Fall 2018

Universal Tube Fixture

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Executive Summary

The goal of this design project was to create a device that can aid in the assembly of glue joints between concentric tubes. In many medical devices, whether they be laser probes, retractable injectors, or other devices with actuating parts, there are often concentric glue joints. The problem we are trying to solve is controlling where the 2 tubes are relative to one another when they are glued.

Imagine Tube A is a large diameter tube 2 inches in length and Tube B is a small diameter tube 1 inch in length. We want to glue Tube B into Tube A such that after the tubes are fixed, there is exactly 0.5 inches of Tube B protruding from the end of Tube A. This device would aid in ensuring that exactly 0.5 inches, or whatever distance the user wants, of Tube B is protruding the end of Tube A. Right now, these glue joints are made by hand with calipers to best approximate the length of the protruding section of Tube B. Ideally, our device would allow for a controlled way to set the tubes at the desired location before gluing. Also, our device would allow for the positioning and gluing of up to 10 tubes at once.

To be clear, this device is a type of scientific instrument and would be used by engineers and trained assembly workers. The user would be given instructions on how to operate the device and careful attention will be given to the device when in use. The device would increase confidence, accuracy, and precision of any assembly where concentric glue joints are present.

MEMS 411: MECHANICAL ENGINEERING DESIGN PROJECT
FALL 2018

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

A variety of medical devices and applications use both plastic and metal tubing. In some of these applications, tubes of different diameters are glued together, to make one continuous stepped tube. For optimal performance, tubes should be fastened together concentrically. Currently, there is no piece of standardized equipment to create the joints with accuracy or precision. Often, researches and engineers will design their own fastening devices. The goal of this device is to make an adjustable and standardized piece of lab equipment that would allow researches and product assemblers to fasten tubes together. Accuracy and precision are important components of the design for peak performance.

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing Designs

Dake Corporation Floor Drill Press

Figure 1. Dake Corporation Floor Drill Pres with Detail [1]

The drill press is a machine often used in the fabrication of parts. The main function of the drill press is to provide a reliable vertical drilling action that is repeatable, reasonably accurate and extremely precise. This is accomplished mainly through a linear rack gear that is mounted vertically along the primary support of the drill press. In Figure 1, this gear mechanism can be seen on the lower right side of the detailed image. The teeth of the gear allow for slow, controlled movement that occurs when the operator turns the handle of the drill press (the three black knobs at the end of steel rods seen near the top of the image). Another major component of this particular drill press is an adjustable depth control. This feature allows the depth of the drilled hole to be consistent and easily repeatable across many different uses of the drill press. The depth control makes the drill press a useful machine in the manufacture of replicated parts.

Figure 2. Mitutoyo Friction Thimble Digimatic Micrometer [2]

The Mitutoyo Friction Thimble Digimatic Micrometer is a precision measurement tool used for small distances. It has a range of 0 to 25 millimeters and a resolution of 0.001 millimeters. This makes the micrometer ideal for small objects. For the Mitutoyo model, there is also a digital display that aids in the reading of the measurement. The digital display increases the speed at which the instrument can be used. The final significant feature is the zeroing function. This is useful in measuring differences/changes as opposed to absolute dimensions. Tracking changes at such small scales is crucial because the minute absolute changes can have large relative effects in this range of measurements.

A current fixture used by Vortex Surgical consists of 5 notches in a plate of metal. At the end of these notches is a small step down in height until the edge of the piece roughly 4mm away. This fixture is used to hold one tube in a notch flush with the step wall. A second, larger, tube is slid over the fixed tube until the distal end is flush with the step wall. At this point, glue is applied to create the glue joint.

2.1.2 Relevant Patents

Patent No. 3,156,480 Self-Centering Chuck Mechanism

The self-centering chuck uses three arms to apply identical forces at evenly distributed points around a center point. The tightening occurs through a single threaded screw so that all three arms move at once and can be relied on to center the held object. This has many applications and is especially useful when dealing with circular members.

Patent No. 1,578,898 Glue Joint Apparatus

This glue joint apparatus is used in the manufacturing of wood (or other) composite materials. The main function of the device is to quickly assemble and hold thin strips of material together for gluing into one larger piece of material. Such larger portions can be used for this such as tabletops

2.1.3 Standards

DI-QCIC-81611 Title: Precision Measurement Equipment Laboratory (Pmel) Quality Manual Summary: This standard may be helpful to us because it focuses on precision measurement lab equipment. Since our device is going to have very tight tolerances and precise measurement characteristics, this standard may be useful to us. We need to make sure our measurements are as accurate as possible, so the tubes are concentric, and the joints are the correct lengths

ASME B5.8 Title: Chucks and Chuck Jaws Summary: Our design includes chucks and chuck jaws to grip the tubes and hold them in place. The chuck and chuck jaws need to be carefully engineered to not crush the tubing, but to hold it securely in place. This standard may assist us in the design of the chuck and chuck jaw.

2.2 USER NEEDS

Table 1: Customer Needs Interview

Product: Universal Tube Fixture (UTF)

Customer: Matthew LaConte, R&D at Vortex Surgical

Notes: After a summer of exposure to the difficulties of small tubing assemblies used in medical devices, Griffin was aware of the demand for assembly fixtures to ensure product accuracy and precision without increasing production time. This interview was conducted over the phone to address specific needs and requirements to be competitive in industry.

Address: 6629 Kingsbury Blvd, St. Louis, MO 63130 Date: September 9, 2018

Question	Customer Statement	Interpreted Need	Imp.
Controlled Dimensions	Needs to make sure the tubes are concentric the inner faces are properly distanced	a) The UTF can ensure concentricity of tubes b) The UTF can control distance between inner faces of tubes.	a) 3 b) 4.5
Potential Concerns	Fixture must not damage the tubes	The UTF cannot damage the tubes (Dent, deform, bend)	5
Time Requirements	Fixture must be really quick and repeatable. If you can average at least 10 glue assemblies/minute you would be in good shape as far as rate goes. Maybe consider fixing multiple tubes at once.	The UTF can provide repeatable results with 10 glue joint taking no more than 1 minute	3

2.3 DESIGN METRICS

Table 2: Interpreted Customer Needs

Number	Need	Importance
1	The UTF can ensure concentricity of tubes	3
2	The UTF can control distance between inner faces of tubes	4.5
3	The UTF cannot damage the tubes (Dent, deform, bend)	5
4	The UTF can provide repeatable results with 10 glue joint taking no more than 1 minute	3
5	The UTF provides aid for clean and consistent glue placement	2

Table 3: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	2	Distance from distal face of inner tube to the distal face of the outer tube	in	Specified Length ± 0.005	Specified Length ± 0.0025
2	4	Time per 2 glue joints	sec	12	10

2.4 PROJECT MANAGEMENT

To help aid with project progress and time management we used the Gantt Chart shown in Figure 3 below.

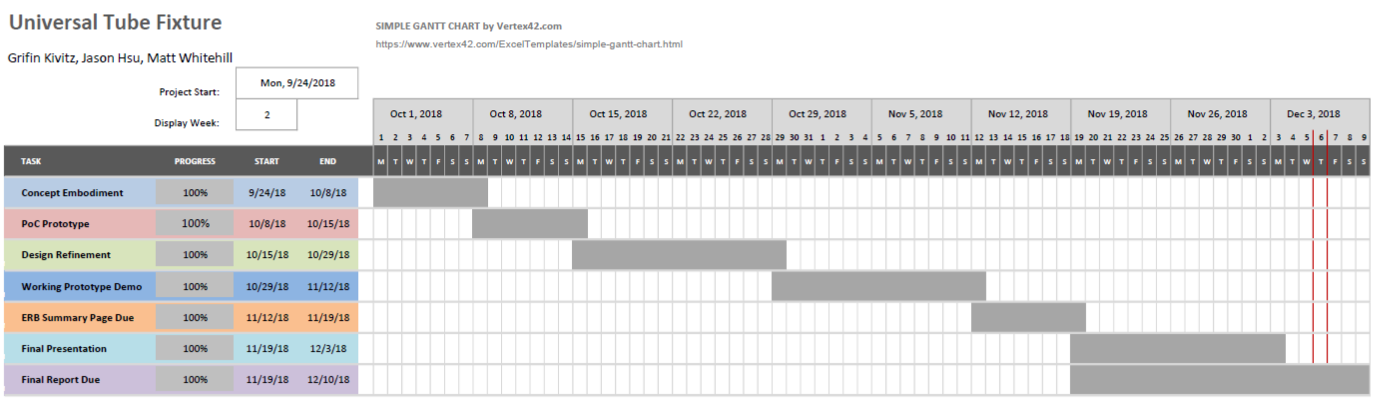


Figure 3: Project Gantt Chart

3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

Figure 4. Frontal view of glue joint aide with carriage in upper position

Figure 5. Frontal view of glue joint aide with carriage in lower position

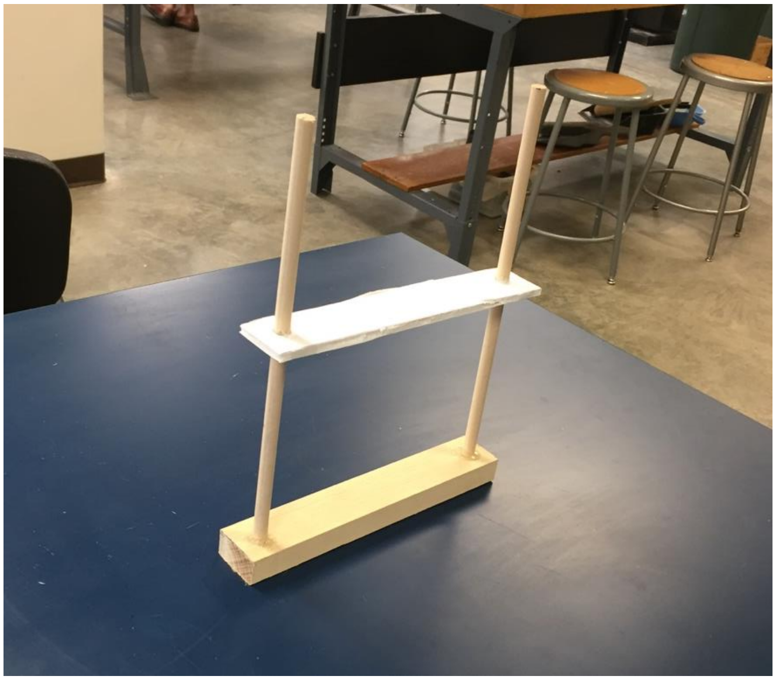


Figure 6. Angled view of glue joint aide mockup

The mockup really let us gain hands on experience with how the mechanism would move. This allowed us to better visualize how to mount the tubes so that it would be easiest to control the overlap between the outer and inner tubes. From our observations moving the carriage up and down, we were able to brainstorm several ideas on how best to measure the distances necessary. The mockup also gave us a better sense of scale and confirmed that vertical tracks would not make the device too large. This is important because we want to minimize the size of the device so that it does not occupy excessive workbench space.

3.2 FUNCTIONAL DECOMPOSITION

3.2.1 Function Tree

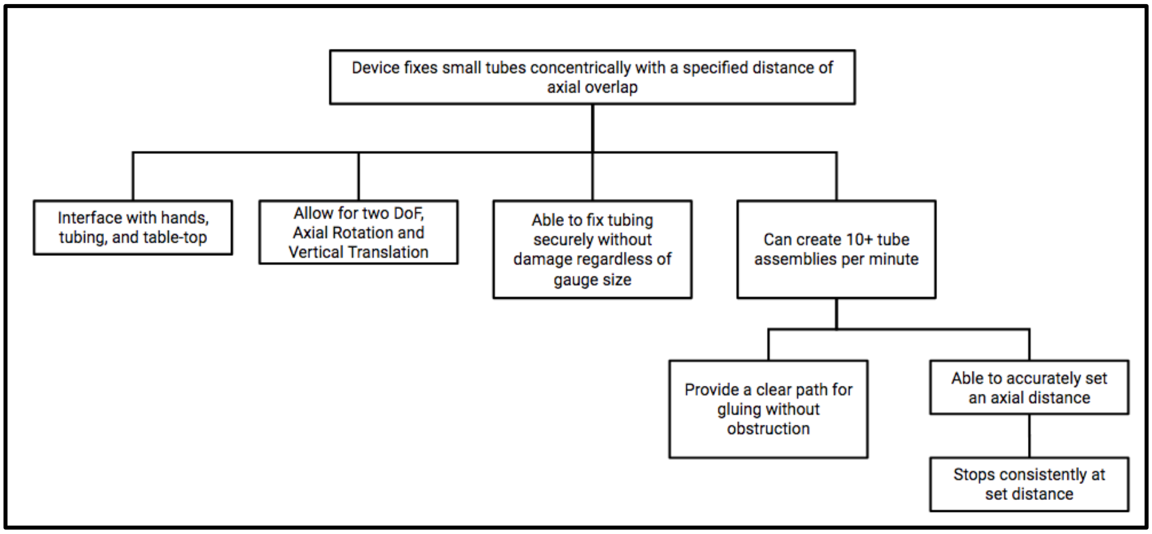


Figure 7. Function Diagram for the Glue Joint Aide

3.2.2 Morphological Charts

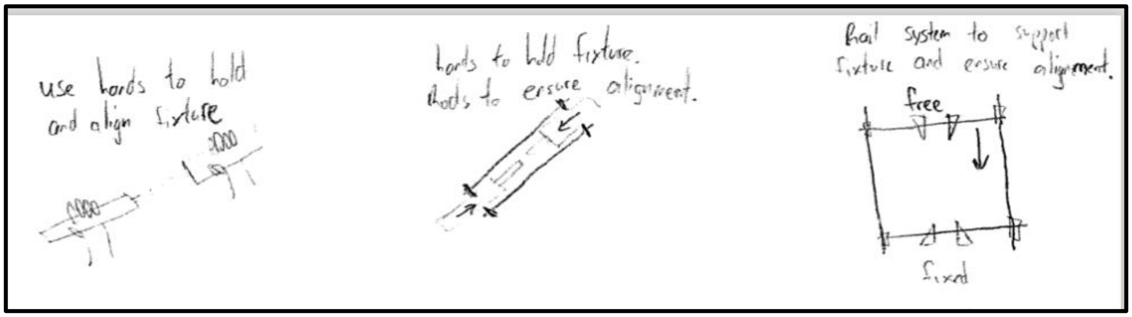


Figure 8. Morphological chart for Interfacing with Hand, Tubing, and Tabletop

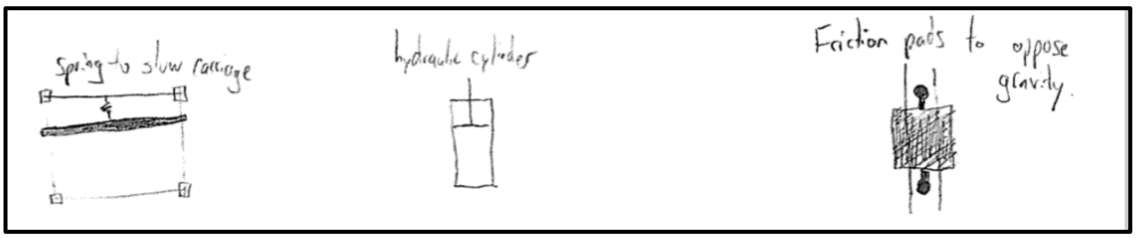


Figure 9. Morphological chart for Carriage System Does Not Crash into Bottom Tubes

