Active Prosthetic

Operation Manual

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Table of Contents

1.0 Introduction

This document instructs users on how to assemble and operate the active prosthetic arm. The prosthetic device is designed to provide below elbow amputees with a functional arm that is actively controlled and provides user feedback. This is accomplished by using foot controlled pressure sensors, arduino and Xbee coding, motors, and sensors to control the motion of the hand. This manual will be able to guide the user to print CAD drawings, assemble the device, implement the electronics, and operate the assembled prosthetic.

1.1 Recommended User Experience

The prosthetic device has many complex elements that could require knowledge and/or experience in certain areas. In order to build the device, it is recommended that the assembler have experience in Arduino/Xbee coding, 3D printing, soldering, and Solidworks CAD. These skills will be particularly useful when using arduinos, printing parts, and wiring electrical components. Assembling the mechanical components of the arm should require no user experience as the instructions for assembly should be fairly easy to follow. It is also necessary to have the following computer programs: Solidworks and Slic3r PE.

2.0 Assembly

This section is broken into detailed descriptions of the subassemblies and how the individual subassemblies are printed and assembled. This section also provides the bill of materials and should be referenced when purchasing all components prior to assembling. Once the subassemblies are put together, the user can follow the subsequent instructions on how to put the full arm assembly together.

2.1 Bill of Materials

In order to build this device, parts must be purchased or printed. The purchased items and printed parts are itemized in the Bill of Materials Tables. The required items that must be purchased can be found in Table 1.

Table 2.1.1: Purchased Bill of Materials

Item Number	Item Name	Quantity
1.1	Battery Booster	1
1.2	Spring	2
1.3	Foam roll	1
1.4	Vibrating motors	2
1.5	M3 Screws	2 (6mm) 8 (8mm)
1.6	Battery 2Ahr	1
1.10	SparkFun RedBot Mainboard	1
2.1	Servo Motors	4
2.2	Servo Motor Screws	16
2.3	Beaded Wire (~2ft strips)	5
3.1	Micro Motor	1
3.2	Micro Motor Screws	2
4.1	Finger Grips	5
4.2	Mini Pressure Sensors	2

4.3	Amphenol FCI Clincher Connector (2 Position, Female)	7
5.1	Shoe Insole Pack	1
5.3	RedBot Screws	4
5.4	XBee 1mW Trace Antenna - Series 1 (802.15.4)	1
5.5	Ankle band	1

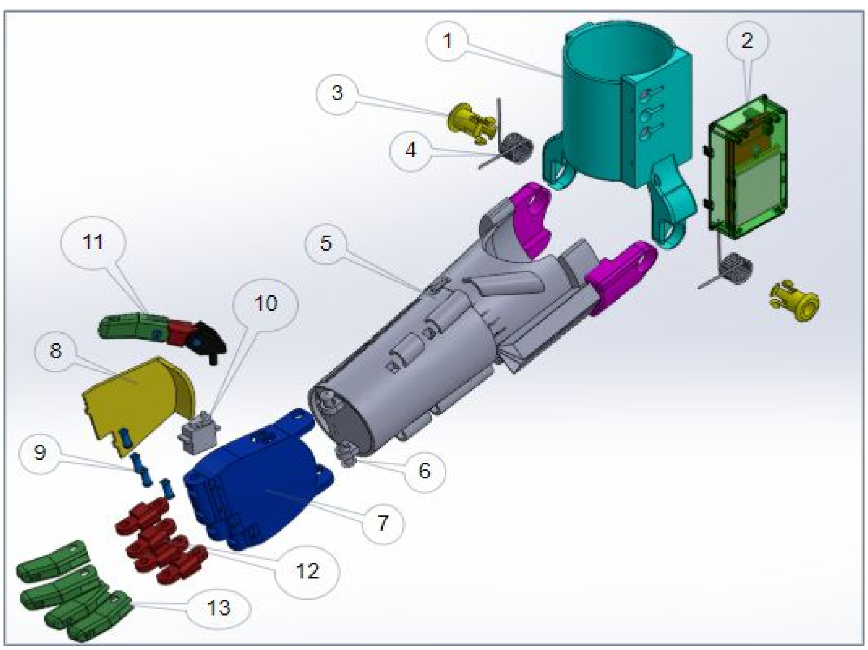
In addition to the purchased items, the 3D printed CAD is required. The parts are to be printed according to the instructions in the manufacturing section of this document. The parts that will be printed are shown in Table 2.

Table 2.1.2: 3D Printed Bill of Materials

Item Number	Item Name	Quantity
1.8	Electronic Cover	1
1.9	Cuff	1
2.4	Arm Back half	1
2.5	Arm Front half	1
2.6	Motor lid	1
2.7	Motor lid pins	2
2.8	Forearm key lock	1
2.9	Palm attachment pins	2
3.3	Palm	1
3.4	Palm Cover	1
3.5	Palm Pin (Long)	1
3.6	Palm Pin (Short)	2
4.4	Finger Hinge Pin	5
4.5	Rotating Base Hinge Pin	1

4.6	Digit 1 Rotating Base	1
4.7	Digit 1 Proximal	1
4.8	Digit 1 Distal	1
4.9	Digit 2 Proximal	1
4.10	Digit 2 Distal	1
4.11	Digit 3 Proximal	1
4.12	Digit 3 Distal	1
4.13	Digit 4 Proximal	1
4.14	Digit 4 Distal	1
4.15	Digit 5 Proximal	1
4.16	Digit 5 Distal	1
5.6	Electronic Cover	1

The completed CAD assembly is shown in figure 2.1.1



Part name	#
Cuff	1
Cuff Motor Assembly	2
Cuff Pin	3
Cuff Spring Attachement	4
Forearm Sub-Assembly with Motor	5
Forearm Pin Attachement	6
Palm	7
Palm Top	8
Palm Pins	9
Thumb Motor	10
Thumb Assembly	11
Proximal Digits	12
Distal Digits	13

Figure 2.1.1: Complete Assembly CAD

2.2 Cuff Assembly

Table 2.2.1: Cuff Components

Item Number	Item Name	Quantity
1.1	Battery Booster	1
1.2	Spring	2
1.3	Foam roll	1
1.4	Vibrating motors	2
1.5	M3 Screws	
1.6	Battery 2Ahr	1
1.8	Electronic Cover	1
1.9	Cuff	1
1.10	SparkFun RedBot Mainboard	1

Manufacturing Cuff

1. When sizing, measure the diameter of recipient affected arm, add twice the thickness of the padding used, and round up. (ex. $\frac{8.25in_{arm}}{\pi} + 2 \times 0.25in_{padding} \simeq 3.3in$)

Figure 2.2.1: Measuring recipient

2. Input diameter into the cuff (1.9) size settings.

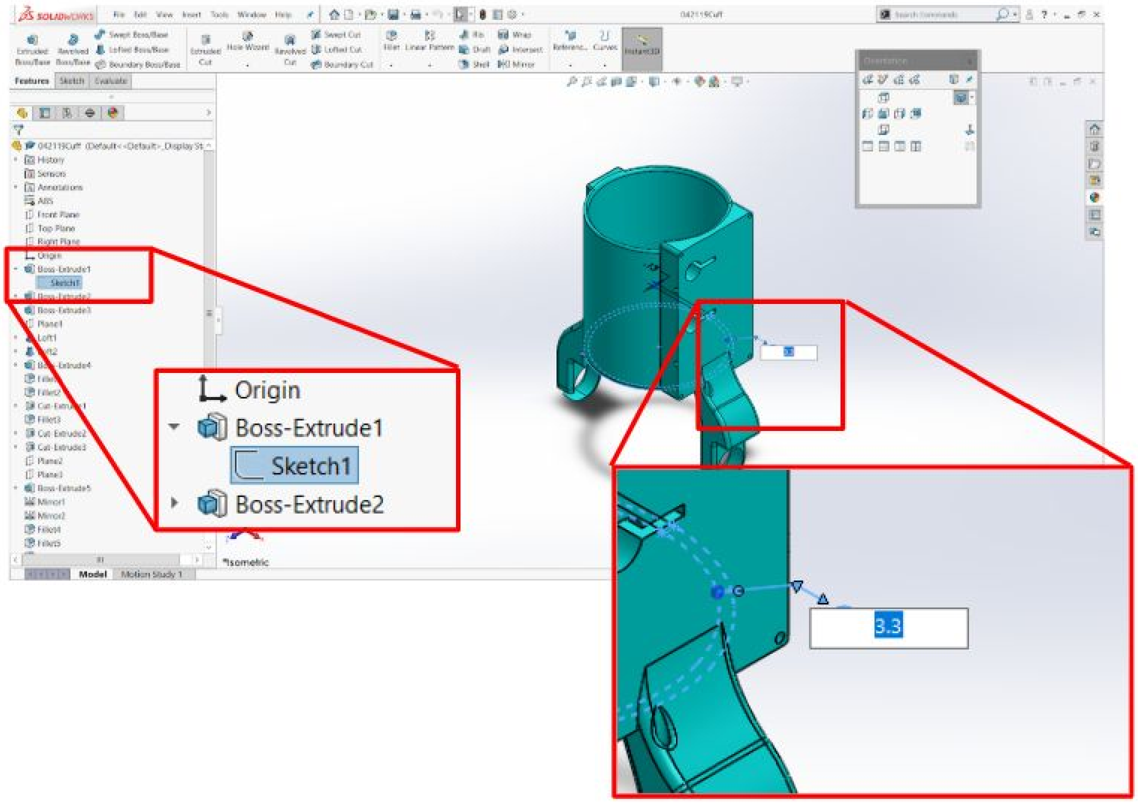


Figure 2.2.2: Sizing in Solidworks

3. Print Cuff vertically, 40% infill, 3 shells, support only on build plate.

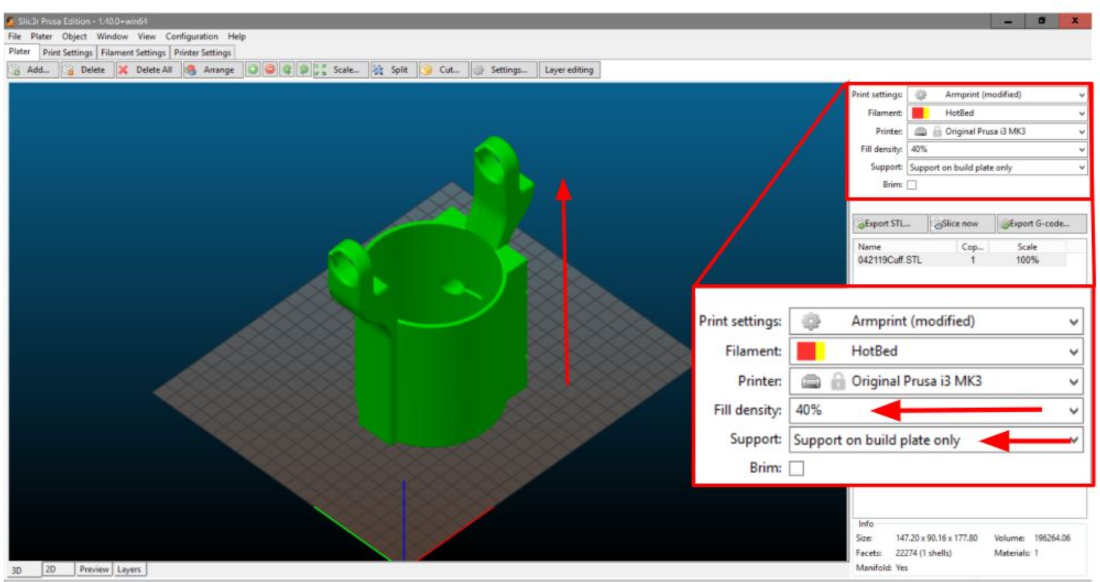


Figure 2.2.3: Settings in Slic3r PE

4. Print electronics holder (1.8) flat.

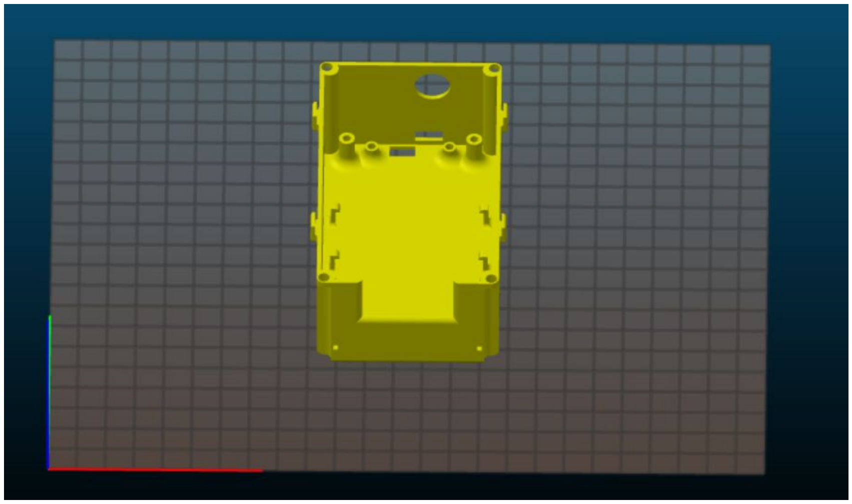


Figure 2.2.4: ecase in Solidworks

Assembling Cuff

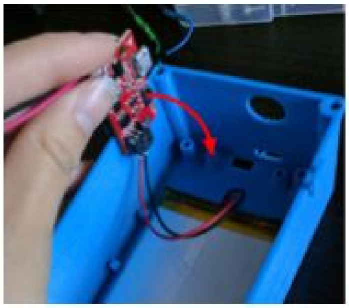
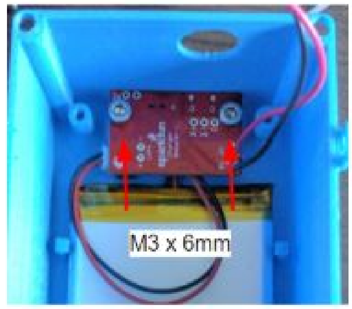
1. Line cuff with padding (1.3)

Figure 2.2.5: Padding (1.3) in Cuff

2. Screw (1.5) electronics into holder

   a. 

