Letter of Transmittal

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December 8, 2021

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Dear Dr.Labossiere,

Kindly find enclosed within this document Team 19's final design submitted on Wednesday, December 8th, 2021. The design report contains a proposed design for an impeller removal tool for Nutrien. In the report, a clear problem statement will be found along with other design deliverables requested by the sponsoring company Nutrien. These deliverables include a final design verification, cost analysis, FEA analysis, Engineering drawings for fabrication, Bill of Materials, maintenance/operation considerations, and recommendations.

As a team, we would like to express our gratitude to Dr. Quinjin Peng for the suggestions and support provided as our advisor for the duration of this project. We would also like to thank our professor Dr. Paul Labossiere for his design recommendations and teaching during the project, Ms. Aidan Topping and Jaime Campos Ordonez for their feedback on subsequent sections of the report, and Mr. Brenden Carlson and Mr. Aric Hanson for providing input and guidance on the design.

Kind Regards,

Avery Darechuk, Paolo Yadao, James Martin Chavez, Toluwaniyin David

Team 19- Prime Consulting, MECH 4860

Final Design Report

MECH4860 Engineering Design

Price Faculty of Engineering
Department of Mechanical Engineering

Nutrien Rocanville Potash: Design of Impeller Removal Tool

Team #19: Prime Consulting

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Wednesday, December 8, 2021

Executive Summary

Prime Consulting has been tasked to design an impeller removal tool to replace the current process at Nutrien's Rocanville potash operation. The existing process involves wrapping a sling around the seized impeller and using the crane to screw the impeller off of the pump shaft. This process introduces hazards to the employees, as there is a risk that the impeller will fall out of the sling, potentially coming into contact with an employee or nearby equipment. Additionally, this process is time consuming and requires operators to be in near-constant interaction with the impeller.

The objectives of this project were to design an impeller removal tool which is able to remove the 12/10, 10/8, and 8/6 impellers from their respective pump shafts. The tool must do so while reducing the risks posed to the operators as compared to the existing process. Additionally, the tool should require no more than two operators and may only utilize a 25-tonne overhead crane and forklift to support the process. The tool should be able to complete the job in a similar or shorter amount of time than the current process takes. Finally, the ability to break the torque of the seized impeller would be considered a favourable, but not required, design feature.

With the input of Nutrien's engineering and operations team, Prime Consulting underwent a conceptual design process, concept screening and scoring, concept combination, and finally an iterative design process to arrive at a final design. The final design is powered by a 5 kN·m pneumatic torque wrench and transmits thew torque through a shaft to which a clamp is attached. The clamp is capable of securing all three impeller sizes to the tool. The design also features a scissor-lift table to adjust the height of the tool and wheels to allow the tool to be easily transported around the shop floor. The final design weighs a total of 926 lbs and has a total cost to purchase and fabricate of [redacted]

When compared against the needs and specifications of the project, the impeller removal tool meets or exceeds all marginal specifications and outperforms the existing process in the highest importance needs. The impeller removal tool is expected to reduce the risk posed to operators during the operation of removing seized impellers, and increase the overall productivity of Nutrien's Rocanville operation.

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1 Glossary of Terms

This sections explains any technical terminology found within the report:

Potash
Potash is the common name given to a group of minerals containing potassium (K) and is essential to all forms of plant and animal life.

Slurry Pump
A type of pump used for pumping liquid containing solid particles Impeller
An impeller is a rotating component equipped with vanes or blades used in turbo machinery (i.e centrifugal pumps).

RPN
Risk priority number is a numeric assessment of risk assigned to a set of steps, or a process during a failure modes and effects analysis.

Pneumatic Torque Wrench
A tool which converts pneumatic energy, typically in the form of compressed air, to rotational kinetic energy. Pneumatic torque wrenches typically are rated based on their maximum torque output.

Reaction Point
When referring to a pneumatic torque wrench, a reaction point is a fixed point against which the pneumatic torque wrench can register. The reaction point prevents the body of the pneumatic torque wrench from rotating, and instead forces the rotation to act on the component to which the pneumatic torque wrench is connected.

2 Introduction

Nutrien is a leading provider of agricultural products, services, and solutions. With approximately 20,000 employees world-wide, Nutrien produces and distributes over 25 million tonnes of potash, nitrogen and phosphate products for customers world-wide [1].

To meet up with such high production volumes, Nutrien has six Canadian potash facilities; 13 nitrogen facilities spread across Canada, US and Trinidad; six phosphate facilities in the US; and a granulation operation in the US [1].

Nutrien has tasked Team 19, also known as Prime Consulting, with the responsibility of creating a slurry pump impeller removal tool that can be used by mechanics during the pump rebuild process. This section will highlight the importance of Potash to Nutrien and expand on the problem Nutrien faces in one of the six Canadian Potash Facilities.

2.1 Background Information

Potash is an important product in Nutrien's business. Potash is the common name given to a group of minerals containing potassium (K) and is essential to all forms of plant and animal life. The mined potash is used to make fertilizer for plant growth, additives in animal feeds, industrial cleaning products, metal finishes, and purified acids[1]. Potash is mined from deep underground deposits left by ancient inland seas or extracted from salt water bodies.

Nutrien is the world's largest producer of Potash with a capacity of over 20 million Tonnes at it's six potash mines in Saskatchewan, Canada. This report focuses on the Rocanville, Saskatchewan mine. Here, multiple boring machines create horizontal tunnels approximately 1 km underground [2]. Then the raw ore is removed from the rock face and a series of underground belts move the product to a production shaft where the ore is hoisted to the surface. This raw ore is then crushed, separated from impurities, dried, and portioned in one of two mills at the Rocanville site. After the final product has met appropriate specifications, it is loaded into rail-cars or trucks and distributed to growers across the world. The process flow diagram shown in figure1 below summarizes the process of mining potash to the finished product which is then distributed by rail and vessel.

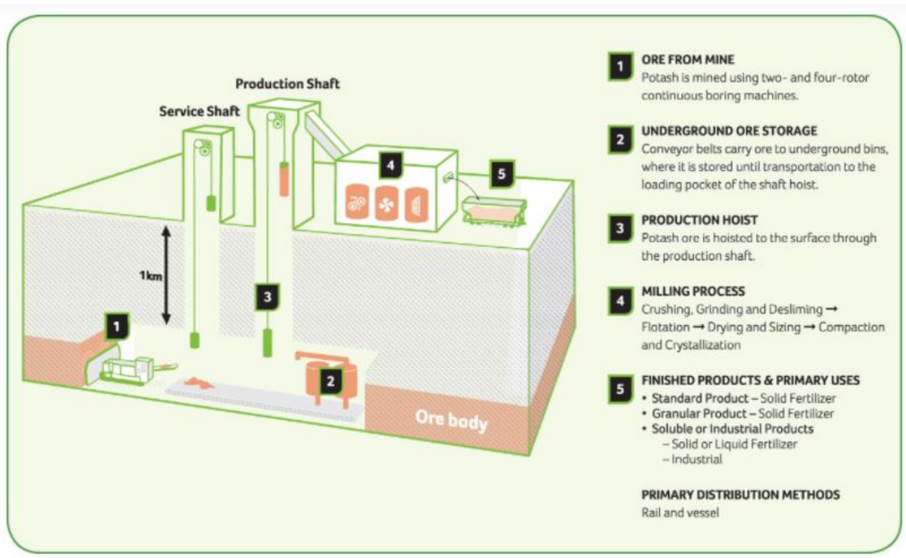


Figure 1: Potash mining process flow diagram. [3]

Multiple complex machines are used in the mining of potash including pumps, conveyor belts, boring machines and other similar industrial equipment. This equipment must be maintained to ensure the plant runs efficiently. One of the maintenance procedures included in Nutrien's Rocanville plant is scheduled pump maintenance where pumps are taken out of service from the field to an onsite maintenance shop. In this shop, mechanics disassemble the pumps to remove end of life or failed parts such as impellers and bearings.

A safety concern was brought forward through Nutrien's employee STAR Program (Safety Together At Rocanville) in which mechanics reported being exposed to a potential falling object hazard when removing impellers during pump rebuilds. The pumps in question are Warman slurry pumps which come in three sizes. Figure 2 below is an image of a slurry pump similar to one used on site. The impeller can also be seen labelled below.

Figure 2: Warman centrifugal slurry pump. [4]

The impellers weigh upwards of 700 kg and are threaded onto a stainless-steel shaft. During the impeller removal process, mechanics can face two scenarios: the first scenario is when the shaft is seized, and the second scenario is when the shaft is not seized. A shaft is said to be seized when extra force is required to unwind the impeller from the shaft due to dirt, residue from process fluid or damaged threading. In both cases, a 25-ton crane and a sling as shown in 2 are used in the removal process. When the shaft is seized, the 25-ton crane and a sling are used to break the torque of the seized impeller and shaft. The impeller is then unwound with the crane and sling until the impeller reaches the end of the shaft. At this stage, there is a possibility of the impeller falling to the floor causing the potential for a serious injury. The second scenario is when the shaft is not seized. Here, the impeller shaft can be spun manually until the impeller reaches the end of the shaft. In both cases, the crane and the sling are present but a safety hazard arises when the position of the shaft with respect to the impeller is unknown. Incidents have occurred in which the impeller has fallen to the ground, posing a risk to workers around. A forklift is often used to catch the impeller; however, this is not considered a best practice.

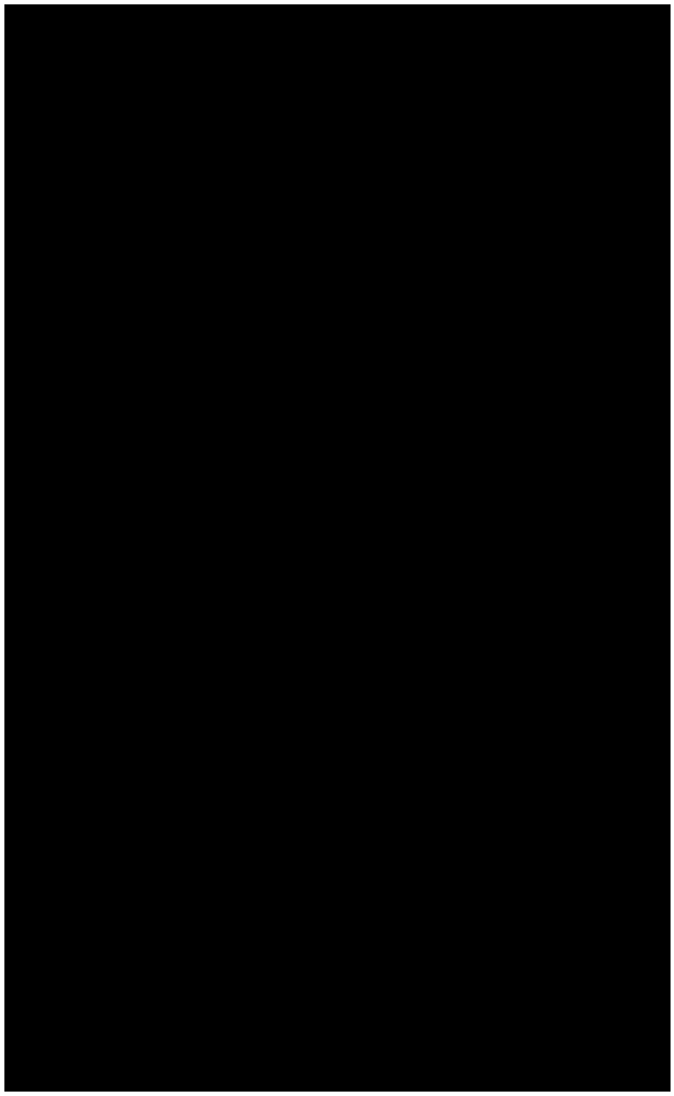


Figure 3: Photo of the existing impeller removal process. [4]

2.2 Problem Statement

Nutrien's impeller removal process creates a dropped object potential due to the tools being used. The potential causes a significant increase in safety risk to operators removing the impeller off the pump shaft. To eliminate the safety risk, the team was tasked to design a cost efficient tool that operators can use to remove the impeller that eliminates the dropped object potential, and to improve the overall pump rebuild process in terms of safety, and duration of the process.

2.3 Project Objectives

The objective of this project was to design a tool or jig that could safely remove impellers from the pumps operated at Nutrien's Rocanville operation. Since Nutrien utilizes various sizes of impellers in their potash mining operations, the tool or jig had to be compatible with different sizes of impellers that must be removed for pump rebuilds. The specified pump sizes with relevant impellers were the Warman 8/6, 10/8. The tool or jig had to eliminate the dropped object potential of the impellers and improve the overall pump rebuild process of the company. The new tool or jig had to replace Nutrien's current process that poses potential hazards without creating further ergonomic hazards to surrounding workers. Designing the new process to be more time efficient while still being cost effective were also important aspects of this project.

2.4 Project Deliverables

The final project deliverables were as follows:

a. 3-5 design options varying in cost and complexity, with 1 or 2 options as a final design.
b. A design report highlighting design methodology, final design verification, cost analysis, maintenance/-operation considerations, and recommendations.
c. FEA on any new components and engineering drawings for fabrication.
d. Bill of Materials.

2.5 Client Needs

The initial requirements provided by Nutrien and outlined in the Project Application form are as follows:

a. Eliminate the dropped object potential without creating further ergonomic hazards.
b. Be quick and easy to set-up and remove.
c. Be adjustable to suit multiple impeller sizes.
d. Be a cost-effective solution.

Initial requirements are turned into a list of needs by gathering relevant data and interpreting the data. This data was gathered by meeting with one of the representatives of Nutrien's Rocanville mechanical engineering team. Our group was given an overview of expectations and was shown the existing method and tools used for the pump impeller removal through a pre-recorded video and a second live demonstration via video call. The initial data acquired from the meeting was interpreted and expanded to seven overarching needs. Each need was expanded further as shown in Table I.

TABLE I: CLIENT NEEDS HIERARCHY

The tool is safe to use.	
1	Adheres to all applicable standards and regulations
2	Reduces risk of injury to operators
The tool is durable.	
3	Can be used repeatedly
4	Operates normally in the presence of contaminants
The tool is robust.	
5	Can support the weight of the impeller
The tool is versatile.	
6	Allows the impeller to be removed from the pump shaft
7	Works on variety of impellers
8	Is easy to maintain with common maintenance tools used in the mining industry
9	Allows for the impeller to be transported after removal
The tool is easy to set-up and use.	
10	The tool can be operated with 2 or less operators
11	Can be operated without the use of the forklift or other heavy equipment; excluding an overhead crane
12	Is implemented in the workspace of the maintenance shop
13	Is quick and easy to set-up and use
The tool reduces cost compared to current process.	
14	Reduces cost to fabricate
15	Reduces yearly cost to maintain
The tool does not damage any pump components.	
16	Can avoid damaging other pump components

The tool is safe to use came from initial requirement 3.1.a. as eliminating dropped object hazard is a safety concern. The need for the tool being durable and robust came from the description of the environment that this tool will be used. Being in a mining machine shop, there are a lot of potential hazards and contaminants that could compromise the performance of the tool. Tool is versatile stemmed from initial requirement 3.1.c. where an adjustable tool is required. In order to suit multiple impeller sizes, the tool has to be versatile. The fifth overarching need is that for the tool to reduce cost compared to the current process which satisfies initial requirement 3.1.d. The last overarching need is for the tool to avoid the other pump components. This need was included in order prevent inadvertent damage to the pump components during the operation of the tool. Once the general needs were established, the needs were organized into a hierarchy. Importance level was assigned to each needs item with the help of the feedback from Nutrien as well as the current rating of the company's existing process where 5 stars indicates an excellent performance. A rating of 5 indicates the highest importance as outlined in Table II.

TABLE II: CLIENT NEEDS

Number	NEEDS	Importance	Nutrien's Existing Process
	The tool:		
1	reduces risk of injury to operators	5	★★
2	can be used repeatedly	4	★★★★
3	operates normally in the presence of contaminants	2	★★★★★
4	can support the weight of the impeller	5	★★★★★
5	allows the impeller to be removed from the pump shaft	5	★★★★★
6	works on variety of impellers	5	★★★★★
7	is easy to maintain with common maintenance tools used in the mining industry	1	★★★
8	allows for the impeller to be transported after removal	4	★★★★
9	can be operated with two or less operators	3	★★★★★
10	can be operated without the use of the forklift or other heavy equipment; excluding an overhead crane	3	★
11	is implemented in the workspace of the maintenance shop	3	★★★★★
12	minimizes operator interaction time	5	★★★
13	reduces cost to fabricate	2	★
14	reduces yearly cost to maintain	3	★★★

2.6 Linking Metrics to Needs

The list of needs was then used to establish the metrics which were needed to gauge, measure or quantify the needs and establish target specifications. Units were assigned to the metrics as shown in Table III, and the metrics were then matched to their corresponding needs.

TABLE III: METRICS AND TARGET SPECIFICATIONS

Metric Number	Needs	Metrics	Importance	Units	Marginal	Ideal	Nutrien's Current Process
1	1	ANSI B11, S-15.1 REG 10	5	binary	PASS	PASS	PASS
2	2	Risk Rating	5	rating	10	1	12
3	2,5	Maximum load supported	5	kN	11.25	22.5	250
4	3	Cycles to failure w/o contaminants	4	cycles	120	240	N/A
5	3,4	Cycles to failure w/ contaminants	2	cycles	90	180	N/A
6	6	Applied torque on impeller	5	kN · m	0	> 25	125
7	6	Allowable translational motion	5	m	0.7	> 0.7	> 0.7
8	7	Impeller sizes	5	list	ALL*	ALL*	ALL*
9	8	Common maintenance tools in mining industry	1	list	10	5	> 10
10	9	Accessibility for impeller transport	4	binary	PASS	PASS	PASS
11	10	Number of operators	3	count	2	1	2
12	11	Heavy machinery in use	3	list	2	0	2
13	12	Process envelope	3	m^2	15	6	10
14	13	Time to set-up and use	2	min	10	5	10
15	14	Unit fabricating cost	2	CAD$	< $50,000	$15,000	N/A
16	15	Unit maintaining cost	3	CAD$/yr	$3,000	$1,200	N/A
17	16	Interference with pump components	4	binary	PASS	PASS	PASS

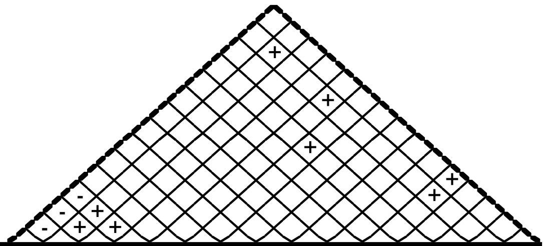
The sixteen client needs were each associated with at least one metric to allow them to be measurable when evaluating concepts. S-15 REG 10 'The Occupational Health and Safety Regulations, 2020' regulated by the Saskatchewan government was used evaluate whether a process was safe or not for this project. ANSI B11 is a general standard for machine safety and was also considered.

By knowing how much load the tool or jig could support, it allowed the team to evaluate whether the heaviest impeller could be safely supported.In addition, determining the cycles to failure with and without the presence of contaminants gauges whether the system could be reliably used repeatedly in each scenario. To evaluate whether the impellers could be removed from the pump shaft, the amount of torque and allowable translational motion were measured. The list of impeller sizes however needed to be confirmed in order to satisfy its relating need. The ease and convenience of maintaining a process was evaluated by determining the number of common maintenance tools found in the mining industry that the process needed. The tool or jig must be determined with a binary test if the accessibility where it allows the impeller to be transported. Compiling a list of the number of operators needed to operate the system indicated the number of operators who had to be available during the time of operation. Compiling a list of heavy machinery needed indicated how much machine resources had to be allocated to the process at that specific time. Determining the area of the process envelope evaluated whether the system could be implemented in the workshop. Measuring the time to set-up and use allowed the team to evaluate the ease and time efficiency of the process. Determining the costs of fabrication and maintenance allowed the team to determine whether the new system provided a cheaper solution. Checking whether the system during the whole operation would interfere with any pump components of all relevant sizes indicates if the system would damage the pumps.

With the metrics and needs established, a structured approach was required in order to translate the needs of the client and the metrics that were identified to a plan on how to execute and to engineering qualities. We implemented the house of quality also known as the quality function deployment shown in Figure 4.

Technical Correlations
Positive: +
Negative: -
None or Negligible: [Blank]

Direction of Improvement
Maximize: ↑
Target: ◊
Minimize: ↓



#	NEEDS \ METRICS	Imp.	1 Risk Rating	2 Maximum load supported	3 Cycles to failure w/ contaminants	4 Cycles to failure w/ contaminants	5 Applied torque on impeller	6 Allowable translational motion	7 Impeller sizes	8 Common maintenance tools in mining industry	9 Accessibility for impeller transport	10 Number of operators	11 Heavy machinery in use	12 Process envelope	13 Time to set-up and use	14 Unit fabricating cost	15 Unit maintaining cost	Nutrien's Existing Process
	Direction of Improvement		↓	↑	↑	↑	↑	↑	◊	↓	◊	↓	↓	↓	↓	↓	↓	
1	reduces risk of injury to operators	5	●	○	▽	▽						▽			▽			★★
2	can be used repeatedly	5			●	▽												★★★★
3	operates normally in the presence of contaminants	4				●												★★★★★
4	can support the weight of the impeller	2	○	●	▽	▽			○									★★★★★
5	allows the impeller to be removed from the pump shaft	5					○	●	▽									★★★★★
6	works on variety of impellers	1							●									★★★★★
7	is easy to maintain with common maintenance tools used in the mining industry	5			▽	▽				●								★★★
8	allows for the impeller to be transported after removal	5						▽			●							★★★★
9	can be operated with two or less operators	1	▽									●	○					★★★★★
10	can be operated without the use of the forklift or other heavy equipment; excluding an overhead crane	4	▽									○	●					★
11	is implemented in the workspace of the maintenance shop	3												●				★★★★★
12	minimizes operator interaction time	3	▽									○			●			★★★
13	reduces cost to fabricate	3														●		★
14	reduces yearly cost to maintain	2								○							●	★★★
	Score		71	60	47	33	15	49	65	18	36	56	36	27	50	18	27	
	Relative Score		11.68%	9.87%	7.73%	5.43%	2.47%	8.06%	10.69%	2.96%	5.92%	9.21%	5.92%	4.44%	8.22%	2.96%	4.44%	
	Imp.		5	5	4	2	5	5	5	1	4	3	3	3	2	2	3	
	Units		rating	kN	cycles	cycles	kN · m	m	list	list	binary	count	list	m^2	min	CAD$	CAD$/yr	
	Marginal		10	11.25	120	90	0	0.7	ALL*	10	PASS	2	2	15	10	<$50,000	3000	
	Ideal		1	22.5	240	180	>25	>0.7	ALL*	5	PASS	1	0	6	5	15000	1200	
	Existing Process		12	250	N/A	N/A	125	> 0.7	ALL*	> 10	PASS	2	2	10	10	N/A	N/A	

Ratings
Importance:
(Lowest - 1) to (Highest - 5)

Relationships:
Strong - ● (9), Medium - ○ (3), Weak - ▽ (1)

Figure 4: House of Quality

3 Initial Assessment

This section will first define any assumptions which will govern the design process for this project. Then an initial analysis of this project and it's requirements will be detailed, which will guide the design process through the life of the project.

3.1 Project Assumptions

Assumptions utilized in the design of this project can be broken down into two broad categories:

- Assumptions related to the design and analysis of the impeller removal tool, and
- Assumptions related to the deployment and operation of the impeller removal tool.

3.1.1 Design and Analysis Assumptions

Assumptions relating to the design of the impeller removal tool can be summarized as, in no particular order:

a. The heaviest impeller that the tool will handle has a mass of 700 kg.
b. Unless explicitly stated, CSA G40.21 300W steel with $\sigma_y = 300\text{MPa}$ and $\rho = 7.8\ \frac{g}{cm^3}$ will be utilized for the tool components. This grade of steel is commonly available and readily worked, reducing the expected cost of fabrication of the tool.
c. A target factor of safety of 3.0 should be implemented into the design of all tool components.
d. It is favourable (but not required) for the tool to break the torque of a seized impeller.
e. Manufacturing capabilities available to Nutrien for the fabrication of the tool include operations utilizing a mill, lathe, water jet cutting, bending, welding, and other common fabrication operations.
f. Failure of the tool via yielding, buckling, and fracture must be considered.
g. For the purpose of stress and failure analyses, all materials will be treated as linear elastic, isotropic, and homogeneous.
h. Any analyses involving plasticity will assume perfectly plastic behaviour.
i. The tool will be utilized once per month.
j. The pump shafts on which the impellers are mounted have 10 threads in total.
k. For the purpose of estimating fabrication costs, the hourly wage of the fabricators has been assumed to be $50 per hour.

3.1.2 Deployment and Operation Assumptions

Assumptions relating to the deployment and operation of the impeller removal tool can be summarized as, in no particular order:

a. The shop floor on which the impeller removal process occurs has sufficient space to accommodate the tool.
b. Both fixed-in-place and mobile/movable tool designs are acceptable.
c. The shop will always have a 25-tonne overhead crane along with suitable rigging equipment available to support the impeller removal process.
d. The shop will often have a forklift available to support the impeller removal process.
e. The shop will always have at least one operator available to conduct the impeller removal process.

3.2 Required Torque for Impeller Removal

Nutrien has indicated that the capability for the tool to break the torque to a seized impeller is a favourable design feature. As such, it is important to define the required torque to achieve this.

In the existing process, operators attach the 25-tonne overhead crane to the impeller via a sling; this process allows the radius of the impeller to act as a moment-arm distance in order to apply a torque about the pump shaft. The crane lifts to apply tension on the sling, and the resulting torque is equal to the lifting force applied multiplied by the radius of the impeller. According to Nutrien's operators, the force required by the crane to break the torque of the seized impeller is typically enough to begin slightly lifting the impeller off the ground. Assuming that the crane lifts one-quarter of the weight to slightly tip the pump, the required force can be assumed to be equal to the one-quarter of mass of the pump. As per [4], the Warman 12/10 pump (the largest pump utilized by Nutrien) has a mass of 4650 kg. This pump is fitted with a 0.8 metre diameter impeller. With that, the torque required to remove the seized impeller can be solved as:

$$T_{req'd} = \frac{mgr}{4}$$

$$T_{req'd} = \frac{(4650)(9.81)(0.4)}{4}$$

$$T_{req'd} = 4560 \text{ N} \cdot \text{m}$$

This value will dictate the target torque for this design project. As such, the tool will be designed to deliver a target of 5000 N·m (3700 lbf·ft) of torque.

4 Concept Generation Methodology

To guide the preliminary concept generation process, a general methodology was established. The general methodology implemented throughout the concept generation phase can be summarized as:

a. Market and patent research
b. Synchronous creation of a concept combination table
c. Individual brainstorming and concept generation driven by the combination table
d. Initial individual concept screening
e. Initial team concept presentation
f. Team concept generation
g. Second-phase individual concept generation and modification
h. Second-phase individual feasibility screening
i. Second team concept presentation
j. Formal concept screening
k. Concept verification and development
l. Concept scoring and selection

4.1 Concept Combination Table

The concept combination table serves to quantify and collect the possible variations in the concept design based on the manners in which the concept can function. Creation of the table generally involves first identifying the required functions that the concept must be capable of in order to meet the customer needs. This process was driven by the customer needs and specifications, which were developed in the previous phase of the project. From there, each identified function was analyzed to brainstorm the ways in which the function could be completed; this can include power sources, materials, movement, and similar design considerations. These functions and their potential manners of operation were captured in a table to allow the information to be readily available. The concept combination table is a very powerful tool for concept generation, as it allows for multiple concepts to be quickly created by combining different combinations of manners in which the required functions may be completed. The concept combination table generated for this project can be found below in Table IV.

TABLE IV: CONCEPT COMBINATION TABLE

How Does it Spin the Impeller	Power Source	How does it Support Multiple Impeller Sizes	Supporting Method	Securement to Impeller	How Does it Move Axially	Material
Uses existing process	Manual	Adjustable component(s)	Mobile on the ground	Outside edge of impeller	Wheels	Steel
Mimics existing process	Electric	Multiple attachments	Fixed to the ground	Inside edge of impeller	Moved by the crane	Aluminum
Direct drive	Hydraulic	Non-adjustable components	Mounted to crane	Craddles impeller	Mounted on rails	Plastic or Composite
Gears	Pneumatic		Mounted to forklift	Wraps around impeller	Linear bearing	
Belts			Mounted to pump case	Face of impeller	Only internal motion	
Chains				Does't contact impeller		
Pulleys						
Ratcheting Action						
Force-Moment Arm						

While the concept combination table likely does not explicitly include all the ways that a concept can vary, it provides an effective way to initiate the concept generation process and can lead to a wealth of concepts being quickly and easily generated. While no hard targets were established in terms of the number of concepts each group member generated in this phase, it was encouraged that all members generate as many as they can, understanding that the number of concepts would be reduced in the coming phases.

4.1.1 Initial Concept Screening and Team Presentation

The next step in the concept generation process was to screen the list of concepts each member generated based on feasibility and expected performance as compared to other concepts. Each member conducted this screening individually on their own concepts. This was intended to be a fast and impartial screening, primarily based on engineering intuition developed through our academic and industry experience. Each member had a target of selecting two to three top concepts.

The concepts which passed the initial screening phase were taken to a team meeting, where each team member presented their concepts. This allowed the team members a chance to see how each other approached the design process and presented the opportunity to adopt similar processes to individual concepts. Following the presentation, the team conducted a concept generation period in which presented concepts were modified and new concepts were created.

Following the team concept generation period, an additional two days were given to dedicate to individual concept generation. This additional time provided an opportunity to adopt what team members had done into the existing or new concepts. This phase heavily utilized the SCAMPER methodology, which stands for [5]:

- **Substitute** - Substitute existing design aspects with others
- **Combine** - Combine existing and/or new design aspects
- **Adapt** - Alter or otherwise change how a component functions based on other designs
- **Modify** - Change the way in which a components operates or the way the a function is completed
- **Put** - Put others to use
- **Eliminate** - Eliminate or remove components to simplify, optimize, or otherwise change the design
- **Reverse** - Turn components upside down, inside out, or reverse direction

4.1.2 Secondary Screening and Team Presentation

With new concepts developed and existing concepts modified, the team went into a second round of individual concept screening. Similar to the initial screening, concepts were screened based on their expected feasibility, cost, and ability to meet the customer needs relative to other concepts. With this phase of screening, each member was to select their top two concepts, which would then be taken to a secondary team presentation for formal screening. The team presentation involved presenting eight total concepts, with a focus on their intended operation, highlights and areas of strength, areas which can be improved, and a general discussion regarding the concepts. Finally, the eight concepts were taken to a formal concept screening phase. The upcoming sections will present the eight concepts taken to the screening phase, and later sections will detail the screening, development, scoring, and selection processes.

4.2 Preliminary External Research

This section contains the external research done by the team of existing jigs or processes that are used for impeller removal processes. The research is classified into two sections: Market Research and Patent Research. With this research, the team hoped to find inspiration or reference for design generation and brainstorming for the project's own jig or process.

4.2.1 Market Research

As market research was conducted, it was discovered that there were no products or processes available on the market that dealt with impellers weighing up to 700 kg. With that being said, there were products on the market that gave the team inspirations or ideas to generate concepts from. These products were not directly related to impeller removal process, but elements and features of these products were taken and implemented in a number of the team's concepts. The mechanism of concepts 'Design 1 - The Three Claw' and 'Design 3 - The Six Claw' were inspired by the mechanical claw found in carnival crane claw games. The mechanism of scissor lifts was taken and implemented in 'Design 4 - Adjustable Height Roller Jig' to obtain a system that could adjust height to accommodate a range of impeller sizes. The chucks that many manufacturing companies use to hold heavy circular objects such as stainless-steel fertilizer tanks inspired the manner of how 'Design 6 - Motorized Cart' plans to hold and rotate the impellers. Including smaller aspects of existing machines or tools, many products on the market that were not necessarily associated with impeller removal allowed the team take certain aspects and assemble ideas into full concepts.

4.2.2 Patent Research

There were also no patents found that specifically dealt with impellers as large as the ones that need removal in Nutrien. The closest ones in terms of relevancy to the team's project objectives were patents that were removal tools or processes that detached smaller impellers compared to the ones Nutrien is dealing with. These patents regarded impellers that were so small that they could be easily held and carried by an average person without endangering their safety or health. Their tools or processes do not run into the main issues or concerns that the team faces with dealing with impellers up to 700 kg such as weight, process envelope, and safety hazards from falling object potential. Hence, the team could not obtain inspiration or ideas from the patents as they were deemed not useful to the project objective.

5 Concept Selection

This section will go into detail on the four concepts that were considered for the final design. Due to constraints on the contents of the final report, this section will only outline the mode of operation for each concept and the weighted decision matrix used in selecting the final concept. Details of cost analysis, hand calculations, and FEA of the four concepts have been placed in the appendix. In addition, details of preliminary concepts used in selecting the four final concepts in this section can also be found in the appendix.

5.1 Preliminary Concept One - Internal Chuck

This concept features an extendable arm bolted to a hydraulic table that has the capacity to lift approximately 5000 pounds. For stability and maximum support, this design can be bolted to the ground. The design is intended to hold on to the holes in front of the impeller as shown in Figure Design 2 accomplishes this with the aid of a chuck which opens outwards when the outer hand-wheel is turned counter clockwise and with a lead-screw like mechanism that extends the arm when the smaller hand-wheel is rotated counter-clockwise . The design aims to eliminate the use of the forklift, needed to catch the impeller after it is unwound from the shaft in the existing process. This is expected to eliminate the dropped object potential brought forward by Nutrien. The entire process can be completed with the use of the available crane and one operator.

The chuck is expected to latch onto the grooves of the impeller while the crane and sling unwind the impeller from the pump shaft. After this step is completed, the impeller will be fully supported by the design.

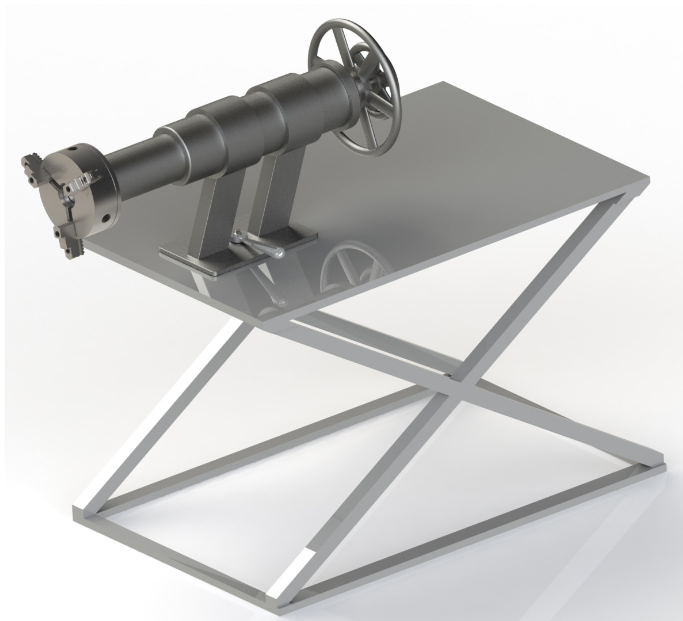


Figure 5: Chuck extended outwards

5.2 Preliminary Concept Two - Adjustable Height Roller Jig

As one of the four concepts that were selected after concept screening, the 'Adjustable Height Roller Jig' was allowed to go through further concept development. The jig can be divided into three main systems from top to bottom: its roller system, its adjustable height system, and its wheel system.

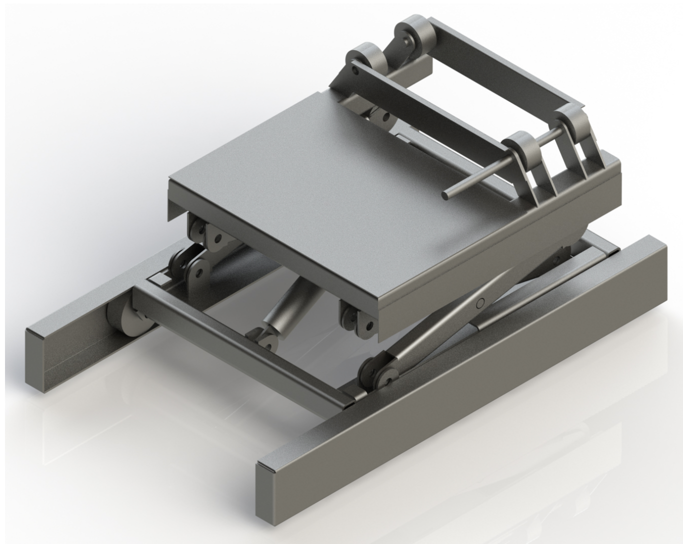


Figure 6: Adjustable height roller jig at lowest position.

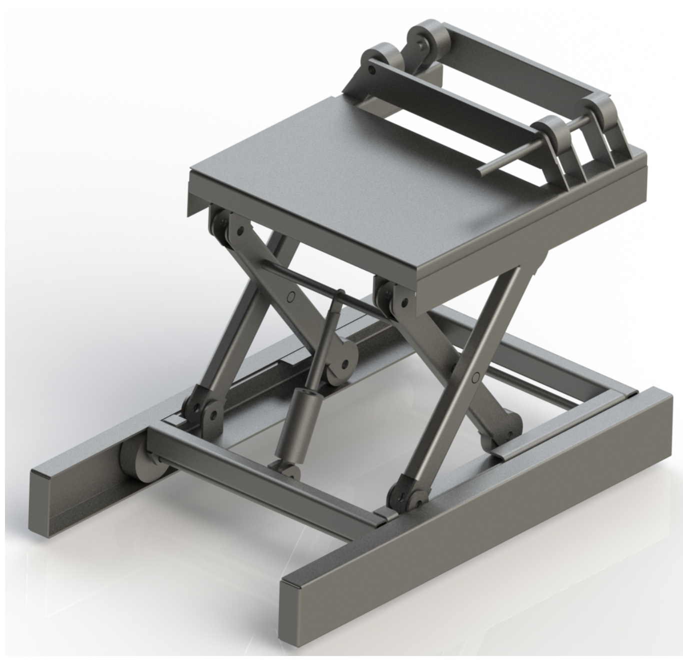


Figure 7: Adjustable height roller jig at highest position.

The roller system on the platform proposes two rollers driven by a drive shaft on one side with two idle rollers on the other. Motor space is allocated on the platform of the rollers where the motor and drive system will be built. The application of torque on the impeller is based on the friction between the rollers and the impeller. Guards were implemented across the rollers to prevent the impeller from falling over and to allow the impeller to push the jig as it is being removed from the pump shaft. As it can be observed on the CAD models, the platform has a gap between the two pairs of rollers to avoid the jig interfering with the studs on the pump casing.

The adjustable height system is to function as a scissor lift with a hydraulic press to provide the means. As the difference radius between the smallest and largest impellers differs less than a metre. The dimensions of the scissor lift components can be optimized as the rollers would not need to change height as much as other existing scissor lift mechanisms.

The wheel system on the bottom is to accommodate the translational motion of the impeller in the axial direction of the pump shaft as it is being removed. Guide rails are implemented to restrict and control the wheel motion in only that specific direction to prevent potential safety hazards top the surrounding.

The proposed operation of the whole process (as sketched in Appendix A.4) only consists of four steps:

1. Wrap sling around impeller.
2. Place jig underneath impeller and adjust height until the jig's roller have good traction on impeller.
3. Turn the motor on and wait.
4. Turn the motor off and transport the impeller with the crane to desired location.

5.3 Preliminary Concept Three - Motor Cart

Concept development for the motor cart concept first involved adopting channels in which the wheels will roll. These channels will restrict the motion of the cart to only along the axis of the pump shaft and will help to protect against unexpected motion or an uncontrolled roll-away of the cart. This design development was done primarily for the safety of the operator. With the wheels captive by the channels, a new mode of transportation for the cart was required. It was assumed that the overhead crane will be used to move the cart; hence, a lifting lug was added to the top of the cart. The intent of this concept was for the cart to be made primarily of structural steel grade CSA G40.21 300W or the equivalent ASTM A36. Structural steel shapes are widely available and generally require neither specialized fabrication nor long lead times, reducing the expected cost of to fabricate the cart.

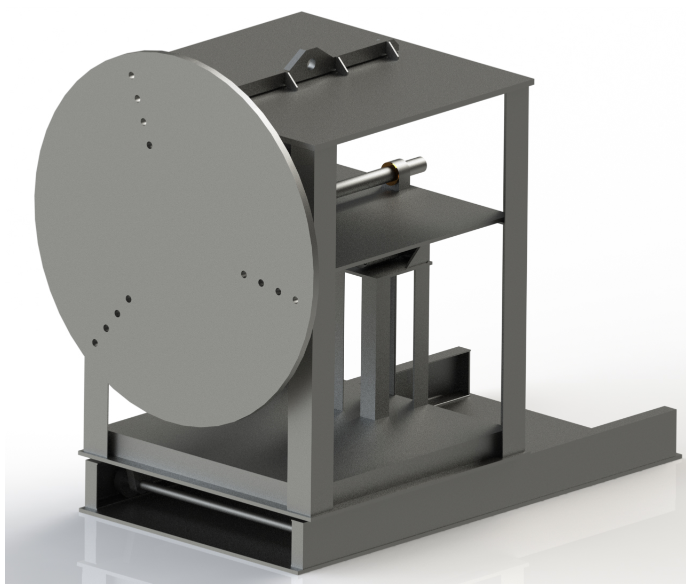


Figure 8: Front isometric view of motor cart concept.

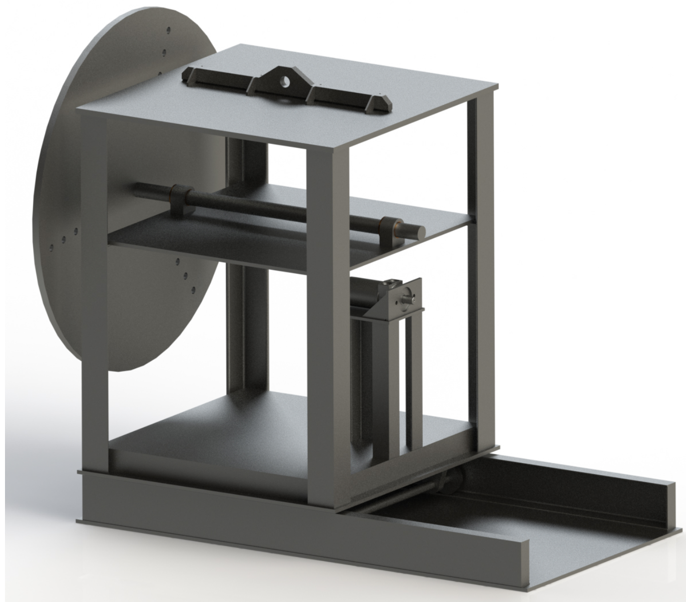


Figure 9: Rear isometric view of motor cart concept.

5.4 Preliminary Concept Four - Height Adjustable Chuck

The height adjustable chuck shown in figure 10 features an I-beam structure with hydraulic rollers to support the pump impeller. After the removal of the pump casing half, the pump is moved in place and the roller-hydraulic assembly are activated and moved in place. The chuck is then expanded to grip on the inside diameter walls of the impeller. The chuck is then connected to a drive shaft which is connected to a motor. When the motor is activated, the torque is transferred to the chuck which spins the impeller free while being supported by the two rollers. As the height adjustable chuck advanced to concept development and verification, there were some minor changes that was made and The final render is shown in Figure .

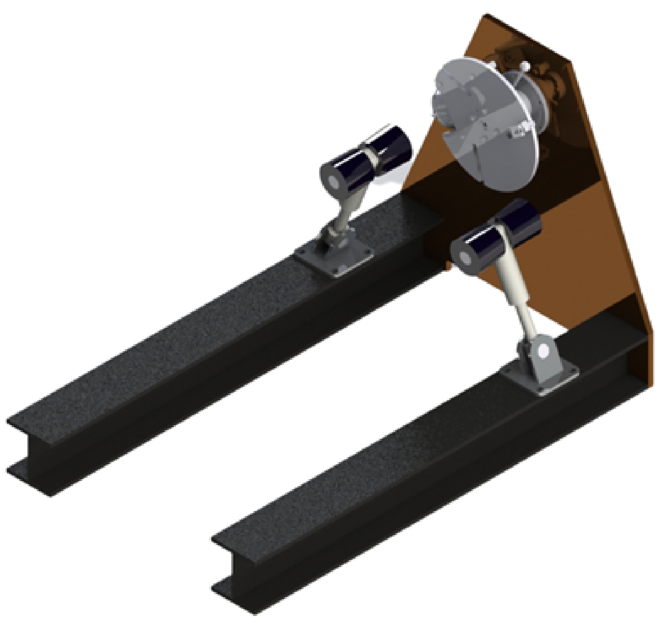


Figure 10: Height adjustable chuck.

5.5 Concept Scoring

This stage of the concept selection process involved the use of a weighted decision matrix to select the final concept. In the decision matrix shown in Table V, the metrics relating to client needs were listed and given a percentage weight. Each percentage weight for the need's metrics were determined based on the level of importance to the client as shown in the house of quality below. Next, each concept was carefully analyzed based on its merits and compared against each other.

