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Prosthetic Hand: Structure

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By

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Abstract

The objective of this project was to design the structure of a prosthetic hand that has articulating fingers and thumb in order to grip various objects. A design was developed that can add to the available options of prosthetics on the market.

In order to create a base hand for the project, the hand was modeled off of rough human hand dimensions. Analyses determined the feasible size of components. Once a base size was found the movement system in both grip and return form were developed and refined. With the parts being modeled in Solidworks and 3D printed, iterations of parts were made in order to refine the fit and the sizing to make them printer friendly. The motion of the hand is facilitated by gear boxes designed for the project.

Testing was conducted by verifying the function of the hand via a grip test in. The results of the analyses of the hand are that the individual fingers require 1.5 pounds of pull in order to reach full grip orientation. Full grip orientation is considered the point where the fingers reach the limit of their travel. Once the full grip orientation is reached, the hand is in position to grab the test object. The chosen test object was a soda can, which the hand is able to grip with 13 ounces of gripping force in order to properly hold the can.

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1. Introduction

a) Motivation for this project is based in the current status of the prosthetic industry. In terms of how developed robotic prosthetics currently are, they use technology like myoelectrics for power and materials like carbon fiber. These systems and materials are generally expensive which makes them unavailable for most amputees. This device is designed to take cost-effectiveness into account with the use of plastics and an affordable form of actuation.

b) Function Statement: A device is needed that will provide an alternative option of a prosthetic for amputees. The necessary structure of this device must contain the actuation components provided.

c) Design Requirements:

- Modeled structure is able to withstand 100 pounds of weight.
- Device is designed with 2 articulation points in mind (fingers, thumb).
- Each finger must have 3 points of natural motion, and the thumb 2 points in order to reach a natural position.
- Limit tabs of the finger joints must be 1/16" thick
- Pins at joints must have a 5 thousandth tolerance in order to have resistance free motion
- Hand must produce a grip force of at least 13 ounces

d) Engineering Merit: The arm structure will be designed in SolidWorks with the actuation hardware in mind. The necessary calculations will include the stress on the various joints that may fail in certain designs. An example of this is the forearm needing to support a 100 pound weight. That will depend on the material properties of ABS and PLA plastics, as well as the stress the forearm can withstand based on the applied load. Other necessary calculations include the reactions due to a 100 pound load, and being able to measure the capable grip pressure of each finger or the whole hand.

e) Scope of Effort: With two individuals working together on the structure and movement, this project stays within the necessary scope of the course. The most time spent on the project will take place during the design and testing portion, where the structure and actuation come together, and necessary changes will be made in order to achieve what is desired. The quantifiable effort will be a total of 12 hours a week at minimum until desirable function is attained.

f) Success Criteria: The device functions like a comparable prosthetic on the market with its similar points of articulation and the pressure that the hand can grip with.

Common equations used within the analysis of the structure are the stress equations in both normal and shear. These equations include:

$$\sigma = Mc/I \quad \tau = V/A \quad \tau = VQ/It$$

2. Design and Analyses

The approach taken in this project is to produce an articulate hand through iterative designs. It will begin with a base structure and refine through each iteration until the result reaches what is desired. Each design iteration will be 3D printed and tested for fit and function so that revisions can be made for the next variation. The chosen style in how this hand is designed is meant to emulate human dimensions as closely as possible so that when it is in use, it looks proportionate to the human body.

In order to confirm that the hand produced is competitive in design, it will be compared to the Bebionic prosthetic in both articulated function and design proportions. The manner in which that prosthetic moves is the benchmark on which this project is aimed toward.

In terms of initial performance of the hand, it is expected that some structural components may fail once they are put into function or the test load from analyses is placed on them. This will lead to some redesign in order to optimize the components an avoid failure. There may also be cases where material choice can be changed due to observations once the components are produced.it may be seen that certain components printed in ABS do not need to be as rigid, so they can instead be made out of PLA.

Analyses necessary for the structure design in the project include calculating bending stress, shear, and torsion on the different components of the hand and in different locations on each. Some may be an analysis on some small element like a tab or hole. Others may be the whole component tested in shear to see what sort of safety factor is involved in the design.

Analyses

A-1: This analysis involves the necessity of a “limit tab” in the design of the fingers. It is proposed that without this tab the joints may return to an over-centered state once actuated back to rest. The calculation used involves a worst case load located on the fingertip so that the limit tab is tested to its maximum. The parameter found through the analysis is the necessary thickness of the limit tab at that load in order to prevent failure. The initially assumed thickness is 1/16” which works out to be just barely sufficient at a stress of 6009 psi compared to the flexural strength property of 6000 psi. This feature can be found in the drawing B-1.

A-2: This analysis is of the pins that hold each finger joint together. The requirement for the pins is to be able to withstand a 50 pound shear. the analysis done calculated the shear to be 4074 psi, which is less than the flexural strength of ABS so that means a pin diameter of 1/8”is sufficient. Also it means that the pin can be made of ABS if desired. There is not a drawing to represent this analysis.

A-3: This is an analysis of a potential palm movement tab that may be used in the case of articulating the palm if necessary. The tab needs to withstand a 5 pound shear load from the articulation. The analysis found that the tab can be 1/8” thick and be plenty sufficient. This analysis is not related to a drawing.

A-4: This analysis is of the palm as a whole. The requirement of the palm is to be able to withstand a 50 pound load in bending based on its supplied human scale dimensions. The analysis found that if the palm has the dimensions of 3 X 3.5 X 1 (LxWxH) then it can withstand the load with an ample safety factor above 100. The current design of the palm has changed to where it is 5 inches wide instead of 3.5, and this can be seen in drawing B-3.

A-5: This analysis is specifying the tolerance on the pins that assemble the joints. The requirement of the pin is that it possesses a tolerance more loose than 1 to 2 thousandths so that the hand joints can move freely without the restriction of friction on the joint. The analysis referenced our machining texts from basic machining and the text specified a tolerance of 5 thou to represent the fit. It was also tested on a display of fit tolerances and 5 thou was the exact fit desired. This tolerance is specified in the design of each joint on the hand.

A-6: Analysis 6 began as a search to find a source that states the maximum strength of ABS glue which was not a searchable property. In the design of the hand it may be necessary to split the finger joints in order to incorporate the actuation components. In order to fuse the halves together ABS glue will be needed so the maximum load it can withstand would be a necessary property. Since the glue is considered permanent, there is no discernable limit for the glue to possess.

A-7: This analysis is of the palm in a hollowed out state for weight saving and housing components. The 100 pound test load is used in a bending form to find the thickness of the palm shell without failure. It was calculated through flexure formula that a wall thickness of 3/8” would provide an ample safety factor of 10 to the palm. The hollowed palm analysis is not related to a drawing.

A-8: This analysis is of the finger joint mounting points and if their dimensions are sufficient. The fixture points need to withstand a 100 pound load as a worst case. The analysis did calculations in shear, torsion, and bending. It was calculated that the tabs could withstand bending with a safety factor of 1.7, but the torsion was at a safety factor of 0.5 or less. Fixture points are visible in all current drawings.

A-9: This analysis is of the redesigned upper finger joint based on the 100 pound test load. The designer of the actuation components needed force in a particular axis to determine if the actuation cam pins will have sufficient size. The force in the direction of shear was needed and it was found to be 80 pounds. The drawing of the upper finger joint can be found in appendix B as B-6.

A-10: This analysis is of the lower finger joint since it is required to be hollowed out to house actuation components. The analysis for the joint was to find the available inner area of the joint so that parts for motion can be contained. The parameter found was that the inner area available with a 1/16" wall would be 0.625 inches. There is not a drawing to represent the dimension found.

A-11: This analysis determined the amount of shear on the upper finger joint due to the 80-pound force component in the shear direction. This value was determined in A-9. The direct shear calculated was 142 psi, which would not result in failure when the flexure modulus of ABS is 6 ksi. The drawing B-6 displays the design of the upper finger joint.

A-12: This analysis is based on the wall dimensions of the lower finger joint discussed in analysis A-10. In order to test the wall thicknesses of the joint, a single side was modeled as a short column. Using Eulers equation the buckling load was found to be 10385 pounds, which seems very high but shows that the thickness of the shelled joint would not induce bucking when facing a 100 pound load like the previous analyses.

After modification of the hand design has taken place, it has been found that additional analysis was necessary as the return system of the fingers was developed. The decided return system has become pegs that keep the rubber bands in tension in order to bring the fingers back. More analysis was also necessary when determining how the thumb must meet the first finger in order to produce a usable gripping area. The pegs on the palm did fail after assembly, even though a 0.125" peg is plenty of material. This failure occurred because doubling up rubber bands in order to achieve tension was not expected.

3. Methods and Construction

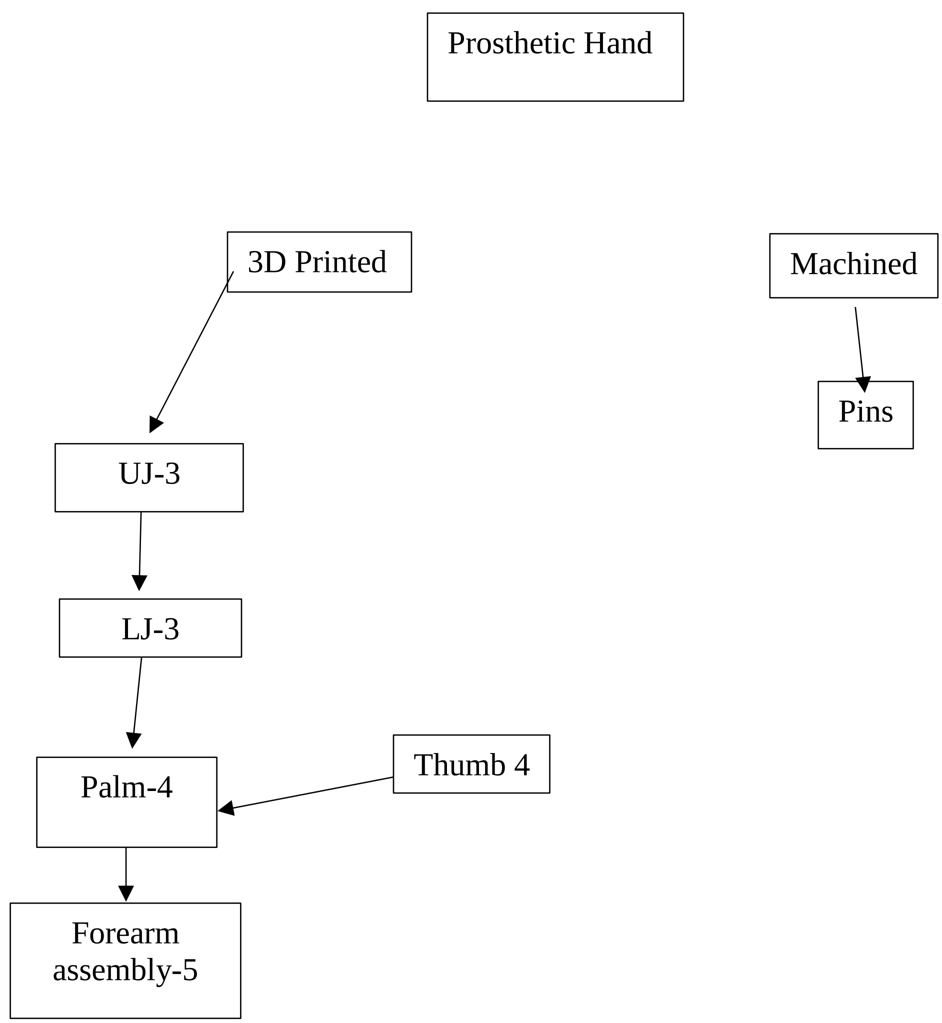
This project began as an idea of a simple prosthetic hand that possesses humanoid movement in both the fingers/thumb and the wrist. As the hand has been developed the initial idea of a design has been tested through analyses of the structure of the hand. These analyses provided parameters on which to base the dimensions of the hand by using requirements of force that the structure must be able to withstand based on the material chosen. The design of the project has taken place in the CWU Hogue Technology building, using the computer lab.

The construction process of the hand will begin with design of the hand components on SolidWorks, with iterative designs shown in the drawings. The hand itself will be comprised of 4 fingers and a thumb that all articulate. The individual fingers will be in 2 components, an angled upper joint consisting of the mid joint and fingertip, and a lower joint that connects the upper joint to the palm. The forearm will be attached via a fixed wrist, where the articulation hardware will be contained. The forearm is split into two components and assembled with guide pins in order to make the part printable on what is available. Fastening the joints will be various pins that are made from 1/8” aluminum welding wire. These pins will hold the joint together as the articulation takes place. The design of the forearm will house the components necessary to provide motion, but it is also intended to be material conservative since it is the longest part of the project.

Modifications that have been necessary to the design include both paths for wire and parts for the finger return system. For the movement using wire, paths were cut into the lower joint and the palm in order to produce a direct path to the upper joint for motion. A wire connector was made so that the wire can be tied to the part and then pressed into place on the underside of the upper joint. The wire connector was abandoned in favor of tying the wire to the fingers themselves. For the rubber band return system, two different slider units were designed to slide in tracks on both the lower joint and the palm, but printing sliders out of plastic to slide on plastic was going to take refining which would take the project off schedule. The pegs for the slider system were kept but the design became using just rubber bands so that it would be kept simple and conserve time.

Within the drawing tree scheme parts are named UJ and LJ-1 both so symbolize the common abbreviations in part design and also to show which iteration of design the part in question is at. Since the refined motion of the hand is expected to be achieved through iterations rather than initially. In Appendix B it is shown that the current drawings have an iteration value of 1, since these values will change as the parts are built and tested. Some first iteration drawings are very simple so that a particular feature can be demonstrated, or a basic dimensioned part is produced as a starting point. Some examples from Appendix B are the drawings B-1 and B-2. In drawing B-1 the part shows what dimension the limit tabs at each joint will have, as well as its designation by design as FT-1. B-2 shows that the middle joint component is an iteration of 1 as well.

General optimization of the design will consist of both the iterative changes during the build process, and the use of minimal material as the motion of the hand comes into shape.



B-1: This drawing represents the analysis A-1 by showing the dimensions found there for the limit tabs that are integral in the motion of the hand.

B-2: Drawing 2 is an initial design of the middle joint where the hand would possess all three joints and articulate fully. This joint also incorporates the limit tabs.

B-3: Drawing 3 represents the base design of the palm of the hand as a single unit. The connections shown designate the locations of each finger and the thumb, as well as the fixture point of the forearm.

In terms of general operation of the project, the hand is meant to be capable of gripping a can because of its pounds of pressure per finger, while also being able to articulate a full range from rest position (open hand) to a full closed fist inclusive of the thumbs function.

The benchmark prosthetic known as the Bebionic hand is constructed differently than the project because of the usage of carbon fiber in that hand, but in terms of motion and general shape, the project hand will move the same. The finger pressure capable on the Bebionic hand is around 10 pounds depending on the grip configuration. Though the project will not have those configurations, it will match the pressure per finger up to 7 pounds.

The initial performance of the project after construction is expected to be at 50% functionality or less, since the design of the hand will need refining to reach the desired functionality with a repeatability of motion in the range of 85%. Once the function reaches 100% of what is desired, then the repeatability factor of how often the motion can be repeated comes into account. Repeatability is meant to be a sort of efficiency of motion for the project.

4. Testing Methods

The ways in which the project will be tested include the use of a scale to measure grip force, as well as the use of various jigs to place the hand in in order to test the hand components in the scenarios described through analysis. The last method of testing the hand will include objects that the hand should be capable of grasping without the object slipping. Some of these objects will include a pop can or a softball. In terms of a testing environment the metallurgy lab (127) will be necessary for the stress testing that was previously discussed.

Using those test methods the success of the hand is based on the ability of the hand to produce individual finger grip force at 7 pounds. The success is also reliant on the hand being able to grip the specified objects and withstand the stress values described through the analyses done. The other testing requirements based on design requirements include that max load as well as the number of articulation points. The points of motion is simply a count, but another portion of data to collect is how much rotation the hand can travel from the designated rest position to the final grip position.

Some initial testing took place as the hand was being assembled. Two points on the hand failed, one was an error in press fit and the other was due to rubber band tension. The press fit failure was due to misalignment and too much pressure, which made one ear of an upper joint snap off. The other failure was the rubber band peg on the palm, since doubling and tripling up weaker bands was not an initial plan.

The first test ran on the hand was to determine the available grip force that the hand possessed. The minimum amount necessary was determined to be 13 ounces, in order to hold a soda can without slipping. The test was set up with a pound of hanging weight in order to enforce a safety factor of 1.2. The result of hanging a pound of weight and proceeding to make the hand move was that one finger’s wire broke free of the fingertip, and that the hand could not move from rest without assistance. The necessary assistance to allow the hand to move was to support the fingers so that they are level, then pull the wires. Also, the amount of force necessary to make the fingers lift is no longer 1.5 pounds, so the motors so move the hand must be stronger than initially determined. Based on this test, the changes necessary within the hand for success involve proper tying of the wires and a way to arrange the wires so that they become equal length for equal pulling. With equal lines the hand will proceed to operate evenly, which it did not during the test. The next test was to determine the new actual force required, so the new motors can be sized appropriately.

The second test determined what the individual linear force on a finger needed to be for gripping a pop can. The predetermined 13 ounces of grip force was split to 3.25 ounces per finger. With that much weight on the index finger, pulling the hand to full grip and measuring with a spring scale provided a value of 9 pounds of force. The true value of this force is most accurately 7.5 pounds because the current state of the pull strings made two fingers move when pulled. So the test value is reduced by the 1.5 pounds it takes to move that second finger. With a value of 7.5 pounds, the resulting force needed to move all four fingers is 30 pounds of pull. With the new motor capable of 36 pounds, that leaves some pull available for the thumb as well.

5. Budget/Schedule/Project Management

The parts list located in Appendix C details the necessary materials for the project as two 1 Kg spools of ABS and PLA. The usage of a kilogram of either is not expected. So that should be enough. The total cost of those spools is $62 for the structure of the project. The entirety of the structure will consist of 3D printing the hand components. All spools of material will be purchased from Amazon. The income source for this project will be out of pocket since the overall cost is low. Due to the use of available cheaper printers, and the filament already purchased, the budget has become an over-estimation. The cost of first print was $14 but the rest of the printing was used with a previously owned spool, so there was no associated cost. As testing caused parts to fail or be determined ineffective, more printing was needed, so another spool of material was purchased for $15 for a final cost of $29. The material chosen, however, should have been of higher quality to avoid print issues. The cheaper spool that was ordered to finish out the printing had material failure during press fits, as well as flex in the print when the parts would not stick to the printbed.

Schedule:

The scheduling of this project is reliant on being able to produce the structure of a prosthetic hand that can interface with the actuation components and reach completion within the time frame of presentation.

The time constraint for the prosthetic hand is the limitation imposed by the capstone course. The project must be completed by the spring quarter for presentation purposes. The schedule for this project is shown in Appendix E. The schedule is detailed along with the Gantt chart in that Appendix. The tasks and milestones are reiterated there as well.

Tasks associated with the project include the test fitting of base components. Which will be printed by 1-3-19 and assembled by 1-6-19. The task that follows base assembly is the refining of the actuation and fitment of those components. That task will begin on 1-6-19 and end on 1-27-19 with a fluidly actuating hand. The final task will be the refining of the material quantity in order to further optimize the design. Expected time spent on these tasks will accrue to 12 hours a week at a total hour count of 120 hours by the end of the build process.

Milestones associated with these tasks are as follows:

- First assembly of hand components
- Initial beginning of interfacing the components
- Finished motion of hand
- Optimization of material use

The schedule became off-track initially because fit of the first component print was very poor and the time to print was substantially longer than expected. The longer time was the consequence of not blowing out the budget to print with ABS. Design of the return system had many options come to mind, which prolonged the process of creating something functional. Schedule issues that arose from testing involve the ability to complete the final test of grabbing the can. Within the last couple weeks before presenting, the thumb design had to change multiple times in order to produce a thumb that can wrap around a can. The time was substantially longer due to the fact that the shrink of parts associated with printing caused some sizing issues. Print time was not long for a thumb, but determining the next dimension was a challenge. The way the final thumb design came about was by intending to oversize the thumb more than it needed to be. Width was added to the thumb in order to attempt a sense of proportion, but then a widening of the grip area was needed as well. Oversizing the area slightly led to a good fit on a can.

Project Management:

Success of the project is expected due to the availability of both equipment for design/testing and the guidance of instructors to provide proper insight to benefit the project. The resume of the principal engineer on the structure of the project can be found in Appendix J. Resources integral to project completion are the CWU 3D printers, as well as SolidWorks as an essential software for design.

6. Discussion

The initial design plan for the project had involved the use of as many humanoid joints as possible. That involved the use of fingers with 3 separate joints, as well as a fully articulate thumb and a wrist that could at least adjust angle if not rotate. These initial designs are evident in both the analyses and the part drawings. Some analyses like A-1 and its corresponding drawing B-1, were simple block shaped designs in order to have a basic joint with the necessary features. There are also some analyses involved with ideas that could be incorporated down the line as the revisions during the build process take place. Those analyses show the progression of ideas that the design process has taken so that the structure can be modeled in the best way possible to facilitate the integration of the actuation components. Many analyses have been done in order to specify dimensions that would not result in the structure failing either in use or in testing. On occasion certain analyses led to an answer that produced a failure because of a feature being too thin when trying to minimize material use. An example of this is in analysis A-7, where the thickness of the palm in its anticipated hollow state was at first estimated too low and produced a failure. Another unsuccessful analysis was when a maximum strength property of ABS glue needed to be determined in order to ensure it would be sufficient for the case of the finger joints being halved in order to fit components. The analysis to reflect that was A-6. Other than those instances, the design process has been successful with some modifications already present as ideas have been solidified. The points of failure mainly came from the low estimation of values before they are tested in an analysis, or from the fact that certain limiting properties do not exist. In this current point of the project the base structure design is of 2-part fingers with a single axis thumb and a fixed wrist. The finger joints being reduced to 2 minimizes the complexity for the articulation designer somewhat, as well as allows the upper joint (middle finger joint and fingertip) to be designed at an angle that naturally facilitates grip. The design decision to make the wrist a fixed unit has also minimized complexity in the motion of the hand. Issues that have been found when manufacturing the iterations of parts from the PLA printer are that the quality of print is low, and that the hole dimensions once printed end up somewhat oblong and needing to be drilled in order to match the modeled dimensions. Also the prints require support material for overhang points, which means more PLA is used in order to fill those gaps. If these prints were done on the ABS printer, the support material could be more easily cleaned off, but the prints would be expensive. With the support material being made of PLA, it must be cleaned out of certain crevices and filing must be done to refine surfaces. The way to fix the quality of prints on the printer is to set the quality higher so that the layer thickness is smaller. This will take more print time but the overall quality will be much higher which may benefit hole dimensions as well. The 'final' iteration of the hand that has been developed for testing no longer uses the return slide system, and instead just uses the pins to hold rubber bands as a simpler method of return. The thumb was also substantially modified so that it can now move and join the index finger with a usable grip area between them and the palm.

Testing of the hand determined issues related to the thickness of certain extrusions on parts of the hand. Failures that require modification included the forearm connection points and the studs for rubber bands on the palm. To resolve these issues, redesign was needed to provide proper thickness of pins so that they do not shear. In order to make the hand able to grip the test object, the thumb also needed a redesign in order to size the grip area accordingly, which helped the hand to pass the final test. Results of testing found that the hand required more linear pull when gripping, compared to free motion. Free motion took 1.5 pounds, and gripping required 7.5 pounds of pull. This result helped to determine that the next motor sizing needed to supply a total of 30 pounds of pull for the fingers, where the large motor chosen can supply 36 pounds of pull. The changes done to the thumb include the width increasing by half an inch to incorporate the space needed to grab a can. The general shape of the thumb was also widened to 0.75 inch for proportionality compared to the sizing of the fingers. The rubber band pins on the palm also have a filleted base so that there is more material at the base to prevent snapping of the pegs.