Figure 2.2.6a: Screws (1.5) Needed

b. 
c. 

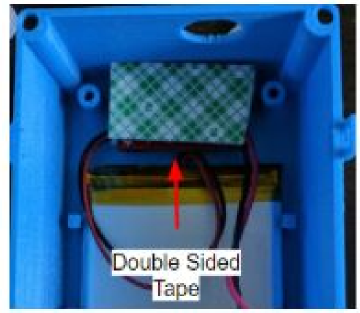
d. 

Figure 2.2.6b-d: Inserting Battery Booster (1.1) and Battery (1.6)

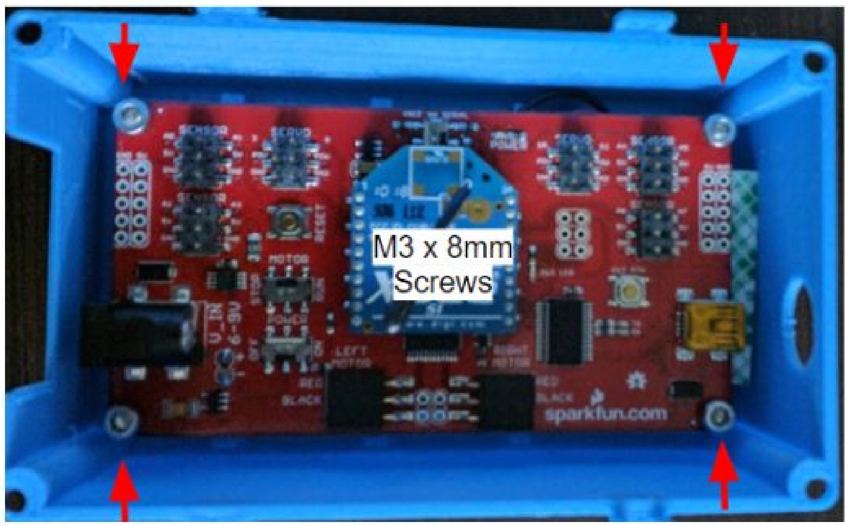
e. 

Figure 2.2.6e: Inserting SparkFun RedBot Mainboard (1.10).

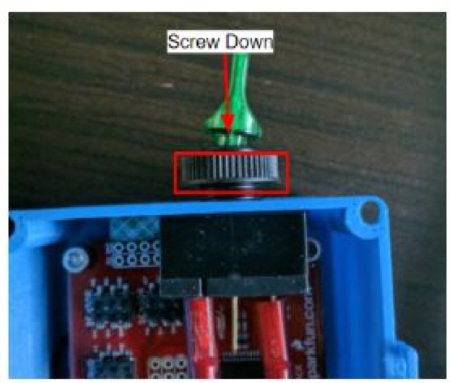
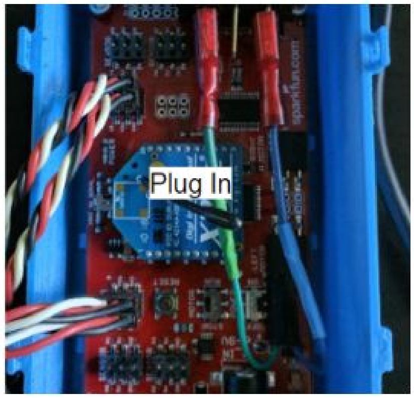
f. 
g. 

Figure 2.2.6f-g: Inserting Switch.

h. 

j. 

Figure 2.2.6h-j: Attaching Wires.

k. 

Figure 2.2.6k: Attaching eCase to Cuff.

Attachment to Forearm

1. Slide one end of spring into hole.

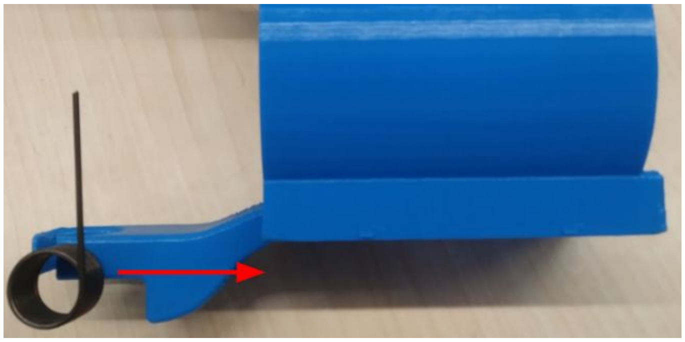


Figure 2.2.7: Insert spring end (1.2) into small hole.

2. Push the spring through the large hole until it snaps into the hole.
   (Make sure the horizontal end of the spring is protruding from the front of the cuff. If the horizontal end is not protruding from the front of the cuff you may have printed the cuff for the wrong arm, left or right. If this is not the case, remove the spring and turn it 90 degrees.)

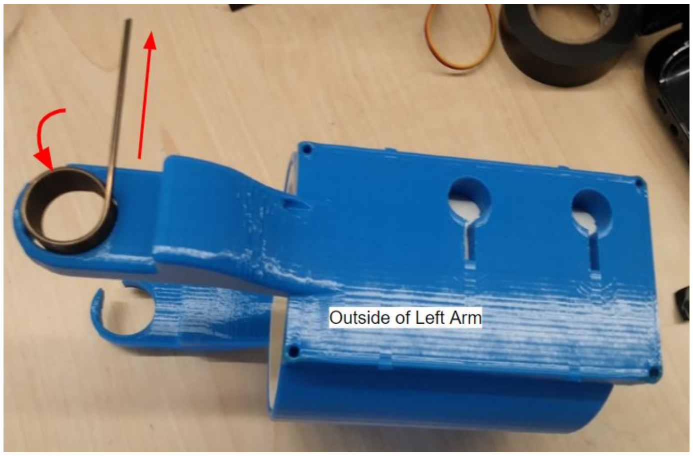


Figure 2.2.8: Pop spring circle into large hole.

3. Repeat for other side

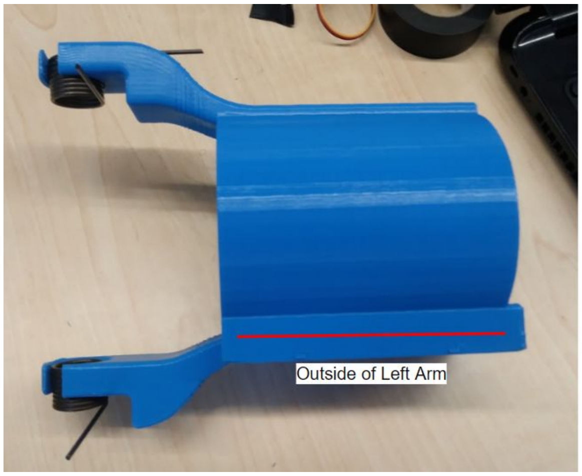


Figure 2.2.9: Springs inserted into both sides of Cuff.

2.3 Forearm Assembly

Table 2.3.1: Forearm Components

Item Number	Item Name	Quantity
2.1	Servo Motors	4
2.2	Servo Motor Screws	16
2.3	Beaded Wire (~2ft strips)	5
2.4	Arm Back half	1
2.5	Arm Front half	1
2.6	Motor lid	1
2.7	Motor lid pins	2
2.8	Forearm key lock	1
2.9	Palm attachment pins	2

The forearm (item 2) takes on a cylindrical shape and must be printed from the bottom up following circular motions in order to reduce shear and splitting of the material. Figure 2.3.1 provides a visual of how the forearm is positioned prior to print. Once printed, trim all excess material from the cut outs and edges so that the final product is smooth and hollow.

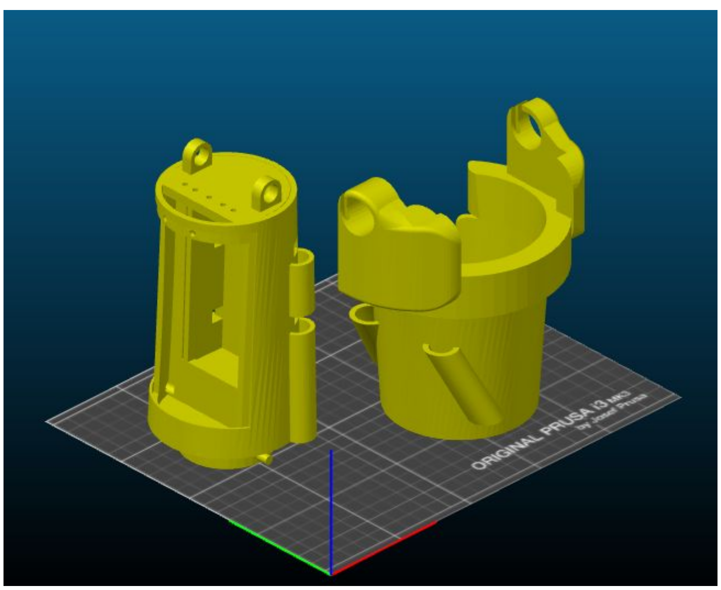


Figure 2.3.1: Slicer Setup

When printing, make sure to print without supports, with 40% infill, and hexagonal infill.

Insert the four servo motors (item 2.1) to the front of the forearm (item 2.5) as shown in figure 2.3.2. Thread the wires through the holes at the base of the forearm and out the back (figure 2.3.3). These wires can now be attached to the arduino for actuation. Screw down the servo motors using item 2.2. The lid (item 2.6) can be placed on top and secured using two pins (item 2.7).

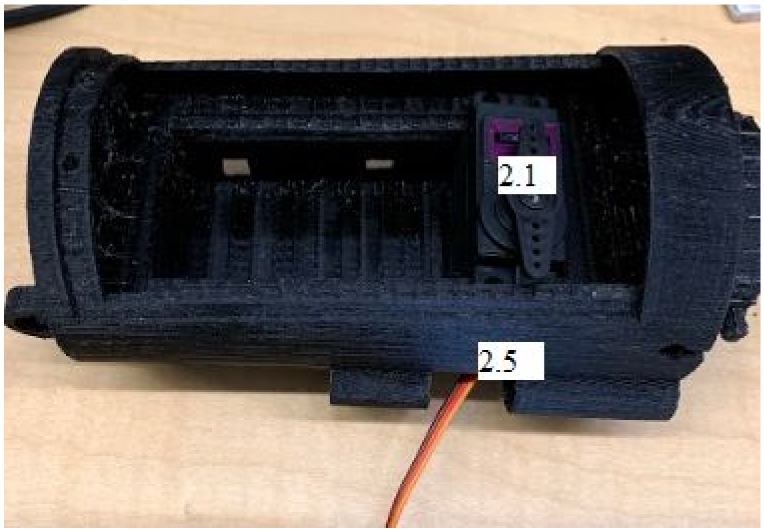


Figure 2.3.2: Inserting Servos

Figure 2.3.3: Threading Wires

Once all motors are screwed down, attach the lid (item 2.6) to the front half. Slide the flat portion of the lid under the back arc of the front half and rest the lid. Push in the lid pins (item 2.7).

The front of the forearm can now be attached to the back of the forearm (item 2.4). To do so, line up the pins on the front to the holes on the back and slide the two pieces together until it stops. Twist the front piece 90° clockwise until it stops, then put the front piece in further to secure it. Figures 2.3.4-2.3.6 provide a visual of the attachment process.