The percentage weights for each metric was derived by assigning a relationship value of 9 (strong), 3 (medium) or 1 (weak) between each need and its corresponding metrics. All the values in each column were then summed up to give a total relationship score. This score was then divided by a sum total to give a percentage weight.

As a scoring system for the weighted decision matrix, a placement number between 1 and 4 was assigned for each need. At the end of the selection process, the adjustable height roller jig scored 80.28 out of a 100, making it the concept most likely to be selected for the project.

TABLE V: CONCEPT SCORING WEIGHTED DECISION MATRIX

			Designs			
		Percentage Weight (%)	Internal Chuck	Adjustable Height Roller Jig	Motor Cart	Height Adjustable Chuck
1	Risk Rating	11.68%	2.00	4.00	1.00	3.00
2	Maximum load supported	9.87%	2.67	4.00	2.22	2.67
3	Cycles to failure w/o contaminants	7.73%	1.78	3.11	3.56	3.11
4	Cycles to failure w/ contaminants	5.43%	1.78	2.67	3.56	2.67
5	Applied torque on impeller	2.47%	3.56	1.33	2.22	2.22
6	Allowable translational motion in axial direction	8.06%	2.22	2.67	4.00	1.33
7	Impeller sizes	10.69%	2.67	2.67	2.67	4.00
8	Common maintenance tools in mining industry	2.96%	2.22	3.56	2.67	2.22
9	Accessibility for impeller transport	5.92%	2.67	3.56	3.11	2.67
10	Number of operators	9.21%	4.00	3.56	3.11	4.00
11	Heavy machinery in use	5.92%	4.00	3.11	3.11	3.56
12	Process envelope	4.44%	1.78	2.22	3.11	3.56
13	Time to set-up and use	8.22%	2.22	4.00	1.33	3.11
14	Unit fabricating cost	2.96%	1.33	2.22	4.00	3.56
15	Unit maintaining cost	4.44%	1.33	3.11	4.00	2.67
	Total	**100.00%**	61.80	80.98	68.60	75.72

6 Details of Final Design

This final design of the impeller removal tool has been created in collaboration with Nutrien's engineering and operations teams. The design has gone through conceptual development, combinations, iterative refinement, and validation to become a final verifiable, feasible solution to the problem posed for this project. This report section will first detail the iterative design process utilized to arrive at the final design. Then, a summary of the final design presented, followed by detailed descriptions of the discrete components of the final design. Finally, the bill of materials and associated cost estimate for the tool will be presented, and the intended integration into Nutrien's operation will be discussed.

6.1 Preliminary Concept Features

The four preliminary concepts were presented to Nutrien's engineering and operations team for feedback, with an emphasis on presenting the winning concept and the reasoning for why it won. While Nutrien agreed with the weighting criteria, they expressed interest in aspects of each design, and requested that the preliminary concepts be combined to arrive at a final design which most effectively meets the needs of the project. Table VI below details the components of each concept which Nutrien was interested in being implemented into the final design.

TABLE VI: FEATURES TO IMPLEMENT IN FINAL DESIGN

Concept	Aspects to Incorporate into Final Design
Internal Chuck	Engages with impeller through centre hole, leaving outside edge of impeller unobstructed.
Adjustable Height Roller Jig	Scissor-lift table to adjust vertical position.
	Tool translates in the axial direction to account for impeller threading off the pump shaft.
Motor Cart	Mobile tool, approporiately counterweighted for stability.
	Torque is transferred through a shaft, with the torque applied opposite of the impeller to provide distance between operator and impeller.
Height Adjustable Chuck	Interfaces with existing pump components, reducing number of parts required to fabricate tool.
	Reliable and repeatable component locations.

6.2 Design Evolution

This section will detail the iterative design process implemented in order to reach the final design. This section serves to present the design process and will not necessarily provide detail on the discrete elements of the design; full design details will be presented in Section 6.3.

6.2.1 First Iteration

The first iteration of the design combined the aspects detailed in Table VI. The first iteration of the design is shown below in Figure 11.

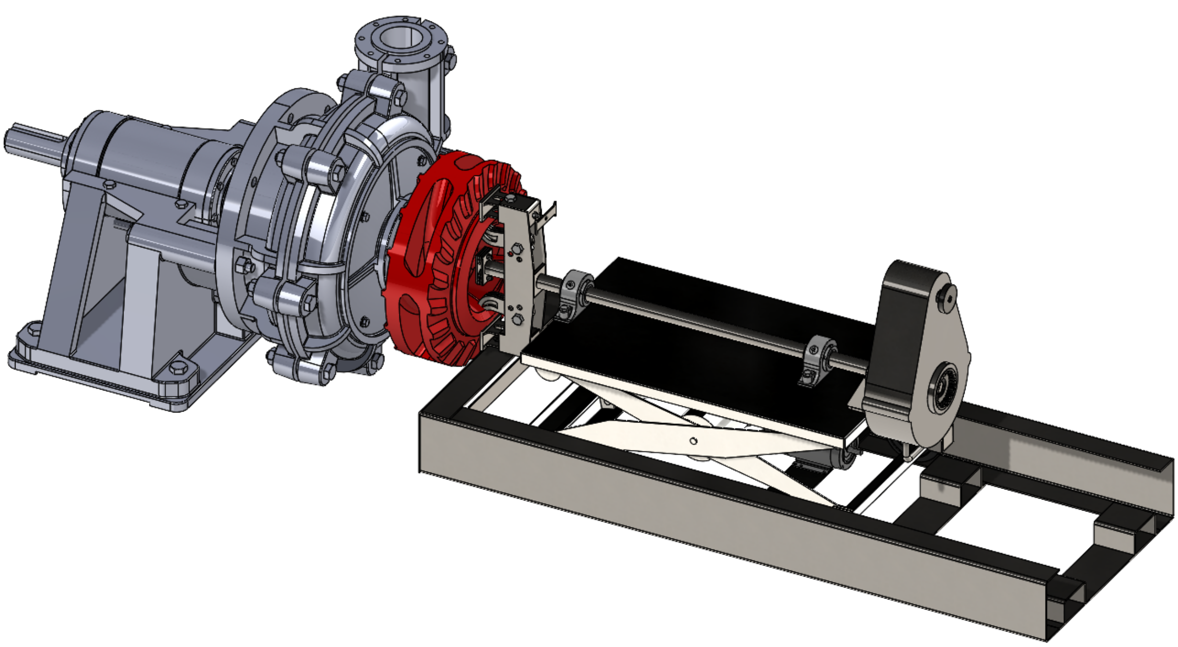


Figure 11: First iteration of final design.

The general features of this design are:

- Scissor-lift table to allow for vertical position adjustments.
- Torque input on rear side of tool and transmitted through a shaft.
- Torque multiplier capable of outputting up to 30,000 ft·lbs of torque with 715 ft·lbs of input torque.
- Clamp design which interfaces with the impeller through the centre impeller hole.
- Wire-rope attachment point to connect the shaft to the outside profile of the impeller fins, allowing the torque to be applied to the impeller.
- Entire tool is mounted on wheels to allow axial movement.
- Wheels are captive in a c-channel frame to limit bounds of motion, and restrict motion to only the axial direction.

The above design features are highlighted below in Figure 12.

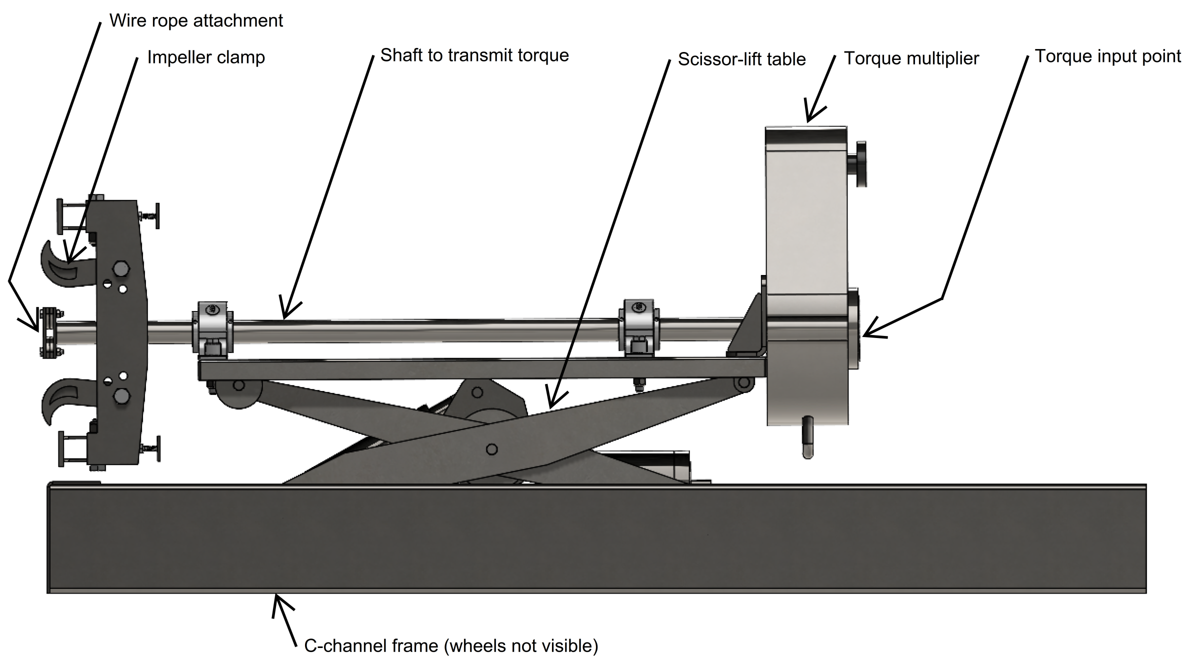


Figure 12: First iteration design features.

6.2.2 Second Iteration

Upon analysing the interaction between the tool and the existing pump base, it was noted that the c-channel frame was too wide to fit between between the narrowest pump base. As the pump bases are an integral component in the deployment of the pumps, it was determined that removal and/or modifications of the bases was not feasible. As such, the c-channel frame was removed from the design.

Upon contacting a supplier for the torque multiplier, the supplier suggested that the proposed torque multiplier is not suitable for this application. As an alternative, the supplier recommended implementing a pneumatic torque wrench into the design as the means of torque application. The pneumatic wrench is capable of producing the required torque, is a more commonly used tool in the mining industry, and would be a much more cost effective solution as compared to the torque multiplier. A number of other design and user interface modifications were made, with the total changes summarized below:

- Removed c-channel frame to prevent interference with existing pump base.
- Replaced torque multiplier with hydraulic torque wrench.

- Modified the input end of the shaft to a $2\frac{3}{16}$" hex to interface with the hex output of the hydraulic torque wrench.
- Added a bent steel plate guard around the shaft to protect against operator injury.
- Added handles to the back of the scissor-lift table to allow the tool to be moved.
- Added handles to the impeller clamps to be more user-friendly.
- Added wedge for hydraulic torque wrench to register against.

The second iteration of the design, with the above changes implemented, can be seen below in Figure 13.

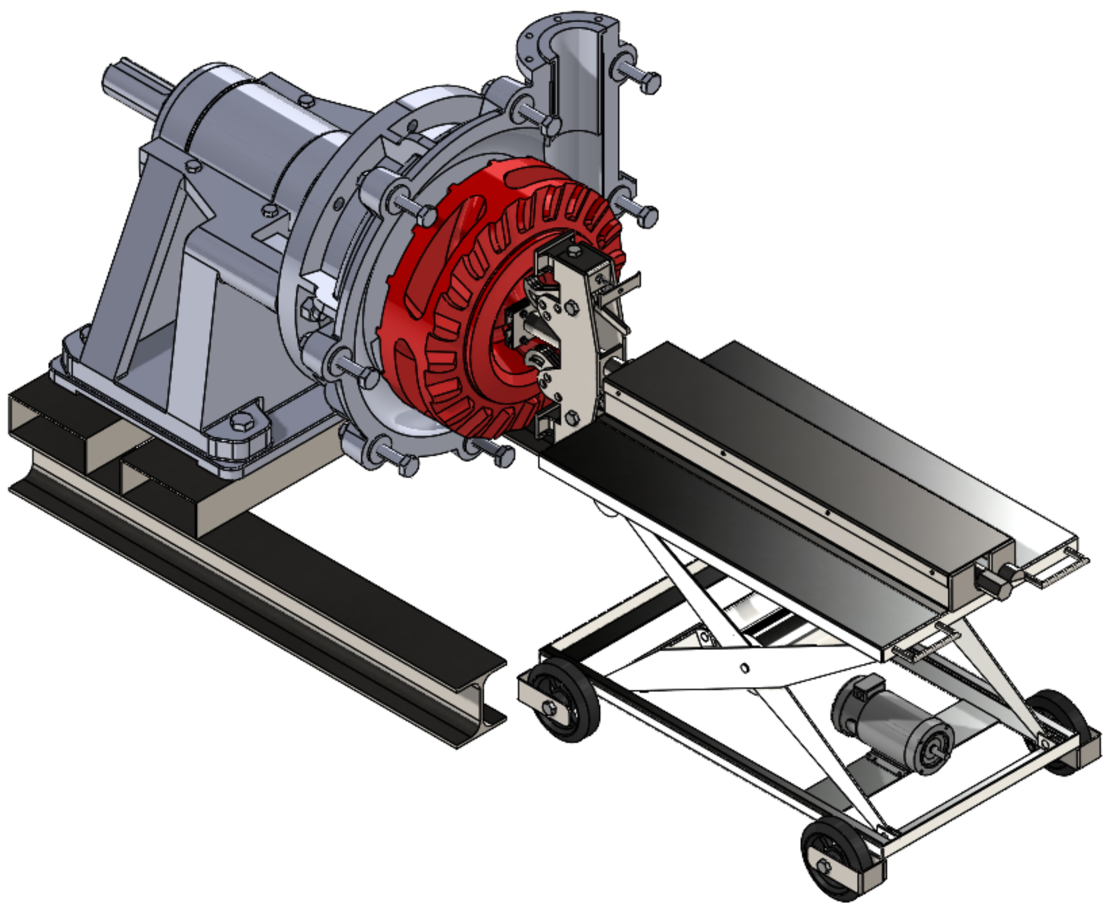


Figure 13: Second iteration of final design.

Note that, while the torque multiplier has been removed, Figure 13 does not include the pneumatic torque wrench for modelling simplicity. The exact hydraulic torque wrench to be implemented will be presented in Section 6.3.

The above mentioned modifications for the second iteration of the design can be seen below in Figure 14.

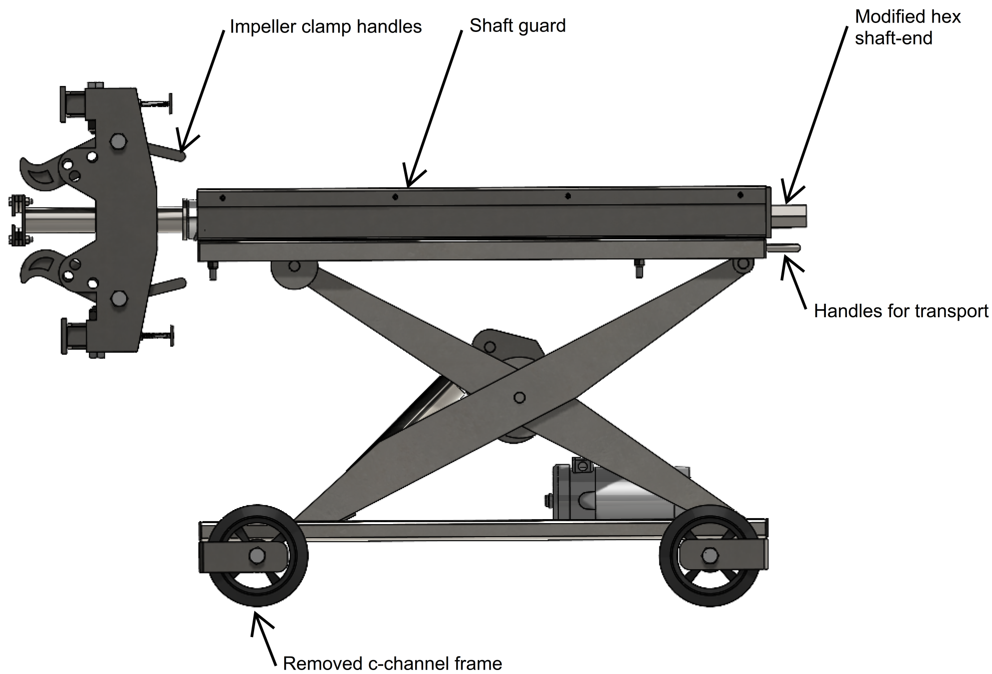


Figure 14: Second iteration design features.

6.2.3 Final Iteration

Upon performing an analysis on the stability of the tool, it was found that the tool would not be stable while supporting the heaviest impeller, and would instead tend to tip forward about the front wheels. To alleviate this, a base-frame was designed upon which the scissor table would be attached to. The base-frame allowed the tool to have a longer effective footprint and resulted in a tool which is expected to be able to support up to 4000 kilograms on the impeller clamp while remaining stable.

The new base-frame design allowed the wheels to be moved directly under the frame, eliminating the cantilever wheel design and hence allowing the wheels to be loaded to their full capacity.

With the c-channel frame from the first iteration removed, it was noted that the tool no longer has a means to mitigate undesired motion. Additionally, the new design allows the tool to be transported by rolling it along the ground, rather than relying on a forklift or overhead crane for motion; as such, it would be desirable to have a means to steer the tool during transport. These two considerations were addressed by implementing lockable swivel caster wheels to the rear of the tool base. These wheels will allow the tool to be steered while in motion, and the wheels can be locked to prevent motion when required.

A number of other components were finalized in the design. The total modifications between the second and last iteration are summarized below:

- Base-frame was extended by 20 inches to increase stability of the tool.
- Wheels were moved to directly under the base frame.
- Lockable pivoting caster wheels were added to the rear side of the base frame.
- Bent clevis pins were implemented to secure the clamp hooks in place.
- Finalized the reaction point for the pneumatic torque wrench.

The final iteration of the design can be seen below in Figure 15.

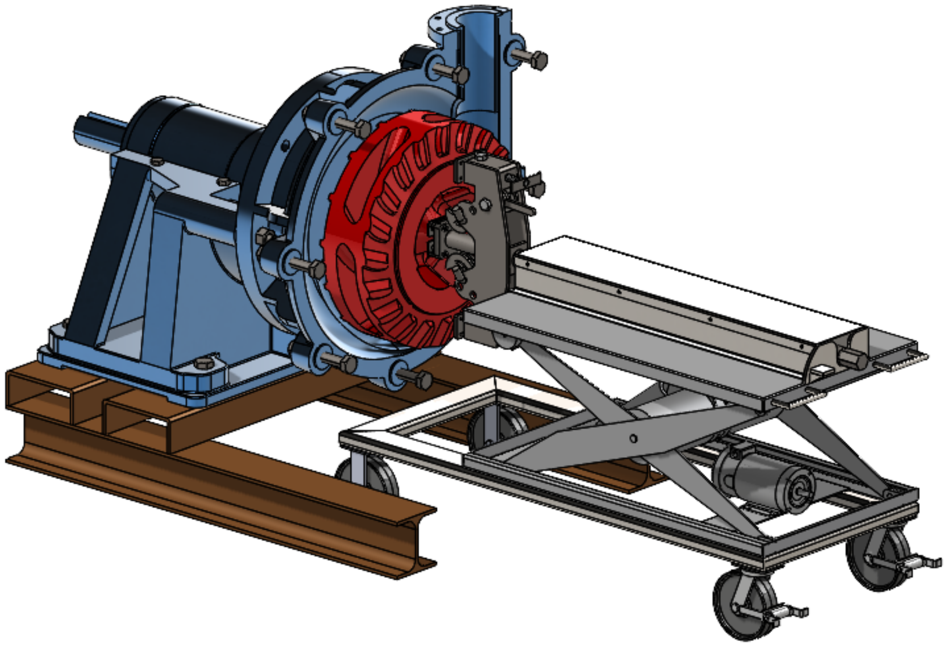


Figure 15: Final design iteration.

6.3 Final Design Summary

The final design of the impeller removal tool is a cart-style tool with provisions to connect to multiple impeller sizes. The tool clamps to the impellers via a set of pivoting clamp hooks; the pivot allows the hooks to be used on the 12/10, 10/8, and 8/6 impeller sizes. Between the two hooks is a connection point for a wire rope. The wire rope is installed through the connection point, is fed through the inside of the impeller, and hooks to the outer surfaces of the impeller fins via two hooks on each end of the cable. This arrangement allows the clamp hooks to support the impeller and mitigate the risk of the impeller falling, and the wire rope to apply the torque to screw the impeller off of the pump shaft. The hook assembly and wire rope connection point are connected to the main shaft of the tool. The opposite end of the shaft is machined into a male hex to interface with a hex socket. The hex end allows a pneumatic torque wrench to be connected to the shaft and act as the torque input for the tool. The wrench applies torque through the shaft, the wire rope connection point, the wire, and subsequently to the impeller. The shaft is housed in two split-type pillowblock bushings and mounted to the top surface of a scissor-lift table. The scissor-lift table allows the height of the tool to be adjusted to accommodate pumps of varying heights. The scissor-lift table is mounted to a lengthened base frame to provide stability when the tool is loaded with an impeller. Finally, wheels are fixed to the bottom of the base frame to allow the tool to translate axially while removing the impeller from the pump shaft, and to be transported around the shop floor where the tool will be implemented. Figure 16 below depicts the final impeller removal tool assembly.

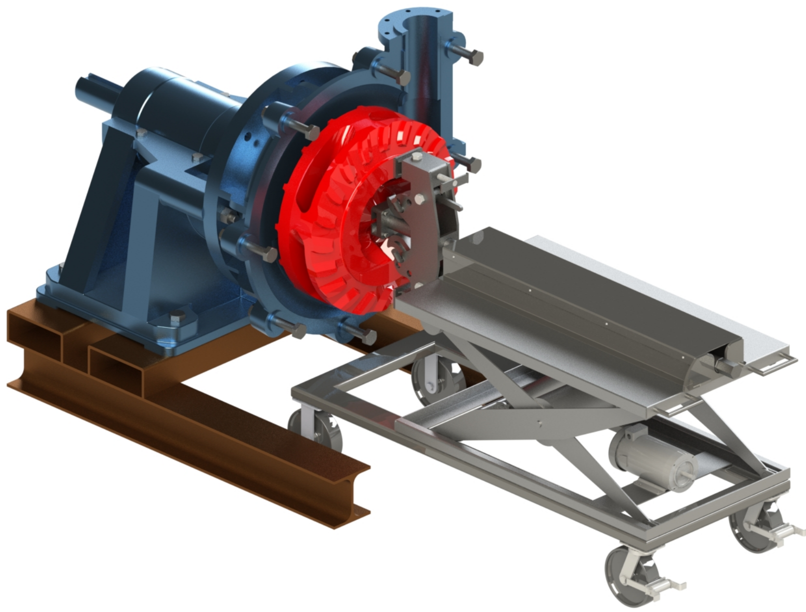


Figure 16: Final impeller removal tool assembly.

6.4 Discrete Component Description

This section will detail the discrete components that make up the impeller removal tool. Note that validation calculations will not be presented in the body of this report. Validations can be found in Appendix A. Unless explicitly stated, all fabricated components are fabricated from CSA G40.21 300W steel.

6.4.1 Impeller Clamp

The impeller clamp is composed of three primary components: the side plates, the clamp hooks, and the contact plate assemblies. The side plates are fabricated from $\frac{1}{2}$" steel plate and feature holes through which the clamp hooks will pivot or be adjusted. The holes in the plates are arranged such that the clamp hooks can be pivoted to fit into each of the three impeller sizes. The clamp side plate is shown below in Figure 17.

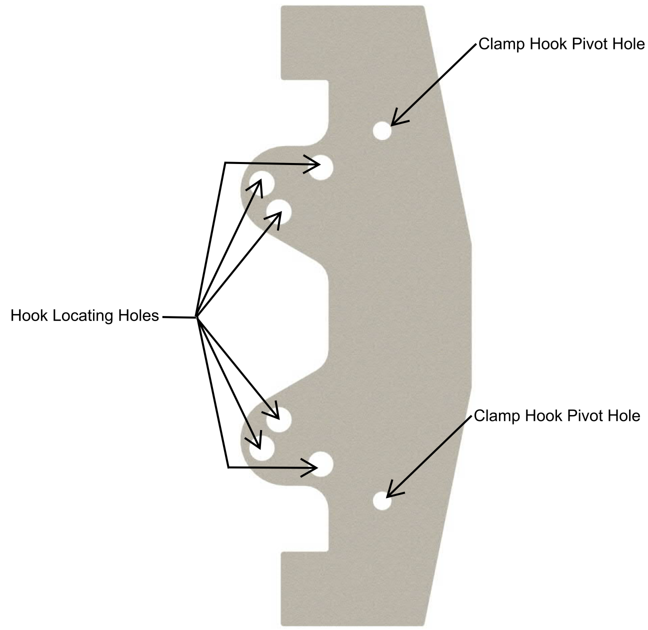


Figure 17: Impeller clamp side plate.

The clamp hooks are constructed of three $\frac{1}{2}$" steel plates placed together to form a $1\frac{1}{2}$" thick hook. The hooks are constructed such that they fit behind the outside edge of the impeller and securely hold the impeller in place. The hooks are connected to the side plates by a pivot-bolt through a hole in the side plates. The additional holes in the side plates allow the position of the hooks to be adjusted, and a 1" diameter clevis pin is inserted through the additional holes to locate the hooks in the required position, based on the size of impeller being removed. The back of the hook features an extended handle to allow operators to easily pivot the hooks into their required position. The clamp hooks can be seen below in Figure 18.

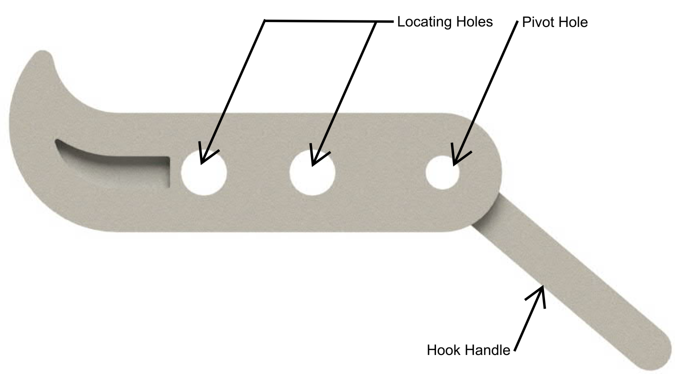


Figure 18: Impeller clamp hook.

Finally, two contact plate assemblies are located at the top and bottom of the clamp assembly. The contact plates feature a $\frac{1}{2}$" plate, an upper slotted bent $\frac{1}{4}$" plate, a lower slotted $\frac{1}{4}$" plate, two $\frac{1}{4}$" side plates, and a threaded rod screw mechanism. As the screw mechanism is hand-turned by the operator, the threaded rod advances forward, pushing the contact plate assembly forward into the impeller. In doing so, the impeller is pushed against the edge of the clamp hooks until the impeller is locked in place between the clamp hooks and the contact plate. As a result, the impeller clamp assembly is able to securely hold the impeller in place. The contact plate assembly is shown below in Figure 19.

Figure 19: Impeller clamp contact plate assembly.

The impeller clamp assembly is welded to the tool shaft, such that the clamp assembly rotates with the shaft. It is important to note that the clamp assembly is not intended to apply torque to the impeller; rather, the purpose of the clamp assembly is to securely fix the impeller to the impeller removal tool. Figure 20 below depicts the overall impeller clamp assembly.

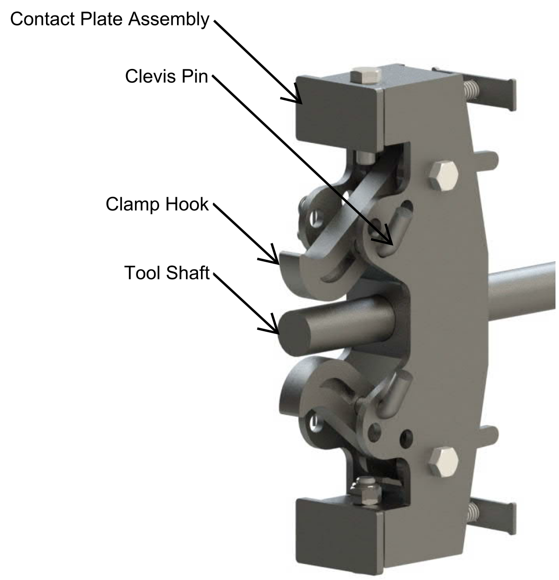


Figure 20: Impeller clamp assembly.

6.4.2 Wire Rope and Attachment Point

As discussed in Section 6.3, the wire rope is used to apply the torque to the impeller. For this tool, a $\frac{5}{8}$" diameter 6x37 extra flexible wire rope supplied by Fastenal will be used [6]. With a breaking strength of 35800 lb, the rope achieves a factor of safety nearly 5.0. The wire rope is fed through the centre of the impeller, and out opposing ends of the impeller. Then, the hooks on the end of the wire rope are attached to the outside surface of the impeller fins. The hooks and associated hardware are supplied by McMaster-Carr [7]. With the rope secured to the impeller, the impeller removal tool is brought into towards the pump and the wire rope is guided into the wire rope attachment. The wire rope attachment consists of a split $\frac{1}{4}$" outer plate, two $\frac{1}{2}$" inner plates cut to a semi-circle of 6" diameter, and a 1" rear plate. The four plates are bolted together, and the attachment assembly is welded to the tool shaft. With the wire rope fixed inside of the wire rope attachment point, rotation of the tool shaft puts tension on the wire rope, and the input torque is transmitted through the wire rope and to the impeller. The wire rope and attachment assembly is shown below in Figure 21.

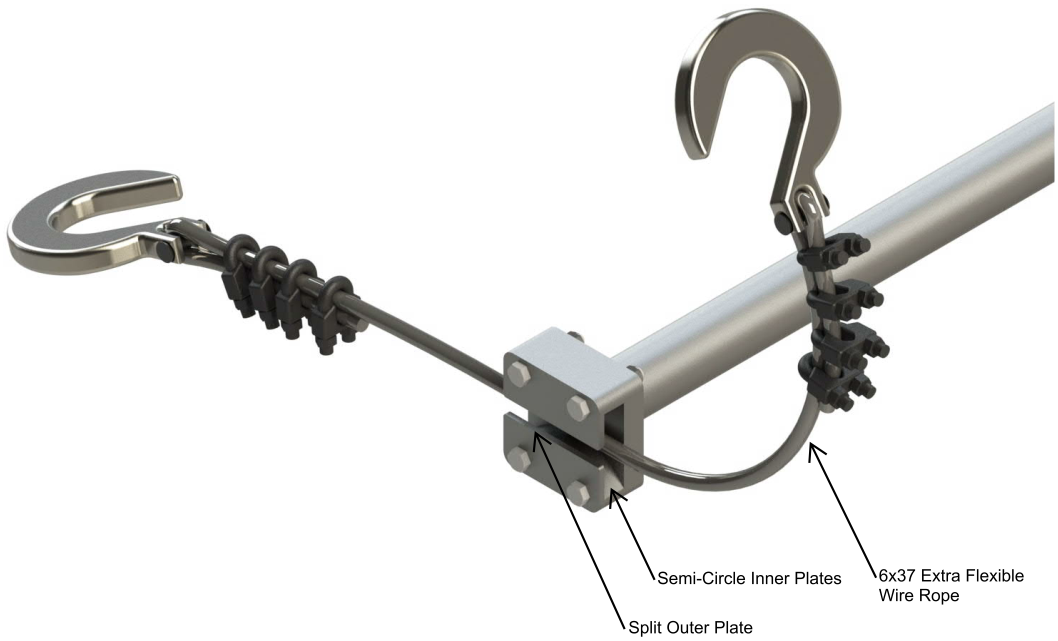


Figure 21: Wire rope and attachment point. Note that the clamping assembly is not shown for clarity.

6.4.3 Tool Shaft

The shaft used for this tool is constructed of $2\frac{1}{2}$" thick round bar and is $76\frac{1}{2}$" long in total. The output side (impeller side) of the shaft has the wire rope attachment point welded to the shaft. Behind the wire rope attachment point, the impeller clamp assembly is welded to the shaft. The shaft has two sets of $4\frac{1}{16}$" O.D. x $2\frac{9}{16}$" I.D. x $\frac{3}{8}$" thick spacers welded to it. These spacers serve to locate the shaft in the pillowblock bearings. The last $3\frac{1}{2}$" on the input side of the shaft are machined into a $2\frac{3}{16}$" male hex. The hex end will allow a socket to be used to apply torque to the shaft. The tool shaft can be seen below in Figure 22.

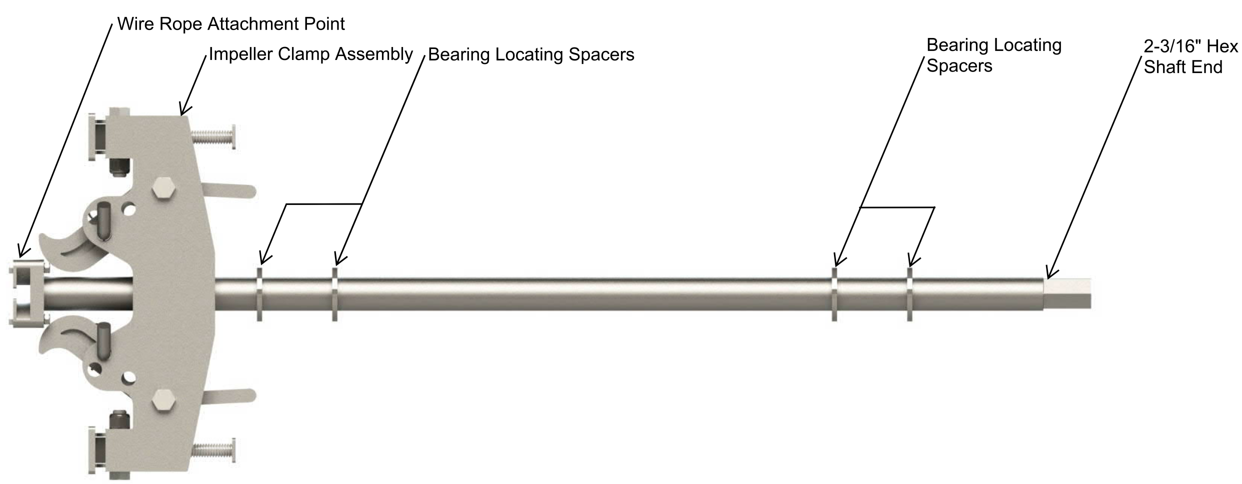


Figure 22: Tool shaft details.

6.4.4 Pneumatic Torque Wrench

The pneumatic torque used for this tool is the Enerpac PTW6000C. This torque wrench is capable of outputting up to 6000 ft·lbs of torque at 2.5 RPM with an input of 100 psi at 50 CFM [8]. The tool features a $1\frac{1}{2}$" square drive output. The tool comes with a reaction arm and Filter-Regulator-Lubricator assembly to provide clean, regulated air to the tool. Additionally, the BSH15219 $2\frac{1}{2}$" drive $2\frac{3}{16}$" socket will be required to connect the torque wrench to the hex end of the tool shaft. The PTW6000C wrench is shown below in Figure 23.

Figure 23: PTW6000C pneumatic torque wrench [8]

The torque wrench requires a reaction point for proper operation. The design utilizes a reaction point constructed of $\frac{1}{2}$" plate welded to the end plate of the shaft guard. This reaction point will provide a fixed location for the torque wrench to register against and transfer it's rotational energy into the tool shaft. Figure 24 below shows the reaction point on the tool.

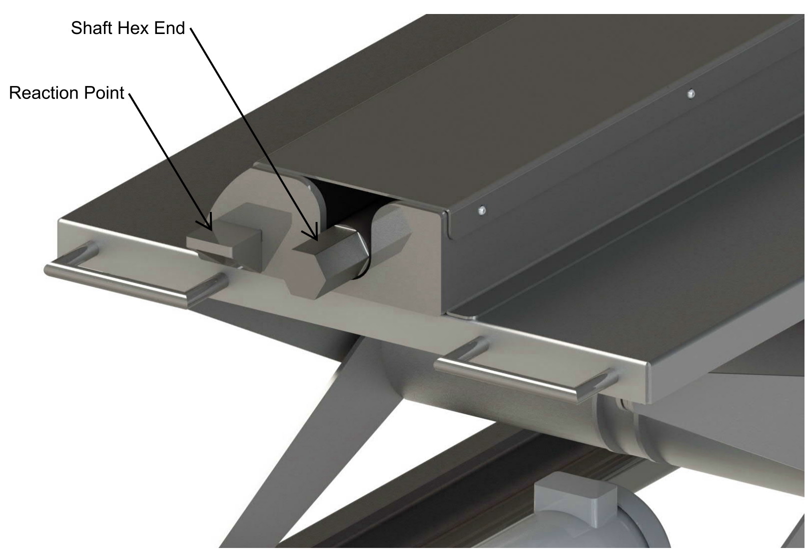


Figure 24: Reaction point for pneumatic torque wrench.

6.4.5 Shaft Bearings

The tool will utilize two $2\frac{1}{2}$" split-housing cast iron babbitt bearings supplied by McMaster-Carr. These bearings measure $4\frac{3}{16}$" high x $8\frac{7}{8}$" long x 5" wide. Babbitt bearings were chosen as these bearings will experience relatively high radial loads and will be operated at low speeds. The selected bearings are rated for 1730 lbf at 30 RPM [9]. Split bearings were chosen to simplify the installation and removal procedure of the shaft during fabrication and maintenance, as split bearings allow the bearing cap to be removed and the entire shaft assembly to be lifted out. The bearings will be mounted to the top surface of the scissor-lift table. Figure 25 below depicts the specified bearing.

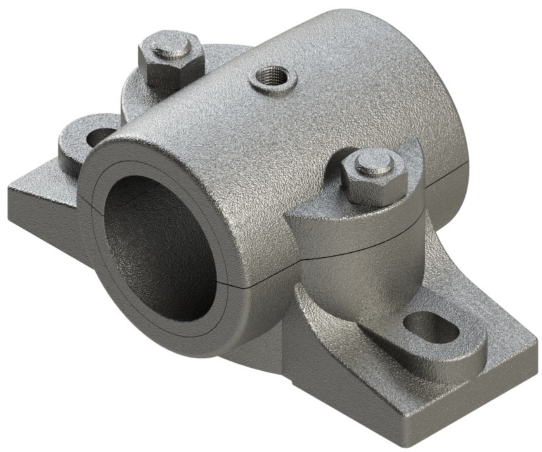


Figure 25: $2\frac{1}{2}$" split housing babbitt bearing [9]

6.4.6 Scissor-Lift Table and Base Frame

The scissor-lift table utilized in the tool is a 56" x 32" table with 5000 lb capacity supplied by McMaster-Carr. The table has a lifting range of 9" to 48". It is electrically powered and operated by a hand-held switch. The table is powered by 120V single-phase AC power [10]. The footprint of the table is extended by the addition of a base frame. The base frame is constructed of 2" x 5" x $\frac{1}{4}$" thick HSS steel, and measures a total of 79" x 32". The base frame was included in the design to increase the stability of the tool when it is holding an impeller. With the addition of the base frame, the tool can support and impeller weighing up to 4000 kg. Finally, wheels have been added to the bottom of the base frame to allow mobility of the tool. The front side of the base frame is fitted with 10" diameter x $2\frac{1}{2}$" wide fixed polyurethane rubber casters [11], while the rear of the base frame is fitted with 10" diameter x $2\frac{1}{2}$" wide swivel polyurethane rubber casters with brakes [12]. Both the front and rear casters each have 2000 lbs capacity. The inclusion of swivel casters will allow the tool to be steered while in transport, while the locking casters will protect against unintended movement of the tool. The base frame assembly can be seen below in Figure 26.

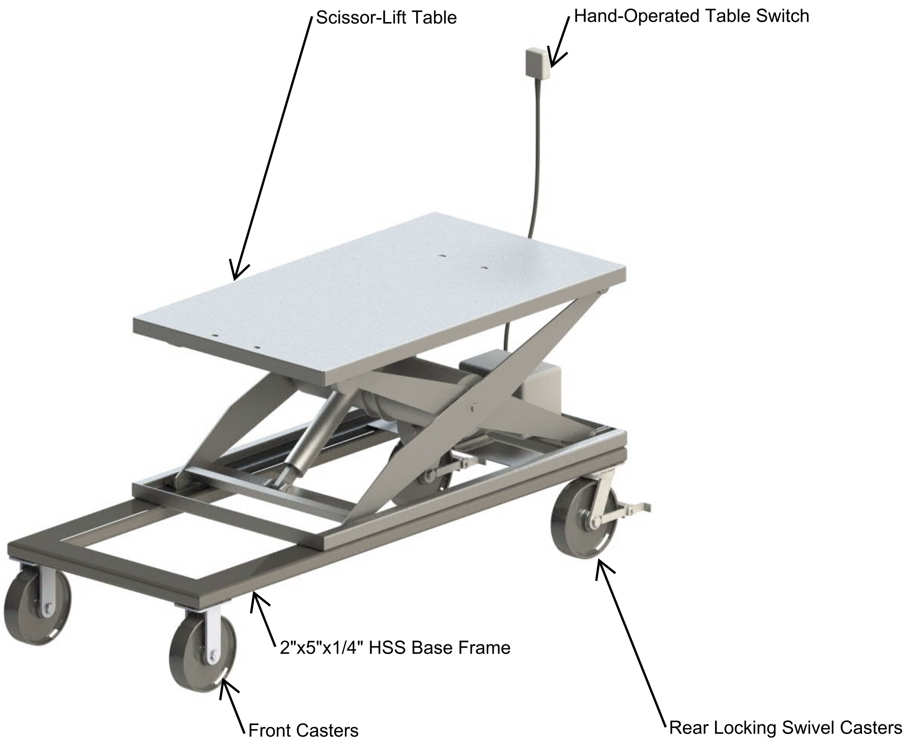


Figure 26: Scissor-lift table and base frame assembly [10] [11] [12]

6.5 Operations Integration

During the preventive maintenance window or emergency maintenance of slurry pumps, the pumps are taken out of service, decoupled from the motor, and taken into the machine shop for maintenance. Nutrien has a dedicated area for pump maintenance where the removal of the impeller takes place. The pump is propped on a base made of I-beams, fabricated to fit certain pump models and sizes. To access the impeller, the pump casing is opened by undoing the bolts and removing the other half. With the impeller exposed, the impeller removal tool can now be used.

Outlined below are the order on how to properly use the impeller removal tool.

1. Move the tool fixture close to the pump. Adjust the position of the tool fixture so that the jaws are facing the impeller, and the wheels line up to go inside the space between the base made of I-beams. Push the tool slowly into position to prevent the tool from ramming into the pump. Ensure that the clamps are retracted.
2. Adjust the height of the table so that the axis of the tool shaft is collinear with the axis of the pump shaft via scissor lift controlled using a controller.
3. While ensuring that the jaws are in the retracted position (tucked in place), thread one end of the steel cables into the eye of the impeller and out one of the vanes. Attach the hook at the end of the steel cables to the end of the vanes. Repeat the process for the other cable. Make sure that there is no noticeable slack in the cables.
4. The clamps are then extended and is permitted to latch on the inner diameter of the eye of the impeller. Once contact is achieved, lock the clamps in place with threaded rods.
5. Insert the pneumatic drill with the correct attachment to the torque multiplier which is situated at the other side of the tool fixture away from the pump. Prior to applying torque, make sure that there is nothing on the shaft and watch the pinch points. Apply the torque until the impeller is off the shaft. Make sure that the impeller is off the shaft by nudging the tool fixture away from the pump.

6. Push the tool away from the pump leaving enough space for the sling. Lock the rear caster wheels prior to wrapping the sling around the impeller and using a crane. Lift the sling until the sling is taut. Do not overdo as the tool shaft might be bent out of shape due to excessive loading.
7. To part the impeller from the tool, the jaws must be loosened by undoing the threaded rods and is retracted. Unhook the hooks from the vane of the impeller, unlock the rear caster wheels and retract the tool fixture.
8. The removed impeller is now held by the crane for disposal.

Outlined below are the order on how to properly store the impeller removal tool.

1. Make sure that the cables and the jaws are retracted.
2. Lower the tool fixture. Remove the tool fixture from the guide rails.
3. When in storage location, lock the rear caster wheels and if possible, cover the tool to avoid dust accumulation.

6.6 Failure Modes and Effects Analysis

A formal failure modes and effects analysis (FMEA) has been conducted on the final design. The results of the FMEA found that no accommodations or component redesigns are required; monitoring and implementing standards and regulations is expected to be sufficient to mitigate the risks posed by the identified failure modes. The full details of the FMEA can be found in Appendix B.

6.7 Preliminary Engineering Drawings

A full package of preliminary engineering drawings detailing the fabrication of the impeller removal tool has been prepared. The drawings package can be found in Appendix E.

6.8 Bill of Materials and Cost Analysis

Table VII below summarizes the total cost to purchase and fabricate the impeller removal tool.

TABLE VII: TOTAL COST SUMMARY

Item	$USD	$CAD
Cost of Raw Materials	$962.84	$1,222.81
Cost to Fabricate Components	$214.50	$272.42
Cost to Assemble Impeller Removal Tool	$383.00	$486.41
Cost to Purchase Off-the-Shelf Components	[redacted]	
Total Tool Cost:	[redacted]	

As shown, the total estimated cost of the impeller removal tool is $23,193.60. Note that this figure assume a raw material cost of $2.00 per pound, and a labour cost of $50.00 per hour.