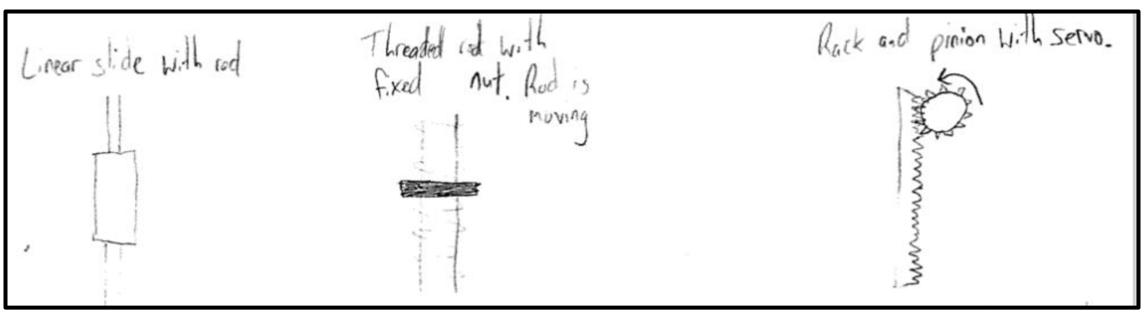


Figure 10. Morphological chart for Carriage Vertical Movement

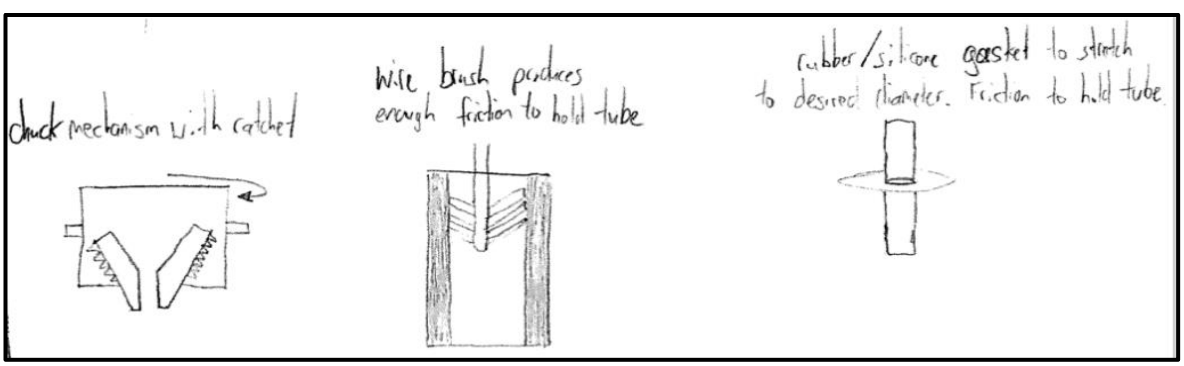


Figure 11. Morphological Chart for Securing Tubes

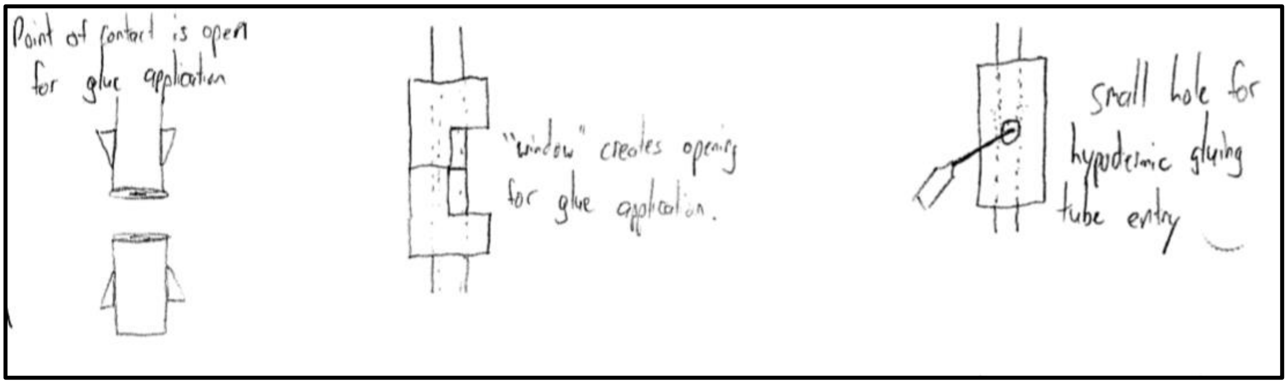


Figure 12. Morphological Chart for Clear Path for Gluing

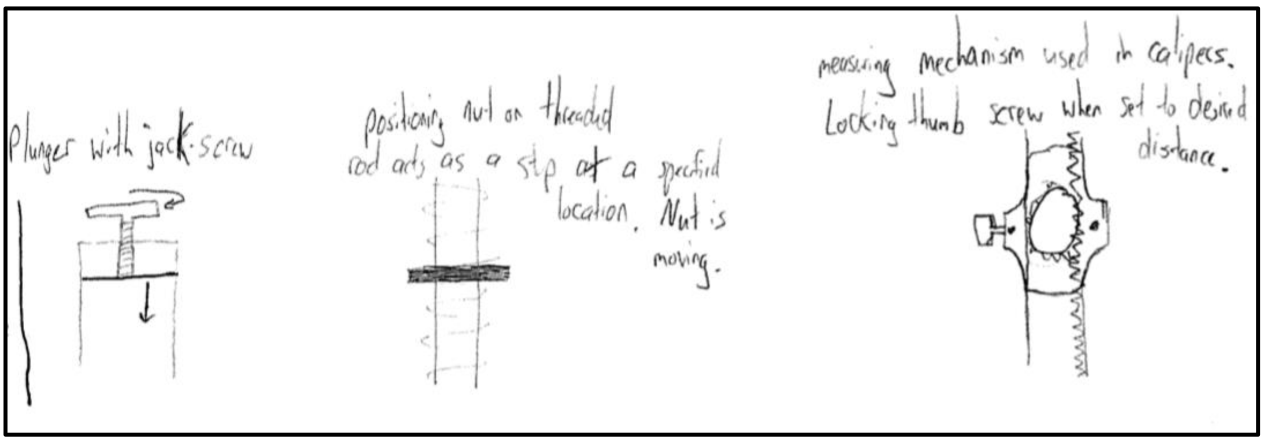


Figure 13. Morphological Chart for Controlling Axial Distance Moved/Overlap

3.3 ALTERNATIVE DESIGN CONCEPTS

3.3.1 Single Tube Fixture – Griffin Kivitz's Design

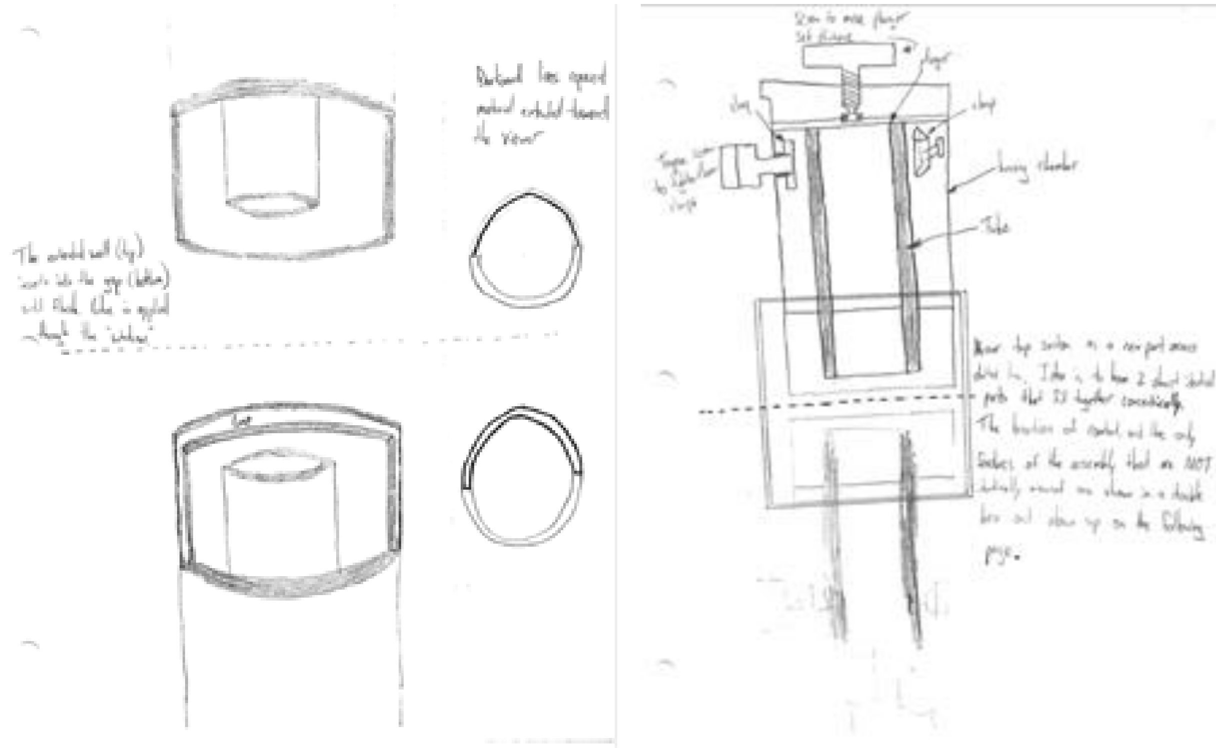


Figure 14. Initial and final sketches of single tube fixture

Description: An outer housing tube is the casing for each of the two parts. A jack screw is turned to set the back plunger to a specified distance. The tube is inserted into the casing flush against the back plunger. A chuck mechanism with a ratchet is used to clamp the tubes in place without over tightening. The two pieces are inserted into one another via a half-cylinder male notch and a half-cylinder female notch. Both notches are concentric arcs, so when the notches are aligned, the entire casing will be concentric. Once the pieces are secured together, glue can be applied through the "window" created by negative space from the notch cut-out.

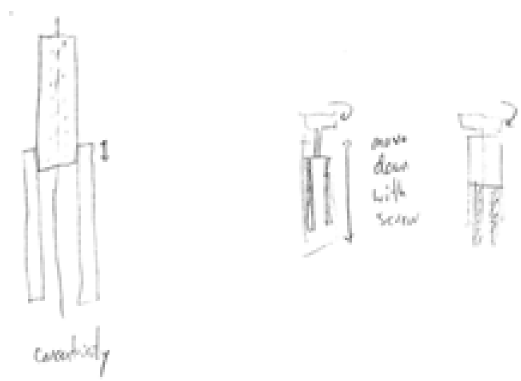


Figure 15. Initial sketches of single tube fixture

Solutions:

1. Use hands to hold and align fixture
2. Chuck/clamp mechanism with ratchet
3. Window cut out for gluing
4. Plunger with jack-screw

3.3.2 Elastic Band Clamps on Double Carriage Frame – Jason Hsu's Design

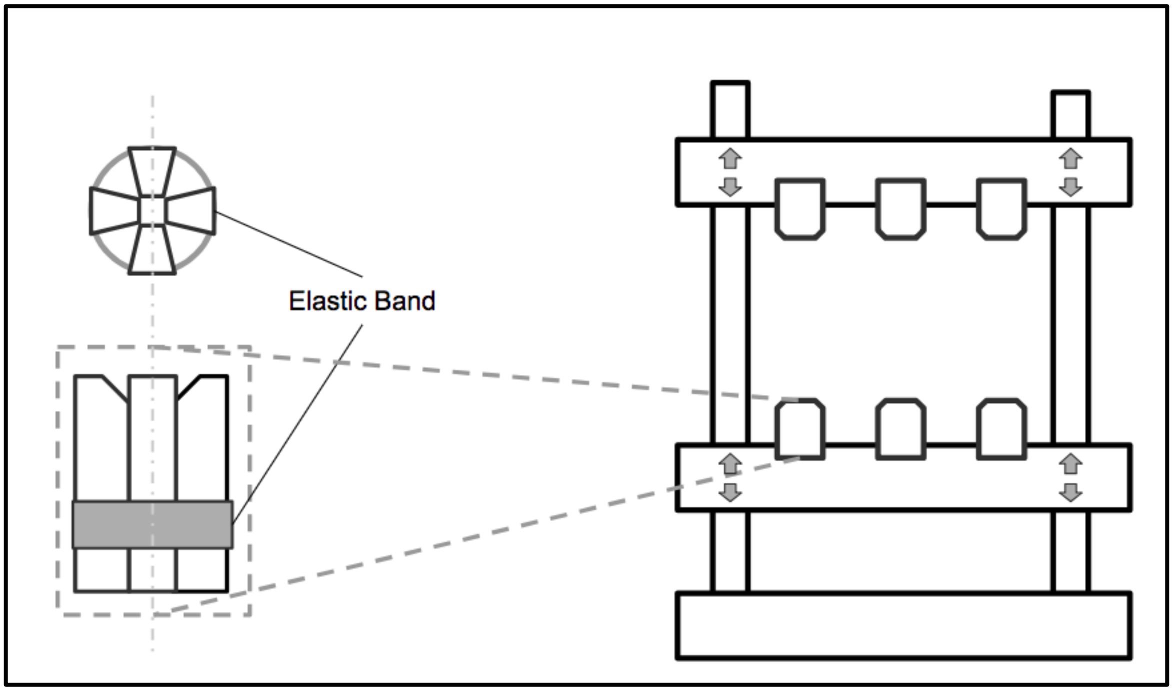


Figure 16. Diagram with Focus on Elastic Clamping Mechanism

Description: The design is based on two main features. The most important change from the other two iterations is an elastic clamping system rather than a self-centering chuck. This decision was based off of two factors. The first is that, after reading the self-centering chuck patent, the physical property used is the even application of pressure from three different points at the same time. An elastic band, if properly made, will also pull the four jaws of the clamp together evenly. The elastic clamp design is able to fulfill the same function as the self-centering chuck. Additionally, the elastic clamp should be quicker to use than the chuck. The tube is gently pushed into the middle of the tapered jaws and the pressure is immediately applied. With the chucks, the jaws need to be unscrewed and screwed again for each chuck. For manufacturing groups of tube assemblies, the time spent for this quickly adds up.

The second major feature of this design is the dual carriage system. The bottom carriage is set so that the length of tubing that juts upwards is known and equal to the desired overlap. The top carriage is then loaded with the larger diameter tubes and lowered onto the smaller, bottom tubes. This should quickly create the appropriate overlap without needing to be measured at every step.

3.3.3 Trolley/Rail System – Matt Whitehill's Design

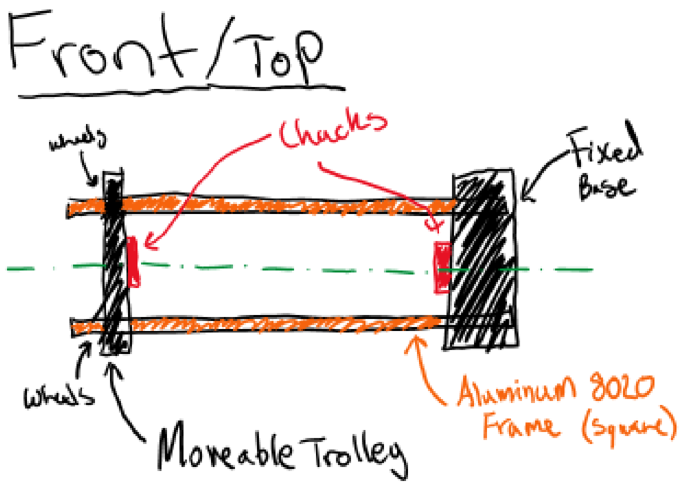


Figure 17. Final sketches of Trolley/Rail System

Description: The Trolley/Rail System consists of a square frame from made from Aluminum 8020 bar. There is a fixed base on one side of the frame and a moveable trolley on the other side. On both the fixed base and trolley, there are adjustable chucks that are perfectly concentric with one another. The device is used by loading the tubing into the chucks and sliding the trolley along the frame until both chucks are flush with one another.