7. Conclusion

The Prosthetic hand structure was analyzed and designed with intent of meeting the specified design requirements. Parts necessary for the assembly of this project have been specified and the quantity of material needed has been budgeted accordingly. With these specifications the device is ready to be developed and tested. This proposal should be accepted because the proposed design will achieve completion in the necessary time frame, as well as it possesses a fraction of the material cost of the device it is benchmarked against. This proposal meets the guidelines of a successful capstone because of the engineering merit involved in the design through SolidWorks and the formulation of a testing method for grip pressure. The project also meets the success guideline of being able to utilize the resources of CWU in order to be completed.

The project meets the necessary guidelines of a senior project by possessing:

1. Engineering merit is present in the design and testing portions of the project.
2. The size of the device is comparable to human dimensions while also having a fraction of the material cost.
3. The project has significant interest to the primary engineer involved.

Acknowledgements:

This project could not have come to the state it is at now without the help of Matt Burvee, Professor Pringle and Professor Johnson, as well as mentorship outside of the school from engineers at Camco. The insight these people have provided has been invaluable, since their recommendations have brought the project to where it is now and wouldn’t be there without them.

Appendix A

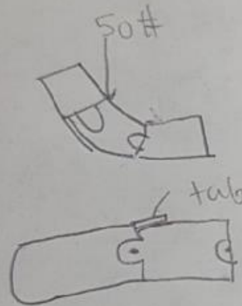
A-1: The scenario for weight being applied solely on the fingers is the basis of this analysis. The fingers are designed with limiting tabs to stop backward rotation and need a minimum specified size.

Riley Smith | Senior Project | 10-9-18

Analysis 1: 50 pound weight hung on solely the fingers

Find: if 50 pounds is a feasible weight when the worst case is it is hung on the fingers

Will the tabs on each joint withstand this or need to be larger?



tab limits bend of finger "backward"

Method: use ABS Mat'l properties w/ stress calculation to see if a tab of 1/16" would be sufficient
↑thickness

Soln:

flexural strength of 6000 psi

1 × 0.25 — I — 0.0625

$$\sigma = \frac{Mc}{I} \qquad M = 50(1.25),\quad c = 0.125,\quad I = \tfrac{1}{12}(1)(0.25)^3$$

inch long finger

$\boxed{\sigma = 6009.6 \text{ psi}}$

barely insufficient

A-2: This analysis was meant to test the pin dimensions of the finger joints. Specifying a 1/8” steel pin.

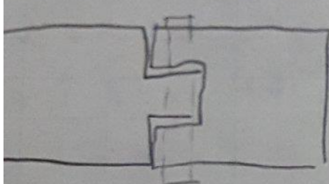
Riley Smith | Senior Project | 10-9-18

Analysis 2:

Given: Each joint in the hand will be pinned togethe[r] estimated size of a pin is 1/8 inch

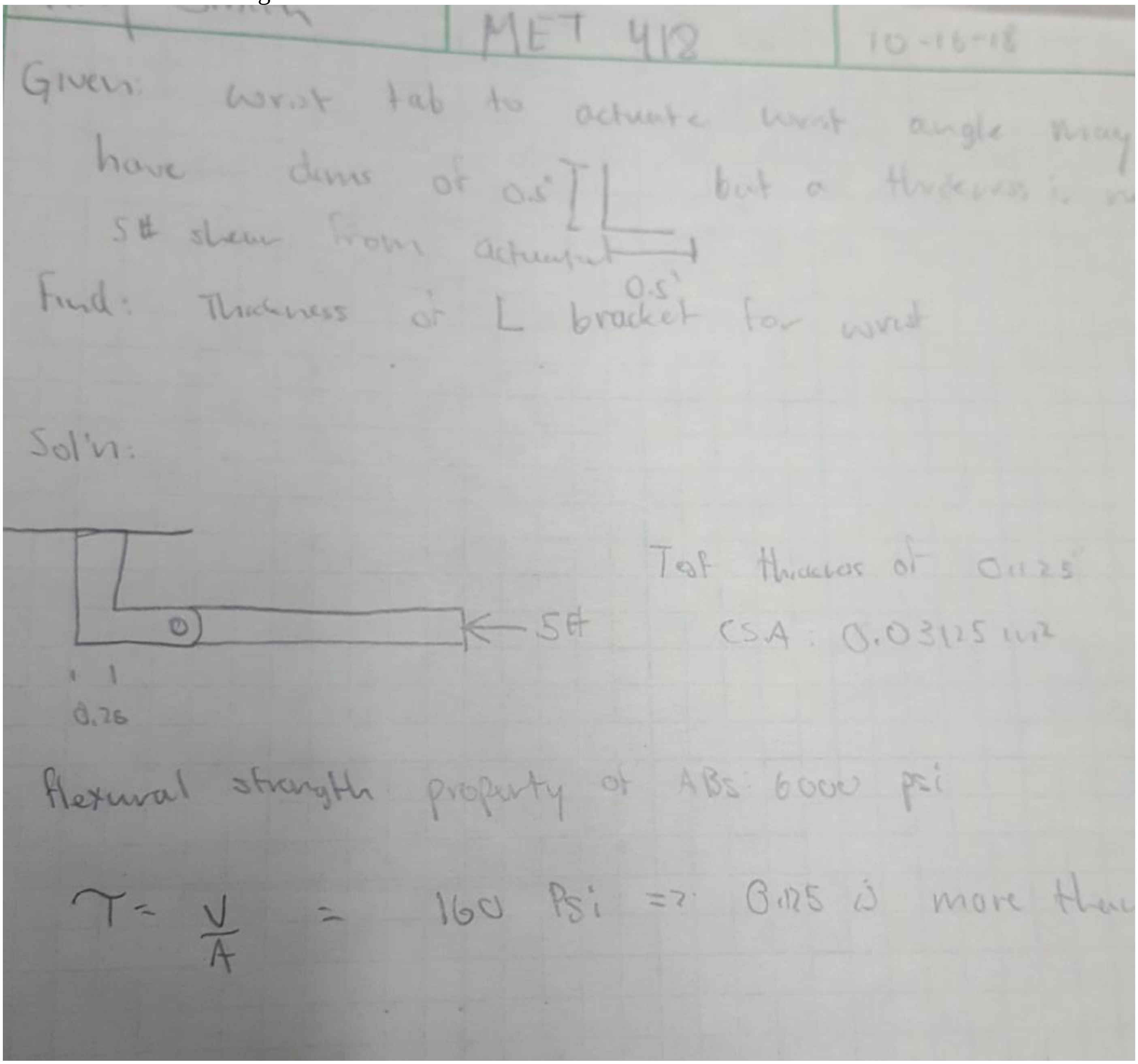
Find: is this pin diameter sufficient for a shear force of 50# ?

$$\tau = \frac{V}{A} \Rightarrow \frac{50\#}{0.0122\,in^2} = \boxed{4074\ Psi}$$



If the rod is assumed mild steel then an 1/8 inch pin is plenty sufficient per joint

A-3: This analysis was for the necessary thickness of the tab that may be used to facilitate the wrist movement at an angle.



MET 418 | 10-16-18

Given: wrist tab to actuate wrist angle may have dims of 0.5" L but a thickness is n
5# shear from actuator
0.5"

Find: Thickness of L bracket for wrist

Sol'n:

Tab thickness of 0.125"

CSA: 0.03125 in²

flexural strength property of ABS: 6000 psi

$\tau = \frac{V}{A} = 160$ psi => 0.125 is more than

A-4: An analysis of what bending stress the palm would be under in a 50 pound load situation, and if it would fail.

Riley Smith | Snr Proj Analysis | 10-17-18

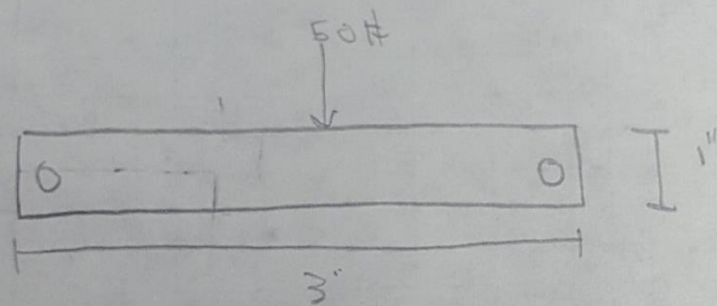
Analysis 1: If a force is Applied to the palm in a way to induce bending, will the palm withstand it or fail based on dimensions?

Find: $\sigma_{bending}$

Soln: L x W x D   50 # load

3 x 3.5 x 1

$$\sigma = \frac{Mc}{I} = \frac{75\,\#\,in\,(1)}{0.292}$$



$\sigma = 257$ psi

↑ will not snap

$$I = \frac{bh^3}{12} \quad \frac{3.5(1)^3}{12} = 0.292\ in^4$$

A-5: An analysis of the necessary fit of the joint pins in order to produce unrestricted movement.

Riley Smith | Sur Proj

Given: The joint pins in the hand need to fit in a way that is not a press fit to limit motion. So there must be a tolerance fit

Find: The tolerance fit of the joint pins

Method: use machining text to define a press fit versus a tolerance fit

Soln: A usual Press fit is within .002 (2 th[illegible]

So if the joint holes are toleranced by $\boxed{\text{5 thou}}$ the motion should not be limited by pin fitment.

0.005 tol

A-6: An initial analysis on the max load of ABS glue as the halves of a joint are tested. A max property could not be found due to the glue being considered permanent in a standard environment.

Given: In order to fit the actuator cams into the fingers, the joint must be hollowed and split into two separate components. This means assembling these pieces may need guide pins as well as certainly ABS glue

Find: if ABS glue will withstand the worst case load of 100 lb

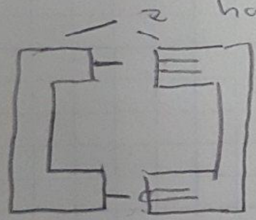
Method: use glue properties with a stress calc

Soln:

no defineable limit is found for ABS glue, since it is meant to permanently bond like PVC cement. but the pins to guide the pieces can be press fit together.

Press fit is defined as a 2 thou tolerance

2 halves of finger joint

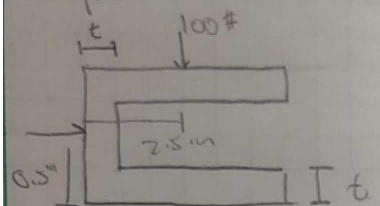


press fit pins

A-7: An analysis of the shell thickness needed to hollow out the palm for articulation purposes.

Requirement: The palm of the hand must be shelle[d] to save weight + provide articulation space. Base[d] loads a certain wall thickness will be necessary may differ from side to top load so an analysis on [illegible] necessary.

Analysis:



using worst case load of
What is the thickness needed

Top: $M = 100\#(2.5\,in) = 250\,\#\,in$

Assume a 0.125" wall thickness for trial 1.

$\sigma = \frac{Mc}{I}$ $\qquad I = \frac{bh^3}{12} = \frac{3(.125^3)}{12} =$

$= \frac{250\#\cdot in(.0625)}{0.0049\,in^4} = 31.8\,ksi$ ✗ too

Try 3/8

$\frac{250\#in(.1875)}{0.0132\,in^4} = \boxed{3551\,psi}$ $\qquad I = \frac{3(.375^3)}{12}$

Proper thi

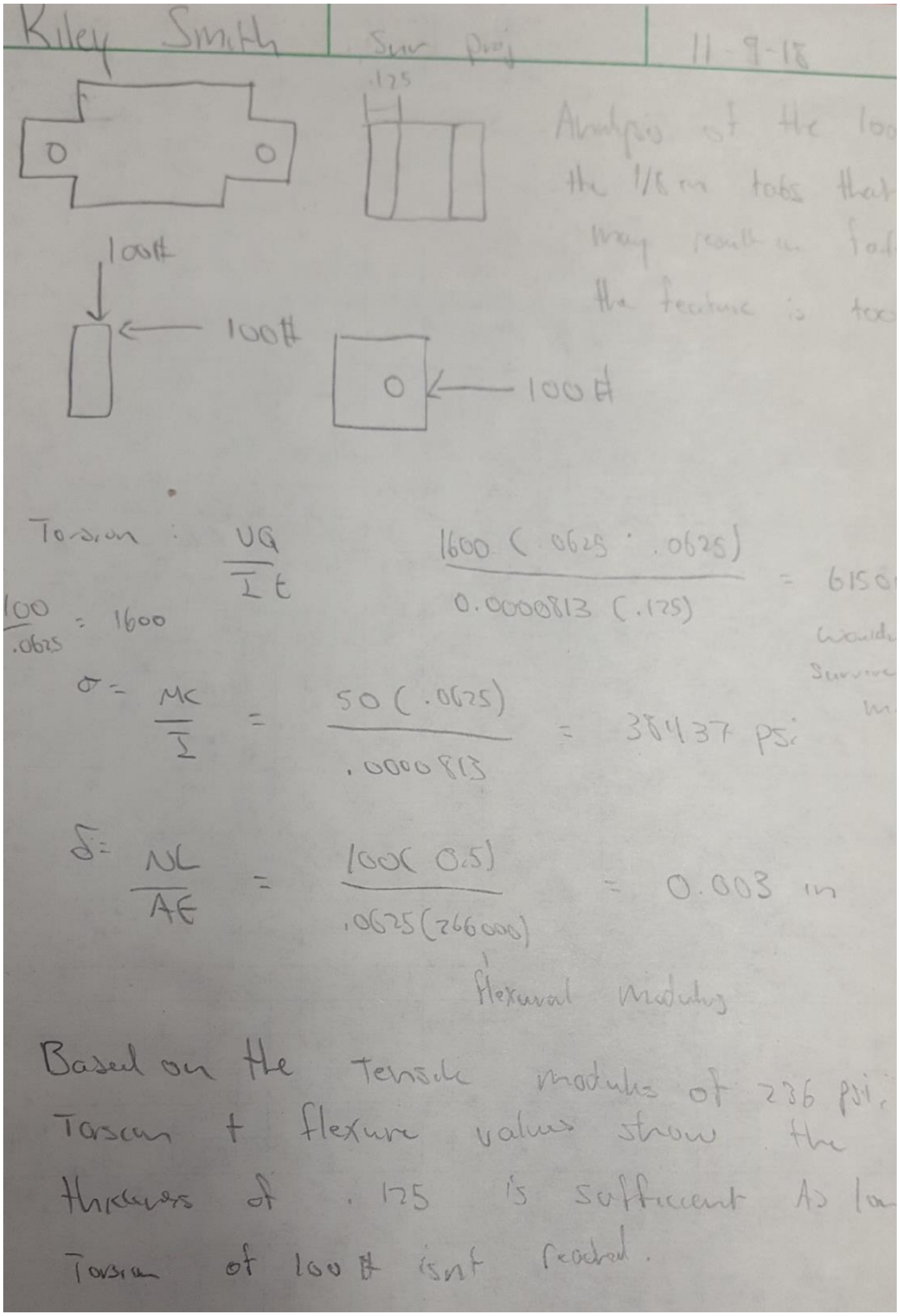
Side: $M = 50\,\#\,in$

$\sigma = \frac{Mc}{I} = \frac{50(.1875)}{0.0132} = \boxed{710\,Psi}$ $\qquad I = \frac{3(.37}{12}$

Parameter: wall thickness of 3/8 is suf

Documentation A-7 + B-4 current week

A-8: An analysis on the potential failure point of the ears on the finger joints. They are the thinnest area, being 1/8 inch thick.



Riley Smith | Sun Proj | 11-9-18

.125

Analysis of the loo[ad on]
the 1/8 in tabs that
may result in fail[ure]
the feature is too

100#

100#

100#

Torsion : $\frac{VQ}{It}$ $\frac{1600(.0625 \cdot .0625)}{0.0000813(.125)} = 6150$

$\frac{100}{.0625} = 1600$

would survive

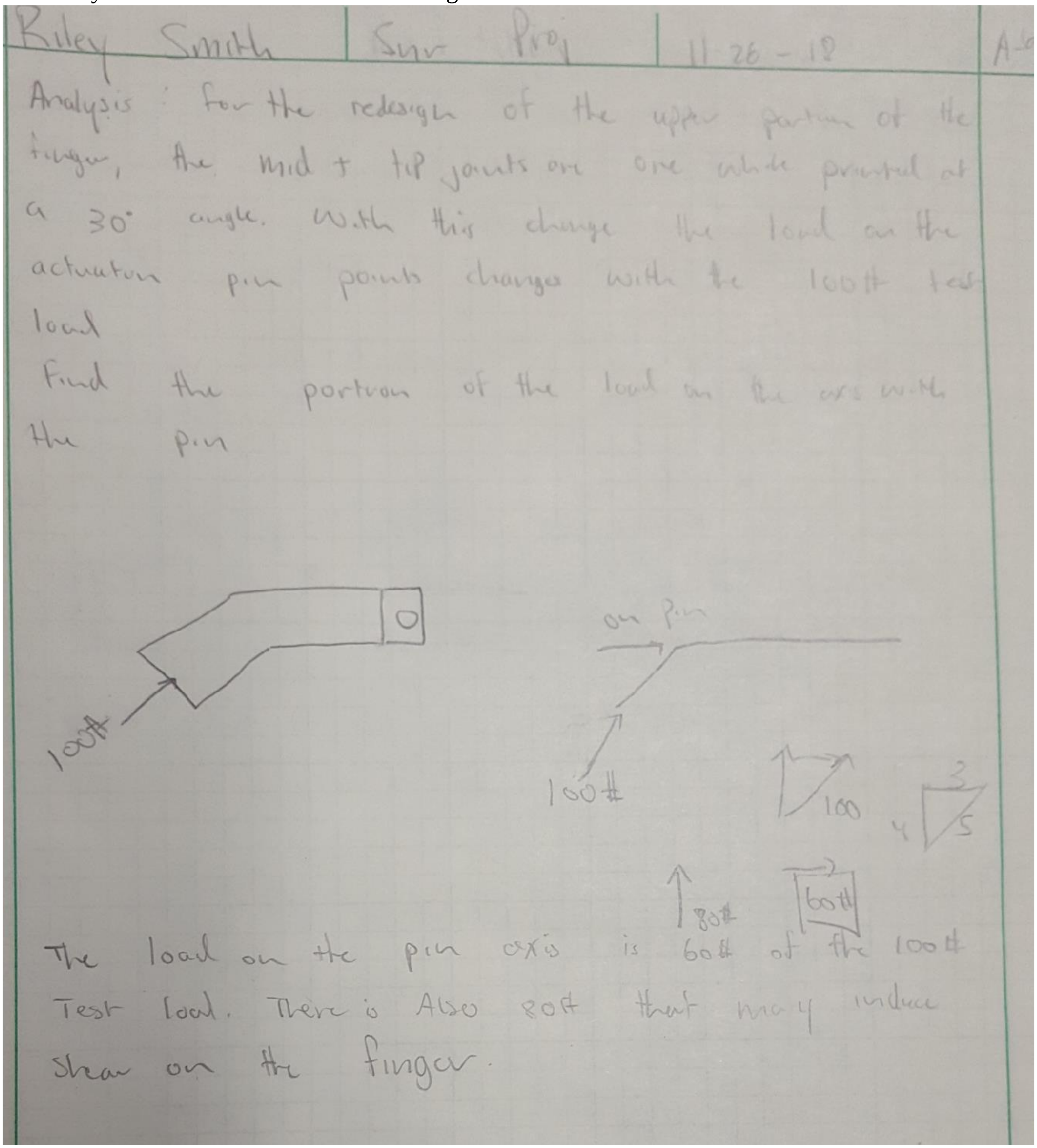
$\sigma = \frac{Mc}{I} = \frac{50(.0625)}{.0000813} = 38437$ psi

$\delta = \frac{NL}{AE} = \frac{100(0.5)}{.0625(266000)} = 0.003$ in

flexural modulus

Based on the Tensile modulus of 236 psi, Torsion + flexure values show the thickness of .125 is sufficient As long Torsion of 100# isn't reached.

A-9: Analysis of the angled upper finger joint in terms of force components in the x and y axis. Necessary information for actuation cam design.



Riley Smith | Snr Proj | 11-26-18 | A-

Analysis: for the redesign of the upper portion of the finger, the mid + tip joints are one whole printed at a 30° angle. With this change the load on the actuator pin points changes with the 100# test load

Find the portion of the load on the axis with the pin

The load on the pin axis is 60# of the 100# Test load. There is Also 80# that may induce shear on the finger.

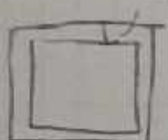
A-10: An analysis of the available area within the lower finger joints so that components for motion have ample room to move.

Riley Smith | Sen Proj | 11-26-18 | A10

Analysis: For housing the finger actuator completely the lower finger joint must be hollowed out. The interior area of the hollow section is necessary for the actuator design to have

Find the area of the interior of the joint minus the wall thickness.

1/16" wall thickness all around



The overall dim is 0.75" square

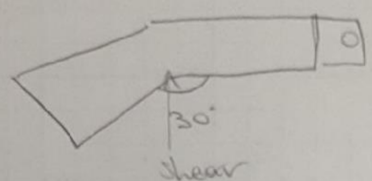
Final dim is $\boxed{0.625}$ square

Mock test to verify wall thickness is good

A-11: This is analysis of the shear component working on the upper finger joint. The 80 pound value was determined from A-9.

Riley Smith | Snr Proj | 11-28-18 | A-11

Given: The angled upper finger has a shear load on the angle of 80#. With the Dimensions and material used it is necessary to know if the finger would have a shear failure at that location



0.75 in sq

$\tau = \frac{V}{A}$ $\quad \frac{80}{0.5625 in^2} = \boxed{142 \text{ psi}}$

no failure

if hollow:

1/16" sq

$\frac{80}{0.0039}$

$\tau = 20480$

↳ Determines that the joint cannot be that thin if hollowed

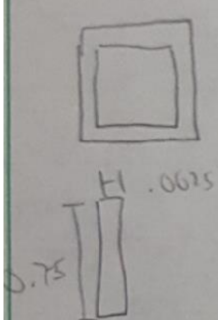
A-12: An analysis of the hollowed lower finger joint as a column. A column analysis was chosen to determine if the joint is susceptible to buckling when the test load is applied.

