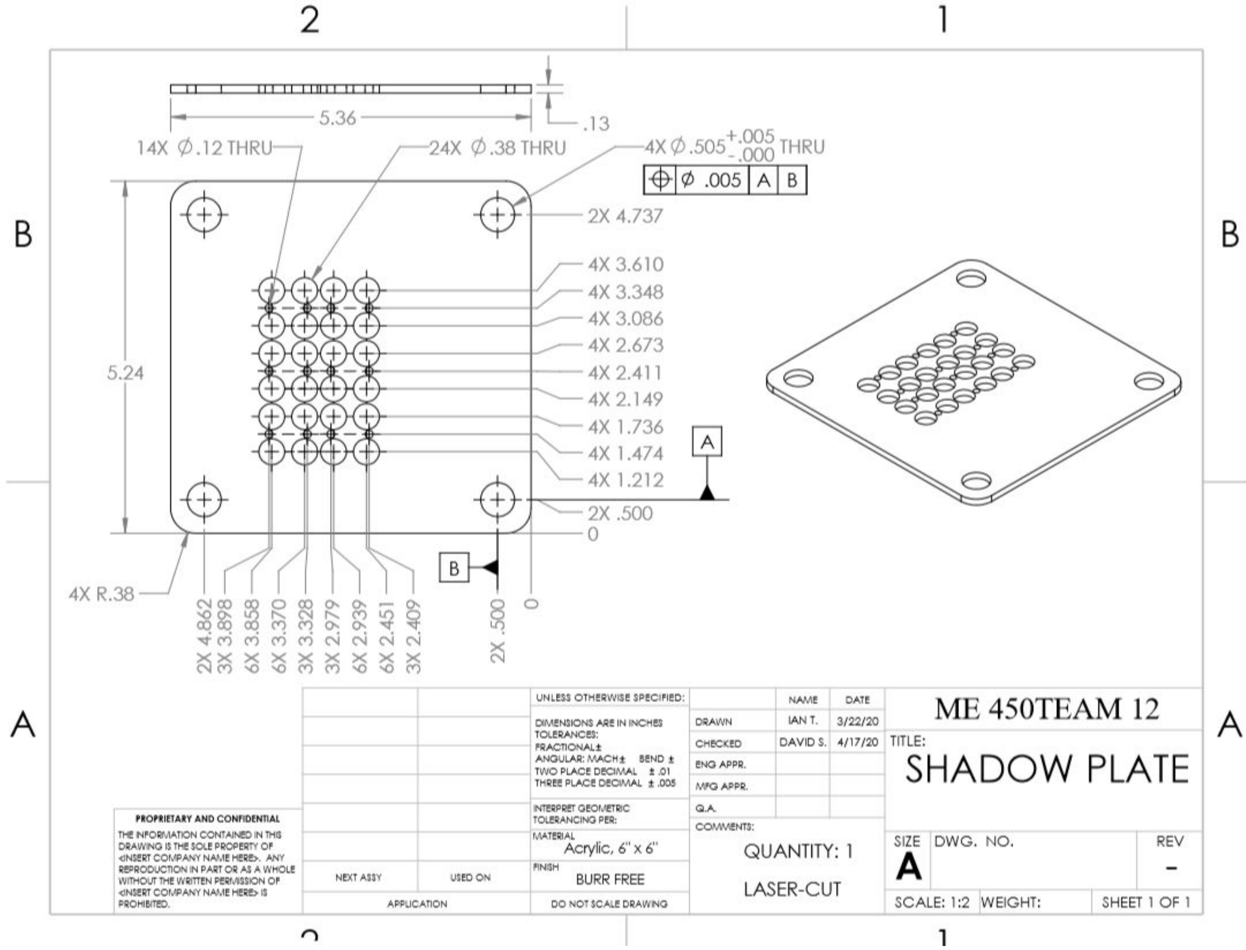


**Figure A.2.** Shadow plate engineering drawing.

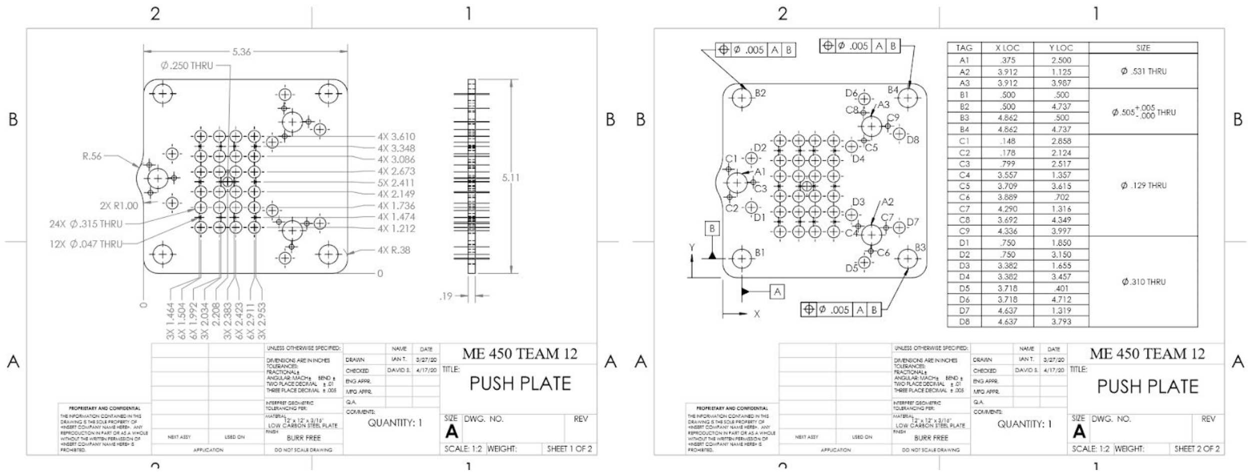

**Figure A.3.** Push plate engineering drawing.

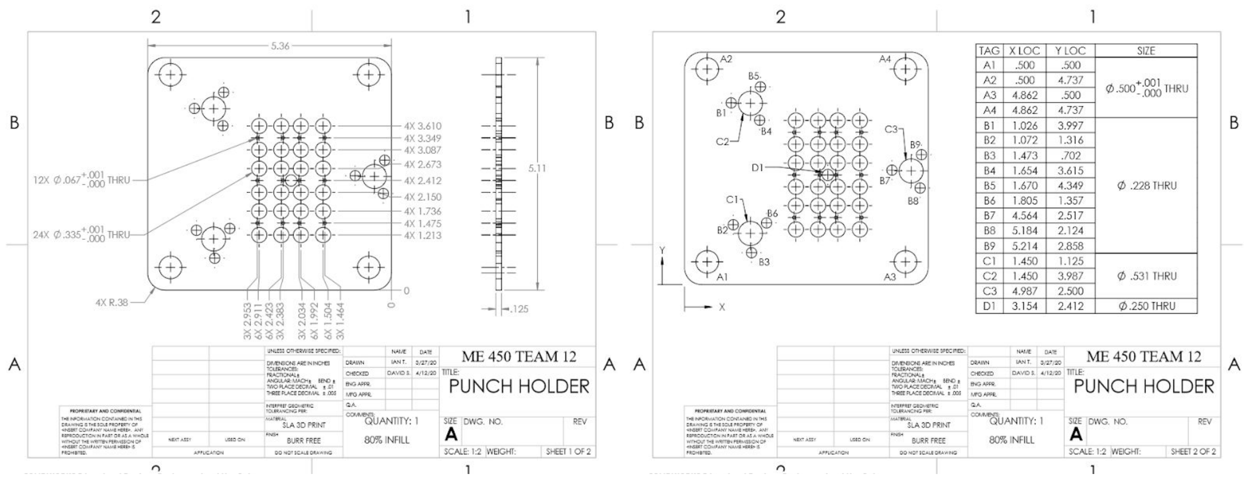


**Figure A.4.** Punch holder engineering drawing.

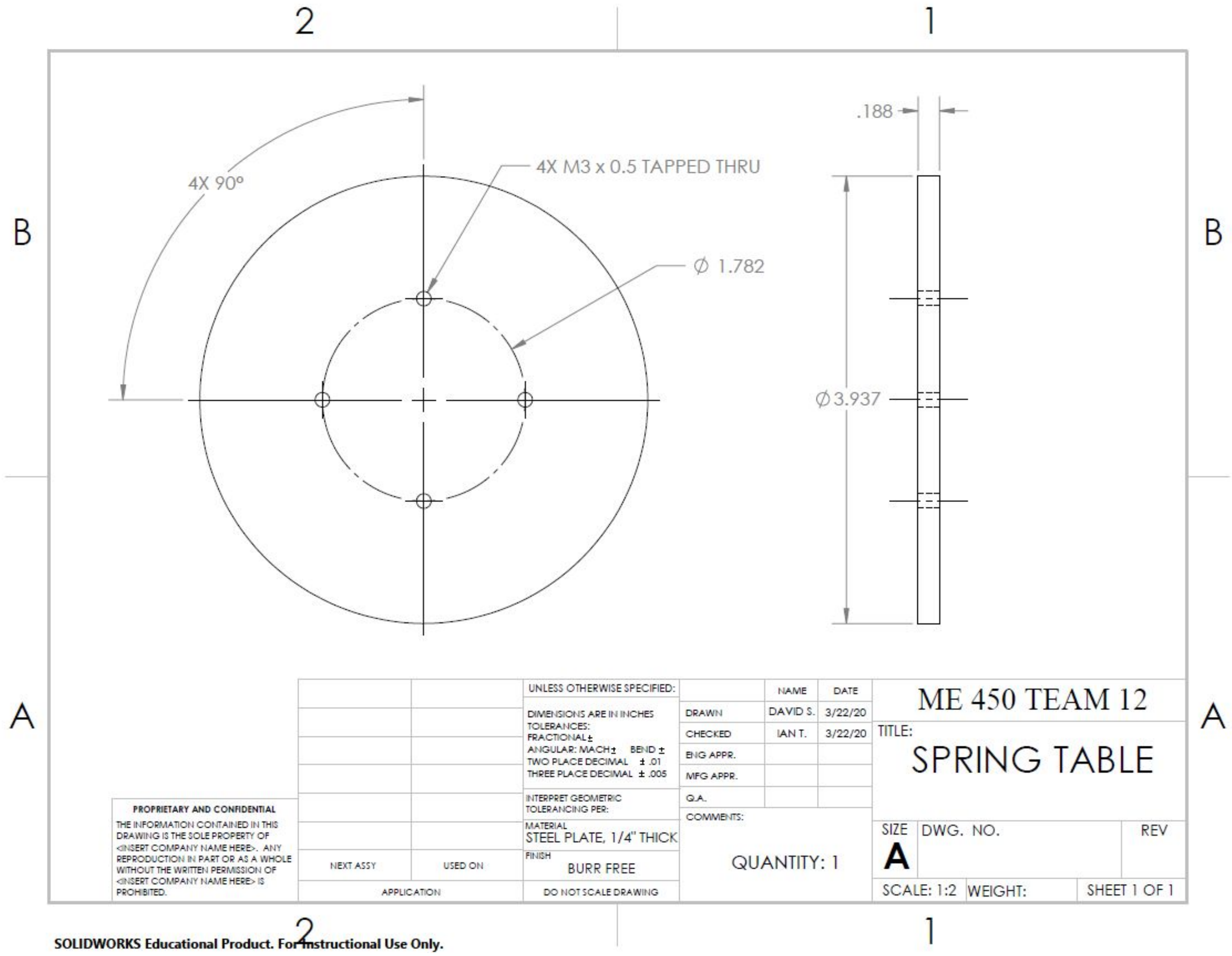


**Figure A.5.** Spring table engineering drawing.

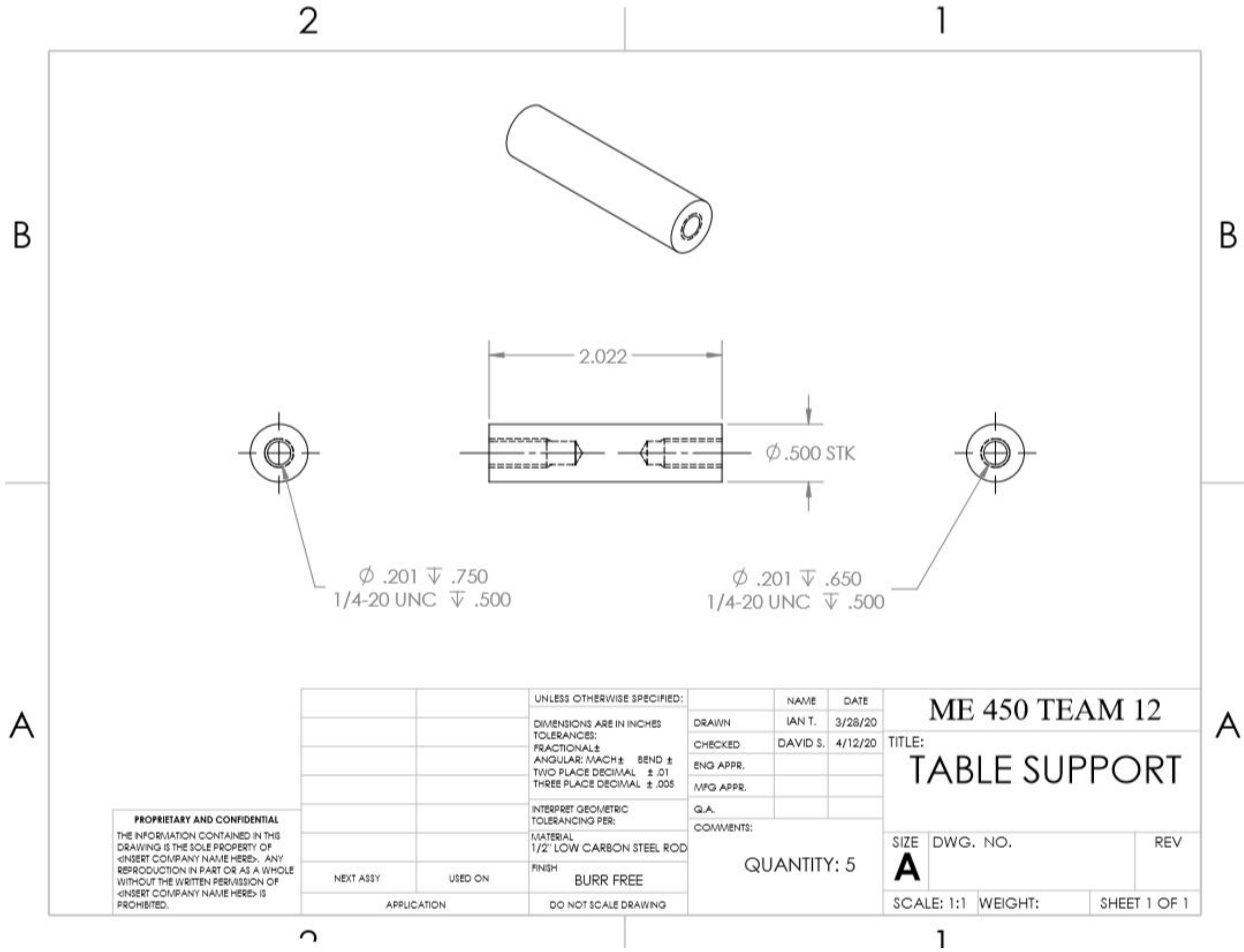


**Figure A.6.** Table support engineering drawing.

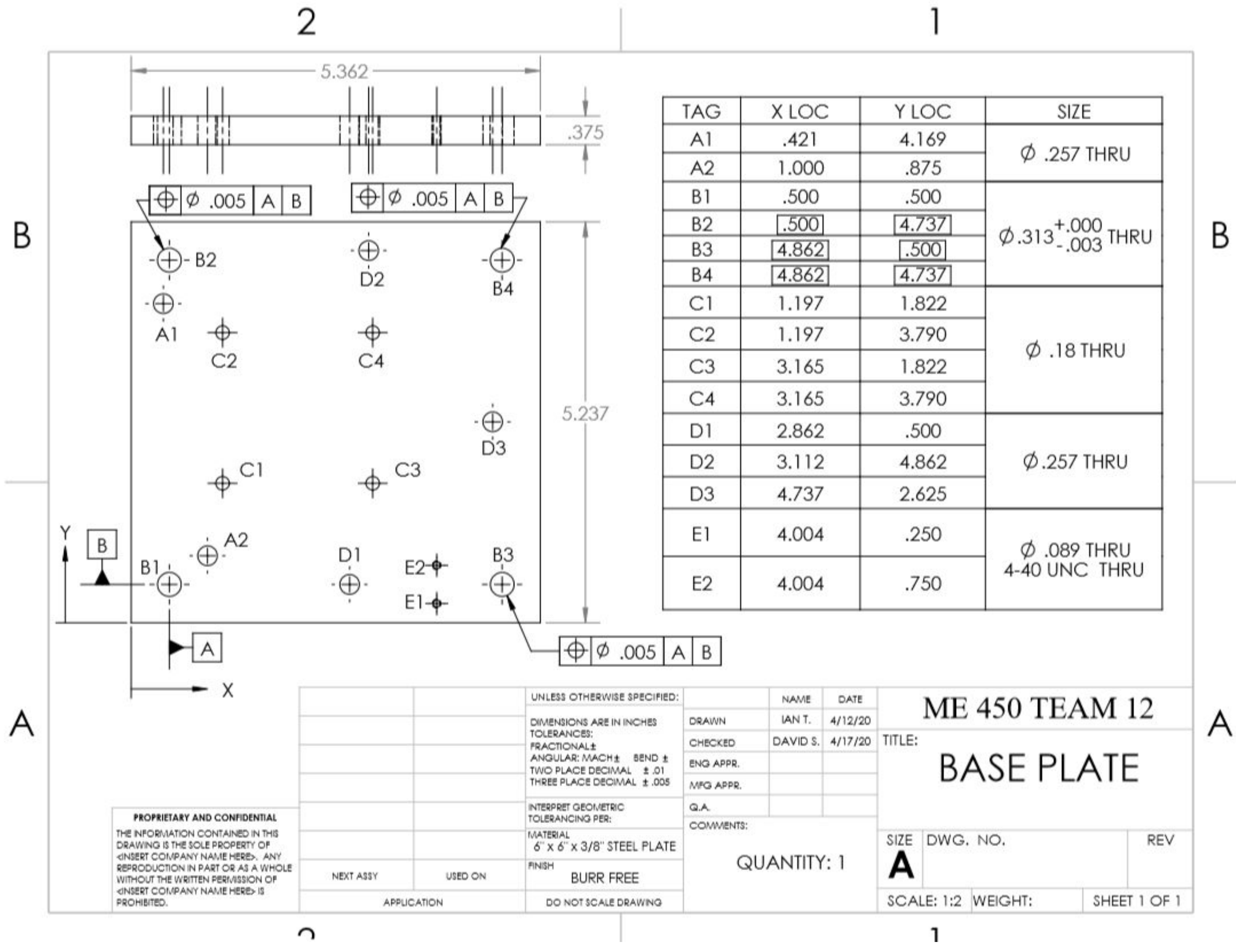


**Figure A.7.** Base plate engineering drawing.

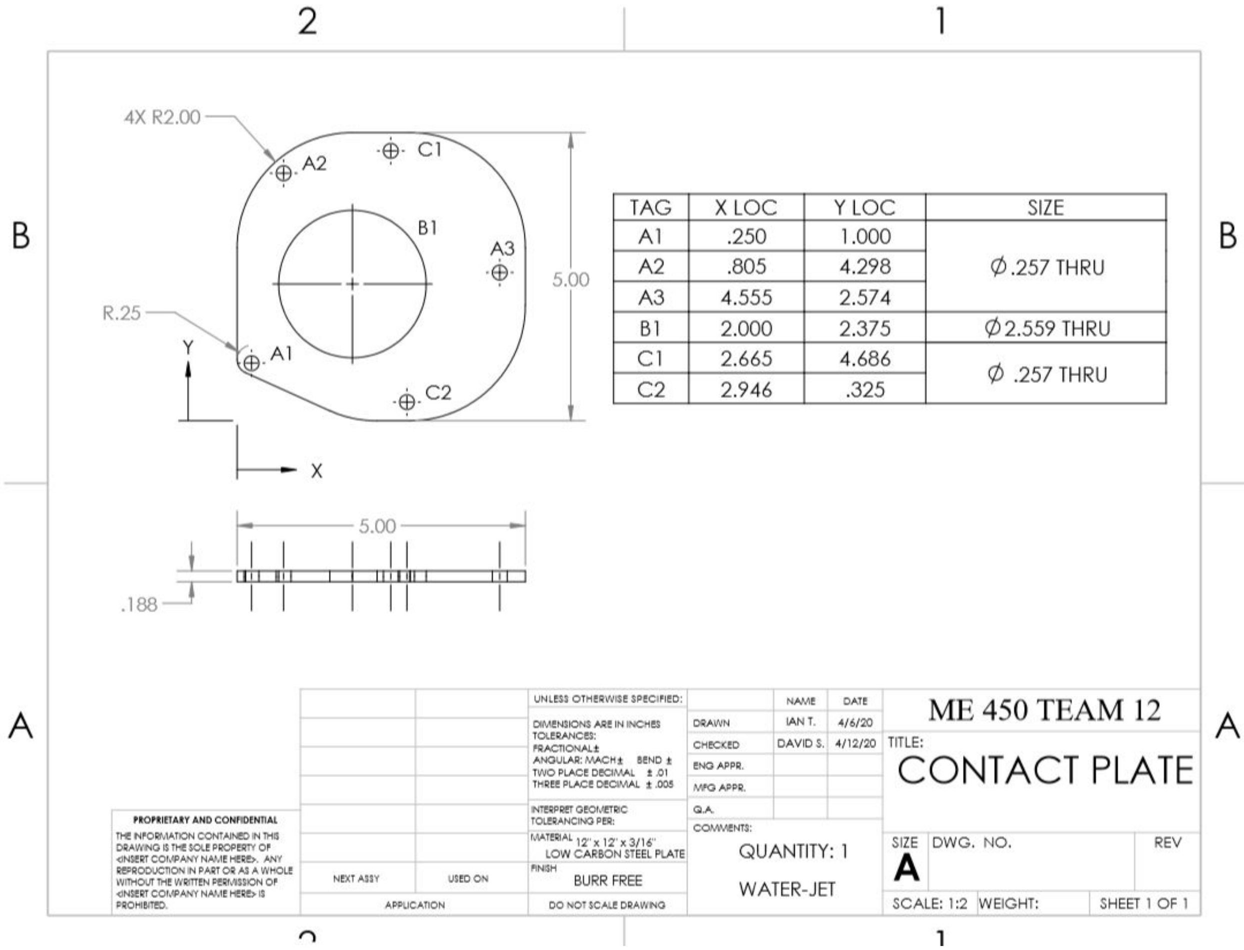


**Figure A.8.** Contact plate engineering drawing.

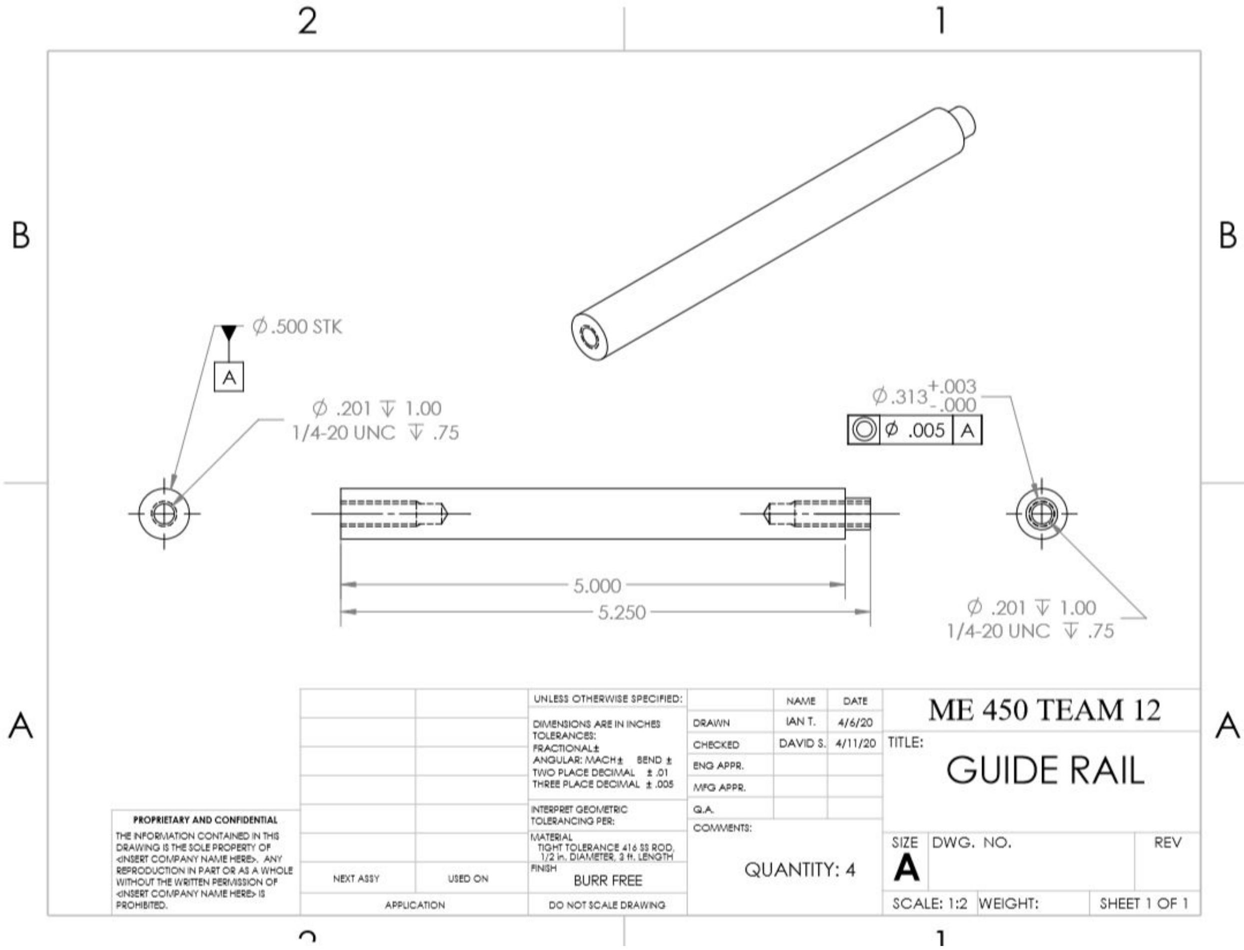


**Figure A.9.** Guide rail engineering drawing.

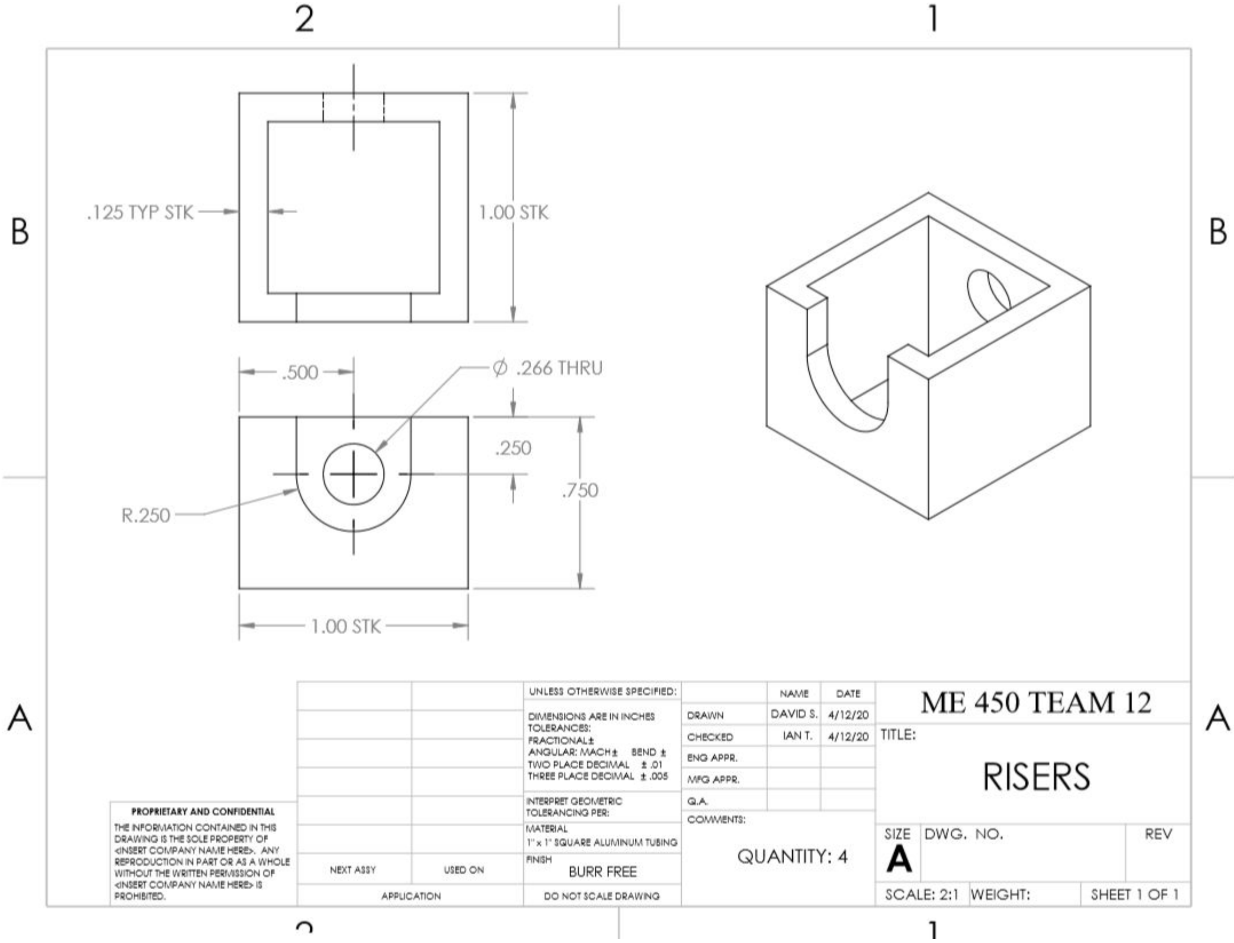


**Figure A.10.** Risers engineering drawing.

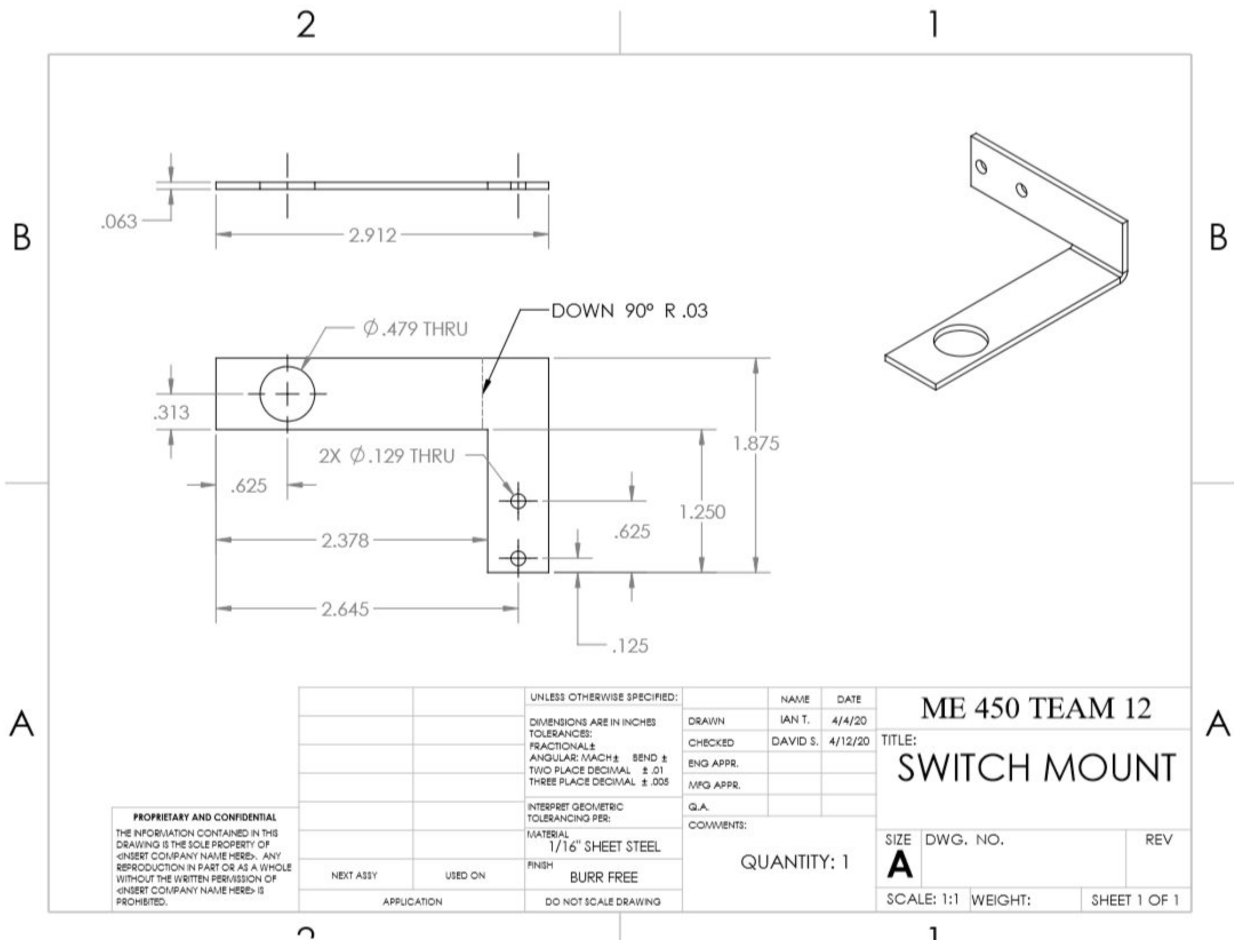


**Figure A.11.** Switch mount engineering drawing.

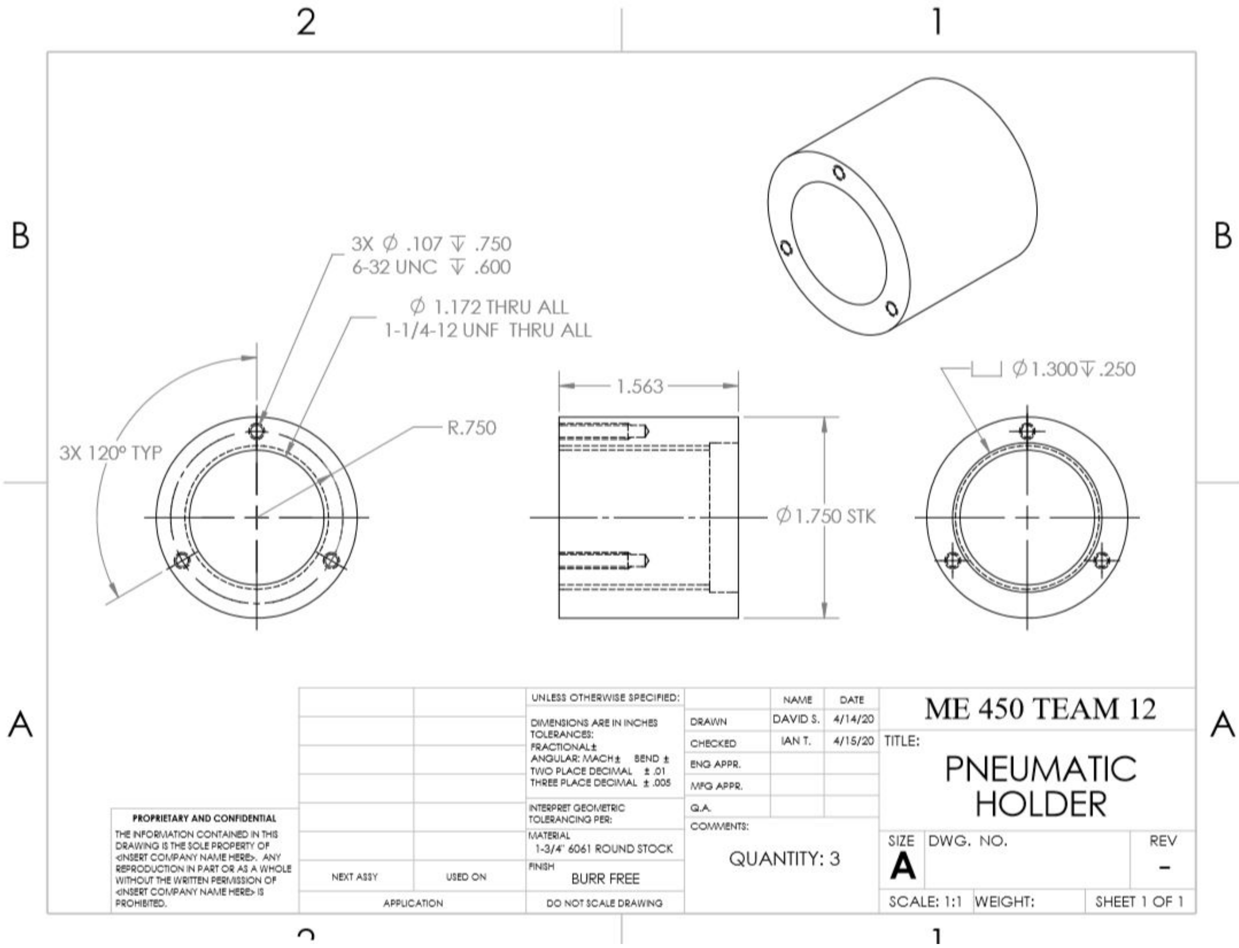


**Figure A.12.** Pneumatic holder engineering drawing.

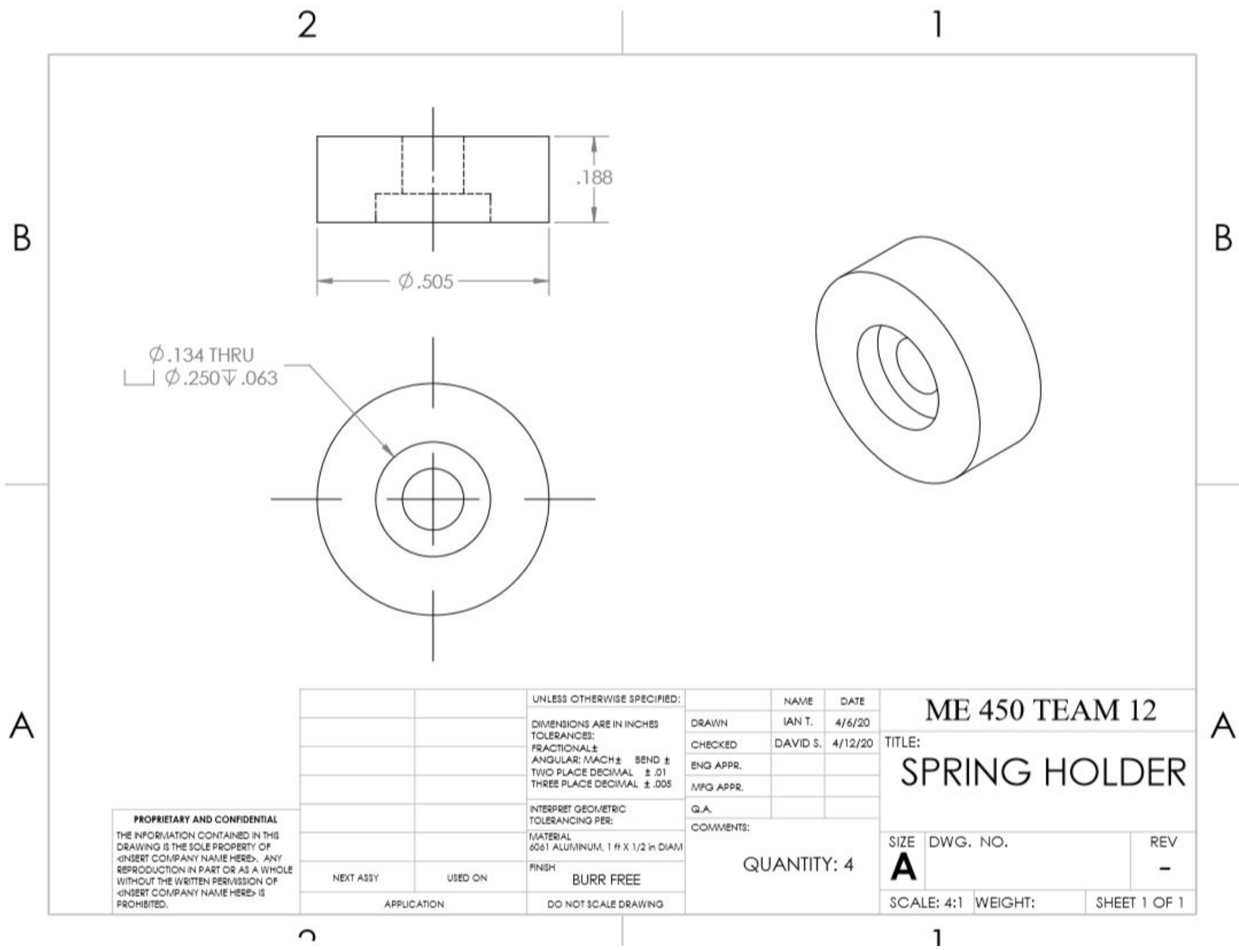


**Figure A.13.** Spring holder engineering drawing.

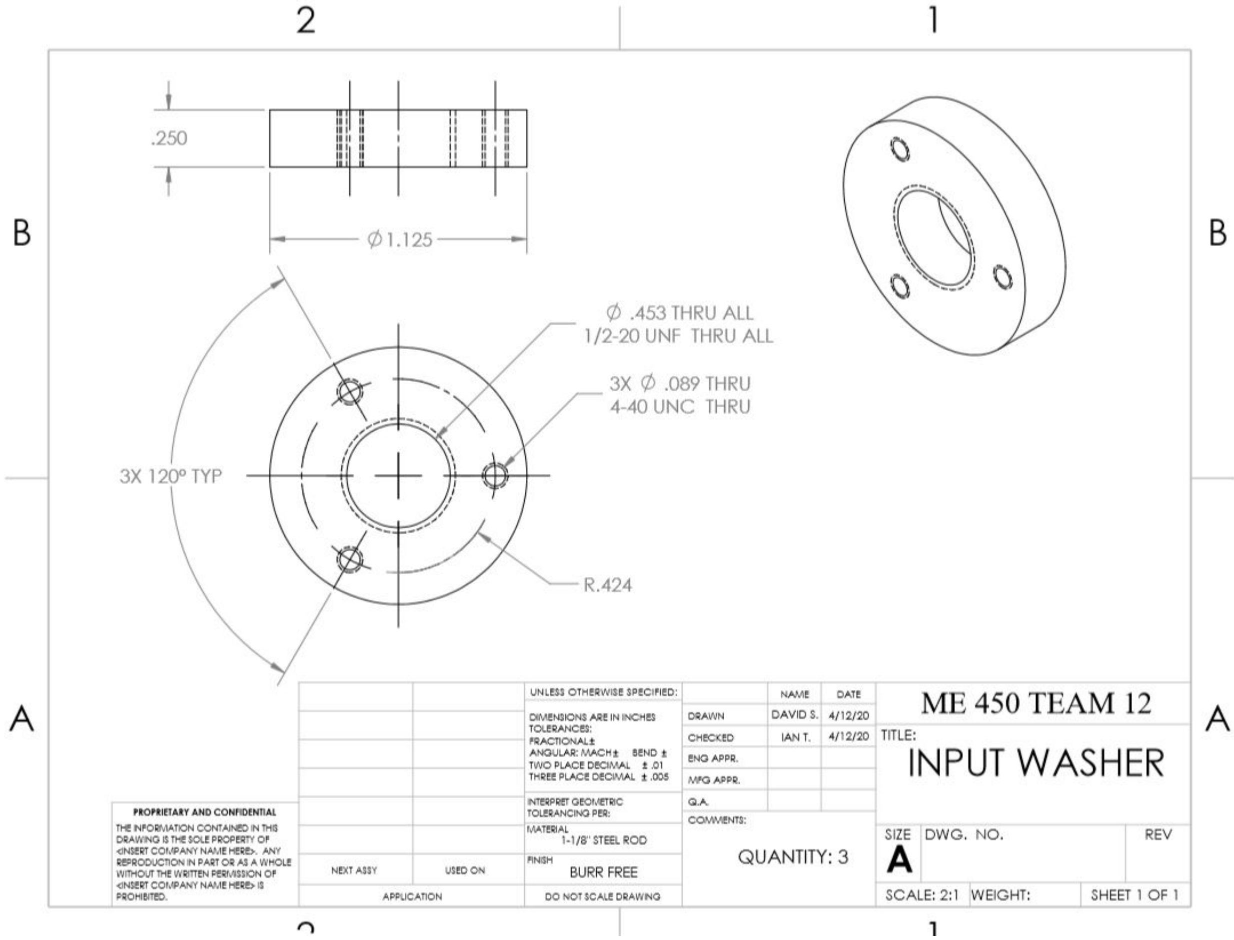


**Figure A.14.** Input washer engineering drawing.

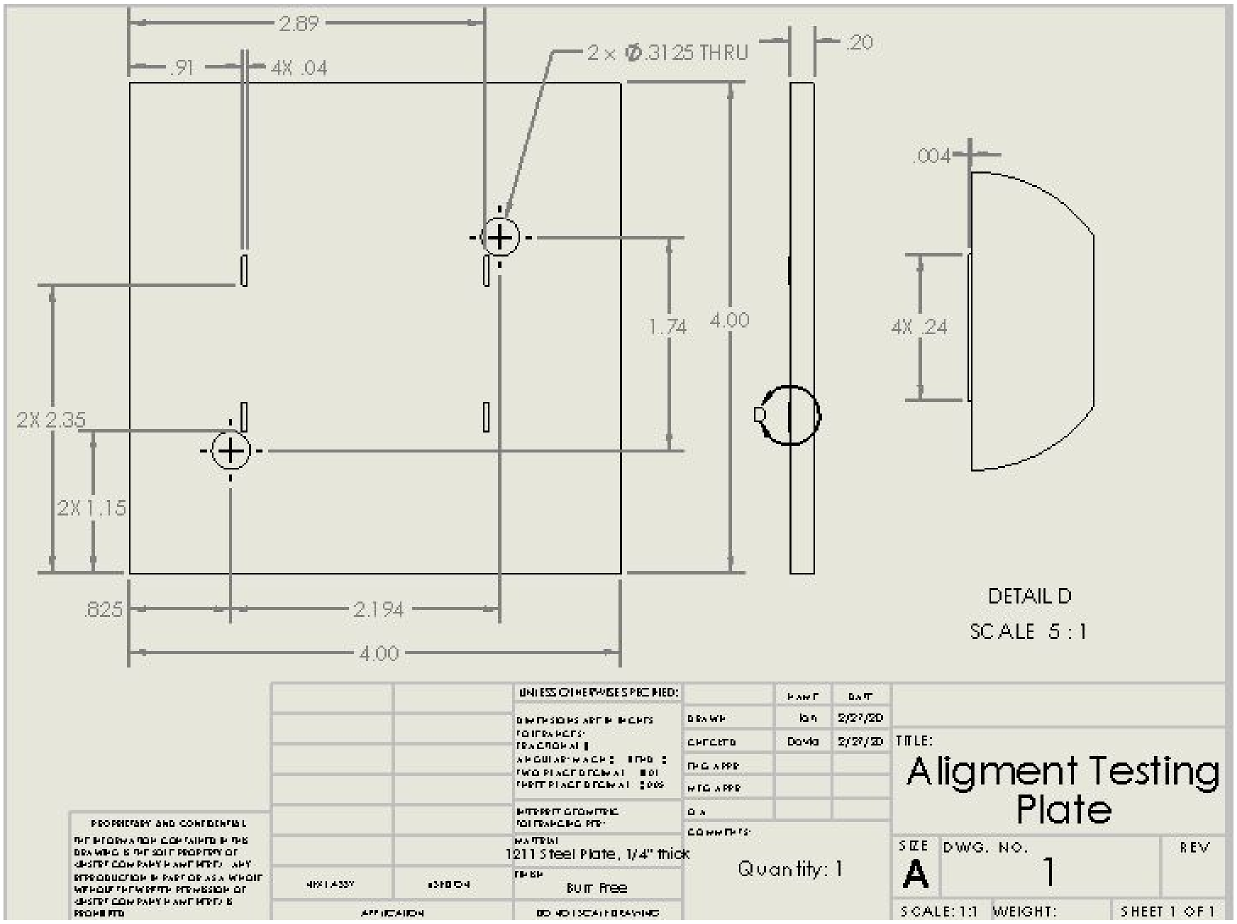


**Figure A.15.** Alignment Testing Plate engineering drawing.

# Appendix B - Manufacturing Plans

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | 1 | | | | |
| Part Title: | Ejector Plate | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| Raw Material Stock | 12" x 12" x 3/16" low carbon steel plate | | | | |
| Step # | Process Description | Machine | Fixture(s) | Tool(s) | Speed(rpm) |
| 1 | Water-jet only the profile of the plate; none of the holes | Water-jet | - | - | - |
| 2 | Retrieve part from water-jet and deburr | - | - | File | - |
| 3 | Place part in the vise, on top of parallels, with > .125" material sticking out | Mill | Vise | 1.375" parallels | - |
| 4 | Locate datum for X- and Y- datum, and move to center of the first .249" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 5 | Measure the outer diamter of the .25" pin. Insert drill bit that is .015" under desired hole size. Drill thru at the first hole location. | Mill | Vise | Mircrometer, drill chuck, drill bit A | 1100 |