For a detailed cost breakdown and bill of materials, please see Appendix C

7 Conclusion and Recommendations

7.1 Evaluation of Final Design

Prime consulting was tasked with designing a tool that Nutrien's operations personnel can utilize to increase the efficiency and decrease the risk associated with their existing process of removing impellers from pumps with seized pump shafts. Based on the client needs and internal target specifications, conceptual designs were generated, concepts were combined and developed, and the final design was arrived at through an iterative design process. The final design has been validated based on engineering analyses and designed to be feasible for manufacturing. As a result, the final design has met Nutrien's needs and, as such, the project is considered a success. In particular, Table VIII below evaluates the final design against the client's five most important needs.

TABLE VIII: CUSTOMER NEEDS SATISFACTION TABLE

Client Need	Need Satisfaction Method
The tool reduces the risk of injury to operators.	The tool is designed such that operator interaction near the impeller is minimized. While operating the tool, the operator has 6 feet of space between them and the impeller, reducing the risk of injury to the operator. Additionally, the tool can be operated by a single opertor, reducing the number of people exposed to the hazard.
The tool can support the weight of the impeller.	The tool has been designed to support the weight of the impeller with a factor of safety of 3.
The tool allows the impeller to be removed from the pump shaft.	The tool rotates while being attached to the impeller, allowing the impeller to be removed from the pump shaft while the tool is attached. Additionally, the tool is mobile, allowing for the impeller to transported on the tool after removal from the pump shaft.
The tool works on a variety of impellers.	The tool has been designed to work with the 12/10, 10/8, and 8/6 impeller sizes.
The tool minimizes operator interaction time.	The tool requires a single operator interaction with the impeller during intial setup. Once setup is complete, the operator is isolated from the impeller and only interacts with the back side of the tool, where the operator is isoltaed from the dangers associated with the impeller removal process.

To evaluate the overall success of this project, the final design must be evaluated against the needs and specifications defined in Table IX, particularly against the existing process. Table IX below evaluates the performance of the final design based on the project specifications.

TABLE IX: EVALUATION OF FINAL DESIGN AGAINST EXISTING PROCESS

Metric Number	Needs	Metrics	Importance	Units	Marginal	Ideal	Nutrien's Current Process	Final Design - Impeller Removal Tool
1	1	ANSI B11, S-15.1 REG 10	5	binary	PASS	PASS	PASS	PASS
2	2	Risk Rating	5	rating	10	1	12	4
3	2,5	Maximum load supported	5	kN	11.25	22.5	250	12.95
4	3	Cycles to failure w/o contaminants	4	cycles	120	240	N/A	85000
5	3,4	Cycles to failure w/ contaminants	2	cycles	90	180	N/A	56000
6	6	Applied torque on impeller	5	kN · m	0	> 25	125	5
7	6	Allowable translational motion	5	m	0.7	> 0.7	> 0.7	∞
8	7	Impeller sizes	5	list	ALL*	ALL*	ALL*	ALL*
9	8	Common maintenance tools in mining industry	1	list	10	5	> 10	<10
10	9	Accessibility for impeller transport	4	binary	PASS	PASS	PASS	PASS
11	10	Number of operators	3	count	2	1	2	1
12	11	Heavy machinery in use	3	list	2	0	2	0
13	12	Process envelope	3	m^2	15	6	10	5
14	13	Time to set-up and use	2	min	10	5	10	7
15	14	Unit fabricating cost	2	CAD$	< $50,000	$15,000	N/A	TBD
16	15	Unit maintaining cost	3	CAD$/yr	$3,000	$1,200	N/A	< $1,000
17	16	Interference with pump components	4	binary	PASS	PASS	PASS	PASS

As shown, the new design both meets or exceeds the marginal values and matches or beats the existing process for all specifications measured thus far. Additionally, while formal evaluations are not available for all specifications at this time, it is expected that the unmeasured specifications of the design will , at a minimum, meet the marginal specifications and match the performance of the current process. As such, this design can be considered a success and it is expected that implementing the design into the impeller removal process will lower the risk to operators, reduce the time that operators interact with the process, and reduce the overall cost of operation as compared to the existing process.

7.2 Recommendations

The design of this impeller removal tool has been based on the assumption that 5 kN·m is a sufficient amount of torque to break free a seized impeller. This assumption was created based on estimations, but has not yet been verified. As such, it is recommended that, prior to implementing this design, Nutrien attaches a load scale between the crane and impeller the next time that they rebuild a pump. Doing so will provide data regarding the force required to break the torque of the seized impeller. This will either serve to validate the design presented in this report, or provide a definitive route for modifications that must be made to the tool for successful implementation.

If Nutrien is to implement this design before validating the required torque assumption and the design does not provide sufficient torque to break free a seized impeller, the impeller may be broken free using the crane as in the existing process. Then, the impeller removal tool may be used to remove the impeller the rest of the way off of the shaft.

8 References

[1] Nutrien Ltd., *About Nutrien*, 2021. [Online]. Available: https://www.nutrien.com/what-we-do, [accessed: 2021-09-24].

[2] P.Labossiere, B.Carlson, A.Hanson, *Mechanical Project Application Form*, UMLEARN, Sep. 2021.

[3] AGCanada. "Nutrien to further bump up potash output." (), [Online]. Available: https://www.agcanada.com/daily/nutrien-to-further-bump-up-potash-output. [accessed: September 24, 2021].

[4] WEIR Minerals, *WARMAN Centrifugal Slurry Pumps,AH Pump*, AH Pump Catalogue, Sep. 2021.

[5] P. Labossiere, *3-Concept Generation*, Lecture Slides, 2021. [Online]. Available: https://universityofmanitoba.desire2learn.com/d2l/le/content/443426/viewContent/2620131/View.

[6] Fastenal, *5/8 6x37 7160lb-wll biwrc ips steel extra flexible wire rope*. [Online]. Available: https://www.fastenal.com/products/details/0528936, [accessed: December 2, 2021].

[7] McMaster-Carr, *Wide mouth lifting hook*. [Online]. Available: https://www.mcmaster.com/3540T29/, [accessed: December 2, 2021].

[8] Enerpac, *Ptw series pneumatic torque wrench*.

[9] McMaster-Carr, *Mounted sleeve bearing*. [Online]. Available: https://www.mcmaster.com/6359K49/, [accessed: November 16, 2021].

[10] McMaster-Carr, *Electric stationary lift table*. [Online]. Available: https://www.mcmaster.com/2900T342/, [accessed: November 24, 2021].

[11] McMaster-Carr, *Viking caster with 6 1/4 x 4 1/2 plate*. [Online]. Available: https://www.mcmaster.com/2771T69/, [accessed: November 28, 2021].

[12] McMaster-Carr, *Viking caster with 6 1/4 x 4 1/2 plate*. [Online]. Available: https://www.mcmaster.com/2771T281/, [accessed: November 28, 2021].

[13] R. G. Budynas and J. K. Nisbett, *Shigley's Mechanical Engineering Design*, 11th. McGraw Hill Education, 2020, ISBN: 978-1-260-56999-5.

[14] V. Campbell, *Risk assessment and mitigation: Failure modes and effects analysis (fmea)*, Lecture Slides, 2021. [Online]. Available: https://universityofmanitoba.desire2learn.com/d2l/le/content/443426/viewContent/2664561/View.

Appendices

Contents

List of Figures

Appendix A Component Design and Verification

This section will detail the analytical and numerical analyses conducted to design and/or verify the various components of the final design. Each distinct component/aspect of the final design will be detailed under it's own subsection.

A.1 Power Transmission Shaft

A.1.1 Shaft Analytical Calculations

The shaft must be capable of transmitting 5 kN·m of torque. From there, the required shaft radius can be found as:

$$\begin{aligned}
\tau &= \frac{Tc}{J} \\
&= \frac{Tc}{\frac{\pi}{2}c^4} \\
&= \frac{T}{\frac{\pi}{2}c^3} \\
c &= \left(\frac{2T}{\tau_{all}\pi}\right)^{\frac{1}{3}} \\
c_{req'd} &= 31.7mm \\
c_{req'd} &= 1.25"
\end{aligned}$$

Therefore, to sustain an applied torque of 5kN·m of torque with a safety factor of 3, the shaft must have a diameter of at lease 2.5".

A.1.2 Shaft Finite Element Analysis

The tool shaft was a major component of interest because torsion as well as bending forces were expected on the shaft during the operation of the tool. Figures A.1 and A.2 below represent the shaft under a bending load of 9.8 kN (comprised of the weight of the largest impeller (700 kg) and the weight of the clamp (300 kg)) and a torsion of 5000 N·m, respectively. The material used to model the shaft was A36 Structural steel with a yield strength of 250 MPa. The bending analysis showed the shaft experiencing a maximum stress of 159 MPa at the first bearing support which was less than the yield strength of the material of the shaft. Figure A.2 showed considerable stresses throughout the body of the shaft when a torque of 5 kN·m was applied. The maximum stress of 249 MPa was observed at the hex on end of the shaft, however this is likely not entirely accurate as the hex is modelled with sharp corners, producing theoretical stress concentrations. Additionally, SolidWorks showed a high stress at the bearing location; however, this is due to the presence of a split line in the model and hence does not represent real conditions. Areas near but not immediately adjacent to these stress concentrations showed stressed closer to 225 MPa, which can be considered realistic. The rest of the shaft experienced a stress from 10-149.4 MPa.

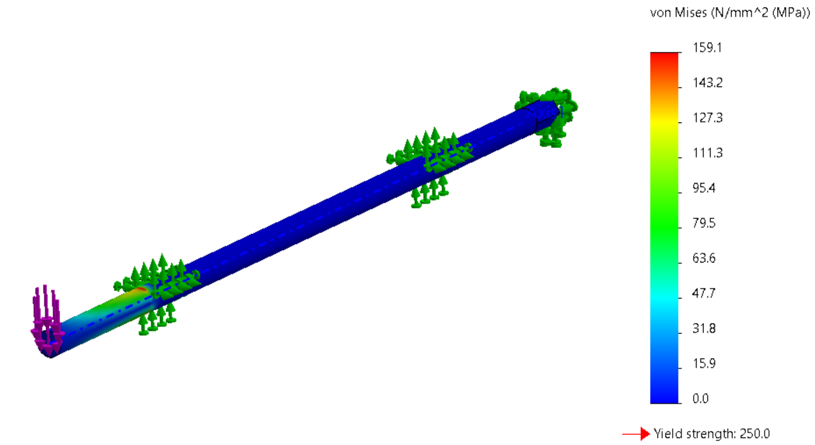


Figure A.1: Shaft under bending load

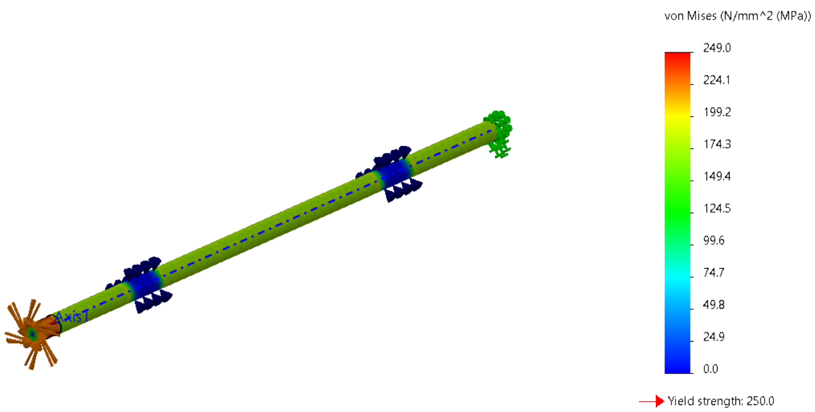


Figure A.2: Shaft under torsion

A.1.3 Shaft Fatigue Analysis

As shown, the torsion experienced by the shaft is the most critical failure mode. As such, this torsion will be used for the fatigue analysis. To start the fatigue analysis, the modified stress endurance limit must be found [13].

$$S_e = S_e^{'} k_a k_b k_c k_d k_e$$

Noting that $S_e^{'}$=293 MPa for the chosen material, and assuming that the shaft has a hot-rolled surface finish, the modified stress endurance limit can be solved as:

$$S_e = 67.89 \text{ MPa}$$

for the shaft in torsion. This is below the actual applied stress; therefore, infinite life is not predicted. To find the service life, the equivalent completely-reversed stress must be solved. Noting that, in the case of torsion on the shaft,

$$\sigma_{max} = 225MPa$$
$$\sigma_{min} = 0MPa$$
$$\sigma_{mean} = 112.5MPa$$
$$\sigma_{amp} = 112.5MPa$$

From there, the completely reversed equivalent stress can be found as:

$$\sigma_{ar} = \frac{\sigma_a}{1 - \frac{\sigma_m}{S_{ut}}}$$
$$\sigma_{ar} = 139.23MPa$$

The expected number of cycles to failure can be solved as:

$$N = \left(\frac{\sigma_{ar}}{a}\right)^{\frac{1}{b}}$$

Where

$$a = \frac{(fS_{ut})^2}{S_e}$$
$$a = 3784.61$$

and

$$b = \frac{-1}{3} log\left(\frac{fS_{ut}}{S_e}\right)$$
$$b = -0.291$$

Finally,

$$N = \left(\frac{139.23}{3784.61}\right)^{\frac{1}{-0.291}}$$
$$N = 85000$$

Therefore, the shaft can withstand 85000 loading cycles before failing due to fatigue. Assuming that the torque is only applied once per operation to break the initial torque, then the shaft is expected to last for 85000 operations - much longer than will be realistically required. As such, failure of the shaft due to fatigue can be determined as a non-concern.

A.2 Bearing Load

To select the proper bearings for this loading application, some preliminary calculations were performed. The following assumptions were made:

a. The weight of the impeller is 700kg and the weight of the clamp is assumed to be 300kg. Giving a total weight of 1000kg
b. The shaft is designed with spacers to prevent translational motion therefore thrust loads on the bearing are assumed to be inconsequential.

Figure A.3 below represents a free body diagram of the tool fully supporting the weight of the impeller. For consistency with manufacturer catalogues, imperial units were in the calculations.

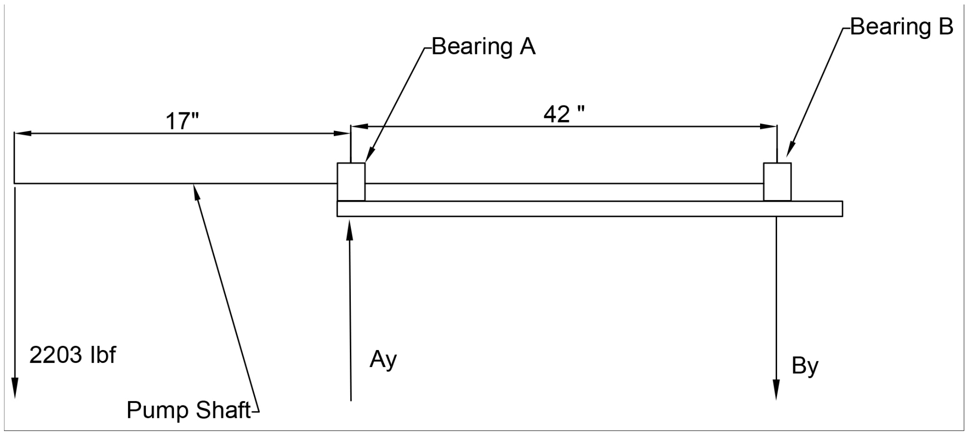


Figure A.3: Bearing Load Free Body Diagram.

Converting all weights to lbf:

$$\text{Total Weight} = m_{clamp} * g + m_{impeller} * g$$
$$\text{Total Weight} = (300 * 9.8) + (1000 * 9.8)$$
$$\text{Total Weight} = 9.8kN$$

Since 1 kN = 224.80894 lbf

$$\text{Total Weight} = 9.8 * 224.8 = 2203.1lbf$$

The reaction forces can be found by taking the sum of moment about Ay:

$$B_y :$$
$$2203.1lbf * 17in = 42in * B_y$$
$$B_y = \frac{2203.1lbf * 17in}{42in}$$
$$B_y = 891lbf \text{ [downwards]}$$

Solving for Ay:

$$A_y :$$
$$A_y = 2203.1lbf + B_y$$
$$A_y = 2203.1lbf - 891lbf$$
$$A_y = 1312.1lbf \text{ [upwards]}$$

From the calculations above, the bearings selected would be required to support a minimum axial load of 1,312.1lbf.

A.3 Impeller Clamp

A.3.1 Impeller Clamp Finite Element Analysis

The Impeller clamp was a key component in the tool as it was expected to be the housing both the impeller clamp hook and the vice. In addition, the clamp was expected to hold the full weight of the largest impeller of 700 kg. An analysis of the clamp face showed the maximum stress on the component as 69.6 Mpa while the yield strength of the material A36 Structured steel was 250 Mpa as seen in figures A.4 and A.5.

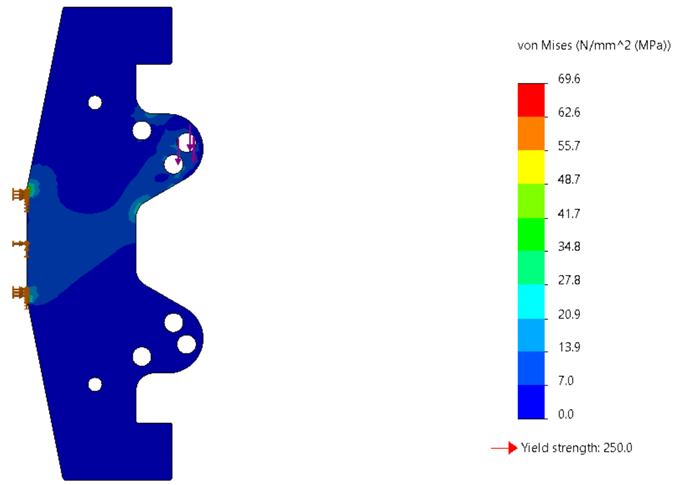


Figure A.4: Impeller clamp face

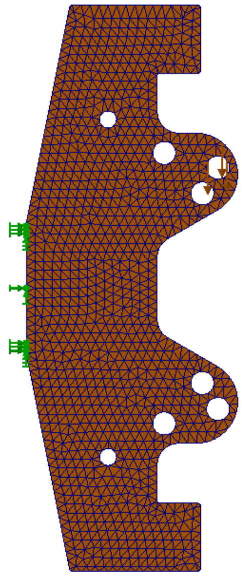


Figure A.5: Impeller clamp face mesh

A.4 Impeller Clamp Hook

A.4.1 Impeller Clamp Hook Finite Element Analysis

The Impeller clamp hook was modelled using A36 Structural Steel which had a yield strength of 250 MPa. The hook was designed to withstand the weight of the largest Impeller of 700 kg. When an analysis was performed on the hook as seen in figures A.6 and A.7, a maximum stress of 27.3 MPa was located in the slots of the hook which was significantly less than the yielding strength of the material.

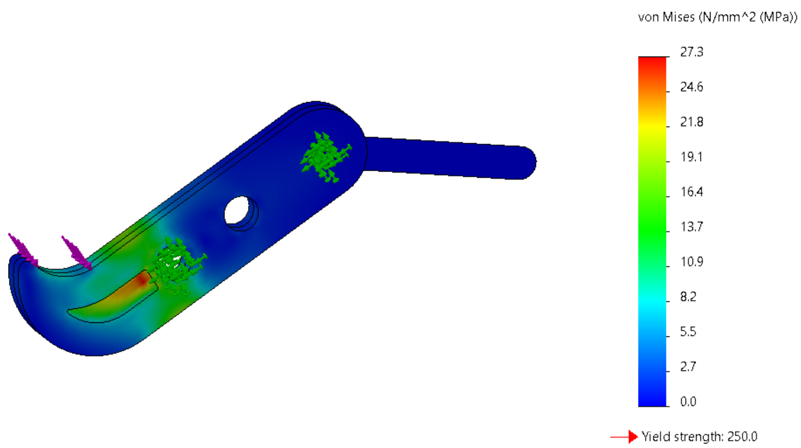


Figure A.6: Impeller clamp hook

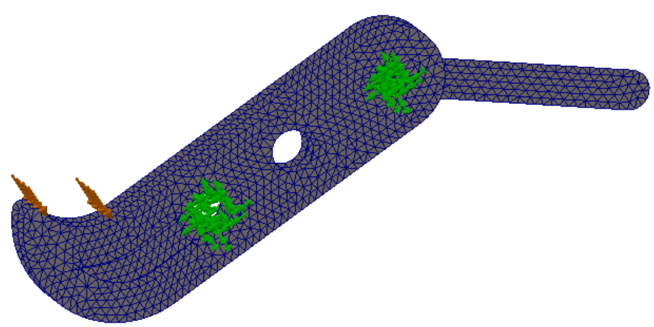


Figure A.7: Impeller clamp hook mesh

A.5 Table Base Frame

In order to stabilize the tool considering the dead load and with the impeller, a simple static analysis is needed to verify the stability. The following equilibrium equations will be used in the tipping analysis.

$$\circlearrowleft + \sum M_A = 0$$
$$\overset{+}{\rightarrow} \sum F_x = 0$$
$$+\uparrow \sum F_y = 0$$

To simplify analysis, calculations will be performed in 2D as the tool is symmetric which makes 2D analysis valid. The major assumption for this analysis are that the components are homogeneous where the center of gravity is at the geometric center of the components and that all components are rigid. These assumptions are chosen to determine the greatest possible reaction forces. Figure A.8 below outlines the center of mass for each component.

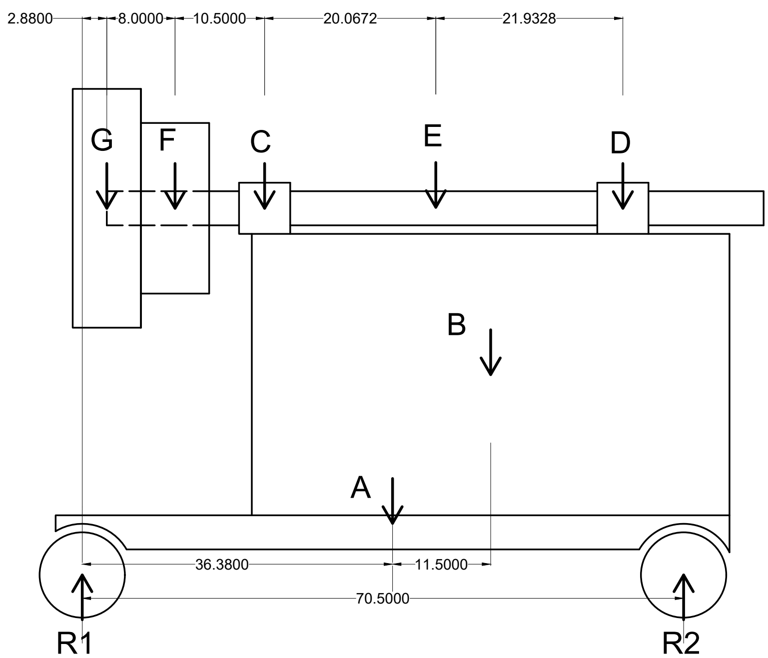


Figure A.8: Simplified Free Body Diagram for Tipping Analysis

The mass for each components are the following which are determined using SolidWorks:

1. A - 180.35 lbs
2. B - 450 lbs
3. CD - 30 lbs
4. E - 186 lbs
5. F - 50 lbs

6. G - 1545 lbs

Moment about R1 is set to zero. This gives the value for R2.

$$\circlearrowleft + \sum M_{R1} = 0$$
$$= -A(36.38) - B(47.88) - C(21.38) - D(63.38) - E(41.45) - F(10.88) - G(2.88) + R2(70.5)$$
$$R2 = \frac{A(36.38) + B(47.88) + C(21.38) + D(63.38) + E(41.45) + F(10.88) + G(2.88)}{70.5}$$
$$R2 = 614.94[lbs]$$

To determine the reaction forces at R1, equilibrium of forces in the y-direction must be achieved.

$$+\uparrow \sum F_y = 0$$
$$= R1 + 614.94 - 180.35 - 450 - 30 - 30 - 186 - 50 - 1545$$
$$R1 = 1856.41[lbs]$$

A.5.1 Table Base Frame Finite Element Analysis

Figures A.9 and A.10 below is the analysis of the base frame tubing when the tool is fully supporting the weight of the impeller. Since the base frame extends further than the scissor lift table, the simulation was set up with a downward point load of 5.98 kN. The material used for the frame was AISI 304 Structural Steel with a yield strength of 206.8 MPa. As seen from the simulation, The maximum stress experienced by the part is 278.3 Mpa which was seen at the corner of the tube as such high stress concentrations were expected. Other major sections of the part experienced a stress between 27.8-167 MPa, far below the yield strength of the material.

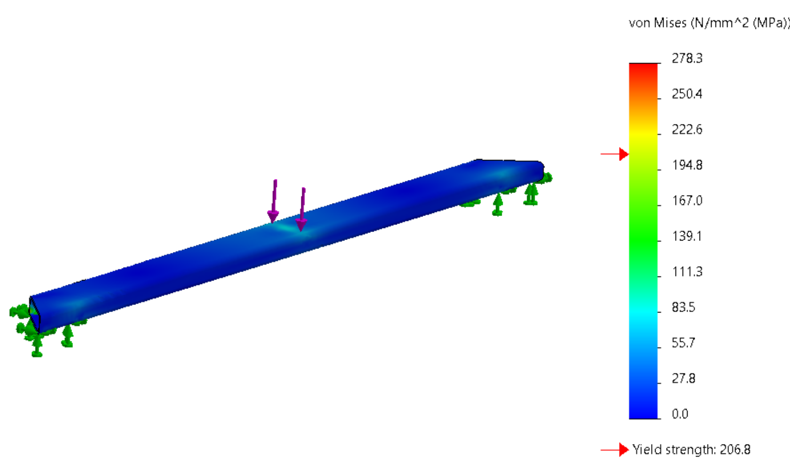


Figure A.9: Base frame tubing FEA

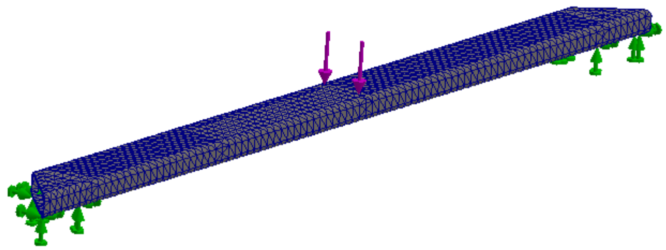


Figure A.10: Base frame tubing FEA Mesh

A.6 Impeller Cable and Cable Guide

In order to calculate the transferred load from the shaft to the cables, a simplified loading condition of the cable plate is analyzed. Figure A.11 below shows the simplified loading condition.

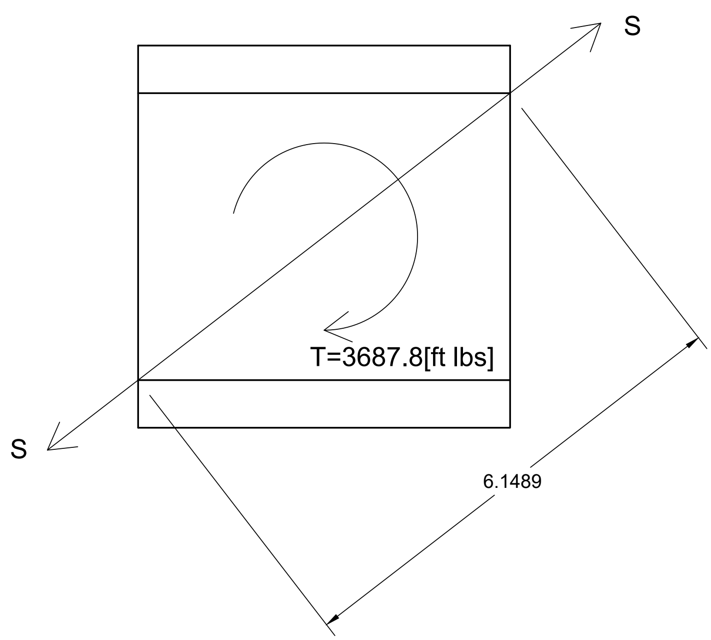


Figure A.11: Simplified Loading Case for Cable Plate

Assuming the torque from the shaft is 5000 [Nm] which is converted to ft lbs for calculation, when the edges of the cable plate bears on the taut string as the shaft rotates, we can determine the wire cable tension denoted by S. D is equals to 6.1489[in] or 0.5124[ft].

$$
\begin{aligned}
T &= 2S \times \frac{D}{2} \\
S &= \frac{T}{D} \\
&= \frac{3687.8}{0.5124} \\
&= 7197[lbs]
\end{aligned}
$$

This tension is then transferred to the hook attached on to the end of the steel cable which is hooked on to the outside edge of the impeller vanes. The vanes of the impeller has an involute profile. From the pictures provided by Nutrien, the tip of the vanes creates a 30°angle with respect to the imaginary tangent line at the outer diameter.

Appendix B Failure Modes and Effects Analysis

The formal failure modes and effects analysis can be found below:

Component	Potential Failure Mode	Potential Effect	Severity	Potential Causes	Frequency	Current Controls	Detection	R.P.N.	Action/ Recommendations
Clamp Assembly FMEA									
Component	**Potential Failure Mode**	**Potential Effect**	**Severity**	**Potential Causes**	**Frequency**	**Current Controls**	**Detection**	**R.P.N.**	**Action/ Recommendations**
Clamp threaded rod	Thread strips.	Impeller is no longer firmly secure on the hook	5	Operator overtightens the clamp.	1	Designed to be hand tightened.	4	20	Hand Tighten only or Specify a maximum torque
Wire rope	Rope fails.	Rope snaps and operator might be caught in line of fire	9	Excessive torque is applied to the rope. Hardware is in disrepair.	2	Limit on allowable torque.	4	72	Specify maximum torque
Wire rope	Fastening hardware fails .	Impeller no longer has torque input from the tool	2	Excessive torque is applied to the rope. Hardware is in disrepair.	1	Multiple fastening hardwares for redundancy.	4	8	Frequent inspections and replacement of hardware
Wire rope	Hooks on wire rope fail.	Impeller no longer has torque input from the tool	2	Hooks in disrepair. End of service life	2	Regular inspections.	2	8	Frequent inspections and replacement of hook
Wire rope attachment point	Rope attachment point fails.	Impeller no longer has torque input from the tool	4	Attachment point over loaded	2	Regular inspections. Limit on allowable torque.	4	32	Frequent inspections and replacement of hook/ Limit on allowable torque
Clamp hooks	Clamp hooks fail.	Impeller is no longer supported by the tool.	7	Hooks are over-loaded from top/ Hooks shear from excess torque	2	Limit on impeller mass. Design factor of safety.	2	28	Ensure tool is not used on impellers exceeding 700 kg in mass. Ensure hook is not being side-loaded during operation. Work envelope should be clear when tool is in being used.
Clamp hook pins	Hook pins fail.	Hooks no longer fixed in place, causing impeller to come loose from the tool.	7	Hook pins are overloaded.	2	Limit on impeller mass. Design factor of safety.	2	28	Ensure tool is not used on impellers exceeding 700 kg in mass.
Scissor Lift Table									
Component	**Potential Failure Mode**	**Potential Effect**	**Severity**	**Potential Causes**	**Frequency**	**Current Controls**	**Detection**	**R.P.N.**	**Action/ Recommendations**
Motor	Motor fails.	Impeller is no longer supported by the tool.	6	Scissor lift table is over-loaded.	2	Motor is controlled by remote.	5	60	Ensure scissorlift does not experience a load of more than 5000 lbs.
Cross bracing	Joints fail.	Impeller is no longer supported by the tool.	6	Scissor lift table is over-loaded.	2	Cross bracing is controlled by motor.	4	48	Ensure scissorlift does not experience a load of more than 5000 lbs.
Scissor lift table	Table becomes unstable.	Tool tips, causing tool and impeller to fall to the ground.	8	Scissor lift table is over-loaded. Scissor lift table is lifted too high.	2	Limit on impeller mass. Height limit in table design.	2	32	Ensure scissorlift does not experience a load of more than 5000 lbs. Do not modify scissor lift. Ensure scissor lift is not extended beyond its limit.
Tool Shaft									
Component	**Potential Failure Mode**	**Potential Effect**	**Severity**	**Potential Causes**	**Frequency**	**Current Controls**	**Detection**	**R.P.N.**	**Action/ Recommendations**
Shaft	Shaft fails due to torsion.	Impeller is no longer supported by the tool.	7	Shaft is over-torqued.	2	Limit on allowable torque. Design factor of safety.	5	70	Ensure applied torque does not exceed 5 kN-m. If specified torque wrench is insufficient for impeller removal, use crane to break impeller torque.
Shaft	Shaft fails due to bending.	Impeller is no longer supported by the tool.	7	Shaft is over-loaded.	2	Limit on allowable impeller weight. Design factor of safety.	5	70	Ensure tool is not used on impellers exceeding 700 kg in mass.
Shaft	Hex end on shaft strips.	Tool can no longer be used without modifications.	5	Improperly sized socket is used. Shaft is over torqued.	3	Specify appropriate socket for use. Limit on allowable torque.	2	30	Ensure only 2-3/16" socket is used on shaft end. Ensure applied torque does not exceed 5 kN-m.
Shaft Bearings	Shaft bearings fail due to wear.	Shaft rotation is no longer aligned with pump shaft axis.	3	Bearings are overloaded. Bearings are in operation too long without maintenance.	2	Maintenance procedures. Shaft load limit.	2	12	Follow approved maintenance schedule. Ensure tool is not used on impellers exceeding 700 kg in mass.
Tool Frame								0	
Component	**Potential Failure Mode**	**Potential Effect**	**Severity**	**Potential Causes**	**Frequency**	**Current Controls**	**Detection**	**R.P.N.**	**Action/ Recommendations**
Wheels	Wheels fail due to overloading.	Wheels get stuck and will be dragged when tool is moved around.	4	Lifting table experiences shock load or overload.	3	Limit on allowable load on the lifting table. Guards in place therefore cannot be used for other purpose.	2	24	Ensure to not add any tools or heavy parts on the lifting table. Only use tool as intended.
Base	Base fails due to overloading.	Base plastically bends and sets tool out of alignment.	5	Lifting table experiences shock load or overload.	2	Limit on allowable load on the lifting table. Guards in place therefore cannot be used for other purpose.	2	20	Ensure to not add any tools or heavy parts on the lifting table. Only use tool as intended.

Severity of Effect		Ranking
Minor	Unreasonable to expect that the minor nature of this failure would cause any substantial effect on system performance or on a subsequent process or service operation. Customer unlikely to either notice or care about failure.	1
Low	Low severity ranking due to nature of failure causing only a slight customer annoyance. Customer will probably notice on a minor degradation of the service perfromance, or a slight impact on a subsequent action; i.e., some quick, minor work.	2
Moderate	Failure causes some customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. Customer will experience some very noticeable inconvenience or performance degradation. May cause either delay due to rework or irreversible damage.	4,5,6
High	High degree of customer dissatisfaction due to the negative impact of the failure such as an inaccurate payroll run, loss of vital data or an inoperable convenience system (i.e., computer crashes). May cause serious disruption to subsequent processing; may require major rework or loss to customer and/or create significant financial hardship.	7,8
Very High	Failure mode involves serious personal safety hazards, potential for civil litigation or noncompliance with government regulations	9,10

Figure A.12: FMEA severity table [14].

Probability of Failure	Ranking	Possible Failure Rates
Remote: Failure is unlikely, No failures ever associated with almost identical processes	1	<1 in 20,000
Very Low: Process is in Statistical Control. Only Isolated failures associated with almost identical processes.	2	1 in 20,000
Low: Process is in Statistical Control. Isolated failures associated with similar processes.	3	1 in 4,000
Moderate: Generally associated with processes similar to previos processes which have experienced occasional failures, but not in major proportions. Process is in Statistical Control.	4	1 in 1000
	5	1 in 400
	6	1 in 80
High: Generally associated with processes similar to previous processes that have often failed. Process is not in Statistical Control.	7	1 in 40
	8	1 in 20
Very High: Failure is almost inevitable,	9	1 in 8
	10	1 in 2

Figure A.13: FMEA frequency table [14]

Detection Rating Scale		
Likelihood of Detection	**Description**	**Ranking**
Very High	Current controls will almost certainly prevent the failure (process automatically prevents most failures)	1,2
High	Current controls have a good chance of detecting failure.	3,4
Moderate	Current contols may detect the failure.	5,6
Low	Current controls have a poor chance of detecting the failure.	7,8
Very Low	Current controls probably will not detect the failure.	9
Absolute Certainity of Non-Detection	Current controls will not or cannot detect the failure.	10

Figure A.14: FMEA detection table [14]

Required Action	RPN
Monitor	<50
Standards and Regulations	50-300
Accommodate	300 - 500
Redesign	500 - 1000

Figure A.15: FMEA required actions table [14]

Appendix C Detailed Cost Analysis and Bill of Materials

Please see below the detailed cost estimate and bill of materials for the final design.

FABRICATION TIME AND COST

Laser-Cut Components

Name	No. Pieces	Perimeter (in.)	Total Length to Cut (in)	
Clamp Bar Plate	2	103	206	
Hook 1	4	44	176	
Hook 2	2	48	96	
Rod Handle	2	18	36	
Rod Plate 1	2	26	52	
Rod Plate 2	2	19	38	
Slotted Plate 1	2	27	54	
Slotted Plate 2	2	32	64	
Support Clamp Plate	4	15	60	
Push Plate	2	9.5	19	
Contact Plate	2	19	38	
Cable Plate 1	1	35	35	
Cable Plate 2	4	14	56	
Cable Plate 3	2	16	32	
End Plate	1	40	40	
			1002	Total Length to Laser/Plasma cut
			20	Cutting Speed (IPM)
			50.1	Cutting Time in minutes assuming 100% Duty Cycle
			62.63	Total Cut Time including 25% for Set-Up

Fabricated Components

Guard Plates	75	Cutting, bending, drilling, and prepping
Base Tubing	20	Cutting, and prepping
Shaft	90	Machining Hex at the end
Handles	10	Cut, and prep
	62.63	**TOTAL TIME TO CUT MATERIALS (min.)**
	1.04	**TOTAL TIME TO CUT MATERIALS (hr.)**

Welded Components

Name	No. Pieces	Perimeter (in)	Total Length to Weld (in)	
Base Tubing	4	18	72	
Cable Plate 1	2	5	10	
Contact Plate Assembly	2	72	144	
Handles	2	11	22	
Lifting Table to Base Tubing	1	156	156	
			404	Total Length of Weld
			2	Weld rate (in/min) includes prep time
			202.00	**TOTAL TIME REQUIRED FOR WELDING (min.)**
			3.37	**TOTAL TIME REQUIRED FOR WELDING (hr.)**

TOTAL ASSEMBLY TIME AND COST

4.41	**TOTAL ASSEMBLY TIME**
$220.52	**TOTAL COST @ $50/hr**

Raw Materials

Total Weight of Raw Materials (lbs)				
481.42			**$962.84**	**TOTAL COST OF RAW MATERIALS @ $2.00/lb**

Purchased Component Cost

Part No.	Solidworks File Name	Description	Material	Source	No. Pieces.	$Unit Price ($USD)	Total Cost ($USD)	LINK
PH001	MOUNTED SLEEVE BEARING	2.5" MOUNTED SLEEVE BEARING	Cast Iron	McMaster-Carr	2	$254.50	$509.00	https://www.mcmaster.com/6359K49/
PH002	VIKING RIGID CASTER	VIKING RIGID CASTER	Iron/Polyurethane Rubber	McMaster-Carr	2	$170.40	$340.80	https://www.mcmaster.com/2771T69/
PH003	VIKING SWIVEL CASTER	VIKING SWIVEL CASTER	Iron/Polyurethane Rubber	McMaster-Carr	2	$300.00	$600.00	https://www.mcmaster.com/2771T281/
PH004	-	6000 FT-LBS PNEUM. TORQUE WRNCH		Enerpac	1	[redacted]		
PH005	-	2-3/16" 2-1/2" DRIVE SOCKET		Enerpac	1	[redacted]		
PH006	LIFT TABLE ASSM	ELECTRIC STATIONARY LIFT TABLE	-	McMaster-Carr	1	$4,384.06	$4,384.06	https://www.mcmaster.com/2900T342/
PH007	0.625IN STEEL EXTRA FLEXIBLE WIRE ROPE	5/8" 6x37 Steel Wire Rope	Steel	Fastenal	1	$1,075.00	$1,075.00	https://www.fastenal.com/products/details/0528936
PH008	WIDE MOUTH LIFTING HOOK	3.5" WIDE MOUTH LIFTING HOOK	Alloy Steel	McMaster-Carr	2	$127.87	$255.74	https://www.mcmaster.com/3540T29/
PF001	ACME HEX NUT	1" ID ACME HEX NUT	Zinc-Plated Steel	McMaster-Carr	2	$14.52	$29.04	https://www.mcmaster.com/98948A770/
PF002	BUTTON HEAD HEX DRIVE SCREW	0.75" BUTTON HEAD HEX DRIVE SCREW	Black-Oxide Alloy Steel	McMaster-Carr	1	$11.27	$11.27	https://www.mcmaster.com/91255A540/
PF003	SNAP-IN NUT	1/4"-20 SNAP-IN NUT	Zinc-Plated Steel	McMaster-Carr	1	$13.26	$13.26	https://www.mcmaster.com/90680A138/
PF004	ZINC-PLATED CARBON STEEL ACME LEAD SCREW	1"-5, 12" ACME LEAD SCREW	Zinc Plated Carbon Steel	McMaster-Carr	2	$22.96	$45.92	https://www.mcmaster.com/98941A755/
PF005	BENT-PULL CLEVIS PIN	1"x5" BENT -PULL CLEVIS PIN	Zinc Plated Carbon Steel	McMaster-Carr	2	$14.65	$29.30	https://www.mcmaster.com/90146A246/
PF006	CAST WIRE ROPE CLAMP	5/8" CAST WIRE ROPE CLAMP	Iron	McMaster-Carr	8	$2.72	$21.76	https://www.mcmaster.com/30325T39/
PF007	NUT	NyLok Nut, 0.625, G5, Z	G5 Steel	McMaster-Carr	4	$14.08	$14.08	https://www.mcmaster.com/nuts/locking-type~nylon-insert/medium-strength-steel-nylon-insert-locknuts-grade-5/
PF008	BOLT	Bolt, 0.625x 5_UNC_G5	G5 Steel	McMaster-Carr	4	$5.62	$22.48	https://www.mcmaster.com/92865A814/
PF009	NUT	NyLok Nut, 0.5, G5, Z	G5 Steel	McMaster-Carr	4	$14.60	$14.60	https://www.mcmaster.com/nuts/locking-type~nylon-insert/medium-strength-steel-nylon-insert-locknuts-grade-5/
PF010	BOLT	Bolt, 0.5x 3_UNC_G5	G5 Steel	McMaster-Carr	4	$6.05	$6.05	https://www.mcmaster.com/92865A724/
PF011	NUT	NyLok Nut, 1, G5, Z	G5 Steel	McMaster-Carr	4	$13.31	$13.31	https://www.mcmaster.com/nuts/locking-type~nylon-insert/medium-strength-steel-nylon-insert-locknuts-grade-5/
PF012	BOLT	Bolt, 1x 4.5_UNC_G5	G5 Steel	McMaster-Carr	2	$15.93	$31.86	https://www.mcmaster.com/92865A928/
PF013	BOLT	Bolt, 1x 6_UNC_G5	G5 Steel	McMaster-Carr	2	$15.93	$31.86	https://www.mcmaster.com/92865A928/
							[redacted]	**TOTAL PURCHASED COMPONENT COST ($USD)**
							[redacted]	**GRAND TOTAL COST ($USD)**
							[redacted]	**GRAND TOTAL COST ($CAD)**