Solutions:

1. Rail system to ensure alignment
2. Chuck mechanism
3. Point of contact is open for glue application

4 CONCEPT SELECTION

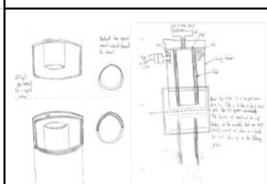
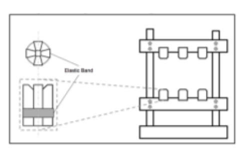
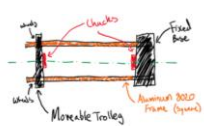
4.1 SELECTION CRITERIA

Table 4: Analytical Hierarchical Process

	Perfectly concentric	Proper axial displacement	Speed of assembly	Ease of Cleaning	Cost of Manufacturing	Easy to use	Row Total	Weight Value	Weight (%)
Perfectly concentric	**1.00**	0.25	1.00	2.00	4.00	7.00	15.25	0.22	22.44%
Proper axial displacement	4.00	**1.00**	2.00	4.00	10.00	7.00	28.00	0.41	41.20%
Speed of assembly	1.00	0.50	**1.00**	3.00	3.00	3.00	11.50	0.17	16.92%
Ease of Cleaning	0.50	0.25	0.33	**1.00**	3.00	1.00	6.08	0.09	8.95%
Cost of Manufacturing	0.25	0.10	0.33	0.33	**1.00**	0.50	2.52	0.04	3.70%
Easy to use	0.14	0.14	0.33	1.00	2.00	**1.00**	4.62	0.07	6.80%
						Column Total:	**67.97**	**1.00**	**100%**

4.2 CONCEPT EVALUATION

Table 5: Evaluation of Three Generated Concepts

		Alternative Deisgn Concepts					
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Perfectly concentric	22.44	4	0.90	3	0.67	5	1.12
Proper axial displacement	41.2	5	2.06	4	1.65	4	1.65
Speed of assembly	16.92	1	0.17	5	0.85	4	0.68
Ease of Cleaning	8.95	1	0.09	3	0.27	3	0.27
Cost of Manufacturing	3.7	4	0.15	3	0.11	3	0.11
Easy to use	6.8	4	0.27	5	0.34	5	0.34
	Total score	**3.636**		**3.887**		**4.166**	
	Rank	**3**		**2**		**1**	

4.3 EVALUATION RESULTS

The results of our concept evaluation show that the Trolley/Rail System is the top ranked design. Its use of chucks help rank it above the other designs for tube concentricity. It also placed high for highly weighted criteria including proper axial displacement and speed of assembly. Although the Trolley/Rail System design was the top ranked design, we think we can combine it with elements of the Double Carriage Frame design to further optimize for selected criteria.

The use of chucks will be important for keeping tubes concentric. The use of multiple chucks in a given design will increase the speed of assembly (since more than one tube can be fastened in one run of the machine). A design such as the Trolley/Rail System or Double Carriage Frame is open and therefore is easy to clean. We also believe that we can make them out of relatively cheap materials, which lowers the cost of manufacturing.

4.4 ENGINEERING MODELS/RELATIONSHIPS

4.4.1 External Pressure Stress on a Tube

The stress due to external pressure σ_r, or radial stress, is defined in Eq. 1 below:

$$\sigma_r = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (p_o - p_i)}{r^2 (r_o^2 - r_i^2)} \tag{1}$$

In Eq. 1 above, p_i and p_o are the internal and external pressures respectively. The radii r_i and r_o denote the radius of the inner tube diameter and the outer tube diameter respectively. The radius term r without a subscript is the radius from the center of the tube to a given point in the tube. For maximum stress, $r=r_o$.

We believe Eq. 1 will help us in the design of the chuck mechanism. One of the things we were worry about with the chuck mechanism was applying too much pressure. We want the chuck to grip the tube and hold it in place, but not deform or bend it. Therefore, it is important to know how much pressure the chuck is applying so it does not ruin the tube. In other words, σ_r should be much less than the elastic limit of the material the tube is made of.

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

The following calculations show how several of our parts and/or part geometries were determined. The first determines the crushing force for the tubes. This parameter was used in the selection of the springs for the clamping mechanism. The second is a calculation to determine the notch size of the slotted insert based on tube diameter. This size can be adjusted for different gauge sizes because the final result is in terms of the tube radius.

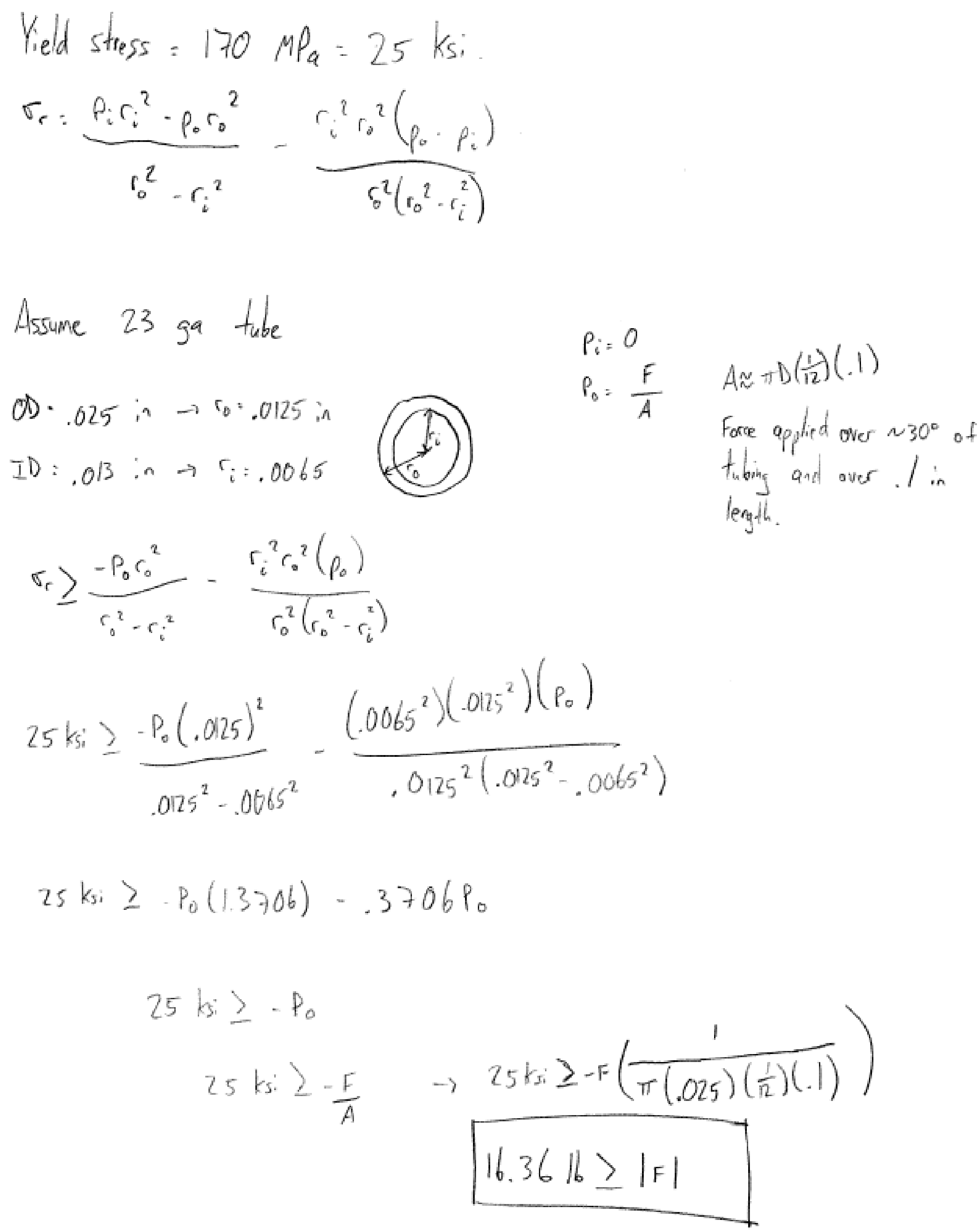


Figure 18: Hoop Stress Calculation

The geometry of the V-slots in our device are very important because they determine where the center line of each tube sits. The goal is the cut different depth v-slots depending on the tubing gauge size, and with these v-slot depths being proportional to the radius of the tube, the center line of each tube in its respective v-slot will be on the same center line as a different size tube in the opposing appropriate v-slot. Using a 60 degree milling flute, we can find the surface and accurately control the depth of each v-slot. In fig. 1 below, you can see the math used to determine the appropriate v-slot depth based on the radius of the tube. It was found that for all tubes to sit on an even plane, the depth of the v-slot cut is

$$cut\ depth = \frac{r}{0.866}$$

Where r is the outer radius of the tube.

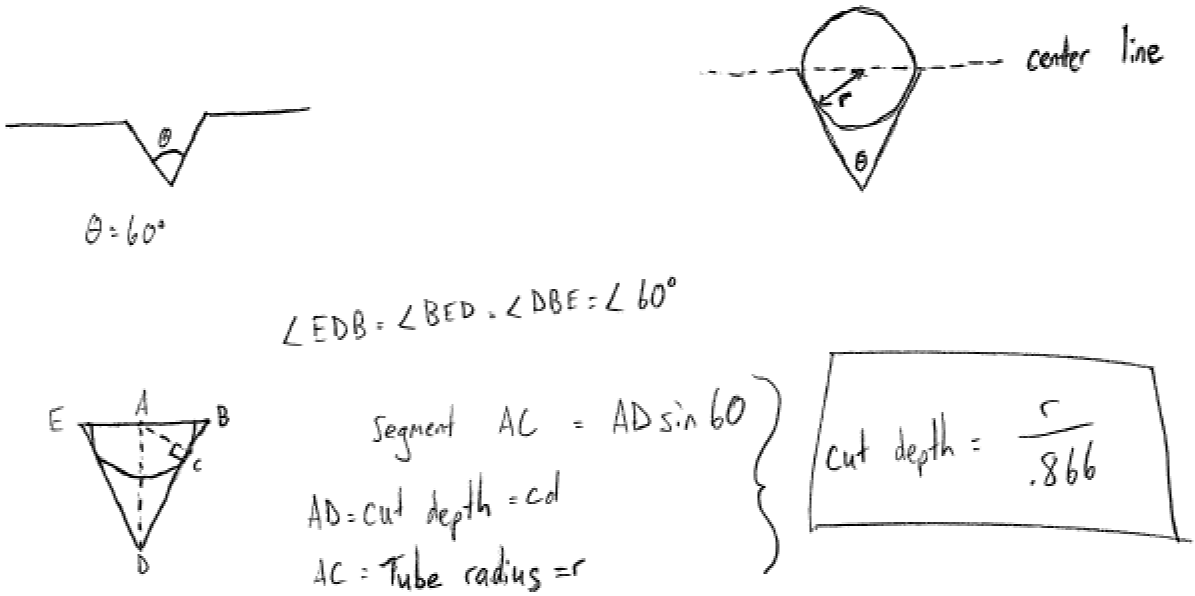


Figure 19: V-shaped Notch Calculation

Another important function of the device is the ability to clamp the tubes in place once they are properly positioned. With very small tubes, it is important that the clamping force on the tubes does not induce plastic deformation. The calculations shown in fig. 2 below are based off the model described in section 4.4. However, because this model assumed uniform radial pressure, the model was only used to generate general guidelines.

First our assumptions used in the calculations must be identified. It was found that the yield stress of 316 stainless steal is 25ksi [3]. Also, is was assumed that the clamping force was applied over a 30 degree arc and a 0.1 inch length of the tubing. Lastly, to generate numerical values, a 23ga tube was used as the tubing size. A 23ga regular wall tube has an outer diameter of 0.025in and an inner diameter of 0.013in.

Following the calculations, it was found that a pressure of 25ksi will induce plastic deformation. With the force applied to an area of roughly .00065 in^2, we determine that a force greater than 16.36lb applied to the specified area will induce plastic deformation. This value of 16.36lb will be the maximum limit of our clamping force.

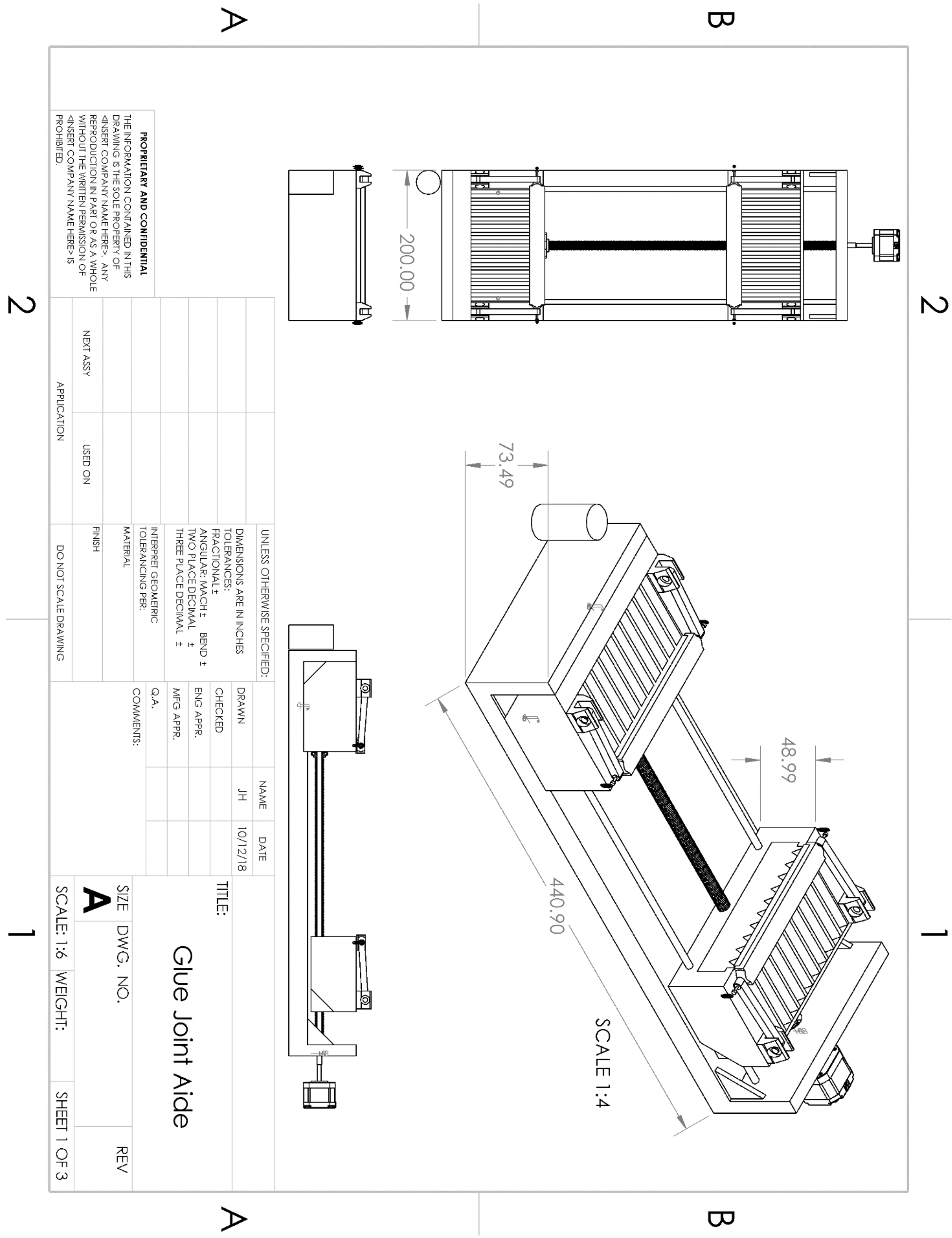
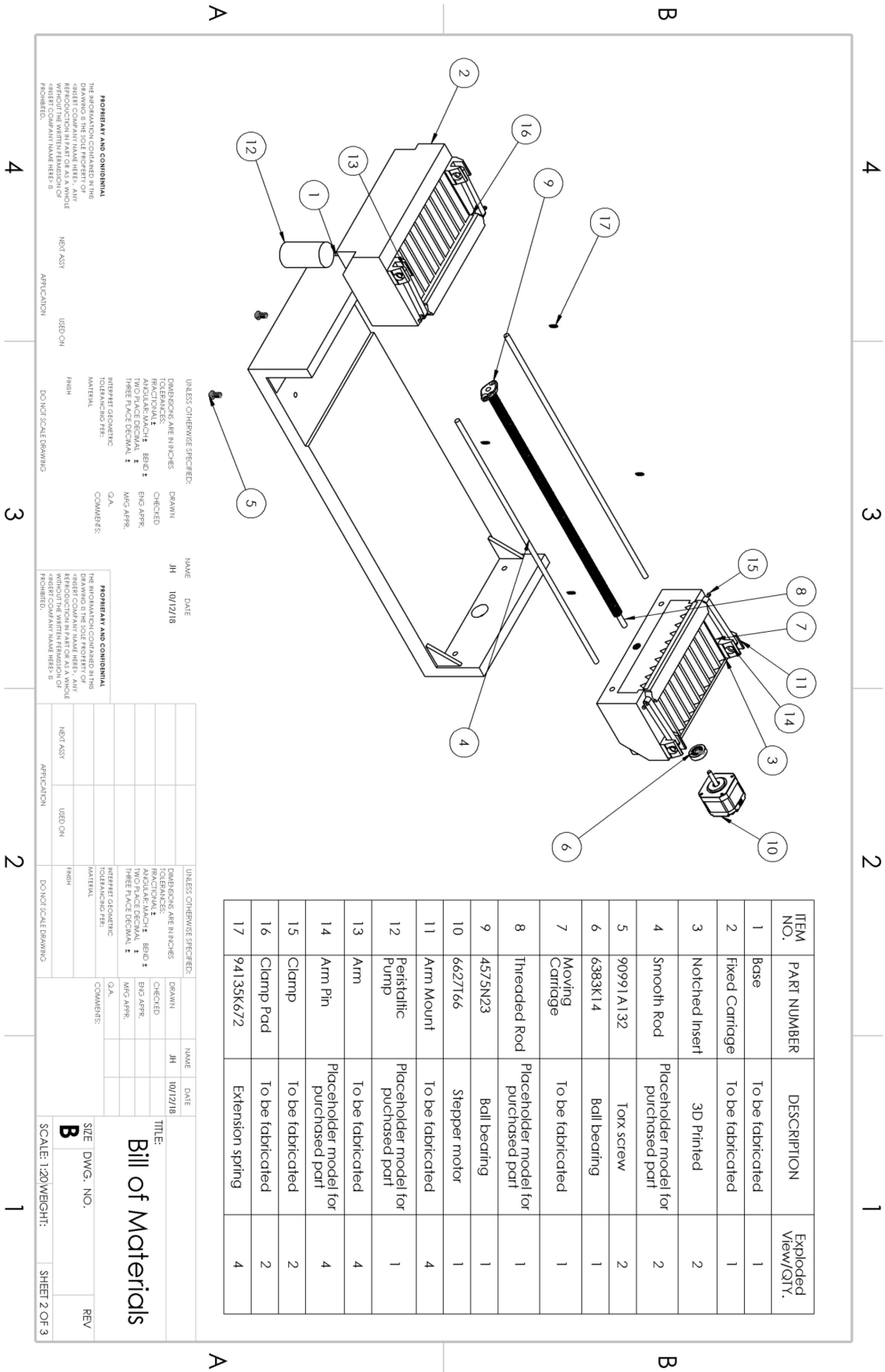


