Price Faculty of Engineering

Department of Mechanical Engineering

MECH 4860 – Engineering Design

Automated Welding Fixture - Final Design Report

Atom Jet Industries

Report Prepared by: Group 16

Matthew Desousa

Matthew Hunt

Yuanxing Li

Andrew Vandendorpe

Executive Summary

This report presents the design of an automated welding fixture developed for Atom Jet Industries to improve the welding process of seeding openers. The design must secure multiple configurations of seeding openers and provide automated rotation about two separate axes to manipulate the seeding openers in space, enabling accessibility to their welding sites from above.

The proposed design utilizes a PLC controlled, servo motor driven, rotary tilt table style welding fixture with a universal mounting system to accurately control the positioning of the seeding opener during the welding process. The design features two axes of rotation which are controlled by independent gearboxes comprised primarily of sheet steel parts which are assembled as bolt together units providing access for maintenance.

The design process undertook an extensive concept generation and selection phase, of which an overview is presented outlining the process taken to produce the final design. The final design is then presented which highlights the main components of the automated welding fixture and provides justification for design decisions.

The tilting and rotational motions of the welding fixture are achieved using independent gearboxes that consist of combined worm and spur gear drive systems. Each gearbox meets the minimum torque requirements of the system with a minimum overall design safety factor of 1.90.

The proposed solution provided to Atom Jet Industries has an estimated cost of $3,488.37 CAD (assembly not included).

Group 16's recommendation is to transition to a prototyping and testing phase to validate the design and fine tune the performance before transitioning to implementation of the design in the welding process of seeding openers.

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1. INTRODUCTION

Mechanical automation is revolutionizing many different industries by making processes safer, more reliable, minimizing waste, and increasing overall efficiency. The client, Atom Jet Industries, has requested an automated welding fixture (AWF) be designed to integrate with their robotic welder (cobot) and improve the overall efficiency of the welding process for their products. The intended role of the automated welding fixture is to accept, hold, and secure various product configurations and position them in multiple orientations for the robot welder to achieve optimal weld quality. This report focuses on the detailed design and analysis of the proposed solution for Atom Jet Industries. An overview of the concept development process is presented in Section 2 followed by a thorough discussion of the final design in Section 3.

1.1. Background

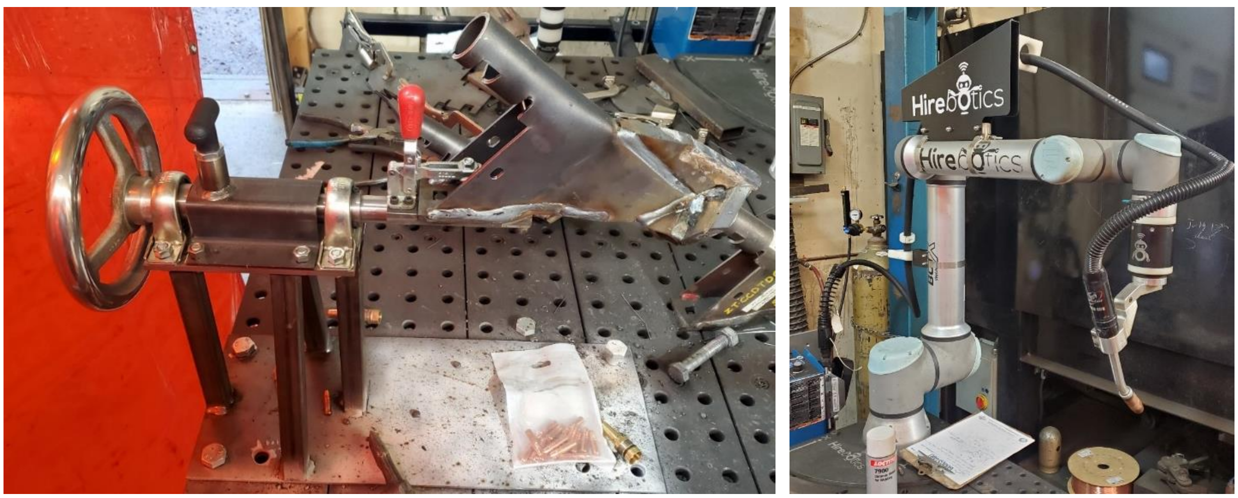
The client, Atom Jet Industries, has been involved in the agriculture industry for over 30 years and currently serves customers all over the world including Canada, United States, Australia, Russia, and Eastern Europe. Their main product offerings, which have been developed in cooperation with farmers, include Seeding Openers, Disk Scrapers, Fertilizer Knives, as well as specialty products and hydraulic systems. Seeding openers, seen in Figure 1, allow farmers to achieve better seed placement, aide in moisture conservation deep within the soil, and have essentially eliminated the need for plugging following seeding. Due to varying seeding requirements, and different equipment manufacturers and models used in agriculture, many different types of seeding openers exist. Atom Jet provides a build to order service of dozens of different seeding openers to farmers and their OEM clients. Seeding Openers, primarily the manufacturing process of vertical seeding openers, is the focus of this project.

C-Shank Side Band Granular [1] Bourgault Paralink Edge on Single Shoot [2] Morris Contour Side Band Liquid [3]

Figure 1: Vertical seeding openers. [Used with permission]

1.2. Current Process

The current manufacturing process of seeding openers requires a variety of steps and is dependent on the specific seeding opener being manufactured. The steel for the seeding opener is laser cut and formed to the specifications for the specific seeding opener being produced. Any back plates, wings, hardened tips, or additional seeding opener features to be added are then tack welded to the formed piece by a welder. A second operator then secures the seeding opener on a single axis rotational tool (welding fixture) with four lockable positions at 90-degree intervals. The operator then engages the cobot to weld the preprogrammed weld paths for the seeding opener in its current position. Once the cobot has completed its weld paths and cleared the space, the operator then rotates the seeding opener 90-degrees to the next position, and then engages the cobot welder to weld the next set of preprogrammed paths.



Operator controlled welding fixture Cobot

Figure 2: Current tools used in the continuous welding process of seeding openers.

The current length of time to weld a seeding opener from start to finish varies depending on the mounting style of the specific seeding opener and the number of continuous welds. However, the length of time for the operator to engage with the current welding fixture in between weld paths averages 5.5 seconds.

1.3. Project Objectives

The objective of the project is to integrate automation into the process by continuously welding seeding openers from start to finish by the cobot. This includes implementation of an automated system which integrates with the cobot welder to position the part when required by the cobot such that the weld paths exist in the horizontal plane, removing operator intervention once the seeding opener has been mounted and welding has begun. The solution must also be able to accept multiple types of openers, with mounting styles such as those seen in Figure 3, and secure them in a repeatable fashion. Finally, the overall completed design must be patternable such that multiple AWF's could be mounted in the design space and sequentially interact with the cobot.

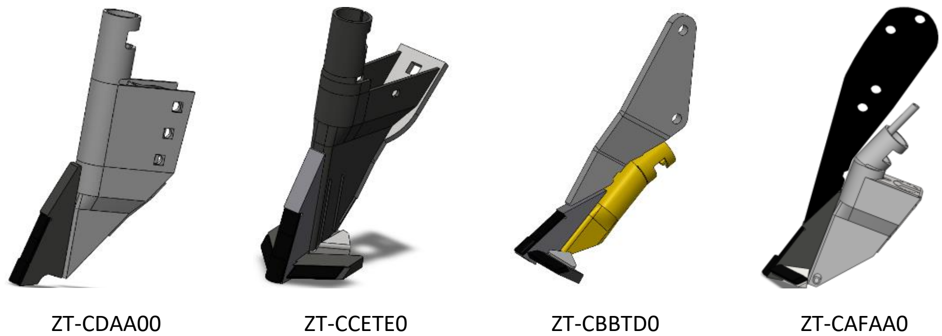


Figure 3: Various seeding openers.

1.4.Scope

Upon consultation with the client, a list of in-scope and out of scope items have been identified for the project and are listed in Table I.

Table I: Scope Definition

In Scope	Out of Scope
• Design of automated welding fixture • Selection of positional control hardware • Sequence of motion operations • Cost Analysis	• Prototyping and testing of final design • Programming of the motors

1.5. Customer Needs

The client has indicated a list of needs for the design which are summarized in Table II. The needs refer to the AWF unless otherwise stated.

Table II: Design Needs

#	Need	Imp
1	Works with all seeding opening mounting styles/configurations	5
2	The seeding opener weld locations are accessible by the cobot from above	5
3	Seeding openers can be interchanged quickly	5
4	Allows the seeding opener to be mounted repeatably.	5
5	Orients the weld paths to exist in a horizontal plane	5
6	Allows clearance for part in all orientations	5
7	Design must be patternable	5
8	Integrates with the current design space	4
9	Height must be within the design space	4
10	The operator can mount the seeding opener easily with both hands.	4
11	The operator only requires simple steps in mounting the seeding opener.	3
12	Overall complexity of the mechanism is kept to a minimum.	2
13	Can be manufactured with ease.	2

1.6. Target Specifications

A list of target specifications has been established for the design. Each metric has an associated marginal and ideal value that will be used to evaluate the success of the final design. The list of target specifications is given in Table III.

Table III: Target Specifications of the Design

#	Need #s			Metric	Imp	Units	Marginal	Ideal
1			1	Number of seeding openers the design can accommodate	4	%	80	100
2			4	Deflection of seeding opener on AWF	2	in	0.03125	0.01563
3	2	4	5	Angle between weld path line and table plane	4	deg	5	0
4	1	5	11	Can an arc be created between welder and part	5	binary	N/A	True
5		7	8	System fastens/mounts to existing table	3	binary	N/A	True
6		7	8	Number of fixtures mounted in design space	3	count	2	3
7	3	10	11	Time for operator to mount tacked assembly	2	s	<45	<30
8			12	Time taken to orient seeding opener	3	s	<10	<5
9	2	4	5	Percentage of parts rejected due to AWF error	4	%	<10	<5
10			6	Distance to nearest obstruction from weld site	4	in	>0.5	>1
11		3	11	Number of steps performed by operator	3	count	<8	<5
12		22	23	Process can be halted by emergency switch	5	binary	N/A	Yes
13			3	Seeding opener mounting repeatability allowance	4	in	0.03125	0

1.7. Project Constraints

The project was governed by a set of constraints which are listed in Table IV.

Table IV: Project Constraints

	Constraint	Description
1	Project Deadline	Dec 8th, 2021
2	Budget	$3,000
3	Operational Feature	Hold and move function and accommodate to multiple products.
4	Design Space	4’ X 4’ X 2’
5	Numerical Control	Integrate with the cobot numerical controller
6	Mounting System	Accommodate multiple product lines
7	Scope	Only the fixture and control system
8	Power Supply	AWF can only be powered by electricity or air
9	Fabrication	Metal process methods

1.8. Project Deliverables

The project deliverables consist of deliverables to the client, Atom Jet Industries, which are listed in Table V and course deliverables for MECH 4860 which are listed in Table VI.

Table V: Client Deliverables

No.	Deliverable
1	3D Model Package
2	Engineering Drawings
3	Bill of Materials
4	Preliminary PLC Flowchart

Table VI Course Deliverables

No.	Deliverable
1	Project Definition Report
2	Concept Design Report
3	Final Design Report
4	Final Design Poster
5	Final Design Presentation

2. CONCEPT GENERATION AND SELECTION

A detailed concept generation and selection process was undertaken for the development of an automated welding fixture and has been included in Appendix A. The concepts were divided into two categories including the clamping mechanism to secure the different seeding opener types repeatably, and the positioning mechanism to both rotate and tilt the clamping mechanism. The best concepts from each category were then combined to create the final concept to proceed to detailed design.

2.1. Positioning Mechanism Concepts

The positioning mechanism concept must rotate and tilt the clamping mechanism. As the clamping mechanism had not yet been designed, the positioning mechanism utilized a plate or shaft which it rotates and tilts. A total of 12 different positioning concepts were evaluated in an initial screening process, where 9 of those concepts proceeded to scoring. The concepts which were scored are seen in Table VII.

Table VII: Position Mechanism Concepts

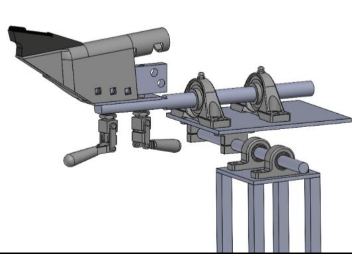
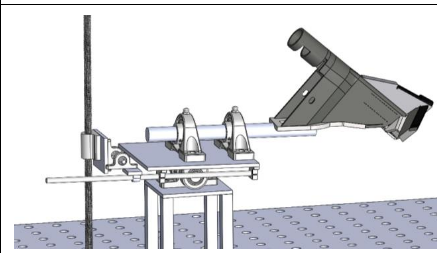
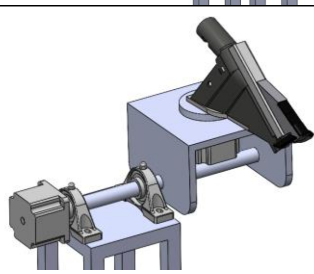
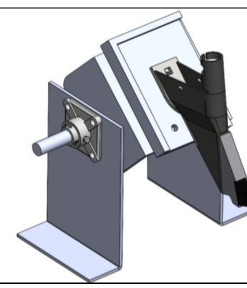
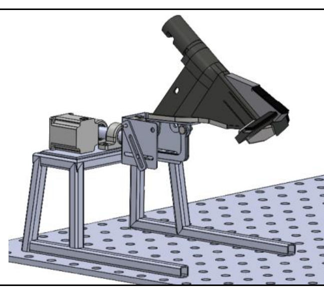
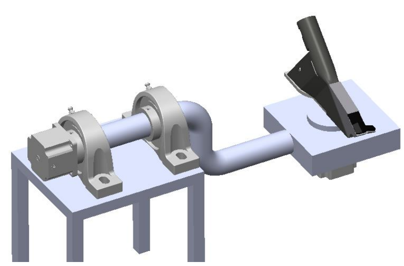
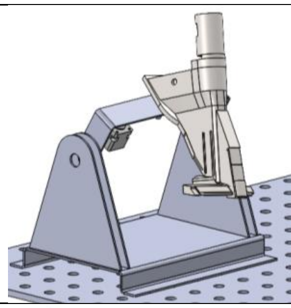
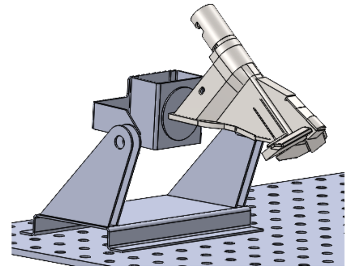
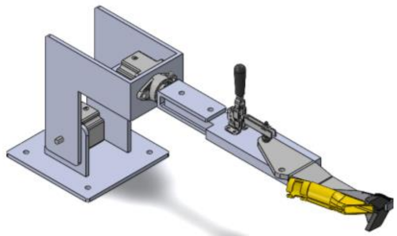
Concept Name	Concept Image	Concept Name	Concept Image
Shaft Driven Tilt Table		Lead Screw Tilt Table	
Rotary Tilt Table		Condensed Rotary Tilt Table	
Bell Crank Linkage Tilt		Rotating Bent Tube Gimbal	

Table VII is continued on the next page.

Single Unit Hinge Tilt		Angled Single Unit Hinge Tilt	
Held Angle Tilt			

The positioning mechanism concepts in Table VII were evaluated and scored based on the selection criteria and scoring seen in Table VIII.

Table VIII: Positioning Mechanism Concept Scoring

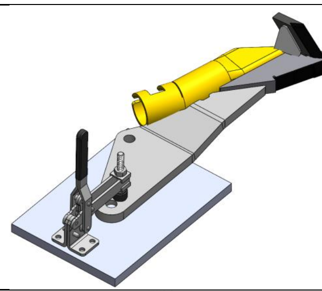
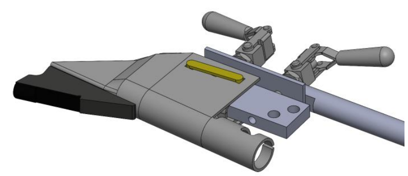
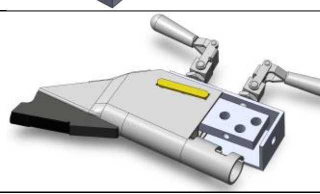
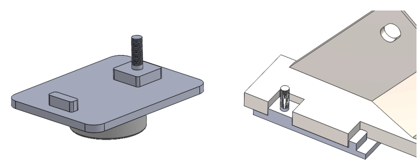
		Concept Variants								
Selection Criteria	WEIGHT	M1.1 - Shaft Driven Tilt Table	M1.2 - Lead Screw Tilt Table	M2.1 - Rotary Tilt Table	M2.2 - Condensed Rotary Tilt Table	M3.3 - Bell Crank Linkage Tilt	M4 - Rotary Bent Tube Gimbal	M6.1 - Single Unit Hinge Tilt	M6.2 - Angled Single Unit Hinge Tilt	M7 - Held Angle Tilt
Allows clearance for part in all orientations.	5	4	4	4	3	5	5	4	4	4
Ensures accessibility of weld locations.	5	5	5	3	3	5	3	4	5	5
Footprint of the mechanism	4	3	3	3	4	3	2	5	4	4
Ease of manufacturing	4	5	1	4	3	2	2	5	5	5
Cost	4	4	2	4	4	4	3	4	4	4
Height of the mechanism	3	2	2	3	3	3	3	4	5	4
Complexity	3	3	2	3	3	2	2	5	4	5
Number of steps to achieve required orientation	3	5	5	4	3	3	4	4	4	3
Minimizes volume of space for part travel	2	2	2	4	5	5	4	4	5	3
Raw Score	33	127	100	117	111	120	103	143	146	139
Score out of 5		3.85	3.03	3.55	3.36	3.64	3.12	4.33	4.42	4.21

The highest scoring positioning mechanism concept was the Angled Single Hinge Tilt concept. This concept scored well in all the evaluated criteria and can meet all the requirements.

2.2. Clamping Mechanism Concepts

The clamping mechanism must use features of the different seeding openers to secure them repeatably to the positioning mechanism. To have the ability to attach to all the positioning mechanism concepts, the clamping mechanism concepts are required to attach to an end plate or shaft. The clamping assembly can utilize many different pieces if necessary to secure the different seeding opener types, however concepts that use fewer pieces are preferred. The concepts which were scored are seen in Table IX.

Table IX: Clamping Mechanism Concepts

Concept Name	Concept Image	Concept Name	Concept Image
Interchangeable Push Clamp Plates		Rotary Table Mount Puller Bar	
Shaft Mount Puller Bar		Interchangeable Thumb Screw Plates	

The concepts in Table IX were evaluated and scored based on previously determined selection criteria. The selection criteria and the scoring of the clamping mechanism concepts can be seen in Table X.

Table X: Clamping Mechanism Concept Scoring

		Concept Variants			
Selection Criteria	Weight	L1 - Interchangeable Push Clamp Plates	L2 - Shaft Mount Puller Bar	L3 - Rotary Table Mount Puller Bar	L4 - Interchangeable Thumb Screw Plates
Works with all tacked product assemblies	5	4	5	5	4
Ensures accessibility of weld locations	5	5	5	5	5
Part can be interchanged quickly	5	2	5	5	2
Allows the tacked assembly to be mounted repeatably.	5	5	5	5	5
Ability to mount the tacked assembly easily with both hands.	4	4	5	5	4
Only simple steps needed in mounting the tacked assembly.	3	3	4	4	3
Complexity	2	3	2	2	3
Ease of manufacturing	2	3	2	2	3
Number of unique mounting fixtures	2	1	4	4	1
Total	33	119	148	148	119
Score out of 5		3.61	4.48	4.48	3.61

The highest scoring clamping mechanism concept was the Rotary Table Mount Puller Bar concept. This concept scored well in all the evaluated criteria and can mount the four different seeding opener mounting styles without the main component being switched.

2.3. Overall Final Design Concept

Through the selection process both the Angled Single Hinge Tilt concept and the Rotary Mount Puller Bar concepts were chosen and were combined to create the final design concept which was brought forward into the detailed design phase of the project. The two separate concepts are seen combined in Figure 4.

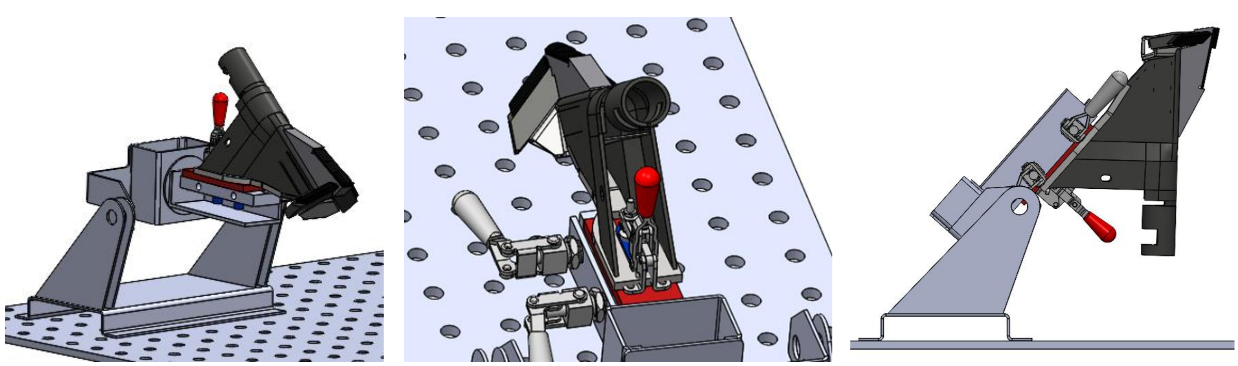


Figure 4: Selected design concept to begin the detailed design phase.

3. DETAILS OF THE DESIGN

The solution developed for Atom Jet Industries is an automated welding fixture (AWF) that utilizes a servo control system to precisely control the seeding opener positions during the welding operation. A universal clamping mechanism was developed to accommodate the various seeding opener types which is used to constrain the seeding openers in all six degrees of freedom during operation. Two separate gearbox mechanisms were designed to control the tilting and rotational motions of the welding fixture and to meet the torque requirements of the system. The assembly was designed using a combination of steel and aluminum parts as a bolt together unit allowing for ease of assembly and maintenance. An overview of the automated welding fixture design is illustrated in Figure 5.

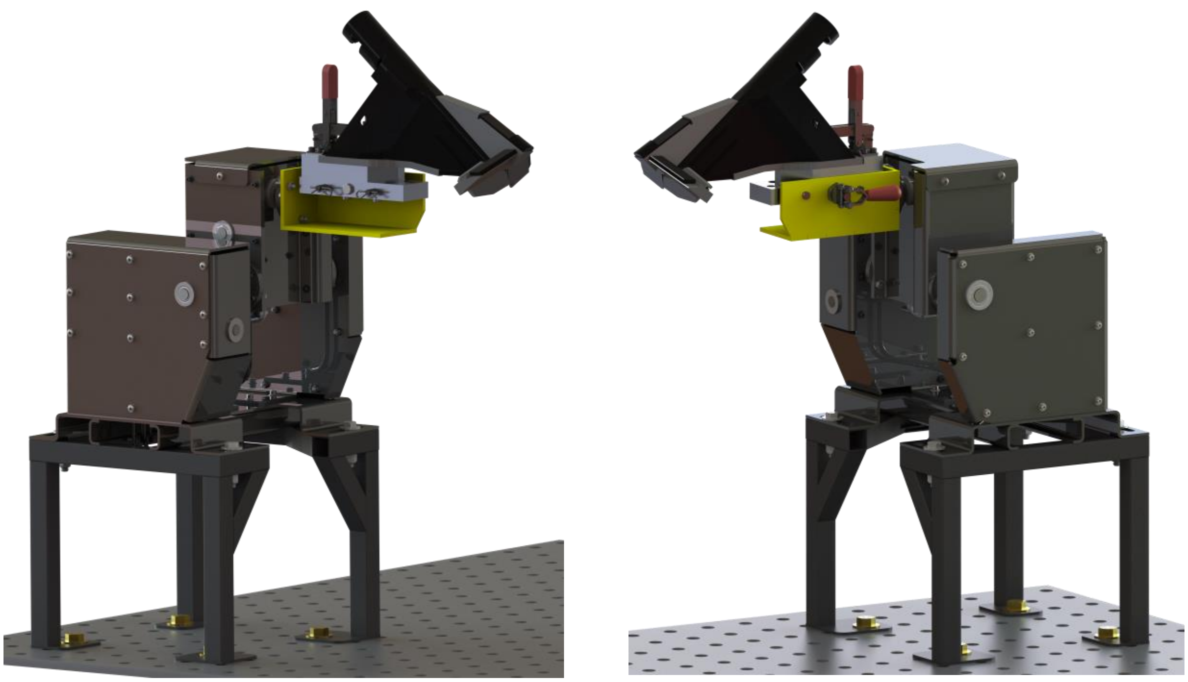


Figure 5: Design overview.

3.1. Servo Control System

Servo motors were selected to provide the precision positional control required by the system. Teknic's ClearPath servo motors were selected as they provide an all-in-one integrated servo system. The layout of the control system framework and the operation of the motors will be discussed. Details regarding the specific control sequence is presented in Section 3.10. The specific servo models selected will be discussed in Sections 3.4.3 and 3.5.3.

3.1.1. Teknic ClearPath Servo System

In contrast to traditional servo motor control systems, Teknic ClearPath servo motors feature integrated servo controllers and servo drivers within the motor housing, eliminating the need for additional system hardware external to the motor. This provides a compact arrangement and simplifies the design. Additionally, ClearPath motors are easy to program and are well suited for a variety of motion applications. A ClearPath servo is shown in Figure 6 for reference.

Figure 6: Teknic ClearPath servo[1] control system [4].

3.1.2. Motor Type

Teknic offers three series of integrated servo systems, namely Step & Direction (SD), Motion Control (MC) and Software Control (SC). Each series is designed for specific applications and operate using different types of input signals. Table XI summarizes the various ClearPath servo series.

Table XI: ClearPath Servo Series [5] [6] [7]

Motor Series	Description
Step & Direction (SD)	Control motion using step and direction signals
Motion Control (MC)	Control motion using simple I/O from a PLC or buttons and switches
Software Control (SC)	Control motion using software

The MC motor series was determined to be the most suitable for this application and was selected as the motor type to use in the design. The MC series is further comprised of two models, namely the MCVC and MCPV models. The MCPV model was selected as it is specifically designed for position and velocity control applications.

[1] Teknic servo motor images and model renders courtesy of Teknic, Inc. https://teknic.com/

3.1.3. Motor Programming and Operating Mode

ClearPath Motors are programmed and setup using the ClearPath MSP (Motor Setup Program) via a USB Micro-B cable that connects to a PC. The motor setup includes selection of the desired operating mode and specification of the motor motion parameters such as maximum speed and acceleration. Once programmed, the motor can be disconnected from the PC and will operate based on the parameters it was setup with.

The MC series of motors offer 13 operating modes which are tailored for specific motion applications. The Pulse Burst Positioning mode was selected as it integrates well with the existing PLC at Atom Jet's facility and offers the greatest positioning and programming flexibility. When operated in this mode, the motors rotate a distance proportional to the number of pulses generated and sent to the motor by the PLC or similar hardware. Figure 7 illustrates how the pulse signals generate the desired motor position control.

Figure 7: Pulse burst timing [8].

Input A to the motor controls the direction of rotation. The direction of rotation is clockwise when Input A is high, while the direction of rotation is counterclockwise when Input A is low. Input B is the pulse input. The number of pulses is directly proportional to the angular displacement of the motor shaft. Upon consultation with the client, it was determined that the existing PLC can provide this required pulse-burst signal and it was thus deemed an acceptable operating mode for the system.

3.1.4. Power Supply

The power supply requirements indicated by Teknic included an operating voltage range of 24-75VDC, the capability to deliver high peak-current and the ability to handle back-EMF [8]. Teknic offers several power supplies that are best suited to their various motor systems which meet all of the requirements mentioned. The IPC-5 power supply from Teknic was selected as it has been specially designed for use with ClearPath motors and is able to power 2-6 motors depending on the power demand. The ability to power up to 6 motors was an important feature as this allows for the potential expansion of the design which the Client indicated is a likely possibility. The Teknic IPC-5 power supply is shown in Figure 8.

Redacted Image. Image was of the Teknic IPC-5 Power Supply Unit

Figure 8: Teknic IPC-5 power supply [9].

3.2. Clamping Mechanism

The clamping mechanism secures and locates the various seeding openers repeatably in the same location to ensure the welding locations are consistent for the robotic welder. A view of the clamping mechanism without any seeding openers is seen in Figure 9.

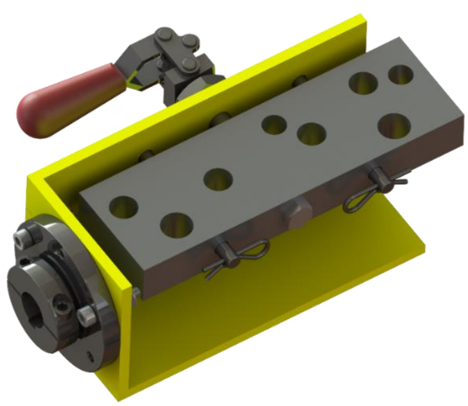


Figure 9: Clamping mechanism

The clamping mechanism features a pulling block which is used to secure the four different mounting style types of the seeding openers. The pulling block slides along two clevis pins and is pulled towards the wall of the clamping mount bracket by a push/pull toggle clamp. The clamping mount bracket is attached to a shaft collar which clamps around the end of the rotational shaft which can then be rotated by the rotational mechanism and tilted by the tilting mechanism.

3.2.1. Operator Interaction

The operator interaction with the clamping mechanism is minimal. The number of operations to secure each seeding opener is limited to 3 or 4 depending on the mounting style of the opener, however they all follow the same approach. The opener is first positioned so its mounting holes align with the pulling block as seen for CDAA00 in Figure 10.

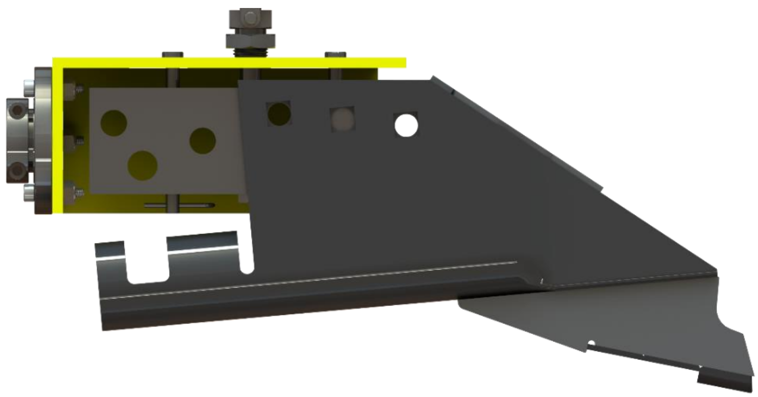


Figure 10: CDAA00 Seeding opener positioned over the pulling block with holes aligned

Once the holes are aligned, the operator must take the alignment pins specific to the seeding opener which is being clamped and slide it through the holes of both the seeding opener and the pulling block. The alignment pins for the CDAA00 seeding opener along with their placement is seen in Figure 11.

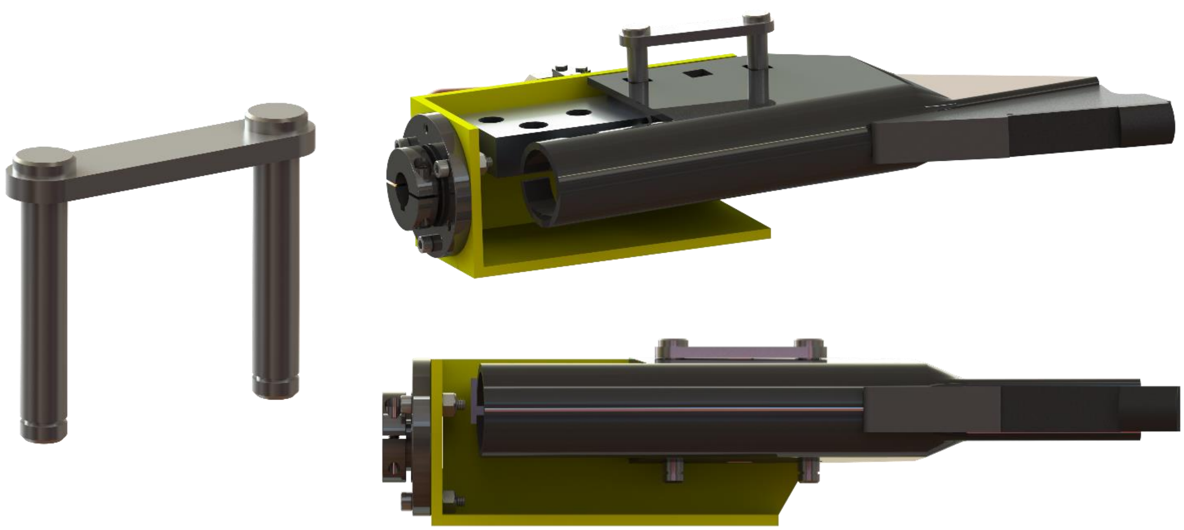


Figure 11: Alignment pins for the CDAA00 seeding opener (left) and its placement to secure the seeding opener

The alignment pins are pushed down through the holes until the plate of the holder is resting up against the seeding opener. Once the holder is touching the seeding opener, the operator holds the holder down onto the seeing opener with one hand while simultaneously pulling on the push/pull clamp, fully securing the seeding opener by pulling it up against the mounting bracket of the clamping mechanism. A render depicting the CDAA00 seeding opener in its clamped and secured position is seen in Figure 12.

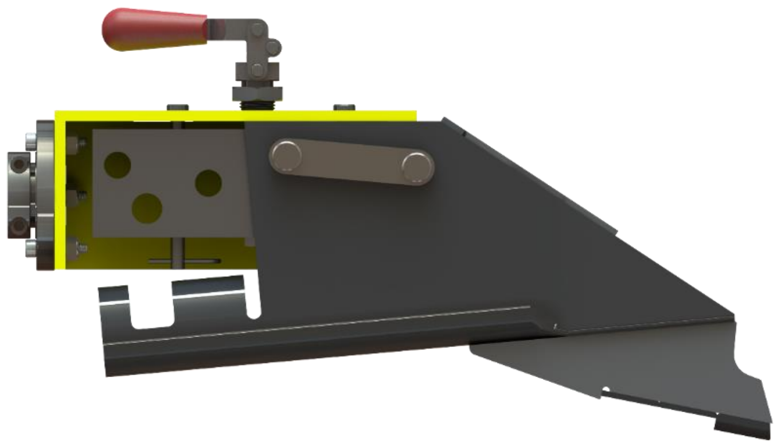


Figure 12: Fully clamped and secured CDAA00 seeding opener

3.2.2. Universal Mounting

The clamping mechanism was designed to be compatible with the various seeding opener types manufactured by Atom Jet. The pulling block previously discussed features specially positioned holes which accommodate the unique alignment pins associated with the different seeding opener types. This universal mounting feature allows for easy changeover of seeding opener types without the need for unique mounting fixtures.

The CAFAA0 seeding opener utilizes the existing holes on the upper portion of the assembly to pass the alignment pins through. Due to the geometry of this portion of the seeding opener, a shim was used between the seeding opener and the sidewall of the clamping assembly to ensure flush contact for clamping. The mounting configuration of the CAFAA0 seeding opener type is illustrate in Figure 13.

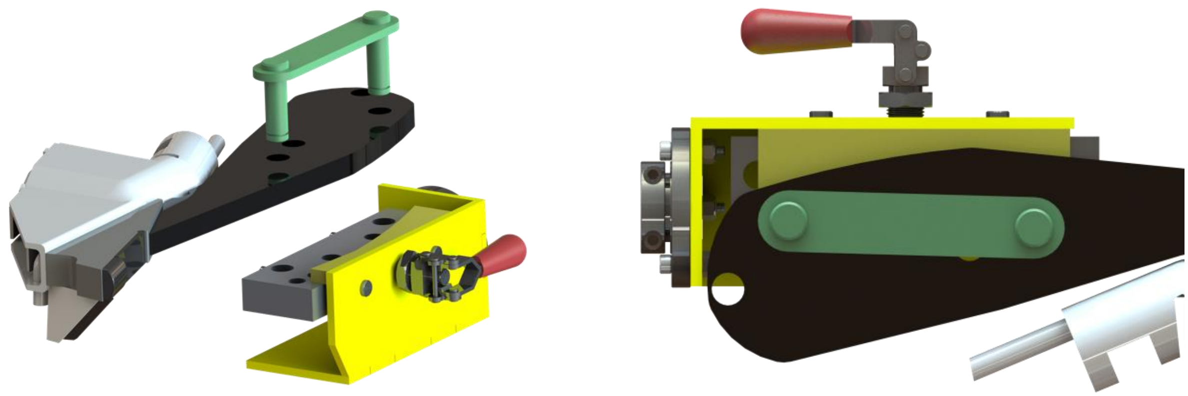


Figure 13: CAFAA0 seeding opener clamping configuration.

The CBBTD0 seeding opener is aligned to the clamping assembly using the existing holes on the upper portion of the seeding opener. The face of the upper portion is then pressed up against the sidewall of the clamp assembly using the push/pull toggle clamp. The mounting configuration of the CBBTD0 seeding opener type is illustrated in Figure 14.

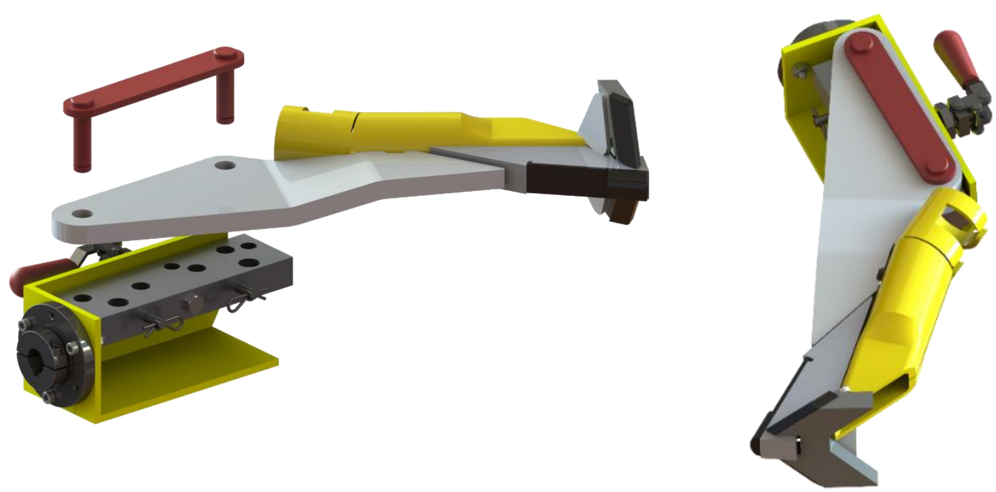


Figure 14: CBBTD0 seeding opener clamping configuration

The CDAA00 seeding opener type is mounted to the clamping assembly using the hole features on the sidewall flanges. Unlike for the other seeding opener types, the puller block sits within the internal geometry of the CDAA00 model. The mounting configuration for the CDAA00 seeding opener is illustrated in Figure 15.

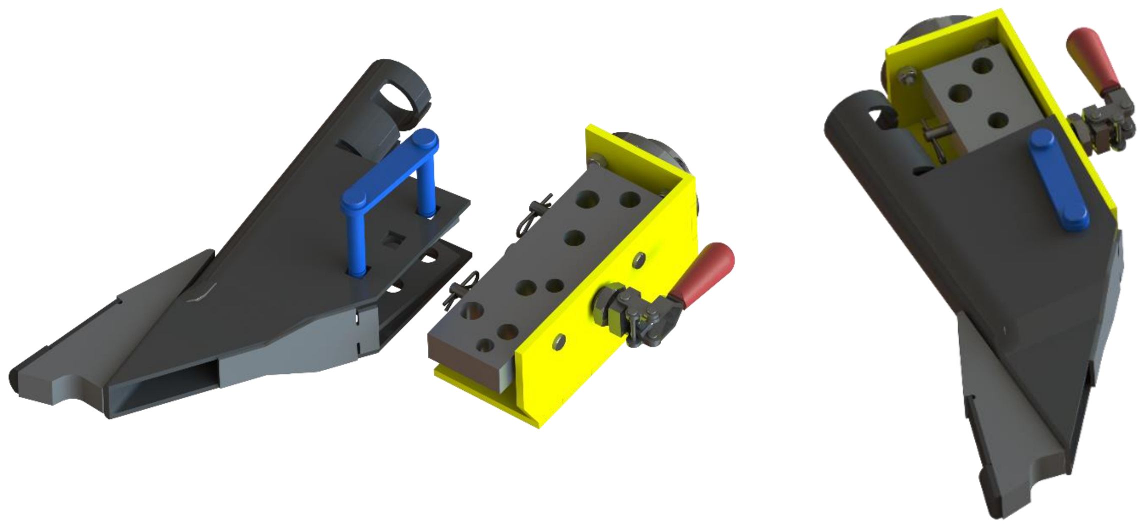


Figure 15: CDAA00 seeding opener clamping configuration.

There is a modification which must be made for seeding openers with an attachment method such as that of CCETE0. While although alignment pins are still utilized, the welding locations on the seeding opener prevent part geometry from being secured against the mounting bracket. To adjust for this an adapter block is used to bring the opener off the pulling block. The adapter is then secured to the pulling block and overall clamping mechanism as the other seeding openers.