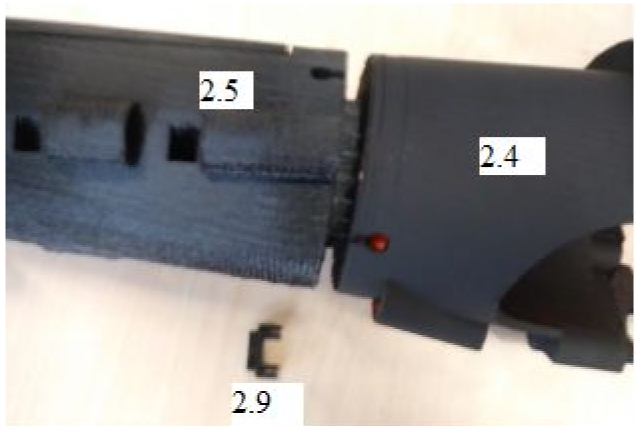


Figure 2.3.4: Lining Up 2.4 and 2.5

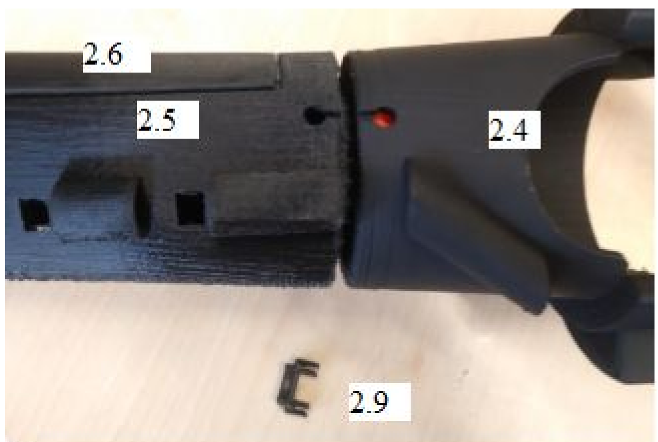


Figure 2.3.5: Clockwise Rotation Until Keyhole Aligns

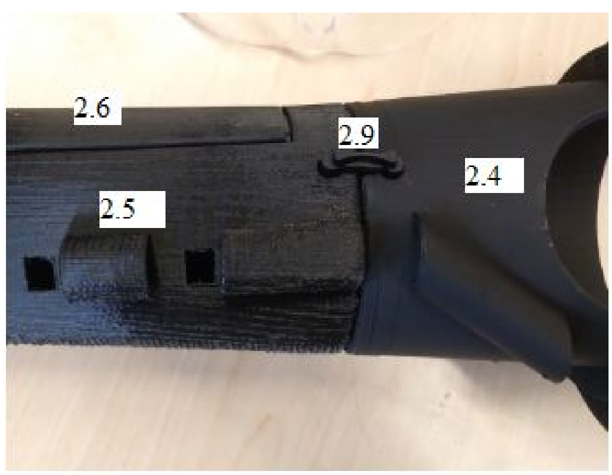


Figure 2.3.6: Insert Key

The key attachment (item 2.8) is used to secure the two halves in place, and can be pressed into the keyholes as figure 2.3.6 depicts.

2.4 Palm Assembly

Table 2.4.1: Palm Components

Item Number	Item Name	Quantity
3.1	Micro Motor	1
3.2	Micro Motor Screws	2
3.3	Palm	1
3.4	Palm Cover	1
3.5	Palm Pin (Long)	1
3.6	Palm Pin (Short)	2

Printing the palm (items 7, 8, 9, 10) is one of the simpler parts of the arm assembly. It should not be necessary to scale the palm to accomodate for a bigger size. This is because if the part gets too big in either direction, the part would lose some function. The palm must be printed front side up (dome side facing upward). The palm top should be printed with the flat side facing down. Both pins should be printed sideways to reduce shear. Each part is printed at 40% infill and no support. A visual of this process can be seen in Figure 2.4.1. This design is the left hand by default. If a person wishes to use if for their right hard, simply right click the palm in slic3r, select mirror, and mirror the palm in the x direction.

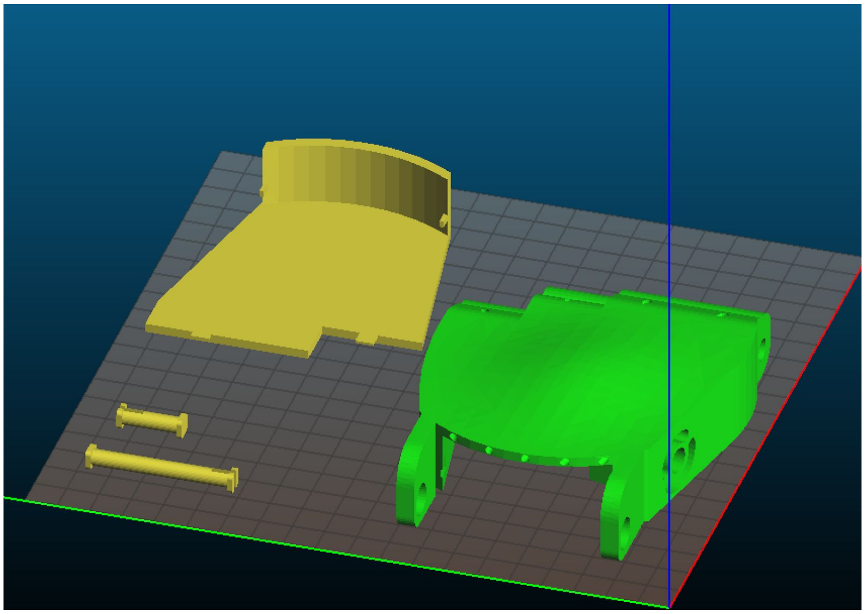


Figure 2.4.1: Assemble in slic3r

Once printed, be sure to strip off any excess printed material. This is especially important for the wire and sensor holes so the fingers have a smooth movement. Gather the necessary motor and screws for the assembly.

First begin by assembling the motor to the palm. Collect the motor, palm, and palm top. Place the motor with the front side facing the thumb opening as shown in the Figure 2.4.2. Grab the two micro motor screws and secure the motor using the screwdriver.

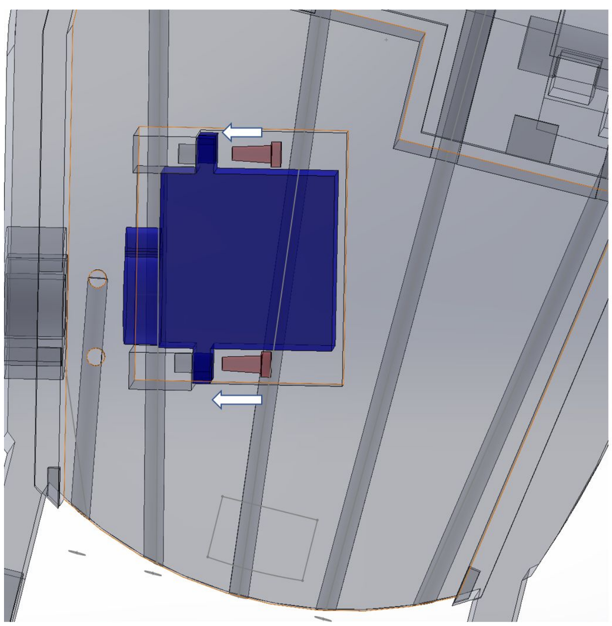


Figure 2.4.2: Figure of Screws to Motor

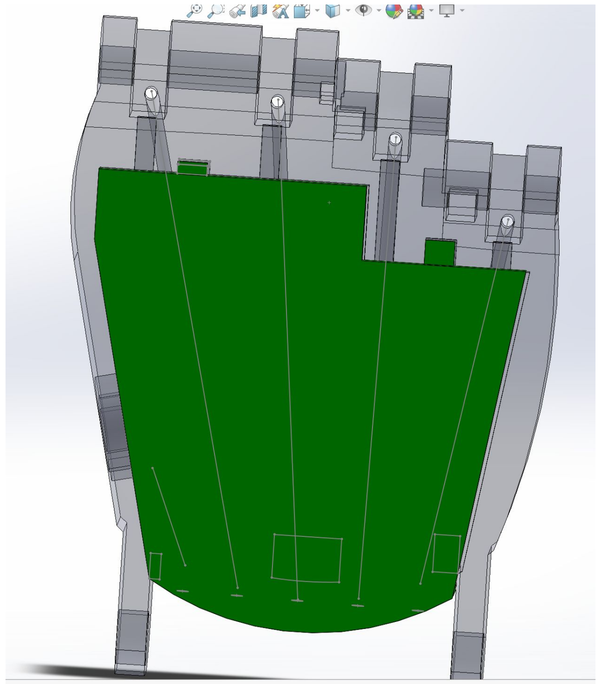


Figure 2.4.3: Palm top to Palm

To assemble each finger, details can be found in the subsequent section 2.7. Be sure that the wire holes are cleared of plastic for the wire to go through. Once the finger components have been placed in the palm, the palmtop can now be placed by pushing the front section toward the fingers until the two front inserts are in place as shown in figure 2.4.3.

2.5 Finger Assembly

Table 2.5.1: Items Required for the Fingers

Item Number	Item Name	Quantity
4.1	Finger Grips	5
4.2	Mini Pressure Sensors	2
4.3	Amphenol FCI Clincher Connector (2 Position, Female)	7
4.4	Finger Hinge Pin	5
4.5	Rotating Base Hinge Pin	1
4.6	Digit 1 Rotating Base	1
4.7	Digit 1 Proximal	1

4.8	Digit 1 Distal	1
4.9	Digit 2 Proximal	1
4.10	Digit 2 Distal	1
4.11	Digit 3 Proximal	1
4.12	Digit 3 Distal	1
4.13	Digit 4 Proximal	1
4.14	Digit 4 Distal	1
4.15	Digit 5 Proximal	1
4.16	Digit 5 Distal	1

Five fingers will be printed. Each finger varies slightly in size and design. However, assembly is same for each. For each finger, there is a proximal and distal segment to each. The fingers have wire running through them as artificial tendons. These tendons allow the fingers to open and close. The fingers are different sizes much like biological fingers. It is important to get them in the correct order so the hand looks natural. Some fingers are specialized for touch and have slightly different designs. The pointer and middle fingers have pressure sensor channels that allow the pressure sensors to run through them.

Before assembling, purchase and print the necessary parts. The printed parts have specified dimensions and printing setting. For dimensioning measure the length of the user's proximal phalanges. (This is the lower half of the finger). To change the dimensions of the fingers open the CAD file and change the length of the proximal segments. The CAD can be edited in SolidWorks. Open the CAD files for each of the proximal segments (Items 4.7, 4.9, 4.11, 4.13, 4.15). Open Boss-Extrude 1 and edit Sketch 1. Double click on the length dimension and enter the patient's length in inches. Reference Figure 2.5.1.

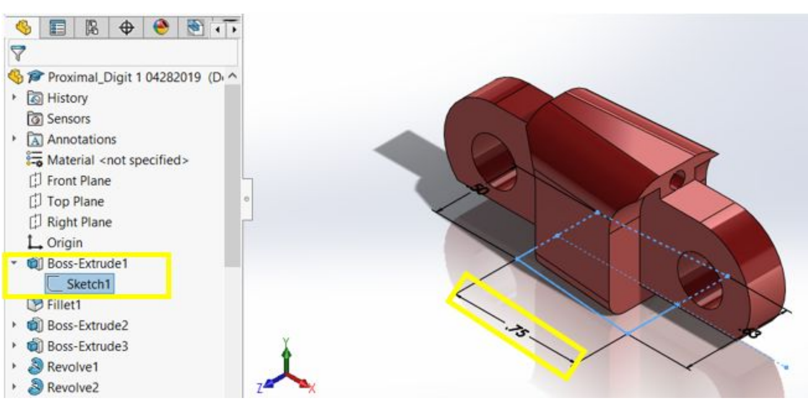


Figure 2.5.1: Editing Finger Length in CAD

Do not change other dimensions. This may cause errors in the part. Once all have been edited, save all parts as STL files. Note: The fingers are the same for both left and right hands.

The next step is to print the CAD. These parts should be printed with 40% infill and without supports. This can be specified in Slic3r. The fingers print best when printed in the orientation seen below.

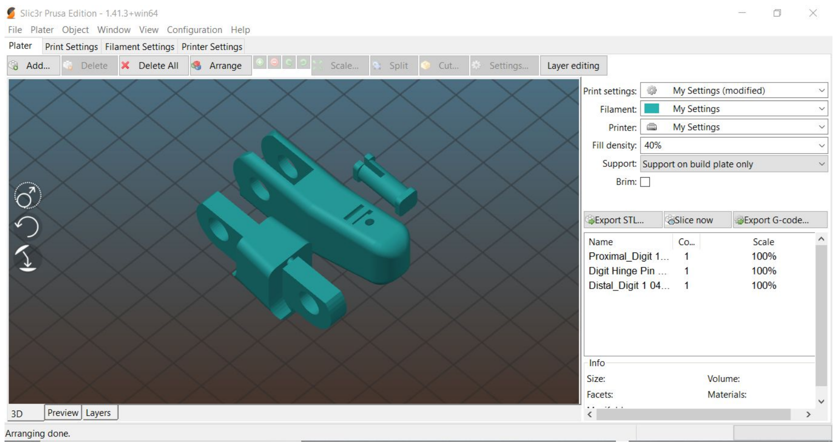


Figure 2.5.2: Finger Set up in Splic3r

After printing the fingers can be assembled. For this assembly, attach the proximal (Items 4.7, 4.9, 4.11, 4.13, 4.15) to the respective distal segment (Items 4.8, 4.10, 4.12, 4.14, 4.16) of each finger. Proximal and distal are anatomical terms. Proximal means the body part is closer to the center of the body or the point of attachment. Distal is the opposite and means farther from the center of the body. The segments of the fingers can be seen in Figure 2.5.3.

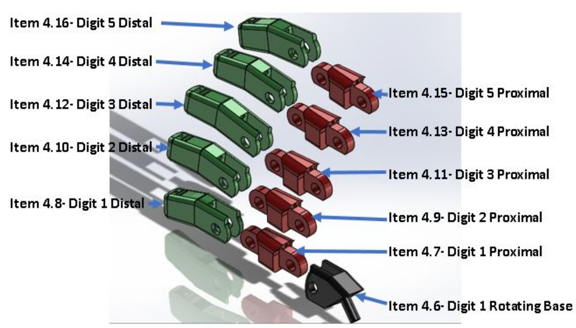


Figure 2.5.3: The Five Fingers and part Segments

The fingers are distinguishable from each other. The main difference it the lengths of each finger. Like the in the human body, the longest finger is the middled, then the ringer and pointer, and the shortest is the pinky. The pointer and middle fingers are distinguishable from the rest because the proximal segments have channels for pressure sensors.