| 6 | Select reamer that is .001" below measured pin diamter and ream hole. | Mill | Vise | Drill chuck, selected .001" undersize ream | 100 |
| 7 | Repeat Steps 5 and 6 for the remaining .249" holes | - | - | - | - |
| 8 | Measure the outer diameter of the 1mm diameter pin. Insert drill bit that is .015" under the desired hole size. Drill thru at the first .039" hole location on the drawing. | Mill | Vise | Micrometer ,drill chuck, #73 drill bit | 1300 |
| 9 | Select reamer that is .001" below measured pin diamter and ream hole. | Mill | Vise | Drill chuck, selected .001" undersize ream | 100 |
| 10 | Repeat Steps 8 and 9 for the remaining .039" holes | - | - | - | - |
| 11 | Install center drill and drill at location of .250" diameter hole. Insert 1/4" drill bit and drill thru material at hole location | Mill | Vise | Drill chuck, center drill, 1/4" drill bit | 900 |
| 12 | Install center drill and drill at location of first .150" diameter hole. Insert #25 drill bit and drill thru material at hole location | Mill | Vise | Center drill, drill chuck, #25 drill bit | 1400 |
| 13 | Repeat Step 11 for remaining .150" diameter holes | - | - | - | - |
| 14 | Install center drill and drill at location of first .257" diameter hole. Insert F drill bit and drill thru material at hole location. | Mill | Vise | Drill chuck, center drill, F drill bit | 950 |
| 15 | Repeat Step 13 for remaining .257" diameter holes | - | - | - | - |
| 16 | Install center drill and drill at location of first 1.250" diameter hole. Remove center drill and insert 1/4" drill bit and drill at loaction of 1.250" diameter hole. | Mill | Vise | Drill chuck, center drill, 1/4" drill bit | 900 |
| 17 | Remove 1/4" diamter hole and insert 3/4" drill bit and drill at location of first 1.250" diameter hole | Mill | Vise | Drill chuck, 3/4" drill bit | 350 |
| 18 | Remove 3/4" drill bit and insert 1 -1/4" drill bit and drill at location of first 1.250" diameter hole. | Mill | Vise | Drill chuck, 1-1/4" drill bit | 200 |
| 19 | Repeat Steps 15-17 for the remaining 1.250" diameter holes | - | - | - | - |
| 20 | Remove part from vise and deburr all holes | - | - | Deburring tool | - |

**Figure B.1.** Ejector plate manufacturing plan.

| | | | | |
|---|---|---|---|---|
| Manufacturing Plan | | | | |
