Crocheting Aid

A Major Qualifying Project Report

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by Samantha Barakian, Hailey Fink, Mariah Haney, Marissa Li,

Taylor Ostrum, Thanh Trac

April 26, 2021

Project Advisor

Professor Eben Cobb

Abstract

Crocheting requires repetitive wrist rotations for extended periods of time making it difficult for those with wrist arthritis to take part in this craft. Currently there are no crocheting devices on the market that assist with these repetitive motions. A comfortable crocheting device that reduces the need for wrist rotation could benefit these users with wrist arthritis. We designed and fabricated a 3D printed device with a spinning disk mechanism that rotates the crochet hook when the user activates it with their thumb. For added user comfort a silicone rubber hand grip was cast to slide onto the handle of the device. Multiple hook sizes are compatible and interchangeable within the mechanism so users can use one device for many projects. The device limits wrist rotation, is small and lightweight, and can be effectively used to crochet. With these attributes our crocheting device will aid users with wrist arthritis.

Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

Needlework is a type of textile art that involves using a needle or a similar tool to create textiles out of thread or yarn. Sewing, knitting, and crocheting are popular types of needlework. Sewing involves using a needle and thread to create stitches, often to attach two fabrics together. Knitting requires the use of knitting needles to create stitches out of yarn. Crocheting is very similar to knitting. While crocheting, yarn is also manipulated by making stitches, but the key difference is that crocheting uses only one hook instead of multiple knitting needles. Unlike a stitch in sewing, a stitch in knitting or crocheting is a loop or a series of loops of yarn.

While sewing, knitting, and crocheting can all be done by hand, machines are also frequently used in textile arts. Sewing machines have greatly improved the tedious aspect of sewing, and knitting machines and looms have also been used to upgrade hand knitting techniques. There are tools that attempt to make crocheting easier and less taxing for an individual. However, there are still no non-industrial machines or mechanisms that can properly automate crochet stitches while also maintaining craftsmanship (CrochetTalk, n.d.).

Needlework can be especially difficult for the elderly and others who struggle with hand mobility. Repetitive motions and joint rotations can cause pain and discomfort when crocheting for long periods. Those with arthritis are particularly affected by discomfort from repetitive wrist rotations when rotating the crochet hook. Currently, there is no crocheting device on the market that is tailored towards people with hand mobility issues. The expected outcome of this project is to create a mechanism that can reduce the need to rotate the wrist when crocheting while maintaining the craftsmanship of the user. The goals of this crocheting device are to reduce discomfort, increase crocheting duration, aid mobility, and maintain craftsmanship for crocheters with hand mobility problems.

Chapter 2 Background

This chapter will discuss the different aspects of crocheting, what crocheting devices are already in existence and the functional requirements of the crocheting aid device we will design. First, we discuss the different basic crochet stitches, grips, and motions. We then explore the various crocheting devices that are already on the market. Finally, we will set the functional requirements that our crocheting aid device needs in order to benefit our target customers.

2.1 Crochet Stitches

There are five fundamental crochet stitches that are used in almost every crochet pattern and project. In United States terms, these stitches include the chain stitch, the slip stitch, the half double crochet, the double crochet, and the single crochet (Solovay, 2020). Each of these stitches use the same hook motion but different numbers of yarn loops in order to be completed. One constant in all of these stitches is the way the hook is gripped; it is held in the dominant hand the same way a pencil would be held. Each of these crochet stitch motions will be described for a right-hand dominant person.

The chain stitch is the foundation stitch of most projects. This stitch starts by forming a slip knot shown in Figure 1. You would then hold the knot between your index finger and thumb with your left hand and grip the hook with your right hand. With the needle held horizontally and the hook facing in the upward direction the yarn gets wrapped over the hook. The hook is then rotated to secure the yarn and pull it through the first loop. This motion creates the first chain, and this procedure can be repeated until the desired number of chains are reached (Solovay, 2020).

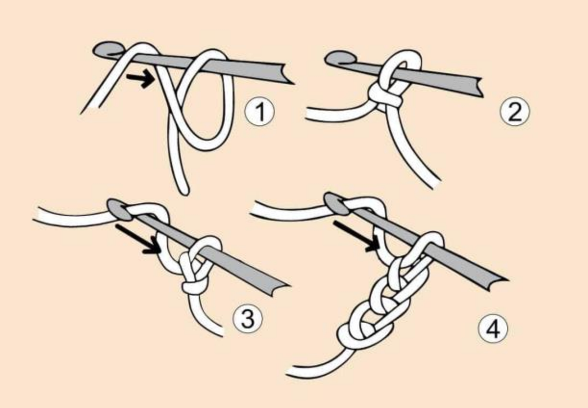


Figure 1. *Motions of a chain stitch.*

The second fundamental stitch is the slip stitch shown in Figure 2. This stitch is performed by inserting the hook into an existing loop, hooking the yarn that you are holding with your nondominant hand, rotating the hook to secure the yarn and pulling it through the working loop and the loop on the hook.

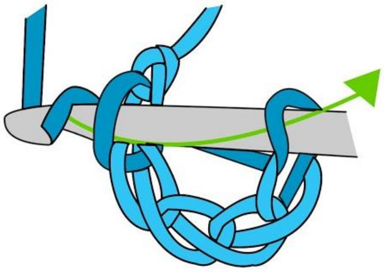


Figure 2. *Slip stitch.*

Next is the half double crochet shown in Figure 3, which is performed by wrapping the yarn over the hook, rotating the hook to secure the yarn, inserting the hook into the loop, wrapping the yarn over the hook, rotating it again and pulling the hook through the loop. There will now be three loops on the hook. To complete this stitch, wrap the yarn over the hook once more and pull it through all of the loops on the hook.

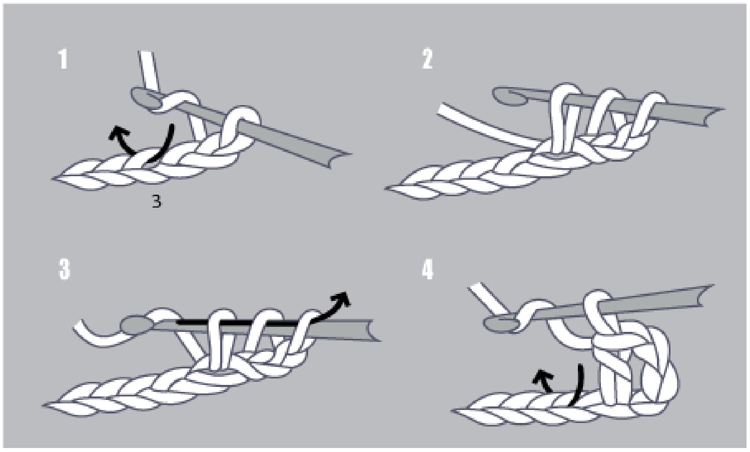


Figure 3. *Half double crochet stitch.*

The double crochet is the fourth fundamental stitch and is very similar to the half double crochet. The procedure is the same until there are three loops on the hook shown in Figure 4. For this stitch you put the yarn over the hook, rotate the hook securing the yarn, and bring it through the first two loops on the hook. Then put the yarn over the hook again, rotate the hook to secure the yarn and pull it through the last two loops on the hook.

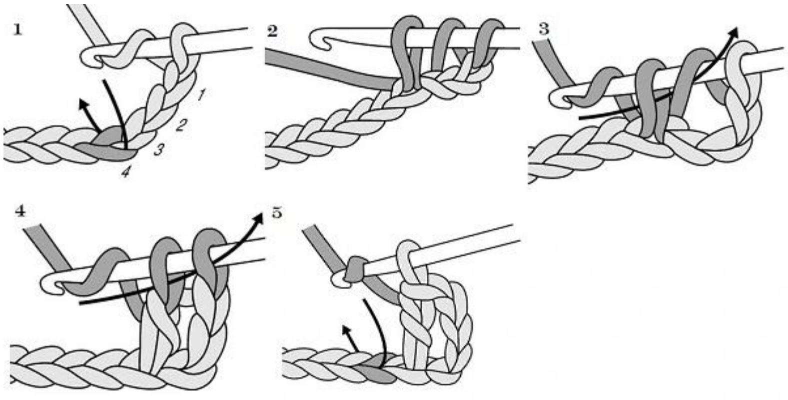


Figure 4. *Double crochet.*

The fifth and final fundamental crochet stitch is the single crochet shown below in Figure 5. To make this stitch, insert the hook into the loop, then wrap the yarn around the hook, rotate the hook to secure the yarn, and pull it through the loop. There will be two loops on the hook at this point. Wrap the yarn over the hook, rotate to secure and pull the yarn through both loops on the hook (Solovay, 2020).

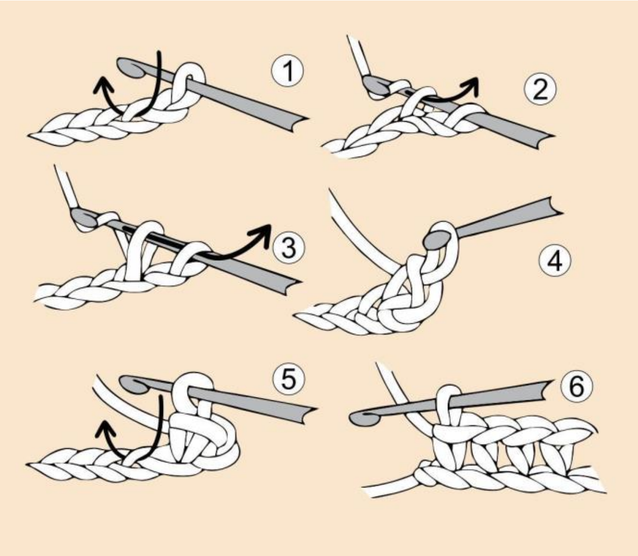


Figure 5. *Single crochet.*

2.2 Arthritis and Crocheting

Arthritis is the inflammation or swelling of joints. There are many types of arthritis, with the most common symptoms being pain and immobility in joints. According to the Centers for Disease Control and Prevention (CDC), osteoarthritis, rheumatoid arthritis, gout, fibromyalgia, lupus, and childhood arthritis are the six most common forms of arthritis (CDC, 2021). In the United States, 1 in 4 adults are affected, and it is estimated that by the year 2040, 26% of US adults will be diagnosed with arthritis (CDC, 2021). It is a disability that is more prevalent in older adults. For example, the age group of 45-64 make up 30.7% of those with arthritis (CDC, 2021). Those with the disease cannot do many simple daily tasks. Limitations of daily functionality include difficulties in grasping small objects, pushing or pulling heavy objects, and even sitting or standing for two hours.

The most common type of arthritis is osteoarthritis (OA), a degenerative joint disease that causes pain, stiffness, swelling, and aches in the hands, knees, and hips. Currently, 32.5 million US adults have it, and the risk of developing OA increases with age (CDC, 2021). This disease can be managed with medications or exercise, yet persistent pain still occurs in close to half of the adults with OA (CDC, 2021). Specific motions do not cause pain and arthritis to flare, but repetitive motion of a long period of time will.

Crocheting is an activity that can relieve stress and allow the participant to be creative, yet older people who enjoy the craft can be limited by their arthritis. Crocheting requires long durations of repetitive hand motions. Over time, the joints get sore and swell, so for those who suffer with arthritis the pain can be unbearable. The art of crocheting is more popular among women. According to Guitard et al., OA is "higher amongst women over 50 years old (66%) compared to men of the same age (34%)" (Guitard, 2018). Common complaints are morning hand stiffness and immobility, and, as a consequence, daily activities cannot be pursued. Active hand exercise is recommended to help relieve the pain by keeping the joints exercising and moving (CDC, 2020).

Wrist arthritis is most commonly associated with gout, rheumatoid arthritis, and osteoarthritis, and it is also more common among women (Penn Medicine, n.d.). Some symptoms of wrist arthritis include stiffness, grinding of the wrist joint, inflammation, and a weak grip (Penn Medicine, n.d.). It is common for those who have arthritis in their wrists to use a wrist brace, and they are also told to be mindful of activities that involve wrist movement. This can be frustrating when crocheting, since it relies so heavily on wrist movement.

When crocheting with arthritis in the hands and wrists it is important to practice proper ergonomics. While crocheting, it is recommended that a person keep their elbows close to their sides, and keep their wrist in line with their forearm instead of having it bent. It is also important to not grip the hook too tightly and to use lightweight hooks (Healthwise Staff, 2019).

2.3 Prior Art

A standard crochet hook consists of five main components, which can be seen in Figure 6. There is the handle where you hold the hook, the grip where the thumb rests, the shaft which determines the length of the hook, the throat which guides the yarn, and the point which is inserted into the stitches. All five of these components can be modified in order to increase ergonomics and alter stitch size. The most common crochet hook is a size 8-H (5mm) hook (Cagle, 2021).

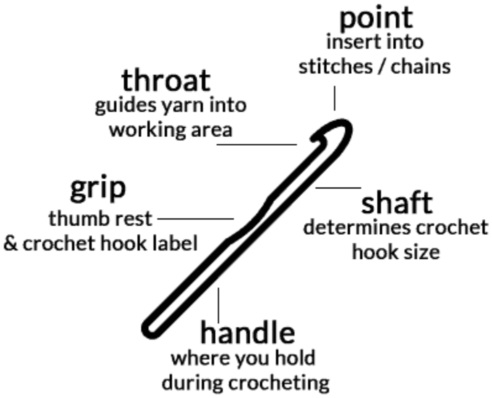


Figure 6. *Crochet hook anatomy.*

As of now, there are not many devices that aid in arthritis pain for crocheters, especially if they suffer from wrist flare ups. This can be due to the fact that machines cannot perform transverse chains that are required to crochet; they can only stitch vertically (Julia, 2021). Common remedies for arthritis pain include heat (copper gloves, soaking hands in warm water), cold (ice packs), stretches, compression, and pain medication. Adjustments to behavior such as stretching, looser grip, and taking frequent breaks, can reduce the effect of long-term repetitive motion. Different materials, such as thicker hooks and yarn, are easier to manipulate during a flare-up (Vann, 2013).

A common method for aiding arthritis while crocheting, to date, is purchasing an ergonomic hook, as shown in Figure 7. These hooks have a soft and padded handle, and are designed for comfort, safety, and ease of use. There are many different types of ergonomic hooks on the market, and the price can range anywhere from $7 - $114.80 for a pack of 10 different sizes (The Woobles, 2021). While the soft handle does aid in grip discomfort, the ergonomic hook does not change the wrist rotation required to complete stitches. Furthermore, some ergonomic hook heads are more curved and require more work to get the hook through the stitch, which increases wrist pain.

Figure 7. *Ergonomic crochet hook.*

There are currently other products on the market that assist crocheters with arthritis, and while they do not reduce wrist rotation, they have been very beneficial for reducing hand pain. Products like copper compression gloves and grip aids are common in the knitting and crocheting fields (Emily, 2019). A yarn holder has also been designed in which users slip the yarn holder onto their index finger on their non-dominant hand, and feed the yarn through to reduce finger movement, as shown in Figure 8 (AccessTR, n.a).

Figure 8. *Kroh's crochet aid.*

Crocheters can also use circular knitting machines to crochet as shown in Figure 9. The user loads the yarn and turns the crank to have the machine crochet. While this is helpful to quickly finish a product and reduce pain, it removes the user from performing the motions of their craft (Littlejohn, n.a).

Figure 9. *Knitting machine.*

Although some crochet arthritis aids already exist, our project focuses on alleviating wrist pain by eliminating wrist rotation. There is not a specific product for this on the market, however, there are design qualities that a person with arthritis can consider when buying a hook. For example, bamboo crochet hooks are recommended because they create less friction between the hook and the yarn. The bamboo also keeps the hand warmer, as metal tends to draw heat away (Stitch & Story, 2021). A hook with a shorter shaft is also beneficial because crocheters push the hook through until the yarn reaches the grip, and if the shaft is shorter than the distance the yarn must be pushed is reduced. A less rounded hook head is also recommended, as it requires less wrist rotation. However, none of these design qualities completely eliminate wrist rotation.

2.4 Functional Requirements

A good engineer always keeps the needs of their customer at the forefront of any design. To do this, specific functional requirements must be met, in order to create a successful mechanism. The functional requirements for this device are:

1. Reducing wrist motion by limiting rotation to a maximum of 10 degrees
2. Reducing grip force needed to operate the device
3. Preserving the craftsmanship of crocheting

4. Occupies a space within a 1 cubic foot
5. Weigh no more than 2 pounds
6. Easy to use
7. Manufacturable at Worcester Polytechnic Institute
8. Affordable consumer cost

The first two of the functional requirements that focus on mobility include reducing wrist rotation, and reducing necessary grip strength. Both rotation and firm grip are a source of significant discomfort for those with arthritis. These motions aggravate the joints, and in turn, cause pain that can severely impair mobility in affected areas. This is especially significant in the case of crocheting, where projects require a considerable number of these triggers, forcing some to give up crocheting entirely. Reducing or removing these motions, along with aiding mobility, will allow for increased comfort while crafting, increased crafting duration, and reduced discomfort after the process. This would allow those who are struggling to craft to continue, and assist those who have previously quit in returning to crafting.

Functional requirement 3 focuses on preserving the craftsmanship of crocheting. There are pre-existing knitting aids that can also be used for crocheting, but these do most of the stitching for you. This project’s mechanism will aim to provide assistance while simultaneously allowing the user to have more direct influence over their projects. To do this, the mechanism will be able to rotate the hook so the user does not need to use as much repetitive motion as they would need to use without the device. Maintaining craftsmanship will keep this hobby special for those who really want to continue improving and developing their skills instead of just letting a mechanism do all of the work. It is important to avoid creating something that only produces crochet crafts that feel manufactured.

Functional requirements 4, 5, and 6 all relate to the specifications of the mechanism. The size of the device should be small enough (within one cubic foot) to use while sitting down, and the weight of the device should be less than 2 pounds, or relatively light, to accommodate any mobility or muscle problems. For example, the user should be able to use it on their lap, while sitting down, or on a table. The device should be easy to use and not rely on learning many new skills.

Functional requirements 7 and 8 pertain to manufacturability and cost. Prototypes of the device should be able to be made with resources available at Worcester Polytechnic Institute, with the addition of purchasing other necessary tools and equipment. In addition, the device should be affordable to purchase to ensure that anyone can enjoy pain-free crocheting.

Chapter 3 Design Concepts

This chapter will discuss the different design concepts that the team came up with to satisfy the design requirements of the crocheting aid device. There were seven design concepts that were made to solve crocheting with mobility issues.

3.1 Primrose

The Primrose concept, seen in Figure 10, was designed to reduce all wrist rotation of the user. It makes use of a simple gear train that rotates the crochet hook by 90 degrees to hook onto the working yarn to make stitches. There is a cylindrical base that is used as the handle, and in this base, there are indents for the user's fingers to fit comfortably in. The base is also much wider than a crochet hook so that the user does not have to have as tight of a grip. There is a lever on the grip that is attached to the first spur gear in the gear train; when this lever is squeezed the spur gear will rotate. The spur gear is meshed with a bevel gear that will rotate with it as the lever is squeezed. Finally, the first bevel gear is meshed with a second bevel gear that will rotate the hook about the Z-axis shown in Figure 10. Attached to the second bevel gear is a mechanism that will hold the crochet hook in place. This mechanism is very similar to that of a compass that is used to hold the pencil. The crochet hook is tightened into place using an adjustable screw located outside of the base. The base will also have a slot 180 degrees around it, so that the screw and hook can rotate freely.

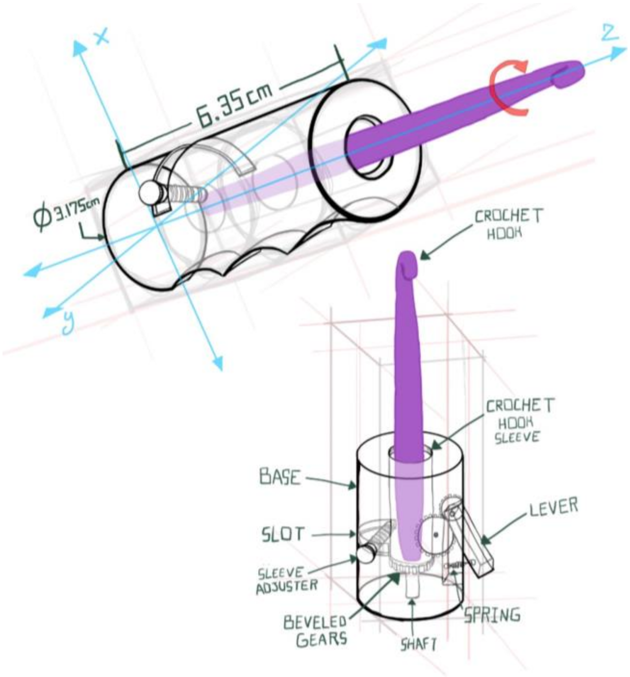


Figure 10. *Primrose design.*

3.2 Shell

The Shell, seen in Figure 11, has a very simple internal mechanism that allows the user to pull the handle away from the device. It is a cylindrical handheld device that allows the crochet hook to rotate by pulling a handle. The handle depresses the attached spring and pulls an internal wire. This wire rotates a disk. Attached to the disk is a sleeve where the hook can be placed. This mechanism allows the hook to be a part of the disk so whenever the disk spins, the hook will spin as well. One end of the wire is attached to the handle and the other end is attached to the disk. The design will pull the disk toward the user making it spin clockwise about the Z-axis shown in Figure 11. The design is suitable for arthritis users since it only needs two fingers to pull the mechanism to make it spin.

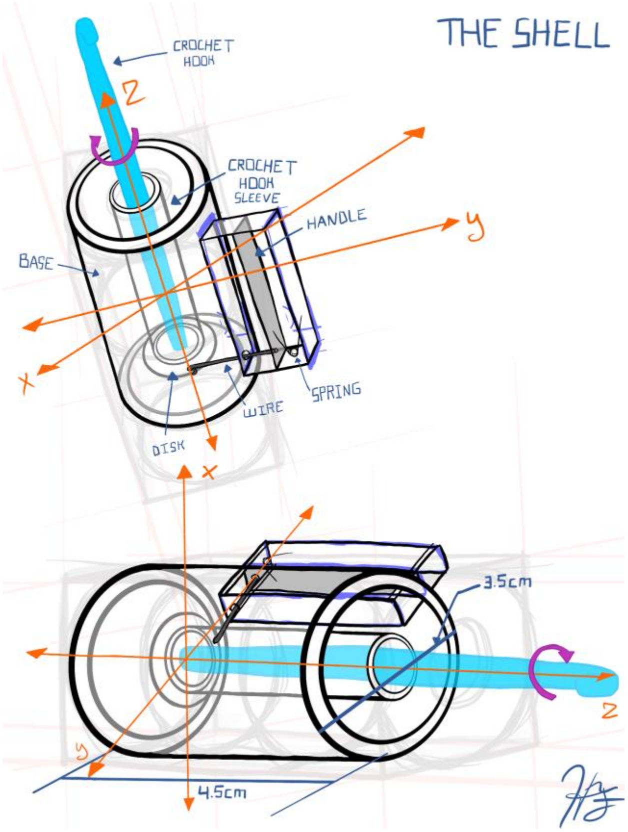


Figure 11. *Shell design.*

3.3 Springer

The Springer concept is a medium sized design that allows the user to place the device on their lap or on a table. The Springer uses The Primrose's gear mechanisms to turn the crochet hook as inspiration. This design is medium sized with a ten-inch push pin adjustable bar, illustrated in Figure 12. The bar can also slide side to side, relying on this linear motion to turn the hook. To turn the hook, the user will push the bar together with their arms. Handles on each side of the bar will assist in gripping the device. On the left handle, there is a removable hook that can be used to hold yarn tension. On the right handle, is the sleeve for a crochet hook. The sleeve is universal, enabling the user to use their own hooks. The sleeve is made of a rubber-like material enclosed in plastic casing that can be tightened, similar to a buckle. It is also placed at an angle to mimic normal crocheting. Alternatively, the device can be turned so that the bar is vertical, and the left handle can be placed on a surface. This would allow the user to push down on the bar to make the hook rotate.

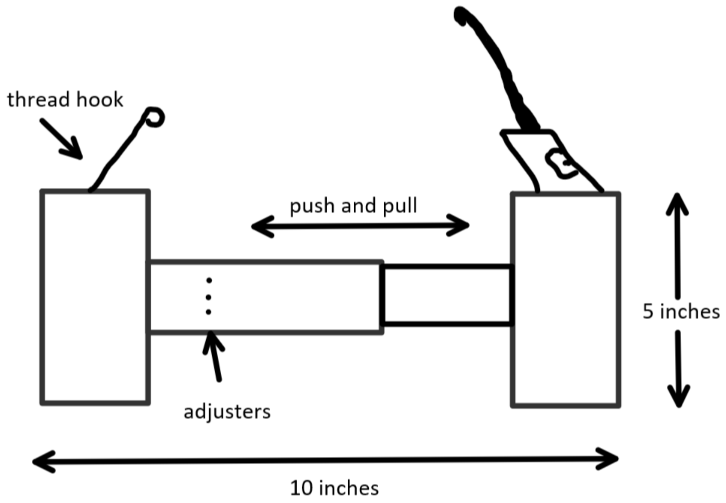


Figure 12. *Springer design.*

3.4 Lap Rest

The Lap Rest design was based on a product called the Knitting Aid. This is a "lightweight cushioned aid that holds your needles to give you support and comfort" ("A simple lightweight", 2020). The padded base would rest on the user's lap or table, and the user would place their hands in the soft rests on top of the base as shown in Figure 13. The dominant hand rest would help the user hold the hook, and both rests would support the wrists. The hand rests are mounted on a rolling track system, guiding the user through left to right movement, while allowing the user to provide most of the movement of the craft.

