Senior Project

Final Report for

Hay Hook

in the partial fulfillment of

TECH 4945

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submitted 12/1/2023

Executive Summary

Hay hooks are not designed with the user in mind. They put pressure on the user's wrist, which may cause sprains during use. The design of this hay hook has taken what is already there and improve on it by dividing up the load from the user's wrist and channeling it onto the forearm via a lever arm. This result supplies more comfort for the user. The hook has a focus on safety, the tip of the tool is rounded to reduce injury from falling on the hook. It has also been overdesigned as to ensure a safety factor in case of improper use.

The hook has been designed based off standard machining practices as well as standard specifications of steel and dimensions. A major part of design and manufacturing is repeatability and availability. It is frequent practice to design things based off available parts and standard materials. Common machinery techniques were used in the design and manufacturing of this hay hook as to ensure it can be reproduced in the future.

Although without its downfalls the production process of the hay hook was simple due to the plan development during the design phase. The hook was designed with standards in mind so there was little need to create tooling other than for a specific bend. During the creation of the tooling for that bend there were many hangups that resulted in delays and issues. However, after a few workarounds, the tooling was made, and the hook was completed on time.

With some minor design flaws the resulting hay hook met all goals that were set out to accomplish as well as had a nice aesthetic factor. It was able to lift the hay bales as designed and felt comfortable to the user. There were some minor issues with the hook section being too stout leading to the hook being overdesigned. It was finished with a nice powder coat making it weather resistant and aesthetically pleasing.

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Introduction

Hay hooks are used to move square hay bales from one place to another. The hook has seen little improvement throughout the years as there is not a vast number of parts to change and improve upon. However, using leverage in tooling is an ergonomic way to improve on what is already there. By adding a lever arm to the hay hook a user can divvy the load and stress that using that tool is putting on their body.

Review of Objectives

This hook will be designed with the user in mind to create a safer and more effective way of lifting square hay bales and moving them from one place to another. This resulting tool will have better ergonomics for the user as well as should be cheap to produce. The tool should be smooth and comfortable to the operator therefore it needs to include smooth edges as well as be light and balanced.

Review of Deliverables

The result of the hay hook will be 2 physical prototypes capable of lifting a 100-pound hay bale without permanent deformation. These hay hooks will have rounded pointed hooks and smooth edges to make it safer for the user. The hooks will also be finished with a powder coat to be weather resistant. Sub deliverables of this project will be a die capable of repeatedly bending the specified arc on the hook section. The project will also result in any necessary calculations collected and tracked as well as a completed assembly file.

Technical Implementation

For the hay hook to come into being a 3D model of the hook had to be designed based off standard dimensions and attainable materials. Using the modeling software by siemens, NX, a 3D model of roughly what would be made was completed as shown in (Figure 1). In NX users can set up beam deflection simulations to see how applied loads will affect models with given constraints. A deflection simulation was setup and ran in NX as shown in (Figure 2) to ensure that the hook section would be able to withstand the applied loads with the constrained materials that were available. Originally the deflection value seemed too great, so the hook was shortened and the calculations were ran until a suitable value was generated.

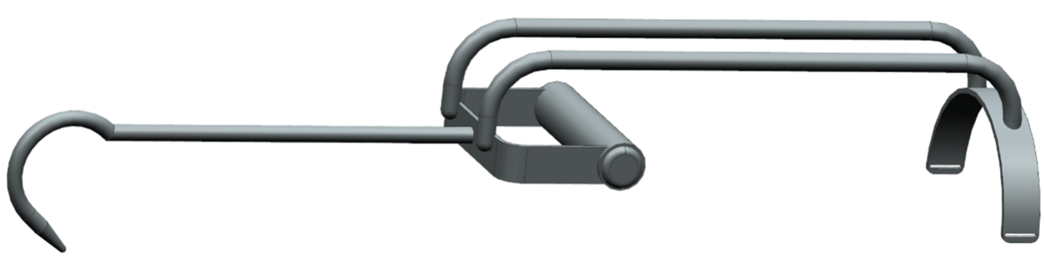

Figure 1 Original Hay Hook Model

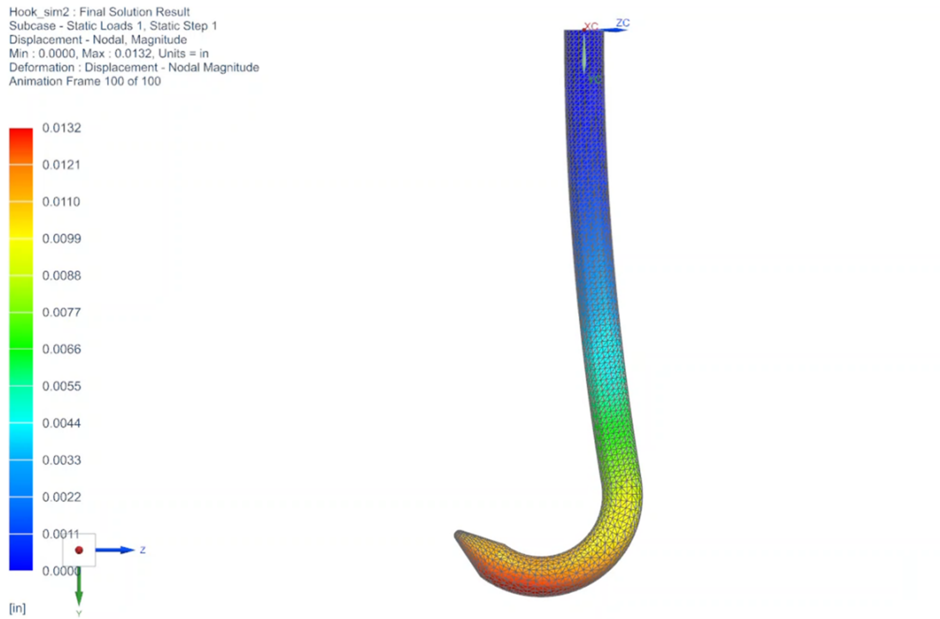

Figure 2 Deflection Simulation

In (Figure 2) the constraining variables are the load and direction. The load is 100 pounds, and the direction of the load is down. There is a fixed constraint at the top face of the bar to act as the anchor point. As shown the max deflection of the beam is 0.013 inches, also called 13 thou, for a hook that is 3/4th inches thick. This value is on the lower range of what was planned for therefore making it tougher than initially designed for.

Before the steel was ordered a bending die was going to have to be designed to bend the curved section on the hook. Based on S7 tool steel that was on hand at the University of Memphis Engineering Technology department a die was created. During the design of the die, it became clear that to get the original design of the curved hook section a complex moving die would need to be made. To make the die simpler the curve of the hook section was changed as shown in (Figure 3). The entire curve is tangent and there are no kickouts as shown in the original model. This change resulted in different geometry to achieve the same result.

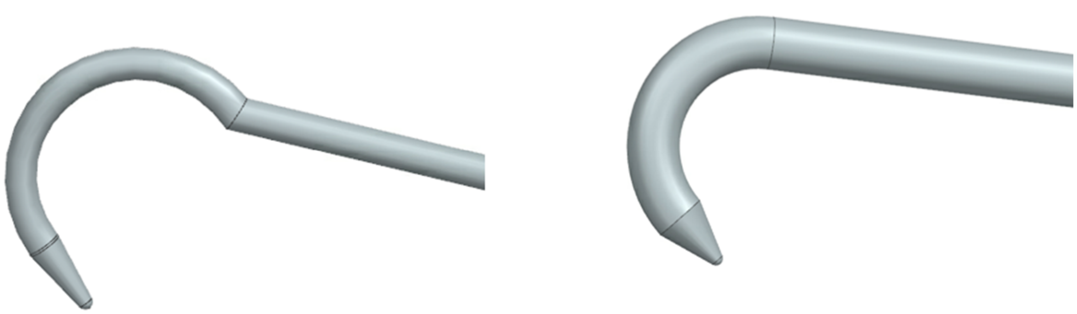

Figure 3 Hook Geometry Change

The B side of this die took the outer radius of the curved hook section and accounted for 1° of spring back. The A side of the die was designed with the inner radius of the curved part of the hook and accounted for the 1° of spring back. Then the hard edges of the die were rounded to make the tool a little bit safer and have a bit of an oversized fit. The A side of the die was going to need to fit in a T-slot adapter so the adapter was measured and the resulting slots were put into the model shown in (Figure 5) The finished models of the dies are shown in (Figure 4) and (Figure 5).

