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Kennesaw State University and United Alloy Corporation Robotic Pick and Place Project

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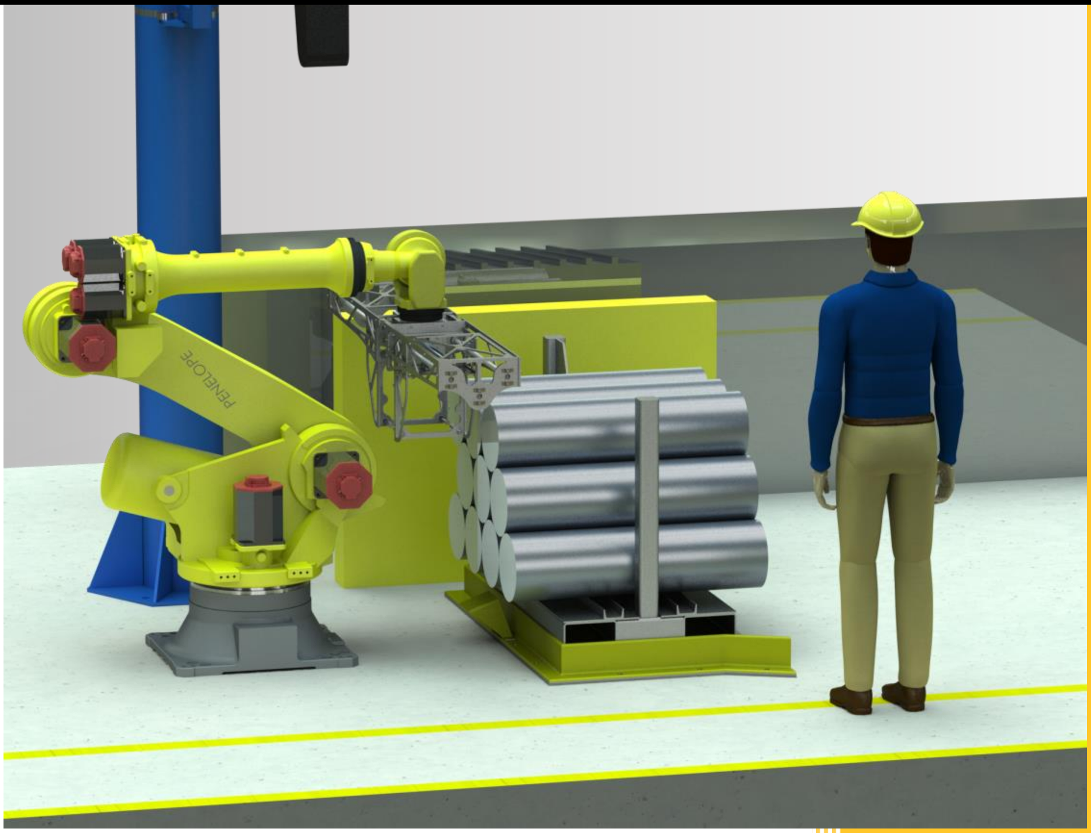
Kennesaw State University and Universal Alloy
Final Design Review:
Project Penelope



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Executive Summary

United Alloy Corporation (UAC), a company specializing in custom aluminum parts for aeronautics, needed a fix to their error prone, labor-intensive billet press operation. The current process allows the problem of adding the wrong size or wrong alloy billet to the induction oven, which results in a waste of raw materials. The billets range from ten to thirty-seven inches in length and weigh up to three hundred pounds. Currently, an operator uses a gantry crane to check and lift the billets from a rack onto the magazine of an induction oven. The induction oven processes around five billets an hour. UAC did not need to speed up the process, but they did want to improve safety and quality assurance in which billet goes in the oven. The company tasked Kennesaw State University (KSU) with a project to fix the issues presently in the process, using a FANUC robot to conduct a pick and place solution. The KSU team then fabricated a gripper to lift the billet, designed code to find the rack in space and complete the quality assurance process, and researched sensors and fencing to build a safety cell around the gripper and robot.

The KSU team visited UAC to check the current process and the best way to code the robot, design the gripper to pick off the rack, and set up the entire cell with the proper features. The gripper needed to lift billets from the rack had to be an end-to-end gripper, which does not exist off the shelf for billets of the size used at UAC. The team created a gripper design using pneumatics to lift the billets vertically from the rack. The team then coded the robot to find the billet on the rack and measure the length to check that the right size billet was going in the oven—this was the first stage of the quality assurance portion. The next was a camera that scans a printed QR code and checks with the recipe card to make sure the right alloy aluminum is picked. The robot, gripper, and camera all work together to solve both the lifting safety and wrong billet problems with the process.

The final step of the project was to fabricate the gripper in a machine shop, test the code with the gripper, and add the safety sensors into the cell to stop unsafe operation. The FANUC robot will be encased in fencing with doors that allow workers to bring the billet rack to the robot. The safety sensors will stop operations when the doors are open, if there is a billet on the floor, or when the operator is inside the robot cell.

After the whole system was completed, UAC took the ASME Y14 drawings for the gripper to create the model and set up the robot cell with the recommended fencing and sensors. UAC has the commented code and will make any changes needed to the operation in the future. The KSU team set up the gripper, cell, and code to function with all aspects of the project in mind. The QR code is the last portion to be added and UAC will need to complete the server to finish the quality

assurance process. The following goes more in depth on the decisions made through the year and the different solutions attempted before the final design was completed.

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Chapter 1: Problem Statement and Requirements

1.1 Introduction

Project Penelope is a Kennesaw State University (KSU) and Universal Alloy Corporation (UAC) collaborative design project. The KSU team has been tasked with designing a robot cell which will automate a picking and placing job for UAC's aluminum extrusion production line. The main purpose of this automation is to free time for the operator who runs the aluminum extrusion process, and to ensure the correct billet is being used for each order. Side benefits to UAC will be a safer work environment by eliminating any physical loading and better quality control through a billet scanning and measuring process that will be implemented.

1.2 System Overview

UAC currently has an induction oven into which aluminum billets are fed and heated so that they may be shaped into built-to-order shapes for aerospace companies. The process currently includes an operator using a gantry crane—Figure 1—to lift billets from a rack onto the oven magazine, which can be dangerous as the billets can weigh a couple hundred pounds. As of today, there have been no accidents, but the possibility of one has prompted UAC to find a different lifting solution for the billets. The current process also has production problems as the human operator can often load the wrong billet length or alloy into the oven. There are currently no numbers on the amount of error billets that get lost in the process; however, UAC believes the issue is large enough to warrant a quality assurance solution to the lifting process as well.

Figure 1. Extrusion process operator loading billet into oven.

The main objective of Project Penelope is to design a robot cell to pick and place aluminum billets into an induction oven with a given robotic arm; a FANUC R-2000iB. The aluminum billets are all ten inches in diameter and vary from ten inches to thirty-seven inches in length. The longest billets weigh three-hundred pounds. The robot cell also needs to be equipped with a QR scanning process. Safety is going to be essential for this robot cell as well as guards and safety gates that will be incorporated with the full design. The process of the automation is shown in Figure 2.

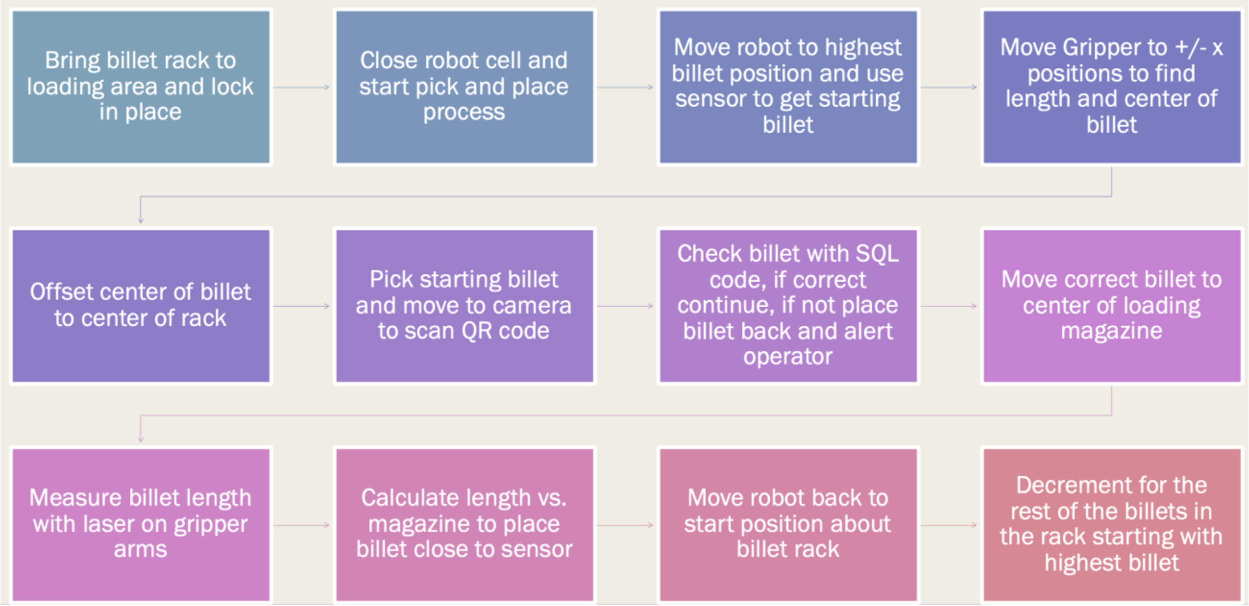


Figure 2: Process Map

1.3 Concept Design

The initial design for the robot cell, shown in Figure 3, includes the vision system in the cell along with the billet loading area, the loading area of the induction oven, the current billet rack, and the robot. The figure below has the dimensions of the caged portion of the cell.

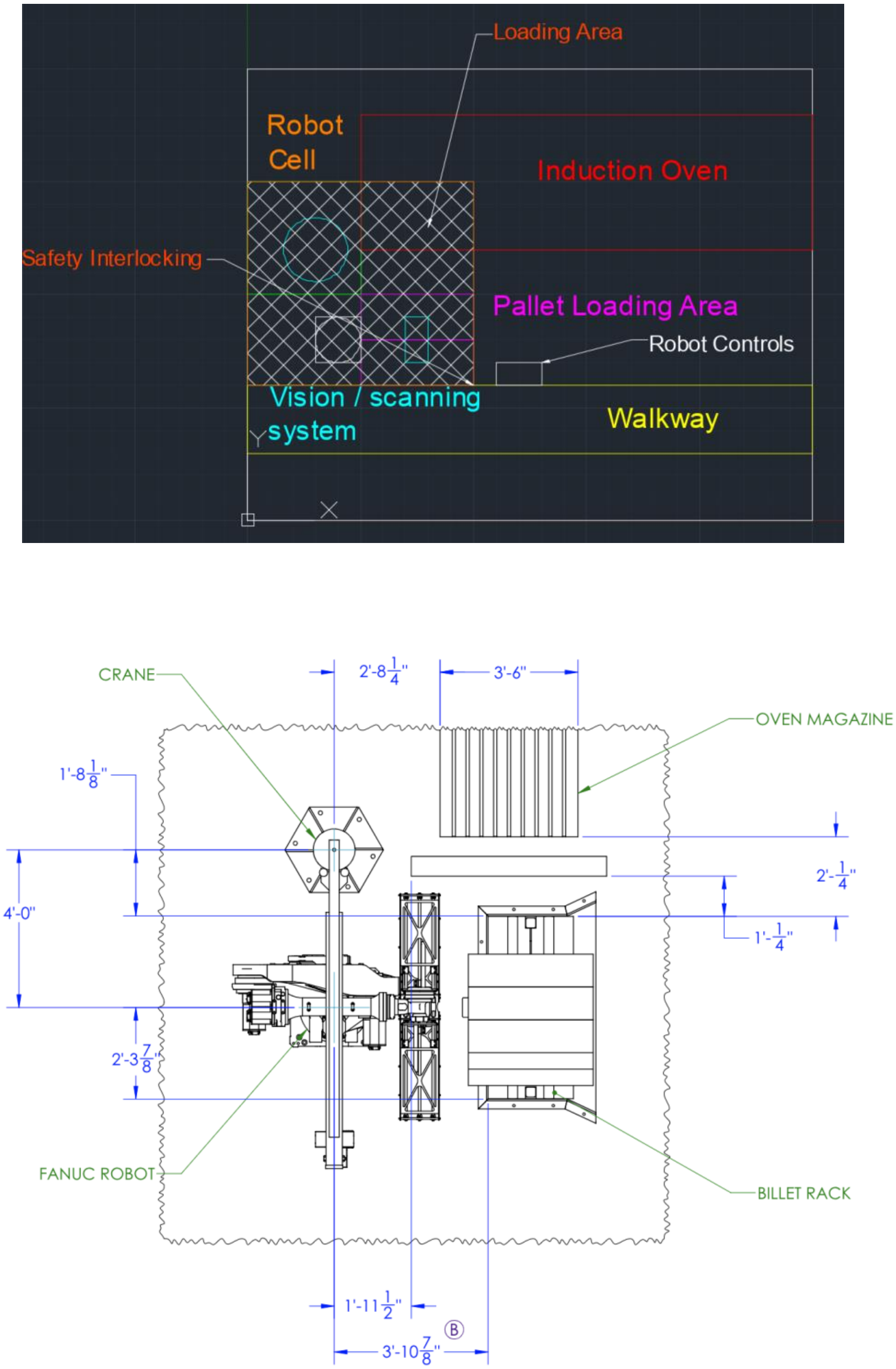


Figure 3: Robot cell layout (a) AutoCAD overview and (b) SolidWorks sketch with dimensions.

The robot controls will remain outside of the cell to comply with the ANSI RIA R15.06-2012 safety standards followed at UAC (American National Standard for Industrial Robots and Robot Systems, 1999). The main concerns when designing the robot cell were the safety standards and the available floor space. The current layout is not much different than the designed robot cell. The robot will be placed in front of the crane that is currently used so that if the robot malfunctions, the crane can be used as a backup. The area will be fenced off so workers will be able to move freely outside the robot working space when the robot is in operation.

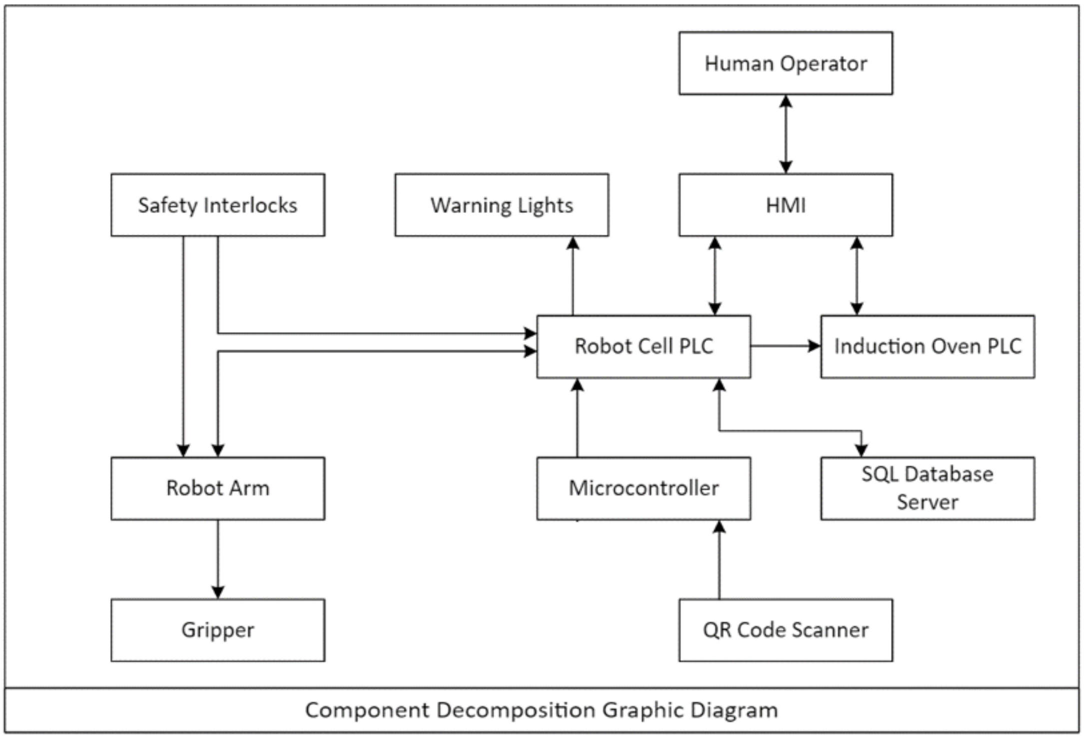


Figure 4: Component Decomposition Diagram

The component diagram shown in Figure 4, depicts the robot cell, programmable logic controller (PLC), and the connections made with the rest of the cell. There will be a SQL database, scanner, and induction oven talking directly with the PLC through code. The PLC will also require the human operator to check with the robot when scanning the billets. The safety interlocks and warning lights are also attached to the PLC for constant safety checks within the cell and with the operator for a hazard free work environment. The robot arm and gripper will run to the robot I/O and communicate to the PLC from there with the vision required. All this is broken down in the Function Diagram in Figure 5.

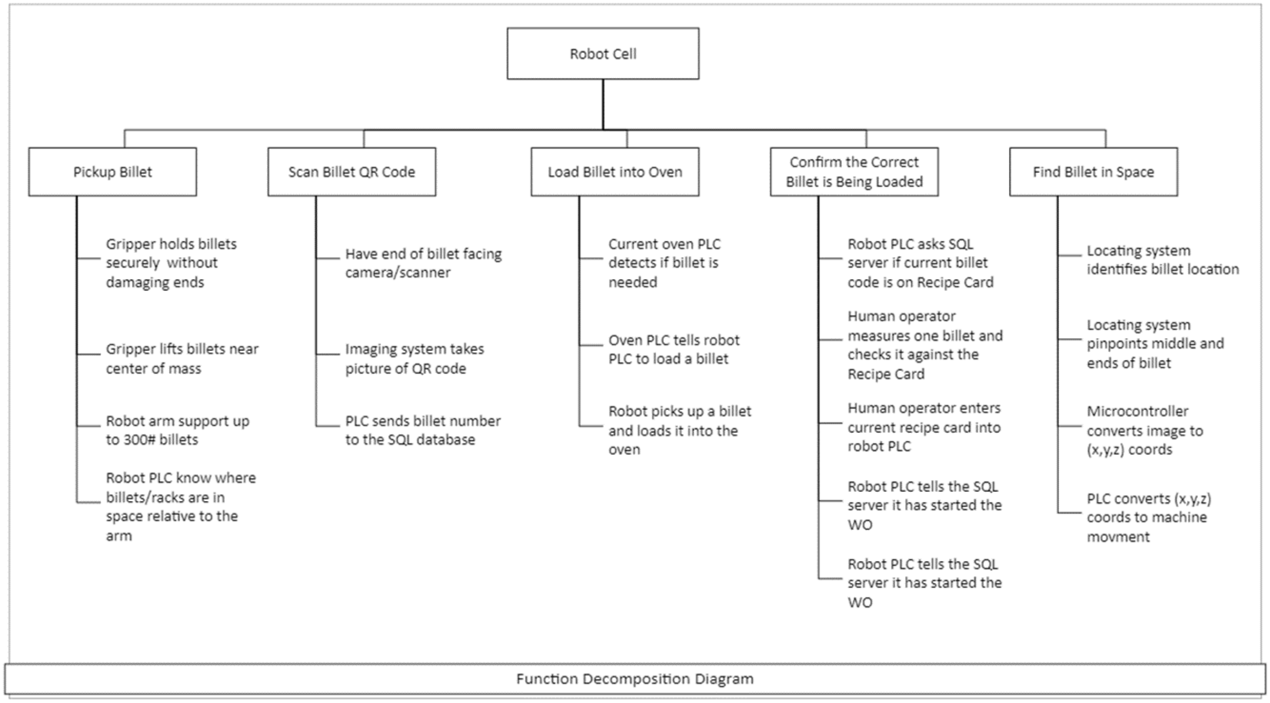


Figure 5: Function Decomposition Diagram

For Project Penelope, UAC gave the team access to a FANUC robot and its operator, Brian Norris, to assist with the coding and setting up of the robot. The bulk of the project was completed using the FANUC robot and the billets in the billet rack to pick and place the items in the induction oven. UAC had a machine shop fabricate the gripper designed in SolidWorks. An essential part of this project is the ability to scan a QR code on the side of the billet and check with the recipe card of the work order to ensure the billet going in the oven is the right billet for the part being made. UAC's IT manager, Matt Ringer, will be completing the SQL database and code because the team is missing a member who would have already had experience with the language. These are the current available hardware and software resources UAC has provided. The school has provided the Microsoft Office suite and SolidWorks for the papers and gripper rendering.

For the testing of the project, UAC provided the team with safety sensors, a mock gripper, and a mock production environment to check the capabilities of the code. The final aspect of the project will be to implement and test the robot cell in its entirety and UAC will provide the safety standards followed at the facility to complete the cell. These resources will help the team create a safe and productive work environment conducive to a quality product.

An upside to this simple cell layout is there is not much modification needed for the area around the cell. The only changes are new fencing will need to be built, the robot will be moved to the floor, and there will be a billet lock-in bolted to the pallet loading area. There will need to be guards in place to protect the robot and the lift. There will also need to be faults implemented into the robot to stop when a collision is imminent. The floor plan will be updated once the code has been designed for the cell and the team knows where everything should be placed on the floor. The safety guards in the cell will need to be programmed with information about where the robot and billet should be so that it can detect when something is out of place, such as a falling billet.

1.4 Minimum Success Criteria

UAC provided four areas on which the team's success would be judged. They are the robot cell safety, the gripper design, the PLC code, and a QA system. The success criteria decided on is listed below.

- Robot cell and safety
    - Give a complete robot cell layout with all dimensions that match live production
        - Including all safeguards, gates, interlocks, and electrical components
        - Fully test safety sensors including gate lock and scanning sensors integrated into robot cell
- Gripper
    - Deliver gripper design with all dimensions and full explanation of design and assembly
    - Assemble and successfully test gripper in mock production environment
- PLC Code
    - Deliver and test working PLC code for mock robot cell with full explanation of its functionality
        - Functions include finding billets, picking billet, placing billet, alerting when billet count is low, alerting when billet rack is empty, and alarm system
        - Make any necessary recommendations for implementation of PLC code into live production environment
- QA System
    - Deliver fully vetted QA system that works with current QR scanning project within UAC
    - Including camera recommendation, camera placement, and full description of scanning system
        - Work with assigned personnel from UAC to successfully implement QR scanning and SQL database

- Create a seamless process as defined by UAC engineering partners

1.5 Scope of Work

The project has been in the planning stages for most of the previous semester, this semester the team visited the robot and worked with Brian to learn simple movements and focus on coding and safety. A few minor issues were found when moving the robot, the knuckle on the fifth joint protrudes too much to lift the billets towards the end of the rack straight up. The fix for this was to turn the robot at around a 10° angle when lifting billets in rows one and three. The code reflects this autonomously for these rows.

Before the robot was installed, the main focus of the meetings was to get a better description of the desired process. The gripper was fabricated, and calculations were performed to ensure it could lift the billet with no problems. The budget was determined and the process map for the project confirmed. Most aspects of the work done so far are mentioned above.

The robot’s extremes were tested in the cell and the dimensions were determined after simulating the gripper on the robot with a cardboard box. The team now knows to keep the billet rack 25 inches from the robot base to ensure the gripper does not collide with the robot. The gripper must also make right angle turns to find the billet edge, which is discussed more in Finding the Billet. The vision system has been simplified as has the picking process when it was determined UAC did not want complicated cameras and microcontrollers mapping out the robot cell. A camera will still be used for QR scanning, but Matt Ringer will need to complete that project to integrate the systems.

Calculations were performed on the gripper with different materials to see which materials were the strongest and lightest. The robot movements were created for the pick and place programs. The main components for the gripper UAC will provide is a proximity sensor from their warehouse and a laser to measure the billets. UAC is also fabricating the gripper in the machine shop as the project is closing.

The team has created safety relays and circuit diagrams for UAC to utilize when creating the cell. There are 3D renderings UAC has access to when they fully implement the robot in live production. All code created was run with a simulated push button box and the head of robotics has the commented code which vividly describes the entire process the code undergoes to pick and place the billets. The final step of the project is implementation, which will be performed by UAC with all of the KSU team’s designs and recommendations.

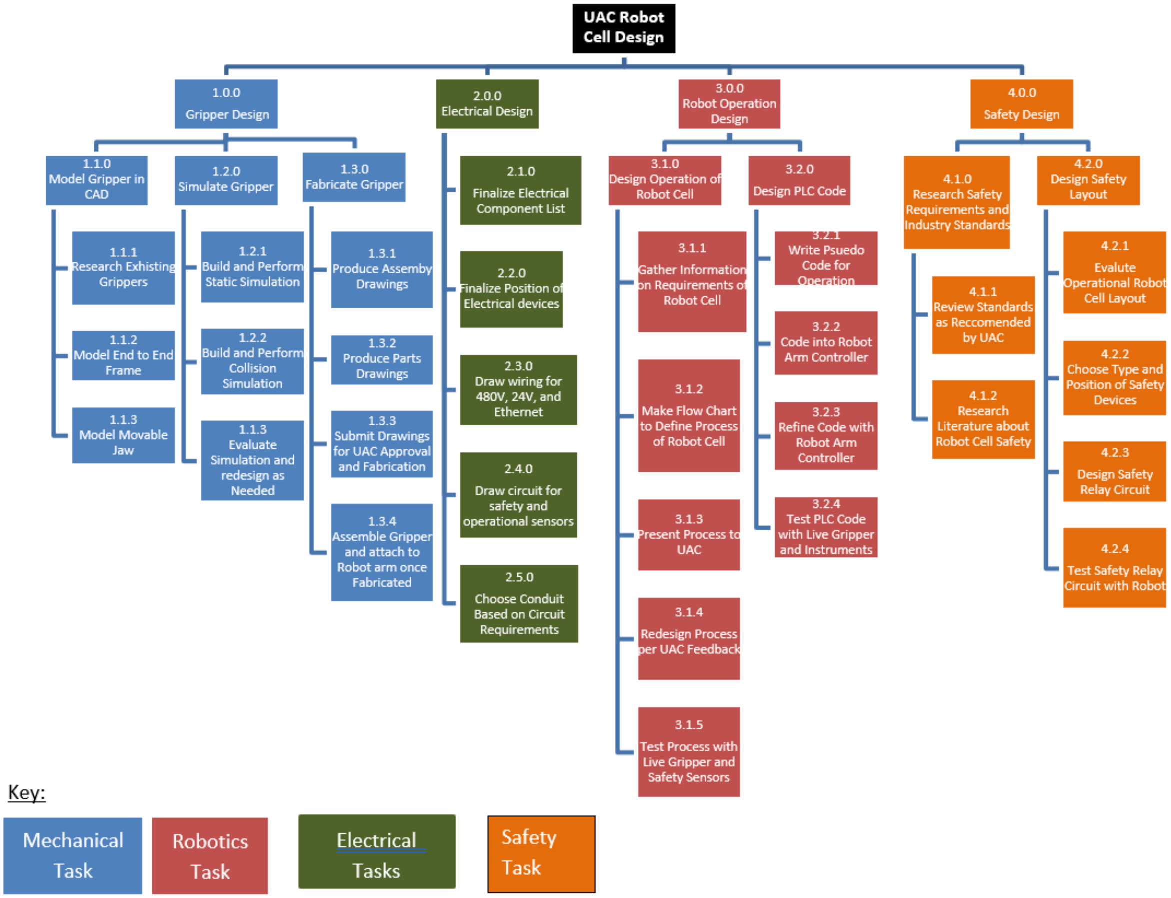


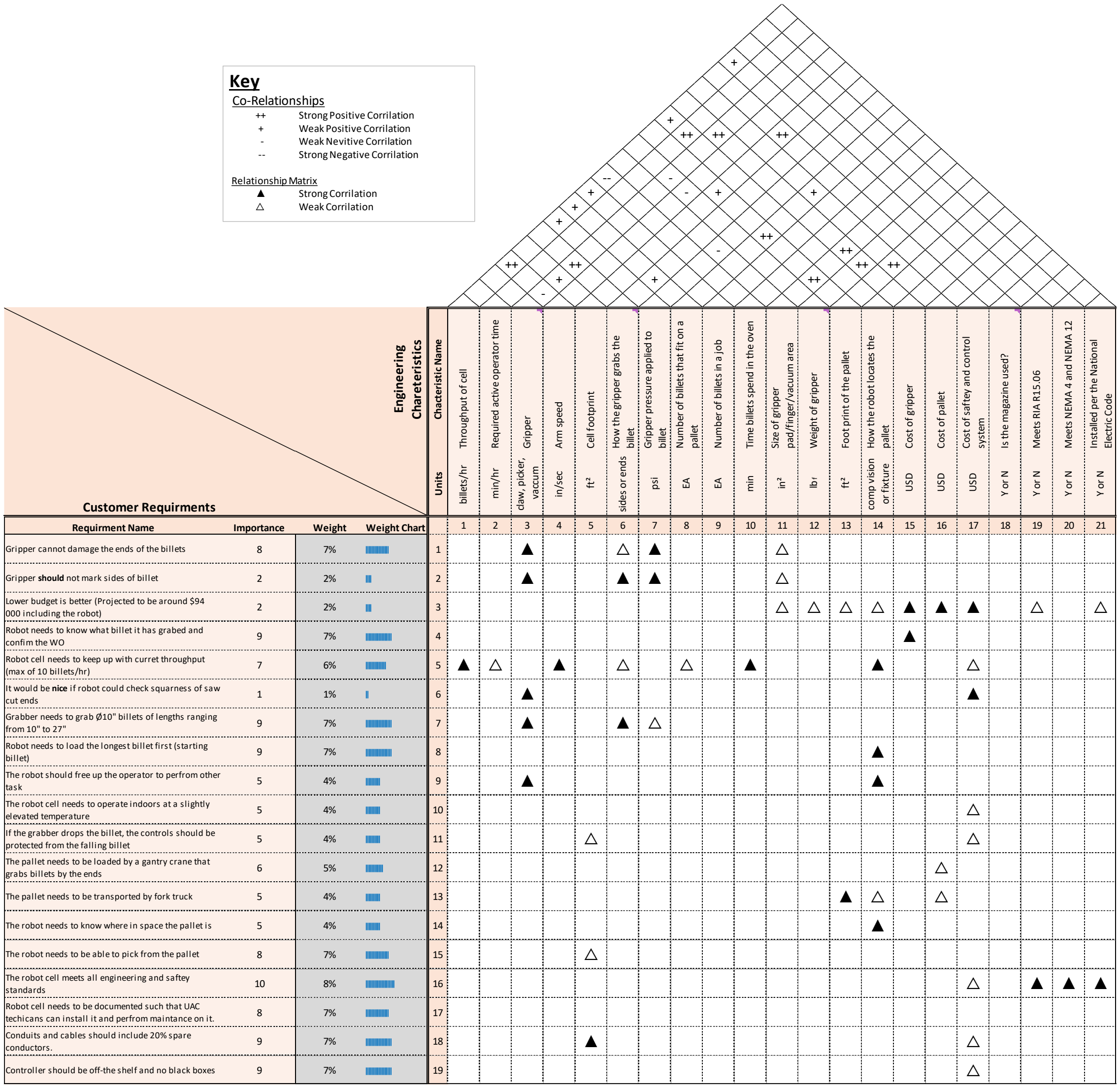
Figure 6. Work assignment breakdown. See Appendix C for a higher resolution image.

1.6 House of Quality

The house of quality (HoQ) shown in Figure 7 was made in the high-level planning phase. For that reason, several potential engineering characteristics are missing. More of these quantitative engineering characteristics are dependent on what style of gripper /pallet/scanner are chosen. Part of the agile approach that the team chose allows for periodic redefinition the problem statement as the project progresses.

The customer requirements on the other hand, are well defined. In meetings with UAC, it was evident that their main goal with the robot, was increased safety. That is reflected in the customer importance ratings. Items related to budget or cost are rated much lower because the Director of Engineering indicated that the budget was open to negotiation. The speed items received similar ratings for the same reason.

Other highly-rated requirements are related to engineering and company standards. These rank highly both because they go hand in hand with safety, and they were emphasized by the Electrical Engineering Manager.



Key

Co-Relationships

++	Strong Positive Corrilation
+	Weak Positive Corrilation
-	Weak Nevitive Corrilation
--	Strong Negative Corrilation

Relationship Matrix

▲	Strong Corrilation
△	Weak Corrilation

Engineering Chareteristics

Customer Requirments

				Chacteristic Name	Throughput of cell	Required active operator time	Gripper	Arm speed	Cell footprint	How the gripper grabs the billet	Gripper pressure applied to billet	Number of billets that fit on a pallet	Number of billets in a job	Time billets spend in the oven	Size of gripper pad/finger/vacuum area	Weight of gripper	Foot print of the pallet	How the robot locates the pallet	Cost of gripper	Cost of pallet	Cost of saftey and control system	Is the magazine used?	Meets RIA R15.06	Meets NEMA 4 and NEMA 12	Installed per the National Electric Code
				Units	billets/hr	min/hr	claw, picker, vaccum	in/sec	ft²	sides or ends	psi	EA	EA	min	in²	lbf	ft²	comp vision or fixture	USD	USD	USD	Y or N	Y or N	Y or N	Y or N
Requirment Name	**Importance**	**Weight**	**Weight Chart**		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Gripper cannot damage the ends of the billets	8	7%		1			▲			△	▲				△										
Gripper **should** not mark sides of billet	2	2%		2			▲			▲	▲				△										
Lower budget is better (Projected to be around $94 000 including the robot)	2	2%		3											△	△	△	△	▲	▲	▲		△		△
Robot needs to know what billet it has grabed and confim the WO	9	7%		4															▲						
Robot cell needs to keep up with curret throughput (max of 10 billets/hr)	7	6%		5	▲	△		▲		△		△		▲				▲			△				
It would be **nice** if robot could check squarness of saw cut ends	1	1%		6			▲														▲				
Grabber needs to grab Ø10" billets of lengths ranging from 10" to 27"	9	7%		7			▲			▲	△														
Robot needs to load the longest billet first (starting billet)	9	7%		8														▲							
The robot should free up the operator to perfrom other task	5	4%		9			▲											▲							
The robot cell needs to operate indoors at a slightly elevated temperature	5	4%		10																	△				
If the grabber drops the billet, the controls should be protected from the falling billet	5	4%		11					△												△				
The pallet needs to be loaded by a gantry crane that grabs billets by the ends	6	5%		12																△					
The pallet needs to be transported by fork truck	5	4%		13													▲	△		△					
The robot needs to know where in space the pallet is	5	4%		14														▲							
The robot needs to be able to pick from the pallet	8	7%		15					△																
The robot cell meets all engineering and saftey standards	10	8%		16																	△		▲	▲	▲
Robot cell needs to be documented such that UAC techicans can install it and perfrom maintance on it.	8	7%		17																					
Conduits and cables should include 20% spare conductors.	9	7%		18					▲												△				
Controller should be off-the shelf and no black boxes	9	7%		19																	△				

Figure 7. Rooms one, two, three, and four of the House of Quality. A higher resolution HoQ is in Appendix B.

1.7 UAC's Desired Cell Layout

While UAC left much of the design open for the team's interpretation, they did lay out specific requirements for the robot cell, gripper, and billet scanning.

1.7(i) Robot Cell Layout

The robot cell will need to allow UAC's loaded billet racks to be brought in, and empty racks removed. It also needs to have fencing to keep workers out when the robot is moving. If workers enter the cell—either for maintenance or to deliver billet racks—the cell needs to cut power to the robot. For this reason, the gripper needs to fail safe such that it does not drop the billet if power is cut.

1.7(ii) Billet Gripper

The production line where this robot will be installed, processes ten-inch diameter billets that range in length from ten inches to thirty-seven inches. The longest billets weigh around three-hundred pounds. The gripper needs to attach to the end of a FANUC R-2000iB robot arm and—when holding a billet—weigh less than the four-hundred and sixty-pounds weight limit of the arm. The gripper needs to be serviceable and replaceable in case of damage.

1.7(iii) PLC and Interaction with the Entire Process

PLC code needs to be written and laid out so that it directs the robot for picking and placing billets. The code needs to handle errors, such as an incorrect billet being on the stack, a billet not being positioned correctly, or a trip in the security fence. The code also needs to communicate with the oven PLC that controls the whole production line. This will tell the robot when it needs to add a billet to the oven.

1.7(iv) Billet Scanning

The robot cell needs to scan a QR code printed on each billet. It then needs to send the billet ID to the oven PLC to confirm that this billet is part of the current recipe card.

As an additional task, UAC would like the robot to measure the billet and compare it against the billet length listed on the recipe card.

Chapter 2: Literary Reviews

This chapter discusses a few papers that the team read. Each section breaks down a research paper, journal, or book section that helped with the engineering design process.

2.1 Robotic Research and Development with a FANUC

With the increased use of robotics in industrial settings, engineers need to understand PLC coding and ladder logic to properly run and code machines. Industrial robots are designed and developed by different companies and can follow their own internal coding, but still use basic ladder logic components in the programing (Parmar, 2017). The FANUC robot that UAC has procured to complete this project comes equipped with joint and linear movements like most robots. There are also various I/O interfaces the engineer must know to properly code the tools and hardware attached to the FANUC. Companies will offer training packages for their robots to teach technicians the basic coding platform for the PLC. UAC has an engineer, Brian Norris, who focuses on coding all the robots in the facility and is helping the team with the logic for picking and placing. The team will bring an idea to Brian and have him streamline and increase the efficiency of the desired robot moves.

As a part of this project, the team has created a gripper design for the end effector and will in turn need to create a tool frame for the gripper. The gripper will most likely just use an offset from the center of joint six. The team will also create user frames to assist with the creation of points in the different codes called from the main program. The way to create user frames is to create a rectangular shape and to use them as a frame of reference to jog the robot in the program (Parmar, 2017). Without formal training on the FANUC system, the team relies on Brian to assist with the programming of the pick and place process and creation of the tool and user frames.

2.2 FANUC Collision Detection

FANUC, the company that makes the robot arm UAC purchased, has a collision detection protocol natively in the robot’s software. For this system to work properly, the operator needs to tell the robot the weight of the payload it is handling. Then, the FANUC can rotate about its J5 and J6 axis. The resistance that the motors encounter, coupled with the payload the user input, can be used to find the mass moment of inertia of the payload. If the robot knows the payloads mass moment of inertia, it can calculate the amount of resistance the motors should encounter for any movement the robotic arm makes. If the robot encounters more resistance than this, it knows it has had a collision.

This collision detection can be used for things other than just shutting off the robot when it hits something. By measuring how much a surface is resisting the movement of the arm, a FANUC robot can follow a contour of a surface, or course correct to grab something. This is a feature of some models of FANUC robots and is referred to as “SOFTFLOAT.” (Cheng, 2010)

2.3 Need for the Pick and Place Correction and Alternative Solutions

The current process is potentially harmful to the safety of the human operator and lowers the production rate of the plant. As discussed in the system overview, the current operation requires the operator to do a dangerous pick movement with a gantry lift on billets that can be up to three hundred pounds. If the billet were to fall the only thing keeping the operator safe would be their steel toed boots. The lift is also heavy, clunky, and difficult to move in the pallet area. Currently, the operator keeps up with the induction oven since the process is an average of five billets per hour. The implementation of the robot is not to increase production, but to ensure the correct billet is going into the oven and to keep the operator from harm’s way when placing the billets in the oven. The design and structural analysis of a good robotic arm reduces manpower and can help on some production aspects (Reddy, 2016).

Some alternatives to the pick and place system would be a conveyor belt with the billets lined up on front of the magazine that would index forward when the induction oven needed a billet. Problems with this method would be the transportation from the billet cutting station to the induction oven. The plant is not equipped to easily transport the billets in anything beyond the billet rack, so the billets would have to be loaded from the rack onto the conveyor belt, which would add an unnecessary step in the process. Another solution would be a pulley system different from the gantry crane that adds more stability to the billet picking. This solution still requires a human operator and UAC wanted an automated solution. UAC purchased the FANUC robot for this specific problem and the KSU team was tasked to fully work with just the robot.