Riley Smith	Snr Proj	11-28-18	A-12

Given: In order to house the articulation components the lower finger joint must be hollow. a minimum wall thickness is needed so that the joint can withstand the 100 # test load

Find: minimum wall thickness

Assume a wall of the joint shell will buckle so that a column model is sufficient



$$P = \frac{\pi^2 E I}{(L_e/r)^2}$$

Assume: short column

$L_e = 0.65(0.75)$

$L_e = 0.4875$ in

$E = 203$ ksi - matweb

$I = 0.00219$ in^4

$r = 0.75$

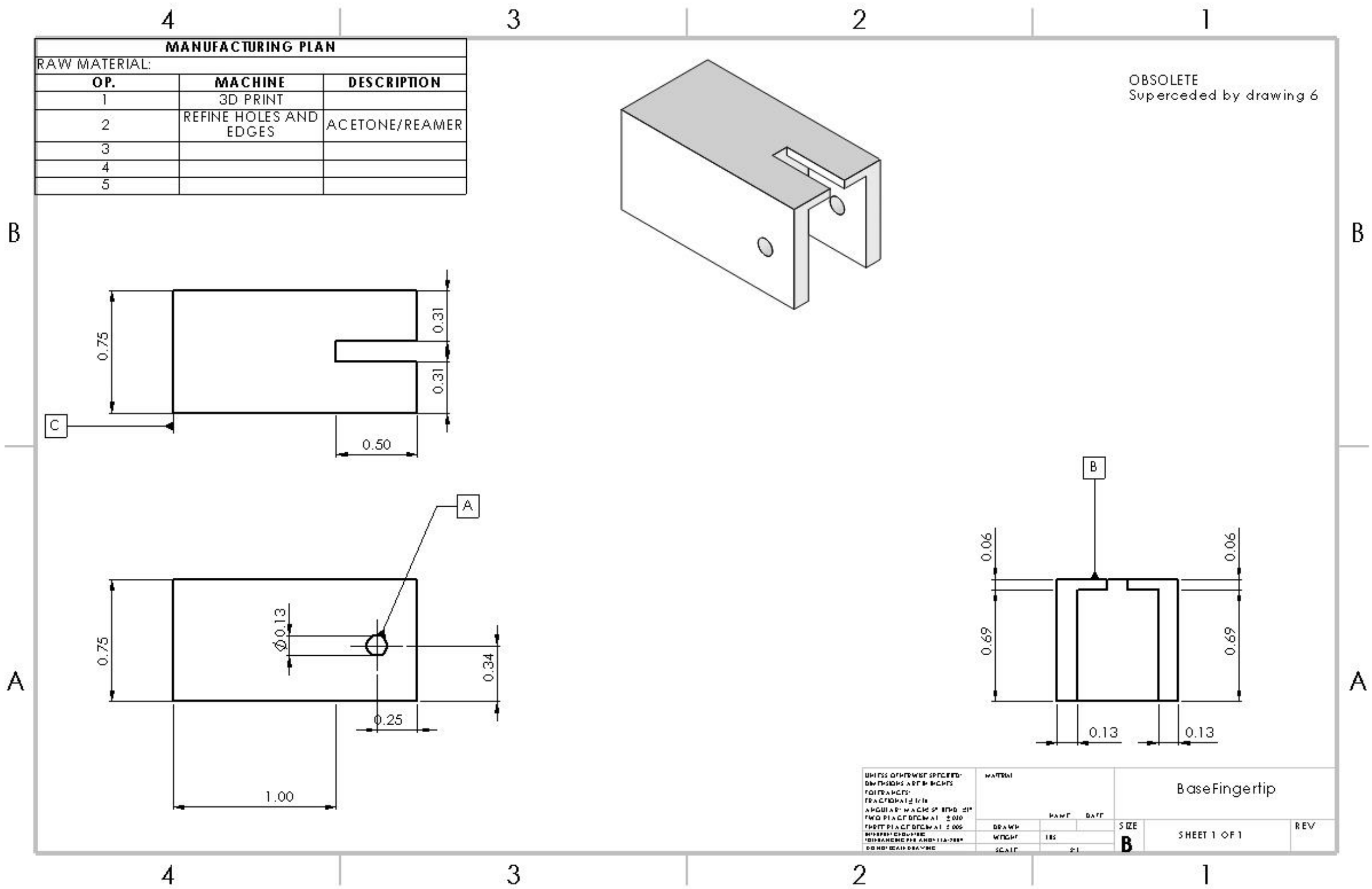
$A = 0.00391$ in^2

$$\boxed{P = 10385\ \#}$$

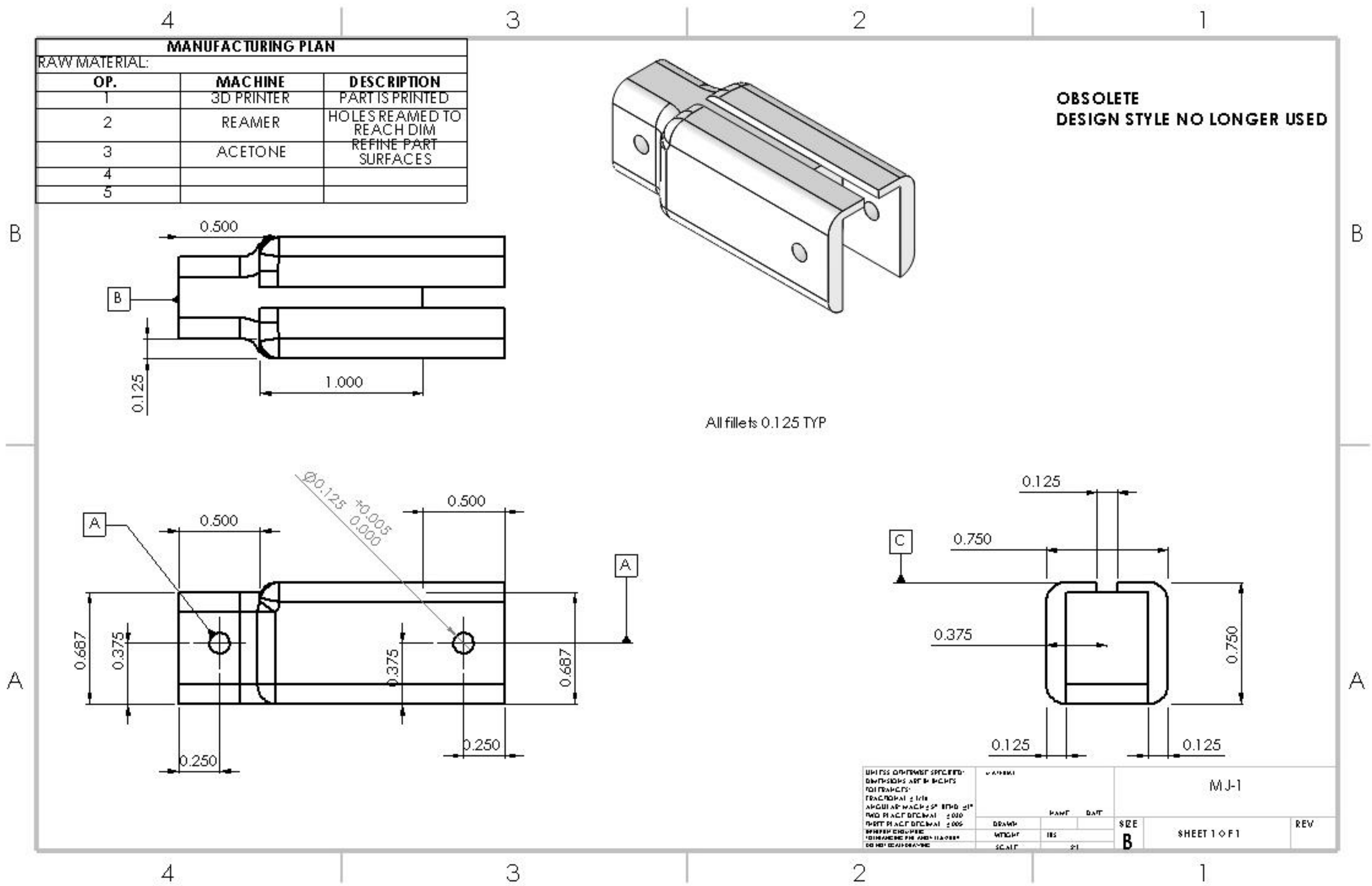
The shell will not buckle

Appendix B

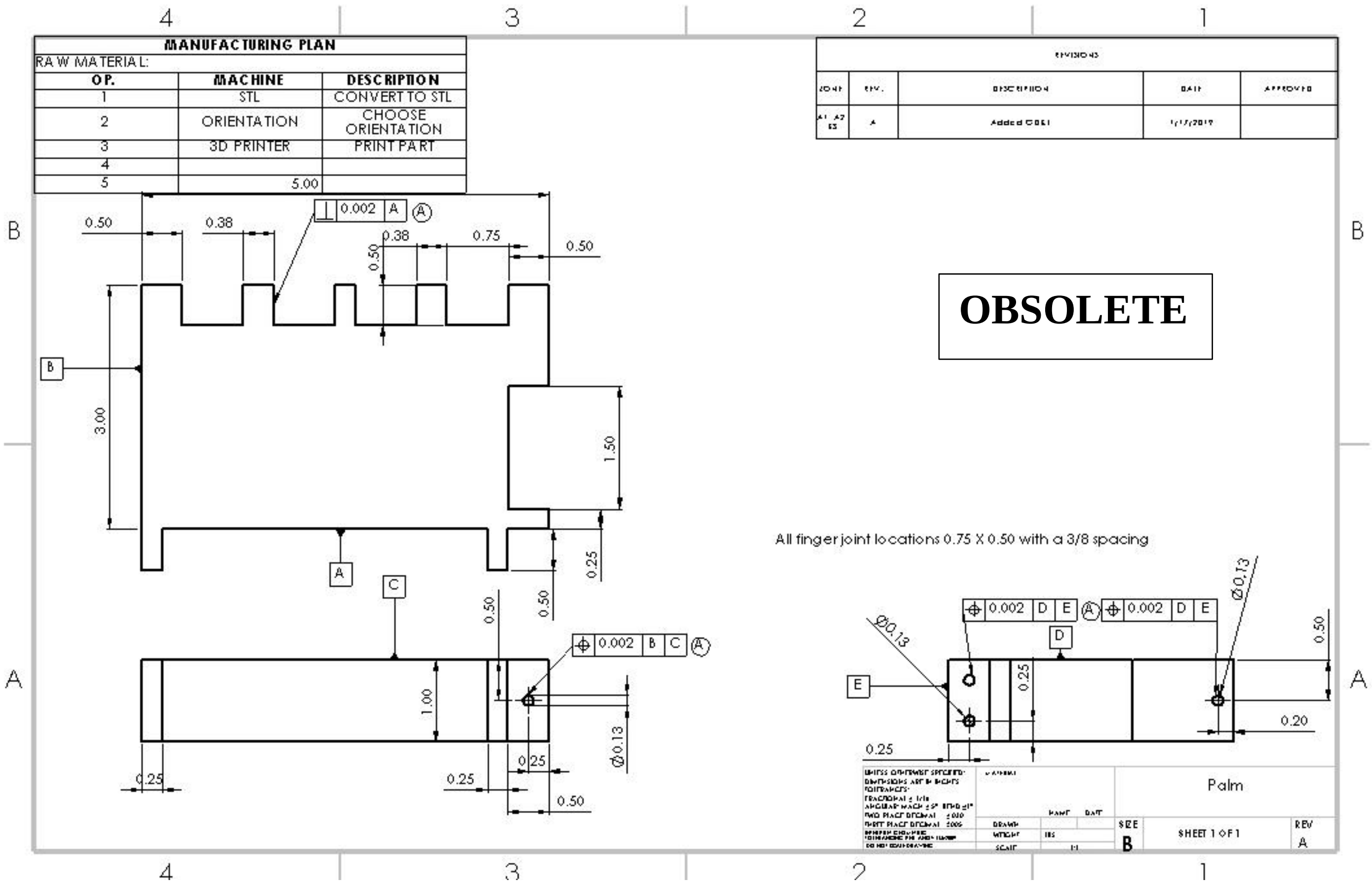
B-1: Drawing of a basic fingertip with the pin holes and Limit tabs.



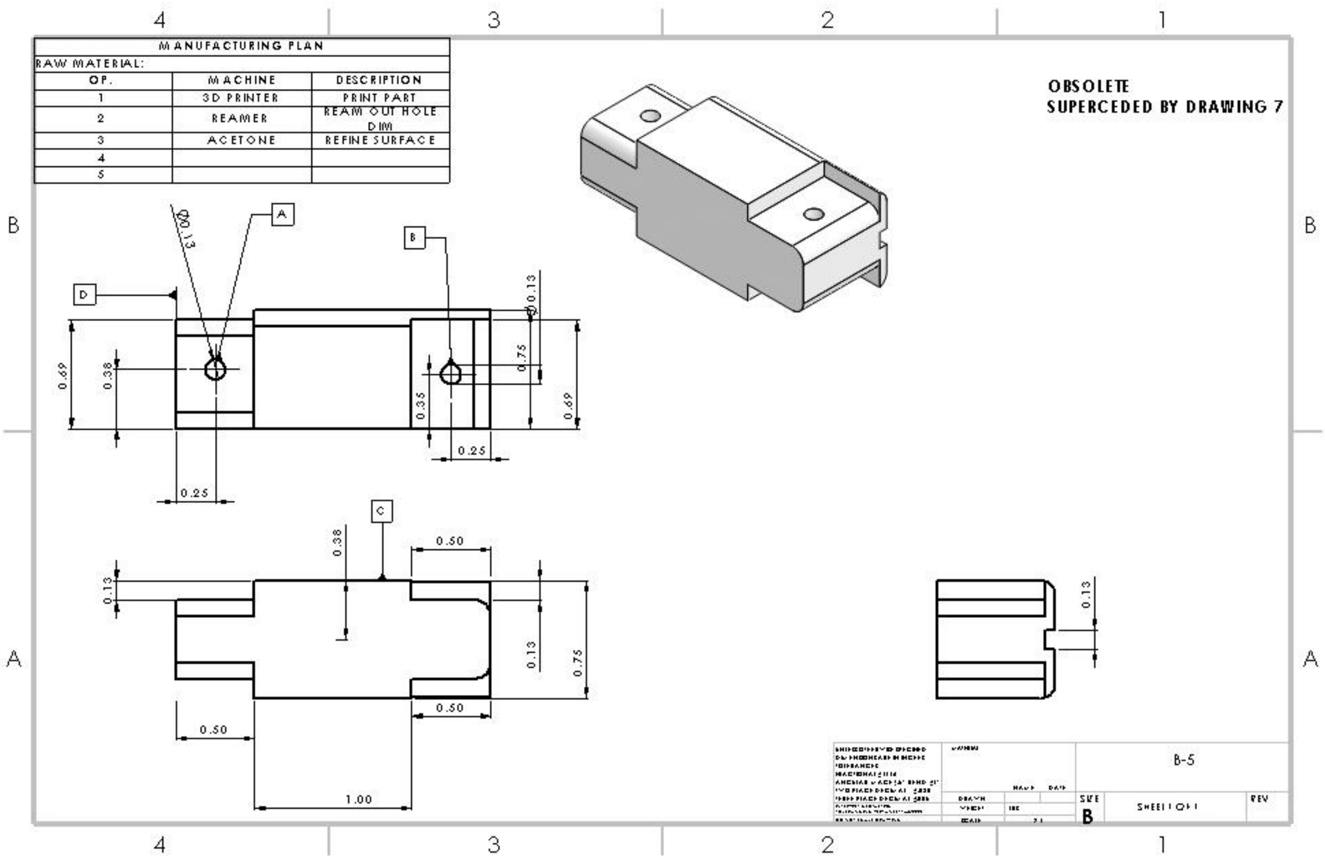
B-2: Drawing of the middle finger joint with the limit tab on one end and the reduced area to fit on the finger tip on the other.



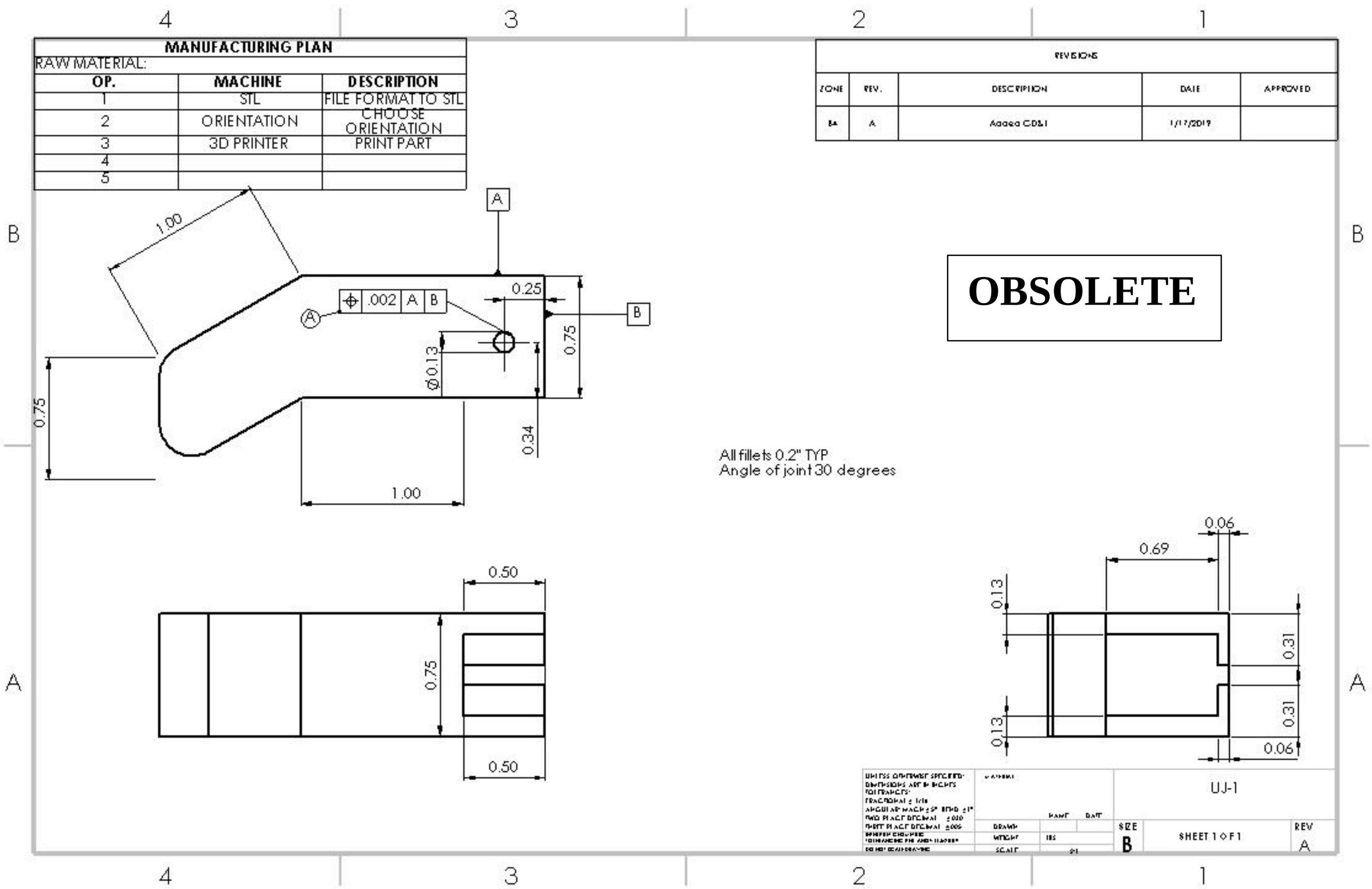
B-3: A drawing of the base design of the palm. Including each joint as well as thumb mount location



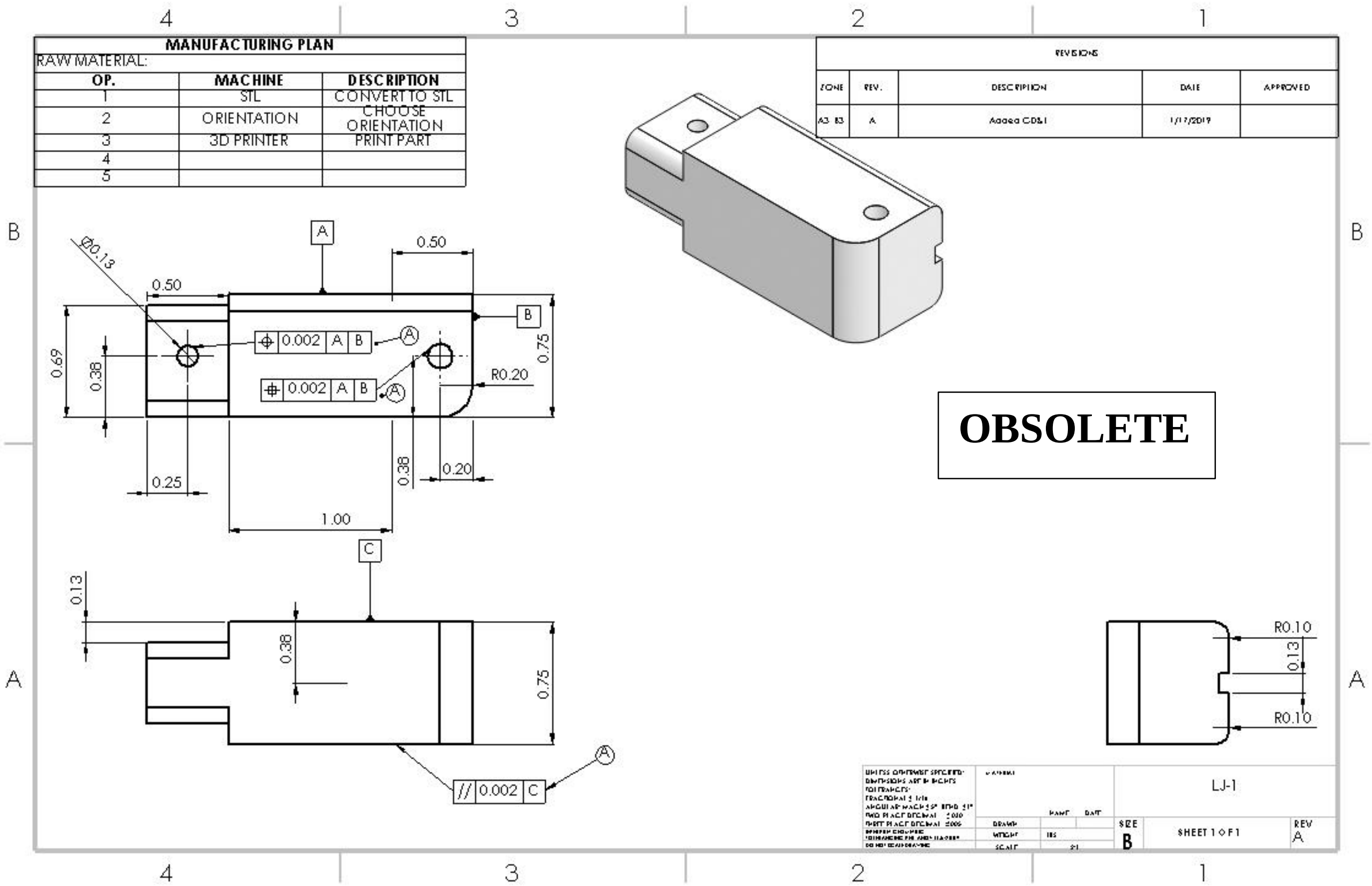
B-5: A drawing of the first finger joint that allows motion by design.



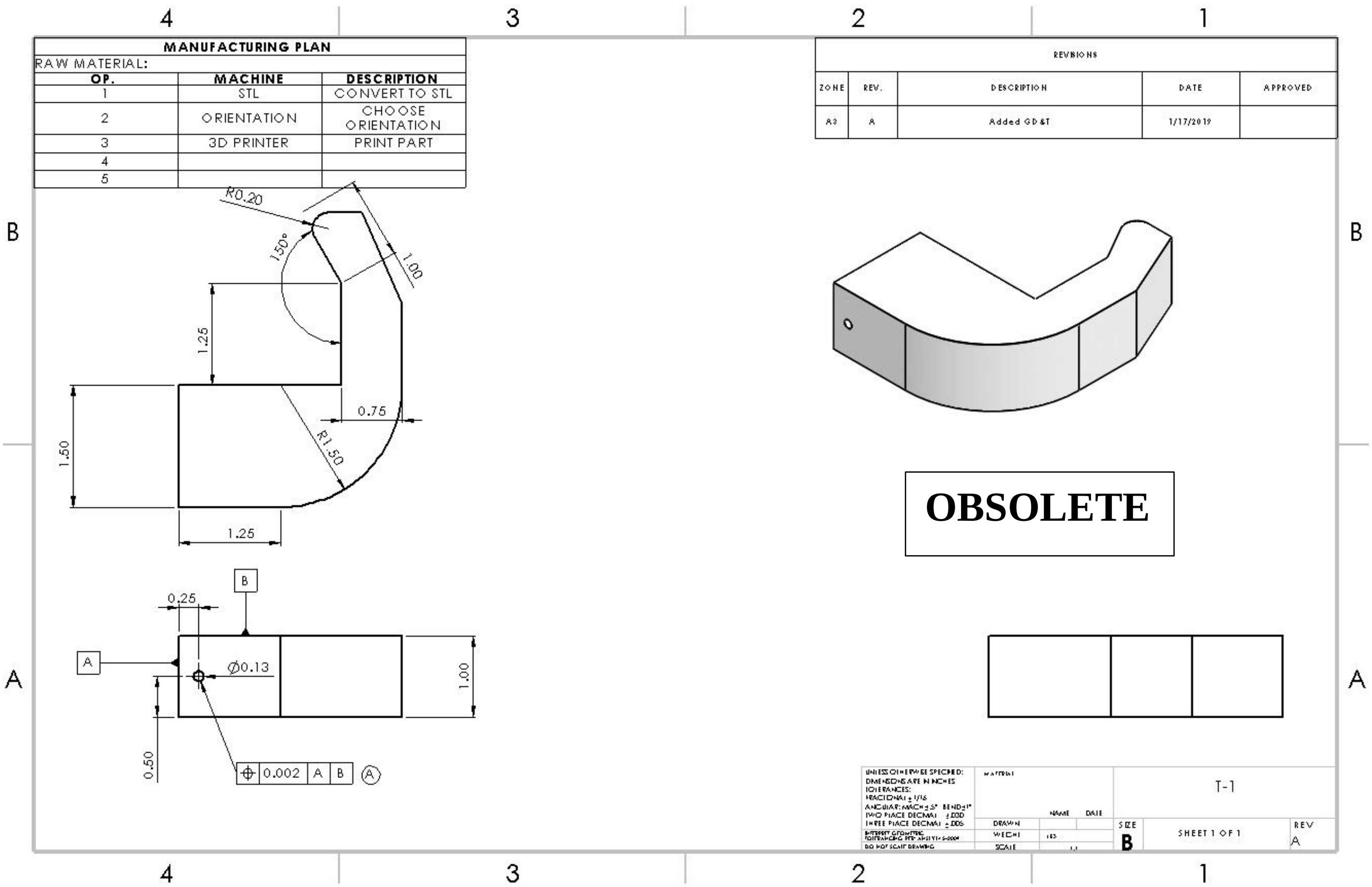
B-6: A drawing of the redesigned finger joint with a predetermined 30 degree joint angle.



