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MEMS 411: Fast Pill Cutter

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SP21 MEMS 411 Mechanical Engineering Design Project

Fast Pill Cutter

This design project attempted to create a new pill-cutting device to help pharmacy technicians split pills quickly, precisely, and safely. The product was intended to occupy a competitive niche with current devices on the market, prioritizing increased cutting speed with potentially greater cost.

In order to achieve this objective, the team chose a rotating cutter design, with a blade sweeping through a circular arc of pills nestled in shaped wells. The design utilizes an automatic impulse mechanism consisting of a network of springs and a trigger arm. When the cutting blade is pressed against a pill, the springs store up energy which is automatically released a certain cutting force is achieved. The resulting impulse cleaves the pill cleanly in two. This design was iterated and updated many times, incorporating various engineering models and taking advantage of the speed of 3-D printing to physically test each new configuration.

The final prototype was tested against one of its most popular competitors. It was found that the prototype was equal to the competitor in cutting speed and cost and required less mechanical work per pill. However, the prototype was slightly less precise in cutting than the competitor. Overall, this design requires some further tuning to truly find a market niche, but the concept has a lot of potential for development.

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1 Introduction

Pharmacies often have to split pills. This happens when the standard pill dosage and the common prescription dosage do not match. Metoprolol is a common example of this as it comes in 25 mg pills that need to regularly be split in half. These pills currently must be split with a manual pill cutter, the most common of which cuts a single pill at a time. This results in a large amount of time each week devoted to cutting pills. In this report the reader will find a proposed solution in the form of an automatic pill cutter (PC). The goal is to create a pill cutter which meets the customer needs and decreases the amount of time spent on cutting pills each week.

2 Problem Understanding

2.1 Existing Devices

The three top pill cutters on the market appear to be the Multiple Pill Splitter, The Equadose Pill Splitter, and Ezy Dose Pill Crusher and Grinder. The Multiple Pill Splitter is our closest competitor as it is the only splitter that is capable of cutting more than one pill at once.

2.1.1 Existing Device #1: Multiple Pill Splitter

Figure 1: Multiple Pill Splitter (Source: Amazon.com)

Link: http://www.pillcut.com/
Description: The Multiple Pill Splitter is a manually operated splitter capable of splitting between five and fifteen pills, depending on pill size. The device functions by aligning pills in a row between two spring loaded arms used to hold the pills in place. The user then closes the cap over the line of pills, cutting the pills in half with a stainless steel knife. This product is one of the more expensive options, but it also comes with a lifetime warranty, making it an attractive option for buyers.

2.1.2 Existing Device #2: The Equadose Pill Splitter

Figure 2: Equadose Pill Cutter: Top View

Figure 3: Equadose Pill Cutter: 3-D View

Link: https://www.amazon.com/dp/B00U84Q8OK?tag=medconsumersus-20
Description: The Equadose Pill Splitter both cuts and stores pills using its rotating cutting wedges. The pill is placed between the wedges and cut; the pill halves can then be stored in the cylindrical chambers by sliding the plastic cover over the top of the device. The Equadose Pill Cutter is made primarily of high-quality metal parts, making it durable and reliable. One major drawback is that the cutter can only cut and store one pill at a time, making mass cutting impractical. The device is also rather costly at $30.

2.1.3 Existing Device #3: Ezy Dose Pill Crusher and Grinder

Figure 4: Ezy Dose Pill Crusher and Grinder

Link : https://www.amazon.com/dp/B000E0ZHFO?tag=medconsumersus-20

Description: This product contains multiple components necessary for medication proportion control. Pill scorer, pill crusher, organizer, and pill drinking cup are integrated into one single device. This device is helpful for anyone with the need to consume medication on daily basis. This device can also hold up to 4 aspirin-sized pills for traveling people.

2.2 Patents

2.2.1 Pill Cutting and Storage Device (US 10,245,215 B2)

The patent describes the design of a manual pill cutter and storage device. The cutter consists of a rotating shell housing two hollow chambers, with a cutting wedge separating them. The two halves of the shell rotate separately. The device works by separating the halves, aligning a pill with the cutting wedge, and bringing the halves together to cut the pill. Each half of the split pill will then rest in one of the hollow chambers. The pills can be stored long-term by closing a rotating plastic cover, sealing off the hollow chambers.

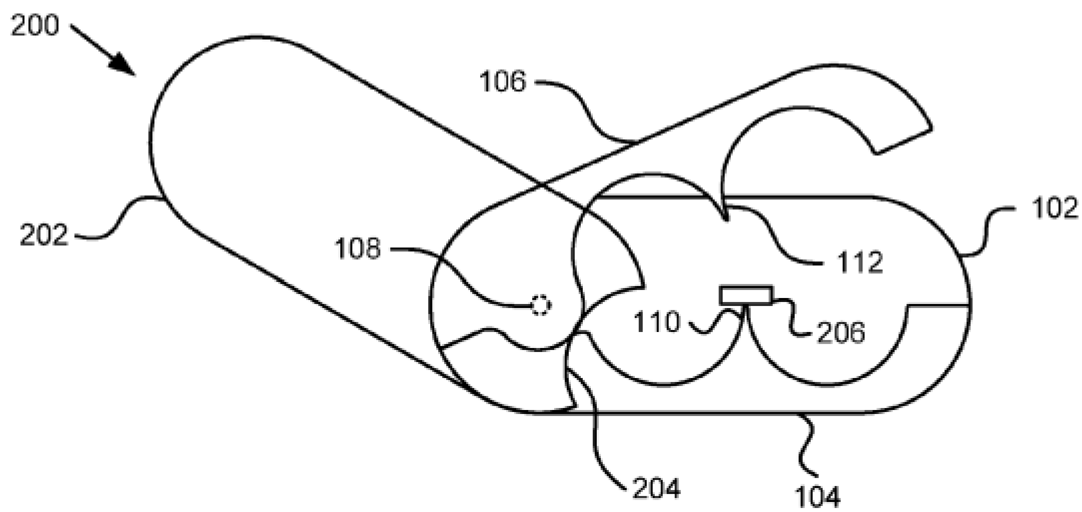


Figure 5: Patent image for US 10,245,215 B2.

2.2.2 Multiple pill or tablet splitter (US 9,827,165 B1)

The patent describes the design of a manual pill splitter that can handle multiple pills. The cutter is made up of two primary sections. The top section (#50 Fig 6), which contains the blade, and the bottom section (#11 Fig 6), which holds the pills in place to be cut. The guide rails on the bottom (#30 in Fig 6) can be adjusted to handle multiple shapes and sizes of pills. The pill cutter can handle up to 9 pills at a time. The splitter works by centering and securing the pills under the blade. Then the top is closed on the pills splitting all the pills at once.

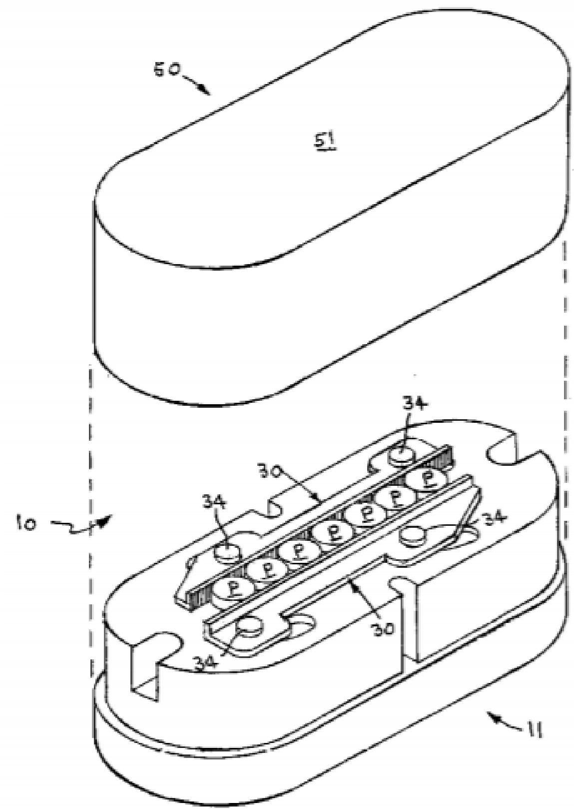


Figure 6: Patent Images multiple pill cutter

2.3 Codes & Standards

2.3.1 Food and Drugs - Allowable Adhesives (21CFR175.105)

This is a Code of Federal Regulations laid out by the Food and Drug Administration (FDA) on the requirements for adhesives in food contact devices. This code specifies when and for what adhesives can be used for in food contact products. We will decide whether or not adhesives are a viable tool for our use depending on the price and functionality of compliant adhesives.

2.3.2 Sanitizing - Equipment Cleaning and Maintenance (21 CFR § 211.67)

This Code of Federal Regulations comes from the Food and Drug Administration and applies specifically to the handling of pharmaceuticals. Within this code are instructions that provide the process by which utilities that process pharmaceuticals aught to be cleaned. It also outlines proper cleaning schedules. Knowledge will teach us how important it is that our design be easily cleanable. It will also provide insight into designing a cutter that will be easy to clean.

2.4 User Needs

We interviewed two potential customers for this project: Anna Sasser from Laynes Pharmacy in Eden, NC and Kyle Copeland from St. Luke's Pharmacy. Important insights from each interview are listed below, along with interpreted user needs and metrics derived from them.

2.4.1 Customer Interview

Interviewee: Anna Sasser (Laynes Pharmacy)
Location: Remote (Phone). Laynes Pharmacy is located in Eden, NC.
Date: February 2^{nd}, 2021
Interview Notes:
How many pills do you split?

- I usually split 30-60 pills in a sitting, once a week. Rarely, I have to split 180 pills in a sitting.

How long does the splitting take?

- 30 pills can be split in 2-3 minutes. 180 pills can take 15 minutes to half an hour.

What pill shapes do you usually split?

- The pills are usually round, sometimes oval. Round pills are easier to split than oval ones.

How much does your current splitter cost?

- $6-8.

How often does a pill split poorly?

- The cutter can crush pills sometimes. I'd estimate 4-5 out of every 30-60 pills have to be trashed.

How often does the splitter need to be cleaned?

- The splitter needs cleaning between different drugs because allergies are a concern. Also, crumbs build up and the cut won't be clean if too many crumbs are in the way. I have to clear out pill crumbs every 2-3 cuts.

How long do your current pill splitters last?

- They aren't very durable. We have 6 or 7 cutters and we switch one out every 2-3 months. When the blade gets dull, we just throw the whole cutter away.

Are there any safety concerns with the current splitter? Is it possible to hurt yourself while using it?

- You might have to hold the pill while lowering the top and you could cut yourself. It happens pretty rarely though, probably once every 3-5 months.

Interviewee: Kyle Copeland (St. Luke's Inpatient Pharmacy)
Location: Remote (Telephone). St. Luke's Inpatient Pharmacy is located in Chesterfield, MO.
Date: February 5^{nd}, 2021
Interview Notes:

How often do you have to split pills?

- Normally two major batches a week and then sporadically. In major batches, 200 to 400 pills are split.

How long does the splitting take?

- It takes between 1.5 and 2 hours to split a major batch of pills.

What pill shapes do you usually split?

– Normally scored circular tablets are split. Elliptical tables are split as well, but this is more rare. The most common pill (Metoprolol) is between 0.5 and 0.75 cm in diameter.

What fractions do you normally split pills into?

– Pills are generally split in half and are split into quarters only 1 to 2% of the time. Pills have a tolerance of ±3%, so eyeballing is sufficient to confirm that the pill has been cut into equal halves.

How much does your current splitter cost?

– $1.97.

How often does a pill split poorly?

– The older cutter consistently crushes half of the tablet. The new crushes only 1 in 100 when the operator is careful.

How often does the splitter need to be cleaned?

– The blade gathers particulates after the first 50 cuts and needs to be wiped after 100 cuts or it will crush tablets. The splitter must be wiped down with alcohol between different types of pills. Cutters that are used to cut medicines classified as hazardous by NIOSH only used to cut one type of hazardous medicine and are never used to cut anything else.

How long do your current pill splitters last?

– A cutter lasts about 10,000 tablets. The blades would be very difficult to replace, so the entire cutter is replaced instead. These comments apply to a cutter made by Apothecary Products.

Are there any safety concerns with the current splitter? Is it possible to hurt yourself while using it?

– It is very rare to cut one's self with this cutter.

2.4.2 Interpreted User Needs

After carefully considering the costumers' comments we compiled the following table to represent the costumer needs that the pill cutter (PC) must fulfill. The we ranked the needs between most important, 5, and least important, 2.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The PC cutter is efficient at cutting pills.	5
2	The PC is affordable.	4
3	The PC can cut pills cleanly.	4
4	The PC can cut pills precisely.	5
5	The PC is safe to use.	4
6	The PC need to be easy to clean/sanitize.	4
7	The PC can queue up a large quantity of pills at once.	2
8	The PC has a long life span.	4
9	The PC meets food safety requirements.	5
10	The PC is easy to operate.	3
11	The PC can cut different-shaped pills.	1
12	The PC can cut different-sized pills.	4

The biggest customer need is for the ability to cut pills much faster than allowed by the pill cutters currently on the marked. Therefore, needs pertaining to the the effectiveness of the cutter, such as efficiency and preciseness were ranked as most important. The customers mostly cut round pills, so the ability to cut multiple pill shapes was considered the least important need.

2.5 Design Metrics

These metrics are based on the quantification of our customer's needs. For a well-designed and novel automatic pill-splitter, some metrics of ours product need to be equivalent or surpass the market-available devices. The ideal and acceptable threshold of these metrics will also depend on the importance of the correspondent customer's need.