2.4 Pneumatic Controls

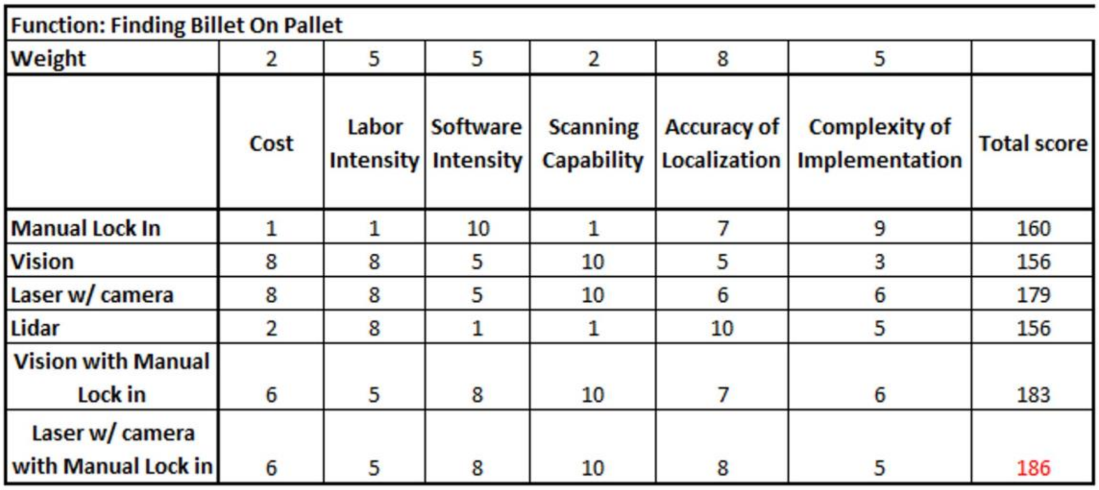
The gripper in this project—which is the focus of Chapter 3:—utilizes pneumatic controls to open and close the arms that will lift the billet. These arms need to have enough strength to hold up to three hundred pounds. More research had to be done to determine how to choose the correct pneumatics and if air was the most efficient way to lift heavy items. The cylinder being used on the robot is heavy duty and double acting. On a study done with a double acting cylinder, the force of gravity on the time of displacement was tested to determine if the horizontal or vertical position was most affected. The study showed that having the cylinder in a horizontal position lacked the effect of gravity on the time. For both horizontal and vertical positions, the higher the pressure the faster the displacement time (Jiménez, 2020). The cylinders on the UAC gripper could have been used in the vertical direction, but the billets would have been too heavy on the cylinder with any gravitational force.

A single acting cylinder is also useful in not having to find the exact force needed to lift the billet. The gripper arms will close and want to close all the way, the billet will stop the gripper arms from getting to their shortest length, and forks on the end of the gripper will lift the billet while the cylinder is still pressurized and in a closed position. Had there been a need for force calculations with a double acting cylinder, a closed feedback control loop would have been useful to achieve the desired strength (Ngo, 2017). The loop would give better control of the system and hold the correct pressure while the arm is in motion. This solution would be better for smaller applications with fragile items being lifted, such as in prosthetics. The billets are made of aluminum and can be squeezed up to the maximum pressure of the cylinders in use, making the force feedback loop unnecessary to create.

2.5 Sensor Implementation

When considering the type of vision needed on the robot cell, the team investigated lasers, cameras, proximity sensors, and LIDAR. The LIDAR was discounted quickly due to the high price and complex coding required to run in the plant. The solution seemed too complicated for what UAC was looking for, which was also the reason cameras were ruled out. The camera solution was found to be unreliable in certain lights and needed a microchip to code the process of finding the billet. Some other downsides to these two are they require time to scan the billet area, are not fast at data processing, can both be expensive if the camera needed add-ons, and reacted poorly in changing environments (Pajor, 2014). The team ultimately decided to go with distance lasers, but only to measure the billet length, and proximity sensors to find the billet. The simple sensor solution is what UAC prefers and will be easy to implement when testing starts. The rack has to be more controlled to make sure the gripper can go to the correct locations, but the production team has said this will be achievable in the future.

Table 1: Trade Study of Sensor Options



Function: Finding Billet On Pallet							
Weight	2	5	5	2	8	5	
	Cost	Labor Intensity	Software Intensity	Scanning Capability	Accuracy of Localization	Complexity of Implementation	Total score
Manual Lock In	1	1	10	1	7	9	160
Vision	8	8	5	10	5	3	156
Laser w/ camera	8	8	5	10	6	6	179
Lidar	2	8	1	1	10	5	156
Vision with Manual Lock in	6	5	8	10	7	6	183
Laser w/ camera with Manual Lock in	6	5	8	10	8	5	186

The team quantified the results for the different vision options to determine which was the best option for the cell. In **Error! Reference source not found.**, each category was given a weight above to see how important the team would find the item. The lower the weight, the less important. Accuracy was one of the biggest factors when initially considering vision. The higher the score of the solution, the better the solution would be to our cause. The highest scored solution was the laser, camera, lock-in combination as chosen by the team. When this was presented to UAC, they requested the use of a proximity sensor in place of a camera to help cheapen the complexity of the system.

As vision systems and industrial robots get more advanced, 3D sensors have become more common place for mapping a cell (Parmar, 2017). The team initially wanted to implement the laser and camera combination to allow the rack and billets more freedom around the cell, but the UAC's engineering team prefers 2D methods of sensors as it is what they have on hand. UAC also wants the quickest to test and run solution with minimal training for their current operators, making the laser and sensor combination the best approach for the customer's needs.

2.6 Safety Research

Safety in robotics is a big concern in manufacturing and industrial environments. The articles researched are overviews of safety in these environments. *Industrial robot safety, managing industrial risk* is about lowering risk factors when working with robots. For example, taking the motion of the robot into account is a huge risk factor that can be minimized when thinking about making sure the motion is slow and away from unsafe areas. (Hoske, 2018). *Robotic Safety Guarding* is about the safety measures that are beneficial to control a robot cell.

This article also gives a straightforward breakdown of what a robot cell needs, which is spot on to the initial assessment of items needed for the robot cell (Mantel, 2019).

2.7 Proximity Sensor Research

A look at the industrial sensors landscape is an article evaluating different sensors in the industrial environment. In exploring the vision system, a vast complexity was found that UAC did not want to take on. This led to the use of proximity sensors in conjunction with control of the billet and rack in the robot cell. In the evaluation of proximity sensors, the inductive proximity sensor was noted as the most reliable in a metallurgic industrial environment. “Inductive proximity sensors are durable and extremely reliable solid-state technology” (Waugh, 2020). Most inductive sensors have a hard time picking up on aluminum because they are designed to be used with steel, but luckily there are specially designed sensors for nonferrous sensors.

> *“Nonferrous sensors will detect metals such as aluminum better than they sense iron, while all-metal sensors will pick up on all kinds of metal at the same sensing distance” (Consider All The Factors When Selecting The Proper Inductive Proximity Sensor, 2020).*

2.8 Safety Relay Research

In looking into safety relays and assessing a multifunctional safety relay the team ran across the below statement.

> *“Very simple applications are often best served by one or two single-function safety relays and don’t require the added expense of multi-function relays. A machine, robot, or other system that may only have an E-stop along with a set of light curtains or door switches is an example of an application where a single-function safety relay would be the best choice.” (Filipkowski, 2014)*

This is exactly what UAC wants implemented. A small single function robot cell only really needs a single function safety relay. It would be less expensive for UAC to incorporate a multifunctional safety relay for their whole extrusion process, but because they are implementing automation in a piecemeal way and the cells can operate somewhat independently, a multifunction relay is not needed.

2.9 Cable Management Research

One of the biggest issues with robot arms is cable management. Robot arms have wiring and tubing on them that needs to move with the robot arm. If the wiring is not allowed to move with the robot, it will wear out faster and eventually break when operating. In an industrial environment this could result in revenue losses and damaged products. Currently, cables are tied down in a restrictive way and not allowed to move. This also can cause them to wear out faster. The prefer methods are to relieve restrictions "with service loops, and a junction box that contains and protects the electrical connectors joining the cables" (igus, 2021). For the team's purposes, only cables that travel between joints six through four on the robot need to be relieved. The rest of the cables are already wired and/or have extra room in the built-in cable carrier on the robot. The four to six joint segments will need to have extra slack provided by the service loop. This will allow the end of the robot arm a lot of freedom to move without compromising the cables. The robot will also have a cable carrier on this segment to protect the cables in an enclosure and make sure they don't get caught on anything while moving.

2.10 Electrical Wiring Research

One portion of the project is the electrical wiring. While all of the physical labor of wiring will be done by UAC, the team does need to make sure the solution provided is a strong design that will define the wiring that needs to be done. Understanding the wiring is a basic but important portion of any industrial electrical project. *Review on Electrical Wiring (Types, Sizes and Installation)* breaks down different types of wiring, what situations they should be used in, and their correlation to power, voltage, and amperes (Mustafa T. Mohammed Alhashimi, 2019).

This is applicable to the project because there are different wiring situations in the robot cell. The main power to the robot is 480-volt three phase power that runs about 18 amps. This will need to be a multi-conductor cable with 3 conductors and a neutral wire. Power also needs to be run via wires to the sensors in the robot cell. This will be 24 volts but will not require a high ampere level, so it can be a low gauge. Other wirings will be input and outputs; these will mostly be somewhere around 24 volts and will include digital, analog, and OSSD signals. Again these are low ampere levels so a small gauge wire is all that is needed.

Chapter 3: End Effector/Gripper

This chapter focuses on the design of the gripper. It explains the philosophy that led to the current design, as well as reviewing some of the alternatives that were considered.

3.1 Examples of Alternatives

This section explores gripper style, construction method, material selection, and fork placement. The design, model, evaluate, loop that was used resulted in many alternatives not being fully fleshed out. The next section details some of the smaller design changes that did not have formal alternatives.

3.1(i) Selection of Gripper Style

UAC left most design choices open to the team. One such choice is the style in which the gripper picks billets. Reference images of the styles considered are in Figure 8. These three styles are discussed and compared in detail below.

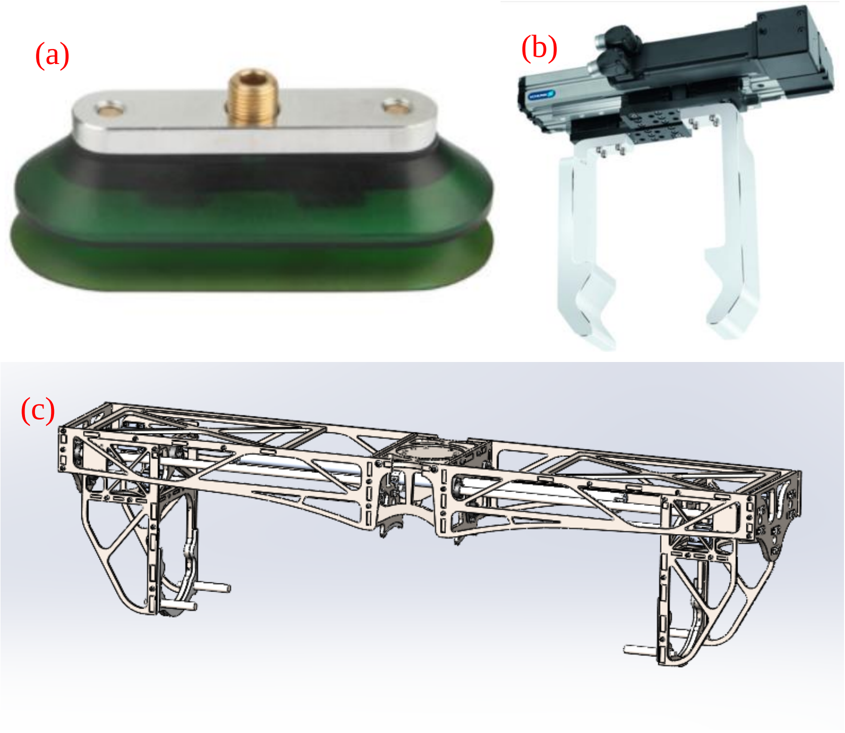


Figure 8. Examples of end-effectors considered. (a) Vacuum gripper from Schmalz (SCHMALZ, 2021). (b) Claw in middle from Schunk (SCHUNK, 2021). (c) SolidWorks model of the picker at both ends.

The UAC engineering manager suggested using a vacuum gripper—such as the one shown in Figure 8(a)—to grab the billet and so this was the first alternative investigated. Unfortunately, vacuum grippers able to conform to such a large diameter are not offered off-the-shelf (OTS).

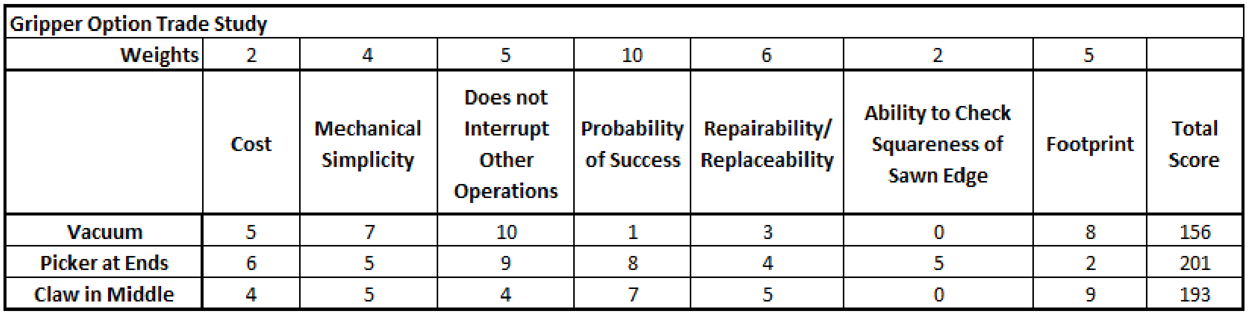
The next gripper style considered was a picker that grabs the billets by the ends—such as the one shown in Figure 8(c). This mechanism requires a large stroke to accommodate the billets UAC loads into the oven.

Figure 9: UAC's current solution for picking up billets.

Currently, UAC operators use a claw that grabs the billets by their middles as shown in Figure 9. This method was the next one investigated—such as the one shown in Figure 8(b). However, the current process requires an operator to manually maneuver the gripper into place over the billet at an awkward angle. It was deemed that this level of tactile feedback was too complex to program.

Ultimately, the picker at both ends was chosen as the best design. The criteria considered are tabulated below in **Error! Reference source not found.**. The highest weighted category ("Probability of Success") looks at the probability that the gripper style will meet all of UAC's requirements. For example, the vacuum gripper scores poorly because no OTS vacuum flange exist for Ø10 inch cylinders. As such, the team would have to design a custom flange, which would not be anywhere as reliable as an OTS option. Similarly, the vacuum scores poorly in the "Reparability/Replaceability" category because the custom flange would require a specialized machine shop to make replacement parts. The vacuum and claw in the middle score best on the "Footprint" category because they are small. The Picker at Ends would need to be longer than the longest billet, so it will take up a lot of floor space. The Claw in the Middle would require a change to UAC's billet rack, so it scores low on the "does not interrupt current operations" category.

Table 2: Trade study of gripper style options.



Gripper Option Trade Study								
Weights	2	4	5	10	6	2	5	
	Cost	**Mechanical Simplicity**	**Does not Interrupt Other Operations**	**Probability of Success**	**Repairability/ Replaceability**	**Ability to Check Squareness of Sawn Edge**	**Footprint**	**Total Score**
Vacuum	5	7	10	1	3	0	8	156
Picker at Ends	6	5	9	8	4	5	2	201
Claw in Middle	4	5	4	7	5	0	9	193

3.1(ii) Selection of Gripper Construction Method

Four styles of gripper construction were originally considered. They were primarily judged on cost, weight, manufacturability, repairability, and probability of success.

The first and most obvious end-to-end gripper construction method is an OTS gripper. These exist and UAC purchases grippers from Schunk for their other robots. However, to do the end-to-end gripping, the gripper needs at least a twenty-seven-inch total stroke. Neither Schunk, nor any other end-effector manufacturers offer an end-effector with this large of a stroke.

The first custom method considered was a welded frame constructed of hollow structural steel (HSS). This design maximized strength and simplicity of manufacture given that all parts could be cut from OTS HSS members and welded together. This design would potentially be heavy, and the welded construction would make repairs more difficult.

The second design involved assembling the gripper using machined chunks of solid aluminum. This design is almost as strong as the HSS frame, but given the size of the billet, would require large—and expensive—custom machined components.

The third design uses sheet metal components that would be waterjet, and then bolted together. This is a compromise between the simplicity of the components in the welded HSS frame, and the interchangeability and ease of repair provided by machined components.

3.1(iii) Material Selection

UAC's original recommendation was to construct the frame out of stainless steel. This recommendation was made because of stainless steel's hardness and abrasion resistance. However, given the large size of the picker style gripper that was chosen, the team is recommending a hot rolled steel (HRS) instead. Stainless steel (SS) has a higher material cost and machining cost. While it does provide additional hardness as mentioned, the team does not feel that these offsets it's additional cost. After meeting with him, UAC's engineering manager agreed. HRS was not the only alternative considered. The team looked at constructing the frame from 304SS ASTM A-240, AISI 1045 HRS, AISI 1018 CRS, and 5052-H52 Al. **Error! Reference source not found.** below breaks down some of the quantitative differences of these metals, but ultimately, the choice came down to either 1045 HRS or 1018 CRS.

Table 3. Notable properties of compared materials.[1]

Materal Grade	Yield Stress	Hardness	Cost for 1'x1' x 1/4" Sheet
304 SS ASTM A-240	30 ksi	215 BH	$66.02
AISI 1045 HRS	45 ksi	163 BH	$33.26
AISI 1018 CRS	64 ksi	126 BH	$48.36
5052-H32 Al	27 ksi	62 BH	$33.15

While the lower price of the 1045 HRS was nice, ultimately it was concern over residual stress that drove the decision to use 1045 HRS. Because so much material is being cut out. The team determined that the residual stresses within a CRS will likely deform the sheets that make up the gripper after it is waterjet, and the gripper will not perform properly.

3.1(iv) Design of Billet Picking Forks

The first end-to-end picker used friction to hold the billets in place. The motion study in Figure 10 was performed to find a pneumatic piston powerful enough to hold onto the billet. UAC ultimately vetoed this design because it would fail deadly. If an airline were cut, or the compressed air failed, the billet would slip out of the gripper and potentially damage something.

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[1] These values come from Table-20 and Table-24 of Shigley's Mechanical Engineering Design (Budynas & Nisbett, 2016).

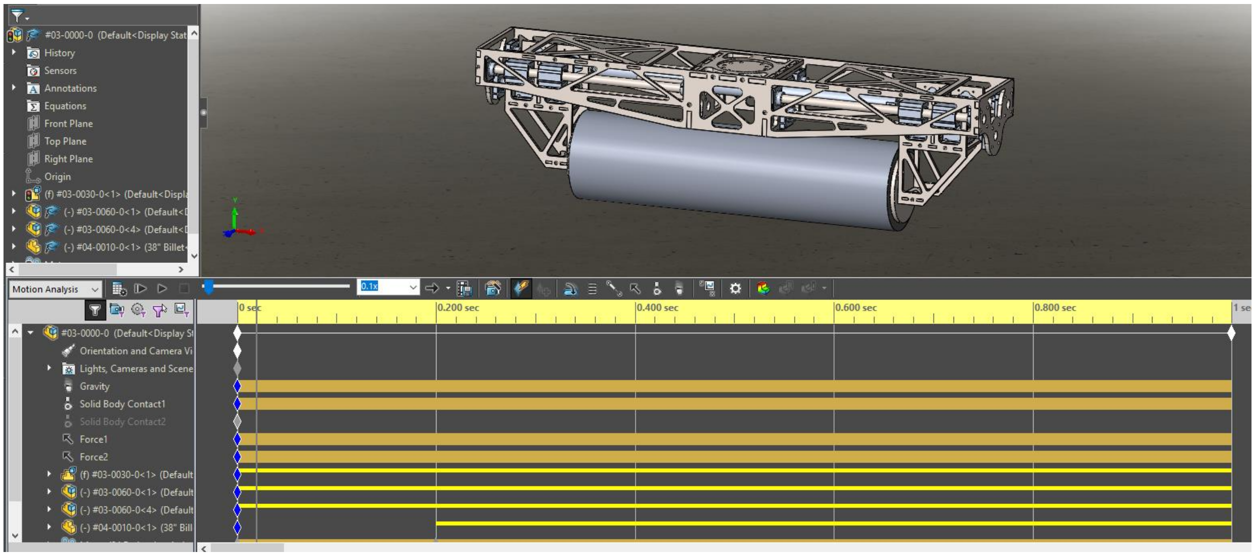
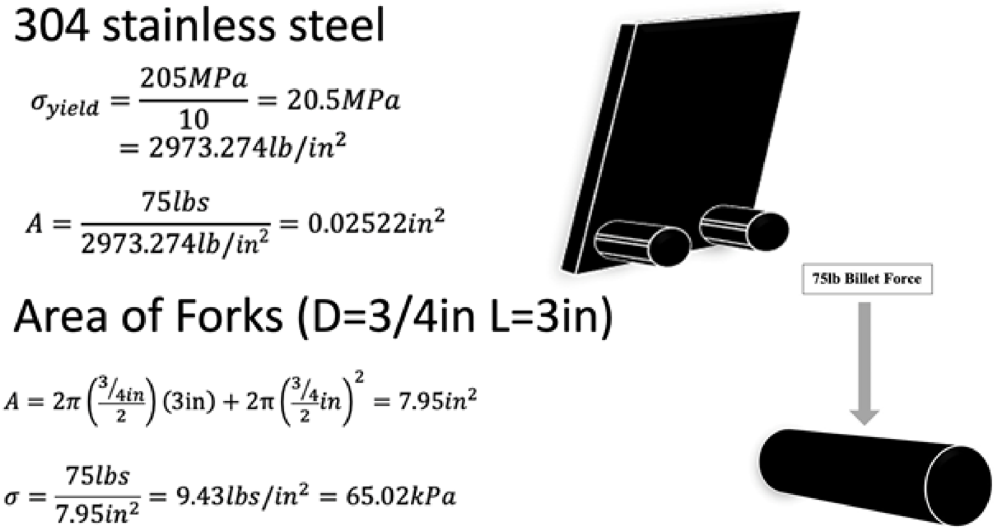


Figure 10. Screenshot of the setup for the motion study in #03-0000-0. The study includes gravity and friction between the arms and billet ends.

The next billet holding method considered was a pair of forks beneath the billet. The arm uses two forks because any more increases the grippers chances of hitting the billet end when the jaws close. Because only two forks were used, extra care had to go into making sure they would be strong enough, and the billet would be securely cradled by the forks in all modes of operation.

Hand calculations were completed to ensure the diameter and length of the forks would lift the heaviest billets without failing. The hand calculations (see Figure 11) were completed with a high Factor of Safety (FoS). The calculations are shown to demonstrate that the forks with a diameter of three quarters inch and length of three inches are more than adequate for the three-hundred-pound billet. Refer to **Error! Reference source not found.** as the legend for the hand calculations.



304 stainless steel

$$\sigma_{yield} = \frac{205MPa}{10} = 20.5MPa$$
$$= 2973.274lb/in^2$$

$$A = \frac{75lbs}{2973.274lb/in^2} = 0.02522in^2$$

Area of Forks (D=3/4in L=3in)

$$A = 2\pi\left(\frac{3/4in}{2}\right)(3\text{in}) + 2\pi\left(\frac{3/4}{2}in\right)^2 = 7.95in^2$$

$$\sigma = \frac{75lbs}{7.95in^2} = 9.43lbs/in^2 = 65.02kPa$$

Figure 11: Gripper Arm Hand Calculations

Table 4: Hand Calculations Legend

Symbol	**Definition**
σ_{yield}	Yield Stress
A	Area
D	Diameter of Forks
L	Length of Forks
σ	Stress

In addition to the size of the forks, the placement of the forks is important. The forks need to cradle the billet when the gripper lifts straight up, and when it lifts at a 10° angle. The forks also need to not hit the other billets. Figure 12 show the sketches that were drawn in SolidWorks to find what position of the forks satisfy these criteria. Figure 12(a) shows the billet being picked up, surrounded by five other billets. Figure 12(b) shows a billet that is next to the rack upright and the three adjacent billets. These need to be picked up at a 10° angle.

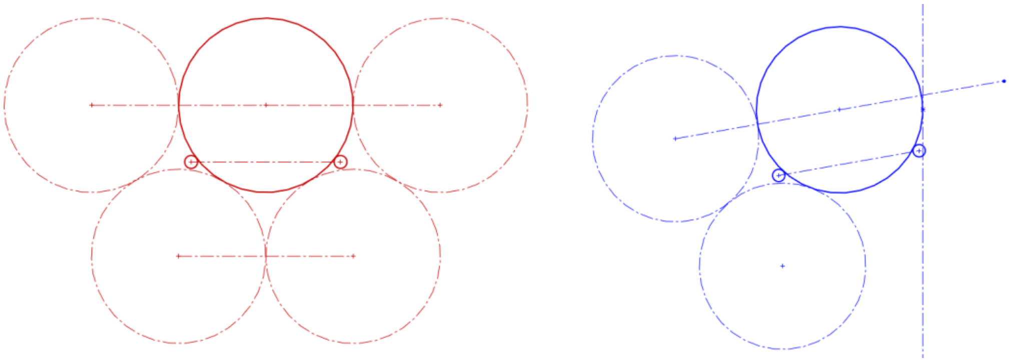


Figure 12. Sketches showing the interactions between the billets, rack, and forks when (a) picking straight up in the middle of the rack and (b) when at a 10° angle picking up the edge billets.

3.2 Parametric Design

The team's design philosophy is fueled by the agile approach. A section of the gripper is designed. It is simulated, it is perfected in a vacuum, and then the next section is added. Next both sections were simulated together, and their interactions are perfected. This was continued until the entire design was completed.

This design philosophy resulted in many incremental decisions as opposed to large decisions that necessitate a formal trade study. Its results can be seen in the gradual shaping of the gripper shown in Figure 13.

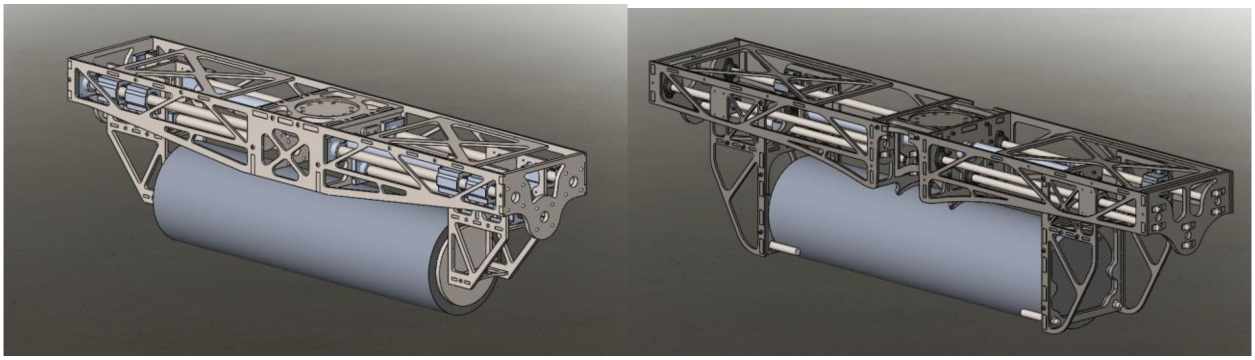


Figure 13: Changes in the gripper design (a) #03-0000-0 is the first iteration of the gripper. It is made from 304SS and uses friction to hold the billet. (b) #03-0000-D uses a different frame made of 1045 HRS and forks to hold the billet.

This section will show a few key examples of the agile design approach and explain why the design decisions were made.

3.2(i) Integration of Vision Systems

An early concept for the design involved the use of many laser measurement devices on the gripper, but this idea was discarded in favor of using cheaper proximity sensors. The original idea was to use the laser sensor to detect the billets in space from above, but modifications to the frame allowed for features that contour to the billet, which can guide the gripper into place. These features, in conjunction with proximity sensors can generate a closed-feedback loop that will locate the gripper over the billet without expensive lasers.

3.2(ii) Cut-out for Fitting around Rack Upright

The first three versions of the gripper assembly use a side plate that spans the entirety of the gripper's length. However, in testing it was discovered that when picking billets at the ends of the racks, this side plate would collide with the uprights of the billet rack (see Figure 14).

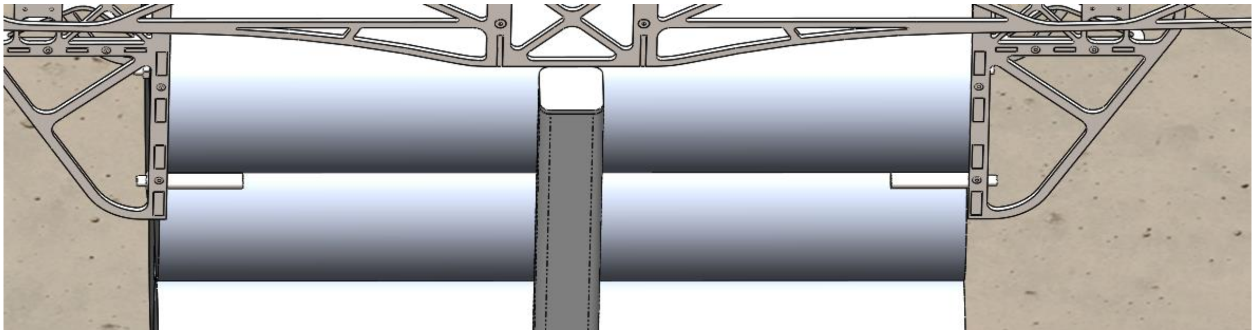


Figure 14. Gripper side plate impacting with the billet rack upright. This screenshot shows the gripper assembly #03-0000-A and is from the plant layout assembly #00-0000-0.

To fix this, #03-0000-B was reworked. The weldment that makes up the frame was split in half, and a new weldment was created at the middle that the two sides bolt to (see Figure 15).

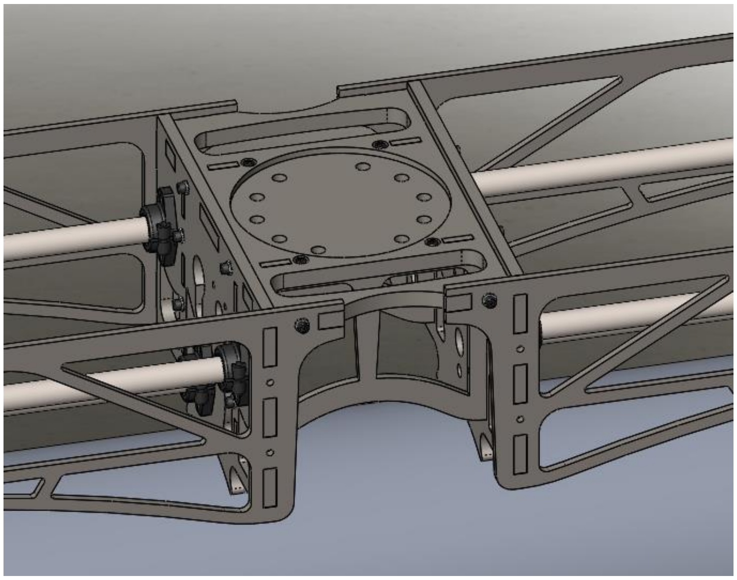


Figure 15. Split frame design. This image is from #03-0000-B

3.2(iii) Changing Movable Jaw Frame for Better Visibility

In the middle of the project, the team changed their approach to scanning billets. Because of this, a camera needed an unobstructed view of the billet end when it was in the gripper. This required a simple change to the geometry of the movable jaw frame. A before and after can be seen in Figure 16.

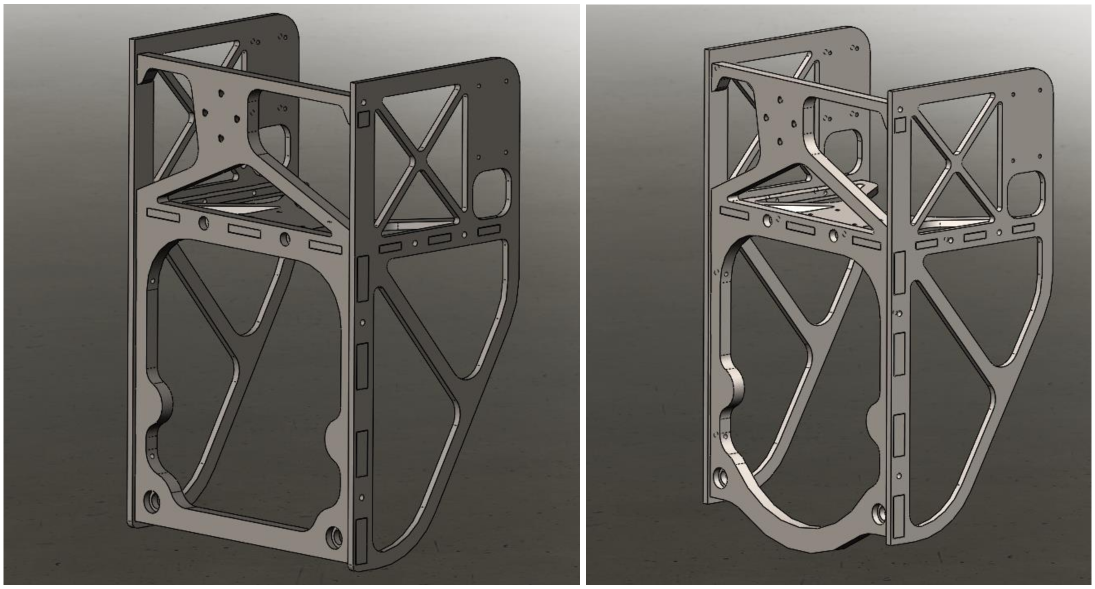


Figure 16. Movable jaw frame changed for better visibility. (a) #03-0210-C with the straight bottom support and (b) #03-0210-D with a curved bottom support.

3.3 Testing and Simulations

Because of the expense of manufacturing a prototype of the gripper, SolidWorks suite of simulation software will be relied upon to inform design.

3.3(i) UAC's Simulation Request

UAC understands the industrial environment that the gripper will operate in. They expect collisions between the gripper, billet racks, the oven, the robot arm, etc. They have requested that the team simulate these conditions.

They have also asked from simulations to show the grippers normal operating conditions. They want to confirm that the gripper will not yield when moving 300 lbs. billets.

3.3(ii) Execution of UAC's Simulation Request

The collisions will be simulated using the “Impact Studies”. The goal is to confirm and maintain a FoS against yield of 1.5 for low-speed collisions with the billet rack and oven. These collisions are being considered “normal operating conditions”. High speed collisions will also be simulated to represent the robot arm being controlled manually, or a fault in the program. The goal of the high-speed collisions simulations is to machine a FoS of 2 against fracture. The assumption is that these collisions will be lost time incidents and may require replacement of parts of the gripper.

The static studies of the gripper holding a 300 lbs. billet will all aim for a FoS against yield of 2.0. These will simply simulate the force of gravity on the gripper and billet, as well as the stress on the bolted connections.

3.3(iii) Static Study Setup

This sub-section details the setup and results of a static study run on #03-0000-F—the top-level forked gripper assembly. Figure 17 below shows the simulation symbols of #03-0000-F.

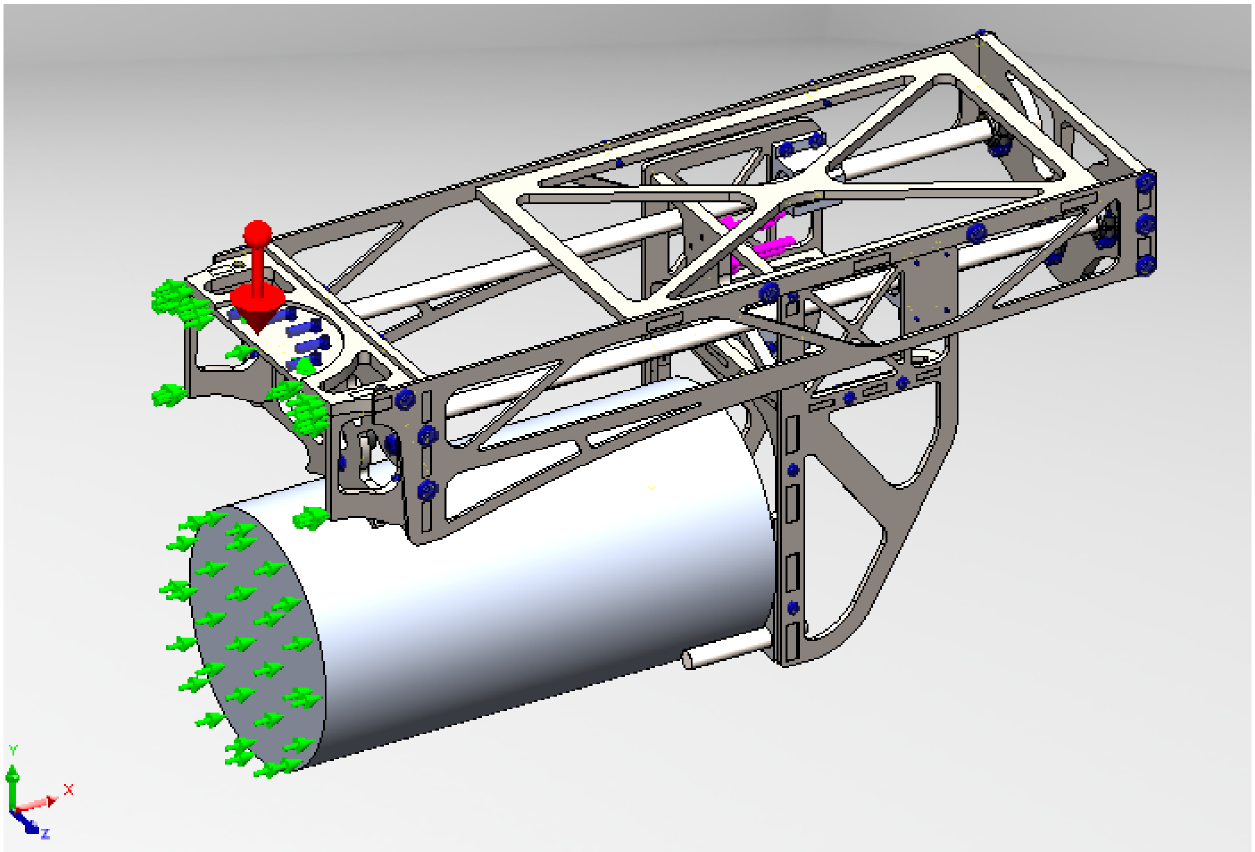
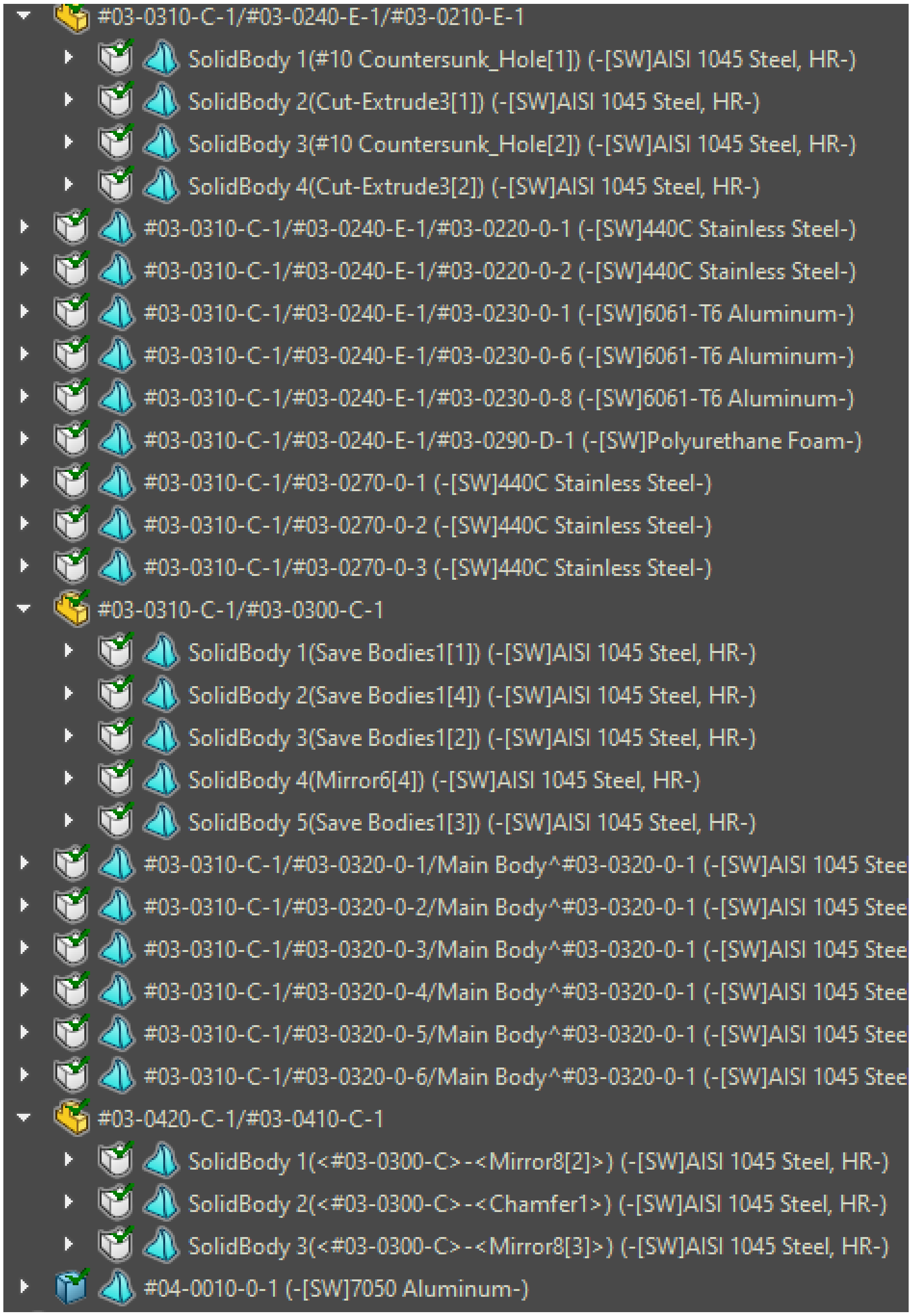


Figure 17. Static simulation screenshot of #03-0000-F.