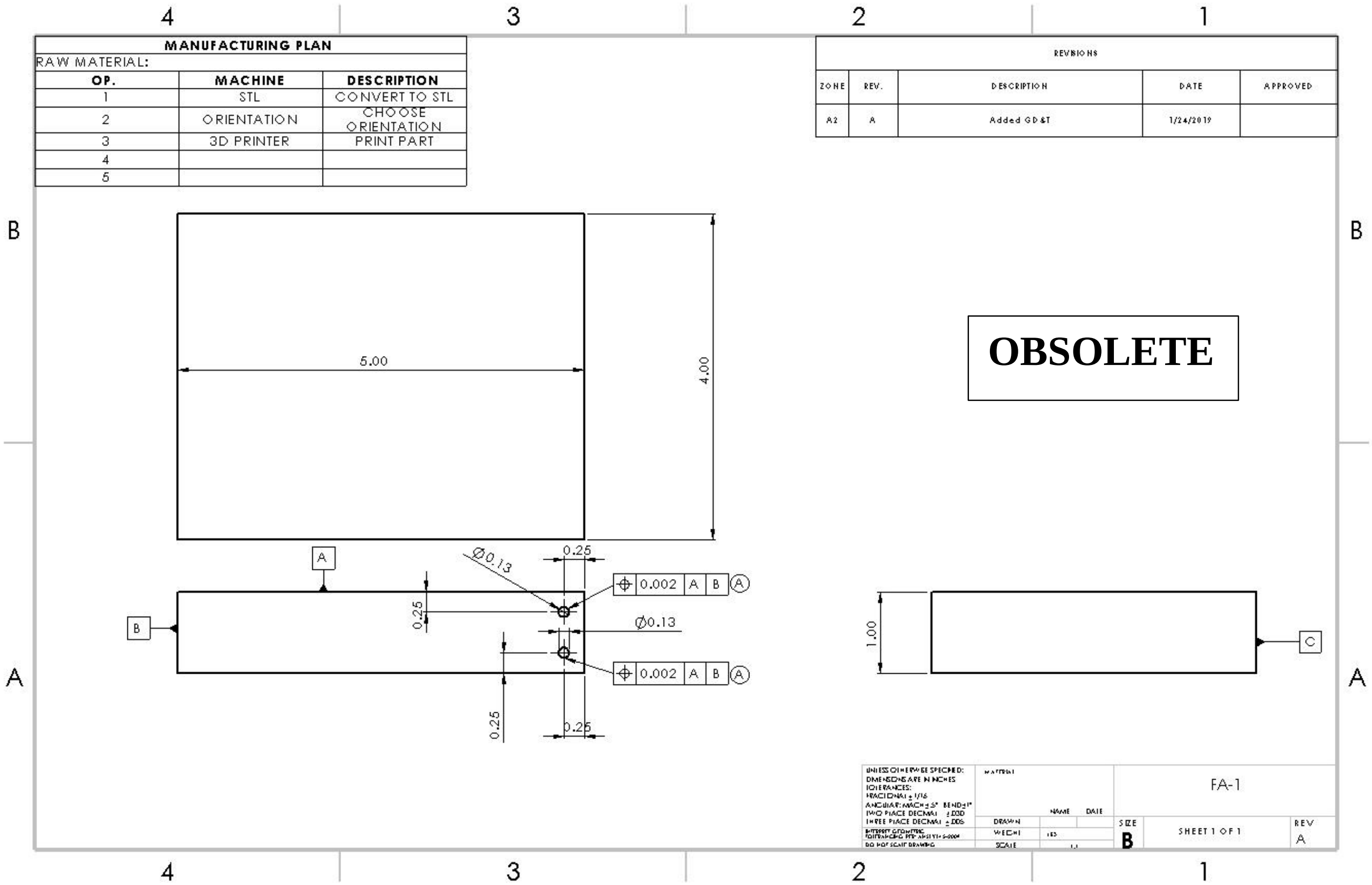
B-7: A drawing of the lower joint of the hand, meant to join the upper joint and be affixed to the knuckle locations in the palm.



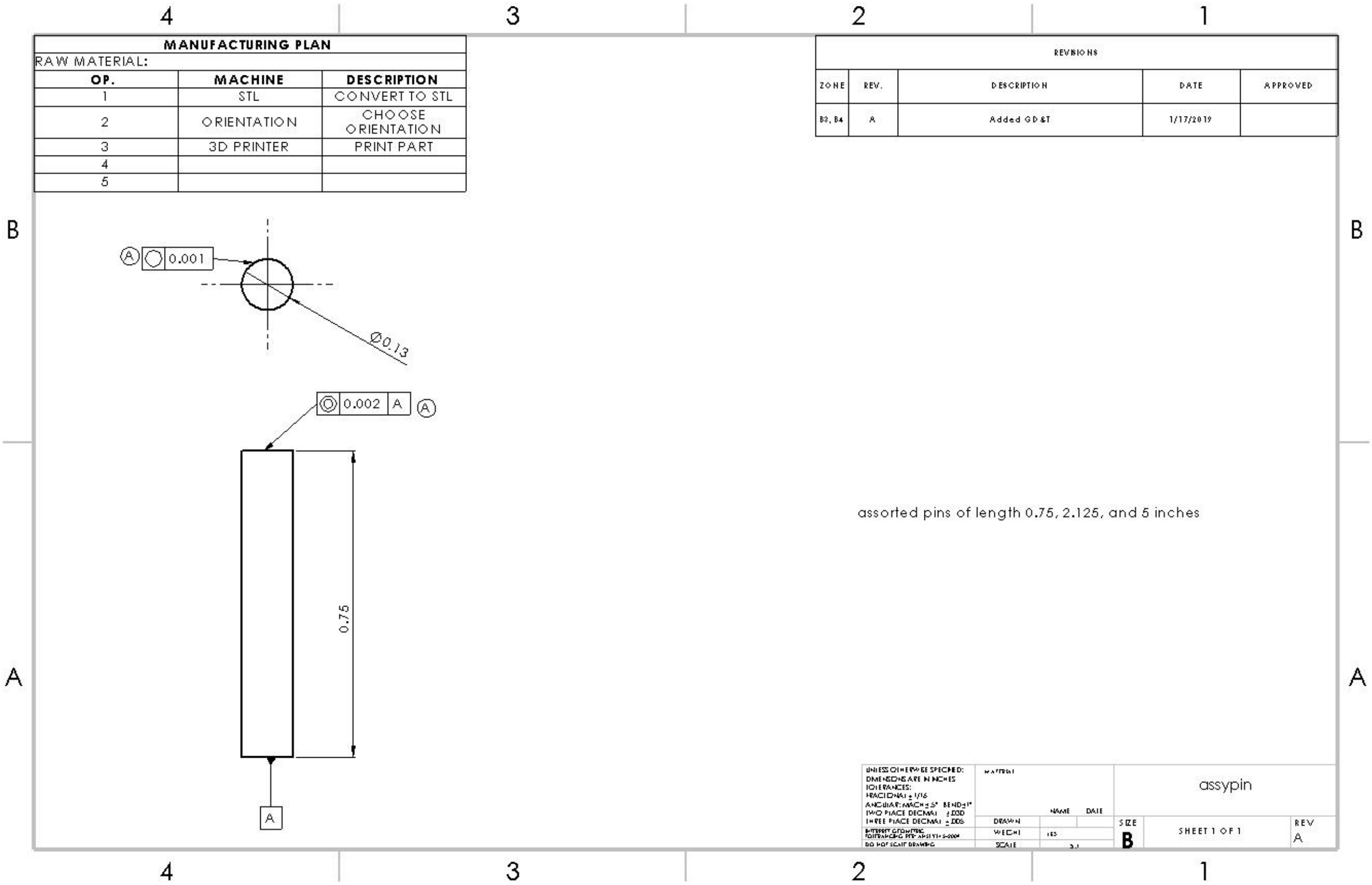
B-8: A drawing of the base thumb design for the hand. Set with a 30 degree angle thumb so that a grip position is easily attained.



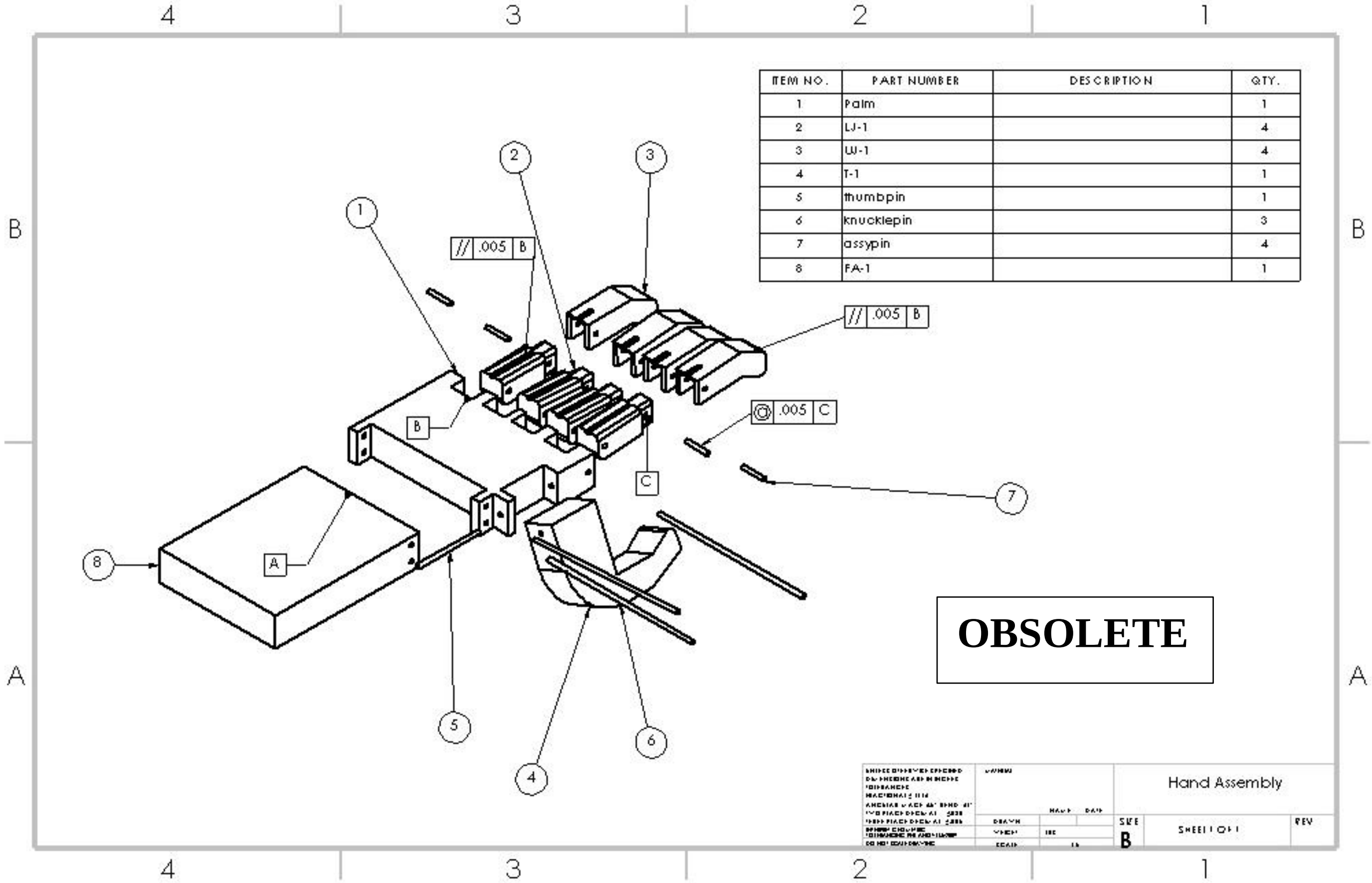
B-9: A drawing of the basic forearm unit that is fixed to the palm. The location and size of actuation components are currently undetermined so the model is simple.



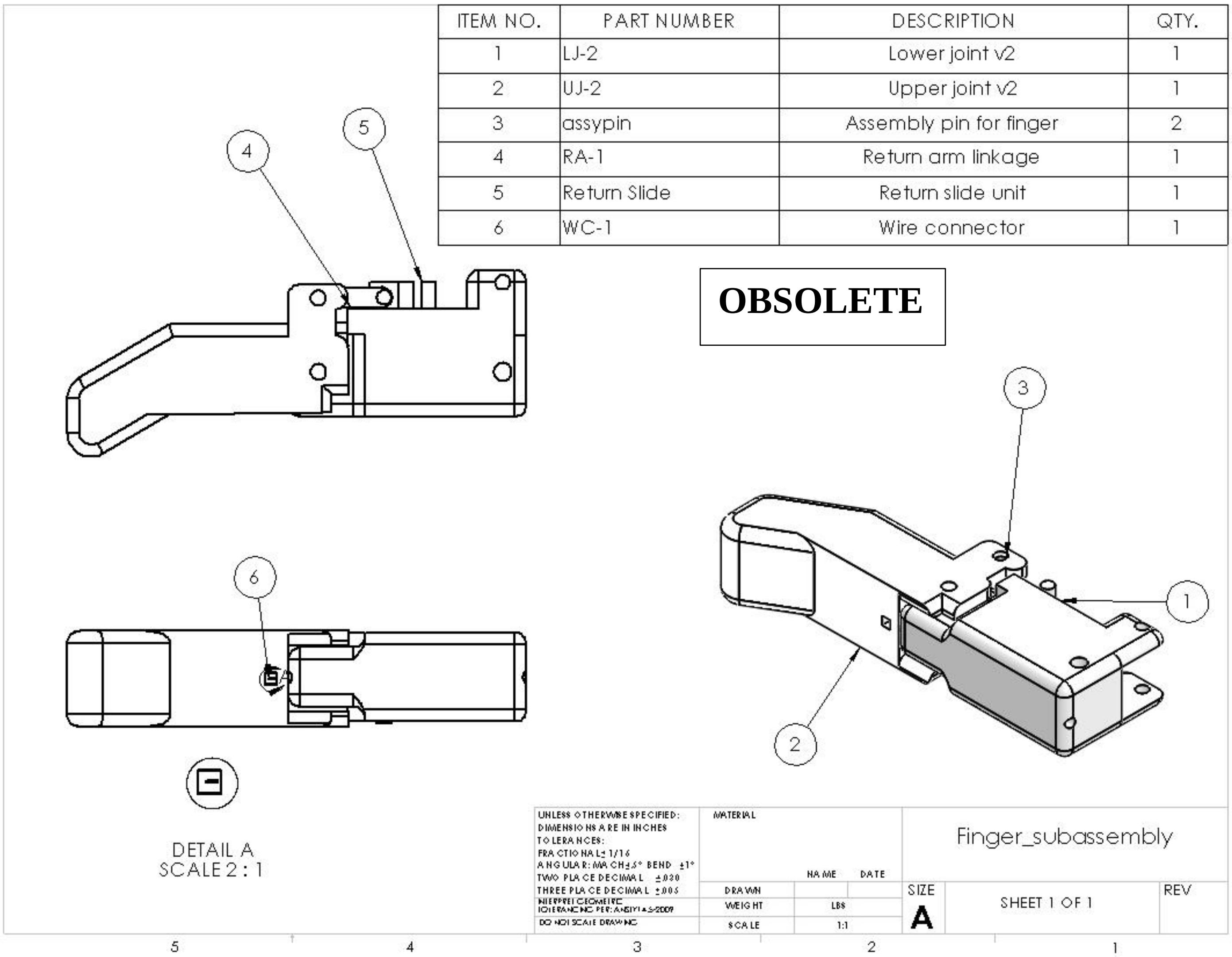
B-10: A drawing of the pins used to initially assemble the hand.



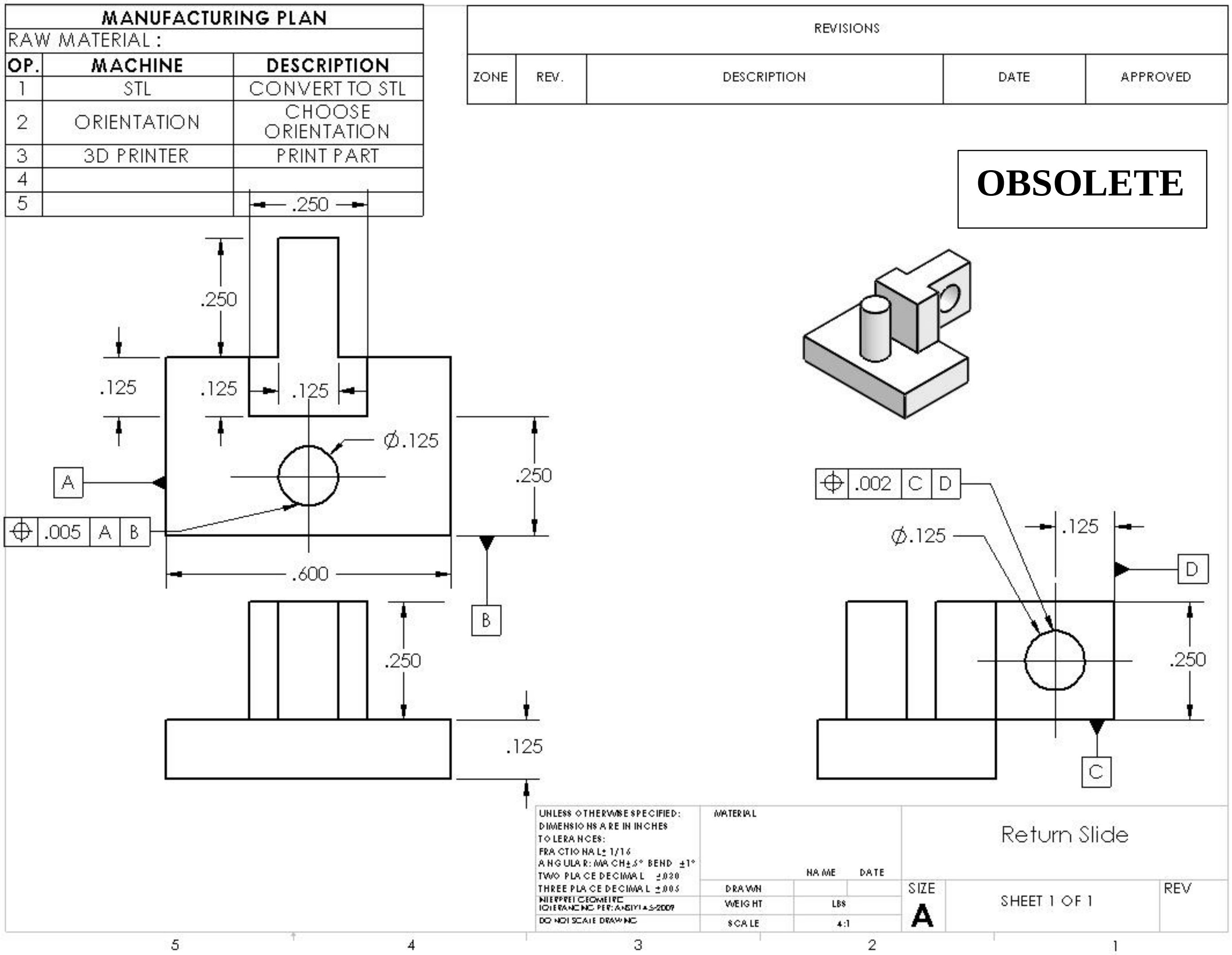
B-11: A drawing of the full assembly of the base hand design.