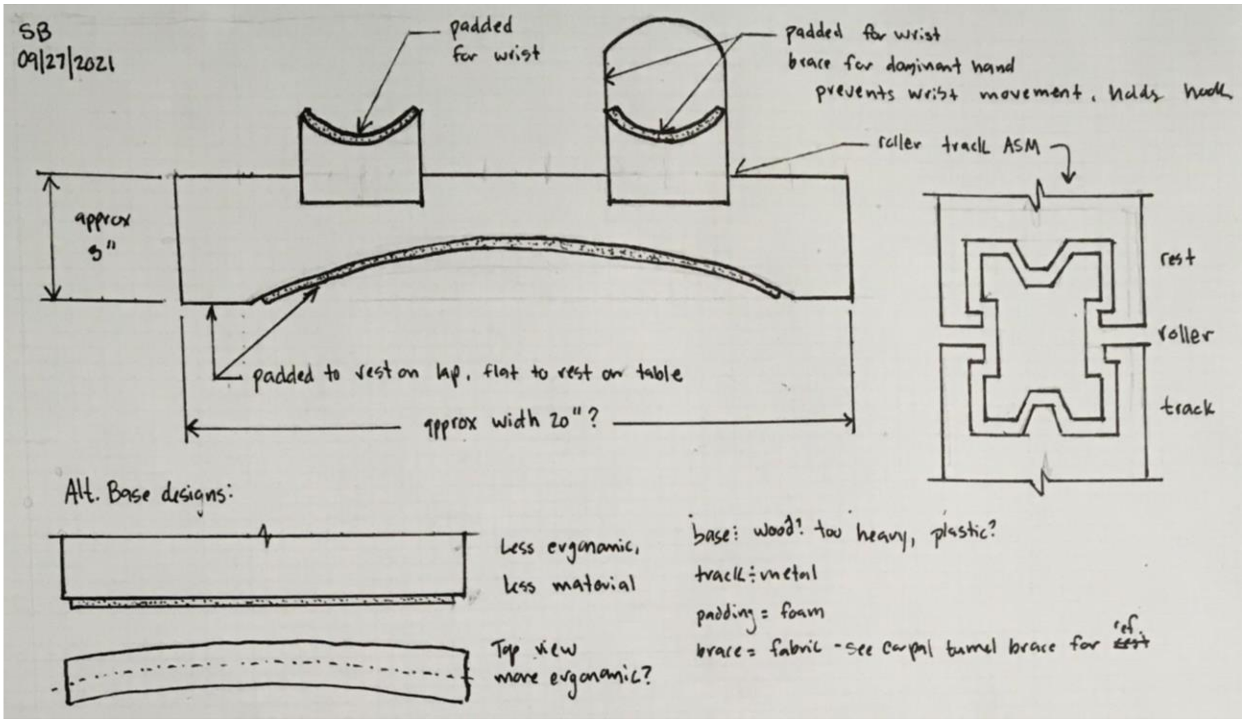


Figure 13. *Lap rest design.*

3.5 Hook Scoop

The Hook Scoop design, shown in Figure 14, was inspired by a handheld ice cream scooper. The purpose of this design is to completely eliminate wrist rotation while maintaining user mobility. The Hook Scoop works by squeezing the handle, compressing a spring that spins a gear at the base of the handle. The spring in turn rotates the arm 90 degrees. This design mimics an ice cream scoop that scrapes the ice cream out of the spoon when the handle is squeezed. The crochet hook would be attached to the rotating arm by a set screw whose tightness could be adjusted to compensate for the size of the crochet hook. The 90-degree rotation and crochet hook holder for this design were inspired by The Primrose, which proved it was possible to design a mechanism that completely eliminates wrist rotation.

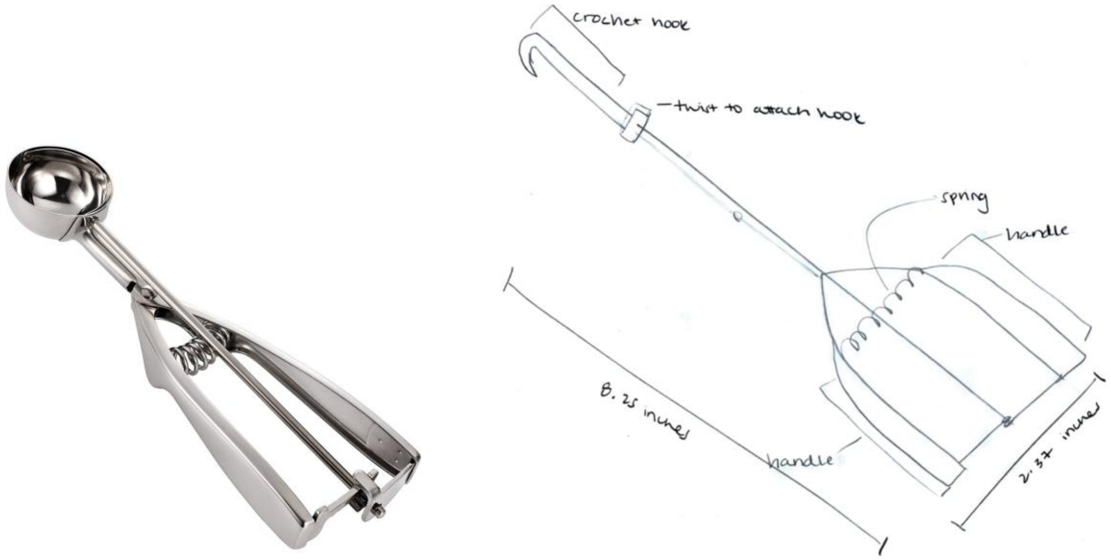


Figure 14. *Hook scoop design.*

3.6 Snips

The Snips design Figure 15, focused on decreasing the minute wrist rotation needed for crocheting and converting it to a large scissoring motion, as occurs in hedge clippers. The left side would hold the thread and the right would hold the crochet hook. Internal gears would allow the scissoring motion of the two sides to rotate the hook.

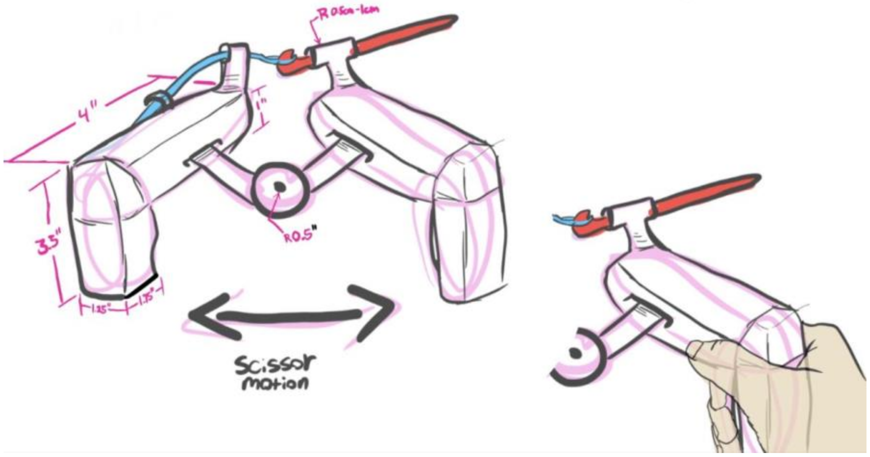


Figure 15. *Snips design.*

3.7 Joystick

The Joystick design in Figure 16 was a second rendition of the Snips design. The design was improved by making the hand-held components smaller and lighter. The left side would still hold the string and the right would hold a crochet hook. Although the user would still need to do a lot of wrist motion to move the hook side of the device, holding a handle instead of a small hook would help those who have weak grip strength.

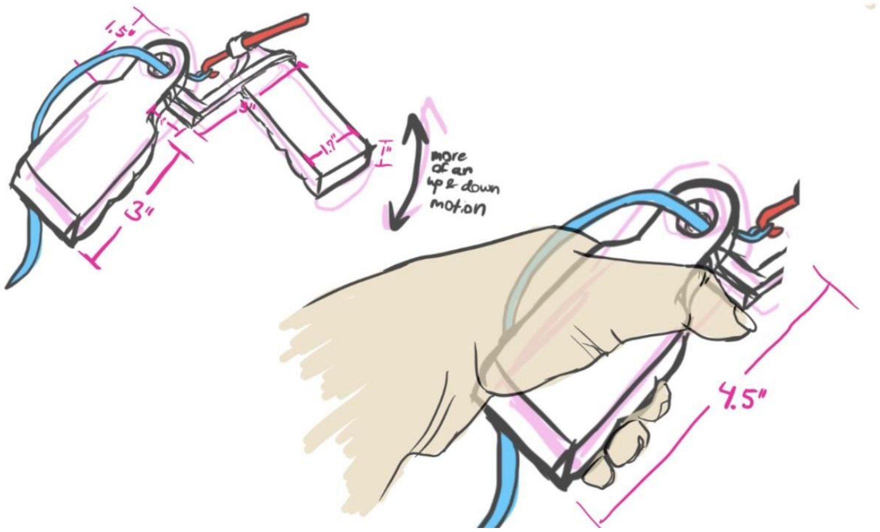


Figure 16. *Joystick design.*

Chapter 4 Synthesis and Analysis

This chapter will investigate the functionality of our device to make sure that it is workable and manufacturable. This includes mechanical advantage calculations, spring constants, and force and stress analyses on the lever and crochet hook.

4.1 Mechanical Advantage

In order for the device to be easily used by an individual with hand mobility issues, the force required to turn the lever should be around 3 N. The length of the lever and its orientation to the rotational disk are critical. If the lever is too short a larger input force will be required. The input force is the force of the user's thumb pushing the lever. To maximize the input force, the transmission angle (angle between the lever and the disk) should be 90 degrees. The following equation was used as reference to justify these factors:

$$Torque = r \times F$$

(Where r is the length of the lever and F is the input force).

Assuming the force F is fixed, then the torque can be increased by increasing the length of the lever. The component of the input force acting on the lever is the perpendicular component. Thus, for the most efficiency, the lever should be 90 degrees from the rotational axis.

4.2 Stress on Lever

For a cantilever beam with a uniform distributed load, the maximum moment and the maximum deflection is given as:

$$M_{max} = \frac{wL^2}{2}$$

$$\delta_{max} = \frac{wL^4}{8EI}$$

(Where E is the modulus of elasticity, I is the area moment of inertia of the beam, L is the length, and w is the distributed load.)

Assuming static equilibrium, the reaction force at the fixed end of the lever equals the force applied. Figure 17 shows a diagram of the lever model.

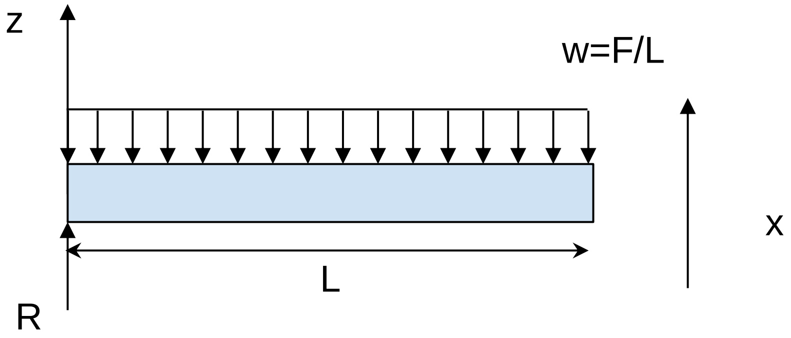


Figure 17. *Lever stress model.*

Assumptions:

- Gravity has a negligible effect
- Model as horizontal cantilever beam
- Lever is uniform, straight, and density is uniformly distributed
- Material: PLA used in the 3D printers (SD3d, n.d.)
    - ○ Modulus of elasticity E = 2.3 GPa
    - ○ Yield strength σ_y= 35.9 MPa
- Length: L = 1.3 cm
- Width: b = 0.2 cm
- Height: h = 0.2 cm
- Force applied is F = 2.2 N
- Force is modeled as a uniformly distributed load across entire lever to represent a thumb pressing against it

$$M_{max} = -\frac{wL^2}{2} = -1.43\ N * cm$$

$$I = \frac{bh^3}{12} = 0.0001333\ cm^4$$

$$\delta_{max} = \frac{wL^4}{8EI} = 0.0197\ cm$$

The maximum bending stress will occur on the surface of the lever, where z, the distance from the neutral axis of the lever to the surface, is $0.2cm/2$

$$\sigma_{max} = \frac{M_{max}z}{I} = 1072.5\ N/cm^2 = 10.725\ MPa$$

Thus, the safety factor of the lever is as follows:

$$SF = \frac{\sigma_y}{\sigma_{max}} = \frac{35.9\ MPa}{10.725\ MPa} = 3.35$$

For an application that will not significantly harm human life, a safety factor of 3.35 is satisfactory and shows that this material is reliable under these loading conditions.

These calculations show that theoretically, the deflection of the lever will be minuscule and the stress will not reach yield, so the lever will not fail. A simulation was also run to compare results, the maximum stress felt on the disk in the simulation was 8.3 MPa, which is close to the calculated results. The plot of the simulation is shown below in Figure 18.

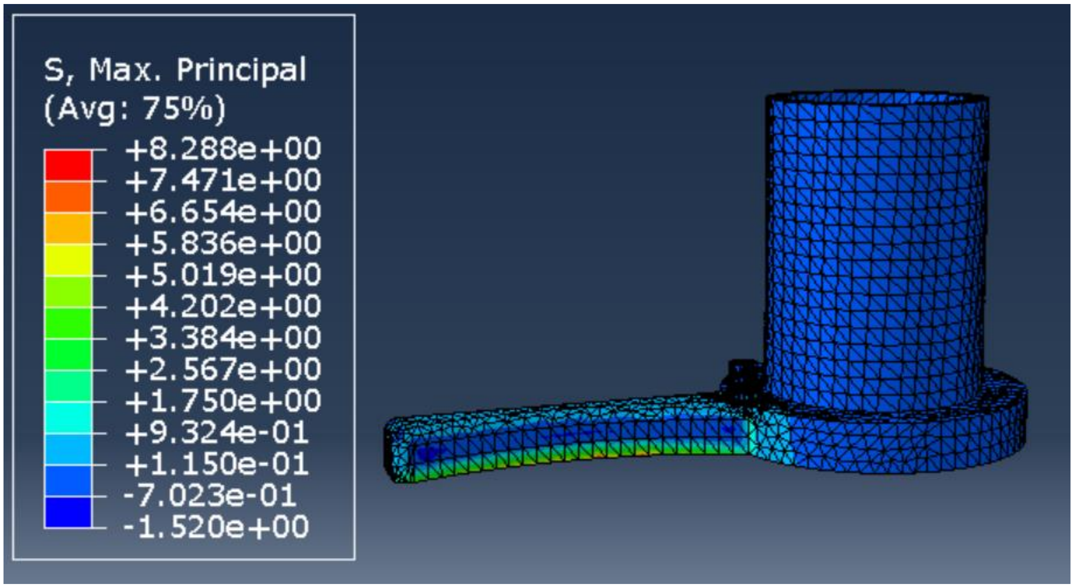


Figure 18. *Stress simulation on disk lever.*

4.3 Spring Constant

The device has a small extension spring that allows the lever to return back to its resting position. The spring should have enough tension to pull back the lever, and should not require too much force to extend. Hooke's law is used as the basis for this calculation.

$$F = kx\ ,$$

(Where k is the linear spring constant and x is the change in length of the spring).

Assumptions:

- Arc length = 3 cm
- Model as linear extension

$$2.2N = k * 3cm$$

$$k = 0.733\ N/cm$$

The spring should have a spring constant of no more than 0.733 N/cm

4.4 Hook Attachment Force

The hook needs to be able to withstand a force of 5 N in order to pull the yarn through a loop. This was concluded by using a spring scale attached to a crochet hook; the hook was used to pull yarn through a loop and the force needed was measured to be 5 N. Using this value of 5 N, an Abaqus simulation was ran on the crochet hook to simulate where the highest stress level would be. The hook experiences the largest stress where it is connected to the base, this stress level is 52 Pa. The simulation shown below in Figure 19 shows that the hook will not fail with a 5 N load. Further testing will confirm these results and show the maximum load this crochet hook can hold.

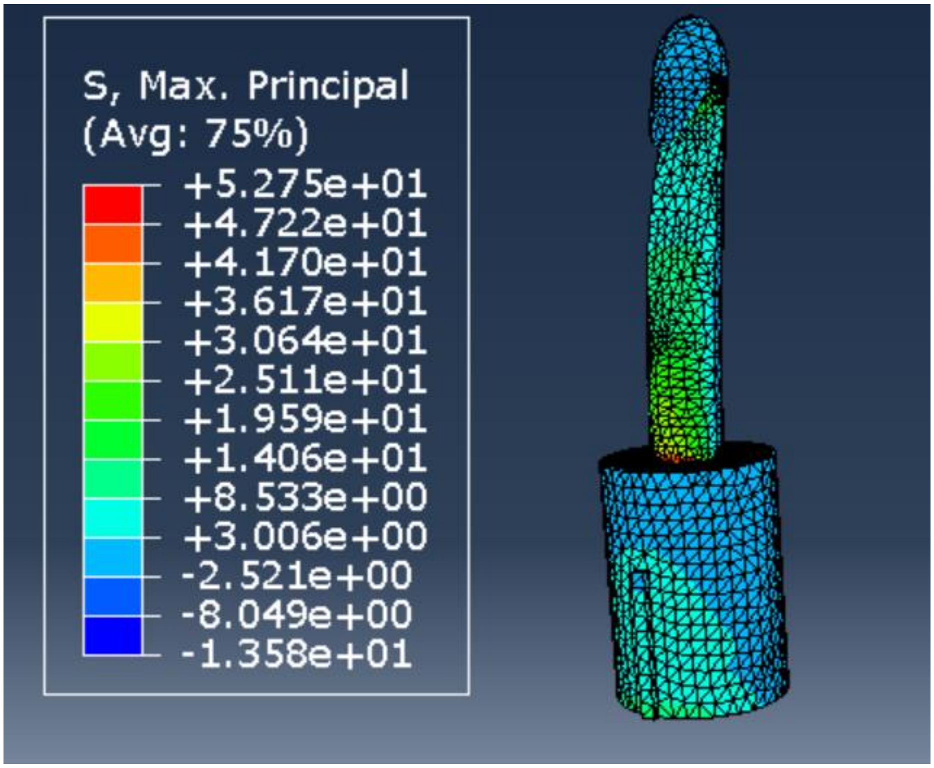


Figure 19. *Stress simulation on crochet hook.*

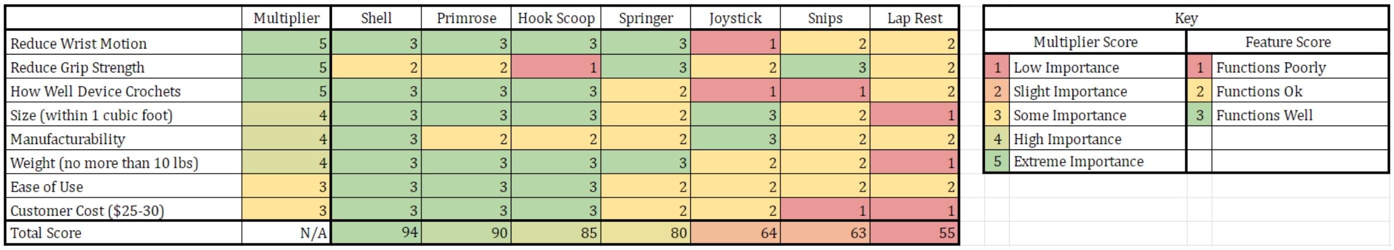
Chapter 5 Design Selection

This chapter will discuss the design selection process that the team implemented to choose the final design and which attributes were a part of that design. There were seven design concepts that were narrowed down to a final two.

5.1 Matrix

In order to decide which design concept had the best features to best meet our functional requirements, we created a design matrix shown in Table 1. The matrix includes eight weighted factors we believe to be most important in the development of our product, to evaluate our seven individual designs previously described in Chapter 3. We scored each weighted factor by a multiplier score on a scale of 1-5, 1 being low importance, and 5 being of extreme importance. The eight weighed factors and their respective scores are “Reduce Wrist Rotation” (5), “Reduce Grip Strength” (5), “How Well Device Crochets” (5), “Size” (4), “Manufacturability” (4), “Weight” (4), “Ease of Use” (3), and “Customer Cost” (3). It is necessary that our product reduces wrist rotation and grip strength without affecting how the user crochets, therefore we gave each of those categories a 5.

Table 1. *Concept design matrix.*



	Multiplier	Shell	Primrose	Hook Scoop	Springer	Joystick	Snips	Lap Rest
Reduce Wrist Motion	5	3	3	3	3	1	2	2
Reduce Grip Strength	5	2	2	1	3	2	3	2
How Well Device Crochets	5	3	3	3	2	1	1	2
Size (within 1 cubic foot)	4	3	3	3	2	3	2	1
Manufacturability	4	3	2	2	2	3	2	2
Weight (no more than 10 lbs)	4	3	3	3	3	2	2	1
Ease of Use	3	3	3	3	2	2	2	2
Customer Cost ($25-30)	3	3	3	3	2	2	1	1
Total Score	N/A	94	90	85	80	64	63	55

Key			
Multiplier Score		Feature Score	
1	Low Importance	1	Functions Poorly
2	Slight Importance	2	Functions Ok
3	Some Importance	3	Functions Well
4	High Importance		
5	Extreme Importance		

To determine which of the seven designs scored the highest, we evaluated each of them with respect to the eight weighted factors. For each category, we scored the design concept by a feature score on a scale of 0-3, with 0 meaning it does not exist, and 3 meaning it functions well. For example, the Shell completely eliminates wrist rotation so we scored it a 3, but the Joystick requires wrist movement so we scored it a 1 for that category. We did this for every category, first determining the design concept’s score on a scale of 0-3, then multiplying that score by the multiplier (0-5) for that weighted factor category. We took the sum of the scores for each category, then compared each design.

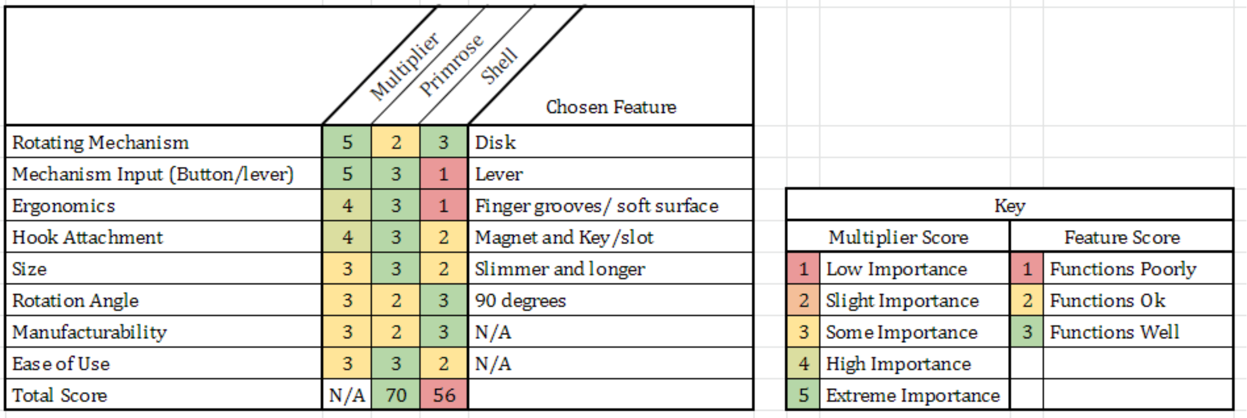
$$\Sigma\ (feature\ score_{design\ i} * multiplier\ score_{design\ i})$$

The Shell scored a 100, the Primrose a 96, the Hook Scoop a 91, the Springer an 86, the Joystick a 70, the Snips a 76, and the Lap Rest a 61. Based on these scores, we selected the Shell and the Primrose for our final design. We prototyped each individually, then made a hybrid device named Frannie that combined the best features of both devices.

5.2 Frannie

Frannie shown in Figure 20 was designed to combine the best features of the Primrose and Shell prototypes, as well as eliminate their weaknesses. From the Frannie design matrix Table 2, we can see that both designs had strengths and weaknesses in different categories. We took the top scoring attributes from each prototype in the matrix and combined them into our final Frannie design.

Table 7. *Manufacturing design matrix: total score.*



	Multiplier	Primrose	Shell	Chosen Feature
Rotating Mechanism	5	2	3	Disk
Mechanism Input (Button/lever)	5	3	1	Lever
Ergonomics	4	3	1	Finger grooves/ soft surface
Hook Attachment	4	3	2	Magnet and Key/slot
Size	3	3	2	Slimmer and longer
Rotation Angle	3	2	3	90 degrees
Manufacturability	3	2	3	N/A
Ease of Use	3	3	2	N/A
Total Score	N/A	70	56	

Key			
Multiplier Score		Feature Score	
1	Low Importance	1	Functions Poorly
2	Slight Importance	2	Functions Ok
3	Some Importance	3	Functions Well
4	High Importance		
5	Extreme Importance		

We chose to use these weighted factors in the Frannie matrix because they have the biggest differences between the two prototypes and are the most critical to the final design. The rotating disk mechanism of the Shell was chosen over the Primrose's gear train to improve the manufacturability, assembly and maintenance of the system. The button/lever design of the Primrose was chosen over the pulling lever in order to reduce grip strength needed to activate the device. Ergonomics are highly important to provide comfort and alleviate joint strain on the user, so we took the ergonomic finger indents and longer base of the Primrose and implemented them into the Frannie design. The hook attachment of the Primrose was chosen over the hook attachment of the Shell. The hook is attached to the rotating disk through the use of magnets and a mechanical key and slot.