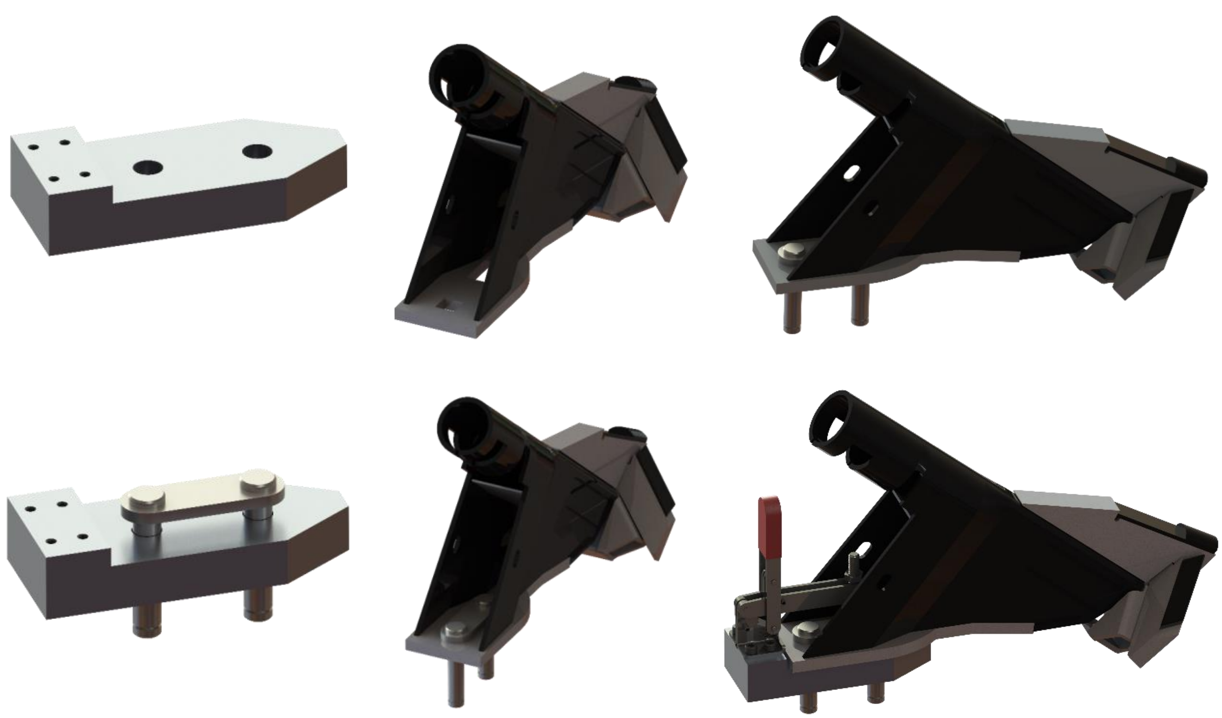


Figure 16: CCETE0 seeding opener with adapter block.

Figure 16 demonstrates the adapter block which is attached to the seeding opener through the utilization of the alignment pins and a hold-down clamp. The alignment pins are first inserted through the holes in the seeding opener, and then through the holes in the adapter block. Once the alignment pins are flush with the seeding opener, the hold-down clamp on the adapter block holds the alignment pins down.

This subassembly is then attached to the clamping mechanism just as the other seeding openers with their alignment pins by sliding the pins through the puller block, and then pulling the push/pull clamp as described earlier. The adapter block with the seeding opener can be seen in Figure 17.

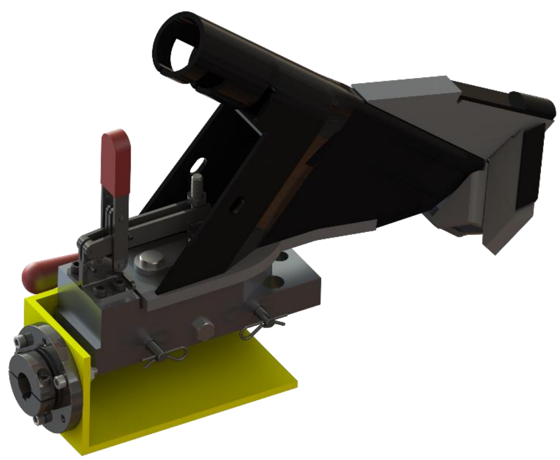


Figure 17: CCETE0 seeding opening secured to the clamping mechanism.

3.2.3. Degrees of Freedom Restrained

The clamping mechanism was designed to ensure that all six degrees of freedom of motion were restrained for each of the four seeding opener types in all orientations. A combination of push-pull clamps and alignment pins were used as discussed above. Figure 18 illustrates how the alignment pins constrain translation of the seeding openers in the x and y axes as well as constrain rotation about the z-axis.

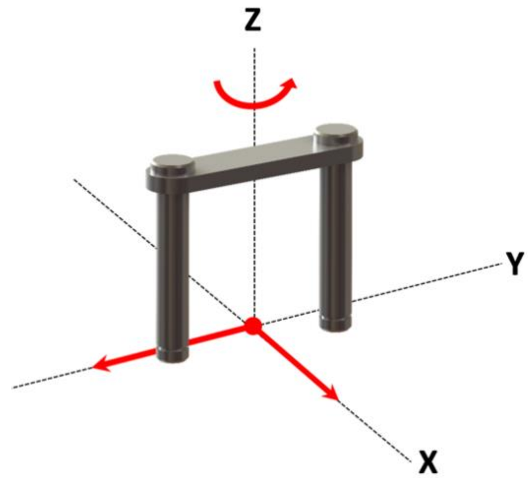


Figure 18: Degrees of freedom constrained by alignment pins.

The clamping force for all seeding opener types prevents translation in the z direction as well as rotation about the x and y axes as illustrated in Figure 19. Since the overall method for constraining motion using clamps is common to all seeding opener types, only one example is shown. However, the exact means by which the various seeding opener types are clamped vary slightly.

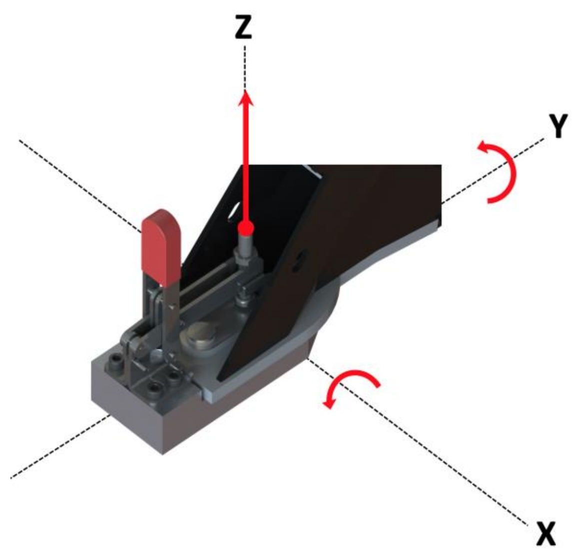


Figure 19: Degrees of freedom constrained by clamp.

3.3.Powertrain System Design Decisions

The powertrain system is designed to provide the required torque, high positional accuracy, maintain compactness, and maintain angular position when not in motion. The torque required by the system is determined by using the center of mass distance from the axis of rotation. The maximum moment created by the center of mass was calculated for both the rotational mechanism and tilting mechanism using the different seeding openers, which set the minimum torque requirements for each system.

3.3.1. Motor Size Selection

The MCPV ClearPath motors selected offer high positional accuracy while coming in a wide variety of sizes, offering varying amounts of torque, and having wide cost margins. In the interest of compactness, the NEMA 23 frame size (the smallest offered) was selected for the motors. This frame size has a face width and height of 2.33”. The length of this frame size varies from 3.34” up to 5.58” and the continuous torque output varying from 13 oz-in to 165 oz-in. The NEMA 23 MCPV motors are also able to support a maximum radial and axial load of 25lbf and 5lbf respectively [10].

3.3.2. Shaft Support

The different configurations of seeding openers vary in their weight, ranging from 4-10lbs, exceeding the axial load capacity of the selected motors when the seeding opener is positioned vertically. To combat this, the load of the seeding opener is taken off the motor shaft and placed on bearings. An option initially considered was thrust bearings mounted on the motor shaft to take the axial loading. However, it was found that they can be quite bulky. Instead, the option chosen was to not place any substantial load on the motor shaft and to use a second shaft to take the load.

To support the axial load of the second shaft, a thin flanged deep groove ball bearing was used. These bearings have radial load limits which far exceed the load created by the seeding opener and their axial load limit is between 25-50% of their static radial load rating, making them a suitable choice for our application. Bushings were also considered as they are low cost and have load ratings sufficient for this application. However, roller bearings provide smoother motion with less friction.

The bearings under the highest loads are those directly supporting the tilt shafts and the rotational shafts with a 0.625” bore. The bearings selected from SKF (D/W R10 R-2Z), have a dynamic and static load rating of 1111lbf and 708lbf respectively [11]. Axially the static load rating would be anywhere from 177lbf to 354lbf. These loads far exceed the loads experience by the shafts in the powertrain design. The smallest bearings used in the design are SKF’s D/W R6 R-2Z with a 0.375” bore. Their dynamic and static load ratings are 555lbf and 252lbf [12] which still far exceed the loads experienced by the powertrain. These bearings are all shielded to prevent clogging due to weld spatter and come pre-greased.

3.3.3. Power Transmission Elements

One of the requirements of the powertrain system is to maintain angular position when not in motion. To eliminate the need for a brake on the motor, the unidirectionality of worm gear drives is utilized. To make use of this advantage, the motor shaft drives a secondary shaft where the worm screw is located. The worm screw rotates to drive a worm wheel located on a tertiary shaft. This tertiary shaft is locked in rotation with either the tilting or clamping mechanism of the system.

Finally, to connect and drive the secondary shaft from the motor shaft, 0.25" wide spur gears are used. Synchronous belts and pulleys were investigated in place of spur gears; however, the belt and pulley would require a larger center to center distance which would increase the overall size of the gear box. The other point to mention is that the pulley width available is substantially larger than that of the spur gears and they would not fit on the motor shaft, unlike the spur gears.

3.4. Rotation Mechanism

The rotational mechanism of the automated welding fixture must provide the rotational torque to the final output shaft necessary to rotate the clamping assembly and must also provide a way for the tilting mechanism to perform its function to tilt the clamping assembly while it is attached to the rotational mechanism.

3.4.1. Gear/Motor Housing

The gear and motor housing consists of a single unit with two internal compartments separated by an inner wall. The main internal compartment houses the NEMA 23 size MCPV ClearPath motor and the worm drive portion of the powertrain system, whereas the second compartment houses the spur gear. An external view of the rotational mechanism can be seen in Figure 20 and an above view with the top cover removed providing a visual of the two compartments can be seen in Figure 21.

Figure 20: External view of the rotational mechanism housing

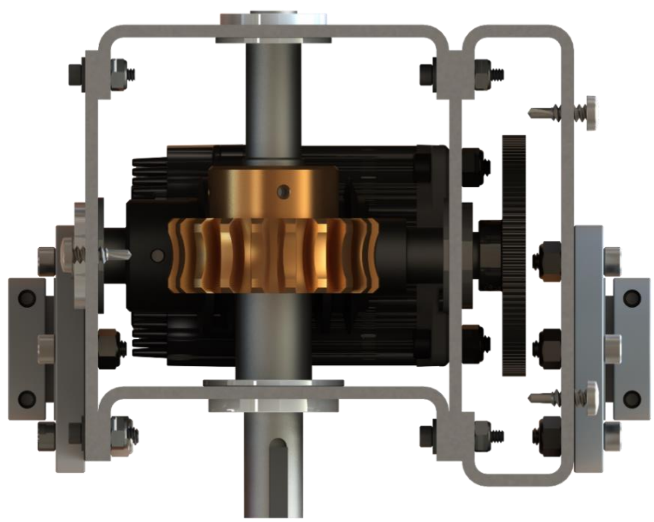


Figure 21: Above view of the rotational mechanism. The motor compartment and worm gear drive is on the left, and the spur gears are housed on the right separated by the inner wall[2].

The above view in Figure 21 provides a visual aid of the general location of the components which exist in the rotational mechanism housing. To improve the visual and better describe the layout of the components, the front cover is also removed, with the side walls made transparent and the mechanism layout visualized in an isomeric perspective seen in Figure 22.

[2] Worm and gear renders courtesy of KHK USA Inc. https://www.khkgears.us/

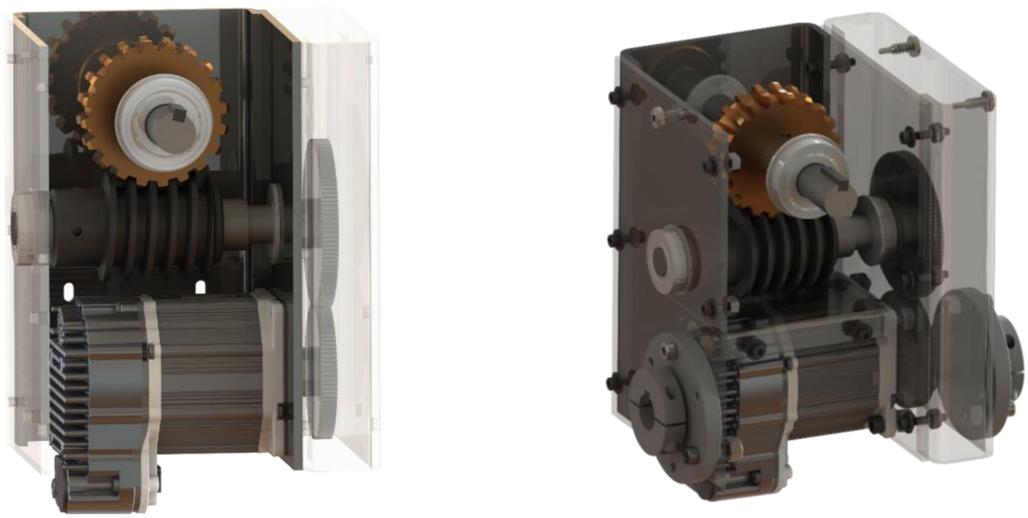


Figure 22: Isometric perspective of the component layout in the rotational mechanism with the top and front walls removed, and the side walls made transparent[3]

As seen in Figure 22, the inner wall provides a mounting surface for the motor face and provides support for the secondary shaft holding the worm gear. To keep the powertrain system compact, the secondary shaft which holds the worm gear is placed above the motor reducing the overall footprint of the rotational mechanism housing to approximately that of the motor with clearance allowance. Finally, the tertiary shaft on which the worm wheel sits is positioned above the secondary shaft perpendicular to the secondary shaft. The second compartment which houses the spur gears prevents dirt, dust, and debris from interfering with the spur gear operation, and adds safety by reducing the ability for clothing or otherwise to get caught between the gears.

An important feature for the rotational mechanism is its ease of assembly and serviceability as all the housing walls utilize mechanical fasteners rather than being using welds or single component construction. For the determination of the reductions required by the rotational mechanism and the gear specifications to provide those reductions, the required output torque was determined.

3.4.2. Rotational Mechanism Required Torque

To determine the required torque of the rotational mechanism, the mass along with the distance from the center of mass to the axis of rotation was found for 4 different configurations of seeding openers. The

[3] NEMA size 23 MCPV ClearPath motor Courtesy of Teknic, Inc., teknic.com

torque required by the system was then determined by the maximum moment created by gravity acting on the center of mass.

The mass of the clamping mechanism with the paired row seeding opener (CCETE0) is 10.11lbs (161.76oz) and has a moment arm length of 1.9011" from the axis of rotation. When the moment arm is perpendicular to gravity, the output shaft will require a minimum output torque of 308 oz-in. The location of the center of mass and the coordinates used to determine its distance from the axis of rotation can be seen in Figure 23.

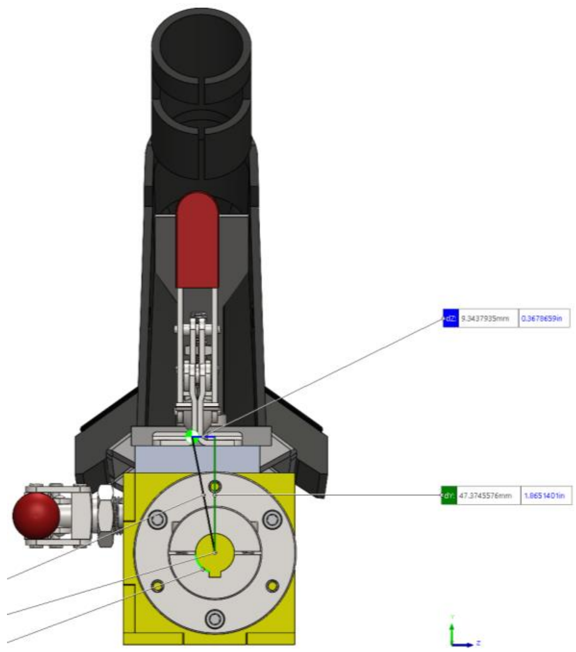


Figure 23: Rotation mechanism center of mass location from axis of rotation.

The mass and distance from the center of mass to the axis of rotation was calculated for the four different mounting types of the openers, and the resulting torque requirements are shown in Table XII.

Table XII: Required Torque for Tilting Gearbox Output

Seeding Opener	Mass (oz)	Length of Moment Arm (in)	Required Torque (oz-in)
CCETE0	161.76	1.9011	308
CDAA00	132.96	0.544	72
CAFAA0	171.52	0.800	137
CBBTD0	164.32	1.511	248

3.4.3. Motor Selection and Powertrain System Reduction

The motor selection and gear reduction values were chosen together for the rotational mechanism as the available torque output from the motor influences the reduction ratio that is required. The cost of the gear and motor pair was also considered. The smallest reduction ratio explored for a worm drive provides a 10:1 reduction. When paired with the motor, which can provide a continuous output torque of 58oz-in at this motor size, provides 580oz-in of torque at the output shaft. The output torque was then increased to 725oz-in using a spur gear reduction ratio of 1.25, accomplished with a 2.5" spur gear, being driven by a 2" spur gear from the motor shaft. This output torque provides a safety factor of 2.35 on the required output torque from the rotational mechanism.

As cost is a consideration, a second motor and gear combination were investigated. A motor can be provided which can provide 44oz-in of continuous torque. When paired with a worm drive providing a 20:1 reduction, in addition to the 1.25:1 reduction from the spur gears, the final continuous output torque was found to be 1100oz-in. This combination of higher reduction ratio, and smaller motor torque produces a safety factor of 3.57 based on the minimum continuous torque requirement and provides a cost savings of $20USD compared to the higher performing motor and smaller gear ratio. The higher safety factor and reduced overall cost results in the second option considered for the selection of rotational mechanism powertrain components. A render of this power train system is seen in Figure 24.

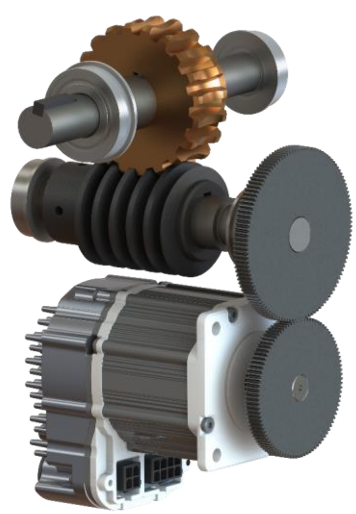


Figure 24: Rotational powertrain system render[4,5].

[4] Spur Gear Renders Courtesy of Stock Drive Products/Sterling Instrument, sdp-si.com.
[5] NEMA size 23 MCPV ClearPath motor Courtesy of Teknic, Inc., teknic.com

3.4.4. Shaft Design and Analysis

The rotational gearbox utilizes two shafts to transmit power from the servo motor to the clamping assembly. Shoulders and keyways were added to both shafts to allow for proper alignment within the gearbox housing and to accommodate the various power transmission elements. Static and fatigue analyses were also conducted to verify that the initial shaft geometries can support the expected loads.

The worm screw shaft consists of six stepped sections which are used to locate the shaft within the gearbox housing and to locate the spur gears and worm screw. The primary purpose of this shaft is to isolate the motor shaft from the axial loading that will result from the worm drive. The worm screw shaft consists of a single key seat which is used to connect the shaft to the worm screw. The diameters of each section were determined based on the bore diameters of the gears and bearings and to allow for proper fits between these elements and the shaft. An overview of the worm screw shaft design is presented in Figure 25. Details regarding the worm screw shaft dimensions can be found on drawing AWF-02-01 in Appendix C.

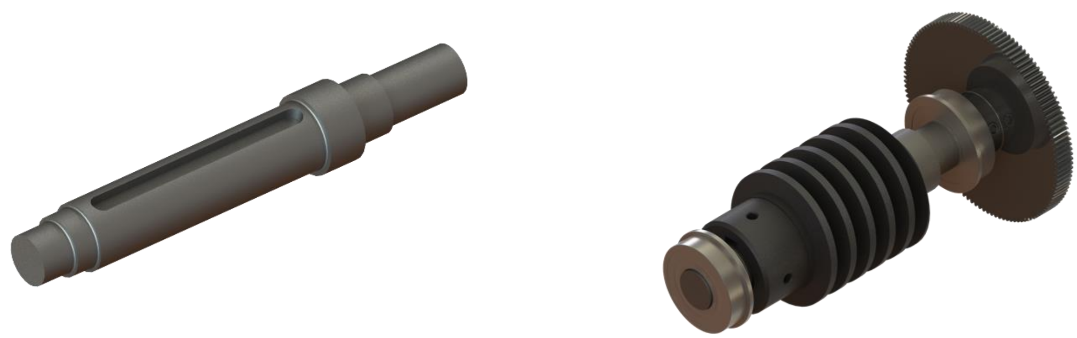


Figure 25: Rotation gearbox worm screw shaft.

The output shaft consists of five stepped sections which are used to locate the shaft within the gearbox housing and to locate the worm wheel and clamping assembly collar. The primary purpose of this shaft is to rotate the clamping assembly. The output shaft consists of two key seats. The first key seat is used to connect the shaft to the worm gear, while the second is used to connect the shaft to the clamping assembly collar. An overview of the rotation gearbox output shaft design is presented in Figure 26. Details regarding shaft dimensions can be found on drawing AWF-02-20 in Appendix C.

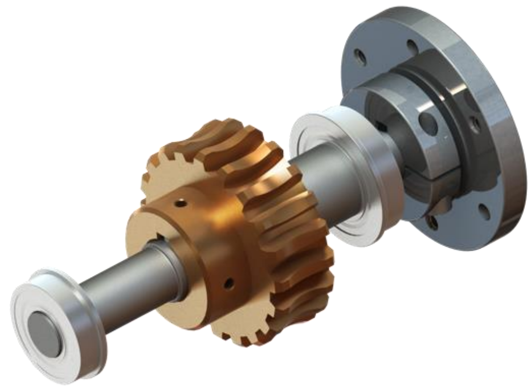



Figure 26: Rotation gearbox output shaft.

Both a stress and deflection analysis were performed on the shafts to ensure that they are within a reasonable safety factor (more than 2). The output shaft is the most critical and under the most load and was the focus of this analysis. The highest stress region is expected to be at the step at the bearing. Since this location is right behind the bearing support which will take some of the load off, it was still conservatively estimated that all the load goes through this step. The load is a function of the angle that the shaft is at with respect to gravity. As another conservative approximation, the maximum value of tension, bending, and torsion was applied to the step simultaneously (Table XIII).

Table XIII: The Geometry and Loading Characteristics of the Rotational Gearbox Output Shaft at the Step.

Parameter	Value
Larger Diameter [D]	20.6mm
Smaller Diameter [d]	15.875mm or 5/8”
Fillet Radius [r]	0.8mm
Tension Force [P]	42.3N
Bending Moment [M]	7.81Nm
Torque [T]	2.13Nm

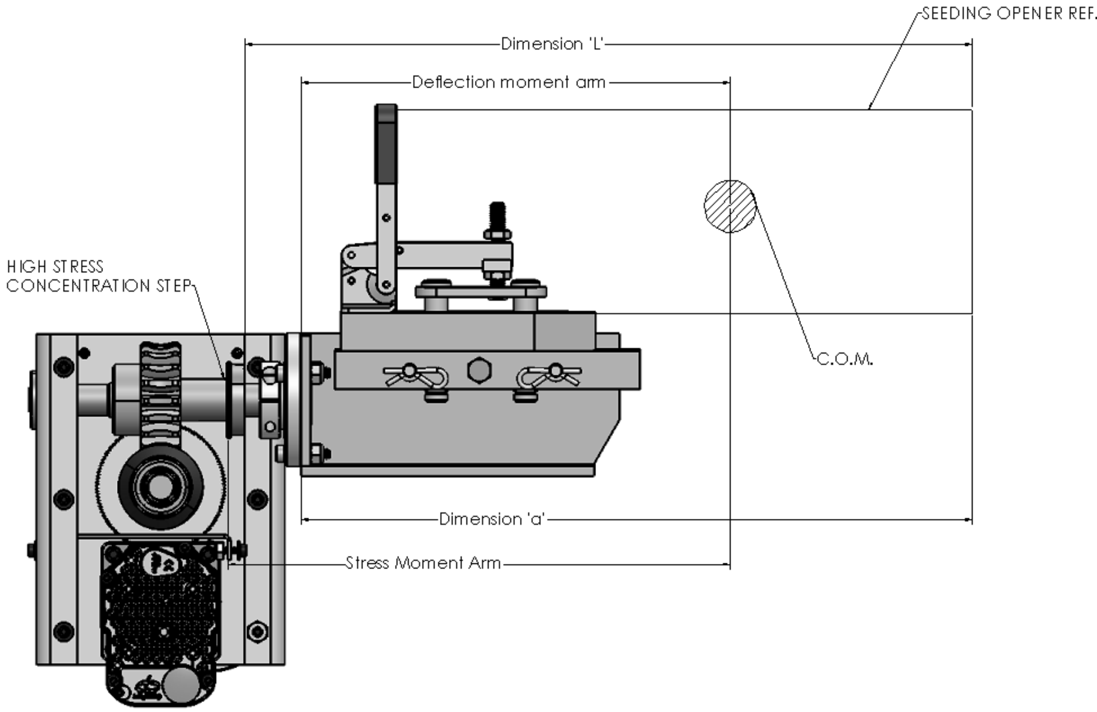


Figure 27: The dimensions concerning the moment, stress, and deflection calculations for the rotational gearbox.

The tension or compression force is maximum when the shaft is pointed vertically upwards or downwards. The bending moment is maximum when the shaft is oriented perpendicularly to gravity, the same goes for torsion. The weight of the seeding opener and clamping mechanism assembly is largest with the paired row opener at 42.3N (9.5lbf). The bending moment arm from the center of mass of this assembly to the step in the shaft is 185mm while the moment arm for torsion is 50mm.

Table XIV: The Stress Concentration Factor Applied to Nominal Stress at the Step and the Corresponding Maximum Stress.

Parameter	Tension	Bending	Torsion
Stress Concentration [K_t]	2.12	2.05	1.61
Nominal Stress [σ_{nom}]	0.21	19.88	2.71
Max Stress [σ_{max}]	0.45	40.77	4.37

The stress concentration factors for the three loading modes were calculated using the equations provided by [13]. The nominal stresses and moments of inertia were calculated using the classical mechanics of materials equations from [14] and given in Equations 1 through 5. The nominal stress was then multiplied by the stress concentration factor to get the value of maximum stress that could result in localized yielding at the step in the shaft.

$$J = \frac{\pi D^4}{32} \tag{1}$$

$$I = \frac{\pi D^4}{64} \tag{2}$$

$$\sigma_{axial} = \frac{P}{A} \tag{3}$$

$$\sigma_{bending} = \frac{Mc}{I} \tag{4}$$

$$\tau_{xy} = \frac{Tc}{J} \tag{5}$$

For this analysis, it was assumed that plane stress conditions apply. This is because the stress element with maximum shear and normal stresses acting on it is contained within a thin layer on the outside diameter of the shaft. It is also the case that the only stress on the element is within a 2D plane (no stress in the radial direction). For plane stress conditions with no stress in the y-direction, the Von-Mises stress was calculated using Equation 6. The stress in the x direction is from the combination of bending and axial stresses while the shear stress is from pure torsion.

$$\sigma' = \left(\sigma_x^2 + 3\tau_{xy}^2\right)^{1/2} \tag{6}$$

This results in a Von-Mises stress of 42MPa resulting in a factor of safety against yielding of 8.6 when AISI 4130 annealed steel is used for the shaft (yield strength of 360MPa [15]). A conservative analysis of fatigue life based on the parameters in Table XV was done using the Goodman criteria. The assumptions used for this analysis were: fully reversed loading, machined surface finish, and a static stress concentration factor of 2.0. Due to the nature of the welding operations of the seeding openers, the shaft may not complete fully reversed cycles meaning the stress amplitude is likely lower in the positive amplitude direction. The fatigue stress concentration factor is based on a static stress concentration factor of 2.05. This is because most of the stress is generated due to bending and will have the largest effect on fatigue life (Table XIV).

Table XV: The Parameters Defining the Fatigue Life of the Shaft Using the Goodman Criteria.

Parameter	Value
S_{ut}	560 MPa
k_a	0.77
S_e	216 MPa
$\sigma_{a,0}$	20.63 MPa
K_f	1.7
σ_a	34.78 MPa
n_f	6.1

Plugging these parameters into the Goodman Criteria (Equation 7) results in a safety factor against yielding of 6.1. In this analysis the mean stress was assumed to be zero, however the results would be identical if the mean stress became negative. A negative mean stress would be more realistic as the seeding opener will not be upside down as often as right side up. Additionally, the bending moment decreases during tilt operations. Therefore, the safety factor against infinite life may be even higher.

$$n_f = (\sigma_a/S_e + \sigma_m/S_u t)^{-1} \quad (7)$$

Perhaps more important than the stress distribution in the shaft is its rigidity. The shaft fastened to the seeding opener should not undergo unreasonable deflection. This would cause the seeding opener to be slightly out of plane with it more exaggerated at the point furthest from the automated welding fixture. However, since a seeding opener type has consistent weight, it will always deflect the same amount when installed. This means that the error due to deflection can be programmed into the weld path. However, the seeding opener should not deflect outside a reasonable tolerance for machine construction (around 1mm).

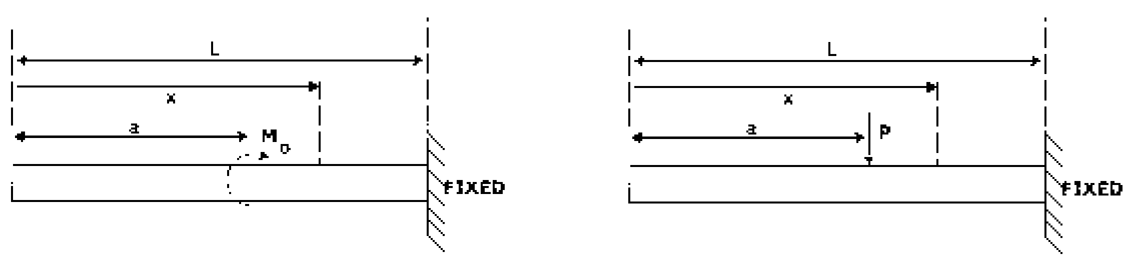


Figure 28: Diagrams how the beams were modeled as cantilevers. The dimensions correspond to the variables used later in calculations. Redrawn from [16].

Table XVI: The Parameters Defining the Shaft Geometry and Stiffness.

Parameter	Value
Diameter	5/8” (15.875 mm)
Modulus of Elasticity ($\boldsymbol{E}$)	210 GPa
Moment of Inertia ($\boldsymbol{I}$)	3117 mm^4
Length ($\boldsymbol{L}$)	363 mm
$\boldsymbol{a}$	335 mm

The seeding opener output shaft protrudes 28mm (a=335mm in Figure 28) from the bearing support to the clamping mechanism. The weight of the paired row opener is 42.2N with its center of mass at a distance of 148mm from the end of the shaft. This creates a moment of 6.25 Nm combined with a transverse load of 42.2 N at the end of the shaft. By the method of superposition, the effective deflection of both loads was added together. The effective length of the beam is the distance from the furthest end of the seeding opener to the bearing support which is 363 mm.

Table XVII: The Deflection at The Far End of The Seeding Opener Caused by Each Load.

Load	Deflection
42.2 N	0.009 mm
6.25 Nm	0.093 mm
Sum	0.102 mm

As can be seen in Table XVII, the deflection due to the bending moment is much larger than that due to the transverse force. However, the total deflection is only 0.102mm or 0.004” which was deemed acceptable. The deflection Equations 8 & 9 are derived from cantilever beam bending equations from [17]. These equations assume that the seeding opener clamping fixture rotates about the angle at the end of the elastically deformed shaft. That is, the seeding opener clamping mechanism does not undergo any deformation itself.

$$\delta_{transverse} = \frac{W}{6EI} 2(L-a)^3 + \frac{W(L-a)^2}{2EI} a \tag{8}$$

$$\delta_{bending} = \frac{M_0(L-a)^2}{2EI} + \frac{M_0(L-a)}{EI} a \tag{9}$$

The gears also carry load and were analyzed, specifically the worm gear system at the output shaft. This is because this is the part of the system with the highest load applied. The spur gears at the servo motor were assumed to be sufficiently strong as there is considerably less torque, and they are made of hardened steel. For the worm gear system, KHK provides a strength calculation [18] based on rotation speed, lubrication, and contact factors. The output shaft is intended to rotate at approximately 20rpm while the worst-case lubricant and contact factors are chosen (Table XVIII). From these input parameters, a tangential load of 430N or equivalently a torque of 10.8Nm is allowed through the worm gear mesh. Since there is only 2.1Nm of torque being provided, a safety factor of 5.1 is achieved.

Table XVIII: The Input Parameters into SKF's Gear Strength Calculator for The Output Worm Gear.

Parameter	Value
Rotating speed	20 rpm
Lubricant Factor	0.5
Contact Factor	1.7

3.4.5. Rotational Mechanism Assembly

The overall design of the rotational gearbox has been thought out to maintain a compact design and deliver the required torque to rotate the clamping assembly and any secured seeding opener. An exploded view of the rotational mechanism and all its hardware and components is given in Figure 29.

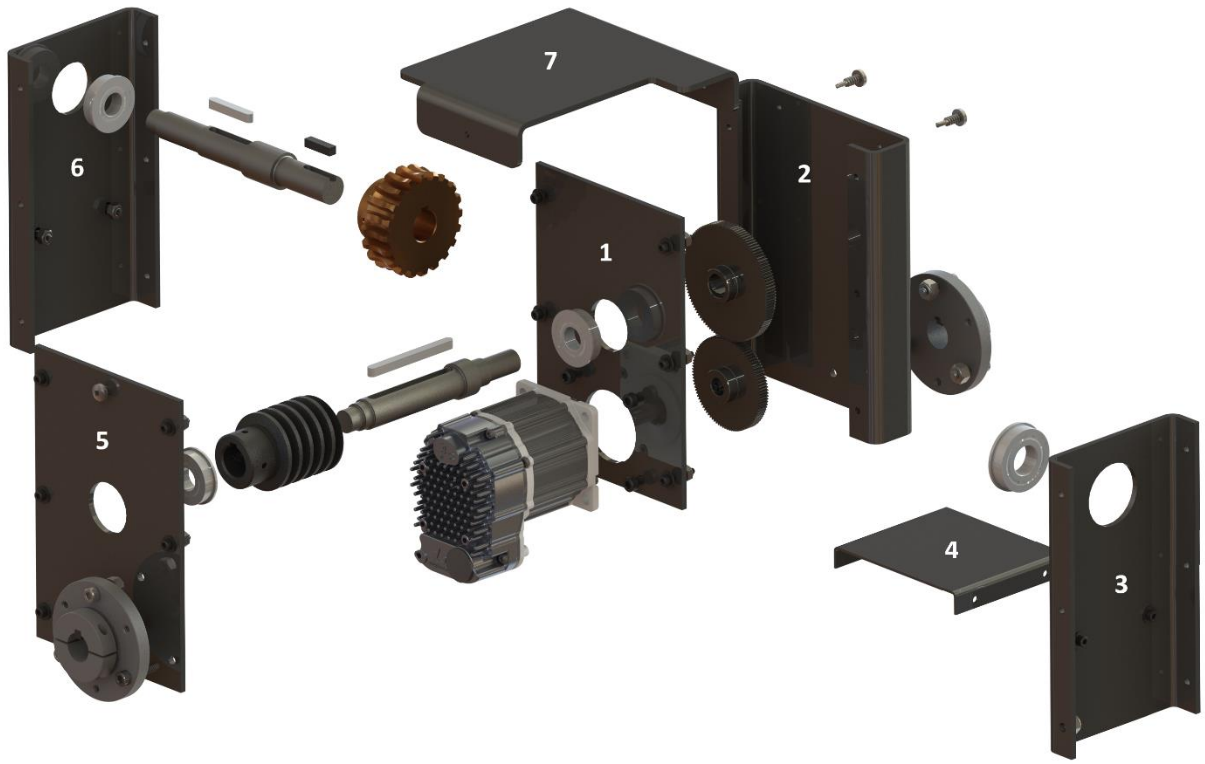


Figure 29: Exploded view of the rotational mechanism assembly.

The positioning and method of assembly for all components was considered in the design. To begin the assembly, all the flanged roller bearings are press fit into the steel walled housing plates with the flanges resting against the inner face of the housing wall. While although an interference fit is desired for the bearings, it is not essential as the shafts are all turned down to the proper abutment diameters for the bearings. This orientation of the bearings prevents axial translation as the flange prevents the shaft from falling out of the housing, while the shaft prevents the bearing from falling into the housing.

Once the bearings are placed in the walls, the motor is mounted to its wall (1), and the collars used by the tilting mechanism mounted to their walls (2 & 5) all through bolted connections. Next, the keys for the worm screw and the worm wheel are placed on their shafts, and both worm gear shafts assembled. The shaft containing the worm screw is then fed through wall 1, and the spur gears attach to the worm screw shaft and the motor shaft on the opposite side of wall 1.

Assembly of the housing can now begin with wall 4 being attached to wall 3. Walls 1, 2, 3, and 5 are then bolted together. The worm wheel shaft is then brought forward and through the bearing in wall 3. Wall 6 is then brought in and the last of the bolted connections made. Lastly, the top is placed on and fastened with screws, completing the assembly of the rotational mechanism.

3.5. Tilting Mechanism

The overall tilting mechanism consists of two housing units. The first is a hollow, two-walled structure which supports the rotational mechanism and removes cantilever action from the shaft driving the tilt. The second housing unit contains the NEMA size 23 MCPV ClearPath motor and the power train system.

3.5.1. Gear/Motor Housing

The gear and motor housing unit consists of a two walled structure with internal support walls which support the shafts and motor. The external housing can be seen in Figure 30.

Outside View Inside View

Figure 30: Enclosed tilting gear box.

The overall design has been modified from that of the selected design concept, however the shaft that drives the tilting of the system is still brought forward and up to the top corner of the mechanical housing. The overall shape has been modified to allow space for the components and provide support for the shafts.

As described in Section 3.3, the power train system consists of a spur gear attached to the motor shaft. This motor shaft spur gear drives a second spur gear located on a separate shaft (worm screw shaft). On the same shaft as the second spur gear, the worm screw is located. The worm screw then drives the worm wheel which is located on an additional shaft (output shaft) of this powertrain system and is locked in rotation with the rotational mechanism. By removing the outer cover of the tiling gear box, the powertrain system is visible as shown in Figure 31.

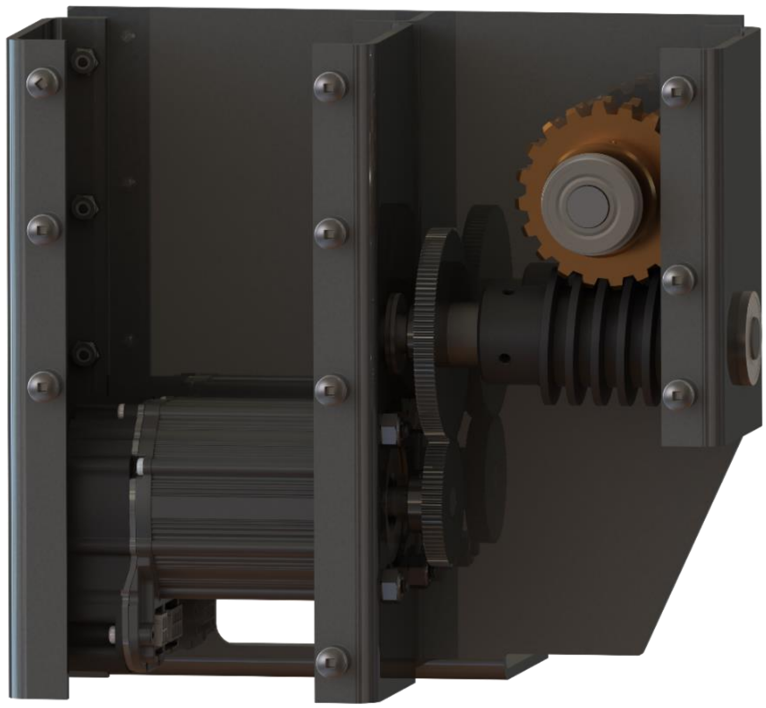


Figure 31: Tilting gear box internals.

The housing includes three vertical support walls fasted to the inner walls using bolts, while the outer wall is attached to the inner walls with screws. The worm screw shaft is supported by bearings on the outside walls of the housing, while the output shaft is supported by the outer walls of the casing. The output shaft location was chosen to be positioned in the upper front corner of the side walls in the concept development phase of the project as discussed in Section 2.3. This placement drives the location of the other powertrain components. The worm screw shaft which contains the worm screw is placed horizontally to be supported by the inner vertical walls and at a separation distance specified by the worm gear manufacturer. The spur gear located on the primary tilt shaft must mesh with the spur gear on the motor shaft, so the distance between the motor shaft and primary shaft is driven by the pitch diameters of the spur gears. Finally, the motor orientation is placed on the opposite side of the center support wall, allowing for lubrication of the gear train without requiring a motor cover.

The motor could have been placed under the gear train system such as in the rotational mechanism, however, shortening the base would have decreased the stability of the tilting gear box while it is supporting the rotational gear box and attached seeding opener. Positioning the motor under the gear train would also require a tray to avoid grease from spilling on the motor, so this position was avoided.

3.5.2. Tilting Mechanism Required Torque

Similar to the rotational mechanism, to determine the required torque for the tilting mechanism, the mass along with the distance from the center of mass to the axis of rotation was found for the entire rotational mechanism with 4 different configurations of seeding openers. The torque required by the system is then determined by the maximum moment created by gravity acting on the center of mass.

The mass of the entire rotational mechanism including the clamping mechanism for the paired row seeding opener (CCETE0) is 22.92lbs and is located 4.679 inches from the center of rotation. When this distance is perpendicular to gravity, this will require a minimum tilt output torque of 1716 oz-in. The location of the center of mass and its distance from the axis of rotation can be seen in Figure 32.