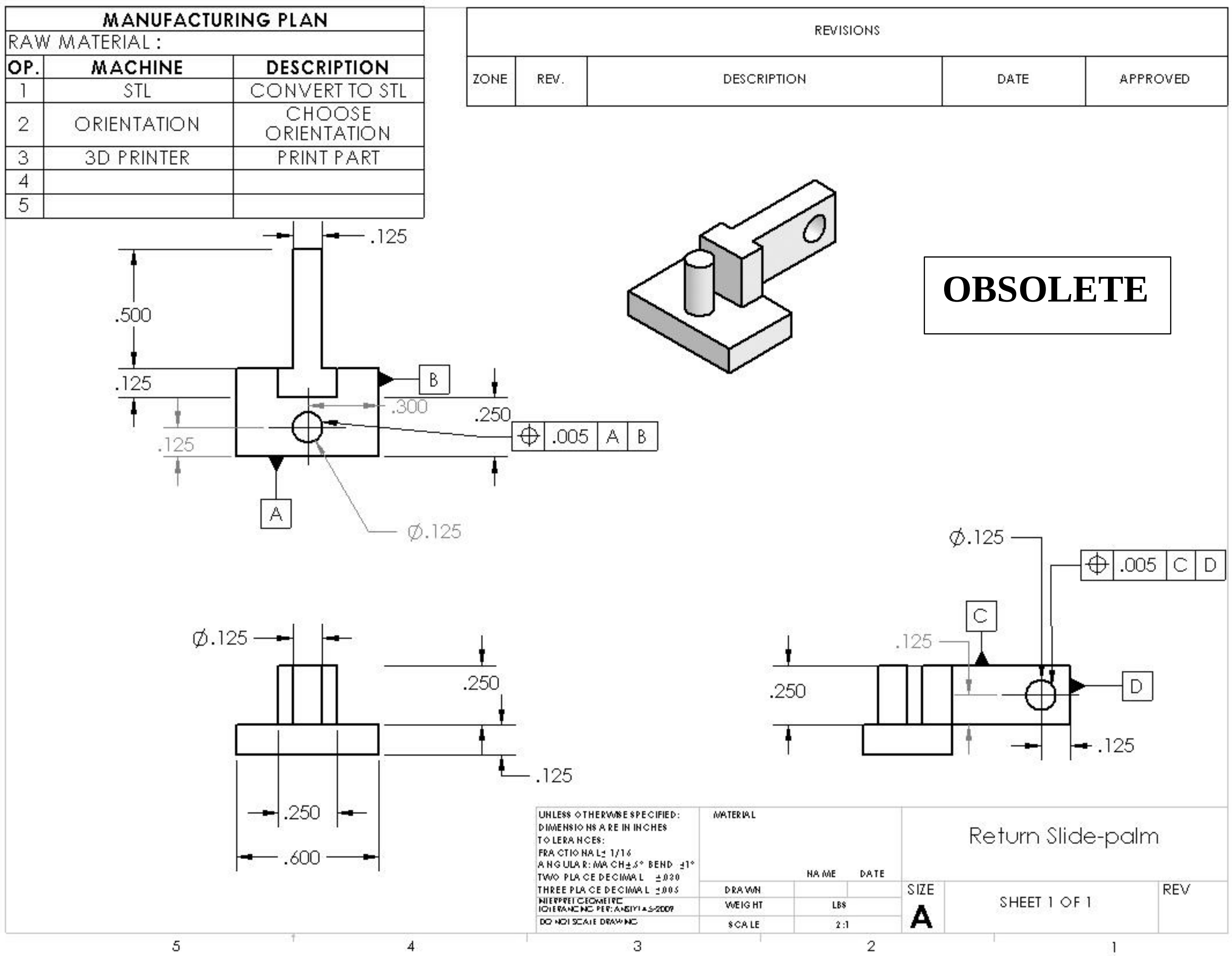
B-12: A drawing of the finger subassembly for the newer design



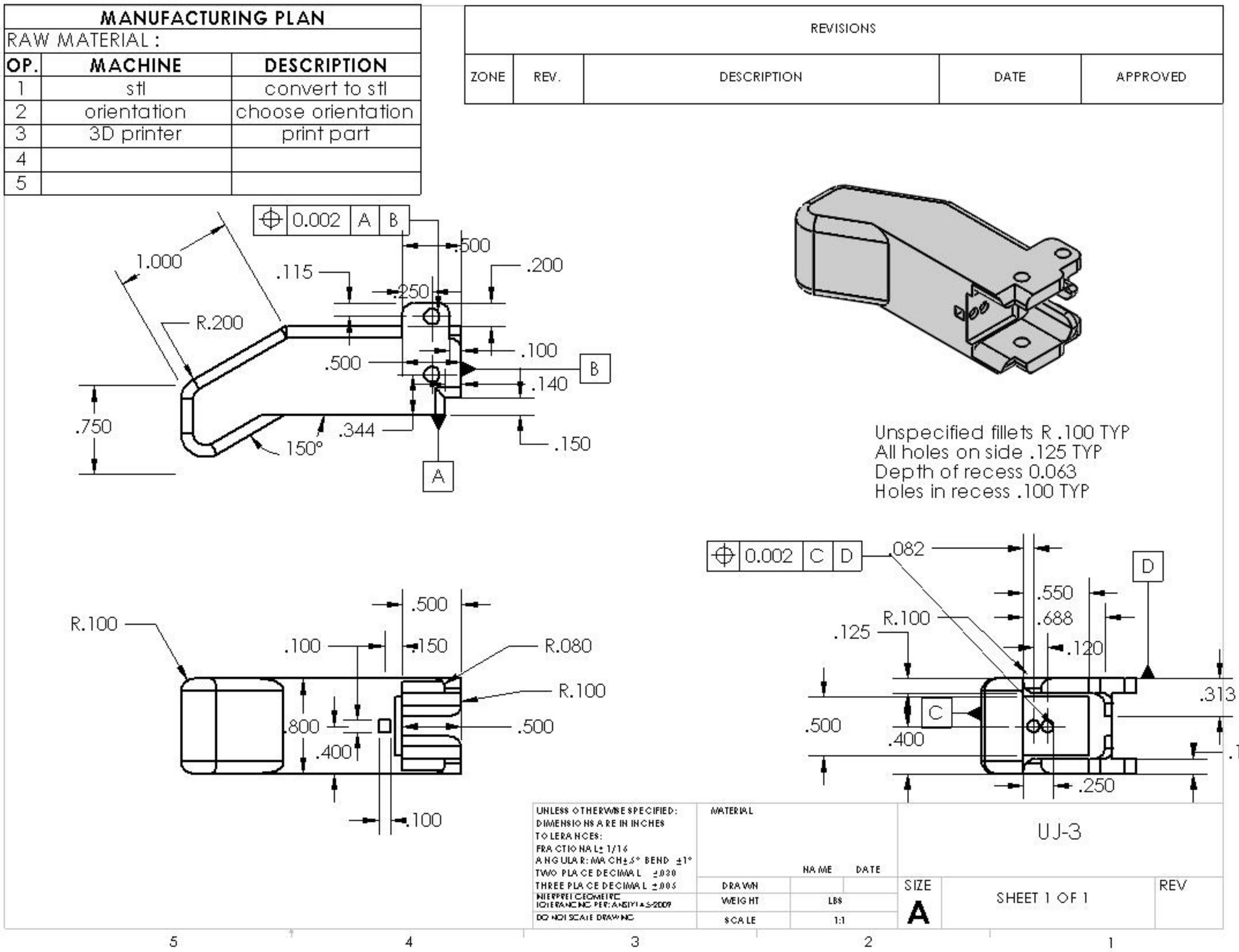
B-13: A drawing of the return slide used to pull the hand back to rest position



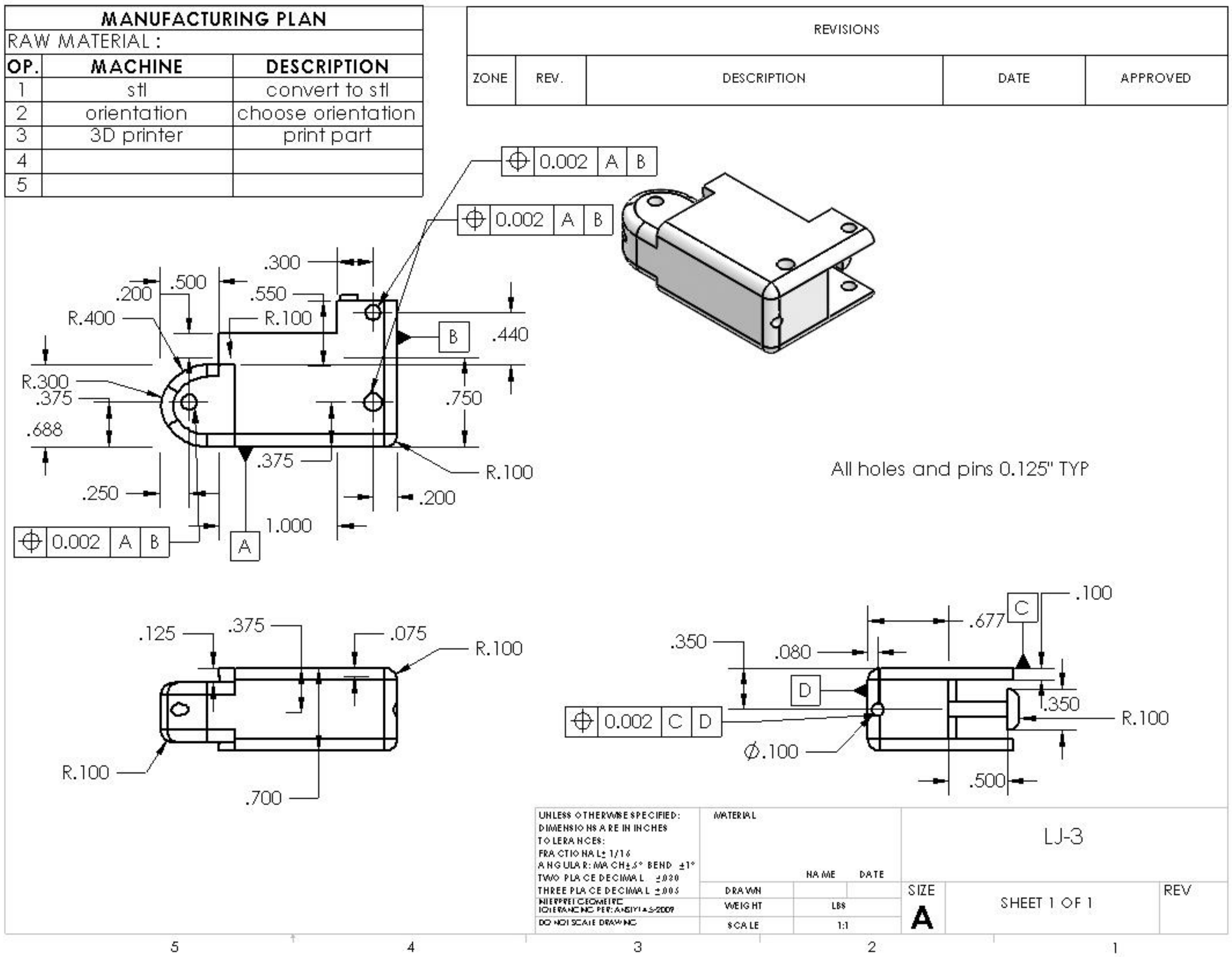
B-14: a drawing of the return slide which operates on the palm. It is slightly longer than the slide to run on the finger itself



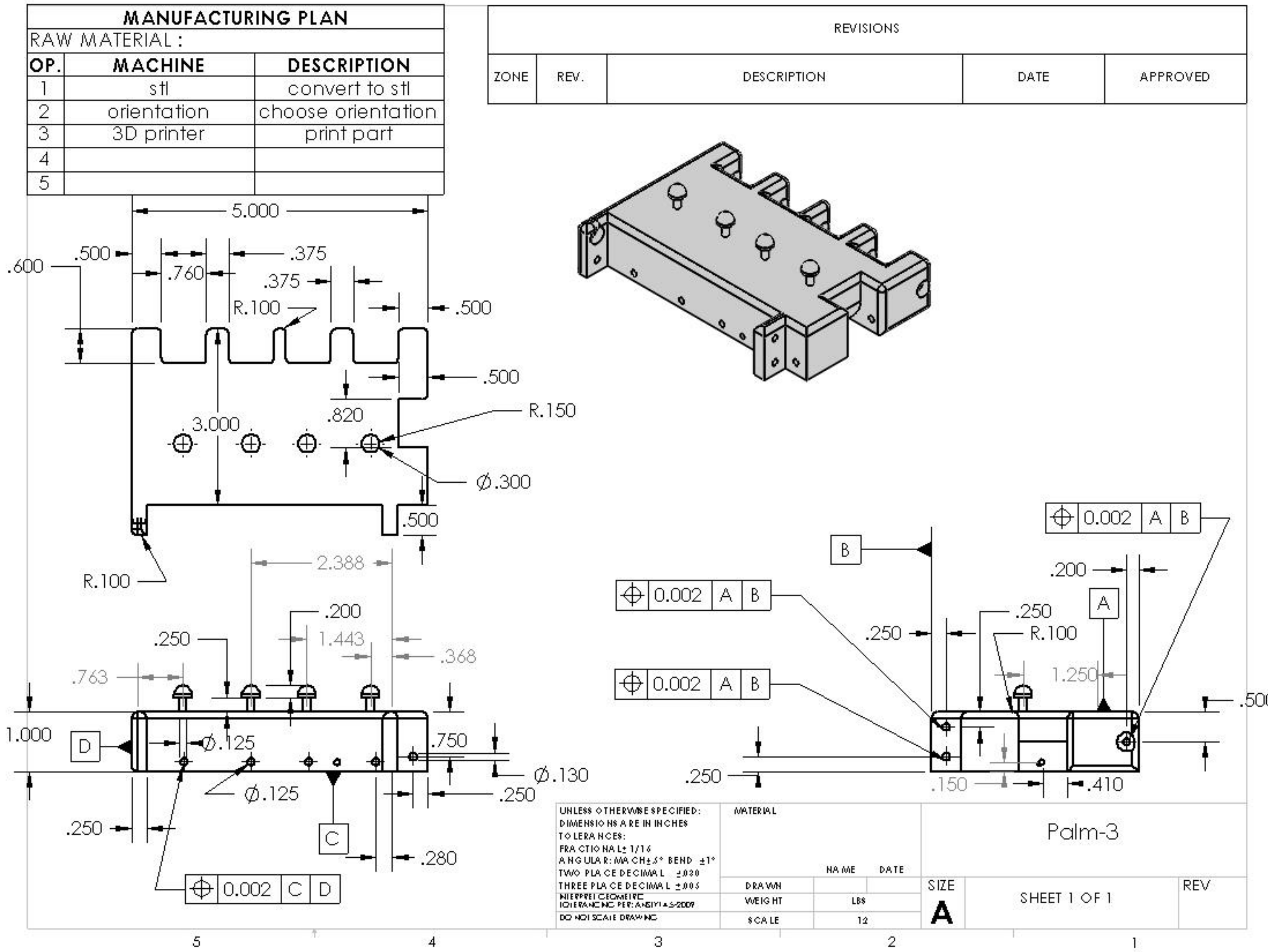
B-15: A drawing of the third iteration of the upper finger joint. The return slides are no longer used but the pin location for it was repurposed for rubber band holding.



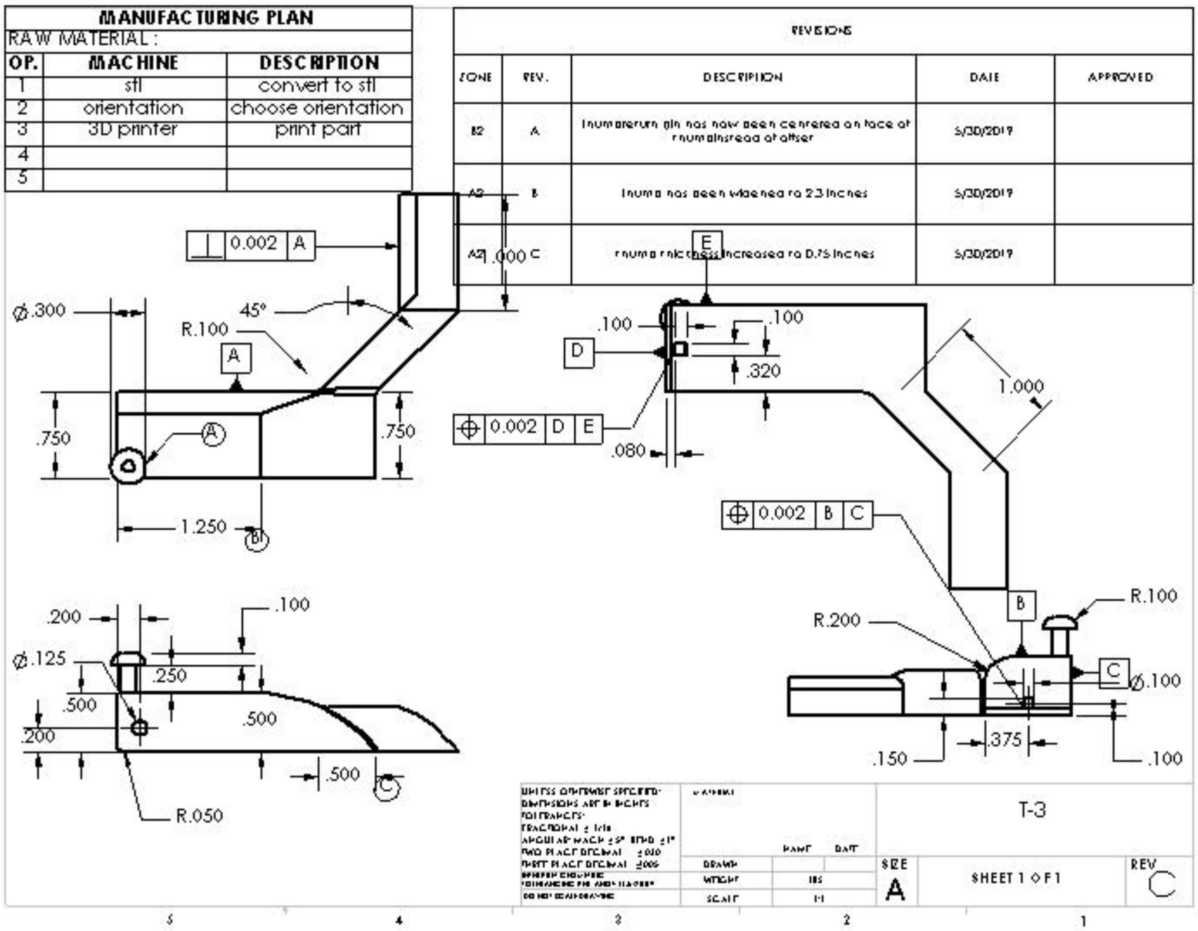
B-16: A drawing of the third iteration lower joint. The return slide tracks were removed, and the space was used to contain the rubber band by using a pin with a tee extrusion.



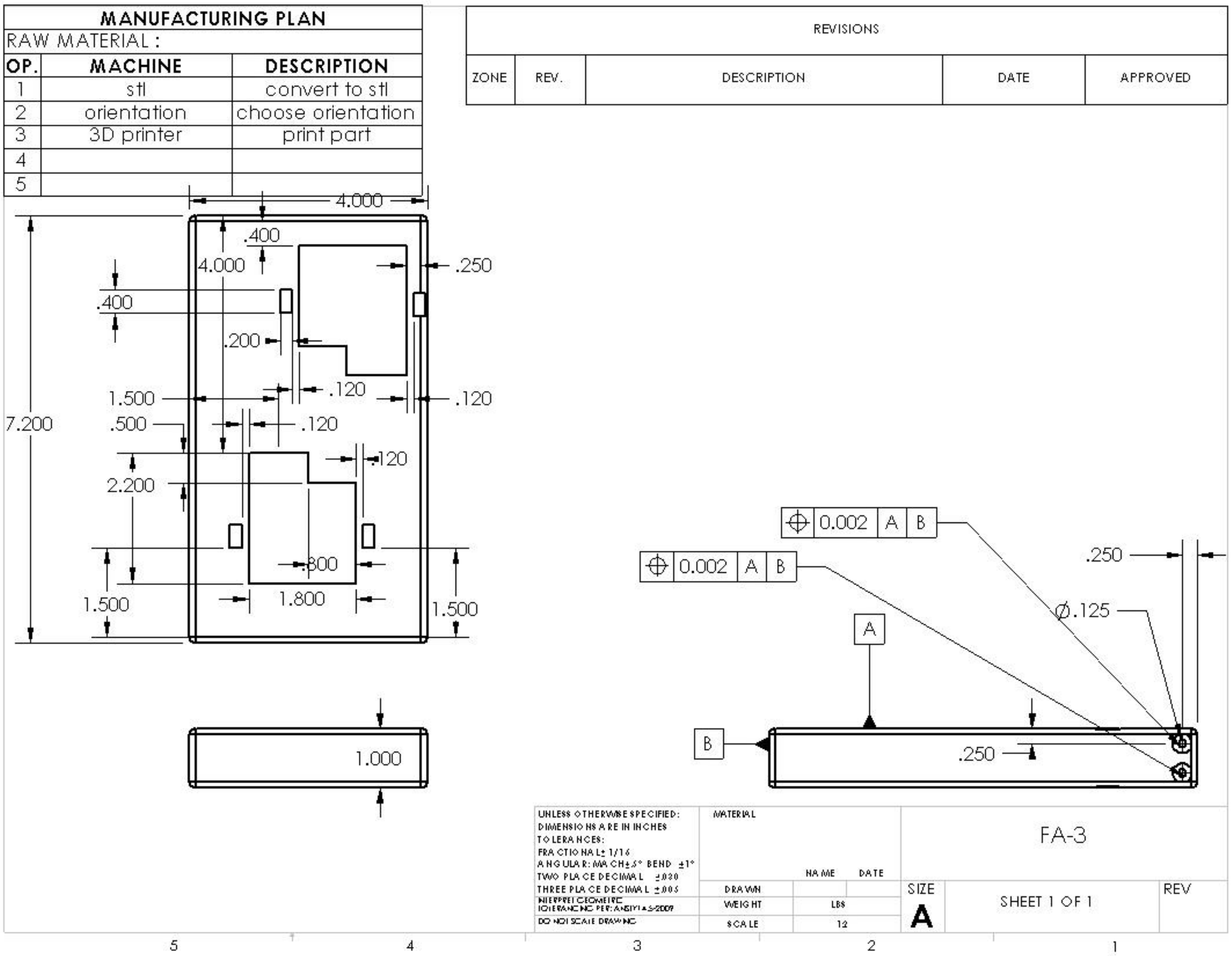
B-17: A drawing of the third iteration palm. There are paths for wire and rubber band pegs used in this design. As well as a smaller recess for the new thumb.



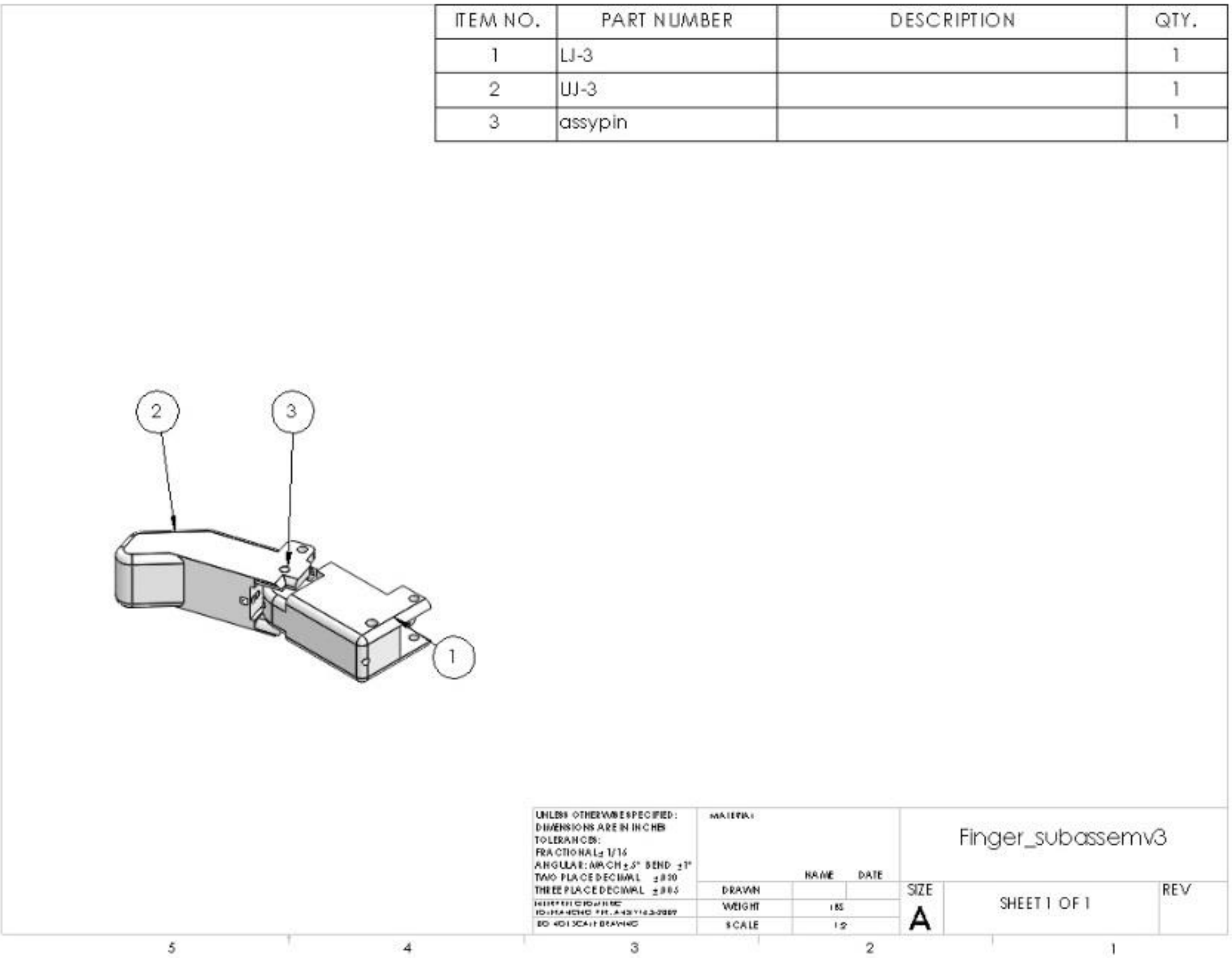
B-18: A drawing of the newest thumb design. This design is capable of meeting the index finger of the hand and producing an area for objects to be gripped.



B-19: A drawing of the forearm component of the hand, which is used to hold the actuators for moving the hand.