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1,6,7	Cutting rate	pills/hour	< 200	< 400
2	2,8	Cost/Operational Life	\$/month	$> \$x$	$> \$x$
3	3	Number of Pills Crushed	fraction	$> x/100$	$> x/100$
4	4	Halves within the 3% tolerance	Boolean	Pass	Pass
5	5	Blades enclosed during operation	Boolean	Pass	Pass
6	9	Food safe (meets 21CFR175.105)	binary	Pass	Pass
7	10	Time to max cutting rate	Batches	3	2
8	11	Compatible pill shapes	list	Circular	Circular, Oval
9	12	Diameter of compatible pills	mm range	5-7.5	4-10

2.6 Project Management

The Gantt chart in Figure 7 gives an overview of the project schedule.

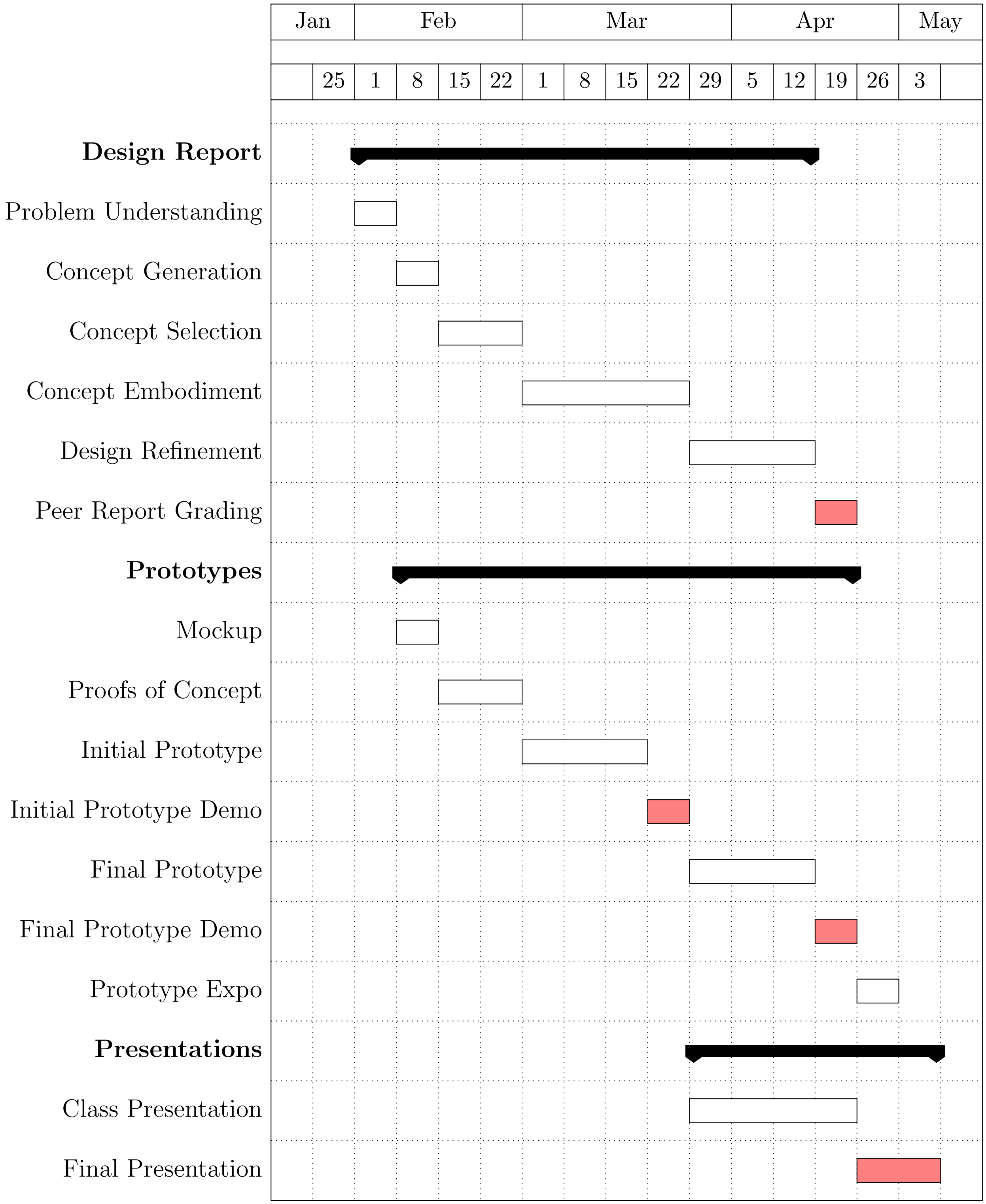
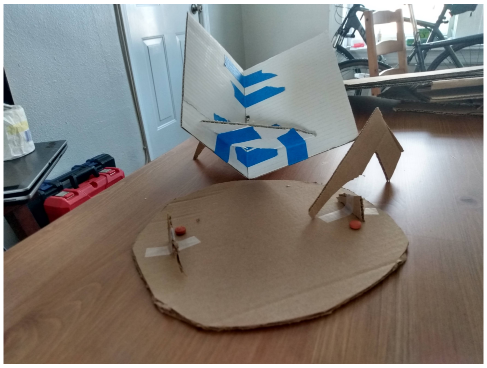


Figure 7: Gantt chart for design project

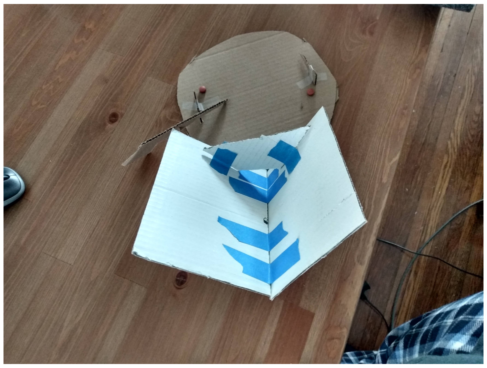
3 Concept Generation

3.1 Mockup Prototype

Figure 8 is a representation of the general concept and scale of our theoretical pill cutter design.



(a) **Front View**



(b) **Top View**

(c) **Back View**

Figure 8: Mockup Example

This design helped clarify the wheel cutter idea demonstrated in the associated morph chart - an idea which was hard to understand from the 2D drawing. It also helped to clarify the scale of the design. Before creation of the model, it was the expectation that the V-shaped pill separator function be a very large contraption. However, after observing the mockup, this function may be successfully built on a smaller scale than originally expected. This is encouraging as one of interviewer's needs is that the device be easy to store in a cramped pharmacy. Finally, the design revealed that the blade will scrape on the spinning platform - a problem we failed to foresee in the drawing phase.

3.2 Functional Decomposition

This function tree represents the cumulative function design of our group. It is an important step in the design and concept generation process. The function tree will then be used as a guide for our morph chart.

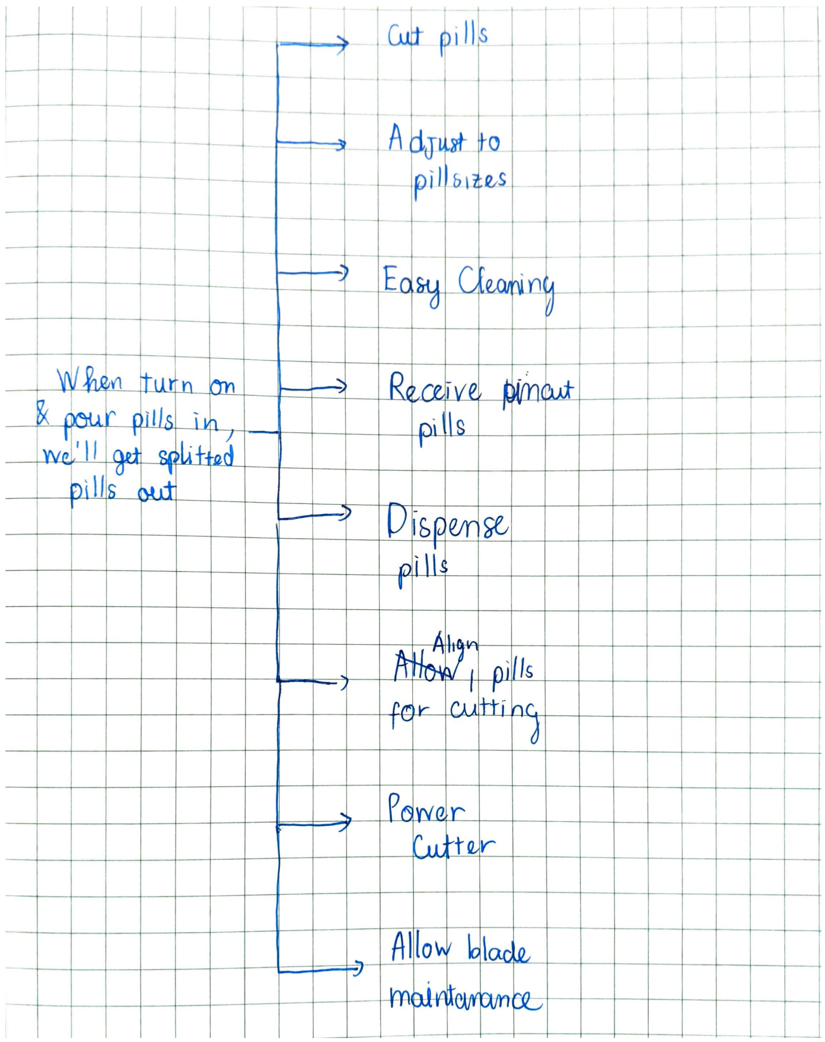


Figure 9: Function tree for the Pill Cutter

3.3 Morphological Chart

The morphological chart allows all the necessary functions of the device to be considered with multiple solutions. This morphological chart is the combination of individual's morph charts. The chart will come in handy in finalizing the ultimate design since solution are visualized.

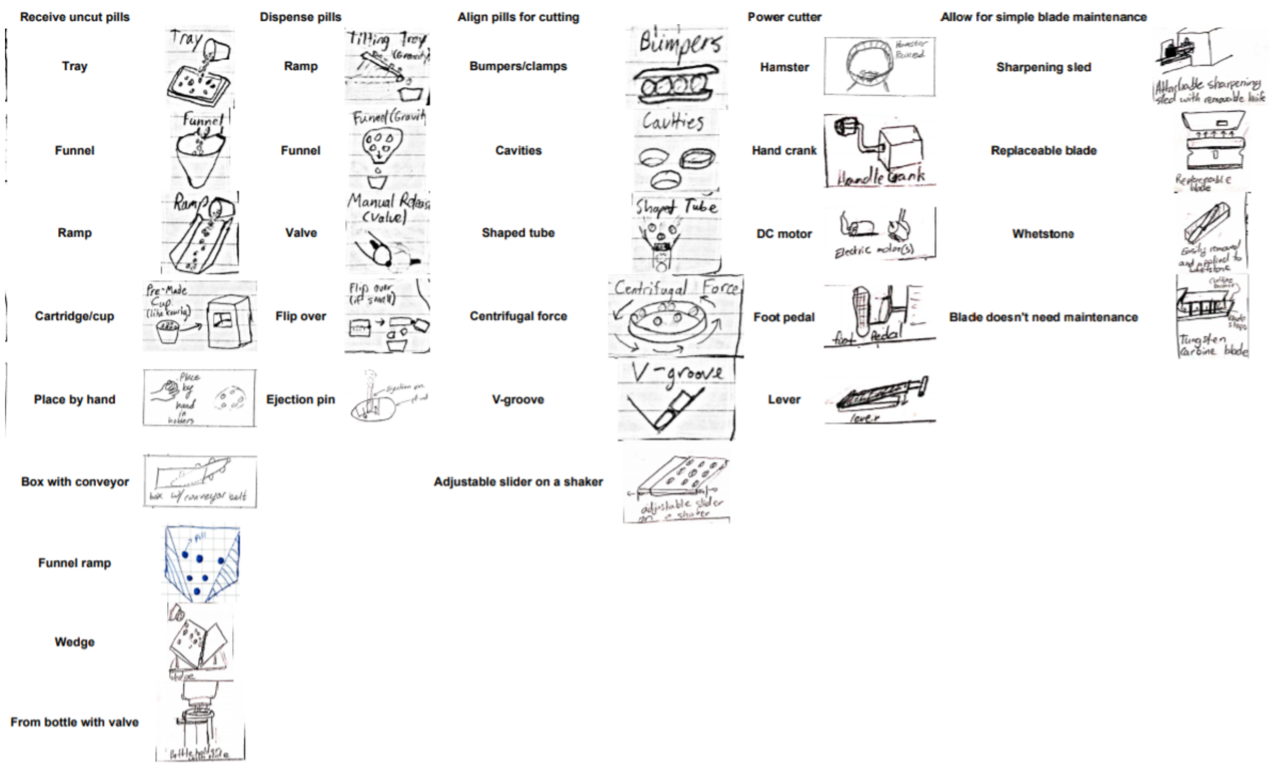
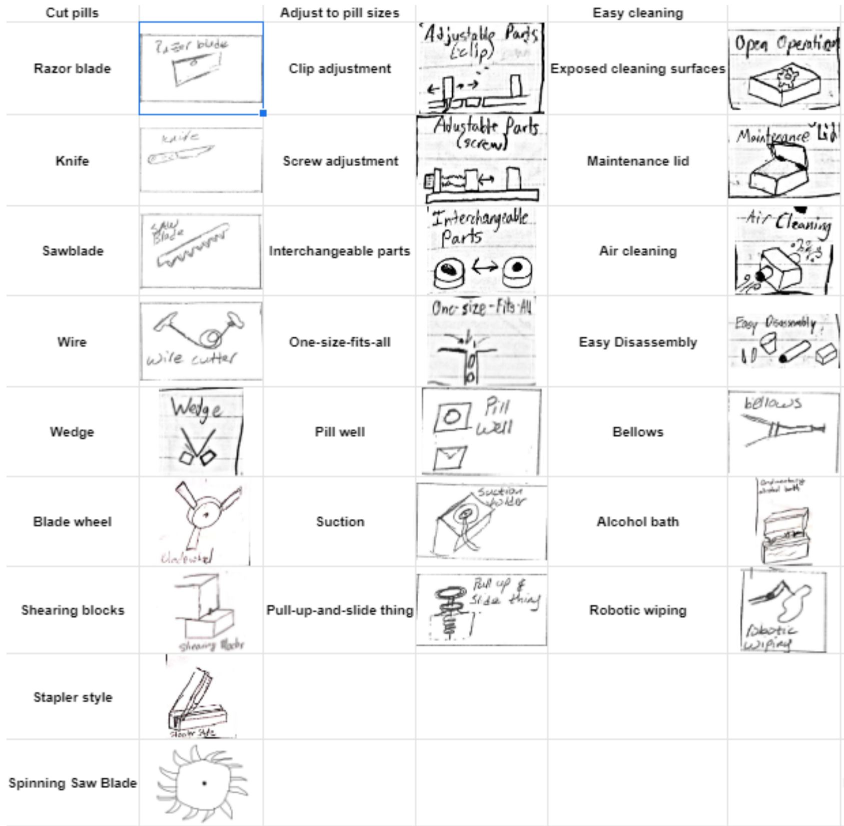