| Part Number: | 2 | | | |
| Part Title: | Shadow Plate | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | |
| | | | | |
| Raw Material Stock: | 6" x 6" Acrylic | | | |
| This part is for Laser Cutting, no manufacturing plan | | | | |

**Figure B.2.** Shadow plate manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | | | | | |
| *Part Title:* | Push Plate | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | low carbon steel plate | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Retrieve part from water-jet and deburr | - | - | File | - |
| 2 | Place part in the vise, on top of parallels, with > .125" material sticking out | Mill | Vise | 1.375" parallels | - |
| 3 | Locate datum for X- and Y- datum, and move to center of the first .315" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 4 | Drill thru at the first .315" hole location. | Mill | Vise | drill chuck, O drill bit | 1000 |
| 5 | Repeat for the remaining .315" holes | Mill | Vise | drill chuck, O drill bit | 1000 |
| 6 | Locate datum for X- and Y- datum, and move to center of the first .047" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 7 | Drill thru at the first .047" hole location. | Mill | Vise | drill chuck, 3/64 drill bit | 1200 |
| 8 | Repeat for the remaining .047" holes | Mill | Vise | drill chuck, 3/64 drill bit | 1200 |
| 9 | Locate datum for X- and Y- datum, and move to center of the first .531" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 10 | Drill thru at the first .531" hole location. | Mill | Vise | drill chuck, 17/32 drill bit | 750 |
| 11 | Repeat for the remaining .531" holes | Mill | Vise | drill chuck, 17/32 drill bit | 750 |
| 12 | Locate datum for X- and Y- datum, and move to center of the first .500" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 13 | Drill thru at the first .500" hole location. | Mill | Vise | drill chuck, 1/2 drill bit | 800 |
| 14 | Repeat for the remaining .500" holes | Mill | Vise | drill chuck, 1/2 drill bit | 800 |
| 15 | Locate datum for X- and Y- datum, and move to center of the first .129" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 16 | Drill thru at the first .129" hole location. | Mill | Vise | drill chuck, #30 drill bit | 1200 |
| 17 | Repeat for the remaining .129" holes | Mill | Vise | drill chuck, #30 drill bit | 1200 |