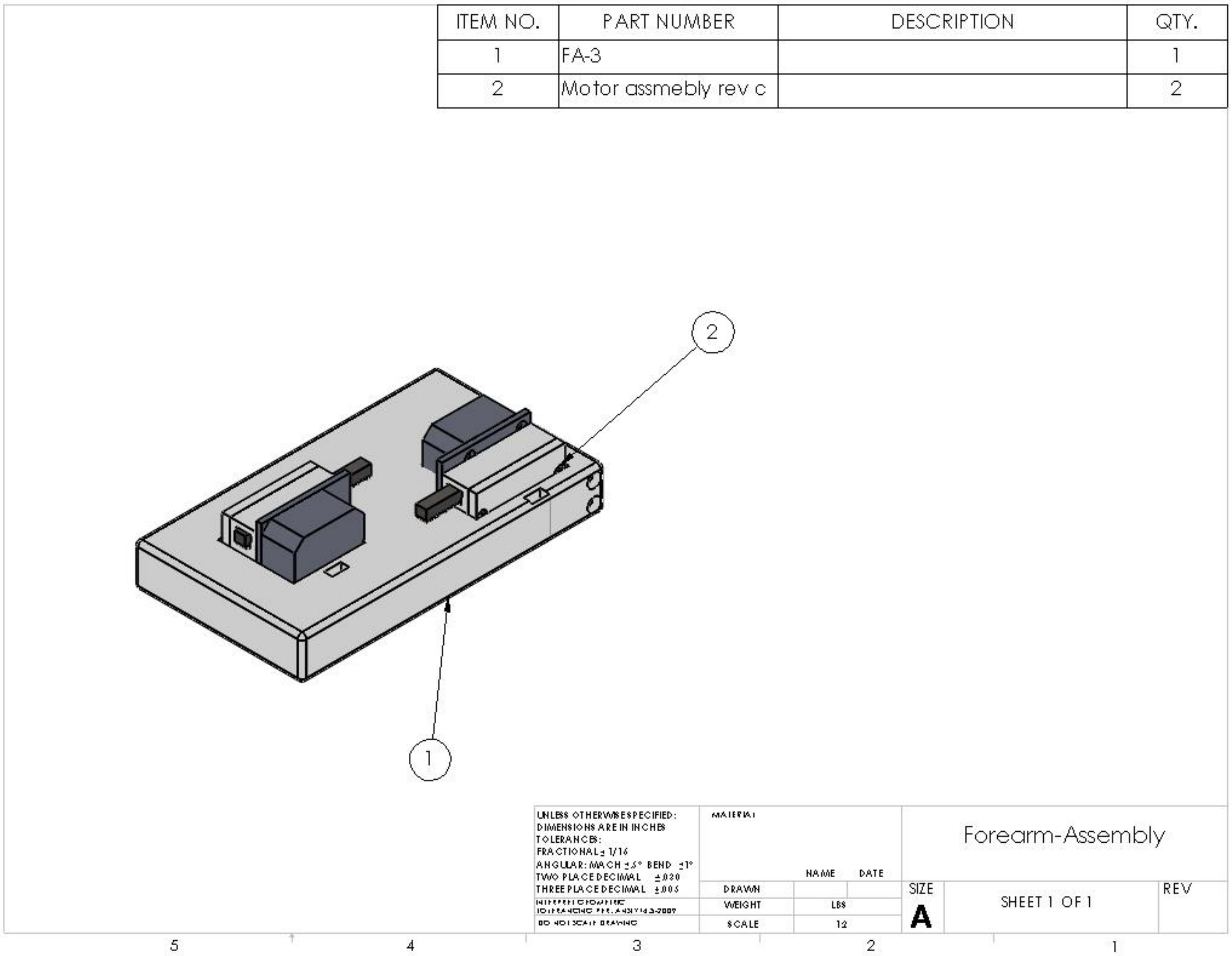


B-20: A drawing of the third iteration finger subassembly used when building the hand.



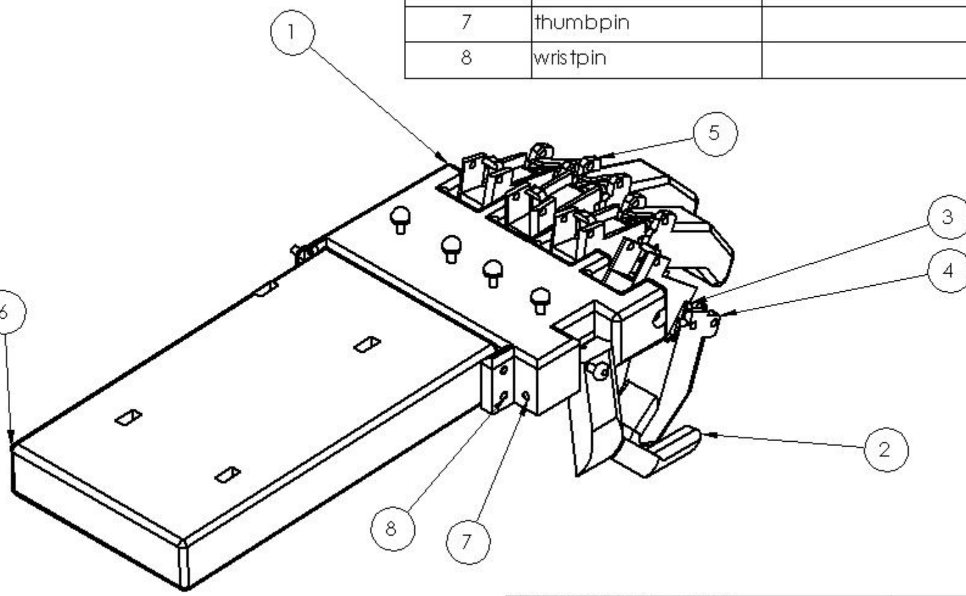
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	LJ-3		1
2	UJ-3		1
3	assypin		1

B-21: A drawing of the forearm subassembly with the actuators placed.

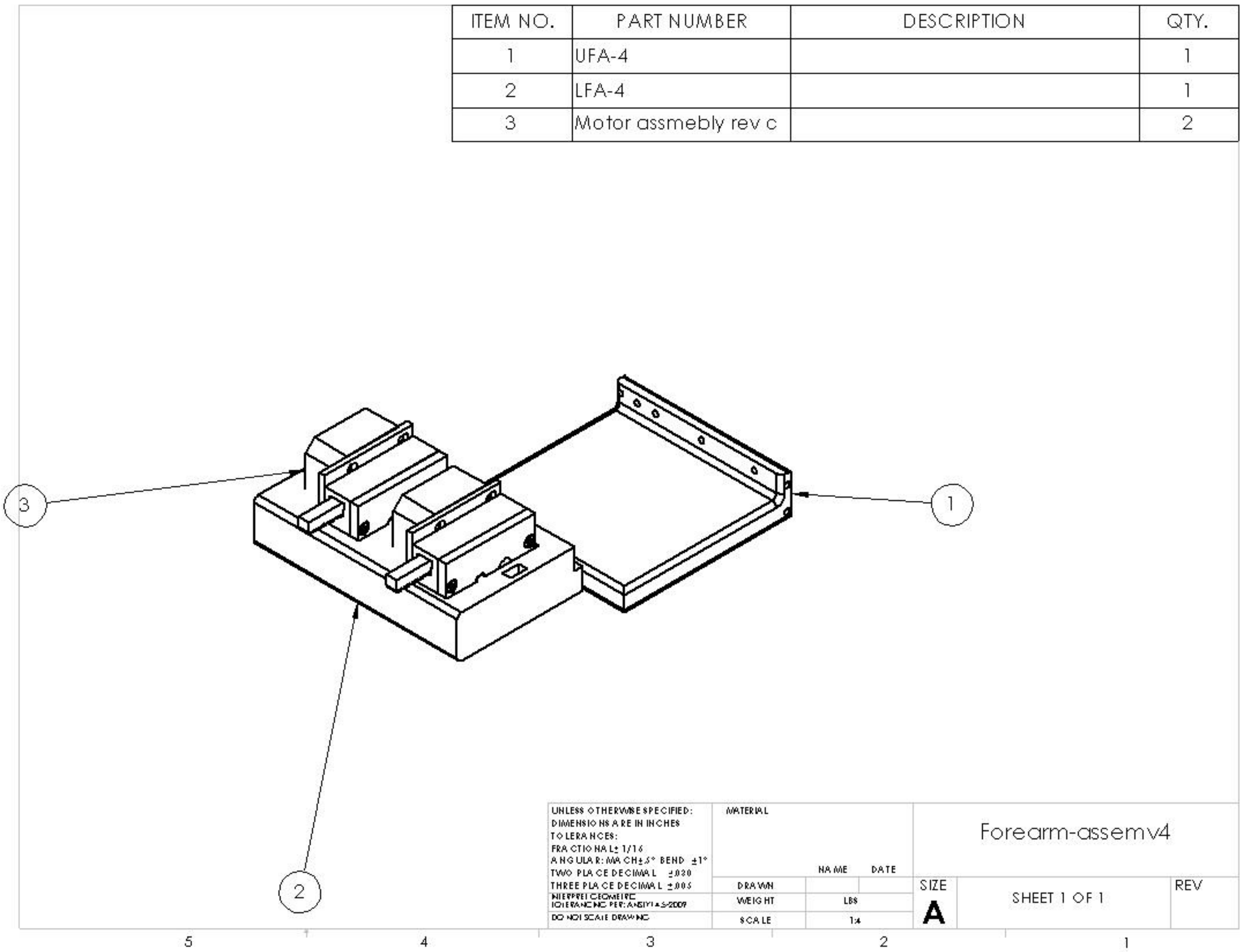


B-22: The full hand assembly using the latest parts.

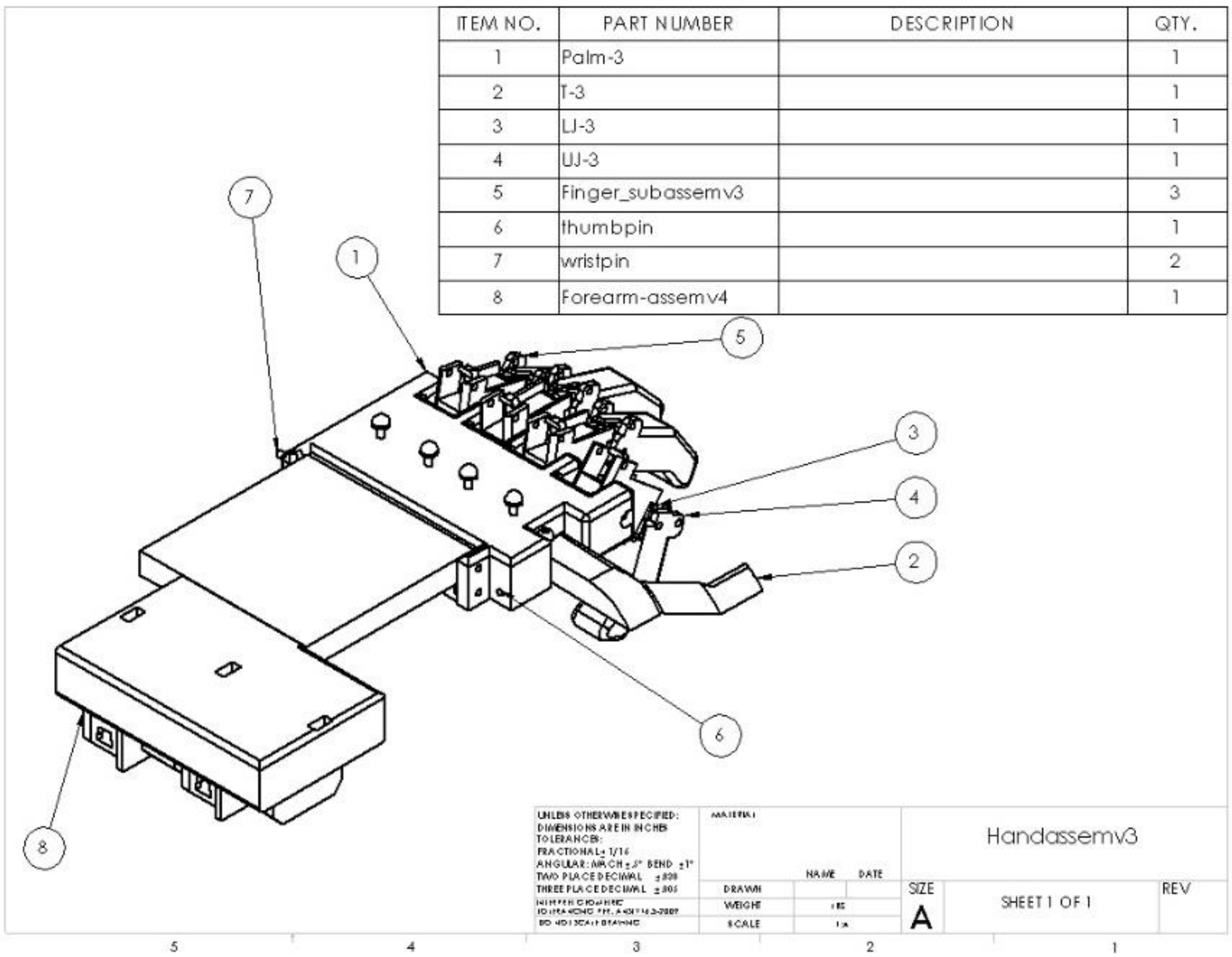
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Palm-3		1
2	T-3		1
3	LJ-3		1
4	UJ-3		1
5	Finger_subassemv3		3
6	Forearm-Assembly		1
7	thumbpin		1
8	wristpin		3



b-23: A drawing of the fourth iteration forearm assembly, with the forearm split in two for printing ease.

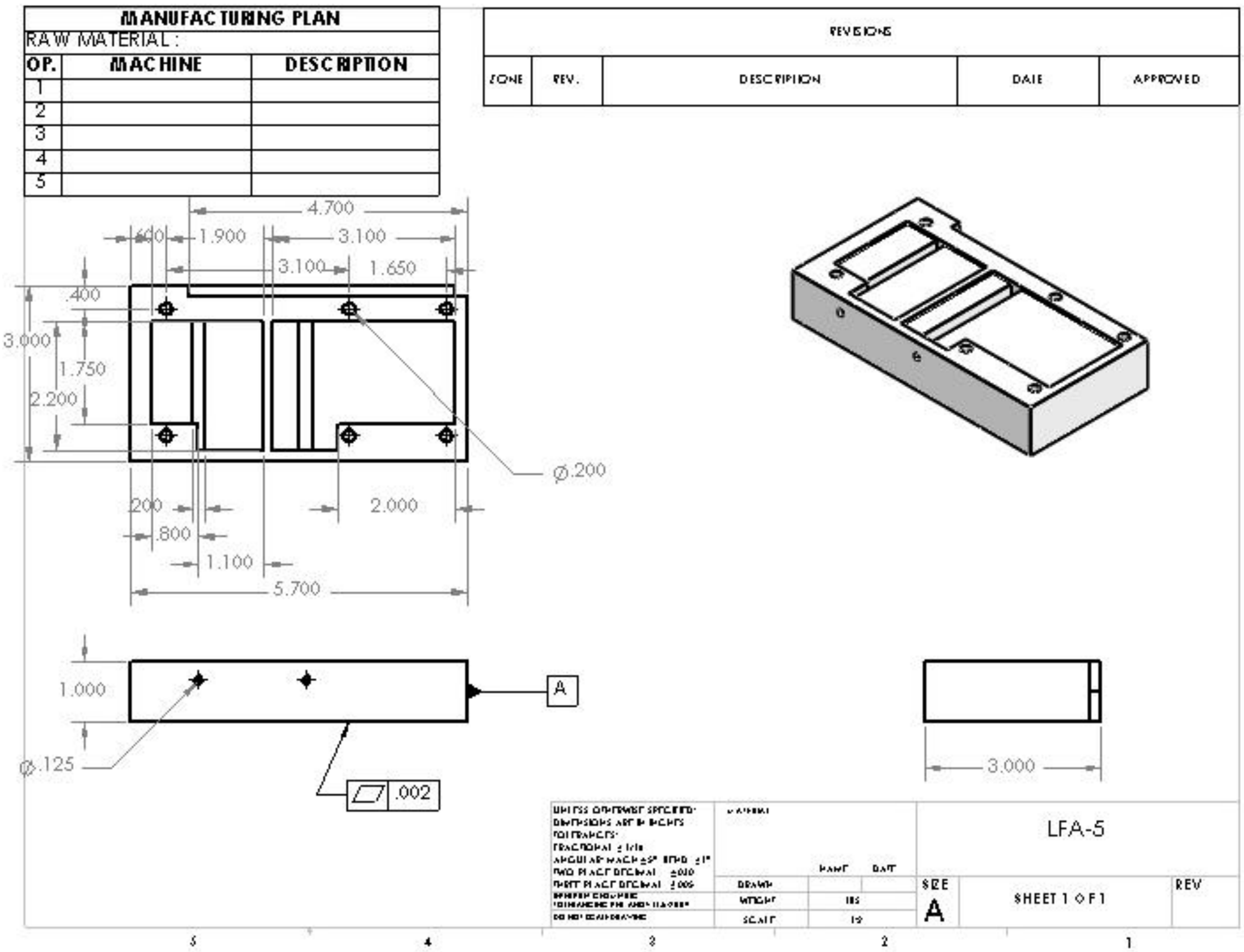


B-24: A drawing of the fourth forearm assembly, using the most current forearm design.

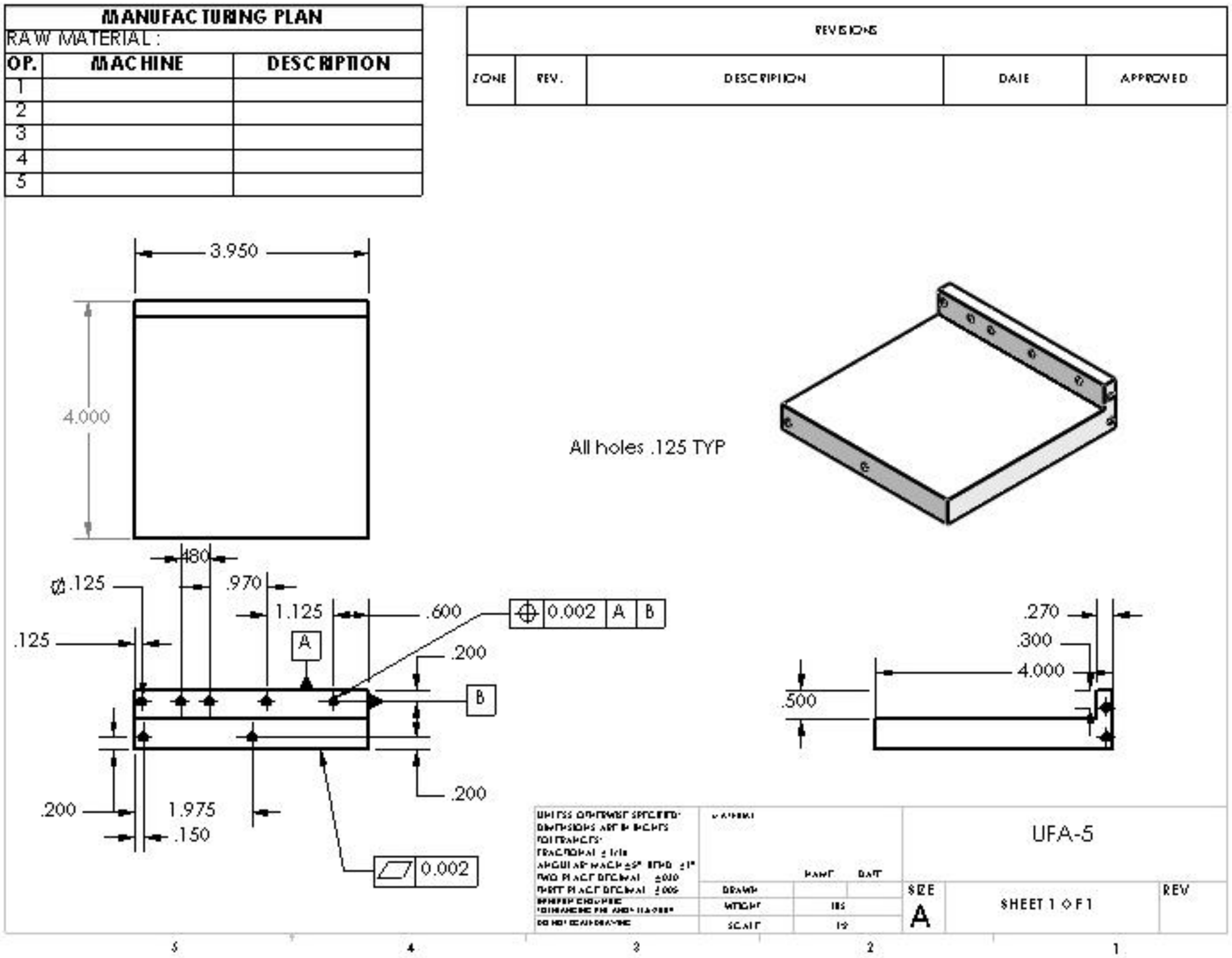


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Palm-3		1
2	T-3		1
3	LJ-3		1
4	UJ-3		1
5	Finger_subassemv3		3
6	thumbpin		1
7	wristpin		2
8	Forearm-assemv4		1

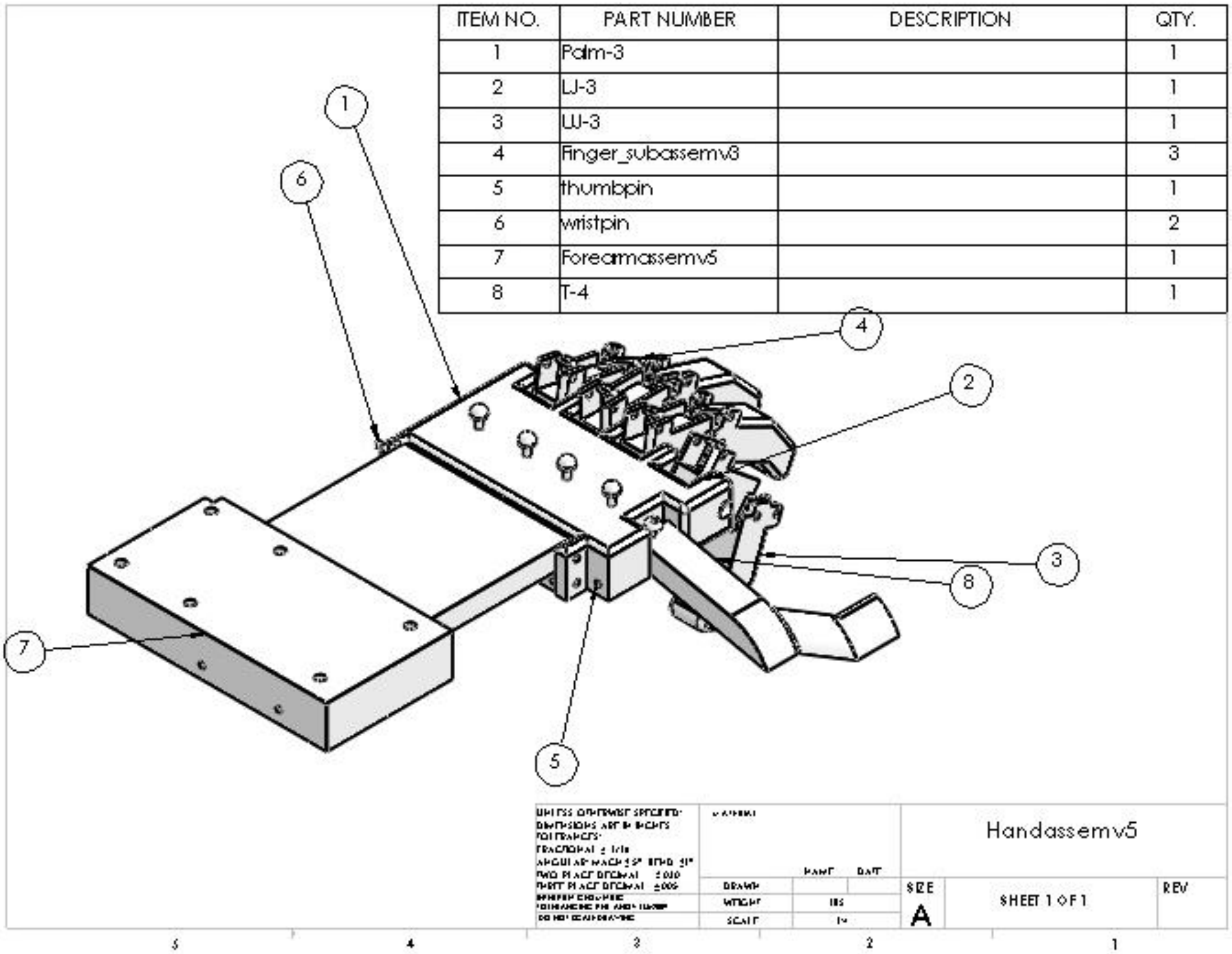
B-25: A drawing of the final iteration lower forearm to house actuators. Forearm is split in two for 3D printing ease.