Figure 10: Morphological Chart Part 1



Cut pills		Adjust to pill sizes		Easy cleaning	
Razor blade		Clip adjustment		Exposed cleaning surfaces	
Knife		Screw adjustment		Maintenance lid	
Sawblade		Interchangeable parts		Air cleaning	
Wire		One-size-fits-all		Easy Disassembly	
Wedge		Pill well		Bellows	
Blade wheel		Suction		Alcohol bath	
Shearing blocks		Pull-up-and-slide thing		Robotic wiping	
Stapler style					
Spinning Saw Blade					

Figure 11: Morphological Chart Part 2

3.3.1 Gravity Tube ()

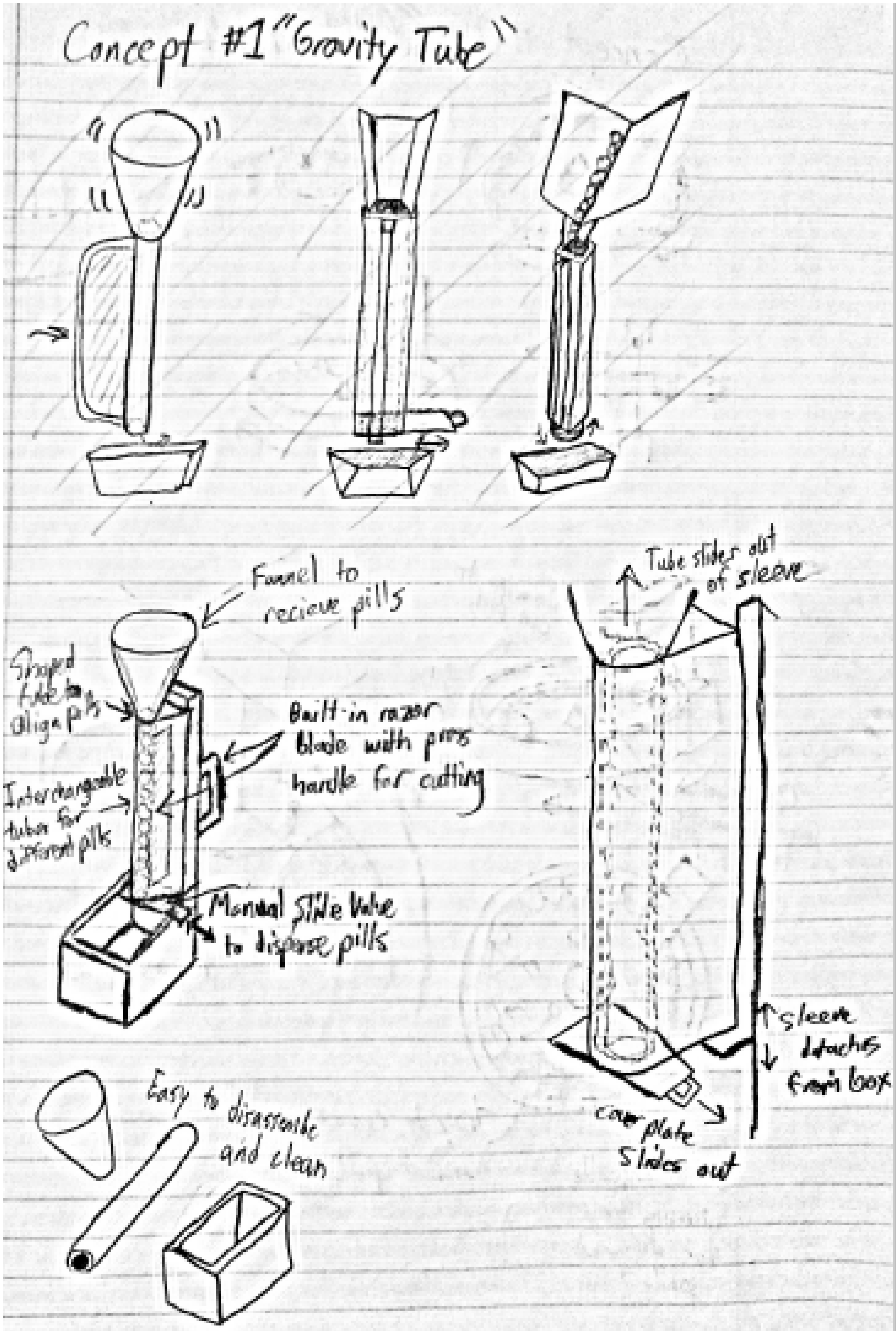


Figure 12: Sketches of Gravity Tube concept.

Solutions from morph chart:

1. Funnel receives pills
2. Shaped tube orients pills for cutting
3. Interchangeable tubes for different pills
4. Razor blade for cutting
5. Sliding valve dispenses pills
6. Easy cleaning is accomplished through disassembly)

Description: The pill cutter consists of separate interlocking parts which can be disassembled easily. These are: funnel, cutting tube, blade, and stand. The funnel allows easy pouring of pills into the cutting tube. The cutting tube is shaped to allow pills to enter in only one orientation, side-on to the vertical cutting blade. The cutting blade is attached to a handle which is pushed inward to slice a vertical row of pills. The stand is the skeleton of the machine and provides support to make the structure rigid during cutting. It also includes a hollow base where the pills can fall after being cut. The last feature of note is a sliding door attached to the base at the bottom of the tube section. This valve traps pills inside the tube until opened, when it allows the pills to flow out into the base bin.

3.3.2 Rotating Pill Cutter ()

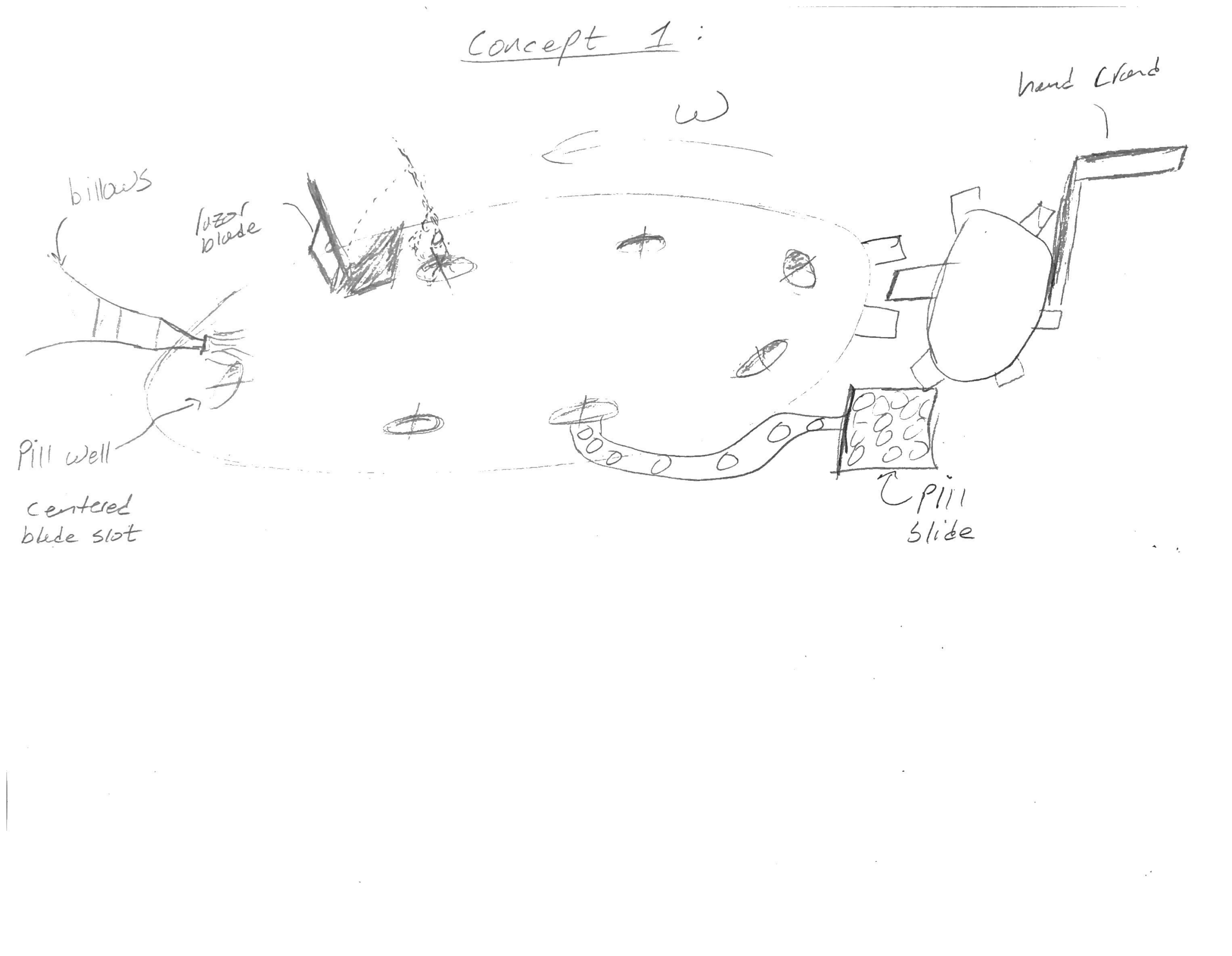


Figure 13: Final sketches of Rotating Pill Cutter concept

<u>Solutions from morph chart</u>:

1. Razor Blade
2. Hand Crank
3. Pill Slide
4. Cavities
5. Pill Well
6. Bellows

<u>Description</u>: The Rotating pill cutter consists of a spinning wheel spun by a hand crank. The pills are fed to the wheel by a pill slide. The wheel has cavities to align the pills for cutting. These cavities are cone shaped to accept different sized pills. The smaller pills will sink lower in the cone

while the large pills stop higher. In both cases the pills are centred an ready to be cut. A stationary razor blade with a spring is located at one point in the rotation. Ramps located in front of the pill wells lift the blade as the wheel spring and then the spring activates and cuts the pill. For cleaning a Bellows or pump can be installed either on the side or on top of the wheel.