ITEM NO.	SOLIDWORKS FILE NAME	PART NO.	DESCRIPTION	MATERIAL	QUANTITY
	NUTRIEN CAPSTONE PROJECT ASSM	TF046	IMPELLER REMOVER JIG	-	1
1	CLAMP AND LIFT TABLE ASSM	TF044	CLAMP AND LIFT TABLE ASSM	-	1
1.1	BUTTON HEAD HEX DRIVE SCREW	PF002	0.75" BUTTON HEAD HEX DRIVE SCREW	BLACK-OXIDE ALLOY STEEL	8
1.2	NUT	PF007	NyLok Nut, 0.625, G5, Z	GRADE 5 STEEL	4
1.3	BOLT	PF008	Bolt, 0.625x 5_UNC_G5	GRADE 5 STEEL	4
1.4	MOUNTED SLEEVE BEARING	PH001	2.5" MOUNTED SLEEVE BEARING	CAST IRON	2
1.5	SHAFT GUARD PARTS	TF021	SHAFT GUARD	10GA CSA G40.21 44W/300W	1
1.6	HANDLE WDMT	TF030	HANDLE WDMT	0.75" MS RD BAR	2
1.6.1	HANDLE PARTS	TF017	HANDLE PIECE 1	3/4" MS ROUND BAR	2
1.6.2	HANDLE PARTS	TF018	HANDLE PIECE 2	3/4" MS ROUND BAR	4
1.7	GUARD MOUNT ASSM	TF031	GUARD MOUNT ASSM	CARBON STEEL	2
1.7.1	SNAP-IN NUT	PF003	1/4"-20 SNAP-IN NUT	-	8
1.7.2	SHAFT GUARD PARTS	TF020	SHAFT GUARD MOUNT	10GA CSA G40.21 44W/300W	2
1.8	LIFT TABLE WDMT	TF033	LIFT TABLE WDMT	-	1
1.8.1	VIKING RIGID CASTER	PH002	VIKING RIGID CASTER	IRON/POLYURETHRANE RUBBER	2
1.8.2	VIKING SWIVEL CASTER	PH003	VIKING SWIVEL CASTER	IRON/POLYURETHRANE RUBBER	2
1.8.3	BASE TUBING WDMT	TF028	BASE TUBING FRAME WDMT	ASTM A500	1
1.8.3.1	BASE TUBING PARTS	TF001	BASE TUBING 1	ASTM A500	2
1.8.3.2	BASE TUBING PARTS	TF002	BASE TUBING 2	ASTM A500	2
1.8.4	LIFT TABLE ASSM	TF032	DRILLED LIFT TABLE	-	1
1.8.4.1	LIFT TABLE ASSM	PH006	ELECTRIC STATIONARY LIFT TABLE	-	1
1.9	SHAFT GUARD END WDMT	TF038	SHAFT GUARD END WDMT	CARBON STEEL	1
1.9.1	SHAFT GUARD PARTS	TF022	SHAFT GUARD END PLATE	1/2" CSA G40.21 44W/300W	1
1.9.2	TORQUE REGISTER WDMT	TF034	TORQUE REACTION PLATE WDMT	1/2" CSA G40.21 44W/300W	1
1.9.2.1	TORQUE REGISTER PARTS	TF023	TORQUE REGISTER 1	1/2" CSA G40.21 44W/300W	1
1.9.2.2	TORQUE REGISTER PARTS	TF027	TORQUE REGISTER 2	1/2" CSA G40.21 44W/300W	2
1.1	CLAMP ATTACHMENT ASSM	TF043	CLAMP ATTACHMENT ASSM	CARBON STEEL	1
1.10.1	BENT-PULL CLEVIS PIN	PF005	1"x5" BENT -PULL CLEVIS PIN	Zinc Plated Carbon Steel	2
1.10.2	NUT	PF009	NYLOK NUT Nut, 0.5, G5, Z	GRADE 5 STEEL	4
1.10.3	BOLT	PF010	BOLT, 0.5x 3_UNC_G5	GRADE 5 STEEL	4
1.10.4	NUT	PF011	NYLOK NUT, 1, G5, Z	GRADE 5 STEEL	4
1.10.5	BOLT	PF012	BOLT, 1x 4.5_UNC_G5	GRADE 5 STEEL	2
1.10.6	BOLT	PF013	BOLT, 1x 6_UNC_G5	GRADE 5 STEEL	2
1.10.7	SPACER	TF024	HOOK SPACER	1/2" CSA G40.21 44W/300W	8
1.10.8	STEEL CABLE CAP WDMT	TF036	STEEL CABLE CAP WDMT	CARBON STEEL	2
1.10.8.1	CLAMP ATTACHMENT PARTS	TF014	CABLE PLATE 2	1/2" CSA G40.21 44W/300W	2
1.10.8.2	CLAMP ATTACHMENT PARTS	TF015	CABLE PLATE 3	1/4" CSA G40.21 44W/300W	2
1.10.9	THREADED ROD AND HANDLE WDMT	TF037	THREADED ROD AND HANDLE WDMT	CARBON STEEL	2
1.10.9.1	CLAMP ATTACHMENT PARTS	TF016	ROD HANDLE	1/4" CSA G40.21 44W/300W	2
1.10.9.2	CUT THREADED ROD	TF029	5" CUT THREADED ROD	ZINC-PLATED CARBON STEEL	2
1.10.9.2.1	ZINC-PLATED CARBON STEEL ACME LEAD SCREW	PF004	1"-5, 12" ACME LEAD SCREW	ZINC-PLATED CARBON STEEL	1
1.10.10	CONTACT PLATE WDMT	TF039	CONTACT PLATE WDMT	CARBON STEEL	2
1.10.10.1	CLAMP ATTACHMENT PARTS	TF004	SLOTTED PLATE 1	1/4" CSA G40.21 44W/300W	2
1.10.10.2	CLAMP ATTACHMENT PARTS	TF005	SLOTTED PLATE 2	1/4" CSA G40.21 44W/300W	2
1.10.10.3	CLAMP ATTACHMENT PARTS	TF006	CONTACT PLATE	1/4" CSA G40.21 44W/300W	2
1.10.10.4	PUSH PLATE	TF019	PUSH PLATE	1/4" CSA G40.21 44W/300W	2
1.10.10.5	SUPPORT CLAMP PLATE	TF026	SUPPORT CLAMP PLATE	1/4" CSA G40.21 44W/300W	4
1.10.11	CLAMP BAR AND SHAFT WDMT	TF041	CLAMP BAR AND SHAFT WDMT	CARBON STEEL	1
1.10.11.1	SHAFT WDMT	TF035	SHAFT WDMT	CARBON STEEL	1
1.10.11.1.1	CLAMP ATTACHMENT PARTS	TF010	SHAFT	2.5" MS ROUND BAR	1
1.10.11.1.2	SPACER	TF025	RETAINING RING	3/8" CSA G40.21 44W/300W	4
1.10.11.2	CLAMP BAR WDMT	TF040	CLAMP BAR WDMT	CARBON STEEL	1
1.10.11.2.1	ACME HEX NUT	PF001	1" ID ACME HEX NUT	ZINC-PLATED STEEL	2
1.10.11.2.2	CLAMP ATTACHMENT PARTS	TF003	CLAMP BAR PLATE	1/2" CSA G40.21 44W/300W	2
1.10.11.2.3	CLAMP ATTACHMENT PARTS	TF007	ROD PLATE 1	1/4" CSA G40.21 44W/300W	2
1.10.11.2.4	CLAMP ATTACHMENT PARTS	TF008	ROD PLATE 2	1/4" CSA G40.21 44W/300W	2
1.10.11.2.5	CLAMP ATTACHMENT PARTS	TF009	SHAFT PLATE	1/2" CSA G40.21 44W/300W	2
1.10.11.3	CABLE PLATE WDMT	TF047	CABLE PLATE WDMT	CARBON STEEL	1
1.10.11.3.1	CLAMP ATTACHMENT PARTS	TF013	CABLE PLATE 1	1" CSA G40.21 44W/300W	1
1.10.11.3.2	CLAMP ATTACHMENT PARTS	TF014	CABLE PLATE 2	1/2" CSA G40.21 44W/300W	2
1.10.12	HOOK WDMT	TF042	HOOK WDMT	CARBON STEEL	2
1.10.12.1	CLAMP ATTACHMENT PARTS	TF011	HOOK 1	1/2" CSA G40.21 44W/300W	4
1.10.12.2	CLAMP ATTACHMENT PARTS	TF012	HOOK 2	1/2" CSA G40.21 44W/300W	2
2	WIRE ROPE ASSM	TF045	WIRE ROPE AND HOOKS ASSM	-	1
2.1	CAST WIRE ROPE CLAMP	PF006	5/8" CAST WIRE ROPE CLAMP	IRON	8
2.2	0.625IN STEEL EXTRA FLEXIBLE WIRE ROPE	PH007	5/8" 6 X 37 STEEL WIRE ROPE	STEEL	1
2.3	WIDE MOUTH LIFTING HOOK	PH008	3.5" WIDE MOUTH LIFTING HOOK	ALLOY STEEL	2

Appendix D Pump Model Drawings

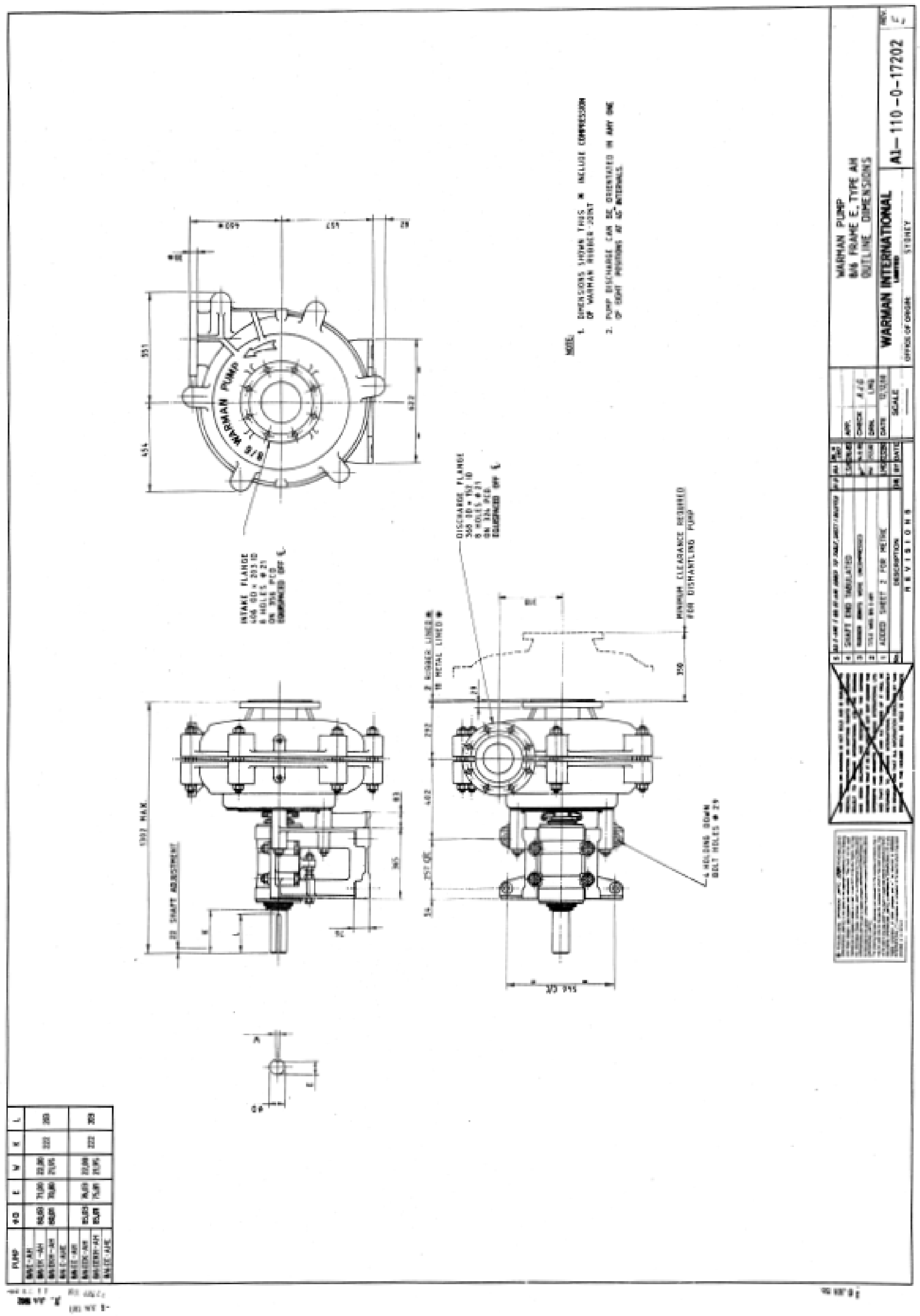


Figure 27: 8/6 Pump Model

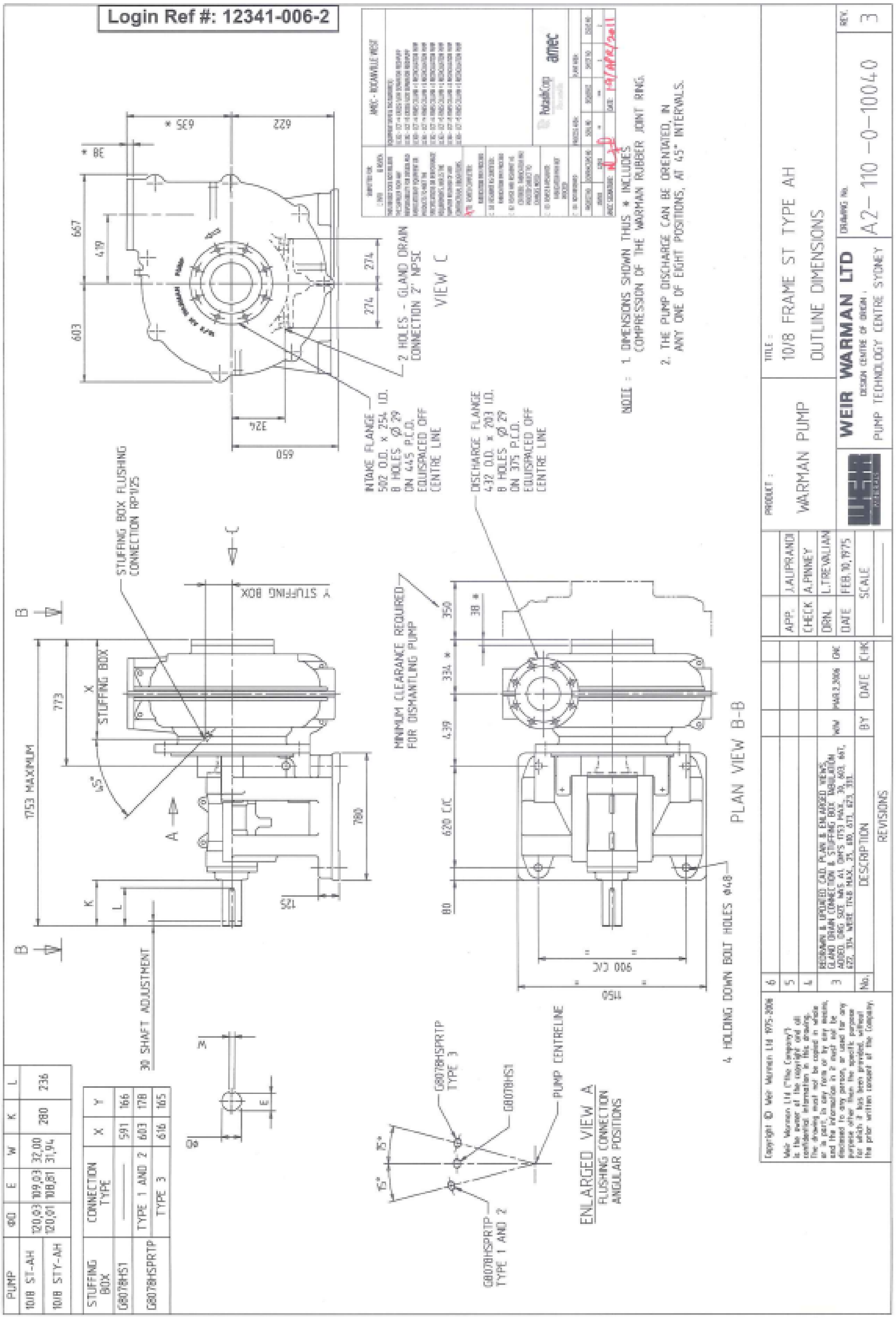


Figure 28: 10/8 Pump Model

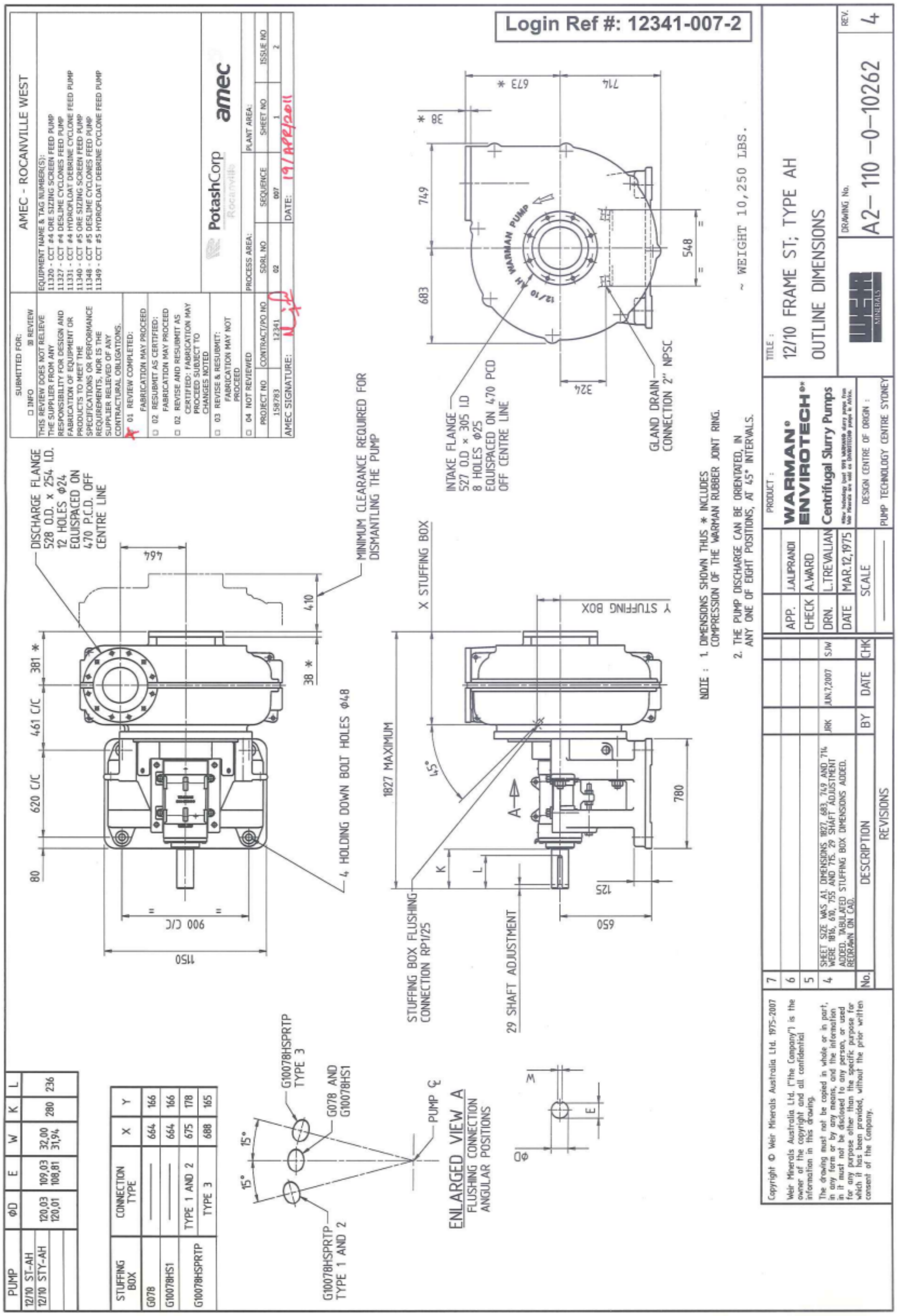


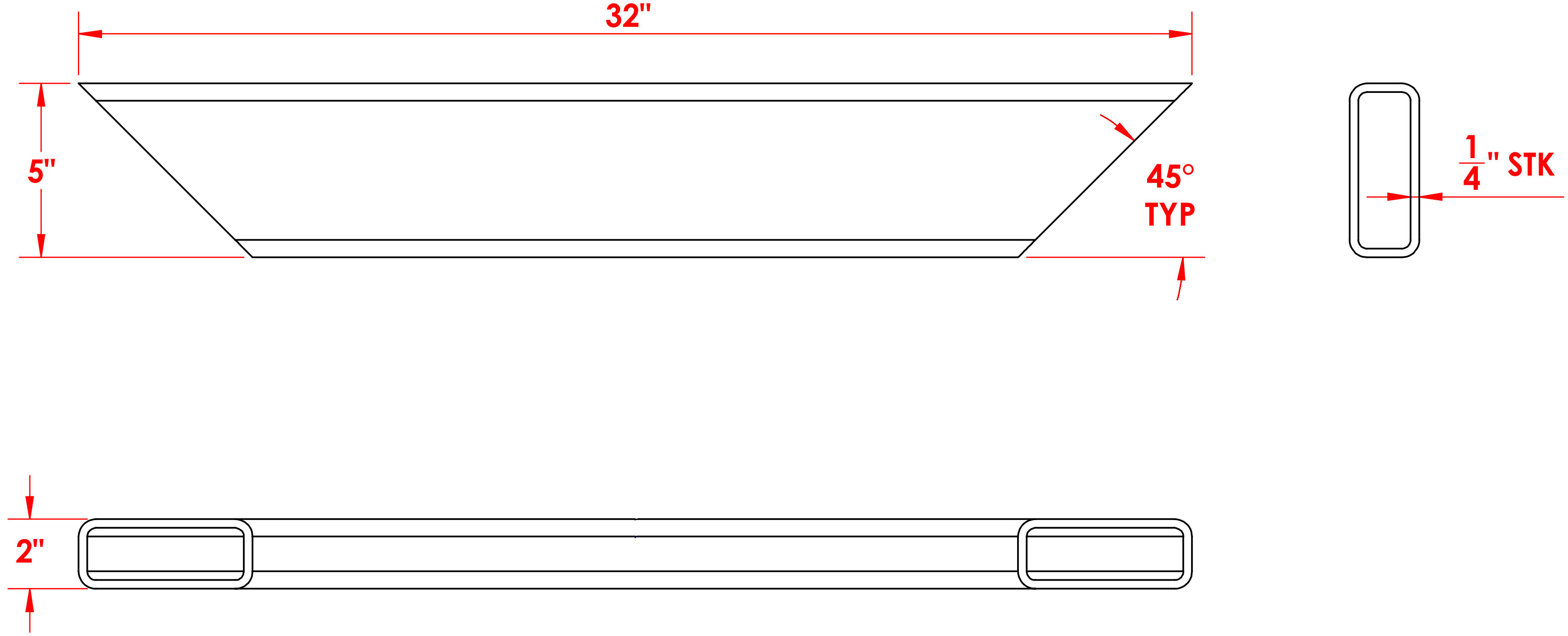
Figure 29: 12/10 Pump Model

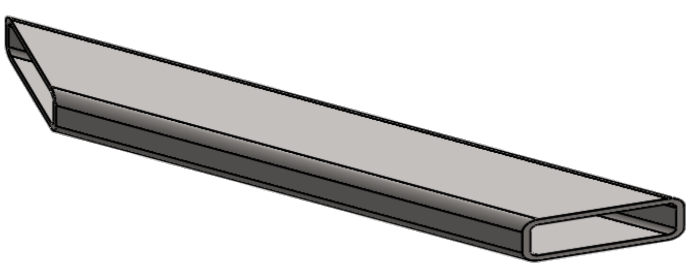
Appendix E Preliminary Engineering Drawings

The preliminary engineering drawings package prepared for this project can be found below.

DWG NO:	REV
TF001	A

REV	DATE	BY	DESCRIPTION
A	2021-12-06	PY	Issue



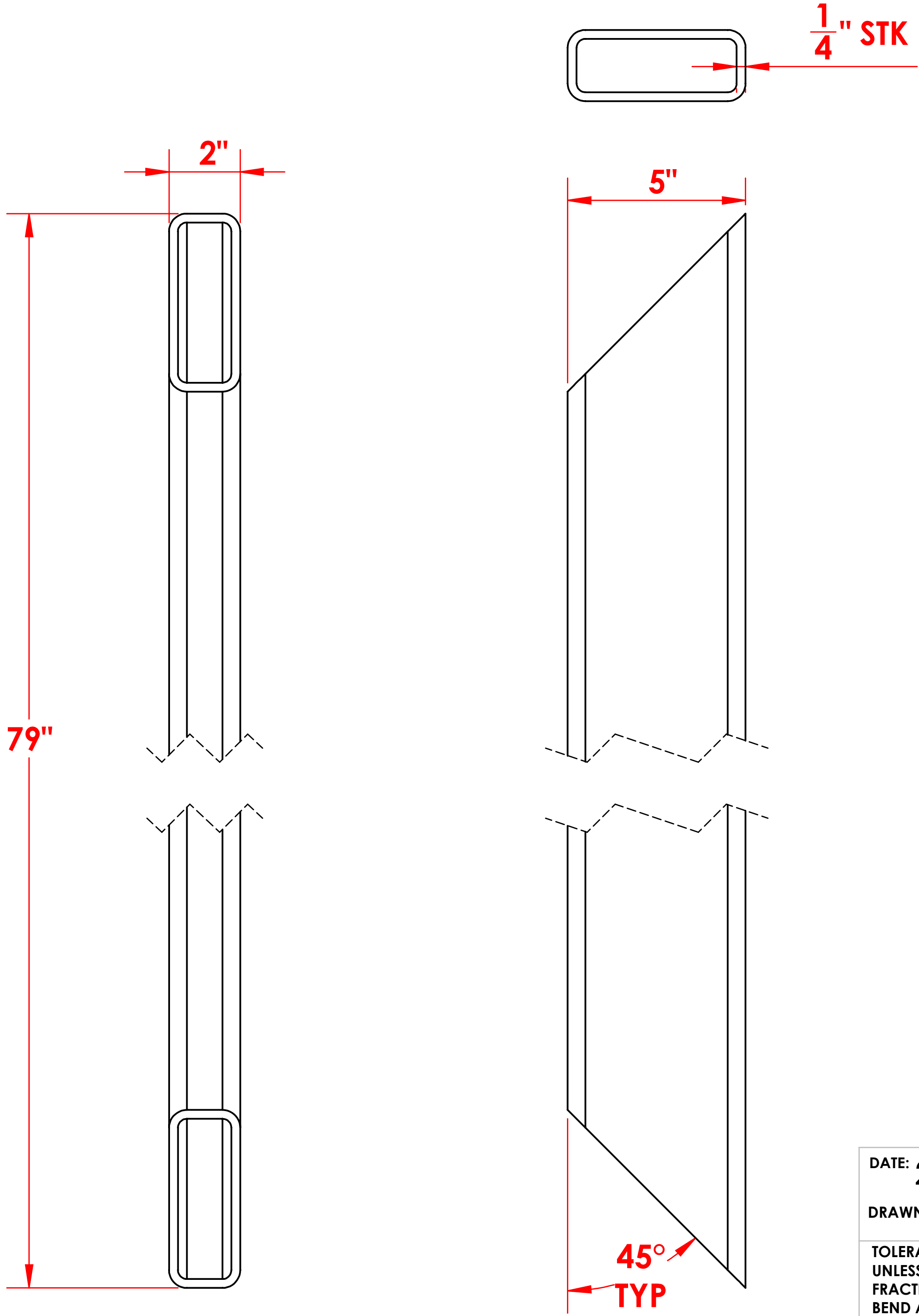


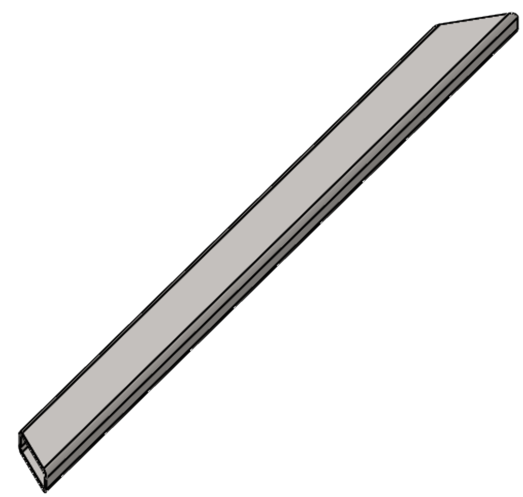
MODEL: Base Tubing Parts
CONFIG: BASE TUBING 1

DATE: 2021-12-06	MATERIAL: ASTM A500		FINISH: 2B	
DRAWN BY: PY	DESCRIPTION: BASE TUBING 1			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF001			REV A
	SIZE A	SCALE 1:5	WEIGHT: 24.106 lbs	SHEET 1 OF 1

DWG NO: TF002 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-06	PY	Issue



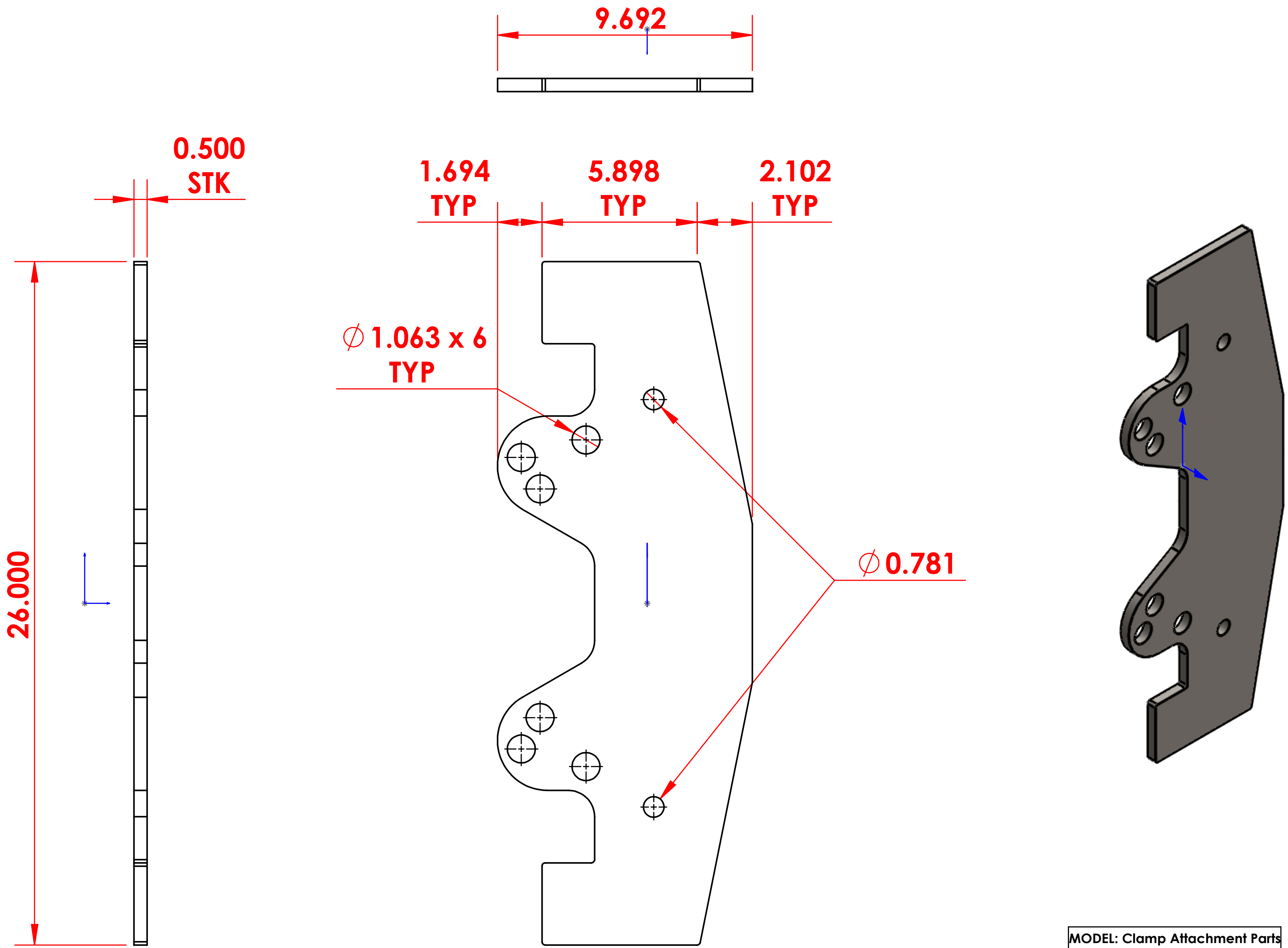


MODEL: Base Tubing Parts
CONFIG: BASE TUBING 2

DATE: 2021-12-06	MATERIAL: ASTM A500			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: BASE TUBING 2			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF002			REV A
	SIZE A	SCALE 1:5	WEIGHT: 66.068 lbs	SHEET 1 OF 1

DWG NO:	REV
TF003	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



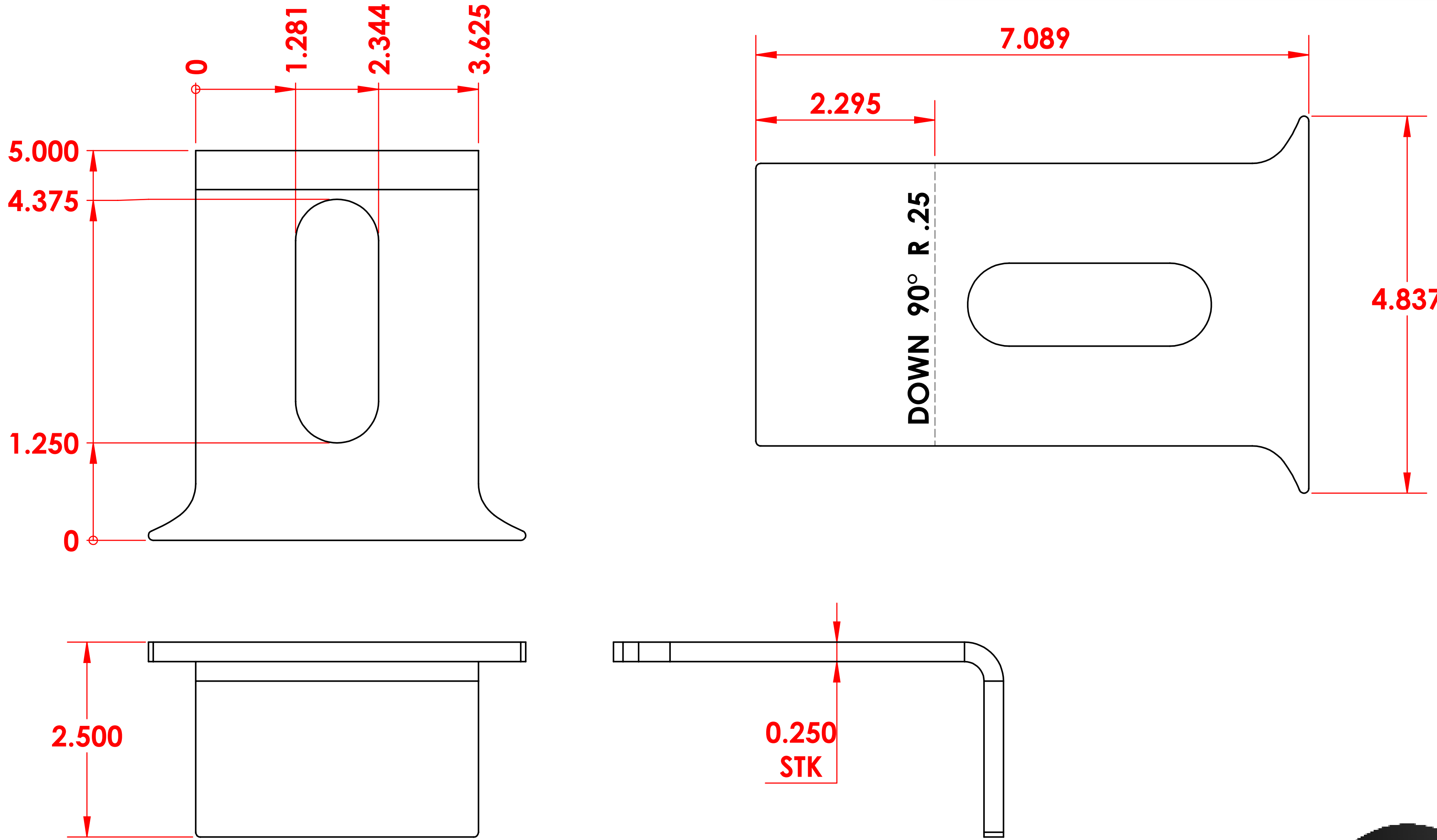
MODEL: Clamp Attachment Parts
CONFIG: CLAMP BAR PLATE

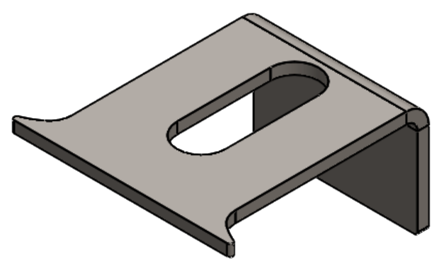
PRIME CONSULTING

DATE: 2021-11-28	MATERIAL: 1/2" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CLAMP BAR PLATE			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF003			REV A
	SIZE A	SCALE 1:6	WEIGHT: 24.223 lbs	SHEET 1 OF 1

DWG NO:	REV
TF004	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



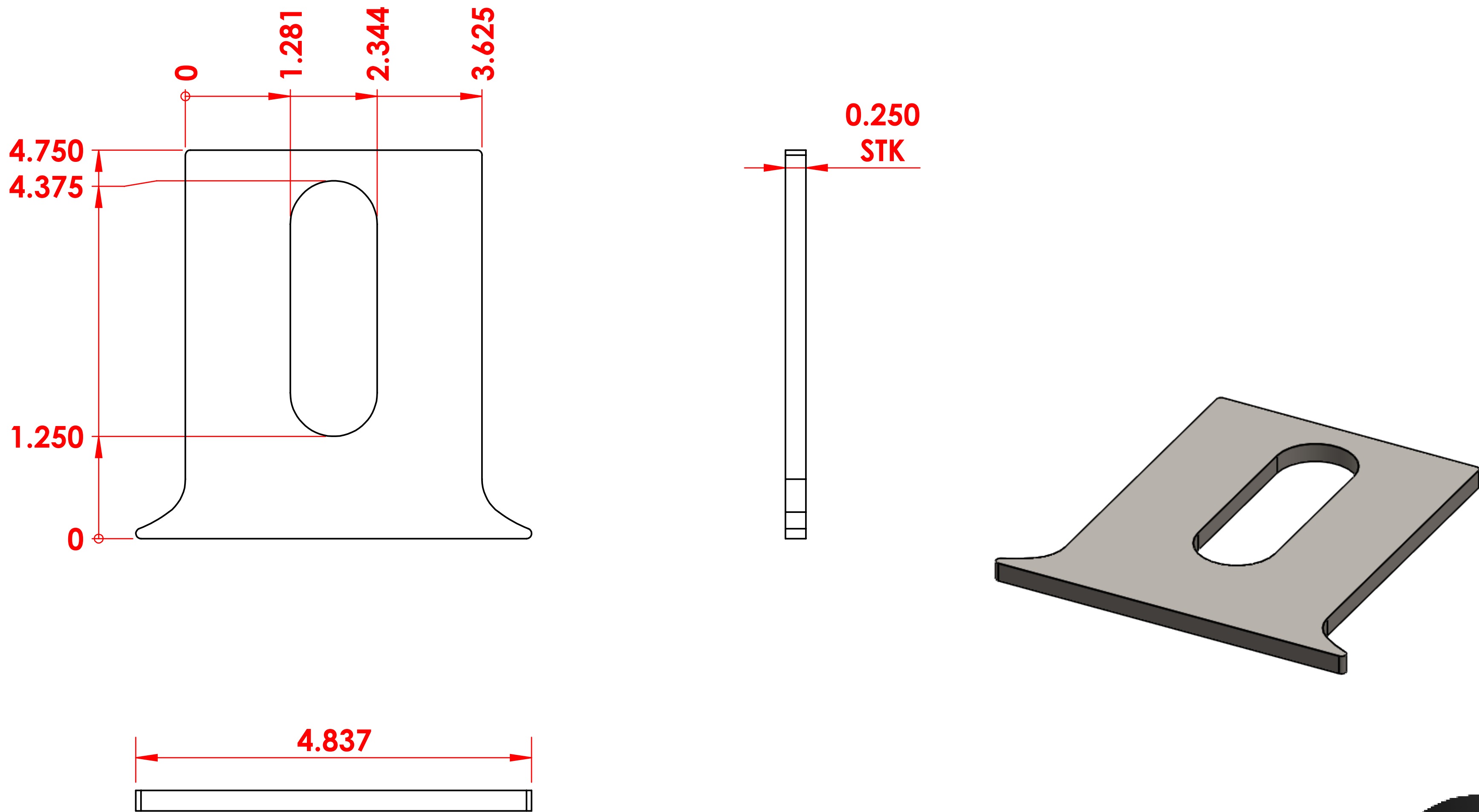


MODEL: Clamp Attachment Parts
CONFIG: SLOTTED PLATE 1

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SLOTTED PLATE 1		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF004		REV A
	SIZE A	SCALE 1:2	WEIGHT: 1.628 lbs	SHEET 1 OF 1

DWG NO: TF005 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue

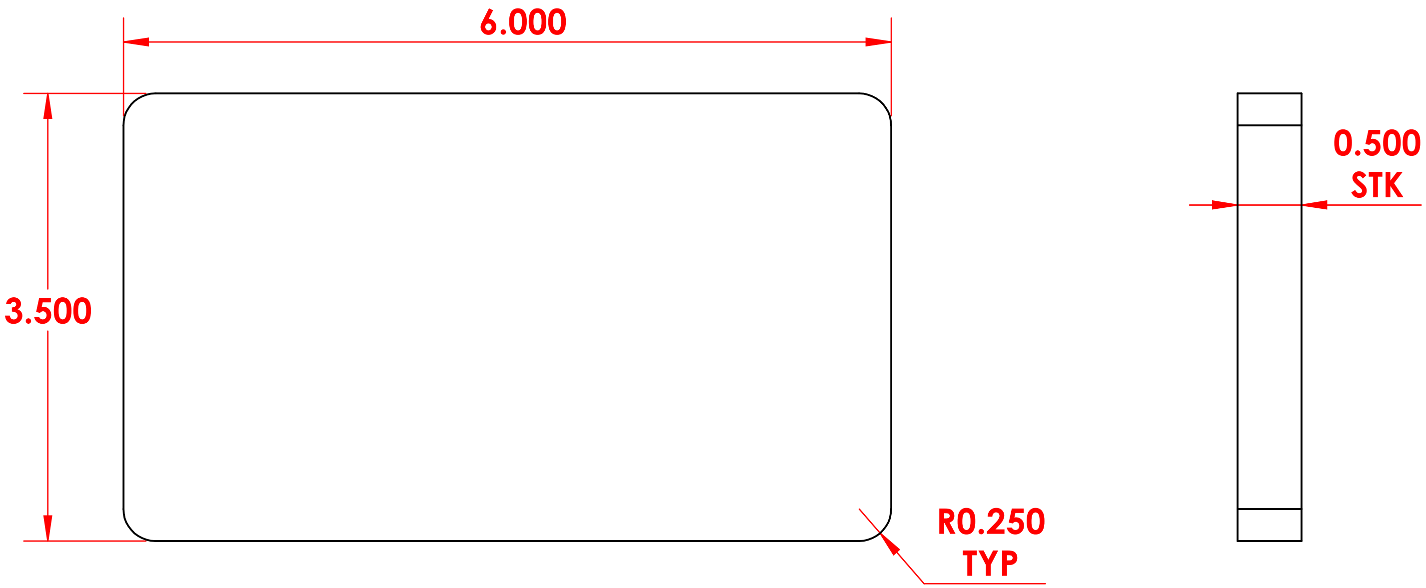


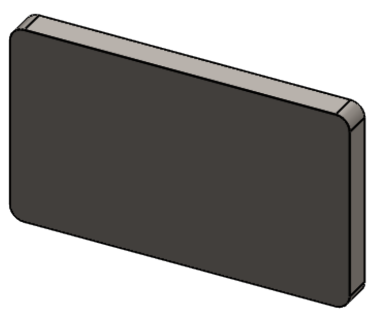
MODEL: Clamp Attachment Parts
CONFIG: SLOTTED PLATE 2

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SLOTTED PLATE 2			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF005			REV A
	SIZE A	SCALE 1:2	WEIGHT: 1.027 lbs	SHEET 1 OF 1