The static study that was run focuses on stress in the frame, bolts, and forks. Thus, pneumatic components, linear bearings, and foam padding was excluded from the study. The billet needs to be included because it resists the force from the pitons, but because its deformation is not the focus of the simulations, it was treated as a rigid body, all other bodies were meshed as solids. Figure 18 shows all the bodies in the simulation.



- #03-0310-C-1/#03-0240-E-1/#03-0210-E-1
  - SolidBody 1(#10 Countersunk_Hole[1]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 2(Cut-Extrude3[1]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 3(#10 Countersunk_Hole[2]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 4(Cut-Extrude3[2]) (-[SW]AISI 1045 Steel, HR-)
- #03-0310-C-1/#03-0240-E-1/#03-0220-0-1 (-[SW]440C Stainless Steel-)
- #03-0310-C-1/#03-0240-E-1/#03-0220-0-2 (-[SW]440C Stainless Steel-)
- #03-0310-C-1/#03-0240-E-1/#03-0230-0-1 (-[SW]6061-T6 Aluminum-)
- #03-0310-C-1/#03-0240-E-1/#03-0230-0-6 (-[SW]6061-T6 Aluminum-)
- #03-0310-C-1/#03-0240-E-1/#03-0230-0-8 (-[SW]6061-T6 Aluminum-)
- #03-0310-C-1/#03-0240-E-1/#03-0290-D-1 (-[SW]Polyurethane Foam-)
- #03-0310-C-1/#03-0270-0-1 (-[SW]440C Stainless Steel-)
- #03-0310-C-1/#03-0270-0-2 (-[SW]440C Stainless Steel-)
- #03-0310-C-1/#03-0270-0-3 (-[SW]440C Stainless Steel-)
- #03-0310-C-1/#03-0300-C-1
  - SolidBody 1(Save Bodies1[1]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 2(Save Bodies1[4]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 3(Save Bodies1[2]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 4(Mirror6[4]) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 5(Save Bodies1[3]) (-[SW]AISI 1045 Steel, HR-)
- #03-0310-C-1/#03-0320-0-1/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0310-C-1/#03-0320-0-2/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0310-C-1/#03-0320-0-3/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0310-C-1/#03-0320-0-4/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0310-C-1/#03-0320-0-5/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0310-C-1/#03-0320-0-6/Main Body^#03-0320-0-1 (-[SW]AISI 1045 Stee
- #03-0420-C-1/#03-0410-C-1
  - SolidBody 1(<#03-0300-C>-<Mirror8[2]>) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 2(<#03-0300-C>-<Chamfer1>) (-[SW]AISI 1045 Steel, HR-)
  - SolidBody 3(<#03-0300-C>-<Mirror8[3]>) (-[SW]AISI 1045 Steel, HR-)
- #04-0010-0-1 (-[SW]7050 Aluminum-)

Figure 18. Bodies list for static simulation of #03-0000-F.

As mentioned above, bolt strength was a key factor, so all bolts were modeled as rigid connectors. Bolt torque values are tabulated below in Table 5.

Table 5. Bolt torque values used in the static simulation of #03-0000-F. Preload values assume no lubrication, and a K value of 0.2.

Bolt size and grade	Bolt Proof stress	Torque in Simulation	Resulting Axial Preload
#10-32, A574	153 ksi[2]	42 lbf-in	840 lbf
#8-36, A574	153 ksi[2]	36 lbf-in	1098 lbf
1/4-28, A574	153 ksi[2]	10 lbf-ft	2160 lbf
M10 X 1.5MM, CLASS 12.9	140 ksi[3]	56 lbf-in	457 lbf

Because the gripper is symmetric through the center, it has a symmetric fixture applied to cut down on simulation time. The flange where the FANUC robot mounts has eight M10 foundation bolts and a circular fixture around the ring. The global contact is no penetration with a friction factor of 0.3.

A downward gravity of 32.2 ft/s² and a force of 40 lbf where the piston attaches were also applied. Figure 19 shows the different materials that bodies were modeled as.

---

[2] Minimum proof strength of A574 comes from Table 8-10 of Shigley’s Mechanical Engineering Design (Budynas & Nisbett, 2016).

[3] Minimum proof strength of Class 12.9 comes from Table 8-11 of Shigley’s Mechanical Engineering Design (Budynas & Nisbett, 2016).

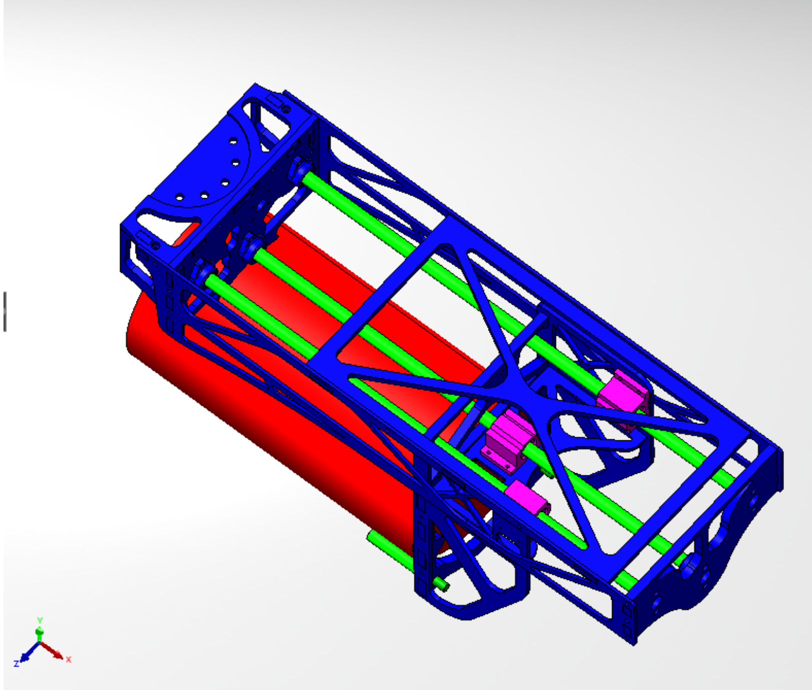


Figure 19. #03-0000-F colored to represent what material each body is made from. Blue is AISI 1045 steel, Green is 440C stainless steel, Purple is 6061-T6 aluminum, and Red is 7050 aluminum.

The assembly was meshed using a blended curvature-based mesh, with local mesh refinement at the tabs and slots. Figure 20 shows the mesh. As explained above, the mesh is finer around the tabs, slots, and bolt holes. The goal was to have the plates be represented at least three elements thick in those regions. The mesh is made of 293718 elements. The maximum element ratio is 100.85, but only three elements have aspect ratios this high, and those elements are not in critical regions.

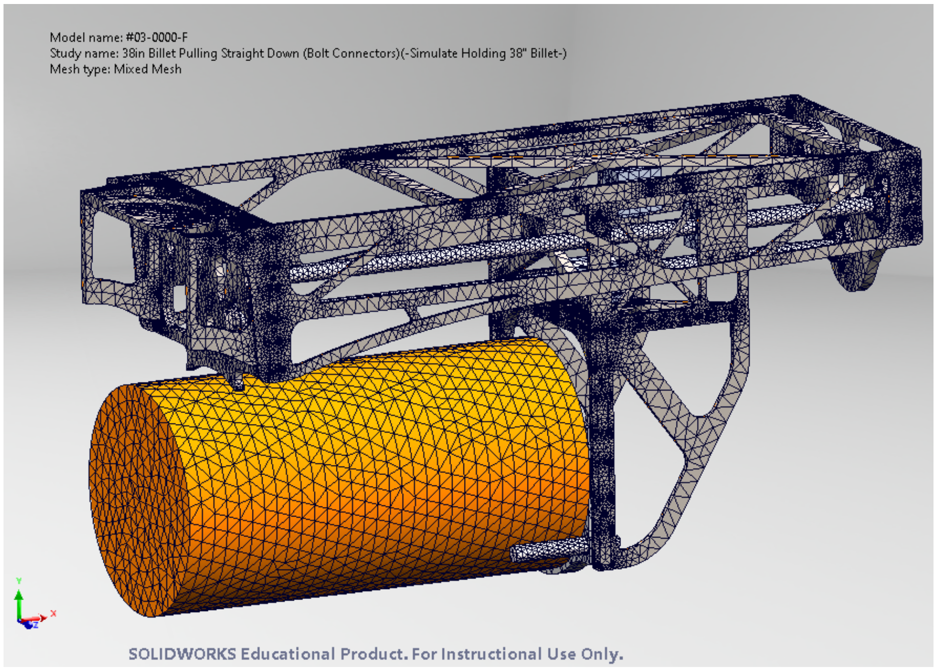


Figure 20. #03-0000-F static simulaiton mesh.

3.3(iv) Static Study Results

The simulation was run, and results were recorded. In the first revision, some areas were yielding, while other regions were underutilized. This can be seen in the Figure 21. Figure 21(a) shows a one of the original shaft flanges that was to be constructed of cast aluminum. The part is below the desired FoS, so a different shaft collar was chosen for subsequent versions. Figure 21(b) shows the close-up of the anti-racking plate. The entirety of this part has a FoS greater than 8.0, so the lightening holes were increased to remove the unnecessary material.

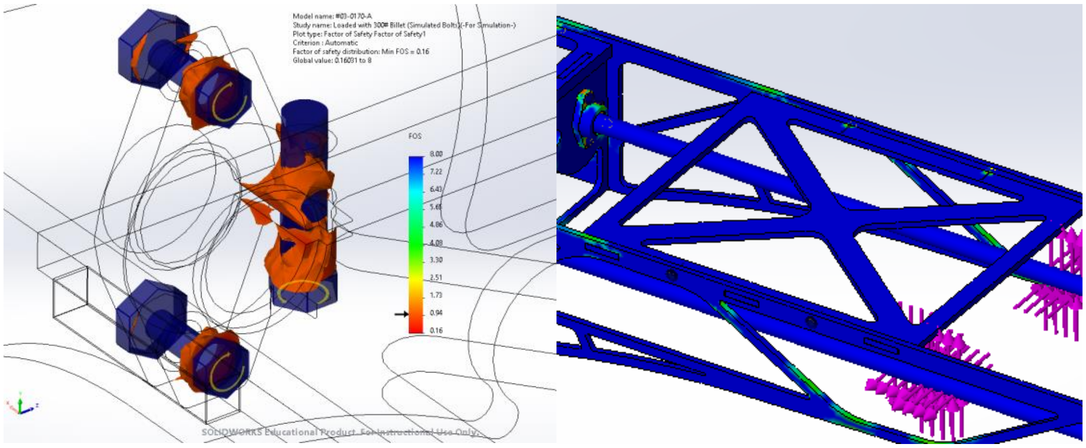


Figure 21. Results from static simulation of #03-0170-A. (a) Regions that yielded around the shaft flanges. (b) The anti-racking plat is being severely underutilized as none of it has a FoS lower than 8.

The version of the top-level assembly that was sent to UAC for approval and fabrication was #03-0000-F. Figure 22 shows the von Mises stress plot of the static study. As expected, higher stress values are round around the bolt holes and the interface with the robot flange. A more

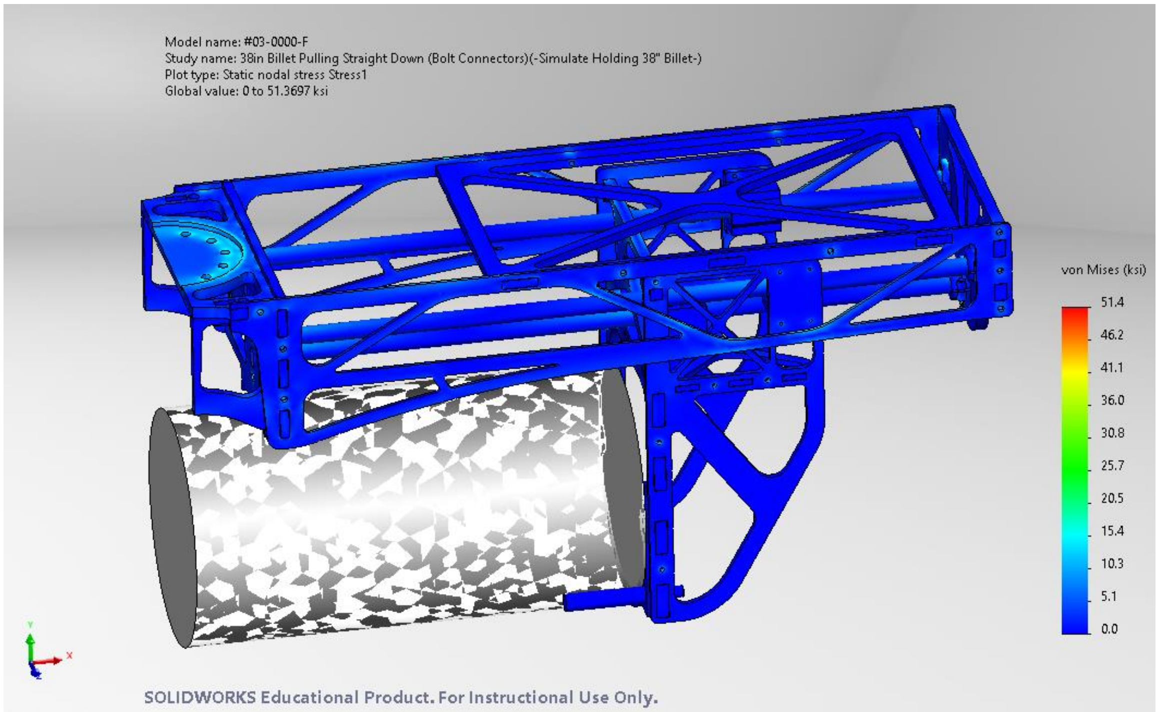
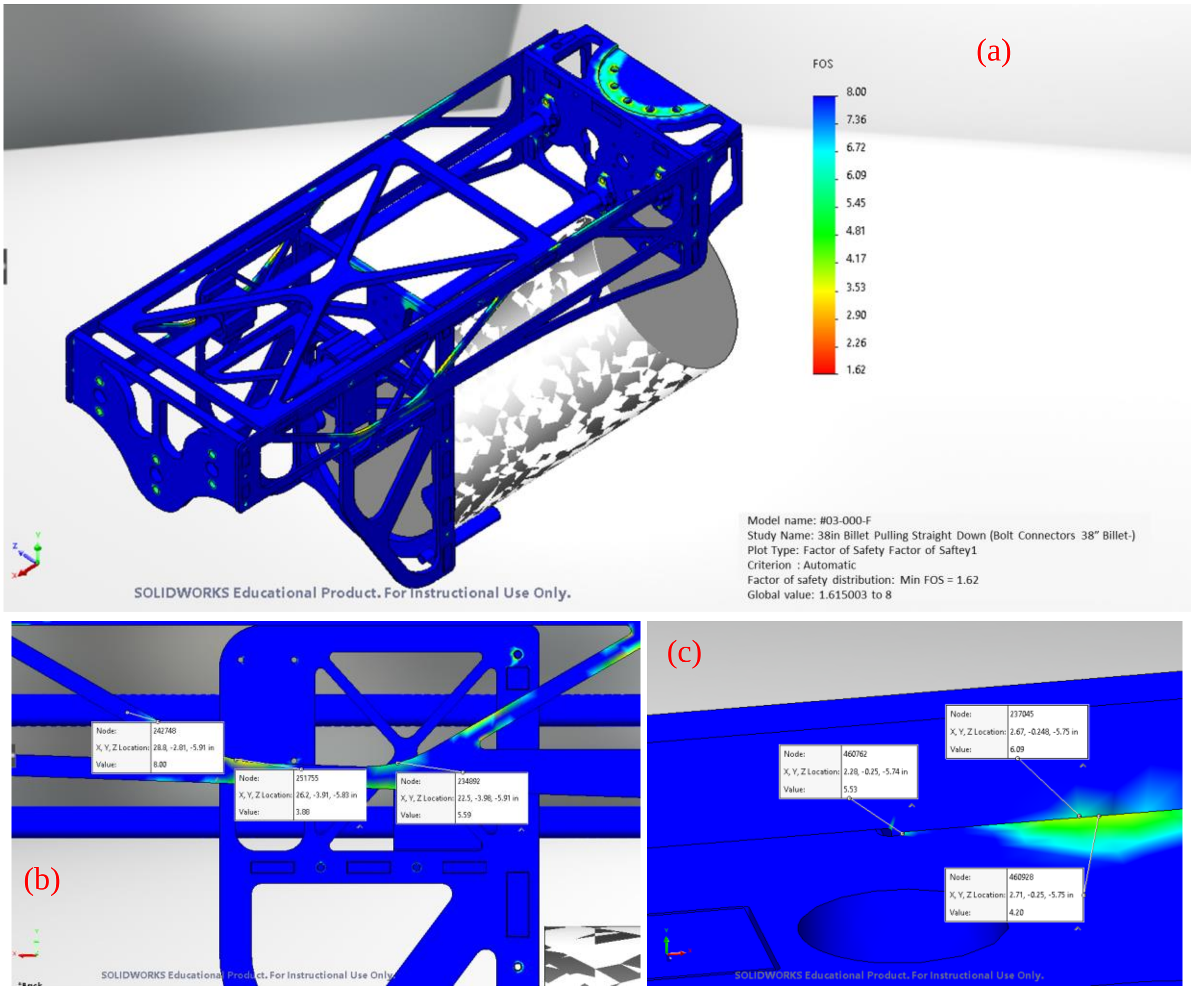

Model name: #03-0000-F
Study name: 38in Billet Pulling Straight Down (Bolt Connectors)(-Simulate Holding 38" Billet-)
Plot type: Static nodal stress Stress1
Global value: 0 to 51.3697 ksi

Figure 22. Results plot of von Mises stress in the #03-0000-F study.

A more telling picture of the results comes from the FoS plot. Snips of it can be seen in Figure 23. Figure 23(a) show the FoS of the entire model. The minimum FoS is greater than 1.5—as was desired. The other snips show areas of interest. Figure 23(b) show the side plate lightening holes with FoS of ~5 at the inside radiuses. Figure 23(c) shows the inside of the bolt holes that connect the side plate to the robot flange plate. This was a high stress region in previous versions, but because of sizing of the bolts, and alterations to the tabs, the minimum FoS in this region is now ~4.



Model name: #03-000-F
Study Name: 38in Billet Pulling Straight Down (Bolt Connectors 38" Billet-)
Plot Type: Factor of Safety Factor of Saftey1
Criterion : Automatic
Factor of safety distribution: Min FOS = 1.62
Global value: 1.615003 to 8

Node:	242748
X, Y, Z Location:	28.8, -2.81, -5.91 in
Value:	8.00

Node:	251755
X, Y, Z Location:	26.2, -3.91, -5.83 in
Value:	3.88

Node:	234892
X, Y, Z Location:	22.5, -3.98, -5.91 in
Value:	5.59

Node:	237045
X, Y, Z Location:	2.67, -0.248, -5.75 in
Value:	6.09

Node:	460762
X, Y, Z Location:	2.28, -0.25, -5.74 in
Value:	5.53

Node:	460928
X, Y, Z Location:	2.71, -0.25, -5.75 in
Value:	4.20

Figure 23. FoS Plots from #03-000-F static study. (a) The whole model. (b) A close-up of the lightening holes. (c) A close-up of the back side of the mounting holes.

The final result plot shown in this report is in Figure 24. It shows the displacement of the model. Because it is critical that the linear rails remain parallel, deflection of the linear rails needed to be held to a minimum. As shown, the rails only deflect by 50 thousand at its steepest. This deflection causes the rails to be at a 0.26° angle, which is within the 1° out of parallelism that the bearings can accommodate (McMaster Carr, n.d.).

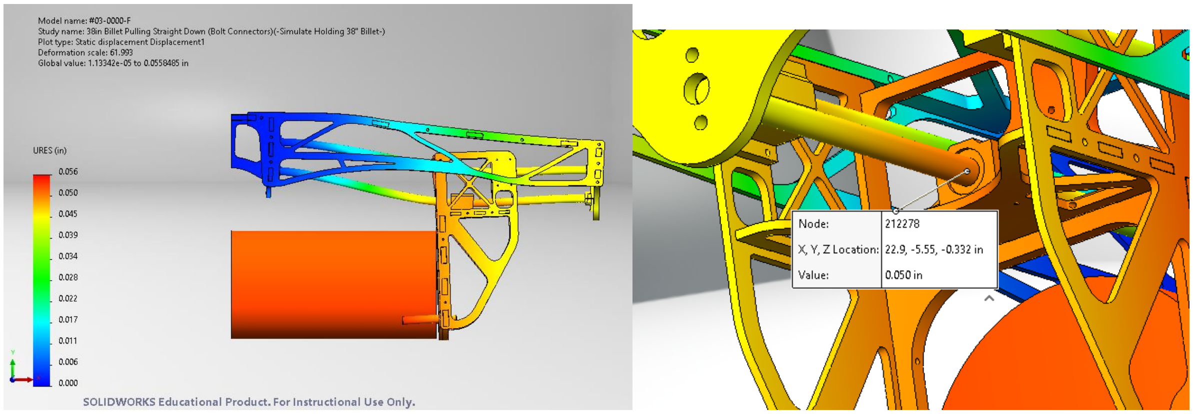


Figure 24. Deformation results from #03-0000-F simulation. (a) Deformation across the whole model. (b) Peak deflection of the linear shaft.

3.3(v) Impact Study Results

In talks with UAC, it was deemed that impact simulations were not necessary. Because cycle times were low, it was deemed that the arm could move slowly, and impacts would be low speed and not likely cause damage.

3.4 Design for Manufacture/Assembly

Because this project will be manufactured, the team considered the tools and methods that will be used to manufacture the gripper. These points have been raised throughout this chapter, but this section will focus on some prime examples of design for manufacture (DFM) and design for assembly (DFA).

3.4(i) Use of GD&T for Drawings

The interface between the robot arm and gripper is formed by a FANUC ISO-flange. The flange—mounted to the robot arm—uses eight M10 bolts, two locating pins, one internal locating bore, and one external locating lip. The gripper design will use the outer lip for positioning, and the eight M10 bolts for securing. This interface needs to be made with tight tolerances to allow the robot code to accurately know the position of the gripper in relation to the world. For these reasons, the flange mounting plate will be one of the parts that utilize GD&T to ensure accurate manufacture (see Figure 25).

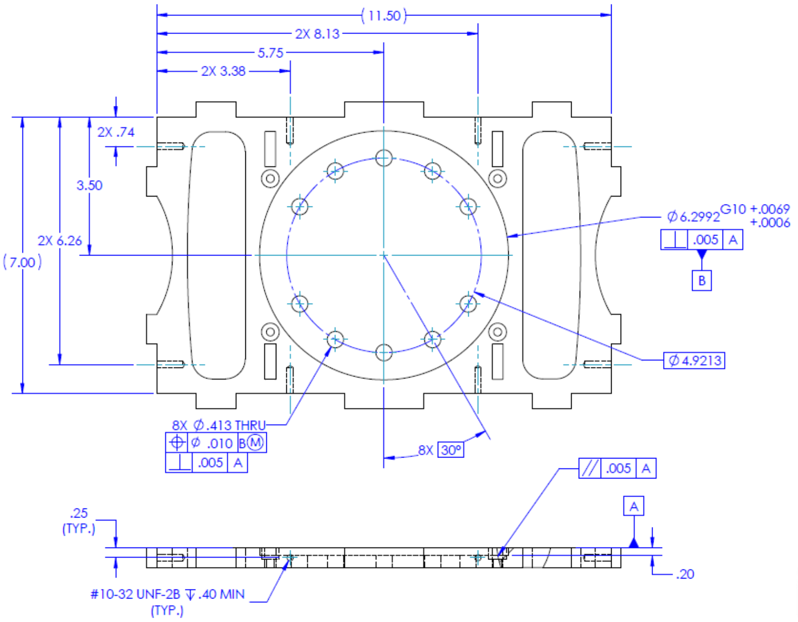


Figure 25: Example of GD&T used on the machining drawing #03-0411-0-A.

3.4(ii) Increased Precision for the Movable Components

The movable elements of the gripper require a higher level of precision to ensure they function smoothly and reliably. This informed the selection of the linear rails, linear bearings, and shaft flanges. The rails were specifically chosen because of their tight dimensional and geometric tolerances, as well as the hardness which allows them to withstand wear from use. The bearings were chosen for their ability to accommodate some out of parallelism of the linear rails. The shaft flanges and accompanying weld nuts were chosen for their ability to adjust the position and angle of the linear rails.

3.4(iii) Hardware Selection

The gripper is assembled using only five different sizes of bolts. The frame is held together almost entirely with #10-32 x 5/8” and 1/4”-28 x 3/4" socket head cap screws (SHCS). The other bolts are for connecting OTS components to the frame. This standardization makes maintenance easier on the gripper. This is also an easy place to implement poka-yoke. By using just one length of #10-32, and one length of 1/4-28, it is not possible to install the wrong sized fastener into a hole.

SHCS were chosen for most of the frame because they offer superior strength as opposed to even Grade 8 hex bolts (Rufe, 2013, p. 296). Because of high stresses observed at some of the tabs during the FEA stage, the stationary frame is constructed with 1/4”-28 12-point screws. These screws provide more resistance to shear forces. But the larger bolts are chosen primarily because they allow for a higher axial preload. That makes the tab and slot connection more rigid. Increasing the axial preload also requires more torque during installation. The 1/4"-28 bolts are 12-point bolts to give more surface are for applying the extra 6 lbf-ft.

3.4(iv) Drawings and Standards Followed

The drawings submitted to UAC were made inside of SolidWorks. The complete drawing package can be seen in Appendix . They are compliant with three drawing standards. The general drawing standard ASME Y14.100-2013 was followed for the drafting standard. One drawing has GD&T which is drawn in accordance with ASME Y14.9-2009. Finally, one drawing has some welding symbology compliant with AWS A2.1:1998. Examples of the GD&T and AWS weld symbology can be seen in Figure 26.

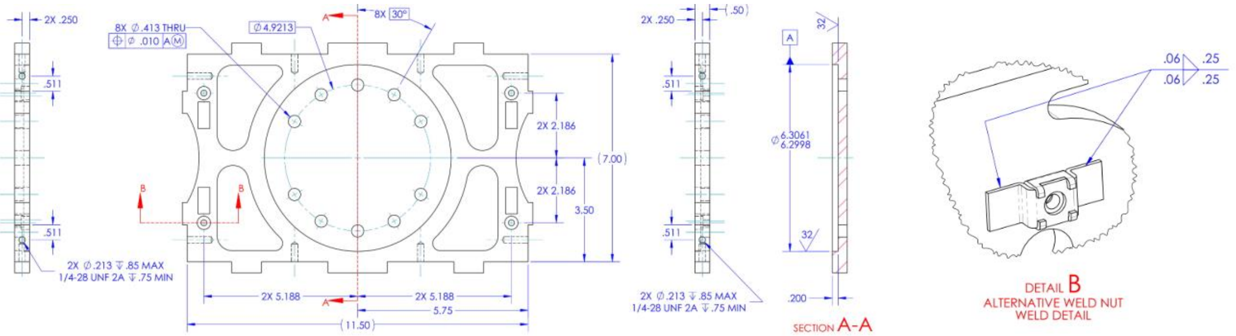


Figure 26. Snips from the drawings submitted to UAC. The snips show (a) an example of GD&T from #03-0411-C-A and (b) one of the weld symbols on #03-0300-C-A.

3.5 Pneumatic system

The gripper is opened and closed by pneumatic cylinders which are actuated using air pressure. The air pressure system is going to be operating at 100 psig. The FANUC robot has a built-in air pressure system that will allows users to plug the hose into the base and have pressurized air available at the robot arm. In the team’s design, there will be a fore pressure regulator put in place to make sure the pressure does not deviate from 100 psig. Also at the base, will be a digital pressure sensor and a lock out valve. The pressure sensor will be set to deactivate the robot if pressure is lost in the system. This is to keep the robot from operating in the event the system loses pressure. The lock out valve’s function allow an operator will be to turn off the air pressure to the robot manually so that maintenance can be done.

The air pressure system is operated by the FANUC controller. The digital air pressure sensor will feed a digital signal to the controller when the air pressure is on. The robot won’t operate unless the air pressure signal is running a high. The controller will have an open gripper close gripper output. This runs to 5-2 solenoid mounted on the robot. When the open gripper output runs high, the inner port is pressurized and the outer port is vented, then the gripper opens. There is also a close gripper output that runs high and pressurizes the inner port and vents the outer port closing the gripper.

Chapter 4: PLC and Robot Code

This section provides some insight into the coding methodology of the team, and the manner in which code picks and places the billets from the billet rack into the induction oven magazine.

Figure 27: Billet Rack with labeled billet positions

The current rack can hold up to 14 billets as shown in Figure 27. The bottom portion of the rack will be welded with three pegs to keep the bottom four billets from rolling while the rack has less than three billets. Billets can be placed anywhere along the center of the rack; therefore, the code will need to reflect different possibilities of centers for each billet. Both the oven PLC and the robot PLC will communicate throughout the whole process to run the pick and place as seamlessly and simply as possible. The rack will need to be controlled to run without a complex vision system as UAC wants this process to be easily replicated. UAC has confirmed the reasoning behind the need for control of the rack and the FANUC operator, Brian Norris, has approved the process.

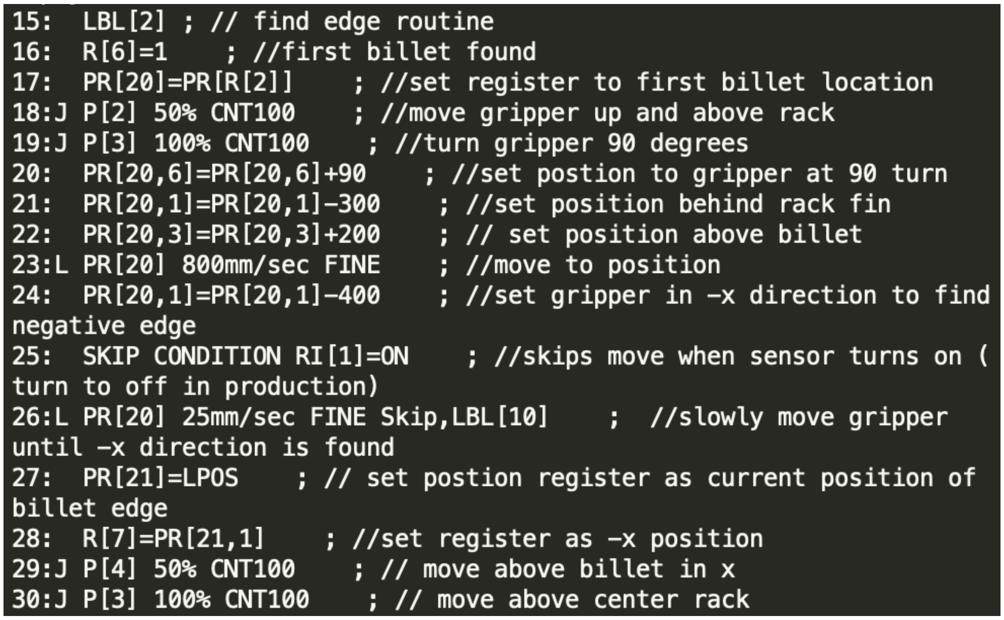
4.1 Robot and Oven PLC Communication

While the FANUC robot has a very complex and intelligent system to code on, the PLC in the oven is easier to set up and stronger to use. The operator will set the oven PLC with the recipe card and it will talk to the robot and send the signals for when a billet is needed, the length and alloy required, and the number of billets in the order. The oven PLC will also have separate alarms from the robot and performs tasks separate from this process in relation to the induction process.

4.2 Pick and Place Process

This section will cover the different codes and ideas set into the billet picking and placing solution using the robot, sensors, and oven to complete the minimum success criteria.

4.2(i) Finding the Billet

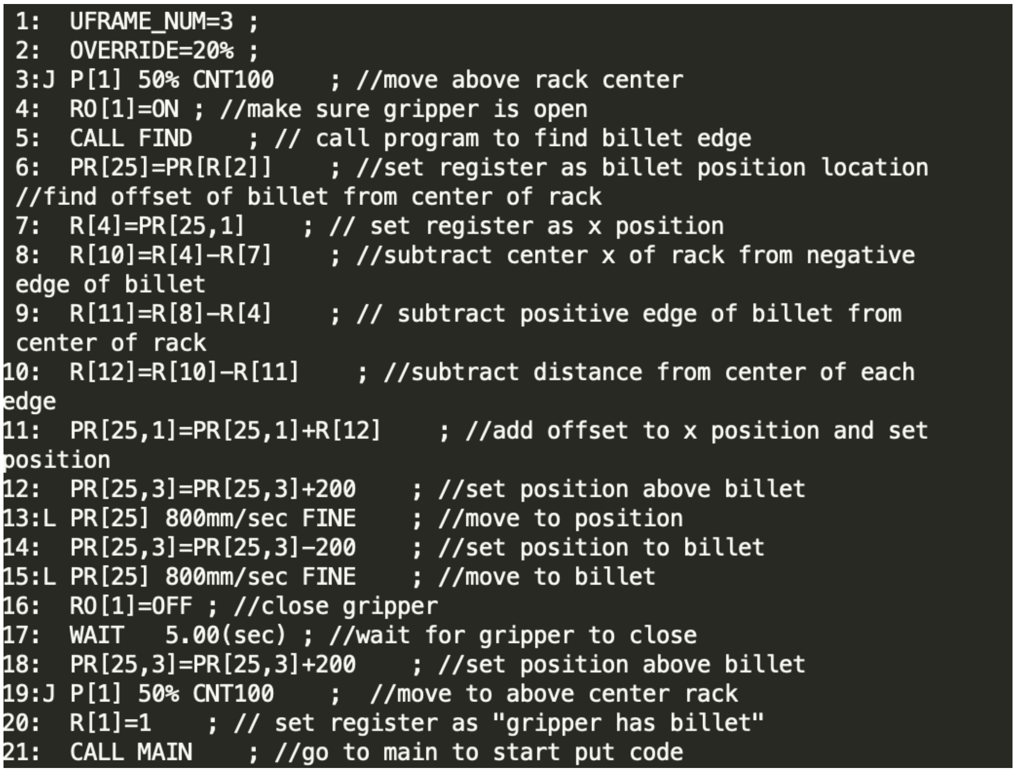


```
15:  LBL[2] ; // find edge routine
16:  R[6]=1    ; //first billet found
17:  PR[20]=PR[R[2]]    ; //set register to first billet location
18:J P[2] 50% CNT100    ; //move gripper up and above rack
19:J P[3] 100% CNT100    ; //turn gripper 90 degrees
20:  PR[20,6]=PR[20,6]+90    ; //set postion to gripper at 90 turn
21:  PR[20,1]=PR[20,1]-300    ; //set position behind rack fin
22:  PR[20,3]=PR[20,3]+200    ; // set position above billet
23:L PR[20] 800mm/sec FINE    ; //move to position
24:  PR[20,1]=PR[20,1]-400    ; //set gripper in -x direction to find
negative edge
25:  SKIP CONDITION RI[1]=ON    ; //skips move when sensor turns on (
turn to off in production)
26:L PR[20] 25mm/sec FINE Skip,LBL[10]    ;  //slowly move gripper
until -x direction is found
27:  PR[21]=LPOS    ; // set postion register as current position of
billet edge
28:  R[7]=PR[21,1]    ; //set register as -x position
29:J P[4] 50% CNT100    ; // move above billet in x
30:J P[3] 100% CNT100    ; // move above center rack
```

Figure 28: FANUC Robot “Find” Code Snippet

To start, the robot will hover above the center of the billet rack and move to position fourteen labeled on the rack, Figure 27, and check if the billet is there with a proximity sensor. The proximity sensor has a range of around seventeen inches to clear the gripper arms and more than halfway through the billet. If the billet is there the arm will move in the positive and negative X positions to find the end points of each billet. The arm needs to turn at a 90° as to not hit the robot when moving back and forth while searching for each edge. The robot PLC saves the positions as registers when the proximity sensor turns off, meaning the end of the billet has been reached. The next step is to subtract these positions from each other, giving the length of the billet for the quality assurance portion of the project to confirm with the oven PLC. The oven PLC is smarter and more capable than the robot PLC and will do most of the heavy lifting process wise. If billet fourteen is not there, the PLC will repeat the process with thirteen and decrement down until the sensor turns on. A portion of the code is shown in Figure 28 as the FANUC robot is coded in the proper syntax. The longest billet will be the starting billet and will have to be chosen first, so UAC will need to make sure the starting billet is at the highest position on the rack according to the PLC. The registers are all set to each different billet position and will send the robot to the exact position it needs to make sure the robot will make the correct moves to get the billet, such as if there needs to be a tilt for the movement.