3.3.3 Saw Style ()

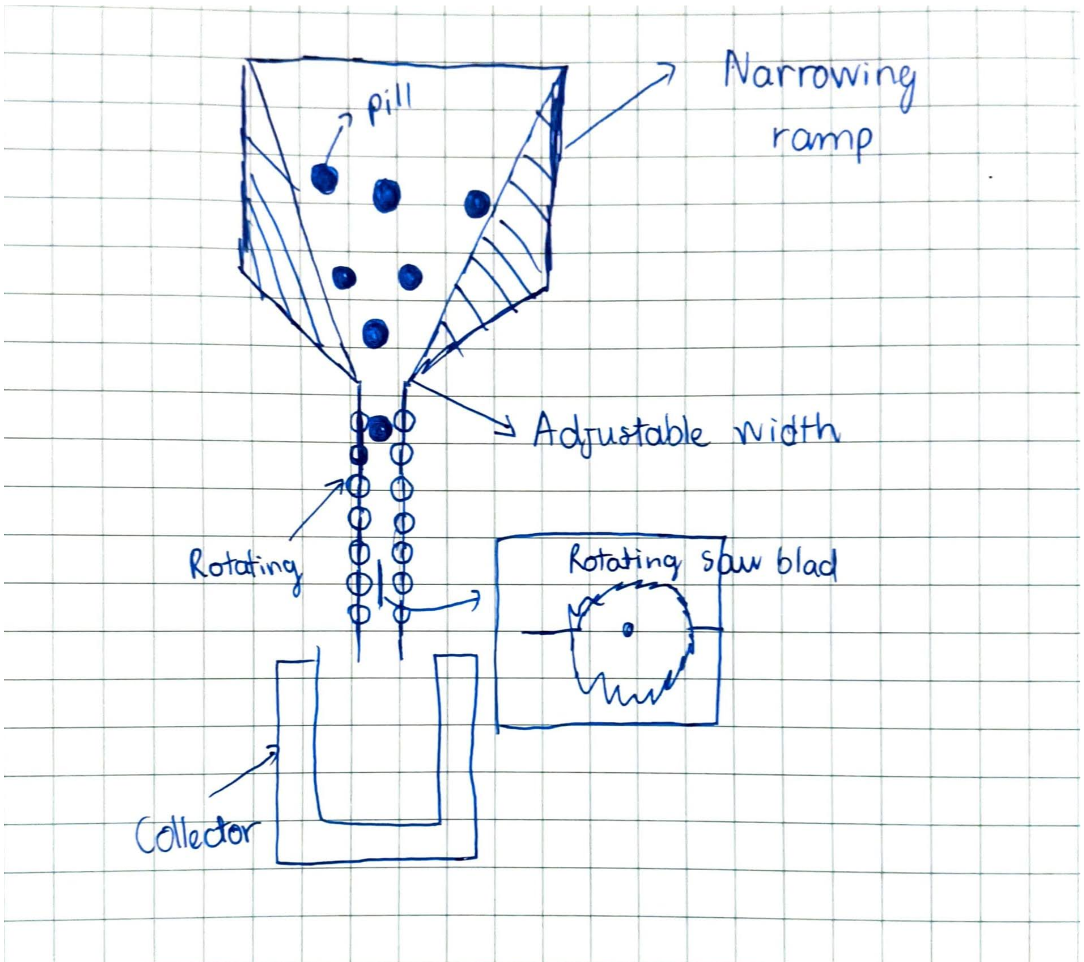


Figure 14: Final sketches of Saw Style concept

Solutions from morph chart:

1. Funnel ramp
2. Spinning Saw Blade
3. Clip adjustment
4. Easy disassembly
5. DC motor
6. Replaceable blade

Description: This concept uses gravity with the assistant of rolling wheels on the sides to transport the pills to a cutting transport slide where pills are cut in half using a rotating saw blade in the middle. This saw blade should be powered by a DC motor. A ramp of 60 degree is used. The pharmacist can pour the batch from top of the ramp. To cut multiple sizes of pills, the ramp is designed with the bottom that can be adjusted to fit the desired pill size. To collect the pills, simply put a box or collector at the end of the transport slide. This pill cutter are meant to cut pill in half only which is the most common splitting ratio.

3.3.4 Pills in Sleds ()

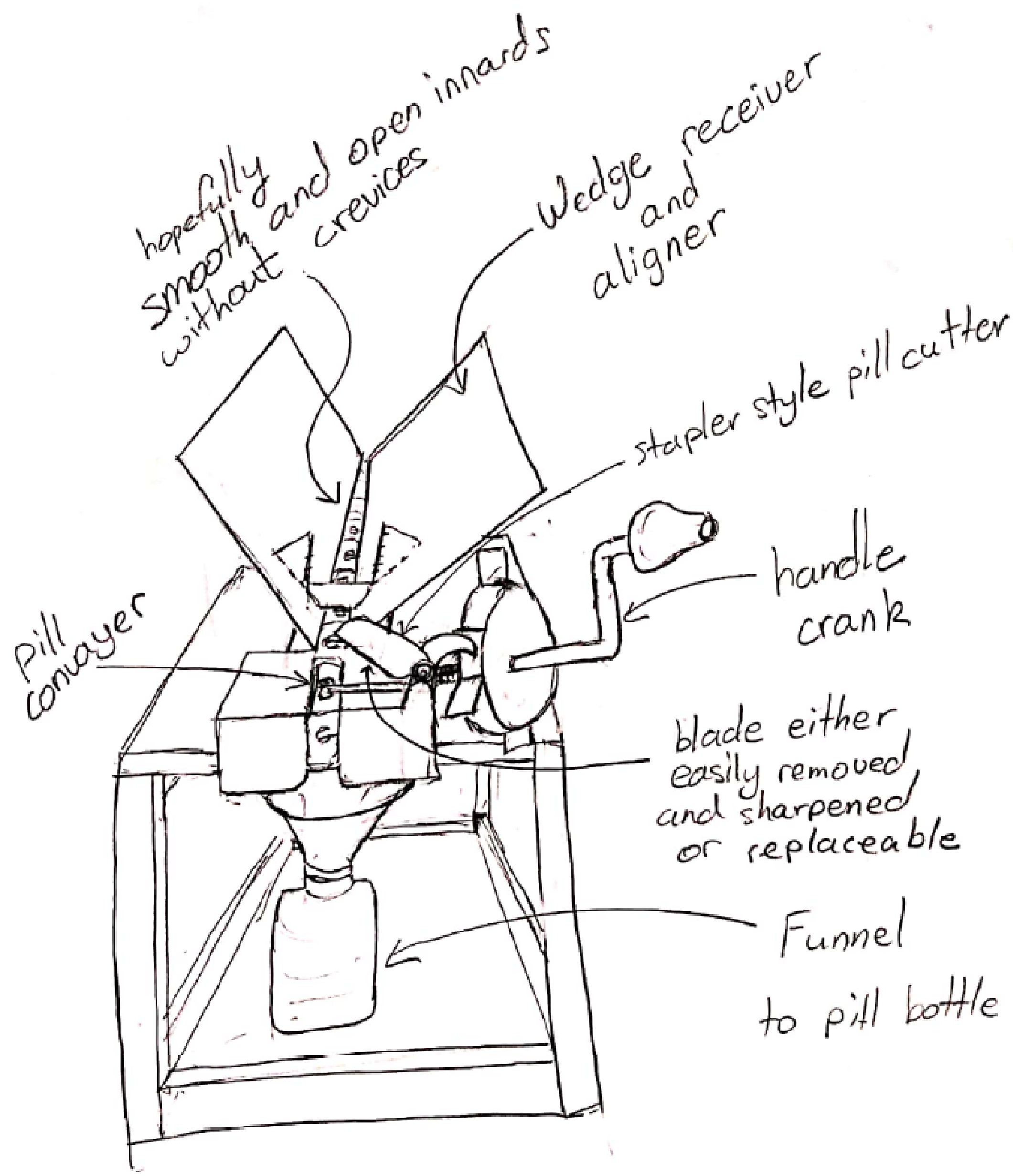


Figure 15: Final sketches of Saw Style concept

Solutions from morph chart:

1. Hand Crank
2. Pill Conveyor
3. Wedge Receiver and Aligner
4. Stapler Style Pill Cutter
5. Funnel to Pill Bottle
6. Blade Easily Replaced/Sharpened
7. Exposed Cleaning Surfaces

Description: This machine accepts pills with a wedge receiver which naturally orients pills to sit vertically, as a tire on a car. At the base of the wedge is a conveyor belt made up sections each containing a single pill well. The pills fill the pill wells and a gate with adjustable height allows only one pill at a time to exit the wedge. A Stapler style blade chops the pills as they exit the wedge. Finally, the pills are tipped from the conveyor belt and funneled into a waiting pill bottle. Each dynamic function of the machine is powered by a single hand crank.

4 Concept Selection

4.1 Selection Criteria

The below categories were determined from the customer needs generated from the customer interviews. The Analysis Hierarchy Process was applied to these needs, rating each need, one at a time, against every other need The resulting weights are given in the table to the right (Fig. 16).

	Affordable	Efficient at Cutting	Cut Pills Precisely	Safe to Use	Easy to Clean/Sanitize	Que Up Multiple Pills	Easy to Operate	Row Total	Weight Value	Weight (%)
Affordable	1.00	0.14	0.20	0.14	1.00	1.00	1.00	4.49	0.05	5.34
Efficient at Cutting	7.00	1.00	1.00	0.33	5.00	5.00	5.00	24.33	0.29	28.95
Cut Pills Precisely	5.00	1.00	1.00	0.33	0.33	3.00	3.00	13.67	0.16	16.26
Safe to Use	7.00	3.00	3.00	1.00	1.00	7.00	7.00	29.00	0.35	34.50
Easy to Clean/Sanitize	1.00	0.20	0.33	0.14	1.00	1.00	1.00	4.68	0.06	5.56
Que Up Multiple Pills	1.00	0.20	0.33	0.14	1.00	1.00	1.00	4.68	0.06	5.56
Easy to Operate	1.00	0.20	0.20	0.14	0.33	0.33	1.00	3.21	0.04	3.82
								84.05	**1.00**	**100.00**

Figure 16: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

The wights of priority determined for the pill cutter design determined in Fig. 16 were applied to the following Weighted Scoring Matrix. The concepts were then rated 1 to 5 in each of the categories. Concept four was chosen as the reference concept as it was the most similar to designs already on the market. The sum of the weighted ratings was then calculated to determine the winning design.

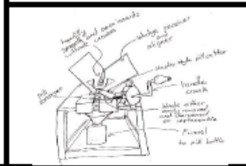
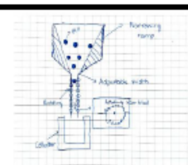
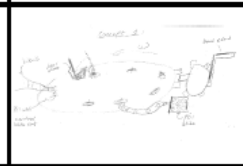
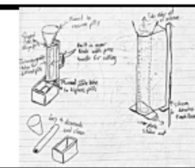
Alternative Design Concepts		Concept #1		Concept #2		Concept #3		Concept #4 (refference)	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Affordable	5.34	0	0.00	1	0.05	2	0.11	3	0.16
Efficient at Cutting	28.95	5	1.45	4	1.16	5	1.45	3	0.87
Cut Pills Precisely	16.26	3	0.49	3	0.49	3	0.49	3	0.49
Safe to Use	34.50	2.5	0.86	3	0.86	2.5	0.86	3	1.04
Easy to Clean/Sanitize	5.56	2	0.11	2	0.11	3	0.17	3	0.17
Que Up Multiple Pills	5.56	4	0.22	2	0.11	4	0.22	3	0.17
Easy to Operate	3.82	4	0.15	4	0.15	4	0.15	3	0.11
	Total score	**3.285**		**2.937**		**3.447**		**3.000**	
	Rank	**2**		**4**		**1**		**3**	

Figure 17: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

Concept 3 was selected by scoring high scores at all the 3 most important criteria of our concept selection: cutting efficiency, cutting precision, and safety. The design is registered as the most efficient cutter due to its rotating mechanism, guarantee even and fast cutting for all the pill in one rotation. The plastic case of the device protects components from flying off the assembly during rotating motion. The device is also safe to clean thanks to its cutting blade protector. With the centripetal force from the rotating crank, high pressure can be applied to the pill to cut the pills in the center. The pills are aligned by cone-shaped cavities on the wheel to create a precise cut. These cavities limit variability for each process. These cavities allow the design to cut several pills in one easy rotation motion. In general, this design is innovative compared to pill splitters on the market and promises several improvements in speed and cutting effectiveness.

4.4 Engineering Models/Relationships

4.4.1 Random Packing Densities

Our pill-cutting solution involves dispensing large batches of cut pills directly into containers for storage or further sorting. Determining the proper volume for these containers is an important design consideration. A small container saves space and makes the cutter more mobile, while a large container increases storage capacity. These two factors together incentivize us to make a storage container that is exactly the right volume for each batch of pills. Unfortunately, we can't simply take the anticipated pill volume per batch, as a mass of pills will also include empty space. That's where random packing comes in. This paper [1] includes estimated packing densities for various common shapes, including cylinders and sphero-cylinders (the shape of many long pills). With these densities, we can get a better idea of how much volume will be required to contain one batch of pills randomly dropped into a container (Fig. 18).

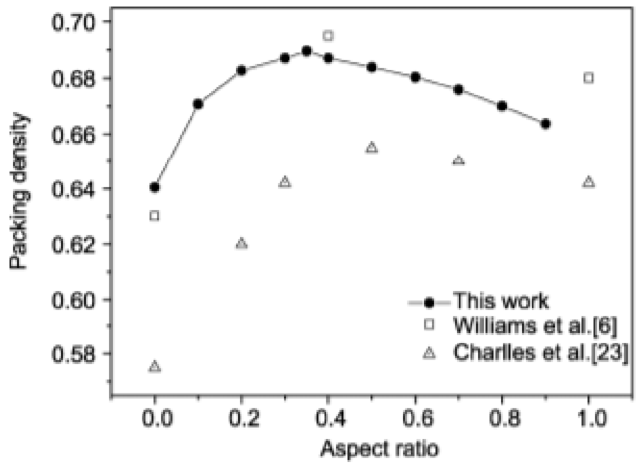


Figure 18: Model for packing density of sphero-cylinders as a function of spehero-cylinder aspect ratio [1].

4.4.2 Relative Rotation of Gears

The selected design is powered by a vertically spinning hand crank. However, the crank drives a horizontally spinning plate. This implies that we will need to turn our applied force, at the handle, ninety degrees to power the plate. This is easily accomplished with gears. Additionally, it will likely require significant torque to turn the horizontal wheel. This is accomplished by powering a large gear with a small one. The following model (Fig. 19) will help us decide the optimal ratio of input rotational speed from the user and output rotational speed at the cutting plate. Specifically, this model will help us compare rotational speeds of the different sized gears.