| 18 | Locate datum for X- and Y- datum, and move to center of the first .310" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 19 | Drill thru at the first .310" hole location. | Mill | Vise | drill chuck, #68 drill bit | 1000 |
| 20 | Repeat for the remaining .310" holes | Mill | Vise | drill chuck, #68 drill bit | 1000 |
| 21 | Deburr all holes | | | deburring tool | |

**Figure B.3.** Push plate manufacturing plan.

| | | | |
|---|---|---|---|
| ***Part Number:*** | 4 | | |
| ***Part Title:*** | Punch Holder | | |
| ***Team Name*** | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | |
| | | | |
| This part is for 3D print, no manufacturing plan | | | |

**Figure B.4.** Punch holder manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | | | | | |
| *Part Title:* | Spring Table | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | 12" x 12" x 3/16" low carbon steel plate | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Water-jet only the profile of the part | Water-jet | - | - | - |
| 2 | Retrieve part from water-jet and deburr | - | - | File | - |
| 3 | Secure part onto parallels in the vise of a mill such that >.125" of material is sticking out | Mill | Vise | 1.375" parallels | - |
| 4 | Insert dial indicator into mill and find central datum for the part | Mill | Vise | Dial indicator | 1000 |
| 5 | Remove dial indicator and insert drill chuck and center drill into drill chuck | Mill | Vise | Drill chuck, center drill | - |
| 6 | Locate hole for first M3 x .5 tapped hole and center drill at location indicated on drawing | Mill | Vise | Drill chuck, center drill | 1000 |
| 7 | Remove center drill and insert the #39 drill bit and plunge drill at the location of the first tapped hole | Mill | Vise | Drill chuck, #39 drill bit | 1500 |
| 8 | Remove drill bit and insert tap wrench with the correct tap for M3 x .5 and tap drilled hole | Mill | Vise | Tap wrench, drill chuck, M3 x .5 tap | - |
| 9 | Repeat Steps 6-8 for the remaining tapped holes | - | - | - | - |
| 10 | Remove part from vise and deburr all holes | - | - | Deburring tool | - |

**Figure B.5.** Spring table manufacturing plan.

| | | | | | |
|---|---|---|---|---|---|
| Part Number: | 6 | | | | |