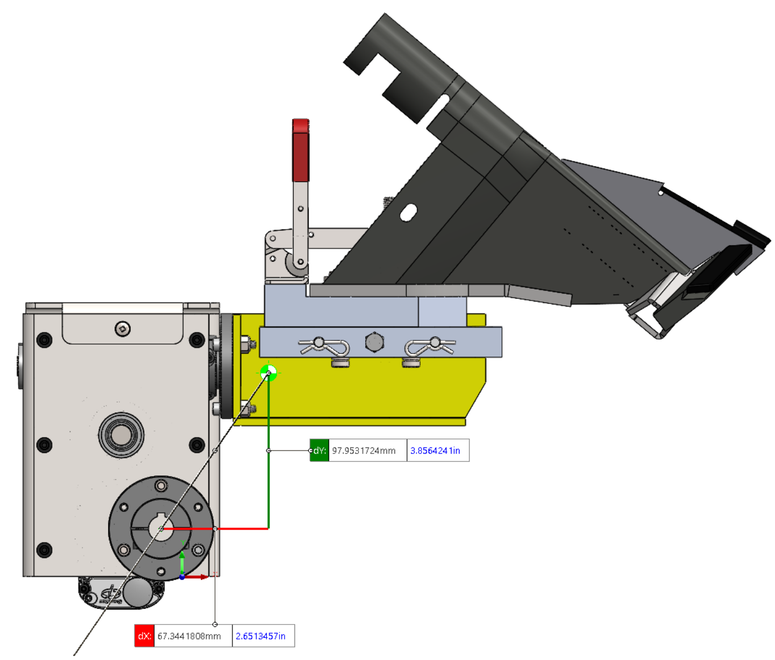


Figure 32: Tilting mechanism center of mass location from axis of rotation.

The mass and distance from the center of mass to the axis of rotation was calculated for the four different mounting types of seeding openers, and the resulting torque requirements are shown in Table XIX.

Table XIX: Required Torque for Tilting Gearbox Output

Seeding Opener	Mass (oz)	Length of Moment Arm (in)	Required Torque (oz-in)
CCETE0	366.72	4.679	1716
CDAA00	336.92	3.626	1222
CAFAA0	375.54	4.4913	1687
CBBTD0	368.32	4.428	1631

3.5.3. Motor Selection and Powertrain System Reduction

The motor selection and gear reduction values were chosen together for the tilting mechanism as in the rotational mechanism. Since the required torque is larger than that of the rotational mechanism, and the size constraints are not as critical, the length of the motor was increased to the next size available, offering higher continuous torque output. Comparing cost to torque, a motor was selected which can provide 98 oz-in of continuous torque with a maximum peak torque of 492 oz-in [19]. The continuous torque was used to evaluate the powertrain system.

The worm gear set utilized in the rotational gear box, which provides a 20:1 reduction, was used as a starting point for the overall reduction ratio. The larger spur gear is limited in its diameter due to the inner width of the casing and so a 120 tooth, 2.5-inch diameter spur gear was selected. The 20:1 reduction increases the continuous torque available from 98oz-in to 1960oz-in. While although this would provide enough torque to tilt the rotational mechanism, there will be frictional losses and so the torque was increased further by reducing the diameter of the spur gear attached to the motor shaft. The motor shaft contains a 72 tooth, 1.5-inch diameter spur gear providing an additional reduction factor of 1.67.

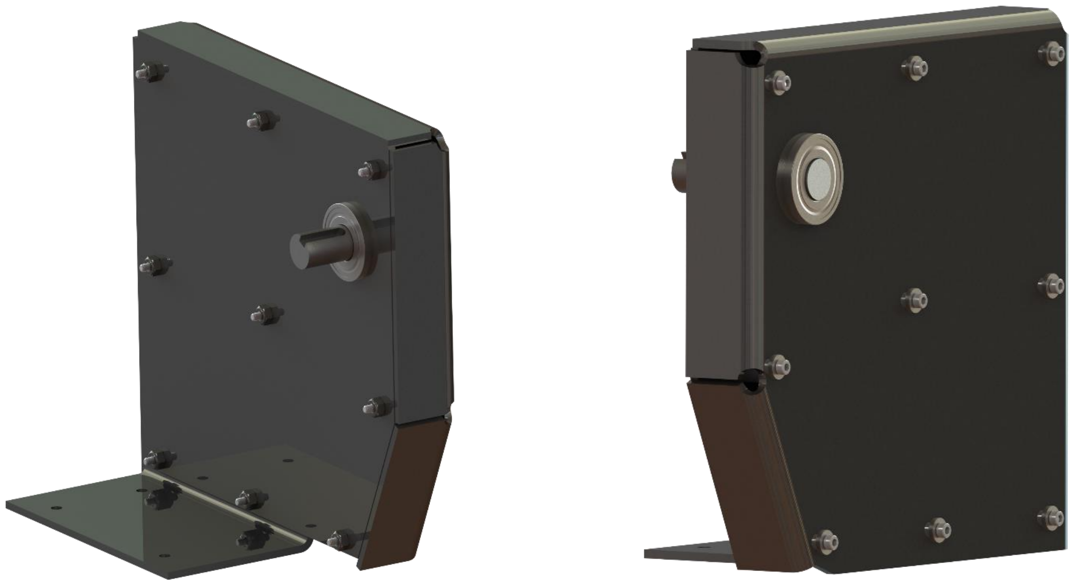
The total gear reduction in the tilting mechanism is 33.33:1, increasing the continuous torque output to 3267oz-in and providing a safety factor of 1.90 on the continuous torque output. This safety factor is large enough to account for small mechanical losses in the system such as friction for example. Additionally, if further torque is required, the motor can increase the incoming current to reach peak torque levels with the reduction factor to output 16400oz-in of torque. A render of the powertrain system which includes the motor, gears, shafts, and bearings is seen in Figure 33.

Figure 33: Tilting powertrain system render[6].

3.5.4. Support Wall Housing

The support wall housing was designed similarly to the motor and gear housing where there are two outer walls which support the shaft which the rotation mechanism is mounted. The support wall removes the cantilever load from the output shaft which provides the tilting torque. As there are no internal components to support, spacers are used to separate the walls. The flanged bearings maintain their flanges on the inside of the wall and are again fixed axially due to the flange and shaft abutment. The outside of the housing can be seen in Figure 34 and an exploded view of the assembly shown in Figure 35.

[6] NEMA size 23 MCPV ClearPath motor Courtesy of Teknic, Inc., teknic.com



Inside Perspective Outside Perspective

Figure 34: Tilting mechanism support wall housing.

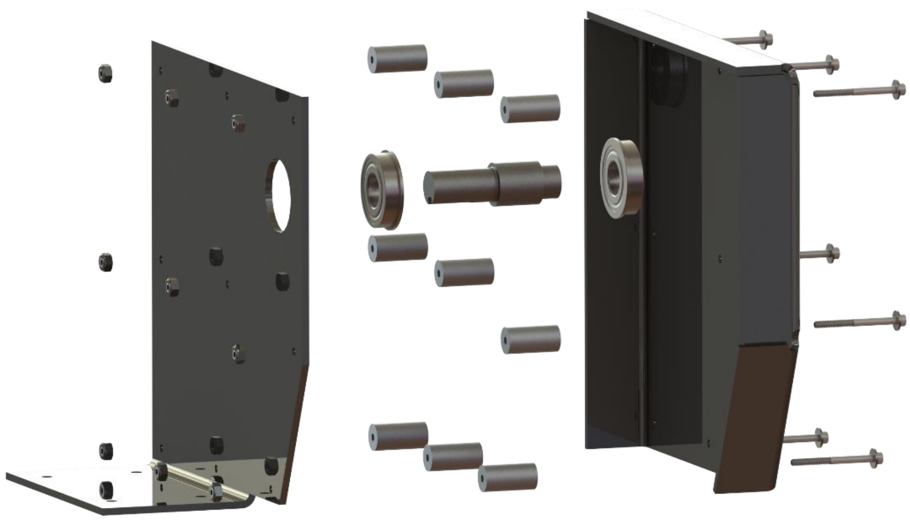


Figure 35: Exploded assembly view of the support wall housing.

3.5.5. Shaft Design and Analysis

The tilting mechanism utilizes three shafts to transfer power from the servo motor to the rotational gearbox. Each shaft incorporates features to accommodate the various power transmission elements that mount to them. Each of the shafts within the tilting mechanism assembly are unique to fit within the space constraints of the gearbox, properly mount between the bearings and accommodate various power transmission elements. Details regarding shaft dimensions can be found in Appendix C.

The output shaft is connected to the flange mounted collar on the rotational gearbox using set screws and a square machine key. A key seat and shoulder were included on the shaft for mounting the worm gear. The shaft also features shoulders with properly dimensioned abutment diameters to mate up against the face of the flange mounted bearings. The output shaft with and without the mounted components is illustrated in Figure 36.

Figure 36: Output shaft.

The worm screw shaft consists of five stepped sections which are used to locate the shaft within the gearbox housing and to locate the gear and clamping assembly collar. The primary purpose of this shaft is to isolate the motor from the axial loading induced by the worm drive. The worm screw shaft consists of a single key seat which is used to connect the worm screw to the shaft. An overview of the worm screw shaft with and without the mounted components is presented in Figure 37.

Figure 37: Worm screw shaft.

The idle shaft rotates freely and is used to support the rotation gear box assembly. It does not connect to any gears and consequently does not transmit power. A single key seat is used to connect the shaft to the collar on the rotation gear box assembly. The idle shaft consists of two shoulders which are used to locate the shaft within the gearbox housing and to mate up against the flange mounted bearings. The idle shaft with and without the mounted components is presented in Figure 38.

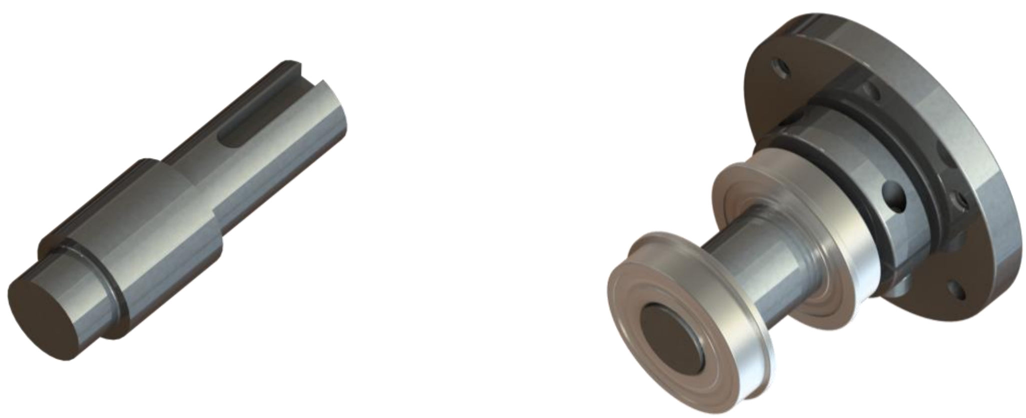


Figure 38: Idle shaft.

An identical analysis was applied to the output shaft from the tilting gear box as was applied to the rotational gearbox. The equations and diagrams will not be repeated from Section 3.4.4, only the relevant parameters and conclusions are outlined. There are two shafts holding the gear box, one in each sidewall. This means that they share the bending moment (half going to the bearing support at each shaft). However, the torque is completely transmitted through the tilt shaft going to the motor and no axial load is applied to the shaft. The shaft step dimensions, and stress concentration factors are the same as those for the rotational shaft.

Table XX: The Geometry and Loading Characteristics of The Rotational Gearbox Output Shaft at The Step.

Parameter	Value
Larger Diameter [D]	20.6 mm
Smaller Diameter [d]	15.875mm or 5/8”
Fillet Radius [r]	0.8mm
Tension Force [P]	0 N
Bending Moment [M]	5.2 Nm
Torque [T]	12.1 Nm

The torque on the shaft has already been determined for the motor selection to be 12.1Nm. The bending moment was calculated as half the rotational gear-box’s weight (51N) at the distance from its center of mass to the bearing support (100mm). The nominal stresses were calculated before applying the static stress concentration factor with results in Table XXI. The stress concentration was calculated at the step closest to the output in Figure 36.

Table XXI: The Stress Concentration Factor Applied to Nominal Stress at The Step and The Corresponding Maximum Stress.

Parameter	Tension	Bending	Torsion
Stress Concentration [K_t]	0	2.05	1.61
Nominal Stress [σ_{nom}]	0	12.20	16.77
Max Stress [σ_{max}]	0	25.00	27.00

The maximum Von-Mises stress is calculated using the bending and torsional stresses as 53Mpa which results in a safety factor of 6.8 against yielding. The fatigue life was analyzed using Goodman’s criteria assuming fully reversed loading. The safety factor against infinite life is 4.0 for the tilting output shaft.

Table XXII: The Parameters Defining the Fatigue Life of The Shaft Using the Goodman Criteria.

Parameter	Value
S_{ut}	560 MPa
k_a	0.77
S_e	216 MPa
$\sigma_{a,0}$	31.5 MPa
K_f	1.7
σ_a	54.2 MPa
n_f	4.0

For the deflection calculations, the shafts on either side of the gear box were modeled as cantilever beams with half the load of the gearbox applied at their ends. The moment applied at the end of the shaft is from the offset of the gearbox to the end of the shaft by 69mm (3.51Nm). The shaft does not undergo as much deflection due to bending when compared to the rotational gearbox since it is not cantilevered out as far, and there is a support wall structure adding additional support. The total deflection due to bending and the transverse load is 0.012mm with most of it caused by the bending moment.

Table XXIII: The Parameters Defining the Geometry and Stiffness of The Shaft.

Parameter	Value
Diameter	5/8” (15.875 mm)
Modulus of Elasticity ($\boldsymbol{E}$)	210 GPa
Moment of Inertia ($\boldsymbol{I}$)	3117 mm^4
Length ($\boldsymbol{L}$)	92 mm
$\boldsymbol{a}$	69 mm

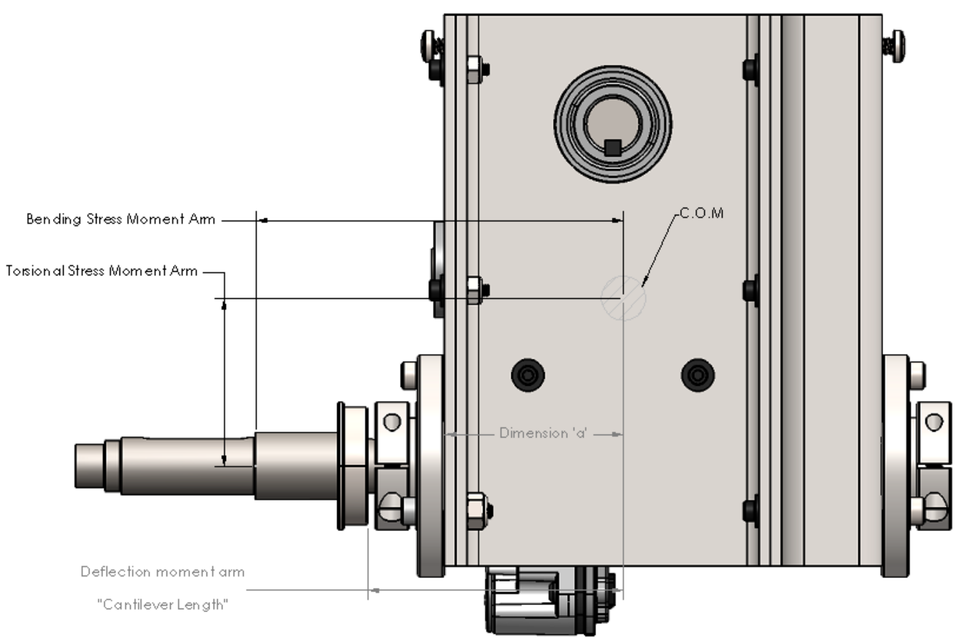


Figure 39: The dimensions used to calculate moments and deflections for the tilting shaft.

Table XXIV: The Deflection at The Far End of The Seeding Opener Caused by Each Load.

Load	Deflection
50.9 N	0.002 mm
3.51 Nm	0.010 mm
Sum	0.012 mm

Additionally, due to the higher torsional load on this shaft the angular twist was also calculated using Equations 10 and 11 with the shear modulus of 4130 steel being 80GPa. The torque on the shaft is provided by the worm gear which is mounted 56mm from the end of the shaft (Figure 40). The stiffness K is 6235 mm^4 resulting in an angle of twist of the shafts end to be 0.0014 radians. The furthest tip of the paired row opener is at a perpendicular distance to the shaft of 420mm. Extending the angle of twist to the linear displacement at this point results in 0.57mm (0.022") of displacement.

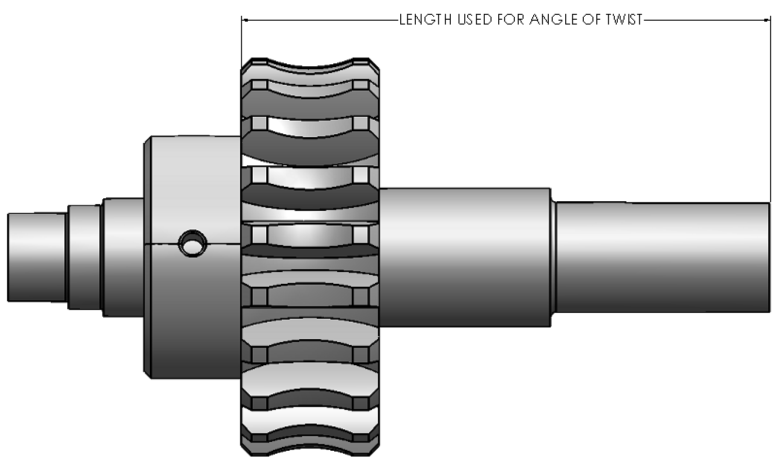


Figure 40: The length used for the angle of twist of the tilting output shaft.

$$\theta = \frac{TL}{KG} \tag{10}$$

$$K = \frac{1}{2}\pi r^4 \tag{11}$$

Deflection of the tilting shaft, combined with its torsion and the deflection of the rotational gearbox shaft results in the total deflection of the seeding opener. The tilting shaft deflects 0.012mm and due to twist moves the seeding opener down by 0.57mm while the rotational gearbox shaft deflects to 0.102mm. Therefore, the furthest point of the paired row opener deflects downwards by 0.68mm. The team accepted this as a reasonably low deflection for this application. As previously stated, the robotic welder's weld path will be programmed to account for this deflection.

The torque on the worm gear mesh is more substantial for the tilting gear box than the rotational gearbox. The maximum torque on the tilting gear box is 11.4Nm (1616 oz-in). Due to the larger torque, it should be ensured that sufficient lubrication and contact can be achieved in the worm gear mesh. To reach a safety factor of 2.2, the lubrication factor should be 0.9. A class 1 high load grease is recommended for this application [20]. The contact factor between the worm and the gear is difficult to determine and is based on the grade of the gears. The gear being used is grade 2 of 12 with 0 being the best, for a conservative estimate it was assumed this is mid-range grade with a contact factor of 1.3 [21].

Table XXV: The Input Parameters into SKF's Gear Strength Calculator for The Output Worm Gear.

Parameter	Value
Rotating speed	20 rpm
Lubricant Factor	0.9
Contact Factor	1.3

3.5.6. Tilting Gearbox Assembly

The overall design of the tilting mechanism housing has been thought out in a similar fashion to the rotational mechanism to maintain a compact design and deliver the required torque to the rotational mechanism with attached clamping assembly and seeding opener. An exploded view of the tilting mechanism and all its hardware and components is given in Figure 41.

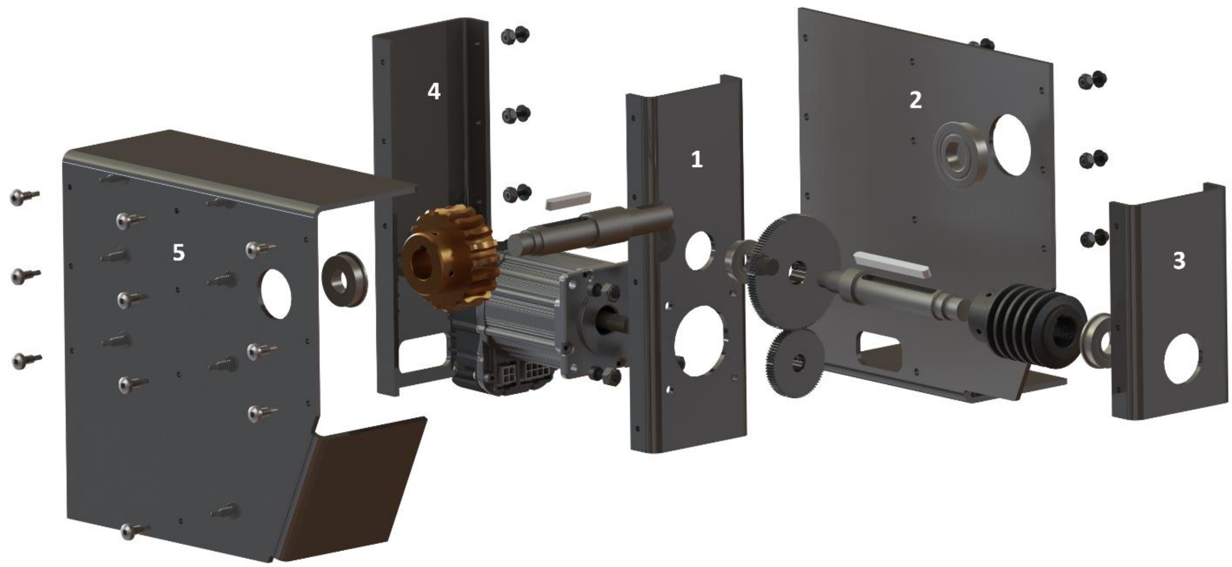


Figure 41: Exploded view of the tilting mechanism assembly.

Similar to the rotational mechanism, the flanged roller bearings are to be press fit into the housing walls, however, are constrained axially due to the flanges and the shaft abutment. Once the bearings are placed in the walls, the motor is mounted to its wall (1) through bolted connections. Next, the keys for the worm screw and the worm wheel are placed on their shafts, and both worm gear shafts assembled. The spur gears are then attached to their respective shafts.

Assembly of the housing then begins by attaching walls 1 and 2 together with their bolted connections. The worm screw shaft with its attached components is then inserted into its bearing on wall 1. The opposite end of the shaft is then to be inserted into wall 3, followed by wall 3 being bolted together with wall 2. Wall 4 which acts to enclose the housing and offer support to the tilting mechanism is then bolted to wall 2. The worm wheel shaft is then inserted into its bearing located in wall 2 and is able to sit above the worm screw while wall 5 is brought in and screwed into place while ensuring the opposite end of the worm wheel shaft sits inside its bearing in wall 5.

3.6. Cable Management and Routing

The ClearPath motors will each have two cables connected during operation. One cable will be connected to the digital input/output port, while the second will be powering the motor. Cutouts were made in the tilting gearbox and base to allow the cables to be routed up and into the housing for connection to the tilting motor. In addition to the power and signal cables, a provision was also made for access to the micro-USB port at the backside of the tilt motor which is required during initial motor setup and programming.

Since the rotation gearbox motor is accessible through the bottom, the cables can be easily connected to the motor without the need for additional cutouts. Figure 42 illustrates the cable routing for the tilting mechanism gearbox, while Figure 43 illustrates the cable routing for the rotation mechanism gearbox.

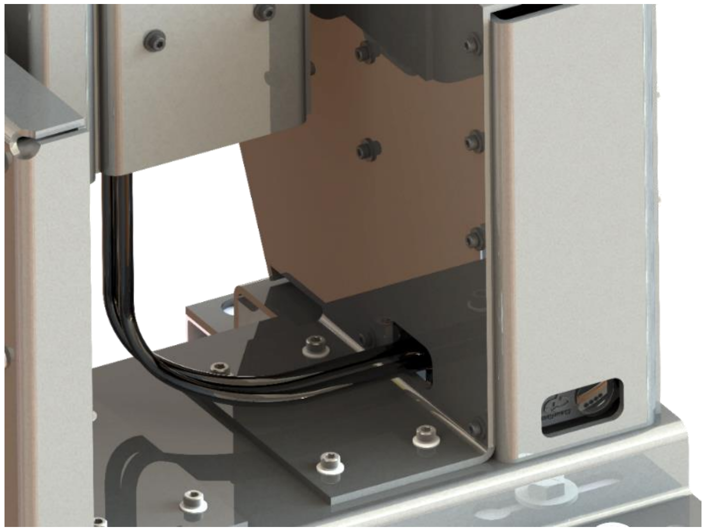
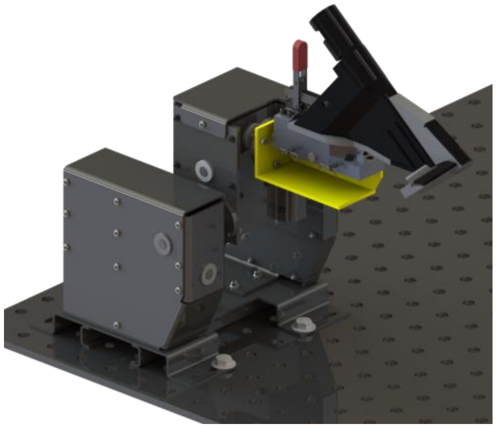


Figure 42: Rotation motor cable routing.

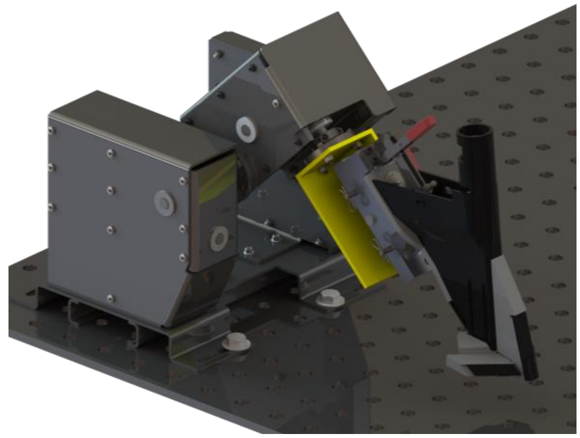
Figure 43: Tilt motor cable routing.

3.7.Base and Riser

The base support is constructed from bent 10-gauge sheet and is designed provide a mounting location for the tilting mechanism and it's supporting wall structure. The dimensions of the base support were driven by the size of the tilting mechanism and the shaft length to maintain a minimal design footprint. The base features laser cut holes which allow it to mount on the welding table with 1/2" bolts, shown in Figure 44. The profile of the base support provides clearance between the table and the fixture allowing space for wire routing underneath the design. The C-channel underneath the base support increases the overall strength and stiffness of the base section to prevent from deflection due to the weight of the supported structure.



View A



View B

Figure 44: Fixture base support.

To provide additional clearance between the welding table and the attached seeding opener, a riser has been designed. The riser allows for a greater range of motion of the AWF and increases the number of orientations possible to engage with the cobot, as certain orientations require a larger volume of space. An example of this is shown in Figure 45.

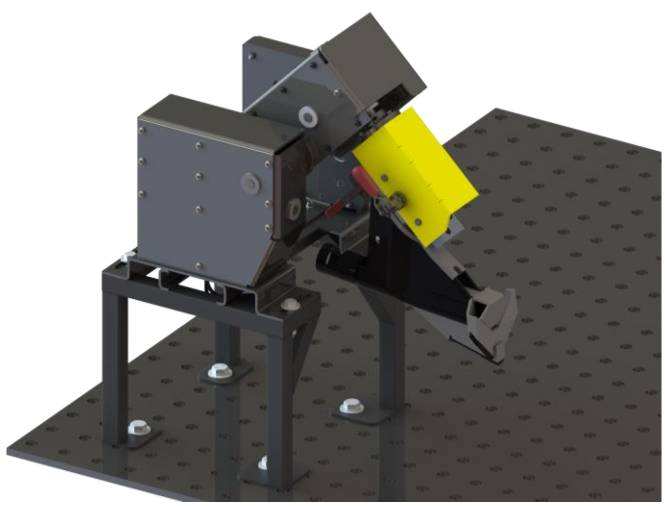


Figure 45 Fixture base support with riser.

The riser is constructed from 1-inch square HSS steel tubing that is welded together, providing high strength and rigidity to the structure. The front tube of the riser is cut and braced for allowing the parts to rotate partially in and under the AWF. The top surface of the riser has 3/8” holes for mounting the base support on while the bottom feet have 1/2" holes for mounting on the table. The holes on the top of the riser are 3/8” as 1/2” is relatively large on 1-inch square tube. The riser design is shown in Figure 46.

Figure 46: AWF riser.

To allow for simple addition or removal of the riser with repeatability, the holes in the base support are aligned with holes in the table even when mounted on the riser, allowing the AWF to only move vertically with respect to the table when the riser is added or removed. The base plate is seen in Figure 47.

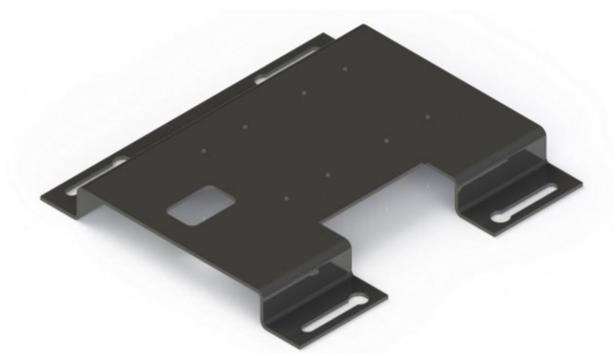


Figure 47: AWF base support.

Through discussions with the client, the cobot can access all orientations of the seeding openers with the riser in place, so it can be installed without being removed. However, if the AWF is configured for different product lines in the future, and the riser is not needed for all orientations, it can be easily removed.

3.8. Material Selection

The materials used in the automated welding fixture design were selected based on strength, ease of manufacturing, availability, machineability, and cost. Since Atom Jet has metal fabrication capabilities in-house and indicated that they would like to manufacture the design, the material selection was influenced by the manufacturing capabilities and standard materials used. Table XXVI summarizes the selected materials and where they are used in the design.

Table XXVI Selected Materials

Material	Application
10 Gauge Sheet Steel	Rotation gearbox housing Tilting gearbox housing Base support
4130 Steel	Shafts
Steel Plate	Clamping assembly - sidewalls
6061 Aluminum	Clamping assembly - puller block
Stainless Steel	Clamping assembly - alignment pins
HSS Steel Tubing	Riser

3.8.1. Gearbox Housings

The material for the gearbox housing is 10-gauge sheet steel. The geometry of the housings require many custom profiles and mounting holes which are best generated by laser cut and formed sheet steel pieces. Creating these complex geometries using laser cut and formed sheet steel is a less expensive alternative to using a machining process since significantly less material is required and the manufacturing process is less complex. Additionally, the accuracy associated with laser cutting made sheet steel an attractive option since tight tolerances are required for the press fit bearings and hole locations.

3.8.2. Shafts

The shafts are all manufactured with 4130 steel. The machineability of this material made it a very suitable choice for manufacturing the shafts since they have many features. Additionally, the high yield strength of 4130 steel makes it a very suitable choice for supporting the axial, bending and torsional loads imposed on the shafts. Finally, 4130 steel is readily available and can be easily purchased by the client.

3.8.3. Clamping Assembly

The clamping assembly is manufactured using three different materials. Laser cut 3/16” thick carbon steel plates are used for the clamping mount assembly. Steel plates were selected instead of the 10-gauge sheet steel that is used elsewhere in the design to improve resistance to potential localized deformation that can occur when the seeding openers are clamped up against the sidewalls. 6061 Aluminum was selected for the clamping assembly mounting blocks given its relatively low weight and good machineability. Lastly, 18-8 stainless steel was used for the alignment pins given its good weldability.

3.8.4. Riser

HSS steel tubing was selected for the riser material. Since the riser is only required to support the weight of the welding fixture, 1-inch HSS tubing was deemed sufficient for this application. Additionally, HSS tubing is a commonly used steel shape that is readily available for purchase and can be easily cut and welded together.

3.9. Efficiency Assessment

An assessment was performed on the overall process efficiency as this was one of the design metrics. The process associated with the proposed design solution was analyzed and directly compared to the existing process at Atom Jet's facility to determine the overall efficiency improvement.

3.9.1. Assessment of Current Process

The current welding fixture requires manual operator interaction to mount and un-mount the seeding openers to the fixture and to reposition the seeding opener between welding steps. This process involves the following manual steps by the operator:

1. Remove locking pin from rotating shaft
2. Rotating seeding opener assembly 90 degrees
3. Re-inserting locking pin to prevent shaft from rotating
4. Pressing switch to command cobot to proceed with next weld step

This process was estimated to have a duration of approximately 5.5 seconds for the CDAA00 seeding opener type as determined from a video taken at Atom Jet's facility. Additionally, it is important to note that since the existing fixture cannot orient the seeding openers for every weld path, the seeding openers must also be welded by an operator once removed from the welding fixture which adds additional process time. A time estimate was not provided by the client for this additional step.

3.9.2. Assessment of Proposed Design

The proposed automated welding fixture design requires manual operator interaction to mount and un-mount the seeding openers but eliminates the need for operator interaction during the weld sequence which enables a significantly reduced cycle time. Since the proposed design can orient the seeding openers to positions that are not possible to achieve using the existing fixture, the efficiency comparison was strictly limited to the rotation of the seeding openers through a single 90-degree rotation.

The rotation of the seeding opener through a 90-degree rotation is accomplished by a single rotation of the output shaft on the rotation gearbox. Assuming an output speed of 15rpm, the amount of time required for a single 90-degree rotation is 1 second. An output rotation speed of 15rpm was assumed for this analysis, though the exact rotation speed will be selected by the client following installation. Additionally, since the automated welding fixture can achieve all possible weld orientations, no additional welding is needed once removed from the fixture. Therefore, the automated welding fixture reduces the overall process cycle time by a factor of at least 5.5. Table XXVII outlines this process efficiency improvement.

Table XXVII: Process Times for The Original and Proposed Fixtures.

	Time for single 90-degree rotation
Current Welding Fixture	5.5s
Proposed Automated Welding Fixture	1s

3.10. PLC Functionality and Operation

As mentioned in Section 3.1.3, the Pulse Burst Positioning mode was selected for the best positioning and programming flexibility. To execute positioning moves, sending a binary code to Input A and a high-speed stream of pulse to Input B, where 0 in Input A turns motor to CCW, 1 turns motor to CW, and each pulse represents an incremental unit of distance. The total distance moved is determined by the number of pulses sent to Input B, and the direction of movement is determined by input A.

When using ClearPath MSP (Motor Setup Program) to setup the Pulse Burst Positioning mode for the motor, the operation interface will be presented as shown in Figure 48, where the speed limits, the acceleration limit and the input resolution can be set. The ClearPath will generate smooth motion of the motor based on the set limits of speed and acceleration. The input resolution setting provides a simple way to change the ratio of quadrature counts input to encoder counts moved. For example, a motor with 800 count per revolution, setting the input resolution to 800 quadrature counts/rev results in a simple 1:1 relationship. In other words, each quadrature count seen at the ClearPath input, the motor shaft will rotate exactly 1 encoder count in this setting.

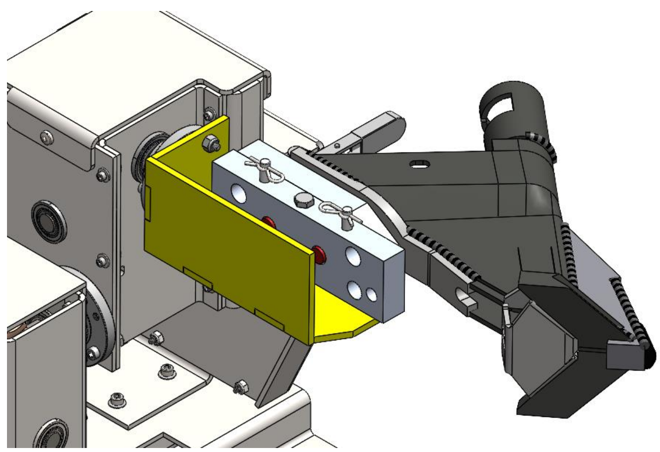
Redacted Image. Image displayed the view window for motor controller setup.

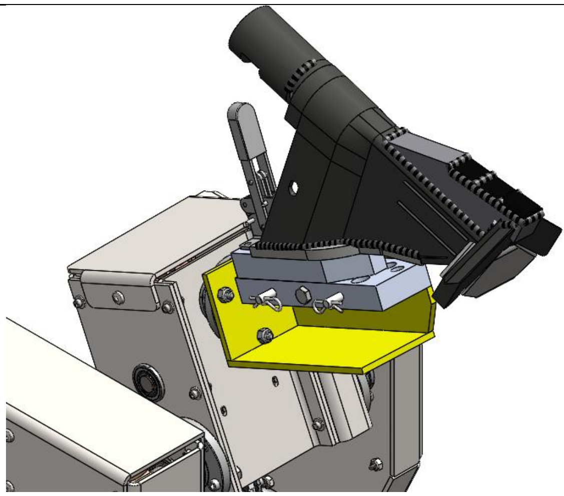
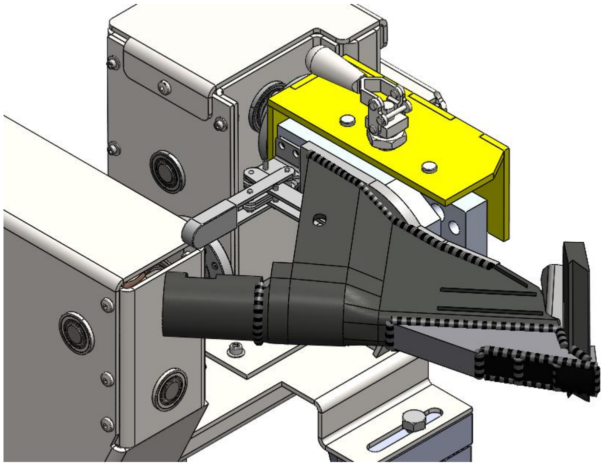
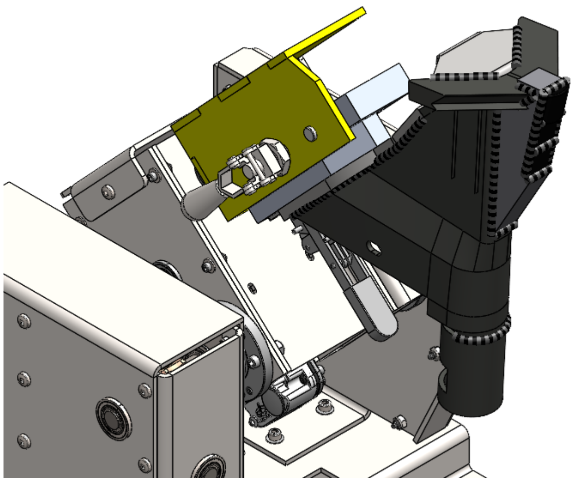
Figure 48: ClearPath MSP Pulse Burst Positioning mode setup [22].

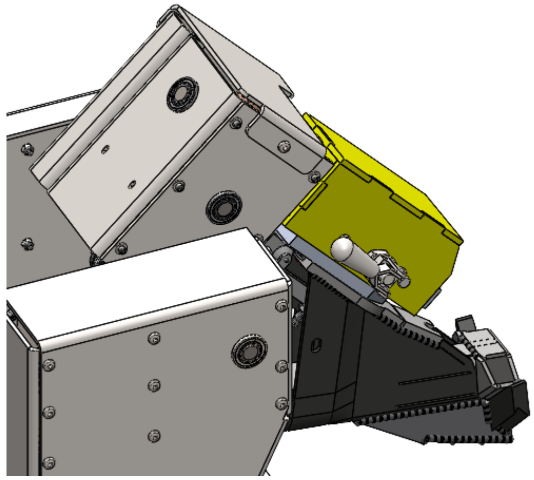
A sample programming of the motor motion for welding the CCETE0 paired row seeding opener, including the welding process using the designed position mechanism and the desired input from the PLC will be presented in detail.

Table XXVIII shows the required weld paths for the paired row opener at each orientation, where all weld paths can exist in a level, horizontal plane, and are accessible by the robotic welder from above. Note that position 1 is the starting position, at which the paired row opener is initially installed to the fixture, and no motion is required before the welding process is started. Once the weld paths have been completed by the cobot, the fixture moves the seeding opener to the next welding position. Position 5 is the last position, which means after all weld paths have been completed, the motor will need to go back to position 1 for loading the next paired row opener by the operator. In addition, from position 1 to 5, the rotation motor rotates only in the counterclockwise (CCW) direction. This is for simplicity of programming and to avoid missing weld paths.

Table XXVIII: Weld Path Sequence of CCETE0 Paired Row Seeding Opener

Position No.	Position
1	 **Figure 49: Weld path at position No.1**

2	 **Figure 50: Weld path at position No.2**
3	 **Figure 51: Weld path at position No.3**
4	 **Figure 52: Weld path at position No.4**

5	 **Figure 53: Weld path at position No.5**

As the resolution of the selected motors are both 0.450 degree, which is 800 count per revolution, the input resolution should be set to 800 to achieve a simple 1:1 ratio from quadrature counts input to encoder counts moves. In this way, one pulse input makes the motor rotate 0.45 degrees and 800 pulse input makes the motor rotate one revolution. On the other hand, the designed powertrain systems have speed reductions of 1:25 for the rotation and 1:33.3 for the tilting. This means that for the clamping mechanism and tilting mechanism to rotate one revolution, the motors must rotate 25 and 33.3 revolutions respectively. In the sample, the required angular displacement of the clamping and tilting mechanisms and their motors correspondingly is listed in Table XXIX to complete the needed weld paths, and the welding process flow chart with the pulse input diagram is shown in Figure 54.