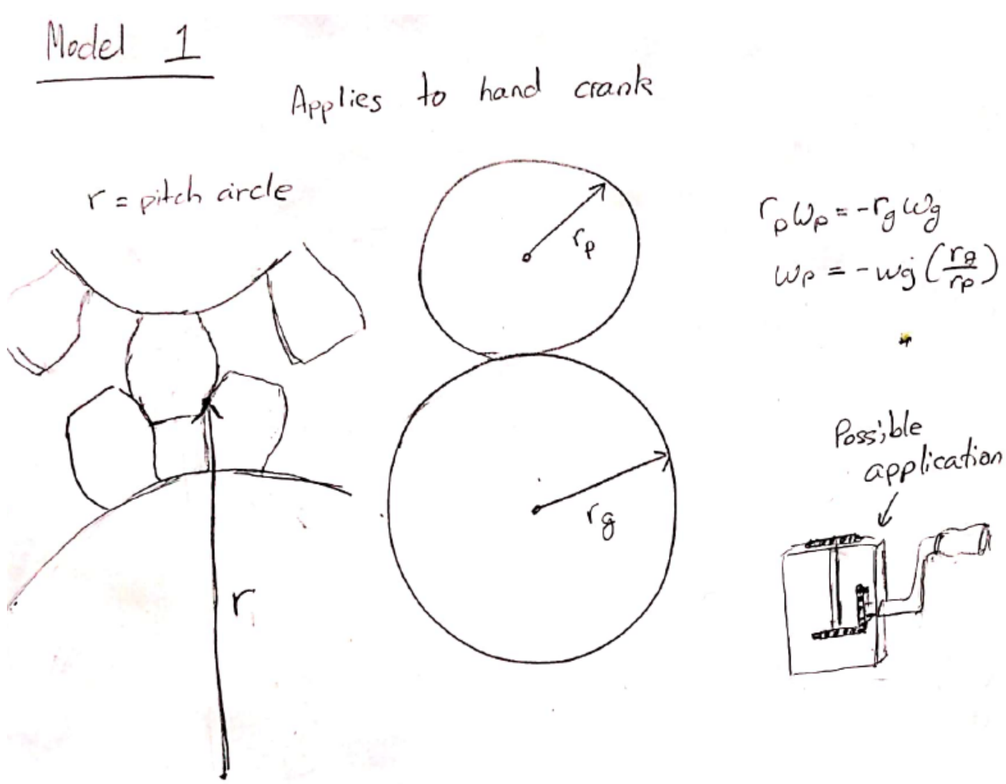


Figure 19: Model for rotational velocities of couple gears.

4.4.3 Required Ramp Angle

The chosen device uses a pill slide to queue up the pills for cutting. This pill slide requires a certain angle to allow the pills to actually slide down to the pill holder. Figure 20 shows a model of a pill on a ramp and the require angle to overcome static friction.

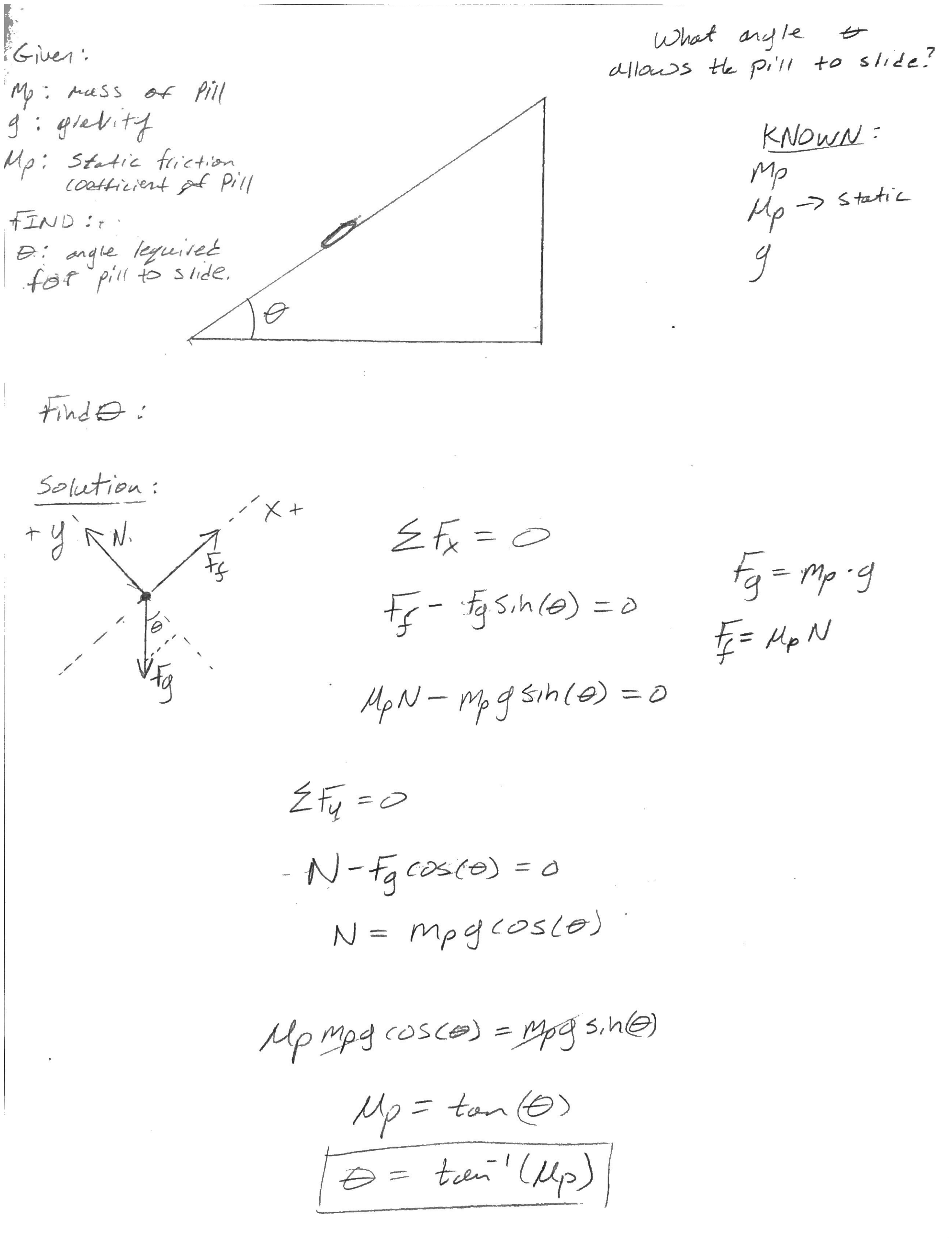


Figure 20: Model for the pill slide.

Figure 20 shows that the angle required for sliding is only dependent upon the friction coefficient.

Additionally, the friction coefficient of the pill could also be determine from this model.

5 Concept Embodiment

5.1 Initial Embodiment

The design team underwent another round of concept selection between the initial selection and the initial prototype focusing on the cutting function. Having settled on the idea of a rotating tray to hold the pills for cutting, we explored three variations of that design in separate teams before deciding which would be taken further.

The first variation, dubbed ”Spinner,” oriented the pills to stand on end in pill wells spaced around the circular tray. The tray rotated while the blade itself was placed in a stationary vertical position to split pills in half as they passed through the blade. This design variation was rejected due to the geometrical constraints of both securing the vertical blade on both ends and making the inner and outer tray pieces rotate together. There was also concern that the design would not produce enough cutting force to properly split the pills.

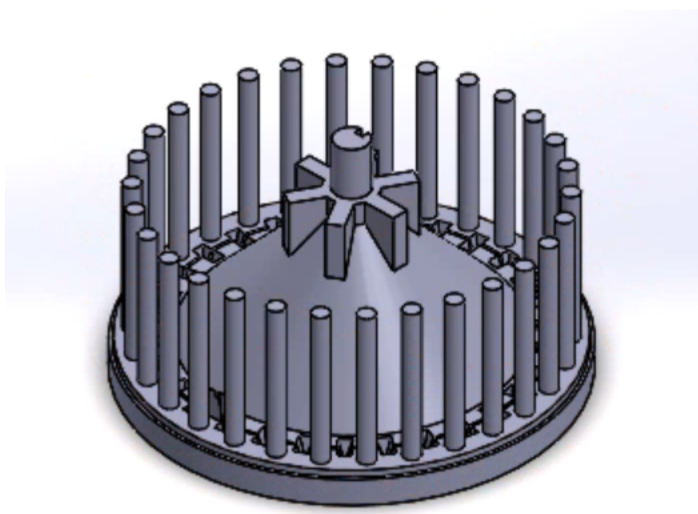


Figure 21: Isometric CAD view for the spinner design.

The second variation, shown in Fig. 22, was called ”Counter-Weighted Stapler.” It used a guillotine-like structure with a sliding blade to chop downward on pills sitting flat in wells on the tray. The chop was to be ”triggered” by a stationery plate above the main spinning tray with inclined planes intended to push the sliding blade down as the tray rotated. This variation was rejected due to its complexity and the requirement of additional parts not included in the original concept design.

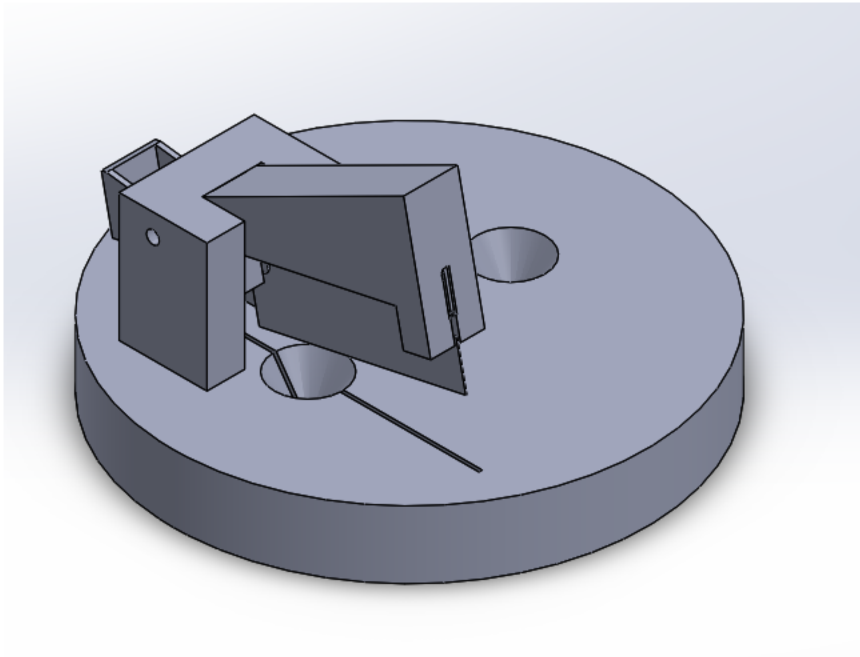


Figure 22: CAD assembly for the Counter-Weighted Stapler design

The last variation (Fig. 23), which was approved, is called "Impulse." This version of the design capitalized on a discovery made during studio experimentation. We discovered that delivering a small impulse to a blade resting against the side of a pill was very effective at cleanly slicing the pill. Because of this, we built a design variation around the idea of a spinning blade which could deliver an impulse to each pill in turn as it makes its way around the pill tray.

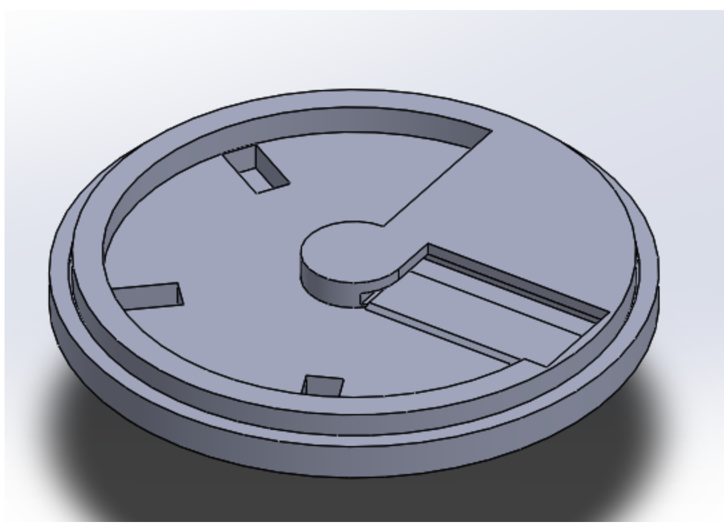


Figure 23: CAD assembly for the impulse design.

5.2 Proofs-of-Concept

The Impulse design takes advantage of the fact that pills tend to fail in a brittle manner. In tension, brittle materials fails normal to the applied force. Therefore, by putting a horizontal force on the pill with a blade, the pill should fail normal to the applied force, causing the blade to cut the pill horizontally. This concept was validated by clamping a pill, vertically, in a vice and then providing a horizontal impulse to cut the pull in half horizontally. The demonstration was successful, cutting the pill in half horizontally as expected for a brittle material.

During cutting tests, the pill was cut most cleanly when an impulse was applied to the blade. With this knowledge, we decided to add an impulse mechanism to our cutter design. Springs are a simple method of storing energy for an impulse, so to predict the type of spring we needed, we measured the amount of impulse energy required to split a pill in half with the blade resting against it.

Potential energy is given by:

$$E_p = mgh \tag{1}$$

where g is the local acceleration due to gravity (9.8 m/s), and m is the mass and h is the height of the object of interest. Spring energy is given by:

$$E_{sp} = \frac{1}{2}kx^2 \tag{2}$$

where k is the spring constant and x is the displacement of the spring.

The energy required to split the pill was determined by dropping a mass onto a blade which was placed sharp end down onto the center of a pill (Fig. 24). We used a 533 g hammer as our mass. After numerous trial drops from heights between 4 cm and 2 cm, the minimum height to cut the pill in half was determined to be .03 cm, giving a potential energy of 0.153 J (Eq. 1). To keep the pill cutter as compact as possible, we decided on spring displacement of only .5 cm, requiring a spring constant of approximately 12.3 kN/m.