4.2(ii) Lifting the Billet



```
   UFRAME_NUM=3 ;
   OVERRIDE=20% ;
 J P[1] 50% CNT100    ; //move above rack center
   RO[1]=ON ; //make sure gripper is open
   CALL FIND    ; // call program to find billet edge
   PR[25]=PR[R[2]]    ; //set register as billet position location
//find offset of billet from center of rack
   R[4]=PR[25,1]    ; // set register as x position
   R[10]=R[4]-R[7]    ; //subtract center x of rack from negative
edge of billet
   R[11]=R[8]-R[4]    ; // subtract positive edge of billet from
center of rack
   R[12]=R[10]-R[11]    ; //subtract distance from center of each
edge
   PR[25,1]=PR[25,1]+R[12]    ; //add offset to x position and set
position
   PR[25,3]=PR[25,3]+200    ; //set position above billet
 L PR[25] 800mm/sec FINE    ; //move to position
   PR[25,3]=PR[25,3]-200    ; //set position to billet
 L PR[25] 800mm/sec FINE    ; //move to billet
   RO[1]=OFF ; //close gripper
   WAIT   5.00(sec) ; //wait for gripper to close
   PR[25,3]=PR[25,3]+200    ; //set position above billet
 J P[1] 50% CNT100    ;  //move to above center rack
   R[1]=1    ; // set register as "gripper has billet"
   CALL MAIN    ; //go to main to start put code
```

Figure 29: FANUC Robot “Get” Code

As shown in Figure 29, after the billet and its endpoints have been found, the code can then compute how off center the billets are to move in the correct X direction to lift the billet without damaging the arms. Say the highest billet is in position eight with an offset of two inches and a total length of thirty-seven inches. The gripper arm can hit the billet at this offset and damage the forks at the end. With this pick process, the robot will adjust to the correct center then move to position eight with the offset. The gripper arms will then turn off and close and a laser will read the distance between the grippers to get the length again. This will reassure the system that it has the correct billet lengthwise. The reason for the pneumatics being set as open is on and closed is off, is so that if the power cuts off and the gripper loses power, the arms will stay closed and not drop the billet. After closing the arms and measuring the length, the robot will move back to the center rack and go to the placing code.

4.2(iii) Placing the Billet in the Oven

This code starts with the assumption that the robot already has a billet in the arms and is currently hovering above the rack. The robot will then move with the billet towards a camera to read the QR code stamped at the side of the billet. The code can be on either side, so if the oven PLC does not confirm a read, the robot will pull back and turn the billet around to check if the other side has a code. If there is no code the robot will throw an alarm, as well as if there is a code but it does not match the recipe card. If the QR code is wrong, the billet will put the billet back in the rack and wait for the operator to start the process again after making sure the new recipe card and billet rack match. If the QR code is correct and says the alloy is the one needed for the order, the robot will use the length taken from the measurements in the find and lift code and subtract it from the length of the magazine. This ensures the billet is placed close enough to the proximity sensor in the magazine that the oven PLC can read the billet there. After the billet has been placed, the robot moves back to the rack and will restart the code to lift the next billet until the oven indicates the last billet in the order has been picked.

4.3 User Alarms

The robot will have several alarms that will raise and warn the operator when the system is not working effectively as possible. In the picking and placing portion of the code, the user alarms will be for when there are no billets on a rack and there should be. The operator will need to bring in a new rack at this point and restart the process. The next alarms would be for the quality assurance portion of the project. If the billets are the wrong length or alloy, the operator will be called and informed the rack is wrong. Other user alarms will raise when the billet is dropped and will be able to tell from the floor sensors talked about in Safety. Lastly, the robot will need to inform the operator when power is cut off from the cell or the robot has had a catastrophic problem that prevents the robot from continuing with the process. The operator will then need to go to the cell and use the gantry crane currently in place to manually lift the billets into the oven. This is the backup solution to issues occurring with the robot.

4.4 Testing and Implementation

The robot is set up in an offsite warehouse near the facility where the code was written and worked on. The code was tested setting up a pushbutton box to send high and low signals to the robot to simulate the PLC oven and camera inputs. Brian set up the pushbutton box to give the robot the expected outcomes for any production run. The team also checked that the robot performed the user alarms and wrong alloy/ billet length portions correctly. If there was a testable outcome for the robot, the team performed it at the warehouse before bringing the code to UAC. After the gripper is fabricated, it will be attached to the robot and tested with the code as well. Once all the outcomes have confirmed the expectations of the robot, it will be brought to the production floor and run in the new environment. The safety features will be added and implemented into the facility, and the project will have been completed from UAC’s end once the robot can run without problems. UAC may make alterations to the code as the needs of the facility change, but the PLC code is commented on to reduce any confusion on the performance of the robot.

4.5 Alternative Solutions

The controllability of the rack is severe due to the lack of a vision system in place. The team considered adding a camera to find the circles from the side of the rack and rectangles over the top of the rack. The camera would need a microcontroller to compute the number of billets and the position the robot would need to go to and pick the billet. The robot does not have a strong enough system to get the data from the microcontroller, it would have to be converted in some way and then sent over to the camera. This solution was too complex for UAC’s liking and they offered the proximity sensor process for the team to follow. There have been many changes made along the way and will continue to have many more as the live testing begins and the system is ensured with the gripper and sensors.

The team also tried to work on collision management with different sensors and cameras, but the system became too expensive for the process. UAC is not concerned about collisions with the robot as the robot will be moving slow to keep up with the low through put of the oven and will be enclosed in a cage. The SOFTFLOAT function mentioned above in FANUC Collision Detection would be a good way to avoid collisions and fault the robot, but the function is an add-on UAC does not want to purchase. The team will use the safety features involved in the cell to stop the robot if any dangerous moves start to occur.

Chapter 5: Safety

A very important aspect of every robot cell is safety. With automation in the industrial environment robot cells are required to meet safety standards. This robot cell is going to use a robot arm to lift heavy metal billets, perform a radial swing about 75° then place that billet. There are many hazards associated with this automation and the design of the cell will need to account for all of them in order to keep the people who work at UAC and UAC's products safe.

The first task to providing a safe robot cell is to conduct research. Section 2.6 shows literature reviews conducted research on safety. From the research, the team learned not only about the safety requirements, but also the vast amount of safety techniques and sensors that are used in the industry. The article, "Robotic Safety Guarding," states the task in simple terms. First, the team needs to get the space dialed in. Then, the team will design where the guards and gate should be positioned. Next, the team chooses safety sensors that relate to the functionality of the robot cell. Finally, the team designs the safety circuit and test how the different parts interact (Mantel, 2019).

5.1 Cell Layout

Before safety was considered, the team had to design how the robot cell was going to function. Once functionality was ironed out, the area of operation was known, the billets entering and exiting the cell was known, and amount of human interaction was known. With this information the first thing that was obvious was that guarding needed to go around the perimeter of the cell with certain equipment remaining outside. "Controls and equipment requiring access during automatic operation shall be located outside the safeguarded space," (ANSI/RIA R15.06-1999) is the standard for installation of robotic machinery. Below is another excerpt of the ANSI RIA that has to do with keeping emergency shut offs unobstructed.

> *"Every robot system shall have a system emergency stop circuit and a safety stop circuit. Each robot system operator workstation and any locations capable of controlling motion shall be provided with a readily accessible, unobstructed emergency stop device." (American National Standard for Industrial Robots and Robot Systems, 1999)*

With this standard it becomes obvious what needs to be inside the guard and outside the guard.

5.1(i) Guarding

The guards need to be at least 6 feet high to keep people and other objects from encountering the machinery inside and keep anything that is supposed to be in the cell from going outside the cell. The gate to the cell needs to be equipped with a lock and sensors to confirm the gate is shut, which will keep the machinery from operating when open. This cell needs an opening of at least 6 feet wide to allow an operator to load and unload a rack of billets into the cell. Because of this, the team chose a double door approach that will open outwardly and lock from the outside. The guard will also need to be strong enough to withstand an impact from the robot arm. The cell is not big enough to cover the area of a robots reach, but since the guard will be strong enough to withstand an impact, this will not be needed. ANSI/RIA requires a

> *"…mechanical limiting devices, including mechanical stops integral to the robot, shall be capable of stopping motion at rated load, maximum speed conditions, and at maximum and minimum extension for the device" (American National Standard for Industrial Robots and Robot Systems, 1999).*

To meet this standard, the fence chosen must be strong enough to contain the robot arm. In looking at fences online they come in a variety of strengths and most are rated to meet this standard.

5.1(ii) Rendering of Cell Layout

Figure 30 shows a bird's eye view of the current layout design. 8-foot-tall guarding surrounds the cell and the overarm crane. A 6-foot-wide double door is on the right side for bringing in the billet racks. Four Keyence SZ-01S floor sensors are placed throughout the cell to provide full coverage. One of them can be seen beneath the fence in the lower right-hand corner. The fencing is placed such that it interfaces with the existing fence and does not block off access to the panels in the billet oven. Finally, the FANUC control cabinet is located outside of the cell in the upper right corner of the image.

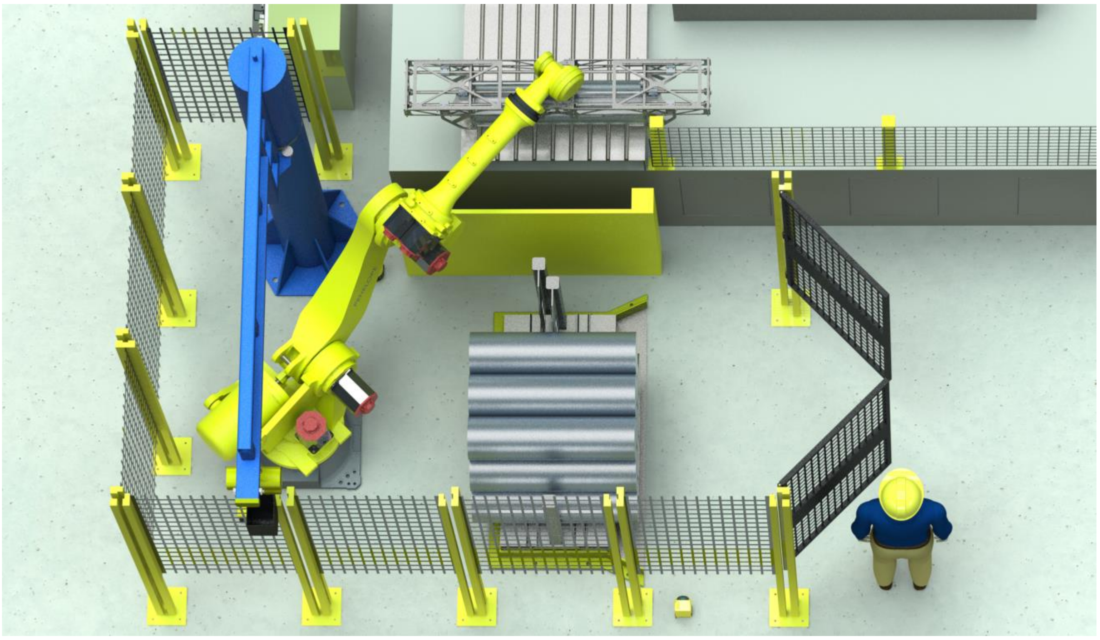


Figure 30. Bird's eye rendering of #00-0000-D.

5.2 Sensors

> *"Once the physical barrier is designed, the specifications for the electronic safety devices can then be determined. These devices include safety interlock switches for door and removable access panels, safety light curtains and safety laser scanners for frequently accessed areas and all the required safety controllers, relays, cables and hardware to design the proper safety circuit."* (Mantel, 2019)

The first thing that needs to be put in place is a sensor that makes sure the robot will not activate unless the gate is closed. Non-contact interlock sensors are magnetic-based sensors that will only allow the robot to activate if they are a closed switch and will deactivate the cell if they are an open switch.

The physical barrier is in place to keep people out while the cell is in operation, but how would one know if a human is already in the cell before you start operating? Robot cells also need to be equipped with scanners that scan the floor and will deactivate the machinery when tripped. This ensures that nothing is in the cell that shouldn't be when the robot is active. To achieve this, as close to complete floor coverage as possible from the floor scanners is required. Example of the OSHA standard below

> *"One or more methods of machine guarding shall be provided to protect the operator and other employees in the machine area from hazards*

> *such as those created by point of operation, ingoing nip points, rotating parts, flying chips and sparks. Examples of guarding methods are barrier guards, two-hand tripping devices, electronic safety devices, etc.”* (Occupational Safety and Health Administration, 2001)

There is a myriad of devices to use for this function, but the reason floor scanners were chosen is because they are specifically built to complete this task. Light curtains are good for horizontal openings or specific areas where someone could enter the cell. Safety mats are also an option but too expensive when having to cover the whole cells floor with mats.

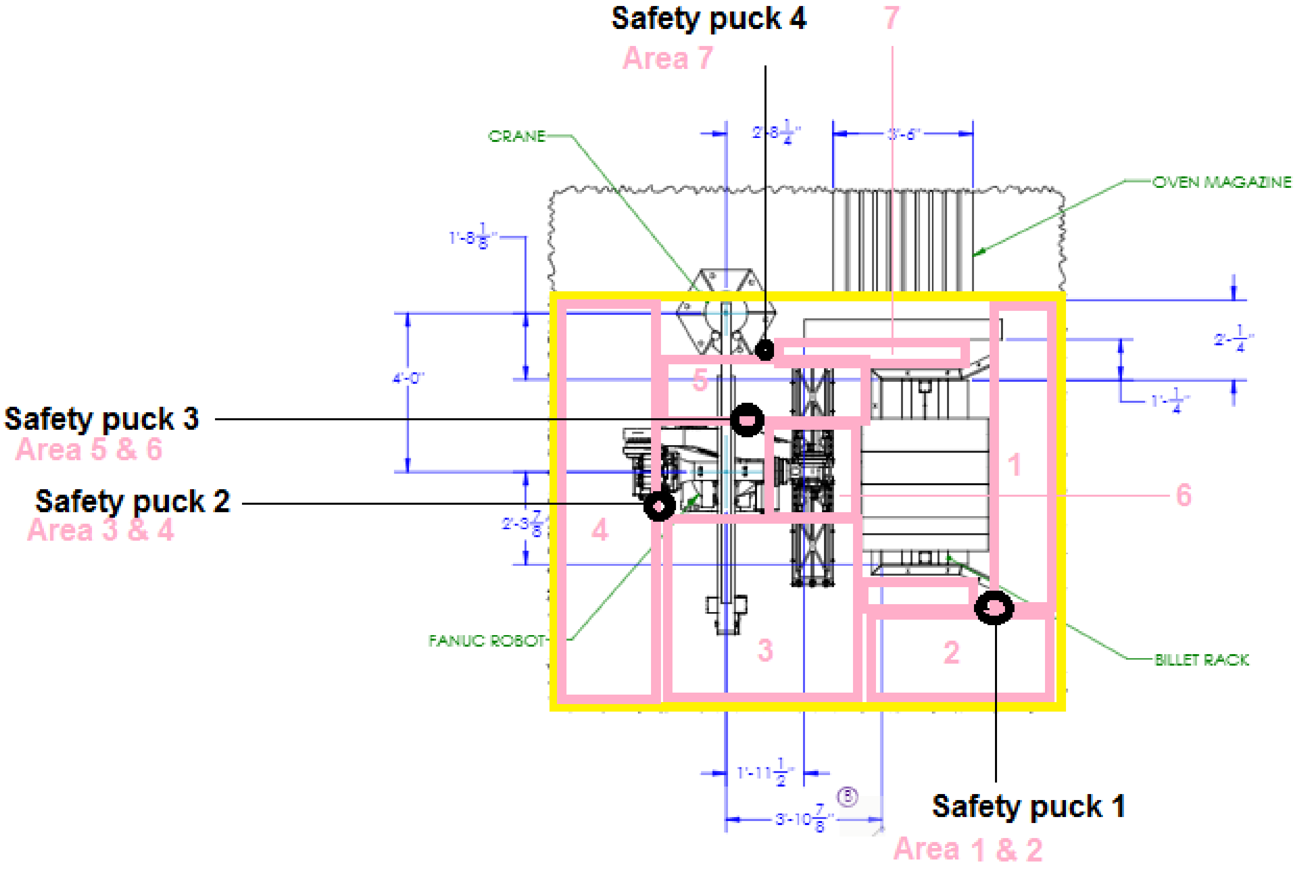


Figure 31. Floor layout showing safety pucks.

Figure 31 is a breakout of floor scanners in the robot cell. The scanning areas are in pink and the floor scanners are labeled as safety pucks in black. This is a preliminary drawing and is subject to change once the floor scanners are selected and UAC reviews our design.

5.2(i) Relay

The relay is the heart of the safety system. This is where all safety sensors are feeding their output signals. When the signal is changed or cut off, the relay sends another signal to the robot arm's faulting mechanism and the robot is essentially turned off in a safe way. Because this is such an essential function, there are multiple relays in the safety system and a complex input and output system is put into place to ensure if there is a minor malfunction in any of the safety sensors or relays, the robot is triggered to fault. The two-relay system is what UAC currently uses. There is a main relay module that connects to all the sensors and a second relay that connects to the main relay and directly to the robot. Understanding more about safety relays and the best methods for them to operate is one of our future items.

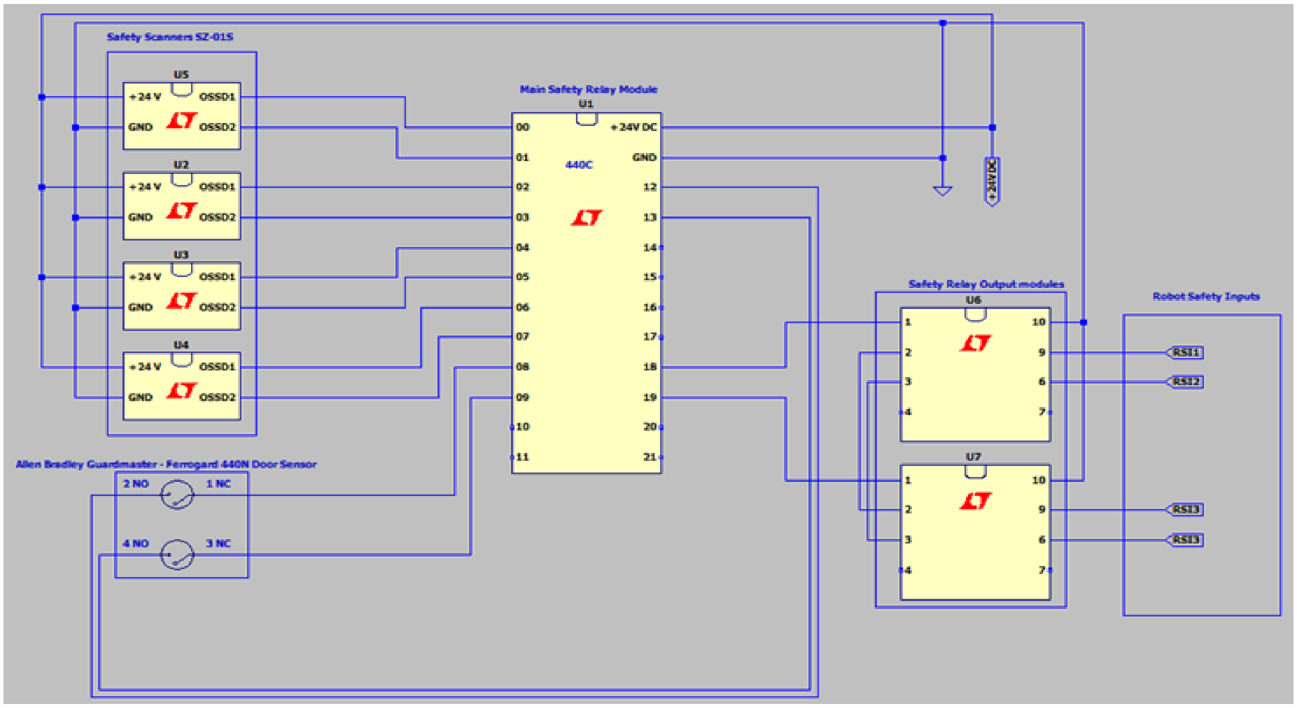


Figure 32. Preliminary safety circuit diagram.

Figure 32 shows a preliminary circuit diagram of the safety sensors for the robot cell. In it is the four floor scanners and the interlock sensor. There is also the main relay and the output relay.

5.2(ii) Air Pressure Safety

Because the team is using pneumatic cylinders, pressure safety sensors are needed as well. This is a future item for prospective research and design into the system.

5.2(iii) Wire covers

There are some safety measures that are less obvious, but just as important. For example, when machinery is operating, the electrical wiring that powers that machinery needs to be protected from that machinery if it falls or drops something. In this instance, the robot is picking and placing up to 300lbs billets, so whatever wiring put in the cell must withstand a 300lbs impact. The wiring put within the cell will have an industrial covering on it.

5.3 Current Safety for the Robot Test Cell

Safety sensors have been ordered by UAC to test with the robot. The safety system of the cell is designed completely and has been approved by UAC. There may be a redesign based on results from testing.

Chapter 6: Electrical

The electrical work up for this project is a simple work up and will be relatively easy to wire. There are a few reasons for this, the first being the availability of massive amounts of power close to the robot cell. The robot cell function is to load billets into an induction oven. The induction oven runs over a thousand amps. Luckily, the 480-volt three phase robot only needs 18 amps. This is a very little power draw in the industrial complex so it is not something that will increase the power bill.

6.1 Digital I/O Wiring

The second reason this is an easy implementation is that the robot is already wired with inputs and outputs. The FANUC robot arm comes prewired with inputs and outputs as well as 24-volt power supply (see Figure 33 for a circuit diagram of the inputs and outputs). The sensors on the gripper can be wired on the arm and will show up on the controller to be coded. The exception to this rule is the analog input the team will need for the laser length measurement. Luckily, the analog input wire from the laser can go into the wire covering on the robot and run directly to the controller.

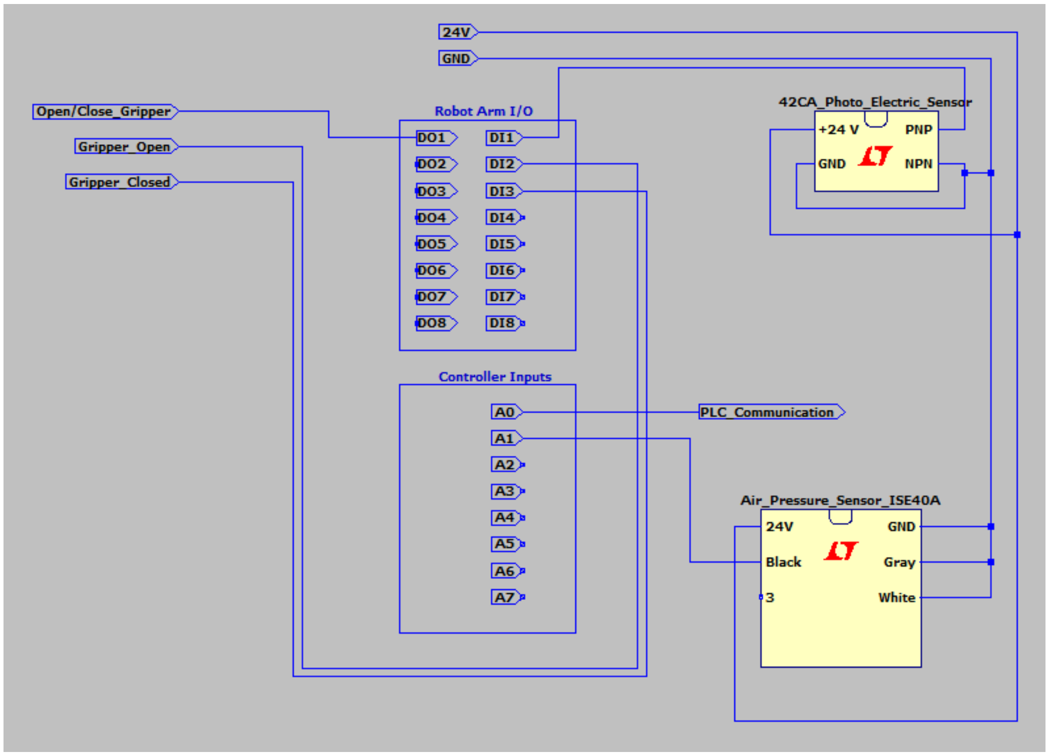


Figure 33. Digital I/O circuit drawing showing all digital inputs and outputs from the robot.

The third reason this electrical implementation is going to be easy is that the FANUC controller has a safety shut off built into it. Despite the safety circuit generally being complex, the FANUC has a plug and play system that allows users to just plug in digital safety switches. The controller has a faulting input plug in its hardware that will fault the robot when tripped. This is user friendly and if it were not built into the robot, then it would have had to been coded into the PLC.

6.2 Wiring Layout

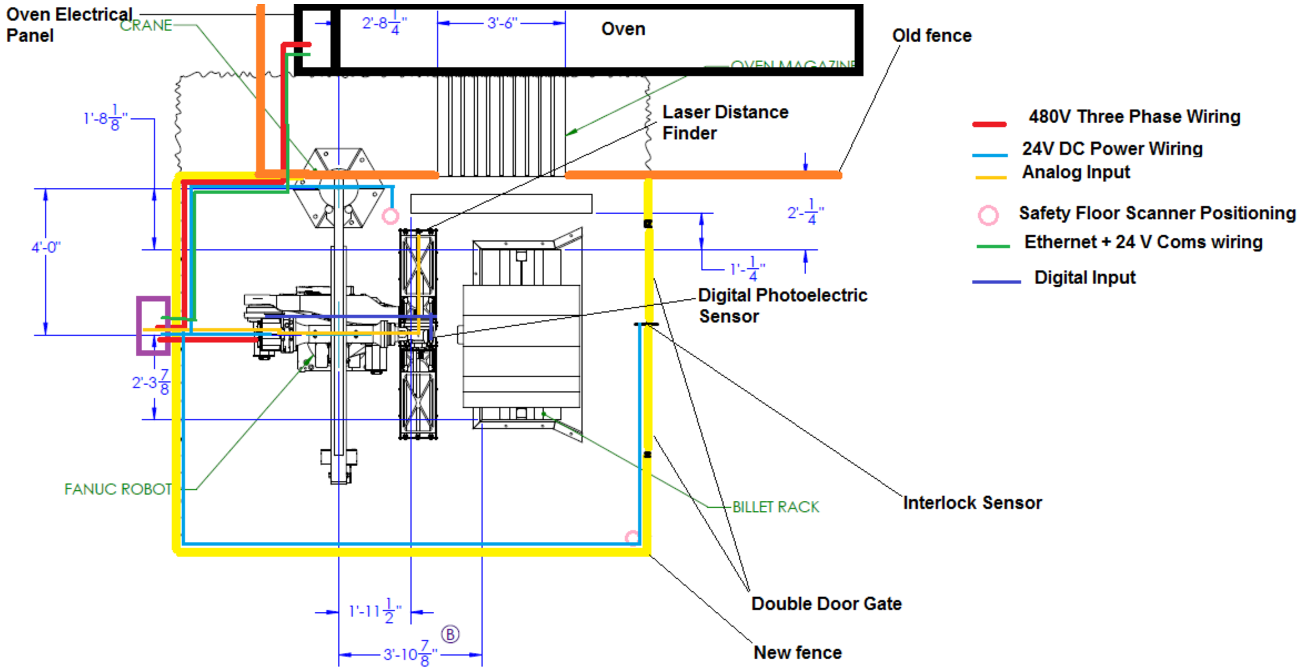


Figure 34. Electrical wiring image showing all electrical wiring in the robot cell

As shown in Figure 34, the power wiring goes from the oven to the robot controller. The controller then runs power to the robot and power to the sensors on the robot. From the controller, power will be run to all the safety sensors on the floor. The inputs and outputs will all be run to the robot controller as well. The controller has an ethernet cable that is run from the controller to the oven PLC for communication. In addition to the ethernet cable, an input wire will be run to the PLC to make sure communication is working. Without this, the robot arm has potential to keep running based on old communication if the PLC goes out or gets stuck.

The electrical design still needs to be reviewed by UAC, but the team is confident it will be accepted.

Chapter 7: Project Management

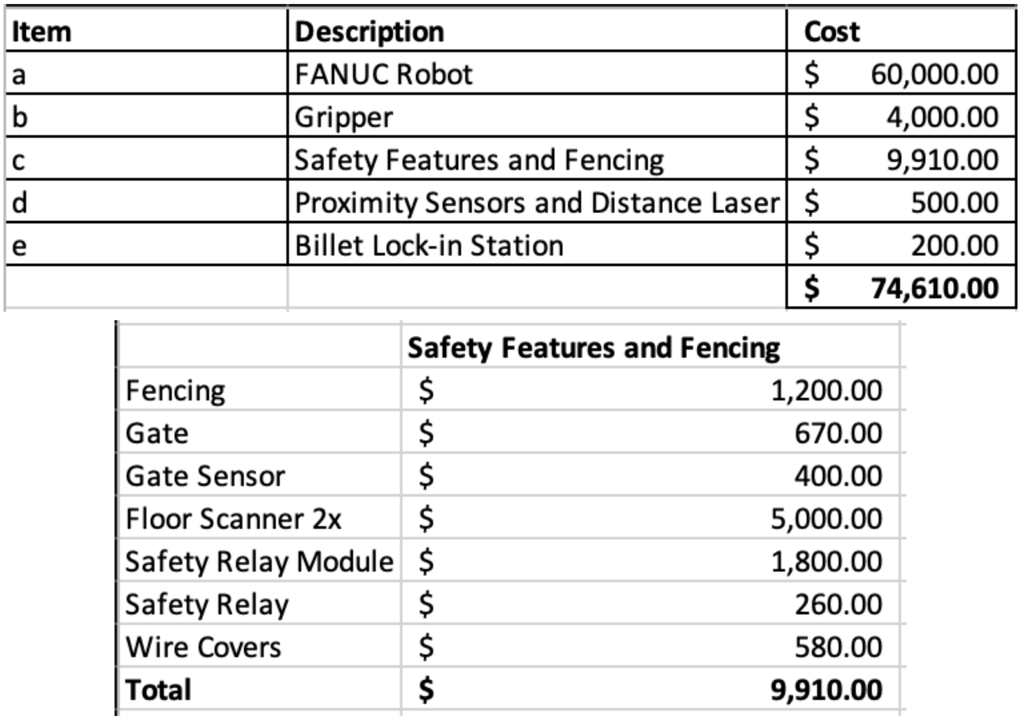
7.1 Gantt Chart

The current Gantt chart has been updated to include the final hand off KSU and UAC need to coordinate. The gripper has yet to be completed as well as the QR scanning. The official design for the project has been tested by the team and ensured before adding the gripper. See Appendix A for the updated detailed Gantt chart that covers the previous gripper assignments, the vision system, the rack, the robot cell, and system implementation and testing. The team has completed the assignment as best they can with the resources provided.

7.2 Budget

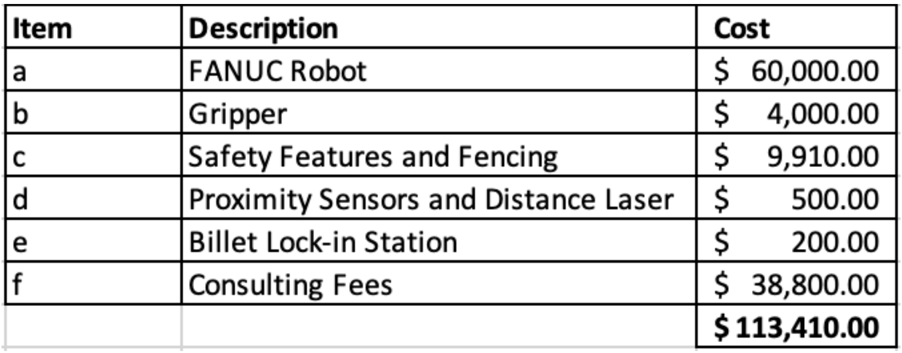
The budget was originally set at $94,000 with the robot costing $60,000, the safety gates and fencing at $10,000, gripper at $10,000, and new racks at $700 a piece needing 20 racks total. With the project farther along now, the current budget, is coming out to $79,610 (see **Error! Reference source not found.**).

Table 6: A) Current Budget (above) B) Itemized Budget Including Consulting (below)



Item	Description	Cost
a	FANUC Robot	$ 60,000.00
b	Gripper	$ 4,000.00
c	Safety Features and Fencing	$ 9,910.00
d	Proximity Sensors and Distance Laser	$ 500.00
e	Billet Lock-in Station	$ 200.00
		$ 74,610.00

	Safety Features and Fencing	
Fencing	$	1,200.00
Gate	$	670.00
Gate Sensor	$	400.00
Floor Scanner 2x	$	5,000.00
Safety Relay Module	$	1,800.00
Safety Relay	$	260.00
Wire Covers	$	580.00
Total	**$**	**9,910.00**



Item	Description	Cost
a	FANUC Robot	$ 60,000.00
b	Gripper	$ 4,000.00
c	Safety Features and Fencing	$ 9,910.00
d	Proximity Sensors and Distance Laser	$ 500.00
e	Billet Lock-in Station	$ 200.00
f	Consulting Fees	$ 38,800.00
		$ 113,410.00

If UAC had gone to a consulting firm the labor cost would be around $135 per hour. This team works around three hours a week together that would be considered billable. For the two semesters worked at UAC the team has completed around a total of thirty-two weeks totaling up to $38,880 of man hour worked. The rest of the man hours such as in the gripper fabrication and the billet rack build are included in the cost of each system. **Error! Reference source not found.** also includes the consulting fees but will not be a part of the actual budget UAC provided.

The robot is still $60,000 but the gripper is much less expensive than anticipated at maximum of $4,000. The safety features are at nearly $10,000 using the saved money from the gripper for the floor sensors. The last portion of the budget goes to the billet picking format used, which is the laser and proximity sensor combination with a lock-in for the billet rack. The cost of the vision system is around $300, and the lock-in station should be $200 to weld in a machine shop. The camera needed for the system is only for scanning the QR code on the billet and is its own separate project with IT now, and not added into the budget for the Pick and Place project. The requirements for the camera include it be pixelated enough to pick up the QR code on the shiny material of the aluminum billet, lighting may be required to make sure the camera can pick up the code in the robot cell. The labor has not been factored in as UAC has not offered guidance on the man hours required or paid to workers and operators.

After more testing, the team decided to use proximity sensors within the range of $50 to find the billet. The billet rack will need to be welded with three blocks, so that the bottom rack of billets will not roll around when the billet rack is less than full. Most of the sensors for the safety gates will be in-house items from the warehouse and will be added after the robot is coded. The code was test ready with sensors by the end of March and the budget was finalized as well.

Chapter 8: Results and Discussion

8.1 What Was Delivered

The team has given UAC a drawing package that details how to construct the design gripper, FANUC code to control the gripper and run the production sequence, and a wiring and safety diagram that shows how to construct the cell. The team has provided UAC with everything they need to pick up the project at a testing stage and move into implementation.

8.1(i) Gripper

The team has given UAC ASME Y14.100, production-ready prints to fabricate and assemble the gripper to. The team has provided UAC with proof that the designed gripper will perform as desired. The team has done this through SolidWorks simulations and experimental testing with a cardboard mock-up.

8.1(ii) PLC and Robot Code

The team has written code for the FANUC robot capable of performing the pick and place operations, the billet position scanning, and moving the billet into position to be scanned.

8.1(iii) Safety

The team has worked with Brian to identify what sensor model numbers are needed for the cell. The team was generated a floor plan that shows where the sensors need to be placed, as well as the layout of the guarding.

8.1(iv) Wiring

The team created diagrams that show how the safety sensors will be wired to the robot PLC and to the oven PLC. The team has also shown how to run the cabling for the robot, as well as the positioning of all electrical components.

8.2 Next Steps for UAC

Because the gripper was not fabricated in time to test, the team was unable to build UAC a functioning production cell in a test environment. UAC will need to perform the testing of the design that the team created.

Because of the lack of testing, UAC will need to modify the FANUC code to fix collisions that may occur when the fabricated gripper is on the end of the robot. They may also discover issues that the team’s testing was not able to uncover.

The team did not receive a chance to test the safety features in a live environment, so UAC will need to test the recommended sensors, and ensure they function with the robot cell. Finally, UAC needs to implement the cell in live production.

Chapter 9: Conclusions

While the team was not able to hit all the success criteria, the team has presented UAC with a finished design for them to implement and test. The gripper succeeded in the simulations requested by UAC, the electrical design met UAC's standards, the safety design meets industrial standards, and the team wrote PLC code that should function in the production environment.

This project has exposed all three members of the team to subjects not typically covered in their respective curriculum. The project also served to encompass the teachings of the three disciplines, and this paper is a good representation of the knowledge the team gathered through their entire college experiences.

UAC's next step needs to be testing the cell. The team has provided all the documentation UAC needs for a testing environment implementation of the cell, so UAC needs to construct the cell and perform the prescribed testing. Finally, UAC needs to implement the cell into production after correcting any errors that arise during testing.