Table XXIX: Angular Displacement Required at Each Position for Fixture and Motors

Position	Rotation of Clamping Mechanism	Rotation of Clamping Motor	Rotation of Tilting Mechanism	Rotation of Tilting Motor
1	$90°$	$2250°$	$30°$	$1000°$
2	$90°$	$2250°$	$-30°$	$-1000°$
3	$90°$	$2250°$	$45°$	$1500°$
4	$0°$	$0°$	$-90°$	$-3000°$
5	$90°$	$2250°$	$45°$	$1500°$

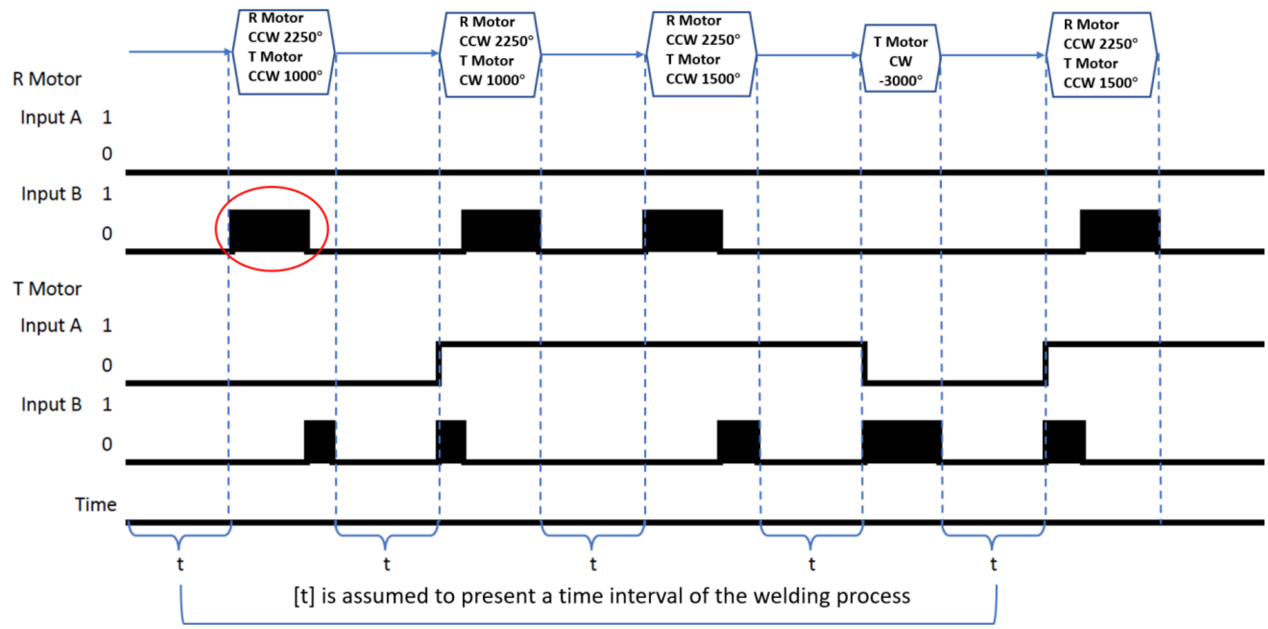


Figure 54: Welding process flowchart with pulse input diagram

In Figure 54, R Motor represents the rotating motor and T Motor represents the tilting motor. Input B for R Motor and T Motor are the pulse inputs, that are specific amounts of pulse calculated based on the angular displacement. As mentioned above, setting the input resolution to 800 gives a 1:1 ratio from amount of pulse input to the motor encoder counts moves, which means each pulse input will rotate the shaft 0.45 degrees. For example, the red highlighted circled pulse input in Figure 54 contains an amount of 5000, which will make the motor rotate 2250 degrees so that the clamp mechanism rotates 90 degrees in the counterclockwise direction with the designed 1:25 speed reduction gear box.

3.11. Evaluation of Design

The final design was evaluated against the list of metrics to determine how well the client needs were met. The marginal and ideal values for each metric along with the expected actual values achieved by the design are presented in Table XXX. Metrics to be evaluated by the client following implementation of the design have been indicated as TBD.

Table XXX: Design Metrics Evaluated

#	Metric	Imp	Units	Marginal	Ideal	Expected Value
1	Number of seeding openers the design can accommodate	4	%	80	100	100
2	Deflection of seeding opener on AWF	2	in	0.03125	0.01563	0.03
3	Angle between weld path line and table plane	4	deg	5	0	0
4	Can an arc be created between welder and part	5	binary	N/A	True	True
5	System fastens/mounts to existing table	3	binary	N/A	True	True
6	Number of fixtures mounted in design space	3	count	2	3	3
7	Time for operator to mount tacked assembly	2	s	<45	<30	TBD
8	Time taken to orient seeding opener	3	s	<10	<5	1.5
9	Percentage of parts rejected due to AWF error	4	%	<10	<5	TBD
10	Distance to nearest obstruction from weld site	4	in	>0.5	>1	0.75
11	Number of steps performed by operator	3	count	<8	<5	2
12	Process can be halted by emergency switch	5	binary	N/A	Yes	Yes
13	Seeding opener mounting repeatability allowance	4	in	0.03125	0	TBD

Table XXX indicates that all metrics which were able to be measured or predicted have been satisfied by the proposed automated welding fixture design.

3.12. Design Cost

The overall project began with a target budget of $3000. This value drove decisions throughout the project when selecting components and choosing one system or model over another and the total cost was monitored carefully throughout the project in attempt to meet the target.

3.12.1. Electrical Equipment

The electrical components of the design include the motors and power supply and have an approximate total cost of $1,185.50 CAD.

3.12.2. Powertrain Equipment

The powertrain components of the design include the shafts, bearings, and gears and have an approximate total cost of $1,188.44 CAD.

3.12.3. Manufactured Parts (Excluding Powertrain)

The manufactured components of the design include all the sheet metal parts for the entire assembly including the rotational mechanism, tilting mechanism, clamping mechanism, base, and the riser and have a total approximate cost of $500.00 CAD.

3.12.4. Hardware

The hardware components of the design include the remaining components such as the fasteners and clamping devices with a total approximate cost of $614.42 CAD.

3.12.5. Cost Summary

The overall approximate cost of the proposed design is $3,488.37 CAD (to be assembled on site by Atom Jet). The value of the overall design is approximately 16.2% over the soft budget set for the project. To reduce costs, multiple vendors could be explored for hardware, manufactured parts, and powertrain equipment providing the reduction ratios remain the same and any change in material does not lead to potential failure due to yielding.

4. CONCLUSION AND RECOMMENDATIONS

The proposed design presented to Atom Jet Industries is an automated, servo controlled, 2-axis welding fixture that accurately, efficiently and repeatably positions seeding openers during the welding process with minimal operator intervention and improved process cycle time.

A rotational gearbox consisting of a combined spur and worm gear drive system is used to deliver the required torque for the rotational motion of the fixture with a safety factor of 3.57 limited to the motor torque. A secondary gearbox consisting of a combined spur and worm gear drive system is used to deliver the required torque for the tilting motion of the fixture with a safety factor of 1.90 limited to the motor torque. A universal clamping mechanism is used to mount the seeding openers to the fixture and is compatible with all four seeding opener mounting types provided by Atom Jet Industries. Teknic's MCPV ClearPath integrated servo motors are used to precisely control the positioning mechanism of the welding fixture and will be controlled by the existing PLC of the cobot robotic welder using the pulse burst positioning mode. The total approximate cost of the design is $3,488.37 CAD.

The design is intended to replace the current manual positioning process for orienting seeding openers during welding with a highly automated process that reduces operator intervention to loading and unloading, improves process cycle time, orients seeding openers such that all weld paths exist in a horizontal plane, and can be easily expanded to include 2 or 3 automated welding fixtures within the design space to operate in series, fully satisfying all customer requirements.

Implementing the proposed design will enable Atom Jet Industries to streamline their seeding opener manufacturing process and improve product quality which is important to their customers. It is recommended that the automated welding fixture move to prototyping and testing to validate the design and fine tune the performance before large scale implementation.

5. REFERENCES

[1] "C-Shank Side Band Granular," Atom-Jet Industries Agriculture, [Online]. Available: https://agriculture.atomjet.com/products/c-shank-side-band-granular/. [Accessed 28 09 2021].

[2] "Bourgault Paralink Edge On Single Shoot," Atom-Jet Industries Agriculture, [Online]. Available: https://agriculture.atomjet.com/products/bourgault-paralink-edge-on-single-shoot/. [Accessed 28 09 2021].

[3] "Morris Contour Side Band Liquid," Atom-Jet Industries Agriculture, [Online]. Available: https://agriculture.atomjet.com/products/morris-contour-side-band-liquid/. [Accessed 28 09 2021].

[4] Teknic Inc., "ClearPath - Integrated Servo Motors," Teknic Inc., [Online]. Available: https://teknic.com/products/clearpath-brushless-dc-servo-motors/. [Accessed 05 11 2021].

[5] Teknic Inc., "ClearPath - SD," Teknic Inc., [Online]. Available: https://teknic.com/products/clearpath-brushless-dc-servo-motors/clearpath-sd-stepper-replacement/. [Accessed 05 11 2021].

[6] Teknic Inc., "ClearPath - MC," Teknic Inc., [Online]. Available: https://teknic.com/products/clearpath-brushless-dc-servo-motors/clearpath-mc/. [Accessed 05 11 2021].

[7] Teknic Inc., "ClearPath - SC," Teknic Inc., [Online]. Available: https://teknic.com/products/clearpath-brushless-dc-servo-motors/clearpath-sc/. [Accessed 05 11 2021].

[8] Teknic Inc., "ClearPath User Manual," Teknic Inc., 2021.

[9] Teknic Inc., "DC Power Supplies," Teknic Inc., [Online]. Available: https://teknic.com/products/servo-motor-dc-power-supply/. [Accessed 05 11 2021].

[10] "CPM-MCPV-2310S-RLN," Teknic Inc., [Online]. Available: https://teknic.com/model-info/CPM-MCPV-2310S-RLN/?model_voltage=75VDC. [Accessed 05 11 2021].

[11] SKF, "D/W R10 R-2Z," [Online]. Available: https://www.skf.com/ca/en/products/rolling-bearings/ball-bearings/deep-groove-ball-bearings/productid-D%2FW%20R10%20R-2Z. [Accessed 3 December 2021].

[12] SKF, "D/W R6 R-2Z," [Online]. Available: https://www.skf.com/ca/en/products/rolling-bearings/ball-bearings/deep-groove-ball-bearings/productid-D%2FW%20R6%20R-2Z. [Accessed 3 December 2021].

[13] AMES WEB, "SHOULDER FILLET IN A STEPPED CIRCULAR SHAFT," [Online]. Available: https://amesweb.info/stress-concentration-factor-calculator/shaft-shoulder-fillet.aspx. [Accessed 30 November 2021].

[14] R. G. Budynas and J. K. Nisbett, Shigley's Mechanical Engineering Design, New York: McGraw-Hill Education, 2020.

[15] MatWeb, "AISI 4130 Steel, annealed at 865°C (1590°F)," [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=f552d649b03e464f96ccdd9760978ee0&ckck=1. [Accessed 1 December 2021].

[16] AMESWEB, "BEAM DEFLECTION CALCULATORS," [Online]. Available: https://amesweb.info/Beam/beam-deflection-calculator.aspx. [Accessed 3 December 2021].

[17] W. C. Young, Roark's Formulas for Stress & Strain, McGraw-Hill, Inc., 1989.

[18] KHK Gears, "AG2.5-20R1J17 Strength calculation of gears," [Online]. Available: https://www.khkgears.co.jp/khkweb/calc/FFCalc.do?catalogno=AG2.5-20R1J17&lang=en. [Accessed 3 December 2021].

[19] "CPM-MCPV-2321S-RLN," Teknic Inc., [Online]. Available: https://teknic.com/model-info/CPM-MCPV-2321S-RLN/?model_voltage=75VDC. [Accessed 05 11 2021].

[20] KHK Gears, "Lubrication of Gears," [Online]. Available: https://khkgears.net/new/gear_knowledge/gear_technical_reference/lubrication-of-gears.html. [Accessed 3 December 2021].

[21] KHK Gears, "SURFACE DURABILITY OF WORM GEAR," [Online]. Available: https://khkgears.net/new/gear_knowledge/gear_technical_reference/surface-durability-worm-gear.html. [Accessed 3 December 2021].

[22] I. Teknic, "ClearPath User Manual Version 3.16," Victor, NY, 2021.

APPENDIX A – CONCEPT DEVELOPMENT

A.1 - CONCEPT GENERATION

To begin the concept generation process, market research was conducting into exiting products, and they do not match the exact needs of Atom Jet. The approach taken by Fincro Consulting was to design a fully customized AWF. The concept generation process was divided into two main areas. The first area includes the motion mechanism of the AWF which focused on developing concepts for how the seeding openers are maneuvered in space. The second area focused on the locating component for the various seeding openers. As there are several seeding opener types each with unique features, the concepts developed were required to accommodate the different types of openers. Sections A.2 - and A.3 - outline the concepts generated for the motion mechanism and locating component respectively. Sketches were used as the starting point for several design concepts and are included in Appendix B for reference.

The motion mechanism designs must be automated which implies the need for a drive system. The drive system (ie. Actuator, Driven Shaft, Ball Screw, etc.) was specified in a general sense for each concept. Since the specifications of the drive systems will heavily depend on the final configuration of the design, material chosen, and analyses performed, the sizing and selection of the driving mechanism was left as a detailed design decision. Therefore, the design concepts were kept relatively adaptable for different drive system sizing and power reduction systems, should they be required in the final design.

A.2 - POSITIONING MECHANISM

The concepts outlined throughout this section focus on the mechanisms which can be implemented to rotate and tilt the seeding openers to ensure that all weld paths can be oriented to exist in a horizontal plane and can be approached by the robotic welder from above. The concepts have been named and numbered. The numbering is preceded by the letter M to denote that they are mechanism concepts.

A.2.1 - Concept M1.1 – Shaft Driven Tilt Table

The current motion mechanism in place at Atom Jet Industries for the welding fixture utilizes a single shaft which rotates and locks in 90° rotations (Figure 55). The Shaft Driven Tilt Table concept elaborates on that design by first controlling the shaft through a motor to enable full control over the angular position of the rotation. Secondly, this first rotation mechanism is installed on a platform or table which has a shaft mounted to it from the underside. The underside shaft has its rotation controller by a second motor and introduces a tilting motion to the mechanism. This concept is shown in Figure 55.

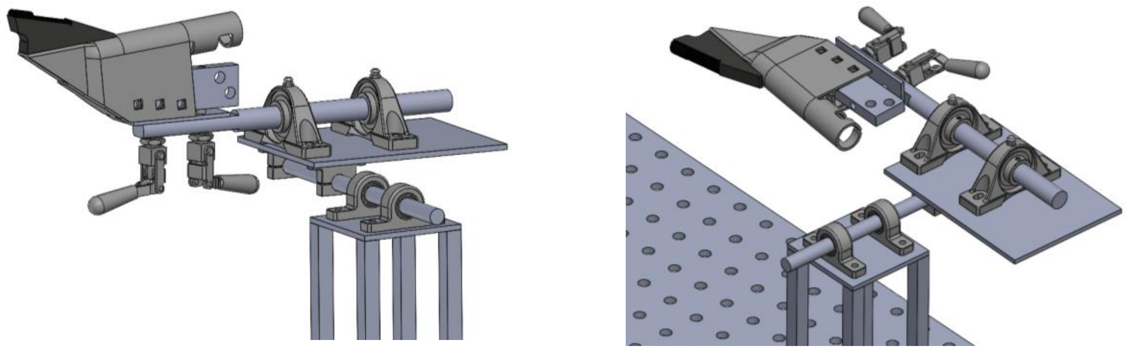


Figure 55 - CAD model of shaft driven tilt table concept.

A.2.2 - Concept M1.2 – Lead Screw Tilt Table

Following the derivation of the Shaft Driven Tilt Table Concept, the Lead Screw Tilt Table concept was developed. This concept removes the motor engagement from the shaft mounted below the tilting table and instead uses it as a pivot point. The tilt is then driven by a translating bushing on a linear guide rail. The translating bushing is connected to a series of mounted bearings and a shaft which fix to a platform nut. The platform nut then moves vertically due to lead screw rotation, which then pushes/pulls the tilt table up/down. The rotation of the locating component remains the same as in the previous concept. A visualization of this concept is shown in Figure 56.

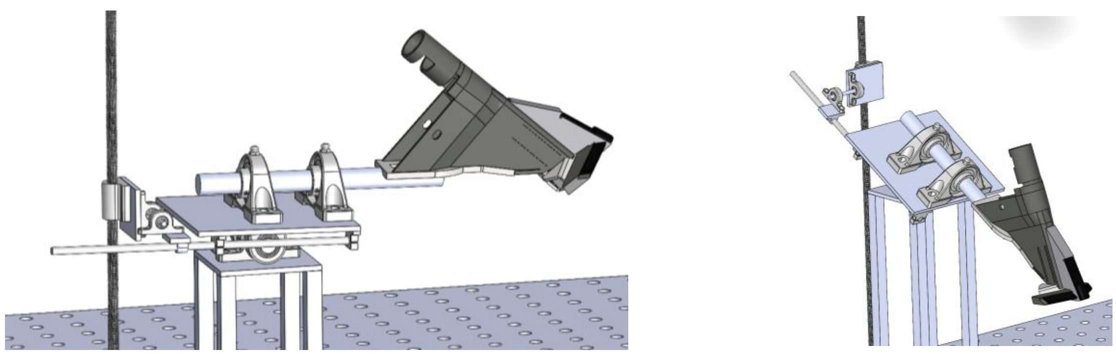


Figure 56 - CAD model of lead screw tilt table concept.

A.2.3 - Concept M2.1 – Rotary Tilt Table

The Rotary Tilt Table concept was developed with inspiration from existing rotary tilt table designs. In contrast to concepts M1.1 and M1.2, the rotary tilt table mechanism achieves the required part orientations while maneuvering the part through a smaller volume of space. It utilizes a central shaft connected to a motor which controls the tilting motion of a mounting bracket. A second motor is mounted to the underside of the tilting bracket which controls the rotation of the seeding opener. By combining these two rotation motions, all required weld paths can be oriented such that they are parallel to the surface of the table and easily accessible to the robotic welder from above.

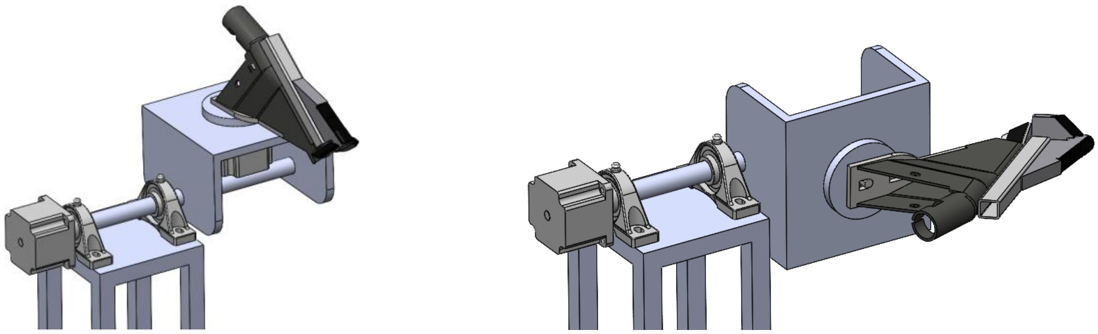


Figure 57: CAD model of the rotary tilt table concept.

A.2.4 - Concept M2.2 – Condensed Rotary Tilt Table

The Condensed Rotary Tilt Table concept is the second iteration of the rotary tilt table concept. It utilizes the same two degrees of freedom to manipulate the part orientation but does so in a more compact arrangement which minimizes the overall footprint of the design. This concept is illustrated in Figure 58.

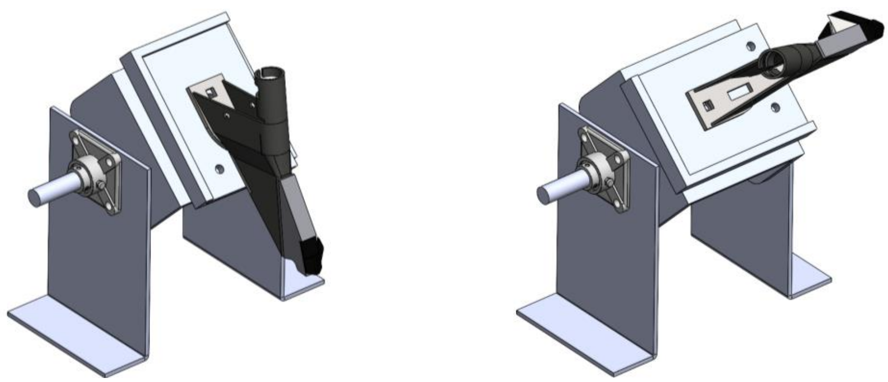


Figure 58 - CAD model of the condensed rotary tilt table concept.

A.2.5 - Concept M3.1 – Pivoting Shaft

The Pivoting Shaft concept utilizes a rotating shaft with a tiltable platform located at one end. The main challenge associated with this design is the axis of the tiltable platform pivot. The axis of rotation of the platform is restricted by the angular position of the main shaft which makes part positioning more complex. This concept is illustrated in Figure 59.

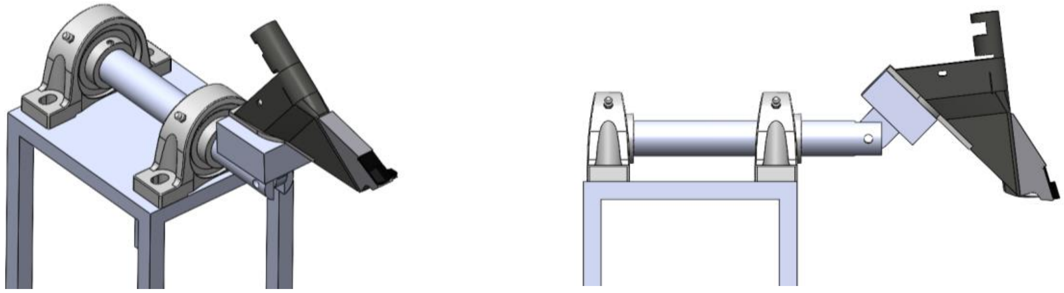


Figure 59 - CAD model of the pivoting shaft concept.

A.2.6 - Concept M3.2 – Linear Actuator Shaft End Tilt

The Linear Actuator Shaft End Tilt concept was developed as a solution to the tilting action of M3.1. The hinge on the end of the rotating shaft is articulated by a linear actuator mounted to the shaft. An advantage of this design is that the axis of rotation is close to the part which allows the seeding opener to tilt without travelling an excessively far distance. The rotating shaft is similar to Atom Jet's current design which has proven to be effective and reliable. A visualization of this concept can be seen in Figure 60.

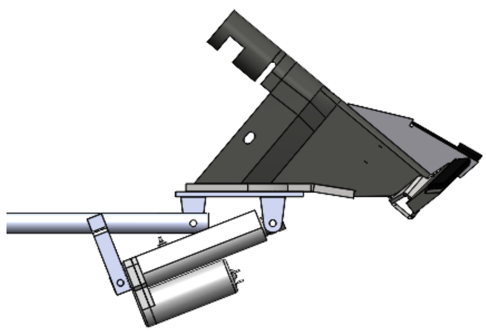


Figure 60: CAD model of the linear actuator shaft end tilt concept.

A.2.7 - Concept M3.3 – Bell Crank Linkage Tilt

The Bell Crank Linkage Tilt concept was developed as an alternative method to locate the tilting action at the end of a rotating shaft. This design aims to enclose the tilting mechanism in a compact space that is protected from weld splatter. The tilting motion is achieved using a small stepper motor which rotates a linkage to provide linear motion to a pin in a slot through the enclosure. The pin then articulates a bell crank up and down which tilts the part to be welded. One advantage of the bell crank is that the lengths of the arms can be tuned to provide a large vertical displacement with a small input displacement. This concept is seen in Figure 61.

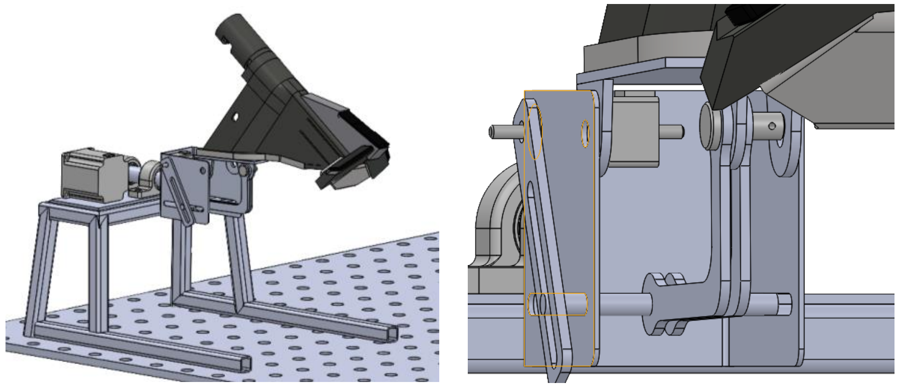


Figure 61 - CAD model of the bell crank linkage tilt concept.

A.2.8 - Concept M4 – Rotating Bent Tube Gimbal

The Rotating Bent Tube Gimbal concept was developed to minimize the volume of space occupied by the seeding opener as it is maneuvered. By implementing a rotating bent tube, the seeding opener rotates through a tight circular path. The rotation of this main shaft controls the tilting motion of the seeding opener which is mounted to a rotating platform. This concept is illustrated in Figure 62.

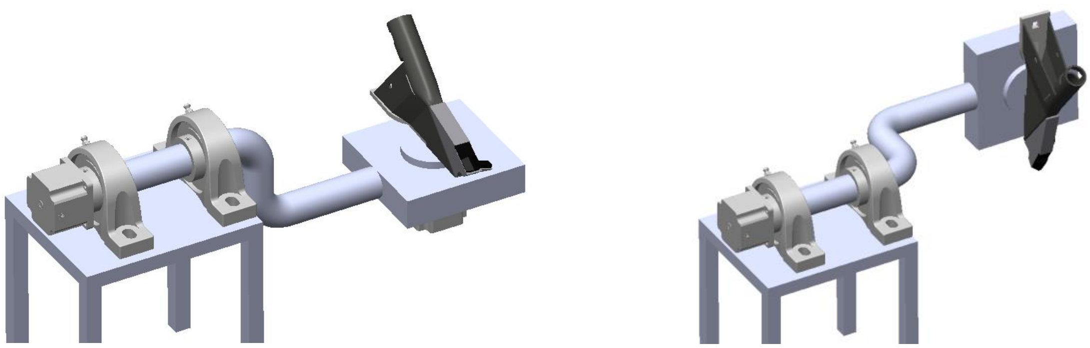


Figure 62: CAD model of rotating bent tube gimbal concept.

A.2.9 - Concept M5 – Universal Joint

The Universal Joint concept implements an alternative approach to tilting the seeding opener. It first splits up the rotational shaft into multiple components connected by universal joints. This allows the input and output shafts to rotate in non-parallel planes. The angle of the output shaft is then controlled by a linear actuator which is attached to a pivoting plate containing a bushing which translates back and forth along the output shaft. This concept is illustrated in Figure 63.

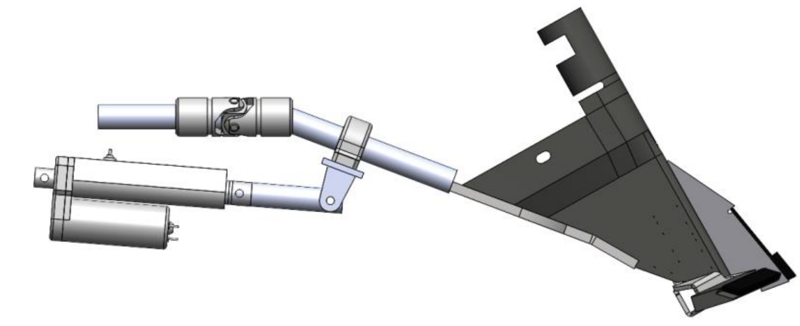


Figure 63 - CAD model of the universal joint design.

A.2.10 - Concept M6.1 – Single Unit Hinge Tilt

The Single Unit Hinge Tilt concept features a large stable base for table mounting as well as a flat mounting surface. The concept utilizes a formed base on to which sidewall supports are mounted. A hinge mechanism is used to rotate on a shaft extending through the top of the sidewalls. The locating component is mounted to the hinge mechanism at its center where it is allowed to rotate about an axis normal to the surface of the hinge. This concept removes the cantilever action seen in other design concepts and aims to minimize deflection by transferring loads to the sidewalls. This concept can be seen in Figure 64.

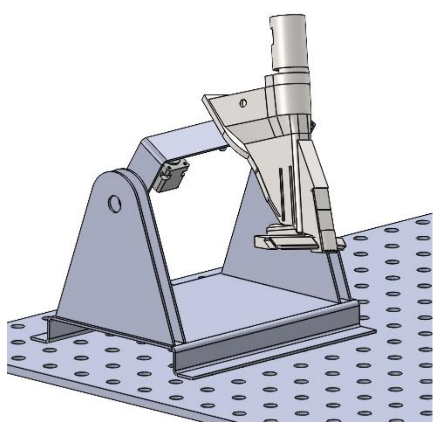


Figure 64 - CAD model of the single unit hinge tilt concept.

A.2.11 - Concept M6.2 – Angled Single Unit Hinge Tilt

The Angled Single Unit Hinge Tilt design is an improvement to concept M6.1. This variation of the design ensures the seeding opener remains clear of the welding fixture during operation by implementing angled sidewalls. This posed a potential design conflict of trying to maintain the part's geometric center close to the axis of rotation. To try and achieve a compromise, the sidewalls were extended forward while the mounting surface was recessed backward. This effectively brought the tilt axis to the rear of the part which helped to minimize linear displacements during rotation.

The locating component will be mounted to a rotary index table driven by a stepper motor. The mounting box is intended to have sufficient room to house both the stepper motor and any speed reduction components. This concept also offers the ability to easily adjust the tilt axis location with respect to the part. This concept is visualized in Figure 65.

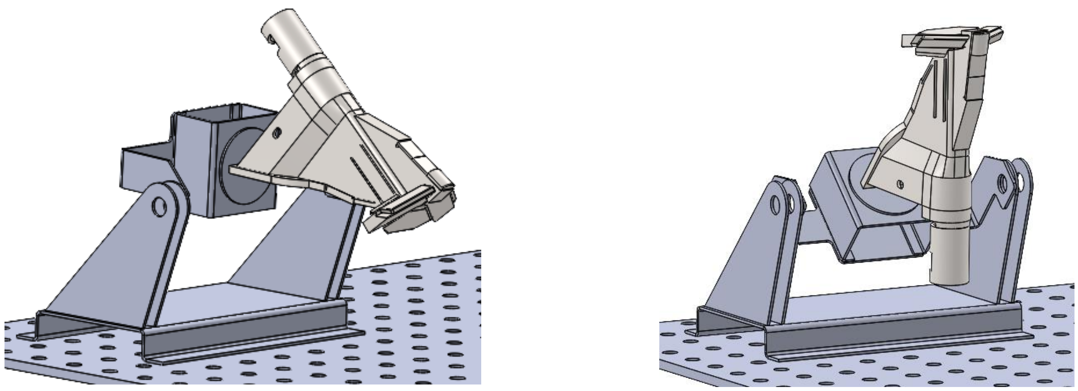


Figure 65: CAD model of angled single unit hinge tilt concept.

A.2.12 - Concept M7 – Held Angle Tilt

The Held Angle Tilt design concept utilizes an L-shaped arm that hinges on the base and holds the part on the other end. One motor will be installed on the base used to rotate the L-shaped arm, which provides a tilt mechanism to ensure the weld paths exist in a horizontal plane. The locating component will also be connected to a motor which rotates the seeding opener automatically. This concept is shown in Figure 66.

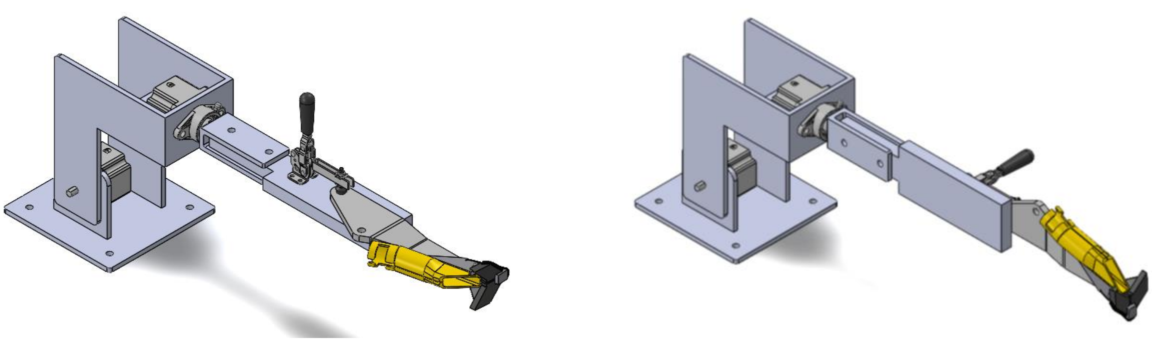


Figure 66: CAD model of held angle tilt concept.

A.3 - CLAMPING MECHANISM

The concepts outlined throughout this section focus on the securement and location of the seeding openers to the motion mechanism concepts outlined in section A.2 - . The locating component must allow accessibility to all weld locations on the seeding opener. The concepts have been named and numbered. The numbering is preceded by the letter L to denote that they are locating component concepts.

A.3.1 - Concept L1 – Interchangeable Push Clamp Plates

This concept utilizes a plate with locating pins that interlock with features on the seeding openers. These pins allow the seeding openers to be consistently and accurately positioned by the operator. A clamp is then used to lock the seeding opener in position and ensure it remains fixed throughout the various motions performed by the mechanism. This concept is illustrated in Figure 67.

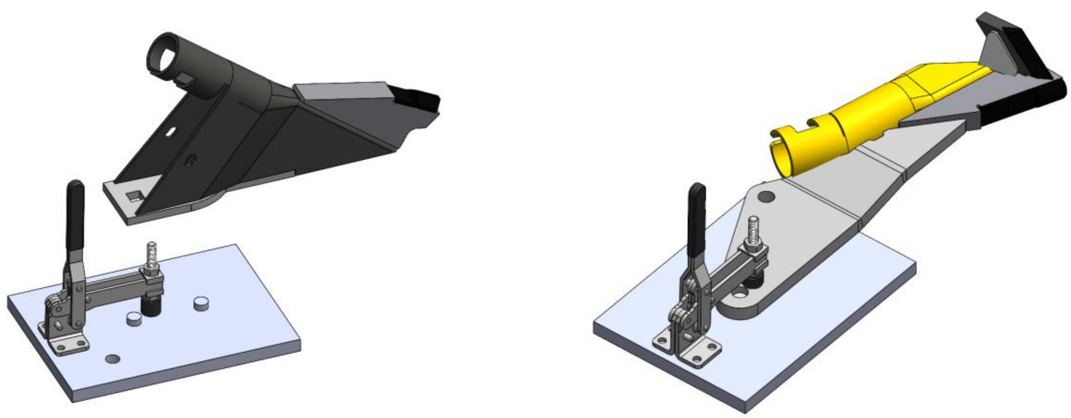


Figure 67 - CAD model of the interchangeable push clamp plates concept.

A.3.2 - Concept L2 – Shaft Mount Puller Bar

This concept uses pins on a plate to go through features on the different openers, and then pulls on these pins with a pulling clamp. This locates an edge (or face) of the opener flush against the flat face of the plate on the shaft. With the pins being pulled by the puller bar, the motion of the opener will be fully constrained and unable to move. In this concept the pullers extend through the rotating shaft. One of the seeding openers can be seen fixtured to the puller bar in Figure 68. The current locating component in place at Atom Jet uses a variety of mounting assemblies which must be swapped for every different opener type. This concept incorporates all mounting hole patterns into one plate so that the fixture does not need to be swapped.

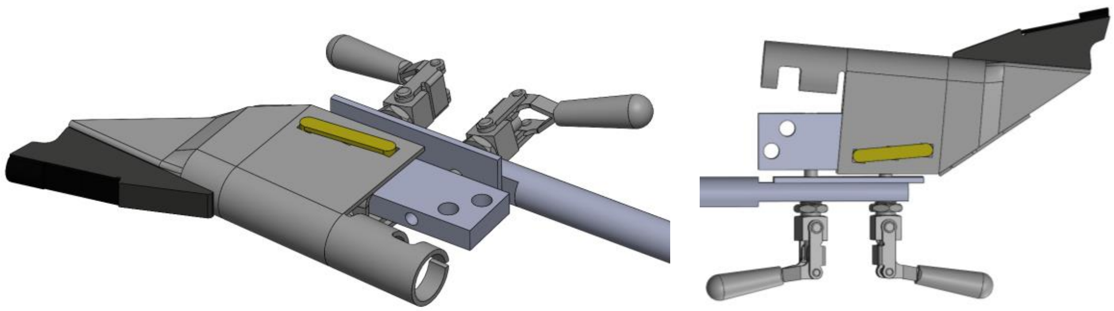


Figure 68 - CAD model of shaft mount puller bar concept.

A.3.3 - Concept L3 – Rotary Table Mount Puller Bar

Following the concept of the Shaft Mount Puller Bar, this concept was adapted to mount onto a flat rotating surface and is seen in Figure 69.

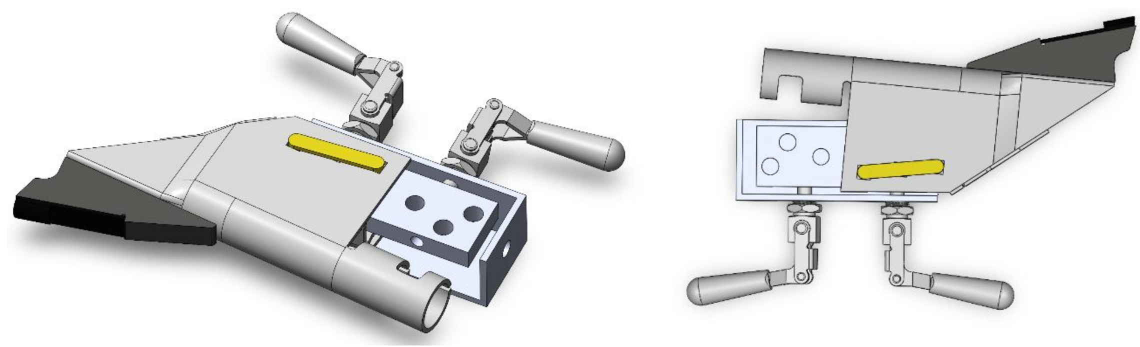


Figure 69 - CAD model of rotary table mount puller bar concept.

A.3.4 - Concept L4 – Interchangeable Thumb Screw Plates

The mating plate on this concept has the pins to match the openings on the seeding opener. Even though only one feature would be required to limit the translational and rotational degrees of freedom, a second is placed in front. The reasoning for this is that the tolerance is greater on the rear pin with the slack taken up by the front pin. The seeding opener is then secured down by a threaded fastener. Care would need to be taken in this design so that the threads would not thermally deform, or the fastener be too hot to remove. This concept is illustrated in Figure 70.

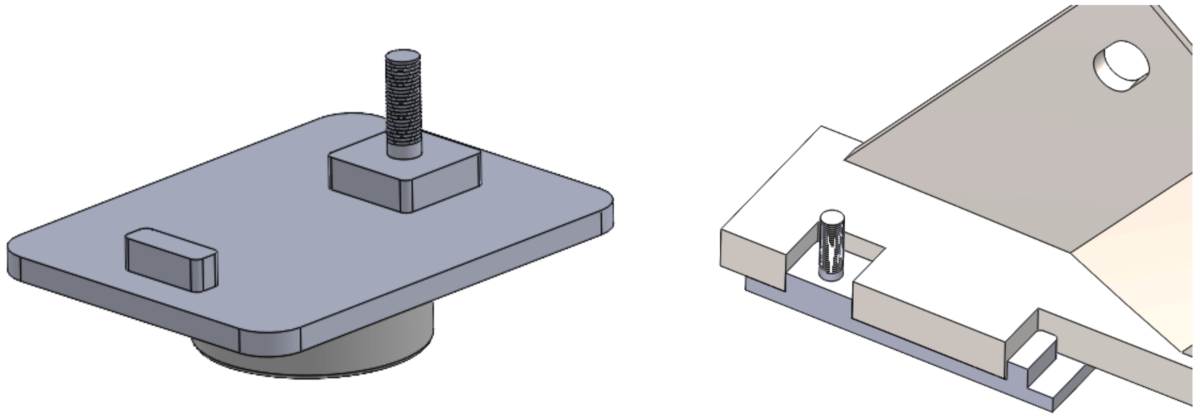


Figure 70: CAD model of interchangeable thumb screw plates concept.

A.4 - CONCEPT ANALYSIS AND SELECTION

The concepts generated in Section A.1 - were evaluated to determine which best meets the needs of the client. The criteria used to evaluate the concepts were established and weighted according to their relative levels of importance and are presented in Section A.5 - . A concept screening process was first taken to quickly identify concepts which were unsuitable for further consideration. Following this, a more rigorous concept selection process was then taken to determine a preliminary design to move forward with, the results of which are presented and discussed in Section A.6 - . The final selected concept is discussed in Section A.7 - .

A.5 - CRITERIA

As the concepts have been divided into two focus areas, the criteria for both the motion mechanism concepts and the locating component concepts were identified separately. The criteria were given a weighting ranging from 1 to 5, with 5 signifying most important, or carrying the most weight.

A.5.1 - Positioning Mechanism Criteria and Weights

The criteria used to evaluate the motion mechanism concepts are identified throughout this section with their weights discussed. A summary of all the criteria and their weights follows the explanations and is given in Table XXXI.

A.5.1.1 - Include part clearance for all welding orientations – 5

The seeding opener should be clear of hitting any part on the jig or the existing welding table that it is mounted on when in welding orientation. This is an extremely important criterion and will affect the ability for the AWF to perform correctly. Therefore, a weight of 5 was assigned.

A.5.1.2 - Weld locations are accessible from above – 5

Fincro evaluated this criterion visually for aspects of the design that could possibly get in the way of providing access to the welding tip from above when the seeding opener is in all orientations. If the weld paths are not accessible, the AWF will not perform as intended. Therefore, a weight of 5 was assigned.

A.5.1.3 - Design footprint – 4

Atom Jet has specified the ability to incorporate 2-3 AWFs on their welding table and so the footprint of the design cannot exceed a size that would prevent that. As there is some flexibility in the size of the footprint to be able to meet the need, it was assigned a weight of 4.

A.5.1.4 - Ease of manufacturing – 4

This criterion relates to the overall serviceability, replaceability, and replicability of the design. Should a breakdown occur, productivity will be negatively impacted, and this must be avoided. Therefore, a weight of 4 was assigned.

A.5.1.5 - Cost – 4

The design must fall within Atom Jet's budget, making this an important criterion. As it is difficult to estimate the cost at this phase, Fincro is more focused on the processes and configuration of the materials used. The overall cost was compared between concepts. For example, a laser-cut or broken sheet metal part is less costly and more desirable than a machined part with the same function in this category, and so a laser cut part would score higher. The relative cost for sourced parts is also compared (lead screw mechanisms can be more complex and costly compared to direct drive motors). As cost is an extremely important criterion but can only be identified relative to other designs, it was assigned a weighting of 4.