DWG NO:	REV
TF006	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



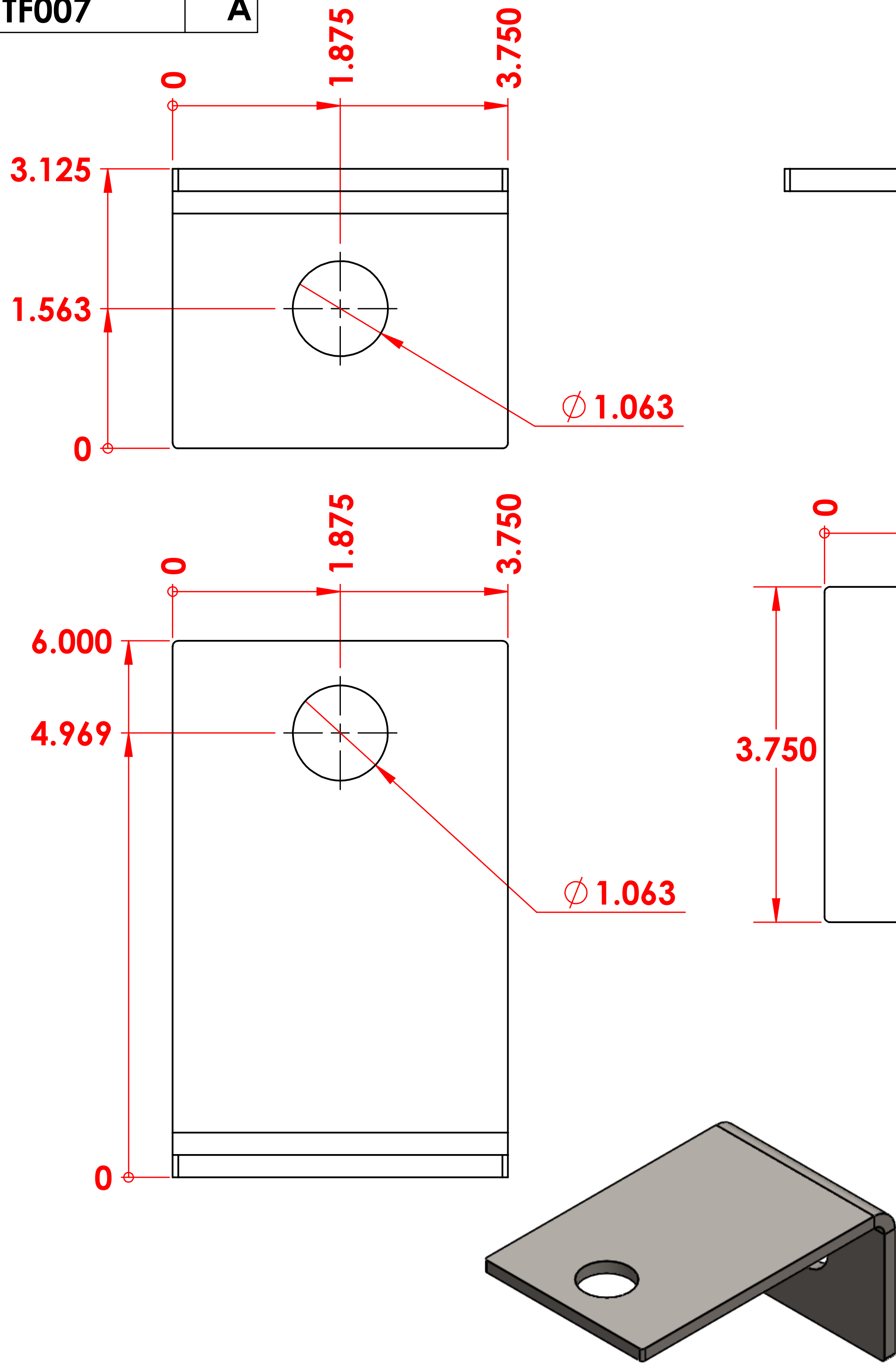


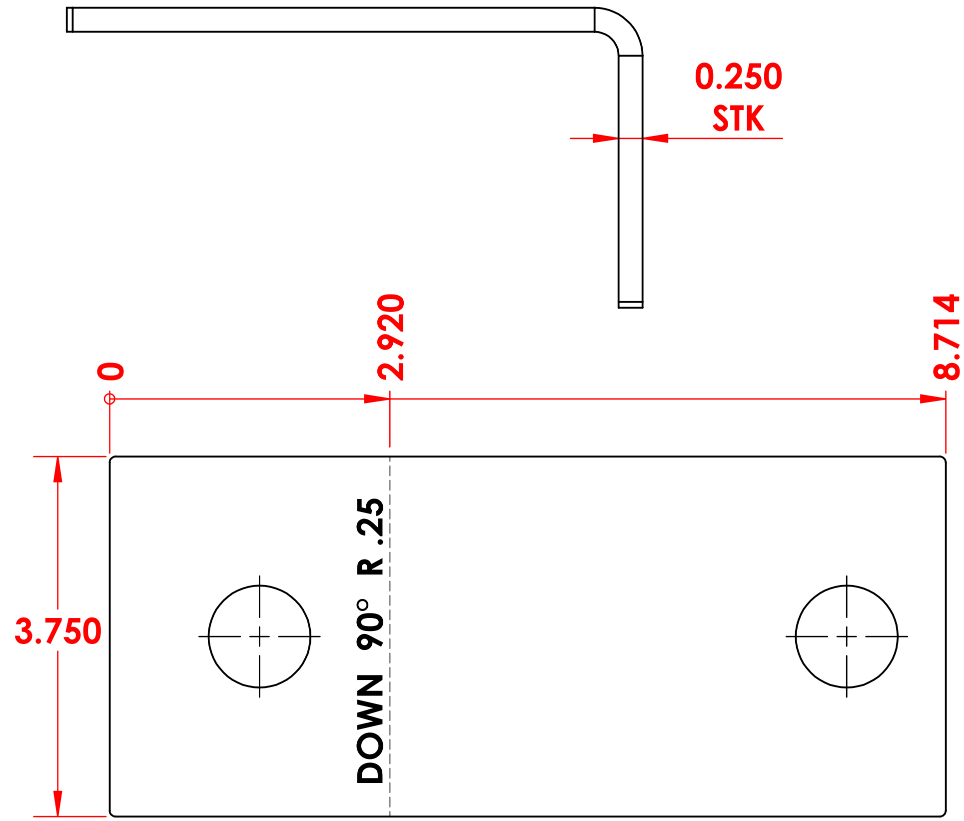
MODEL: Clamp Attachment Parts
CONFIG: CONTACT PLATE

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CONTACT PLATE			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF006			REV A
	SIZE A	SCALE 2:3	WEIGHT: 2.970 lbs	SHEET 1 OF 1

DWG NO:	REV
TF007	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



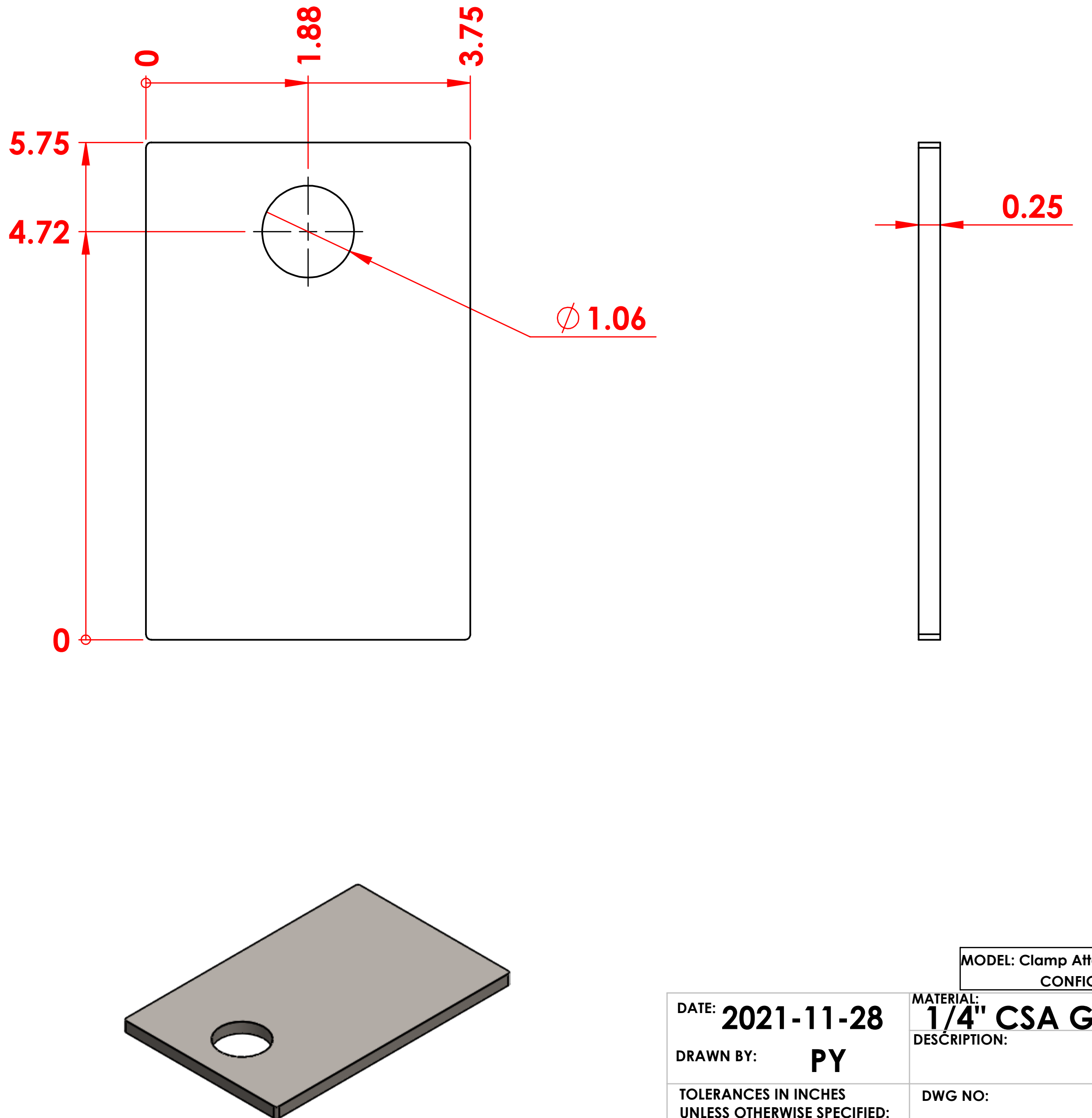


MODEL: Clamp Attachment Parts
CONFIG: ROD PLATE 1

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: ROD PLATE 1		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF007		REV A
	SIZE A	SCALE 1:2	WEIGHT: 2.191 lbs	SHEET 1 OF 1

DWG NO:	REV
TF008	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue

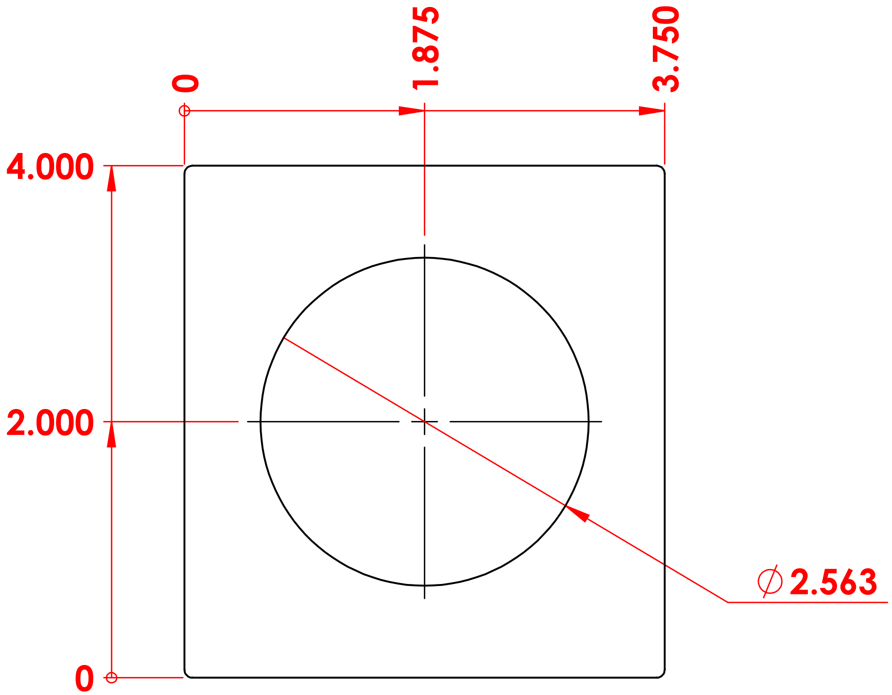


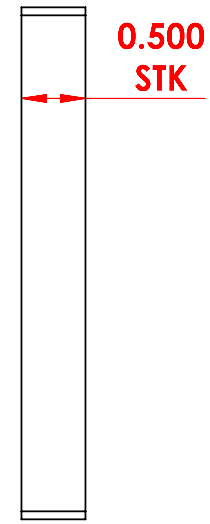
MODEL: Clamp Attachment Parts
CONFIG: ROD PLATE 2

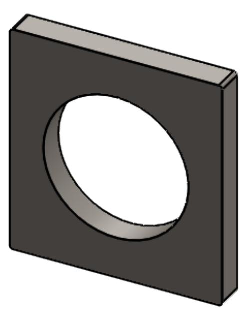
DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: ROD PLATE 2			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF008			REV A
	SIZE A	SCALE 1:2	WEIGHT: 1.466 lbs	SHEET 1 OF 1

DWG NO:	REV
TF009	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue





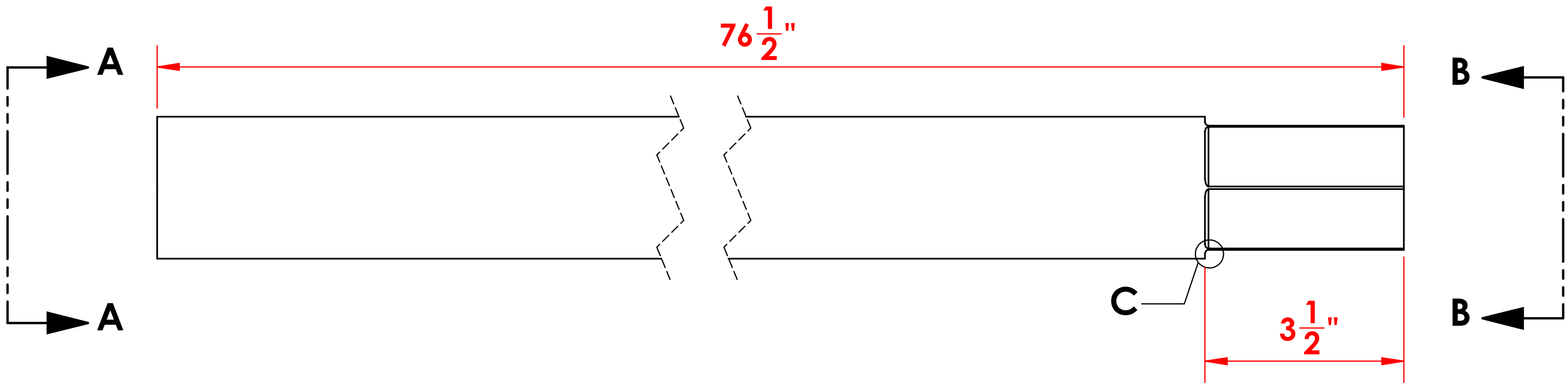


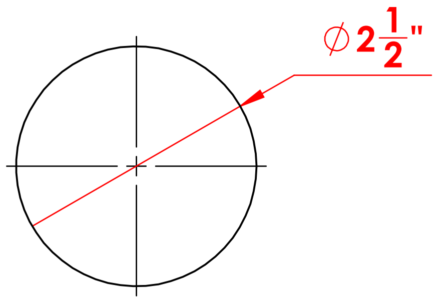
MODEL: Clamp Attachment Parts
CONFIG: SHAFT PLATE

DATE: 2021-11-28	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SHAFT PLATE		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF009		REV: A
	SIZE: A	SCALE: 2:3	WEIGHT: 1.395 lbs
	SHEET: 1 OF 1		

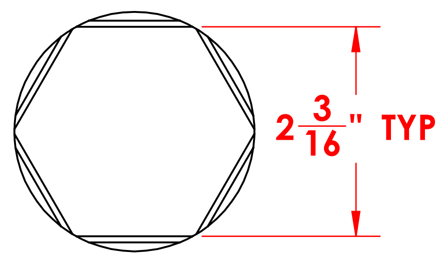
DWG NO:	REV
TF010	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue

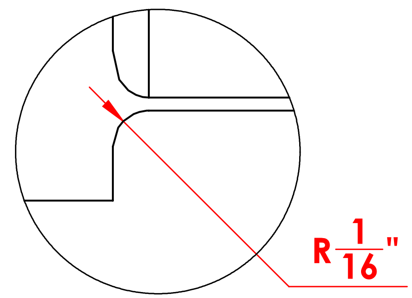




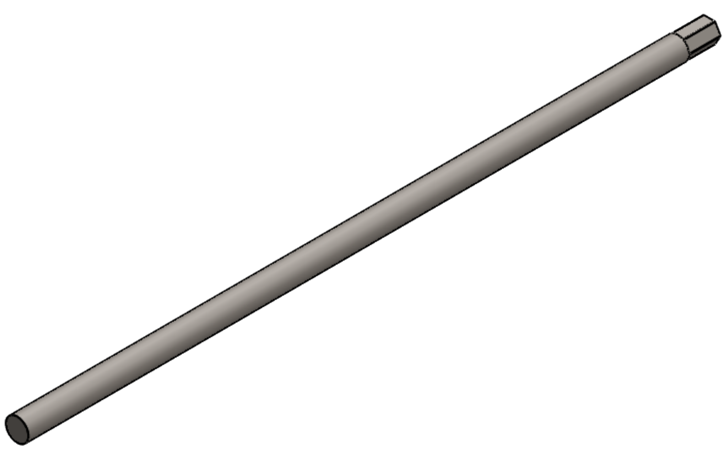
SECTION A-A
SCALE 1 : 2



SECTION B-B
SCALE 1 : 2



DETAIL C
SCALE 3 : 1

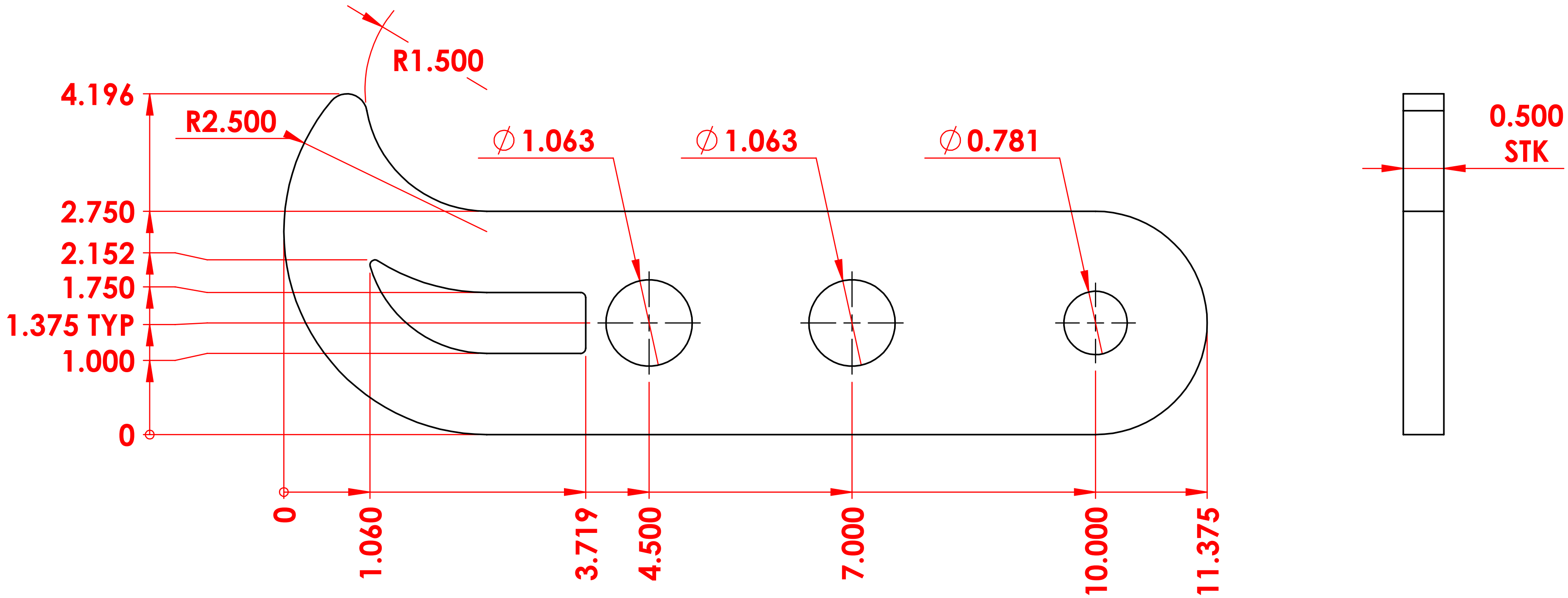


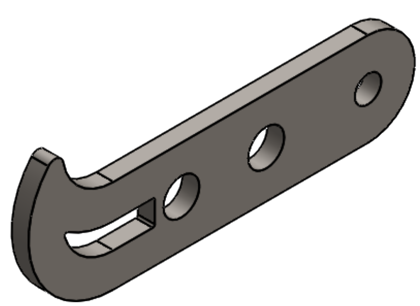
MODEL: Clamp Attachment Parts
CONFIG: SHAFT

DATE: 2021-11-28	MATERIAL: 2.5" MS ROUND BAR			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SHAFT			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF010			REV A
	SIZE A	SCALE 1:3	WEIGHT: 105.738 lbs	SHEET 1 OF 1

DWG NO: TF011 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



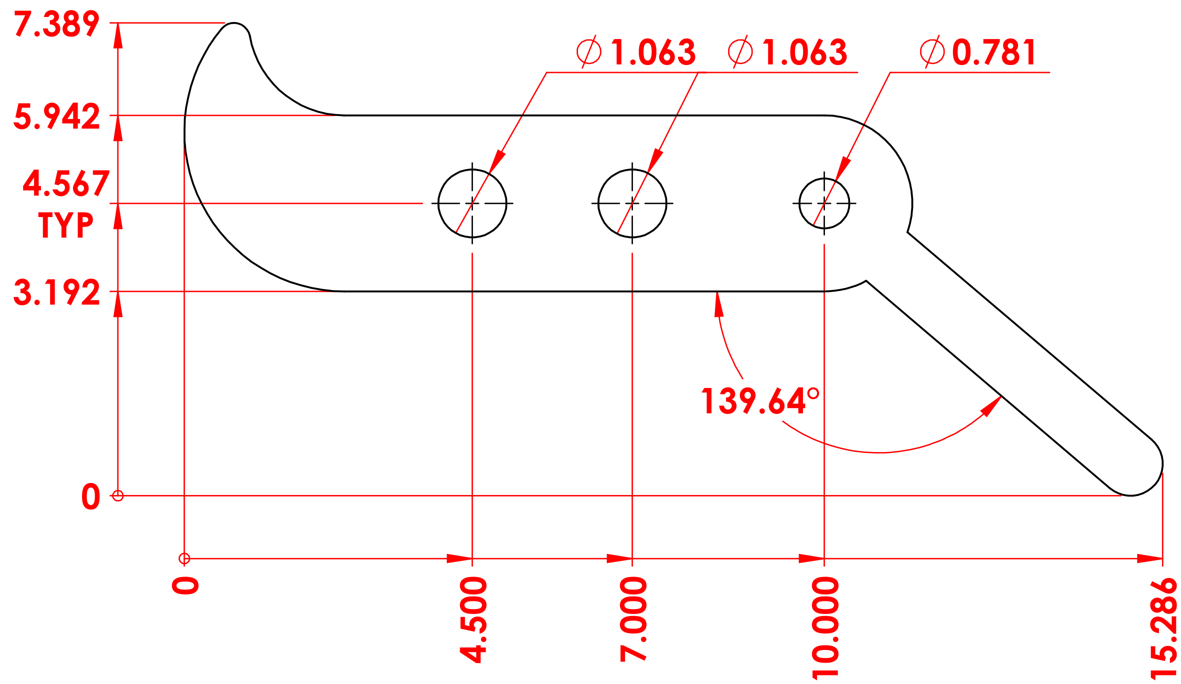


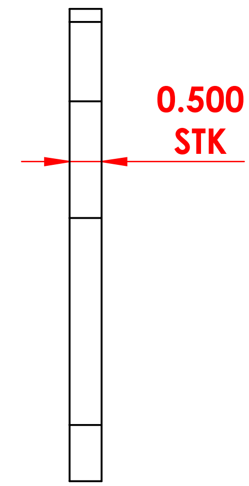
MODEL: Clamp Attachment Parts
CONFIG: HOOK 1

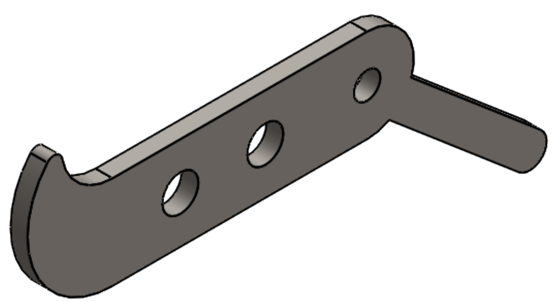
DATE: 2021-11-28	MATERIAL: 1/2" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: HOOK 1			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF011			REV A
	SIZE A	SCALE 1:2	WEIGHT: 3.779 lbs	SHEET 1 OF 1

DWG NO:	REV
TF012	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue





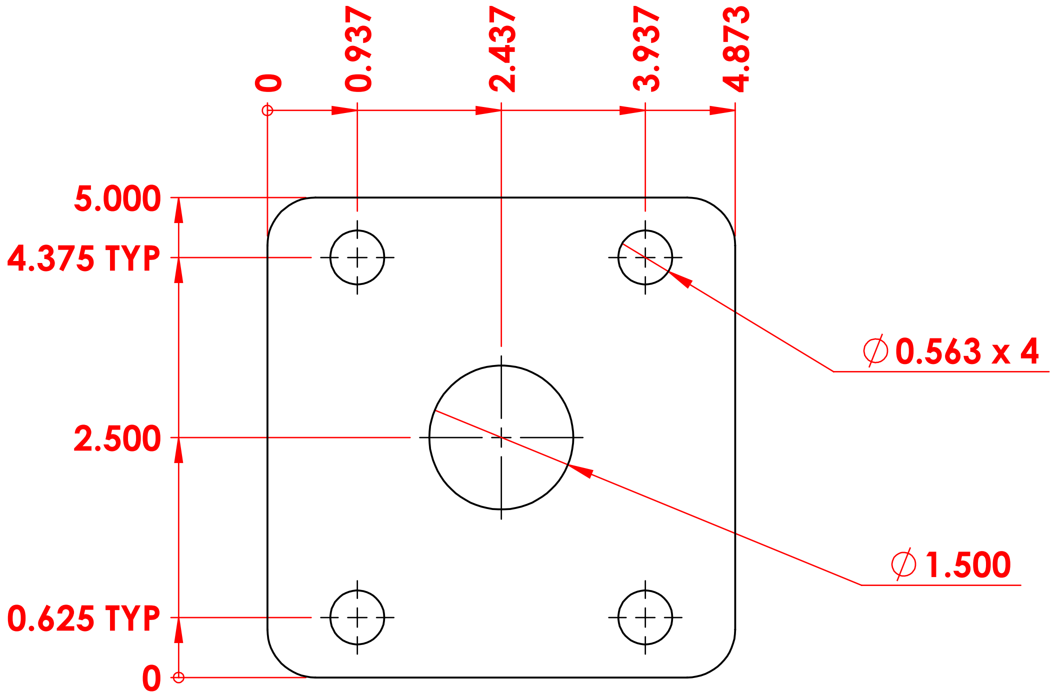


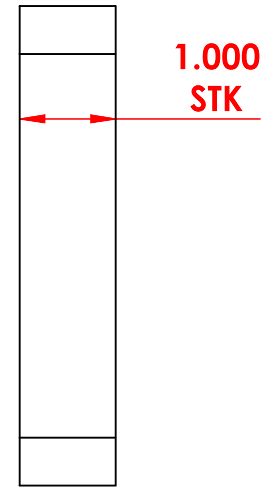
MODEL: Clamp Attachment Parts
CONFIG: HOOK 2

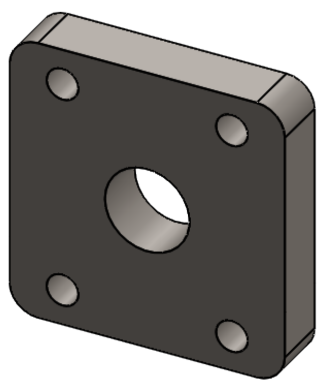
DATE: 2021-11-28	MATERIAL: 1/2" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: HOOK 2			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF012			REV A
	SIZE A	SCALE 1:3	WEIGHT: 4.789 lbs	SHEET 1 OF 1

DWG NO:	REV
TF013	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue





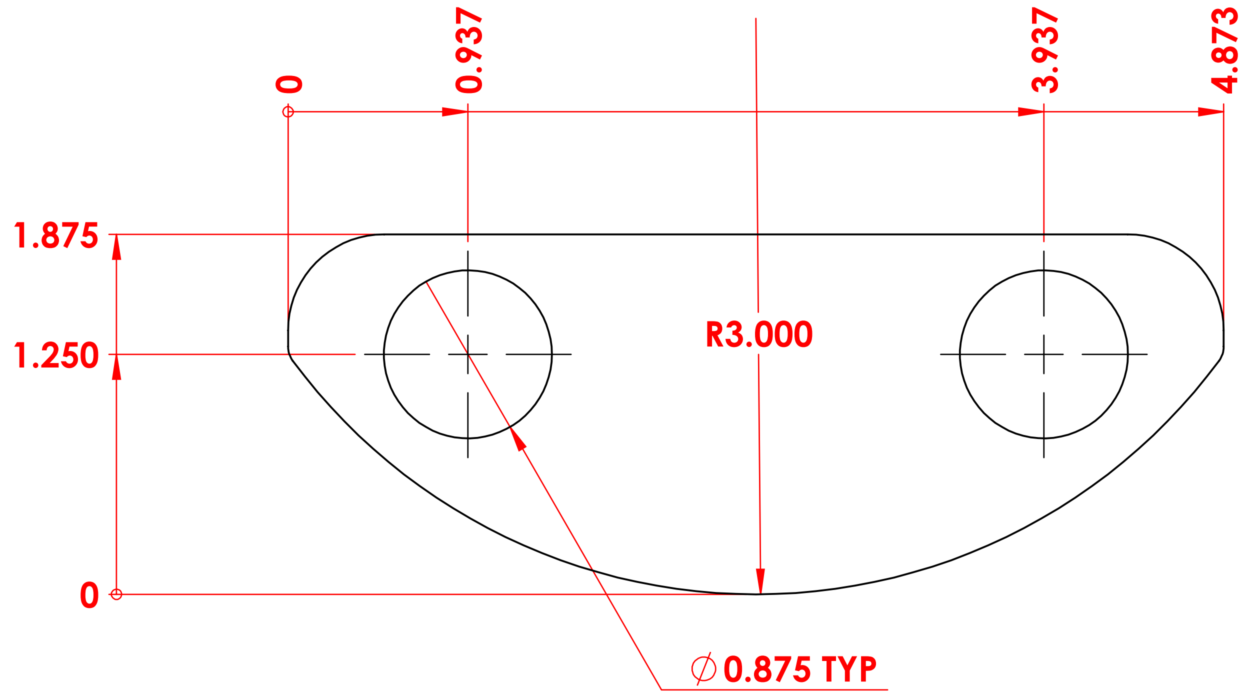


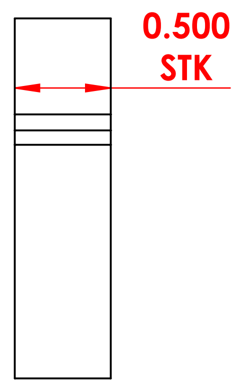
MODEL: Clamp Attachment Parts
CONFIG: CABLE PLATE 1

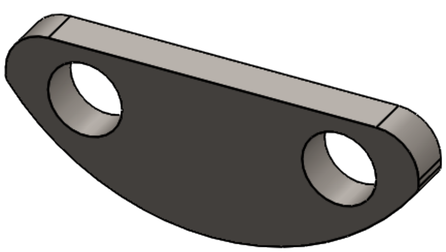
DATE: 2021-11-28	MATERIAL: 1" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CABLE PLATE 1		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF013		REV A
	SIZE A	SCALE 1:2	WEIGHT: 6.067 lbs
			SHEET 1 OF 1

DWG NO:	REV
TF014	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue





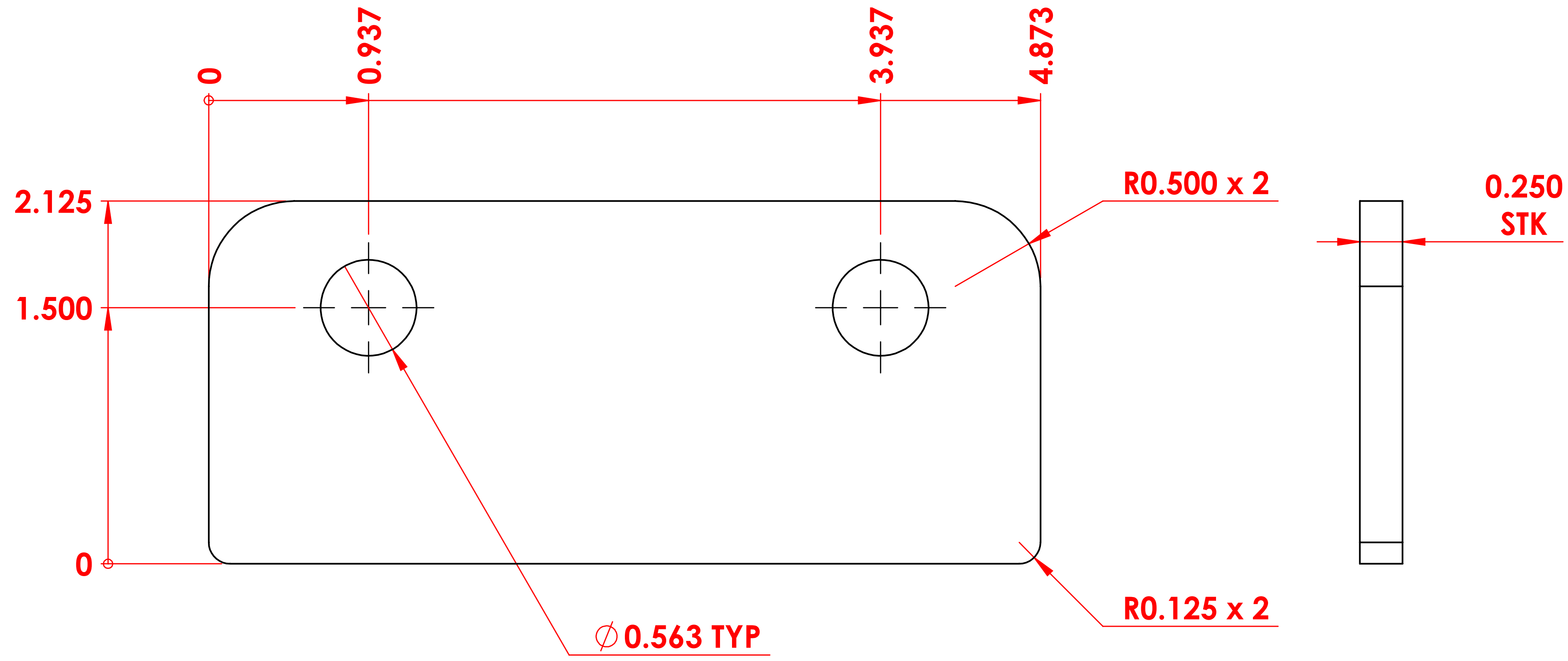


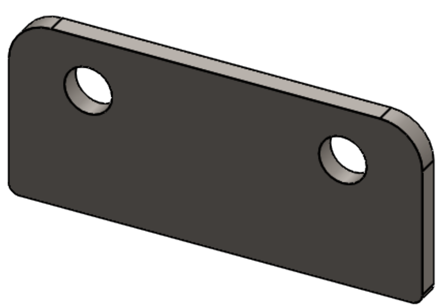
MODEL: Clamp Attachment Parts
CONFIG: CABLE PLATE 2

DATE: 2021-11-28	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CABLE PLATE 2		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF014		REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.851 lbs	SHEET 1 OF 1

DWG NO:	REV
TF015	A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



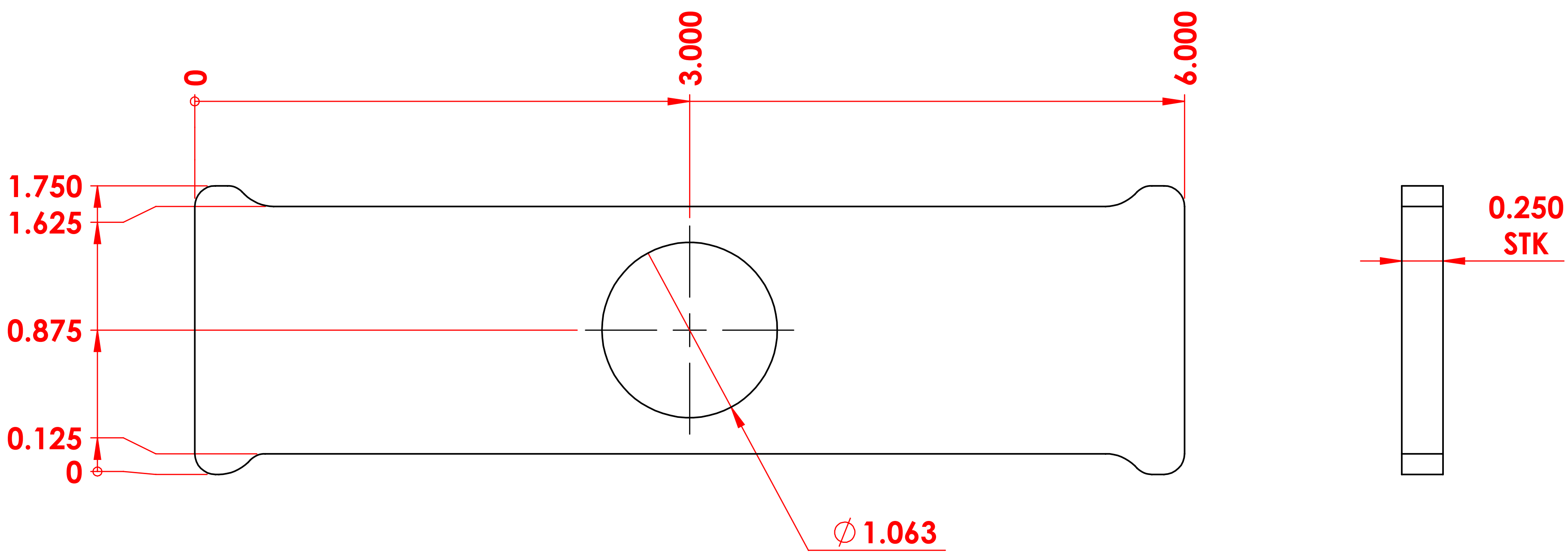


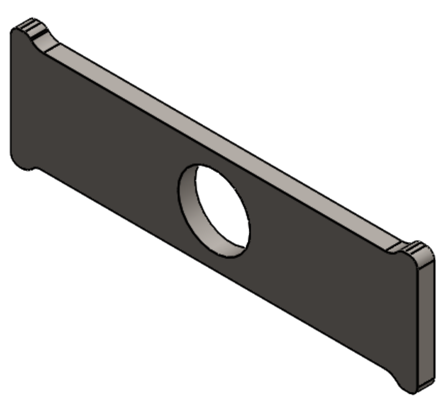
MODEL: Clamp Attachment Parts
CONFIG: CABLE PLATE 3

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CABLE PLATE 3		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF015		REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.691 lbs	SHEET 1 OF 1

DWG NO: TF016 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-11-28	PY	Issue



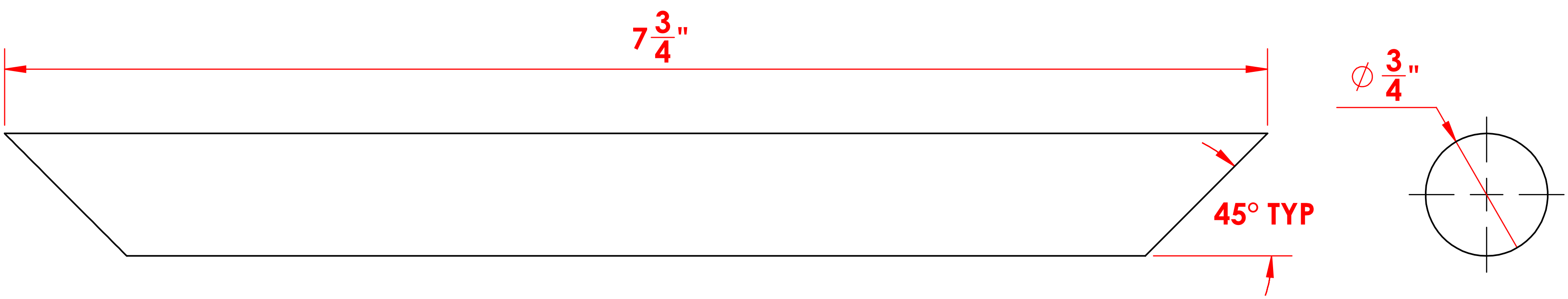


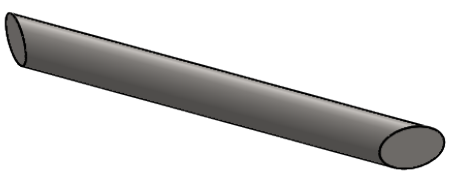
MODEL: Clamp Attachment Parts
CONFIG: ROD HANDLE

DATE: 2021-11-28	MATERIAL: 1/4" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: ROD HANDLE			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF016			REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.586 lbs	SHEET 1 OF 1

DWG NO: TF017	REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-04	PY	Issue



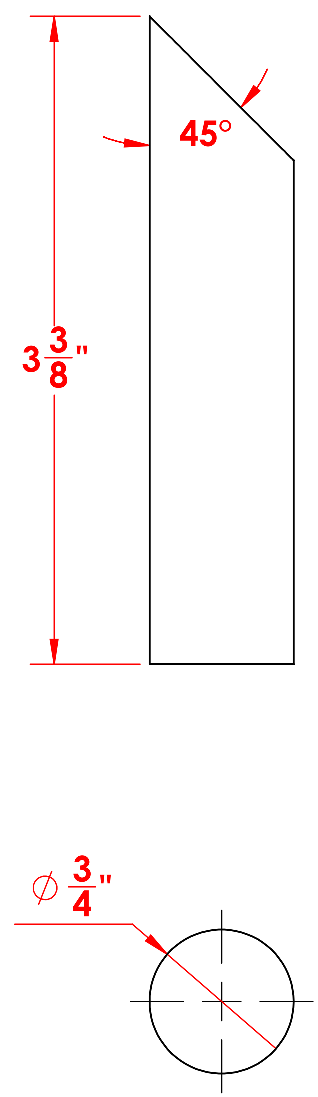


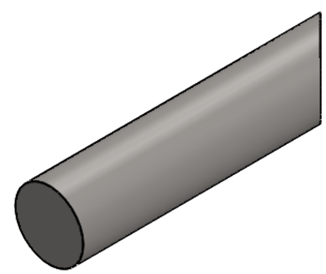
MODEL: Handle Parts
CONFIG: HANDLE 1

DATE: 2021-12-04	MATERIAL: 3/4" MS ROUND BAR			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: HANDLE PIECE 1			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF017			REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.894 lbs	SHEET 1 OF 1

DWG NO:	REV
TF018	A

REV	DATE	BY	DESCRIPTION
A	2021-12-04	PY	Issue



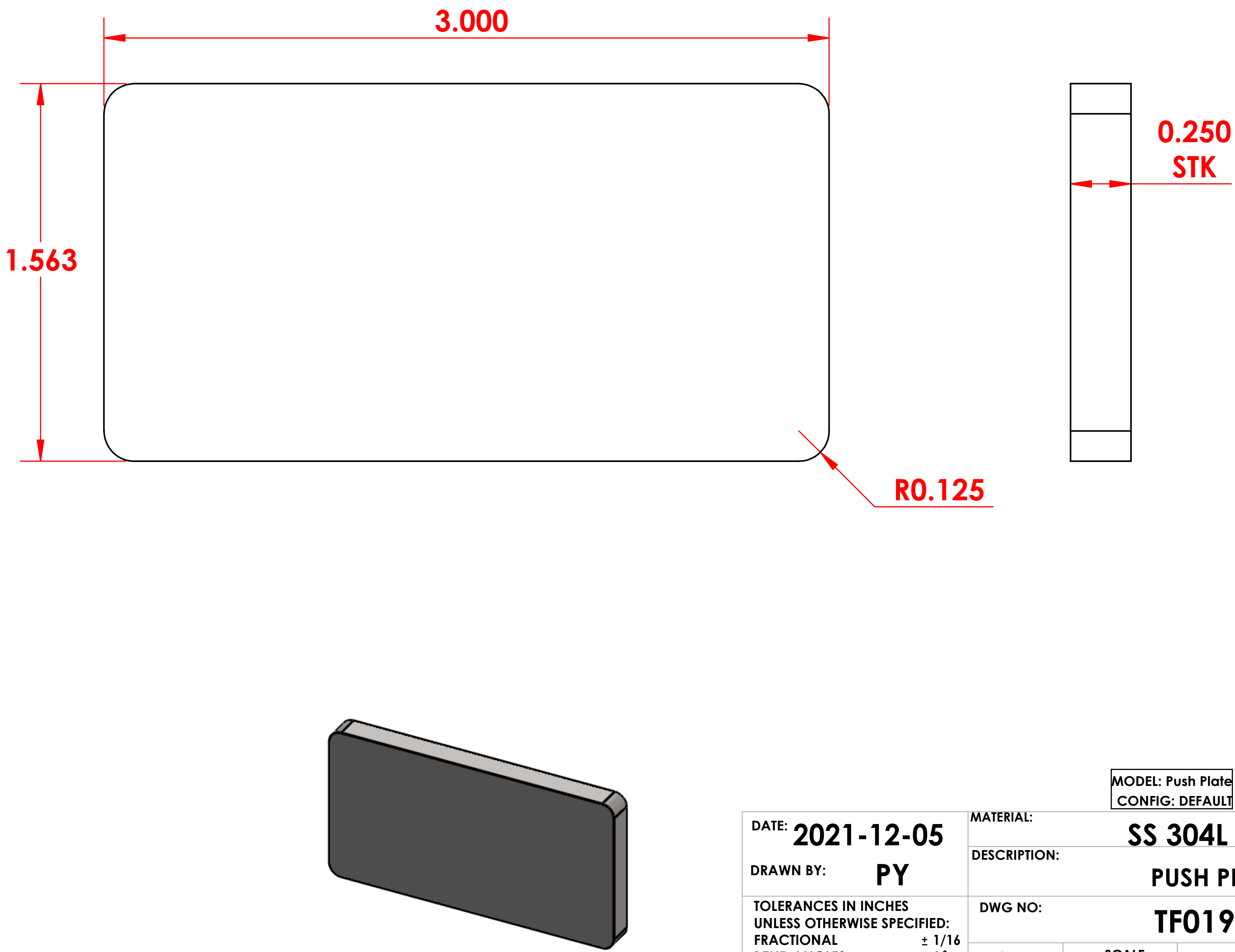


MODEL: Handle Parts
CONFIG: HANDLE 2

DATE: 2021-12-04	MATERIAL: 3/4" MS ROUND BAR		FINISH: 2B
DRAWN BY:	DESCRIPTION: HANDLE PIECE 2		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:	DWG NO: TF018		REV A
FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	SIZE A	SCALE 1:1	WEIGHT: 0.383 lbs
			SHEET 1 OF 1