| Part Title: | Table Support | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| Raw Material Stock | .5" DIA x 1' Steel Rod | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Cut stock to 1.5" overlength | Horizontal Bandsaw | Vise | - | 300 ft/min |
| 2 | Remove burrs | - | - | File | - |
| 3 | Insert piece into collet with >1" sticking out | Lathe | collet | - | - |
| 4 | Face one end of part to create machined surface | Lathe | Collet | Cutting tool | 750 |
| 5 | Remove part from collet, rotate 180 degrees, fasten into collet again and face the surface | Lathe | Collet | Cutting tool | 750 |
| 6 | Place tool at end of the part so that it is flush with the edge of the piece and zero the X- and Z- datums | Lathe | Collet | Cutting Tool | 750 |
| 7 | Attach drill chuck to the tailstock of the lathe | Lathe | Collet | Drill Chuck | - |
| 8 | Insert center drill into drill chuck and center drill part | Lathe | Collet | Drill chuck, center drill | 1000 |
| 9 | Remove center drill and insert #7 drill bit and drill 0.75" into the part | Lathe | Collet | Drill chuck, #7 drill bit | 850 |
| 10 | Remove drill bit and insert tap wrench with 1/4 - 20 tap and tap hole up to .50" into part | Lathe | Collet | Drill chuck, tap wrench, 1/4-20 tap | - |
| 11 | Remove part from collet and rotate 180 degrees so that opposite end is exposed | Lathe | Collet | - | - |
| 12 | Insert center drill into drill chuck and center drill part | Lathe | Collet | Drill chuck, center drill | 1000 |
| 13 | Remove center drill and insert #7 drill bit and drill 0.65" into the part | Lathe | Collet | Drill chuck, #7 drill bit | 850 |
| 14 | Remove drill bit and insert tap wrench with 1/4 - 20 tap and tap hole up to .50" into part | Lathe | Collet | Drill chuck, tap wrench, 1/4-20 tap | - |
| 15 | Using the parting tool, travel 2.022" down the length of the part and separate | Lathe | Collet | Parting tool | 750 |
| 16 | Collect part and deburr | - | - | File, deburring tool | - |

**Figure B.6.** Table support manufacturing plan.Loca

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | | | | | |
| Part Title: | Base Plate | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| Raw Material Stock | 6" X 6" X 3/8" Steel Plate | | | | |
| | | | | | |
| **Step #** | **Process Description** | **Machine** | **Fixture(s)** | **Tool(s)** | **Speed(rpm)** |