A.5.1.6 - Mechanism height – 3

The robotic welder has limited range in height. Atom Jet has set a ceiling of 2 feet with a short and compact design being more desirable. However, there is flexibility with this, so it was assigned a weight of 3.

A.5.1.7 - Complexity – 3

Complexity has been defined as the number of different parts required to generate the desired motion in each concept as well as the anticipated challenge of programming. Since complexity does not necessarily limit the functionality of the design, it was assigned a weight of 3.

A.5.1.8 - Number of steps to achieve required orientation – 3

The fewer number of steps required to reach the desired weld angle results in a more efficient and reliable welding fixture. However, the importance of this is only moderate since, provided there are no collisions, the fixture can operate as expected. This criterion was therefore assigned a value of 3.

A.5.1.9 - Minimize volume of part travel – 2

The volume of space that the seeding opener travels through during the motion operations is ideally minimized. The ranking is of lower importance as it is not essential to the operation of the fixture and was thus assigned a weight of 2.

A summary of all the criteria and their weights is shown in Table XXXI.

Table XXXI: Criteria and Their Weights for Motion Mechanism Concepts

Selection Criteria	Weight
Allows clearance for part in all orientations	5
Ensures accessibility of weld locations from above	5
Footprint of the mechanism	4
Ease of manufacturing	4
Cost	4
Height of the mechanism	3
Complexity	3
Number of steps to achieve required orientation	3
Minimizes volume of space for part travel	2

A.5.2 - Locating Component

The criteria used to evaluate the locating component design concepts identified throughout this section with their weights are discussed.

A.5.2.1 - Works with all tacked assemblies – 5

The locating component design must be able to accommodate the various styles of seeding openers that require welding. A weight of 5 was assigned based on the high level of importance indicated by the client.

A.5.2.2 - Ensures accessibility of weld locations – 5

The locating component must ensure that all weld locations are easily accessible by the robotic welder. Failure to access weld locations would render the design ineffective. This criterion was therefore assigned a weight of 5.

A.5.2.3 - Seeding openers can be interchanged quickly – 5

The time associated with mounting and un-mounting seeding openers has a significant influence on the efficiency of the overall process and was thus assigned a weight of 5.

A.5.2.4 - Allows tacked seeding opener to be mounted repeatably – 5

The accuracy of the welding operation performed by the robotic welder is dependent on the consistent positioning of the seeding openers with respect to the AWF and was thus assigned a weight of 5.

*A.5.2.5 - **Ability to mount the tacked seeding opener easily with both hands** – 4*

The ability to mount the tacked seeding openers with both hands is important as there will only be one operator mounting and un-mounting the seeding openers, resulting in this criterion being assigned a weight of 4.

*A.5.2.6 - **Only simple steps required to mount the tacked assembly – 3***

This criterion is only of moderate importance while although simple steps such as pulling a lever are desirable, if the step does not affect the efficiency of the mounting/unmounting and result in a process bottleneck, this will have only a moderate impact, and so has been assigned a weight of 3.

A.5.2.7 - Complexity – 2

The complexity of each locating component was evaluated qualitatively based on the expected number of required parts and intuitive judgement. Since the level of complexity does not necessarily inhibit the functionality of the design, a lower weight of 2 was assigned to this selection criterion.

*A.5.2.8 - **Ease of manufacturing** – 2*

The ease of manufacturing the locating components is less important than for the motion mechanism as overall functionality and ease of use are substantially more important and thus a weight of 2 was assigned.

*A.5.2.9 - **Number of unique mounting fixtures - 2***

The locating component(s) should be able to accommodate each product line. Ideally this could be accomplished with a single locating component. However, given the various geometries of the seeding openers, more than a single locating component may be necessary. Since this will not affect performance once the component is mounted, this criterion was assigned a weight of 2 (Fewer components required to mount the various fixtures is desired).

A summary of the criteria and their weights is given in Table XXXII.

Table XXXII: Criteria and Their Weights for Locating Component Concepts

Selection Criteria	Weight
Works with all tacked product assemblies	5
Ensures accessibility of weld locations.	5
Part can be interchanged quickly	5
Allows the tacked assembly to be mounted repeatably.	5
Ability to mount the tacked assembly easily with both hands.	4
Only needs to perform simple steps in mounting the tacked assembly.	3
Complexity	2
Ease of manufacturing	2
Number of unique mounting fixtures	2

A.6 - CONCEPT SCORING

A.6.1 - Positioning Mechanism

The results from the concept screening process resulted in the elimination of the pivoting shaft, linear actuator shaft end tilt, and the universal joint concepts from further evaluation. The results of the concept scoring process for the remaining motion mechanism concepts are presented in Table XXXIII.

Table XXXIII: Concept Scoring of Motion Mechanisms

		Concept Variants								
Selection Criteria	WEIGHT	M1.1 - Shaft Driven Tilt Table	M1.2 - Lead Screw Tilt Table	M2.1 - Rotary Tilt Table	M2.2 - Condensed Rotary Tilt Table	M3.3 - Bell Crank Linkage Tilt	M4 - Rotary Bent Tube Gimbal	M6.1 - Single Unit Hinge Tilt	M6.2 - Angled Single Unit Hinge Tilt	M7 - Held Angle Tilt
Allows clearance for part in all orientations.	5	4	4	4	3	5	5	4	4	4
Ensures accessibility of weld locations.	5	5	5	3	3	5	3	4	5	5
Footprint of the mechanism	4	3	3	3	4	3	2	5	4	4
Ease of manufacturing	4	5	1	4	3	2	2	5	5	5
Cost	4	4	2	4	4	4	3	4	4	4
Height of the mechanism	3	2	2	3	3	3	3	4	5	4
Complexity	3	3	2	3	3	2	2	5	4	5
Number of steps to achieve required orientation	3	5	5	4	3	3	4	4	4	3
Minimizes volume of space for part travel	2	2	2	4	5	5	4	4	5	3
Raw Score	33	127	100	117	111	120	103	143	146	139
Normalized Score		3.85	3.03	3.55	3.36	3.64	3.12	4.33	4.42	4.21

The results of the concept scoring identify the Angled Single Unit Hinge Tilt as the best concept.

A.6.2 - Clamping Mechanism

The locating components were evaluated against the criteria outlined in Section A.5.2 - . The scoring and results are seen in Table XXXIV.

Table XXXIV - Concept Scoring of Locating Component

		Concept Variants			
Selection Criteria	Weight	L1 - Interchangeable Push Clamp Plates	L2 - Shaft Mount Puller Bar	L3 - Rotary Table Mount Puller Bar	L4 - Interchangeable Thumb Screw Plates
Works with all tacked product assemblies	5	4	5	5	4
Ensures accessibility of weld locations	5	5	5	5	5
Part can be interchanged quickly	5	2	5	5	2
Allows the tacked assembly to be mounted repeatably.	5	5	5	5	5
Ability to mount the tacked assembly easily with both hands.	4	4	5	5	4
Only simple steps needed in mounting the tacked assembly.	3	3	4	4	3
Complexity	2	3	2	2	3
Ease of manufacturing	2	3	2	2	3
Number of unique mounting fixtures	2	1	4	4	1
Total	33	119	148	148	119
Normalized Score		3.61	4.48	4.48	3.61

The results of the concept scoring identify the puller bar concepts as the best solutions. Since the motion mechanism selected utilizes a rotary table, the Rotary Table Mount Puller Bar was selected.

A.7 - FINAL CONCEPT SELECTED

The design concepts for each aspect of the design have been selected and are able to integrate with one another. The final concept is named the Angled Hinged Tilt Rotary Table with Universal Puller Bar and preliminary design images are seen in Figure 71 with the paired row opener attached to the fixture mechanism (motors not shown).

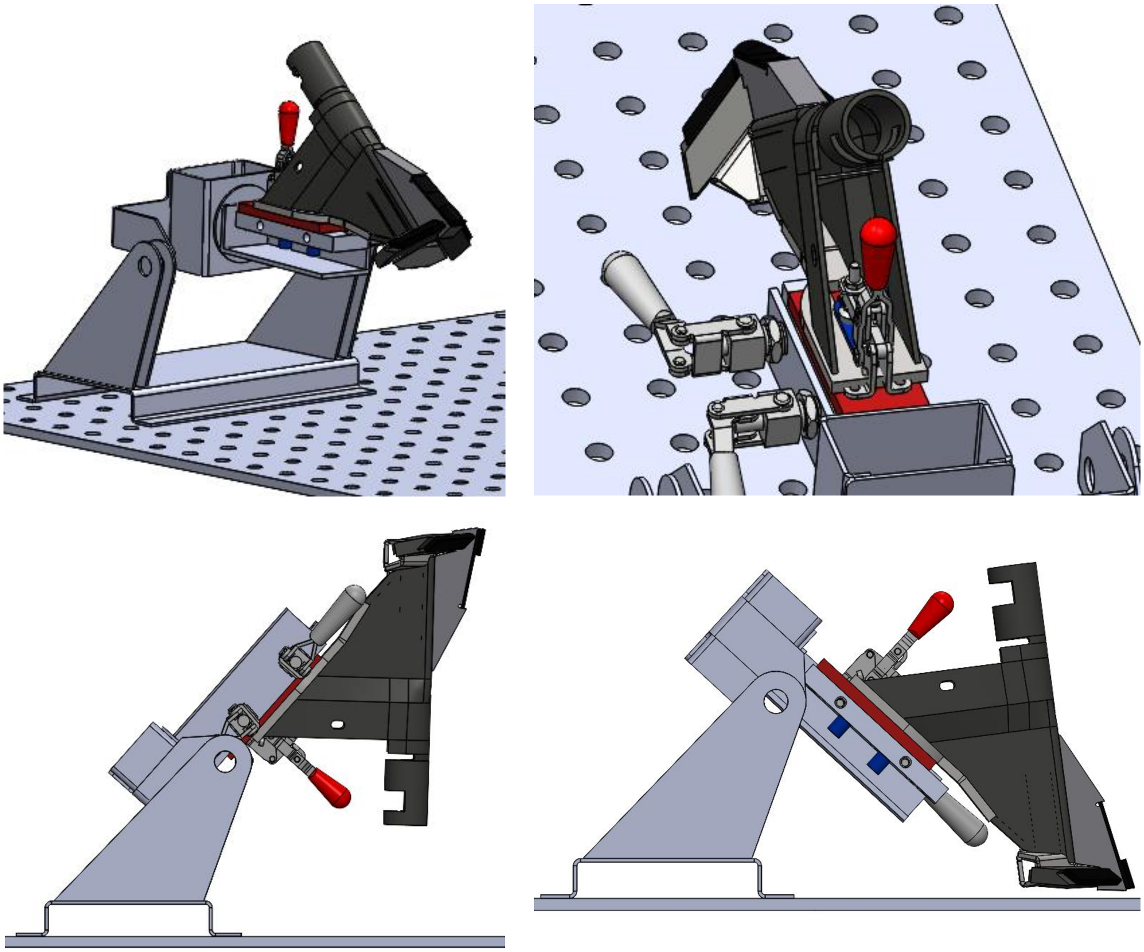


Figure 71 – The angled hinged tilt rotary table with universal puller bar.

A feature of the final selected design not yet mentioned is that, if required, the dual vertical wall support system for the rotary table could be used to house a speed reduction system which would increase the torque of the design. This feature allows for increased flexibility in motor selection in the detailed design phase of the project.

APPENDIX B – ANALYSES

B.1 - SHAFT ANALYSES

The following is the python code used to calculate the static and dynamic safety factors as well as deflections for the shafts.

```
import numpy as np
D=20.6
d=15.875
r=0.8
S_y=360
A=np.pi*(d/2)**2
J=np.pi*d**4/32
I=J/2
E=210e3
#Static load analysis
#Rotational gear box output shaft:
P=42.3
M=7.81*1000
T=2.13*1000
#Calculated from https://amesweb.info/stress-concentration-factor-calculator/calculators.aspx
sigma_a=P/A
sigma_b=M*d/2/I
tau=T*d/2/J
stress_nom=np.array([sigma_a, sigma_b, tau])
K_t=np.array([2.12, 2.05, 1.61])
stress_max=stress_nom*K_t
sigma_x=abs(stress_max[1])+abs(stress_max[2])
sigma_v=(sigma_x**2+3*tau**2)**0.5
n_y=S_y/sigma_v
print(n_y)
#Dynamic load analysis
S_ut=560
k_a=0.77 #Machined surface
S_e=0.5*S_ut*k_a
print(S_e)
q=0.686 #Notch sensitivity for notch radius of 0.8mm
K_f=np.max(1+q*(K_t-1))
sigma_a0=sigma_a+sigma_b
sigma_am=sigma_a0*K_f
print(sigma_am)
sigma_m=0 #Fully reversed loading assumed
```

```
n_f=(sigma_am/S_e+sigma_m/S_ut)**-1
print(n_f)
#Deflection analysis
L=363
a=335
l_moment=148 #Center of mass to end of shaft
M0=P*l_moment
delta_t=P/6/E/I*2*(L-a)**3+P/2/E/I/(L-a)**2*a
delta_b=M0*(L-a)**2/2/E/I+M0*(L-a)/E/I*a
delta_total=delta_t+delta_b

print(delta_total)
```

B.2 - TORQUE REQUIREMENT FOR MOTOR SELECTION

The torque requirement for motor selection has been outlined in the body of Sections 3.4.2 & 3.5.2. This section focuses on the calculation and displays the center of mass for all systems. Equations 12 & 13 outline the calculation of the minimum required final output torque of the motor shafts.

$$Moment\ Arm\ Length = \sqrt{(XLength)^2 + (ZLength)^2} \tag{12}$$

$$Required\ Output\ Torque\ [oz \cdot in] = Moment\ Arm\ Length\ [in] \times System\ Mass\ [oz] \tag{13}$$

B.2.1 - Rotational Gear Box

B.2.1.1 - CDAA00:

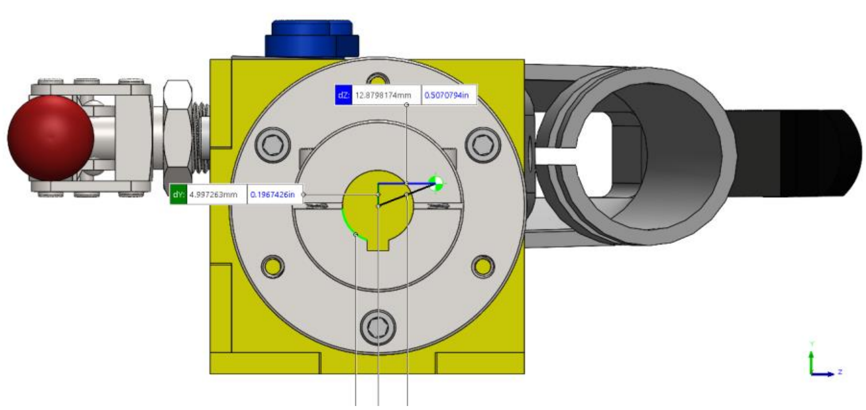


Figure 72: Clamping mechanism with CDAA00 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(0.1967426)^2 + (0.5070769)^2} = 0.544\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 0.544\ [in] \times 132.96\ [oz] = 72 \text{ oz-in}$$

B.2.1.2 - CAFAA0:

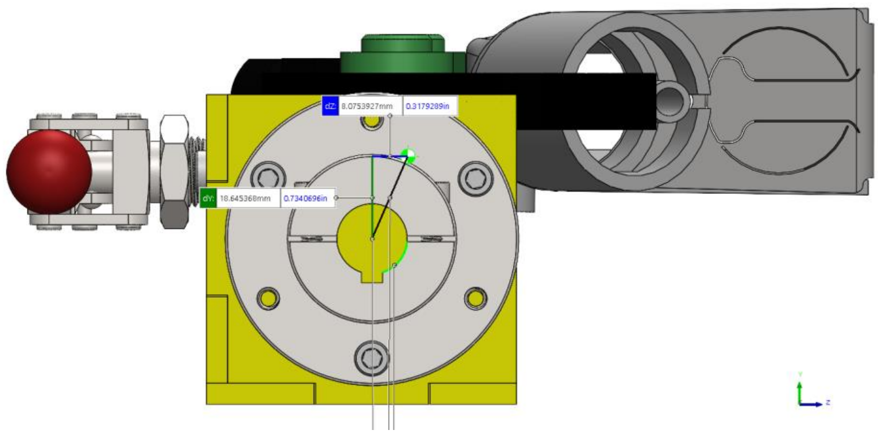


Figure 73: Clamping mechanism with CAFAA0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(0.7340696)^2 + (0.3179289)^2} = 0.8\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 0.8\ [in] \times 171.52\ [oz] = 137 \text{ oz-in}$$

B.2.1.3 - CBBTD0:

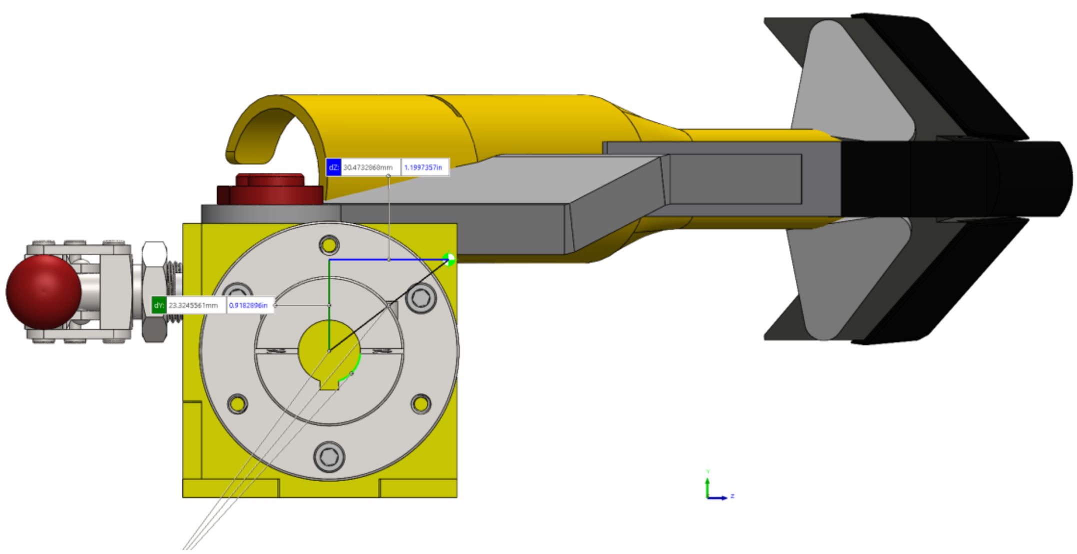


Figure 74: Clamping mechanism with CBBTD0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(0.9182896)^2 + (1.1997357)^2} = 1.51\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 1.51\ [in] \times 164.32[oz] = 248.26 \text{ oz-in}$$

B.2.1.4 - CCETE0:

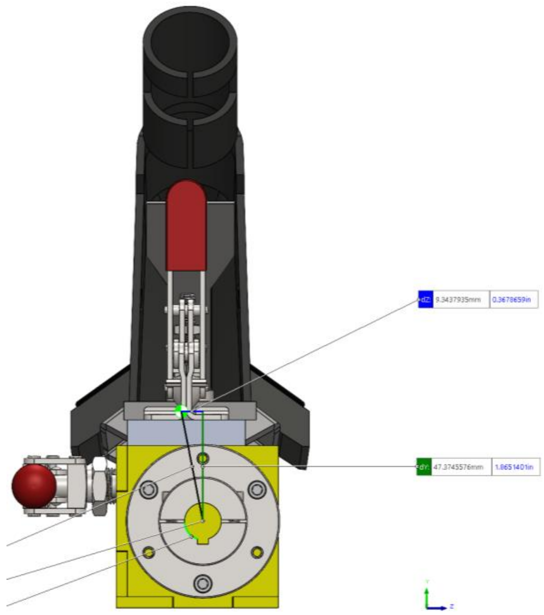


Figure 75: Clamping mechanism with CCETE0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(0.3678659)^2 + (1.865141)^2} = 1.901\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 1.091\ [in] \times 161.76[oz] = 308 \text{ oz-in}$$

B.2.2 - Tilting Gear Box

B.2.2.1 - CDAA00:

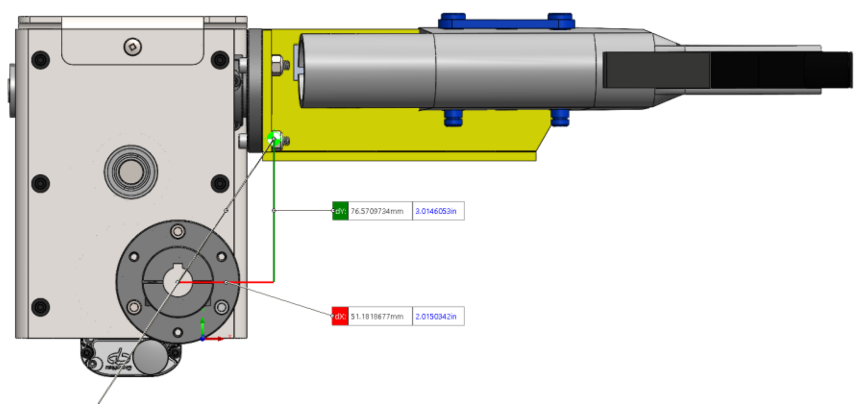


Figure 76: Clamping mechanism with CDAA00 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(2.01150342)^2 + (3.0146053)^2} = 3.626\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 3.626\ [in] \times 336.93\ [oz] = 1222 \text{ oz-in}$$

B.2.2.2 - CAFAA0:

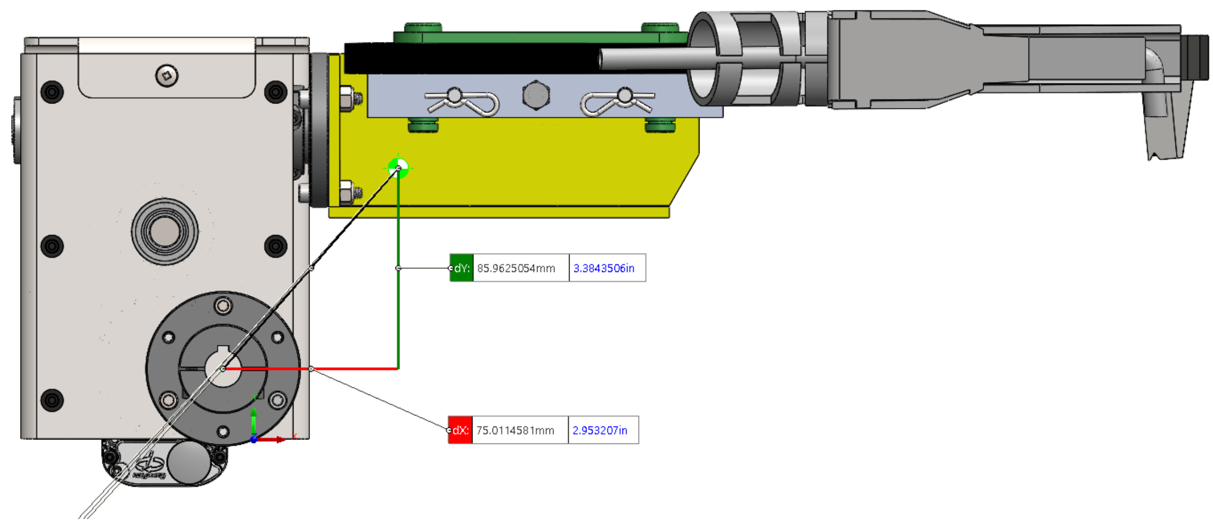


Figure 77: Clamping mechanism with CAFAA0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(2.953207)^2 + (3.3843506)^2} = 4.4913\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 4.4913\ [in] \times 375.54\ [oz] = 1687 \text{ oz-in}$$

B.2.2.3 - CBBTD0:

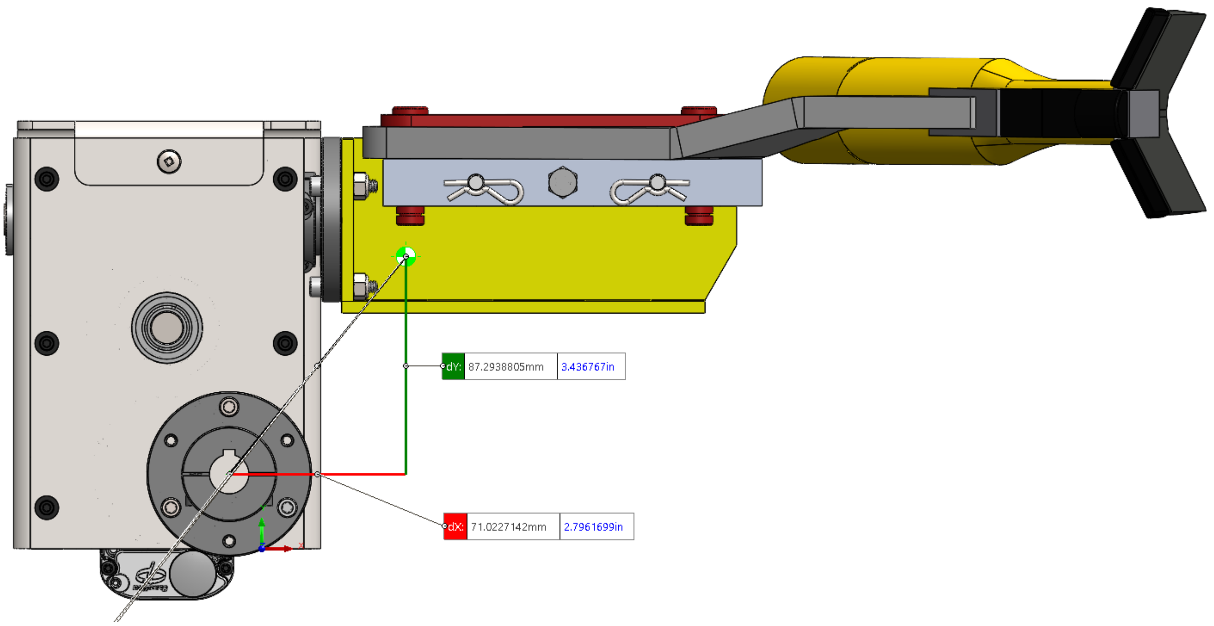


Figure 78: Clamping mechanism with CBBTD0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(2.7961699)^2 + (3.436767)^2} = 4.428\ in$$

$$Required\ Output\ Torque\ [oz \cdot in] = 4.428\ [in] \times 368.32[oz] = 1631 \text{ oz-in}$$

B.2.2.4 - CCETE0:

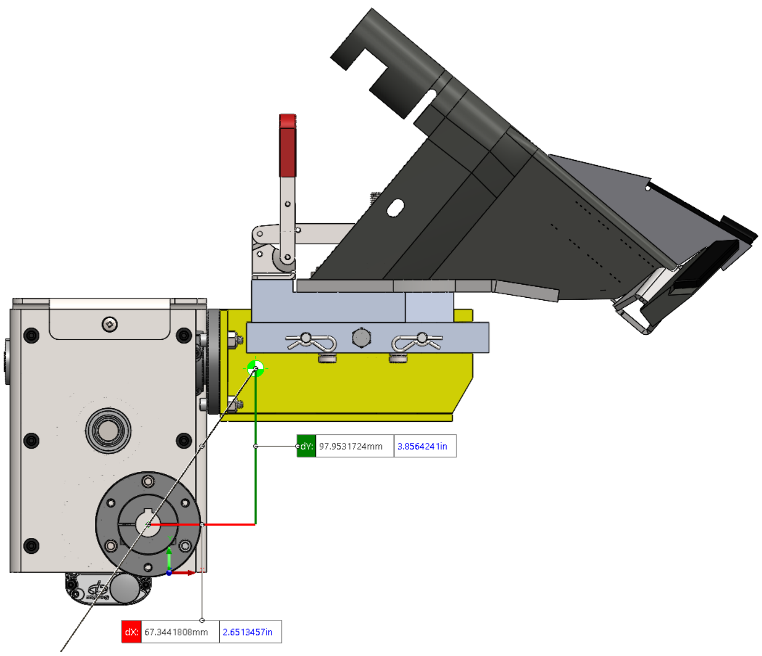
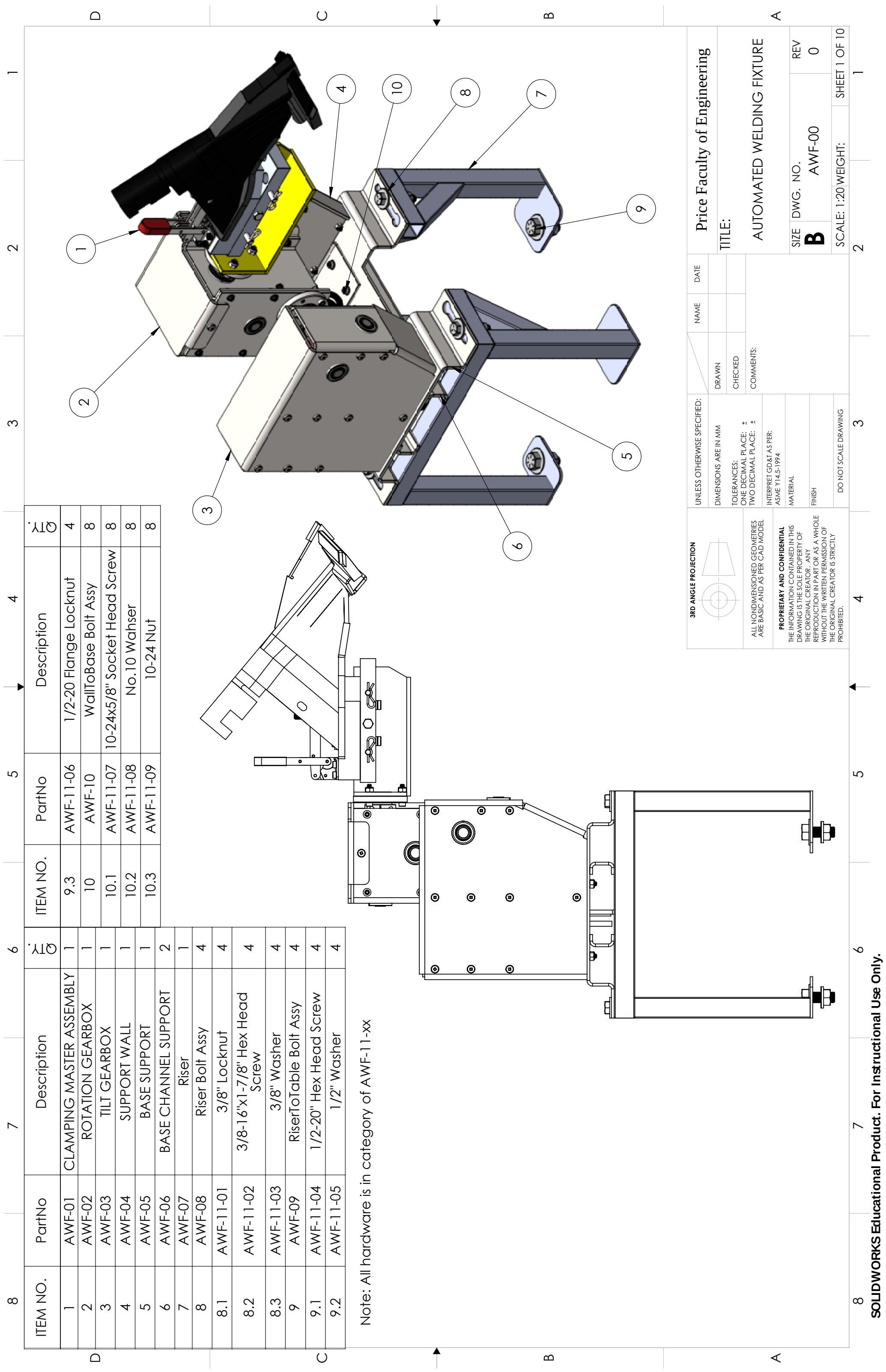


Figure 79: Clamping mechanism with CCETE0 seeding opener.

$$Moment\ Arm\ Length = \sqrt{(2.6513457)^2 + (3.8564241)^2} = 4.679\ in$$

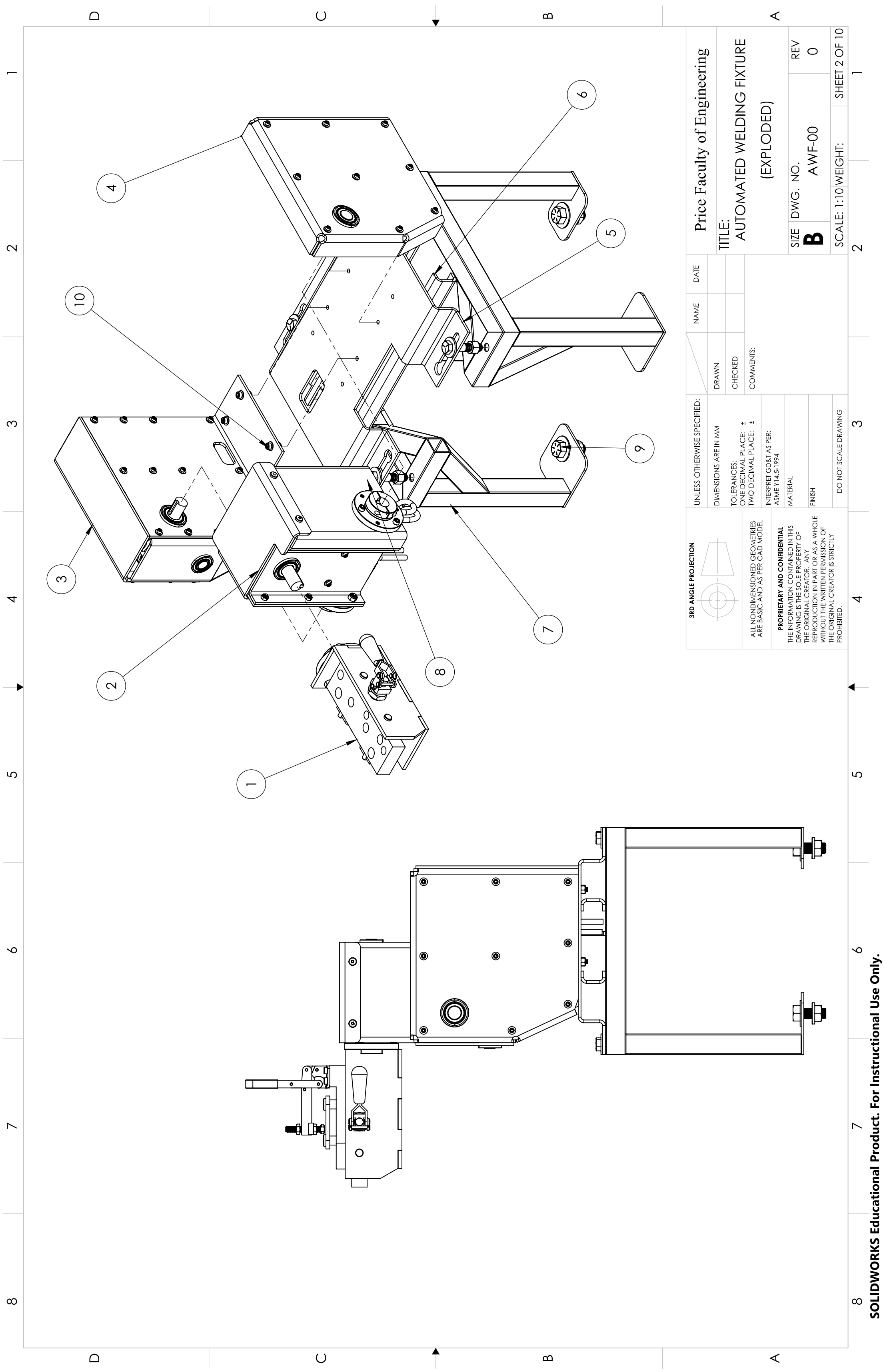
$$Required\ Output\ Torque\ [oz \cdot in] = 4.679\ [in] \times 366.72[oz] = 1716 \text{ oz-in}$$

APPENDIX C - ENGINEERING DRAWINGS



ITEM NO.	PartNo	Description	QTY.
1	AWF-01	CLAMPING MASTER ASSEMBLY	1
2	AWF-02	ROTATION GEARBOX	1
3	AWF-03	TILT GEARBOX	1
4	AWF-04	SUPPORT WALL	1
5	AWF-05	BASE SUPPORT	1
6	AWF-06	BASE CHANNEL SUPPORT	2
7	AWF-07	Riser	1
8	AWF-08	Riser Bolt Assy	4
8.1	AWF-11-01	3/8" Locknut	4
8.2	AWF-11-02	3/8-16"x1-7/8" Hex Head Screw	4
8.3	AWF-11-03	3/8" Washer	4
9	AWF-09	RiserToTable Bolt Assy	4
9.1	AWF-11-04	1/2-20" Hex Head Screw	4
9.2	AWF-11-05	1/2" Washer	4
9.3	AWF-11-06	1/2-20 Flange Locknut	4
10	AWF-10	WallToBase Bolt Assy	8
10.1	AWF-11-07	10-24x5/8" Socket Head Screw	8
10.2	AWF-11-08	No.10 Wahser	8
10.3	AWF-11-09	10-24 Nut	8

Note: All hardware is in category of AWF-11-xx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(EXPLODED)
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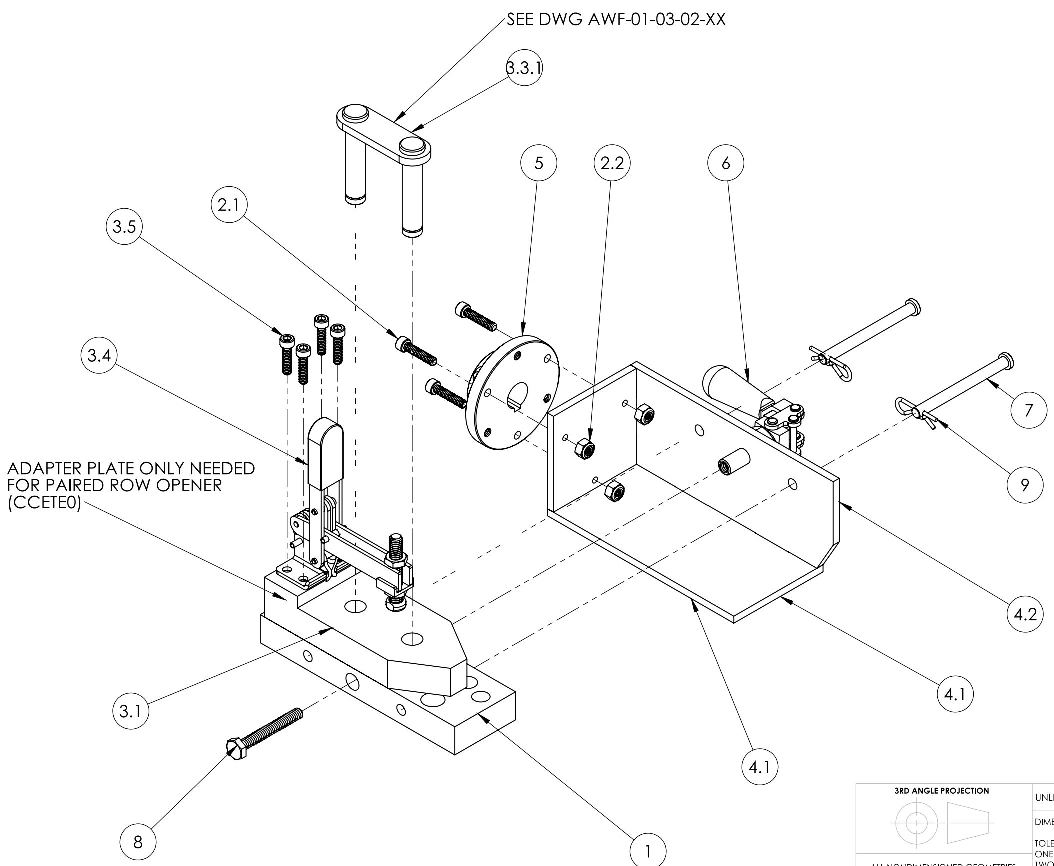

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1	AWF-01-01	PULLER BAR	1
2	AWF-01-02	Flange Collar Large Bolt_Assy	3
2.1	AWF-11-16	Socket Head Screw, 10-24 Thread Size, 7/8" Long	1
2.2	AWF-11-09	10-24 Nut	1
3	AWF-01-03	Row Opener Adapter	1
3.1	AWF-01-03-01	ADAPTER MOUNTING BLOCK	1
3.3	AWF-01-03-02	CCETE0 Holding Mech	1
3.4	AWF-11-21	Hold-Down Toggle Clamp	1
3.5	AWF-11-10	Socket Head Screw, 10-24 Thread Size, 3/4" Long	4
4	AWF-01-04	CLAMPING MOUNT ASSEMBLY	1
4.1	AWF-01-04-01	BOTTOM	1
4.2	AWF-01-04-02	SIDE	1
4.3	AWF-01-04-03	BACK	1
5	AWF-01-05	Flange-Mount Shaft Collar	1
6	AWF-11-20	Push/Pull Toggle Clamp	1
7	AWF-11-25	1/4" Diameter, 2-9/16" Length Clevis Pin	2
8	AWF-11-26	Hex Head Screw 1/4"-20 Thread Size, 1-7/8" Long	1
9	AWF-11-27	Hairpin Cotter Pin 1/4"-3/8" Pin Diameter, 5/64" Wire Diameter	2