DWG NO:	REV
TF019	A

REV	DATE	BY	DESCRIPTION
A	2021-12-05	PY	Issue

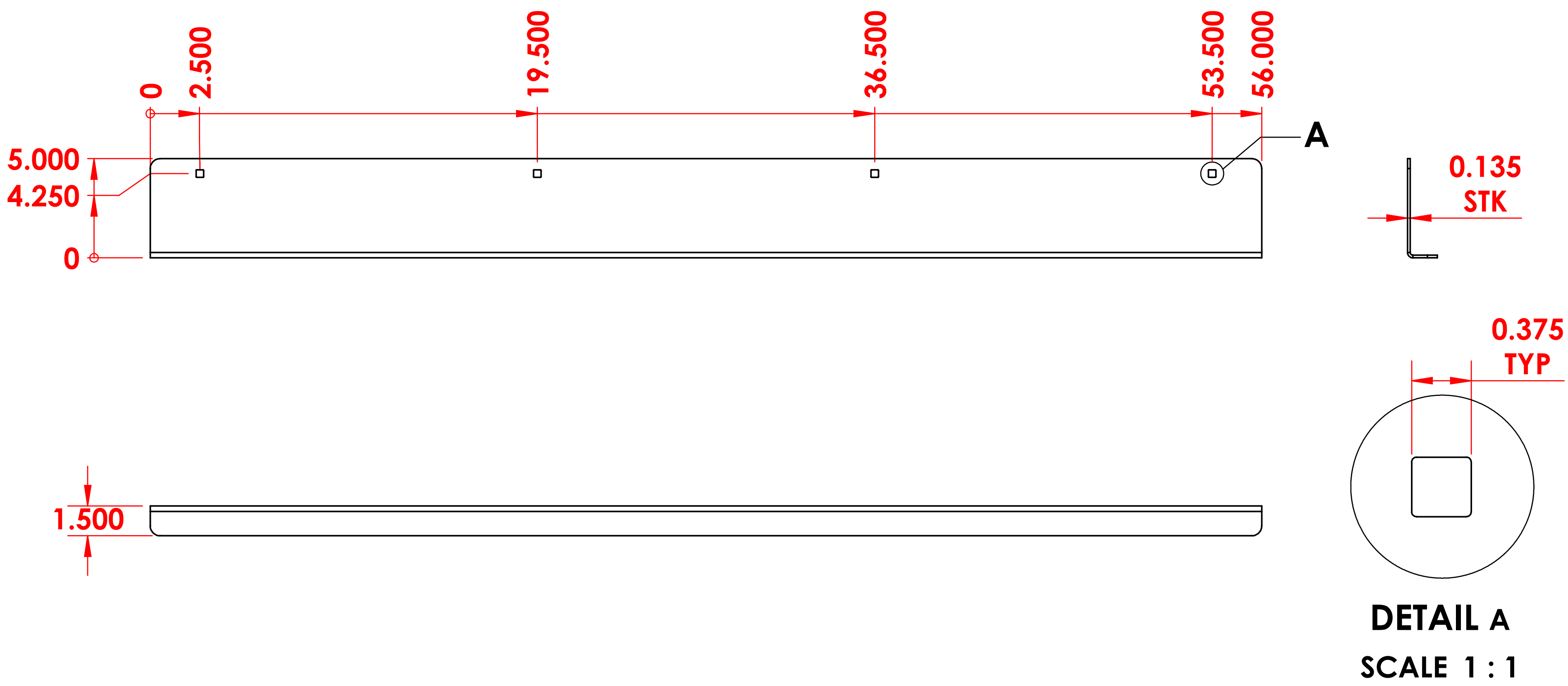


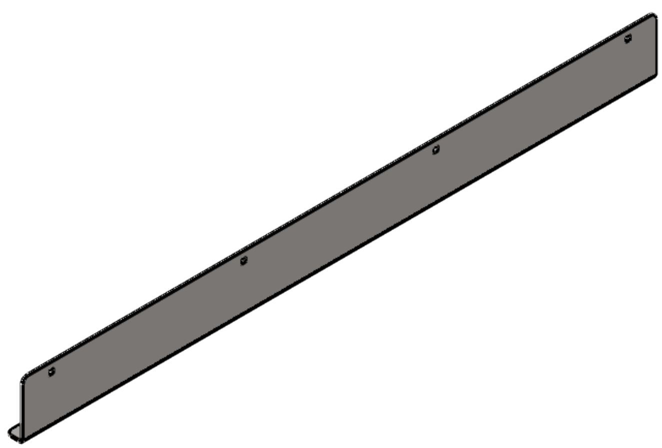
MODEL: Push Plate
CONFIG: DEFAULT

DATE: 2021-12-05	MATERIAL: SS 304L		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: PUSH PLATE		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF019		REV A
	SIZE A	SCALE 3:2	WEIGHT: 0.338 lbs
	SHEET 1 OF 1		

DWG NO: TF020 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-04	PY	Issue



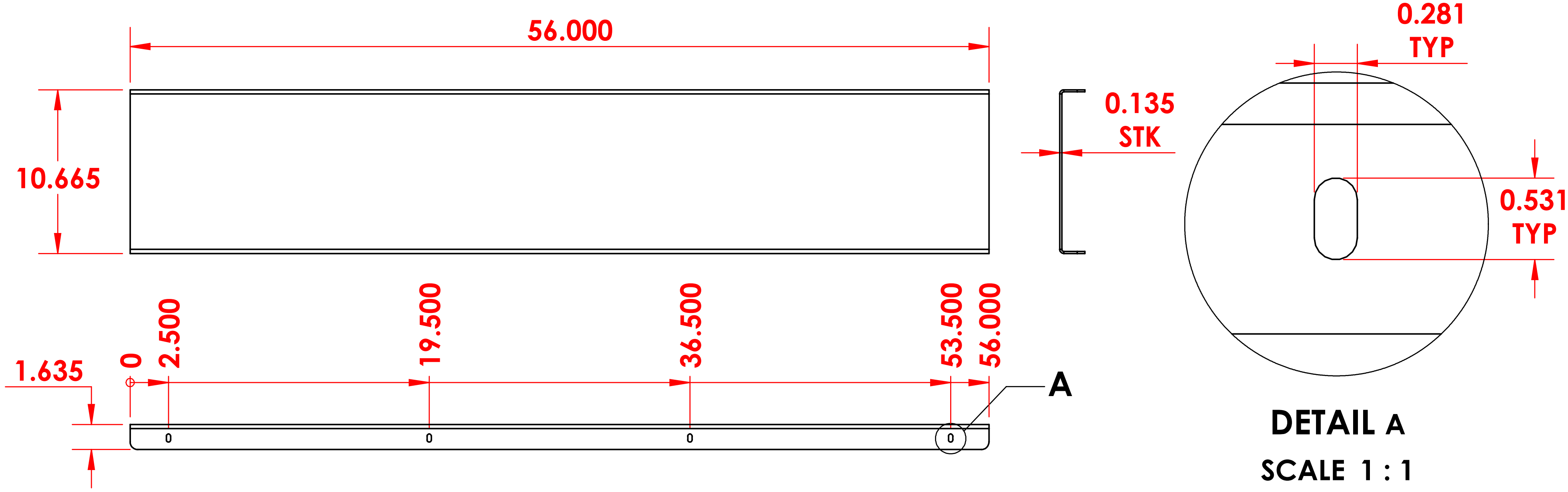


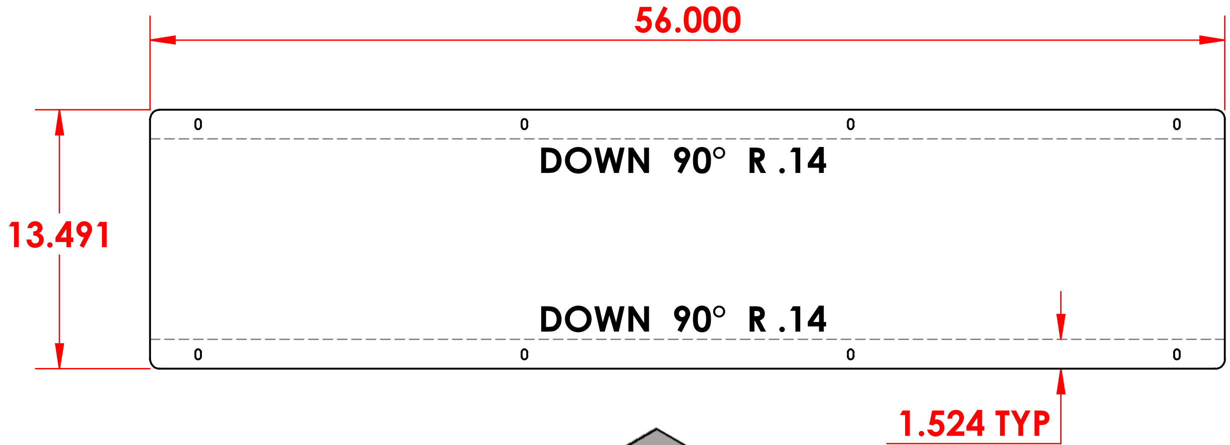
MODEL: Shaft Guard Parts
CONFIG: GUARD MOUNT

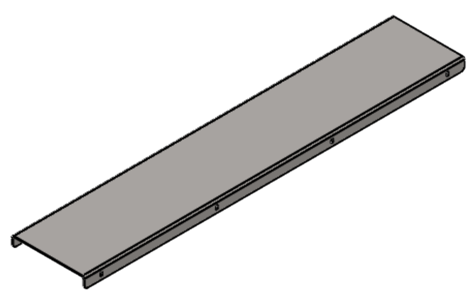
DATE: 2021-12-04	MATERIAL: 10GA CSA G40.21 44W/300W				FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SHAFT GUARD MOUNT				
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF020			REV A	
	SIZE A	SCALE 1:8	WEIGHT: 13.687 lbs	SHEET 1 OF 1	

DWG NO:	REV
TF021	A

REV	DATE	BY	DESCRIPTION
A	2021-12-04	PY	Issue





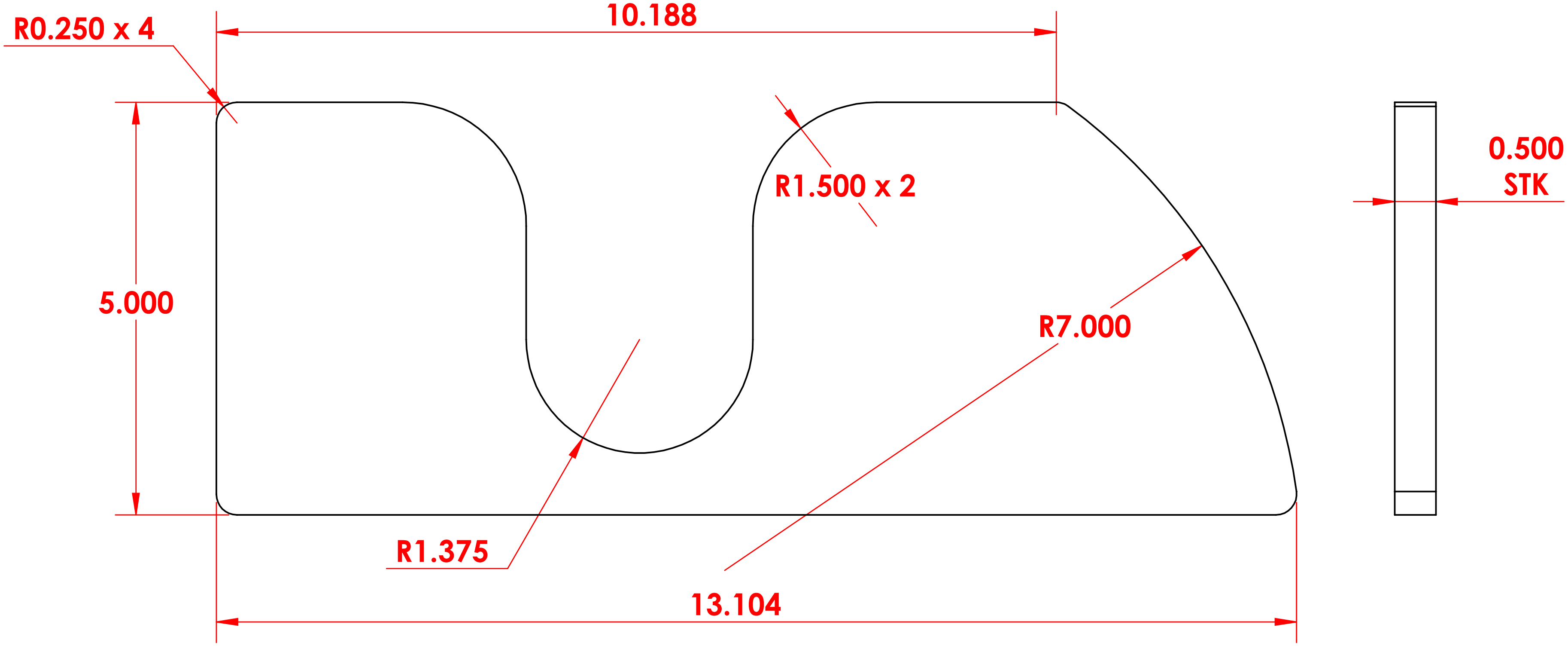


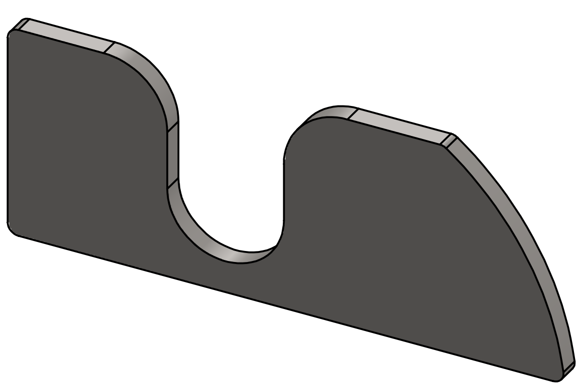
MODEL: Shaft Guard Parts
CONFIG: GUARD

DATE: 2021-12-04	MATERIAL: 10GA CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SHAFT GUARD			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF021			REV A
	SIZE A	SCALE 1:10	WEIGHT: 29.428 lbs	SHEET 1 OF 1

DWG NO: TF022	REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-04	PY	Issue



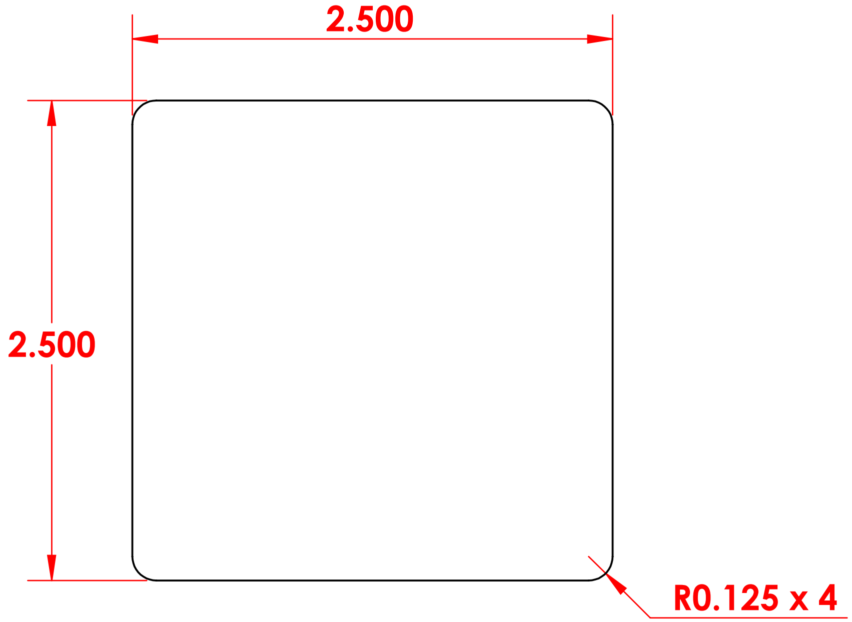


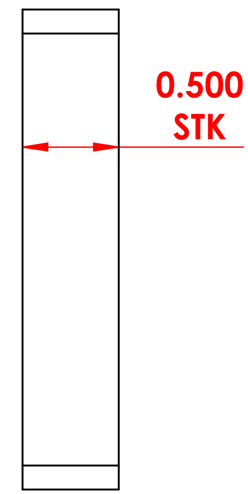
MODEL: Shaft Guard Parts
CONFIG: END PLATE

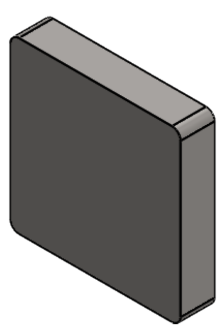
DATE: 2021-12-04	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SHAFT GUARD END PLATE		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF022		REV A
	SIZE A	SCALE 1:2	WEIGHT: 7.085 lbs	SHEET 1 OF 1

DWG NO: TF023	REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-07	PY	Issue





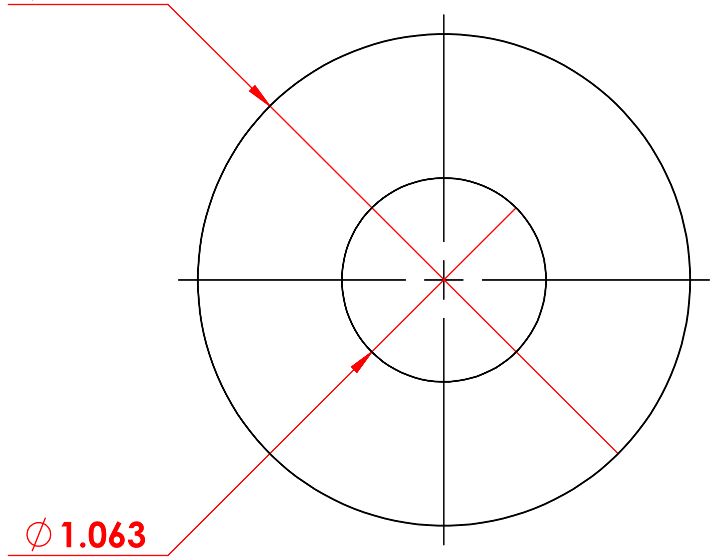


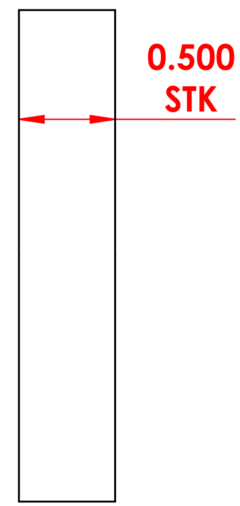
MODEL: Torque Register Parts
CONFIG: REGISTER 1

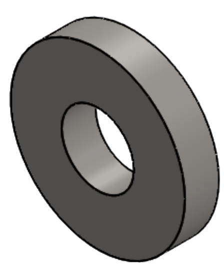
DATE: 2021-12-07	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: TORQUE REGISTER 1		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:	DWG NO: TF023		REV A
FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	SIZE A	SCALE 1:1	WEIGHT: 0.901 lbs
			SHEET 1 OF 1

DWG NO:	REV
TF024	A

REV	DATE	BY	DESCRIPTION
A	2021-12-05	PY	Issue





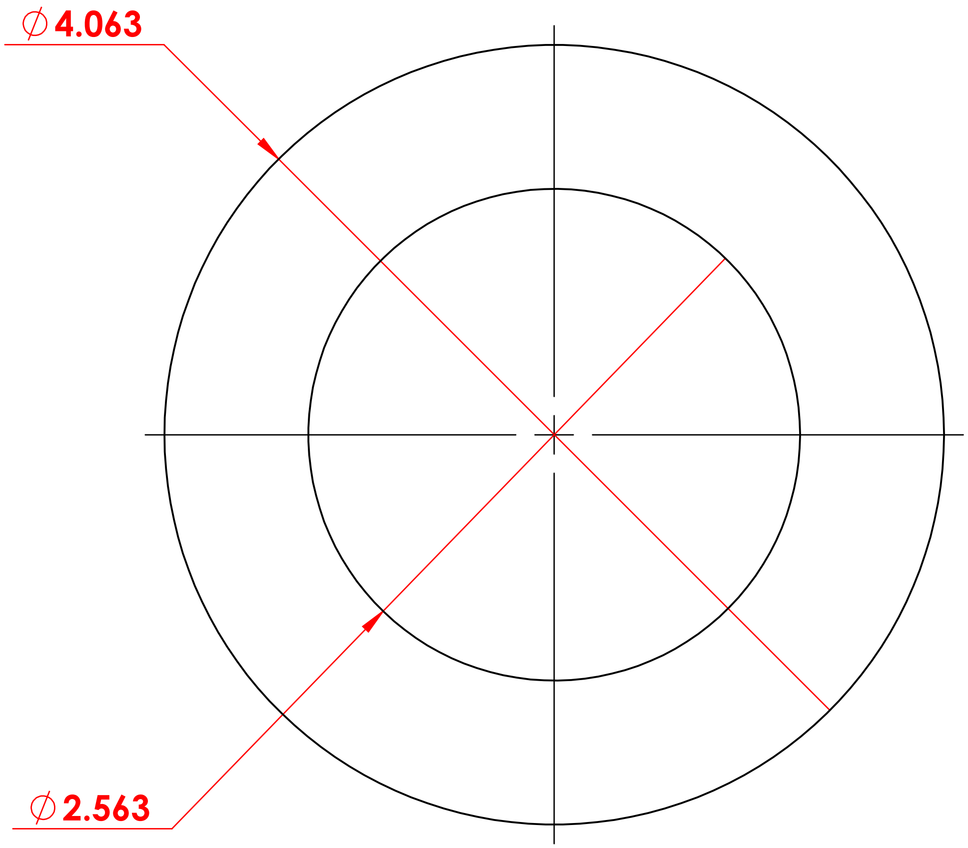


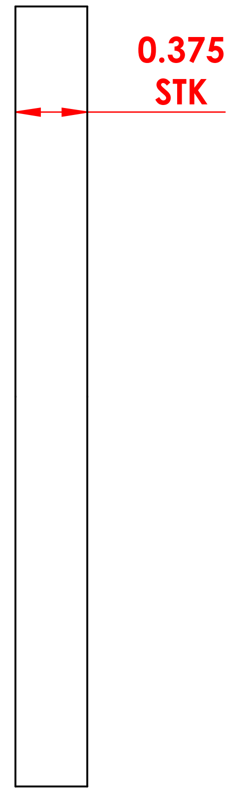
MODEL: Spacer
CONFIG: SPACER

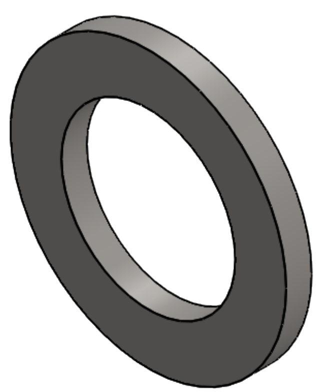
DATE: 2021-12-05	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: HOOK SPACER		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF024		REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.617 lbs
			SHEET 1 OF 1

DWG NO:	REV
TF025	A

REV	DATE	BY	DESCRIPTION
A	2021-12-05	PY	Issue





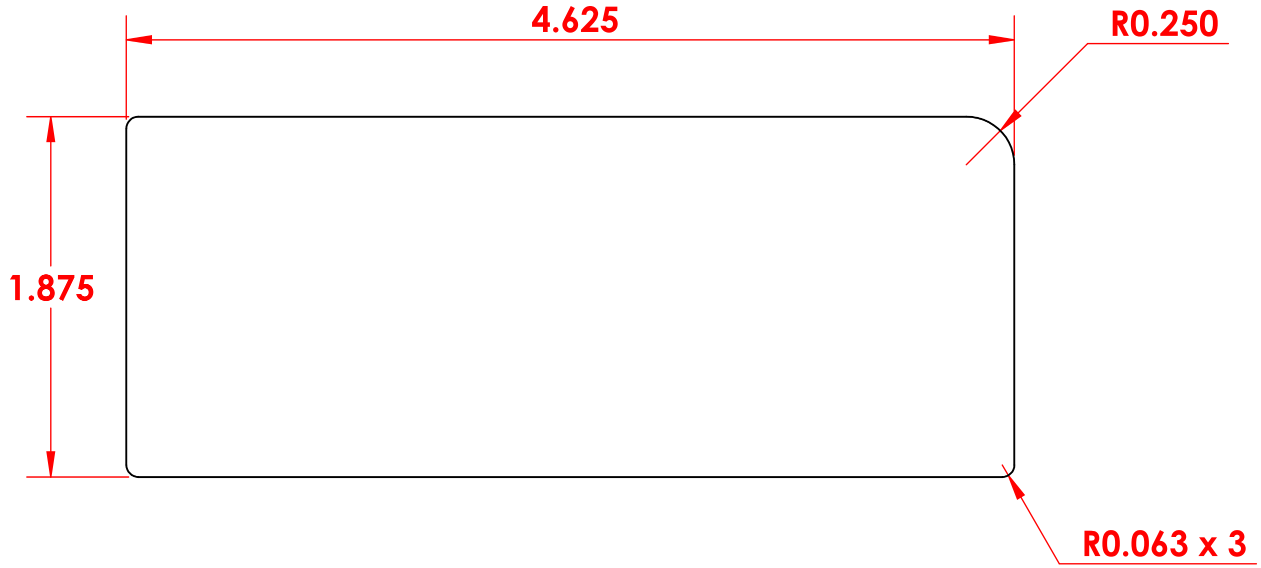


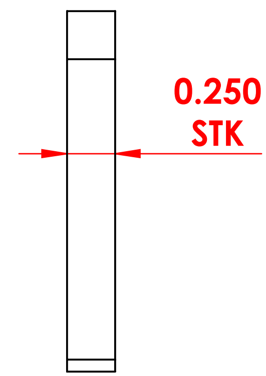
MODEL: Spacer
CONFIG: RETAINING RING

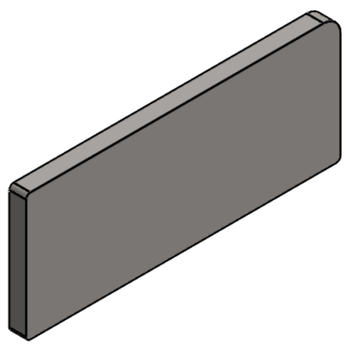
DATE: 2021-12-05	MATERIAL: 3/8" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: RETAINING RING		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF025		REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.846 lbs
			SHEET 1 OF 1

DWG NO:	REV
TF026	A

REV	DATE	BY	DESCRIPTION
A	2021-12-05	PY	Issue





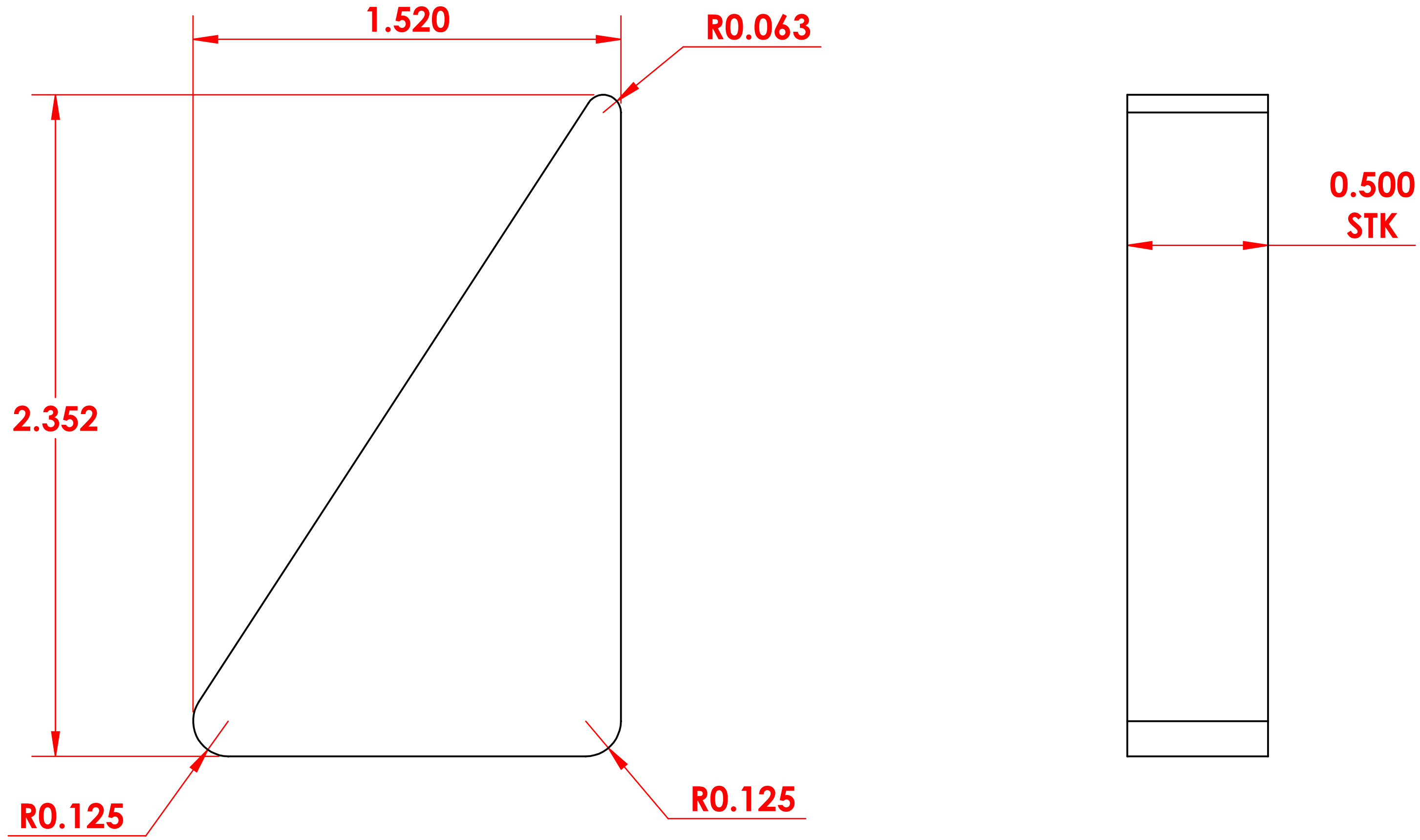


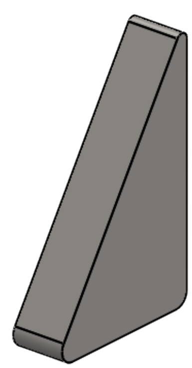
MODEL: Support Clamp Plate
CONFIG: DEFAULT

DATE: 2021-12-05	MATERIAL: 1/4" CSA G40.21 44W/300W			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: SUPPORT CLAMP PLATE			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF026			REV A
	SIZE A	SCALE 1:1	WEIGHT: 0.625 lbs	SHEET 1 OF 1

DWG NO: TF027	REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-07	PY	Issue



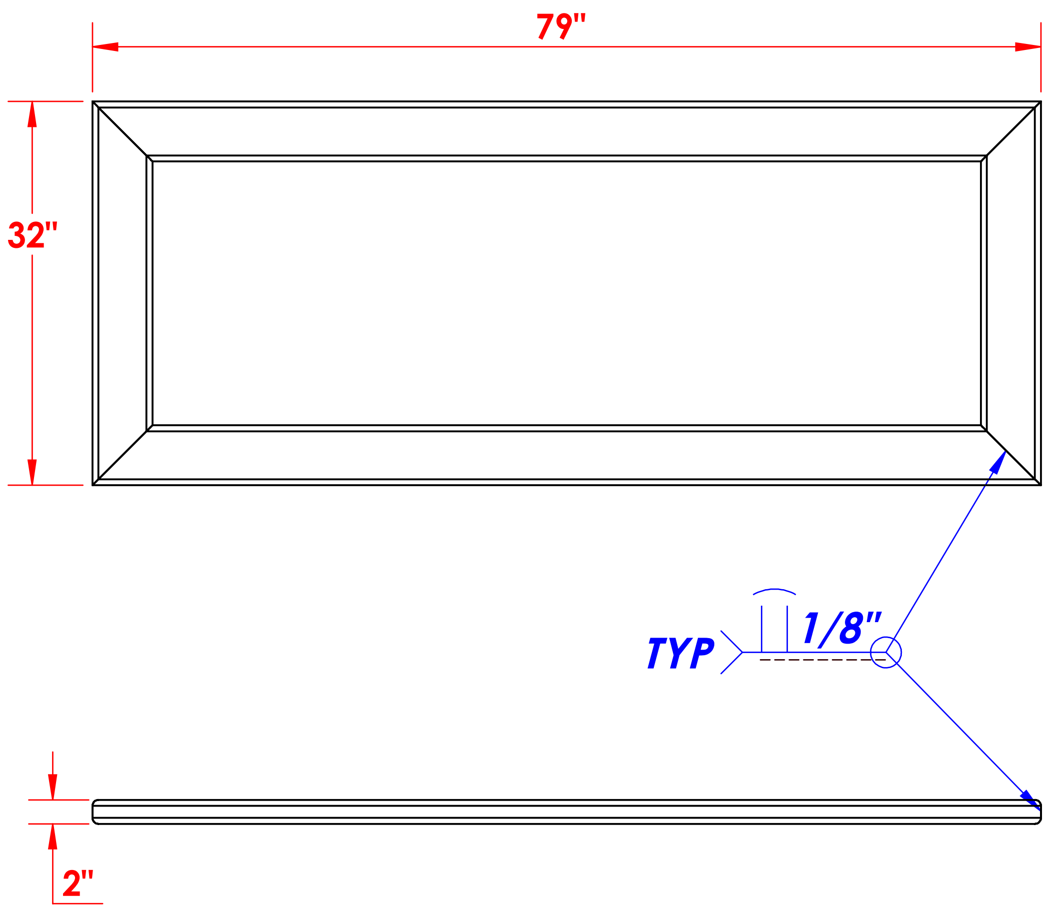


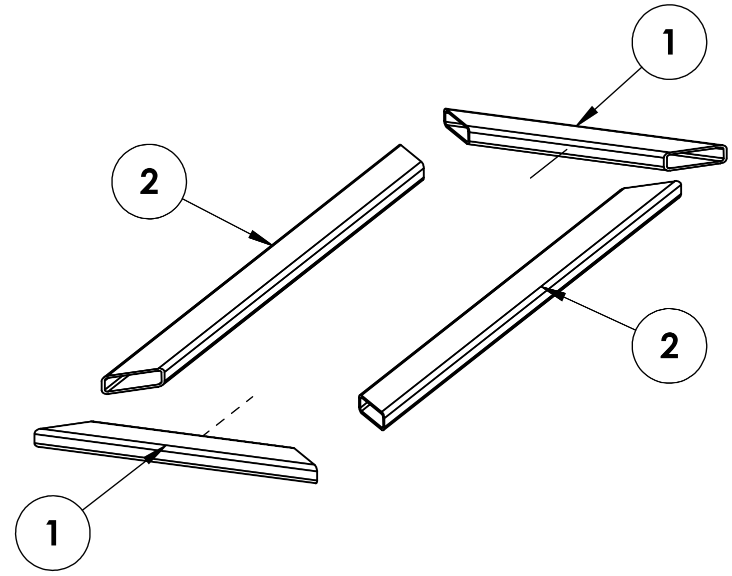
MODEL: Torque Register Parts
CONFIG: REGISTER 2

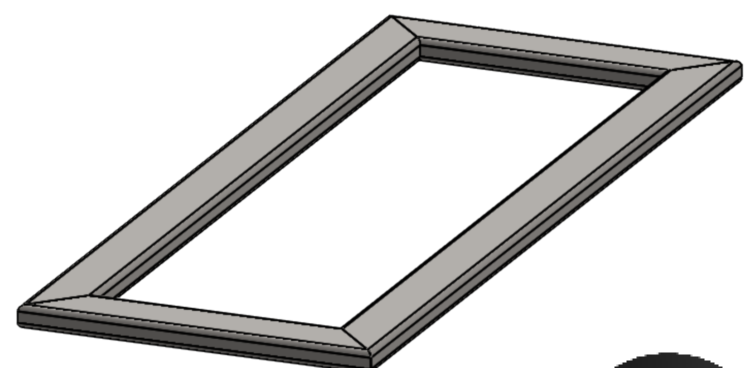
DATE: 2021-12-07	MATERIAL: 1/2" CSA G40.21 44W/300W				FINISH: 2B
DRAWN BY: PY	DESCRIPTION: TORQUE REGISTER 2				
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:	DWG NO: TF027			REV A	
FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	SIZE A	SCALE 3:2	WEIGHT: 0.290 lbs	SHEET 1 OF 1	

DWG NO:	REV
TF028	A

REV	DATE	BY	DESCRIPTION
A	2021-12-07	PY	Issue







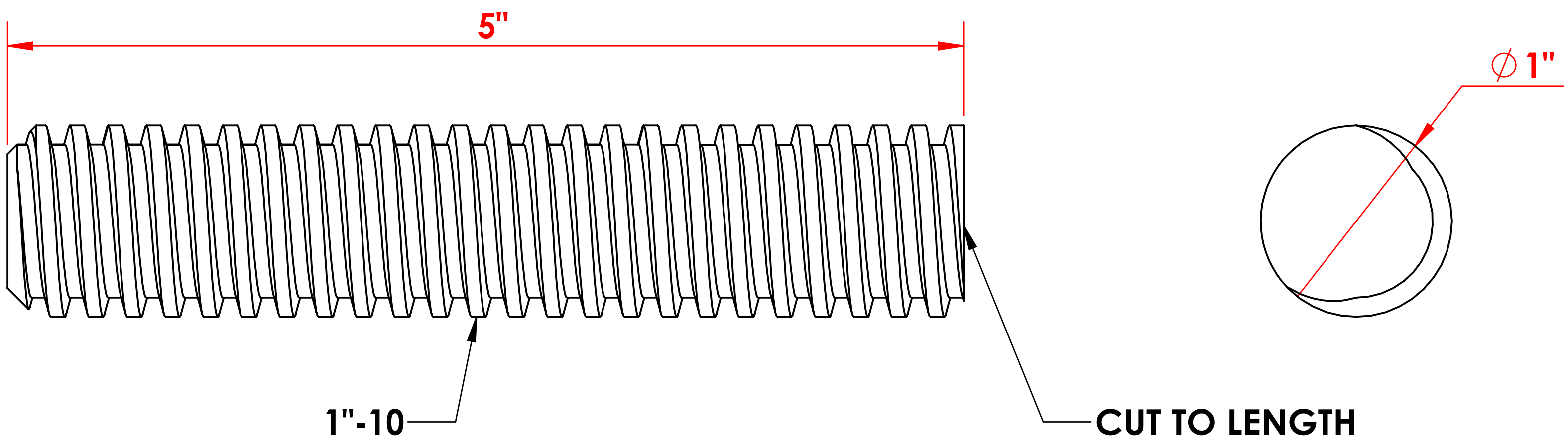
MODEL: Base Tubing Wdmt
CONFIG: Default

DATE: 2021-12-07	MATERIAL: ASTM A500			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: BASE TUBING FRAME WDMT			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF028			REV A
	SIZE A	SCALE 1:16	WEIGHT: 180.349 lbs	SHEET 1 OF 1

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF001	A	BASE TUBING 1	2
2	TF002	A	BASE TUBING 2	2

DWG NO: TF029 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-10-22	PY	Issue



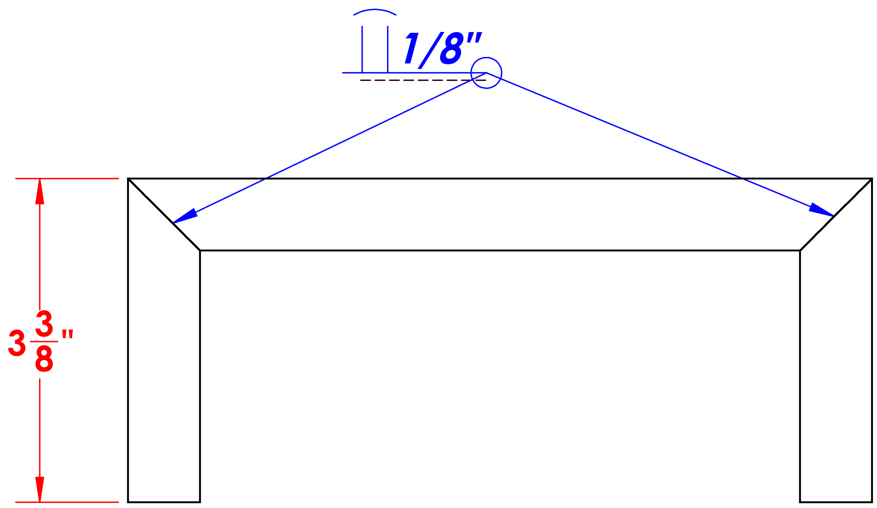
MODEL: Cut Threaded Rod
CONFIG: Default

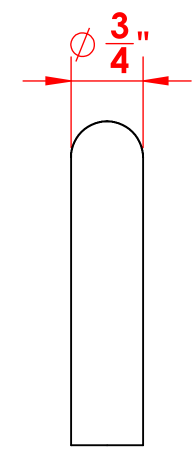
DATE: 2021-10-22	MATERIAL: Zinc Plated Carbon Steel		FINISH: -
DRAWN BY: PY	DESCRIPTION: 5" CUT THREADED ROD		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF029		REV A
SIZE A	SCALE 1:1	WEIGHT: 0.115 lbs	SHEET 1 OF 1

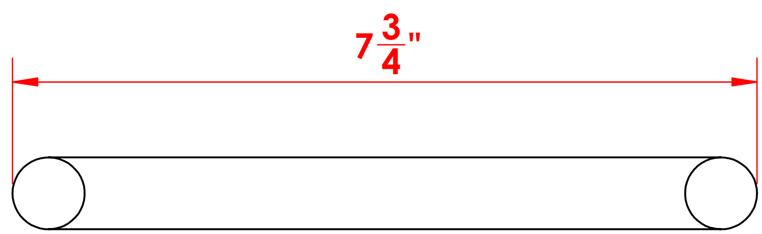
ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF004	A	1"-10, 12" ACME LEAD SCREW	1

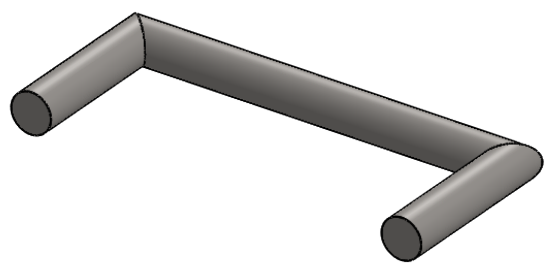
DWG NO: TF030 REV A

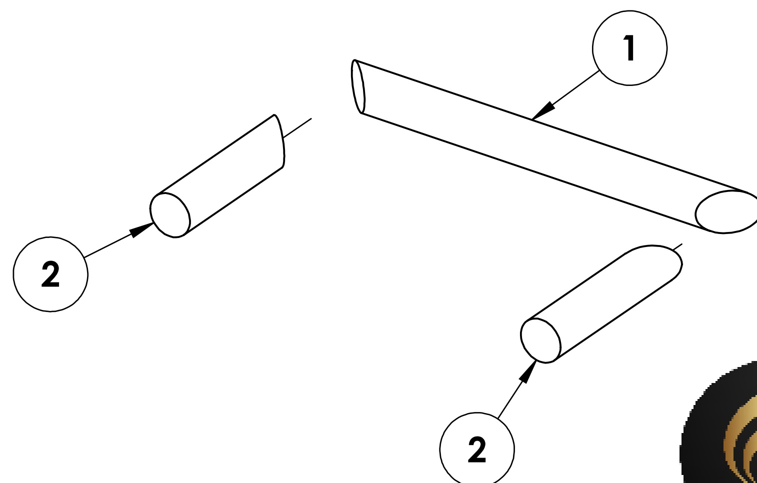
REV	DATE	BY	DESCRIPTION
A	2021-12-07	PY	Issue