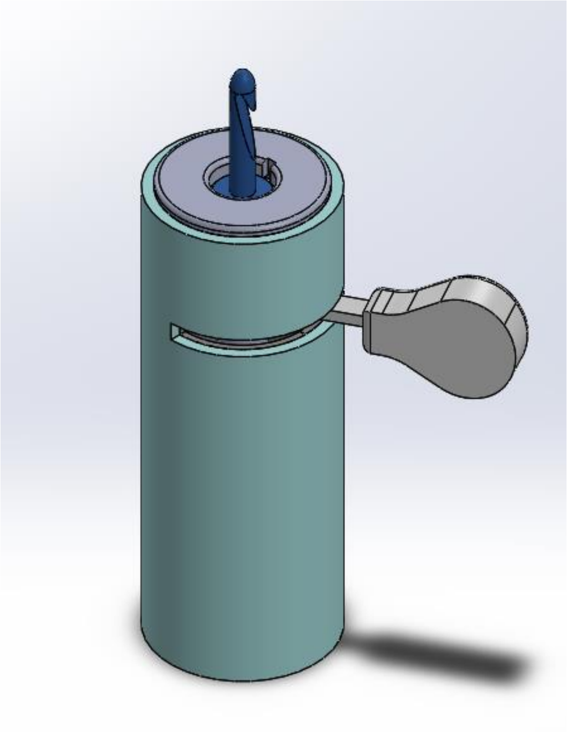


Figure 20. *Frannie design.*

Chapter 6 Detailed Design Description

This chapter will discuss the design for the crocheting device and ergonomic hand grip in detail. It will discuss why certain design choices were made, and what materials were chosen.

6.1 Crocheting Mechanism

The crocheting mechanism is made of thirteen parts, two of these being industry standard parts such as magnets and an extension spring. Eleven non-standard parts can be shown in Appendix C are the left and right handles, storage compartment, cover, storage cover, shaft, disk, shaft collar, spring brackets, paddle, and the 5 mm crochet hook. Each of these non-standard pieces are made of polylactic acid (PLA) plastic. The team wanted the device to be lightweight and inexpensive, and it needed to be manufactured using 3D printers at WPI. Due to these limitations the best material that was available to use for printing was the PLA as it was the cheapest option and one of the lightest weight options. This material is also more environmentally friendly than the others.

The overall diameter of the handle once it is fully assembled is 3.5 cm and the height is 10.76 cm shown in Appendix C. The diameter of the device cannot be any smaller than what it currently is due to the magnet used for the crocheting hook attachment. The magnet needs to be strong enough to withstand a maximum force of 5 N, so the smallest one that could withstand this force was 0.8 cm. The disk then needed to be large enough for the hook to slide into a sleeve and for the extension spring to be attached, so the diameter of this component needed to be 2.25 cm, Appendix B. The handle was designed to have a 3.5 cm outer diameter and a 3.2 cm inner diameter. The inner diameter gives the spring and disk a clearance of 0.95 cm to be able to rotate. The handle’s thickness is 0.3 cm. This is the minimum value this dimension could be in order to be strong enough while the user is gripping the device.

The total length of the device was chosen to be 10.76 cm so that when the user was holding the device the whole thing was resting on their hand for comfort. The storage compartment was designed to be 4.5 cm long so that it would be long enough to store extra accessories such as other hooks. The slot in the left and right handles was 2.94 cm from the bottom of these pieces, and 7.82 cm from the bottom of the device. This dimension was chosen for comfort, as the slot is placed where the user’s thumb would naturally rest on the device. Since the user’s thumb acts as the driving power for this device the slot needs to be in a comfortable spot. The lever of the disk was modeled to be 2.5 cm long, so it was long enough for the paddle to be placed in a location comfortable for the user to push.

The shaft was designed to be 3.8 cm long so that the disk would rest in the correct position for the lever to be inserted into the slot of the handle. The collar was designed to be small enough to fit inside of the magnet sleeve of the disk. In order for the top cover and bottom cover to fit seamlessly on the handle, their diameters were 3.5 cm. The top cover is designed to be a close fit so that it snaps onto the device, but can be taken off if an internal component needs to be repaired. There is a mechanical key slot on the top cover so that the crochet hook's mechanical key can slide into place. The final non-standard component was the spring bracket. This component was designed in order to hold the extension spring onto the handle and the disk. The device can be held in any orientation, and the spring will not slip out of place. Each one of these components are shown in Appendix B.

6.2 Ergonomic Hand Grip

The grip's dimensions, material, and shape were all determined based on the best suited ergonomic properties for a power grip, which is a hand grip around a cylindrical object (Patkin, n.d). Contrary to ergonomic crochet hooks with different shaped grips on the market, a uniform diameter was chosen for the mechanism to enhance user mobility. Furthermore, the grip was made to have a smooth exterior to provide hand comfort as well as prevent injuries such as skin damage.

The molded grip was made of silicone rubber, as the material is easy to obtain and cast, as well as being lightweight and providing the necessary softness (Appendix B). The mold for the grip was printed from PLA in three pieces: the outer left side, outer right side, and the core. It was printed this way in order for the grip to be easily removed from the mold. The mold was designed to be 11 cm tall and 4.5 cm wide so that it was large enough to cover the assembled device. In addition, it was designed to produce a thin smooth handgrip with a thickness of 0.25 cm. The grip is thin enough so that the device does not become bulky and uncomfortable to use. After molding, a slot was cut into the grip for the lever to pass through. The slot needs to be 135 degrees around the handle and 0.4 cm thick. This slot allows the hook to make a rotation to an angle desired by the user.

Chapter 7 Prototype Manufacturing

This chapter will discuss the manufacturing and assembly processes used to fabricate the crocheting mechanism and the ergonomic hand grip. Problems in the manufacturing and assembly process occurred that made the team reconsider and redesign certain components.

7.1 Rapid Prototyping and Assembly of Mechanism

In order to manufacture the crocheting device at WPI, the team decided to use rapid prototyping using a 3D printer. The team was able to fabricate the crocheting device out of Polylactic Acid plastic (PLA) and manufacture each part rapidly with adequate precision. The manufacturing process of the device was first to design and assemble each component in Solidworks, then to convert these files and export them into a 3D printing software, 3D Printing OS. The third step was to print the parts using an Ultimaker 3D printer due to its precision in making small parts, and finally magnets and springs were purchased from the store. The team ran into some issues while 3D printing and assembling such as tolerancing, slicing the pieces, and the device configuration.

Each component's tolerance was too tight the first time printing, so the dimensions of each part needed to be adjusted and reprinted. Some of the components such as the crochet hook and the handle needed to be reconfigured to print successfully, so the handle was cut into three pieces to print and the crochet hook was reoriented on the print bed. The original design consisted of a button, wire, and compression spring as the rotation activation method. While assembling this configuration some problems arose due to the size of the mechanism. Since the mechanism is small, the wire did not have enough space to be pushed in by the button to make a full 90-degree rotation. Since the mechanism was unable to rotate the full 90 degrees the team chose to reconfigure the design with a push lever attached to the disk, an extension spring and a slot 100 degrees around the handle of the device.

The crocheting device was assembled in two sub-assemblies, and then a final assembly. The first sub-assembly was the hook, a magnet was attached to the magnet sleeve at the bottom of the hook shown in Figure 21.

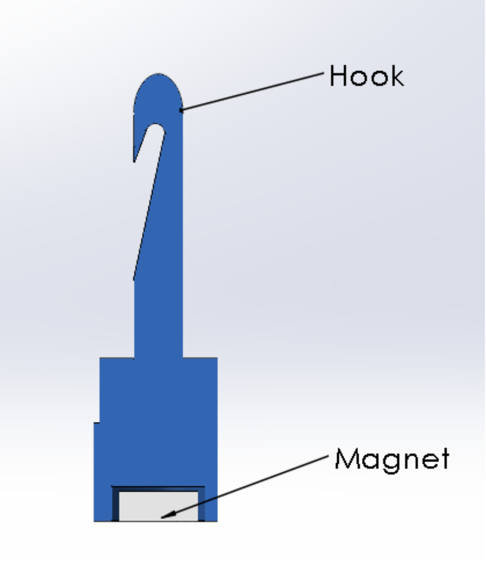


Figure 21. Hook and magnet sub-assembly.

The disk mechanism was the second sub-assembly; the disk was placed on the shaft resting on the shaft lip. A shaft collar was then adhered to the shaft over the disk in order to keep the disk in place. A magnet was attached with super glue to the magnet sleeve of the disk so that it spins with the disk as the lever is pushed, this sub-assembly is shown in Figure 22. The drawing for this figure can be found in Appendix C. The extension spring and spring holder are adhered onto the cylindrical spring mount on the disk.

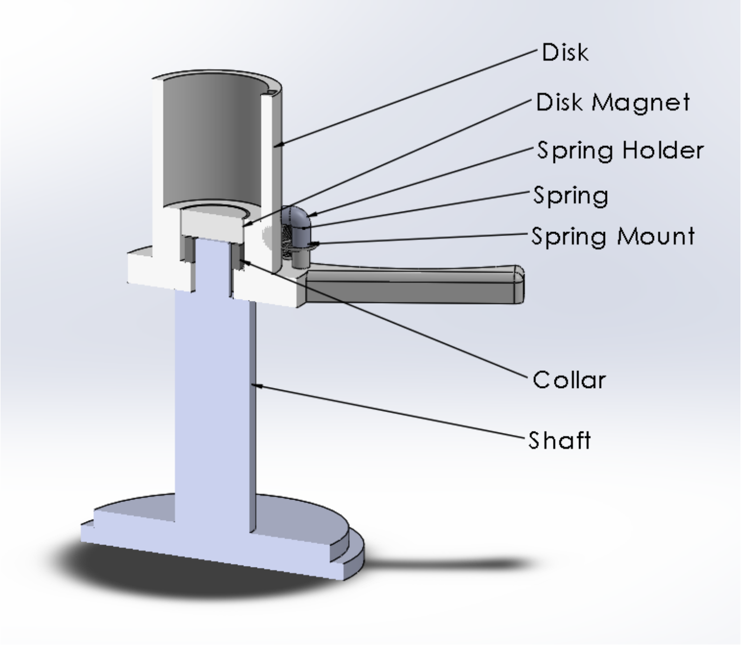


***Figure 22.** Disk and shaft sub-assembly.*

The final assembly consists of the outer handle of the mechanism, the cover, storage compartment, and the two sub-assemblies. The first step in this assembly process was to adhere the disk sub-assembly to the left and right halves of the handle in order for the thumb lever to slide into the handle. The spring was stretched and placed onto the cylindrical spring mount on the handle and the spring holder was adhered to the mount and handle so that it did not slip off. Next, the storage compartment was adhered to the bottom of the handle, and the top and bottom covers were put into place. Finally, the hook was slid into the mechanism by aligning the key of the hook to the slot of the cover and pushing down until the hook magnet and disk magnet attached to each other. The final assembly for the mechanism is shown below in Figure 23, the drawing for this figure can be found in Appendix C.

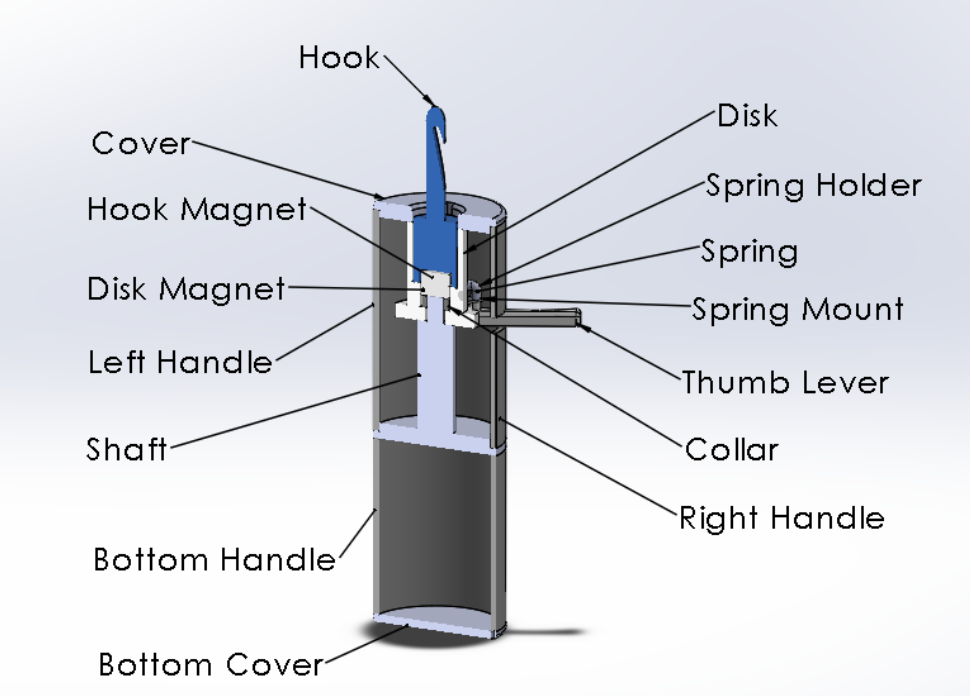


Figure 23. *Final crocheting mechanism assembly.*

7.2 Prototyping and Assembly of Ergonomic Hand Grip

In order to manufacture the grip for the crocheting device, the team explored two different methods. First, after researching ergonomic handle designs, the team used polymer clay to make grips that fit the form of a hand. Due to limitations in this material, the finish was not adequate for the crocheting device. The team then expanded its research to bike handles and other types of grips to see what is commonly used. This led to a slide-on grip design similar to the pencil grips shown in Figure 24.

Figure 24. *Pencil grip inspiration.*

To get the desired finish and flexibility, the team decided to cast rubber silicone. The product that was used is frequently used to make molds, but in this case, it was used as the casting material in a 3D printed mold. First, a 3D model of the mold had to be made. It was designed to be printed in two halves with a removable core, as seen in Figure 25. This would allow for a quick release mixture to be fully applied.

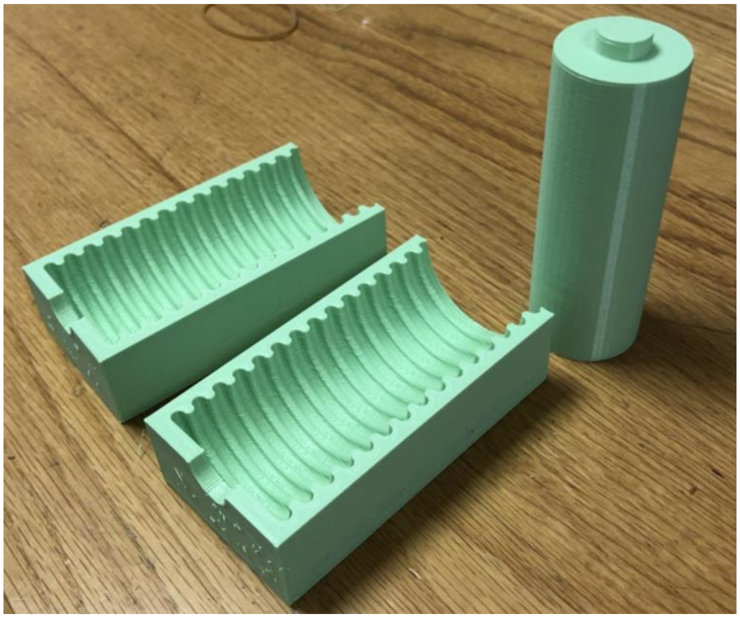


Figure 25. *3D printed grip mold.*

Once the mold was printed and cleaned, it was assembled for casting. The mold was held together with rubber bands as seen in Figure 26.

Figure 26. *Assembled mold.*

A two-part pourable silicone (*Smooth-On's* OOMOO™ 25 Tin-Cure Silicone Rubber-Mix Ratio of 1A:1B by volume) was used for the casting. This type of silicone required the team to determine how much A+B silicone mix was required. This meant that the volume of the mold was estimated and divided in half. The most common way to do this is to fill the mold with water and measure that value, however, because the mold was a 3D print, the water seeped into the mold. With this method, the best estimation came out to 2 oz. The mold was then emptied of water, disassembled, and left to fully dry. It was then prepared for the silicone.

First, a thin coat of Vaseline was applied to the core for easy removal. Then the mold was reassembled and secured with the rubber bands. A thin layer of hot-glue was added to the seams. Next equal parts A and B silicone were measured at 1 oz each, shown below in Figure 27.

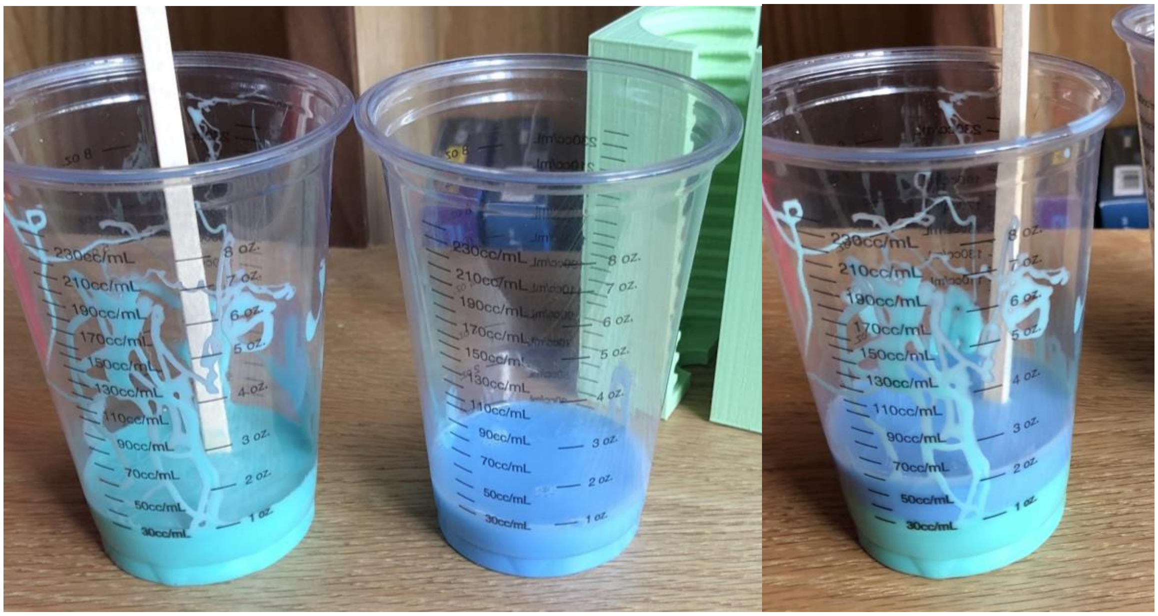


Figure 27. *A and B silicone.*

Then A and B were combined as instructed and mixed thoroughly until it was one solid color. Next the combined mixture was poured into the mold. However, for the first trial, the core was not secured in the mold before the pour started. This means there was significant leakage out of the base of the mold, which contributed to the failure of the first cast. The core was then secured in place as seen in Figure 28.

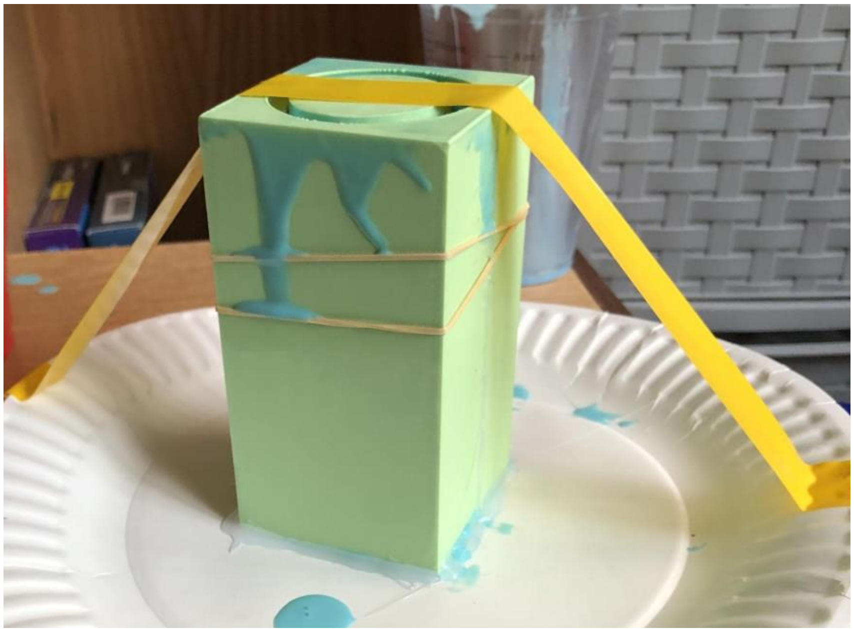


Figure 28. *First trial mold configuration.*

Before the success of the cast could be evaluated, the silicone had to cure over a period of around 80 minutes. Once removed, it was clear that this casting was a failure. The grip was too short, not enough silicone was mixed to fill the mold, and there was too much leakage. However, the team did determine that the silicone was appropriate for the device because it was soft and could be easily squeezed for comfort. To ensure that the second trial was a success, extra precautions were taken. The same mold was used; however, the core was placed first and sealed with hot glue. A layer of tape was wrapped around the entirety of the mold before any pouring began. For this cast about 3 oz of the combined two-part silicone was prepared and poured as seen in Figure 29.

Figure 29. *Second trial mold configuration.*

The team waited for the silicone to cure and removed the grip from the mold. When examining the removed grip, the team quickly noticed multiple holes; these holes result from air bubbles in the silicone mix usually created from stirring the two parts together. In more professional settings, the silicone can be placed into a pressure pot to vacuum out all the bubbles. Once the grip was slid onto the device an X-Acto knife was used to cut a hole for the lever. The completed grip is shown in Figure 30.

Figure 30. *Final mold with bumps.*

It was decided to model a thinner mold for a silicone grip that is smooth in order to compare the two designs. However, the thin mold was difficult to cast due to the viscosity of the rubber silicone, so the thin grip failed. From what could be salvaged from the cast, the thickness is what the team was looking for in terms of comfort.

7.3 Environmental Impacts

The crocheting device consists of two materials: a steel spring and PLA plastic. Environmentally friendly materials are best for sustainable designs since they can be recycled or manufactured cleanly. In order for this device to be sustainable, one might think that using an alternative to plastic is best; however, this might not be the case for our device. One of the main functional requirements of the design is to make the device as comfortable as possible, which means the device must be lightweight. Plastic is a better material since it is lightweight and much more comfortable to use than a material like steel. The best environmentally friendly plastic option would be a bioplastic, a biodegradable plastic that breaks down over time. PLA is a bioplastic which is recyclable, compostable, and biodegradable (Krieger, 2018). It is made from plant-based materials such as corn sugar, unlike regular plastic which uses fossil fuel (Krieger, 2018). However, it is not perfect since, like any other material, it takes a long time to break down in a landfill. The best way to have the PLA degrade is under industrial anaerobic composting conditions (V, 2019).

Nonetheless, it is still a viable option as a material for our product and it is the best in weight and functionally. Since the product is relatively small and simple, it does not demand much material or complicated processes or parts for manufacturing. In terms of the environmental impact, our product does not have a considerable carbon footprint. If processes and waste are managed properly, our product can be very environmentally friendly.

Chapter 8 Testing

In this section, data and conclusions from testing the crocheting aid will be discussed. Five different types of tests were conducted, a dimension test, fatigue test, bending and load tests, drop and shaking tests and crocheting test. The device passed all of the tests and shows that it functions as intended.

8.1 Dimension Test

One of the functional requirements of the device is to meet size and weight specifications. To satisfy the size functional requirement, the device needs to fit within one cubic foot, or 1,728 in^3. The size of the device was measured as approximately 2 in by 2 in by 6 in.

$$2in * 2in * 6in = 24in^3$$

This dimension satisfies the functional requirement. The device also needs to weigh less than 2 lbs. to ensure ease of use. A kitchen scale was used to weigh the crocheting aid with the successful silicone grip, and the weight was found to be 4.2 oz, satisfying the weight functional requirement.

8.2 Fatigue Test

A fatigue test was done to see if the lever could be spun 500 times with no significant problems. To complete this, the lever was rotated 500 cycles. One cycle is defined as pushing the lever 90 degrees and having it return back to its resting position. The team member testing this made note of any changes that could be felt throughout the testing. After 150 rotations, the spring became slightly looser, allowing it to be rotated easier. After 500 rotations, no significant changes could be determined. The device continued to work as intended.

8.3 Bending and Load Tests

A horizontal load test was done on the crochet hook to test the bending of the hook. A spring scale was used to measure the force in Newtons. The crocheting aid was attached to the end of a table horizontally with the spring scale secured near the end of the hook, shown in Figure 31.