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TITLE:
CLAMPING MECHANISM
WELDING FIXTURE

SIZE B | DWG. NO. AWF-01 | REV 0

SCALE: 1:5 | WEIGHT: | SHEET 3 OF 10

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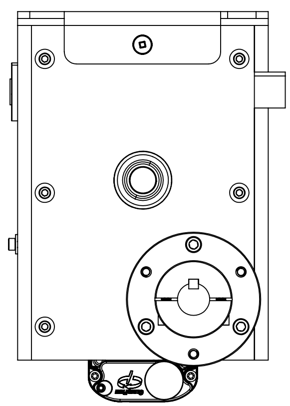
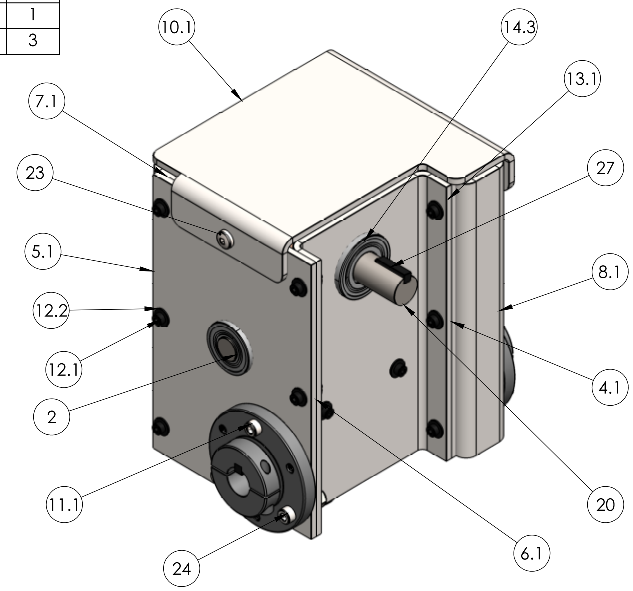
ITEM NO.	PartNo	Description	QTY.
1	AWF-01-05	Flange-Mount Shaft Collar	2
2	AWF-02-01	Worm Shaft GearBox 1	1
3	AWF-02-02	96 Teeth, 20° Pressure Angle, Hdened Alloy Steel Gear	1
4	AWF-02-03	MOTOR MOUNT PLATE	1
5	AWF-02-04	OUTER WALL	1
6	AWF-02-05	GEAR BOX FLANGE FRONT	1
7	AWF-02-06	GEAR BOX FLANGE BACK	1
8	AWF-02-07	GEAR COVER FLANGE	1
9	AWF-02-08	ClearPath® - Integrated Servo System	1
10	AWF-02-09	TOP COVER	1
11	AWF-02-10	FlangeCollar_BoltAssy	5
11.1	AWF-11-15	10-24x3/4" Socket Head Screw	1
11.2	AWF-11-09	10-24 Nut	1
12	AWF-02-11	RotaionGearBox_BoltAssy_1	9
12.1	AWF-11-11	6-32x9/16" Socket Head Screw	1
12.2	AWF-11-12	No. 6 Washer	1
12.3	AWF-11-13	6-32 Locknut	1
13	AWF-02-12	RotationGearBox_BoltAssy_2	6
13.1	AWF-11-14	6/32x3/4" Socket Head Screw	1
13.2	AWF-11-12	No. 6 Washer	1
13.3	AWF-11-13	6-32 Locknut	1
14	AWF-02-13	Flanged Deep Groove Ball Bearing 0.625" Bore	1
15	AWF-02-14	Motor Bolt Assy	4
15.1	AWF-11-07	10-24x5/8" Socket Head Screw	1
15.2	AWF-11-09	10-24 Locknut	1
16	AWF-02-15	MOTOR COVER	1
17	AWF-02-17	AG Worm Wheels	1
18	AWF-02-18	SWG Ground Worms	1
19	AWF-02-19	Flanged Deep Groove Ball Bearing 0.500" Bore	3
20	AWF-02-20	Output Shaft GearBox 1	1
21	AWF-02-21	120 Teeth, 20° Pressure Angle, Hdened Alloy Steel Gear	1
22	AWF-11-09	10-24 Nut	1
23	AWF-11-16	No.10x5/8" Sheet Metal Screws	3
24	AWF-11-16	Socket Head Screw, 10-24 Thread Size, 7/8" Long	1
25	AWF-11-17	5x5x32mm Key Rounded	1
26	AWF-11-18	5x5x60mm Key Rounded	1
27	AWF-11-19	3/16 x 3/16 x 0.75in Key Square	3





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COMMENTS:		

Price Faculty of Engineering

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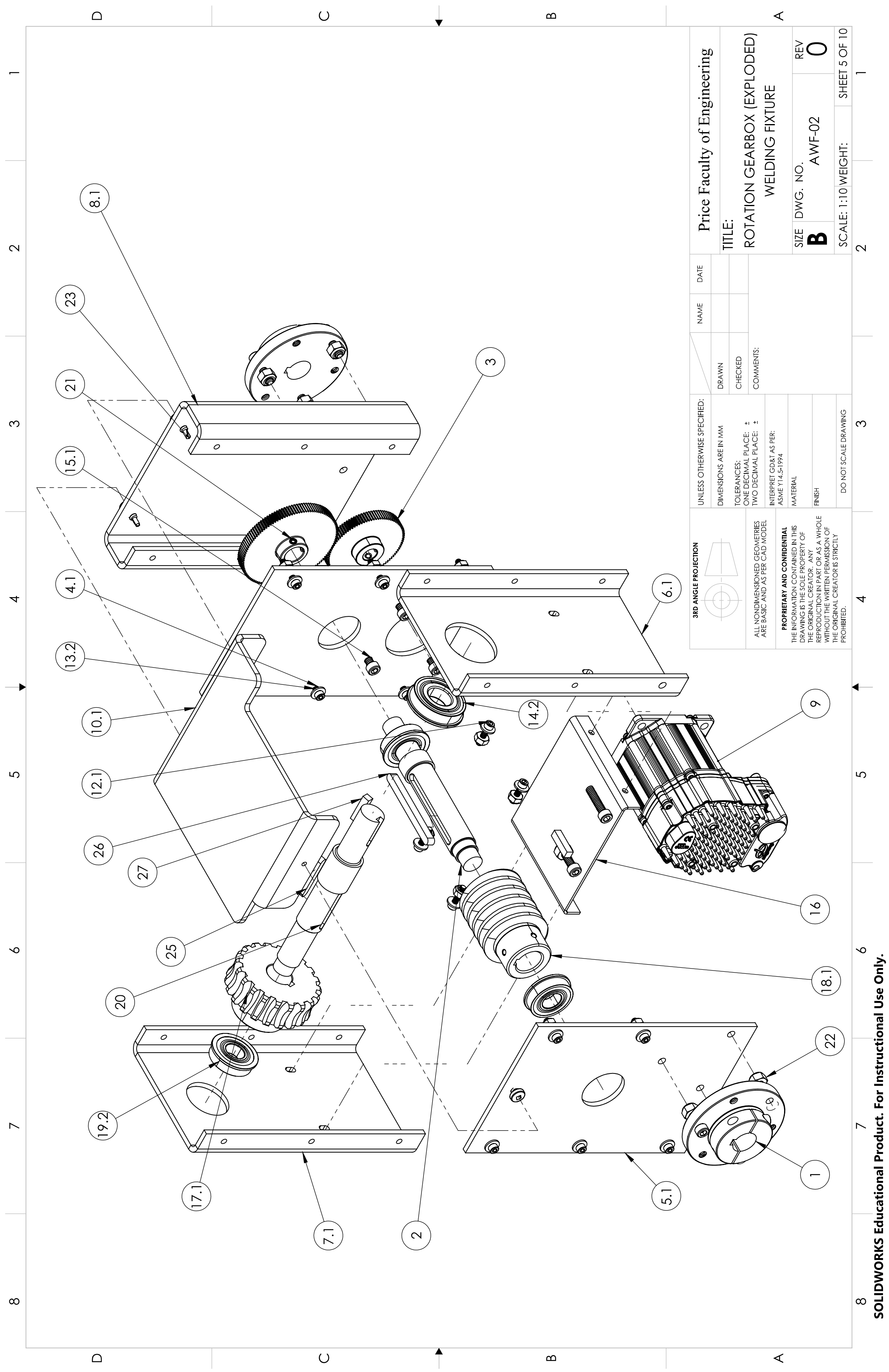
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WELDING FIXTURE
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DWG. NO. AWF-02
REV 0
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WEIGHT:
SHEET 5 OF 10
UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
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TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
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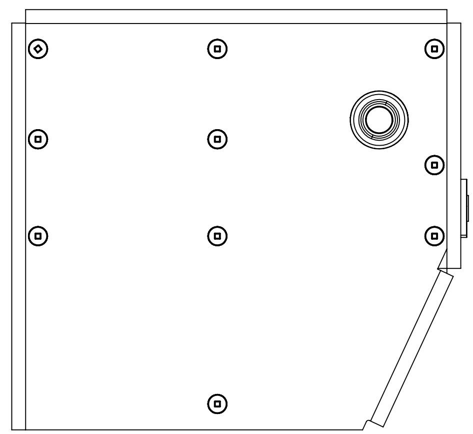
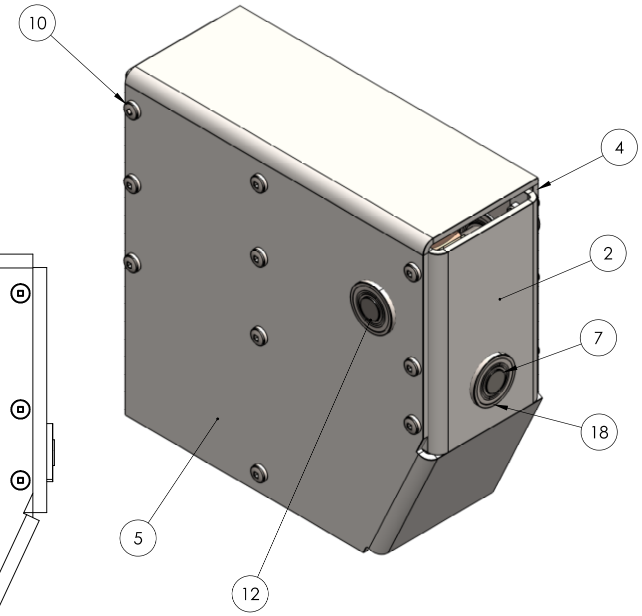
ITEM NO.	PartNo	Description	QTY.
1	AWF-03-01	MIDDLE WALL	1
2	AWF-03-04	TILT GEARBOX INNER WALL	1
3	AWF-03-06	ClearPath® - Integrated Servo System	1
4	AWF-03-05	TILT GEARBOX OUTER WALL	1
5	AWF-03-02	FRONT WALL	1
6	AWF-03-07	Worm Shaft GearBox 2	1
7	AWF-03-08	Flanged Deep Groove Ball Bearing 0.375" Bore	1
8	AWF-03-09	72 Teeth, 20° Pressure Angle, Hardened Alloy Steel Gear.	1
9	AWF-03-03	BACK WALL	1
10	AWF-11-16	No.10x5/8" Sheet Metal Screws	10
11	AWF-03-10	GearBox2 Bolt Assy	11
11.1	AWF-11-11	Socket Head Screw 6-32 Thread Size, 9/16" Long	1
11.2	AWF-11-12	No. 6 Washer	1
11.3	AWF-11-13	6-32 Locknut	1
12	AWF-03-12	Outout Shaft GearBox 2	1
13	AWF-02-21	120 Teeth, 20° Pressure Angle, Hdened Alloy Steel Gear	1
14	AWF-02-14	Motor Bolt Assy	4
14.1	AWF-11-07	10-24x5/8" Socket Head Screw	1
14.2	AWF-11-09	10-24 Locknut	1
15	AWF-02-17	AG Worm Wheels	1
16	AWF-02-18	SWG Ground Worms	1
17	AWF-02-13	Flanged Deep Groove Ball Bearing 0.625" Bore	1
18	AWF-02-19	Flanged Deep Groove Ball Bearing 0.500" Bore	2
19	AWF-11-17	5x5x32mm Key Rounded	1
20	AWF-11-18	5x5x60mm Key Rounded	1





3RD ANGLE PROJECTION

ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL

PROPRIETARY AND CONFIDENTIAL
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DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
COMMENTS:		

Price Faculty of Engineering

TITLE: TILT GEARBOX WELDING FIXTURE

SIZE: B | DWG. NO.: AWF-03 | REV: 0

SCALE: 1:5 | WEIGHT: | SHEET 6 OF 10

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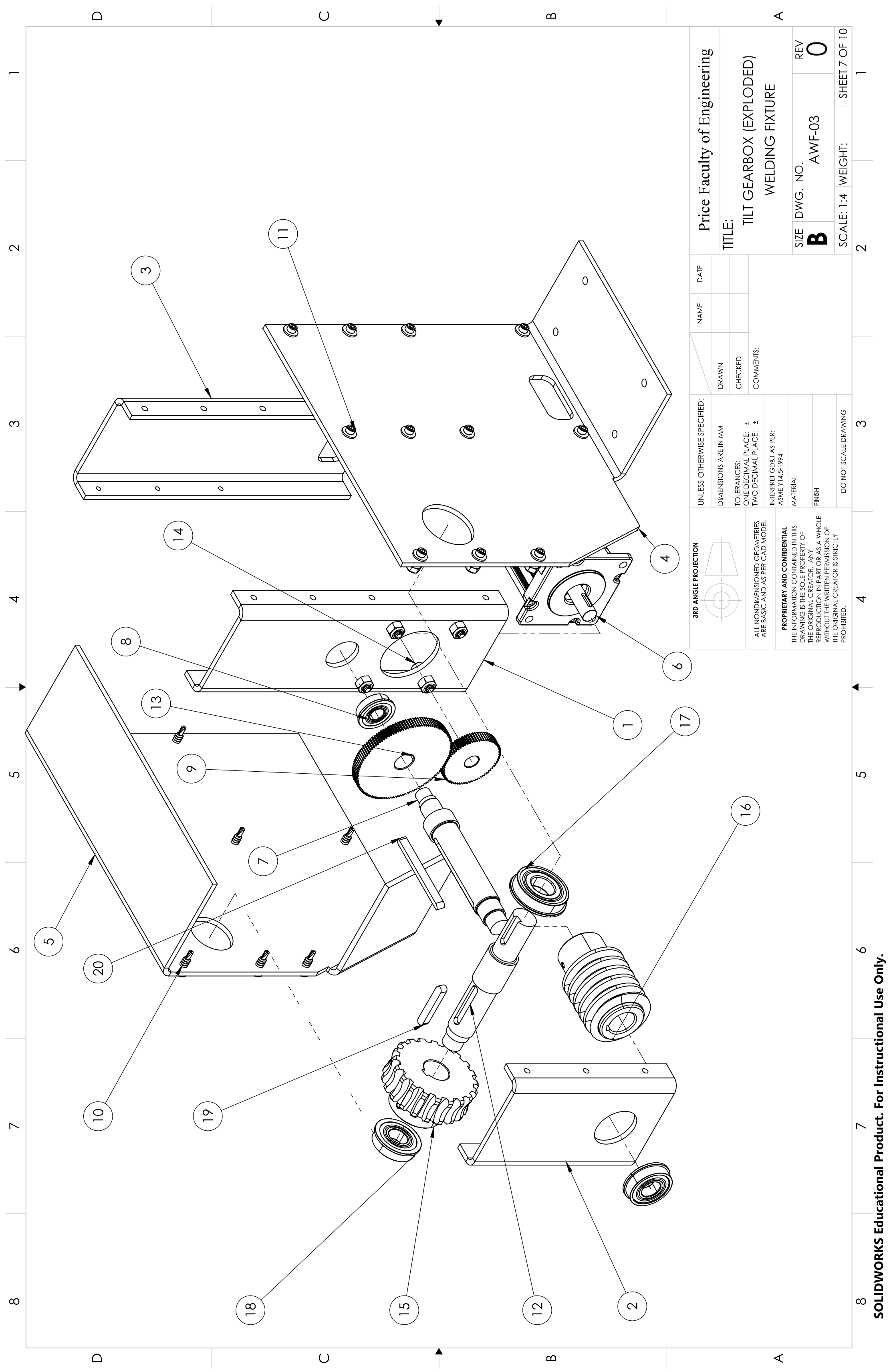
Price Faculty of Engineering
TITLE:
TILT GEARBOX (EXPLODED)
WELDING FIXTURE
SIZE B
DWG. NO. AWF-03
REV 0
SCALE: 1:4
WEIGHT:
SHEET 7 OF 10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
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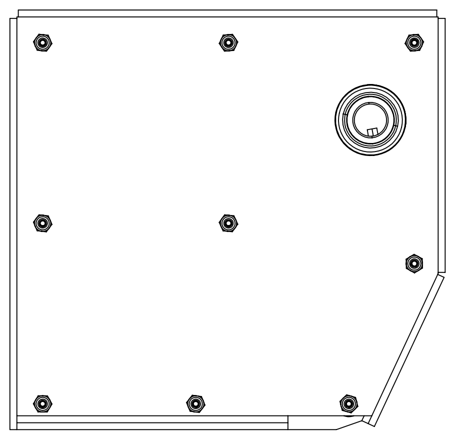
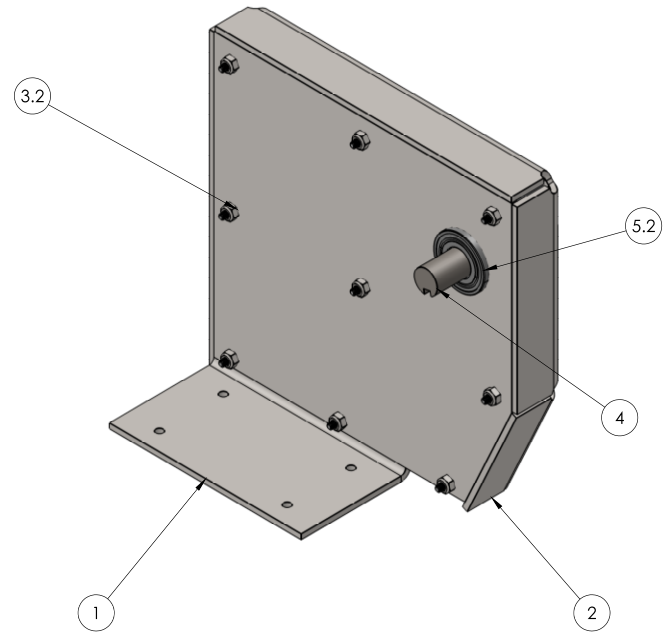
ITEM NO.	PartNo	Description	QTY.
1	AWF-04-01	SUPPORT WALL - INNER	1
2	AWF-04-02	SUPPORT WALL - OUTER	1
3	AWF-04-03	Right Wall Bolt Assy	9
3.1	AWF-11-23	No. 6 x 1" Spacer	1
3.2	AWF-11-24	6-32x1-5/8" Socket Head Screw	1
3.3	AWF-11-12	No. 6 Washer	1
3.4	AWF-11-13	6-32 Locknut	1
4	AWF-04-04	Idle Shaft	1
5	AWF-02-13	Flanged Deep Groove Ball Bearing 0.625" Bore	2





3RD ANGLE PROJECTION

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		

COMMENTS:

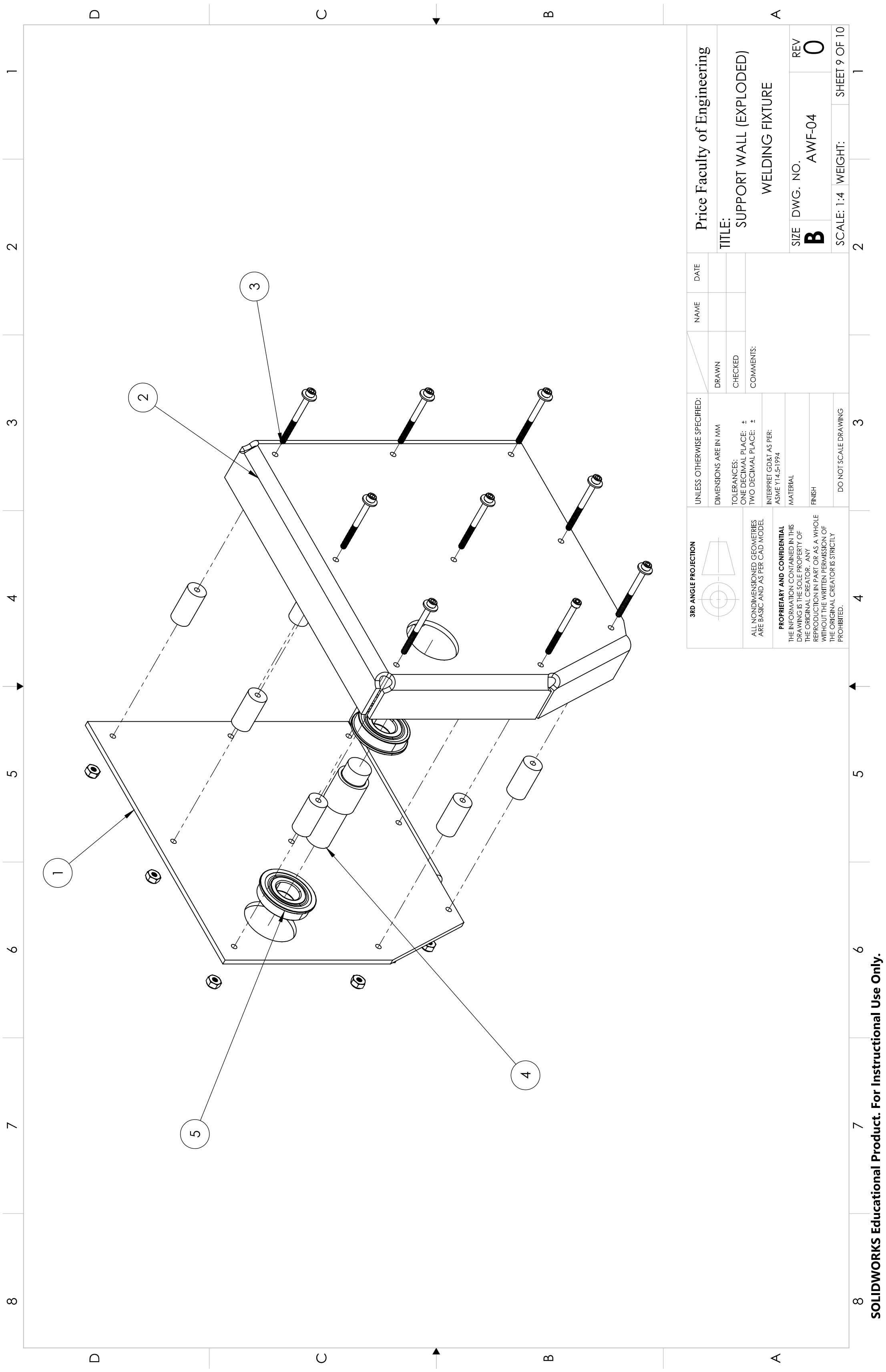
Price Faculty of Engineering

TITLE: SUPPORT WALL WELDING FIXTURE

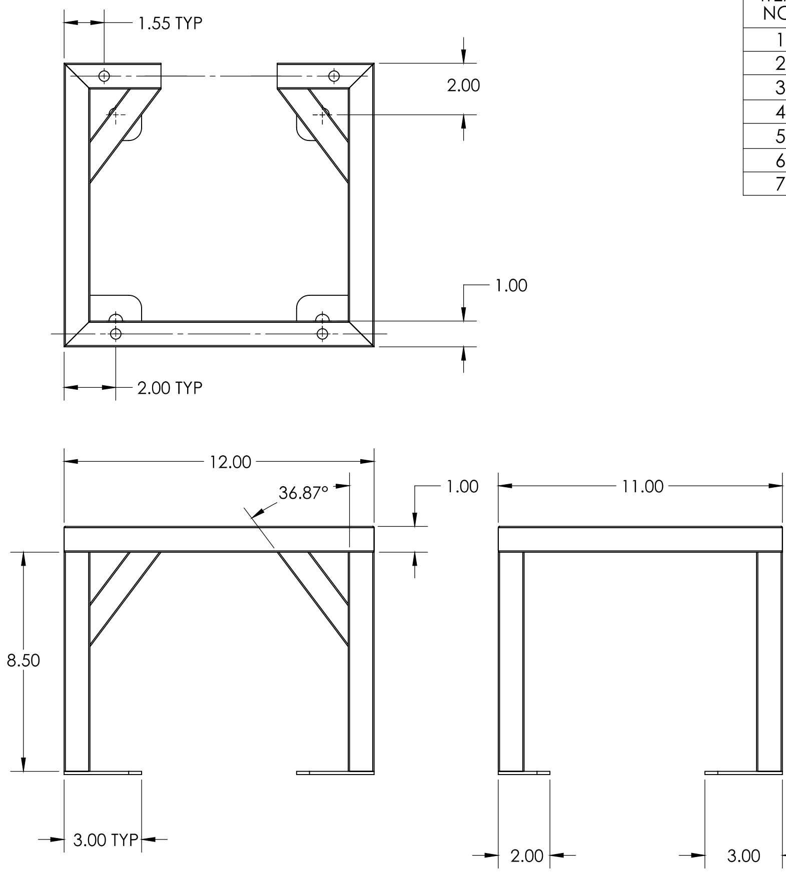
SIZE B | DWG. NO. AWF-04 | REV 0

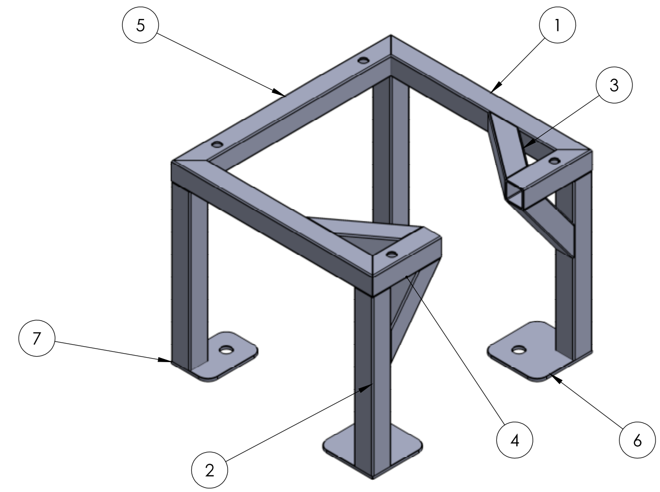
SCALE: 1:4 | WEIGHT: | SHEET 8 OF 10

SOLIDWORKS Educational Product. For Instructional Use Only.


Price Faculty of Engineering
TITLE:
SUPPORT WALL (EXPLODED)
WELDING FIXTURE
SIZE B
DWG. NO. AWF-04
REV 0
SCALE: 1:4
WEIGHT:
SHEET 9 OF 10
3RD ANGLE PROJECTION
DO NOT SCALE DRAWING
SOLIDWORKS Educational Product. For Instructional Use Only.

ITEM NO.	QTY.	LENGTH	ANGLE1	ANGLE2	TOTAL LENGTH	Bounding Box Length	Bounding Box Width	Sheet Metal Thickness
1	2	11	45°	45°	93.83			
2	4	8.5	0°	0°	93.83			
3	4	4.58	53.13°	36.87°	93.83			
4	2	3.75	0°	45°	93.83			
5	1	12	45°	45°	93.83			
6	2					3	3	0.13
7	2					3	2	0.13





3RD ANGLE PROJECTION

ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL

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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL: 1"X1"X0.12" Square Tube
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
COMMENTS:		

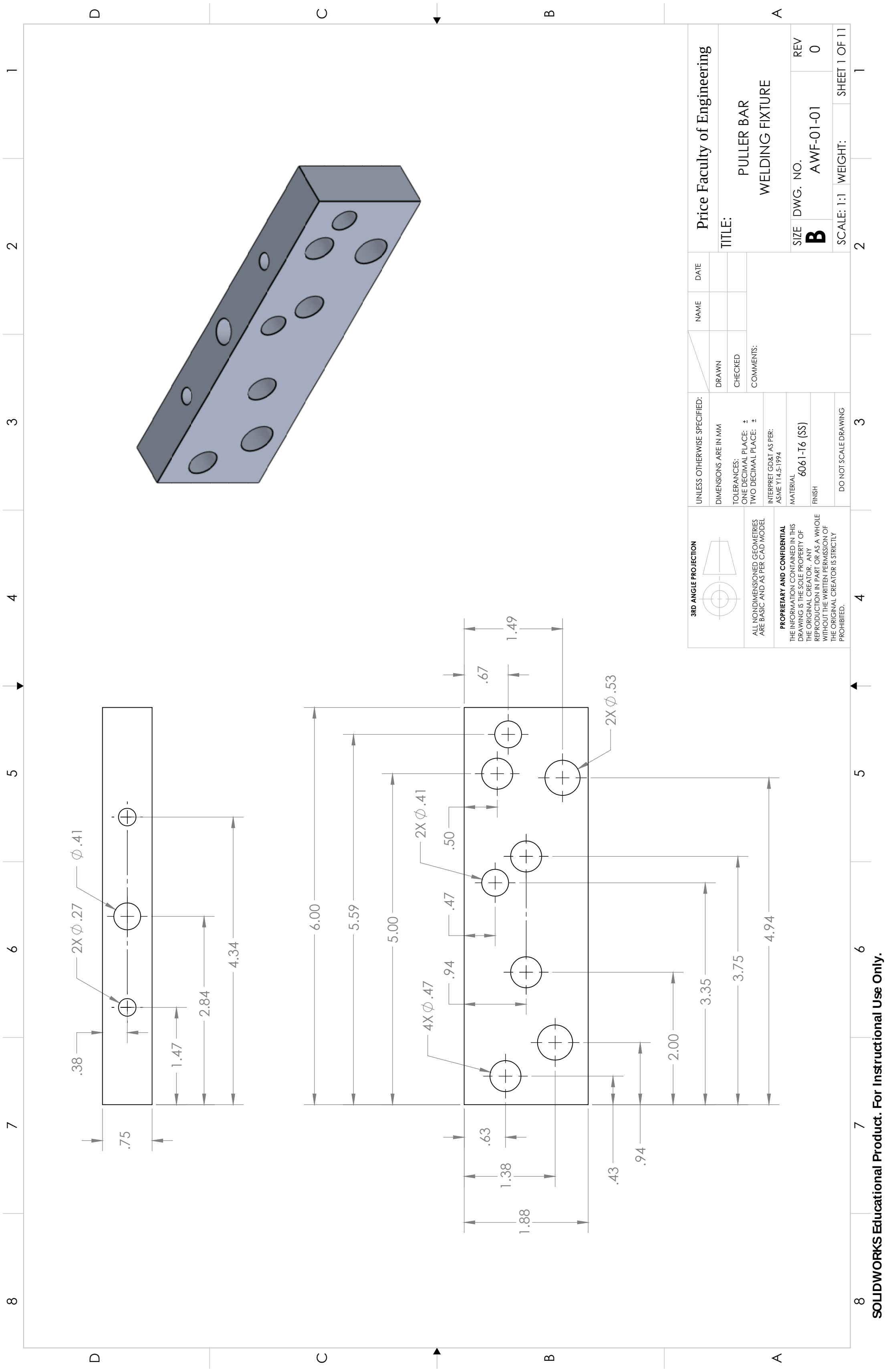
Price Faculty of Engineering

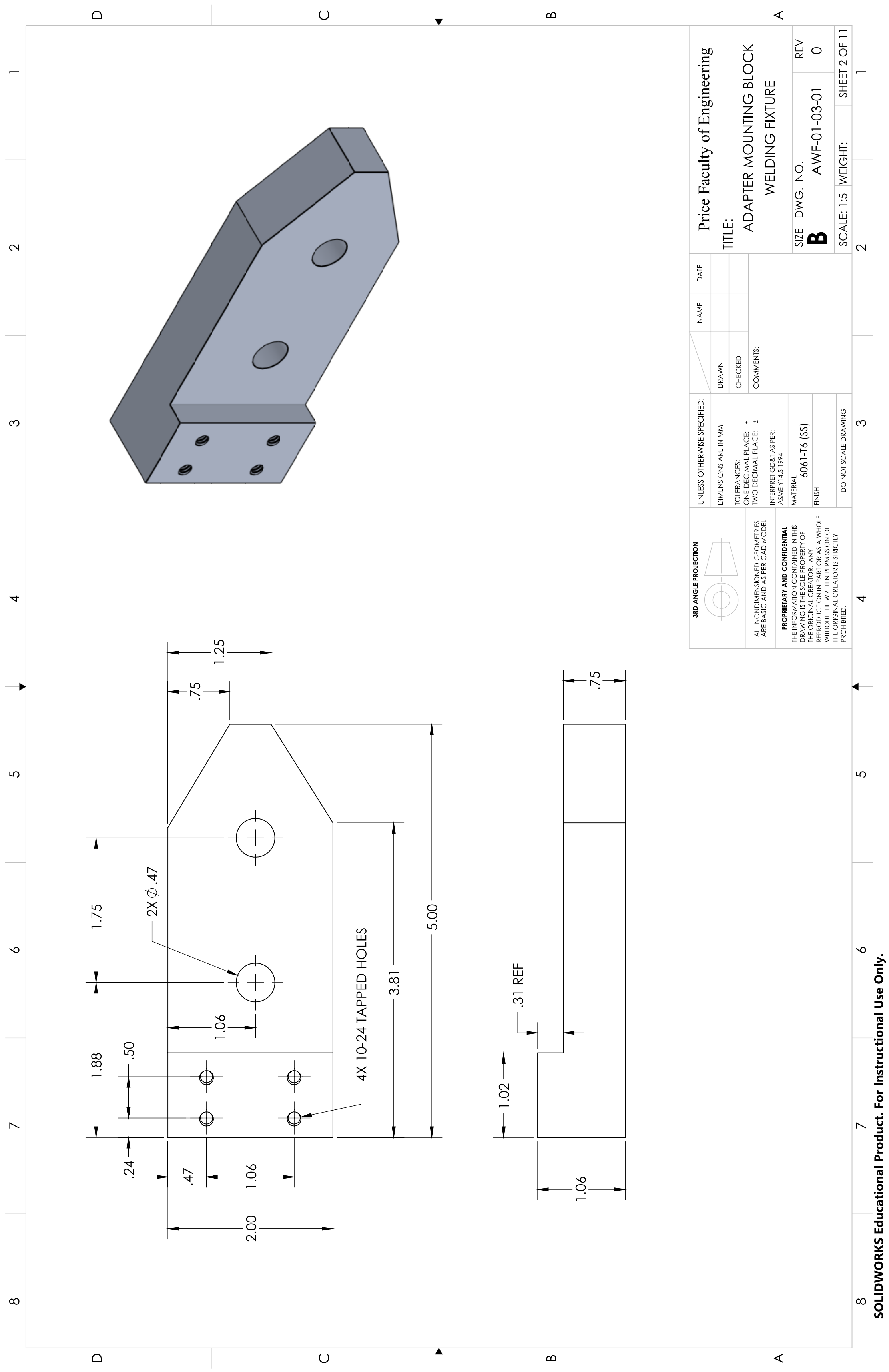
TITLE: RISER WELDING FIXTURE

SIZE: B | DWG. NO.: AWF-07 | REV: 0

SCALE: 1:5 | WEIGHT: | SHEET 10 OF 10

SOLIDWORKS Educational Product. For Instructional Use Only.


Price Faculty of Engineering
TITLE:
PULLER BAR
WELDING FIXTURE
SIZE B
DWG. NO. AWF-01-01
REV 0
SCALE: 1:1
WEIGHT:
SHEET 1 OF 11
MATERIAL
6061-T6 (SS)
SOLIDWORKS Educational Product. For Instructional Use Only.


Price Faculty of Engineering
TITLE:
ADAPTER MOUNTING BLOCK
WELDING FIXTURE
SIZE B
DWG. NO. AWF-01-03-01
REV 0
SCALE: 1:5
WEIGHT:
SHEET 2 OF 11
DRAWN
CHECKED
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
6061-T6 (SS)
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
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2X ⌀ .47
4X 10-24 TAPPED HOLES
1.25
.75
1.75
1.88
.50
.24
.47
1.06
1.06
2.00
3.81
5.00
.75
.31 REF
1.02
1.06
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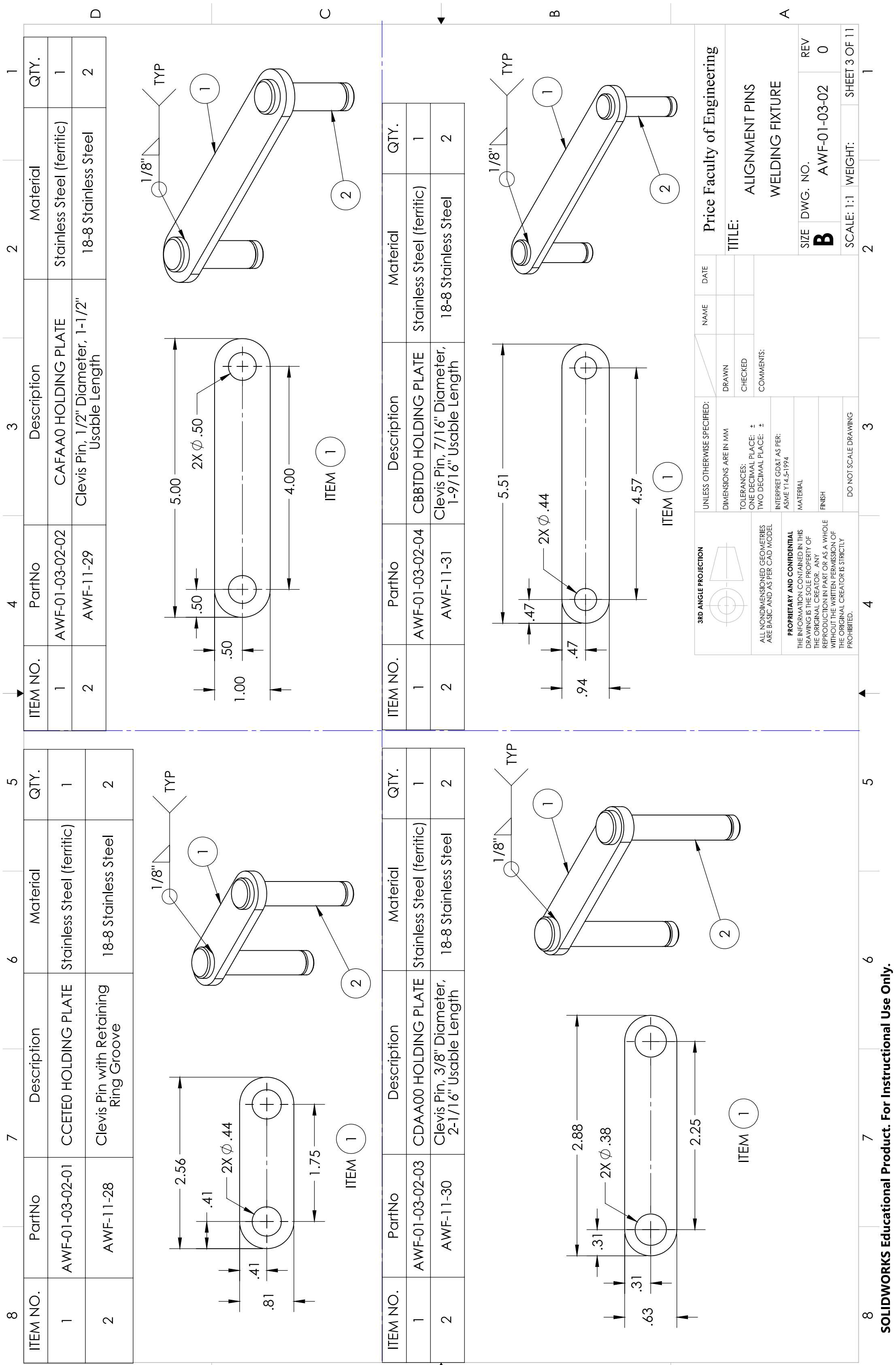
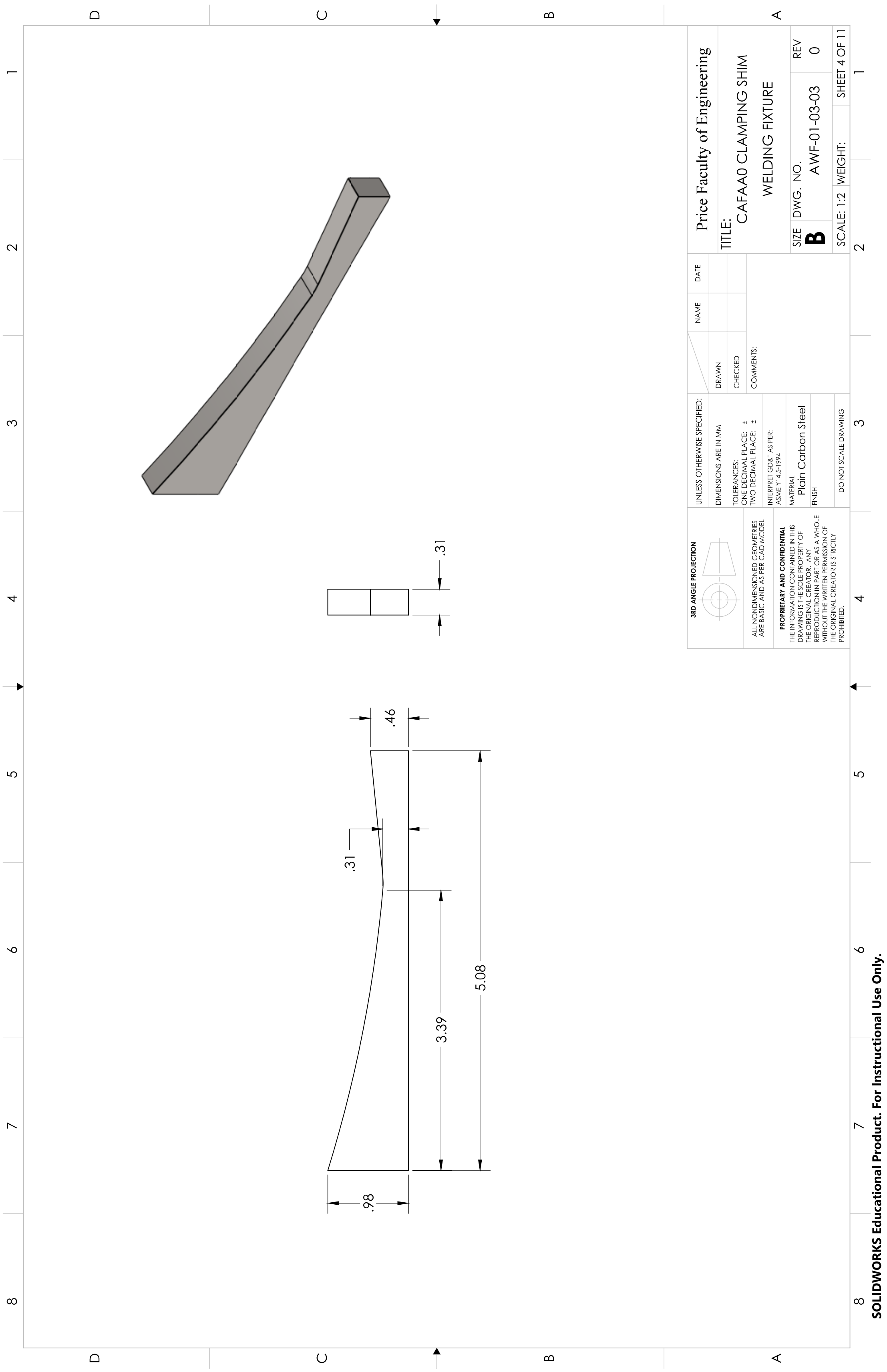


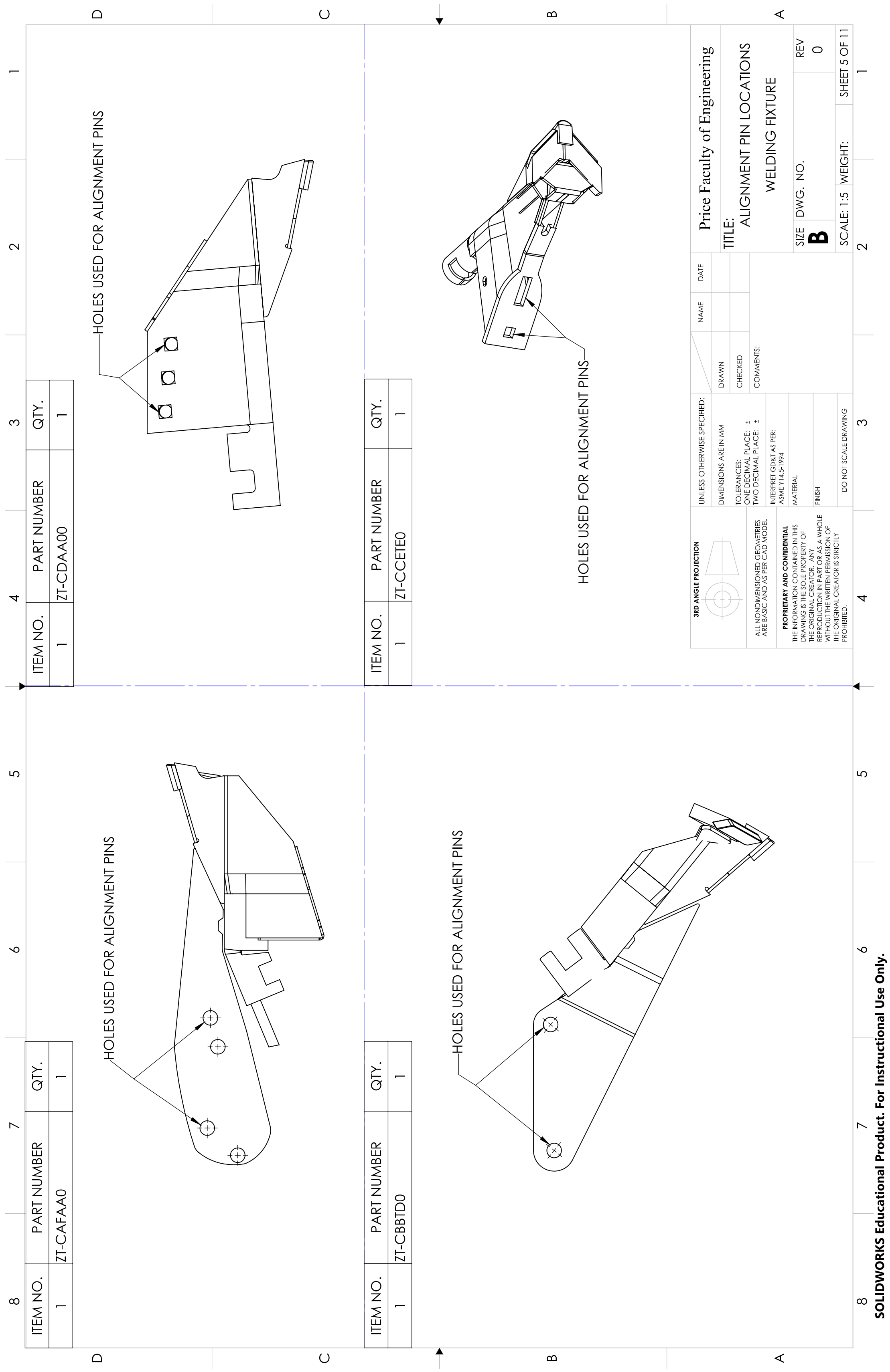
ITEM NO.	PartNo	Description	Material	QTY.
1	AWF-01-03-02-01	CCETE0 HOLDING PLATE	Stainless Steel (ferritic)	1
2	AWF-11-28	Clevis Pin with Retaining Ring Groove	18-8 Stainless Steel	2

ITEM NO.	PartNo	Description	Material	QTY.
1	AWF-01-03-02-02	CAFAA0 HOLDING PLATE	Stainless Steel (ferritic)	1
2	AWF-11-29	Clevis Pin, 1/2" Diameter, 1-1/2" Usable Length	18-8 Stainless Steel	2

ITEM NO.	PartNo	Description	Material	QTY.
1	AWF-01-03-02-03	CDAA00 HOLDING PLATE	Stainless Steel (ferritic)	1
2	AWF-11-30	Clevis Pin, 3/8" Diameter, 2-1/16" Usable Length	18-8 Stainless Steel	2

ITEM NO.	PartNo	Description	Material	QTY.
1	AWF-01-03-02-04	CBBTD0 HOLDING PLATE	Stainless Steel (ferritic)	1
2	AWF-11-31	Clevis Pin, 7/16" Diameter, 1-9/16" Usable Length	18-8 Stainless Steel	2


Price Faculty of Engineering
TITLE:
CAFAA0 CLAMPING SHIM
WELDING FIXTURE
SIZE B
DWG. NO. AWF-01-03-03
REV 0
SCALE: 1:2
WEIGHT:
SHEET 4 OF 11
MATERIAL Plain Carbon Steel
FINISH
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
INTERPRET GD&T AS PER: ASME Y14.5-1994
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
DRAWN
CHECKED
COMMENTS:
NAME
DATE
.31
.46
.31
5.08
3.39
.98
SOLIDWORKS Educational Product. For Instructional Use Only.