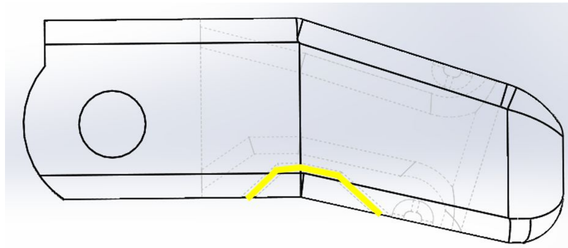


Figure 2.5.4 Distinguishing Feature/ Sensor Channel

Attaching the proximal and distal segments done by slipping the distal segments (Items 4.8, 4.10, 4.12, 4.14, 4.16) into the notch of the respective proximal segments (Items 4.7, 4.9, 4.11, 4.13, 4.15). Line up the knuckle so the holes are concentric. Then, squeeze the head of the hinge pin (Item 4.4) so the head is small enough to fit through the hole. See Figure 2.5.5.

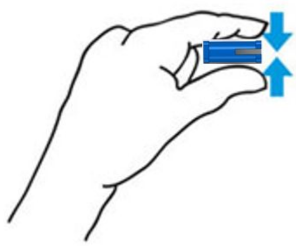


Figure 2.5.5 How to Squeeze the Pinhead

Once the pinhead is pinched and can fit in the hole, push the pin through to create a hinging finger joint. See Figure 2.5.6 below.

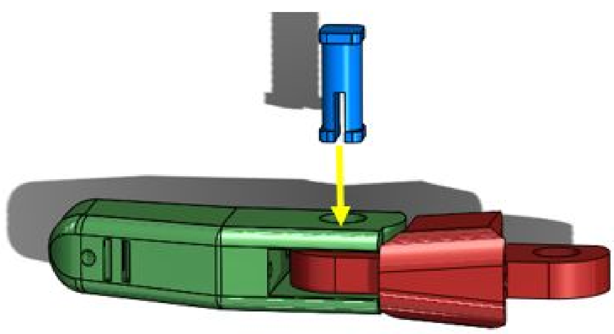


Figure 2.5.6 Placing the Hinge Pin to Attach Finger Segments

For the thumb, attach the proximal end to the rotating base (Item 4.6) in a similar manner as before. Attaching the proximal and rotating base of the thumb segments done by slipping the distal segments (Items 4.8) into the notch of the rotating base segments (Item 4.6). Use the rotating base pin (Item 4.5) to create a hinging finger joint. See Figure 2.5.7 below.

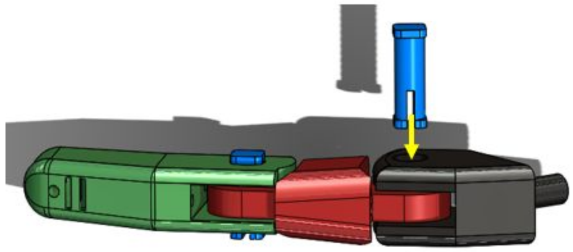


Figure 2.5.7: Attaching Digit 1 to the Rotating Base

Next, thread the tendons through the finger channels. Cut the beaded wire (Item 2.3) into strands. These need to be at least two arm lengths because the wire will lope from the forearm to the fingertips and back. The tendons will travel through the front and backsides of the fingers. Tie the tendons at the fingertips. See Figure 2.5.8 below. The wire will be threaded through the fingers, palm, and forearms to attach to the motors.

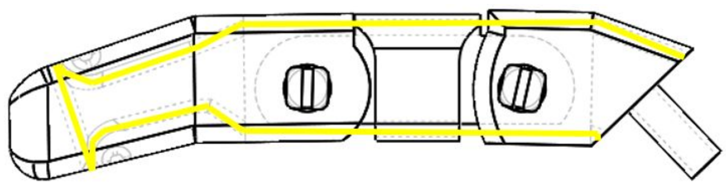


Figure 2.5.8: Wire threading through the Finger

Finally, insert the pressure sensors (Item 4.2) and add grips (Item 4.1). The pressure sensors will be inserted into the pointer and middle fingers. Before putting the sensors into the fingers, they need to be attached to their clinchers (Item 4.3). This is done by puting the end of the sensor into the clincher and pressing it into place. It should look like Figure 2.5.9.

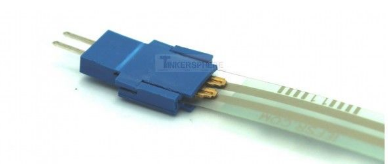


Figure 2.5.9: Pressure sensor and Clincher Attachment

Next, the sensor goes through the specialized channel as seen in Figure 2.5.10.

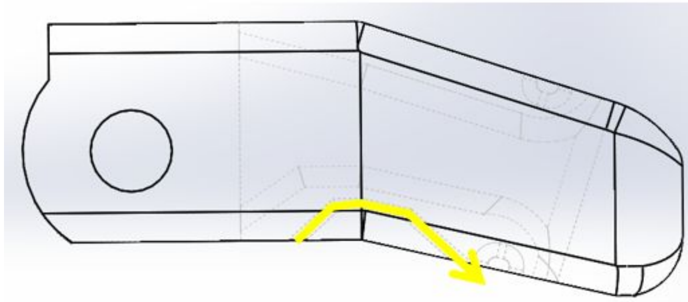


Figure 2.5.10: Pressure sensor Threading

Lastly, the finger grips (Item 4.1) are slipped over all the fingertips. The fingers are ready to be connected to the palm.

2.6 How to Assemble Complete Product

As shown in Figure 2.6.1, the user should have 4 separate but fully assembled subsystems. It is easier to assemble the arm starting with the palm and fingers.

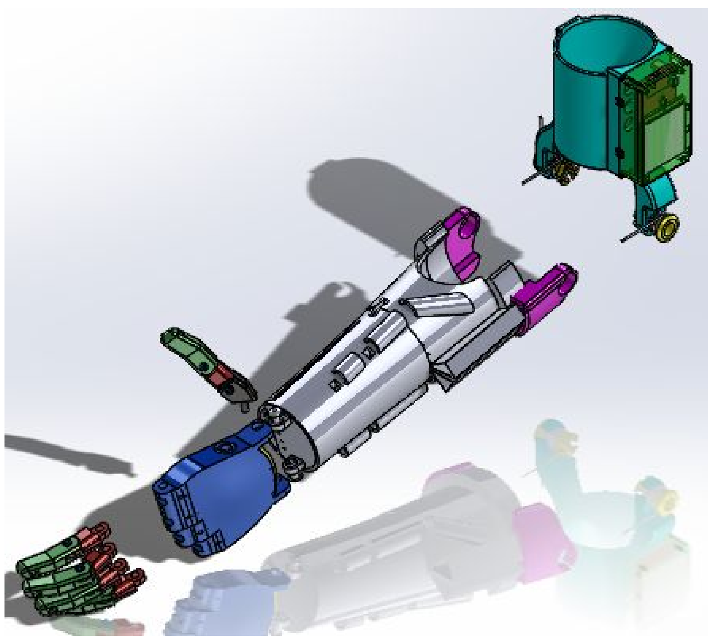


Figure 2.6.1: Exploded view of the Arm

Gather the assembled fingers and the palm. Begin with the finger placement to the left of the pinky. Rotate the finger so that the back of the finger adjacent to the back of the palm. Gather the wire coming out of the back of finger. Loop this wire through the corresponding palm hole. See Figure 2.6.2.

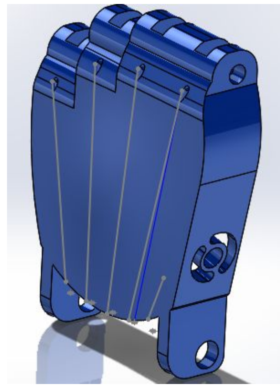


Figure 2.6.2: Threading the Wire through the Palm

Gather the wire from the front of the finger and lace it through the hole directly at the bottom of the finger. Pull the wire through. Secure this finger attachment with the short palm pin (item 3.6). A visual of this process can be found in Figure 2.6.3.

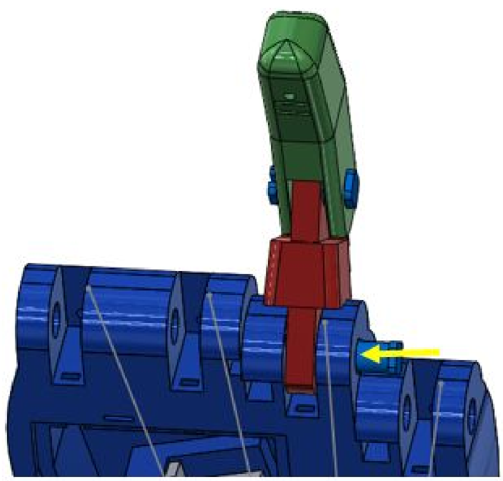


Figure 2.6.3: Finger Attachment to Palm

Repeat this step with the pinky finger and then with the top two fingers (index and middle fingers). With the top two fingers, secure these attachments with the long finger pin (Item 3.5).

For the thumb, attach the shaft of the thumb base (Item 4.6) to the motor by pushing it through the hole on the flat surface of the palm. Once the shaft is through the hole the end of the shaft slides snuggly over the micro motor's (Item 3.1) shaft. See Figure 2.6.4. The tendon wires are threaded through the semicircular canals around the shaft hole.

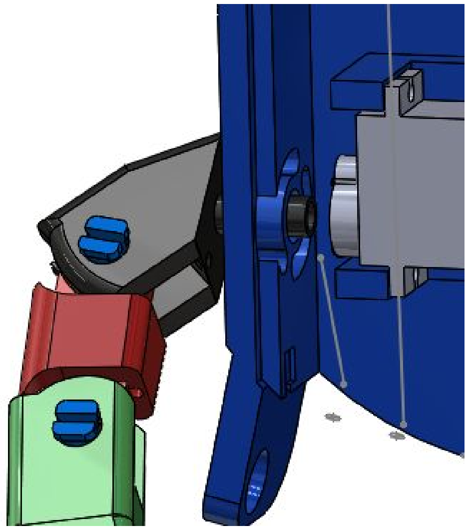


Figure 2.6.4: Thumb Attachment to Palm

Moving to the forearm attachment, gather the palm, finger subsystem and the two palm attachment pins (Item 2.9). It would be easier to start with the wires through the forearm wire holes. Start with the pinky finger first. Lace both wires through the whole on the far right. Repeat this step with all five fingers. Once this is complete, place the palm pins through either side of the palm.

Figure 2.6.5: Tendon threading from Palm to Forearm

To assemble the motors through the wires, begin with the pinky finger once again. As shown in figure 2.6.5, wrap the two wires around the backmost motor with one approaching from the left and the other from the right. Make sure that the wires are not loose in any way. Repeat this process on the same back motor for the ring finger next to the pinky. For the middle finger, repeat the wrapping process on the second to last motor. The pointer finger will be wrapped around the third to last motor while the thumb will be wrapped around the fourth. The micro motor should go through the forearm tube along the wire line.

Figure 2.6.6: Figure of Wires Through Forearm Motor

The final attachment is between the forearm and cuff. These subassemblies are connected via the springs (Item 1.2) in the cuff assembly. Recall how the springs (Item 1.2) was attached to the cuff and repeat for the forearm attachment.

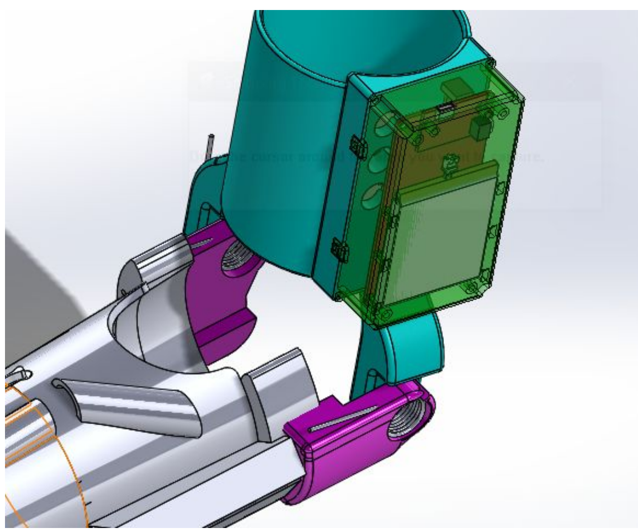


Figure 2.6.7: Cuff and Forearm Attachment

The arm should be fully assembled at this point and should look like Figure 2.6.8.

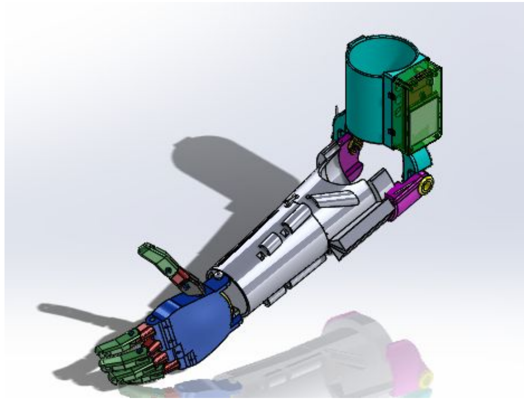


Figure 2.6.6: Full Arm Assembly

3.0 Instruction for Use

Once the arm is assembled, the patient can put on the arm by sliding their remaining limb into the cuff. The padding inside the cuff should be tight enough that the arm does not slip, but loose enough that circulation is not disrupted. This section includes details on how to use the toe activation sensors to control finger motion of the prosthetic. This section also covers how to charge the battery and possible troubleshooting if problems arise.