Figure 31. *Horizontal load test configuration.*

Then, weights were added to the spring scale, and the deformation of the crochet hook was analyzed. The first signs of deformation began when 7 N of force was applied. Even more deflection was visually experienced at 11 N, and significant plastic deformations occurred at 20 N, which can be seen in Figure 32. The hook snapped after approximately 50 N of force was applied at its weak point from; this weak point occurs from how the 3D printer oriented the PLA layers.

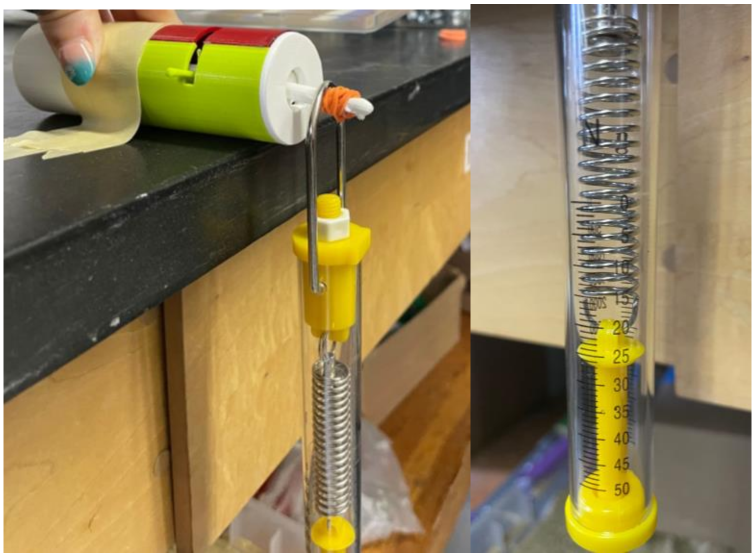


Figure 32. *Hook deformation at 25 Newtons.*

A vertical load test was done to test the magnetic strength of the hook attachment. For this test, the crocheting aid was fixed upside down using a clamp. The spring scale was secured to the end of the crochet hook, and then weights were added. The magnet detached when 12 N was applied, and no deformation of the hook occurred.

8.4 Drop and Shaking Test

A small device like the crocheting aid could be dropped on accident with daily use. Therefore, a drop test was performed to see whether the device would break. The device was dropped from 3 ft onto hard flooring, and no damage was observed. Additionally, the device was held upside down and shaken to see if any parts would become loose or detach. After shaking it, the device remained operational with no loosened parts.

8.5 Crocheting Test

The final and most important test that was performed on the crocheting device was the actual crocheting test. This device should be easy to use, comfortable to hold, reduce wrist rotation, and the user should actually be able to crochet with it. The device was tested with the grip, without the grip, with the paddles, and without the paddles. The user was able to use our device to crochet with and without the grip and paddles. The device was very easy to crochet with once the user was able to practice with it for some time. The way one would normally crochet needs to be slightly modified in order to use this device, but after doing a few rows of stitches it became very easy. The device's rotation mechanism works well and rotates very smoothly to the desired rotation angle. While the user was crocheting, they did not need to rotate their wrist at all to complete the stitches.

The device fit very comfortably in the user's hand without the grip and felt very light weight. None of the paddles were used without the grip since the user did not find it difficult to rotate the hook to the desired orientation. Once the grip was added the device still felt comfortable and lightweight. The grip was very comfortable in the user's hand and did not feel slippery. The user found the smallest paddle to be the easiest to use out of the three available sizes. Very little grip strength was needed from the user to hold and manipulate the crocheting device. This device satisfied the two most important functional requirements of actually being able to crochet with it, and reducing wrist rotation.

Chapter 9 Conclusions and Recommendations

9.1 Conclusions

This project achieved its initial goal to create a mechanism that can reduce the need to rotate the wrist when crocheting while maintaining the craftsmanship of the user. The 3D printed device limits wrist rotation, is small and lightweight, and can be used to successfully crochet. Furthermore, the device has interchangeable hooks that can be altered based on the user's preference, and contains a storage compartment that can hold said hooks or other tools. The team also molded an ergonomic hand grip from silicone that can further alleviate arthritis pain. This device can be used to successfully aid users with wrist arthritis.

9.2 Broader Impacts

From the initial design process to the final prototype, safety and comfort were the fundamental requirements of our device. Since the goal of the device is to be a medical assistive device for arthritis users, every part of the design was created with this in mind. The limitation of wrist motion was the most critical part of the functional requirement, so the mechanism of the device was designed to allow the user to use their thumb to drive the rotation. An ergonomic handgrip made from rubber silicone was designed to make the device easier to hold and comfortable. Frannie is also small, lightweight, and durable, so it will be suitable for prolonged usage. Also, since the team designed it to be customizable with different size hooks, Frannie can be used with multiple weights of yarn.

Frannie was created to aid the art of crocheting; the device was designed to help people with arthritis regain their skills. Since 1 in 4 adults develop arthritis in the United States, many find it difficult to complete daily activities, and it discourages people from doing the activities they want. Crocheting is not just a fun hobby, but it is also a type of source of livelihood. People crochet to make gifts, to sell, or to make clothing for themselves. Hand making a project is fulfilling, and it can become a piece of art that people can display or wear. Due to the high number of Americans with arthritis, there is a chance for people who currently crochet to have it in the future; yet, they should not be forced to give up their hobbies because of disabilities. Frannie gives users, especially the older generation, a chance to experience the activity again.

In terms of sustainability, Frannie is mostly made of the material PLA, which is recyclable and biodegradable. The device is also tested for durability, and can withstand damage and pressure, proving to be long-lasting. Overall, Frannie does not have significant environmental impacts and can last a long time.

Some important notes to consider is that the device has not been rigorously tested and may fatigue the hand. Since the device has not been through cyclic testing, the effects on the material such as creep and fatigue are unknown. Since the team only designed using two materials, there could be a different material that is better suited. Despite that, Frannie is capable of being an aid, and it has the potential to be improved as well.

9.3 Recommendations

The team developed a list of recommendations to improve the device if this project were to be expanded upon. While the crochet device created from this project is functional, and a successful proof of concept, it has room for refinement. The recommended improvements can be categorized as either a functional improvement, aesthetic improvement or a manufacturing improvement. The first functional improvement the team recommends is to make the grip smaller. While the team found the silicone bump grip to be the desired consistency and hand feel, it was agreed that once it was placed on the device, it was much larger and bulkier than desired. The team attempted to cast a thinner grip but because the 2-part silicone is very viscous it was very difficult to effectively fill the thinner mold. If a future team was to reattempt pouring a thinner grip, they could print or obtain a clear mold to make sure the entire mold is filled, use a machine that vibrates containers to help the silicone flow down the mold & a use a “pressure pot” to eliminate bubbles in the silicone that causes voids in the final grip.

The next functional improvement the team recommends, is to make the overall mechanism less noisy, it's possible this can be fixed with a different spring or industrial lubrication, but the current device squeaks when the lever is pressed. The last functional improvement the team recommends is to incorporate a universal hook. While the magnet allows for many different sized hooks, they all require the specific magnet base. This could seem like a positive from a marketing standpoint, but there is still the possibility to make the device able to hold any pre-existing crochet hook.

The aesthetic improvements the team recommends are to further develop and refine the marketable qualities of the device. Many components of the device can be made in different colors, including the body, levers, hooks and grips. Grip sizes, hook sizes and lever sizes can also add to the marketability of a final design that is shelf ready. Future teams can improve the device by making it compatible for both right-handed and left-handed individuals, as well as decrease the overall size of the mechanism for more comfortable and agile operations.

The team also did not have the opportunity to have older people, with arthritis, test the device within the timeframe of the project. Future teams could find potential customers, and have them give more feedback on the device.

9.4 Redesign for Mass Manufacturing

The prototype of this device was manufactured with 3D printing, as this production method is cheap and versatile which is ideal for prototyping. The resulting prints were then glued together to form the final product. While effective for prototyping, this method is not suitable for mass production due to the time it takes to print each part. In order to mass produce such a product, a mass manufacturing production and assembly process must be achieved. In order to select a mass manufacturing method best suited for this product, a series of design matrices were created.

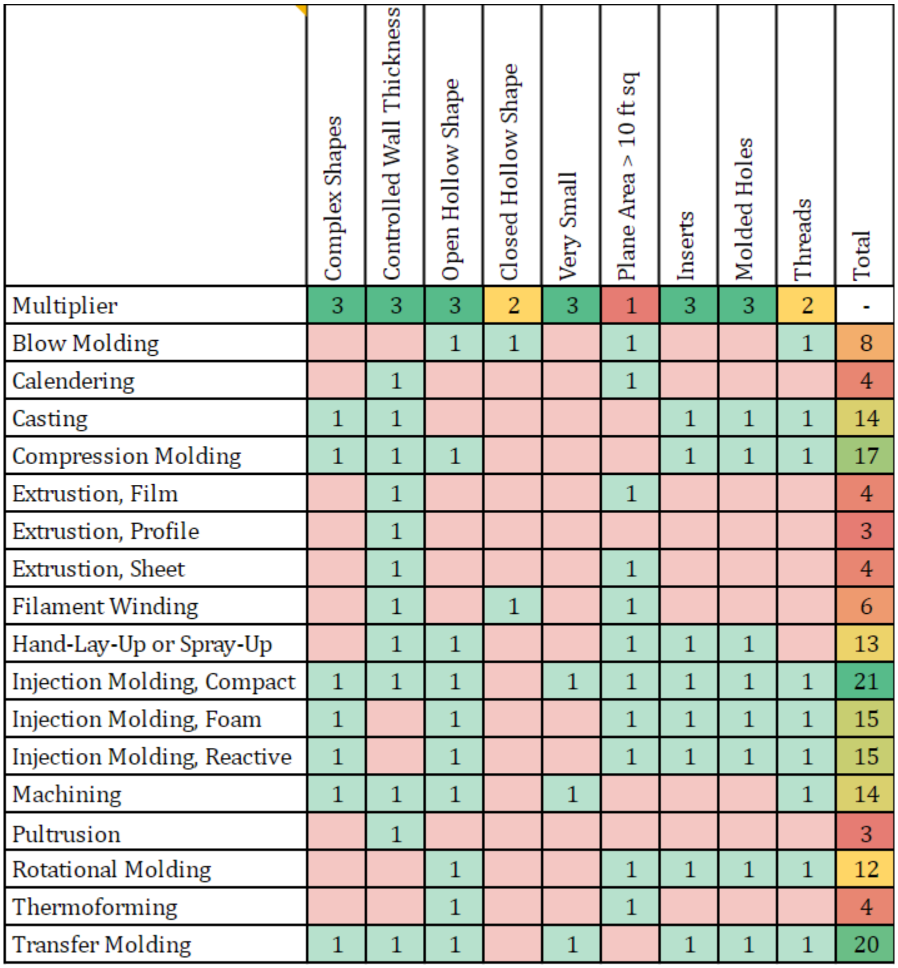
9.4.1 Selecting a Mass Manufacturing Process

Geometric capabilities are the most critical feature of a manufacturing process. If a process is unable to produce the required geometry, it is not suitable for the project, regardless of any other positive factors. Table 3 displays a decision matrix of various plastic manufacturing processes and the geometry they are capable of creating. Each geometric feature was given a feature multiplier score to rank its importance to the crocheting aid product. “Complex Shapes”, “Controlled Wall Thickness”, “Open Hollow Shape”, “Very Small”, “Inserts”, and “Molded Holes” were all given a score of 3. The hook and grip are organic, complex shapes, the handles are hollow open shapes, the spring retention pins are very small, and the space for the magnets are both inserts and molded holes. “Closed Hollow Shape” and “Threads” were given a score of 2, as they are not currently involved in the geometry of the prototype but could be utilized in a redesign for a chosen manufacturing process. “Plane Area > 10 square feet” was given a score of

1. The prototype is only 2 in by 2 in by 6 in, far beneath the 10 ft^2 threshold, and therefore will not reach that size in a redesign.

Each feature the process was capable of completing was given one feature point. The total score for each process was calculated by multiplying each feature point by the corresponding feature multiplier, then taking the sum of points.

Table 3. *Manufacturing design matrix: shape.*



	Complex Shapes	Controlled Wall Thickness	Open Hollow Shape	Closed Hollow Shape	Very Small	Plane Area > 10 ft sq	Inserts	Molded Holes	Threads	Total
Multiplier	3	3	3	2	3	1	3	3	2	-
Blow Molding			1	1		1			1	8
Calendering		1				1				4
Casting	1	1					1	1	1	14
Compression Molding	1	1	1				1	1	1	17
Extrustion, Film		1				1				4
Extrustion, Profile		1								3
Extrustion, Sheet		1				1				4
Filament Winding		1		1		1				6
Hand-Lay-Up or Spray-Up		1	1			1	1	1		13
Injection Molding, Compact	1	1	1		1	1	1	1	1	21
Injection Molding, Foam	1		1			1	1	1	1	15
Injection Molding, Reactive	1		1			1	1	1	1	15
Machining	1	1	1		1				1	14
Pultrusion		1								3
Rotational Molding			1			1	1	1	1	12
Thermoforming			1			1				4
Transfer Molding	1	1	1		1		1	1	1	20

Table 4 displays the equipment costs of each manufacturing process, while Table 5 displays the tooling costs. In both of these tables, each process was scored 1 to 10 based on the cost of each process: a score of 1 indicates an equipment or tooling cost greater than $250,000, a score of 9 indicates an equipment or tooling cost less than $20,000, and a score of 10 indicates no equipment or tooling cost for that process.

Table 4. *Manufacturing design matrix: equipment cost.*

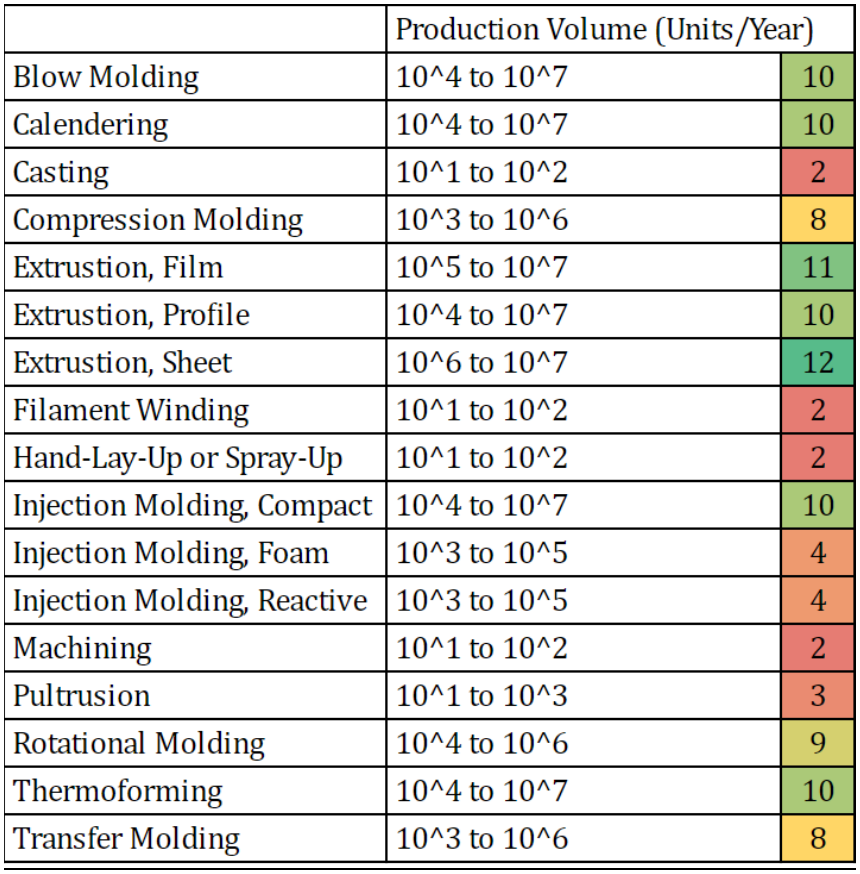
	Equipment Costs (USD)	
Blow Molding	$50,000 to $249,999	4
Calendering	< $20,000	9
Casting	< $20,000	9
Compression Molding	$50,000 to $249,999	4
Extrustion, Film	$100,000 to > $250,000	2
Extrustion, Profile	$50,000 to $249,999	4
Extrustion, Sheet	$100,000 to > $250,000	2
Filament Winding	$50,000 to $249,999	4
Hand-Lay-Up or Spray-Up	$20,000 to $49,999	7
Injection Molding, Compact	$50,000 to > $250,000	2
Injection Molding, Foam	> $250,000	1
Injection Molding, Reactive	$20,000 to $99,999	6
Machining	$20,000 to $49,999	7
Pultrusion	$20,000 to $49,999	7
Rotational Molding	$50,000 to $249,999	4
Thermoforming	$50,000 to $249,999	4
Transfer Molding	$50,000 to $249,999	4

Table 5. *Manufacturing design matrix: tooling cost.*

	Tooling Costs (USD)	
Blow Molding	$200,000 to $99,999	6
Calendering	None	10
Casting	< $20,000	9
Compression Molding	$50,000 to $99,999	5
Extrustion, Film	$100,000 to $249,999	3
Extrustion, Profile	$50,000 to $99,999	5
Extrustion, Sheet	$100,000 to $249,999	3
Filament Winding	< $20,000 to $99,999	7
Hand-Lay-Up or Spray-Up	None	10
Injection Molding, Compact	$50,000 to $249,999	4
Injection Molding, Foam	$50,000 to $249,999	4
Injection Molding, Reactive	$20,000 to $99,999	6
Machining	< $20,000	9
Pultrusion	$20,000 to $99,999	6
Rotational Molding	$20,000 to $99,999	6
Thermoforming	$20,000 to $99,999	6
Transfer Molding	$50,000 to $249,999	4

Table 6 once again lists the plastic manufacturing processes and their production volumes. Production volumes were ranked on a scale from 1 to 13, with a score of 1 for 10 units per year and a score of 13 for 10^7 units per year.

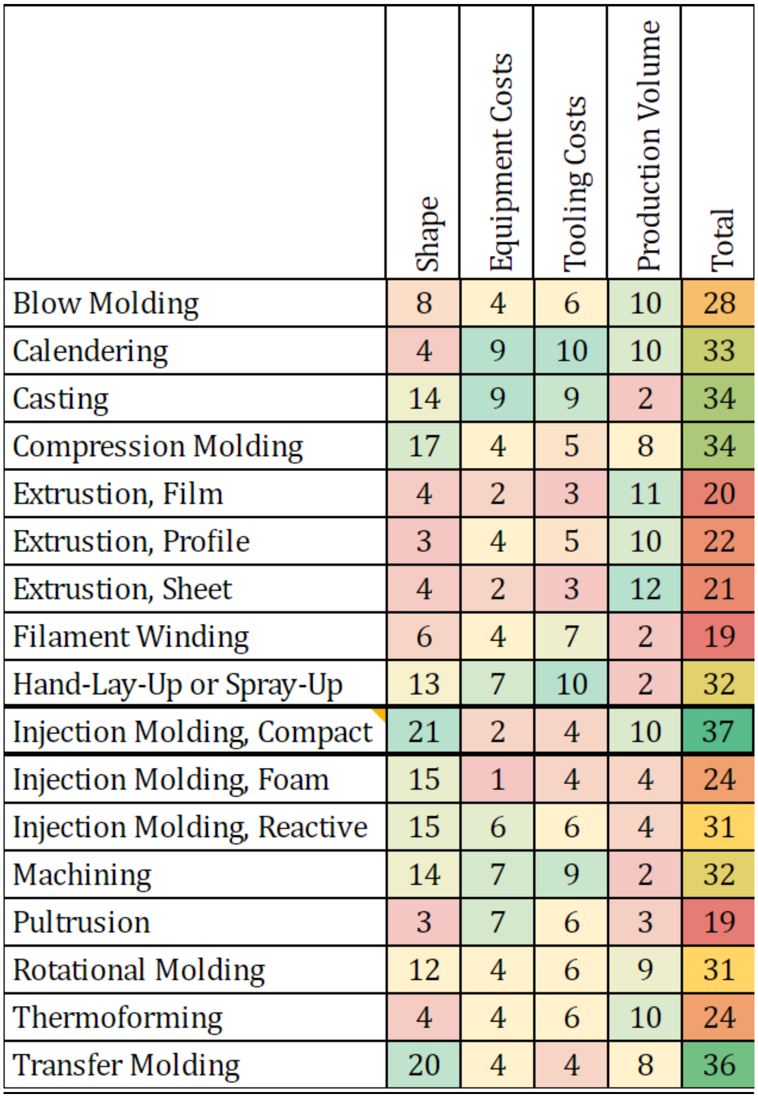
Table 6. *Manufacturing design matrix: production volume.*



	Production Volume (Units/Year)	
Blow Molding	10^4 to 10^7	10
Calendering	10^4 to 10^7	10
Casting	10^1 to 10^2	2
Compression Molding	10^3 to 10^6	8
Extrustion, Film	10^5 to 10^7	11
Extrustion, Profile	10^4 to 10^7	10
Extrustion, Sheet	10^6 to 10^7	12
Filament Winding	10^1 to 10^2	2
Hand-Lay-Up or Spray-Up	10^1 to 10^2	2
Injection Molding, Compact	10^4 to 10^7	10
Injection Molding, Foam	10^3 to 10^5	4
Injection Molding, Reactive	10^3 to 10^5	4
Machining	10^1 to 10^2	2
Pultrusion	10^1 to 10^3	3
Rotational Molding	10^4 to 10^6	9
Thermoforming	10^4 to 10^7	10
Transfer Molding	10^3 to 10^6	8

Lastly, the total score from each table was inserted into the final “Total Score” table, Table 7, with the final score being the sum of previous scores. As shown, compact injection molding is the process best suited for this product with a total score of 37.

Table 7. *Manufacturing design matrix: total score.*



	Shape	Equipment Costs	Tooling Costs	Production Volume	Total
Blow Molding	8	4	6	10	28
Calendering	4	9	10	10	33
Casting	14	9	9	2	34
Compression Molding	17	4	5	8	34
Extrustion, Film	4	2	3	11	20
Extrustion, Profile	3	4	5	10	22
Extrustion, Sheet	4	2	3	12	21
Filament Winding	6	4	7	2	19
Hand-Lay-Up or Spray-Up	13	7	10	2	32
Injection Molding, Compact	21	2	4	10	37
Injection Molding, Foam	15	1	4	4	24
Injection Molding, Reactive	15	6	6	4	31
Machining	14	7	9	2	32
Pultrusion	3	7	6	3	19
Rotational Molding	12	4	6	9	31
Thermoforming	4	4	6	10	24
Transfer Molding	20	4	4	8	36

9.4.2 Material Selection for Mass Manufacturing

As previously mentioned, the majority of the final prototype of the crocheting aid was 3D printed with PLA. This material was chosen as it was cheap, allowing us to make multiple prototypes at minimal cost, while still fulfilling the properties we required. However, these materials may not be the best choice for the plastic injection molding process. Due to the large variety of existing materials, Granata Edupack software was used to determine the best choice of material for this product.

Edupack is a material selection software that allows users to apply “stages" to a main database, filtering materials that fit the user’s desired properties. We have selected the database containing all polymers for out material selection process. Stage one limited results to those that were “excellent” for “polymer injection molding.”

The maximum bending stress this project will undergo is 10.725 MPa on the surface of the lever, as calculated previously. The material must not deform or fail under this load, so stage two has limited results to those with a yield strength greater than or equal to 10.725 MPa.

Two functional requirements of this device are applicable to mass manufacturing material selection: “weigh no more than 2 pounds” and “affordable consumer cost.” In order to remain within this weight limit, we have calculated the required density of the material using the following formulas:

$$\rho = m/V$$

(Where ρ is density, m is mass, and V is volume).

$$W = m * g$$

(Where W is is weight, m is mass, and g is acceleration due to gravity).

Combining these formulas results in the following formula, which allows us to relate the weight of the prototype to its volume and density.

$$W = (\rho * V) * g$$

The weight of our prototype is 4.2 oz. The total volume of the PLA parts, as calculated by Solidworks, is 37.235 cm^3, and the total volume of the grip is 60.904 cm^3, for a total of 98.139 cm^3. We will be assuming the rubber grip and plastic parts have an equal density for the sake of these calculations. Using these variables, we have calculated the maximum potential density of our material to be 1213.03 kg/m^3.

$$4.2\ oz = (\rho * \ 98.139\ cm^3) * 9.807\ m/s^2$$

$$\rho = 1.2133g/cm^3 = 1213.03kg/m^3$$

As such, stage 3 in Edupack has limited results to materials within this range of densities. This has narrowed our materials down to seven options: Linear Low-Density Polyethylene, Ethylene Vinyl Acetate, Low-Density Polyethylene, Nitrile Butadiene Rubber + Poly Vinyl Chloride blend, Thermoplastic Polyolefin Elastomer Shore A55, Thermoplastic Polyolefin Elastomer Shore A75, and Thermoplastic Polyolefin Elastomer Barium Sulfate blend.

Stage 4 displays a chart of cost per material volume, shown in Figure 33. Each horizontal bar on the chart displays the range of costs for a single material. As shown, linear low-density polyethylene has the lowest cost, making it the best material to injection mold this product.