ITEM NO. | PART NUMBER | QTY.
1 | ZT-CDAA00 | 1
HOLES USED FOR ALIGNMENT PINS
ITEM NO. | PART NUMBER | QTY.
1 | ZT-CCETE0 | 1
HOLES USED FOR ALIGNMENT PINS
ITEM NO. | PART NUMBER | QTY.
1 | ZT-CAFAA0 | 1
HOLES USED FOR ALIGNMENT PINS
ITEM NO. | PART NUMBER | QTY.
1 | ZT-CBBTD0 | 1
HOLES USED FOR ALIGNMENT PINS
Price Faculty of Engineering
TITLE:
ALIGNMENT PIN LOCATIONS
WELDING FIXTURE
SIZE B
DWG. NO.
REV 0
SCALE: 1:5
WEIGHT:
SHEET 5 OF 11
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
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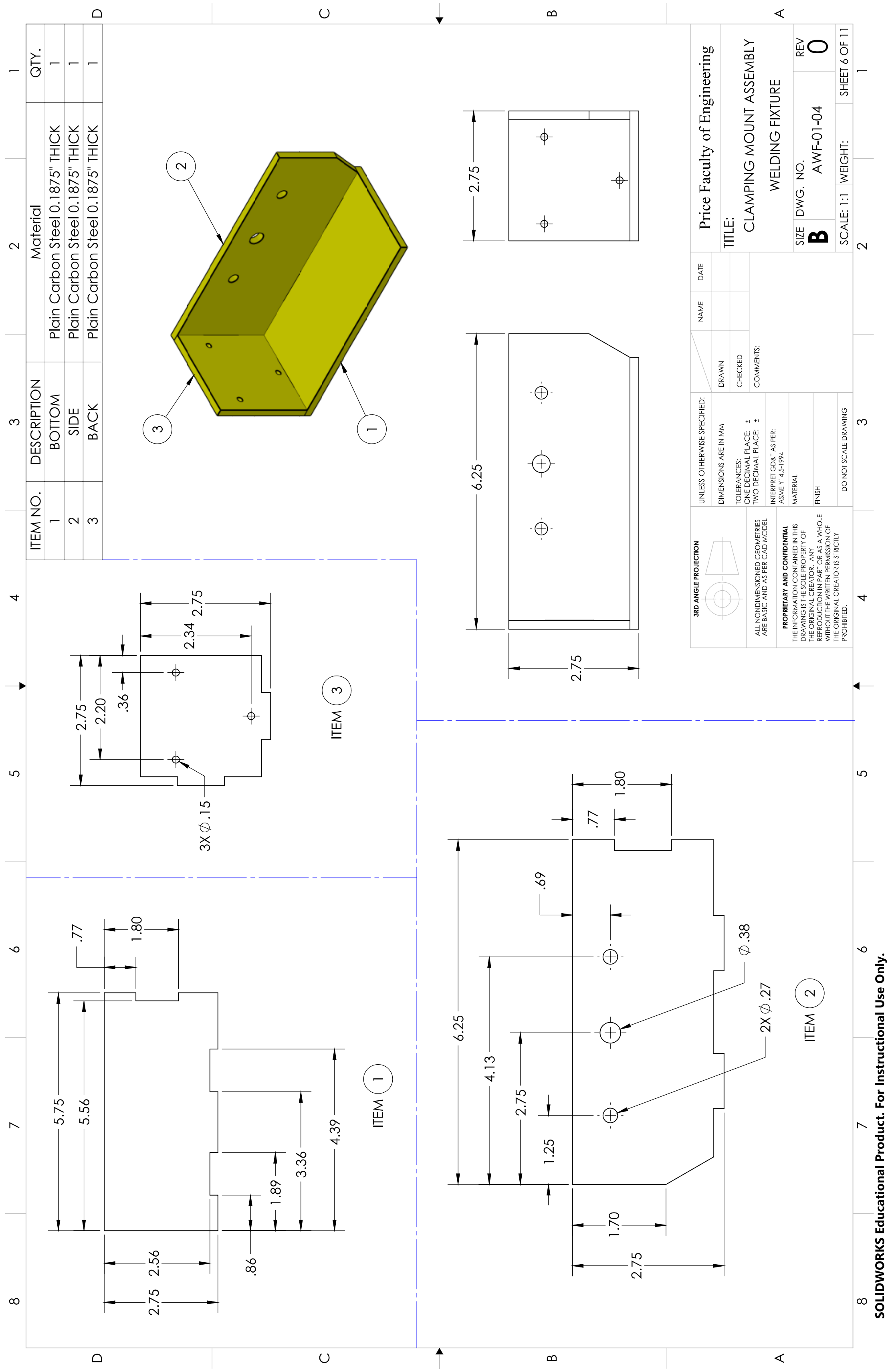
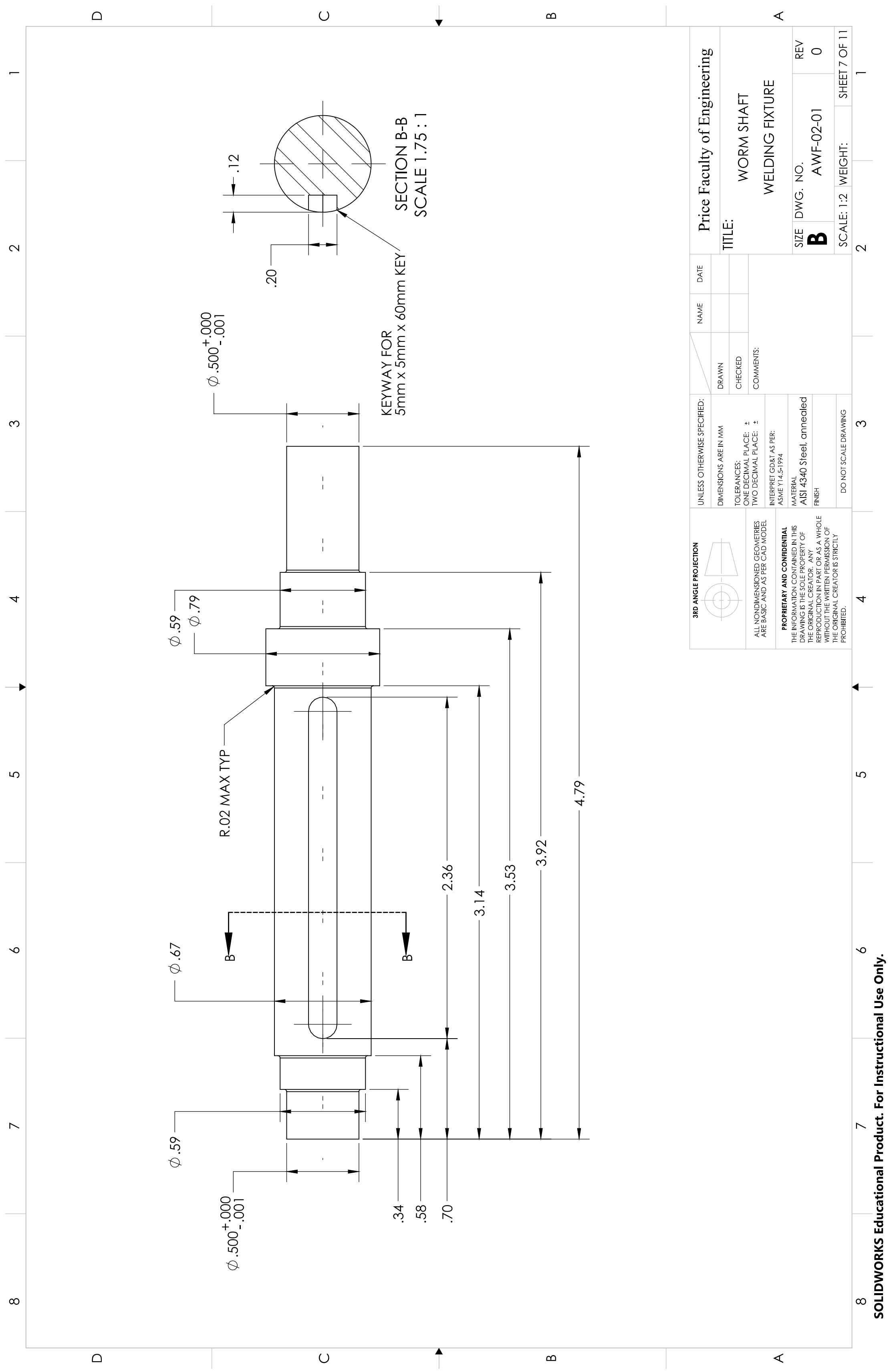

ITEM NO. | DESCRIPTION | Material | QTY.
1 | BOTTOM | Plain Carbon Steel 0.1875" THICK | 1
2 | SIDE | Plain Carbon Steel 0.1875" THICK | 1
3 | BACK | Plain Carbon Steel 0.1875" THICK | 1
ITEM 1
ITEM 2
ITEM 3
3X ⌀.15
2X ⌀.27
⌀.38
Price Faculty of Engineering
TITLE:
CLAMPING MOUNT ASSEMBLY
WELDING FIXTURE
SIZE B
DWG. NO. AWF-01-04
REV 0
SCALE: 1:1
WEIGHT:
SHEET 6 OF 11
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
DRAWN
CHECKED
COMMENTS:
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
SOLIDWORKS Educational Product. For Instructional Use Only.


SECTION B-B
SCALE 1.75 : 1
.12
.20
KEYWAY FOR
5mm x 5mm x 60mm KEY
Ø.500+.000 -.001
Ø.59
Ø.79
R.02 MAX TYP
Ø.67
Ø.59
Ø.500+.000 -.001
.34
.58
.70
2.36
3.14
3.53
3.92
4.79
B
B
Price Faculty of Engineering
TITLE:
WORM SHAFT
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-02-01
REV
0
SCALE: 1:2
WEIGHT:
SHEET 7 OF 11
DRAWN
CHECKED
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
AISI 4340 Steel, annealed
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES
ARE BASIC AND AS PER CAD MODEL
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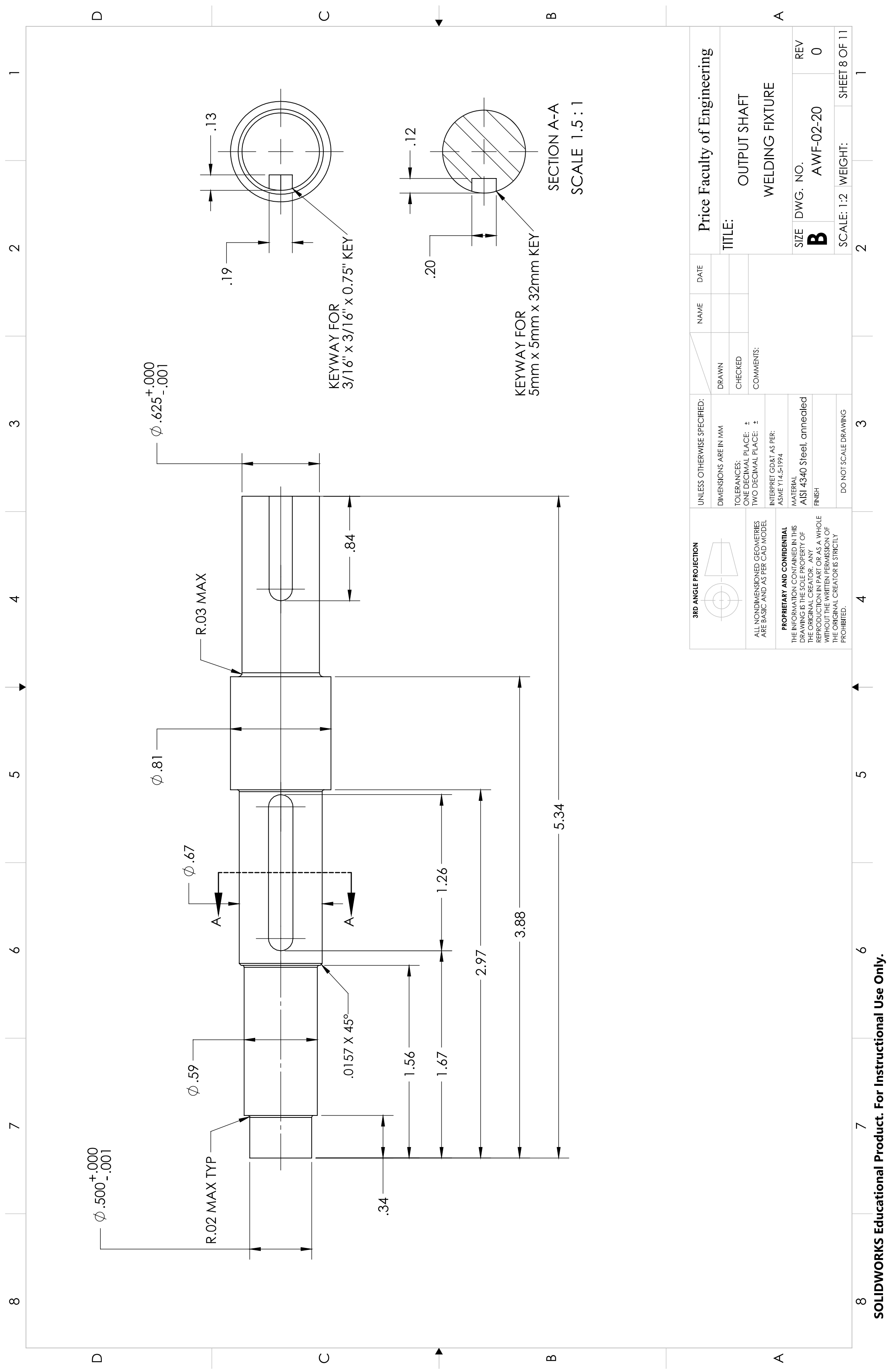
Price Faculty of Engineering
TITLE:
OUTPUT SHAFT
WELDING FIXTURE
SIZE B
DWG. NO. AWF-02-20
REV 0
SCALE: 1:2
WEIGHT:
SHEET 8 OF 11
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
AISI 4340 Steel, annealed
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
SECTION A-A
SCALE 1.5 : 1
KEYWAY FOR 3/16" x 3/16" x 0.75" KEY
KEYWAY FOR 5mm x 5mm x 32mm KEY
Ø.625 +.000 -.001
Ø.500 +.000 -.001
Ø.81
Ø.67
Ø.59
R.03 MAX
R.02 MAX TYP
.0157 X 45°
.13
.19
.12
.20
.84
1.26
1.56
1.67
2.97
3.88
5.34
.34
A
A
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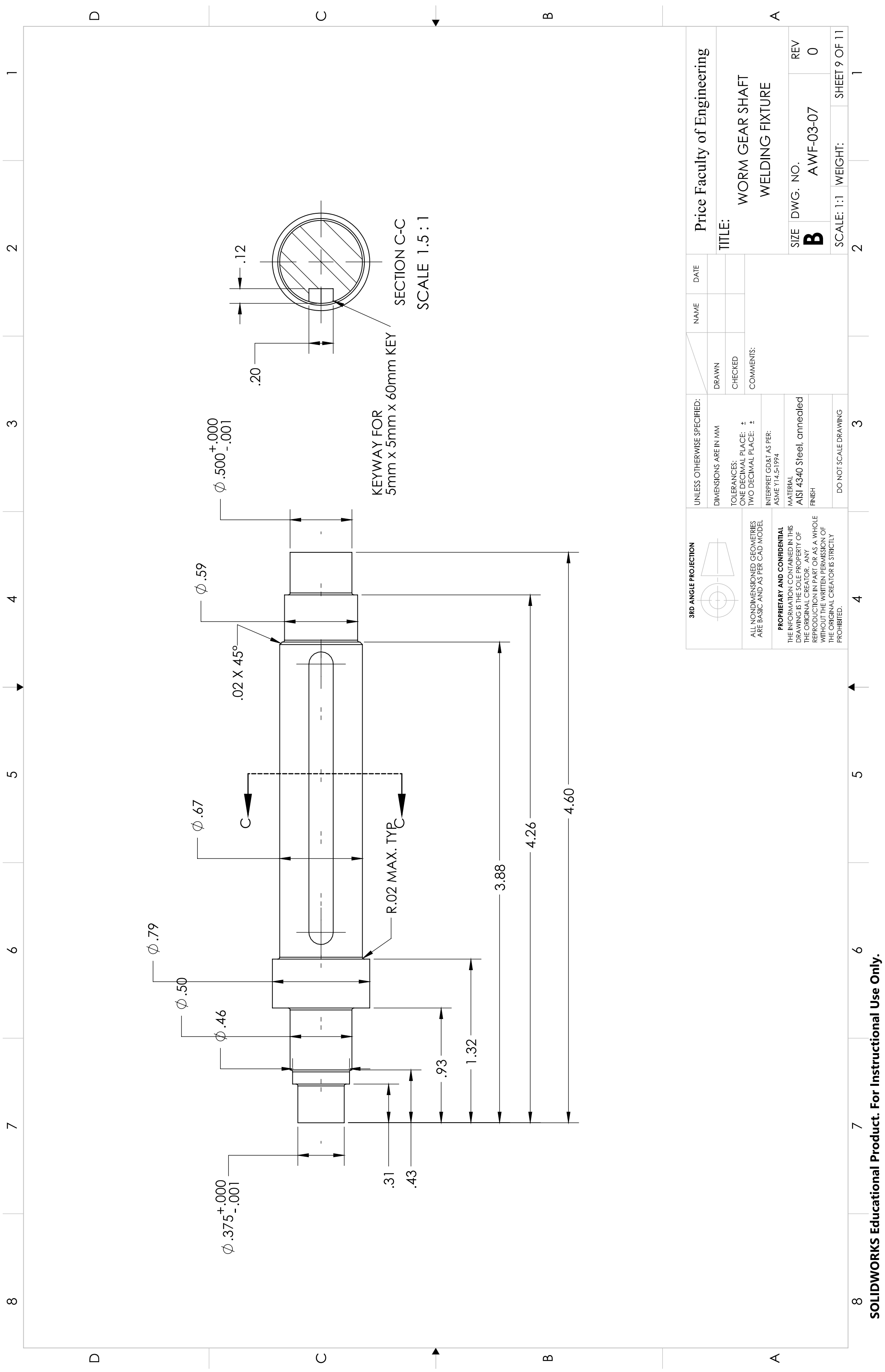
Price Faculty of Engineering
TITLE:
WORM GEAR SHAFT
WELDING FIXTURE
SIZE B
DWG. NO. AWF-03-07
REV 0
SCALE: 1:1
WEIGHT:
SHEET 9 OF 11
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
AISI 4340 Steel, annealed
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
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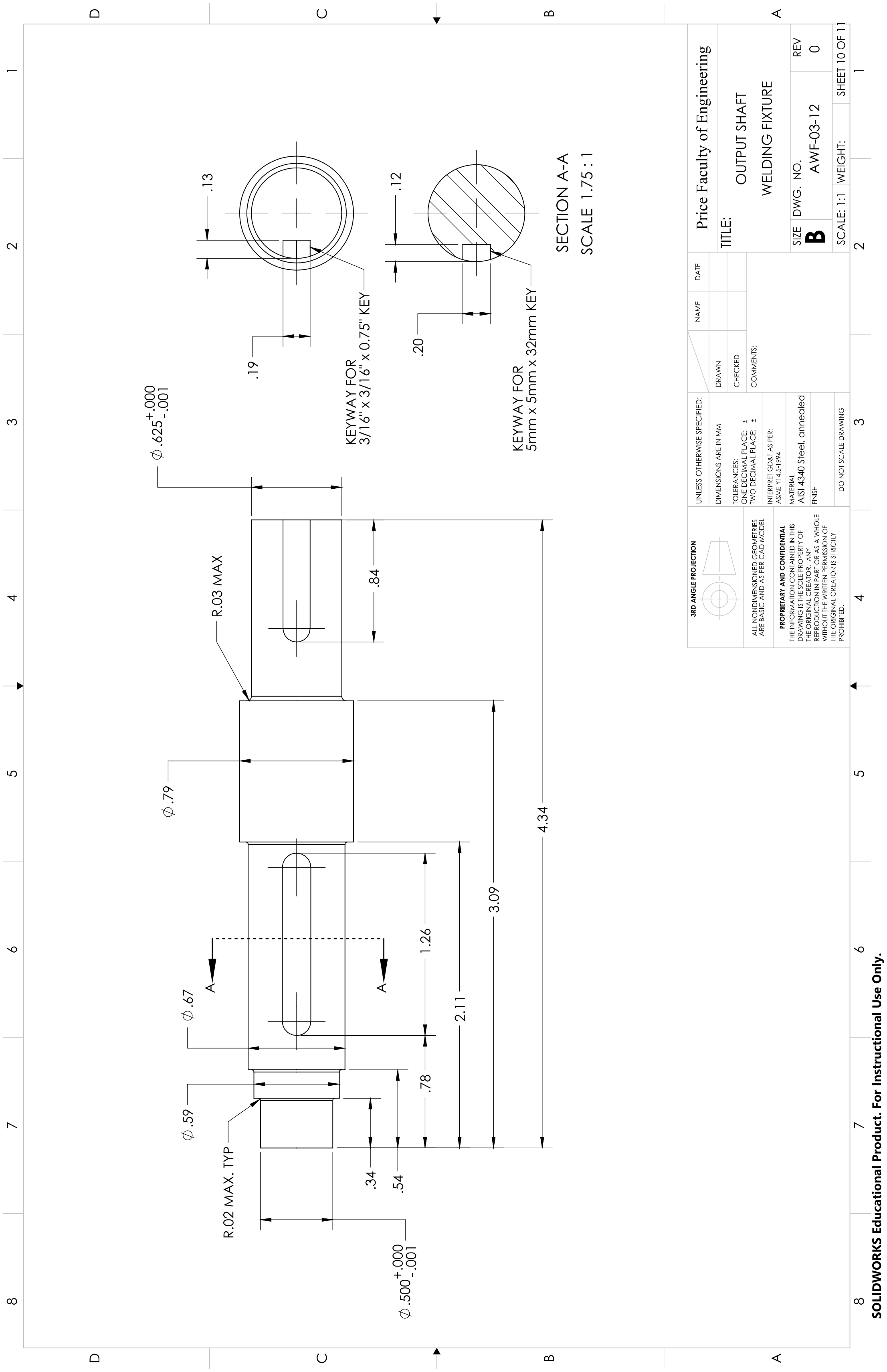
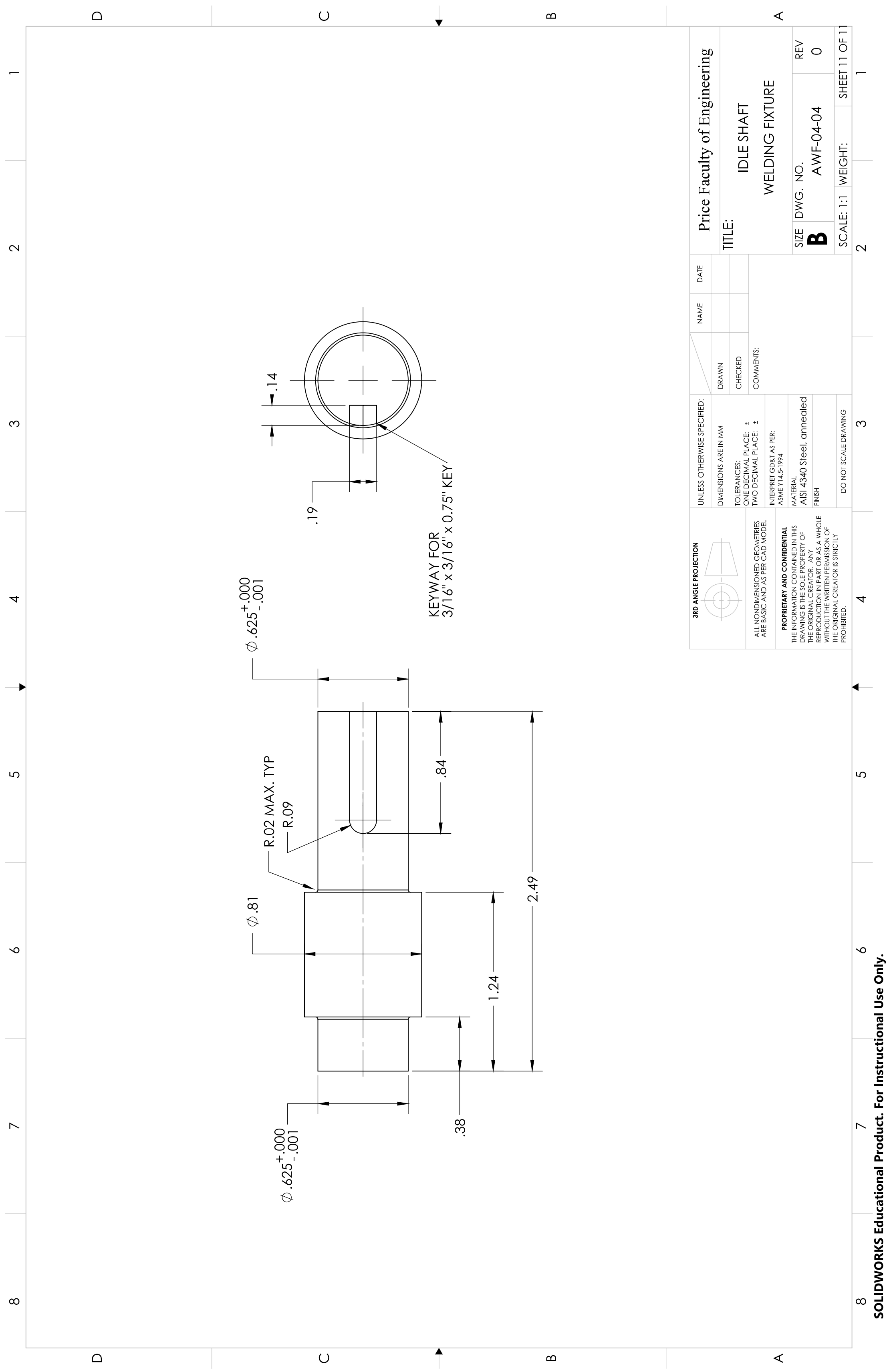
SECTION C-C
SCALE 1.5 : 1
KEYWAY FOR
5mm x 5mm x 60mm KEY
.12
.20
Ø .500 +.000 -.001
Ø .59
.02 X 45°
Ø .67
R.02 MAX. TYP.
Ø .79
Ø .50
Ø .46
Ø .375 +.000 -.001
.31
.43
.93
1.32
3.88
4.26
4.60
SOLIDWORKS Educational Product. For Instructional Use Only.


SECTION A-A
SCALE 1.75 : 1
KEYWAY FOR
3/16" x 3/16" x 0.75" KEY
KEYWAY FOR
5mm x 5mm x 32mm KEY
R.03 MAX
R.02 MAX. TYP
Price Faculty of Engineering
TITLE:
OUTPUT SHAFT
WELDING FIXTURE
SIZE B
DWG. NO. AWF-03-12
REV 0
SCALE: 1:1
WEIGHT:
SHEET 10 OF 11
MATERIAL
AISI 4340 Steel, annealed
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
SOLIDWORKS Educational Product. For Instructional Use Only.



Price Faculty of Engineering
TITLE:
IDLE SHAFT
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-04-04
REV
0
SCALE: 1:1
WEIGHT:
SHEET 11 OF 11
NAME
DATE
DRAWN
CHECKED
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
AISI 4340 Steel, annealed
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
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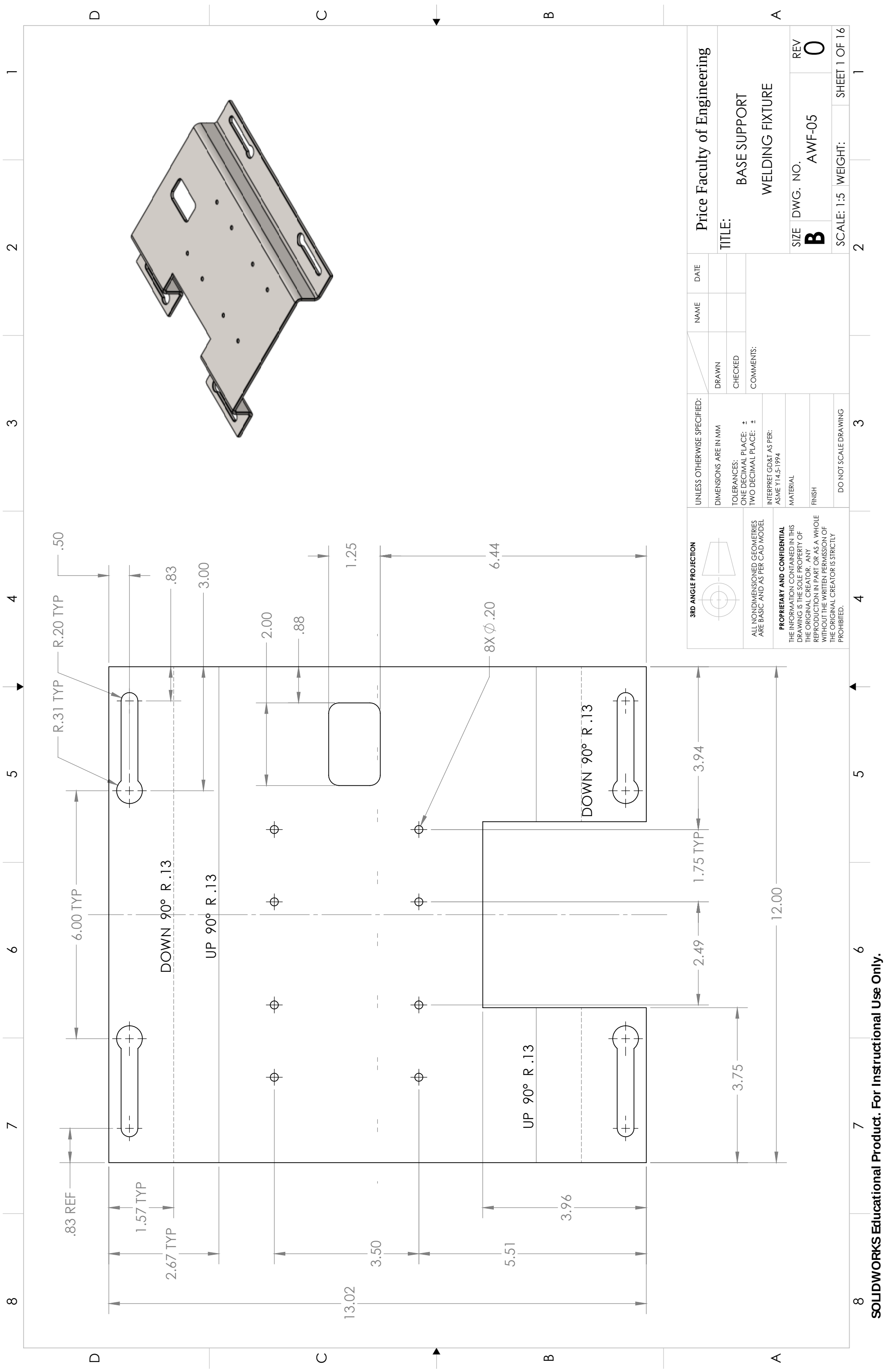
.14
.19
KEYWAY FOR
3/16" x 3/16" x 0.75" KEY
⌀.625 +.000 -.001
R.02 MAX. TYP
R.09
.84
⌀.81
2.49
1.24
.38
⌀.625 +.000 -.001
SOLIDWORKS Educational Product. For Instructional Use Only.