| 1 | Choose 2 flute endmill to fit 3/8" side of partand install into collet. Face off each side of part until length of 5.6" is reached | Mill | Vise, stop | 3/4" endmill, collet, parallels | 1000 |
| 2 | Rotate part to face off other two opposing edges until a length of 5." is reached | Mill | Vise, stop | 3/4" endmill, collet, parallels | 1000 |
| 3 | Place part in the vise, on top of parallels, with > .125" material sticking out | Mill | Vise | 1.375" parallels | - |
| 4 | Locate datum for X- and Y- datum, and move to center of the first .257" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 5 | Drill thru at the first .257" hole location. | Mill | Vise | drill chuck, F drill bit | 1000 |
| 6 | Repeat for the remaining .257" holes | Mill | Vise | drill chuck, F drill bit | 1000 |
| 7 | Locate datum for X- and Y- datum, and move to center of the first .313" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 8 | Drill thru at the first .313" hole location. | Mill | Vise | drill chuck, 5/16 drill bit | 1000 |
| 9 | Repeat for the remaining .313" holes | Mill | Vise | drill chuck, 5/16 drill bit | 1000 |
| 10 | Locate datum for X- and Y- datum, and move to center of the first .177" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 11 | Drill thru at the first .177" hole location. | Mill | Vise | drill chuck, #16 drill bit | 1000 |
| 12 | Repeat for the remaining .177" holes | Mill | Vise | drill chuck, #16 drill bit | 1000 |
| 13 | Locate datum for X- and Y- datum, and move to center of the first .257" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 14 | Drill thru at the first .257" hole location. | Mill | Vise | drill chuck, F drill bit | 1000 |
| 15 | Repeat for the remaining .257" holes | Mill | Vise | drill chuck, F drill bit | 1000 |
| 16 | Locate datum for X- and Y- datum, and move to center of the first .089" diameter hole | Mill | Vise | Edge finder, drill chuck | 1000 |
| 17 | Drill thru at the first .089" hole location. | Mill | Vise | drill chuck, #43 drill bit | 1000 |
| 18 | Repeat for the remaining .089" holes | Mill | Vise | drill chuck, #43 drill bit | 1000 |
| 19 | Choose 4-40 tap drill and tap all .089" holes | tap drill | vise | 4-40 tap drill, vise | |
| 20 | Deburr all holes | | | deburring tool | |