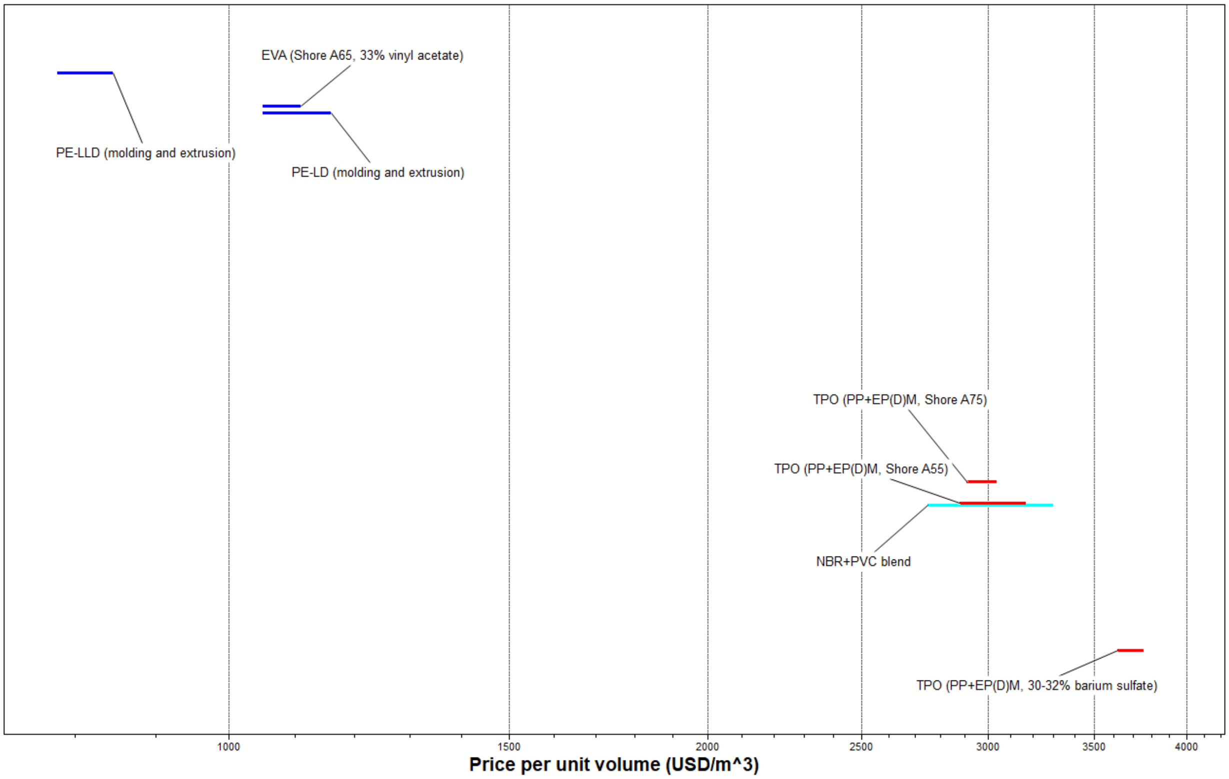


Figure 33. *Material price per unit volume.*

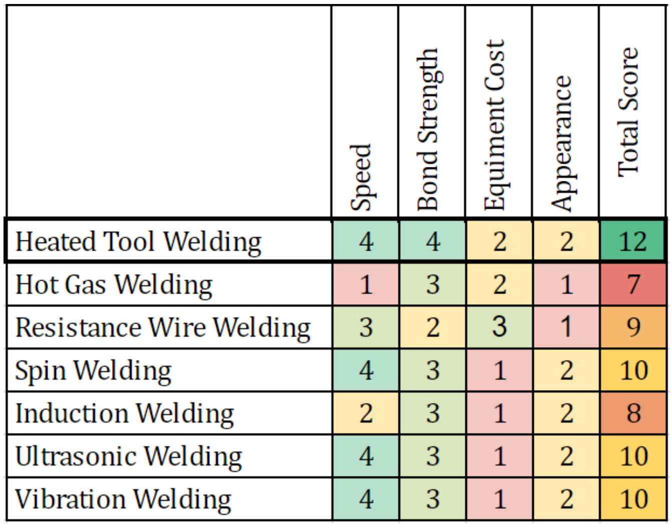
As previously mentioned in Table 3, compact injection molding is capable of a large range of shapes but not closed molds. This suits our prototype design well, as there are no closed shapes involved. However, redesigning the product will come with its own new geometric adjustments corresponding to its assembly.

9.4.3 Assembly Method for Mass Manufacturing

Plastic assembly can generally be sorted into five categories: adhesion, heat welding, solvent welding, mechanical fastening, and self-assembly. Solvent welding and self-assembly processes are incompatible with our material choice; polyethylene’s resist solvents, have difficulty bonding, and are not stiff enough for self-assembly. Adhesion and mechanical fasteners are both relatively slow processes, making them less than ideal for large production volumes. For these reasons, polyethylene’s are typically assembled with heat welding. This process quickly bonds the two parts, making it ideal for large-scale production, and works with a majority of plastics, including polyethylene’s.

Table 8 lists six heat welding processes, as well as four properties of the processes: “Speed,” “Bond Strength,” Equipment Cost,” and “Appearance.” “Speed” was ranked on a scale from 1 to 4, with 1 being slow and 4 being very fast. “Bond Strength” was also ranked on a scale from 1 to 4, with 1 being weak, and 4 being very strong. “Equipment Cost” was ranked on a scale from 1 to 3, with 1 being high cost and 3 being low cost. The “Appearance” was also ranked on a scale from 1 to 3, with 1 being poor appearance and 3 being good appearance. The total score is the sum of feature scores. As shown, heated tool welding is the best process for our needs.

Table 8. *Manufacturing design matrix: heat joining processes.*



	Speed	Bond Strength	Equiment Cost	Appearance	Total Score
Heated Tool Welding	4	4	2	2	12
Hot Gas Welding	1	3	2	1	7
Resistance Wire Welding	3	2	3	1	9
Spin Welding	4	3	1	2	10
Induction Welding	2	3	1	2	8
Ultrasonic Welding	4	3	1	2	10
Vibration Welding	4	3	1	2	10

For the most successful results, the joints of the heat weld need to take two factors into consideration: surface area and flash. The strength of the weld bond is directly related to the surface area in contact between the two parts. In order to match the strength of the material around it, the surface area should be approximately 2 to 2.5 times the area of the cross-section. This can easily be achieved with a V-shape where the two joints contact, shown in Figure 34.

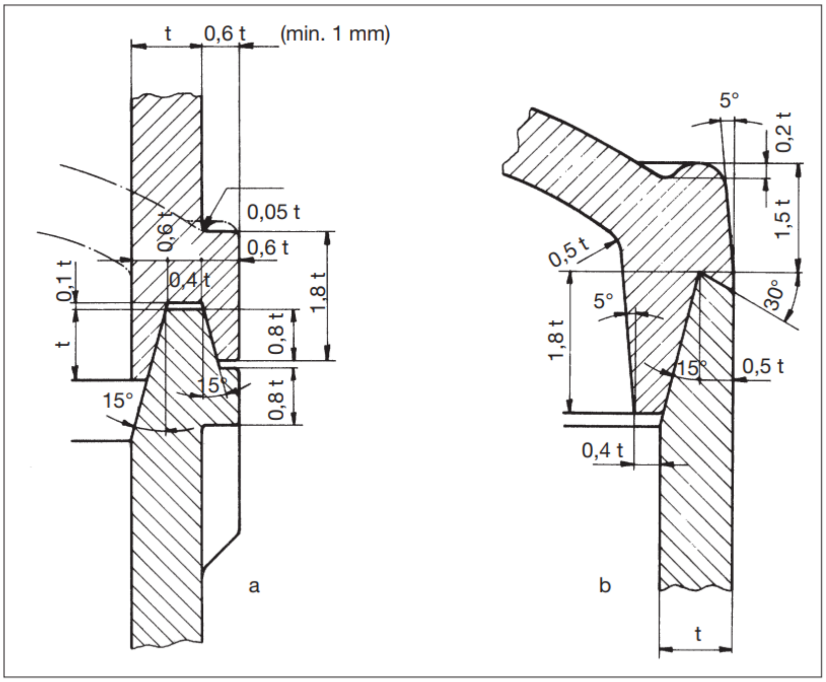


***Figure 34.** Heat weld joint profiles.*

When the joints are heated and pushed together, some of the molten plastic will ooze out of the joint, called flash. Approximately one millimeter of material is displaced as flash, so parts should contain an extra millimeter of material to compensate for this, which is already accounted for in the geometry of Figure 34.

In addition to the thickness of the displaced material, we must also consider where the material goes. Welding two flat surfaces creates a lump of flash on all edges of the weld, which can upset the overall size of the part as well as the appearance. As such, heat-welded joints often incorporate “flash traps" to contain this displaced material, which is displayed in Figure 35. We have used a design similar to Figure 35 C, which allows the flash to flow into the small slots in the joint.

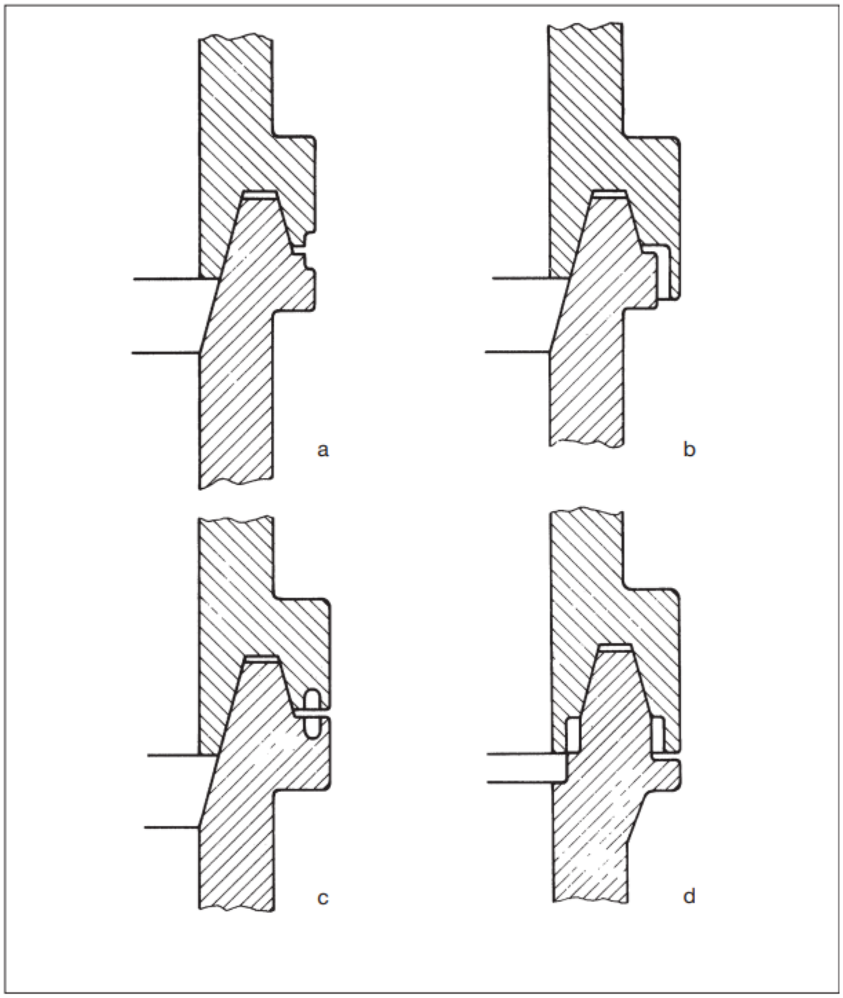


Figure 35. *Heat weld joint profiles for flash.*

9.4.4 Redesign

Taking all of these constraints into consideration, the crocheting aid prototype was redesigned as shown in the drawings in Appendix D. The crochet hook, disk, and paddle have undergone minimal changes, with the disk absorbing the shaft collar part. All three parts have adjusted geometry to optimize the molding process. The handle parts have been redesigned into three pieces, front grip, back grip, and top grip, with the front grip and back grip parts surrounding the shaft. The top grip attaches after the disk and spring have been installed. The spring brackets and corresponding parts on both the disk and grip have been replaced with through holes to better facilitate the molding process, and the spring has been changed to use hooks instead of loops to attach. All parts have been adjusted to accommodate the heat tooling joints.

Appendices

Appendix A Bibliography

A simple lightweight aid that makes knitting easier. (2021). Knitting Aid. Retrieved December 6, 2021, from https://www.knittingaid.com/

Centers for Disease Control and Prevention [CDC]. (2020, May 22). *Joint Pain and Arthritis.* Retrieved October 3, 2021, from https://www.cdc.gov/arthritis/pain/index.htm

Centers for Disease Control and Prevention. (2021, April 15). *Arthritis*. Centers for Disease Control and Prevention. Retrieved October 11, 2021, from https://www.cdc.gov/arthritis/index.htm.

CrochetTalk. (n.d.). *Do Crochet Machines Exist?* Retrieved October 2, 2021, from https://crochettalk.com/crochet-machines/

Distrupol. (n.d.). Assembly Techniques – Category II Welding, Adhesive Bonding. Distrupol.com. Retrieved April 25, 2022, from https://www.distrupol.com/General_Design_Principles_for_Assembly_Techniques_Welding_Adhesive_Bonding.pdf

Emily (2019, May 1). *5 Best Compression Gloves For Knitting and Crocheting.* The Creative Folk. Retrieved October 10, 2021, from https://www.thecreativefolk.com/best-compression-gloves-knitting-crocheting/

Guitard, P., Brosseau, L., Wells, G. A., Paquet, N., Paterson, G., Toupin-April, K., Cavallo, S., Aydin, S. Z., Léonard, G., & De Angelis, G. (2018). The knitting community-based trial for older women with osteoarthritis of the hands: design and rationale of a randomized controlled trial. BMC musculoskeletal disorders, 19(1), 56. https://doi.org/10.1186/s12891-018-1965-2

Harper, C. A. (2006). Handbook of plastic processes: Harper/handbook of plastic processes (C. A. Harper, Ed.). John Wiley & Sons.

Healthwise Staff. (2019, June 26). *Wrist care: Preventing carpal tunnel syndrome.* Retrieved October 10, 2021, from https://www.healthlinkbc.ca/health-topics/tn9041

Hot-plate welding design guidelines. (2017, May 8). EXTOL, INC. https://www.extolinc.com/technology/hot-plate-welding/design-guidelines/

Julia (2021). *Are There Crochet Machines? (I Asked an Expert).* Little World of Whimsy. Retrieved October 10, 2021, from https://littleworldofwhimsy.com/are-there-crochet-machines-i-asked-an-expert/

Kaliszak, A. (2019, October 22). *How to make a chain stitch.* Medium. Retrieved October 10, 2021, from https://medium.com/swlh/how-to-make-a-chain-stitch-6f2fc0248704

Krieger, A. (2018, August 28). *Are bioplastics really better for the environment? read the fine print*. Greenbiz. Retrieved April 15, 2022, from https://www.greenbiz.com/article/are-bioplastics-really-better-environment-read-fine-print

Kroh's Crochet Aid. (n.d.) Access TR. Retrieved October 10, 2021, https://accesstr.com/krohs-crochet-aid/

Littlejohn, A. (n.d.) *Are Crochet Machines A SCAM? (SOLVED).* Littlejohn's Yarn. Retrieved October 10, 2021, https://littlejohnsyarn.com/can-crochet-be-done-by-machine/

Mitchell, P. E. (Ed.). (1996). *Tool and Manufacturing Engineers' Handbook: Plastic Part Manufacturing V.8* (4th ed.). Society of Manufacturing Engineers. https://ia601602.us.archive.org/11/items/ToolAndManufacturingEngineersHandbook/8.%20Plastic%20Part%20Manufacturing%20%281996%29.pdf

Patkin, Michael. (n.d). *A Check-List for Handle Design*. Retrieved April 4, 2022, https://mpatkin.org/ergonomics/handle_checklist.htm.

Penn Medicine. (n.d.). *Wrist Arthritis Treatment.* Retrieved October 9, 2021, from https://www.pennmedicine.org/for-patients-and-visitors/find-a-program-or-service/orthopaedics/hand-and-wrist-pain/arthritis-in-hand-and-wrist-treatment/wrist-arthritis-treatment

Solovay, A. (2020, April 4). *6 Basic Crochet Stitches for Beginners.* The Spruce Crafts. Retrieved September 27, 2021, from https://www.thesprucecrafts.com/basic-stitches-in-crochet-978516

SD3D. (n.d.) *PLA Technical Data Sheet.* SD3D. Retrieved March 23, 2022, from https://www.sd3d.com/portfolio/pla/

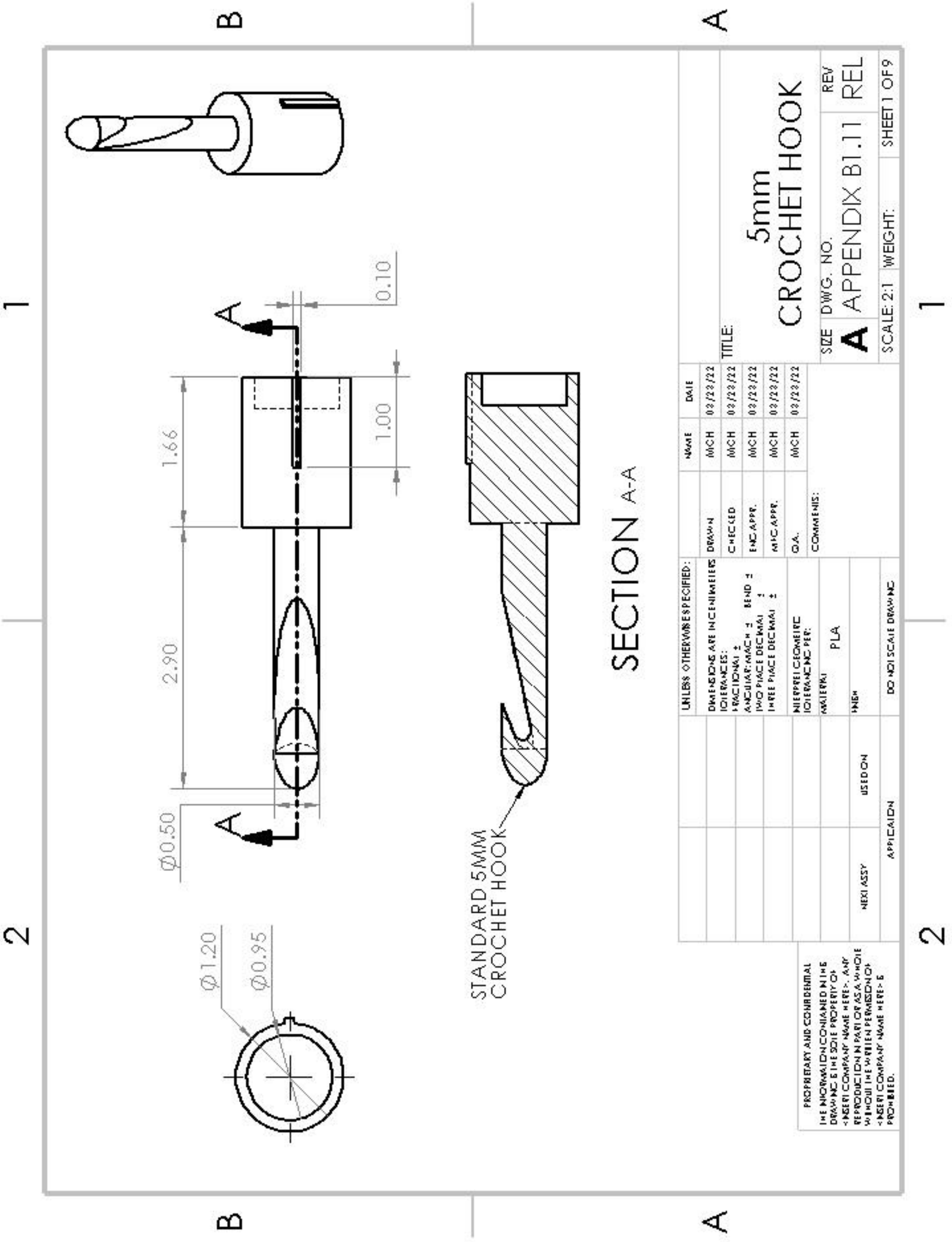
Stitch & Story (2021). *4 Knitting Needle/Crochet Hook Materials & Why We Chose Bamboo*. Retrieved October 10, 2021, from https://www.stitchandstory.com/blogs/getting-started/4-knitting-needle-crochet-hook-materials-why-we-chose-bamboo

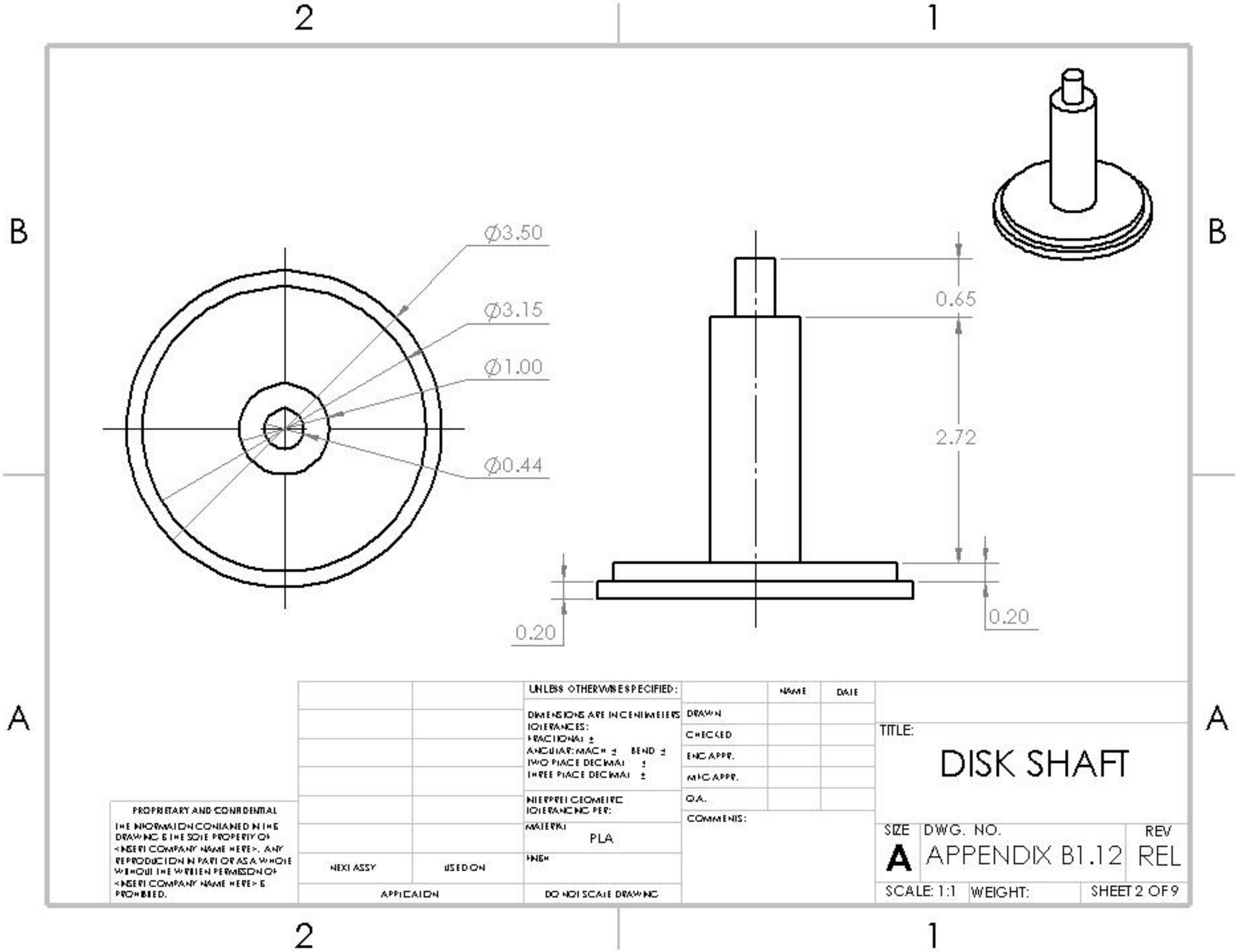
The 5 Best Ergonomic Crochet Hooks. (2021, February 10). The Woobles. Retrieved October 4, 2021, from https://thewoobles.com/blogs/news/the-best-ergonomic-crochet-hooks

Vann, M. R. (2013, March 8). *The "Knitty" Gritty: Crocheting with Rheumatoid Arthritis.* Everyday Health. Retrieved October 4, 2021, from https://www.everydayhealth.com/rheumatoid-arthritis/living-with/crafting-with-ra/

V, C. (2019, July 23). *Is PLA filament actually biodegradable?* 3Dnatives. Retrieved April15, 2022, from https://www.3dnatives.com/en/pla-filament-230720194/