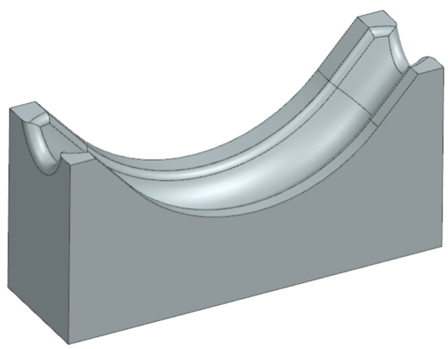

Figure 4 B Side Die

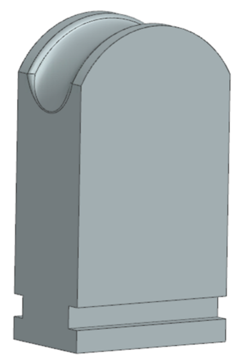

Figure 5 A Side Die

After the first finished models of the dies were ready, a safety check was performed by checking that the materials could withstand the forces applied by the 55-ton Ironworker. To run this check, values need to be plugged into the Bending Force equation shown in (Equation 1).

$$\text{Bending Force [BF]} = \frac{\text{K Factor [k]} * \text{ Bend length [L]} * \text{ Tensile Strength [St]} * \text{ Thickness [t]}^2}{\text{Die Opening [d]}}$$

Equation 1 Bending Force

The yield strength of the bar stock that is going to be bent is 60,000 psi, this is saying that 60,000 psi is the point on the stress strain curve where the material begins to permanently deform. The K factor used for these calculations is a constant 0.446 which is a standard ratio. The thickness of the bar and the length of the die opening is 0.75 and 3.5 inches, respectively. The length of the bend is the contact length of the bend touching the die. These values were rounded up a little to provide a bit of cushion. As shown in (Equation 2) the resulting force that the die needs to withstand is roughly 15,000 pounds which is well within limit for the 55-ton press and the 290,000 psi ultimate yield strength of the S7 tool steel.

$$15052.5 \text{ (lbs)} = \frac{0.446 * 3.5 \text{ (in)} * \text{ } 60000 \text{ (psi)} * \text{ } 0.75^2 (in)}{3.5 \text{ (in)}}$$

Equation 2 Bending Force Solved

Once it was found that the hook would work in theory the process of physical construction began. Before anything could be bought it was imperative that the correct amount of steel was ordered.

Bending analysis calculations were preformed to find the correct length of each material that was needed and then a loose safety factor was applied to ensure that there would be extra material.

After confirming the correct amount of steel needed, the steel was ordered from Memphis Metal Supermarkets. Then the steel was picked up at their warehouse location and taken back to the University of Memphis for storage and work. Since the steel was bought with the intention of making two hay hooks the first thing to do was to cut the pieces of steel to rough lengths so that it would be easier to manage.

Now that the steel was on hand the process of physically making the bending die could begin. The major dimensions of the blank needed to match the major dimensions of the die. Both blanks were set up in a knee mill and a face milling tool was used to get the dimensions needed. The exact dimensions of the blank were recorded and geometry in NX was created based on those dimensions. From there the setup of the Haas TM-1B machine was put into NX to generate the correct G-code for the machine as shown in (Figure 6).

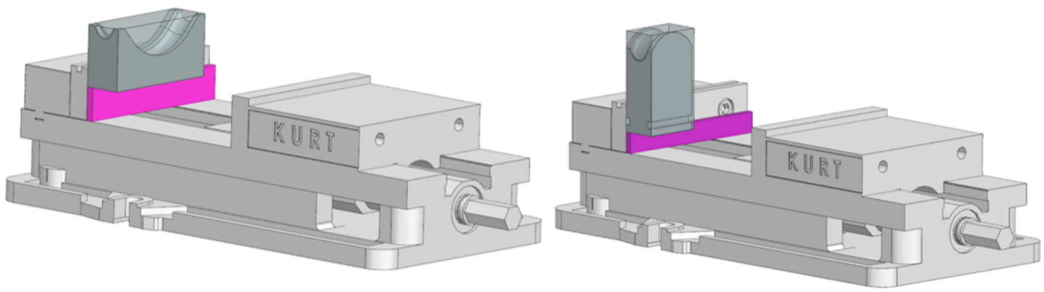

Figure 6 NX Die Setup A & B

There were two operations created to properly mill off the material, A roughing cycle with a 0.5" carbide end mill and a 0.25" ball nose carbide end mill to do a finishing cycle and make the rounded edges. Once the G-code was generated the blank was put in the CNC machine as shown in (Figure 6) and the work offset was setup. After a crash of the CNC machine and a shattered ball end mill the correct offsets were input into the machine and it was ready to run the G-code.

There was an issue where the incorrect tool was set up in the machine but that was rectified, and the program was ran creating the die. For the B side a bit of sanding was done to knock off the sharp edges. Once the A side was completed a 0.125" end mill was setup, and the t-slot was cut out in the CNC machine by manually moving the dial. Once this was done and it was verified to fit in the T-slot adapter the A side of the die was sanded to knock off the hard edges. The finished dies are shown in (Figure 7), Die B is shown on the left and Die A is shown in the T slot adapter for the 55-ton ironworker on the right.

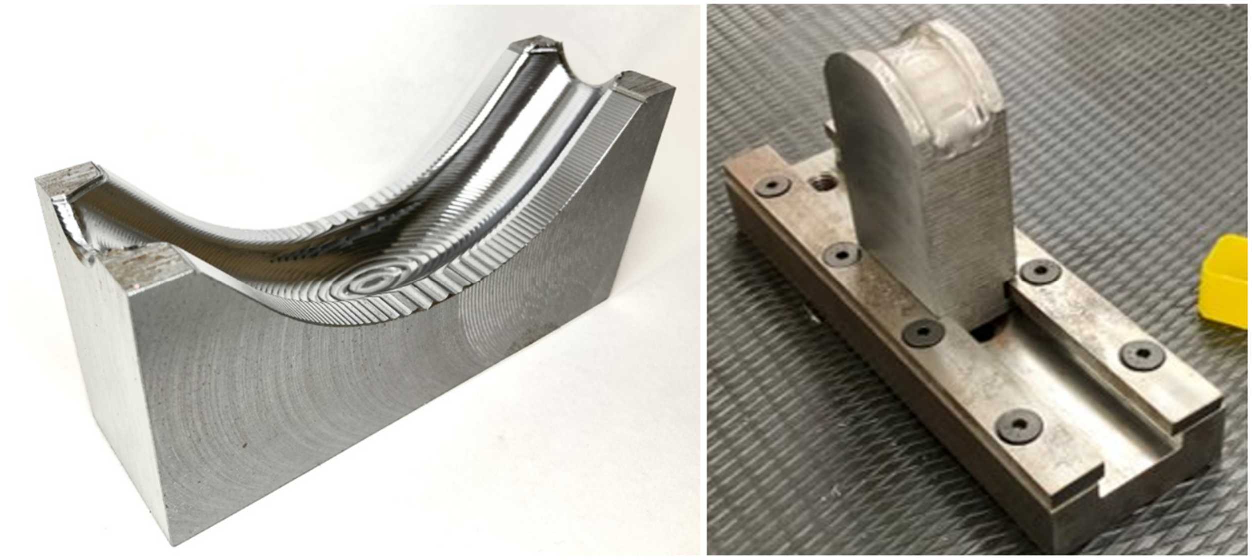

Figure 7 Finished Dies A & B

The next step in the process is to heat treat the tool steel to take it from roughly mid-40’s Rockwell C scale to mid-50’s Rockwell C. Using a data sheet from Latrobe Specialty Steel Company on S7 Shock-Resisting Tool steel and how to heat treat it the given values were used. Next the operator preheated the oven, Initially the oven was set to 1500°C due to the operator not knowing the oven was measured in Celsius. Once it was made aware that the oven was in a different unit of measure conversions were done and the oven was set to 838°C.

The oven was having an issue with holding heat due to operator error, so when the oven got to temperature it was unable to hold that temperature and cooled down at a slow rate for the next few hours. Once the operator was able to find a way to set the oven to hold the temperature the steel soaked at around 838°C for 45 minutes. After that time passed the steel was taken out of the oven and left on a metal mesh shelf overnight. The next day the dies were put in a small toaster oven at 450°F to temper for 1 hour. After that was complete it was taken out of the toaster oven and left to cool for a few hours on stone bricks. Once cool the dies were sanded and deburred to ensure there were no sharp edges.