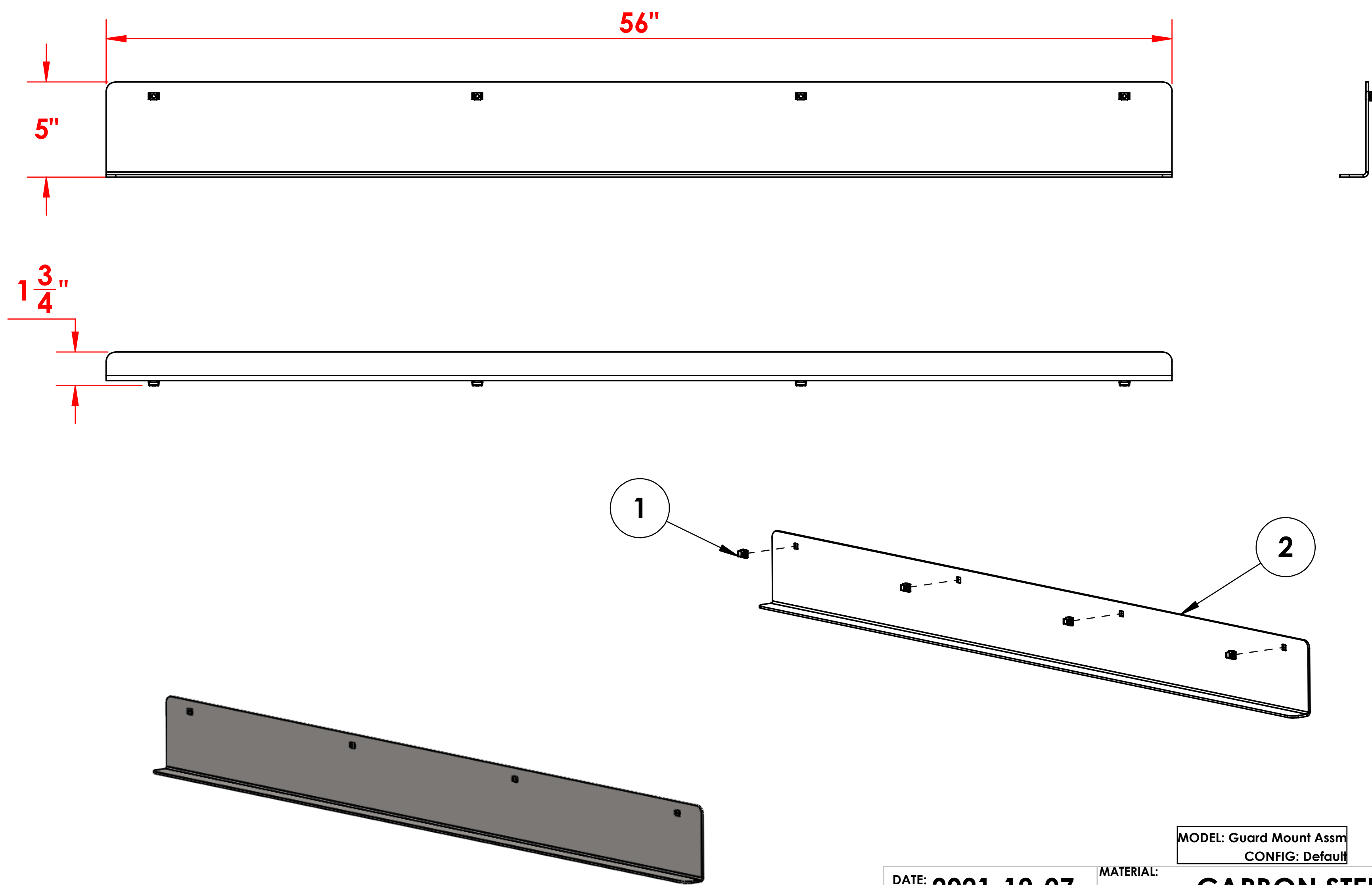
MODEL: Handle Wdmt
CONFIG: Default

DATE: 2021-12-07	MATERIAL: 0.75" MS RD BAR		FINISH: -
DRAWN BY: PY	DESCRIPTION: HANDLE WDMT		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF030		REV A
	SIZE A	SCALE 1:2	WEIGHT: 1.660 lbs	SHEET 1 OF 1

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF017	A	HANDLE PIECE 1	1
2	TF018	A	HANDLE PIECE 2	2

DWG NO:	REV
TF031	A

REV	DATE	BY	DESCRIPTION
A	2021-12-07	PY	Issue



MODEL: Guard Mount Assm
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF003	A	1/4"-20 SNAP-IN NUT	4
2	TF020	A	SHAFT GUARD MOUNT	1

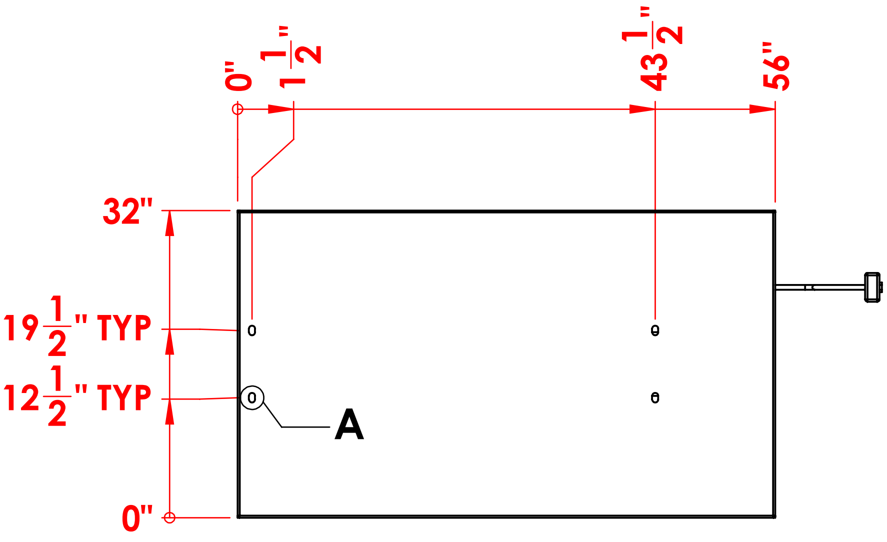
DATE: 2021-12-07
DRAWN BY: PY

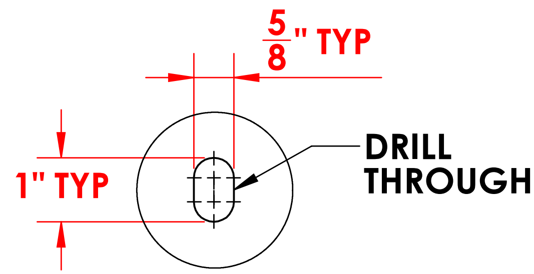
TOLERANCES IN INCHES
UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

MATERIAL: CARBON STEEL
FINISH: -
DESCRIPTION: GUARD MOUNT ASSM
DWG NO: TF031
REV: A
SIZE: A
SCALE: 1:8
WEIGHT: 13.694 lbs
SHEET: 1 OF 1

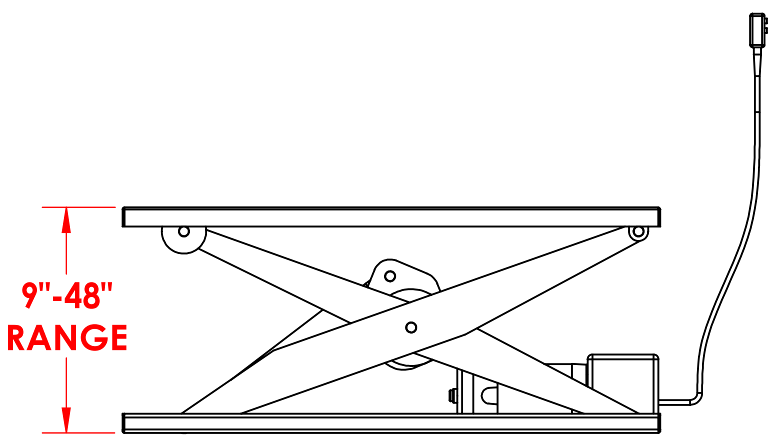
DWG NO:	REV
TF032	A

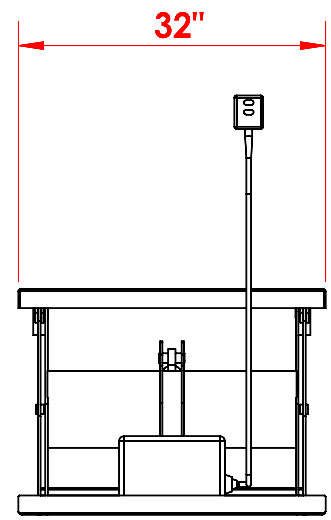
REV	DATE	BY	DESCRIPTION
A	2021-11-21	PY	Issue

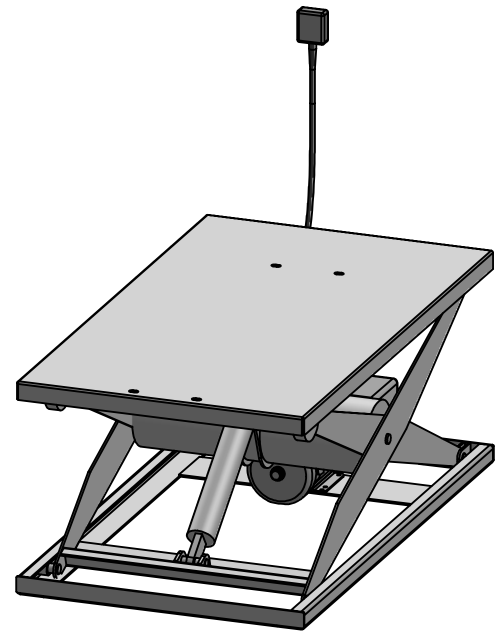




DETAIL A
SCALE 1 : 3







MODEL: Lift Table Assm
CONFIG: Centreline

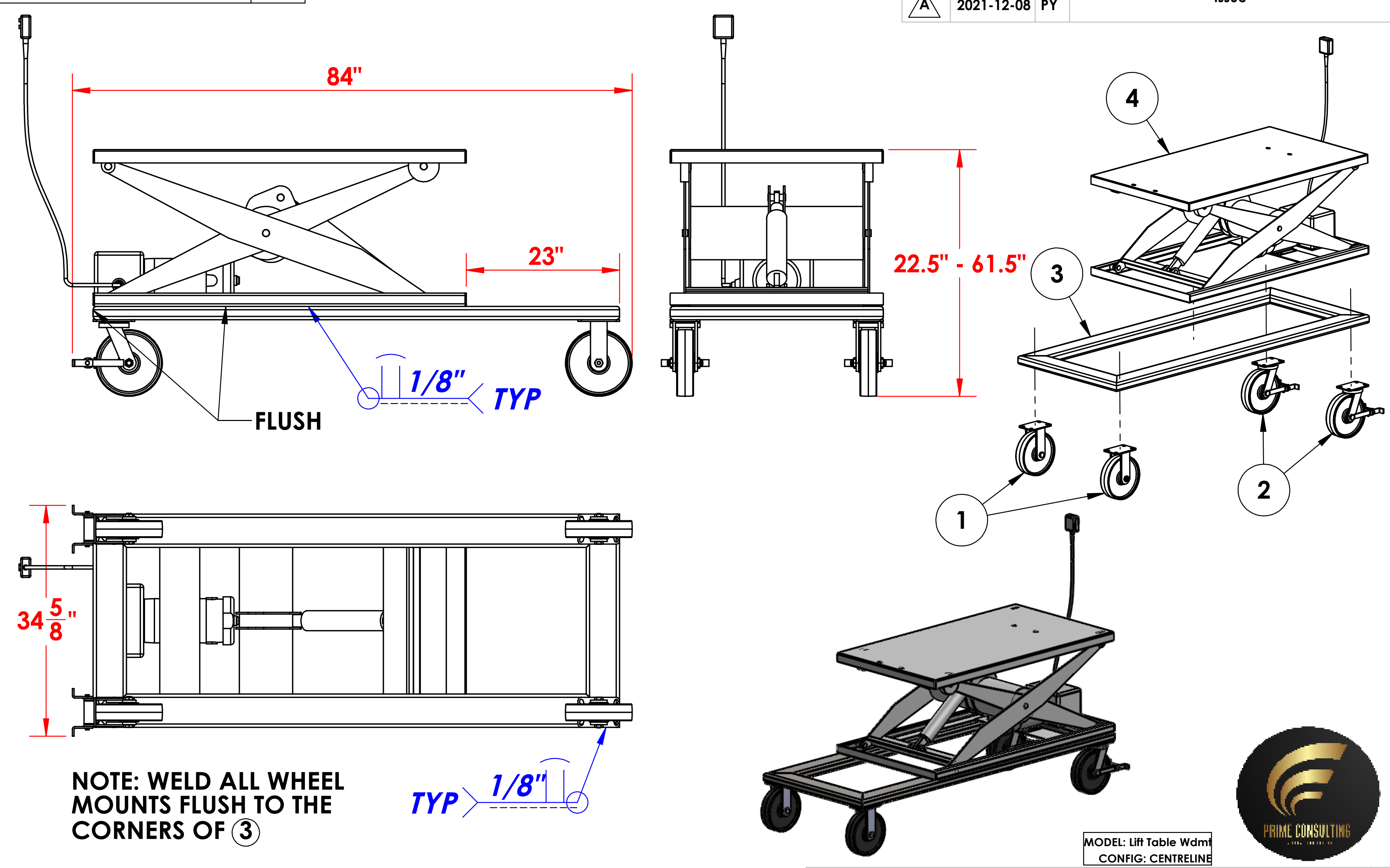
DATE: 2021-11-21	MATERIAL: -		FINISH: -
DRAWN BY: PY	DESCRIPTION: DRILLED LIFT TABLE		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF032		REV A
	SIZE A	SCALE 1:20	WEIGHT: 124.741 lbs
			SHEET 1 OF 1

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PH006	A	ELECTRIC STATIONARY LIFT TABLE	1

6 | 5 | 4 | 3 | 2 | 1

DWG NO: **TF033** REV **A**

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



NOTE: WELD ALL WHEEL MOUNTS FLUSH TO THE CORNERS OF (3)

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PH002	A	VIKING RIGID CASTER	2
2	PH003	A	VIKING SWIVEL CASTER	2
3	TF028	A	BASE TUBING FRAME WDMT	1
4	TF032	A	DRILLED LIFT TABLE	1

DATE: 2021-12-08

DRAWN BY: PY

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

MATERIAL: -

FINISH: -

DESCRIPTION: LIFT TABLE WDMT

DWG NO: TF033

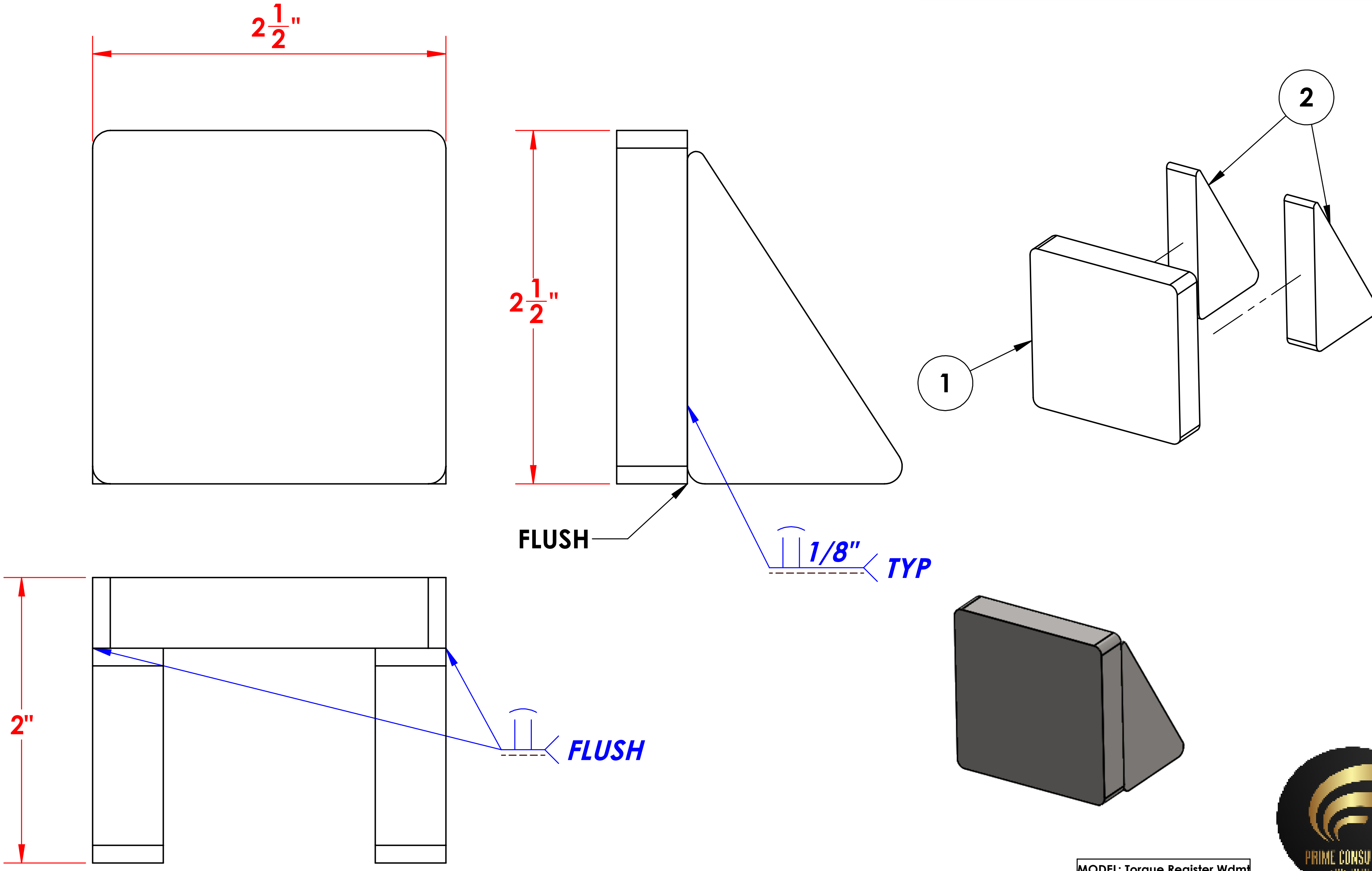
REV: A

SIZE	SCALE	WEIGHT:	SHEET
A	1:20	327.471 lbs	1 OF 1

6 | 5 | 4 | 3 | 2 | 1

DWG NO: **TF034** REV **A**

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



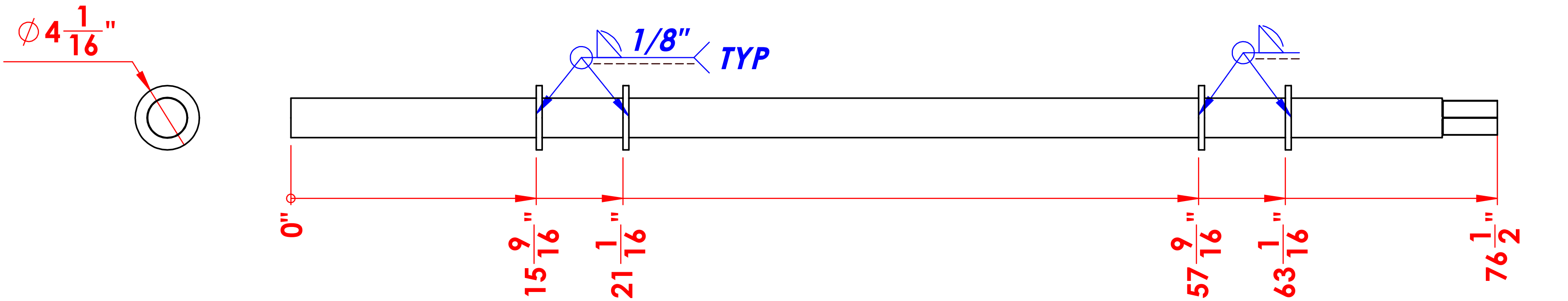
MODEL: Torque Register Wdmt
CONFIG: Default

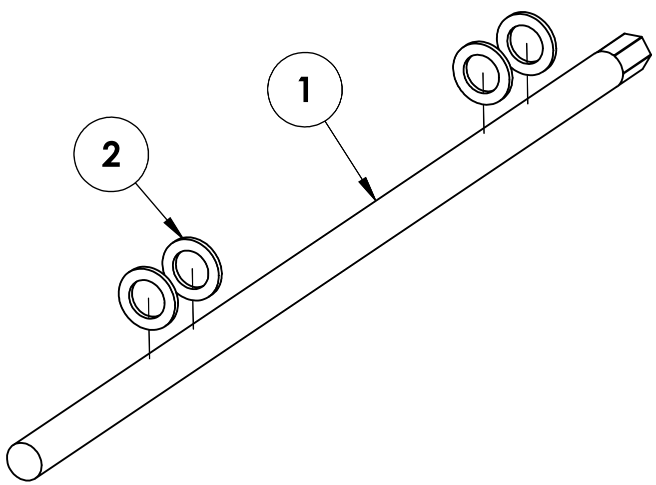
DATE: 2021-12-08	MATERIAL: 1/2" CSA G40.21 44W/300W		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: TORQUE REACTION PLATE WDMT		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF034		REV: A
	SIZE: A	SCALE: 1:1	WEIGHT: 1.482 lbs	SHEET: 1 OF 1

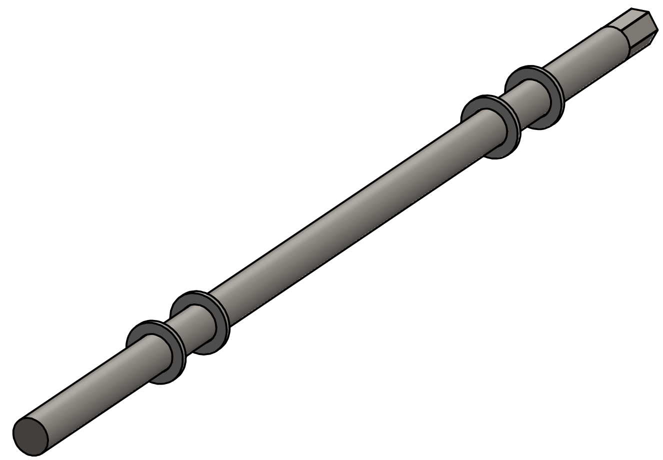
ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF023	A	TORQUE REGISTER 1	1
2	TF027	A	TORQUE REGISTER 2	2

DWG NO: TF035 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue





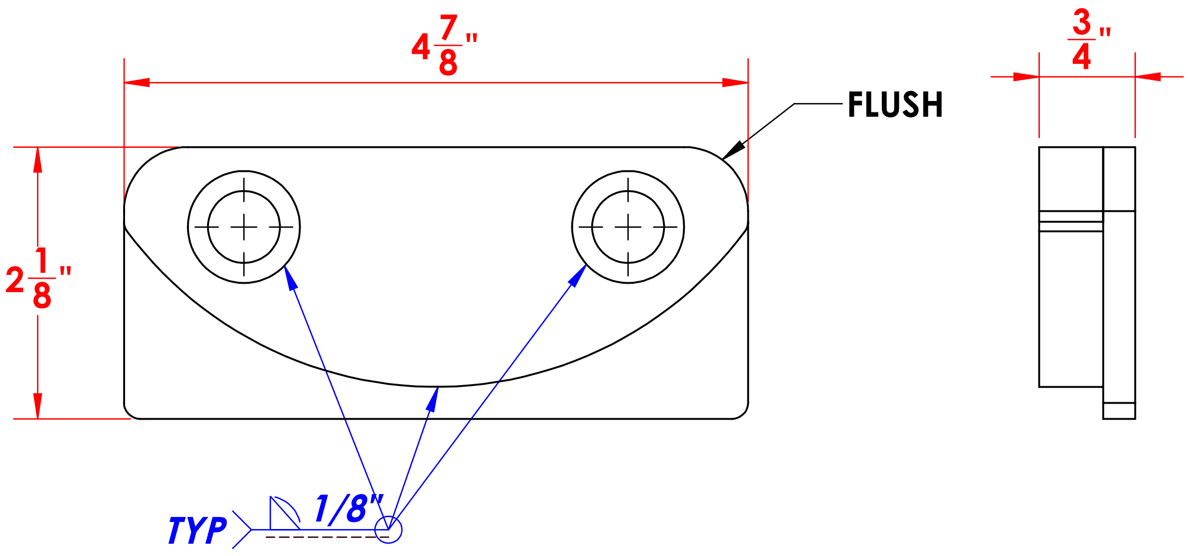


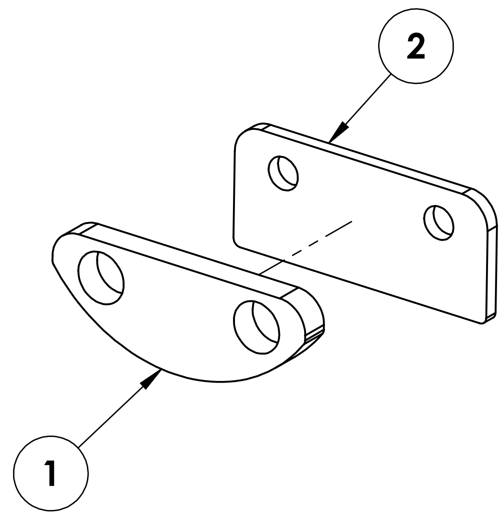
MODEL: Shaft Wdmt
CONFIG: Default

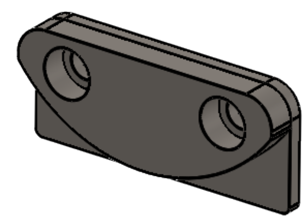
DATE: 2021-12-08	MATERIAL: CARBON STEEL			FINISH: -
DRAWN BY: PY	DESCRIPTION: SHAFT WDMT			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF035			REV A
	SIZE A	SCALE 1:10	WEIGHT: 109.121 lbs	SHEET 1 OF 1

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF010	A	SHAFT	1
2	TF025	A	RETAINING RING	4

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue







MODEL: Steel Cable Cap Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF014	A	CABLE PLATE 2	1
2	TF015	A	CABLE PLATE 3	1

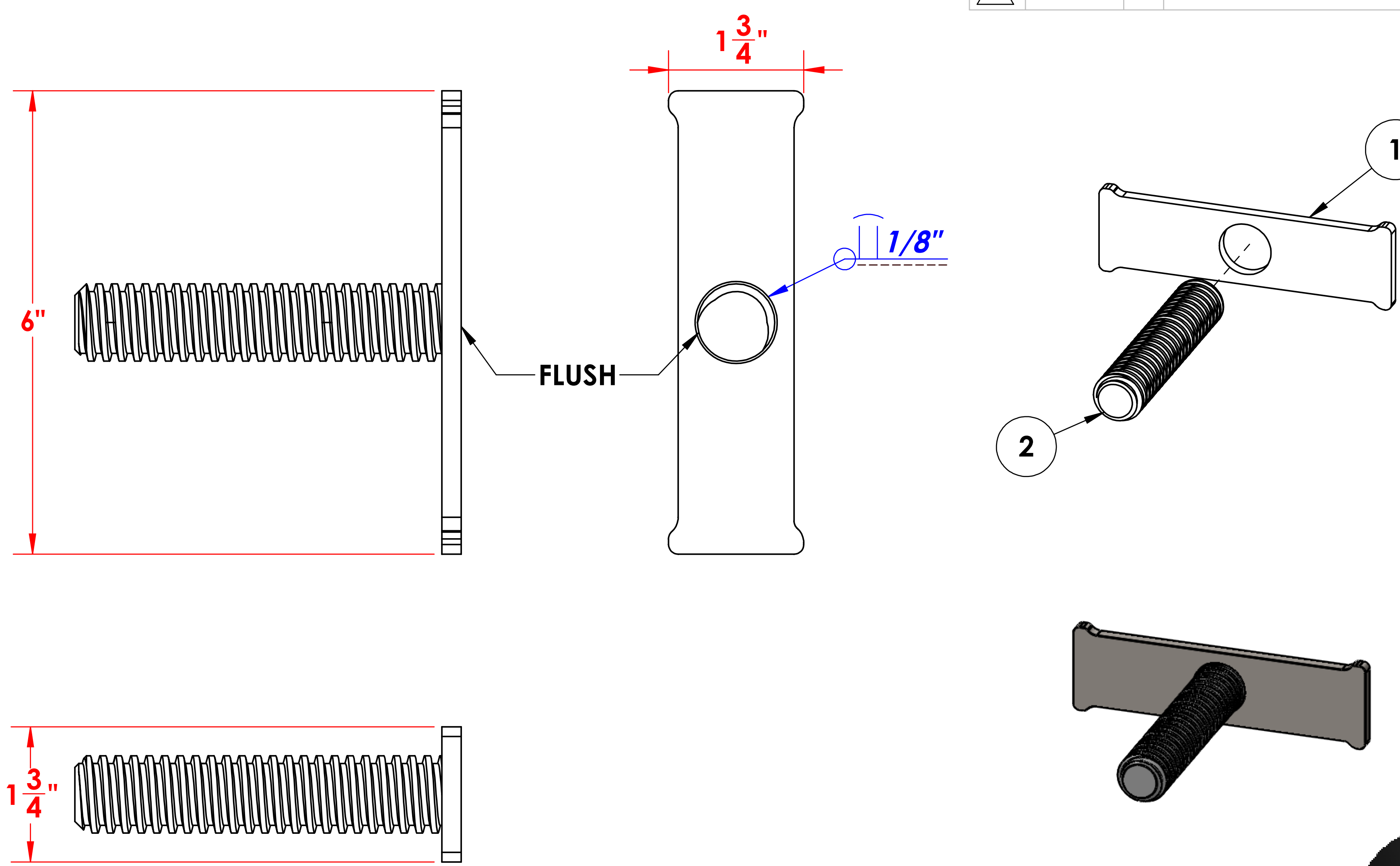
DATE: 2021-12-08
DRAWN BY: PY
MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: STEEL CABLE CAP WDMT

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF036
REV: A
SIZE: A
SCALE: 2:3
WEIGHT: 1.542 lbs
SHEET: 1 OF 1

DWG NO: TF037 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



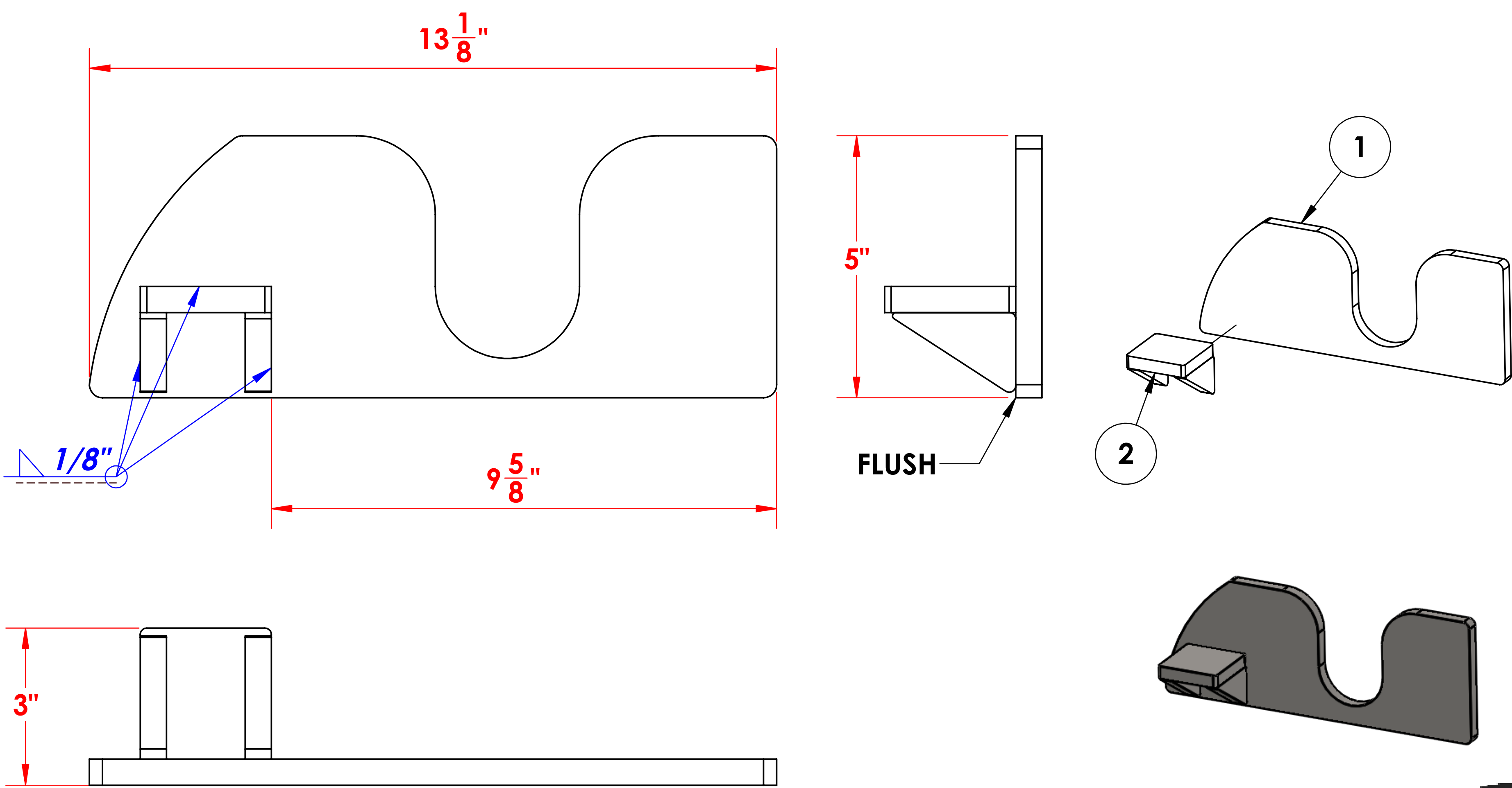
MODEL: Threaded Rod and Handle Wdmt
CONFIG: Default

DATE: 2021-12-08	MATERIAL: CARBON STEEL		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: THREADED ROD AND HANDLE WDMT		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF037		REV A
SIZE A	SCALE 1:2	WEIGHT: 0.701 lbs	SHEET 1 OF 1

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF016	A	ROD HANDLE	1
2	TF029	A	5" CUT THREADED ROD	1

DWG NO: TF038 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



MODEL: Shaft Guard End Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF022	A	SHAFT GUARD END PLATE	1
2	TF034	A	TORQUE REACTION PLATE WDMT	1

DATE: 2021-12-08
DRAWN BY: PY
MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: SHAFT GUARD END WDMT

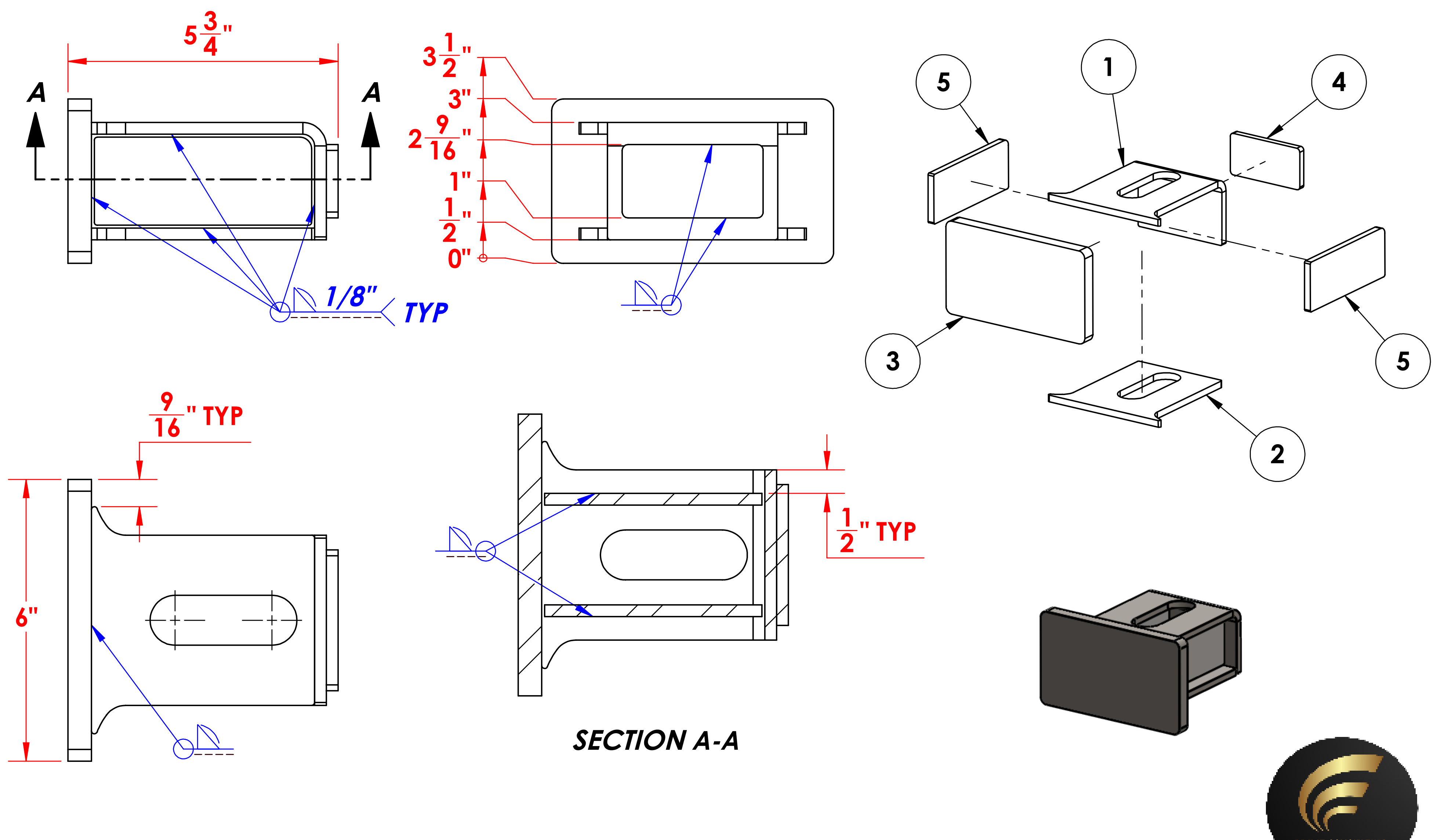
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF038
REV: A

SIZE	SCALE	WEIGHT:	SHEET
A	1:3	8.567 lbs	1 OF 1

DWG NO: TF039 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



MODEL: Contact Plate Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF004	A	SLOTTED PLATE 1	1
2	TF005	A	SLOTTED PLATE 2	1
3	TF006	A	CONTACT PLATE	1
4	TF019	A	PUSH PLATE	1
5	TF026	A	SUPPORT CLAMP PLATE	2

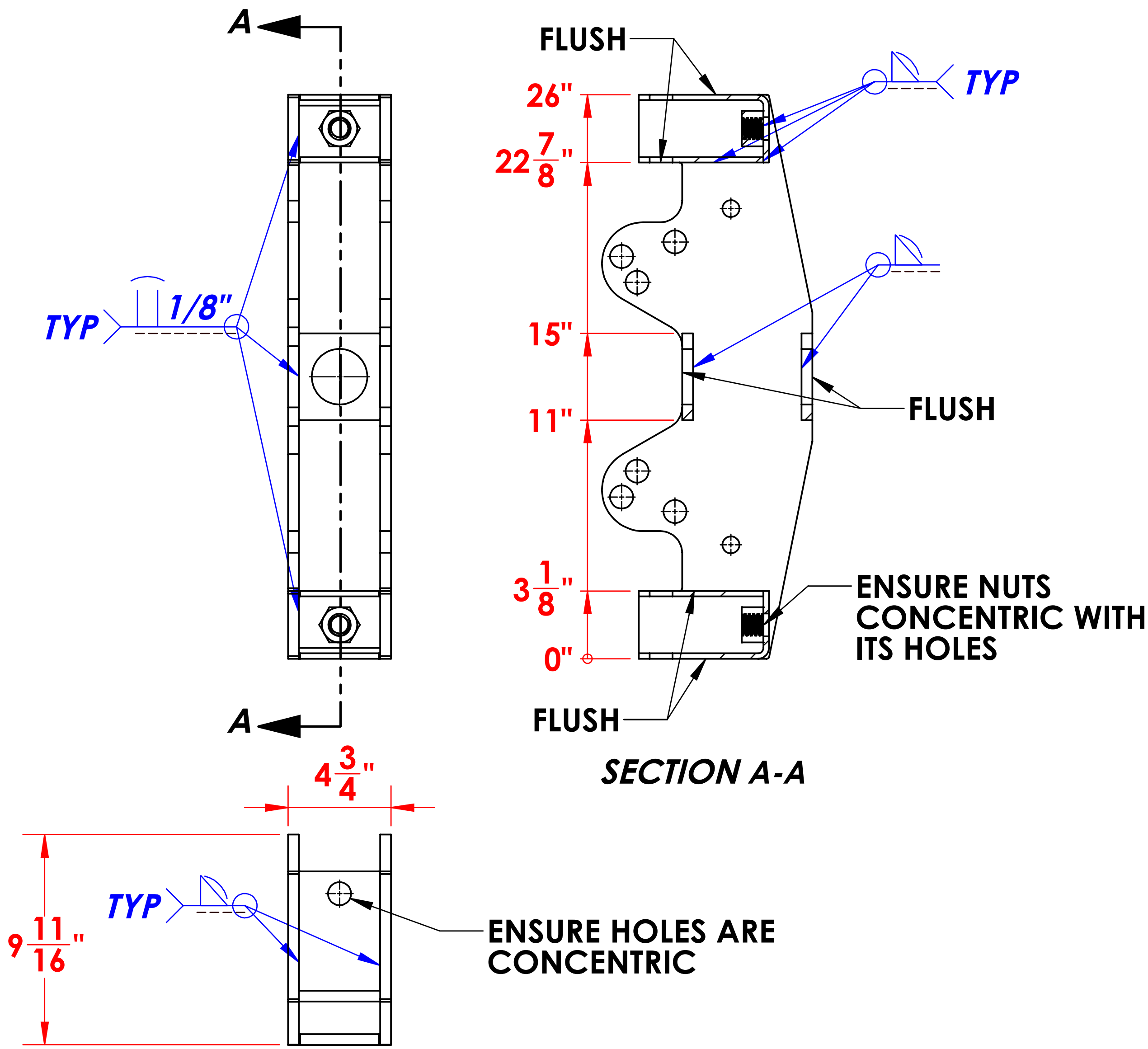
DATE: 2021-12-08
DRAWN BY: PY

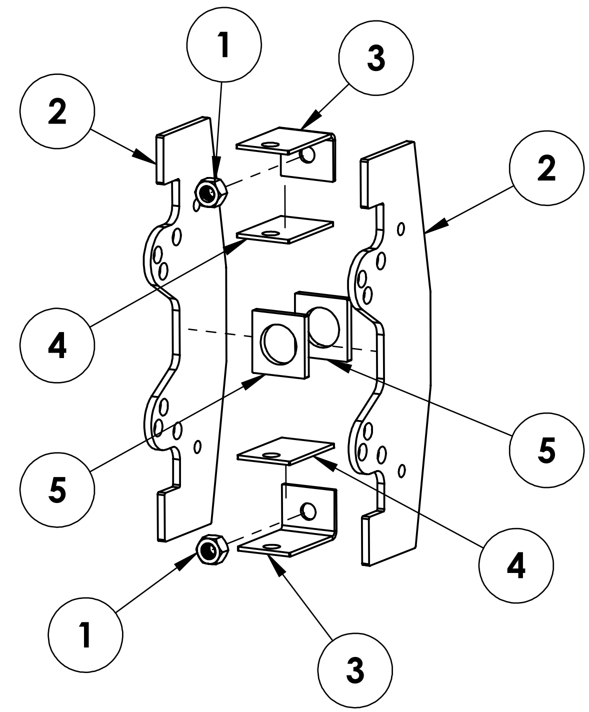
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

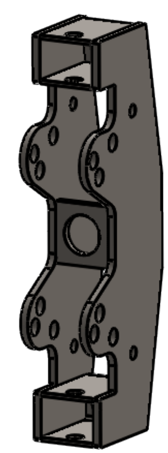
MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: CONTACT PLATE WDMT
DWG NO: TF039
REV: A
SIZE: A
SCALE: 1:3
WEIGHT: 7.213 lbs
SHEET: 1 OF 1