Figure 20. CAD embodiment of assembled concept



ITEM NO.	PART NUMBER	DESCRIPTION	Exploded View/QTY.
1	Base	To be fabricated	1
2	Fixed Carriage	To be fabricated	1
3	Notched Insert	3D Printed	2
4	Smooth Rod	Placeholder model for purchased part	2
5	90991A132	Torx screw	2
6	6383K14	Ball bearing	1
7	Moving Carriage	To be fabricated	1
8	Threaded Rod	Placeholder model for purchased part	1
9	4575N23	Ball bearing	1
10	6627T66	Stepper motor	1
11	Arm Mount	To be fabricated	4
12	Peristaltic Pump	Placeholder model for purchased part	1
13	Arm	To be fabricated	4
14	Arm Pin	Placeholder model for purchased part	4
15	Clamp	To be fabricated	2
16	Clamp Pad	To be fabricated	2
17	94135K672	Extension spring	4

Figure 21. Exploded view of assembled concept with BoM

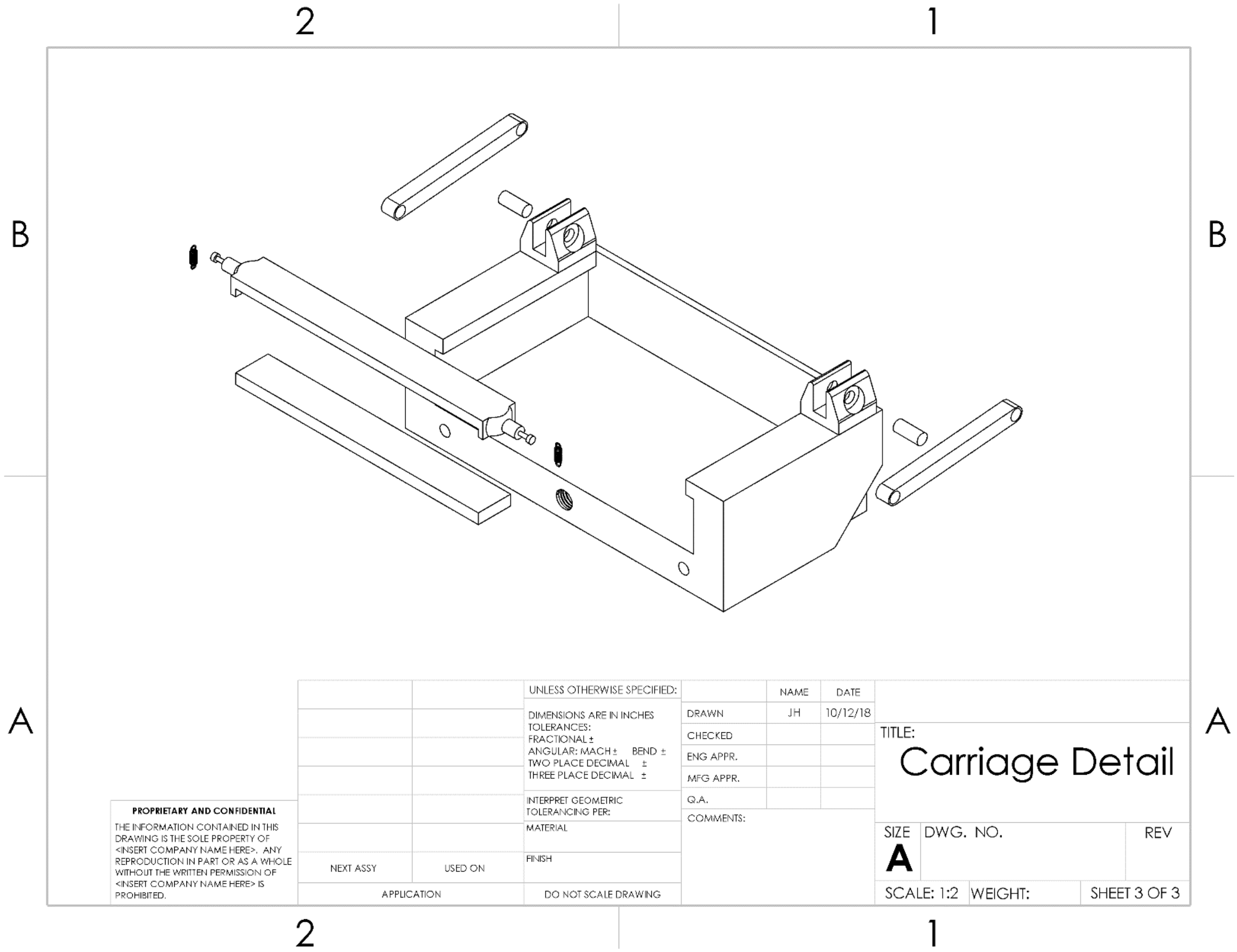


Figure 22. Detailed exploded view of one carriage assembly

Table 6. Preliminary parts list

Part	URL	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
Tygon PVC Clear Tubing	McMaster	6516T150	Clear	$14.00	1	$14.00
Metric 18-8 Stainless Steel Button Head Torx Screws	McMaster	90991A132	Metallic	$7.30	1	$7.30
Metric 18-8 Stainless Steel Threaded Rods	McMaster	90024A232	Metallic	$14.48	1	$14.48
Stepper Motor - 68 oz. in (400 steps/rev)	SparkFun	6627T660	Motor	$16.95	1	$16.95
Peristaltic Pump	Amazon	zjchao202	Black/Metallic	$12.59	1	$12.59
Light Duty Mounted Ball Bearings with Two-Bolt Flange	McMaster	4575N230	Bearing	$9.70	1	$9.70
Light Duty Ball Bearings	McMaster	6383K140	Bearing	$5.42	1	$5.42
Lightweight Linear Motion Shafts	McMaster	5911K110	Shaft	$27.62	1	$27.62
Extension Spring	McMaster	94135K672	Spring	$9.38	1	$9.38
						$117.44

5.2 PROOF-OF-CONCEPT

The following table shows the three goals that the proof of concept should meet before the final design is decided.

Table 7. Proof of concept goals

Goal	Description
Time/Speed of assembly	Device takes 50 seconds for mounting and positioning of tubes prior to gluing.
Tolerances	Precision and accuracy of desired critical dimension for all 10 tubes, joined at the same time ((±.0005 in)
Clamping force/no damage to tubes	With 10 tubes clamped in the device at the same time, a force of 60g applied axially to each tube, one at a time, does not induce movement of the tube.

Accuracy and precision measurements are among the most important features of the device. Since moving parts introduce tolerances and play within the system, it is desirable to have as few moving parts as possible. By using the linear motion slide, the device is limited to one degree of freedom. This is acceptable for the device's functionality, since only one degree of freedom is needed.

The device uses one linear motion slide to push a moving carriage towards a fixed carriage. The slide controls a different mount for the tubing fixtures. Since controlling the distance between the fixtures is critical to the design and success of the device, the type of linear motion actuator is important.

A threaded screw is most desirable. This is because it can be easily controlled with a servo motor and fine tuned to a certain distance.

A threaded screw design is also desirable because it can easily be fabricated cheaply. After some online searches, other options were deemed too expensive for the given budget. An advantage of making the part is that it would save a lot of money. A disadvantage is that it may not be as tight of a tolerance compared to prefabricated devices. This is a significant disadvantage, since the glue joint aide aims to minimize tolerances.

The peristaltic pump would be used in the device to dispense glue. Using the correct amount of glue is important to the device's success. Too much glue could create barriers in the tubing and leak out onto the V shaped inserts on the device. Too little glue will not adequately fasten the tubes together. The pump would be able to dispense the recommended amount of glue. Its use would reduce the risk of over or under gluing the joints and prevent glue from coming into contact with the device.

The most important and heavily weighted part of the design is the ability to get the tube overlap as accurate and precise as possible. It was determined that the level of accuracy and precision needed for the device was not feasible using analog instruments. Therefore, a digital readout system (like lathes and mills) is used to ensure measurements are as accurate as possible.

6 WORKING PROTOTYPE

6.1 OVERVIEW

Our proof of concept (PoC) was a good embodiment of our design, however it was not equipped to meet any of our performance goals. Our PoC was made of wood and did not have functional notches or a threaded rod. Although we could not test any of our performance goals, the PoC was an accurate embodiment of our final design.

The working prototype was essentially a linear slide with two aluminum dowels for support. The prototype had two end plates each press fitted with the two aluminum supporting rods and ball bearings supporting the threaded rod. The carriages were made using the 3D printer. Instead of taping a long hole in the moving carriage, we press fitted a nut into the carriage. This allowed the carriage to move along the threaded rod with ease.

Inserts to hold the tubes were also 3D printed. These inserts had shallow V-shaped notches to hold the tubes in place. The notched inserts were attached to the moving carriages via small circular magnets.

The working prototype was powered by a stepper motor attached to two 3D printed gears. These gears had to be put on an angle due to imperfections in the 3D printing process. The protoype is operated by pressing the button which powers the stepper motor and turns the threaded rod. This causes the moving carriage to advance toward or away for the stationary carriage (depending on which direction the threaded rod was spinning).

6.2 DEMONSTRATION DOCUMENTATION

The final working prototype is shown in Figures 23-25.