Since all the tooling needed to complete the prototype was finished, physical work began on the parts to make the hay hook. For the first part a lathe was used to turn the end points of the hook. The tool post of the lathe was set up at a 40° angle and the point was turned. Once the hook was turned a file was used to smooth out the tip. The basic geometry of the hook was complete and all that was left to do on that part was to bend it. For the arm plate a piece of flat stock was taken to a belt sander and the edges were rounded.

Next the lever arms were going to be produced. The 0.5” CR1018 steel was cut to length and put in the lathe. Once in the lathe a file was used to rough out, the curvature of the notch. The workpiece was taken over to a knee mill and the notch was milled out. Once notched it was taken over to a band saw to cut the ends at an angle. The band saw was set to 30° and the steel was cut, the mirror side used the same operations except it was flipped upside down to get the opposite angle. Once all the basic parts had most of the straight geometry completed bending centers were marked out. This is where the previously calculated bending analysis was used to find the center of the bend.

The shield part of the hook was taken to the 55-Ton Iron Worker hydraulic press and a 1” diameter punch die was inserted. The flat stock was put into position by lining up the point on the die with the edge of the stock and the press was activated, this operation was repeated on the opposite side. Once the semi circles were punched out a v block was put on the press side of the Iron Worker. The flat bar was put in a the bottom of the die and lined up to the previously made mark on the flat stock and bend to 90°. This operation was also repeated on the opposite side. The lever arms were put in the same V die and bent in the same manner.

The arm plate section was taken to a slip roll to get an even arc. The slip roll was not working so the operator used a press brake instead to get the rough shape. The stock was secured in and bent then after the bend it was unclamped and moved a short distance and the operation was repeated. This piece was then put into the slip roll to smooth out the harder bends.

The hook bend was the last thing to do to make the individual parts. The previously mentioned bending die was set up in the iron worker with plates of S7 steel under the B side die to get the correct depth. Once set up, an acetylene torch was lit, and the upper section of the bar was heated until glowing. Once hot it was taken to the die and set up. After a cycle of the die the rod was moved and the cycle repeated until the correct shape.

Now that all the individual parts were made the assembly can take shape. Using standard welding practices, modular welding fixtures were used to weld each piece together, the finished welded assembly is shown in (Figure 8). Once the welds were done, they were cleaned with an angle grinder. After the welds were cleaned up a test was preformed where an operator stood on the hook to assess how the welds would hold up as well as dropping the hook to endure so shock would break the welds. Next the hook was taken to Rick’s Powder Coating in Memphis, TN to get a finishing powder coat. Once the coated hooks were complete, they were taken back to the university where the end caps were put on by using a vise. Now that the hay hooks were completed as shown in (Figure 9), they were evaluated by lifting 100-pound hay bales and moving them.

Figure 8 Welded Assembly

Figure 9 Completed Hay Hooks

Evaluation of Plan of Work

The timeline for this project was loose. The “final” design was completed way ahead of schedule and then a sabbatical was taken during the time the steel was supposed to be ordered. This was a bit of a setback but not really since the project was planned to be finished early. Towards the end of the deadline for the project to be completed the time constraints started getting a little tight. Even with the tight time towards the end the project got completed early.

The design section of the work process was straight forward and simple. There was a constraint to design off standard stocks with availability and that was accomplished. There were a few design changes throughout the entire process, but they were simple and didn’t require any extra steel. In the end the punched-out section of the arm plate ended up getting taken out due to the geometry of the slot being too weak to hold onto a user’s arm safely.

The steel supplier was a great choice due to them being a local place with the availability of what was needed and having standard quality ANSI 1018 standard steel. The steel should have been ordered after the die was created, this would have been the safer option as if the die design did not work more steel might have been ordered. The entire workflow was thrown off due to the die not being made first, the die should have been finished entirely before any of the physical parts began besides cut to length.

During the process of making the die the 3D model of it was not correct for much of the time. The entire time it was being designed it was being constrained off arc distances when it should have just been based on degrees. Basing the die on degrees would’ve made the entire series of design calculations much easier. Along with that the hook could’ve just been input in NX along with the die blank and then subtracted from the main geometry making it incredibly simpler.

Setting up the Haas CNC machine with the offsets was a huge mistake that occurred. Originally the G54 work offsets were setup correctly however there was difficulty setting up the tool length offset as the tool was being zero based on the bottom of the vise. During a lapse of judgement, the operator ended up running the program at full speed. The resulting catastrophe ensued, the tool rammed full speed into the vise and shattered on impact right after leaving a divot in the vise. The safeguards for the Haas worked as they should have and shut down the machine. Once the operator had learned the proper way to input the tool offset the machine ran as expected.

The next issue that occurred with the Haas was that the 0.5” end mill that was planned and set up in the machine ended up being made from high-speed steel. Using highspeed steel on S7 steel is very inefficient since the highspeed steel is close to the hardness of the S7 steel. The result of this was the highspeed steel end mill was wearing out at an alarming rate as well as skating off the surface of the workpiece which also caused a large amount of load to occur on the tool. Once the tool was switched to carbide the program ran as expected and it sounded better than with the high-speed steel.

An issue occurred while putting in the t-slot on the A side of the die. When the slots were being cut the offset information was input at the corner of the die so that correct calculations could be made on the exact location of the slot. This worked well for one side but when it came time for the other side an error was made, and the tool diameter was accounted for 2 times making the slot ½ as big as it should have been as shown in (Figure 10). Luckily, it was on the opposite side of the critical connection point for the t-slot, so the die still fit perfectly in the adapter.

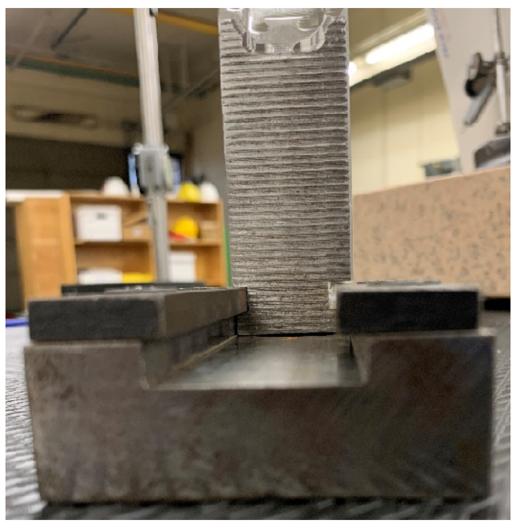

Figure 10 T-Slot Issue

When it came time to do the heat treating there should have been more research done to properly work the furnace that was being used. The heat didn’t stick around long enough when it was raised and then lowered which caused the heat treat to mess up. Along with the heat not holding for a long time there was too much time in between the quench and the temper. On top of that since the heat treat was not standard the temper ended up being longer due to safety to make sure the die was soft enough.

The arm plate ended up being skewed. The reason for this is because the slip roll was not working very well, and it was swapped out with a press brake. The result of this change made the part the wrong dimensions. A similar issue happened with the shield, the punch out operation wasn’t the same for each side and part. The shield turned out lopsided and thus throwing off all the welding.

The welding was fully modular, there was no fixture of any kind. This made the welds somewhat difficult as there wasn't a lot of options to use for round bar. Once the machine got dialed in the welds were solid but there was some skew here and there. During the second hook being assembled the operator learned what worked and what didn't, and the second assembly turned out much better. In a production run a welding fixture is necessary to get the correct constraints.

Evaluation Results

The manual calculations done for the initial deflection estimates were done incorrectly leading the thickness of the hook to be increased and shortened the entire length up. The ending value of the simulated deflection analysis ended up being a little too rigid. A value around .5" or .25" would have been sufficient however it ended up having .013". Most of this value comes from the hook thickness as the decreasing value of that affects the final value exponentially more than the length of the hook. In the future the hook can be a large margin thinner therefore resulting in cheaper steel.

The A die ended up testing on a Rockwell C scale at 38 Rc while the B die ended up testing at 43 Rc. This could be due to where it was being assessed which was near the center however it is most likely due to the heat treating being bad and the time between the quench and temper. It was an innovative idea to heat up the hook to bend it because there was a chance of it shattering in the press or completely deforming.