However, in retrospect, this constant seemed unreasonably large. So, we ordered a box of assorted springs from amazon to use for our proofs of concept. When we reach a final design, we will probably use our knowledge of the energy required to cut a pill in half to order the exact spring we need. Based on our initial calculation for spring constant, our spring displacement will be more than 0.5 cm to make the spring constant a more reasonable value.

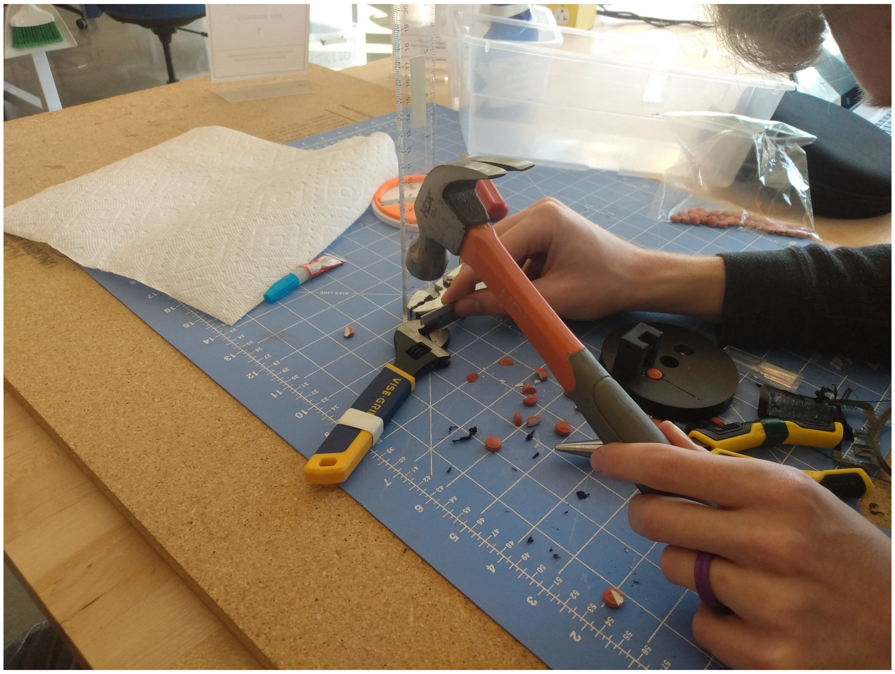


Figure 24: Dropping a hammer onto pill to calculate potential energy required to cut pill [1].

The impulse design is inspired by the commercial center punch. The device consisted of two pieces that slide into each other at the final position. The first piece will have a cutout for the second piece to slide into as they come together. Both of them will be hooked to springs which store potential energy to release in an impulse. Before the operation, the second piece is off centered. As we slide our device in the desired direction, both pieces are loaded. For the second piece, the geometry of the side wall will eventually guide it to be centered and hold it back. As the second piece is centered and held back, a space is opened for the first piece cut out to slide into the second piece at high releasing velocity, generate a strong impulse to cut our pill in half. The mechanism can be understand better using Fig.25

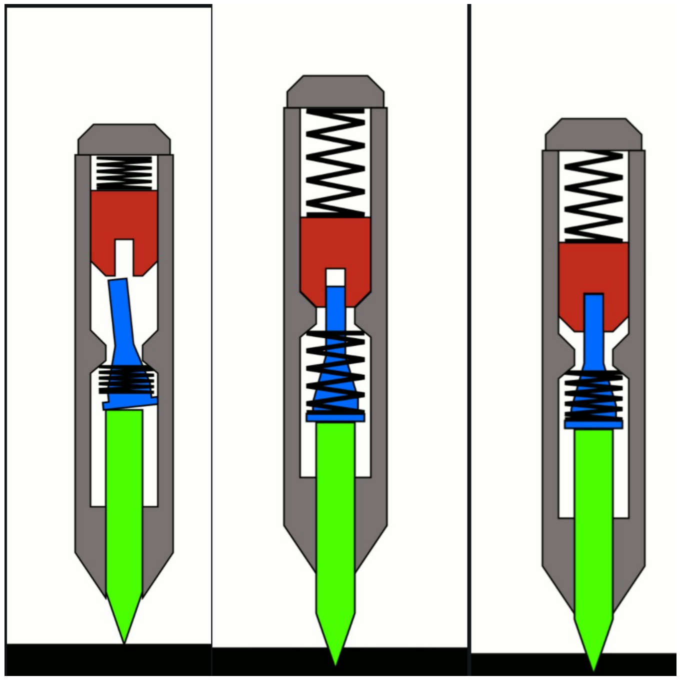


Figure 25: Motion of a center punch (from Left to Right): (1) Before Centering, (2) After Centering , (3) Impulse release [2].

5.3 Performance Goals

1. Device makes ”acceptable” cuts > 9/10 times.
2. Mechanical work per pill is < 1/4 of current method.
3. The device cuts pills >x 4x as fast as current method.

5.4 CAD Designs

The current impulse design incorporates the mechanics of the auto center punch into a rotational pill cutter. Figures 26 - 28 show the CAD representation of the current design for the cutting of pills. This currently does not deliver an impulse, however, with the introduction of a floating mass surrounded by springs and a spring loaded trigger, we believe that it will successfully deliver an impulse to the pill.

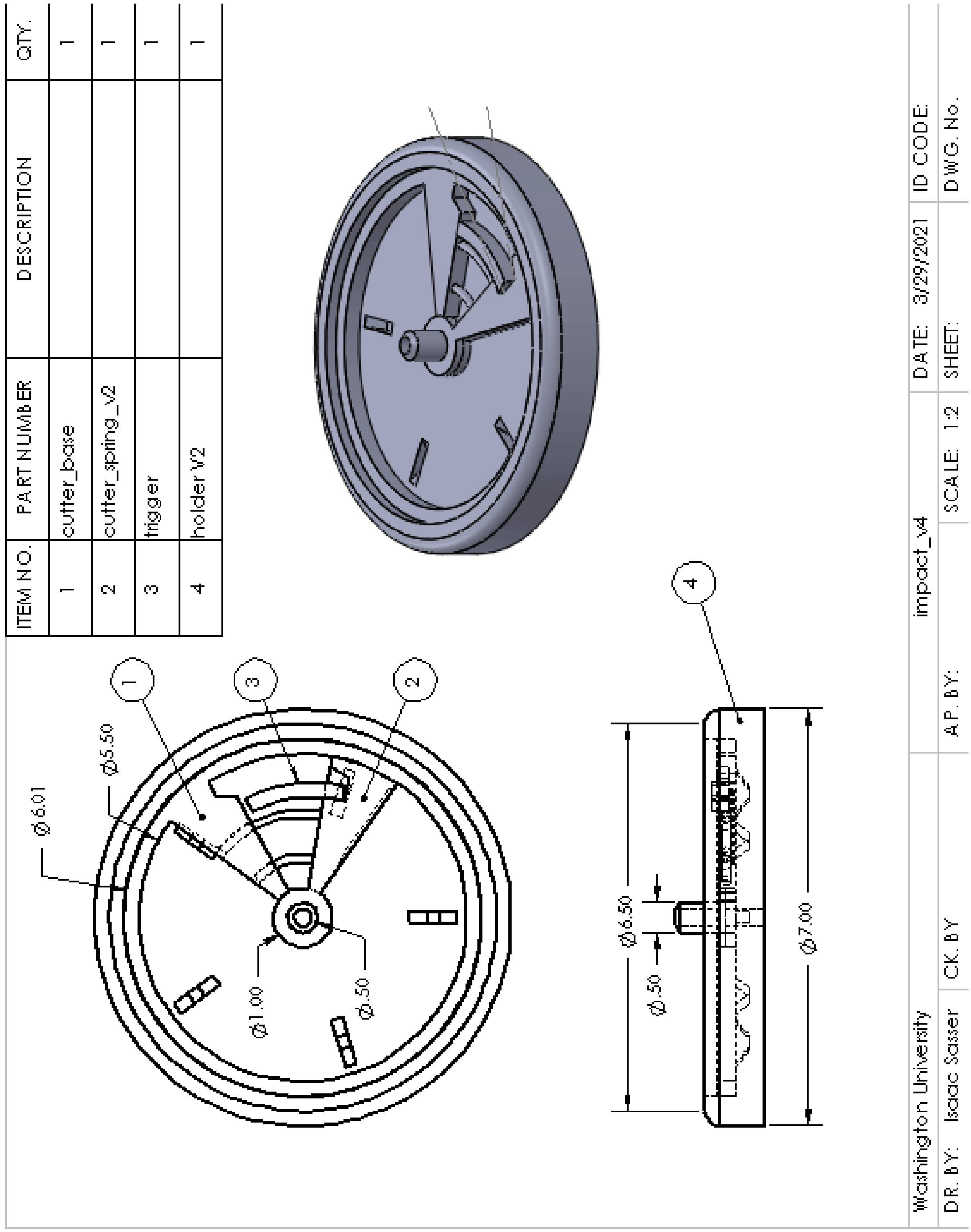


Figure 26: Assembled projected views with overall dimensions

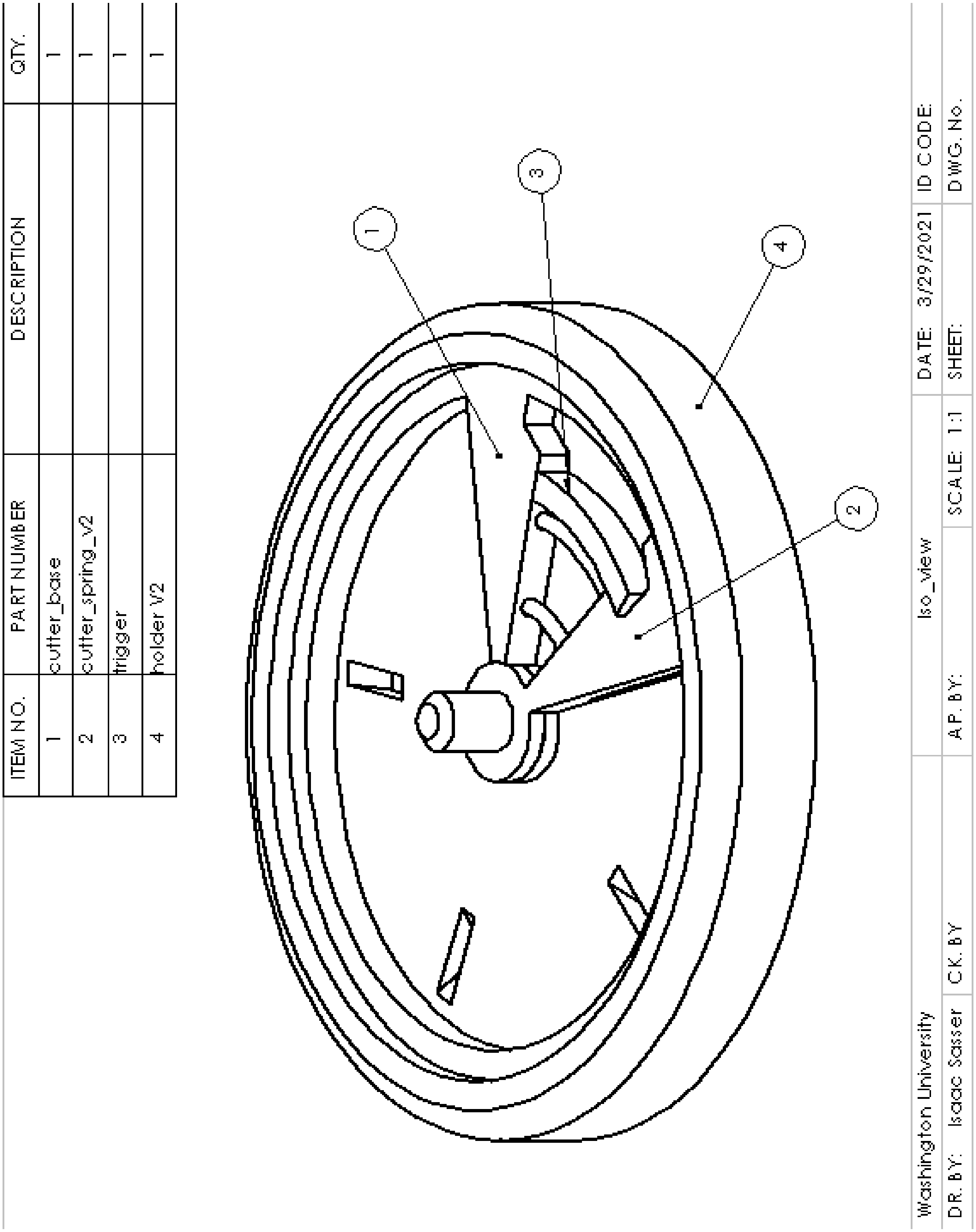


Figure 27: Assembled isometric view with bill of materials (BOM)