3.1 Actuation

The pressure sensors are aligned with three on the user's most dominant foot and two on the recessive foot. There is a pressure sensor for the thumb's rotation, the thumb's bending, the pointer finger's bending, the middle finger's bending, and the ring and pinky fingers bending. The pressure sensor under the big toe on the dominant foot controls the rotation of the prosthetic thumb. The sensor under the big toe of the recessive foot controls the bending of the thumb. The sensor under the pinky toe of the dominant foot controls the pointer finger. The sensor under the middle toes of the dominant foot are the ring and pinky finger bending. The sensor under the pinky on the recessive foot is the middle finger's bending.

There is a switch on the cuff that tells the arduino when the user is walking and when they are still. When this switch is flipped to "off" or "walking", the fingers will be held in their current position even as pressure is removed from sensors or placed on others. This feature is to ensure that the fingers do not move when the user is walking. When the switch is flipped to "on" or "not walking", the fingers can move according to their pressure sensors once more,

3.2 Charging

The cuff has a charging port that takes a Micro USB charging cable. The battery can last up to 12 hours of constant use.

To charge, remove the arm and plug in the cuff to a power source. It should take approximately 6 hours to charge completely.

4.0 Maintenance

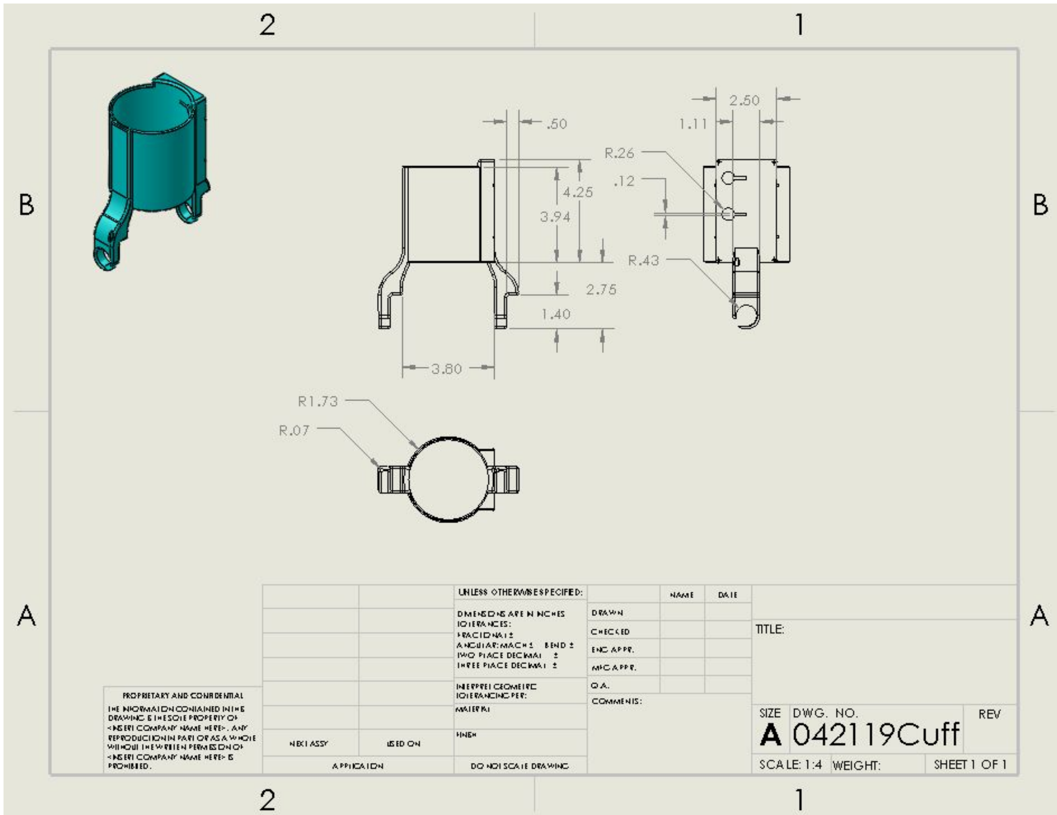
The least durable component of the prosthetic are the pin attachments.These components are easy to 3D print in a short amount of time, and cost little amounts of filament to do so. These pins can also be replaced with metal pins to increase durability.

Majority of the mechanical components of the arm are 3D printed. If a larger component cracks or breaks, it will need to be 3D printed again. The arm was designed with many interchangeable parts so that when one component breaks, it can easily be removed from the assembly and replaced with the newly 3D printed part, instead of replacing the entire assembly.

If an electric component malfunctions or is damaged, it will most likely need to be replaced with a new component. If it was an XBee or Arduino that is damaged, the new XBee or Arduino will need to have the code reuploaded to it.

The arm is made using PLA filament. For cleaning, take a small cloth dipped in isopropyl alcohol. Run the cloth over dirty areas of the arm to remove dirt and stains. The arm should not be placed in water in order to avoid damage to the electronics.

5.0 Appendix



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R.43
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R1.73
R.07
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MFG APPR.
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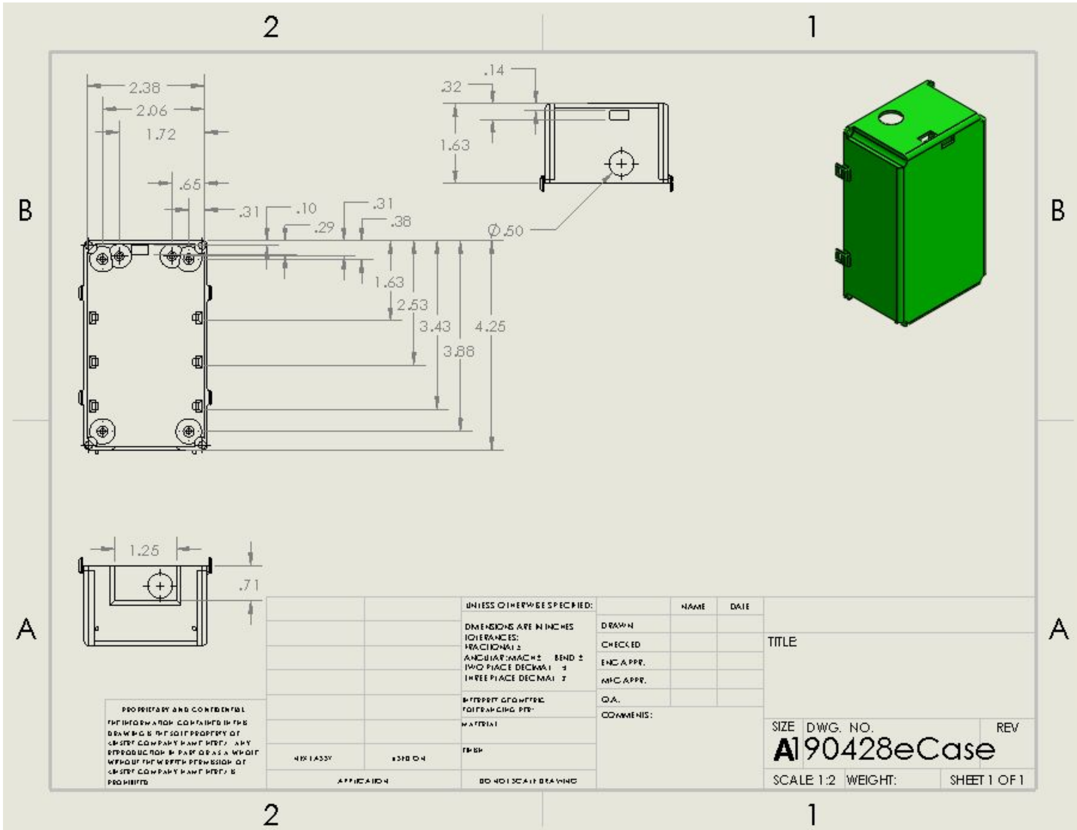
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MFG APPR.
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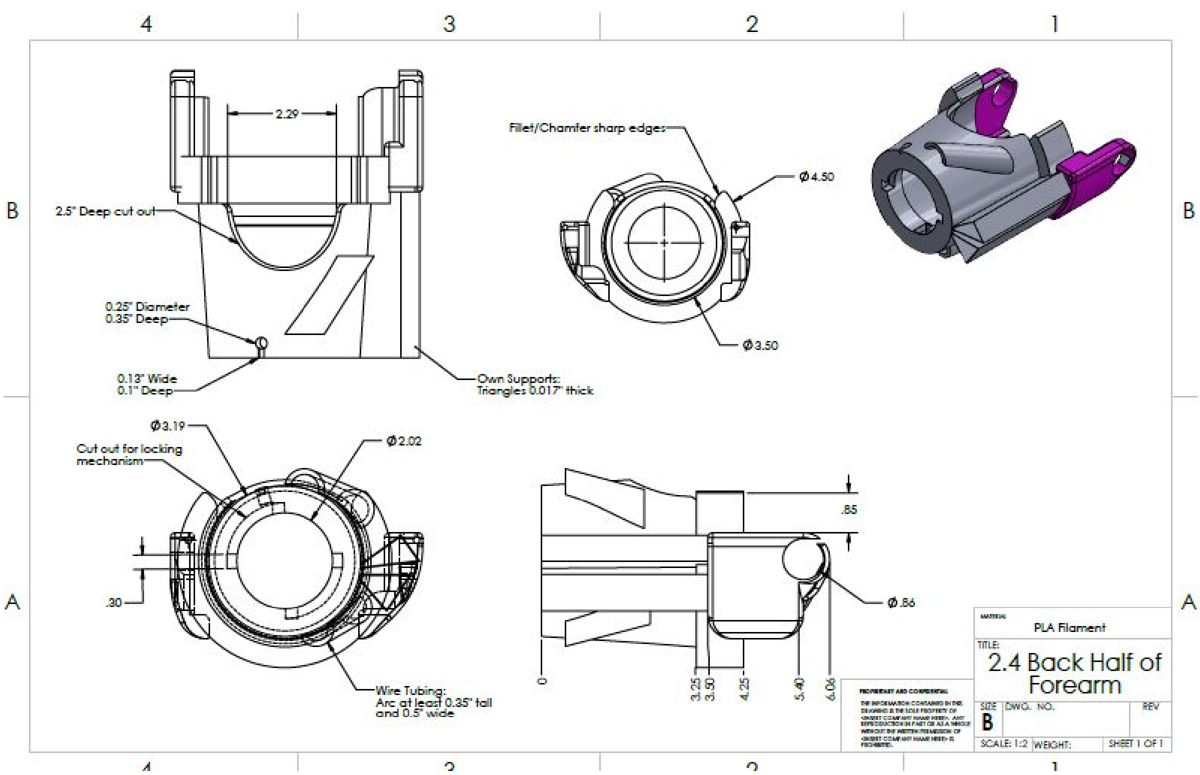
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2.5" Deep cut out
0.25" Diameter
0.35" Deep
0.13" Wide
0.1" Deep
Own Supports:
Triangles 0.017" thick
Fillet/Chamfer sharp edges
Ø4.50
Ø3.50
Ø3.19
Cut out for locking mechanism
Ø2.02
.30
Wire Tubing:
Arc at least 0.35" tall
and 0.5" wide
.85
Ø.86
0
3.25
3.50
4.25
5.40
6.06
MATERIAL:
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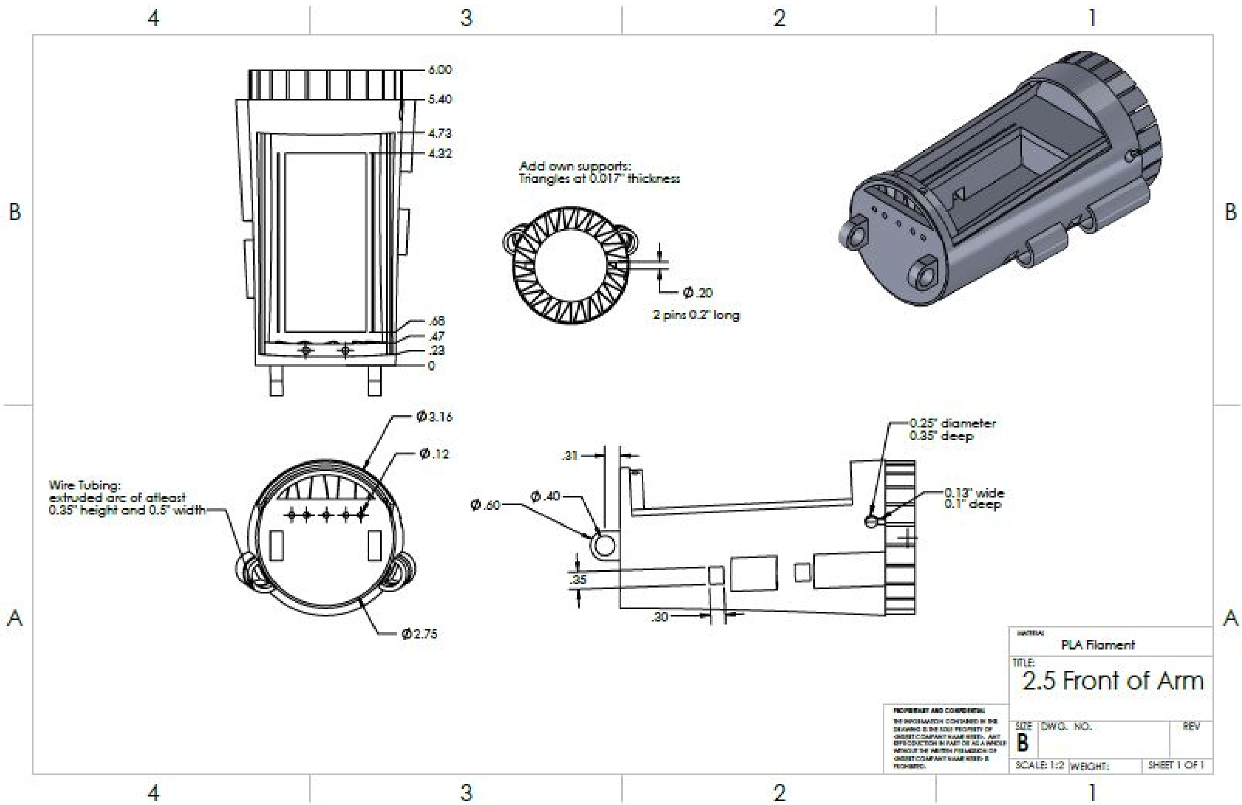
PROPRIETARY AND CONFIDENTIAL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5.40
4.73
4.32
.68
.47
.23
0
Add own supports:
Triangles at 0.017" thickness
Ø.20
2 pins 0.2" long
Ø3.16
Ø.12
Wire Tubing:
extruded arc of atleast
0.35" height and 0.5" width
Ø2.75
.31
Ø.60
Ø.40
.35
.30
0.25" diameter
0.35" deep
0.13" wide
0.1" deep
PLA Filament
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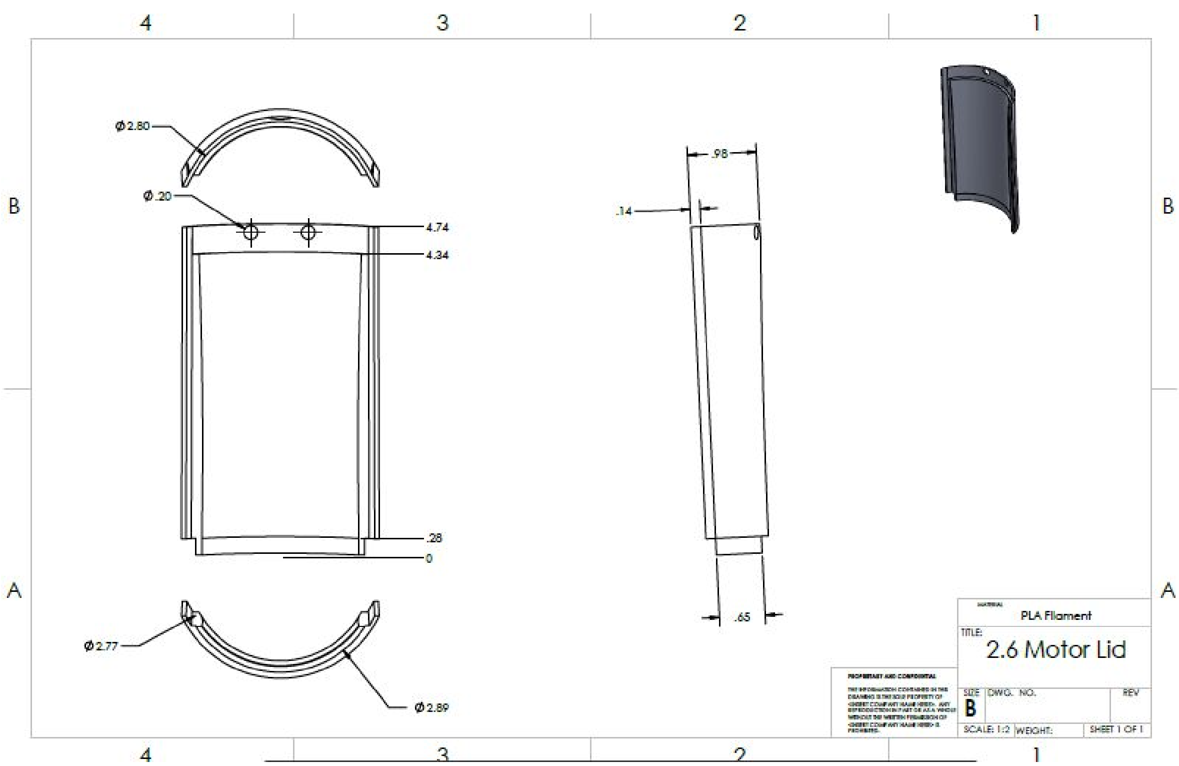
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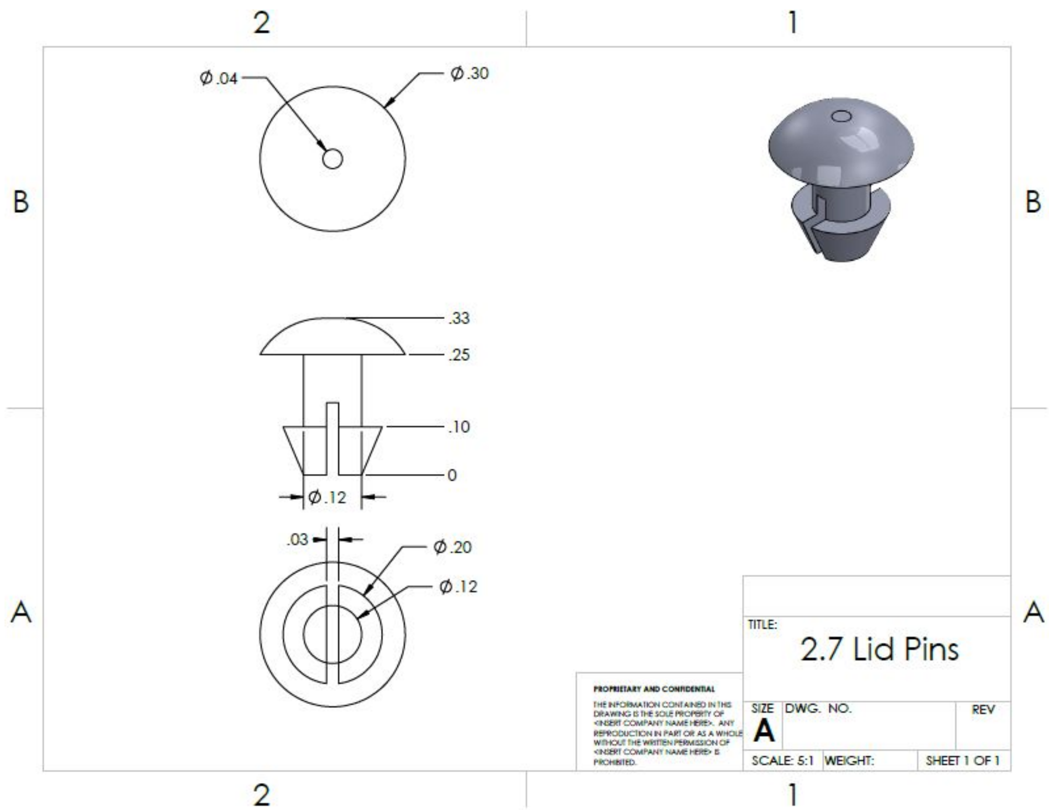