Conclusions

The hook worked as designed, It lifted the hay bales as expected with no permanent deflection. There were a few issues like the hook being a bit too stout which made it hard to get a secure hold of the bale. The hook should be sharper and have a sharper angle to counteract that. The balance of the hook turned out to be very centralized, the diameter could be dropped down but it might throw off the balance. During the tests after welding when the operator was standing on the hook it ended up permanently deforming the shield. This was unexpected but the way to counteract that might be to add a section of plate there or to beef up the thickness of the shield.

The result of the hay hook was great. It looked very professional minus a few spotty welds here and there. It was exceptionally durable and didn't break due to a shock drop test. The price ended up being a little more on the high side so these hooks wouldn't be able to be produced at the same price as the ones at Harbor Freight. After some revision this design could be taken to market as a viable alternative design for hay hooks.

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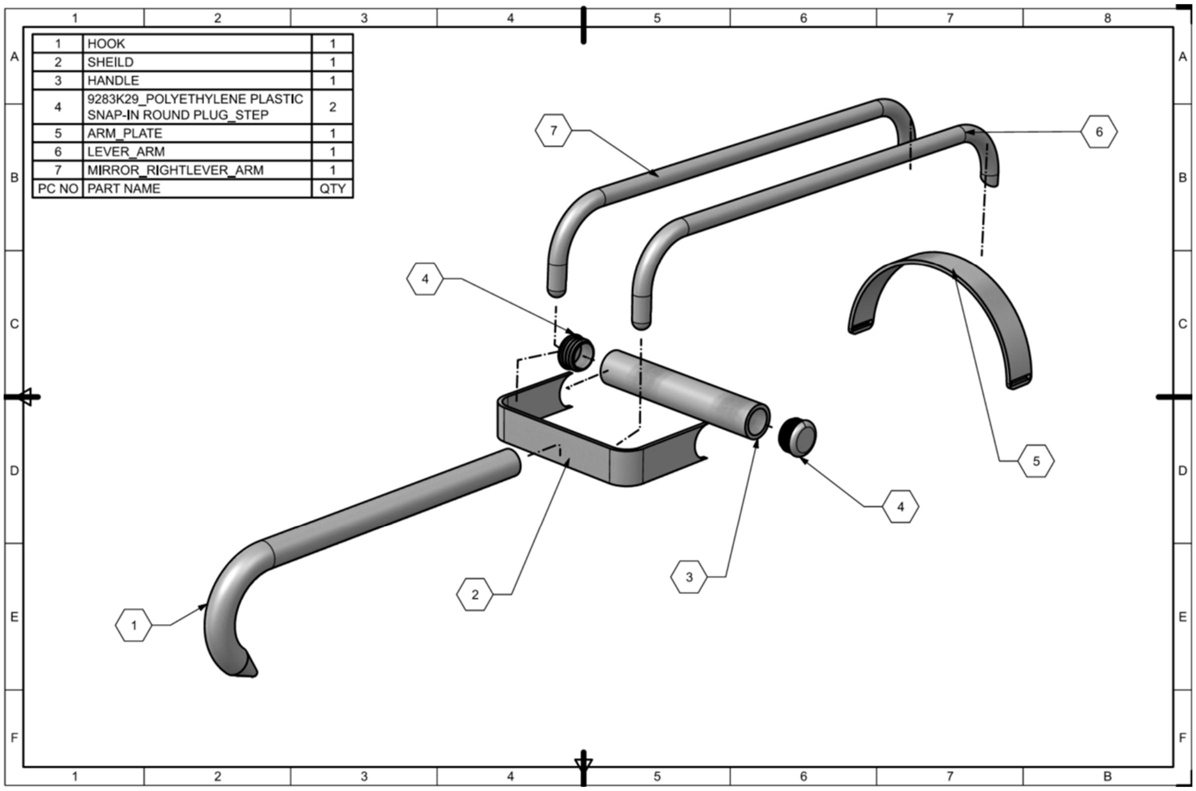
Appendix A – Detailed Drawings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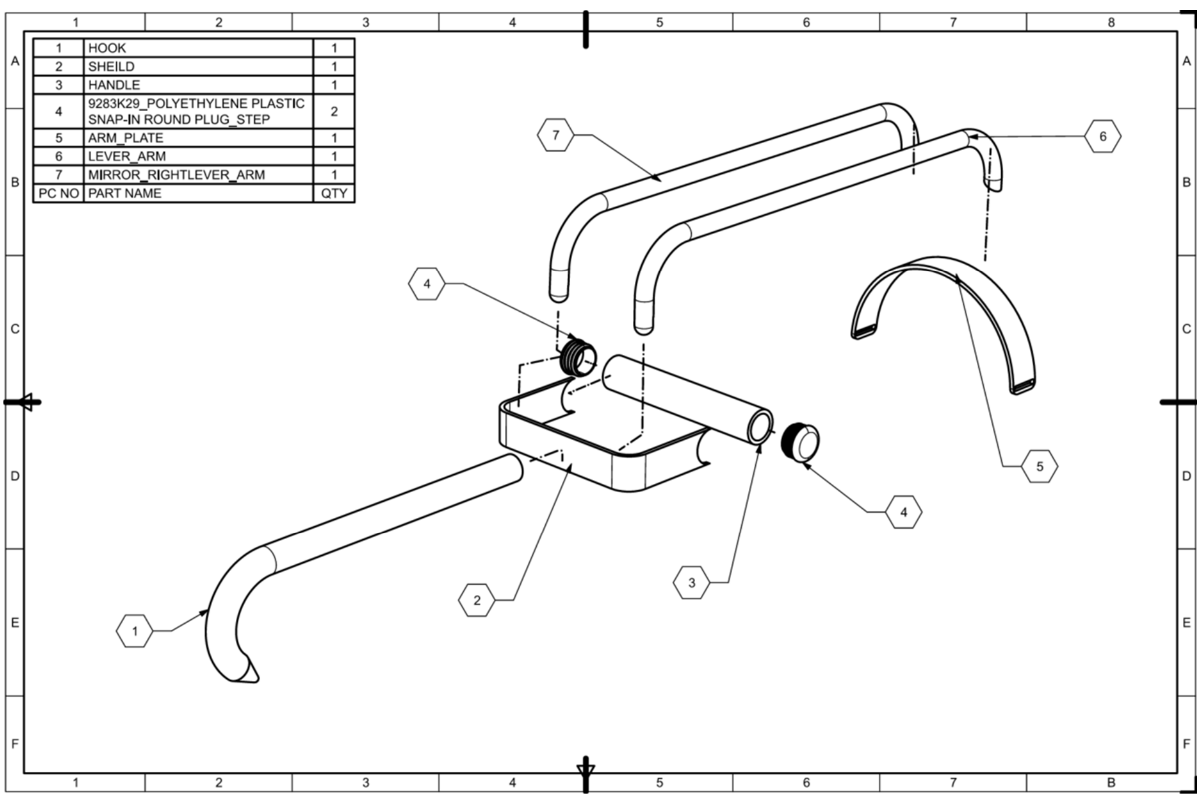
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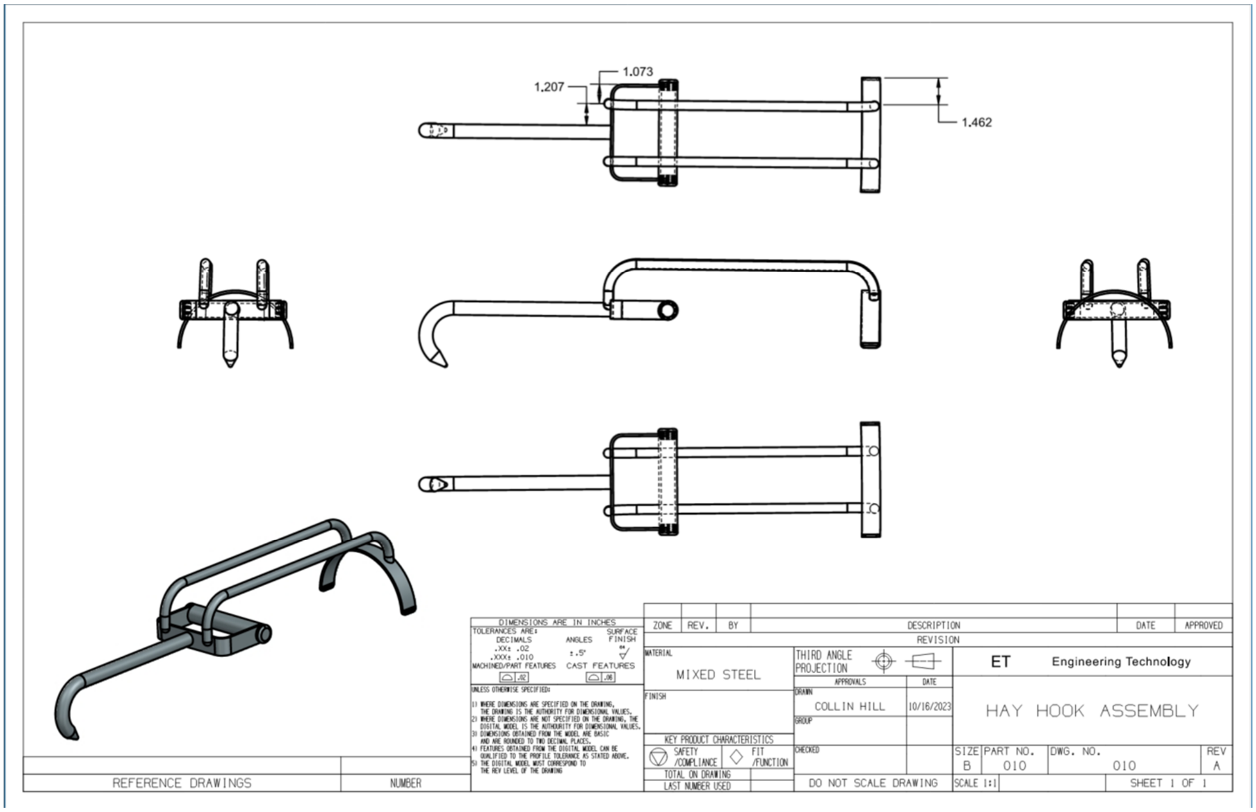
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THIRD ANGLE PROJECTION
ET Engineering Technology
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HAY HOOK ASSEMBLY
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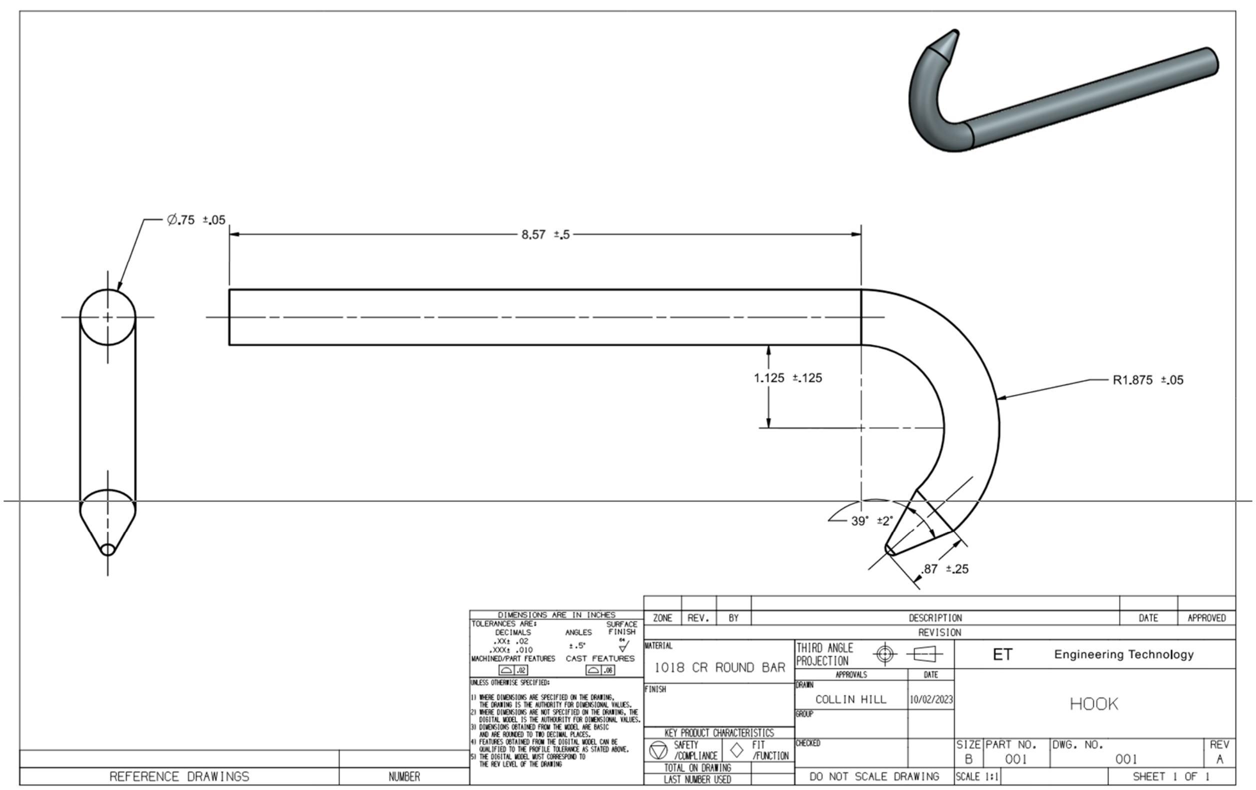
NUMBER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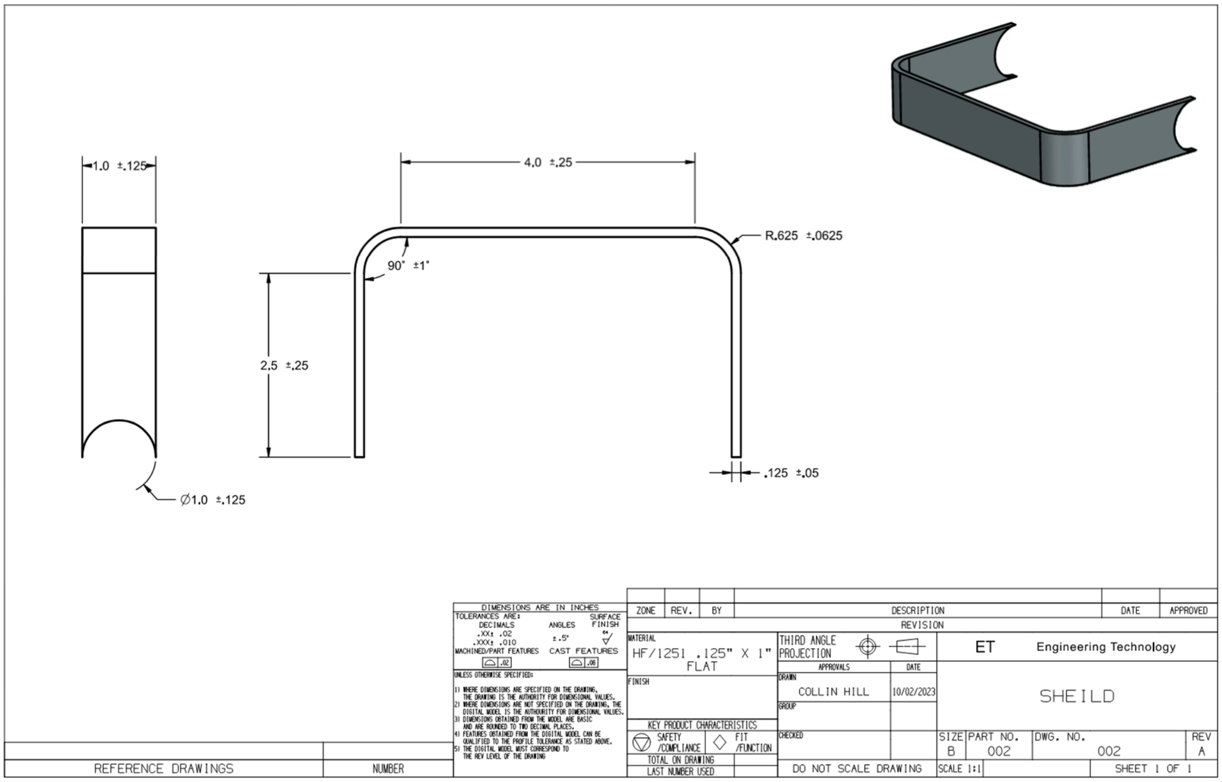