Appendix B Part Drawings



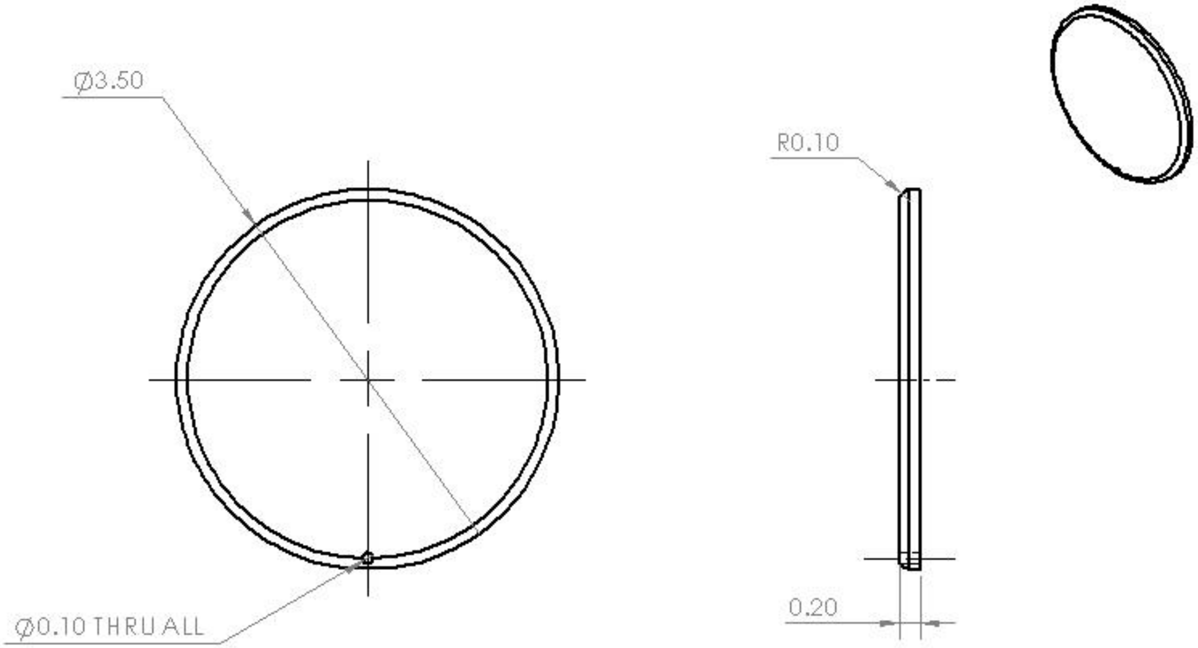


UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:
DISK SHAFT
SIZE A
DWG. NO. APPENDIX B1.12
REV REL
SCALE: 1:1
WEIGHT:
SHEET 2 OF 9

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

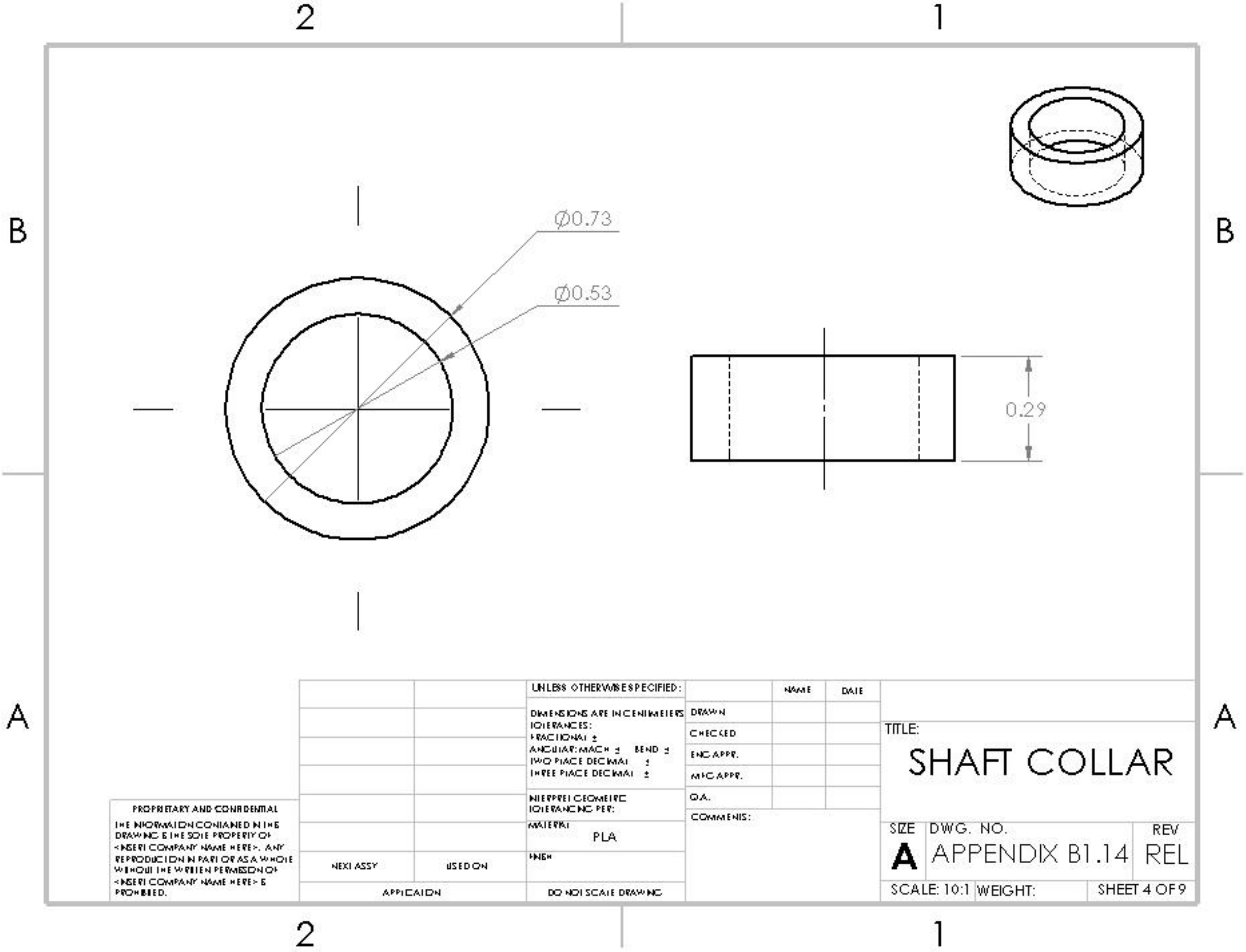
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

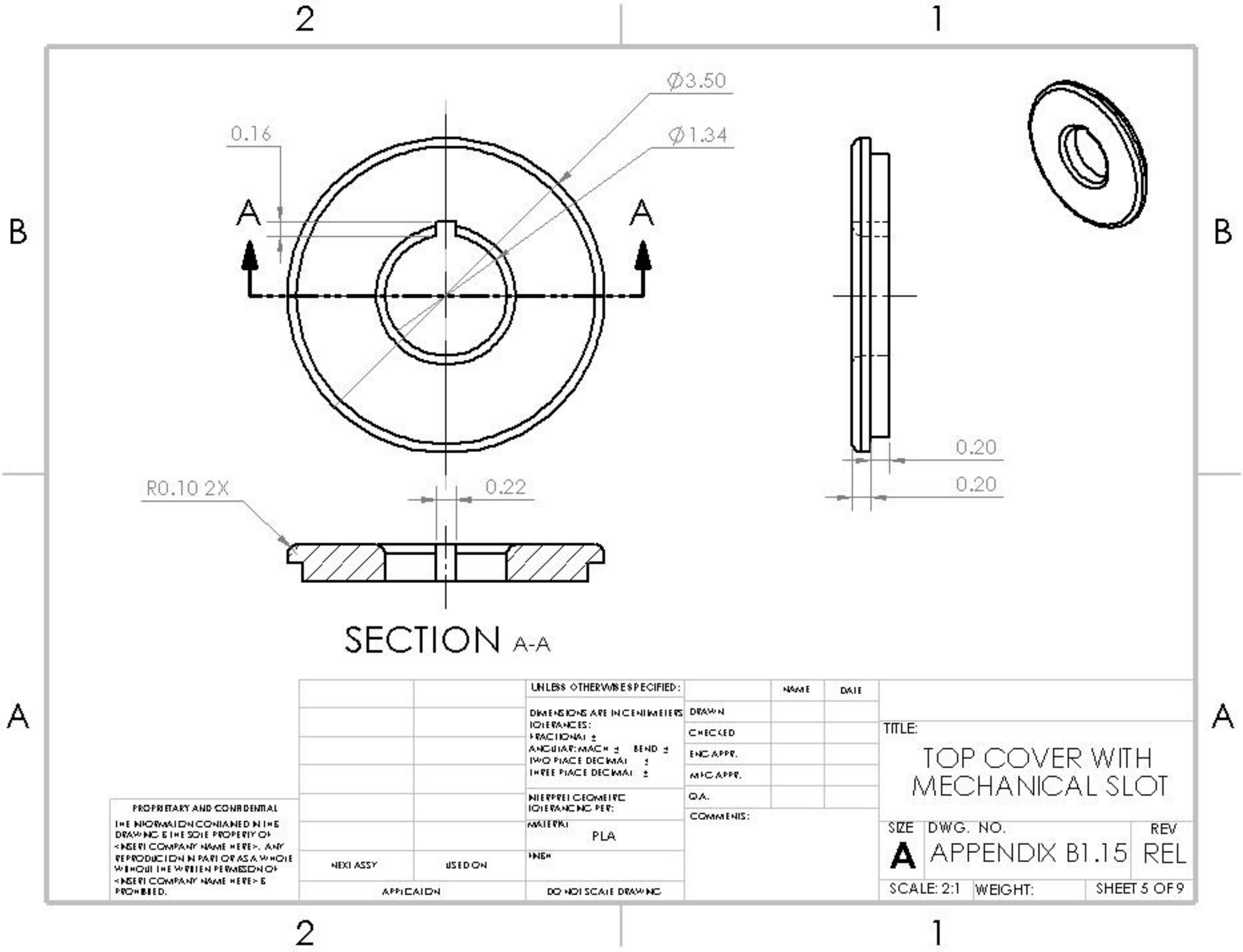
COMMENTS:

TITLE:
BOTTOM STORAGE COVER

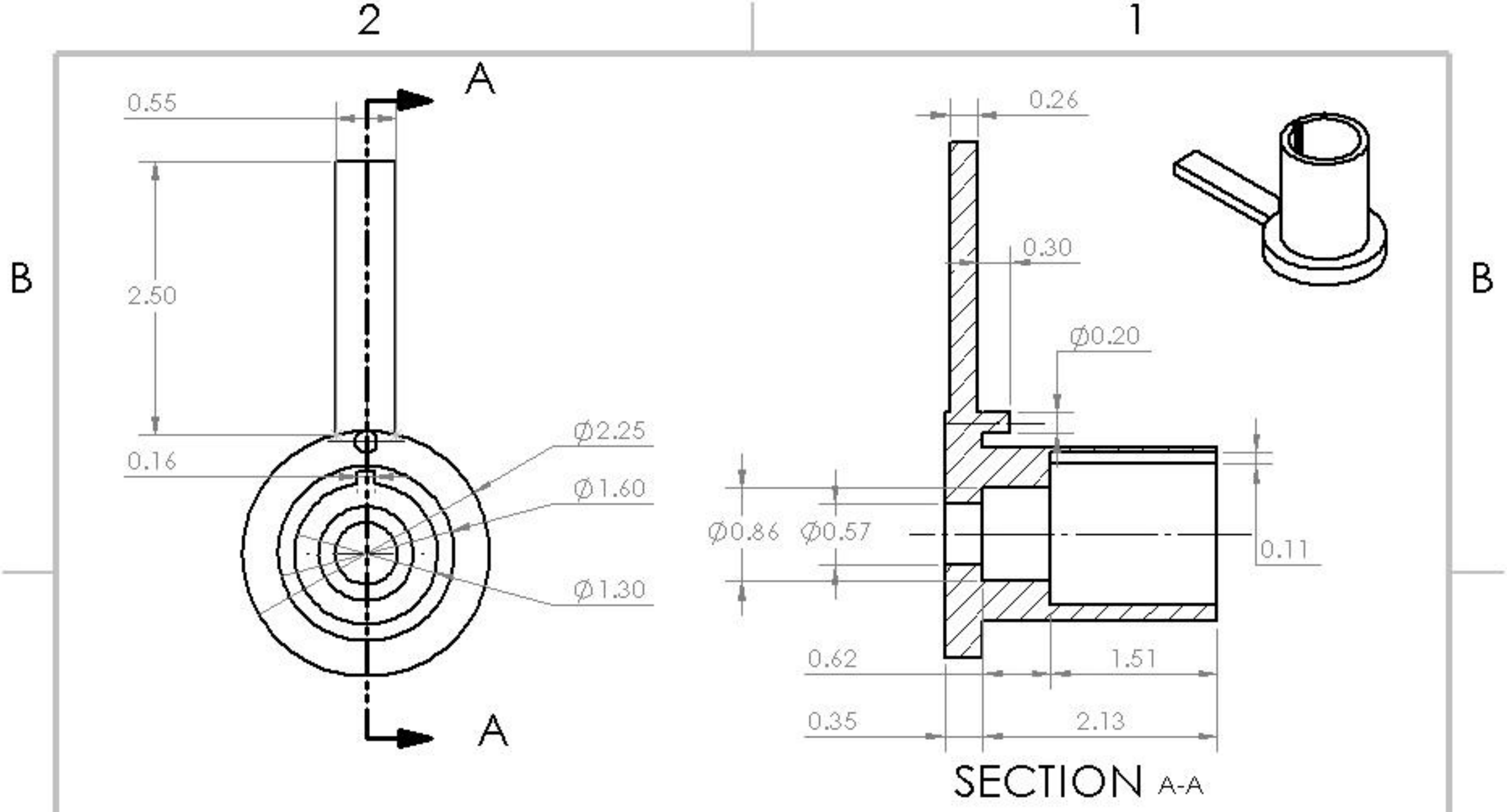
SIZE A
DWG. NO. APPENDIX B1.13
REV REL
SCALE: 2:1
WEIGHT:
SHEET 3 OF 9



2
1
B
A
Ø0.73
Ø0.53
0.29
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SHAFT COLLAR
SIZE
A
DWG. NO.
APPENDIX B1.14
REV
REL
SCALE: 10:1
WEIGHT:
SHEET 4 OF 9
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.



2
1
B
A
Ø3.50
Ø1.34
0.16
A
A
0.20
0.20
R0.10 2X
0.22
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
TOP COVER WITH
MECHANICAL SLOT
SIZE
A
DWG. NO.
APPENDIX B1.15
REV
REL
SCALE: 2:1
WEIGHT:
SHEET 5 OF 9
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

NEXT ASSY
USED ON
APPLICATION

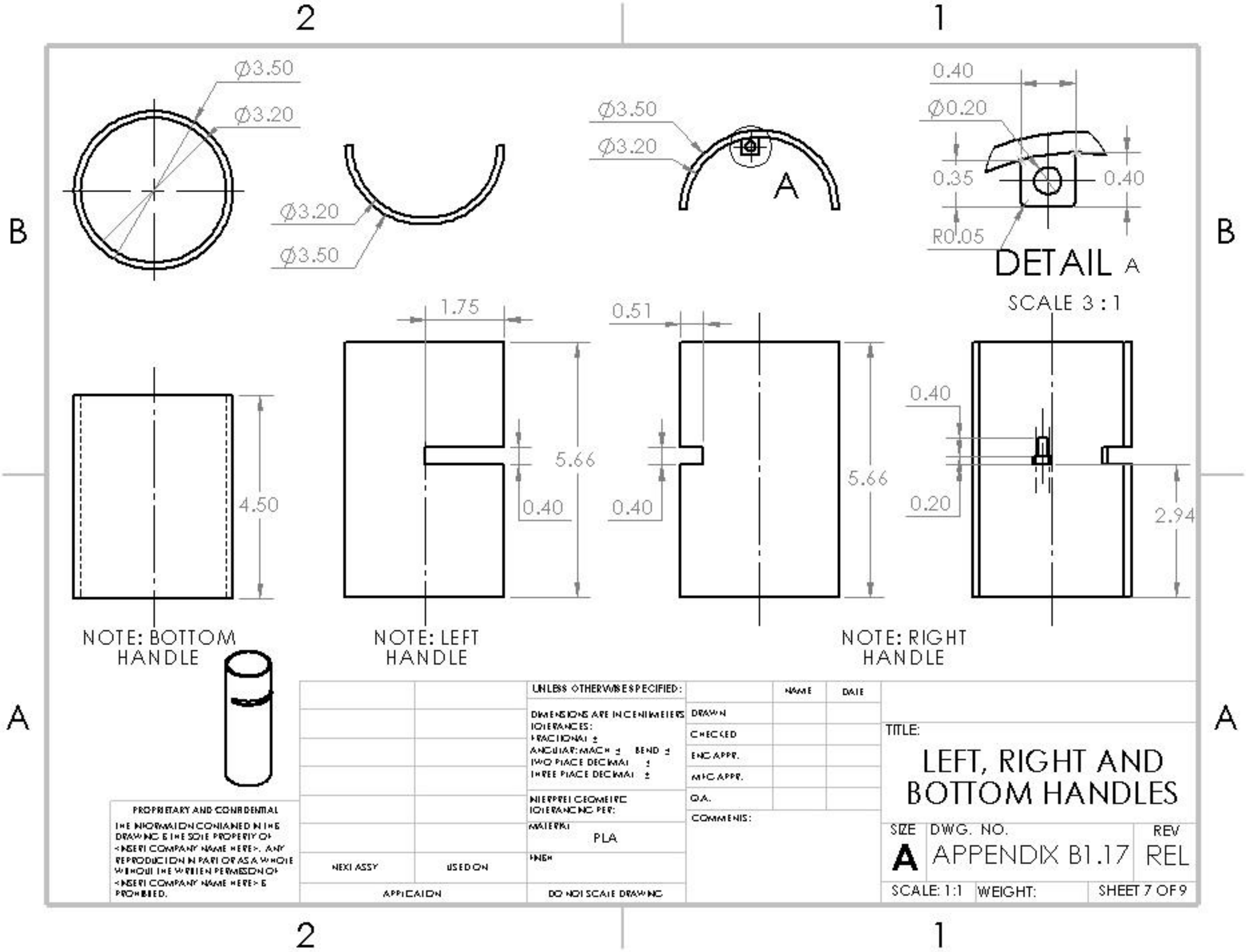
PROPRIETARY AND CONFIDENTIAL

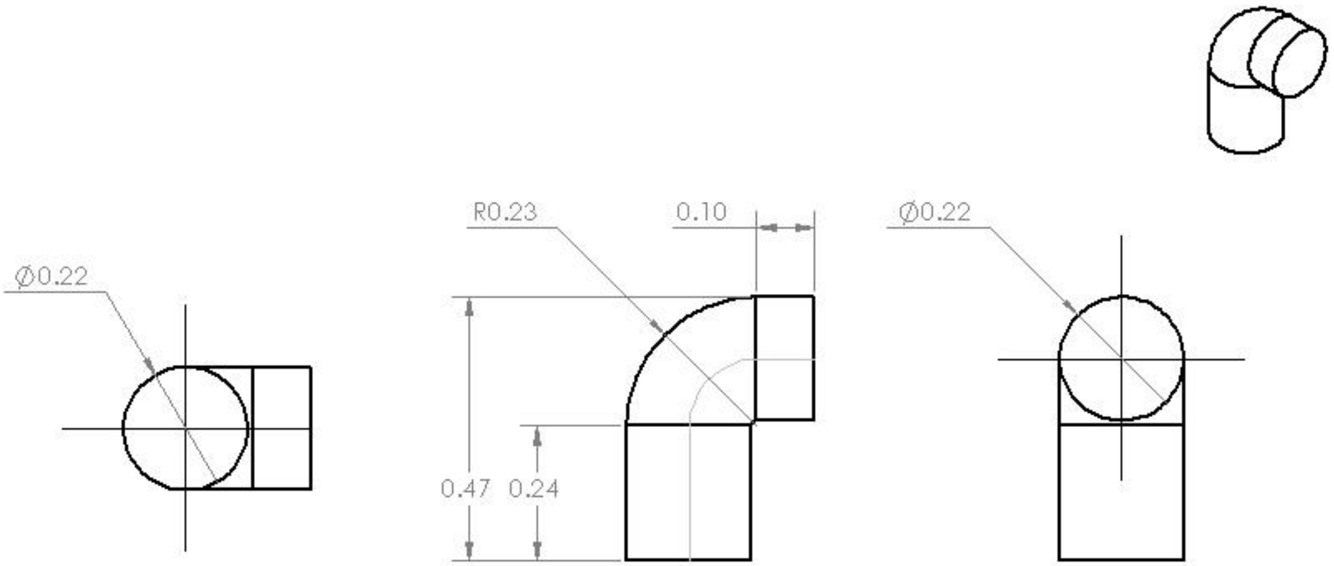
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

TITLE:

DISK WITH THUMB LEVER

SIZE A
DWG. NO. APPENDIX B1.16
REV REL
SCALE: 2:1
WEIGHT:
SHEET 6 OF 9


2
1
B
A
Ø3.50
Ø3.20
Ø3.20
Ø3.50
Ø3.50
Ø3.20
A
0.40
Ø0.20
0.35
0.40
R0.05
DETAIL A
SCALE 3 : 1
1.75
0.51
0.40
5.66
0.40
5.66
0.40
0.20
2.94
4.50
NOTE: BOTTOM HANDLE
NOTE: LEFT HANDLE
NOTE: RIGHT HANDLE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
LEFT, RIGHT AND BOTTOM HANDLES
SIZE
A
DWG. NO.
APPENDIX B1.17
REV
REL
SCALE: 1:1
WEIGHT:
SHEET 7 OF 9
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL PLA
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

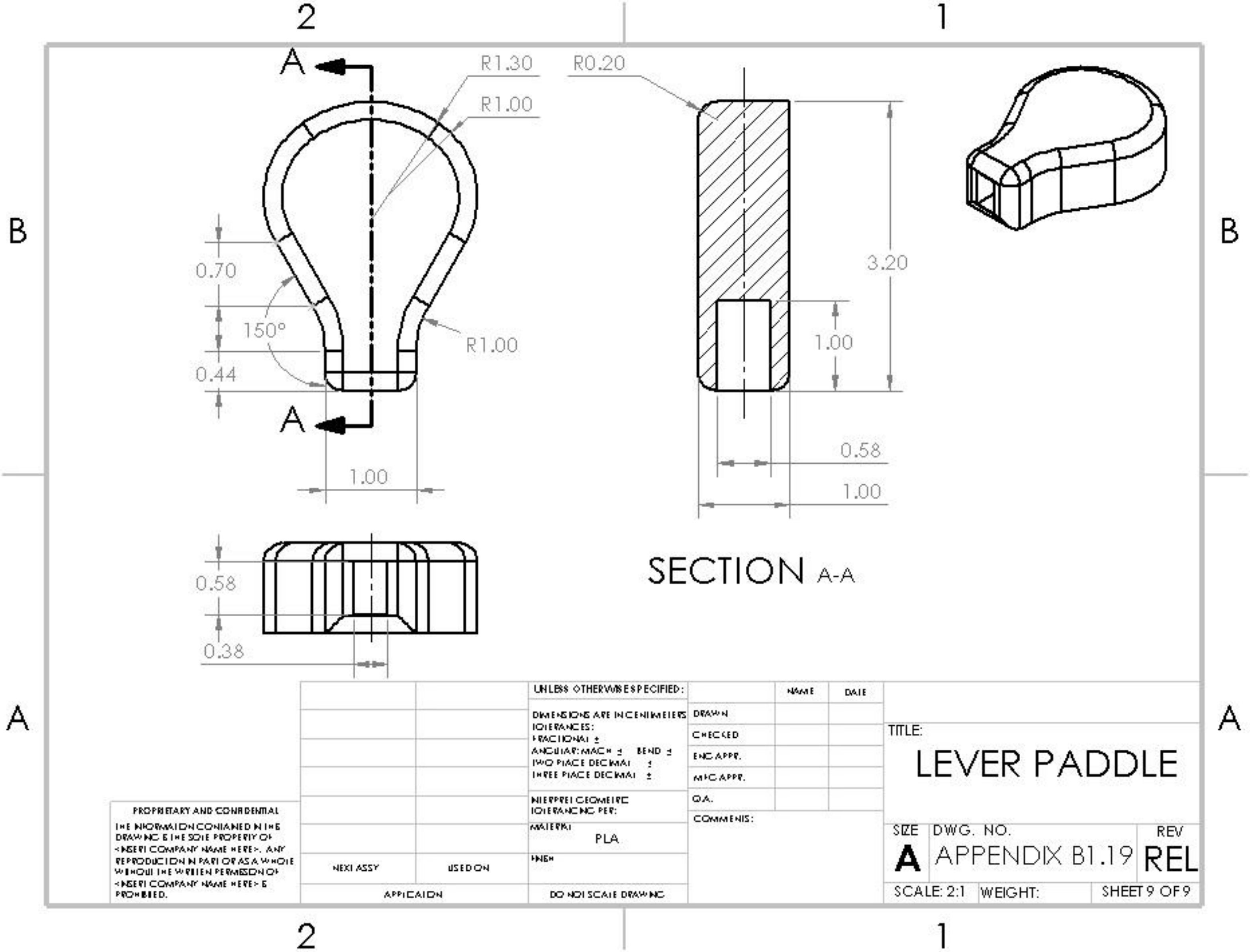
COMMENTS:

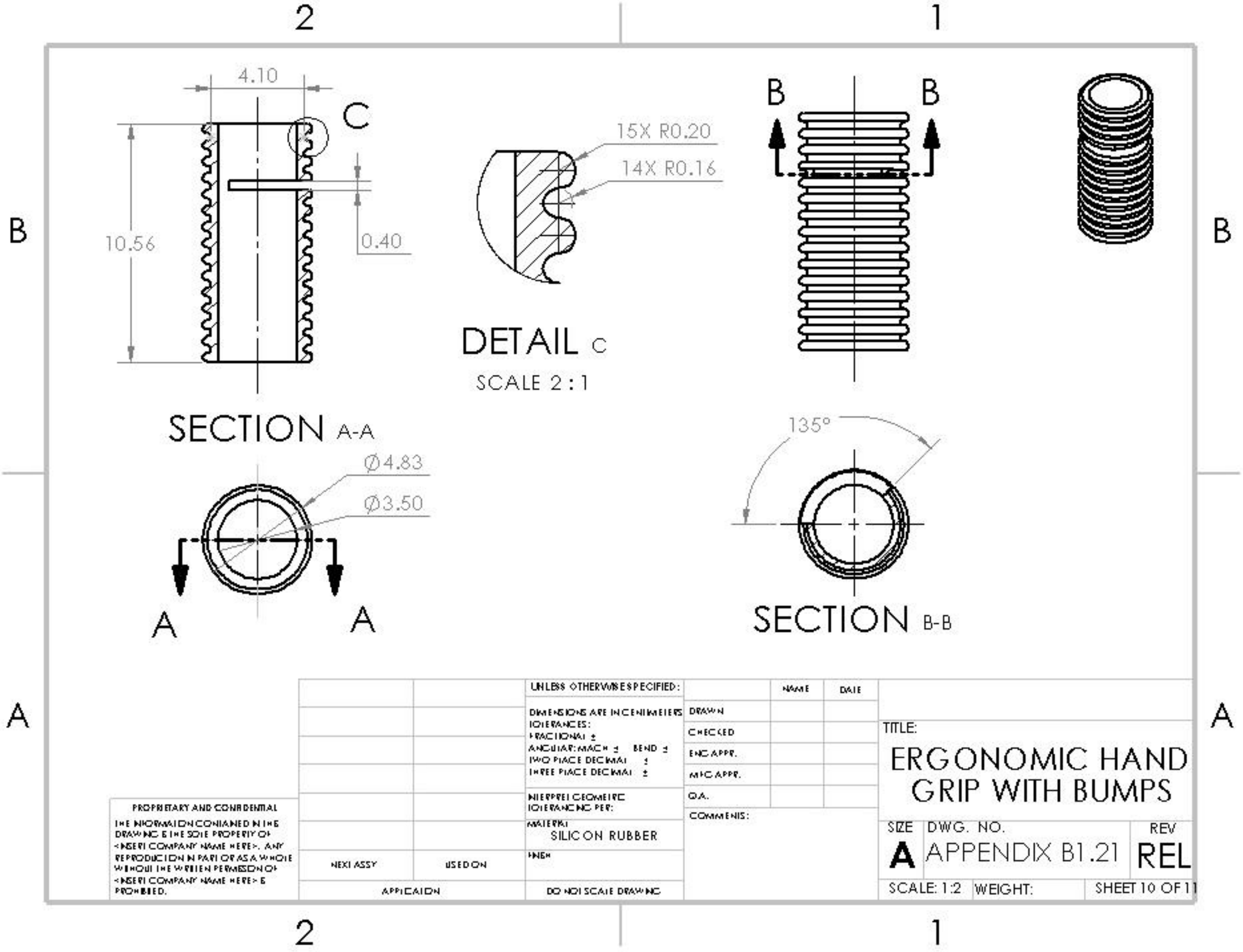
NEXT ASSY
USED ON
APPLICATION

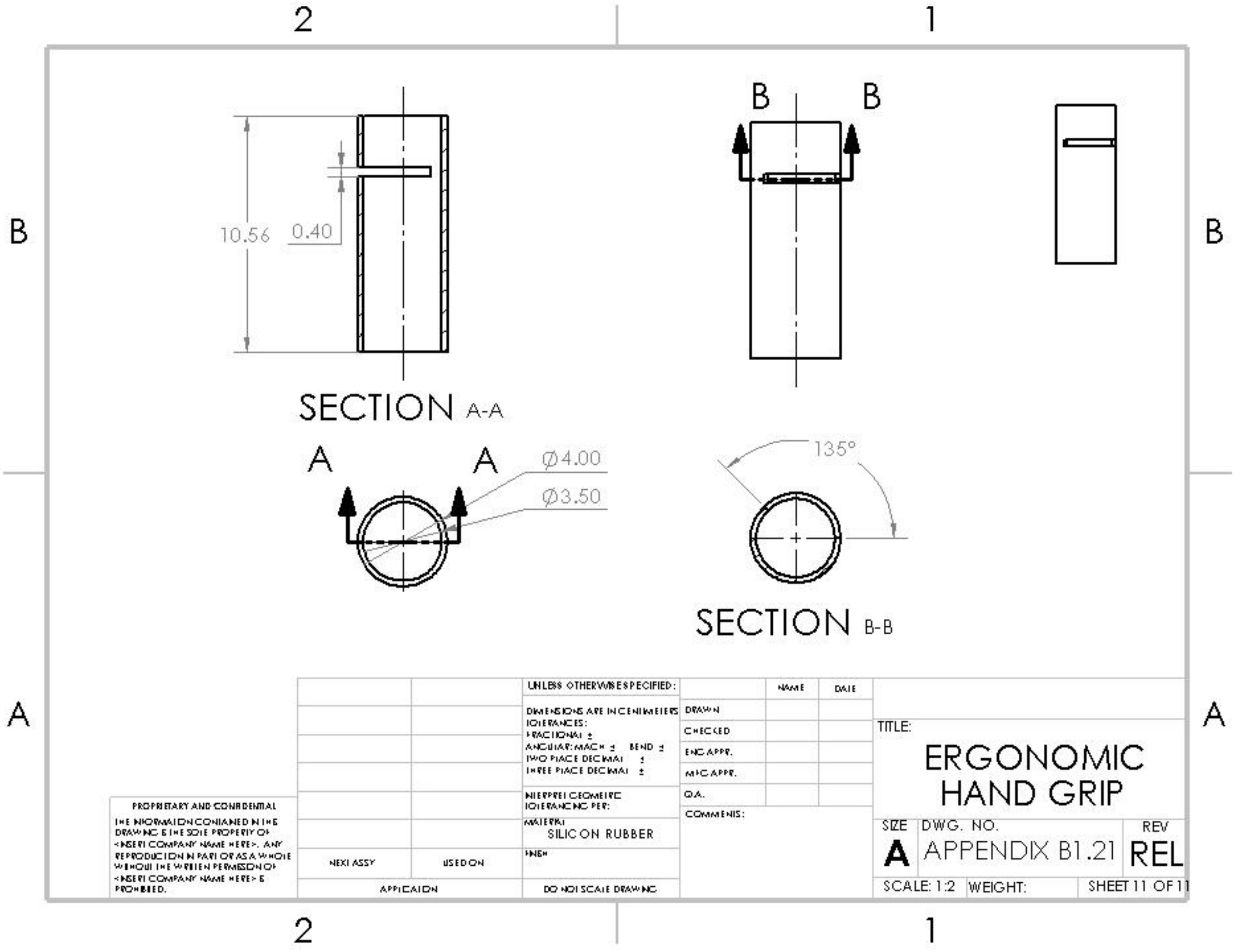
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

TITLE:
SPRING BRACKET

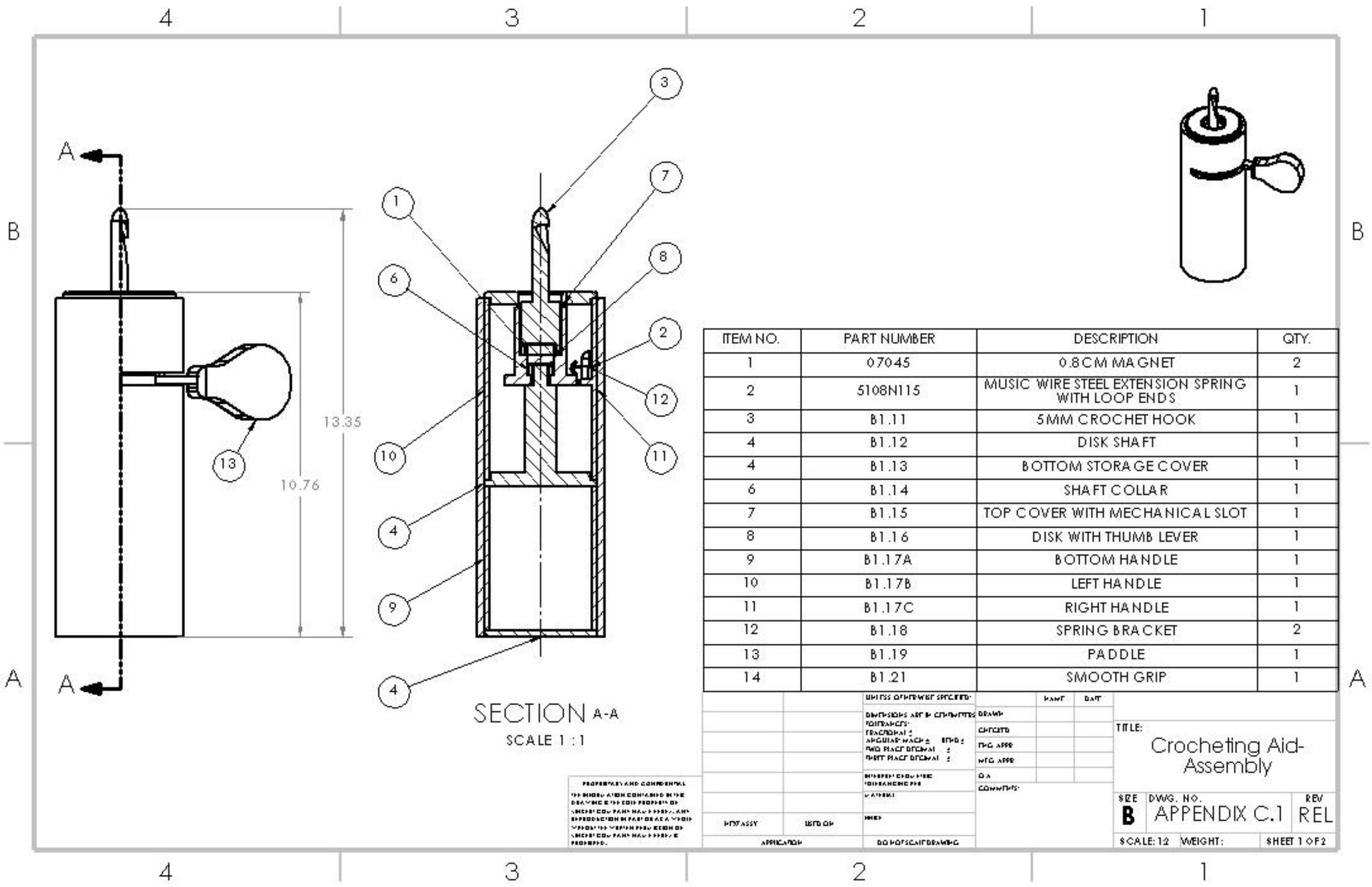
SIZE A
DWG. NO. APPENDIX B1.18
REV REL
SCALE: 10:1
WEIGHT:
SHEET 8 OF 9


A
A
R1.30
R1.00
R1.00
150°
0.70
0.44
1.00
0.58
0.38
R0.20
3.20
1.00
0.58
1.00
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
LEVER PADDLE
SIZE
A
DWG. NO.
APPENDIX B1.19
REV
REL
SCALE: 2:1
WEIGHT:
SHEET 9 OF 9
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
2
1
B
A

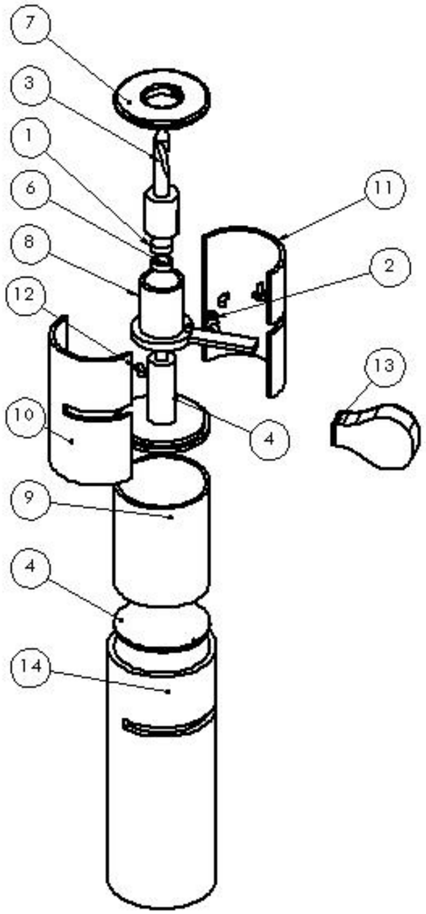

2
1
B
A
4.10
10.56
C
0.40
SECTION A-A
Ø4.83
Ø3.50
A
A
15X R0.20
14X R0.16
DETAIL C
SCALE 2 : 1
B
B
135°
SECTION B-B
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
SILICON RUBBER
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
ERGONOMIC HAND GRIP WITH BUMPS
SIZE
A
DWG. NO.
APPENDIX B1.21
REV
REL
SCALE: 1:2
WEIGHT:
SHEET 10 OF 11


2
1
B
A
SECTION A-A
10.56
0.40
A
A
Ø4.00
Ø3.50
B
B
135°
SECTION B-B
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
SILICON RUBBER
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
ERGONOMIC
HAND GRIP
SIZE
A
DWG. NO.
APPENDIX B1.21
REV
REL
SCALE: 1:2
WEIGHT:
SHEET 11 OF 11
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

Appendix C Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	07045	0.8CM MAGNET	2
2	5108N115	MUSIC WIRE STEEL EXTENSION SPRING WITH LOOP ENDS	1
3	B1.11	5MM CROCHET HOOK	1
4	B1.12	DISK SHAFT	1
4	B1.13	BOTTOM STORAGE COVER	1
6	B1.14	SHAFT COLLAR	1
7	B1.15	TOP COVER WITH MECHANICAL SLOT	1
8	B1.16	DISK WITH THUMB LEVER	1
9	B1.17A	BOTTOM HANDLE	1
10	B1.17B	LEFT HANDLE	1
11	B1.17C	RIGHT HANDLE	1
12	B1.18	SPRING BRACKET	2
13	B1.19	PADDLE	1
14	B1.21	SMOOTH GRIP	1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	07045	0.8CM MAGNET	2
2	5108N115	MUSIC WIRE STEEL EXTENSION SPRING WITH LOOP ENDS	1
3	B1.11	5 MM CROCHET HOOK	1
4	B1.12	DISK SHAFT	1
5	B1.13	BOTTOM STORAGE COVER	1
6	B1.14	SHAFT COLLAR	1
7	B1.15	TOP COVER WITH MECHANICAL SLOT	1
8	B1.16	DISK WITH THUMB LEVER	1
9	B1.17A	BOTTOM HANDLE	1
10	B1.17B	LEFT HANDLE	1
11	B1.17C	RIGHT HANDLE	1
12	B1.18	SPRING BRACKET	2
13	B1.19	PADDLE	1
14	B1.21	SMOOTH GRIP	1

NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
EXPLODED CORHCETING
AID ASSEMBLY

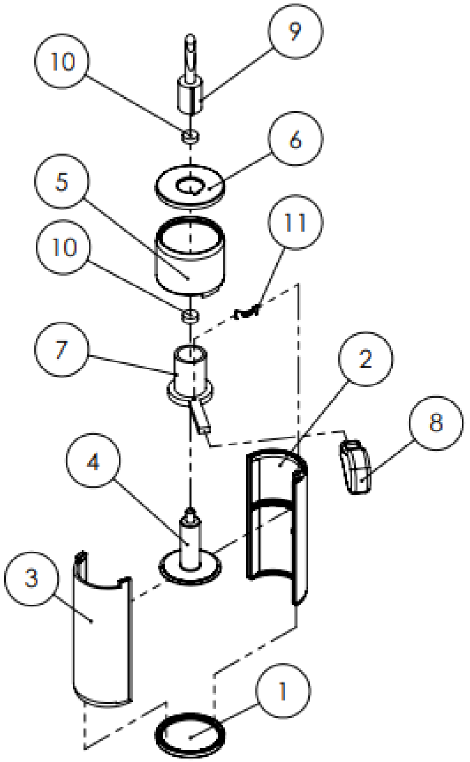
SIZE B
DWG. NO. APPENDIX C.2
REV REL
SCALE: 1:1.5
WEIGHT:
SHEET 2 OF 2

Appendix D Redesign for Mass Manufacturing Drawings

2 1

B

A



ITEM NO.	DESCRIPTION	QTY.
1	BOTTOM COVER	1
2	BOTTOM RIGHT GRIP	1
3	BOTTOM LEFT GRIP	1
4	SHAFT	1
5	TOP GRIP	1
6	TOP COVER	1
7	DISK	1
8	PADDLE	1
9	5 MM CROCHET HOOK	1
10	MAGNET	2
11	SPRING	1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

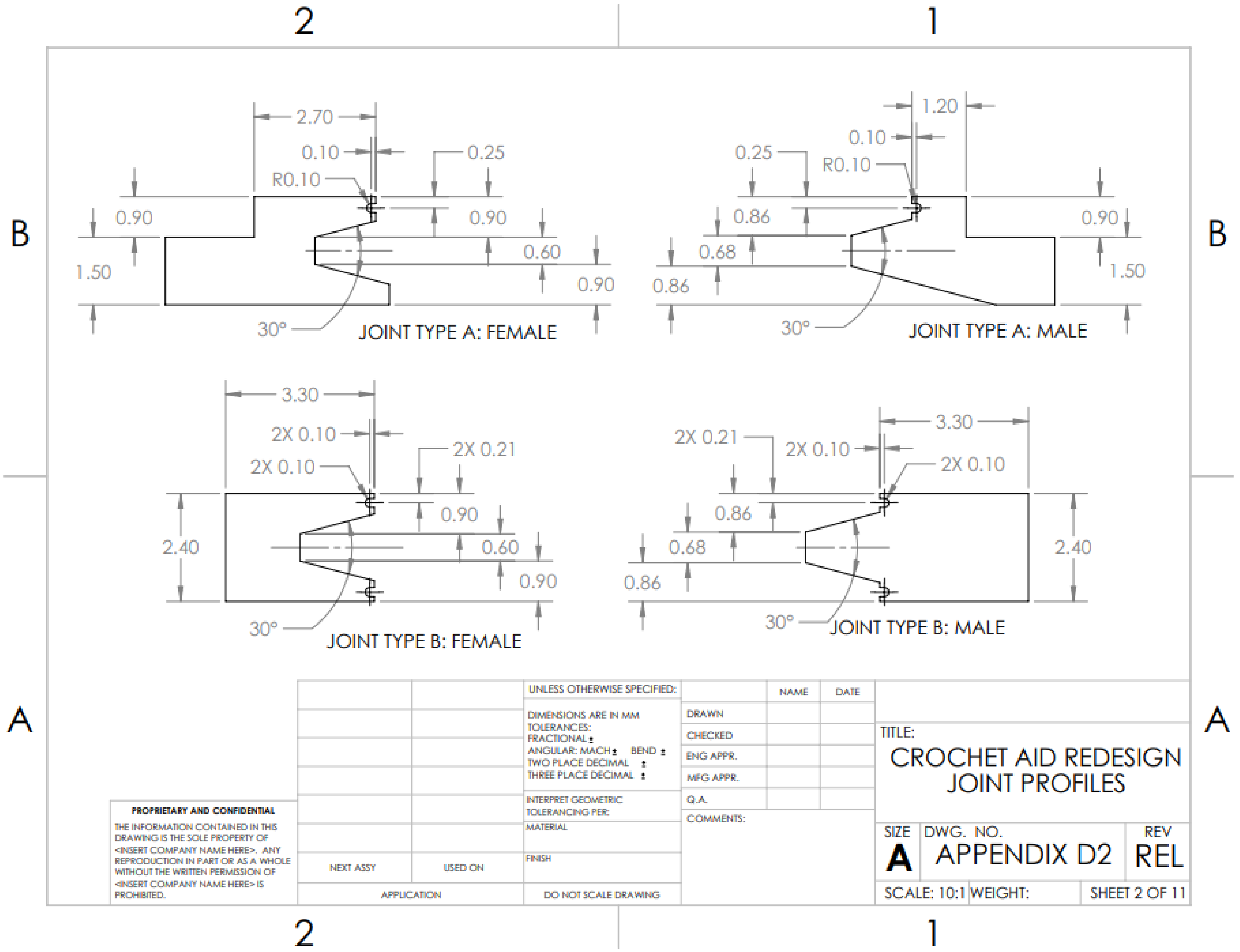
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

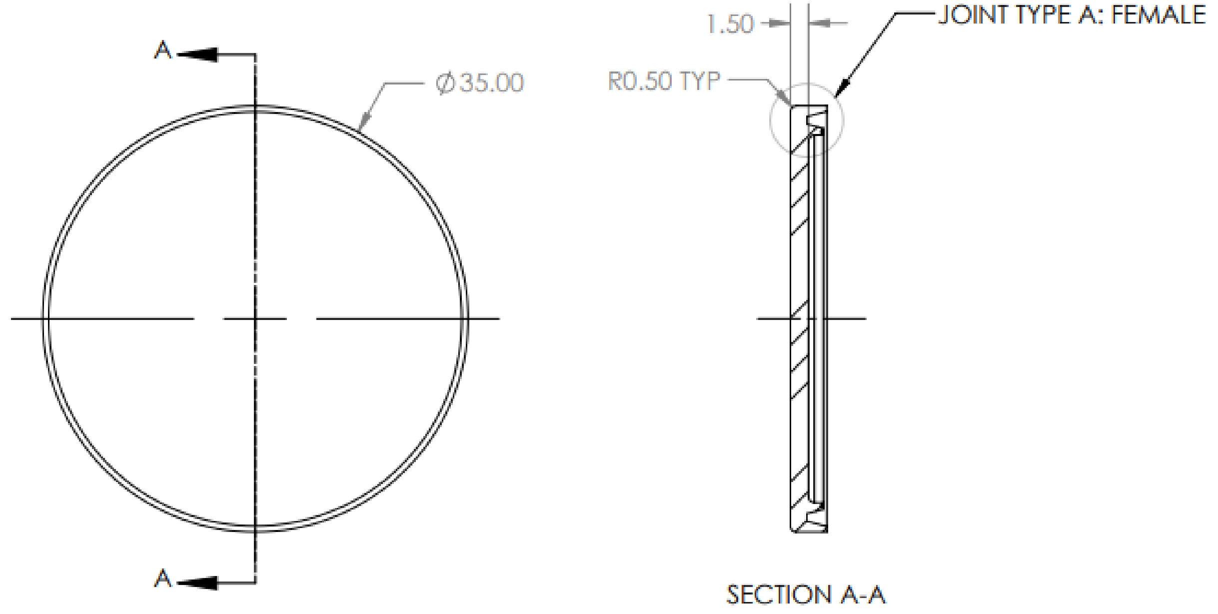
COMMENTS:

TITLE:
CROCHET AID REDESIGN
ASSEMBLY

SIZE A
DWG. NO. APPENDIX D1
REV REL
SCALE: 1:3
WEIGHT:
SHEET 1 OF 11

2 1

2
1
B
A
2.70
0.10
R0.10
0.25
0.90
0.90
1.50
0.60
0.90
30°
JOINT TYPE A: FEMALE
1.20
0.10
0.25
R0.10
0.86
0.68
0.86
0.90
1.50
30°
JOINT TYPE A: MALE
3.30
2X 0.10
2X 0.10
2X 0.21
0.90
2.40
0.60
0.90
30°
JOINT TYPE B: FEMALE
2X 0.21
2X 0.10
3.30
2X 0.10
0.86
0.68
0.86
2.40
30°
JOINT TYPE B: MALE
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
CROCHET AID REDESIGN
JOINT PROFILES
SIZE
A
DWG. NO.
APPENDIX D2
REV
REL
SCALE: 10:1
WEIGHT:
SHEET 2 OF 11