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Ø.12
.03
Ø.20
Ø.12
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THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
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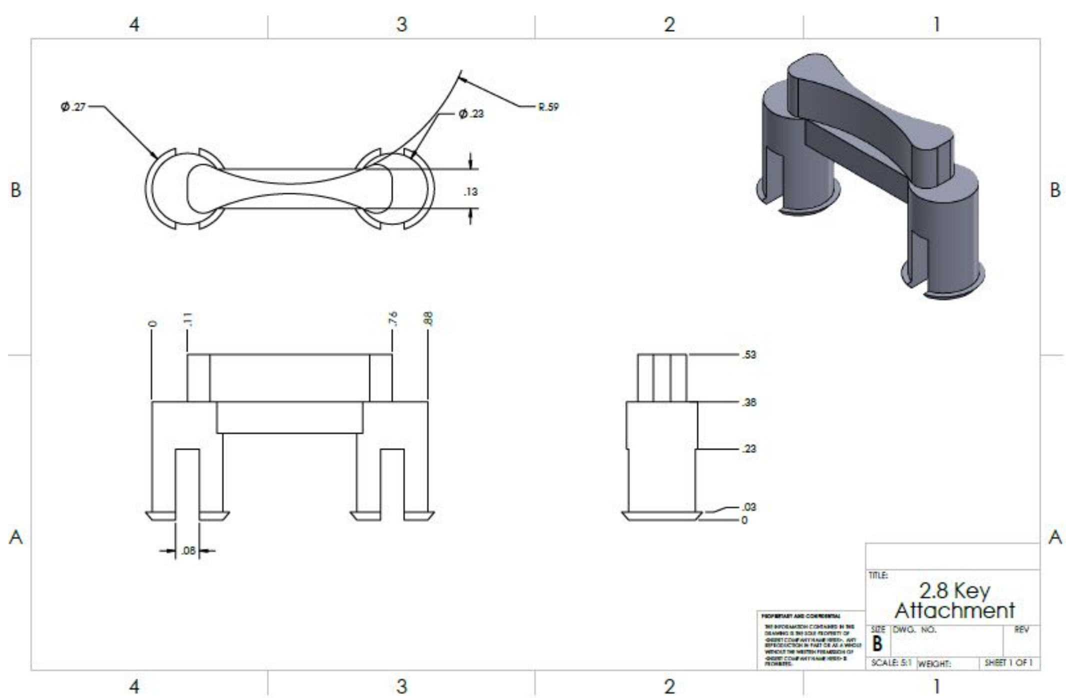