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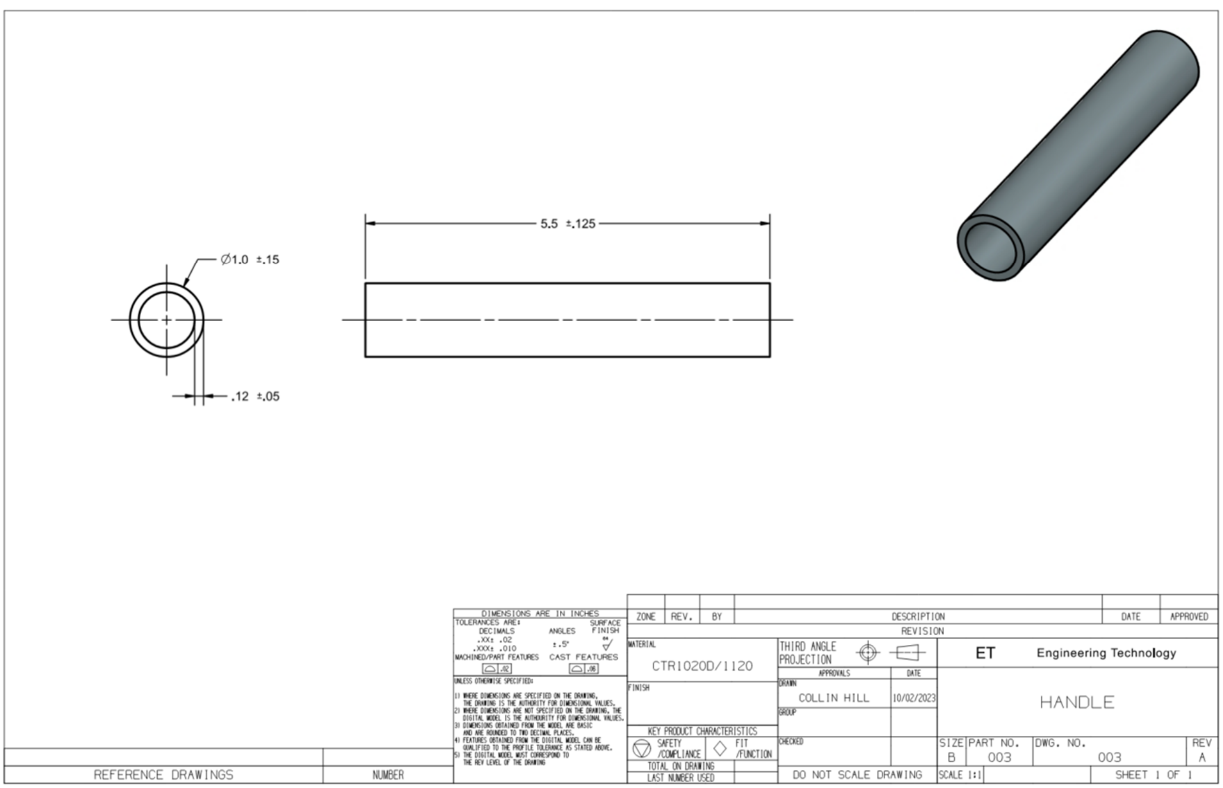
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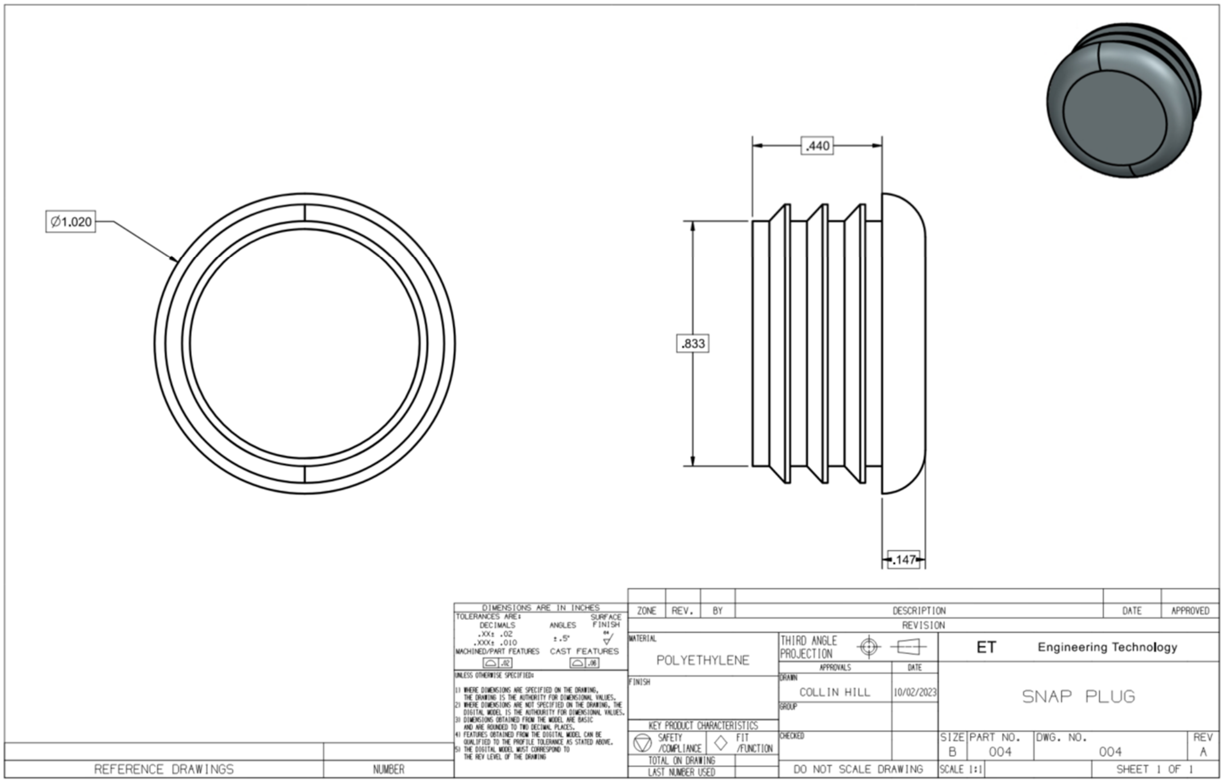
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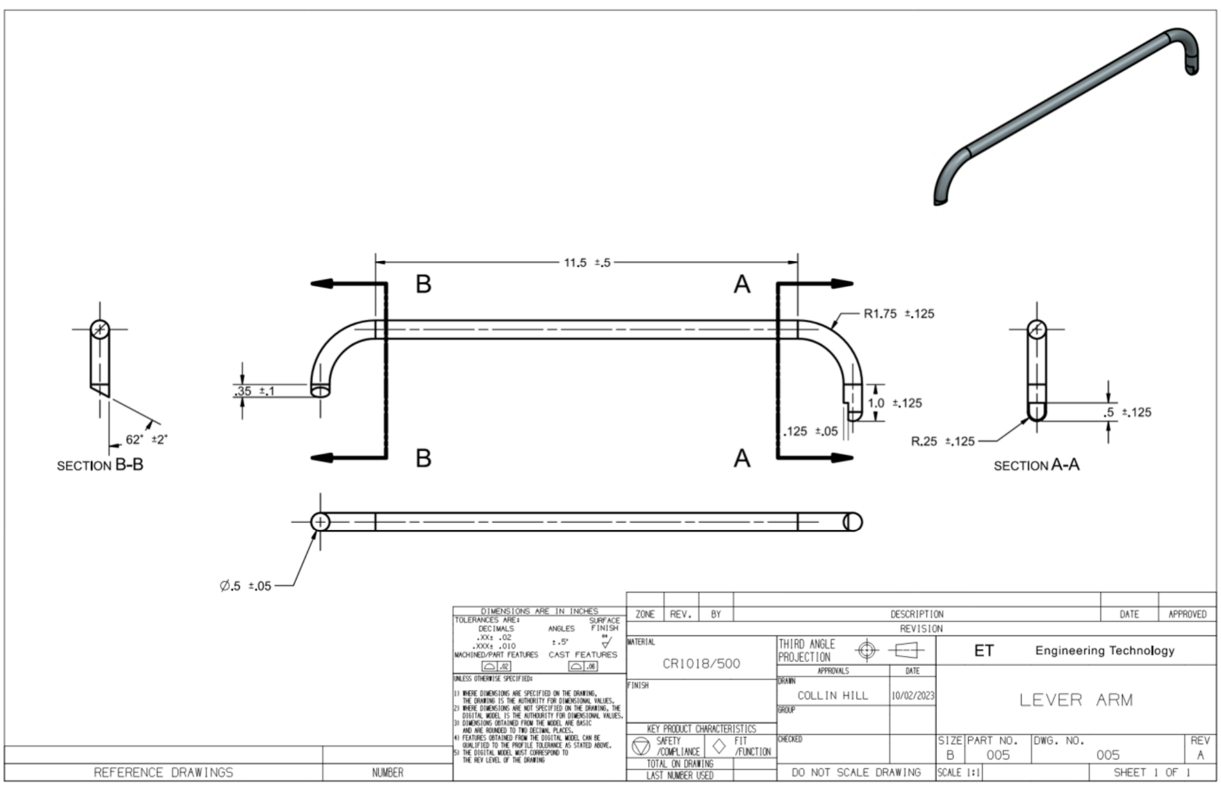
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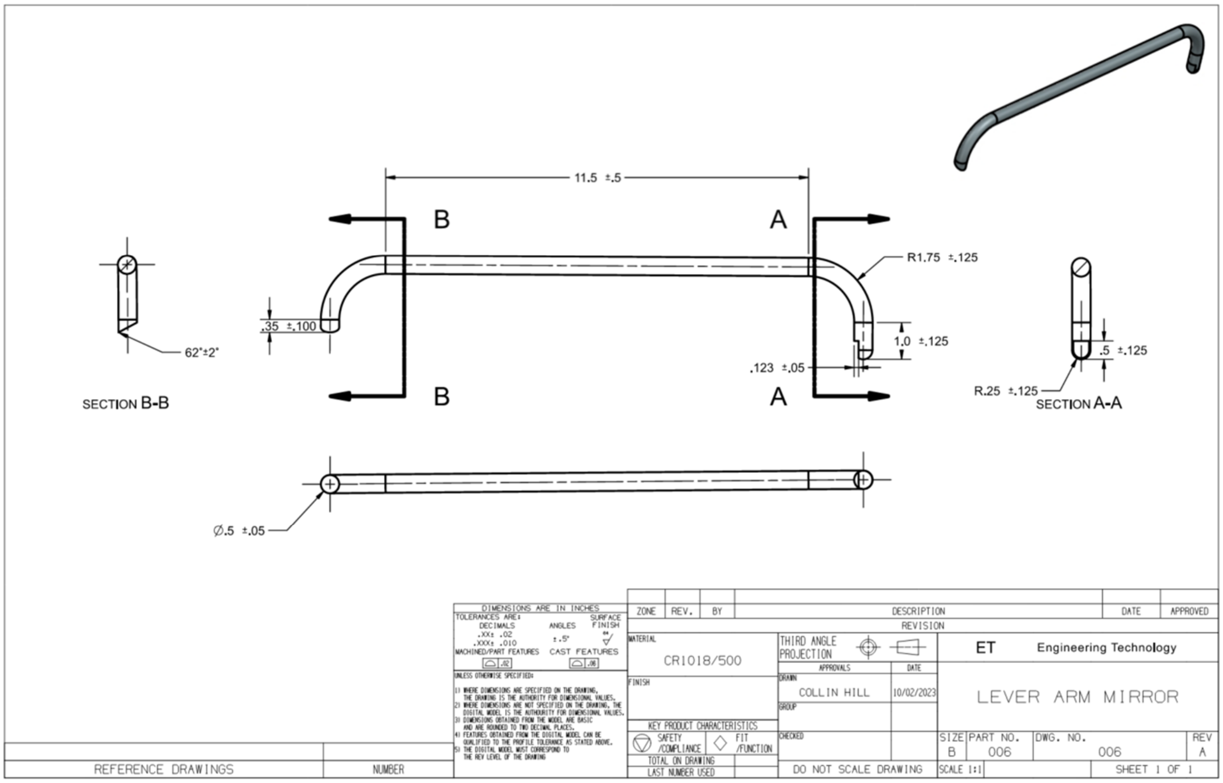
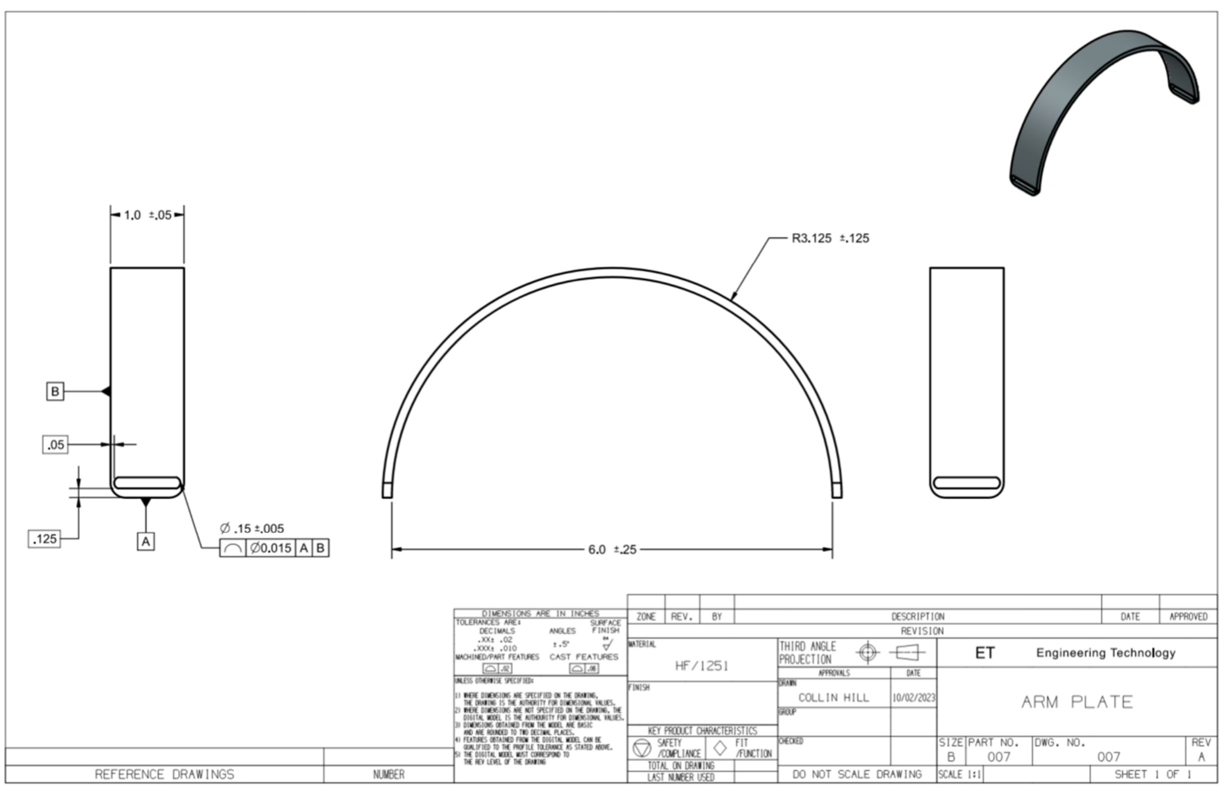
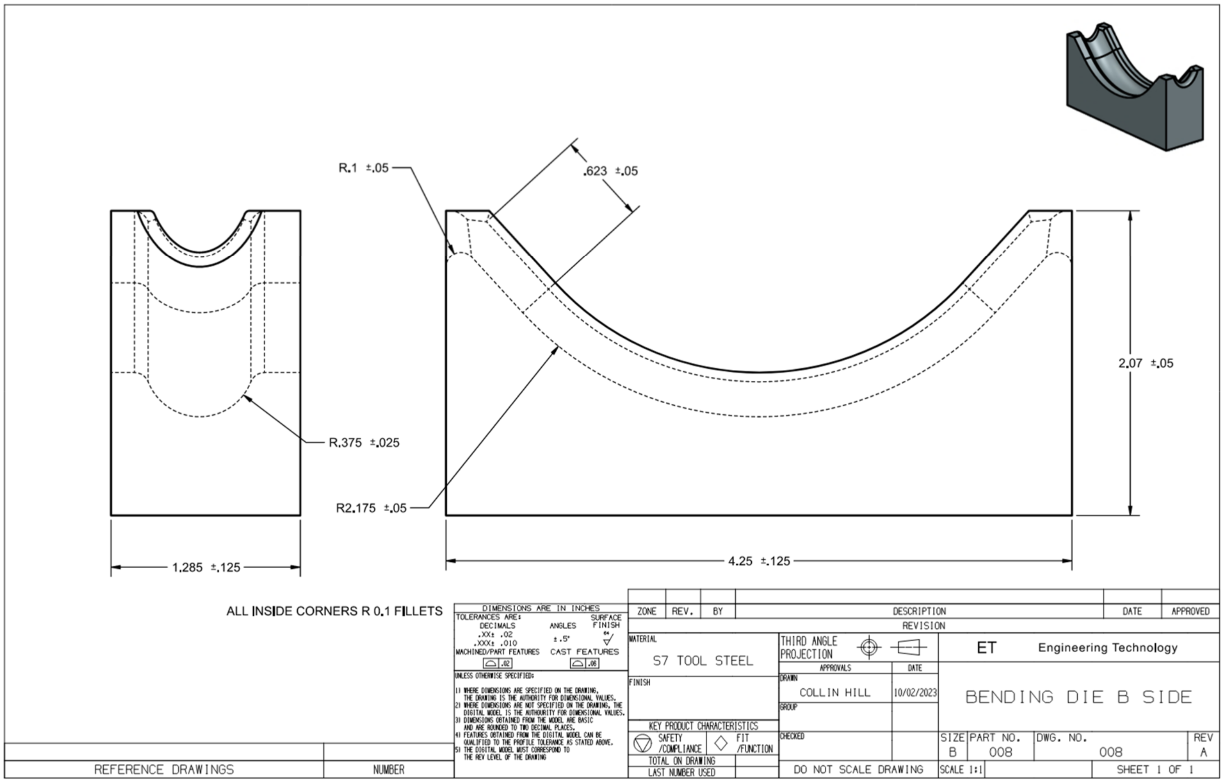
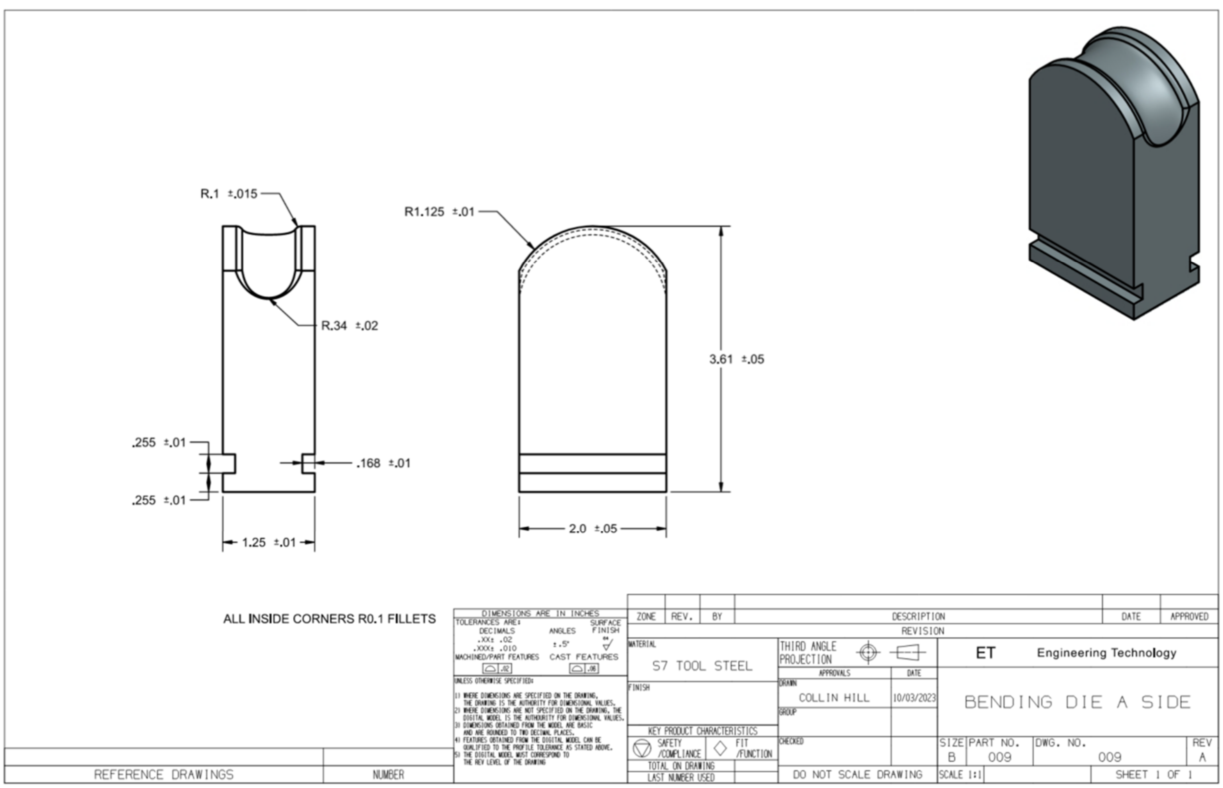
1.0 ±.125
.125 ±.05
.5 ±.125
R.25 ±.125
62° ±2°
SECTION B-B
SECTION A-A
Ø.5 ±.05
DIMENSIONS ARE IN INCHES
MATERIAL
CR1018/500
THIRD ANGLE PROJECTION
DRAWN
COLLIN HILL
10/02/2023
ET
Engineering Technology
LEVER ARM
SIZE B
PART NO. 005
DWG. NO. 005
REV A
DO NOT SCALE DRAWING
SCALE 1:1
SHEET 1 OF 1
REFERENCE DRAWINGS
NUMBER