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

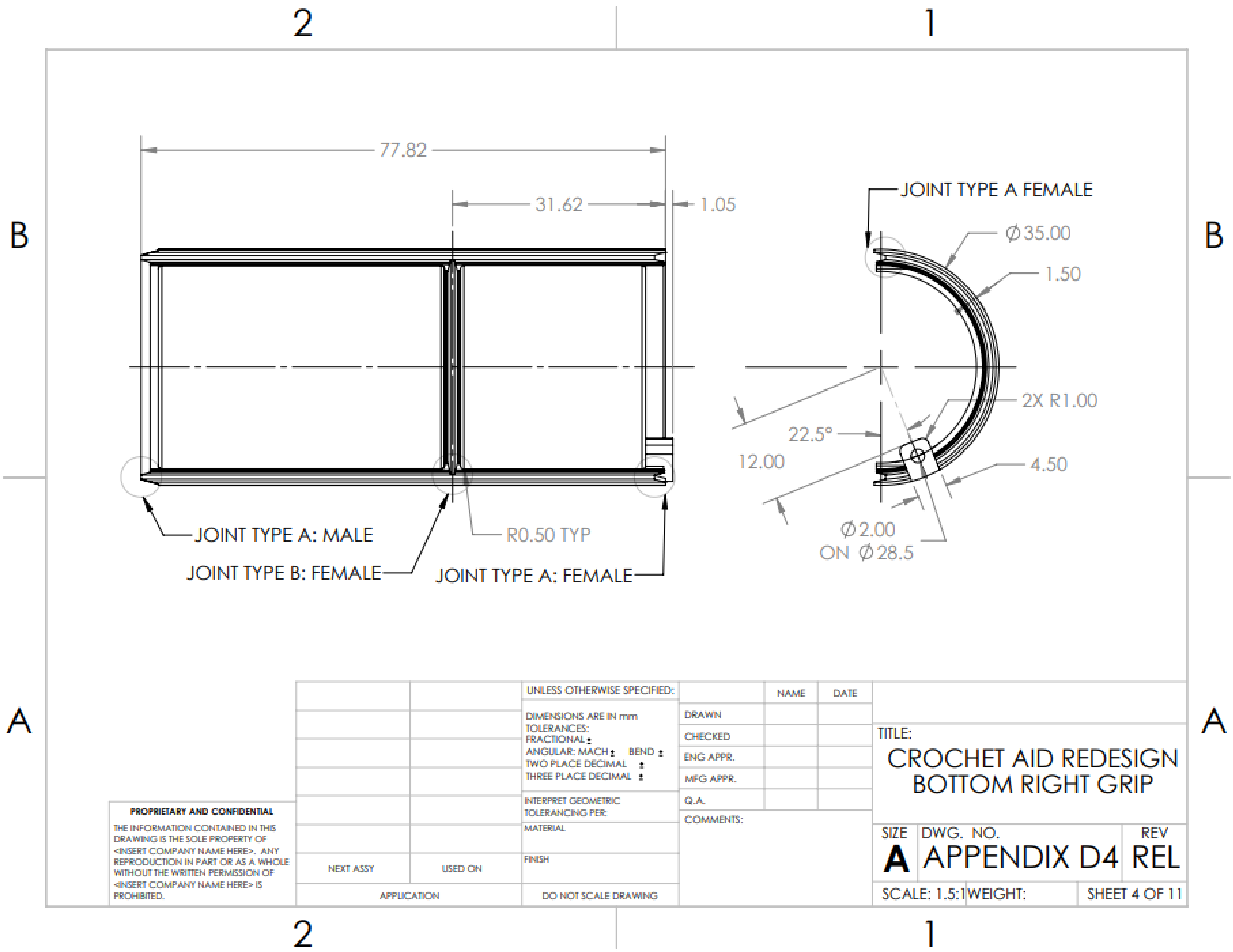
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

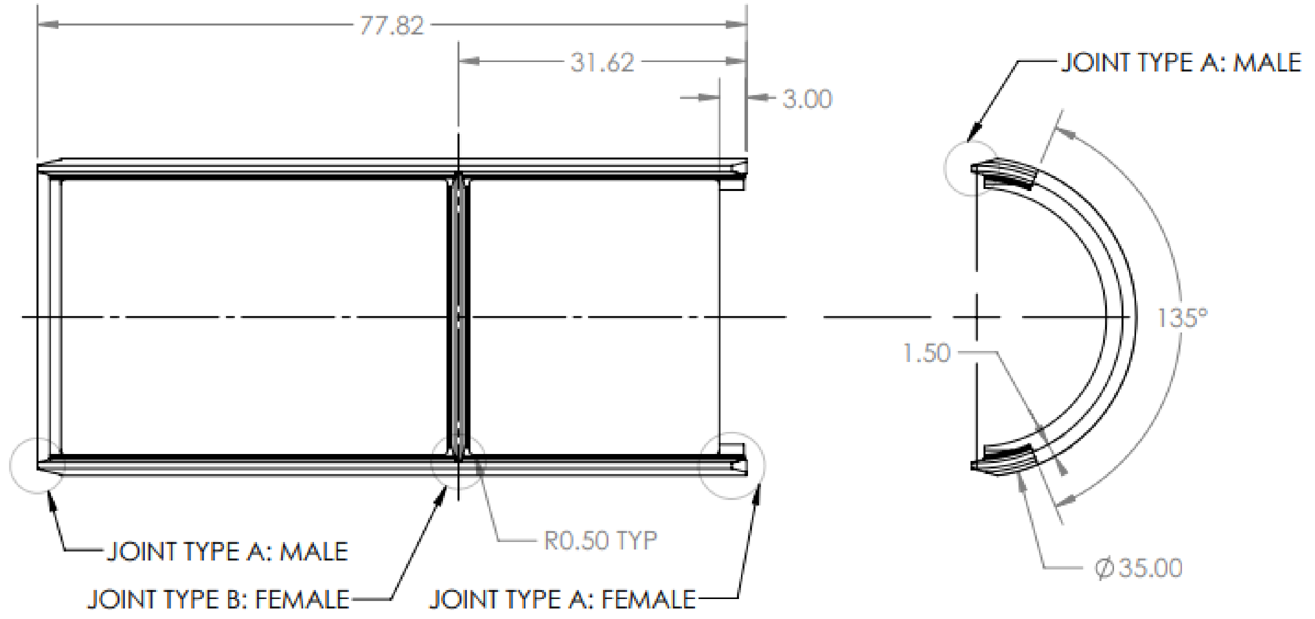
COMMENTS:

TITLE:
CROCHET AID REDESIGN
TOP COVER

SIZE	DWG. NO.	REV
A	APPENDIX D3	REL

SCALE: 2:1 WEIGHT: SHEET 3 OF 11


2
1
B
A
77.82
31.62
1.05
JOINT TYPE A: MALE
JOINT TYPE B: FEMALE
R0.50 TYP
JOINT TYPE A: FEMALE
JOINT TYPE A FEMALE
Ø35.00
1.50
2X R1.00
22.5°
12.00
4.50
Ø2.00
ON Ø28.5
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN mm
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
CROCHET AID REDESIGN
BOTTOM RIGHT GRIP
SIZE
A
DWG. NO.
APPENDIX D4
REV
REL
SCALE: 1.5:1
WEIGHT:
SHEET 4 OF 11



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

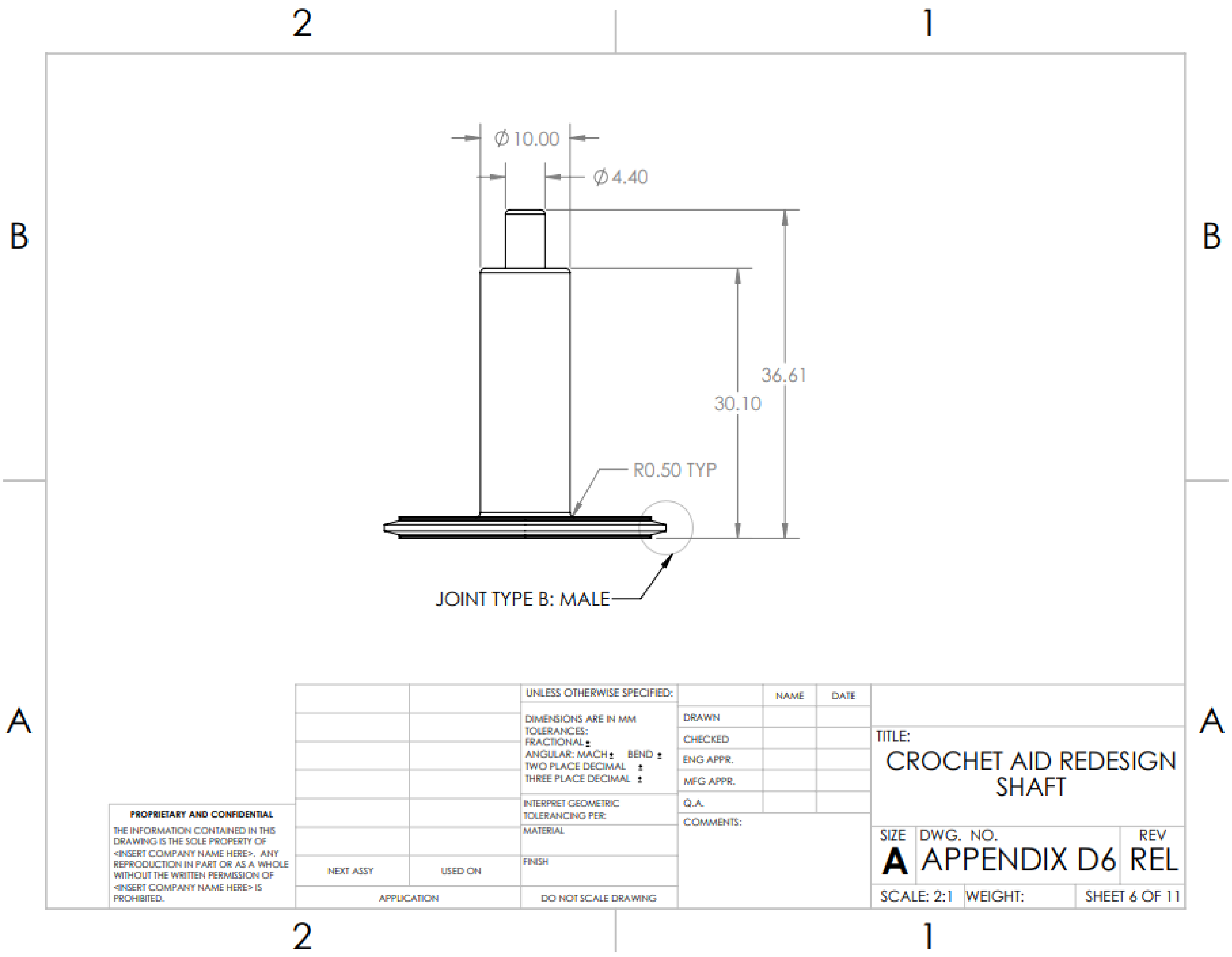
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
CROCHET AID REDESIGN
BOTTOM LEFT GRIP

SIZE **A**
DWG. NO. APPENDIX D5
REV REL
SCALE: 1.5:1
WEIGHT:
SHEET 5 OF 11



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY
USED ON
APPLICATION

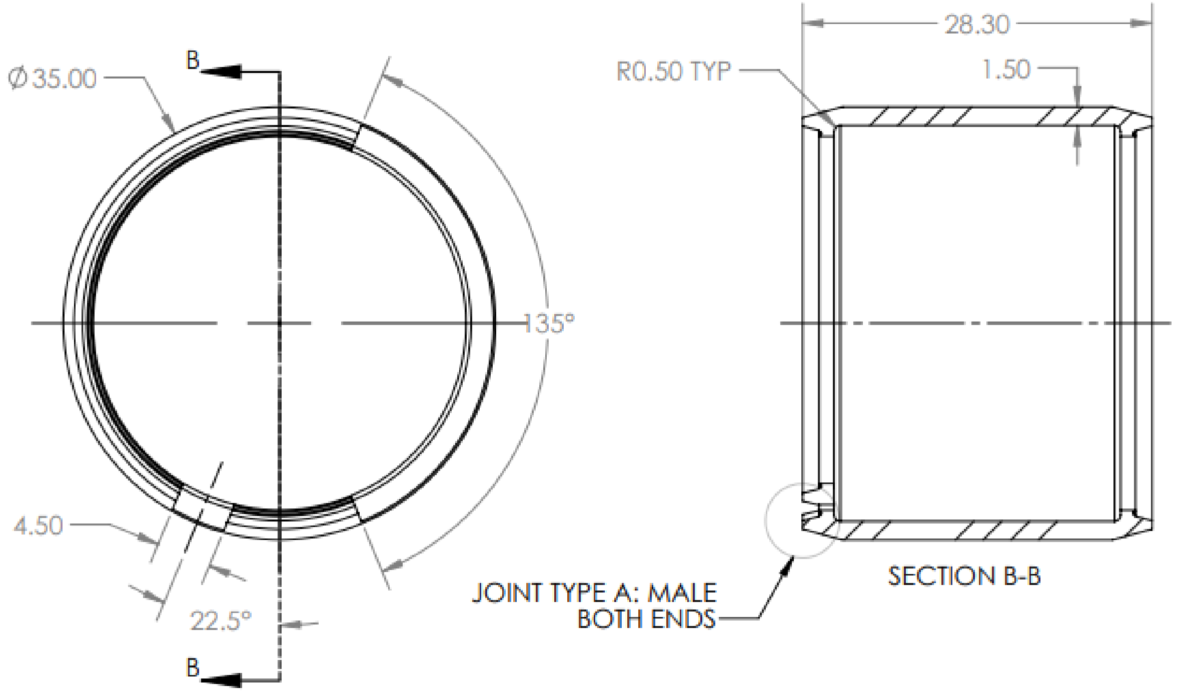
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
CROCHET AID REDESIGN
SHAFT

SIZE A
DWG. NO. APPENDIX D6
REV REL
SCALE: 2:1
WEIGHT:
SHEET 6 OF 11



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

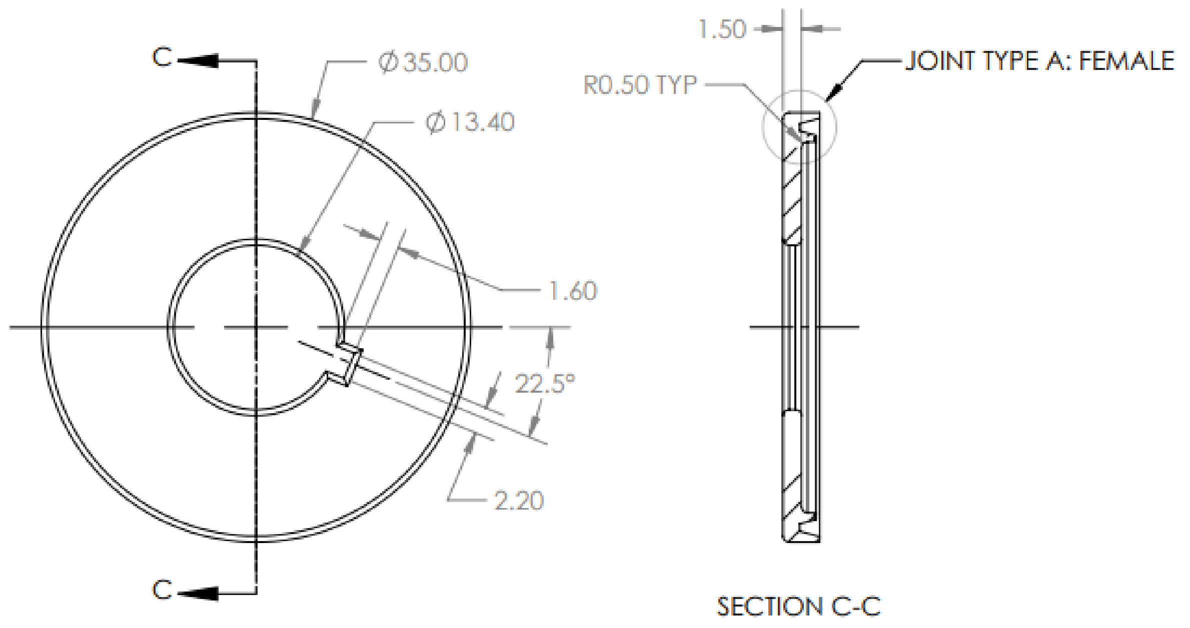
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
CROCHET AID REDESIGN
TOP GRIP

SIZE A
DWG. NO. APPENDIX D7
REV REL
SCALE: 2:1
WEIGHT:
SHEET 7 OF 11



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

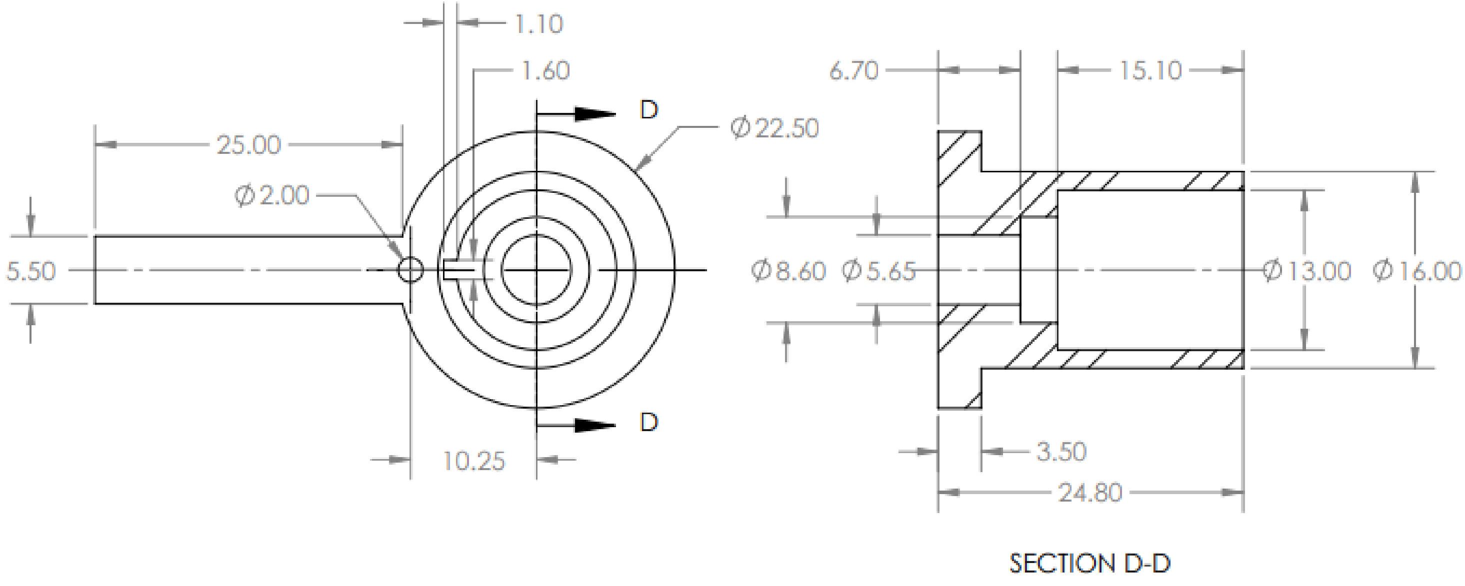
		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

TITLE:

CROCHET AID REDESIGN
TOP COVER

SIZE	DWG. NO.	REV
A	APPENDIX D8	REL

SCALE: 2:1 WEIGHT: SHEET 8 OF 11



PROPRIETARY AND CONFIDENTIAL

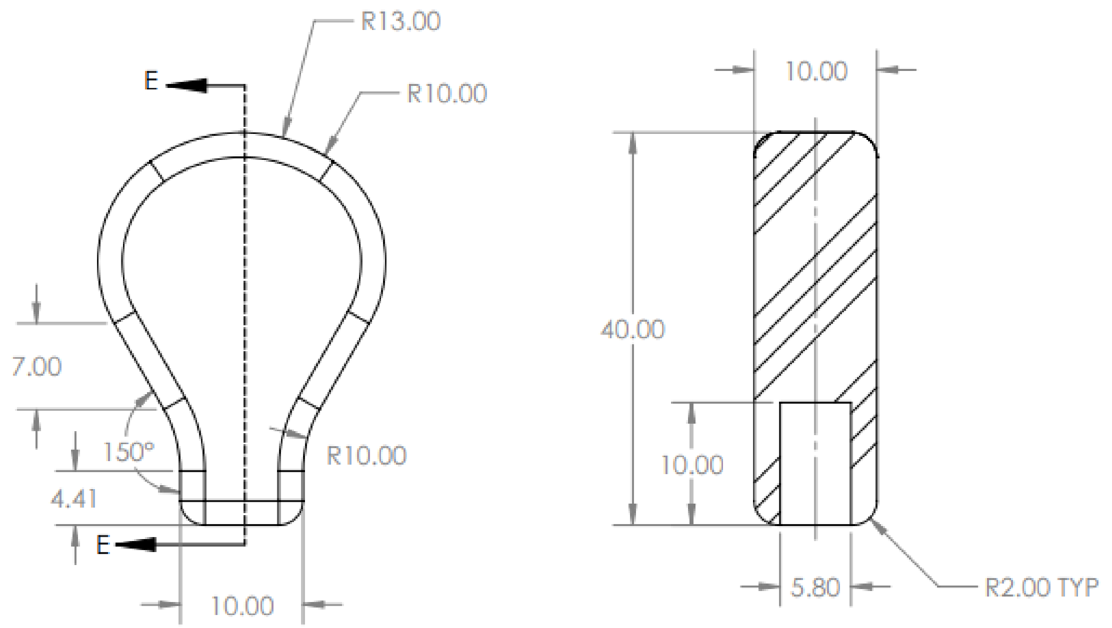
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
APPLICATION		DIMENSIONS ARE IN MM TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
		FINISH			
		DO NOT SCALE DRAWING			

TITLE:

CROCHET AID REDESIGN
DISK

SIZE	DWG. NO.	REV
A	APPENDIX D9	REL
SCALE: 2:1	WEIGHT:	SHEET 9 OF 11



SECTION E-E

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

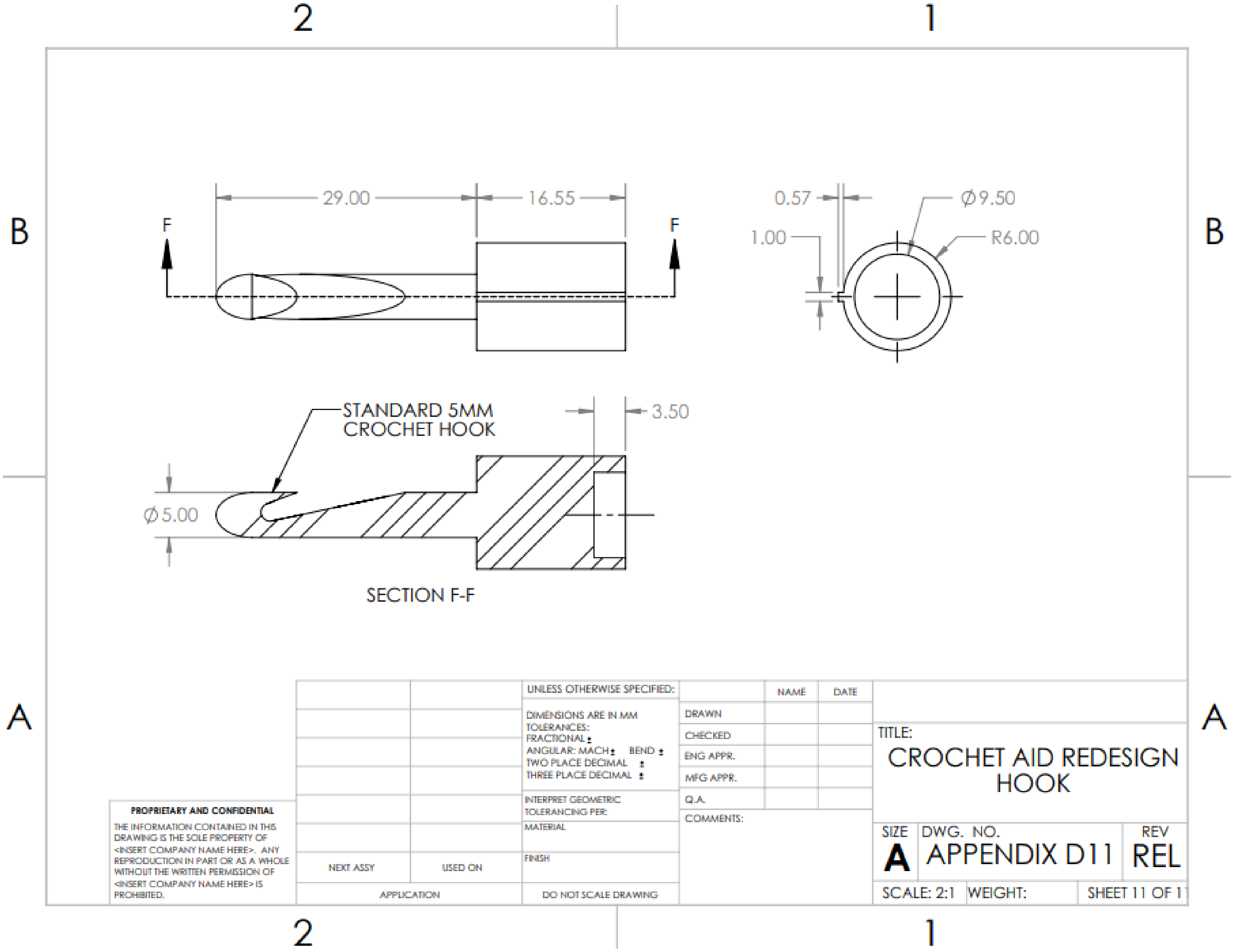
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
CROCHET AID REDESIGN
PADDLE

SIZE **A** DWG. NO. APPENDIX D10 REV REL

SCALE: 2:1 WEIGHT: SHEET 10 OF 1


2
1
B
A
F
F
29.00
16.55
0.57
1.00
Ø9.50
R6.00
STANDARD 5MM
CROCHET HOOK
3.50
Ø5.00
SECTION F-F
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
CROCHET AID REDESIGN HOOK
SIZE
A
DWG. NO.
APPENDIX D11
REV
REL
SCALE: 2:1
WEIGHT:
SHEET 11 OF 1

Appendix E Authorship Page

Chapter	**Authors**
Abstract	Mariah, Marissa, and Taylor
Introduction	Marissa
Background	Hailey, Mariah, Marissa, Samantha, Taylor, and Thanh
Design Concepts	Hailey, Mariah, Marissa, Samantha, Taylor, and Thanh
Synthesis and Analysis	Mariah, Marissa and Taylor
Design Selection	Hailey and Taylor
Detailed Design Description	Mariah, Samantha, and Taylor
Manufacturing	Hailey, Mariah, and Thanh
Testing	Hailey, Mariah and Marissa
Conclusions and Recommendations	Hailey, Samantha, Taylor, and Thanh