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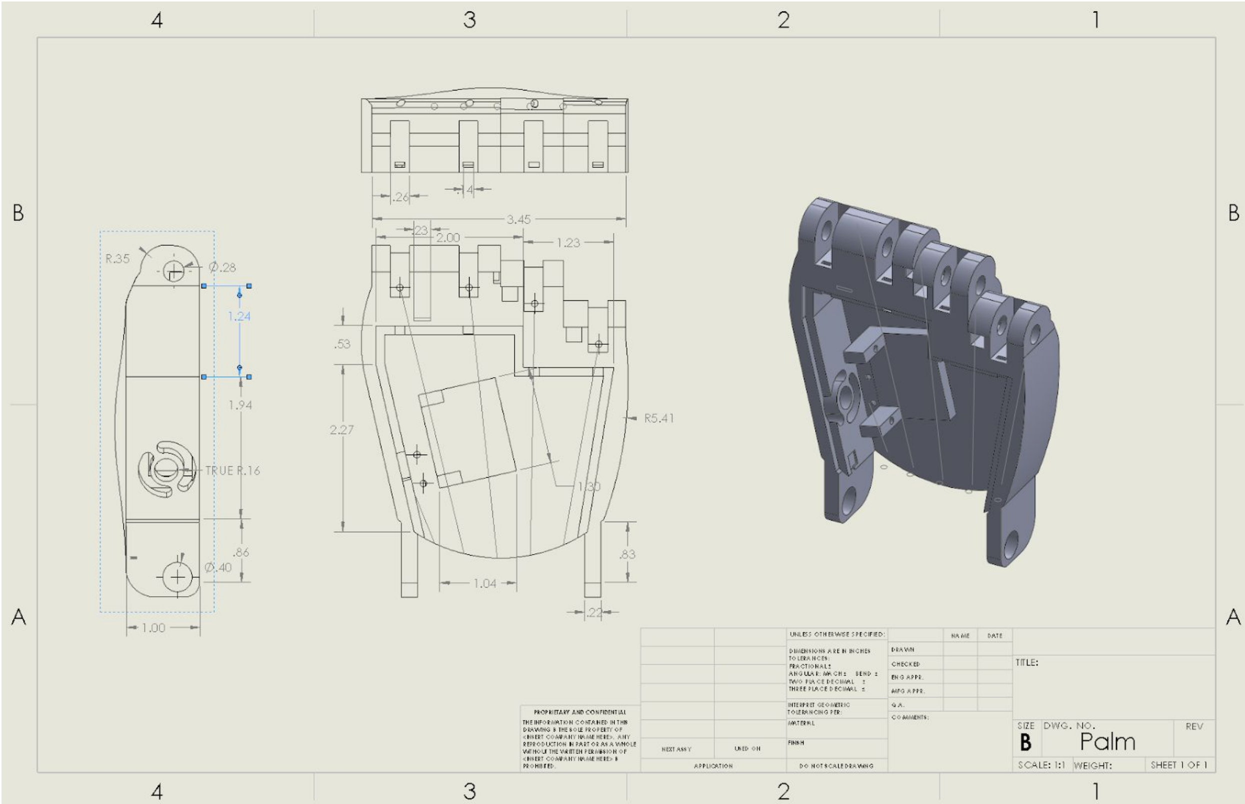
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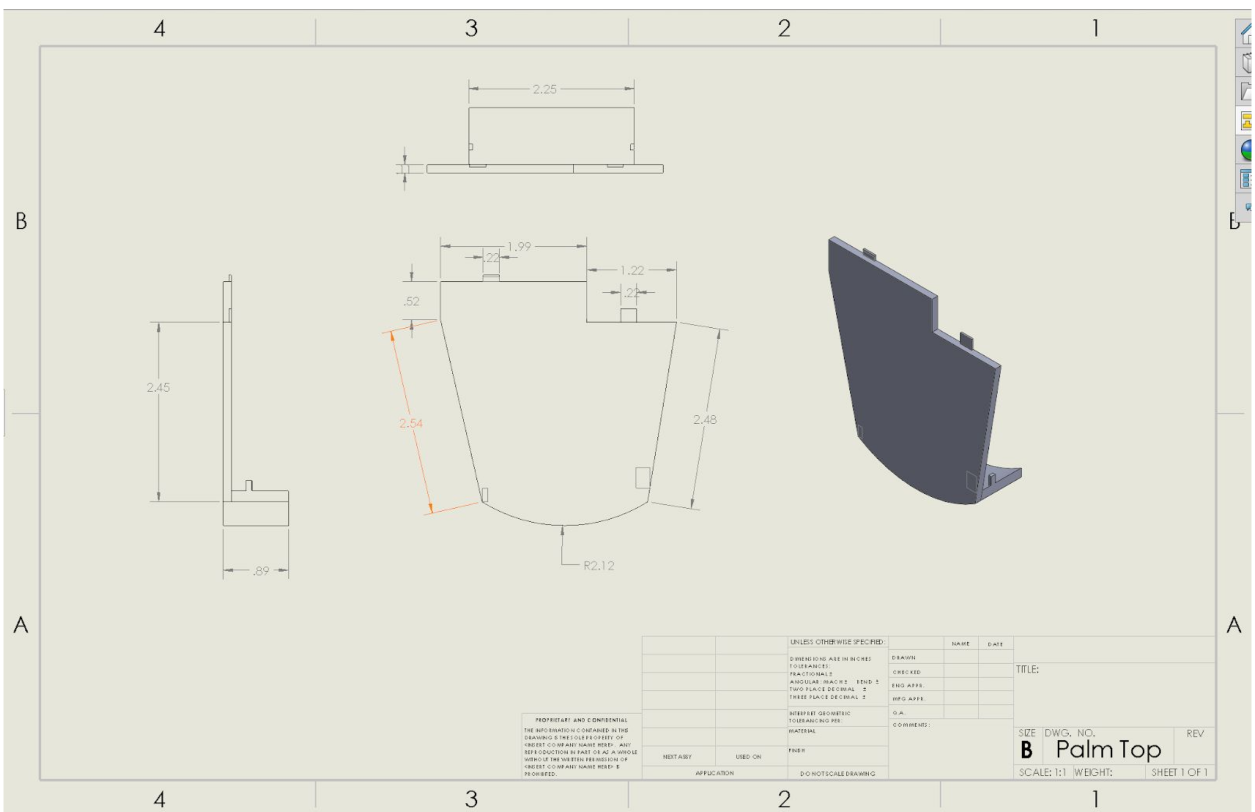
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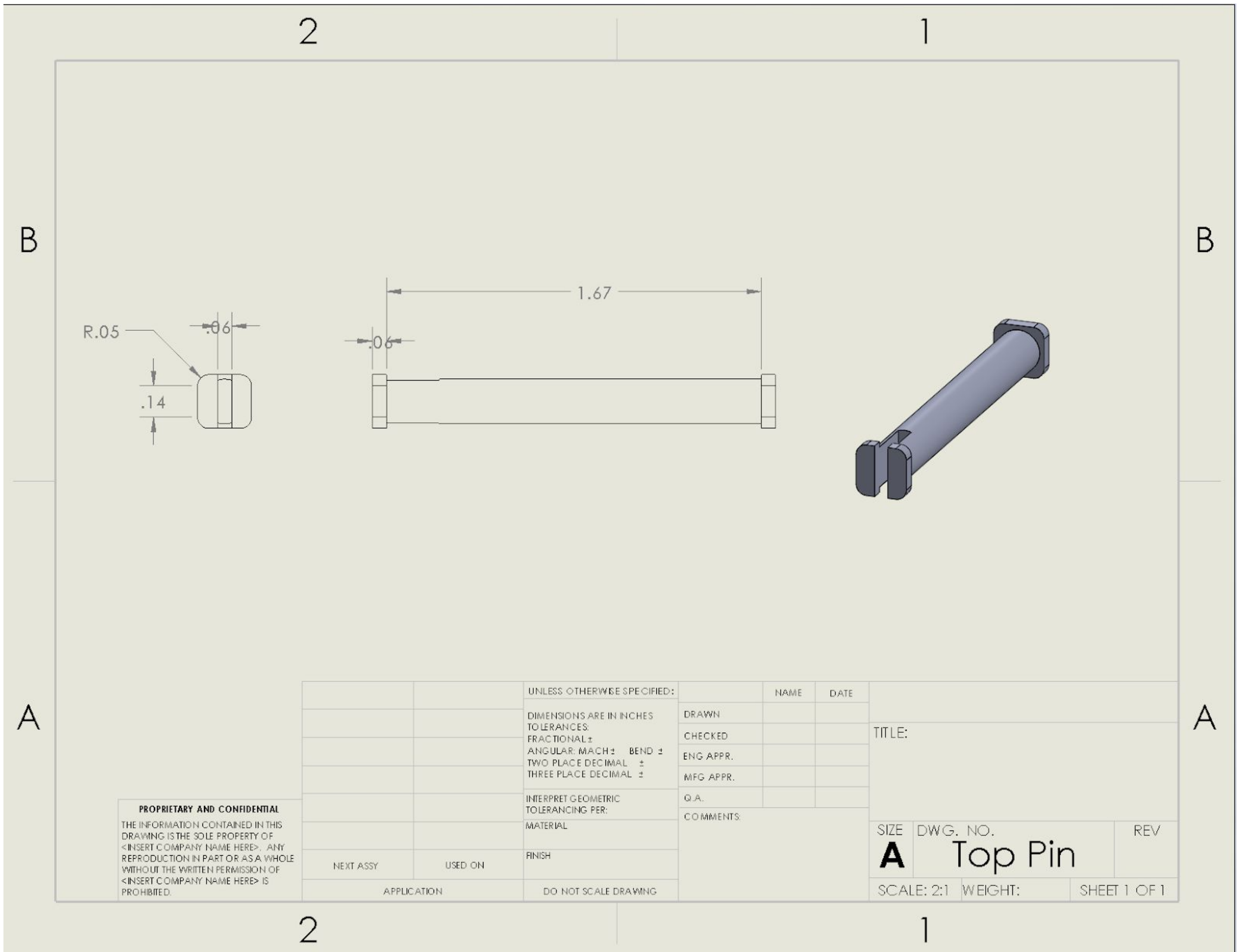
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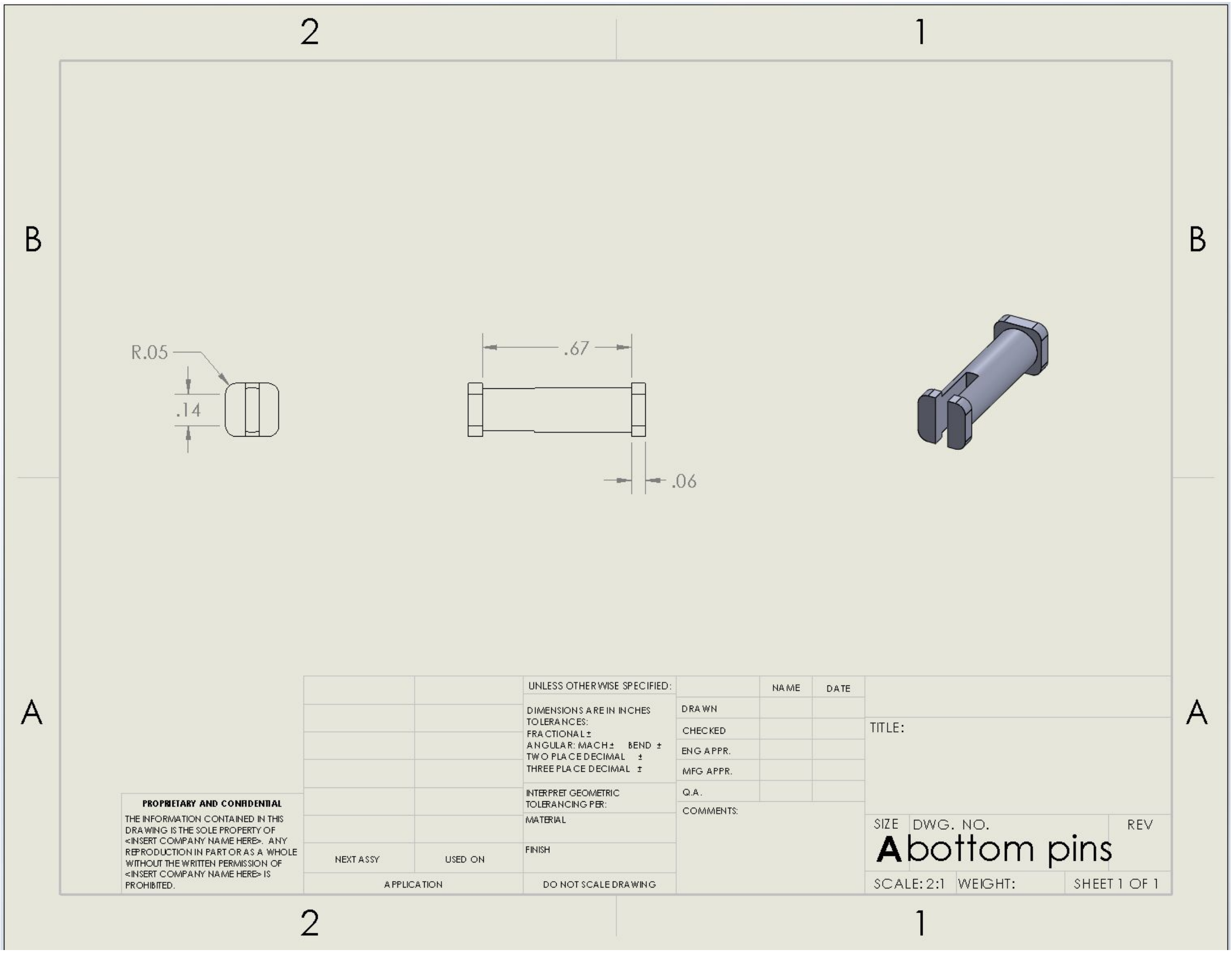
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THREE PLACE DECIMAL ±