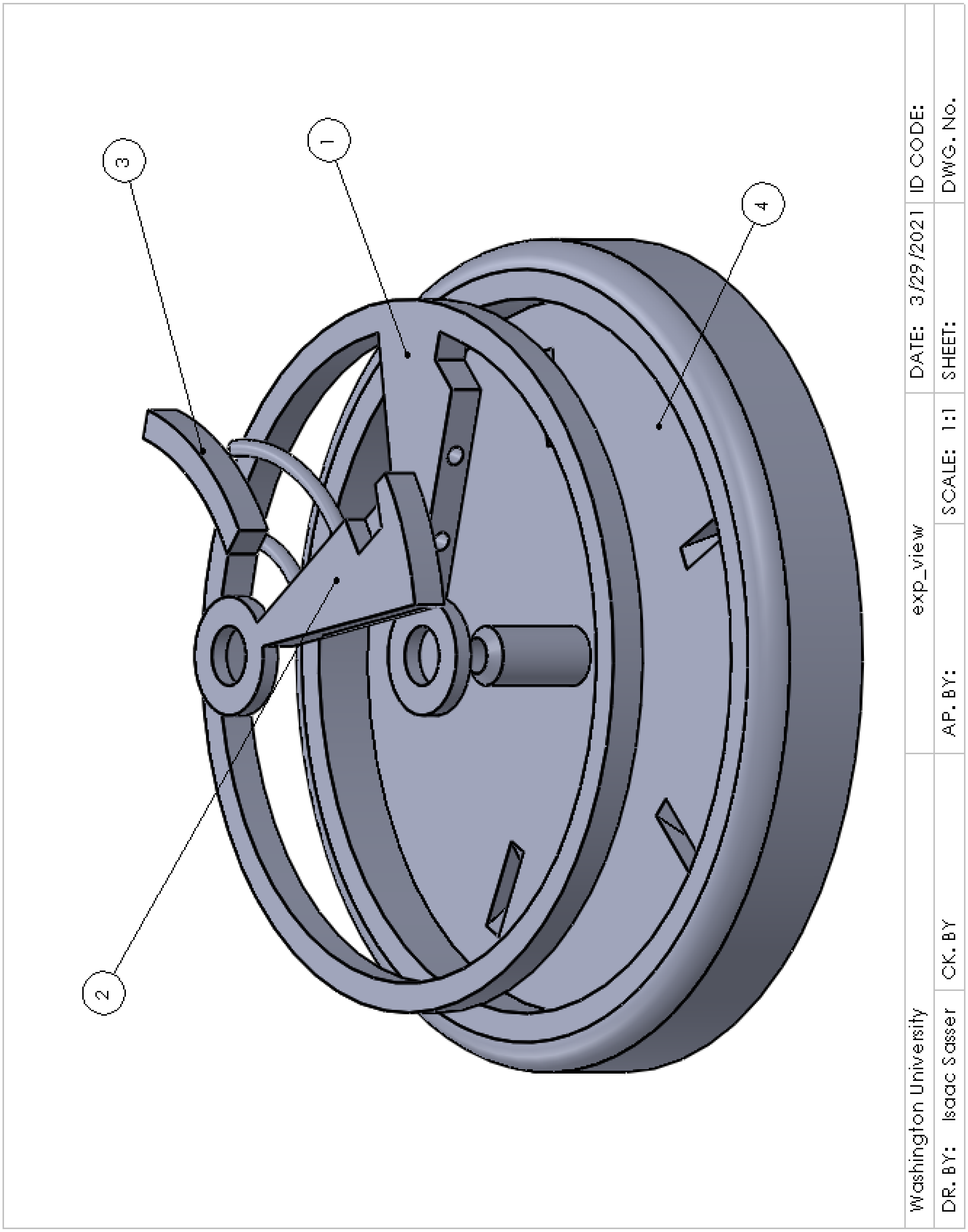


Figure 28: Exploded view with callout to BOM

6 Design Refinement

6.1 Model-Based Design Decisions

6.1.1 Potential Energy

We used the energy model to determine the spring constant necessary to cut through a pill. Potential energy is given by

$$E_p = mgh \tag{3}$$

where g is the local acceleration due to gravity (9.8 m/s), and m is the mass and h is the height of the object of interest. Spring energy is given by:

$$E_{sp} = \frac{1}{2}kx^2 \tag{4}$$

where k is the spring constant in kg/m and x is the displacement of the spring in m.

The energy required to split the pill was determined by dropping a mass onto a blade which was placed sharp end down onto the center of a pill (Fig. 24). We used a .533 kg hammer as our mass. After numerous trial drops from heights between .04 m and .02 m, the minimum height to cut the pill in half was determined to be .03 m, giving a potential energy of 0.153 J (Eq. 1). To keep the pill cutter as compact as possible, we decided on spring displacement of only .05 m, requiring a spring constant of approximately 12.3 kN/m. The calculations for this determination are as follows (Fig. 29).

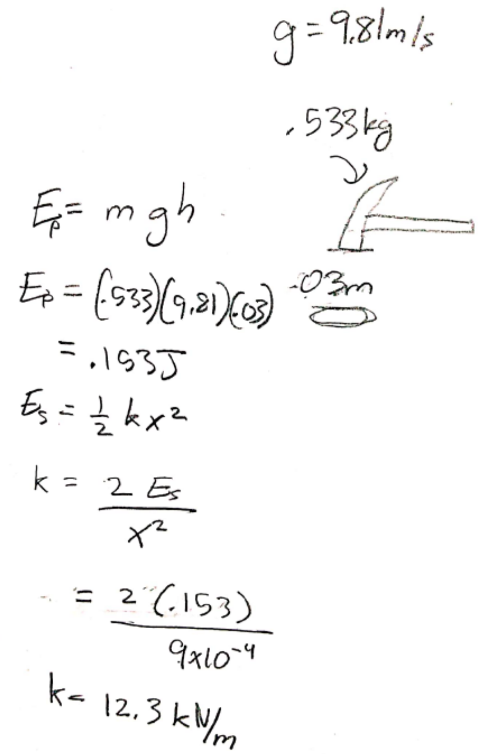


Figure 29: Spring constant experiment set up and calculations.

6.1.2 Force Balance

One of the key components of the design is the impulse generated to cut the pill. For this impulse to be consistently generated by our device, the trigger needs to consistently slot into the gap shown in Fig. 26. Figure 30 shows two different geometries considered for the trigger.

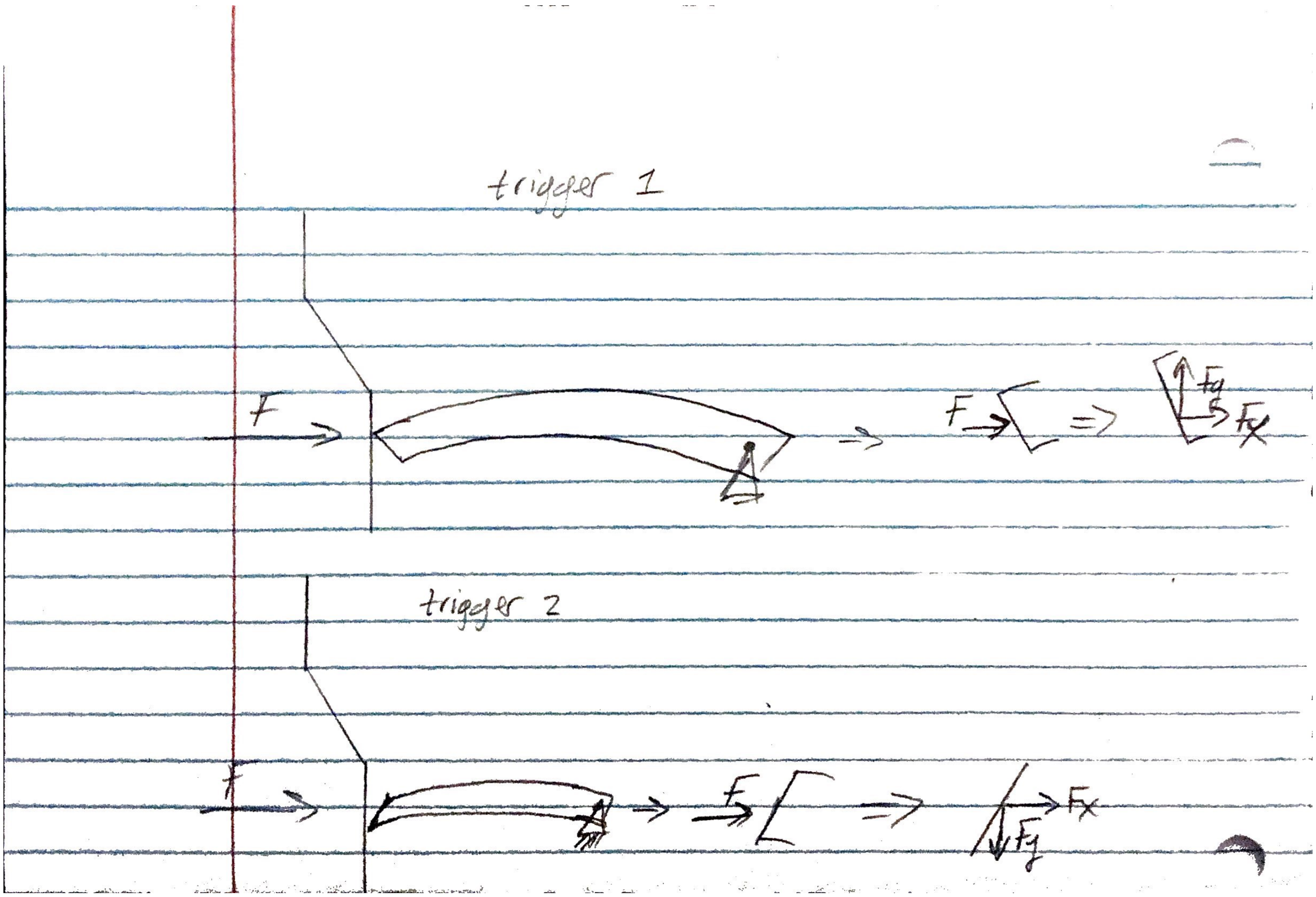


Figure 30: Geometric and force considerations for the shape of the trigger.

The trigger needs to move in the positive y direction (up), when a force is applied as shown. Trigger 1 accomplishes this as a small component of the force is upward. However, trigger 2 will have relative motion downward. Trigger 1 only works provided that its start position has some of the angled face in contact with the wall. If it slides down far enough that the top of the trigger is in contact with the wall than the situation of trigger 2 occurs. This has led to the inclusion of a block to force the trigger to an set equilibrium position in one of the current prototypes.

6.1.3 Pill Divot Geometry

The following figure models the geometry that will hold an Ibuprofen pill in a pill well such that the pill sits on base of the well and has its sides held secure by touching the rising slopes of the pill well. It was found that, given a pill of diameter 3/16 in. and a slot 3/4 in. wide, the pill should have walls sloping downward at 30 degrees and a bottom flat spot of approximately 1/10 in. The calculations to determine this are as follows (Fig 31):

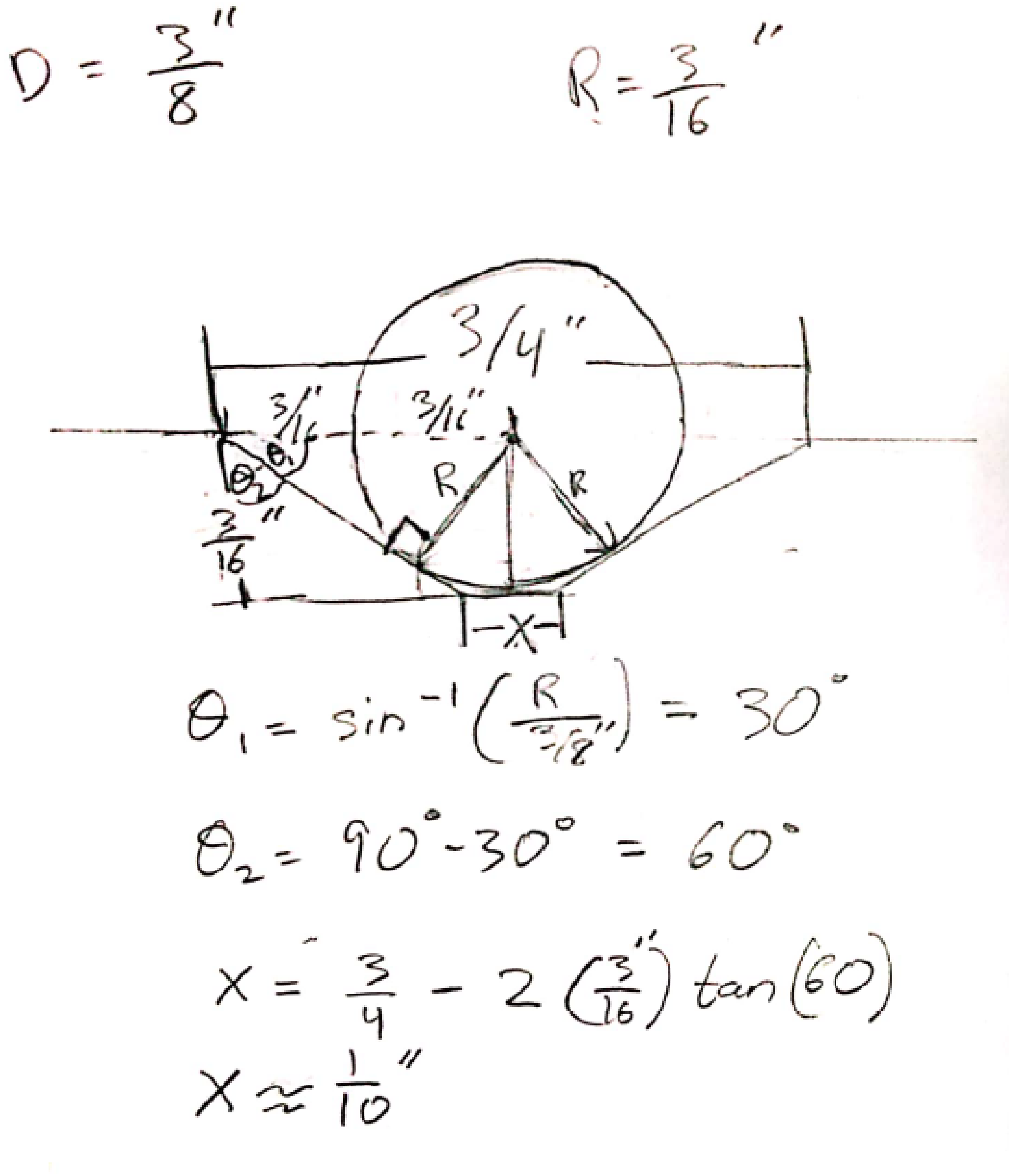


Figure 31: Geometry required to hold a pill properly.