Chapter 10: References

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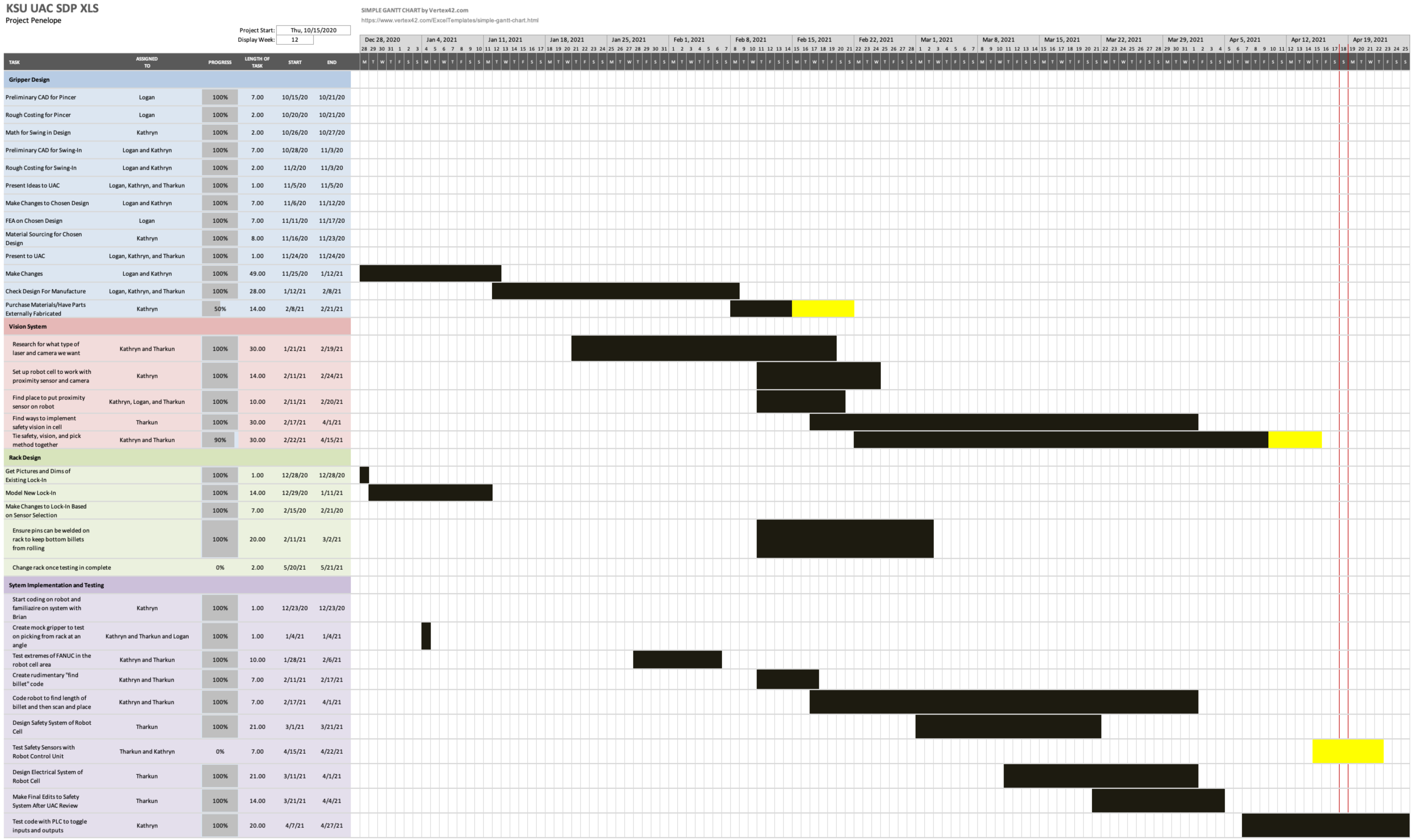
Chapter 11: Appendix A (Gantt Chart)



KSU UAC SDP XLS

Project Penelope

Project Start: Thu, 10/15/2020

Display Week: 12

TASK	ASSIGNED TO	PROGRESS	LENGTH OF TASK	START	END
Gripper Design					
Preliminary CAD for Pincer	Logan	100%	7.00	10/15/20	10/21/20
Rough Costing for Pincer	Logan	100%	2.00	10/20/20	10/21/20
Math for Swing in Design	Kathryn	100%	2.00	10/26/20	10/27/20
Preliminary CAD for Swing-In	Logan and Kathryn	100%	7.00	10/28/20	11/3/20
Rough Costing for Swing-In	Logan and Kathryn	100%	2.00	11/2/20	11/3/20
Present Ideas to UAC	Logan, Kathryn, and Tharkun	100%	1.00	11/5/20	11/5/20
Make Changes to Chosen Design	Logan and Kathryn	100%	7.00	11/6/20	11/12/20
FEA on Chosen Design	Logan	100%	7.00	11/11/20	11/17/20
Material Sourcing for Chosen Design	Kathryn	100%	8.00	11/16/20	11/23/20
Present to UAC	Logan, Kathryn, and Tharkun	100%	1.00	11/24/20	11/24/20
Make Changes	Logan and Kathryn	100%	49.00	11/25/20	1/12/21
Check Design For Manufacture	Logan, Kathryn, and Tharkun	100%	28.00	1/12/21	2/8/21
Purchase Materials/Have Parts Externally Fabricated	Kathryn	50%	14.00	2/8/21	2/21/21
Vision System					
Research for what type of laser and camera we want	Kathryn and Tharkun	100%	30.00	1/21/21	2/19/21
Set up robot cell to work with proximity sensor and camera	Kathryn	100%	14.00	2/11/21	2/24/21
Find place to put proximity sensor on robot	Kathryn, Logan, and Tharkun	100%	10.00	2/11/21	2/20/21
Find ways to implement safety vision in cell	Tharkun	100%	30.00	2/17/21	4/1/21
Tie safety, vision, and pick method together	Kathryn and Tharkun	90%	30.00	2/22/21	4/15/21
Rack Design					
Get Pictures and Dims of Existing Lock-In		100%	1.00	12/28/20	12/28/20
Model New Lock-In		100%	14.00	12/29/20	1/11/21
Make Changes to Lock-In Based on Sensor Selection		100%	7.00	2/15/20	2/21/20
Ensure pins can be welded on rack to keep bottom billets from rolling		100%	20.00	2/11/21	3/2/21
Change rack once testing in complete		0%	2.00	5/20/21	5/21/21
Sytem Implementation and Testing					
Start coding on robot and familiazire on system with Brian	Kathryn	100%	1.00	12/23/20	12/23/20
Create mock gripper to test on picking from rack at an angle	Kathryn and Tharkun and Logan	100%	1.00	1/4/21	1/4/21
Test extremes of FANUC in the robot cell area	Kathryn and Tharkun	100%	10.00	1/28/21	2/6/21
Create rudimentary "find billet" code	Kathryn and Tharkun	100%	7.00	2/11/21	2/17/21
Code robot to find length of billet and then scan and place	Kathryn and Tharkun	100%	7.00	2/17/21	4/1/21
Design Safety System of Robot Cell	Tharkun	100%	21.00	3/1/21	3/21/21
Test Safety Sensors with Robot Control Unit	Tharkun and Kathryn	0%	7.00	4/15/21	4/22/21
Design Electrical System of Robot Cell	Tharkun	100%	21.00	3/11/21	4/1/21
Make Final Edits to Safety System After UAC Review	Tharkun	100%	14.00	3/21/21	4/4/21
Test code with PLC to toggle inputs and outputs	Kathryn	100%	20.00	4/7/21	4/27/21

Chapter 12: Appendix B (House Ofof Quality)

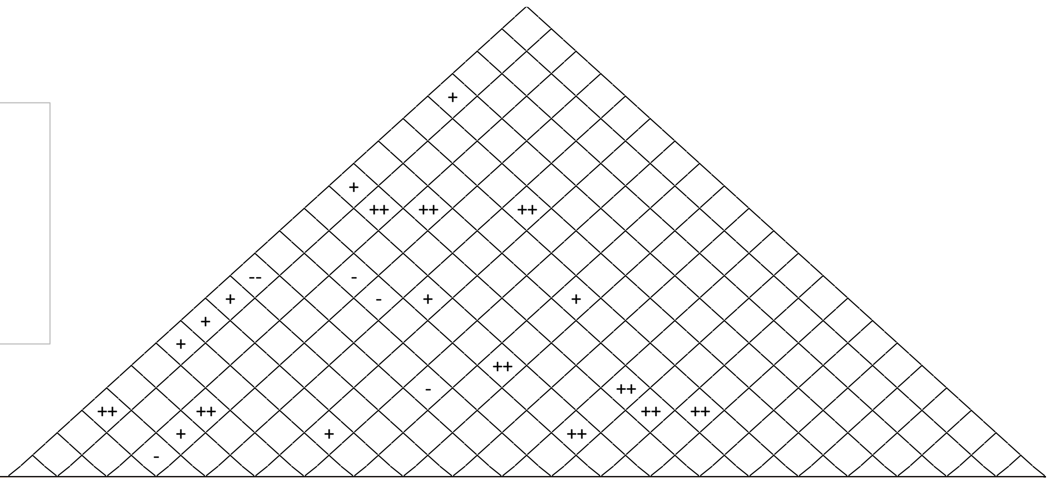
Key

Co-Relationships

++	Strong Positive Corrilation
+	Weak Positive Corrilation
-	Weak Nevitive Corrilation
--	Strong Negative Corrilation

Relationship Matrix

▲	Strong Corrilation
△	Weak Corrilation



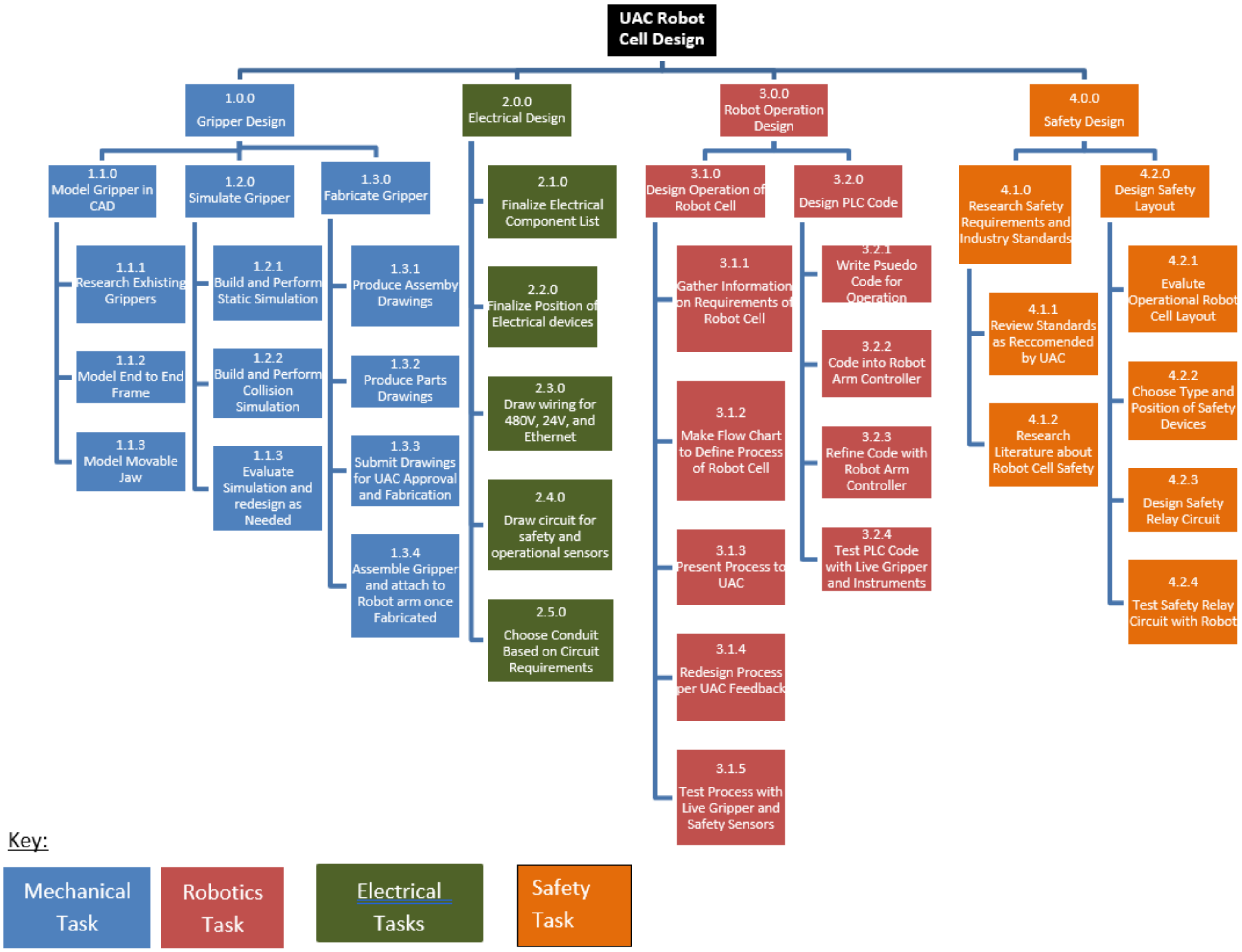
Engineering Chareteristics

Customer Requirments

Requirment Name	Importance	Weight	Weight Chart	Chacteristic Name	Throughput of cell	Required active operator time	Gripper	Arm speed	Cell footprint	How the gripper grabs the billet	Gripper pressure applied to billet	Number of billets that fit on a pallet	Number of billets in a job	Time billets spend in the oven	Size of gripper pad/finger/vacuum area	Weight of gripper	Foot print of the pallet	How the robot locates the pallet	Cost of gripper	Cost of pallet	Cost of saftey and control system	Is the magazine used?	Meets RIA R15.06	Meets NEMA 4 and NEMA 12	Installed per the National Electric Code
				Units	billets/hr	min/hr	claw, picker, vaccum	in/sec	ft²	sides or ends	psi	EA	EA	min	in²	lbf	ft²	comp vision or fixture	USD	USD	USD	Y or N	Y or N	Y or N	Y or N
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Gripper cannot damage the ends of the billets	8	7%	▮	1			▲			△	▲				△										
Gripper **should** not mark sides of billet	2	2%	▮	2			▲			▲	▲				△										
Lower budget is better (Projected to be around $94 000 including the robot)	2	2%	▮	3											△	△	△	△	▲	▲	▲		△		△
Robot needs to know what billet it has grabed and confim the WO	9	7%	▮	4															▲						
Robot cell needs to keep up with curret throughput (max of 10 billets/hr)	7	6%	▮	5	▲	△		▲		△		△		▲				▲			△				
It would be **nice** if robot could check squarness of saw cut ends	1	1%	▮	6			▲														▲				
Grabber needs to grab Ø10" billets of lengths ranging from 10" to 27"	9	7%	▮	7			▲			▲	△														
Robot needs to load the longest billet first (starting billet)	9	7%	▮	8														▲							
The robot should free up the operator to perfrom other task	5	4%	▮	9			▲											▲							
The robot cell needs to operate indoors at a slightly elevated temperature	5	4%	▮	10																	△				
If the grabber drops the billet, the controls should be protected from the falling billet	5	4%	▮	11					△												△				
The pallet needs to be loaded by a gantry crane that grabs billets by the ends	6	5%	▮	12																△					
The pallet needs to be transported by fork truck	5	4%	▮	13													▲	△		△					
The robot needs to know where in space the pallet is	5	4%	▮	14														▲							
The robot needs to be able to pick from the pallet	8	7%	▮	15					△																
The robot cell meets all engineering and saftey standards	10	8%	▮	16																	△		▲	▲	▲
Robot cell needs to be documented such that UAC techicans can install it and perfrom maintance on it.	8	7%	▮	17																					
Conduits and cables should include 20% spare conductors.	9	7%	▮	18					▲												△				
Controller should be off-the shelf and no black boxes	9	7%	▮	19																	△				

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Performance	Current Design	8	10	c	5	85	s	0	14		3	n/a	50	10		8,000	700	0	y	n	y	y
	Forked Gripper w/ Lockin	6	5	p	1	150	s	100	14		6	n/a	160	10		4,000	750	16,000	y	y	y	y
	Forked Gripper w/ Vision	6	5	p	1	200	s	100	14		6	n/a	160	10		4,000	750	20,000	y	y	y	y
	Claw in Middle w/ Lockin	6	5	c	1	150	e	60	12		6	n/a	100	10		3,000	850	16,000	y	y	y	y
	Claw in Middle w/ Vision	6	5	c	1	200	e	60	12		6	n/a	100	10		3,000	850	20,000	y	y	y	y
	Vaccum Gripper w/ Lockin	5	5	v	1	150	s	-20	14		10	26	50	10		2,500	700	18,000	y	y	y	y
	Vacumm Gripper w/ Vision	5	5	v	1	200	s	-20	14		10	26	50	10		2,500	700	22,000	y	y	y	y

Chapter 13: Appendix C (Work Assignment Breakdown)



Chapter 14: Appendix D Acknowledgements (Acknowledgments)

This project could not have been completed without the help of Brian Norris, head of the FANUC robots, at UAC. He was a vital component in coding the process and determining the best positions for the billet rack and picking positions. He was also the go between for plant production and the head office at UAC. Any production problems and admissions needed went through him first. A special thank you goes from the team to Brian.

We would also like to thank the team at UAC, Matt Yaeger, Greg Baugh, Lori Thompson, and Matt Ringer. They were the head of electrical, plant operations, HR, and IT respectively. Greg and Matt Yaeger set standards for the project and approved all designs as the project progressed. Lori assisted in all of the early communications between KSU and UAC. Matt Ringer, as head of IT, took over the QR scanning project since the team lost their CS major who was set to work on the SQL code. They were all a big help in the early stages of the project.

The team would like to give a nod to Kevin McFall, the first professor to assist the team during the first semester. Professor McFall was also the advisor to the UAC team and assisted in the vital early decisions of the type of gripper to use and the type of vision system to offer to UAC.

Lastly, thank you to Adeel Khalid, the professor during the second semester of the project. Professor Khalid started the standard of writing the project report and went over all the papers leading to this final submission.

Chapter 15: Appendix E (Contact Information)

Please feel free to contact us with any questions.

Tharkun Hudlow

Electrical Engineer

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Phone #: 404-542-4593

Kathryn Bharadwaj:

Mechatronics Engineer

Email: KathrynBharadwaj@gmail.com

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Logan Spencer

Mechanical Engineer / Manufacturing Engineering Minor

Email: lspencer9349@gmail.com

Phone #: 404-719-0551

Chapter 16: Appendix F (Reflections)

16.1 Tharkun Hudlow:

The interdisciplinary project was a great experience for me. It was great working with other engineers and bouncing ideas around with them. I was amazed by the abilities of the other engineers on my team. Logan is a wizard with SolidWorks and great at explaining static and dynamic mathematics. Kathryn is a robot whisperer and did a great job developing the robot code for our project despite never having written any similar code before, this experience working with UAC gave me great insight into the day to day of an engineer especially in manufacturing. Our contact, Brian, at UAC was very knowledgeable in many areas and knows every detail of the manufacturing process at UAC.

I think this project was a great practical experience. The second semester was dominated by this research paper and did not allow for as much designing and practical work, but I think it was helpful for us to put our ideas on paper versus just thinking them and using them practically. Unfortunately, this project will still need more work after we are done. Because we never got a software engineer on the team, we were not able to complete the database. The QR scanning portion is also not finished because the internal project at UAC is not finished. Those two portions will be completed by UAC internally. We are hopeful that the gripper will come in from the machine shop soon and we can do some live testing this semester. If this doesn’t happen UAC will have the do the testing without us. We are going to work up our designs and a description of their function for UAC.

16.2 Kathryn Bharadwaj:

This interdisciplinary approach to the senior project, with heavy company involvement, was a very interesting and pragmatic solution to students graduating from college with little to no experience working in the field. I loved the way I got to interact and learn from mechanical and electrical engineers and see how far their schooling progressed past mine in our respective fields. It was also very useful to have a company give us a project to set our goals with and to guide us on the path of how real engineering works. While the class gave us a look into the inner workings of companies reaching out for consulting information, some problems we faced focused on a lack of prompt communication from our business partners. Understandably, these companies had many other aspects of the business to look after and got busy, but this made it harder for us to receive feedback and to know how to successfully complete the project without their input on hurdles along the way. There was also the contingency that the project be completed and tested with the gripper in place, but the gripper getting held up at a machine shop for weeks put the testing on hold and required the team to work with stand ins. While we feel we completed the project to the best of our ability, having frequent contact with UAC would have helped us complete this project to the fullest.

16.3 Logan Spencer:

Overall, I viewed this project as a valuable learning experience. I think that one of the biggest oversights of the Mechanical Engineering department, is a lack of exposure to the electrical engineering and mechatronics department. In my five years, I never learned anything about robot coding, electrical routing, or project management. While I am by no means now an expert in any of those areas, I enjoyed listening to my teammates discuss solutions, and feel that next time I work on a project involving robots, I will be able to actively participate in those discussions.

I think the reason we failed to meet all of our minimum success criteria was twofold. Primarily, I think we underestimated the work UAC wanted us to do. Initially, we thought our role was as design consulting, and they did not want much in person testing. Secondly, the transition from Dr. McFall’s teaching style to Dr. Khalid’s style was very jarring. Dr. McFall’s focus was on our interactions with the UAC, and only wanted us to do presentations. Dr. Khalid on the other hand was focused on a paper. I do not think that either style is better, but we went into the 2nd semester expecting more of the same, and struggled to balance the workload of the paper, and our direct work with UAC.

Chapter 17: Appendix G (Team Member Contributions)

The following two tables breakdown which member did which work.

Table 7. Chapter Contributions by each member.

CHAPTER NUMBER	PRIMARY CONTRIBUTOR	SECONDARY CONTRIBUTOR
CHAPTER 1	Tharkun	
CHAPTER 2	Whole Group	
CHAPTER 3	Logan	
CHAPTER 4	Kathryn	Tharkun
CHAPTER 5	Tharkun	
CHAPTER 6	Tharkun	
CHAPTER 7	Kathryn	
CHAPTER 8	Logan	Kathryn
CHAPTER 9	Logan	
CHAPTER 10	Whole Group	
CHAPTER 11	Kathryn	
CHAPTER 12	Logan	
CHAPTER 13	Tharkun	
CHAPTER 14	Kathryn	
CHAPTER 15	Whole Group	
CHAPTER 16	Whole Group	
CHAPTER 17	Logan	
CHAPTER 18	Logan	Kathryn

Table 8. Work contributions by each member.

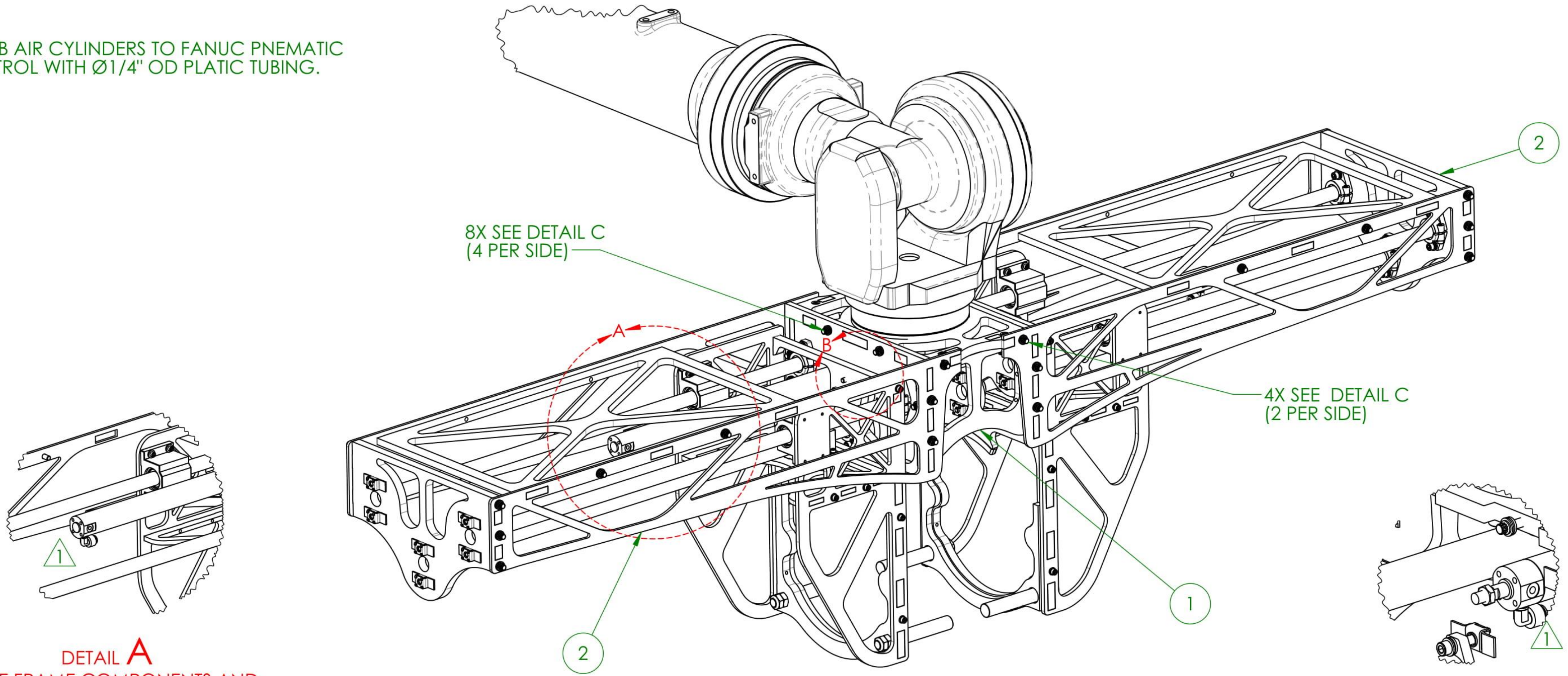
CHAPTER NUMBER	PRIMARY CONTRIBUTOR	SECONDARY CONTRIBUTOR
GRIPPER DESIGN	Logan	
GRIPPER SIMULATION	Logan	
GRIPPER DRAWINGS	Logan	
ROBOT CODE	Kathryn	
OPERATION ORDER	Kathryn	Tharkun
MEMES	Whole Group	
ELECTRICAL DESIGN	Tharkun	
SAFETY DESIGN	Tharkun	
SAFETY REVIEW	Tharkun	
GRIPPER RESEARCH	Logan	
ROBOTIC ARM RESEARCH	Kathryn	Logan
ELECTRICAL RESEARCH	Tharkun	
SAFETY RESEARCH	Tharkun	

Chapter 18: Appendix G Gripper Drawings

Chapter 19: H (Gripper Drawings)

This appendix includes the drawings the team sent to UAC.

NOTES:
1. PLUMB AIR CYLINDERS TO FANUC PNEMATIC CONTROL WITH Ø1/4" OD PLATIC TUBING.



DETAIL A
SOME FRAME COMPONENTS AND FASTNERS ARE REMOVED FOR CLARITY

DETAIL B
SOME FRAME COMPONENTS AND FASTNERS ARE REMOVED FOR CLARITY
SCALE 1 : 3

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#03-0440-0	1	ROBOT FLANGE INSTALLED ON FANUC	SEE BOM	MAKE
2	#03-0310-C	2	STATIONARY FRAME ARM SUB-ASM (SPLIT; FORKED; MACH SHAFT FLANGE; 1/4-28 BOLTS)	Material <not specified>	MAKE
3	#10-0033-0	16	1/4"-28 X 3/4", 12-POINT SCREW, ALLOY STEEL BO	IFI 115 STEEL	BUY
4	#10-0034-0	16	1/4" X Ø.5", OVERSIZED FLAT WASHER, ZP STEEL	ZINC-PLATED STEEL	BUY
5	#10-0035-0	16	1/4", SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 769.005
PART DESC'P: GRABBER TOP LEVEL ASM
FINISHED P/N: #03-0450-0
MAKE FROM: SEE BOM

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: GRIPPER TOP LEVEL ASM - BOM
DWG NUM: #03-0450-0-A
REV: A
SCALE: 1:6
SIZE: B
SHEET: 1 OF 2

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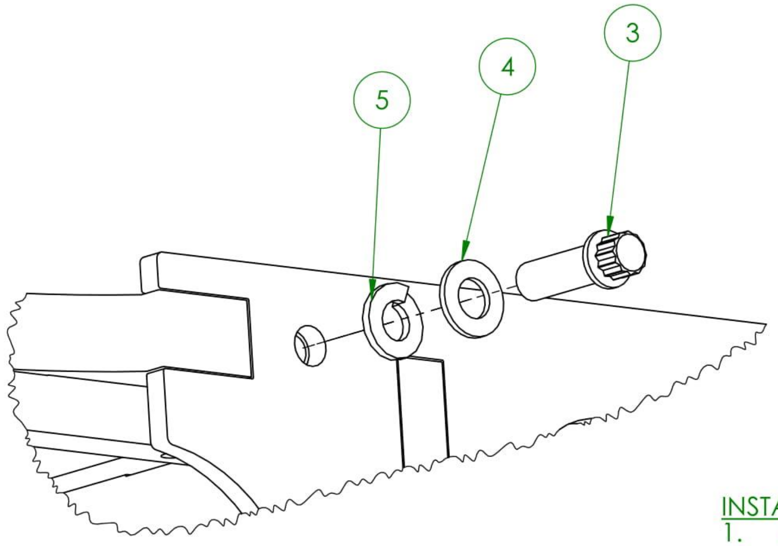
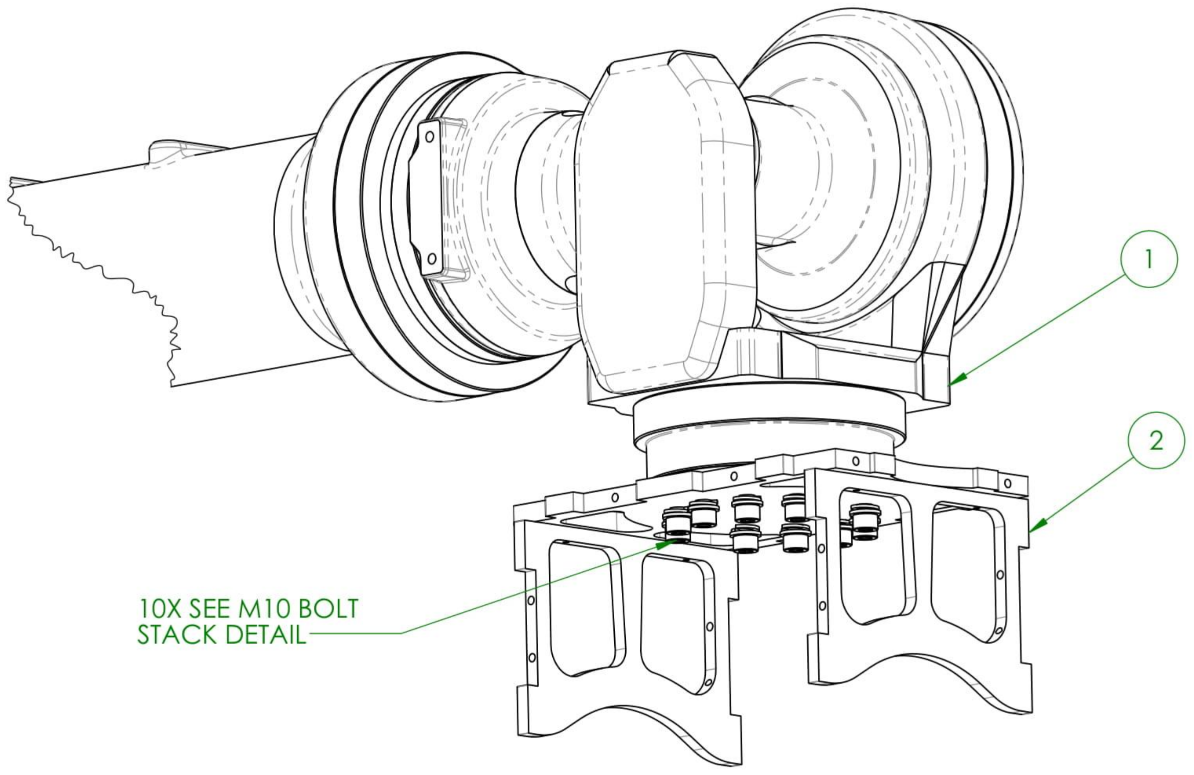


DETAIL C
TYP. 1/4-28 BOLT STACK

INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 10 FT-LB ±5%.

SHEET TITLE: GRIPPER TOP LEVEL ASM - BOLT TORQUE
DWG NUM: #03-0450-0-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 2 OF 2

NOTES:
1. TORQUE BOLTS IN STAR PATTERN.



ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#01-0000-0	1	R-2000IB/210F ROBOT AS ASEEMBLY	SEE VENDOR DRAWINGS	BUY
2	#03-0420-C	1	ROBOT FLANGE TO SPLIT ARM ASM	SEE BOM	MAKE
3	#10-0037-0	10	M10X1.5mm X 25mm, SOCKET HEAD CAP SCREW, BO STEEL	CLASS 10.9 STEEL	BUY
4	91202A242	10	M10 SPLIT WASHER, ZP STEEL	DIN 127B STEEL	BUY
5	#10-0039-0	10	M10 X Ø20MM, FLAT WASHER, ZP STEEL	ISO 7089 STEEL	BUY

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

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INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .050
.XXX ± .005

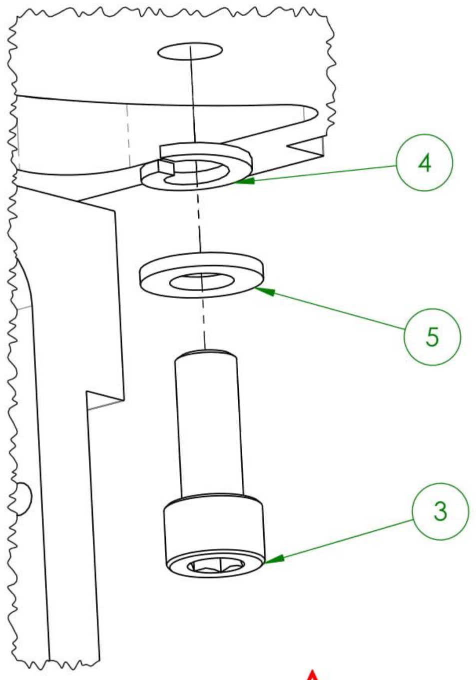
FINISH: AS ASSEMBLED
WEIGHT (LBS): 641.826

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

PART DESC'P: ROBOT FLANGE INSTALLED ON FANUC
FINISHED P/N: #03-0440-0
MAKE FROM: SEE BOM

KENNESAW STATE UNIVERSITY

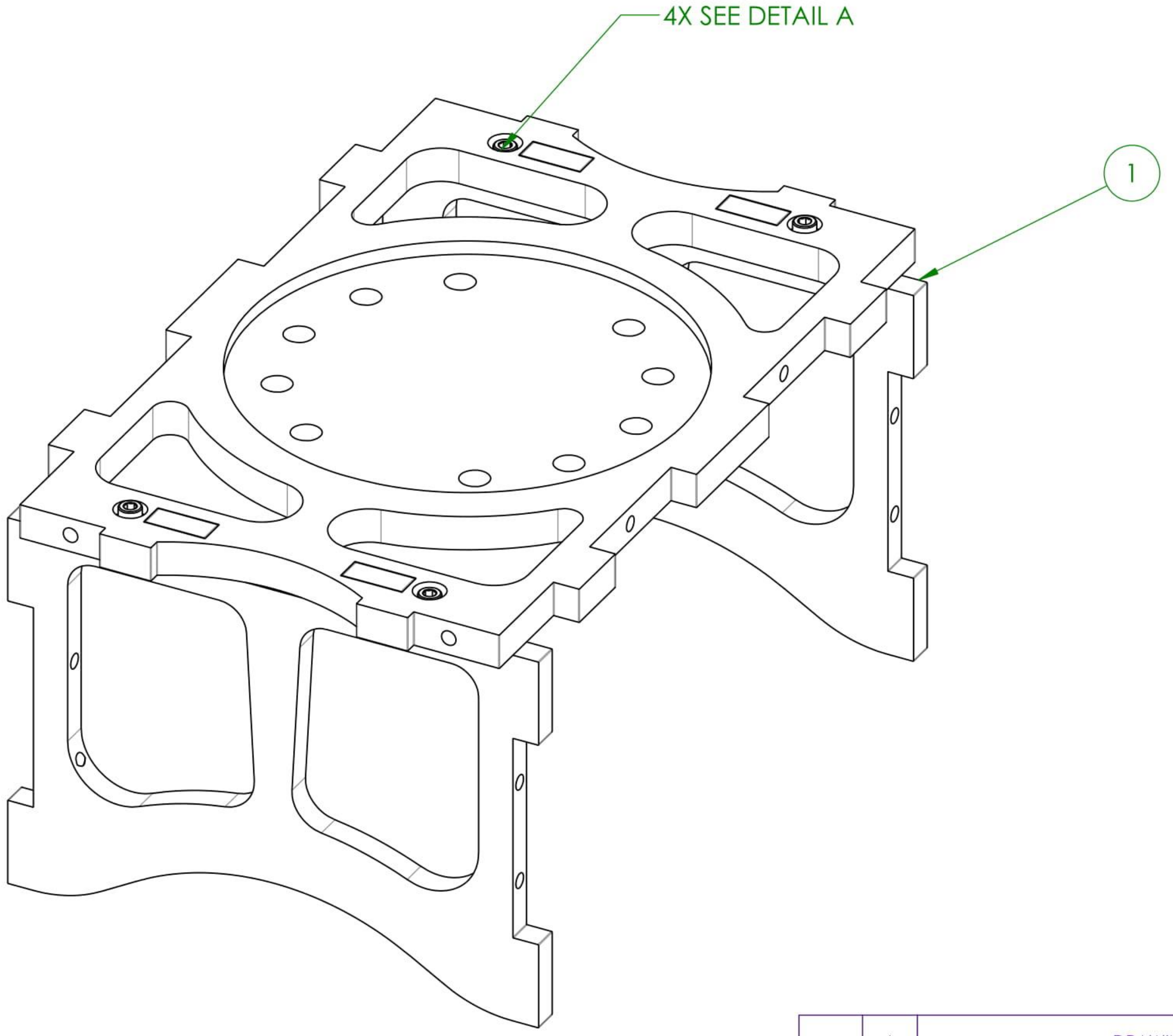
SHEET TITLE: ROBOT FLANGE INSTALLED - ASM DRAWING
DWG NUM: #03-0440-0-A
REV: A
SCALE: 1:4
SIZE: B
SHEET: 1 OF 2



DETAIL A
TYP. M10 BOLT STACK

INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 36 IN-LB ±5%.

SHEET TITLE:
ROBOT FLANGE INSTALLED - BOLT DETAILS
DWG NUM: #03-0440-0-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 2 OF 2



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#03-0410-C	1	ROBOT FLANGE TO ARM ADPATING WELDMENT	AISI 1045 STEEL, HR	MAKE
2	#10-0032-0	4	#10, SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
3	#10-0018-0	4	#10 X Ø.5", SAE FLAT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
4	#10-0024-0	4	#10-32 X 5/8", SOCKET HEAD SCREW, BO ALLOY STEEL	ASTM A574 ALLOY STEEL	BUY

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 11.341

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

PART DESC'P: ROBOT FLANGE TO SPLIT ARM ASM
FINISHED P/N: #03-0420-C
MAKE FROM: SEE BOM

KENNESAW STATE UNIVERSITY

SHEET TITLE: ROBOT FLANGE TO SPLIT ARM - BOM
DWG NUM: #03-0420-C-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 2

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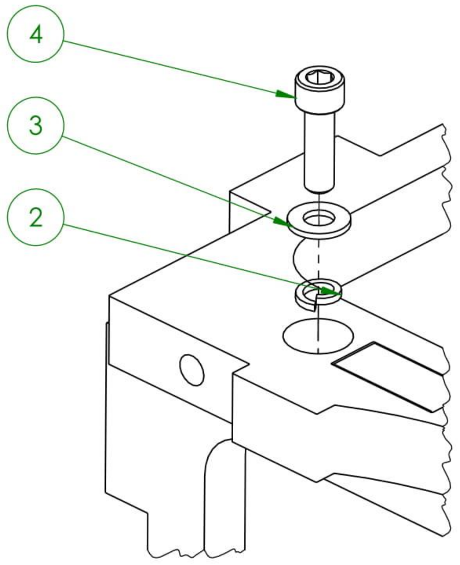
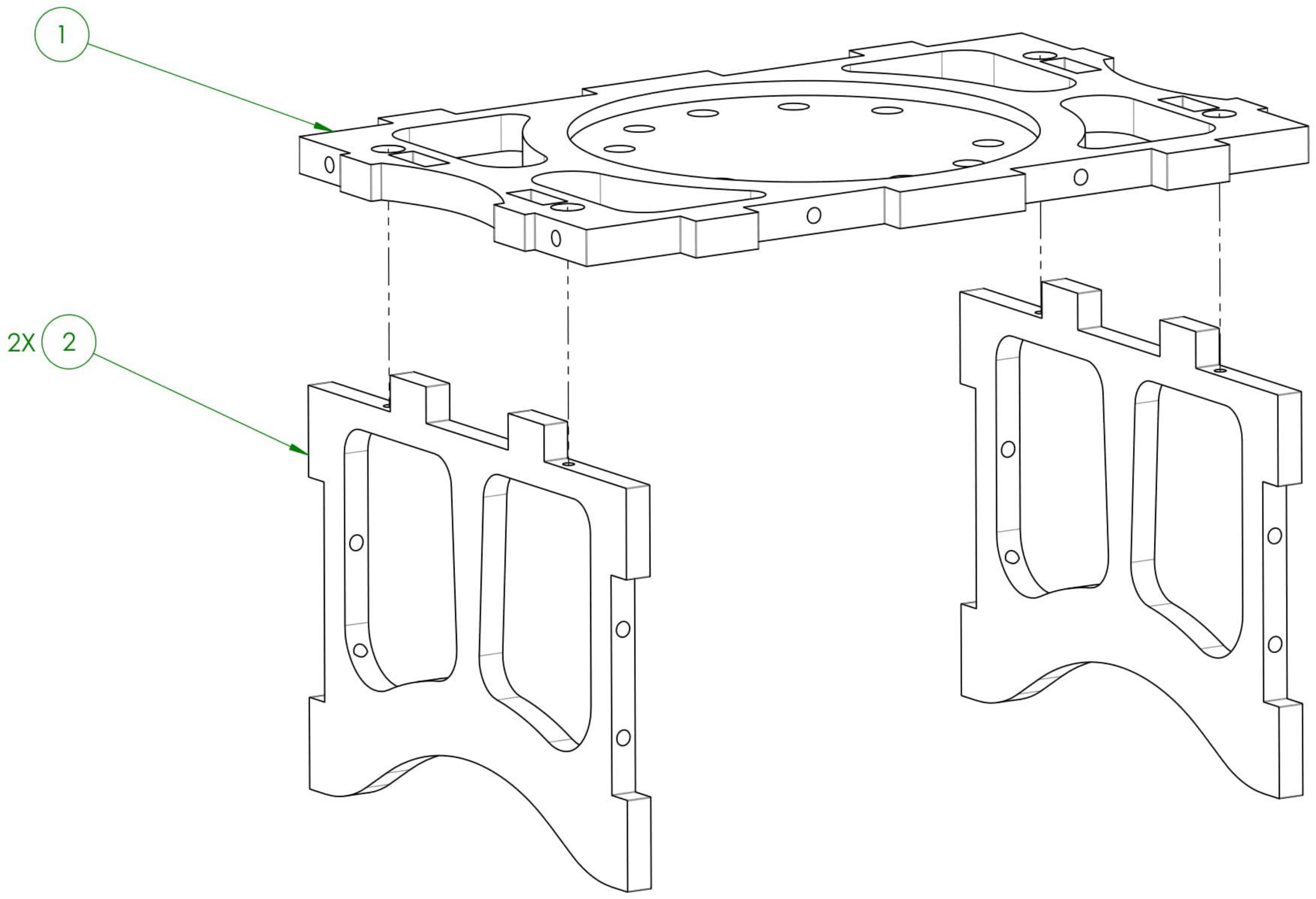


DETAIL A
TYP. #10-32 BOLT STACK

INSTALLATION NOTES:

1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 42 IN-LB ±5%.