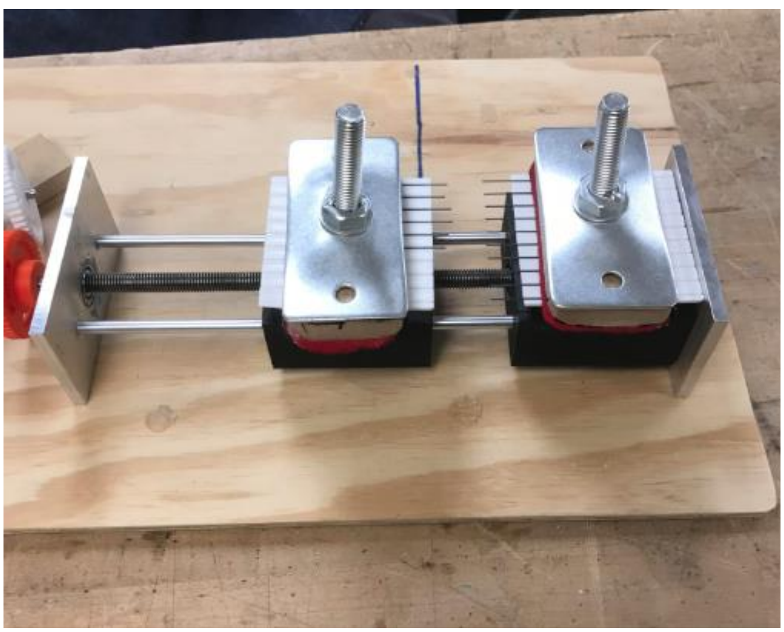


Figure 23: Final Working Prototype: Mechanical Assembly

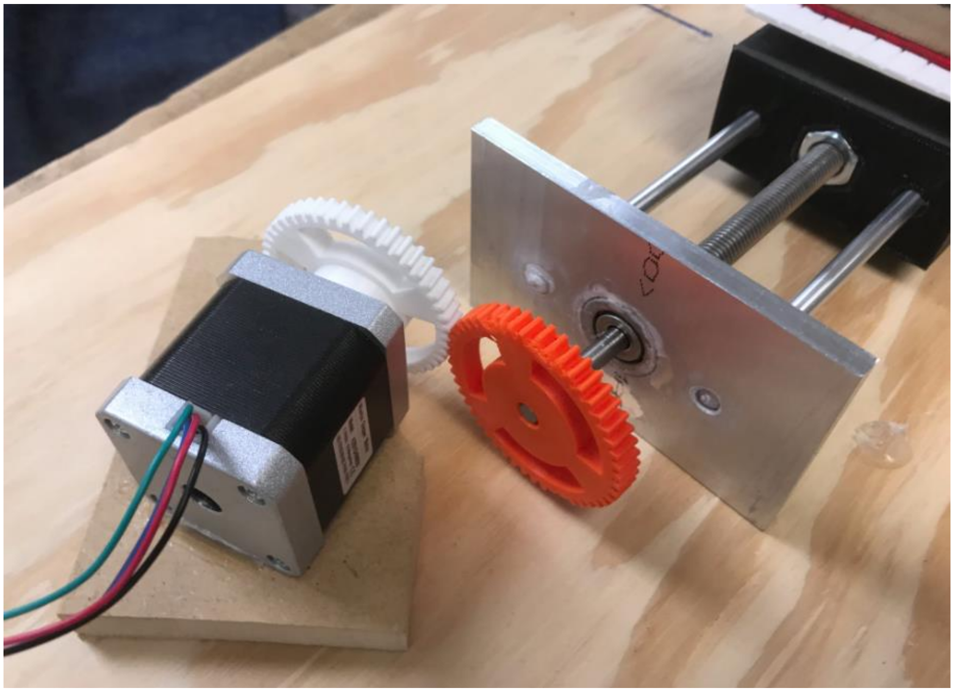


Figure 24: Final Working Prototype: Gears and Stepper Motor

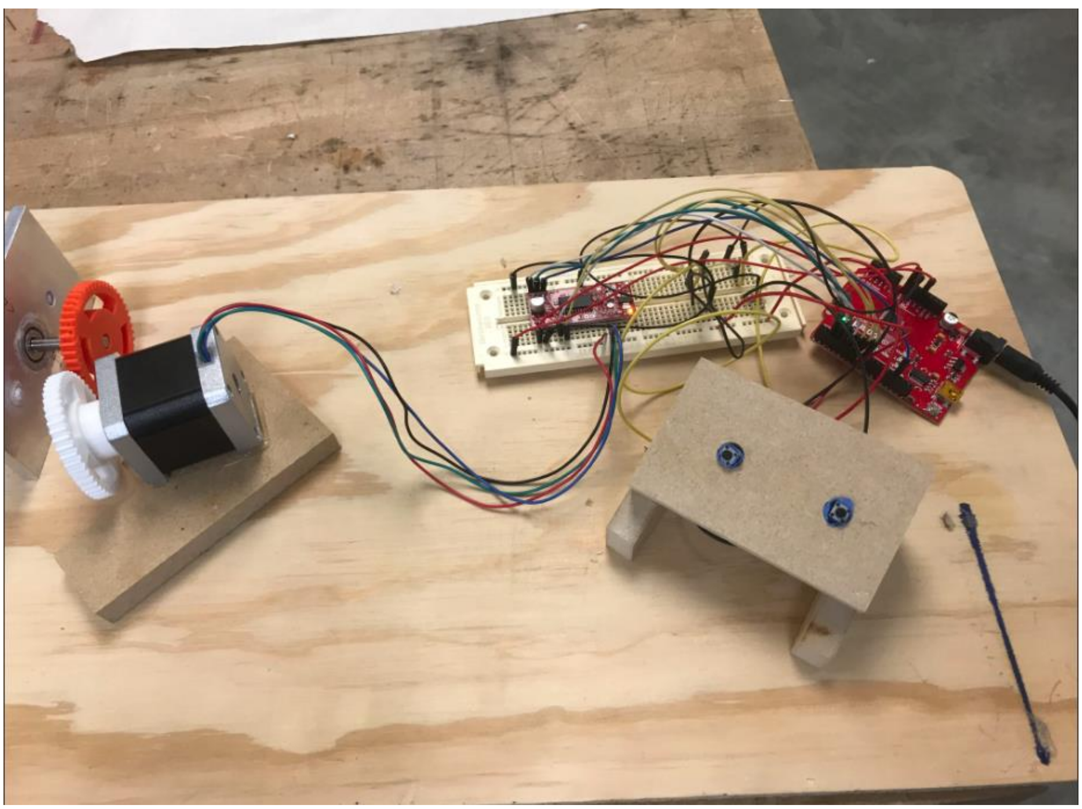


Figure 25: Final Working Prototype: Electronics

6.3 EXPERIMENTAL RESULTS

Performance Goals:

Speed of Assembly:

The purpose of this performance goal was to see if using the device was faster and more efficient than traditional methods. Our goal was to place the tubes in the notches, prepare the device, and run it in a maximum of 50 seconds. After a couple of trials, we were unable to meet this goal with our working prototype.

One of the biggest challenges we faced when testing this performance goal was setting up the tubes. When tubes were placed in the V-shaped notches, they did not stay in the notches and would slide/fall out. We concluded that this problem would be resolved if we made the V-shaped notches deeper. This would ensure the tubes were snug in the notches and not prone to rolling out.

Tolerances:

The purpose of this performance goal was to ensure that the tube overlap was within the acceptable tolerance ranges. Our goal was to operate our device such that we could closely control the tube overlap.

However, we were unable to meet this performance goal in our working prototype. The tolerance we were aiming for was incredibly low, which made measuring it very difficult. We did not have the equipment to measure and ensure the overlap was meeting the tolerance requirement. Furthermore, budget constraints restricted us from being able to use more costly and precise tools and components. To meet this performance goal, we would need a very precise threaded rod and stepper motor. This would allow us to control forward and backward movement with high precision. A digital readout would also aid as a visual real-time measurement of tube overlap.

Clamping Force:

The purpose of this performance goal was to see ensure that the tubes would remain fixed in the notches without being radially crushed by the clamp. To test this goal, we placed our clamp over the tubes and inspected the tubes for movements and deformation.

Our weighted clamp was essentially a wood block with a felt base, attached to a weighted metal handle and plate. The clamp was successfully able to immobilize the tubes in the inserts without crushing them. The felt base allowed the clamp to form fit around the tubes and prevented any individual tube from receiving too much force. The width of the clamp also allowed the clamping force to be distributed across the length of the tube (to prevent high point forces).

7 DESIGN REFINEMENT

7.1 DESIGN FOR SAFETY

Risk Name: Pinch risk
Description: Body part (most likely a hand/finger) gets stuck between the two carriages as they move together
Impact: Injury to the body part. If the advancing button is pressed for too long before noticing, mild bruising or cuts could occur. Anything more severe is unlikely because the motor is relatively weak and may be unable to move the carriage further if the path is obstructed. **(3)**
Likelihood: This issue is very unlikely because the carriage is moving much more slowly than an average reaction time. Also, the carriage only moves when the one of the buttons is pressed so the corrective response of the user is simply to let go of the button. **(2)**

Risk Name: Tubes falling/flying off
Description: Improperly set/clamped tubes hit each other and fall out of the device. In an extreme case, the tubes become airborne.
Impact: The carriage will not be moving at high speeds, so the tubes will not have much kinetic energy even if they become loose from the device. The impact will be minimal as long as the clamps do not fail, which is addressed separately. **(2)**
Likelihood: Tubes naturally fall into place because of the sloped V-shape design of the slots. The clamp also falls naturally into place by spring force. **(1)**

Risk Name: Glue pump dispenses too much glue or from unexpected areas
Description: Tubing leaks at connection or ruptures. Pump could also develop an air bubble that results in an excess of glue dispensed.
Impact: In the worst-case scenario, the glue will end up in a sensitive area, such as the eyes. Otherwise, the glue does not drastically affect most skin. User will likely be wearing eye protection. **(2)**
Likelihood: Tubes will be securely attached and are designed to be flexible. Under normal use, the tubes will not fail for a significant amount of time. Air bubbles will only form if the glue reservoir is nearly empty. The glue level will be visible. **(1)**

Risk Name: Short circuit
Description: Wiring is damaged/get water spilled on it.
Impact: The only effect will be that the device stops working. **(1)**
Likelihood: The electronics will be physically shielded by a cover. The only way for this to happen is during maintenance or if the power cord casing is damaged. **(1)**

Risk Name: Springs become detached in a projectile manner
Description: Springs get detached from the clamp/device. Especially relevant when the clamp is in the raised position (spring is at max tension).
Impact: The springs are light but will potentially be moderately energetic. However, the stiffness has been selected to be just enough to hold the tubes in position. If the spring does hit the face or some other part, it might scratch. **(5)**
Likelihood: Springs are securely attached. Most likely failure is if the spring breaks along its length, which is unlikely to happen if there are no defects in the spring. **(3)**

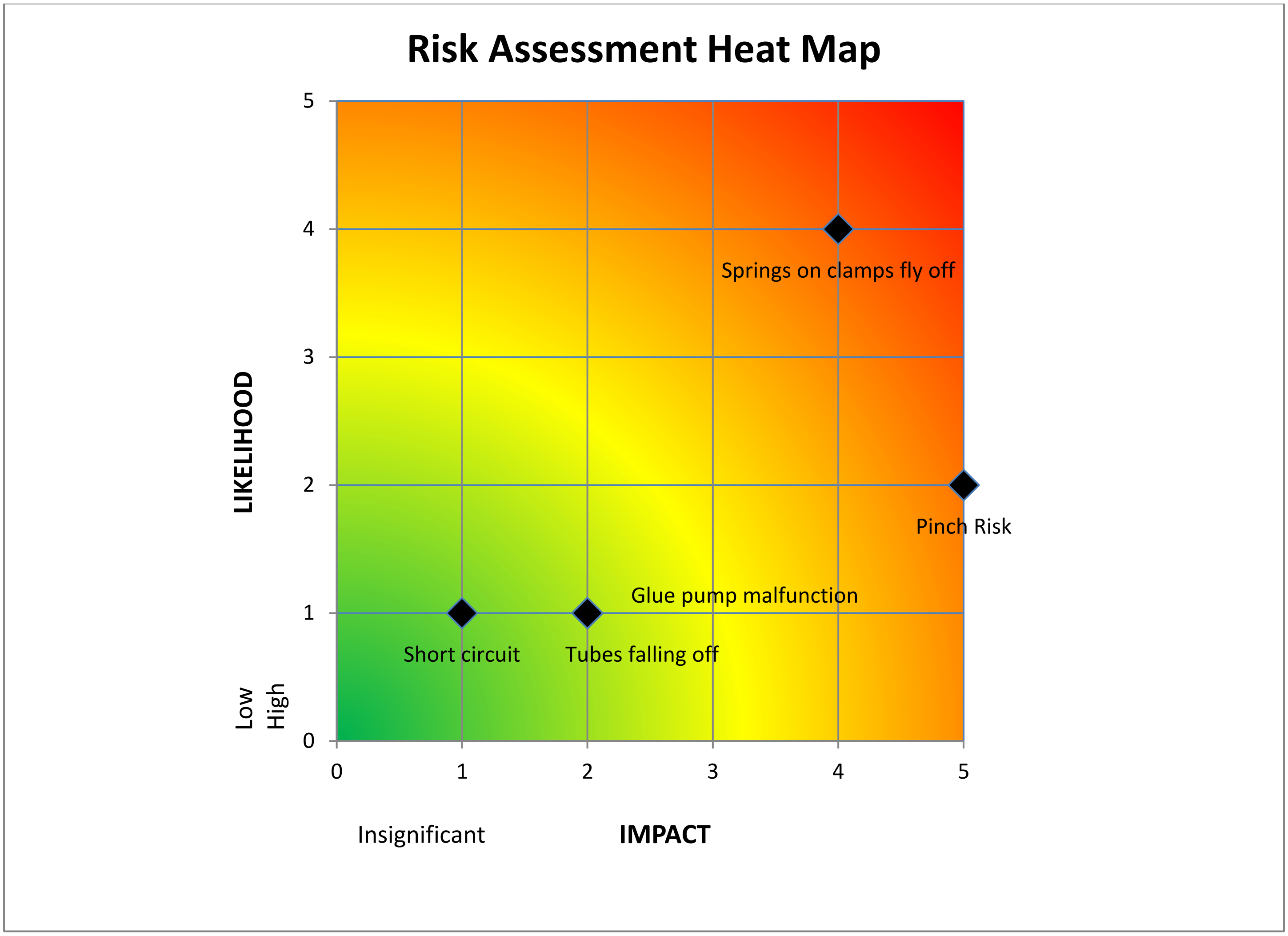


Figure 26. Risk Assessment Heat Map for Glue Joint Aide

The most important risk to manage is the spring failure. It is most likely to happen and has the most potential for injury. The next most important factor is the pinch risk. While the potential injury is more extreme, the likelihood is far less. This is because it requires a button to be pressed for long after the issue should be detected or can cause harm. The pinch risk will most likely cause harm in the extreme case that some inanimate object has fallen on the button; however, because the whole device is so small, the user will always be able to reach the button to clear the obstruction. The other three risks have about the same priority. They are all highly unlikely in the current design. The electronics are internal. The device is designed to guide the tubes into the correct position. The glue pump failure is very unlikely with a non-defective tube. Also, the impact of the events is very low. The glue pump malfunction is in most cases more of a cleanup inconvenience than a safety hazard. The electronics are running with very little power/current. Even if it does short circuit, nothing will explode. The tubes falling off do not have the potential to be loaded in such a way that they move quickly.

7.2 DESIGN FOR MANUFACTURING

Draft Analysis:

A draft analysis for an injection molding was carried out on our most simple part. This is shown in figure 2 below.

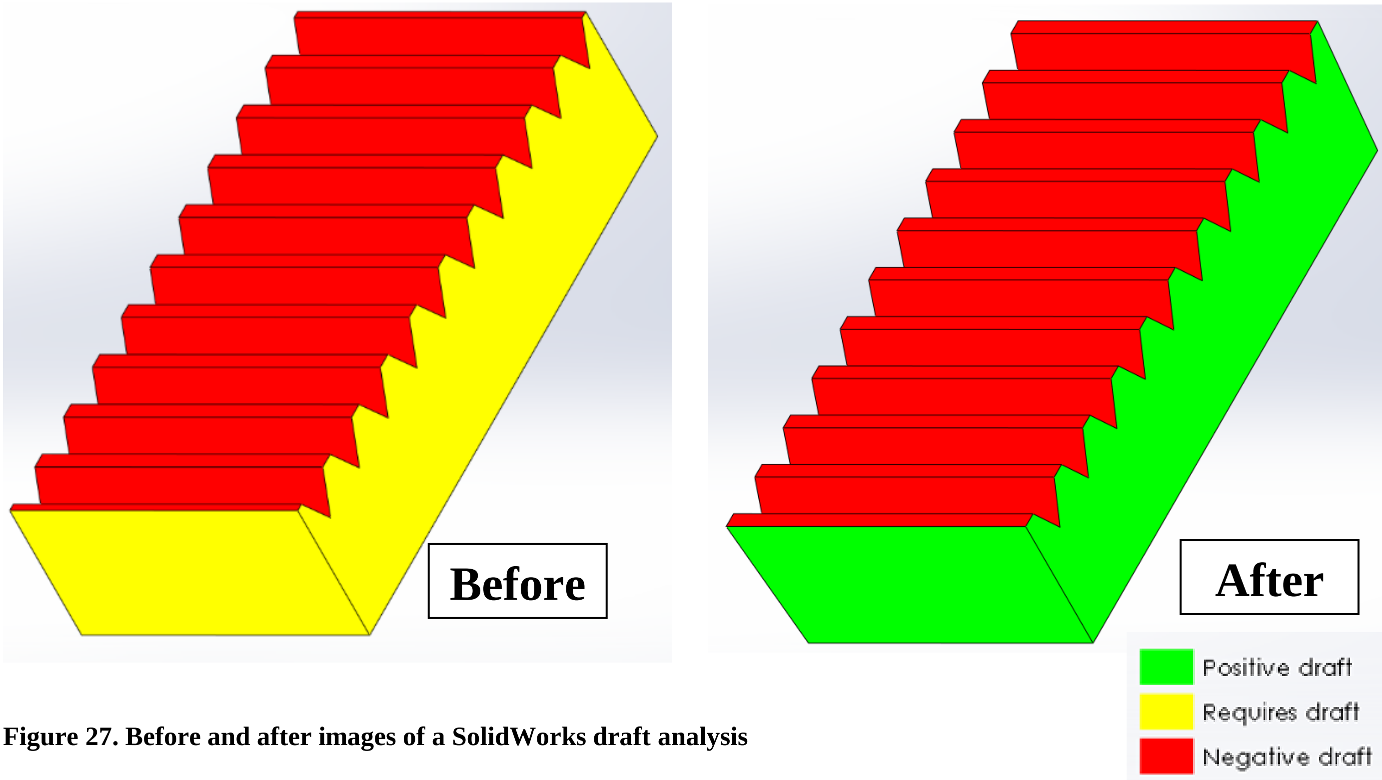


Figure 27. Before and after images of a SolidWorks draft analysis

The vertical faces of the part shown in Figure 27 had to be modified to fulfill draft requirements. The draft of the vertical faces was set at 3°. This solved the "Requires Draft" requirement, and the yellow sections of the part turned green. Therefore, the part was successfully modified to be compatible for molding.