6.2 Design for Safety

Overall, there are not many safety risks associated with our design. However, there is a rotating blade that can cause pill particles to fly. Eventually, this problems can be mitigated by enclosing the cutting compartment. However, this design step remains undone, posing a dangerous but unlikely risk to the user from the spinning blade. A breakdown of this and other device safety concerns follows:

6.2.1 Risks

What is the risk?	Describe the identified risk	Severity	Probability	Steps to Mitigate Risk
Cut your finger with the blade	Cuts finger on blade during cleaning or operation.	Critical	Occasional	Enclosed blade during operation.
Pinching in the	You could pinch yourslef on things	Marginal	Unlikely	Enclosed moving parts that potentially allow user to stuck their finger into during operation
Particulate	Pill fragments could fly off when cutting the pill.	Negligible	Frequent	Enclosed cutting surface or users have to wear safety glasses
Contamination	Contamination between controlled pills/ pills with potential birth defects.	Catastrophic	Likely	Different cutters for controlled substances/those that cannot be cleaned well.
Snagging	Clothes or long hair caught in exposed gears	Negligible	Seldom	No exposed gears

Figure 32: The risks that we pose in our design

6.2.2 Risk Heat Map

A visualization of the risks in our design can be shown in Fig. 33

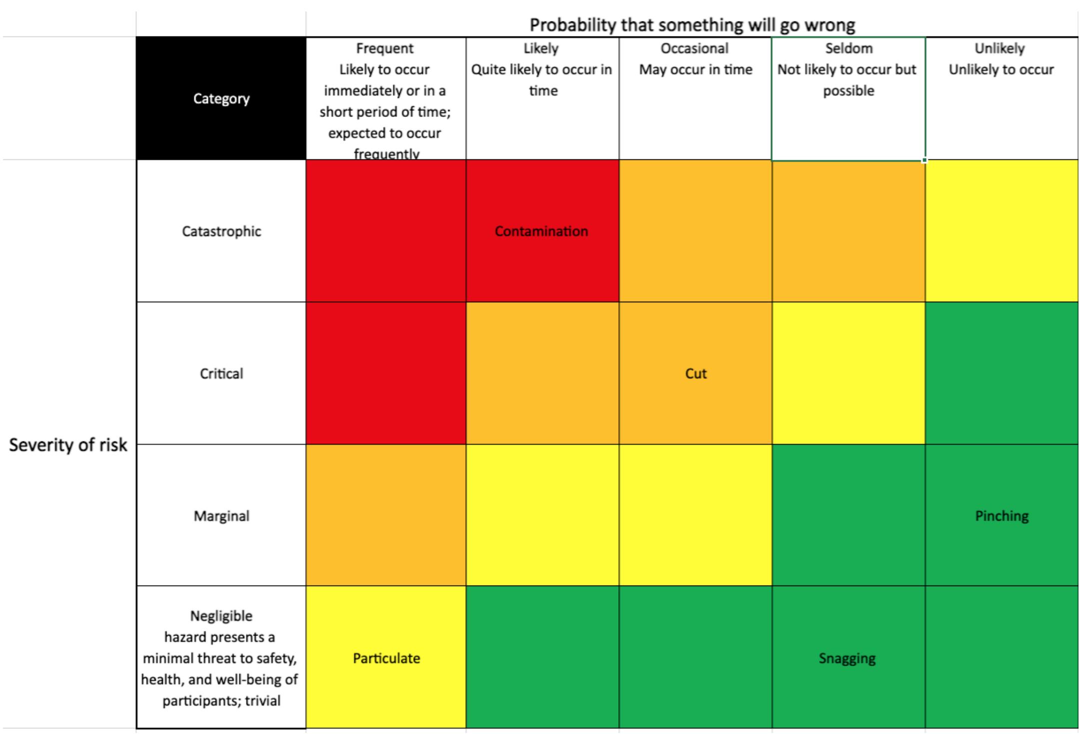


Figure 33: The risk heat map

6.2.3 Prioritization of different risks

As the heat map suggests, the most severe risk from this device is pill contamination, which needs our attention to strictly follow the CDC guidelines. The next risk on the list is operator cut damage, which can be avoided by mindful operation. However, due to the highly repetitive nature of the process, mindful operation might not always be the case, hence we need solutions to protect the operator from being injured. On the same note but with less severity is the risk of being injured in the eyes by the particles coming out of the pills. Particles fly out of the cutting process is not rare but causing damage to the eyes is. Another injury risk is from pinching and snagging. Both of these risks are unlikely and cannot hurt the operator too much.

6.3 Design for Manufacturing

6.3.1 Part Overview

Design Iteration: "Impulse V5" Total Parts: 11
Threaded Fasteners: 0
Theoretically Necessary Components (TNCs):

1. Base
2. Cutter Front
3. Cutter Mid
4. Cutter Back
5. Razor Blade
6. Trigger
7. Swivel Springs (x2)
8. Trigger Springs (x2)

6.3.2 TNC Explanation

Base: The base plate of the pill cutter is necessary for two reasons: It holds all the main parts in their proper place and it contains the wells where the pills rest for cutting.
Razor Blade: The razor blade is required to actually cut the pills. It is theoretically possible to cut the pills with a sharp wedge on a plastic part, but the applied force required is so great that the design would not be practical. The only way to achieve a clean cut is therefore to incorporate a razor blade.
Trigger: The trigger refers to a small plastic bar wedged between two of our cutting mechanism pieces, which rotates about a pin on the "cutter front." The trigger is a crucial part of our design because it enables the impulse that is required for a clean, easy cut.
Swivel Springs: The swivel springs are two compression springs placed on guiding rods in the impulse mechanism. It is these springs that store the energy necessary to deliver the impulse. When the rotating cutter is pushed up against a pill, force builds up in the swivel springs which is then released when the trigger snaps into a slot. Without the swivel springs, there could be no impulse.

6.3.3 Possible Simplifications

The most obvious simplification would be to change the "trigger" and "cutter front" parts so that the trigger snaps onto a stationary shaft built into the cutter front. This would eliminate the need for the "trigger pin," which currently serves to hold the trigger in place while allowing it to rotate. While this same function could be achieved by a loose snap joint between trigger and cutter front, the tolerances required are too precise to justify the change. It is much less trouble to simply print another part (the trigger pin) to provide the desired connection. The only other simplification that would not seriously compromise the device's functionality is to combine the two pairs of spring into one spring each. This would reduce the total number of parts by 2, and could be accomplished fairly easily by finding a spring with the same spring constant as the two relevant springs combined. However, this might also subtly change the direction of the spring forces in our impulse mechanism, especially for the trigger. Such a change could compromise the reliability of the impulse mechanism.

6.4 Design for Usability

6.4.1 Vision Impairment

One of the risks associated with pill cutters is cross contamination. Our solution to this problem is the use of multiple cutters for different pill types. Using color coding in our design to signify cutters for different pill types could be problematic for those with colorblindness. One solution would be to use pictures or place a large label on each cutter to distinguish it from the others.

6.4.2 Hearing Impairment

We believe that hearing impairments pose little if any obstacle to the use of our device. The cutter operates manually and vibrates with a noticeable impulse when each pill is cut, meaning that the noise of the pill splitting isn't necessary to know whether a cut is complete. Additionally, sweeping the cutter through a full 360 degree turn is guaranteed to cut all pills in the tray as a matter of geometry, so no audio cue is needed to signal that the cutting sweep is complete.

6.4.3 Physical Impairment

The crank handle of our product requires significant force to be applied to charge up the springs that provide our impulse. It may be challenging for some to turn a crank handle, though one of the main goals of our final prototype is to minimize the force required to trigger the impulse. This depends on the intricate inner workings of our impulse mechanism, and we fully expect to achieve our prototype performance goal of the device requiring less than 1/4 the applied force of current cutters.

6.4.4 Control Impairment

Our design requires the placement of pills into specific locations to be cut. This could require significant dexterity. One solution for those without fine motor control could be to modify the design to require less precision; for example, instead of placing the pills, pouring them into a funnel-and-tube system that can deposit them for the user.

7 Final Prototype

The final prototype for the pill cutter in shown in Fig. 34.

Figure 34: Shows the final prototype for the pill cutter.

Additionally, Fig. 35, shows the parts of the final prototype labeled.

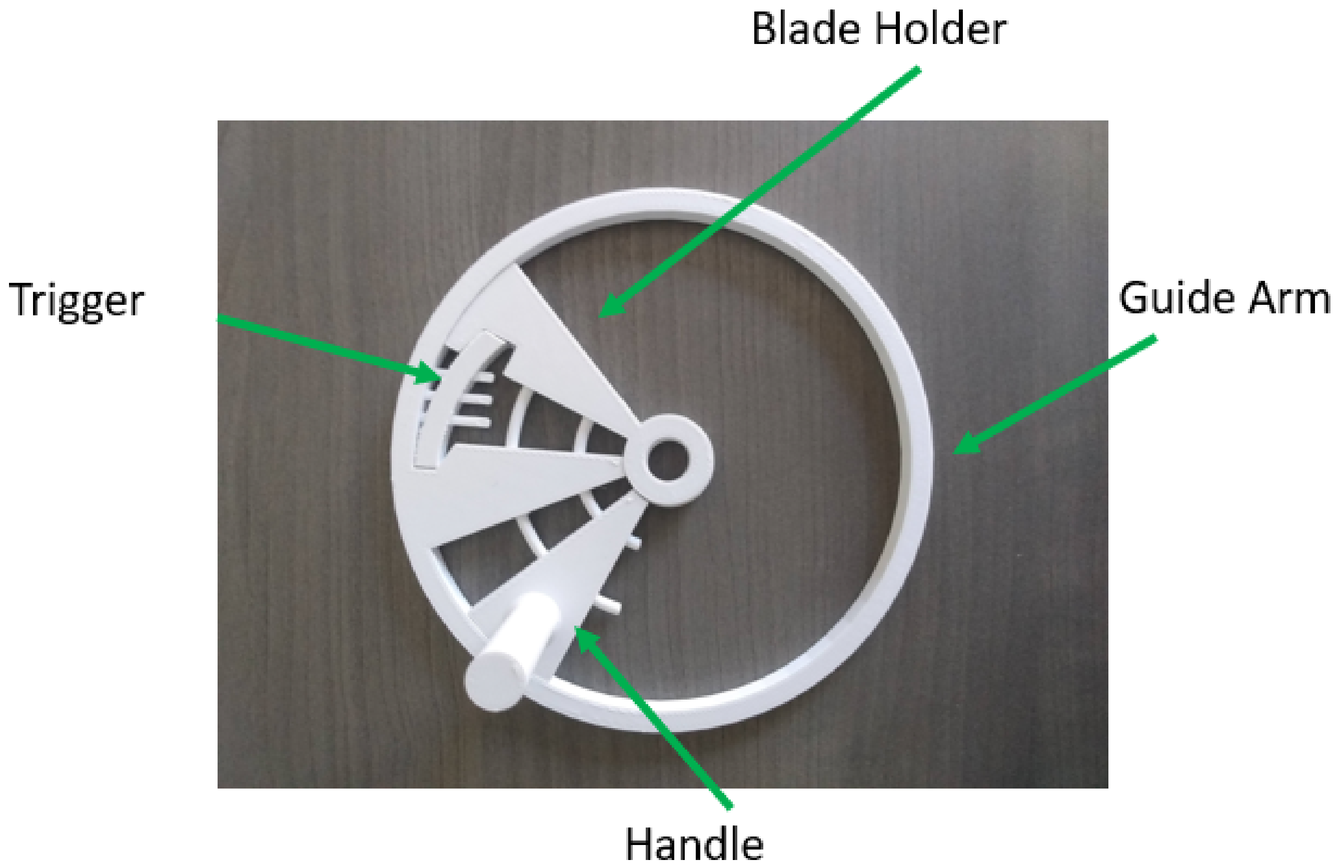


Figure 35: Shows an earlier version of the prototype with parts labeled.

The final prototype makes use of an impulse to cut the pills. As the handle is turned and the blade comes into contact with the pills, the blade holder is pushed back. As the blade holder is pushed back the trigger slides along the guide arm and builds up potential energy in springs that are seen in Fig. 34 between the handle and the guide arm. As energy is built up, the trigger slowly moves towards the slot in the guide arm. Once the trigger reaches the slot, the potential energy is released and cuts the pills.

We discovered that this method of delivering an impulse to the pills actually works really well in cutting the pills. We were able to achieve the following results.

1. Performance goal 1: 8.2/10
2. Performance goal 2:
3. Performance goal 3: Did not measure

We nearly met all the performance goals.

Bibliography

[1] ShuiXiang Li et al. *Maximum Packing Densities of Basic 3D Objects*. URL: https://link.springer.com/article/10.1007/s11434-009-0650-0.

[2] wikipedia.org. *Automatic center punch*. URL: https://en.wikipedia.org/wiki/Automatic_center_punch.