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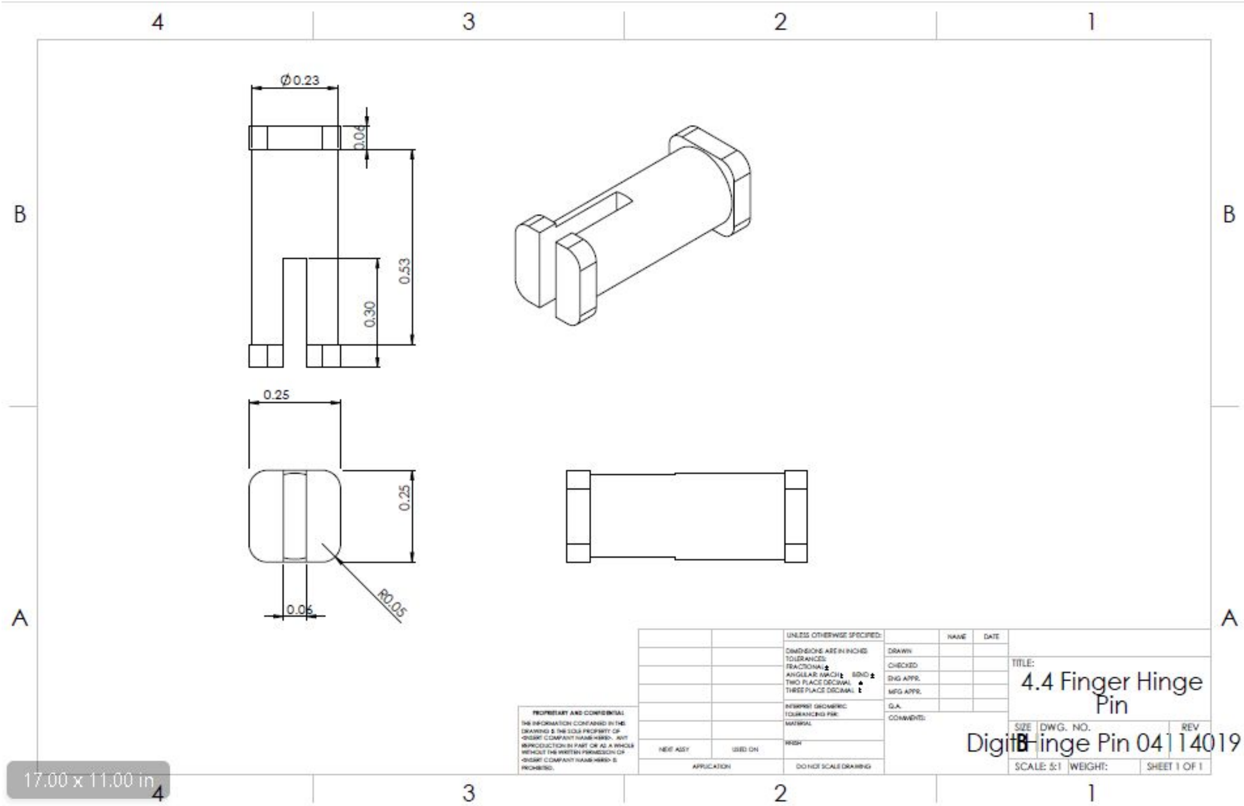
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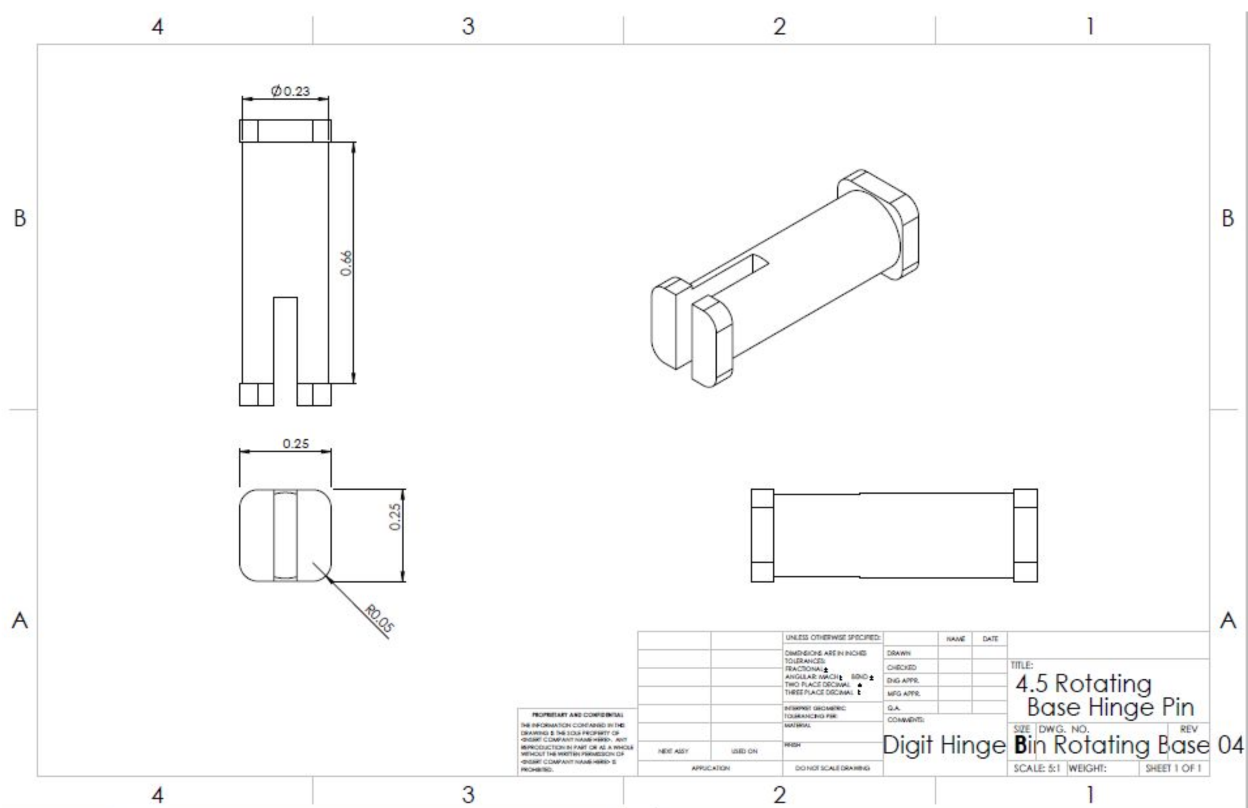
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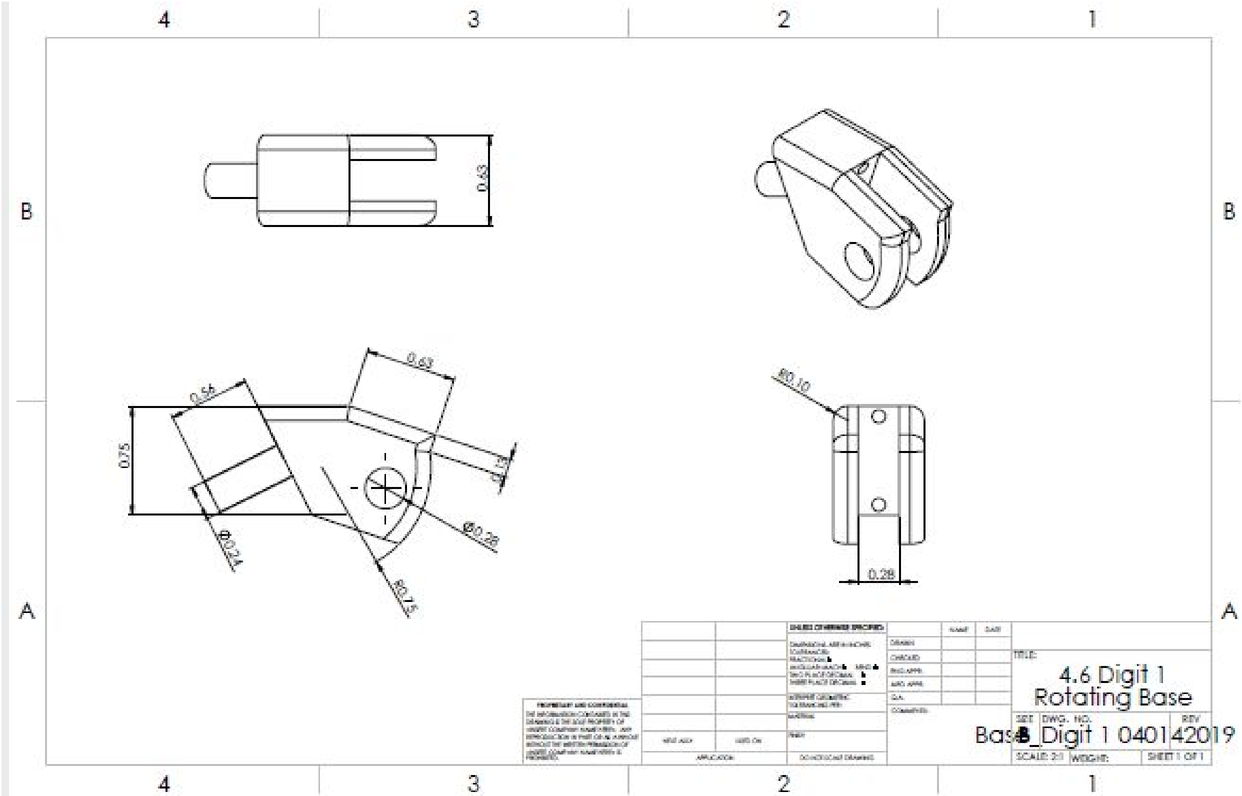
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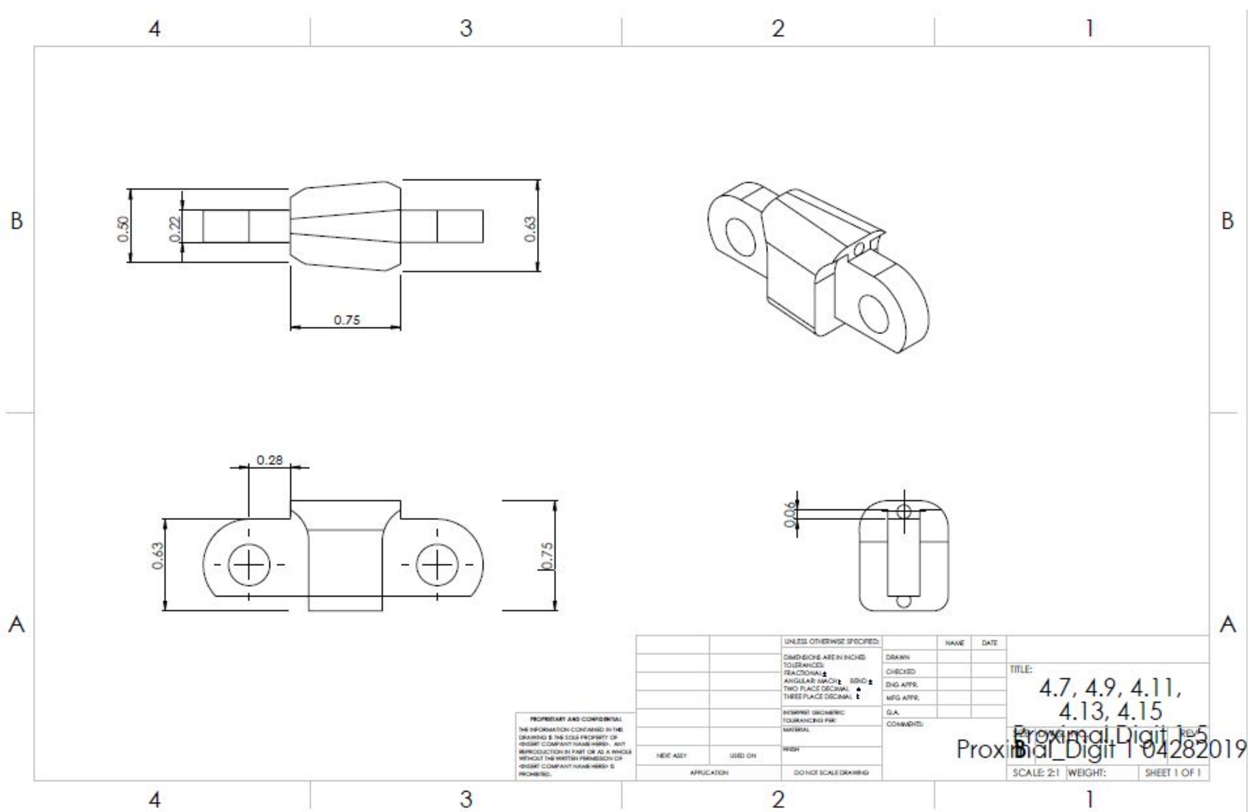
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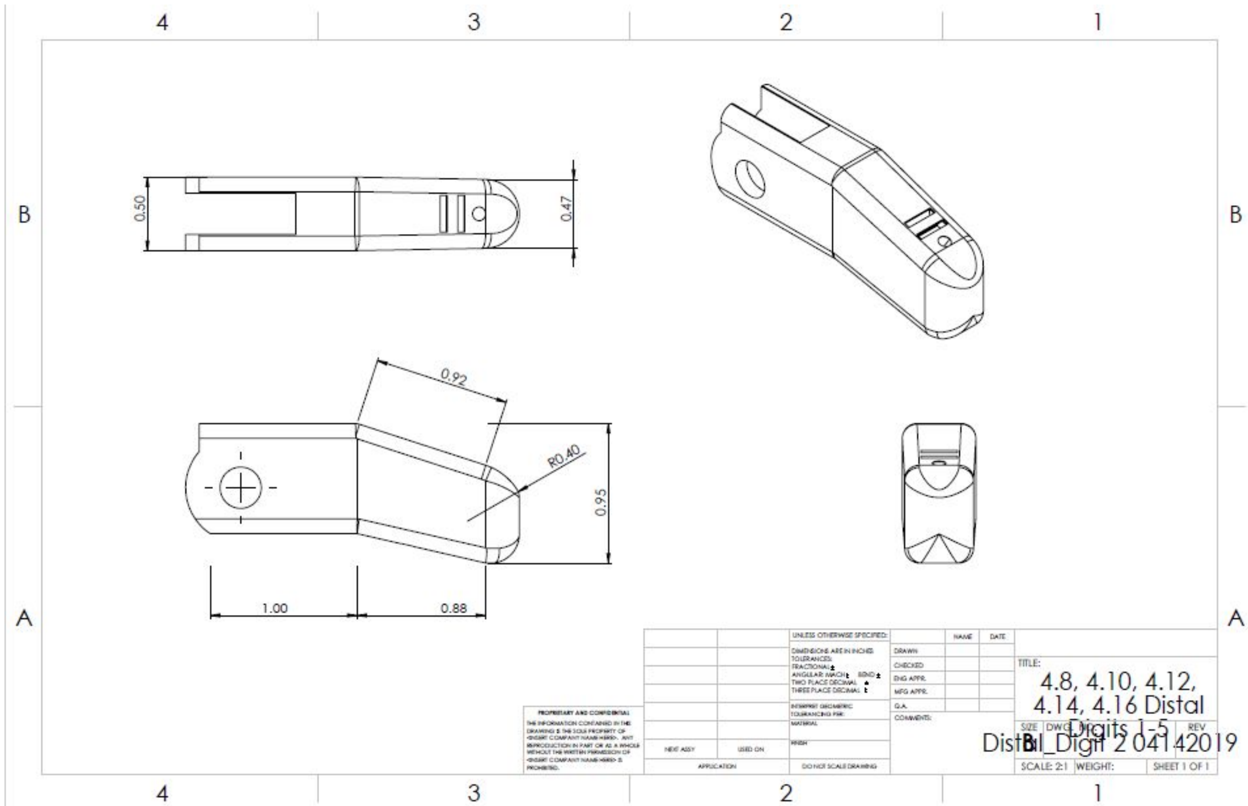
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