B-26: A drawing of the upper portion of the final iteration forearm system.



B-27: A drawing of the fifth iteration full hand assembly that was presented and used as the final version for the end of the project.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Palm-3		1
2	LJ-3		1
3	LW-3		1
4	Finger_subassemv3		3
5	thumbpin		1
6	wristpin		2
7	Forearmassemv5		1
8	T-4		1

Appendix C

Parts List								
Item ID	Item Description	Item Source	Brand info	Model/SN	Price/Cost (USD/Hr)	Quantity	Subtotal	Actual
1	Upper Joint	CWU				4		
2	Lower joint	CWU				4		
3	knucklepin	CWU				3		
4	Assembly pin	CWU				4		
5	Thumb	CWU				1		
6	Thumb pin	CWU				1		
7	Palm	CWU				1		
8	UpperForearm	CWU				1		
9	LowerForearm	CWU				1		
						Total $	$62	

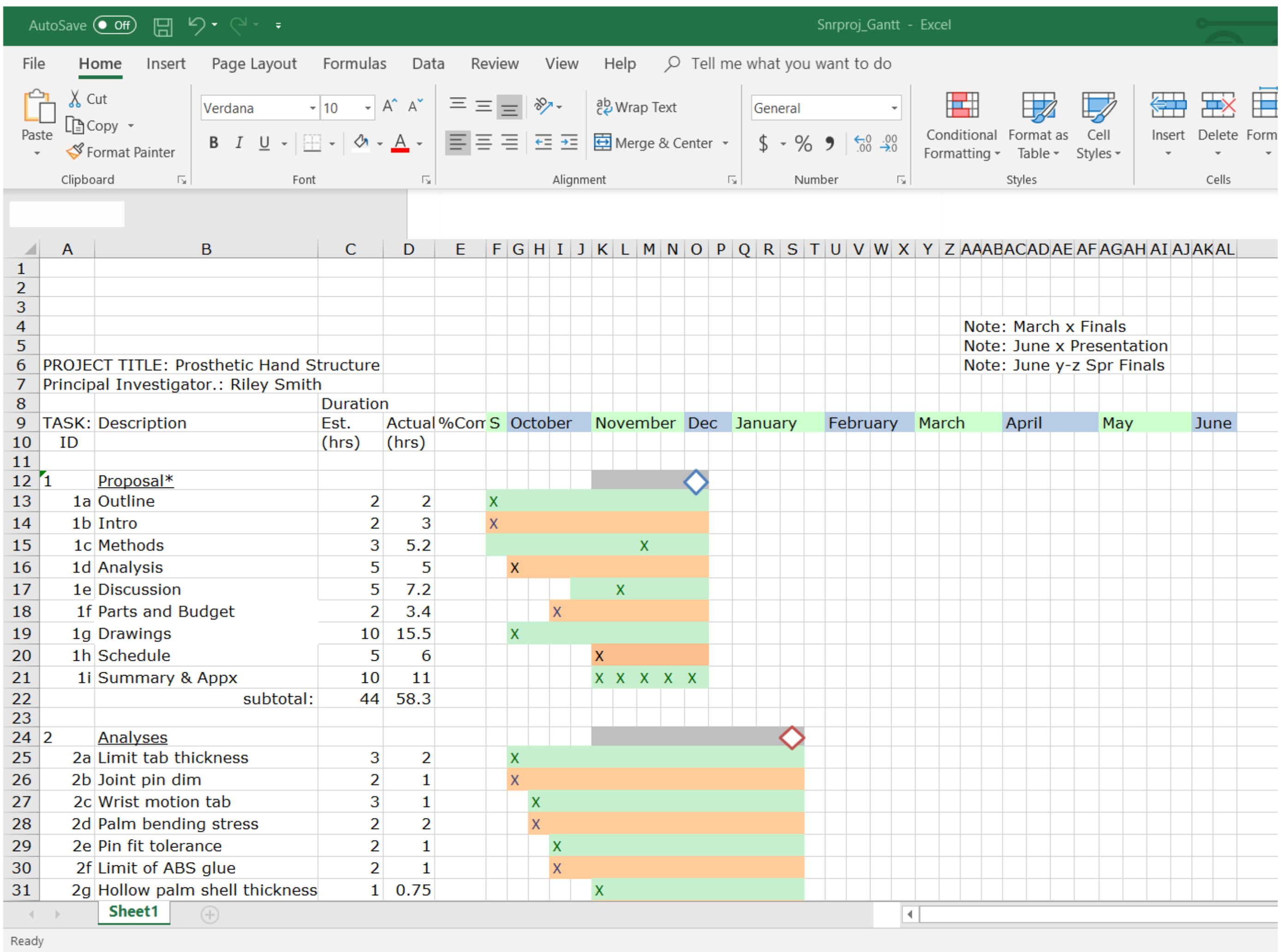
20 parts

Appendix D

Budget: with the material cost total estimating at $62 when sourced from Matterhackers, the budget that can be set is $100, so that there is potential to purchase other material if necessary. Total amount spent on filament reached $28 since the material choice became PLA only due to the cost of ABS.

Appendix E - Schedule

Due to the complexity and detail in the parts necessary to provide a functional prosthetic by the June deadline, a detailed schedule is necessary so that the project milestones and whole components are completed on time. The timeframe of each milestone is detailed in the Gantt chart. The beginning task is the design abd analysis process in use to correlate ideas bewtween the structure and articulation design.this task is enacted during the time of September to December, which will signify one milestone in the project. The next task is the building and revision of the prosthesis based on changes noted as the unit is tested. Redesign will be common in this process in order to provide the functional prosthetic by the deadline. The revising process will finish at the end of the next qaurter in march as the next milestone. The final task is the preparation of the project for presentation which is the final completion milestone. Present issues in scheduling the completion of the project involve the necessary time to incorporate the actuation components. The initial scheduled time to have full actuation integrated to the structure passed without initial unification of parts, so the deadline for that process has been extended.



Note: March x Finals
Note: June x Presentation
Note: June y-z Spr Finals

PROJECT TITLE: Prosthetic Hand Structure
Principal Investigator.: Riley Smith

TASK: ID	Description	Duration Est. (hrs)	Actual (hrs)	%Com	Schedule (S, October, November, Dec, January, February, March, April, May, June)
1	Proposal*				
1a	Outline	2	2		X
1b	Intro	2	3		X
1c	Methods	3	5.2		X
1d	Analysis	5	5		X
1e	Discussion	5	7.2		X
1f	Parts and Budget	2	3.4		X
1g	Drawings	10	15.5		X
1h	Schedule	5	6		X
1i	Summary & Appx	10	11		X X X X X
	subtotal:	44	58.3		
2	Analyses				
2a	Limit tab thickness	3	2		X
2b	Joint pin dim	2	1		X
2c	Wrist motion tab	3	1		X
2d	Palm bending stress	2	2		X
2e	Pin fit tolerance	2	1		X
2f	Limit of ABS glue	2	1		X
2g	Hollow palm shell thickness	1	0.75		X

Appendix G- Testing Data

The measured results for the tests are represented as both a pass/fail result and actual measured values of force on the hand. The results are as follows:

Test	Result
Full hand able to grip 1.2 pounds	Able, one pull string broke
One finger lifts 3.25 ounces	7.5 pounds of linear pull to achieve
Hand able to grip soda can	Pass

Appendix I- Testing Report

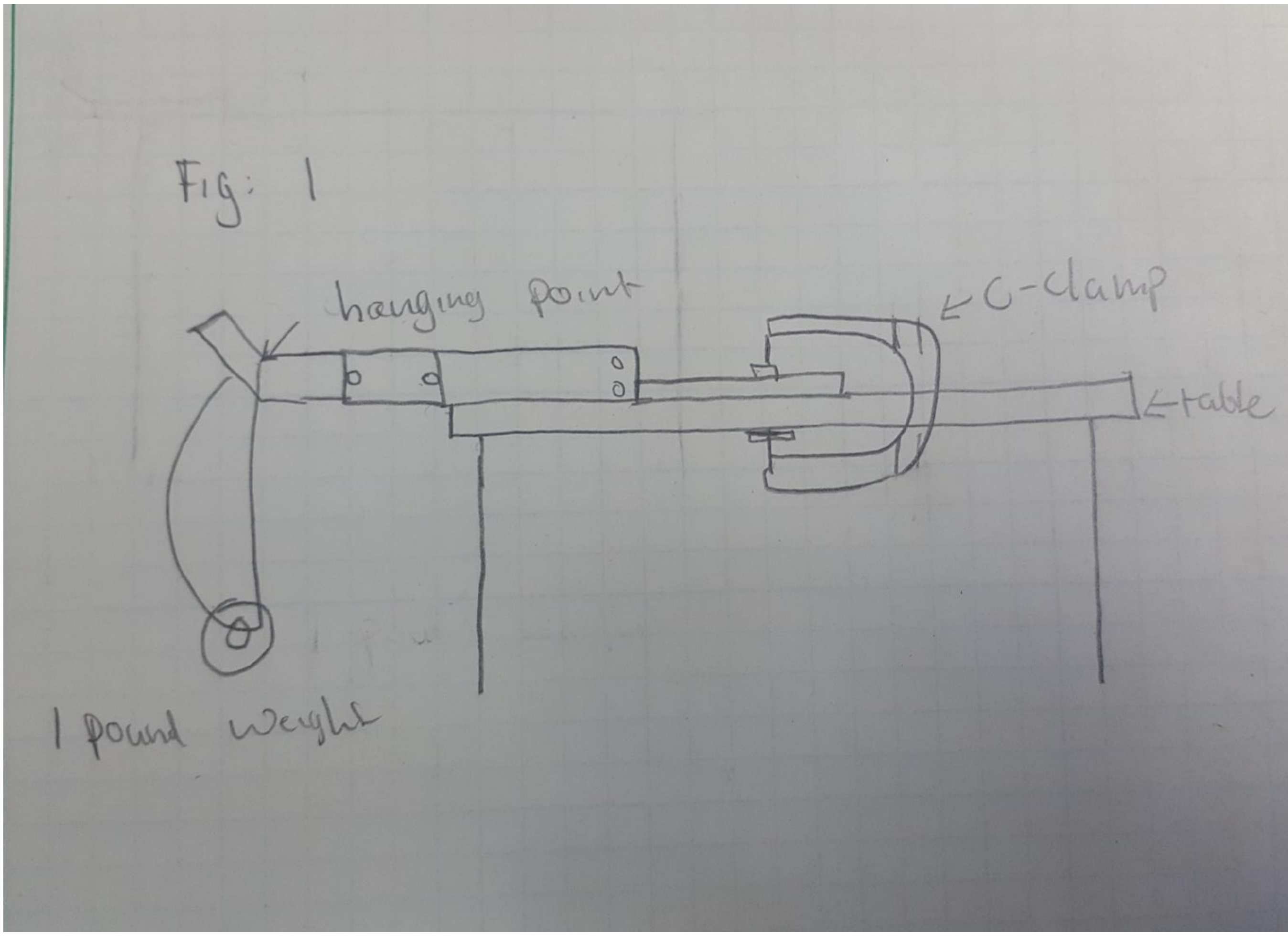
The requirements of the hand structure that need to be tested conform to the need of the hand to grip a test object in order to verify function. Other requirements that involve part failure are not parameters of interest that lead to the success of the hand. The main parameter is the ability of the hand to produce a grip force of 13 ounces. Due to the initial state of the hand design, it is predicted that the hand will fail this parameter at first, since some structure redesign is necessary. The data for this testing is force measurements done by spring scale when the hand is actuated. As referenced in the Gantt chart, the final testing of the hand will take place at the end of April/beginning of May.

Resources used when conducting testing include the use of the materials lab, and the use of its tools. The tools used include the clamps, scale, spring scale, and objects like washers and nuts. People resources include the instructors that confirmed the testing ideas, and the engineering mentors that were communicated with in order to proceed with design edits after testing results. External resources include the tools of a family owned shop. Data for the testing was documented using images and video. The video portion of testing shows how the variance in a spring scale reading can affect the data accuracy. The general method associated with the testing procedures is to affix the hand to a table while inciting motion manually. The procedures include the use of different weight levels, at first a hand test, then a finger test. The final procedure will not have the hand affixed, since grabbing a standing object is the final test. The only operational limitation of this testing is failures of the hand from others testing that may occur. This limitation will require the hand to be repaired in order to proceed with structural testing. The precision of the testing data is reliant on the tools used to measure. An example being the spring scale used to measure linear pounds of pull on the fingers. With the finest measure being pounds on the unit, that limits the nature of the acquired data. Values reported like 1.5 pounds of pull per finger were found with a digital spring scale that had a higher precision. The accuracy of force measurement is affected by the current state of the hand. With the pull strings uneven, an extra finger moves when trying to test an individual finger. This adds extra load to the result, which can be minimized based on prior measurements on individual finger forces. The readings found in each test will be presented in a table to show a pass, fail, or data value.

Test Procedure

- The overall testing procedure for the hand will be to affix the hand to a table surface and test various aspects of the hand. One primary aspect is the ability of the hand to grip a soda can with the proper force to prevent slip. The design requirement based around this test is that the hand will grip with a force of 13 ounces. To test this requirement with a safety factor, the grip of the hand is tested against a 1-pound weight. This employs a safety factor of 1.3 when the hand can grip while resisting the weight.

- The setup time of this test should take approximately 15 minutes, and the actual testing would take a further 10 minutes to complete.
- The testing location will be Hogue 127 (Materials lab)
- The needed resources for this test are a c-clamp, a spool of spider wire, and a 1-pound weight
- Specified procedure:
    1. Use the c-clamp to affix the hand to the table by clamping the underside of the forearm to the underside lip of the table. The hand would be in the palm facing upward orientation.
    2. Loop a 1-foot length of spider wire through/around the weight and tie it off as a loop.
    3. Hang the weight on the fingers so that the spider wire rides in the angle present in the fingertips. (see figure 1)
    4. Actuate the hand so that it moves into grip orientation as much as it can, while resisting the hanging weight.
    5. Record completion or failure of the hand reaching its maximum travel.
- The main risk associated with the test is if the hand becomes free from the table, or the weight is freed. Parts should not fail or splinter in this test, but safety glasses will still be used for precaution.
- This test proves the primary function goal of the hand once it is successful. The intention of the hand was to be able to grab a single object, so when it has the strength to hold that object and resist friction, it is considered a success.



- Test 2 procedure:

For the second test, the resources are the same. The difference is what portion of the hand is being tested. An added tool of a spring scale is used to determine the needed force on one finger for gripping the soda can. The setup of the test is the same as the first procedure, but the weight hanging is minimized to 3.25 ounces, and is hung on one finger for the test. The figure above also dictates the setup for this test.

- Test 3 procedure:

Being the soda can test, test 3 does not require the hand to be clamped down, instead the hand is held so that it may grip the can and is then actuated to demonstrate that the hand can grab and hold the object. The result of this test is deemed pass or fail, and if it fails changes must be made so that it is successful.

The parameter values determined during testing were the required force per finger for gripping the can, as well as the associated whole hand grip that determines whether the current motor produces enough torque. The test parameter these values were based around was that the hand would posses a grip force of 13 ounces for the test object. When measuring the linear pull of the fingers, a value of 7.5 pounds was measured. For full hand grip this equates to 30 pounds of linear pull to reach the required grip strength. The larger motor now used has a potential of 36 pounds of pull, so there is room to then accommodate friction and other resistive forces. The 36 pounds of capable pull was a value calculated from the torque rating provided for the motor in use. Being able to move the hand into grip orientation with the testing load was part of the success criteria associated with testing. The other criteria in the case of the second test was whether a measurable value could be found using tools. With the completion of the final test of the hand, the conclusion of testing is that the hand reached the goals of the set parameters, so that the design of the hand is determined to be a success.

Appendix

Test	Result
Full hand able to grip 1.2 pounds	Able, one pull string broke
One finger lifts 3.25 ounces	7.5 pounds of linear pull to achieve
Hand able to grip soda can	Pass

0	Device Evaluation		
10a	written up testing plan	5	5
10b	Testing	5	11
10c		0	0
10d		0	0

Appendix J- Job safety analysis

Engineering Technologies, Safety, and Construction Department

JOB HAZARD ANALYSIS
Prep of 3D components

Prepared by: Riley Smith	Reviewed by: Approved by:

Location of Task:	Machine shop 107, PC lab 118
Required Equipment / Training for Task:	3D printers, proper surface finish technique for 3D printed plastics, drill press with reamer
Reference Materials as appropriate:	

Personal Protective Equipment (PPE) Required (Check the box for required PPE and list any additional/specific PPE to be used in "Controls" section)						
Gloves	Dust Mask	Eye Protection	Welding Mask	Appropriate Footwear	Hearing Protection	Protective Clothing
☒	☐	☒	☐	☐	☐	☒
Use of any respiratory protective device beyond a filtering facepiece respirator (dust mask) is voluntary by the user.						

PICTURES (if applicable)	TASK DESCRIPTION	HAZARDS	CONTROLS
	3D printing process	Heat	Printer needs to be closed during process
	Use of Acetone to clean printed components	chemical	Usage of listed PPE to keep acetone away from skin and eyes
	Reaming out the holes on each printed component	Cut/puncture, being ensnared by machine	Listed PPE as well as proper SOP known

Appendix K- Resume

Riley J. Smith

944 Beverly Burke Rd N Quincy, WA 98848 | 509-750-3787 | rjsmith96@hotmail.com

Education

GENERAL EDUCATION | JUNE 2015 | EPHRATA HIGH SCHOOL

MECHANICAL ENGINEERING TECHNOLOGY/ ROBOTICS AND AUTOMATION| JUNE 2020 | CENTRAL WASHINGTON UNIVERSITY

Experience

SHOP ASSISTANT | CAMCO RACING INNOVATIONS | SUMMER 2013-2016

- Gathered necessary tools for each task
- Lent an extra hand when more than one person is needed for a job

STUDENT TECHNICIAN | EHS TECH DEPARTMENT | SUMMER 2014

- Pulled CAT 5 cable in ceilings of schools
- Performed cable management in server rooms
- Kept tech shop tidy and packaged surplus items
- Managed inventory of school district technology
- Worked with a team of two full-time technicians

LABORER| IRWIN ALBRECHT | SUMMER 2012

- Pulled weeds in one of the fields
- Helped a Harrow bed operator by setting the poles in the hay that he stacked.

FIELD TECHNICIAN | MINERLOGIC | SUMMER 2018

- Unboxed and set up server hardware at on-site locations
- Maintained customer systems while monitoring software was developed
- Built customer servers with specified hardware
- Performed maintenance on server sites to keep dust levels down
- Aided electrician side of company with manual tasks when necessary
- Maintained dialogue with customer in order to answer questions
- Ordered and maintained part flow so that server building did not stall

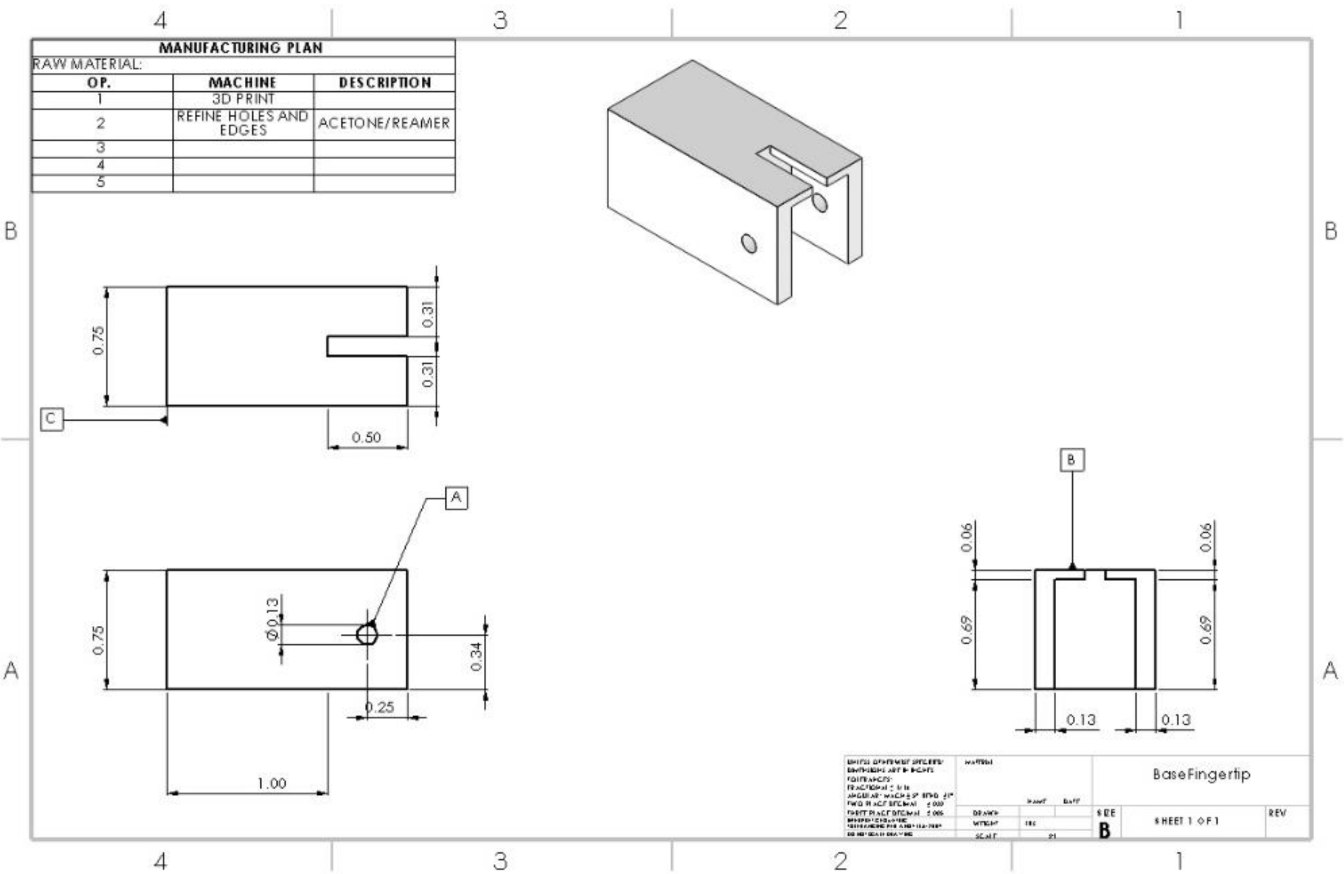
Skills

- Proficient in computer building
- Certified SolidWorks Associate
- Possess basic command Linux skills
- Microsoft Office products