DWG NO:	REV
TF040	A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue







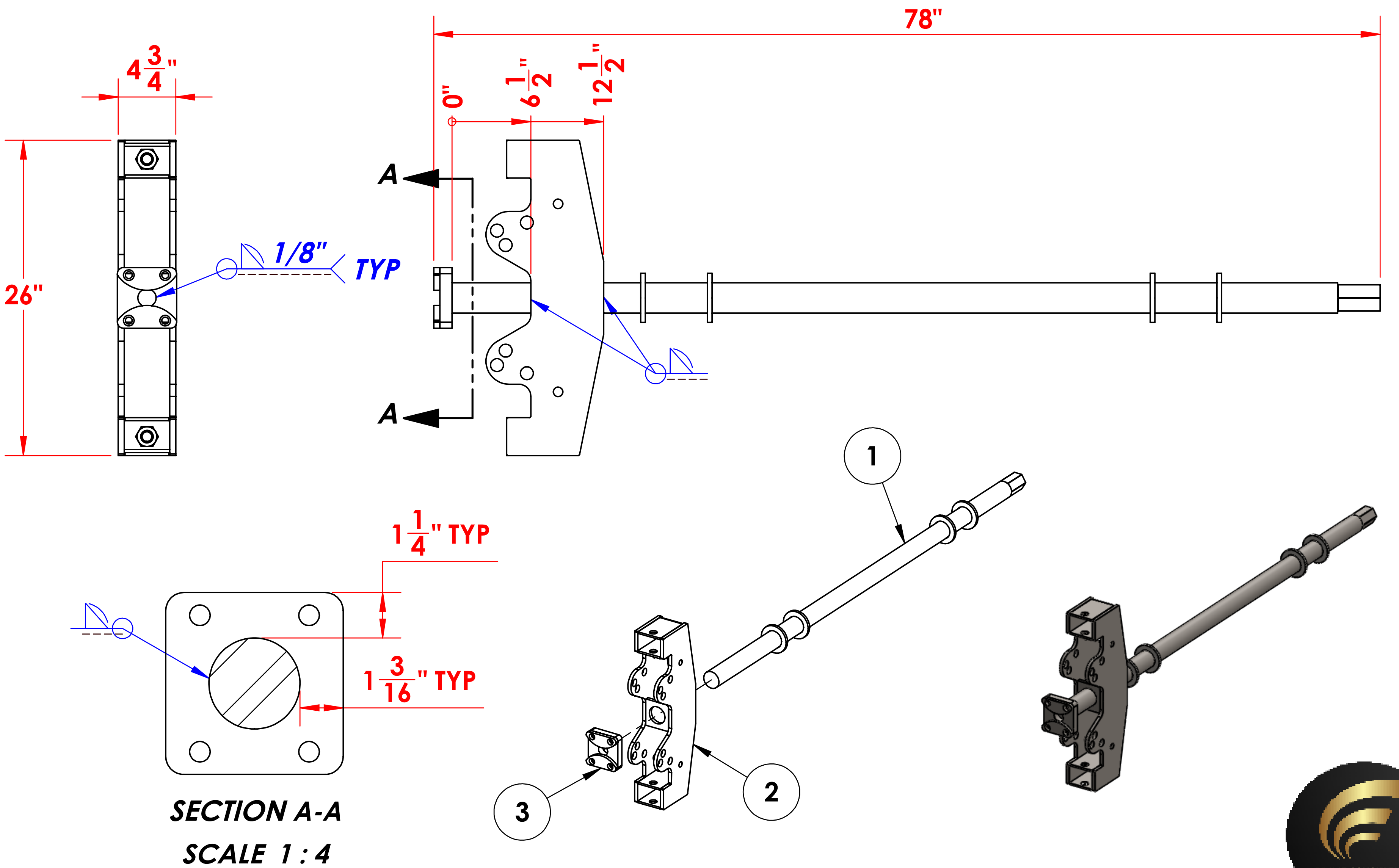
MODEL: Clamp Bar Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF001	A	1/2" ID ACME HEX NUT	2
2	TF003	A	CLAMP BAR PLATE	2
3	TF007	A	ROD PLATE 1	2
4	TF008	A	ROD PLATE 2	2
5	TF009	A	SHAFT PLATE	2

DATE: 2021-12-08	MATERIAL: CARBON STEEL		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CLAMP BAR WDMT		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16; BEND ANGLES ± 1°; TWO DECIMAL PLACES ± .05; THREE DECIMAL PLACES ± .01	DWG NO: TF040		REV: A
	SIZE: A	SCALE: 1:8	WEIGHT: 58.666 lbs
			SHEET: 1 OF 1

DWG NO: TF041 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



SECTION A-A
SCALE 1 : 4

MODEL: Clamp Bar and Shaft Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF035	A	SHAFT WDMT	1
2	TF040	A	CLAMP BAR WDMT	1
3	TF047	A	CABLE PLATE WDMT	1

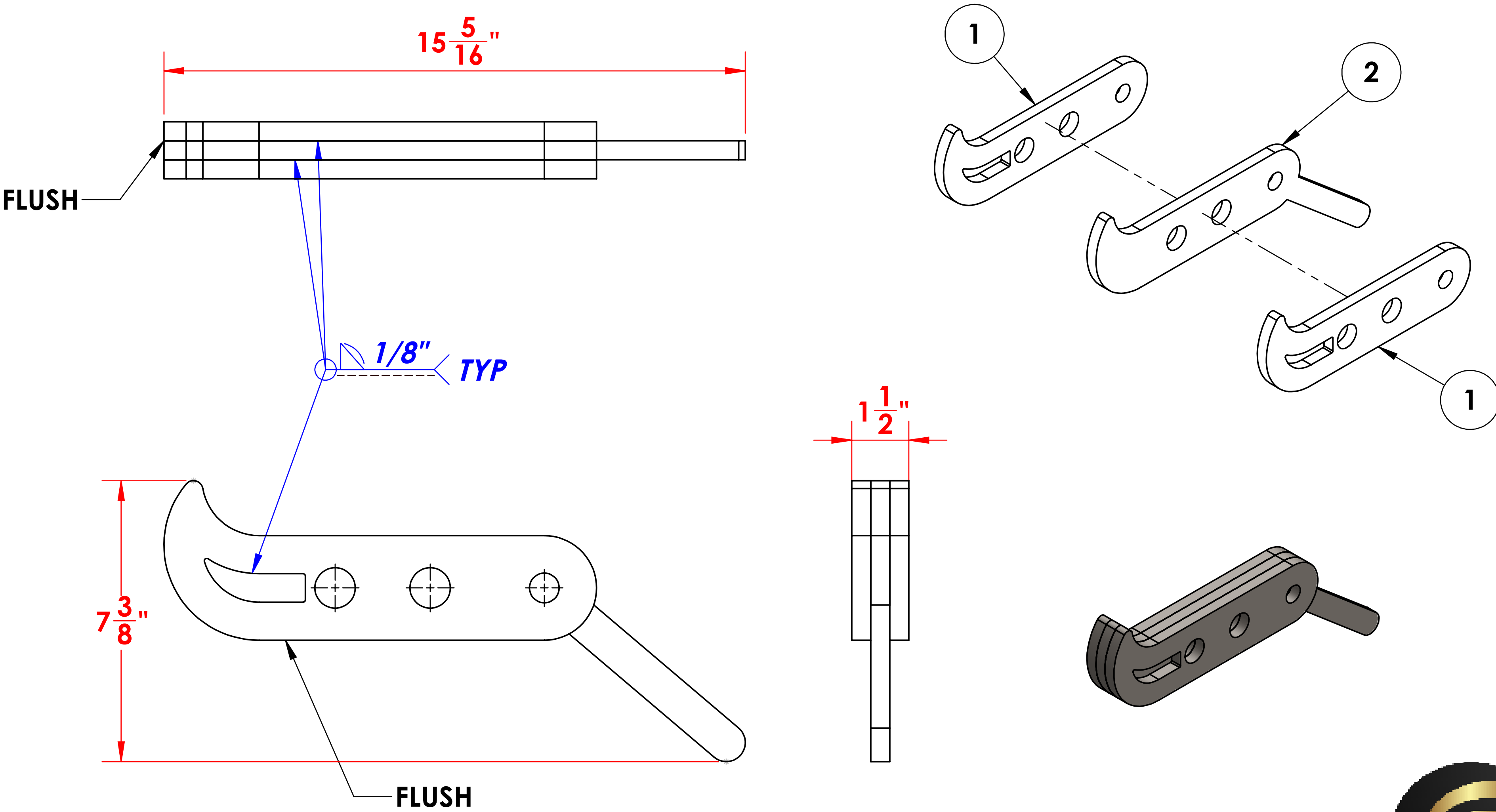
DATE: 2021-12-08
DRAWN BY: PY
MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: CLAMP BAR AND SHAFT WDMT

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF041 REV A
SIZE: A
SCALE: 1:12
WEIGHT: 175.556 lbs
SHEET: 1 OF 1

DWG NO:	REV
TF042	A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



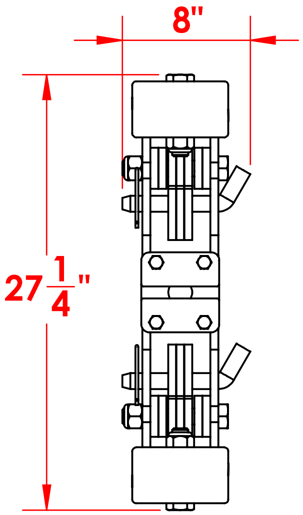
MODEL: Hook Wdmt
CONFIG: Default

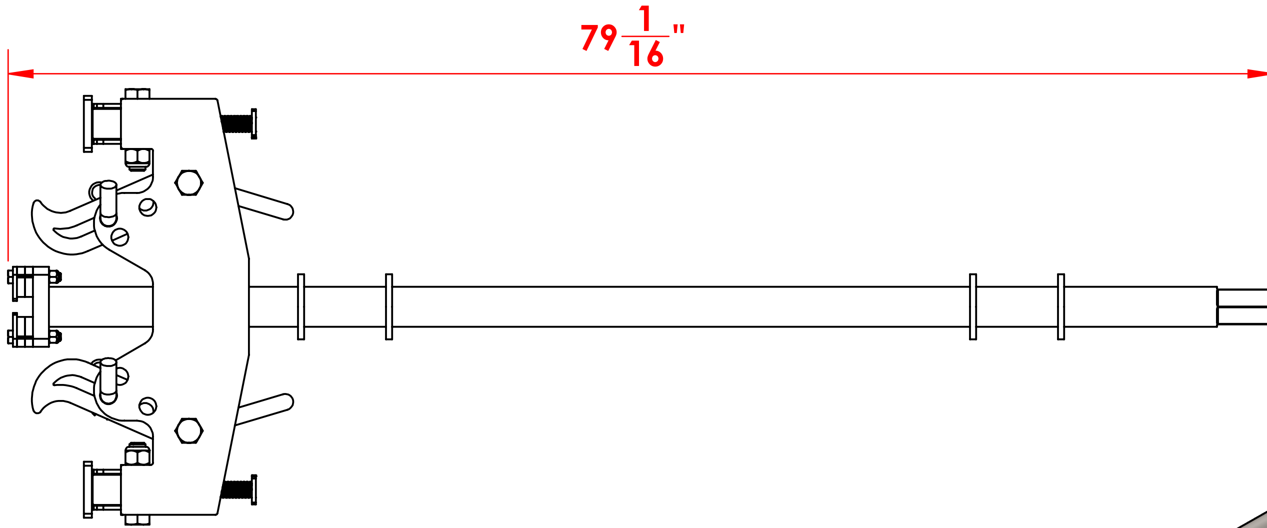
ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF011	A	HOOK 1	2
2	TF012	A	HOOK 2	1

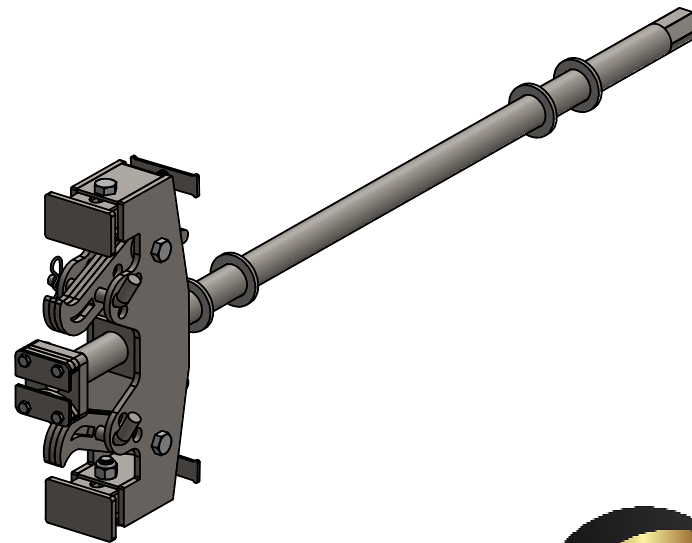
DATE: 2021-12-08	MATERIAL: CARBON STEEL			FINISH: 2B
DRAWN BY: PY	DESCRIPTION: HOOK WDMT			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF042			REV A
	SIZE A	SCALE 1:4	WEIGHT: 12.347 lbs	SHEET 1 OF 1

DWG NO: TF043 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue







ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF005	A	1"x5" BENT -PULL CLEVIS PIN	2
2	PF009	A	NyLok Nut, 0.5, G5, Z	4
3	PF010	A	Bolt, 0.5x 3_UNC_G5	4
4	PF011	A	NyLok Nut, 1, G5, Z	4
5	PF012	A	Bolt, 1x 4.5_UNC_G5	2
6	PF013	A	Bolt, 1x 6_UNC_G5	2
7	TF024	A	HOOK SPACER	8
8	TF036	A	STEEL CABLE CAP WDMT	2
9	TF037	A	THREADED ROD AND HANDLE WDMT	2
10	TF039	A	CONTACT PLATE WDMT	2
11	TF041	A	CLAMP BAR AND SHAFT WDMT	1
12	TF042	A	HOOK WDMT	2

MODEL: Clamp Attachment Assm
CONFIG: Default

DATE: 2021-12-08
DRAWN BY: PY

MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: CLAMP ATTACHMENT ASSM

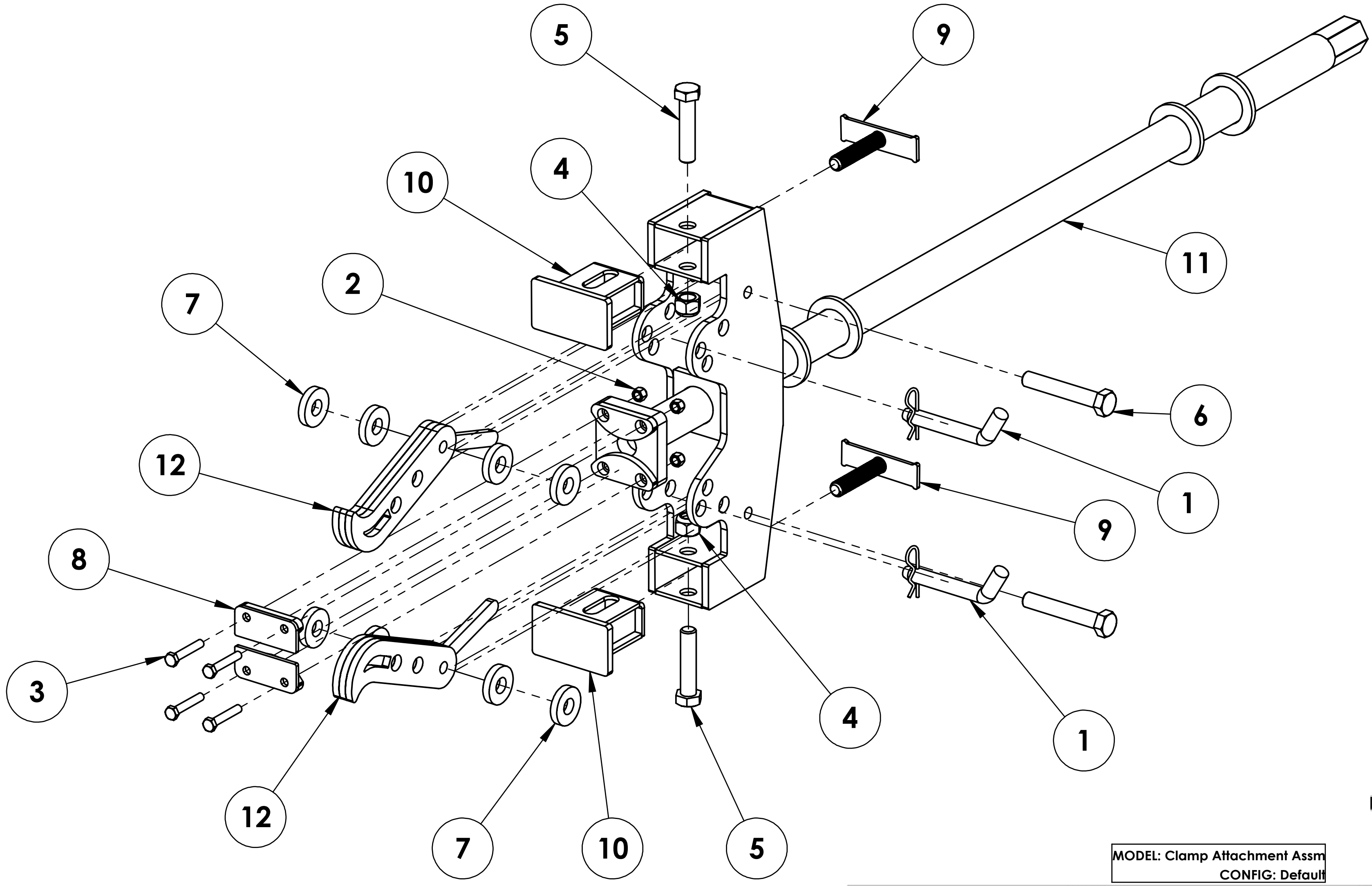
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF043 | REV: A

SIZE: A | SCALE: 1:12 | WEIGHT: 230.524 lbs | SHEET: 1 OF 2

DWG NO: TF043	REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue

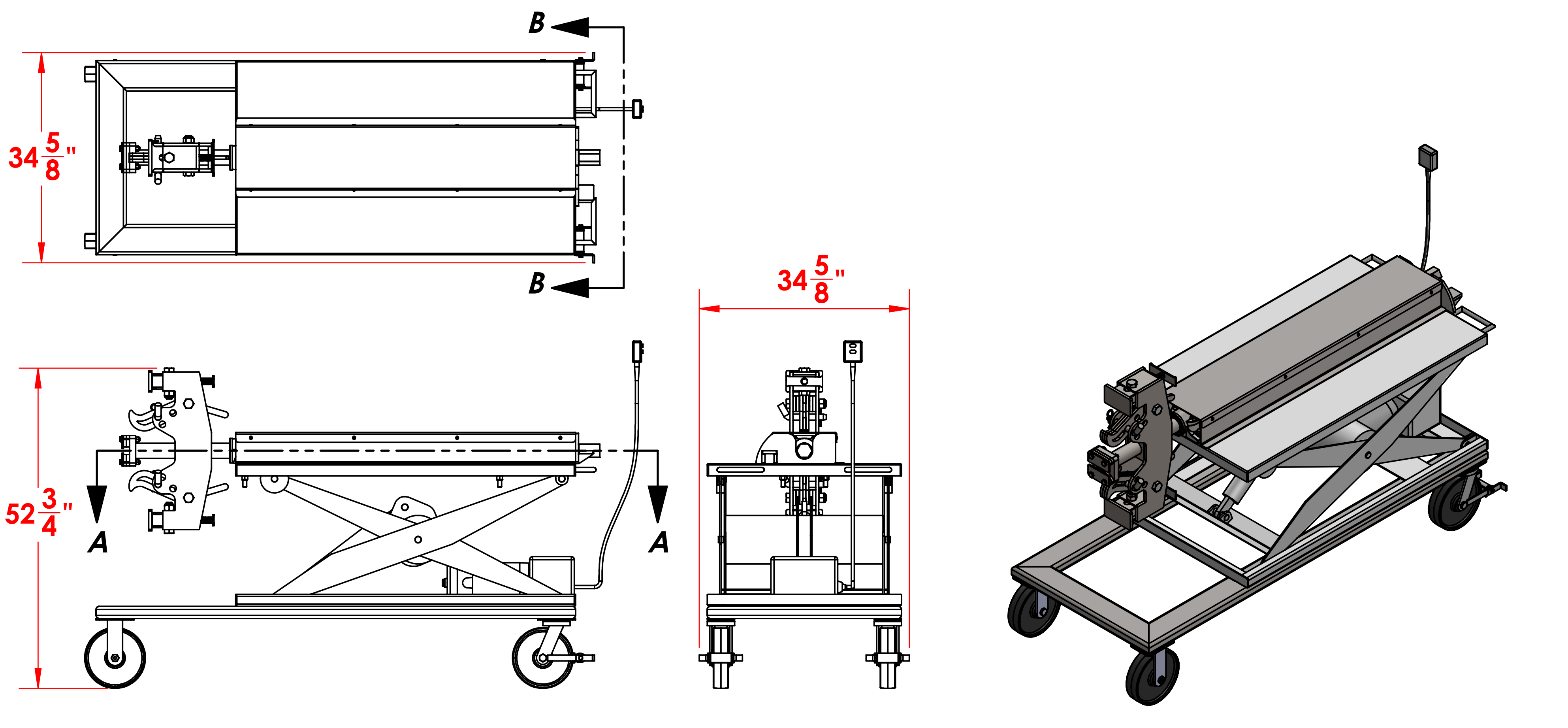


MODEL: Clamp Attachment Assm
CONFIG: Default

DATE: 2021-12-08	MATERIAL: CARBON STEEL		FINISH: 2B
DRAWN BY: PY	DESCRIPTION: CLAMP ATTACHMENT ASSM		
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:	DWG NO: TF043		REV A
FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	SIZE A	SCALE 1:12	WEIGHT: 230.524 lbs / SHEET 2 OF 2

DWG NO:	REV
TF044	A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF002	A	0.75" BUTTON HEAD HEX DRIVE SCREW	8
2	PF007	A	NyLok Nut, 0.625, G5, Z	4
3	PF008	A	Bolt, 0.625x 5_UNC_G5	4
4	PH001	A	2.5" MOUNTED SLEEVE BEARING	2
5	TF021	A	SHAFT GUARD	1
6	TF030	A	HANDLE WDMT	2
7	TF031	A	GUARD MOUNT ASSM	2
8	TF033	A	LIFT TABLE WDMT	1
9	TF038	A	SHAFT GUARD END WDMT	1
10	TF043	A	CLAMP ATTACHMENT ASSM	1

MODEL: Clamp and Lift Table Assm
CONFIG: CENTRELINE

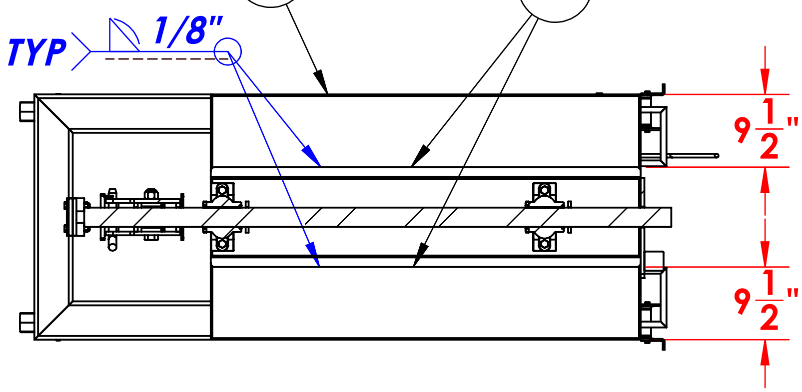
PRIME CONSULTING

DATE:	2021-12-08
DRAWN BY:	PY
MATERIAL:	-
FINISH:	-
DESCRIPTION:	CLAMP AND LIFT TABLE ASSM
DWG NO:	TF044
REV	A
SIZE	A
SCALE	1:25
WEIGHT:	631.914 lbs
SHEET	1 OF 2

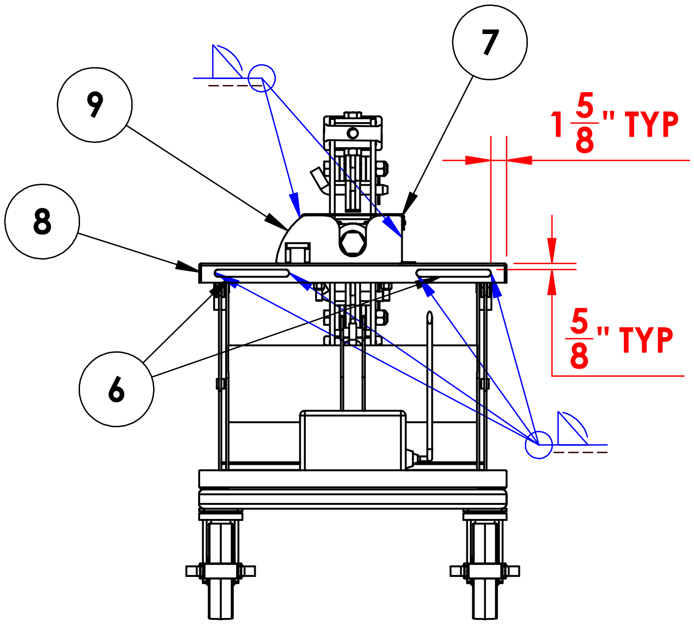
TOLERANCES IN INCHES
UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF044 | REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue

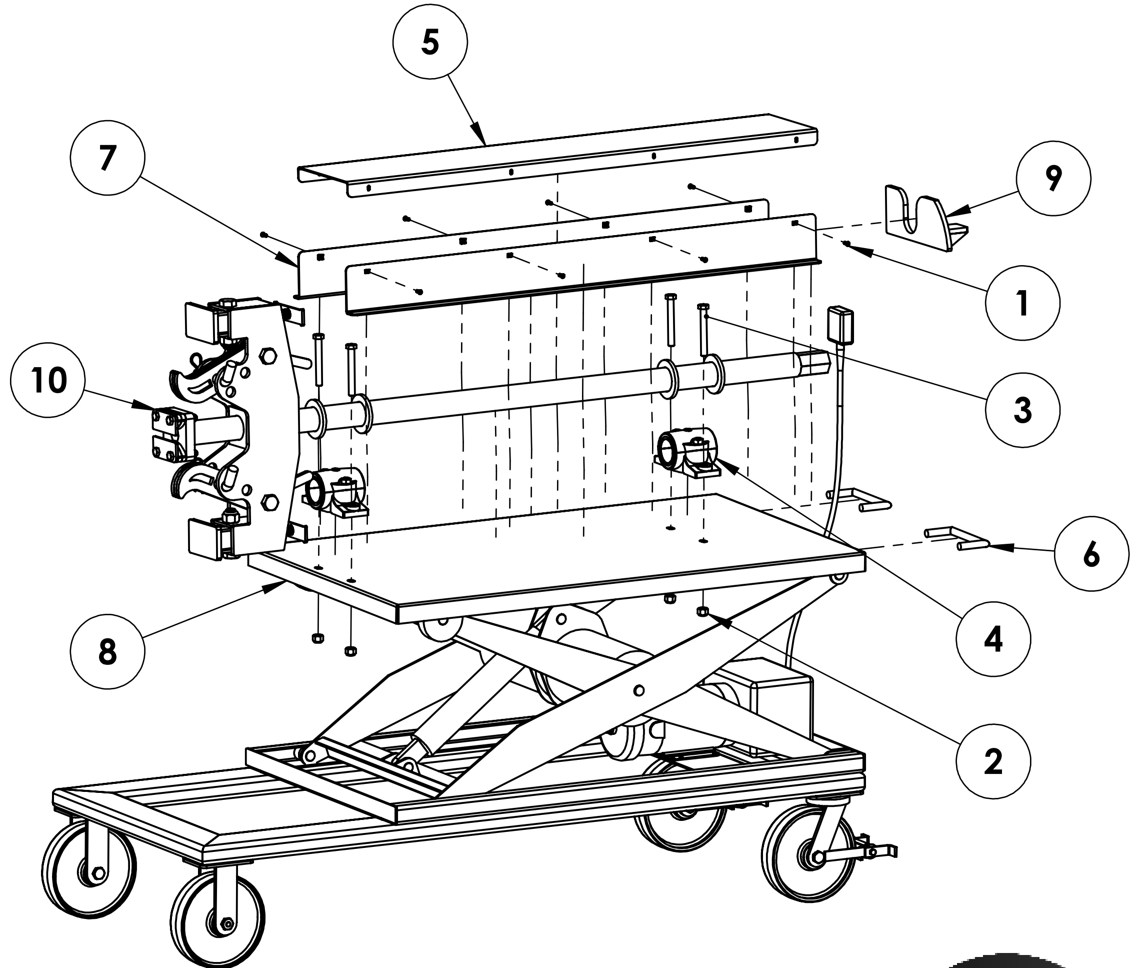


SECTION A-A



SECTION B-B

SCALE 1 : 20



MODEL: Clamp and Lift Table Assm
CONFIG: CENTRELINE

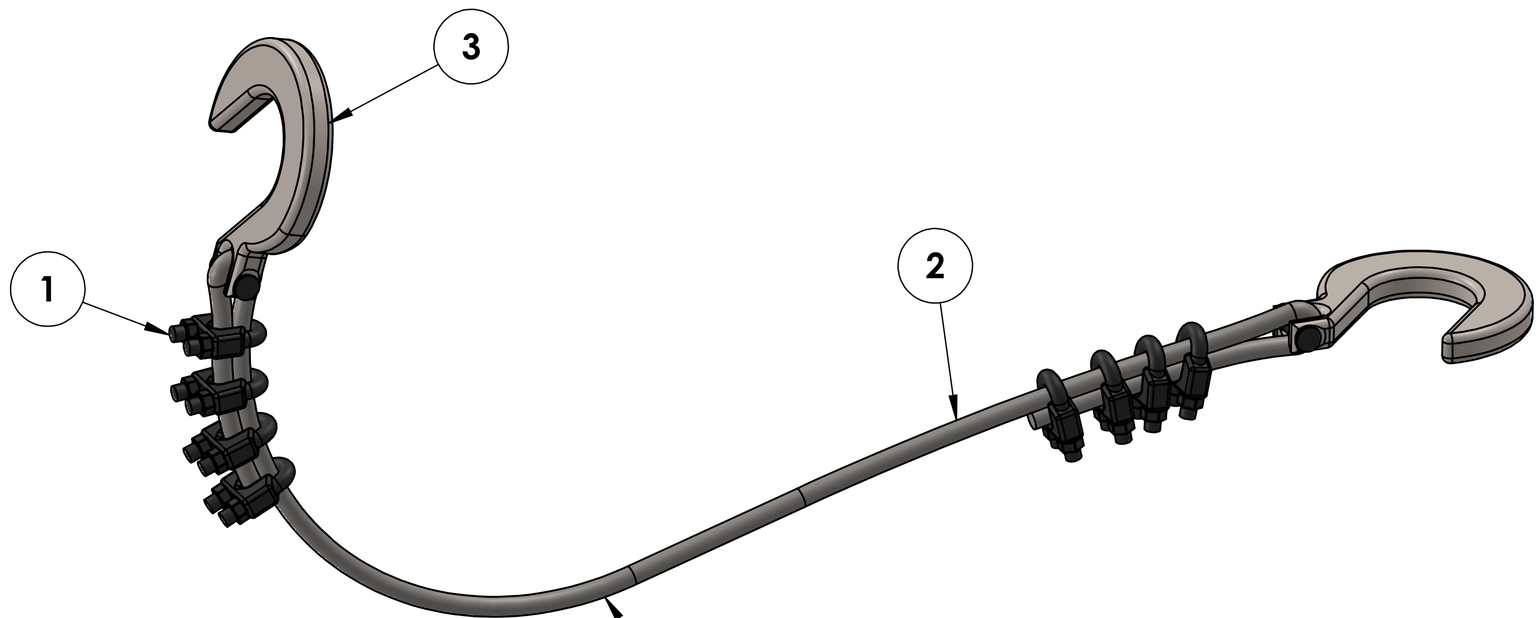
DATE:	2021-12-08
DRAWN BY:	PY
MATERIAL:	-
FINISH:	-
DESCRIPTION:	CLAMP AND LIFT TABLE ASSM
DWG NO:	TF044
REV	A
SIZE	A
SCALE	1:25
WEIGHT:	631.914 lbs
SHEET	2 OF 2

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:

FRACTIONAL	± 1/16
BEND ANGLES	± 1°
TWO DECIMAL PLACES	± .05
THREE DECIMAL PLACES	± .01

DWG NO: TF045 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue



CUT WIRE ROPE TO LENGTH ON SITE ACCORDING TO 12-10 IMPELLER.

RESULTING LENGTH WOULD ALSO WORK FOR SMALLER IMPELLERS.

MODEL: Wire Rope Assm
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	PF006	A	5/8" CAST WIRE ROPE CLAMP	8
2	PH007	A	0.625" STEEL EXTRA FLEXIBLE WIRE ROPE	1
3	PH008	A	3.5" WIDE MOUTH LIFTING HOOK	2

DATE: 2021-12-08
DRAWN BY: PY

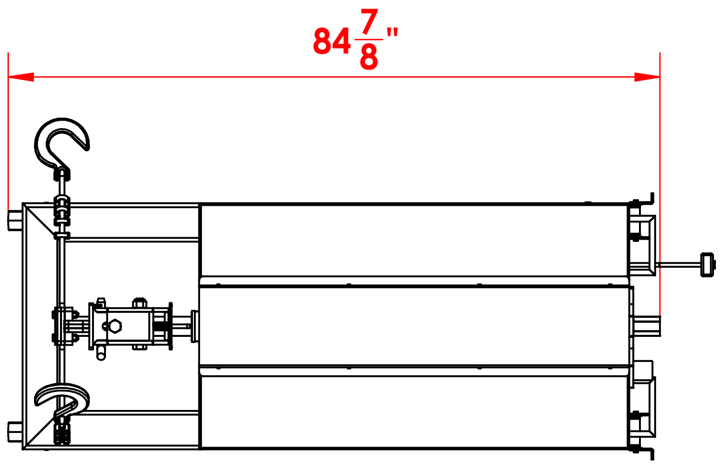
MATERIAL: -
FINISH: -
DESCRIPTION: WIRE ROPE AND HOOKS ASSM

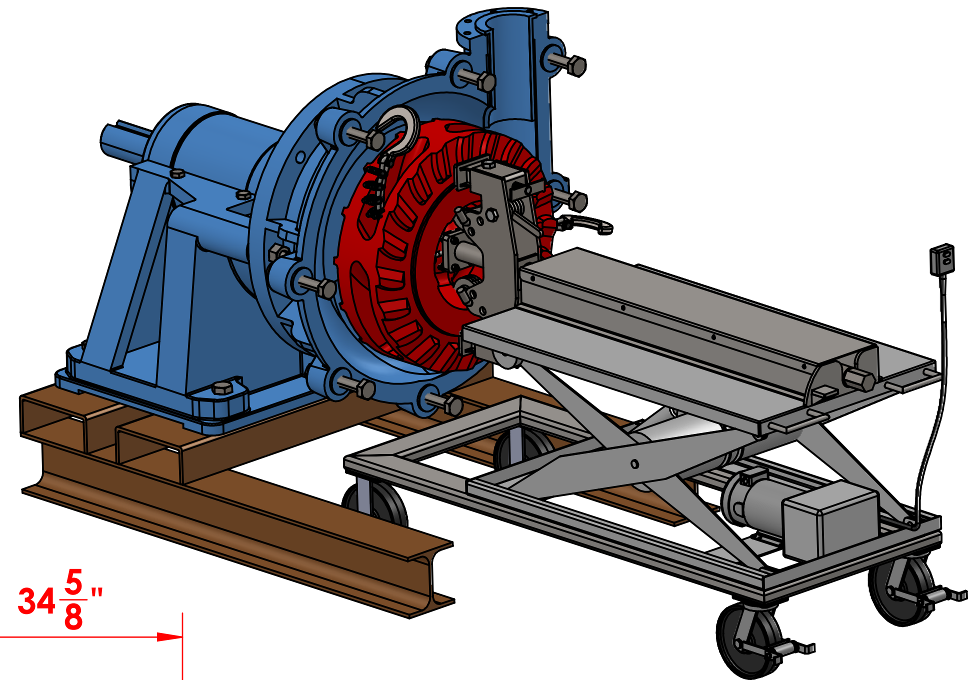
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

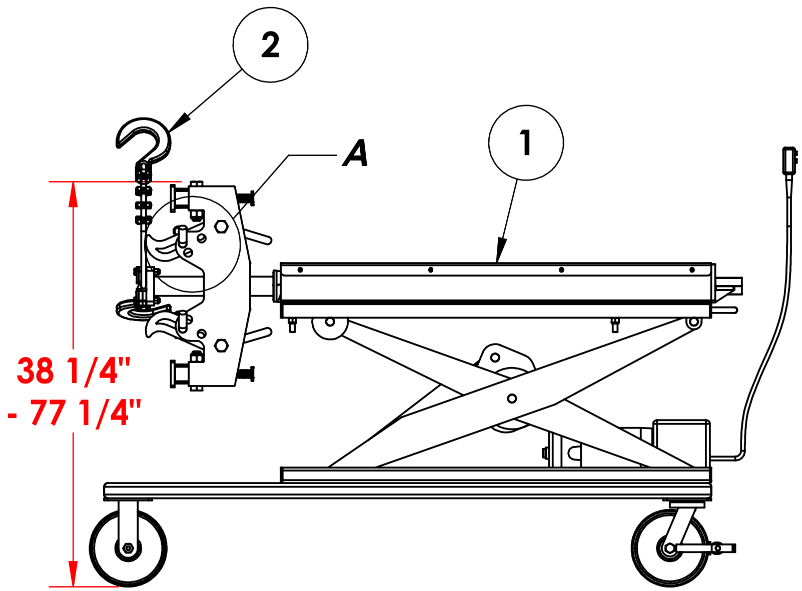
DWG NO: TF045
REV: A
SIZE: A
SCALE: 1:6
WEIGHT: 23.741 lbs
SHEET: 1 OF 1

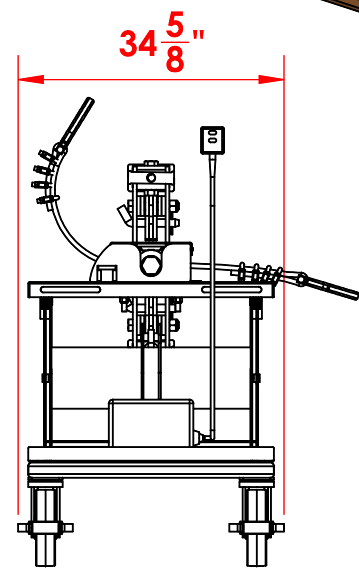
DWG NO: TF046 | REV A

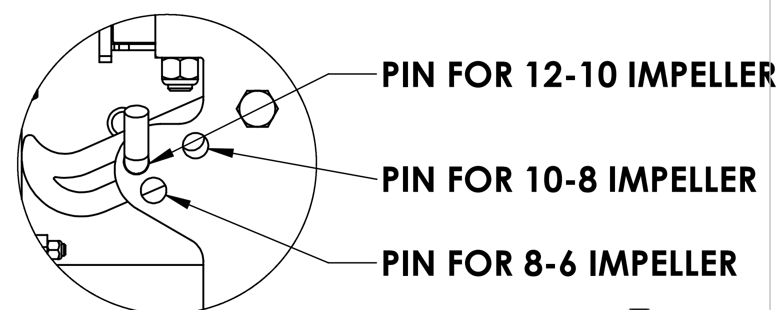
REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue











DETAIL A
SCALE 1 : 8

MODEL: Nutrien Capstone Project Assm
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF044	A	CLAMP AND LIFT TABLE ASSM	1
2	TF045	A	WIRE ROPE AND HOOKS ASSM	1

DATE: 2021-12-08
DRAWN BY: PY
MATERIAL: -
FINISH: -
DESCRIPTION: IMPELLER REMOVER JIG

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF046 | REV: A
SIZE: A | SCALE: 1:25 | WEIGHT: 555.509 lbs | SHEET 1 OF 2

DWG NO: TF046 | REV A

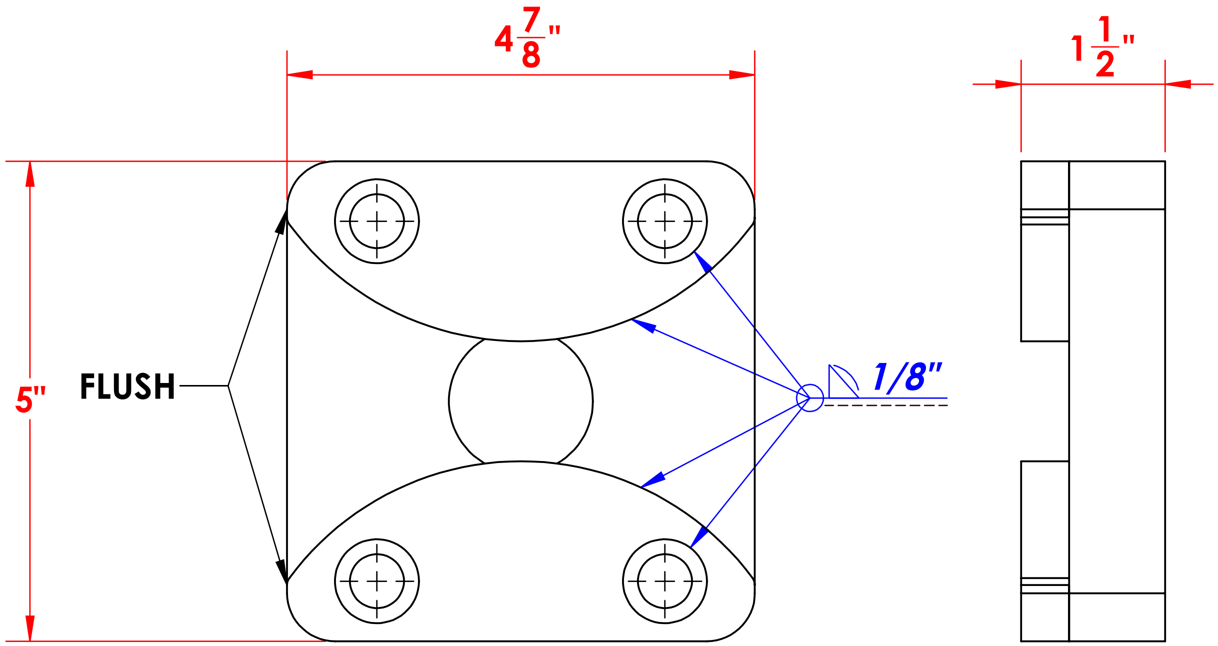
REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue

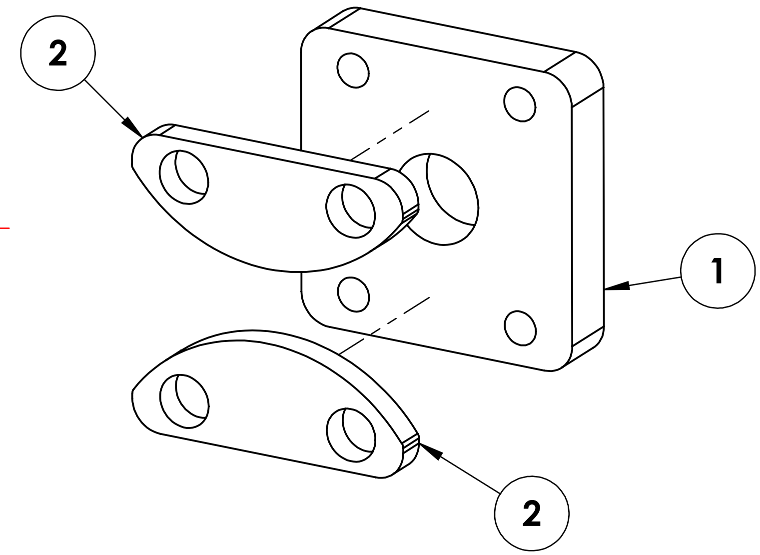
MODEL: Nutrien Capstone Project Assm
CONFIG: Default

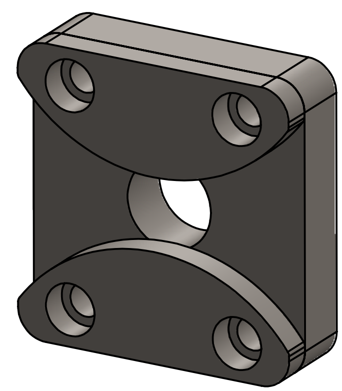
DATE: 2021-12-08	MATERIAL: -		FINISH: -	
DRAWN BY: PY	DESCRIPTION: IMPELLER REMOVER JIG			
TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED: FRACTIONAL ± 1/16 BEND ANGLES ± 1° TWO DECIMAL PLACES ± .05 THREE DECIMAL PLACES ± .01	DWG NO: TF046			REV A
	SIZE A	SCALE 1:48	WEIGHT: 55.509 lbs	SHEET 2 OF 2

DWG NO: TF047 REV A

REV	DATE	BY	DESCRIPTION
A	2021-12-08	PY	Issue







MODEL: Cable Plate Wdmt
CONFIG: Default

ITEM NO.	PartNo	Rev	DESCRIPTION	QTY.
1	TF013	A	CABLE PLATE 1	1
2	TF014	A	CABLE PLATE 2	2

DATE: 2021-12-08
DRAWN BY: PY
MATERIAL: CARBON STEEL
FINISH: 2B
DESCRIPTION: CABLE PLATE WDMT

TOLERANCES IN INCHES UNLESS OTHERWISE SPECIFIED:
FRACTIONAL ± 1/16
BEND ANGLES ± 1°
TWO DECIMAL PLACES ± .05
THREE DECIMAL PLACES ± .01

DWG NO: TF047
REV: A
SIZE: A
SCALE: 1:2
WEIGHT: 7.769 lbs
SHEET: 1 OF 1