11.5 ±.5
B
A
R1.75 ±.125
.35 ±.100
1.0 ±.125
.123 ±.05
.5 ±.125
62°±2°
SECTION B-B
B
A
R.25 ±.125
SECTION A-A
Ø.5 ±.05
DIMENSIONS ARE IN INCHES
ZONE REV. BY
DESCRIPTION
DATE APPROVED
REVISION
MATERIAL
CR1018/500
THIRD ANGLE PROJECTION
ET Engineering Technology
FINISH
DRAWN
COLLIN HILL 10/02/2023
LEVER ARM MIRROR
KEY PRODUCT CHARACTERISTICS
SAFETY /COMPLIANCE
FIT /FUNCTION
CHECKED
SIZE B PART NO. 006 DWG. NO. 006 REV A
TOTAL ON DRAWING
LAST NUMBER USED
DO NOT SCALE DRAWING
SCALE 1:1
SHEET 1 OF 1
REFERENCE DRAWINGS
NUMBER


1.0 ±.05
R3.125 ±.125
B
.05
.125
A
Ø .15 ±.005
Ø0.015 A B
6.0 ±.25
DIMENSIONS ARE IN INCHES
ZONE REV. BY
DESCRIPTION
DATE APPROVED
REVISION
MATERIAL
HF/1251
THIRD ANGLE PROJECTION
ET Engineering Technology
FINISH
DRAWN
COLLIN HILL 10/02/2023
ARM PLATE
KEY PRODUCT CHARACTERISTICS
SAFETY /COMPLIANCE
FIT /FUNCTION
CHECKED
SIZE B PART NO. 007 DWG. NO. 007 REV A
TOTAL ON DRAWING
LAST NUMBER USED
DO NOT SCALE DRAWING
SCALE 1:1
SHEET 1 OF 1
REFERENCE DRAWINGS
NUMBER