DFM Analysis

We also carried out a Design for Manufacturing (DFM) Analysis for our carriage. The results of the DFM analysis is shown in Figures 28 and 29 below.

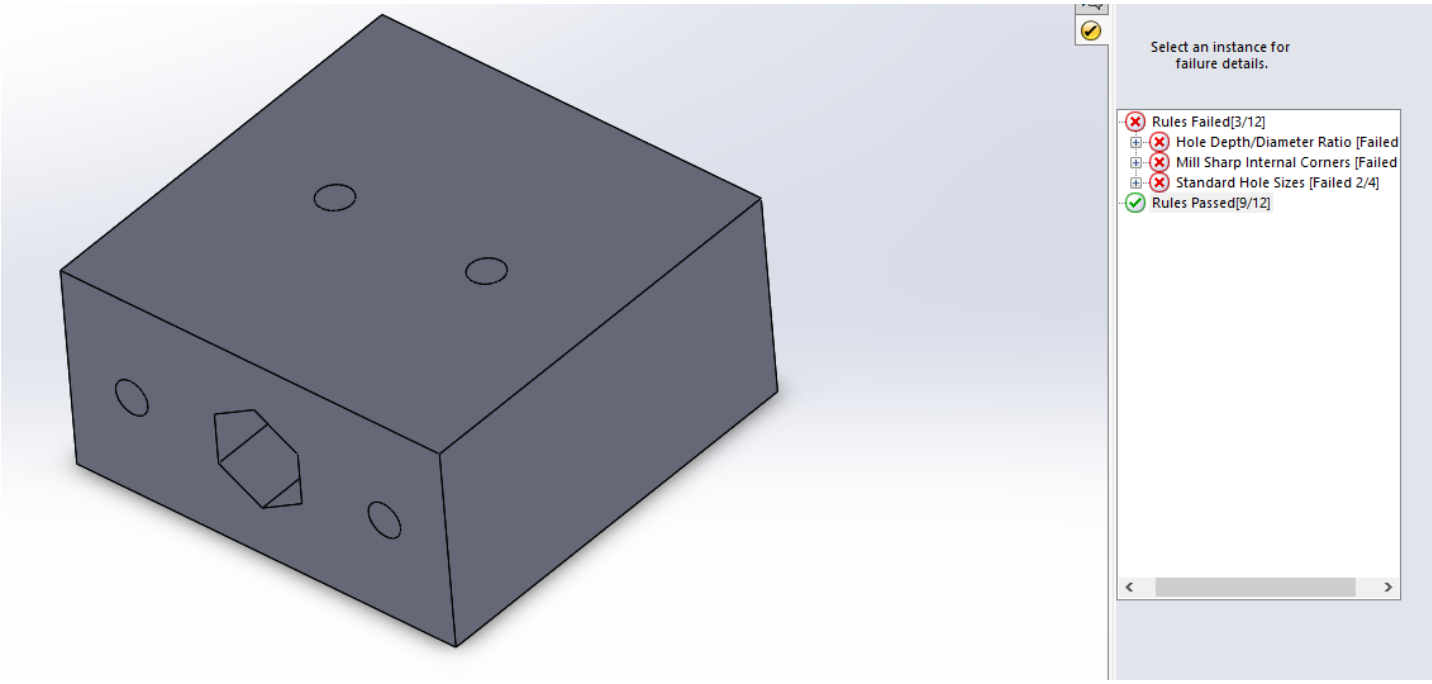


Figure 28. Turn with mill drill manufacturing process results with errors

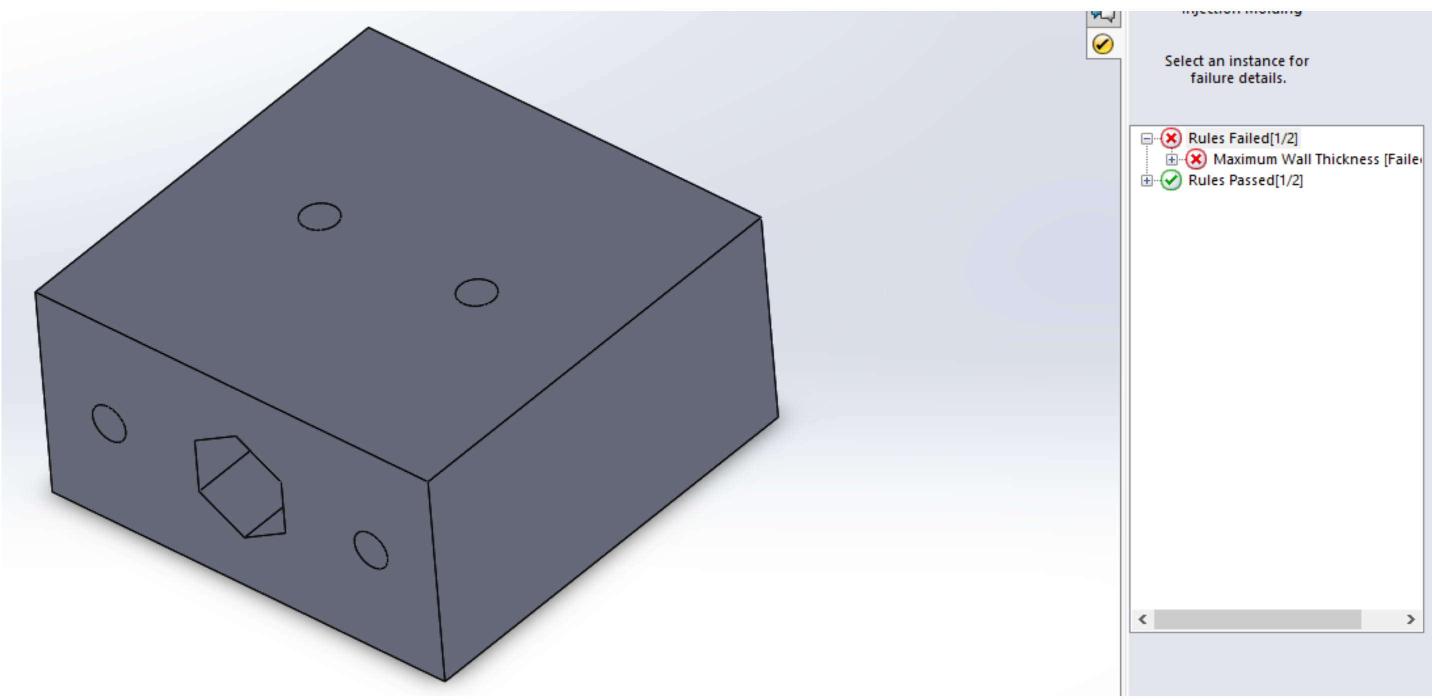


Figure 29. Injection mold manufacturing process results with errors

We carried out our DFM analysis on the moving carriage. The two manufacturing processes tested were “turn with mill drill” and “injection molding”. The “turn with mill drill” process failed 3/12 rules while the “injection molding” process failed ½ rules. From looking at the failed rules, it can be concluded that the part cannot be modified to satisfy manufacture criteria for “turn with mill drill” and or “injection molding”.

7.3 DESIGN FOR USABILITY

Vision Impairment

A vision impairment such as color blindness would not affect the usability of our device. Our device is made of components that are not color coded nor require color coding to operate. If a user does not cannot see a certain color, it will in no way limit their ability to use the device.

Loss or blurred vision (such as presbyopia) could have an impact on the user's ability to read the numbers on the digital readout. This would only occur if the digital numbers were very small. Therefore, a design modification would be increasing the size of the numbers so they are bigger and not blurry.

Hearing Impairment

A hearing impairment will not affect our device. Our device does not make any critical or warning sounds, so hearing is not necessary for its operation. The only sound the device would make would be the hum of the motor running. It could be useful to hear the motor running to know when the device is on and operating. However, if this is the case, the carriage will also be moving, so it will be obvious that the device is running.

Physical Impairments

The only physical impairment that would affect usability would be missing/no fingers. It is necessary that the user have fingers to load tubes into the device to set it up and make it run. There are not any particular modifications to the device that we could make to get around this impairment.

Language Impairments

A language impairment/barrier will not affect the usability of our device. Language is not used in the set up or operation of the device. However, the digital readout uses numbers, so the user must be familiar with the numerical system and units being used. Luckily, since lab technicians are the expected users of our product, it is assumed that they have mathematical and scientific knowledge about how to use numbers and units. Therefore, we do not need to make any design modifications for language impairments.

Control Impairments

Control is critical to ensure that the tubes are placed correctly in the notches. If tubes are placed incorrectly, tubes may buckle or fall out. Any shakiness or impairment in coordination will make it hard to place the tubes in the notches. A modification that will make this less of an issue would be to make the notches wider. With wider notches, tubes can fall into place. Wider notches do not require as precise of a placement as more narrow notches.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

8.1.1 Does the final project result align with its initial project description?

The final project result does align with the project descriptions. We were successfully able to make a device that could be used to glue tubes together. However, our final device was lacking in the precision needed to make the device useful for its intended purpose. We were able to make the overall physical design, but time and costly fine tuning are required before our device can meet its performance goals.

8.1.2 Was the project more or less difficult than expected?

The project was more difficult than expected. We kept changing our design because new problems or ideas popped up throughout the design process. We knew this would happen since the design process is iterative and frequently changes.

Our project was also more difficult because we had to create parts using the limited resources we had. For example, we were originally going to make the notched inserts out of metal and machine the V-shaped notches. Due to resource constraints, we were not able to do this. As a result, we 3D printed the notched inserts. This caused a lot of problems because these inserts had the tightest tolerances of our entire device and 3D printing caused a bunch of issues such as warping and grooves.

Overall, the project was more difficult because the level of precision needed was very hard to achieve using limited resources.

8.1.3 On which part(s) of the design process should your group have spent more time? Which parts required less time?

We think more time actually building the physical model would have led to a better final product. We agree that a lot of time should be spent planning and brainstorming, but we almost all of our changes and adjustments came as we were physically building our device. We stumbled on factors we did not consider and we were able to work out possible solutions.

With that being said, we think a lot of the advanced planning and models were not necessary for our final design. We spent a lot of time in the beginning coming up with models and refining our design. However, the models we used and researched weren't applicable to our working prototype.

8.1.4 Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

The notched inserts were probably the hardest component to build and assemble. We decided to 3D print the inserts because it was by far the best available option. However, we struggled with warping and misalignment in the 3D printed parts. We had to print the inserts many times because warping was throwing off the alignment of the notches. We also had to figure out a way to make the insert secure on the carriage but also removable.

The easiest part of the prototype was the linear slide mechanism. We thought the precision of this mechanism would be hardest to control in our manufacturing. However, we created a very good linear slide on our first try. The carriages were perfectly aligned and the mechanism worked.

8.1.5 In hindsight, was there another design concept that might have been more successful than the chosen concept?

Looking back at our design concepts, we think we chose the best design. The other designs were either too big, wouldn't meet our performances goals, or well outside of the time and budget constraints of the course. Some of our original designs called for using concentric chucks, similar to a lathe, to line up the tubes. However, loading 20 tubes into 20 chucks would be timely and require a large device.

Unlike our alternative designs, our chosen design was simple, compact, and easy to use. It was definitely the best option for the given performance goals.

8.2 DESIGN RESOURCES

8.2.1 How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

Since our device was intended to be a scientific instrument, we decided that lab standards would be relevant to our project. Our initial designs also had included chucks, so we also researched standards revolving around chucks and their use. We did not have particularly high voltages, currents, or fast moving objects, so many safety codes were not necessary.

The standards we chose for our project did not influence our design concepts. The standard we needed for lab equipment was pricy and we could not acquire it. Since we did not end up using chucks in our final design, standards for chucks were not needed.

8.2.2 Was your group missing any critical information when it generated and evaluated concepts?

The ability to obtain the conceptualized parts was significantly overestimated. This past summer when working at Vortex Surgical, I took for granted the ability to design a part in CAD and have that ordered from a precision machining company. The product that was delivered, was exactly what we wanted. During this assignment, it was difficult to find the means to create the parts that we had designed. Access to the machine shop was limited, and the machine shop did not contain the tools that were necessary for machining of a critical component. When this component was 3-D printed, warping of the part and the inaccuracy of 3D printing caused problems in terms of the part working in conjunction with the other components.

8.2.3 Were there additional engineering analyses that could have helped guide your design?

We do not think there were additional engineering analyses needed to guide our design. There were not any high loads or stresses in our final design, so FEM, stress, and strain analysis were not needed.

Originally, we were worried about vibration of the motor potentially dislodging and moving the tubes. However in our final design, vibrations were not an issue, so not vibrational analysis was needed.

Since the hardest piece for us to manufacture was the notched insert, a potential trade study on the part and its manufacturing methods could have been beneficial. However, this would have taken too much time for the requirements of the course.

8.2.4 If you were able to redo the course, what would you have done differently the second time around?

We would have picked a different project to pursue. We believe this device and the precision required for this device to work well enough to be used by our customer was outside the scope of this class. This device was meant to be used as lab equipment and perform with a certain consistency and accuracy that is expected of lab equipment. We probably would have decided to pursue the automatic French press coffee maker. The coffee machine was in the scope of this class as is does not require “finished” materials, tight tolerances, or a particularly high level of confidence. If a small amount extra of coffee grounds end up in the coffee, it’s not a big deal. If the tube fixture doesn’t perform properly and causes a medical device to malfunction during surgery, that is a VERY big deal.

8.2.5 Given more time and money, what upgrades could be made to the working prototype?

Given more time, the device must be calibrated to be able to perform accurately. Given more money, a ball screw should have been used in conjunction with the carriage instead of a nut. The ball screw would provide a higher level of precision. In addition to the ball screw, a digital read out should be incorporated to provide a real time indication of where the carriage, and subsequently the tubes are located. Also, ideally none of our parts would be 3D printed. The parts should be made of aluminum or Delrin and should be machined by a professional to ensure accuracy.

8.3 TEAM ORGANIZTION

8.3.1 Were team members' skills complementary? Are there additional skills that would have benefitted this project?

Team members' skills were complementary. Specifically, Jason's knowledge of circuits, Arduinos, and overall electronics was valuable because this was an area that neither Matt nor Griffin particularly excelled in. Griffin's knowledge that he gained during his internship was helpful because he knew a lot about the industry and the needs of the consumer. He was also aware of common materials used in the industry and challenges that are commonly faced. Matthew's organizational skills and encouraging words were excellent motivation and kept us on schedule. While his machining was acceptable, it would have been helpful if a team member had exceptional machining skills and was well versed in tolerancing (i.e. press fit a shaft through a ball bearing. This is something we were not taught how to do).

8.3.2 Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

This design experience was frustrating because of our budget and access need for precision. While we do believe this design is valid in theory and will work well assuming the parts are properly made, any design project relating to this idea is not achievable without professional help (professional machining). The idea of design projects is still something that we are very open to attempting. However, we are not inspired to pursue a project relating in any way to our current project.