**Figure B.7.** Base plate manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | 8 | | | | |
| *Part Title:* | Contact Plate | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | 12" x 12" x 3/16"<br>LOW CARBON STEEL PLATE | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Use Water jet to cut the finish shape, including hole B1, and deburr | Waterjet | - | File | - |
| 2 | Place part in the vise, on top of parallels, with > .125" material sticking out | Mill | Vise | 1.375" parallels | - |
| 3 | Using the edgefinder, zero the mill to the bottom left corner of the plate (refer to drawing for better idea)<br>Establish XY location | Mill | Vise | Edge finder, drill chuck | 1000 |
| 4 | Using a center drill, drill at 0.250" in the x, and 1.000" in the y at A1 | Mill | Drill Chuck | Center Drill | 1000 |
| 5 | Using an F drill plunge all the way through the plate at A1 | Mill | Drill Chuck | F Drill | 800 |
| 6 | Repeat step 4 and 5 for location A2 and A3 | Mill | Drill Chuck | - | - |
| 7 | Using a center drill, drill at 2.665" in the x, and 4.686" in the y at C1 | Mill | Drill Chuck | Center Drill | 1000 |
| 8 | Using an F drill plunge all the way through the plate at C1 | Mill | Drill Chuck | F Drill | 800 |
| 9 | Repeat step 4 and 5 for location C2 | Mill | Drill Chuck | - | - |
| 10 | Deburr the part | - | - | File | - |

**Figure B.8.** Contact plate manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | | | | | |
| *Part Title:* | Guide Rail | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | .5" DIA x 3ft Tight Tolerance Easy to Machine Stainless Steel | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Cut stock to 1.5" overlength | Horizontal Bandsaw | Vise | - | 300 ft/min |
| 2 | Remove burrs | - | - | File | - |
| 3 | Insert piece into collet with >1" sticking out | Lathe | collet | - | - |
| 4 | Face one end of part to create machined surface | Lathe | Collet | Cutting tool | 750 |
| 5 | Remove part from collet, rotate 180 degrees, fasten into collet again and face the surface | Lathe | Collet | Cutting tool | 750 |
| 6 | Place tool at end of the part so that it is flush with the edge of the piece and zero the X- and Z- datums | Lathe | Collet | Cutting Tool | 750 |
| 7 | Remove .187 inch of material from the diameter of the part, travelling .250 inches from the face of part in the Z- direction | Lathe | Collet | Cutting Tool | 750 |
| 8 | Attach drill chuck to the tailstock of the lathe | Lathe | Collet | Drill Chuck | - |
| 9 | Insert center drill into drill chuck and center drill part | Lathe | Collet | Drill chuck, center drill | 1000 |
| 10 | Remove center drill and insert #7 drill bit and drill 1" into the part | Lathe | Collet | Drill chuck, #7 drill bit | 850 |
| 11 | Remove drill bit and insert tap wrench with 1/4 - 20 tap and tap hole up to .75" into part | Lathe | Collet | Drill chuck, tap wrench, 1/4-20 tap | - |
| 12 | Remove part from collet and rotate 180 degrees so that opposite end is exposed | Lathe | Collet | - | - |
| 13 | Repeat steps 9-11 for the second hole indicated on the drawing | - | - | - | - |
| 14 | Using the parting tool, travel 5.250" down the length of the part and separate | Lathe | Collet | Parting tool | 750 |
| 15 | Collect part and deburr | - | - | File, deburring tool | - |

**Figure B.9.** Guide rail manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | 10 | | | | |
| Part Title: | Risers | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| Raw Material Stock | .5' x 1" x 1" 6061 1/8" Square Tube | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Cut stock to 1.5" overlength | Horizontal Bandsaw | Vise | - | 300 ft/min |
| 2 | Remove Burrs | - | - | File | - |
| 3 | Secure part onto parallels in the vice of a mill exposing >0.125" of material | Mill | Vise | 1.375" parallels | - |
| 4 | Place the cutting tool against edge of part and create a machined surface. | Mill | Vise | Cutting tool | 750 |
| 5 | Remove part, and reinstall at 180 degrees, and create a machined surface. | Mill | Vise | Cutting Tool | 750 |
| 6 | Use the edge finder and zero the X- and Y- datum. | Mill | Vise | Edge finder | 1000 |
| 7 | Place the cutting tool and face end of part to length. | Mill | Vise | Cutting tool | 750 |
| 8 | Locate datum for X- and Y- datum, and move to center of the 0.50" diameter cut-out | Mill | Vise | Edge finder | 1000 |
| 9 | Insert center drill into drill chuck and center drill part | Mill | Vise | Center Drill | 1000 |
| 10 | Remove center drill and insert 1/2 drill bit and drill through face | Mill | Vise | 1/2 Drill | 1000 |
| 11 | Remove drill bit and insert 1/2 face cutter to face down slot | Mill | Vise | 1/2 Face cutter | 1000 |
| 12 | Remove drill bit and insert center drill into drill chuck and center drill 0.266" hole | Mill | Vise | Center drill | 1000 |
| 13 | Remove center drill and insert H drill and drill through face | Mill | Vise | H drill | 1000 |
| 14 | Remove part and deburr holes | - | - | File | - |

**Figure B.10.** Risers manufacturing plan

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | | | | | |
| *Part Title:* | Switch Mount | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | 1/16" sheet steel | | | | |
| | | | | | |
| **Step #** | **Process Description** | **Machine** | **Fixture(s)** | **Tool(s)** | **Speed(rpm)** |
| 1 | Waterjet profile and inner holes of switch mount | waterjet | | | |
| 2 | Place sheet metal in brake press and bend to create 90 degree angle | brake press | | | |
| 3 | Deburr all holes | | | deburring tool | |

**Figure B.11.** Switch mount manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | 12 | | | | |
| Part Title: | Pneumatic Holder | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| Raw Material Stock | 1-3/4" 6061 ROUND STOCK | | | | |
| | | | | | |
| **Step #** | **Process Description** | **Machine** | **Fixture(s)** | **Tool(s)** | **Speed(rpm)** |
| 1 | Locate the required round stock. Use the band saw to cut 0.25" over the finished length. | Band Saw | - | Pen | 200ft/min |
| 2 | Install the material into the 1.75" collet with a stop into the Lathe spindle. | Lathe | Collet | | |
| 3 | Rotate the potentiometer speed control all the way counterclockwise to zero then turn the power on to the lathe. Place spindle guard down. Move the cutting tool to the front tip of the material, and set your x and z axes equal to 0. | Lathe | Collet | | |
| 4 | Move the cutting tool a few inches away from the round stock. Then, adjust the velocity to approximately 300 rpm by rotating the spindle speed control potentiometer clockwise. | Lathe | Collet | Cutting Tool | 300 |
| 5 | With spindle moving, move the tool to the end of the part and remove 0.10" of material off the Z-axis, repeat this two more times just to make sure we have flat surface. Remove all burrs at this point. | Lathe | Collet | Hand File | 300 |
| 6 | Install the drill chuck into the quill of the tailstock and then install the center drill. Move the tailstock within range of the part and lock it into position. Apply cutting oil to the center drill and drill to a depth of approx. three quarters of the way up the secondary taper using the peck drill method. | Lathe | Collet | Centerdrill | 300 |
| 7 | Remove center drill and install 1 11/64 drill bit into the drill chuck. Drill through the part, liberally applying cutting oil. | Lathe | Collet | 1 11/64 drill | 200 |
| 8 | Tap though the hole using 1-1/4-12 UNF tap tool | Lathe | Collet | 1-1/4-12 UNF tap tool | - |
| 9 | Install 1 19/64 drill bit into the drill chuck. Peck drill into part at 0.25", liberally applying cutting oil. | Lathe | Collet | 1 19/64 drill | 200 |
| 10 | Turn off the lathe. Remove the #60 drill as well as the round stock, then take out the collet. | Lathe | Collet | - | - |
| 11 | Place part in the vise, on top of parallels, with > . 125" material sticking out. The tapped hole should face up | Mill | Vise | parallels | - |
| 12 | Using a center drill, drill at first hole on top | Mill | Vise | drill chuck | - |
| 13 | Using a #36 drill 0.750" at the location | Mill | Drill Chuck | #36 Drill | 800 |
| 14 | Tap the hole using 6-32 UNC tap tool down to 0.600" | Mill | Drill Chuck | 6-32 UNC | - |
| 15 | Repeat step 12-14 for another two locations | Mill | - | - | - |
| 16 | Deburr the part | - | - | File | - |