SHEET TITLE: ROBOT FLANGE TO SPLIT ARM - BOLT TORQUE		
DWG NUM: #03-0420-C-A		REV: A
SCALE: 1:1	SIZE: B	SHEET: 2 OF 2



ITEM NO.	PARTNO	QTY.	DESCRIPTION	MATERIAL
1	#03-0411-C	1	ROBOT FLANGE MOUNTING PLATE	AISI 1045 STEEL, HR
2	#03-0412-C	2	VERTICAL SUPPORT PLATE	AISI 1045 STEEL, HR

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED		LAS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

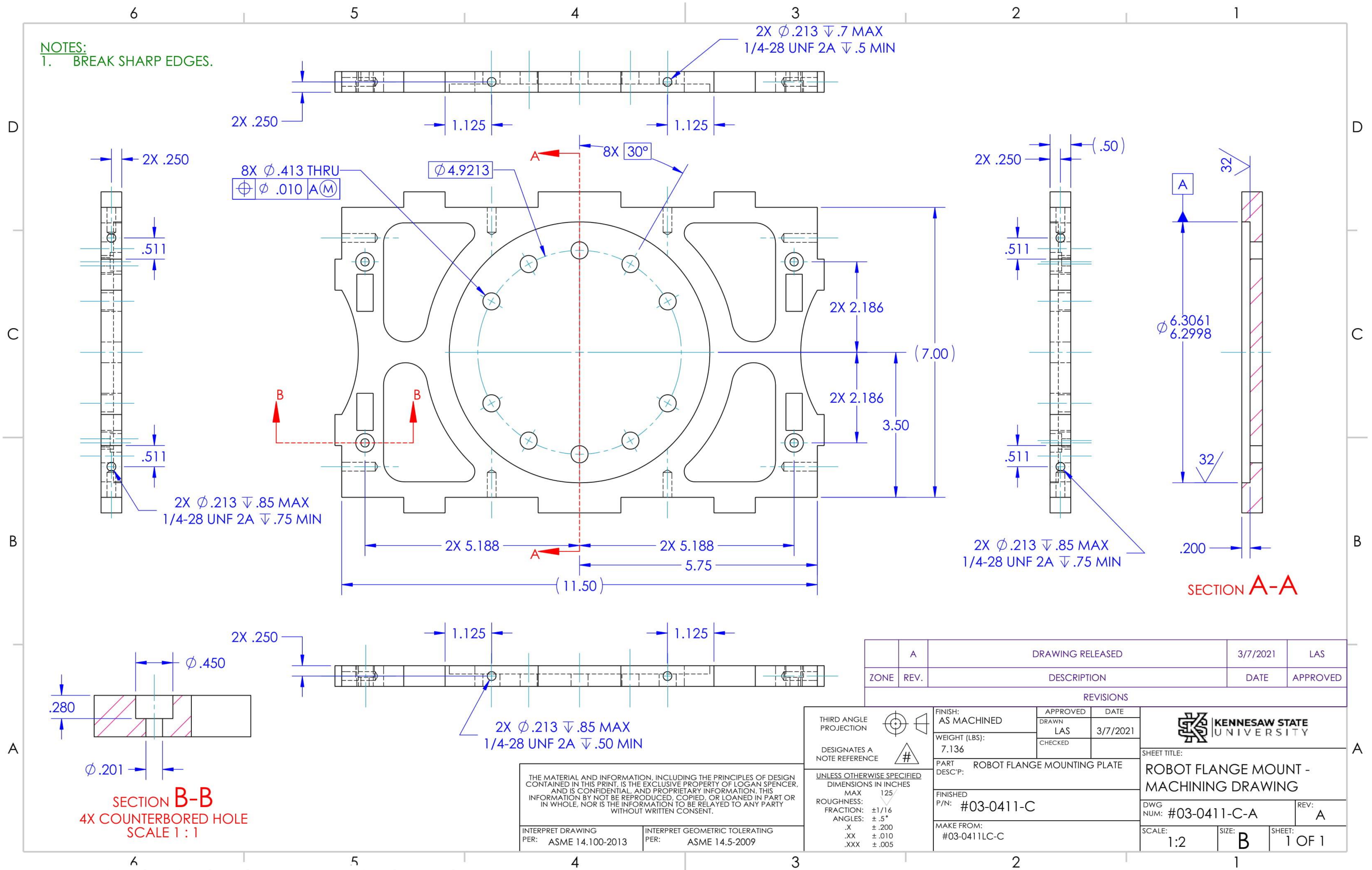
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 11.301
PART DESC'P: ROBOT FLANGE TO ARM ADPATING WELDMENT
FINISHED P/N: #03-0410-C
MAKE FROM: SEE BOM

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: ROBOT FLANGE TO ARM - FRAME DRAWING
DWG NUM: #03-0410-C-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1


NOTES:
1. BREAK SHARP EDGES.
2X Ø.213 ↧.7 MAX
1/4-28 UNF 2A ↧.5 MIN
2X .250
1.125
1.125
2X .250
8X Ø.413 THRU
⌖ Ø .010 A Ⓜ
Ø4.9213
A
8X 30°
2X .250
(.50)
A
32
.511
.511
2X 2.186
(7.00)
2X 2.186
3.50
Ø 6.3061 6.2998
.511
.511
32
B
B
2X Ø.213 ↧.85 MAX
1/4-28 UNF 2A ↧.75 MIN
2X 5.188
2X 5.188
A
5.75
(11.50)
2X Ø.213 ↧.85 MAX
1/4-28 UNF 2A ↧.75 MIN
.200
SECTION A-A
2X .250
1.125
1.125
Ø.450
.280
Ø.201
2X Ø.213 ↧.85 MAX
1/4-28 UNF 2A ↧.50 MIN
SECTION B-B
4X COUNTERBORED HOLE
SCALE 1 : 1
A | DRAWING RELEASED | 3/7/2021 | LAS
ZONE | REV. | DESCRIPTION | DATE | APPROVED
REVISIONS
THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #
FINISH: AS MACHINED
APPROVED DATE
DRAWN LAS 3/7/2021
CHECKED
WEIGHT (LBS): 7.136
PART DESC'P: ROBOT FLANGE MOUNTING PLATE
KENNESAW STATE UNIVERSITY
SHEET TITLE: ROBOT FLANGE MOUNT - MACHINING DRAWING
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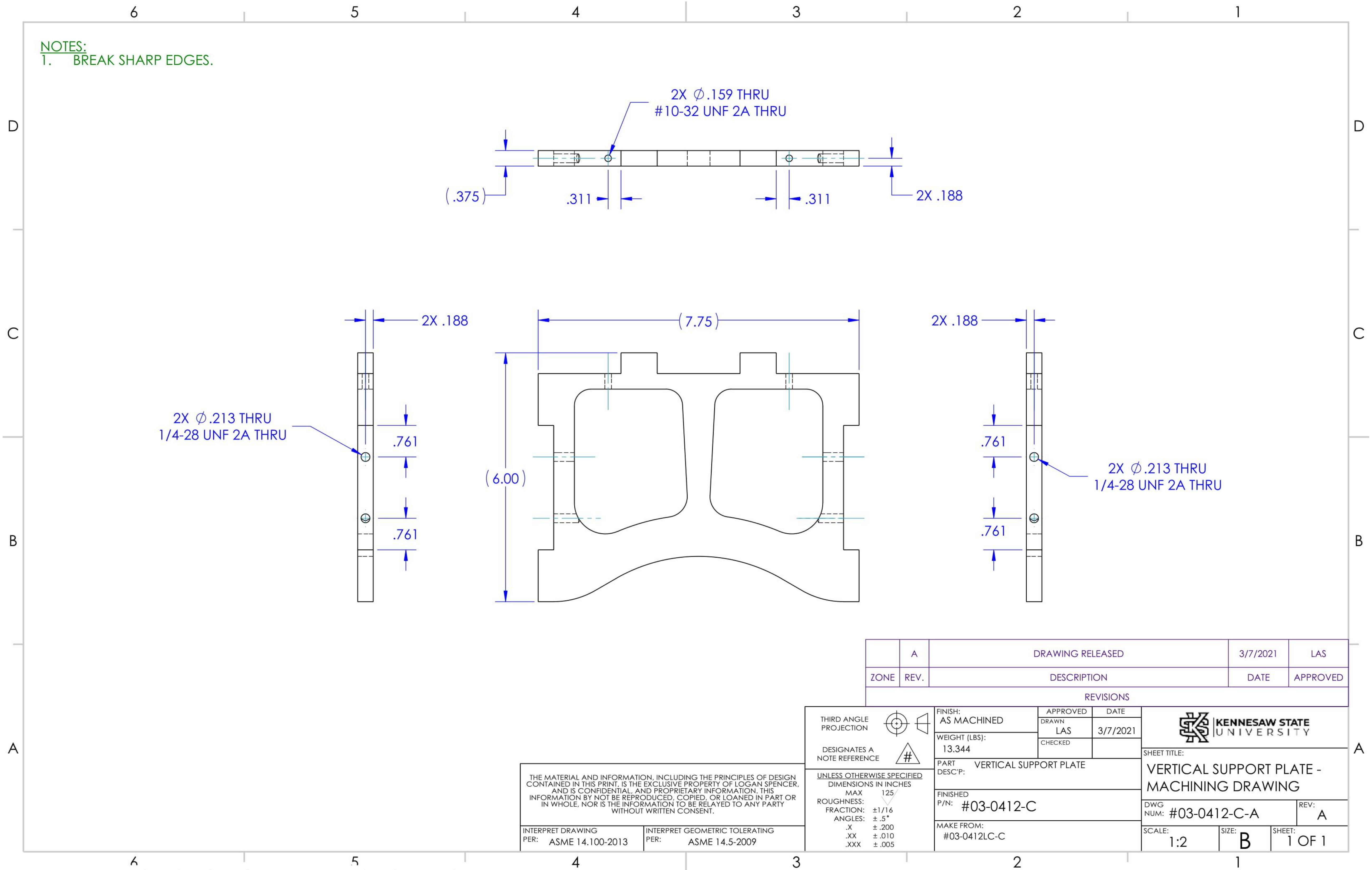
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
ROUGHNESS: MAX 125
FRACTION: ±1/16
ANGLES: ±.5°
.X ±.200
.XX ±.010
.XXX ±.005
FINISHED P/N: #03-0411-C
DWG NUM: #03-0411-C-A
REV: A
INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009
MAKE FROM: #03-0411LC-C
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1
6 5 4 3 2 1
D C B A



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED
WEIGHT (LBS): 13.344
PART DESC'P: VERTICAL SUPPORT PLATE
FINISHED P/N: #03-0412-C
MAKE FROM: #03-0412LC-C

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: VERTICAL SUPPORT PLATE - MACHINING DRAWING
DWG NUM: #03-0412-C-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1

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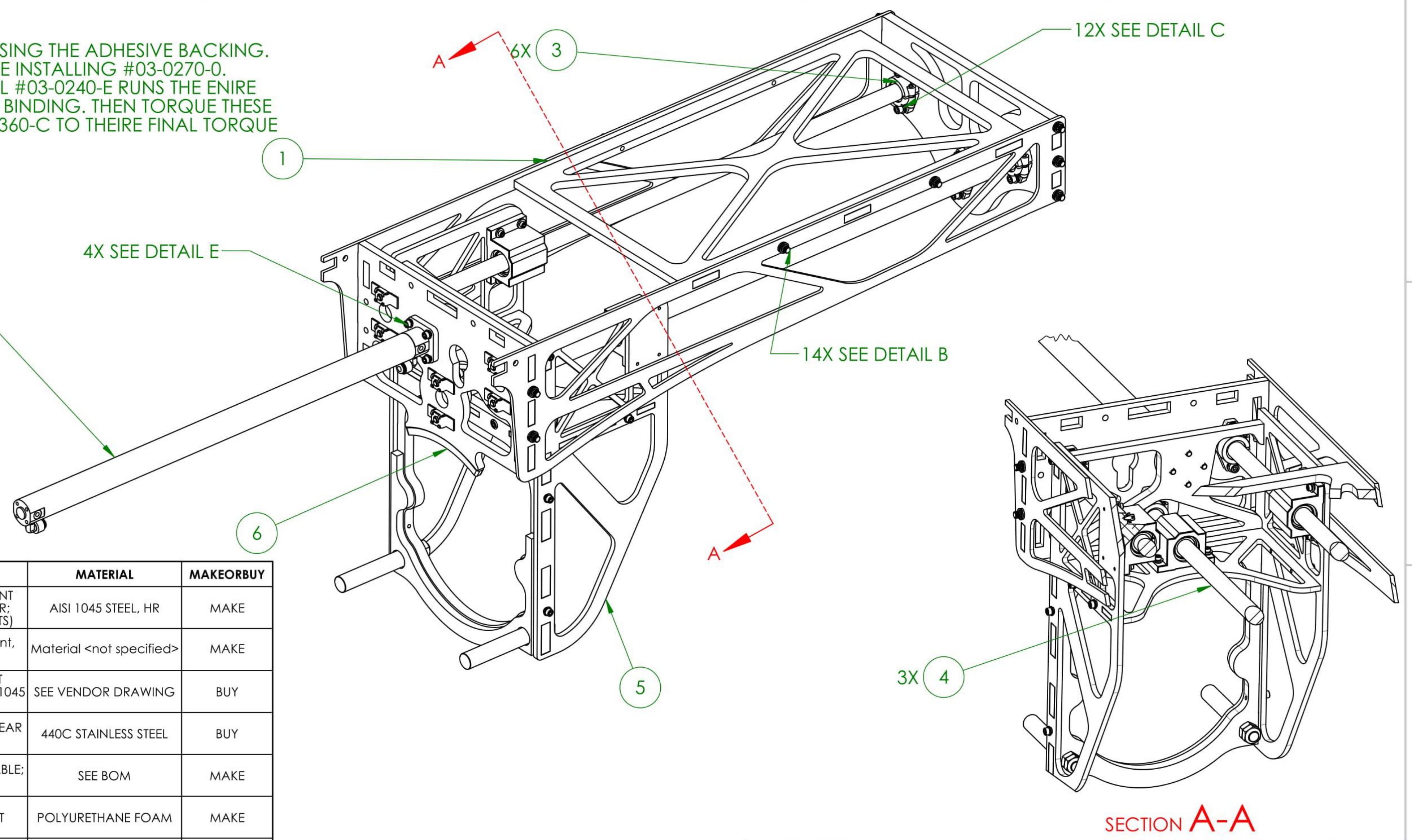
NOTES:

1. ATTACH #03-0360-C TO #03-0300-C USING THE ADHESIVE BACKING.
2. PLACE #03-0240-E IN POSITION BEFORE INSTALLING #03-0270-0.
3. LEAVE WELD NUTS SCEWS LOOSE UNTIL #03-0240-E RUNS THE ENIRE LENGTH OF THE LINIAR RAILS WITHOUT BINDING. THEN TORQUE THESE BOLTS, AND THE #8-36 BOLTS IN #03-0360-C TO THEIRE FINAL TORQUE VALUES.



ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#03-0300-C	1	STATIONARY FRAME ARM WELDMENT WITH WELDNUTS (FORKED GRABBER; MISUMI SHAFT FLANGE; 1/4-28 BOLTS)	AISI 1045 STEEL, HR	MAKE
2	#03-0140-C	1	20" Stroke Piston Asm, Internal Mount, and Fittings	Material <not specified>	MAKE
3	#03-0320-0	6	FLANGE-MOUNTED, 2 BOLT SHAFT SUPPORT FOR 3/4" SHAFT DIAMETER, 1045 STEEL	SEE VENDOR DRAWING	BUY
4	#03-0270-0	3	Ø3/4" X 30" STRAIGHT PRECISION LINEAR SHAFT, 440C SS	440C STAINLESS STEEL	BUY
5	#03-0240-E	1	MOVABLE JAW FRAME ASM (ANGLABLE; SIDWAYS PIST; SPLIT; FORKED)	SEE BOM	MAKE
6	#03-0360-C	1	FOAM PADDING AT TOP OF BILLET	POLYURETHANE FOAM	MAKE
7	#10-0020-0	12	1/4"-28 X 1-1/4", SOCKET HEAD SCREW, ALLOY STEEL BO	ASTM A574 ALLOY STEEL	BUY
8	#10-0034-0	26	1/4" X Ø.5", OVERSIZED FLAT WASHER, ZP STEEL	ZINC-PLATED STEEL	BUY
9	#10-0035-0	26	1/4", SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
10	#10-0033-0	14	1/4"-28 X 3/4", 12-POINT SCREW, ALLOY STEEL BO	IFI 115 STEEL	BUY
11	#10-0024-0	4	#10-32 X 5/8", SOCKET HEAD SCREW, BO ALLOY STEEL	ASTM A574 ALLOY STEEL	BUY
12	#10-0018-0	4	#10 X Ø.5", SAE FLAT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
13	#10-0032-0	4	#10, SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

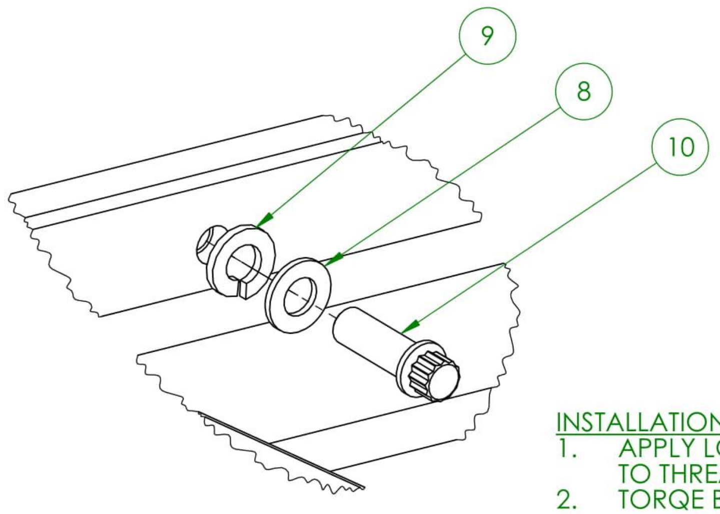
THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 63.434
APPROVED / DATE
DRAWN: LAS 3/2/2021
CHECKED:
PART DESC'P: STATIONARY FRAME ARM SUB-ASM (SPLIT; FORKED; MACH SHAFT FLANGE; 1/4-28 BOLTS)
FINISHED P/N: #03-0310-C
MAKE FROM: SEE BOM

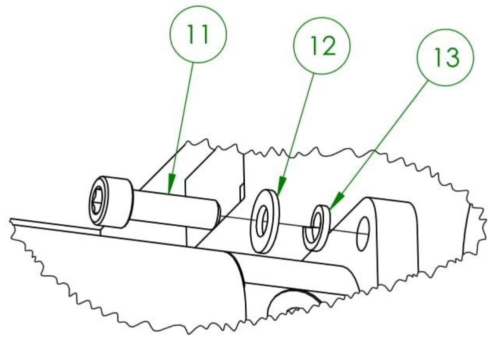
KENNESAW STATE UNIVERSITY

SHEET TITLE: STATIONARY FRAME SUB-ASM - BOM
DWG NUM: #03-0310-C-A
REV: A
SCALE: 1:5
SIZE: B
SHEET: 1 OF 2



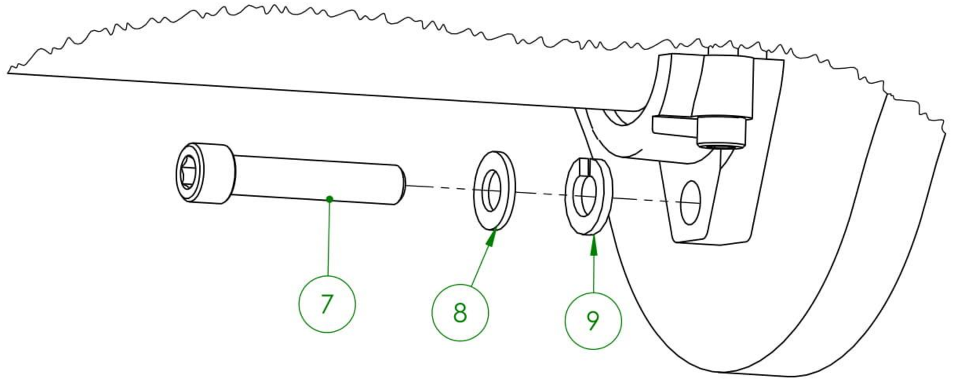
INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 10 FT-LB ±5%.

DETAIL B
TYP. 1/4-28 12-POINT BOLT STACK



INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 42 IN-LB ±5%.

DETAIL D
TYP. #10-32 BOLT STACK



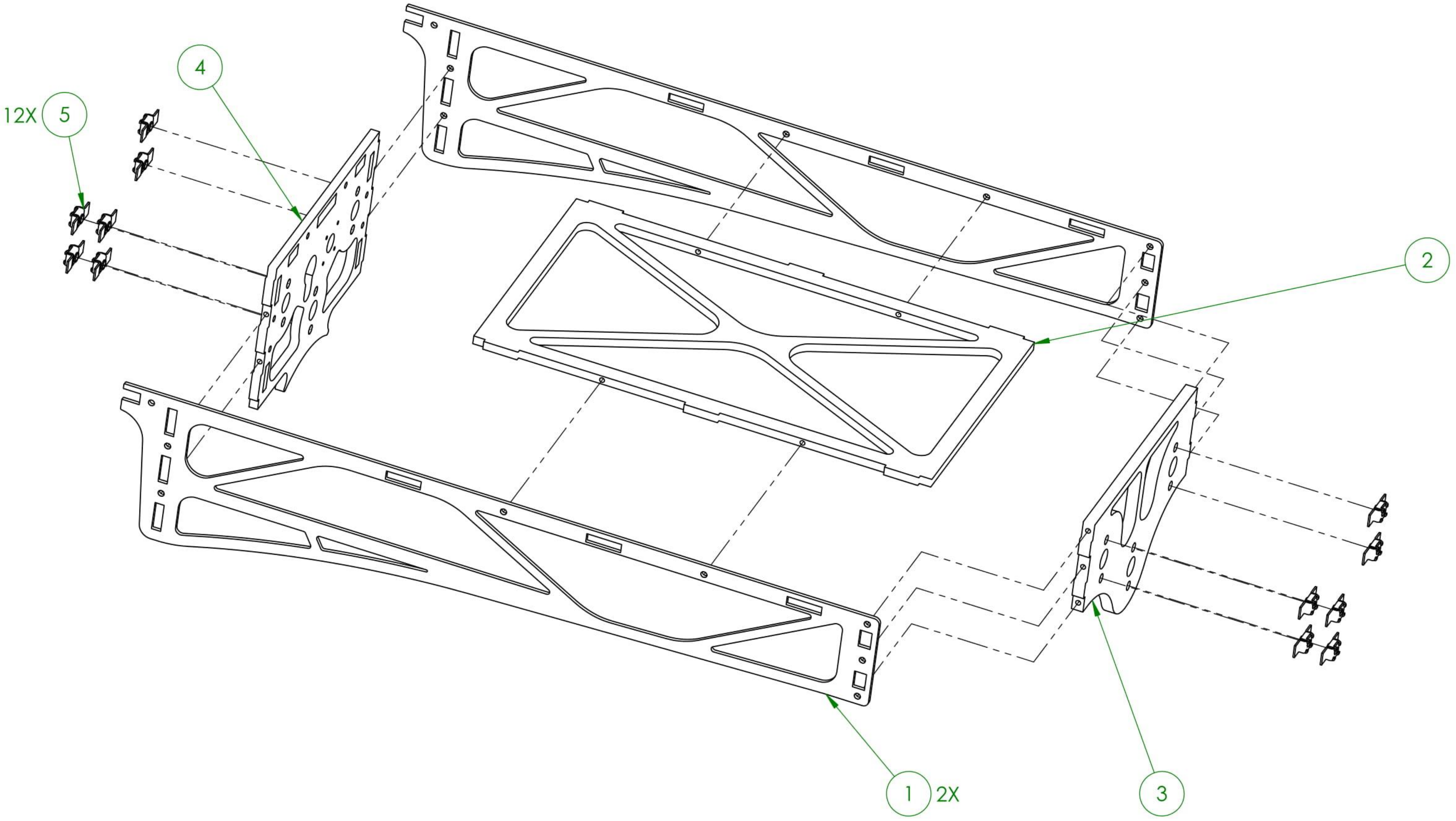
INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 10 FT-LB ±5%.

DETAIL C
TYP. 1/4-28 SHCS BOLT STACK

SHEET TITLE: STATIONARY FRAME SUB-ASM - BOLT TORQUE	
DWG NUM: #03-0310-C-A	REV: A

SCALE: 1:1	SIZE: B	SHEET: 2 OF 2

NOTES:
1. WELD #10-0006-0 TO FRAME PER EITHER WELD DETAIL.



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

ITEM NO.	PARTNO	QTY.	DESCRIPTION	MATERIAL
1	#03-0301-C	2	SIDE PLATE	AISI 1045 STEEL, HR
2	#03-0302-C	1	ANTI-RACKING PLATE	AISI 1045 STEEL, HR
3	#03-0303-C	1	END SUPPORT PLATE	AISI 1045 STEEL, HR
4	#03-0304-C	1	PISTON SUPPORT PLATE	AISI 1045 STEEL, HR
5	#10-0006-0	12	1/4"-28, Aligning Weld Nut, Steel Retainer	AISI 1008 STEEL

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

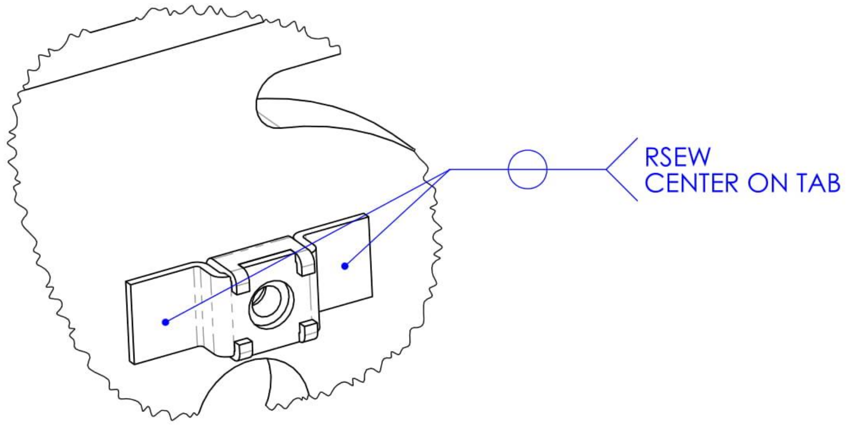
FINISH: AS ASSEMBLED
WEIGHT (LBS): 27.668

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

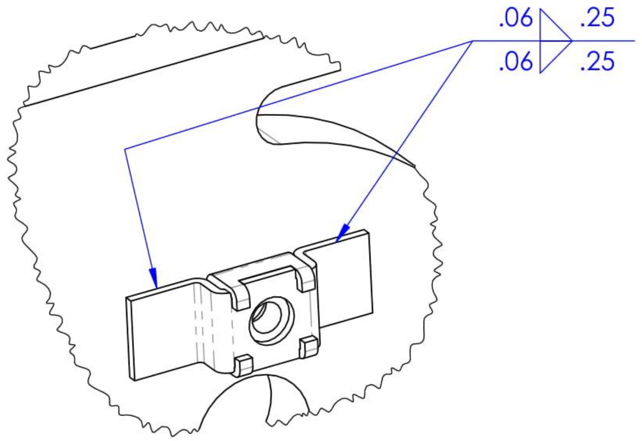
PART DESC'P: STATIONARY FRAME ARM WELDMENT WITH WELDNUTS (FORKED GRABBER; MISUMI SHAFT FLANGE; 1/4-28 BOLTS)
FINISHED P/N: #03-0300-C
MAKE FROM: SEE BOM

KENNESAW STATE UNIVERSITY

SHEET TITLE: STATIONARY FRAME WELDMENT - FRAME DWG
DWG NUM: #03-0300-C-A
REV: A
SCALE: 1:5
SIZE: B
SHEET: 1 OF 2

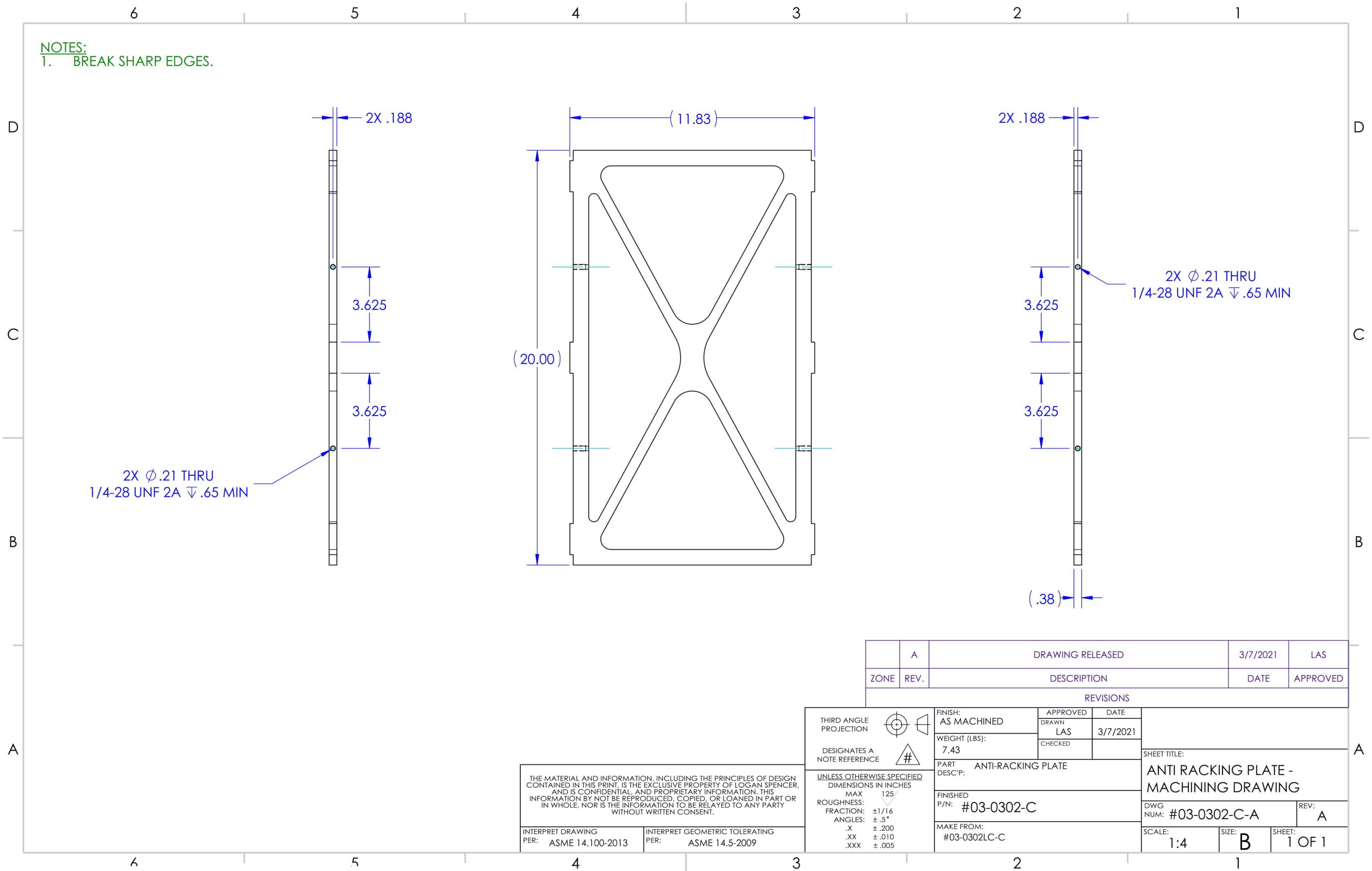


DETAIL A
WELD NUT WELD DETAIL



DETAIL B
ALTERNATIVE WELD NUT
WELD DETAIL

SHEET TITLE: STATIONARY FRAME WELDMENT - WELD DETAILS			
DWG NUM: #03-0300-C-A			REV: A
SCALE: 1:1	SIZE: B	SHEET: 2 OF 2	


NOTES:
1. BREAK SHARP EDGES.
2X .188
(11.83)
2X .188
3.625
3.625
(20.00)
3.625
3.625
2X ∅.21 THRU
1/4-28 UNF 2A ⊽.65 MIN
2X ∅.21 THRU
1/4-28 UNF 2A ⊽.65 MIN
(.38)
A
DRAWING RELEASED
3/7/2021
LAS
ZONE
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE
#
FINISH: AS MACHINED
APPROVED
DATE
DRAWN LAS 3/7/2021
CHECKED
WEIGHT (LBS): 7.43
PART DESC'P: ANTI-RACKING PLATE
FINISHED P/N: #03-0302-C
MAKE FROM: #03-0302LC-C
SHEET TITLE: ANTI RACKING PLATE - MACHINING DRAWING
DWG NUM: #03-0302-C-A
REV: A
SCALE: 1:4
SIZE: B
SHEET: 1 OF 1
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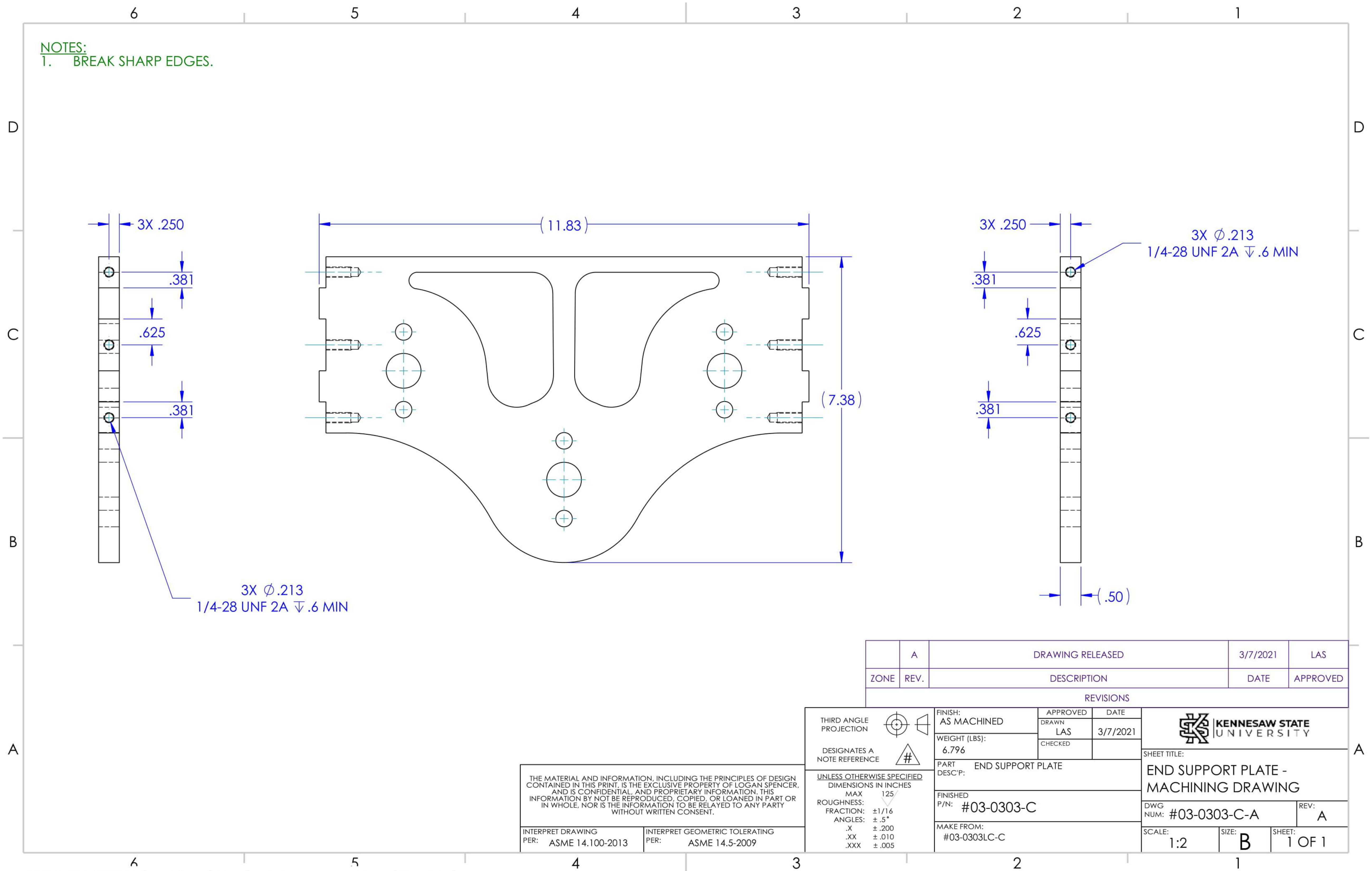
INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005
6
5
4
3
2
1
D
C
B
A



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013

INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED

WEIGHT (LBS): 6.796

PART DESC'P: END SUPPORT PLATE

FINISHED P/N: #03-0303-C

MAKE FROM: #03-0303LC-C

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: END SUPPORT PLATE - MACHINING DRAWING

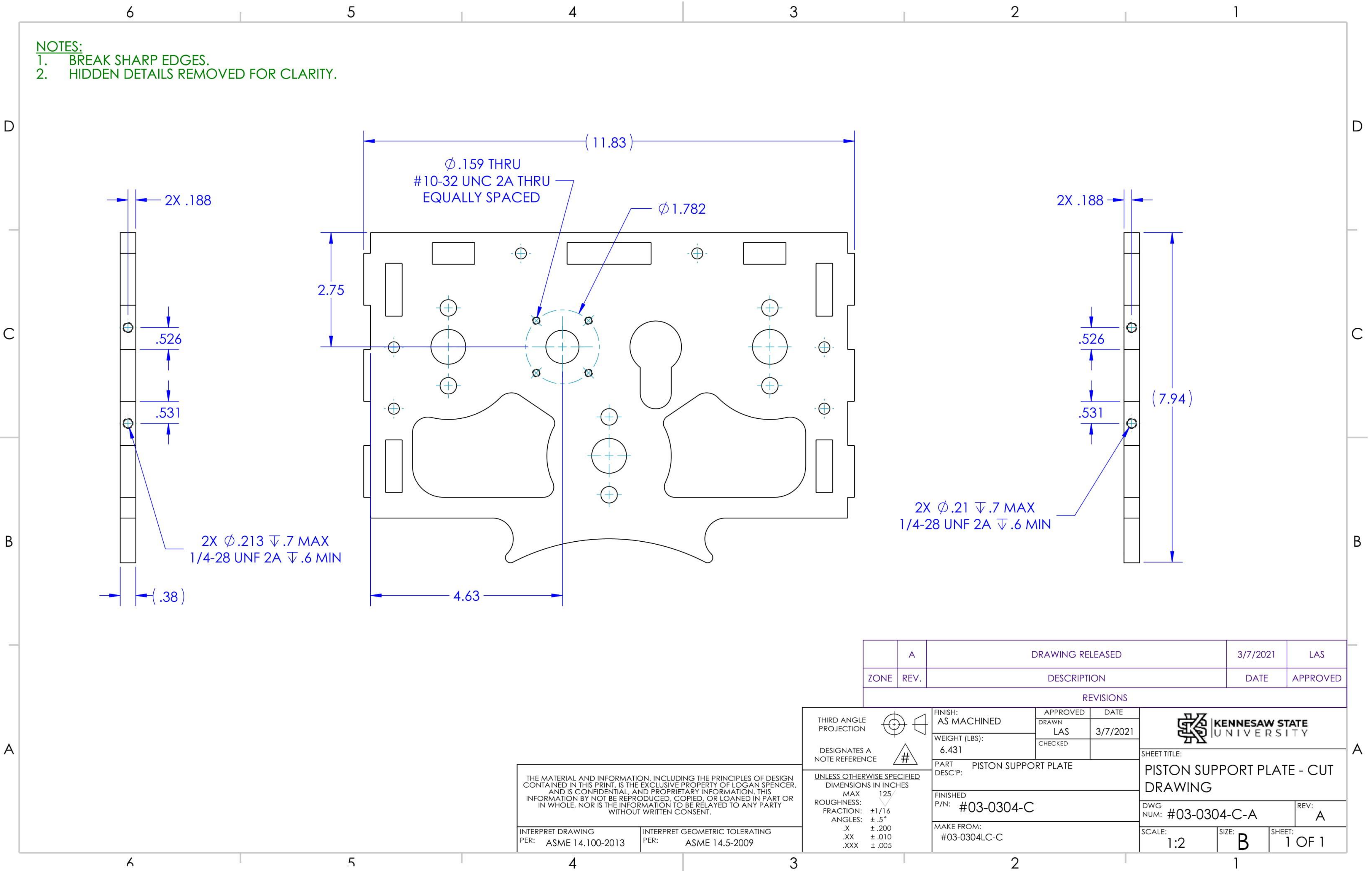
DWG NUM: #03-0303-C-A

REV: A

SCALE: 1:2

SIZE: B

SHEET: 1 OF 1



NOTES:
1. BREAK SHARP EDGES.
2. HIDDEN DETAILS REMOVED FOR CLARITY.