APPENDIX A – COST ACCOUNTING WORKSHEET

Table 8: Final Cost Accounting Worksheet

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	Stepper Motor	SparkFun	ROB-10846	Motor with silver shaft	$16.95	1	$16.95
2	SparkFun RedBoard	SparkFun	DEV-13975 ROHS	Microproccesor	$19.95	1	$19.95
3	Wall Adapter Power Supply	SparkFun	TOL-00298 ROHS	Wall Plug	$5.95	1	$5.95
4	Mini Pushbutton Switch	SparkFun	COM-00097 ROHS	Buttons	$0.35	2	$0.70
5	EasyDriver	SparkFun	ROB-12779 ROHS	Smaller chip	$14.95	1	$14.95
6	SchmartB Headers	Microcenter (In Store)	999805	Male-male connection pins for breadboard	$5.00	1	$5.00
7	Solder Prototyping board	Microcenter (In Store)	422790	Perforated solder boards	$4.99	1	$4.99
8	S/H from SparkFun	-	-	-	$12.89	1	$12.89
9	Torx Screws	McMaster	90991A132		$7.30	1	$7.30
10	Light duty mounted ball bearing	McMaster	4575N23	Mounted bearing	$9.70	1	$9.70
12	Ball bearing, Light duty	McMaster	6383K14	Inset Bearing	$5.42	2	$10.84
13	Tight tolerance aluminum rod	McMaster	9062K26	Plain rod	$13.86	2	$27.72
14	Stainless steel threaded rod	McMaster	90024A232	Threaded rod	$11.48	1	$11.48
15	6061 Aluminum Sheet	McMaster	8975K514	Sheet metal	$27.43	1	$27.43
16	Power Supply	Microcenter (In Store)		12V, 2A	20.91	1	$20.91
Total:							$196.76

APPENDIX B – FINAL DESIGN DOCUMENTATION

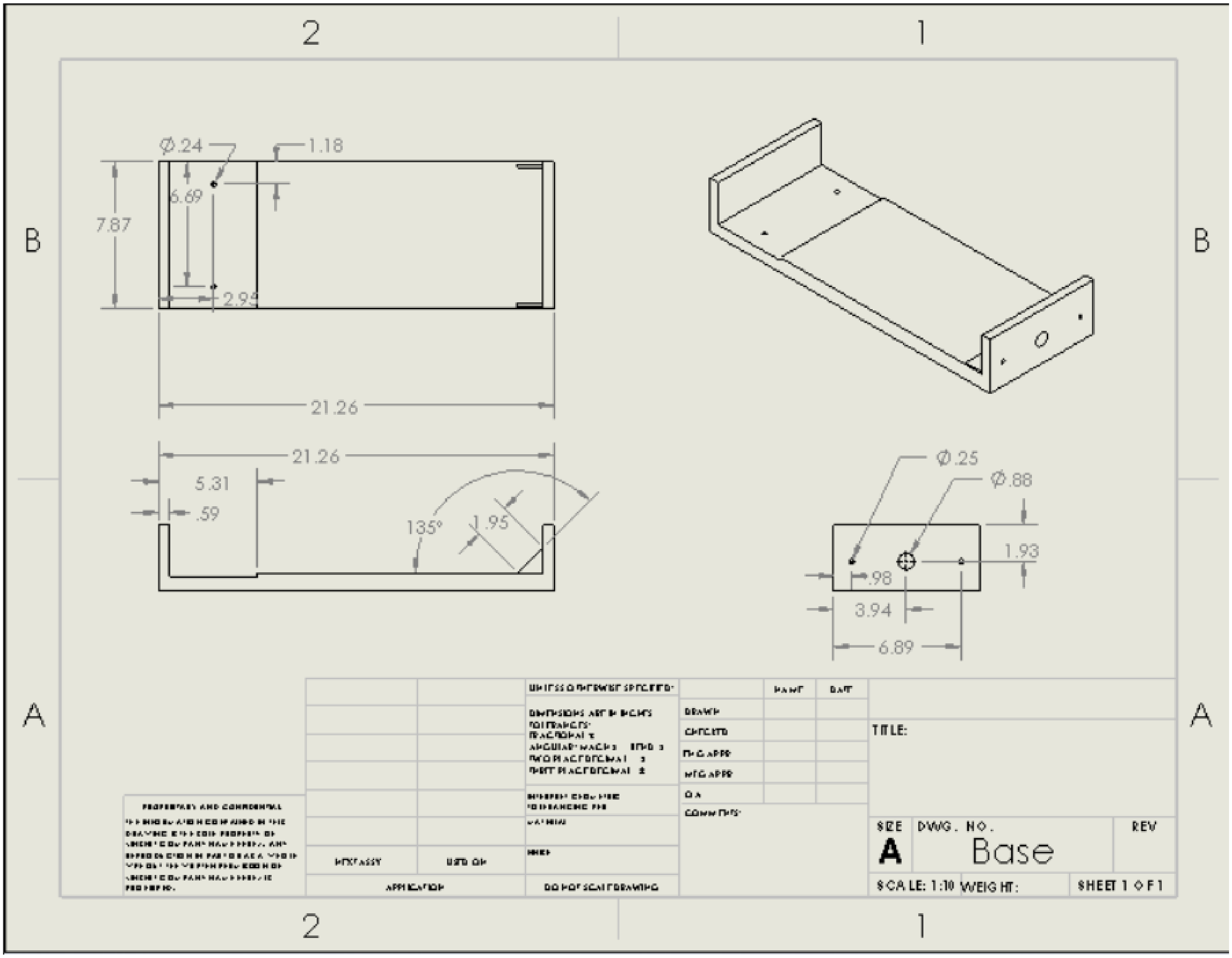


Figure 30: CAD Drawing of the Base

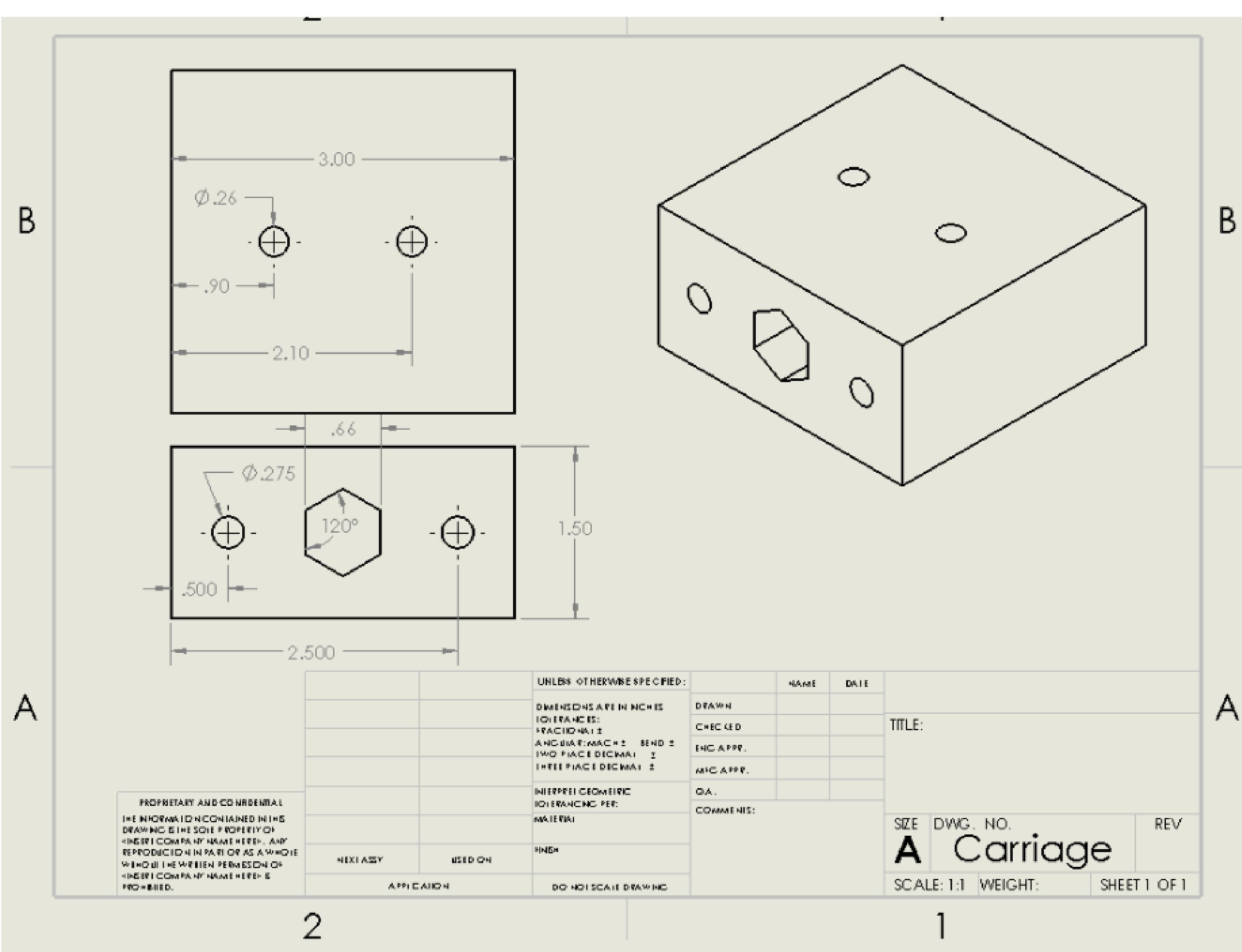


Figure 31: CAD Drawing of Carriage

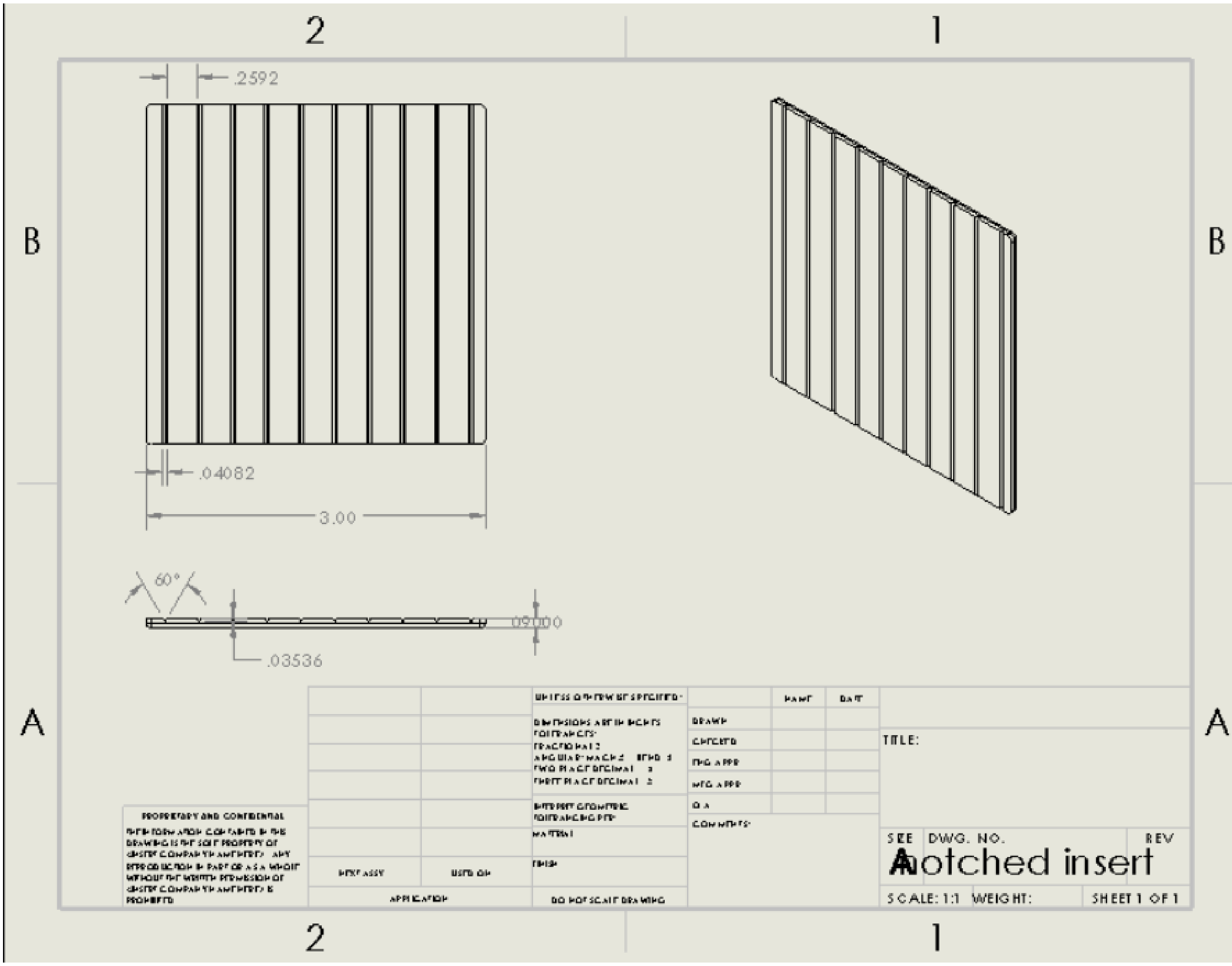


Figure 32: CAD Drawing of Notched Insert

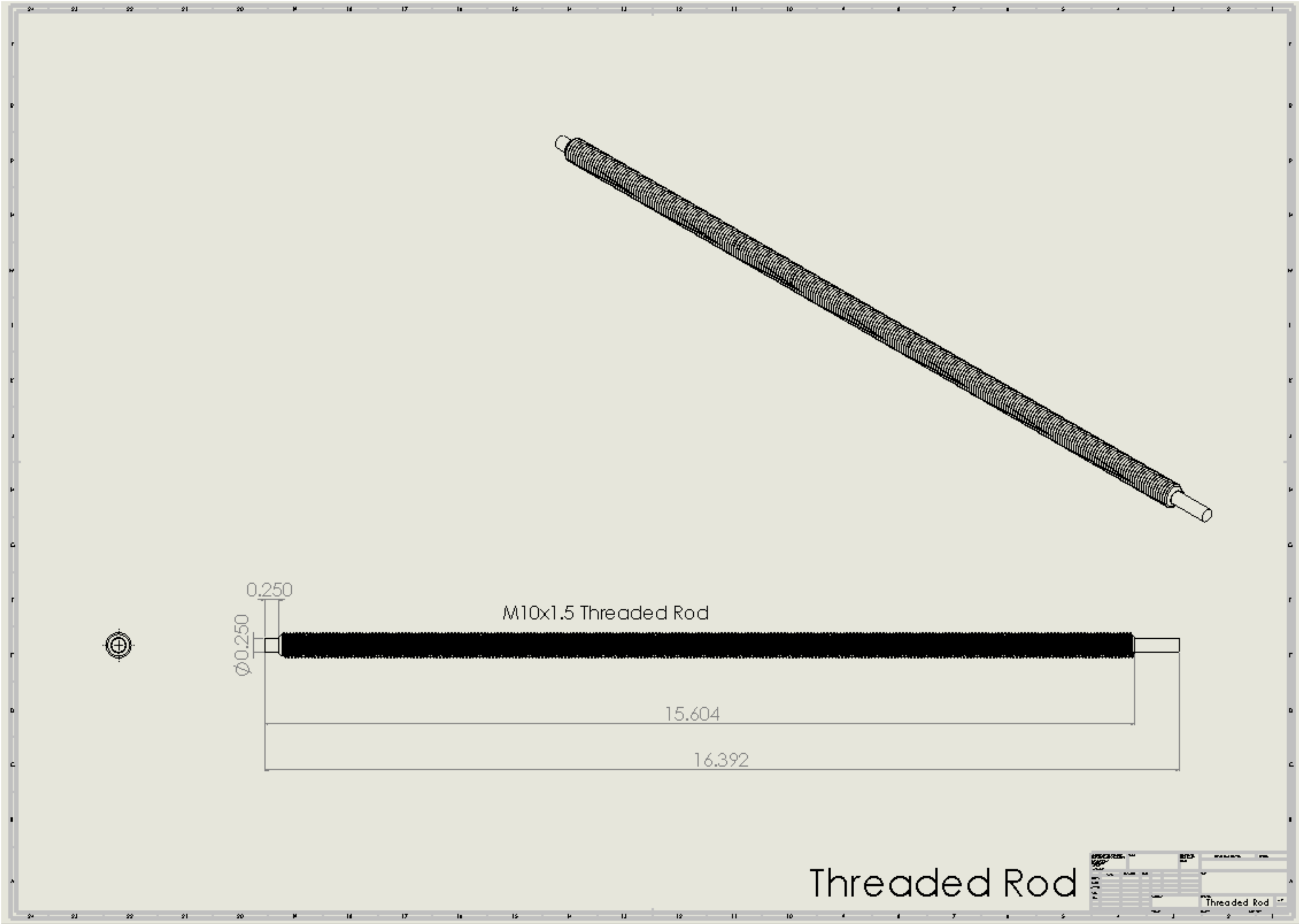


Figure 33: CAD Drawing of Threaded Rod

APPENDIX C – ADDITIONAL DETAILED DOCUMENTS: SKETCHES

Although we scanned our sketches at 300 DPI, we felt that a picture would be clearer. We have attached these additional copies of sketches that may be clearer than the scanned copies. For the final report we will not include repeats of sketches, but for the purpose of this assignment, we felt these additional copies could make our sketches clearer.