R.1 ±.05
.623 ±.05
2.07 ±.05
R.375 ±.025
R2.175 ±.05
1.285 ±.125
4.25 ±.125
ALL INSIDE CORNERS R 0.1 FILLETS
DIMENSIONS ARE IN INCHES
S7 TOOL STEEL
THIRD ANGLE PROJECTION
COLLIN HILL
10/02/2023
ET Engineering Technology
BENDING DIE B SIDE
SIZE B
PART NO. 008
DWG. NO. 008
REV A
DO NOT SCALE DRAWING
SCALE 1:1
SHEET 1 OF 1
REFERENCE DRAWINGS
NUMBER


R.1 ±.015
R1.125 ±.01
R.34 ±.02
3.61 ±.05
.255 ±.01
.168 ±.01
.255 ±.01
1.25 ±.01
2.0 ±.05
ALL INSIDE CORNERS R0.1 FILLETS
DIMENSIONS ARE IN INCHES
S7 TOOL STEEL
THIRD ANGLE PROJECTION
COLLIN HILL
10/03/2023
ET Engineering Technology
BENDING DIE A SIDE
SIZE B
PART NO. 009
DWG. NO. 009
REV A
DO NOT SCALE DRAWING
SCALE 1:1
SHEET 1 OF 1
REFERENCE DRAWINGS
NUMBER