	A	DRAWING RELEASED	3/7/2021	LAS
ZONE	REV.	DESCRIPTION	DATE	APPROVED
REVISIONS				

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED
WEIGHT (LBS): 6.431
PART DESC'P: PISTON SUPPORT PLATE
FINISHED P/N: #03-0304-C
MAKE FROM: #03-0304LC-C

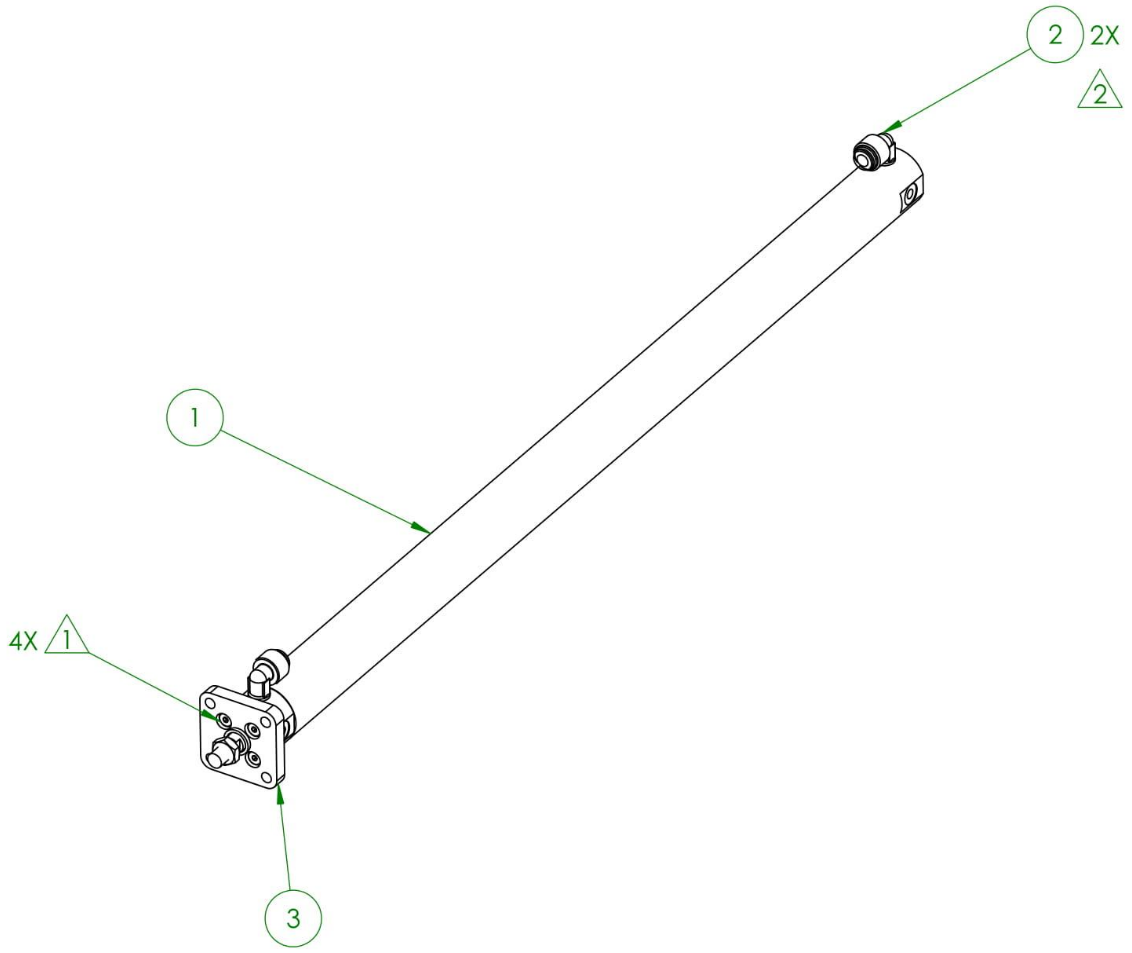
	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

SHEET TITLE: PISTON SUPPORT PLATE - CUT DRAWING
DWG NUM: #03-0304-C-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:

1. USE #10-32 SCREWS INCLUDED IN #03-0380-0 TO CONNECT FLANGE TO THE PISTON. APPLY LOCTITE® THREADLOCKER 243™ AND TORQUE TO WRENCH TIGHT.
2. WRAP NPT THREADS OF #03-0150-0 IN PTFE THREAD TAPE AND TORQUE TO WRENCH TIGHT.



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#03-0400-0	1	ALUMINUM DOUBLE-ACTING PISON CYLINDER, 1" BORE, 1.22" OD, 20" STROKE	SEE VENDOR DRAWING	BUY
2	#03-0150-0	2	PUSH-TO-CONNECT FITTING, ELBOW ADAPTER, 1/4" TUBE OD X 1/8 NPTF MALE	ACETAL	BUY
3	#03-0380-0	1	FLANGE FOR 1" BORE ROUND BODY AIR PISTON CYLINDER (WITH HARDWARE)	AISI 1045 STEEL, CD	BUY

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INTERPRET DRAWING PER: ASME 14.100-2013

INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

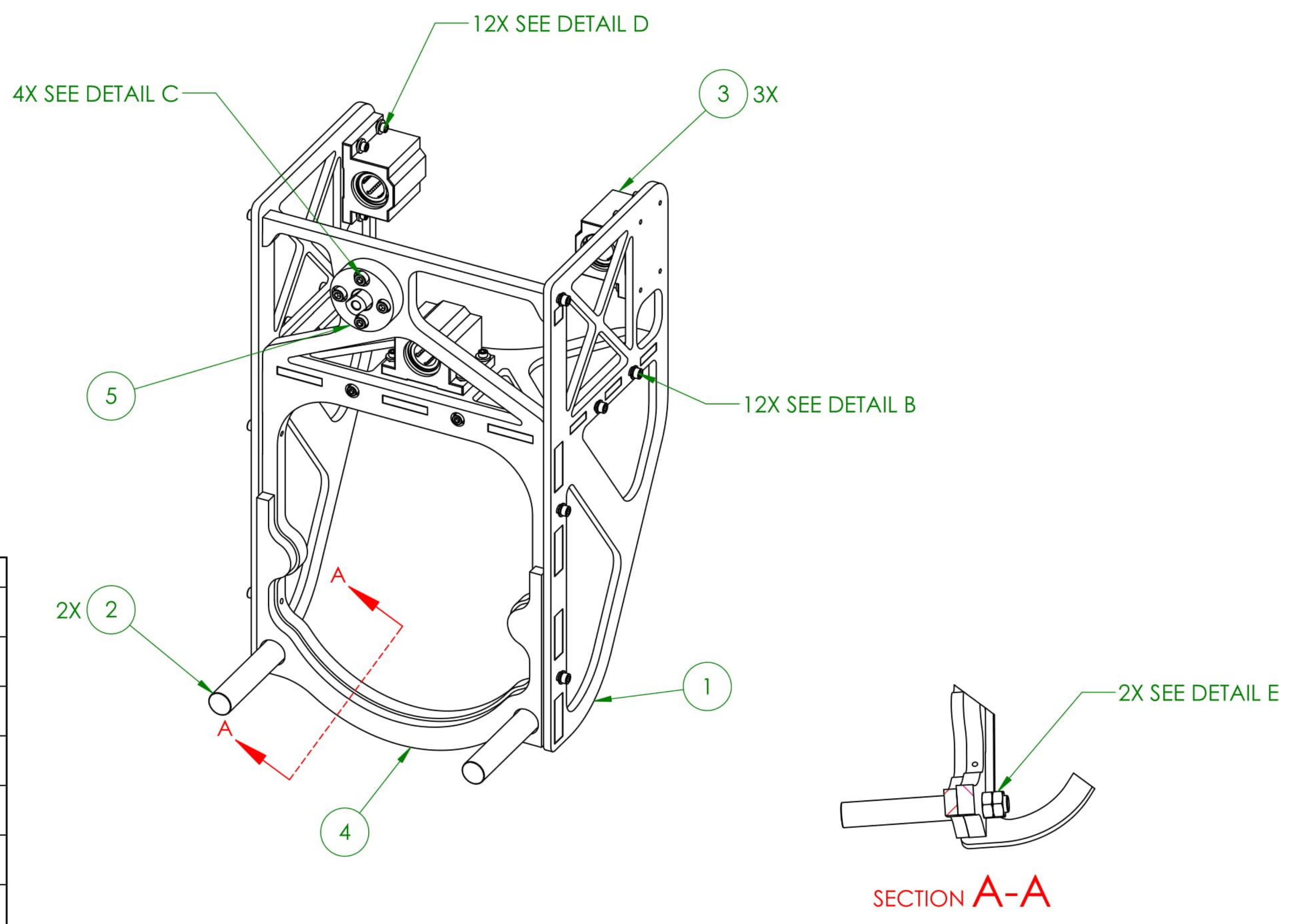
FINISH:
WEIGHT (LBS): 2.071
PART DESC'P: 20" STROKE PISTON ASM, INTERNAL MOUNT, AND FITTINGS
FINISHED P/N: #03-0140-C
MAKE FROM: SEE BOM

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: PISTON ASM - ASSEMBLY DRAWING
DWG NUM: #03-0140-C-A
REV: A
SCALE: 1:3
SIZE: B
SHEET: 1 OF 1

NOTES:
1. LEAVE #8-36 BOLTS LOSE DURING ASSEMBLY.
2. ATTACH #03-0290-D TO #03-0210-E USING THE ADHESIVE BACKING.



ITEM NO.	PARTNO	QTY	DESCRIPTION	MATERIAL	MAKEORBUY
1	#03-0210-E	1	MOVABLE JAW FRAME WELDMENT (ANGLABLE; SIDWAYS PIST; SPLIT; FORKED)	SEE BOM	MAKE
2	#03-0220-0	2	Ø3/4" X 4" LINIAR MOTION SHAFT, 1/2"-13TPI X 1" REUCED END, 440C SS	440C STAINLESS STEEL	BUY
3	#03-0230-0	3	MOUNTED LINEAR BALL BEARING SELF ALIGNING, FOR 3/4" SHAFT DIAMETER	SEE VENDOR	BUY
4	#03-0290-D	1	FOAM PADDING FOR BILLET END	POLYURETHANE FOAM	MAKE
5	#03-0390-C	1	5/16"-24 FLOATING FLANGE WITH COUTERBORES FOR SPLIT WASHER	AISI 1045 STEEL, CD	MAKE
6	#10-0015-0	4	1/2"-13, THIN JAM NUT, 18-8 SS	18-8 STAINLESS STEEL	BUY
7	#10-0024-0	12	#10-32 X 5/8", SOCKET HEAD SCREW, BO ALLOY STEEL	ASTM A574 ALLOY STEEL	BUY
8	#10-0018-0	12	#10 X Ø.5", SAE FLAT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
9	#10-0032-0	12	#10, SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
10	#10-0020-0	4	1/4"-28 X 1-1/4", SOCKET HEAD SCREW, ALLOY STEEL BO	ASTM A574 ALLOY STEEL	BUY
11	#10-0035-0	4	1/4", SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
12	#10-0034-0	4	1/4" X Ø.5", OVERSIZED FLAT WASHER, ZP STEEL	ZINC-PLATED STEEL	BUY
13	#10-0028-0	12	#8-36 X 5/8", SOCKET HEAD CAP SCREW, BO STEEL	ASTM A574 ALLOY STEEL	BUY
14	#10-0029-0	12	#8 X Ø.438", SAE FLAT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY
15	#10-0036-0	12	#8, SPLIT WASHER, ZP STEEL	ASME B18.21.1 STEEL	BUY

	A	DRAWING RELEASED	2/28/2021	LAS
ZONE	REV.	DESCRIPTION	DATE	APPROVED

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

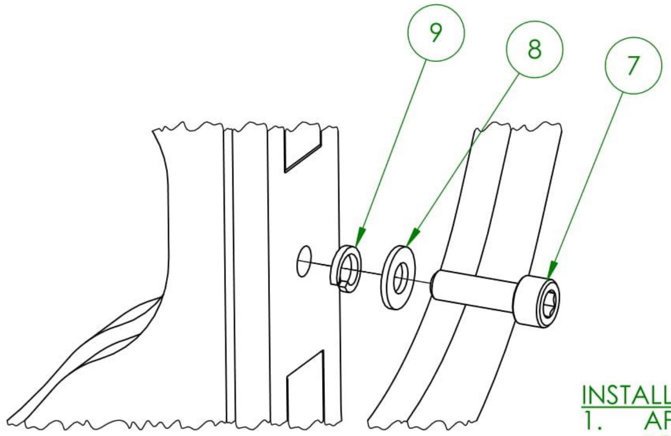
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 20.136
PART DESC'P: MOVABLE JAW FRAME ASM (ANGLABLE; SIDWAYS PIST; SPLIT; FORKED)
FINISHED P/N: #03-0240-E
MAKE FROM: SEE BOM

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

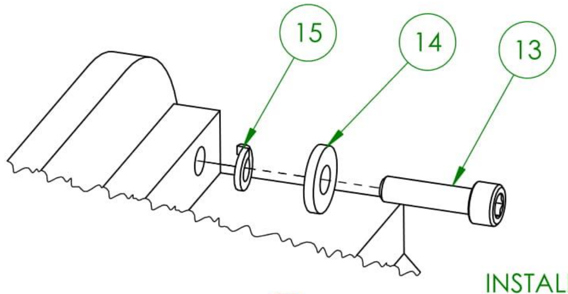
KENNESAW STATE UNIVERSITY

SHEET TITLE: MOVABLE JAW SUBASSEMBLY - BOM
DWG NUM: #03-0240-E-A
REV: A
SCALE: 1:4
SIZE: B
SHEET: 1 OF 2



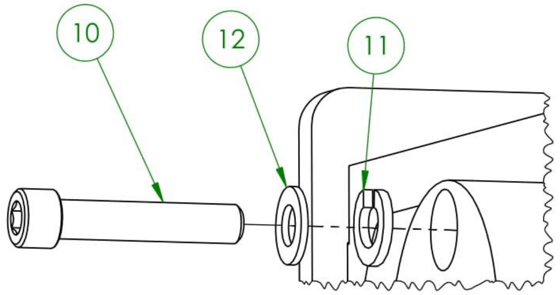
DETAIL B
TYP. #10-32 BOLT STACK

INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 42 IN-LB ±5%.



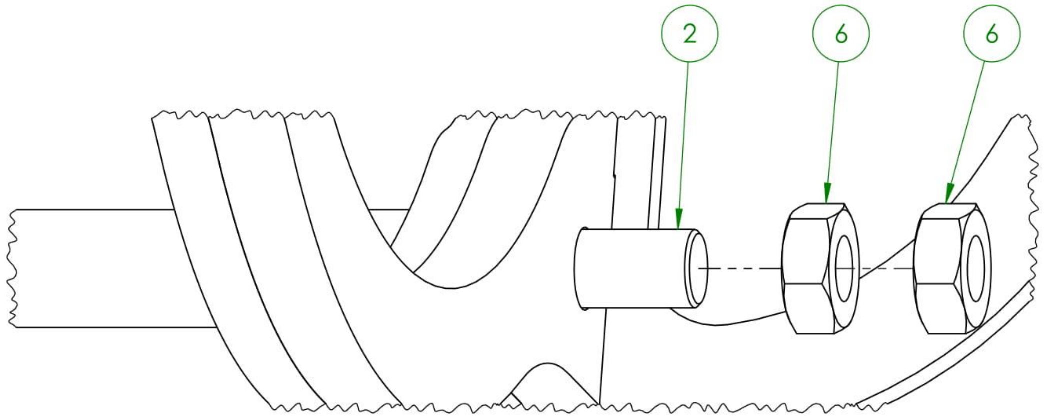
DETAIL D
TYP. #8-36 BOLT STACK

INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 36 IN-LB ±5%.



DETAIL C
TYP. 1/4-28 BOLT STACK

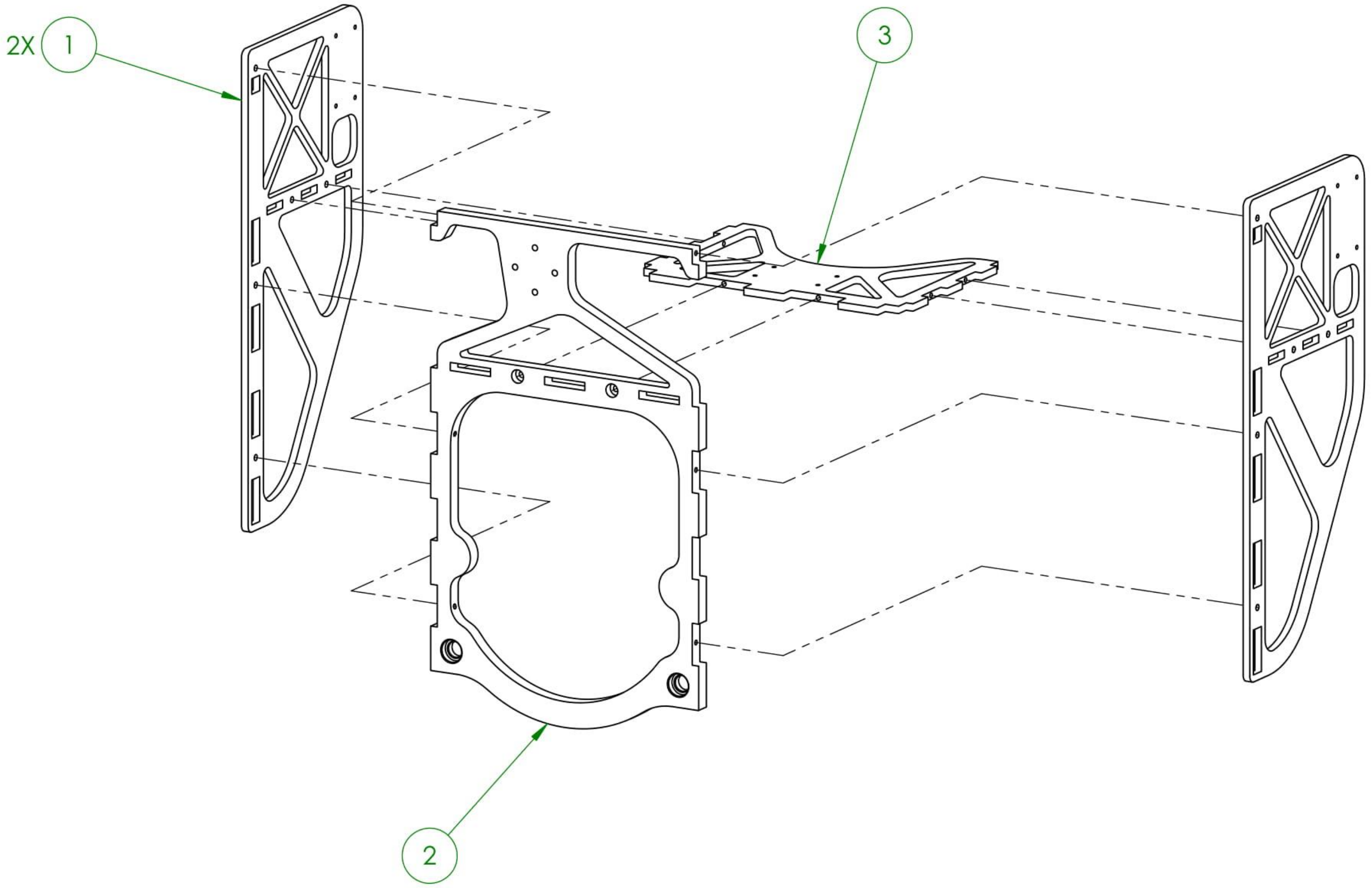
INSTALLATION NOTES:
1. APPLY LOCTITE® THREADLOCKER 243™ TO THREADS PRIOIR TO ASSMEBLY.
2. TORQE BOLT TO 10 FT-LB ±5%.

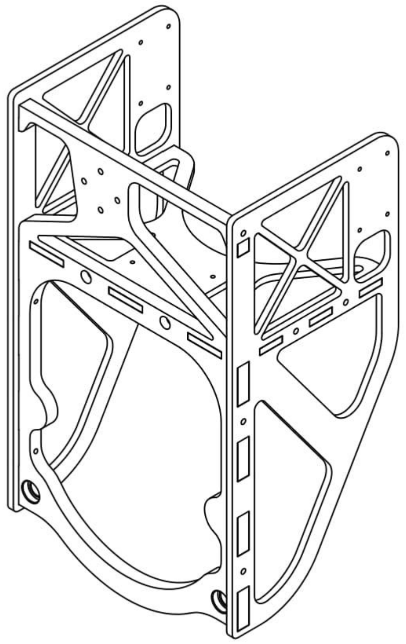


DETAIL E
TYP. 1/2-13 THREADED FORK STACK

INSTALLATION NOTES:
1. APPLY LOCTITE® LB 771™ ANTI-SEIZE TO THREADS PRIOIR TO ASSMEBLY.
2. TIGHTEN FIRST NUT WRENCH TIGHT.
3. TIGHTEN SECOND NUT WRENCH TIGHT.

SHEET TITLE:
MOVABLE JAW SUBASSEMBLY - BOLT TORQUE
DWG NUM: #03-0240-E-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 2 OF 2




FOR REFERENCE ONLY

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

ITEM NO.	PARTNO	QTY.	DESCRIPTION	MATERIAL
1	#03-0211-E	2	JAW SIDE PLATE	AISI 1045 STEEL, HR
2	#03-0213-E	1	JAW FRONT PLATE	AISI 1045 STEEL, HR
3	#03-0214-E	1	JAW MIDDLE TIE-IN PLATE	AISI 1045 STEEL, HR

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS ASSEMBLED
WEIGHT (LBS): 16.310

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

PART DESC'P: MOVABLE JAW FRAME WELDMENT (ANGLABLE; SIDWAYS PIST; SPLIT; FORKED)
FINISHED P/N: #03-0210-E
MAKE FROM: SEE BOM

KENNESAW STATE UNIVERSITY

SHEET TITLE: MOVABLE JAW WELDMENT - FRAME DRAWING
DWG NUM: #03-0210-E-A
REV: A
SCALE: 1:5
SIZE: B
SHEET: 1 OF 1

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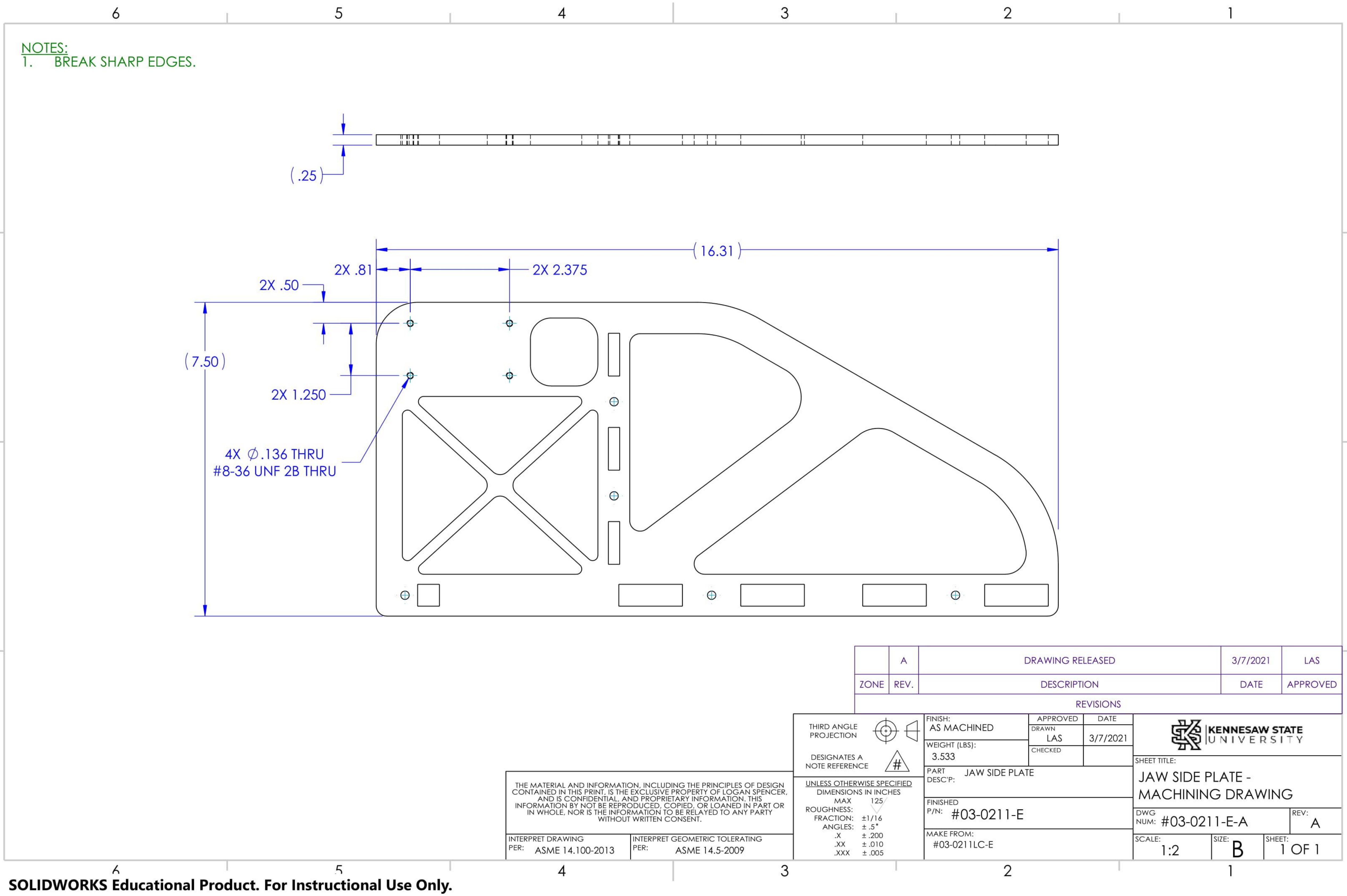

NOTES:
1. BREAK SHARP EDGES.

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED
WEIGHT (LBS): 3.533
PART DESC'P: JAW SIDE PLATE
FINISHED P/N: #03-0211-E
MAKE FROM: #03-0211LC-E

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

KENNESAW STATE UNIVERSITY

SHEET TITLE: JAW SIDE PLATE - MACHINING DRAWING
DWG NUM: #03-0211-E-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1

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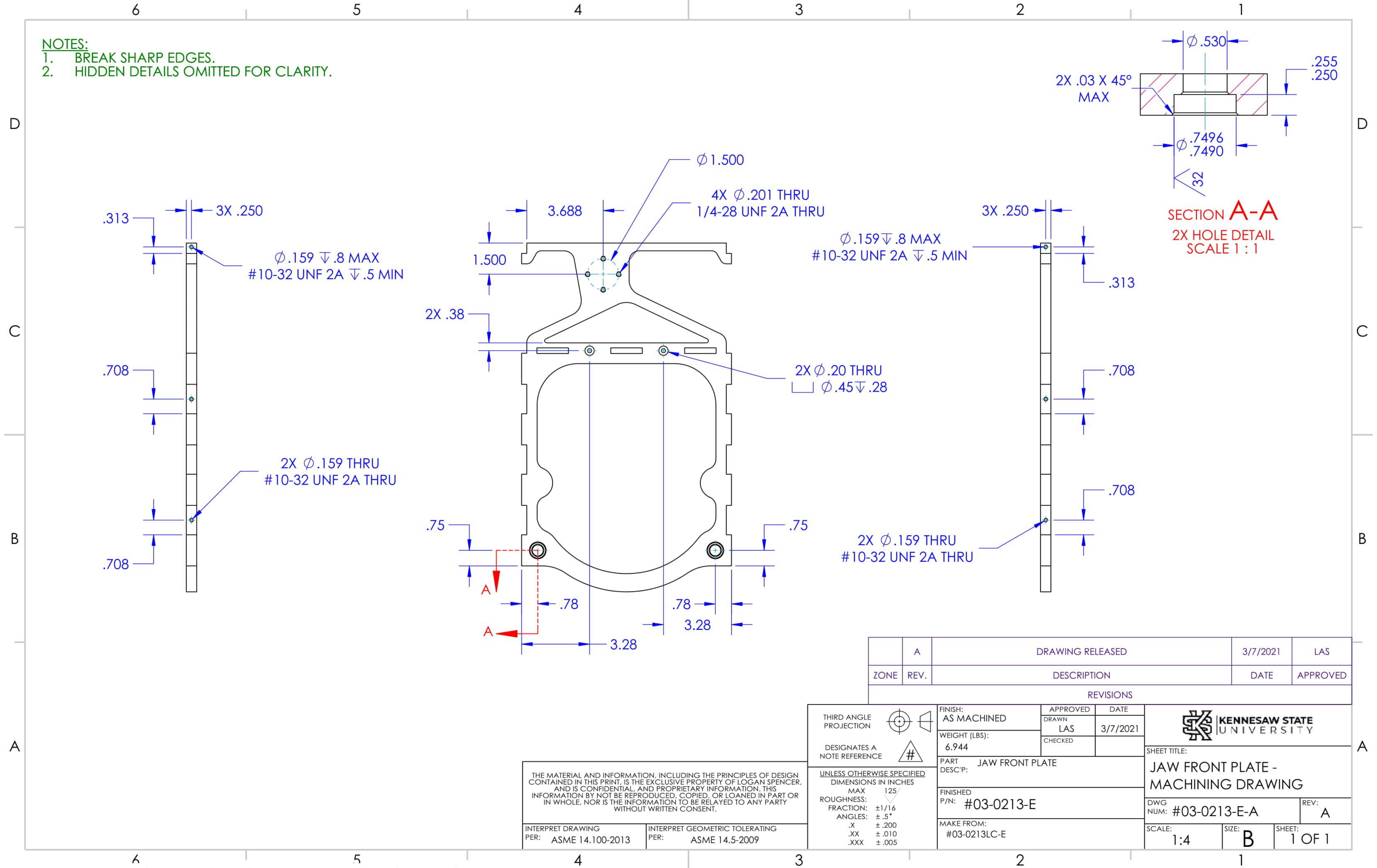
NOTES:
1. BREAK SHARP EDGES.
2. HIDDEN DETAILS OMITTED FOR CLARITY.
.313
3X .250
∅.159 ↧.8 MAX
#10-32 UNF 2A ↧.5 MIN
.708
2X ∅.159 THRU
#10-32 UNF 2A THRU
.708
3.688
1.500
∅1.500
4X ∅.201 THRU
1/4-28 UNF 2A THRU
2X .38
2X ∅.20 THRU
⌴ ∅.45↧.28
.75
.75
.78
.78
3.28
3.28
A
A
3X .250
∅.159↧.8 MAX
#10-32 UNF 2A ↧.5 MIN
.313
.708
.708
2X ∅.159 THRU
#10-32 UNF 2A THRU
∅.530
.255
.250
2X .03 X 45°
MAX
∅.7496
.7490
32
SECTION A-A
2X HOLE DETAIL
SCALE 1 : 1
A
DRAWING RELEASED
3/7/2021
LAS
ZONE
REV.
DESCRIPTION
DATE
APPROVED
REVISIONS
THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE
#
FINISH:
AS MACHINED
APPROVED
DATE
DRAWN
LAS
3/7/2021
CHECKED
WEIGHT (LBS):
6.944
KENNESAW STATE UNIVERSITY
SHEET TITLE:
JAW FRONT PLATE -
MACHINING DRAWING
PART DESC'P:
JAW FRONT PLATE
FINISHED P/N:
#03-0213-E
DWG NUM:
#03-0213-E-A
REV:
A
MAKE FROM:
#03-0213LC-E
SCALE:
1:4
SIZE:
B
SHEET:
1 OF 1
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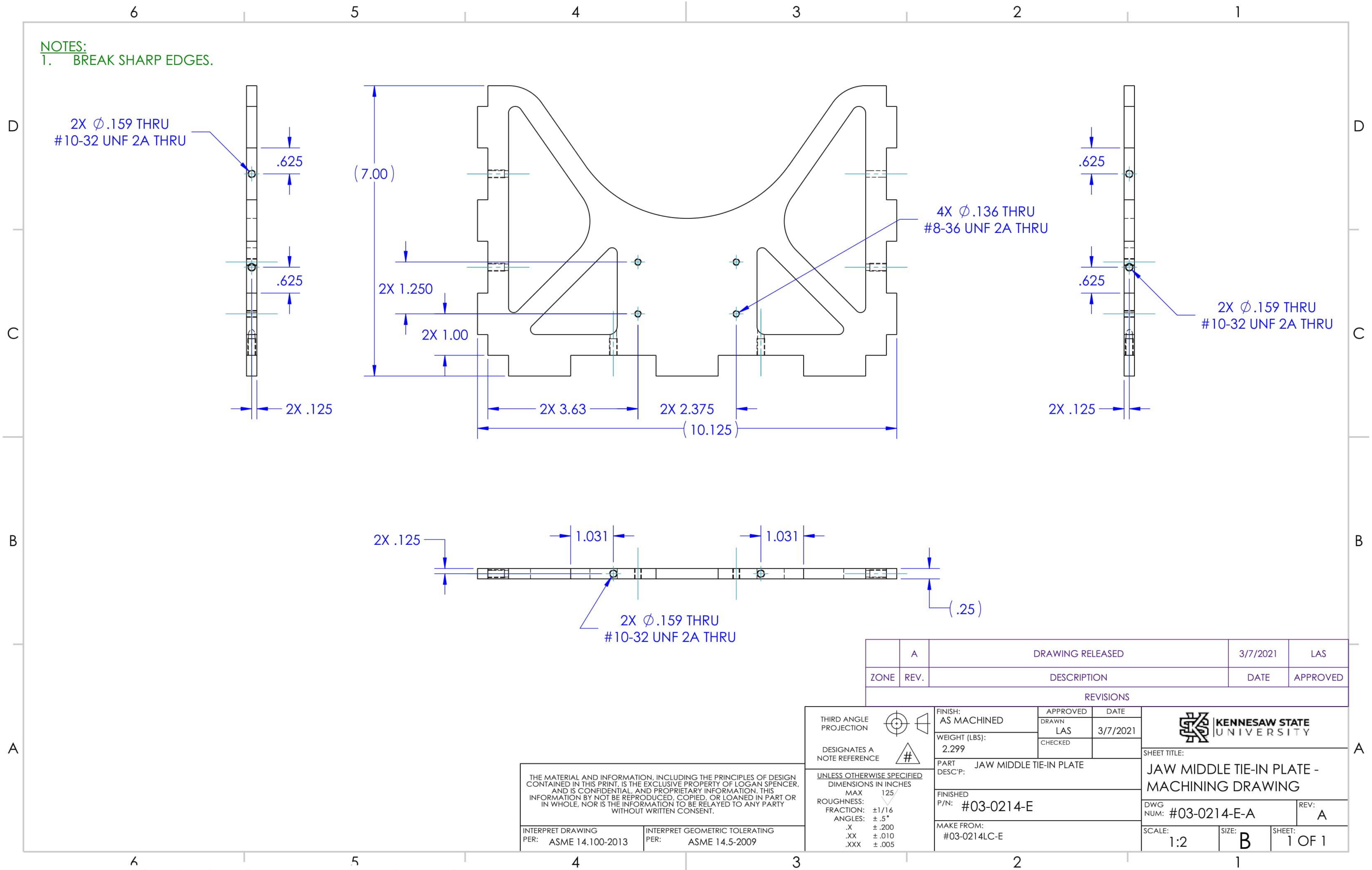
INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009
UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005
6
5
4
3
2
1
D
C
B
A



NOTES:
1. BREAK SHARP EDGES.

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

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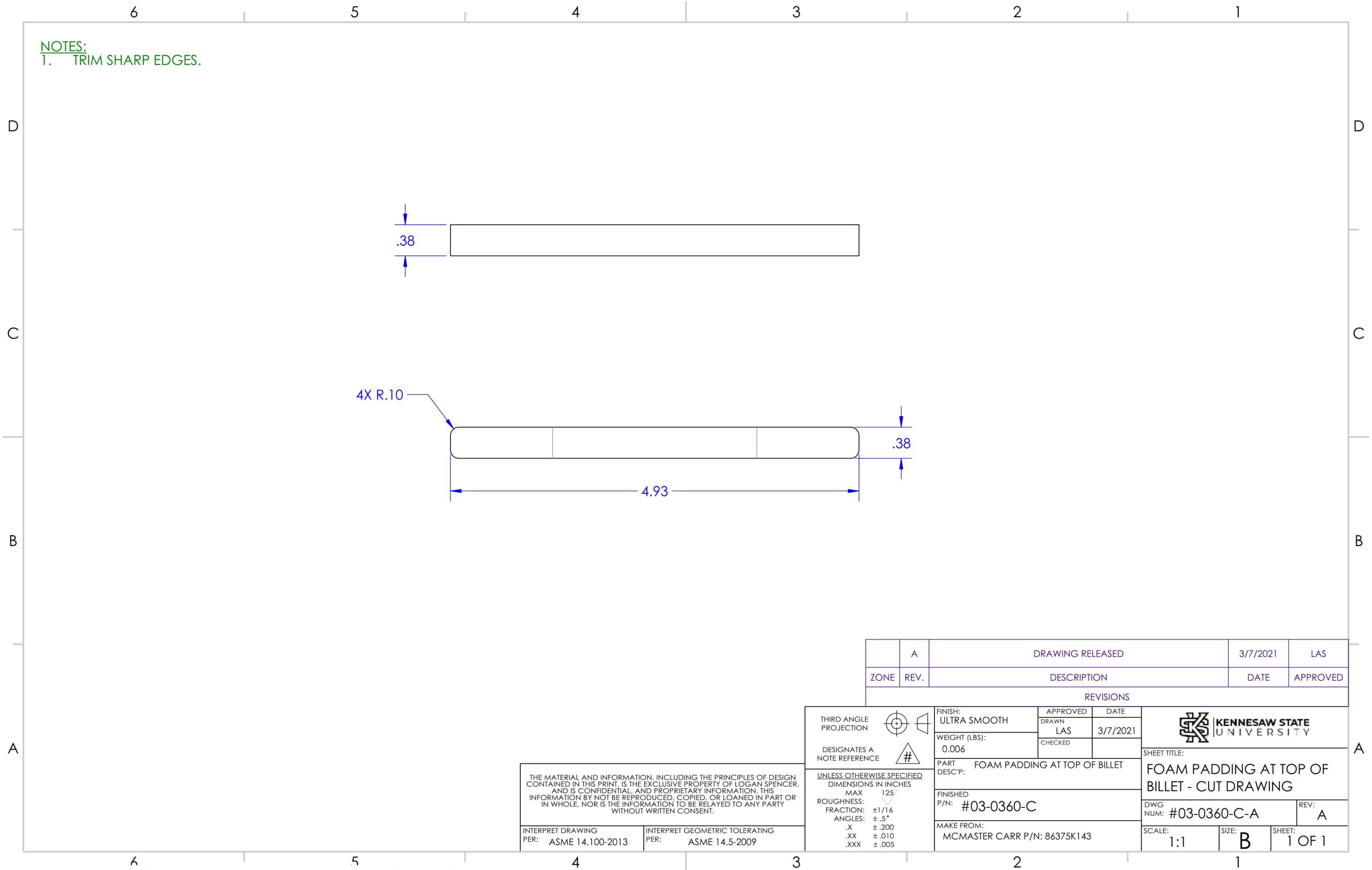
INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED
WEIGHT (LBS): 2.299
APPROVED / DATE
DRAWN: LAS 3/7/2021
CHECKED:
PART DESC'P: JAW MIDDLE TIE-IN PLATE
FINISHED P/N: #03-0214-E
MAKE FROM: #03-0214LC-E
SHEET TITLE: JAW MIDDLE TIE-IN PLATE - MACHINING DRAWING
DWG NUM: #03-0214-E-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1



NOTES:
1. TRIM SHARP EDGES.