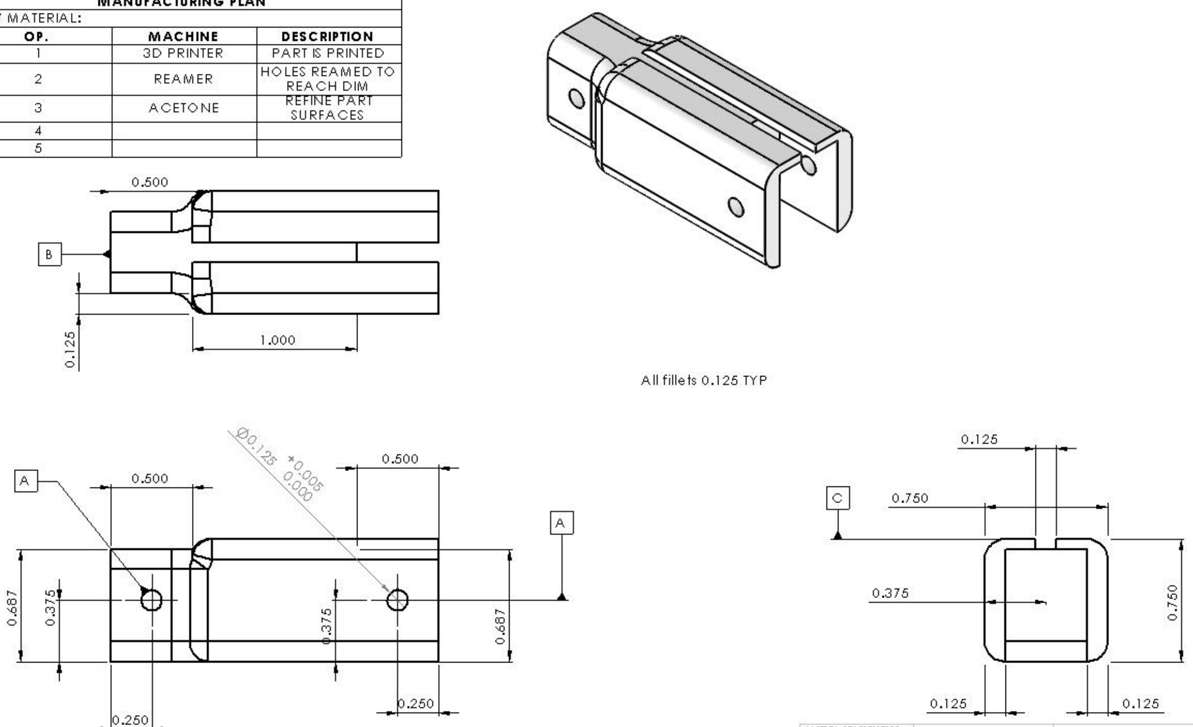
- Basic skills in metal fabrication/machining

Appendix L

MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	**MACHINE**	**DESCRIPTION**
1	3D PRINT	
2	REFINE HOLES AND EDGES	ACETONE/REAMER
3		
4		
5		

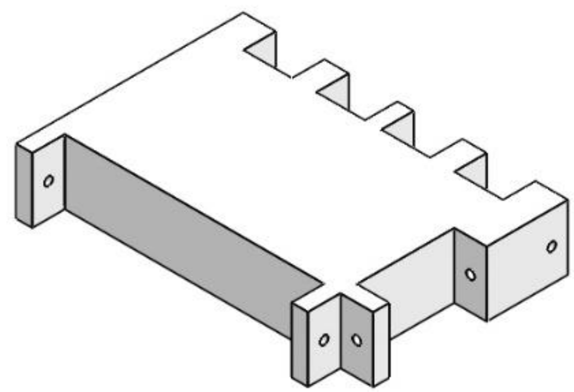


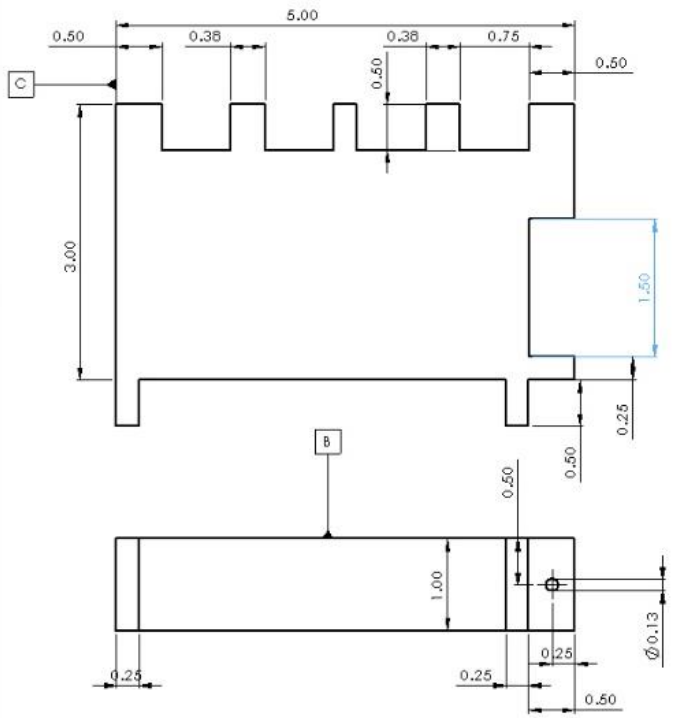
MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PART IS PRINTED
2	REAMER	HOLES REAMED TO REACH DIM
3	ACETONE	REFINE PART SURFACES
4		
5		



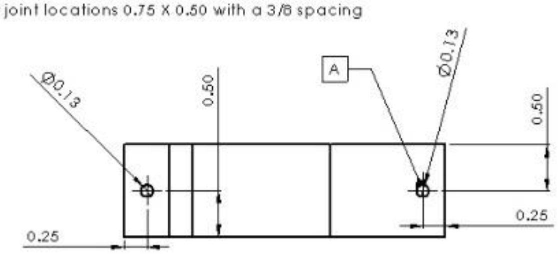
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16 ANGULAR: MACH ± .5° BEND ± 1° TWO PLACE DECIMAL ± .030 THREE PLACE DECIMAL ± .005	MATERIAL	NAME	DATE	MJ-1
	DRAWN			SIZE B — SHEET 1 OF 1 — REV
INTERPRET GEOMETRIC TOLERANCING PER: ASME Y14.5-2009	WEIGHT			
DO NOT SCALE DRAWING	SCALE	2:1		

MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PRINT PART
2	REAMER ON DRILL	REAM HOLES
3	ACETONE	CLEAN SURFACE
4		
5		





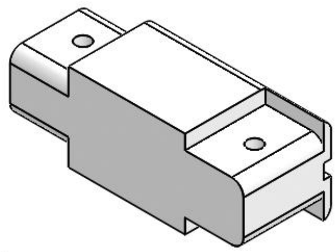
All finger joint locations 0.75 X 0.50 with a 3/8 spacing

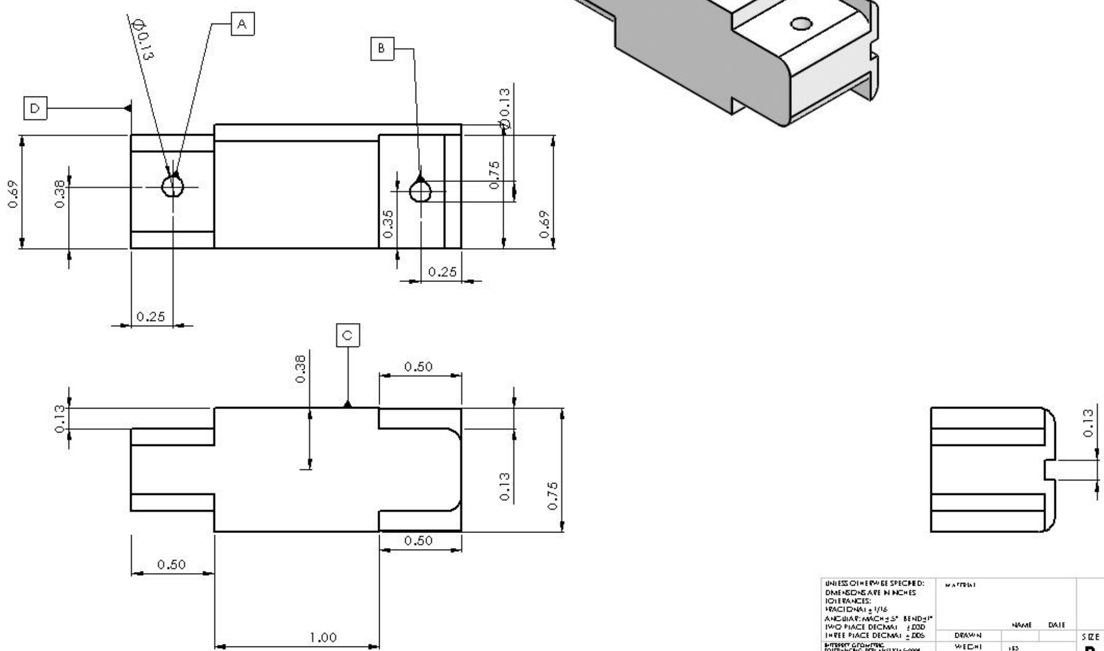


Palm

SIZE B | SHEET 1 OF 1 | REV

MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PRINT PART
2	REAMER	REAM OUT HOLE DIM
3	ACETONE	REFINE SURFACE
4		
5		





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
ANGULAR: MACH ± .5° BEND ± 1°
TWO PLACE DECIMAL ± .030
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009
DO NOT SCALE DRAWING

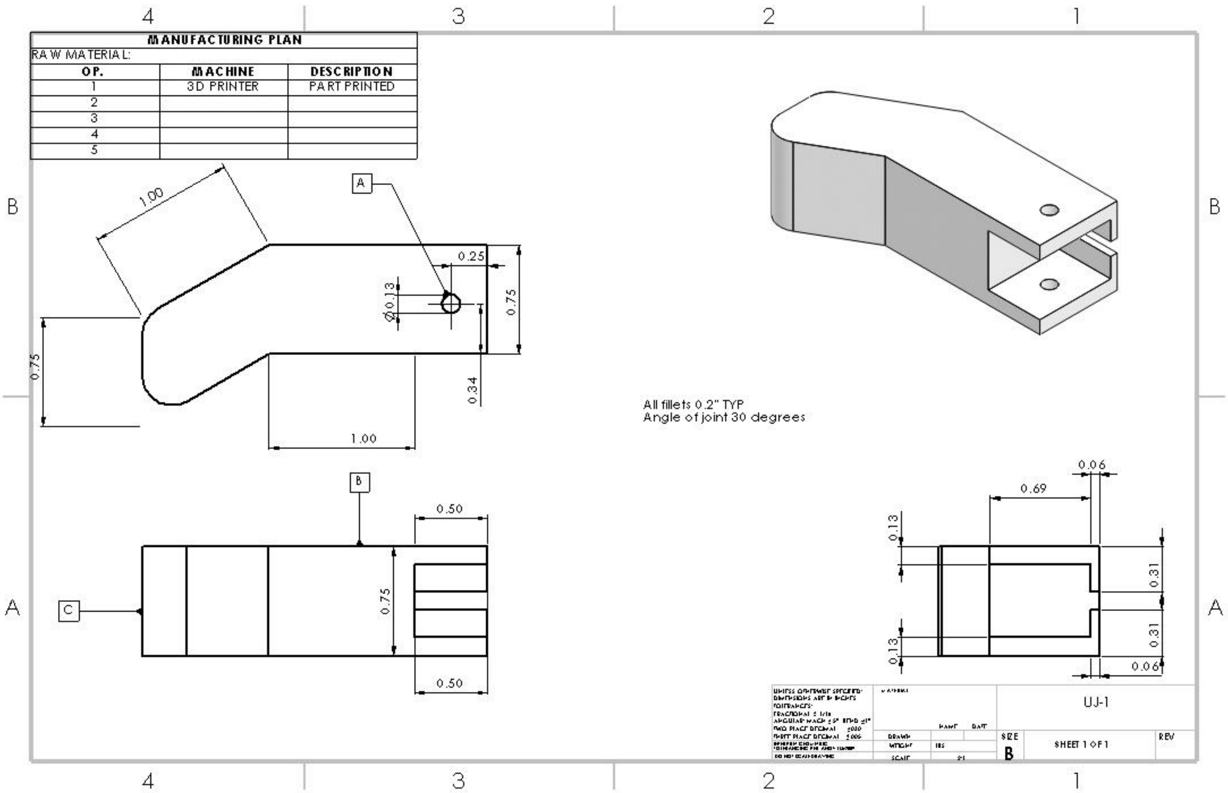
MATERIAL

	NAME	DATE
DRAWN		
WEIGHT		
SCALE	2:1	

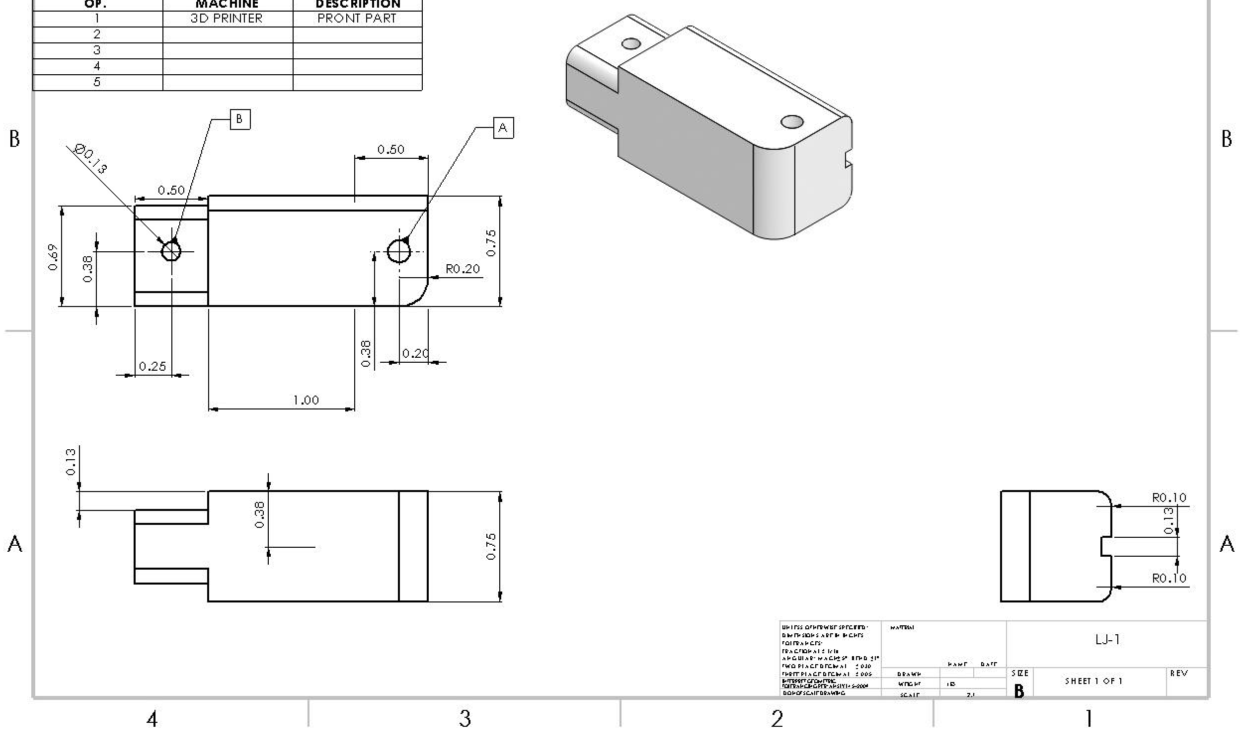
B-5

SIZE B | SHEET 1 OF 1 | REV

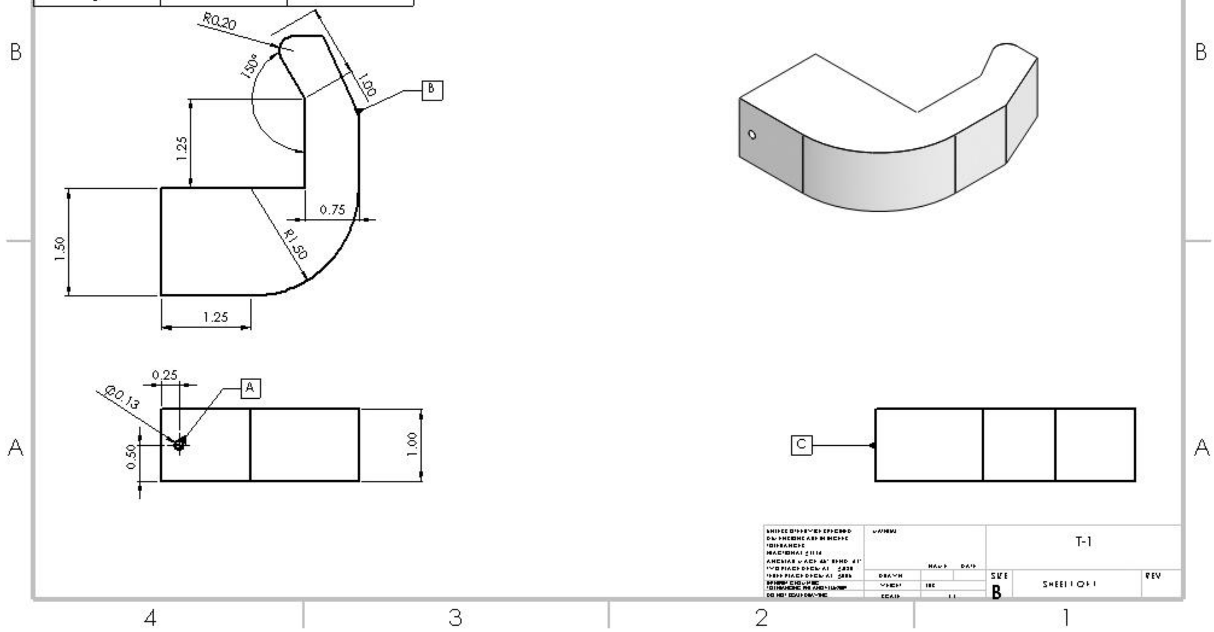
MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PART PRINTED
2		
3		
4		
5		



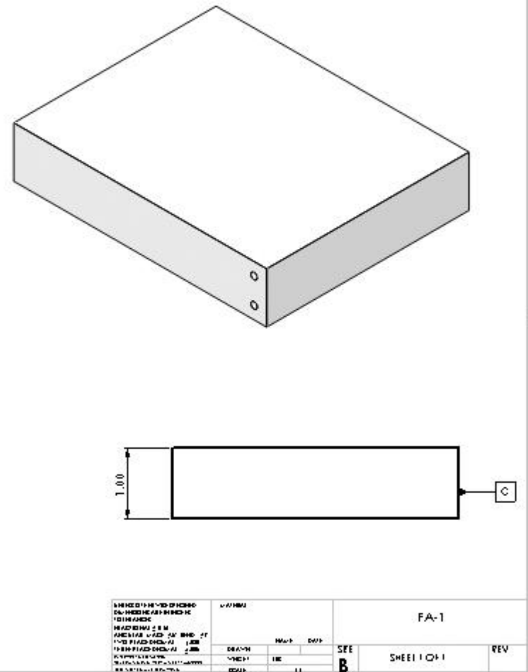
MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PRONT PART
2		
3		
4		
5		

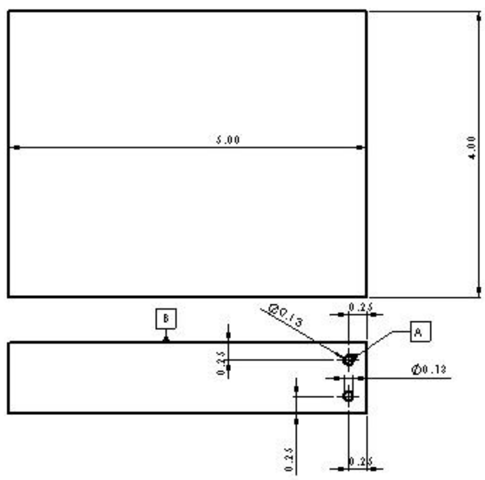


MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PRINT PART
2		
3		
4		
5		



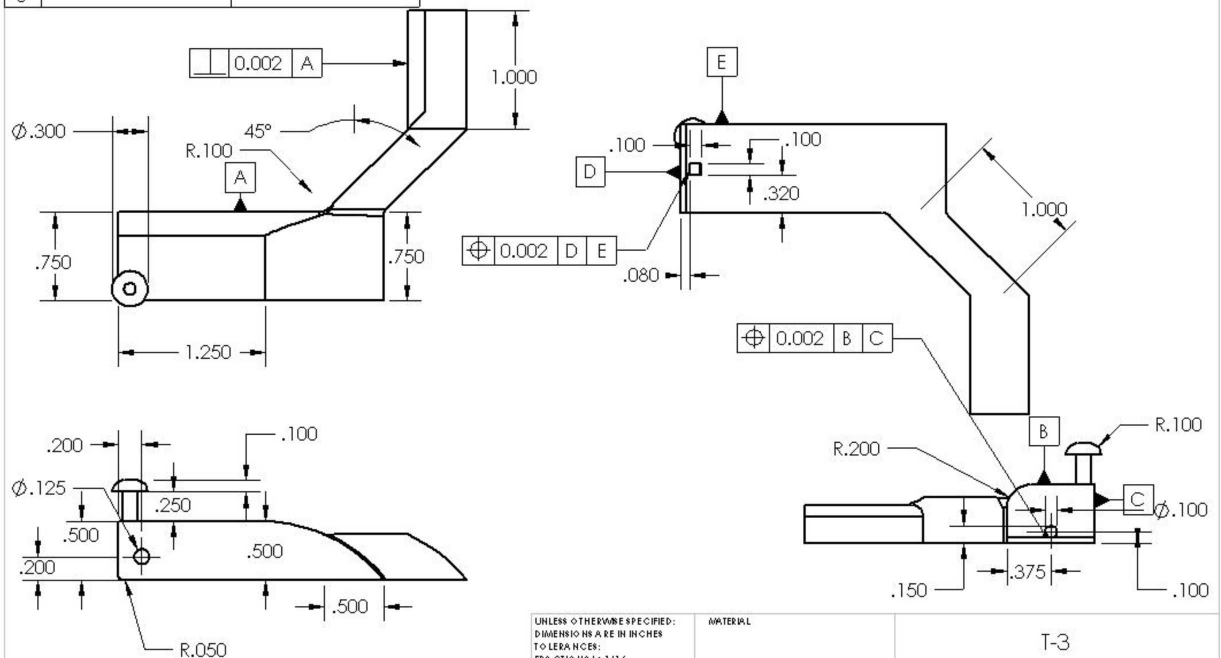
MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	MACHINE	DESCRIPTION
1	3D PRINTER	PART PRINTED
2		
3		
4		
5		





MANUFACTURING PLAN		
RAW MATERIAL :		
OP.	**MACHINE**	**DESCRIPTION**
1	stl	convert to stl
2	orientation	choose orientation
3	3D printer	print part
4		
5		

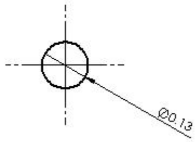
REVISIONS				
ZONE	REV.	DESCRIPTION	DATE	APPROVED

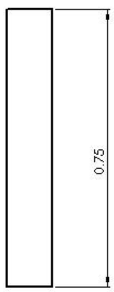


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± 1/16 ANGULAR: MACH ± .5° BEND ± 1° TWO PLACE DECIMAL ± .030 THREE PLACE DECIMAL ± .005	MATERIAL	NAME	DATE	T-3		
	DRAWN			SIZE A	SHEET 1 OF 1	REV
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14.5-2009	WEIGHT	LBS				
DO NOT SCALE DRAWING	SCALE	1:1				

5 4 3 2 1

MANUFACTURING PLAN		
RAW MATERIAL:		
OP.	**MACHINE**	**DESCRIPTION**
1	3D PRINTER	PRINT PART
2		
3		
4		
5		





assorted pins of length 0.75, 2.125, and 5 inches

MATERIAL	NAME	DATE	assypin
DRAWN			SIZE B
WEIGHT	LBS		SHEET 1 OF 1
SCALE			REV