**Figure B.12.** Pneumatic holder manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| *Part Number:* | | | | | |
| *Part Title:* | Spring Holder | | | | |
| *Team Name* | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| *Raw Material Stock* | 9/16" DIA 6061 Round Stk x 1 | | | | |
| | | | | | |
| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
| 1 | Cut stock to 1" over finish length | Horizontal Bandsaw | Vise | - | 300 ft/min |
| 2 | Deburr part | - | - | File | - |
| 3 | Insert part into collet of lathe with >1" sticking out | Lathe | Collet | - | - |
| 4 | Place the cutting tool against the edge of the part and zero the X- and Z- datum. Face end of part to create a machined surface | Lathe | Collet | Cutting tool | 750 |
| 5 | Attach drill chuck to tailstock of lathe | Lathe | Collet | Drill chuck | - |
| 6 | Insert center drill into drill chuck and center drill part | Lathe | Collet | Drill chuck, center drill | 1000 |
| 7 | Remove center drill and insert 3.4 mm drill bit and drill .188" into part | Lathe | Collet | Drill chuck, 3.4mm drill bit | 1500 |
| 8 | Remove drill chuck from the lathe and insert a 1/4" collet and 1/4" endmill into the tailstock of the lathe | Lathe | Collet | 1/4" collet, 1/4" endmill | - |
| 9 | Mill .063" into the part | Lathe | Collet | 1/4" collet, 1/4" endmill | 1400 |
| 10 | Travel .188" along the part in the Z-direction and separate the material | Lathe | Collet | Parting tool | 750 |
| 11 | Repeat Steps 5-10 for the remaining spring holders | - | - | - | - |
| 12 | Collect parts and deburr | - | - | Deburring tool | - |

**Figure B.13.** Spring holder manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | 14 | | | | |
| Part Title: | Input Washer | | | | |
| Team Name | ME 450 Team 12, Reconfigurable Puncher for Microfluidic Devices | | | | |
| | | | | | |
| Raw Material Stock | 1-1/8"Dia x 1' low carbon rod | | | | |

| ***Step #*** | ***Process Description*** | ***Machine*** | ***Fixture(s)*** | ***Tool(s)*** | ***Speed(rpm)*** |
|---|---|---|---|---|---|
| 1 | Locate the required round stock. Use the band saw to cut 0.25" over the finished length. | Band Saw | - | Pen | 200ft/min |
| 2 | Install the material into the 1.50" collet with a stop into the Lathe spindle. | Lathe | Collet | | |
| 3 | Rotate the potentiometer speed control all the way counterclockwise to zero then turn the power on to the lathe. Place spindle guard down. Move the cutting tool to the front tip of the material, and set your x and z axes equal to 0. | Lathe | Collet | | |
| 4 | Move the cutting tool a few inches away from the round stock. Then, adjust the velocity to approximately 300 rpm by rotating the spindle speed control potentiometer clockwise. | Lathe | Collet | Cutting Tool | 300 |
| 5 | With spindle moving, move the tool to the end of the part and remove 0.10" of material off the Z-axis, repeat this two more times just to make sure we have a flat surface. Remove all burrs at this point. | Lathe | Collet | Hand File | 300 |
| 6 | Install the drill chuck into the quill of the tailstock and then install the center drill. Move the tailstock within range of the part and lock it into position. Apply cutting oil to the center drill and drill to a depth of approx. three quarters of the way up the secondary taper using the peck drill method. | Lathe | Collet | Centerdrill | 300 |
| 7 | Remove center drill and install 29/64 drill bit into the drill chuck. Drill through the part, liberally applying cutting oil. | Lathe | Collet | 29/64 drill | 200 |
| 8 | Tap though the hole using 1/2-20 UNF tap tool | Lathe | Collet | 1/2-20 UNF tap tool | - |
| 9 | Turn off the lathe. Remove the drill as well as the round stock, then take out the collet. | Lathe | Collet | - | - |
| 10 | Place part in the vise, on top of parallels, with > .125" material sticking out. | Mill | Vise | parallels | - |
| 11 | Using a center drill, drill at first hole on top | Mill | Vise | drill chuck | - |
| 12 | Drill through first hole location using a #43 drill bit | Mill | Drill Chuck | #43 Drill | 800 |
| 13 | Tap the hole using 4-40 UNC tap tool through the part | Mill | Drill Chuck | 6-32 UNC | - |
| 14 | Repeat step 11-13 for other two locations | Mill | - | - | - |
| 15 | Deburr the part | - | - | File | - |

**Figure B.14.** Input washer manufacturing plan.

| Manufacturing Plan | | | | | |
|---|---|---|---|---|---|
| Part Number: | 1 | | | | |
| Part Title: | Alignment Testing Plate | | | | |
| Team Name: | Team 12 | | | | |
| Raw Material Stock: | Steel Plate, 1/4" x 4" x 4" | | | | |
| **Step #** | **Process Description** | **Machine** | **Fixture(s)** | **Tool(s)** | **Speed (RPM)** |
| 1 | Cut Aluminum Plate Stock toe .125" greater than finish length on horizontal bandsaw | Horizontal Bandsaw | Vise | - | 300 ft/min |
| 2 | Mount part in vise of mill such that >.125" is stiking out from the top of the vise and >.5" of the part is stiking out of the side of the vise | Mill | Vise | Parallels | - |
| 3 | Insert 3/4" collet and 3/4" endmill and face the material | Mill | Vise | 3/4" collet, 3/4" Endmill | 350 |
| 4 | Insert drill chuck with edgefinder to locate and zero the x- and y-datums on part | Mill | Vise | Drill chuck, Edge finder | 1000 |
| 5 | Using a center drill, center drill at the hole locations specified on the drawing | Mill | Vise | Drill chuck, Centerdrill | 900 |
| 6 | Using an 19/64" drill, plunge all the way through the plate at the first hole and second hole | Mill | Vise | Drill chuck, 19/64" drill bit | 500 |
| 7 | Using an 5/16 reamer, plunge all the way through the plate at the pre-drilled hole locations in low gear setting | Mill | Vise | 5/16 ream bit | 200 |
| 8 | Remove ream and drill chuck and insert 3/4" collet and endmill and mill the grooves according to the drawing | Mill | Vise | 3/4" Collet, 3/4" endmill | 350 |
| 9 | Remove part from vise and deburr | - | - | File | - |

**Figure B.15.** Alignment Testing Plate manufacturing plan.

## Appendix C - Parts List

| Part # | Name | Distributor | Model # | Unit cost ( | Quantity | Total cost |
|---|---|---|---|---|---|---|
| 1 | XYTheta Stage | Focus Optics | MAXYR-60L | $203.00 | 1 | $203.00 |
| 2 | 1/4" 4-way plastic connector (pack of 10) | McMaster | 5463K96 | $16.00 | 1 | $16.00 |
| 3 | Compression Spring (pack of 12) | McMaster | 9657K279 | $11.09 | 1 | $11.09 |
| 4 | .125" NPT .25" Hose barb | McMaster | 5350K31 | $4.18 | 3 | $12.54 |
| 5 | 2.5in Pneumatic Actuator | McMaster | 6498K589 | $73.25 | 3 | $219.75 |
| 6 | Hand Operater Miniature Air Control Valve | McMaster | 62475K39 | $39.95 | 1 | $39.95 |
| 7 | Air Flow Control Valve | McMaster | 6857K25 | $34.00 | 1 | $34.00 |
| 8 | .25in x 1in Pin (pack of 10) | McMaster | 90145A542 | $6.52 | 3 | $19.56 |
| 9 | 1mm x 24mm Pin (pack of 5) | McMaster | 91585A327 | $5.42 | 3 | $16.26 |
| 10 | Shadow Plate (6"x6" Acrylic) | McMaster | 4615T91 | $2.39 | 1 | $2.39 |
| 11 | Table Support (.5"DIA x 1' Steel Rod) | McMaster | 8920K152 | $3.66 | 1 | $3.66 |
| 12 | Guide Rail ( .5" DIA x 3ft Tight Tolerance Easy to Machine | McMaster | 7014T4 | $50.32 | 1 | $50.32 |
| 13 | Push Plate (12" x 12" x 3/16" Low Carbon Steel Plate | McMaster | 1388K75 | $50.79 | 1 | $50.79 |
| 14 | Ejector Plate (12" x 12" x 3/16" sheet) | McMaster | 1388K75 | $0.00 | 1 | $0.00 |
| 15 | Contact Plate (12" x 12" x 3/16" sheet) | McMaster | 1388K75 | $0.00 | 1 | $0.00 |
| 16 | Spring Table (12" x 12" x 3/16" sheet) | McMaster | 1388K75 | $0.00 | 1 | $0.00 |
| 17 | Input Washer (1-1/8"Dia x 1ft low carbon rod) | McMaster | 8920K251 | $15.05 | 1 | $15.05 |
| 18 | 1/4" NPT to 1/4" Hose barb (pack of 10) | McMaster | 5372K112 | $4.81 | 1 | $4.81 |
| 19 | 1/4" ID Air Hose (per foot) | McMaster | 5304K14 | $0.79 | 10 | $7.90 |
| 20 | Hose Clamps (packs of 10 | McMaster | 5388K14 | $6.26 | 1 | $6.26 |
| 21 | Camera | ?? | ?? | $50.00 | 1 | $50.00 |
| 22 | Risers (.5' x 1" x 1" 6061 1/8" Square Tube) | McMaster | 6546K21 | $4.89 | 1 | $4.89 |
| 23 | Base Plate (6" x 6" x3/8" Steel) | McMaster | 6544K28 | $35.37 | 1 | $35.37 |
| 24 | 1/2" #6-32 (Pack of 100) | McMaster | 91255A148 | $13.05 | 1 | $13.05 |
| 25 | 3/8" #4-40 (Pack of 100) | McMaster | 91255a108 | $12.70 | 1 | $12.70 |
| 26 | 1" 1/4-20 (Pack of 50) | McMaster | 91255a542 | $10.18 | 1 | $10.18 |
| 27 | M3 x 0.50 8mm Long (Pack of 100) | McMaster | 91239A113 | $7.27 | 1 | $7.27 |
| 28 | Spring Holder (9/16" DIA 6061 Round Stk x 1') | McMaster | 8974K46 | $2.84 | 1 | $2.84 |
| 29 | Punch Holder (3D SLA Print) | ME Undegrad Shop | | | | $0.00 |
| 30 | Pneumatic Holder | McMaster | 8974K68 | $12.23 | 1 | $12.23 |
| 31 | Switch Mount (3"x3"x 1/16" | McMaster | 1388K142 | | | $0.00 |
| Total | | | | | | $861.86 |

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