	A	DRAWING RELEASED	3/7/2021	LAS
ZONE	REV.	DESCRIPTION	DATE	APPROVED

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: ULTRA SMOOTH
WEIGHT (LBS): 0.006

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

PART DESC'P: FOAM PADDING AT TOP OF BILLET
FINISHED P/N: #03-0360-C
MAKE FROM: MCMASTER CARR P/N: 86375K143

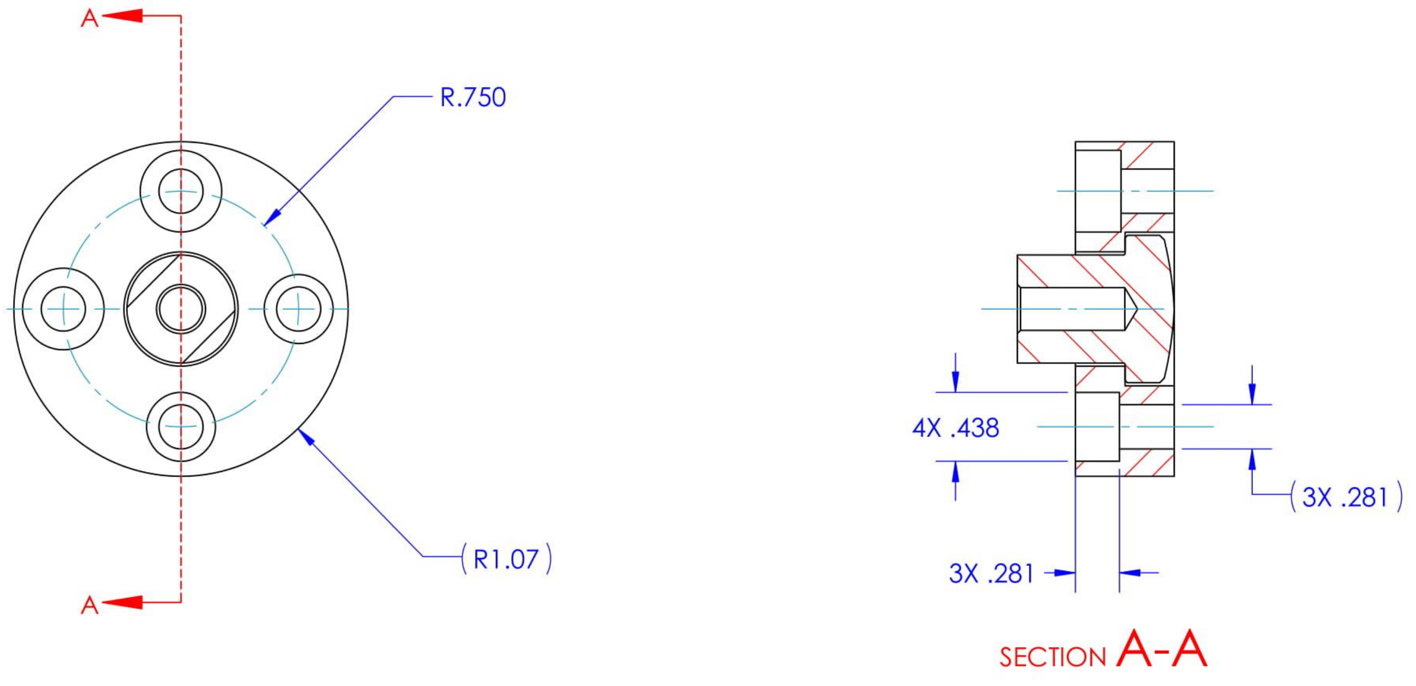
KENNESAW STATE UNIVERSITY

SHEET TITLE: FOAM PADDING AT TOP OF BILLET - CUT DRAWING
DWG NUM: #03-0360-C-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:

1. BREAK SHARP EDGES.



	A	DRAWING RELEASED	3/7/2021	LAS
ZONE	REV.	DESCRIPTION	DATE	APPROVED

REVISIONS

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

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INTERPRET DRAWING PER: ASME 14.100-2013

INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: AS MACHINED

WEIGHT (LBS): 0.557

	APPROVED	DATE
DRAWN	LAS	3/4/2021
CHECKED		

PART DESC'P: 5/16"-24 FLOATING FLANGE WITH COUTERBORES FOR SPLIT WASHER

FINISHED P/N: #03-0390-C

MAKE FROM: #03-0430-0

KENNESAW STATE UNIVERSITY

SHEET TITLE: FLOATING FLANGE - MACHINING DRAWING

DWG NUM: #03-0390-C-A

REV: A

SCALE: 1:1

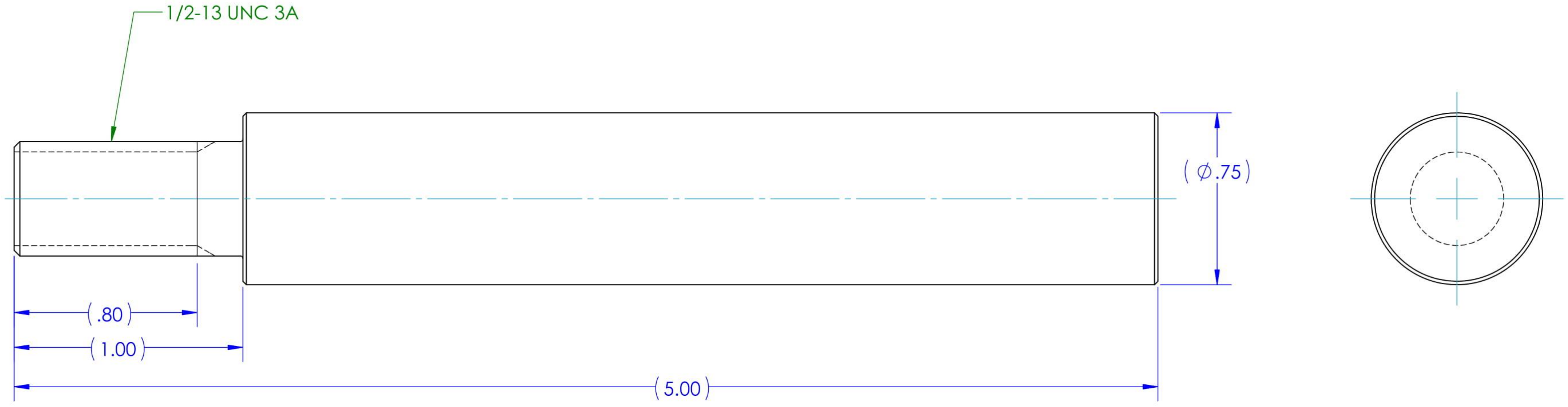
SIZE: B

SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. THIS IS A VENDER DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	MiSUMi
VENDOR DESCIPTION	ONE THREADED ENDPRECISION LINEAR SHAFT - INCH MEASUREMENTS (MISUMI)
VENDOR PARTNO	U-SSFAN0.75-L4-F1-B0.8-T0.5
VENDOR COST	31.62
PURCHASE URL	https://us.misumi-ec.com/vona2/detail/110302148940/?HissuCode=U-SSFAN0.75-L4-F1-B0.8-T0.5&PNSearch=U-SSFAN0.75-L4-F1-B0.8-T0.5&searchFlow=results2type&KWSearch=U-SSFAN0.75-L4-F1-B0.8-T0.5



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

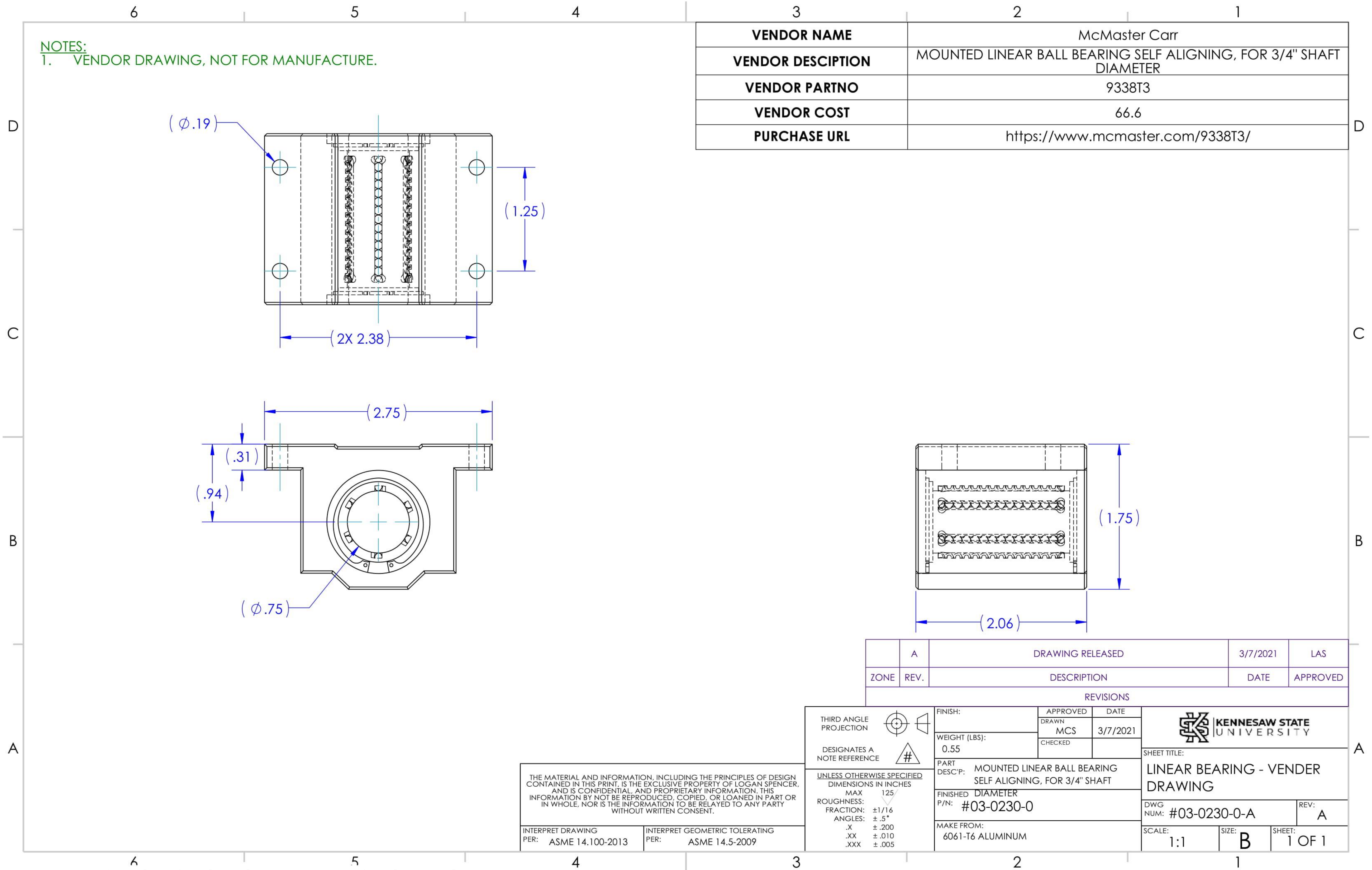
THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: INDUCTION HARD
WEIGHT (LBS): 0.553
APPROVED DRAWN: LAS DATE: 3/7/2021
CHECKED:
PART DESC'P: Ø3/4" X 4" LINIAR MOTION SHAFT, 1/2"-13TPI X 1" REUCED END, 440C SS
FINISHED P/N: #03-0220-0
MAKE FROM: 440C STAINLESS STEEL

KENNESAW STATE UNIVERSITY
SHEET TITLE: LINIAR SHAFT - VENDOR DRAWING
DWG NUM: #03-0220-0-A
REV: A
SCALE: 2:1
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.



NOTES:
1. VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	McMaster Carr
VENDOR DESCIPTION	MOUNTED LINEAR BALL BEARING SELF ALIGNING, FOR 3/4" SHAFT DIAMETER
VENDOR PARTNO	9338T3
VENDOR COST	66.6
PURCHASE URL	https://www.mcmaster.com/9338T3/

REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

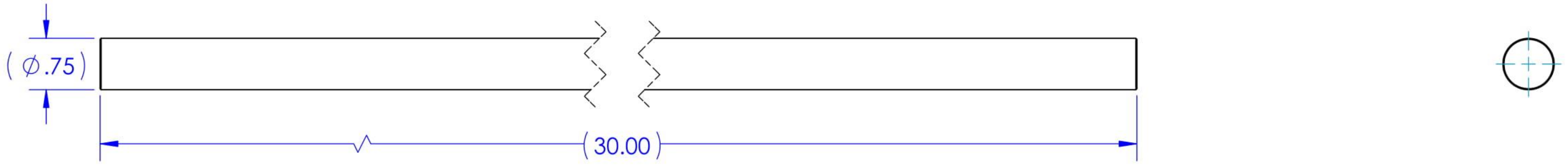
FINISH:
WEIGHT (LBS): 0.55
APPROVED DATE
DRAWN MCS 3/7/2021
CHECKED
PART DESC'P: MOUNTED LINEAR BALL BEARING SELF ALIGNING, FOR 3/4" SHAFT DIAMETER
FINISHED P/N: #03-0230-0
MAKE FROM: 6061-T6 ALUMINUM

KENNESAW STATE UNIVERSITY
SHEET TITLE: LINEAR BEARING - VENDER DRAWING
DWG NUM: #03-0230-0-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. THIS IS A VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	MiSUMi
VENDOR DESCIPTION	STRAIGHT PRECISION LINEAR SHAFT - INCH MEASUREMENTS (MISUMI)
VENDOR PARTNO	U-SSFJ0.75-L30
VENDOR COST	83.92
PURCHASE URL	https://us.misumi-ec.com/vona2/detail/110302148420/?HissuCode=U-SSFJ0.75-L30&PNSearch=U-SSFJ0.75-L30&searchFlow=results2type&KWSearch=U-SSFJ0.75-L30



REVISIONS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: INDUCTION HARD
WEIGHT (LBS): 3.737
PART DESC'P: Ø3/4" X 30" STRAIGHT PRECISION LINEAR SHAFT, 440C SS
FINISHED P/N: #03-0270-0
MAKE FROM: 440C STAINLESS STEEL

	APPROVED	DATE
DRAWN	LAS	3/7/2021
CHECKED		

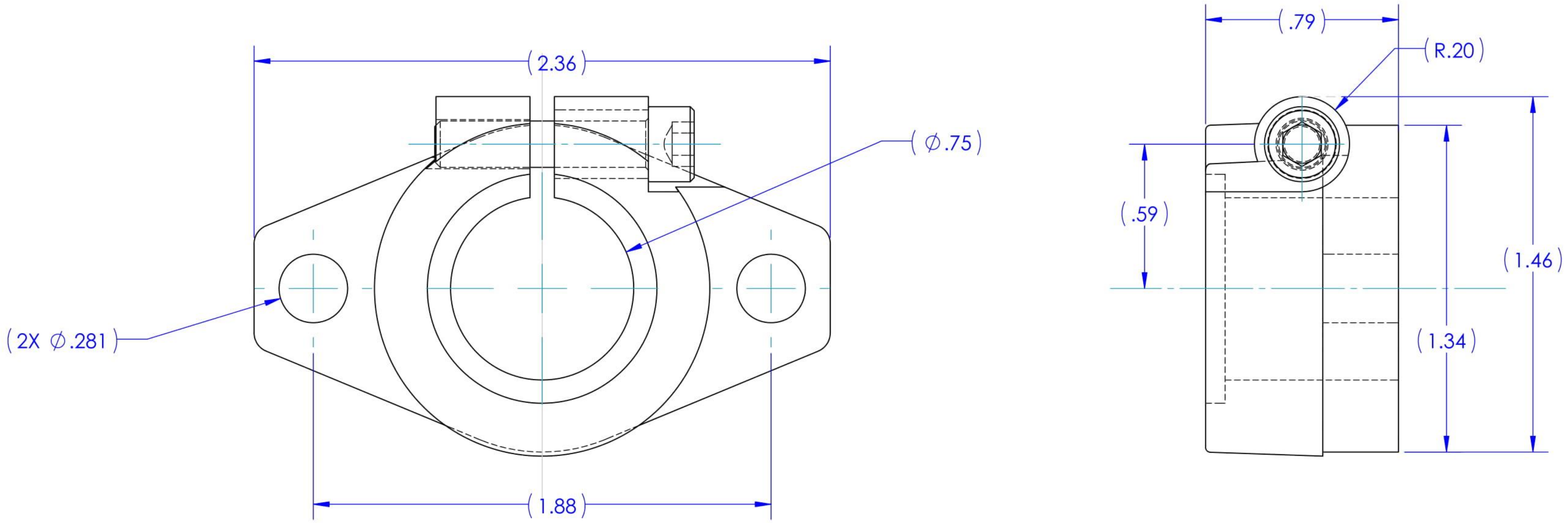
KENNESAW STATE UNIVERSITY

SHEET TITLE: PERSICION LINIAR SHAFT - VENDOR DRAWING
DWG NUM: #03-0270-0-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	MiSUMi
VENDOR DESCIPTION	SHAFT SUPPORTS - FLANGE MOUNTED, CAST, INCH MEASUREMENTS (MISUMI)
VENDOR PARTNO	U-SHFT0.75
VENDOR COST	37.27
PURCHASE URL	https://us.misumi-ec.com/vona2/detail/110302153570/?HissuCode=U-SHFT0.75&PNSearch=U-SHFT0.75&searchFlow=results2type&KWSearch=U-SHFT0.75



ZONE	DESCRIPTION	REV.	DATE	APPROVED
	DRAWING RELEASED	A	3/7/2021	LAS

REVISIONS

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

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INTERPRET DRAWING PER: ASME 14.100-2013

INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: BLACK OXIDE

WEIGHT (LBS): 0.28

	APPROVED	DATE
DRAWN		3/7/2021
CHECKED		

PART DESC'P: FLANGE-MOUNTED, 2 BOLT SHAFT SUPPORT FOR 3/4" SHAFT DIAMETER, 1045 STEEL

FINISHED P/N: #03-0320-0

MAKE FROM:

KENNESAW STATE UNIVERSITY

SHEET TITLE: SHEET 1

DWG NUM: #03-0320-0-A

REV: A

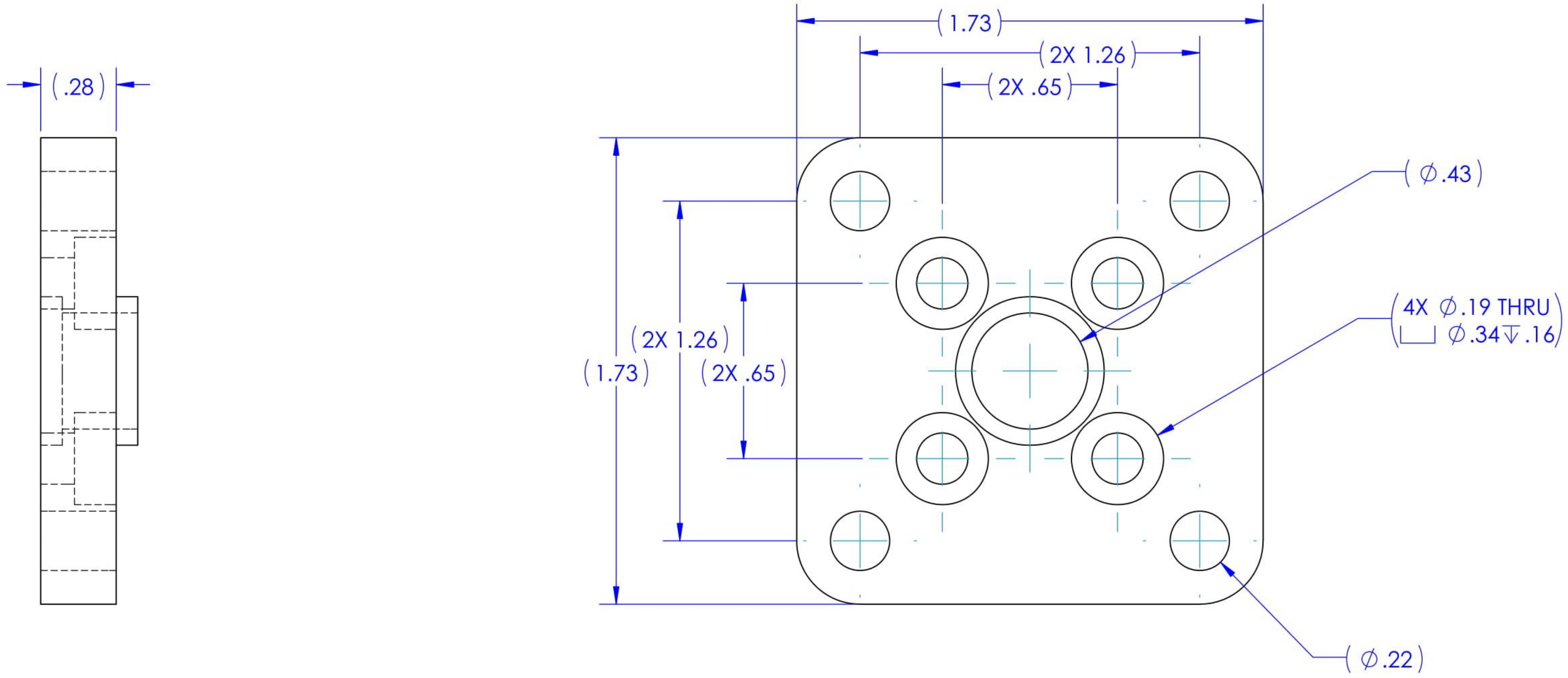
SCALE: 2:1

SIZE: B

SHEET: 1 OF 1

NOTES:
1. VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	McMaster Carr
VENDOR DESCRIPTION	FRONT/REAR FLANGE FOR 1" BORE SIZE ALUMINUM IMPACT-RESISTANT ROUND BODY AIR CYLINDER
VENDOR PARTNO	6471K52
VENDOR COST	4.88
PURCHASE URL	https://www.mcmaster.com/6471K52/



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2020	LAS

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: NICKLE-PLATED
WEIGHT (LBS): 0.190
PART DESC'P: FLANGE FOR 1" BORE ROUND BODY AIR PISTON CYLINDER (WITH HARDWARE)
FINISHED P/N: #03-0380-0
MAKE FROM: CR STEEL

	APPROVED	DATE
DRAWN	MMC	3/7/2021
CHECKED		

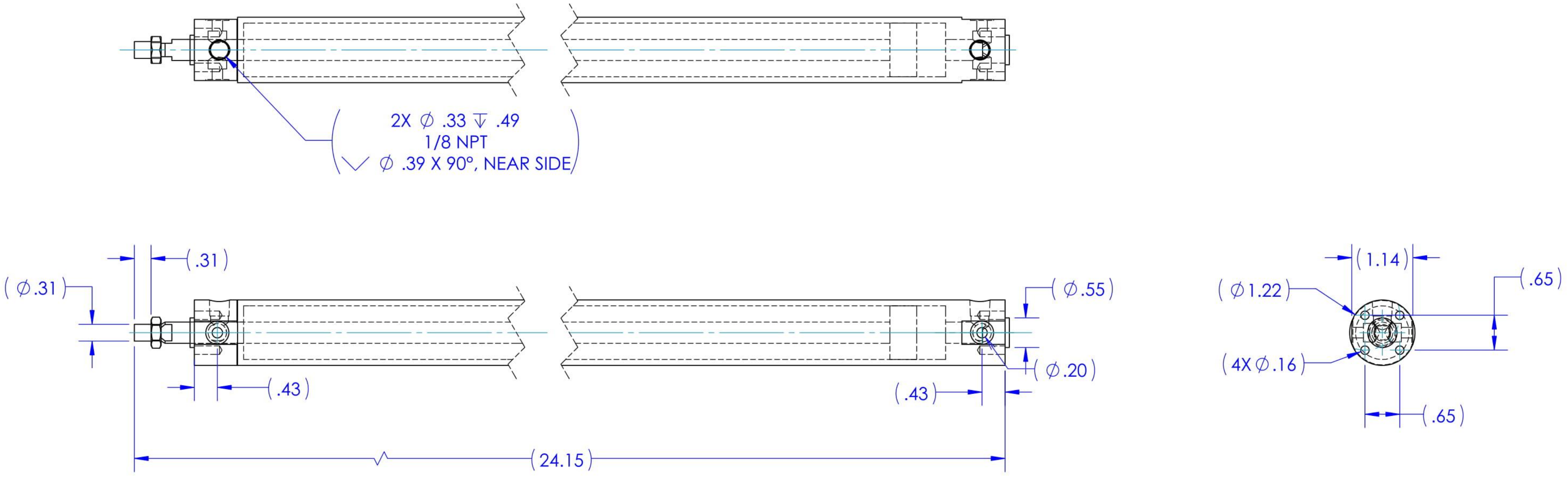
KENNESAW STATE UNIVERSITY

SHEET TITLE: PISTON FLANGE - VENDOR DRAWING
DWG NUM: #03-0380-0-A
REV: A
SCALE: 2:1
SIZE: B
SHEET: 1 OF 1

SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	McMaster Carr
VENDOR DESCIPTION	IMPACT-RESISTANT ROUND BODY AIR CYLINDER ALUMINUM, DOUBLE ACTING, 1" BORE SIZE, 1.22" OD, 20" STROKE
VENDOR PARTNO	6471K373
VENDOR COST	72.42
PURCHASE URL	https://www.mcmaster.com/6471K373/



ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

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INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH:
WEIGHT (LBS): 1.844

	APPROVED	DATE
DRAWN	MMC	3/7/2021
CHECKED		

PART DESC'P: ALUMINUM DOUBLE-ACTING PISON CYLINDER, 1" BORE, 1.22" OD, 20" STROKE
FINISHED P/N: #03-0400-0
MAKE FROM: ALUMINUM

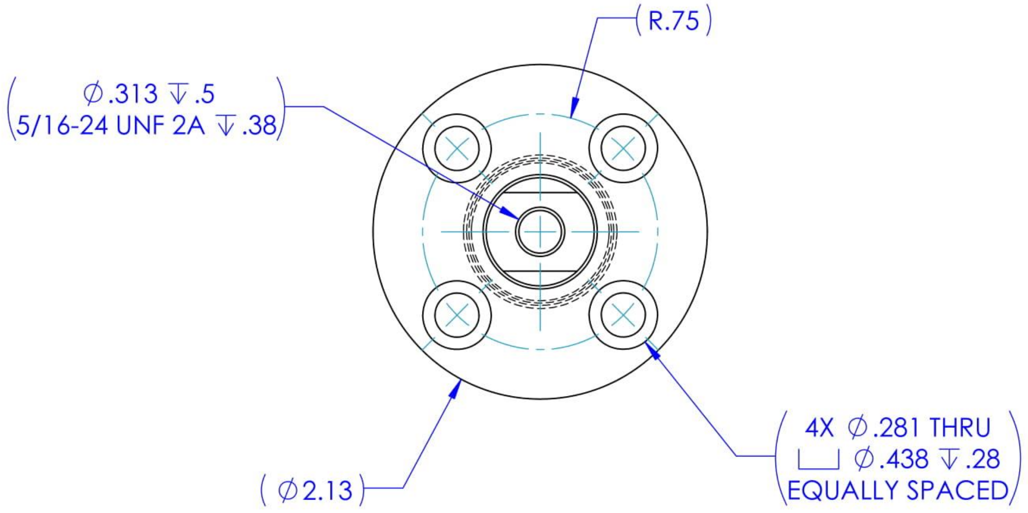
KENNESAW STATE UNIVERSITY

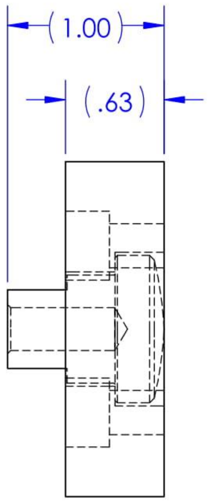
SHEET TITLE: AIR PISTON - VENDOR DRAWING
DWG NUM: #03-0400-0-A
REV: A
SCALE: 1:2
SIZE: B
SHEET: 1 OF 1

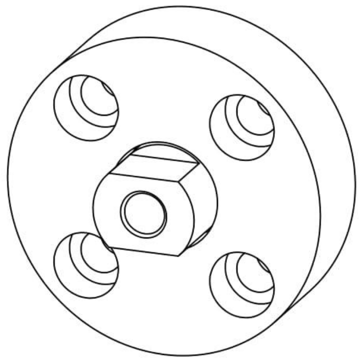
SOLIDWORKS Educational Product. For Instructional Use Only.

NOTES:
1. VENDOR DRAWING, NOT FOR MANUFACTURE.

VENDOR NAME	MiSUMi
VENDOR DESCRIPTION	FLOATING JOINTS - MOUNTING FLANGES, COMPLETE SETS, INCH MEASUREMENTS (MISUMI)
VENDOR PARTNO	U-FJA0.31
VENDOR COST	17.56
PURCHASE URL	https://us.misumi-ec.com/vona2/detail/110302172830/?HissuCode=U-FJA0.31&PNSearch=U-FJA0.31&searchFlow=results2type&KWSearch=U-FJA0.31







FOR REFERANCE ONLY
SCALE: NTS

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	DRAWING RELEASED	3/7/2021	LAS

REVISIONS

INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

THIRD ANGLE PROJECTION
DESIGNATES A NOTE REFERENCE #

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ± .5°
.X ± .200
.XX ± .010
.XXX ± .005

FINISH: BLACK-OXIDE
WEIGHT (LBS): 0.57

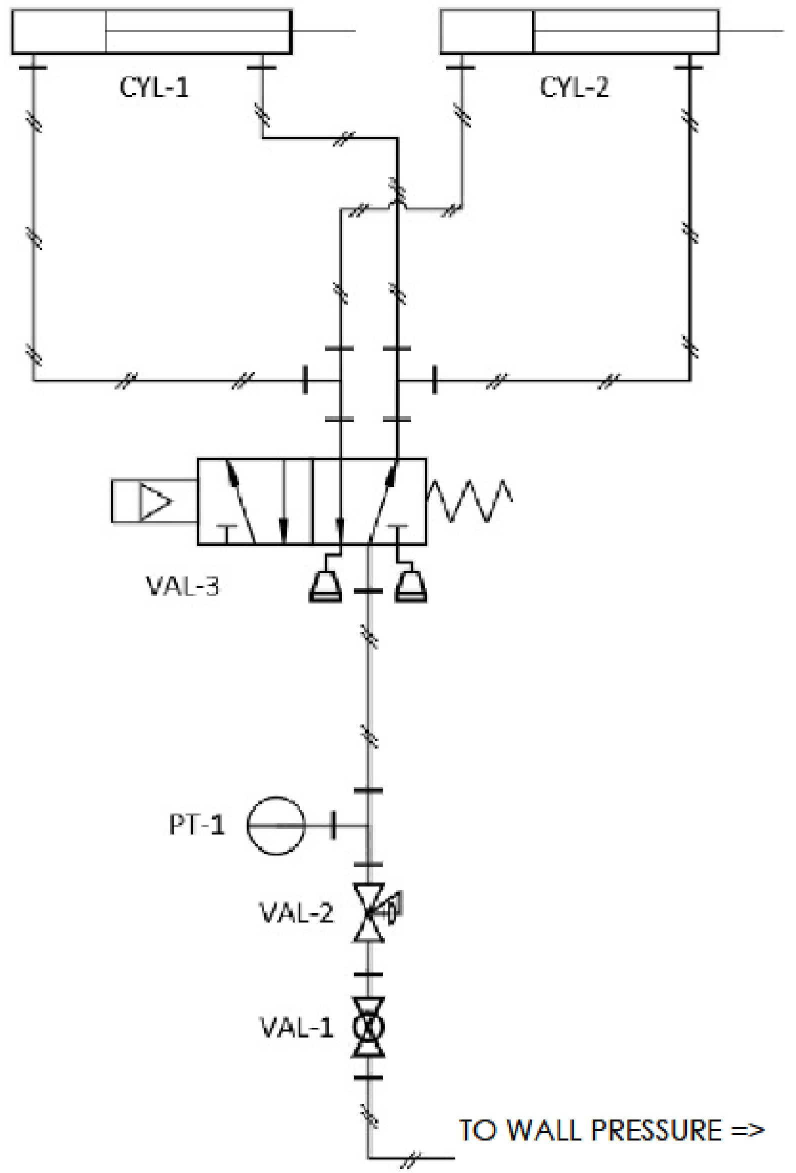
	APPROVED	DATE
DRAWN	MIS	3/7/2021
CHECKED		

PART DESC'P: 5/16"-24 FLANGE MOUNT, FLOATING JOINT
FINISHED P/N: #03-0430-0
MAKE FROM: 1045 STEEL

KENNESAW STATE UNIVERSITY

SHEET TITLE: FLOATING JOINT - VENDOR DRAWING
DWG NUM: #03-0430-0-A
REV: A
SCALE: 1:1
SIZE: B
SHEET: 1 OF 1

NOTES:
1. TO BE PLUMBED WITH Ø1/4" OD PLASTIC TUBING RATED FOR 120 PSIG.
2. SEAL ALL THREADED FITTINGS WITH PTFE TAPE.
3. LEAK CHECK ALL FITTINGS BY PRESSUREISING AND APPLYING SNOOP AFTER ASSEMBLY.



P&ID LEGEND

CYL-1	LEFT PNEUMATIC CYLINDER (P/N: #03-0400-0)
CYL-2	RIGHT PNEUMATIC CYLINDER (P/N: #03-0400-0)
PT-1	100 PSIG PRESSURE SWITCH (SMC P/N: ISE40A-N01-V-P)
VAL-1	PRESSURE LOCKOUT SWITCH (SMC P/N: VHS30-N03B-Z)
VAL-2	FORE PRESSURE REGULATOR ANF FILTER (SMC P/N: AW30K-N03-Z-B)
VAL-3	5-2 MONO STABLE SOLENIOD VALVE (FESTO P/N: VSVA-B-M52-MZD-A2-1T1L)

ZONE	REV.	DESCRIPTION	DATE	APPROVED
	A	INITAL RELEASE	4/7/2021	LAS

REVISIONS

THIRD ANGLE PROJECTION

DESIGNATES A NOTE REFERENCE #

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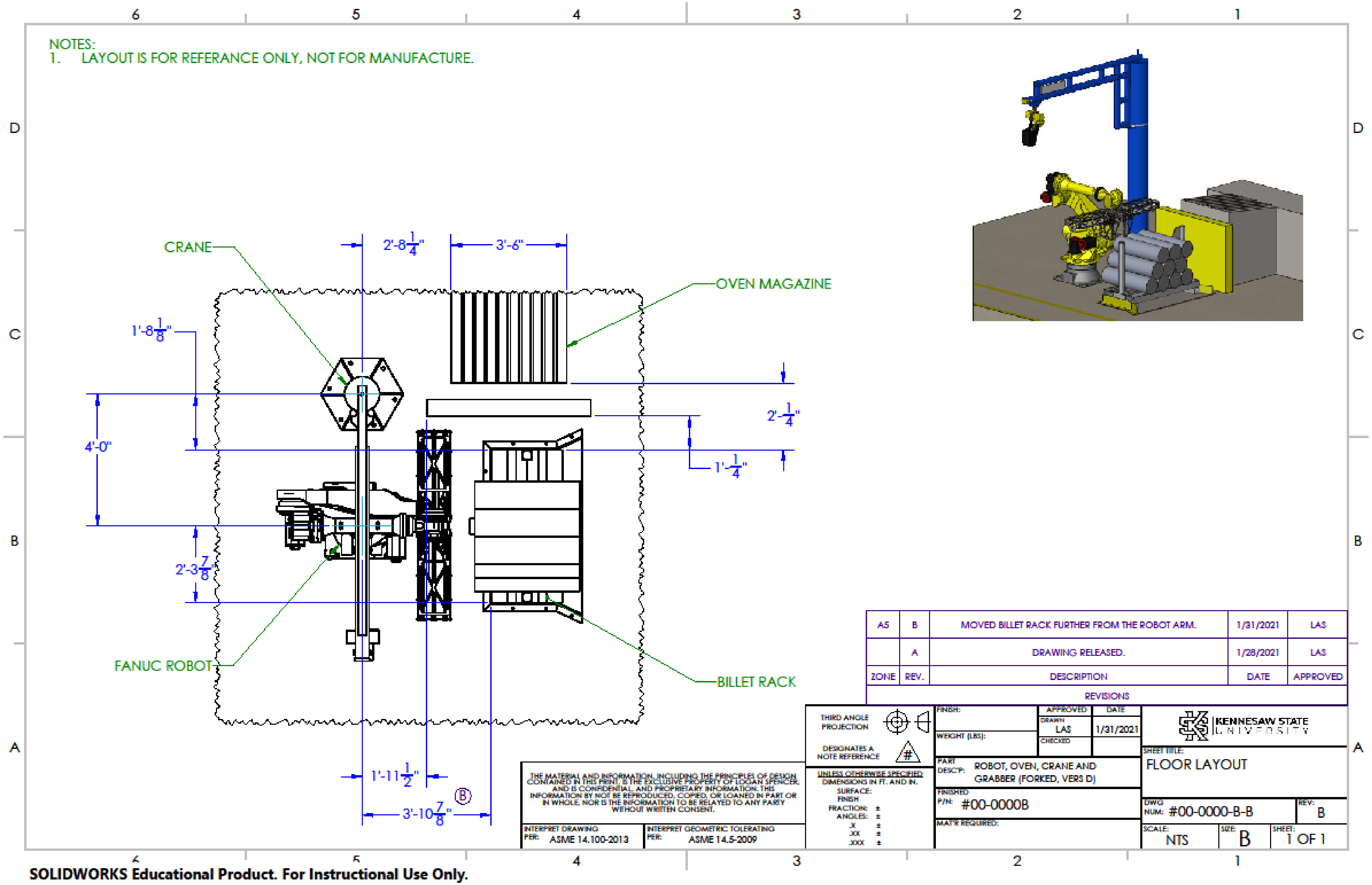
INTERPRET DRAWING PER: ASME 14.100-2013
INTERPRET GEOMETRIC TOLERATING PER: ASME 14.5-2009

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
MAX ROUGHNESS: 125
FRACTION: ±1/16
ANGLES: ±.5°
.X ±.200
.XX ±.050
.XXX ±.005

FINISH:
WEIGHT (LBS):
APPROVED DATE
DRAWN LAS 4/7/2021
CHECKED
PART DESC'P: GRIPPER PNEMATIC CONTROL SYSTEM
FINISHED P/N:
MAKE FROM:

KENNESAW STATE UNIVERSITY
SHEET TITLE: PNEUMATICS P&ID
DWG NUM: #06-0000-0
REV: A
SCALE: 1:10
SIZE: B
SHEET: 1 OF 1



ZONE	REV.	DESCRIPTION	DATE	APPROVED
A5	B	MOVED BILLET RACK FURTHER FROM THE ROBOT ARM.	1/31/2021	LAS
	A	DRAWING RELEASED.	1/28/2021	LAS

REVISIONS

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