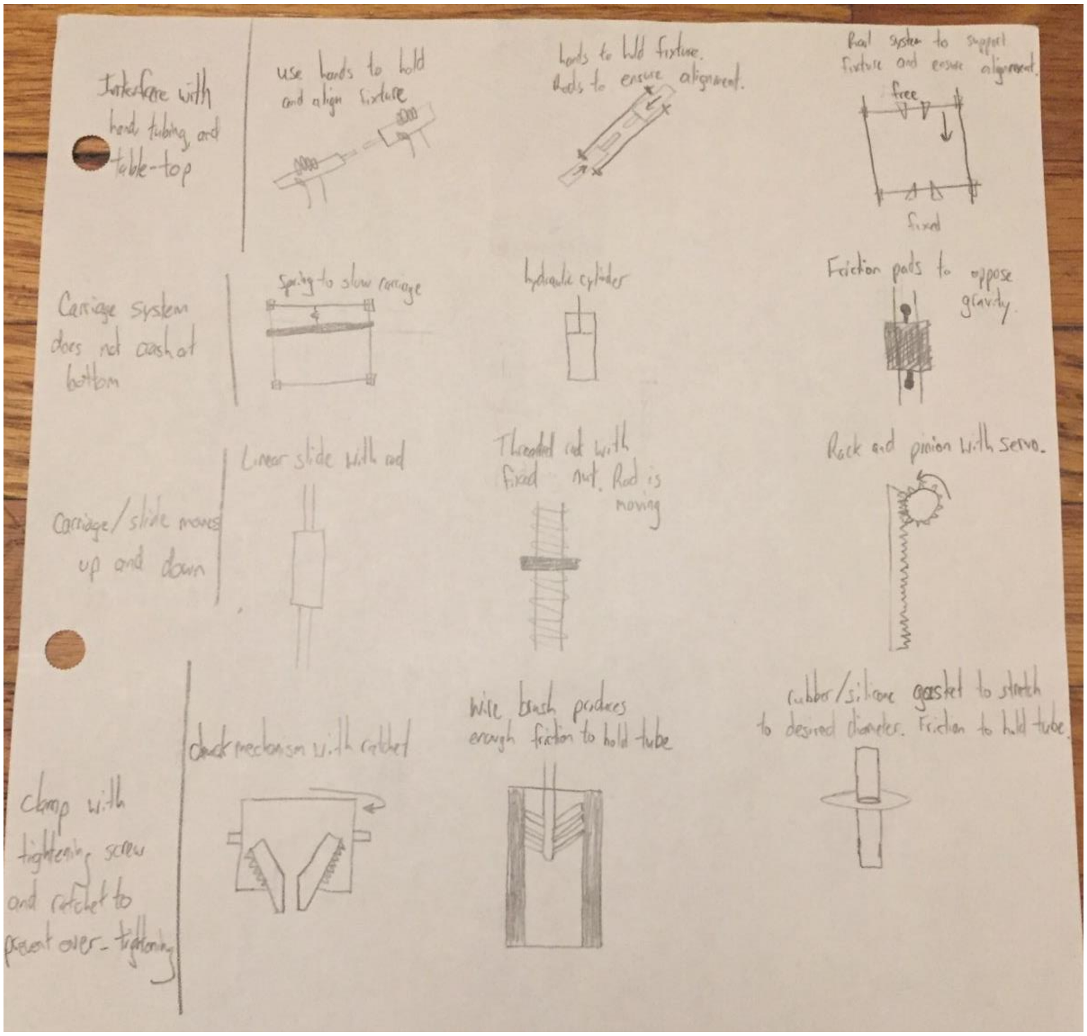


Figure 34: Mechanism Sketches

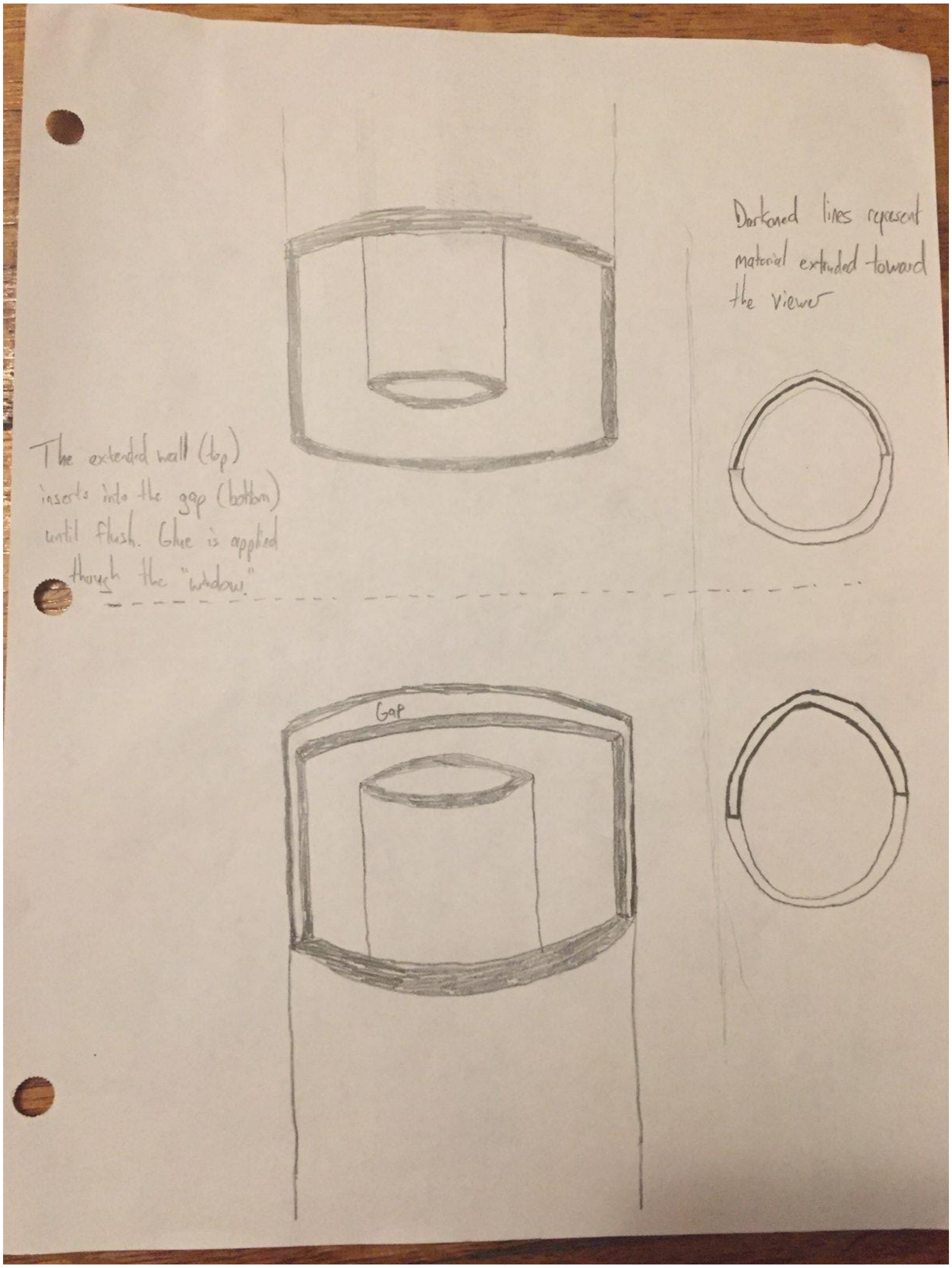


Figure 35: Mechanism Sketches

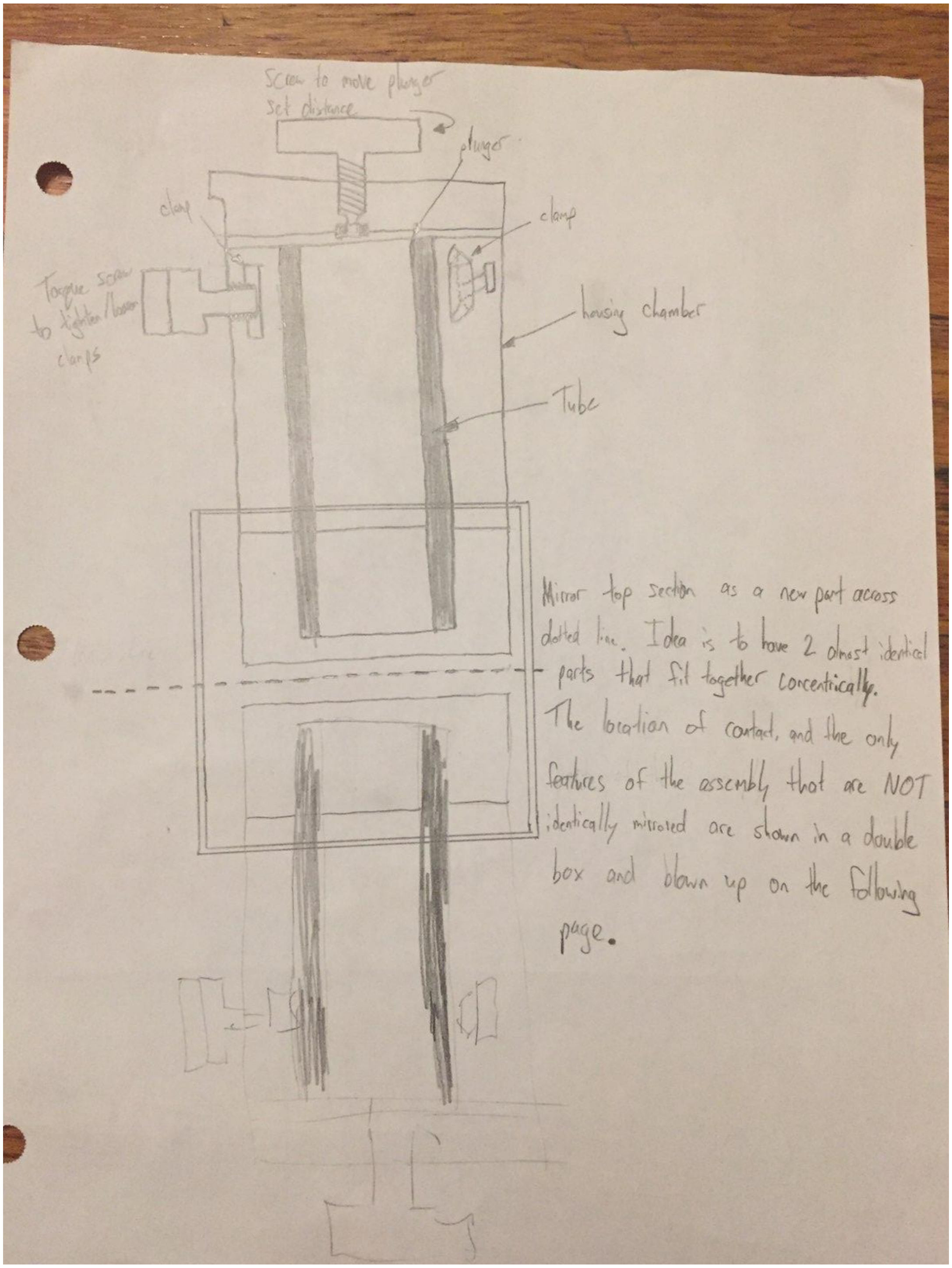


Figure 36: Mechanism Sketches

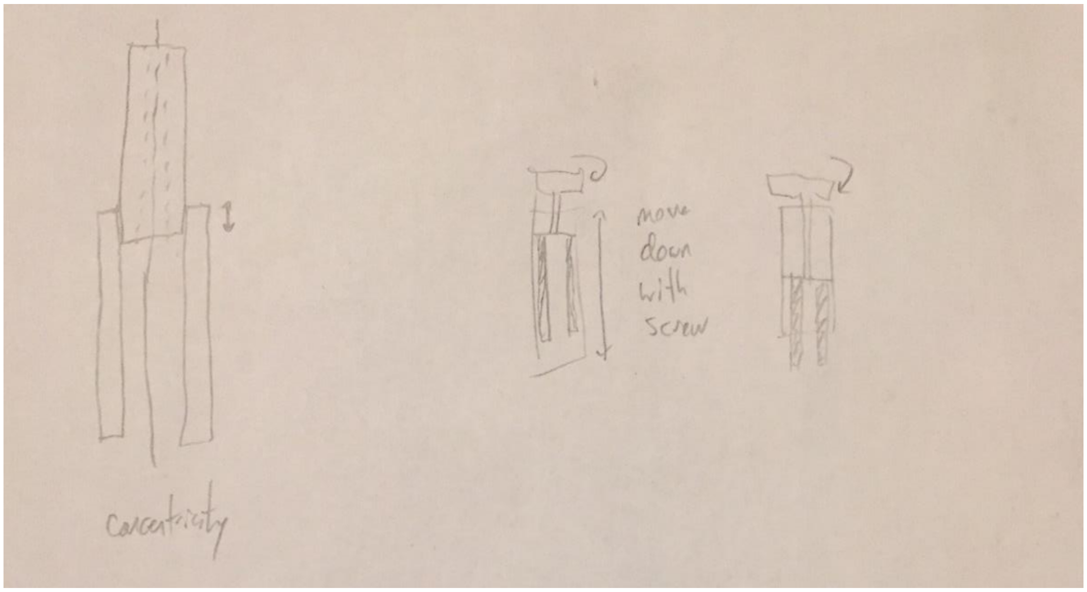


Figure 37: Mechanism Sketches

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[1] "1/2 Motor HP Floor Drill Press, Belt Drive Type, 14-1/8' Swing, 120 Voltage." *Grainger - For the Ones Who Get It Done.*, www.grainger.com/product/DAKE-CORPORATION-1-2-Motor-HP-Floor-Drill-Press-40F110

[2] "Friction Thimble Digimatic Micrometer, 0-1'/0 to 25mm Range (In./Mm)." *Grainger - For the Ones Who Get It Done.*, www.grainger.com/product/MITUTOYO-Friction-Thimble-Digimatic-4LA76.

The first two citations are from Granger, a trusted manufacturer of many engineering parts and tools. We used images of Granger Products from these sources

[3] "Mechanical Properties for Common Stainless Steels." *SSINA: Stainless Steel: Composition/Properties*, www.ssina.com/composition/mechanical.html.

This citation was used to acquire properties of stainless steel. It was a credible source since it was a database of material properties.