Price Faculty of Engineering
TITLE:
BASE SUPPORT
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-05
REV
0
SCALE: 1:5
WEIGHT:
SHEET 1 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
DRAWN
CHECKED
COMMENTS:
NAME
DATE
MATERIAL
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
R.31 TYP
R.20 TYP
.50
.83
3.00
2.00
.88
1.25
6.44
8X ∅.20
DOWN 90° R.13
UP 90° R.13
DOWN 90° R.13
UP 90° R.13
6.00 TYP
3.94
1.75 TYP
2.49
12.00
3.75
.83 REF
1.57 TYP
2.67 TYP
3.50
5.51
3.96
13.02
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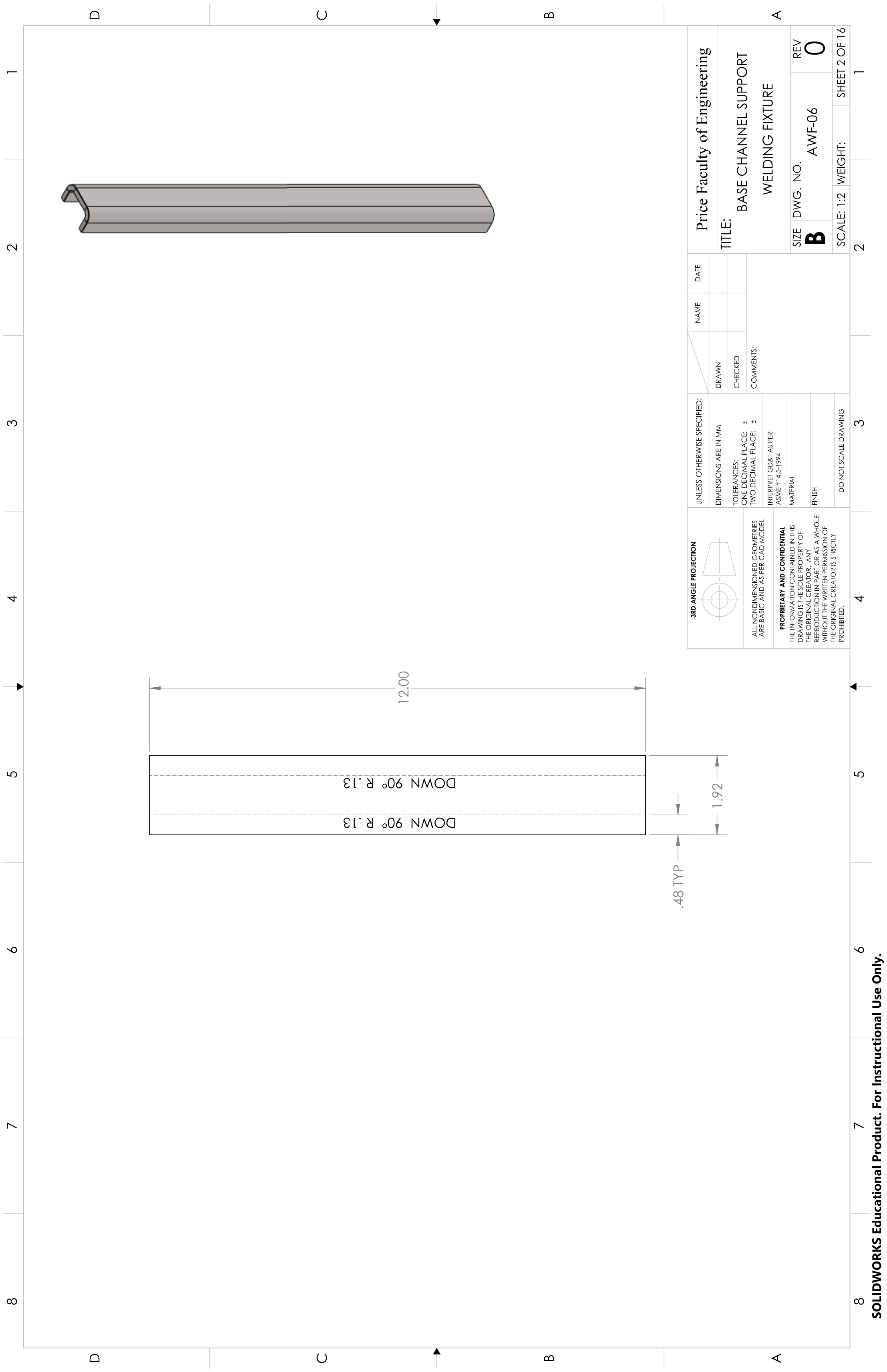
Price Faculty of Engineering
TITLE:
BASE CHANNEL SUPPORT
WELDING FIXTURE
SIZE B
DWG. NO.
AWF-06
REV 0
SCALE: 1:2
WEIGHT:
SHEET 2 OF 16
12.00
DOWN 90° R .13
DOWN 90° R .13
1.92
.48 TYP
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
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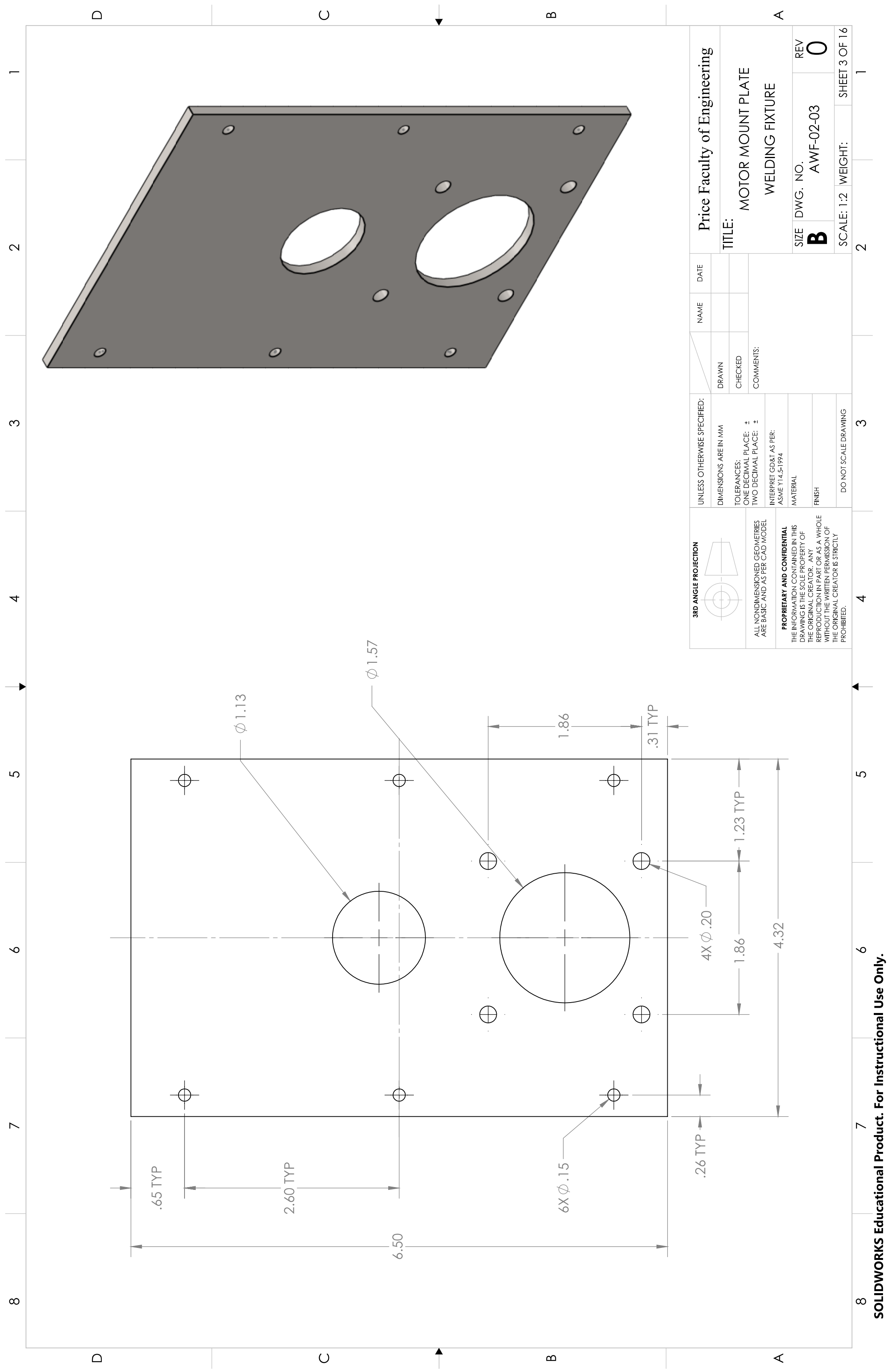

Price Faculty of Engineering
TITLE:
MOTOR MOUNT PLATE
WELDING FIXTURE
SIZE B
DWG. NO. AWF-02-03
REV 0
SCALE: 1:2
WEIGHT:
SHEET 3 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
DRAWN
CHECKED
COMMENTS:
NAME
DATE
MATERIAL
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
Ø1.13
Ø1.57
1.86
.31 TYP
1.23 TYP
4X Ø.20
1.86
4.32
.26 TYP
6X Ø.15
.65 TYP
2.60 TYP
6.50
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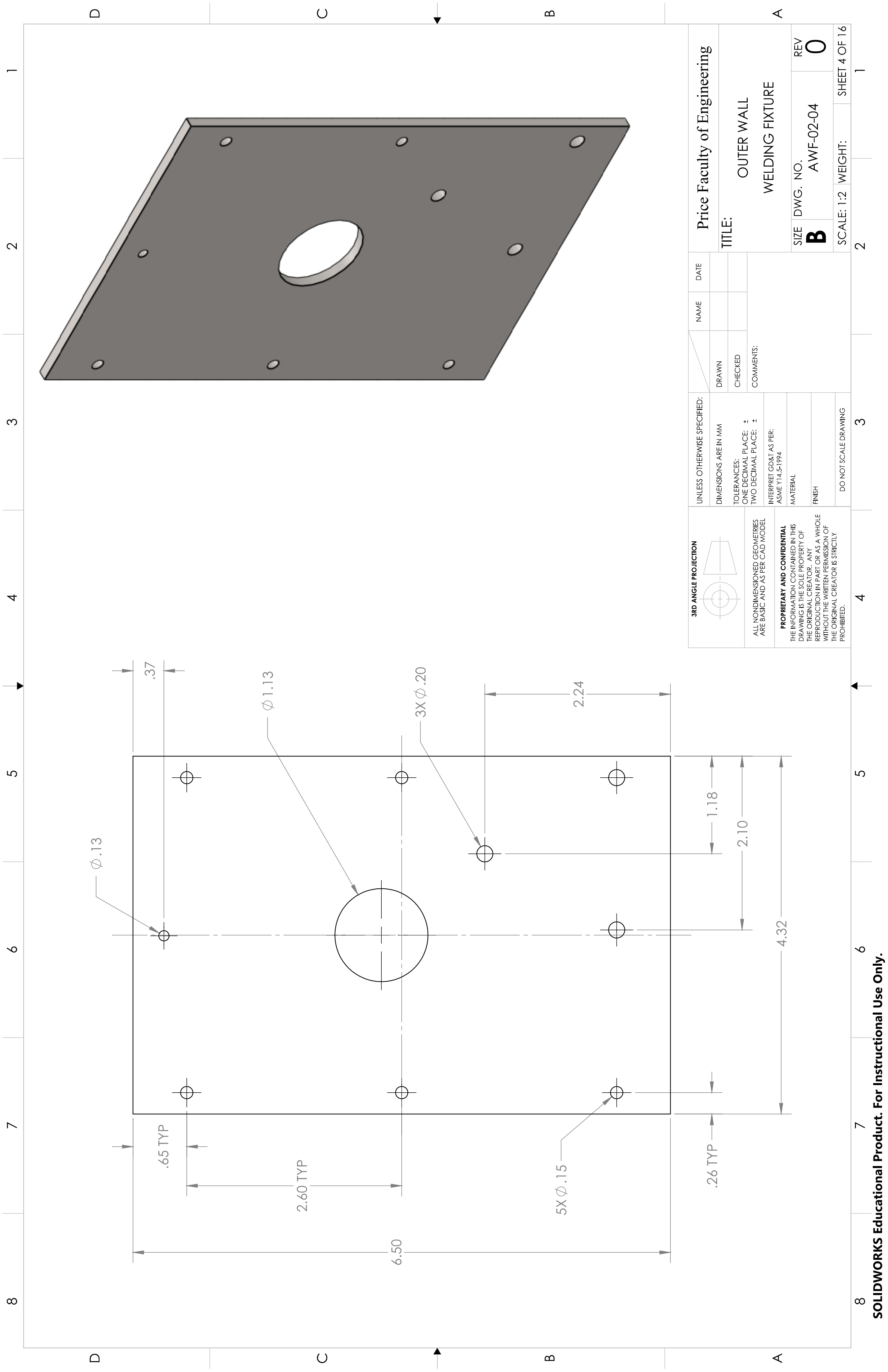

Price Faculty of Engineering
TITLE:
OUTER WALL
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-02-04
REV
0
SCALE: 1:2
WEIGHT:
SHEET 4 OF 16
DRAWN
CHECKED
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
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3RD ANGLE PROJECTION
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.37
Ø1.13
3X Ø.20
2.24
Ø.13
1.18
2.10
4.32
.65 TYP
2.60 TYP
5X Ø.15
.26 TYP
6.50
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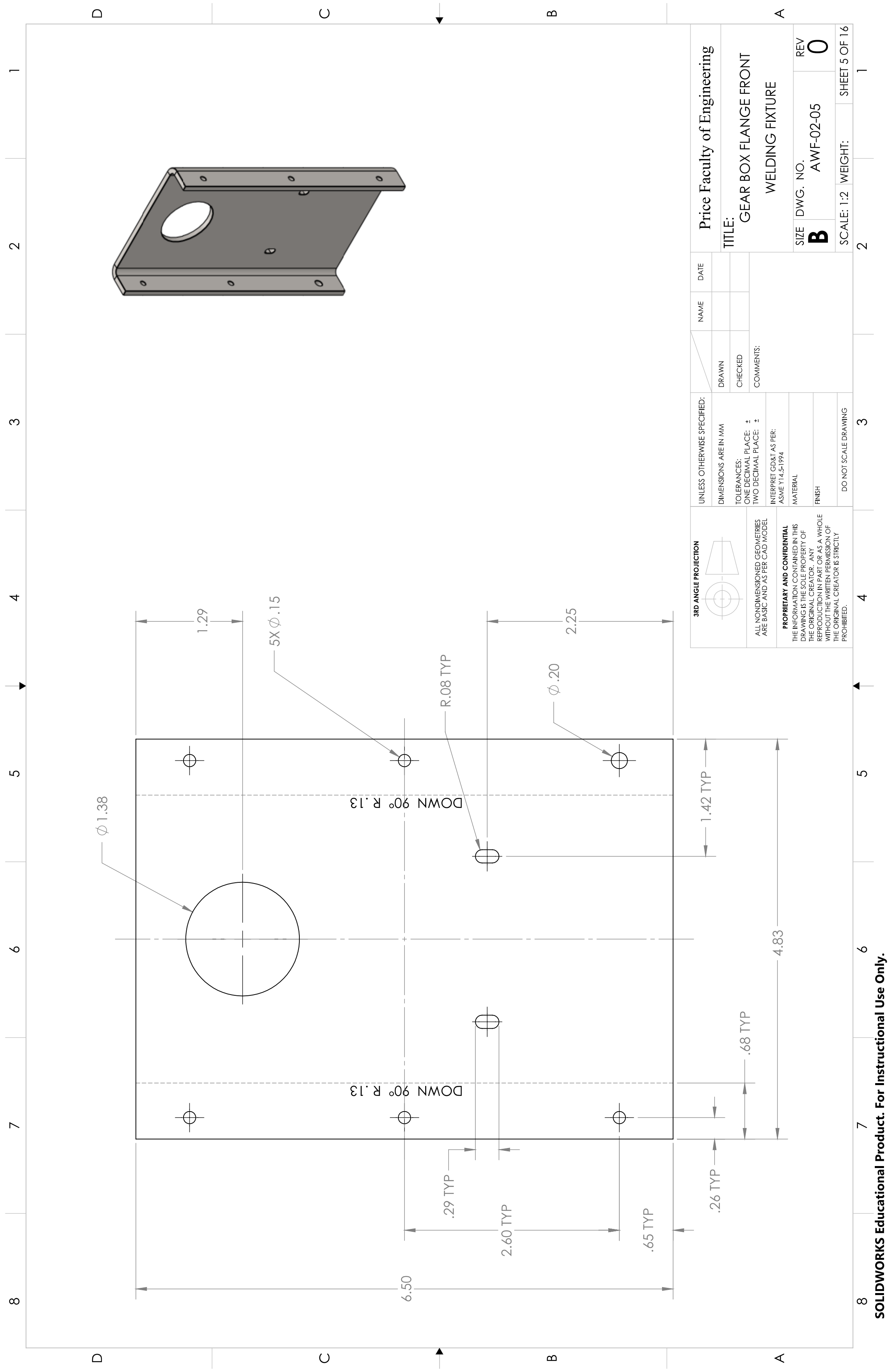
Price Faculty of Engineering
TITLE:
GEAR BOX FLANGE FRONT
WELDING FIXTURE
SIZE B
DWG. NO. AWF-02-05
REV 0
SCALE: 1:2
WEIGHT:
SHEET 5 OF 16
DRAWN
CHECKED
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
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1.29
5X ⌀.15
2.25
R.08 TYP
⌀.20
⌀1.38
DOWN 90° R.13
DOWN 90° R.13
1.42 TYP
4.83
.68 TYP
.29 TYP
.26 TYP
2.60 TYP
.65 TYP
6.50
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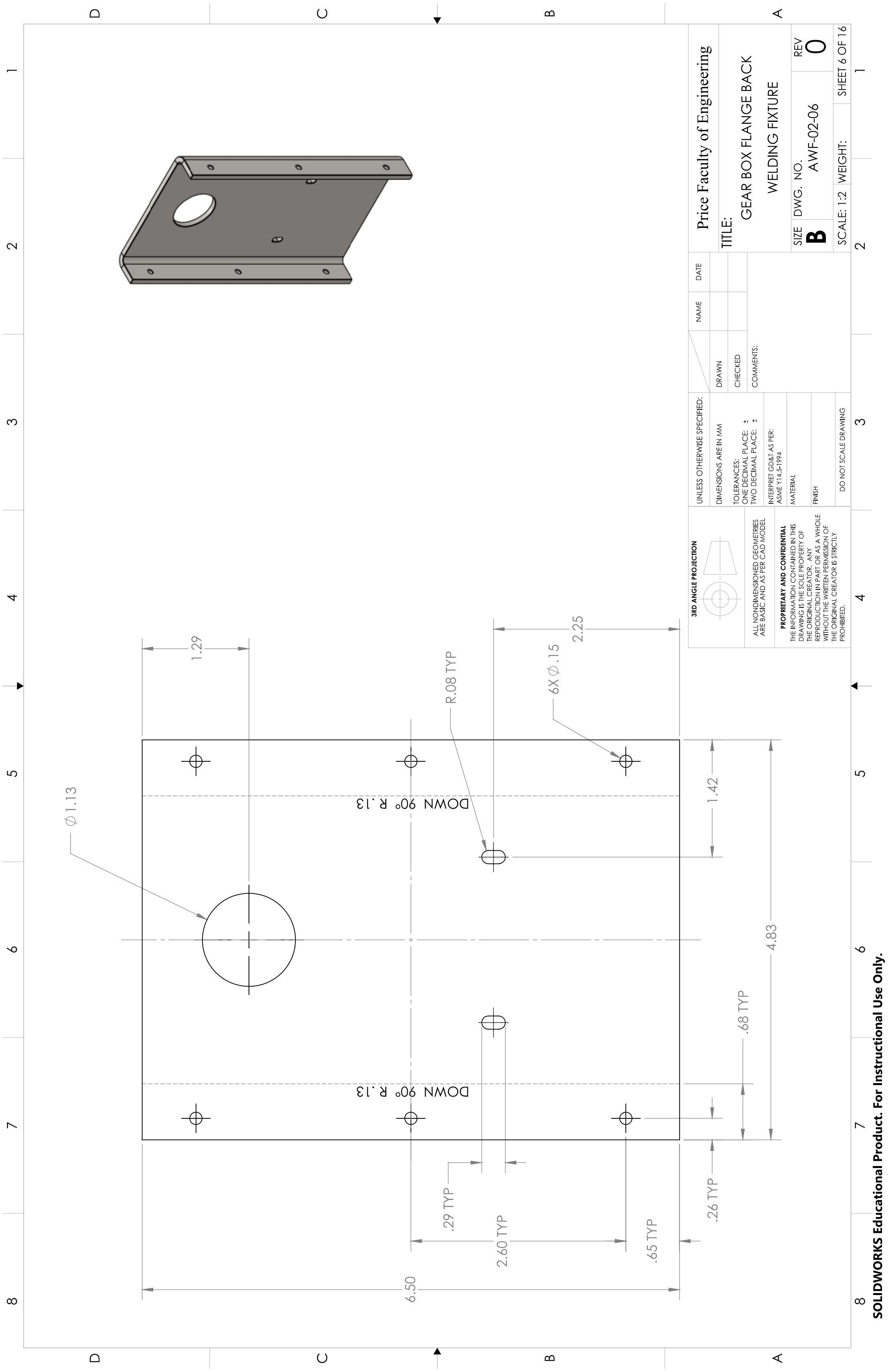
Price Faculty of Engineering
TITLE:
GEAR BOX FLANGE BACK
WELDING FIXTURE
SIZE B
DWG. NO. AWF-02-06
REV 0
SCALE: 1:2
WEIGHT:
SHEET 6 OF 16
NAME
DATE
DRAWN
CHECKED
COMMENTS:
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
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1.29
2.25
R.08 TYP
6X ∅.15
∅1.13
DOWN 90° R.13
DOWN 90° R.13
1.42
4.83
.68 TYP
.26 TYP
.29 TYP
2.60 TYP
.65 TYP
6.50
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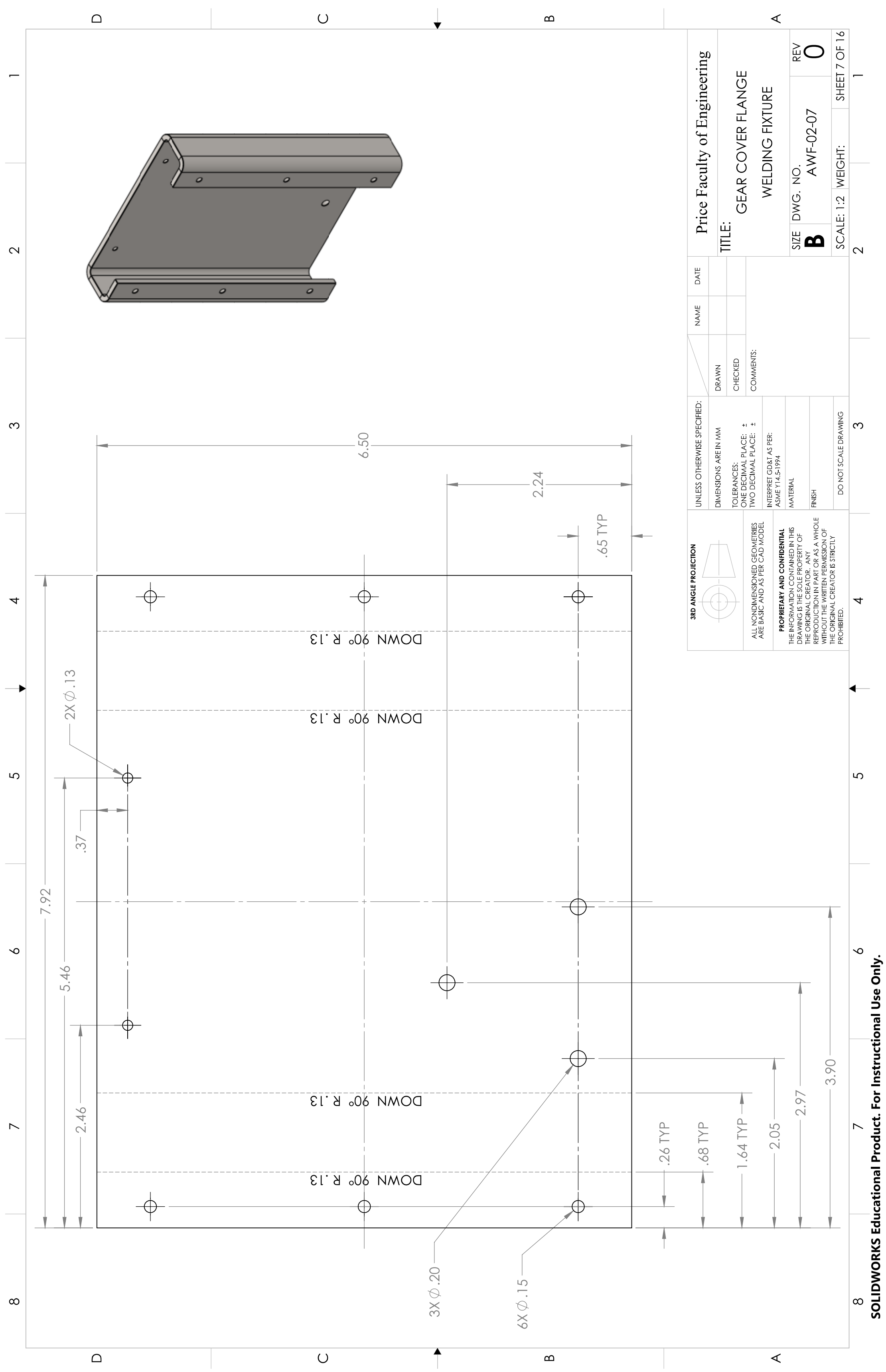
Price Faculty of Engineering
TITLE:
GEAR COVER FLANGE
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-02-07
REV
0
SCALE: 1:2
WEIGHT:
SHEET 7 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
DOWN 90° R .13
DOWN 90° R .13
DOWN 90° R .13
DOWN 90° R .13
6.50
2.24
.65 TYP
2X Ø.13
.37
7.92
5.46
2.46
.26 TYP
.68 TYP
1.64 TYP
2.05
2.97
3.90
3X Ø.20
6X Ø.15
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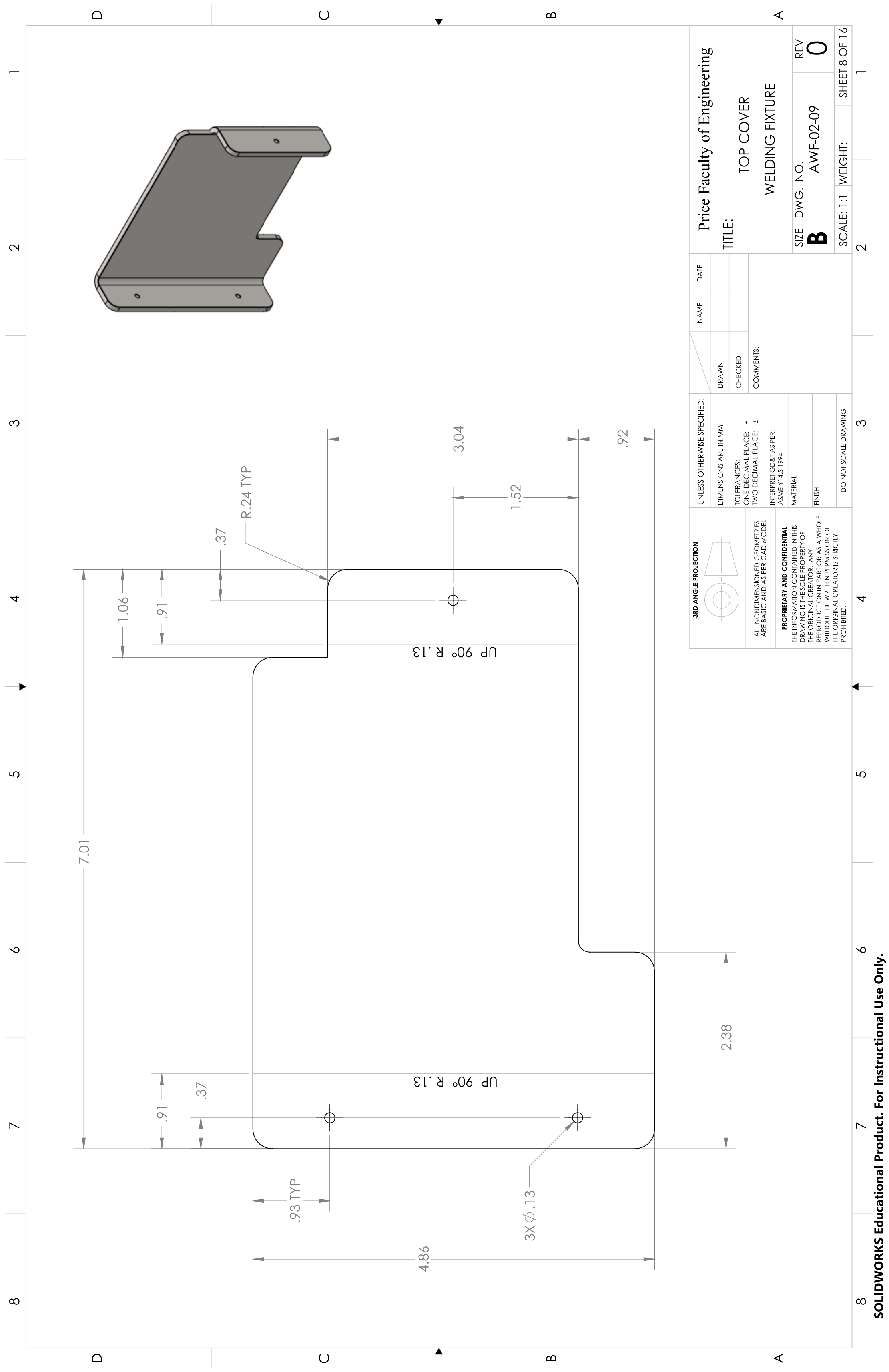
Price Faculty of Engineering
TITLE:
TOP COVER
WELDING FIXTURE
SIZE B
DWG. NO.
AWF-02-09
REV 0
SCALE: 1:1
WEIGHT:
SHEET 8 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
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3.04
.92
1.52
R.24 TYP
.37
1.06
.91
UP 90° R.13
UP 90° R.13
7.01
2.38
.91
.37
.93 TYP
3X ⌀.13
4.86
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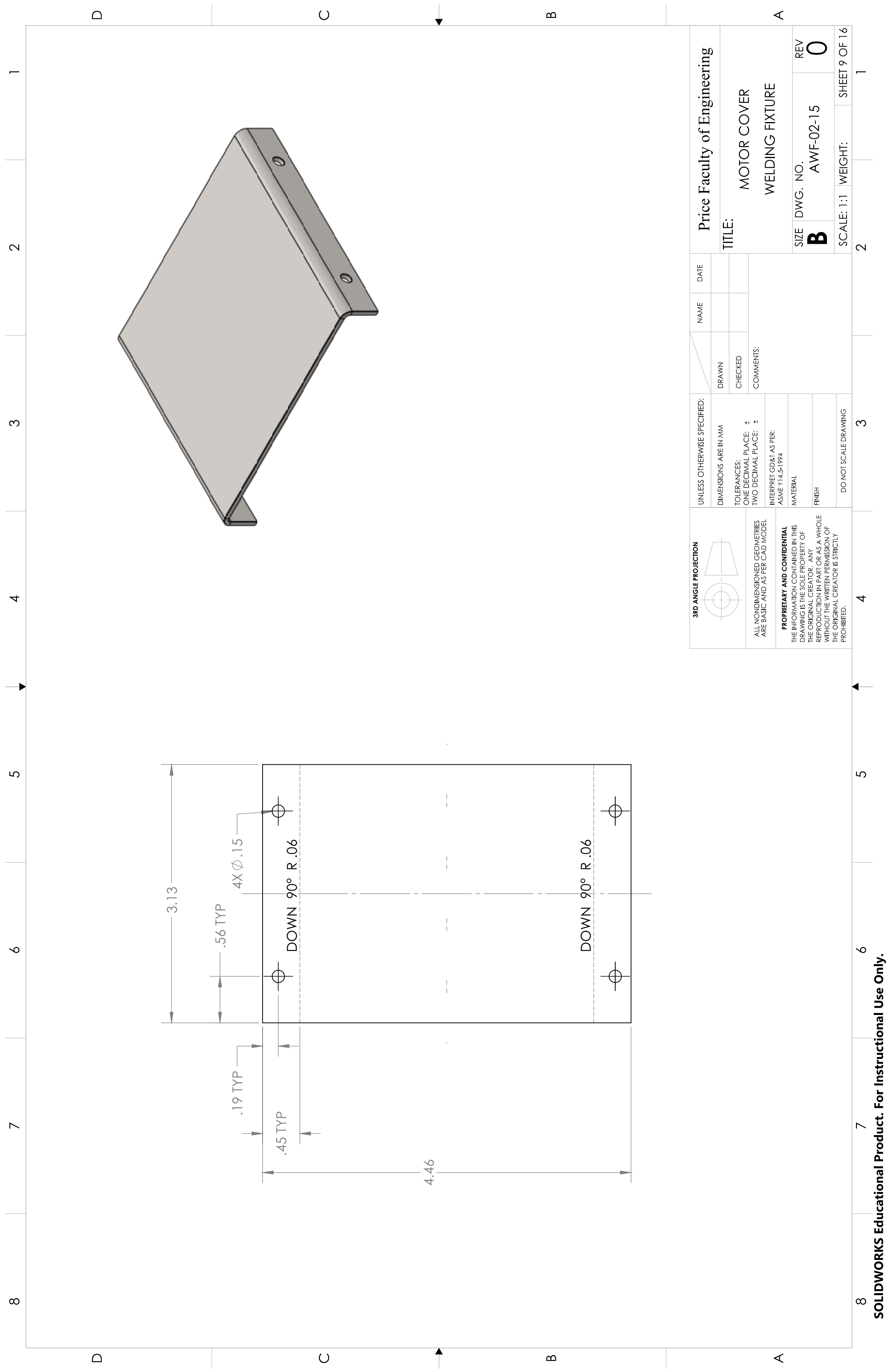
Price Faculty of Engineering
TITLE:
MOTOR COVER
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-02-15
REV
0
SCALE: 1:1
WEIGHT:
SHEET 9 OF 16
UNLESS OTHERWISE SPECIFIED:
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
DO NOT SCALE DRAWING
3.13
.56 TYP
4X ∅.15
DOWN 90° R .06
DOWN 90° R .06
.19 TYP
.45 TYP
4.46
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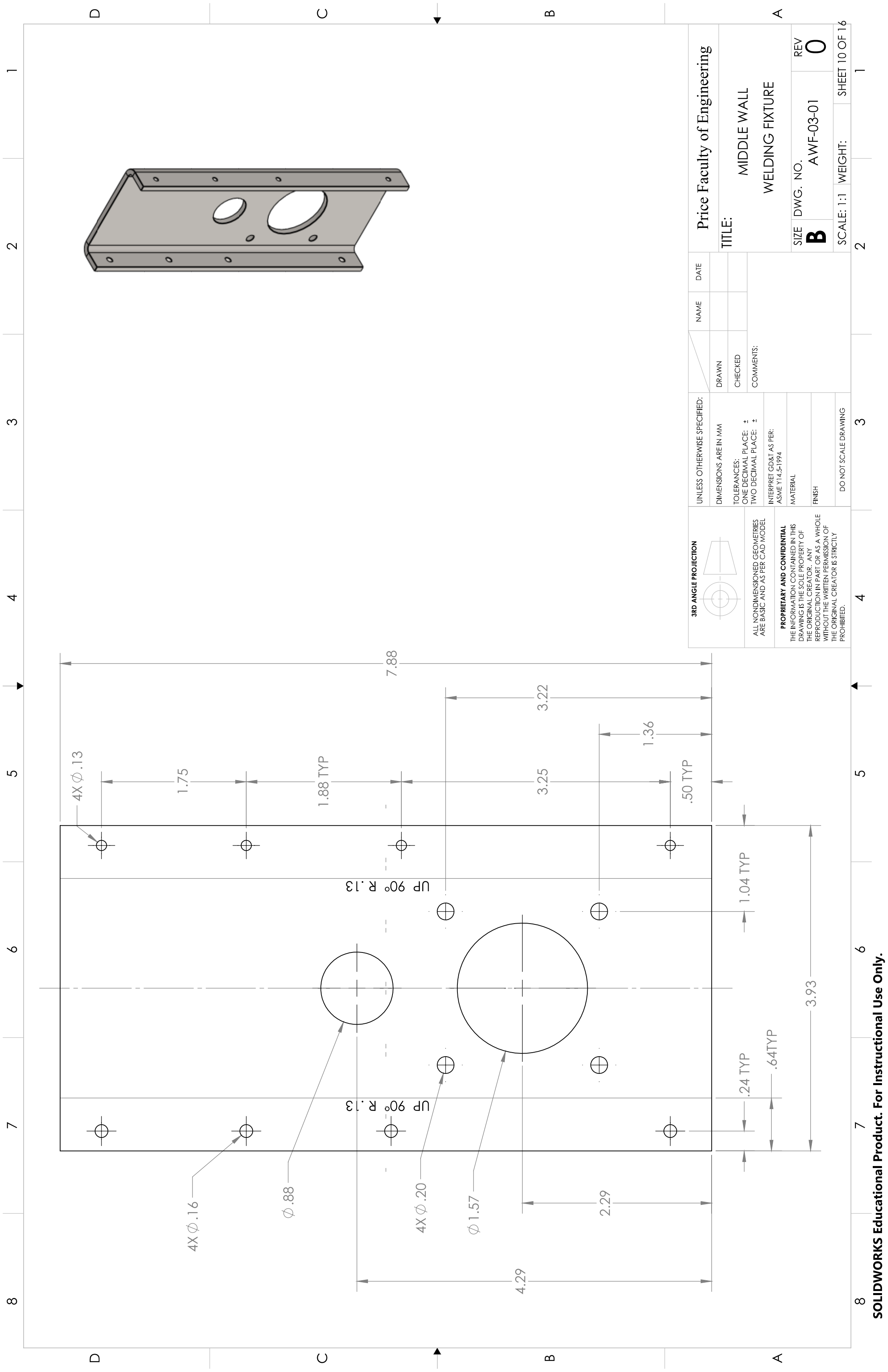
Price Faculty of Engineering
TITLE:
MIDDLE WALL
WELDING FIXTURE
SIZE
B
DWG. NO.
AWF-03-01
REV
0
SCALE: 1:1
WEIGHT:
SHEET 10 OF 16
7.88
3.22
1.36
4X ∅.13
1.75
1.88 TYP
3.25
.50 TYP
UP 90° R .13
1.04 TYP
3.93
.24 TYP
.64TYP
4X ∅.16
∅.88
4X ∅.20
∅1.57
2.29
4.29
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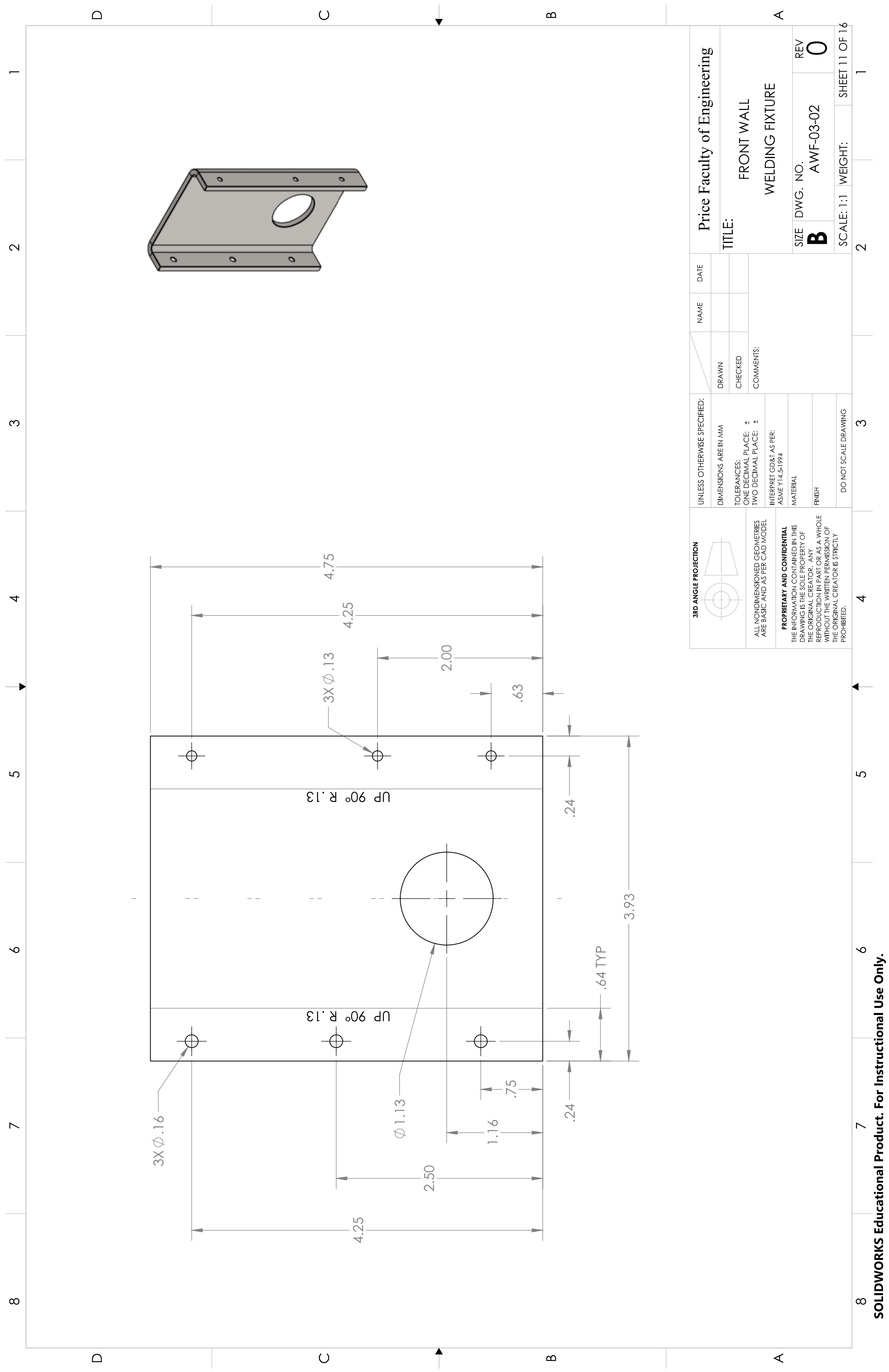

Price Faculty of Engineering
TITLE:
FRONT WALL WELDING FIXTURE
SIZE B
DWG. NO. AWF-03-02
REV 0
SCALE: 1:1
WEIGHT:
SHEET 11 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
DRAWN
CHECKED
COMMENTS:
NAME
DATE
MATERIAL
FINISH
DO NOT SCALE DRAWING
3RD ANGLE PROJECTION
UP 90° R .13
3X ∅.13
3X ∅.16
∅1.13
4.75
4.25
2.00
.63
.24
3.93
.64 TYP
.75
1.16
2.50
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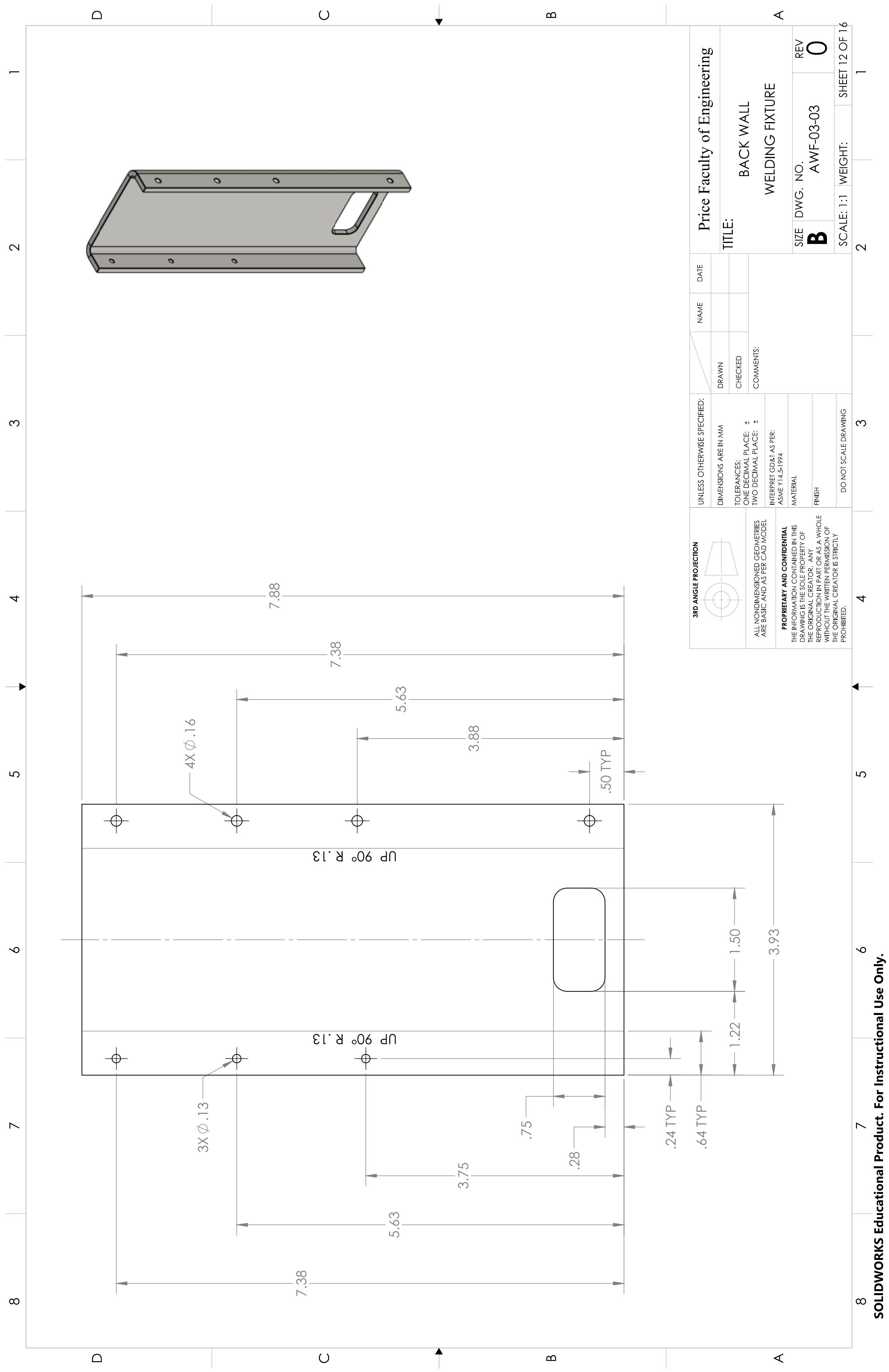
Price Faculty of Engineering
TITLE:
BACK WALL
WELDING FIXTURE
SIZE B
DWG. NO.
AWF-03-03
REV 0
SCALE: 1:1
WEIGHT:
SHEET 12 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
DO NOT SCALE DRAWING
MATERIAL
FINISH
UP 90° R.13
4X Ø.16
3X Ø.13
.50 TYP
.24 TYP
.64 TYP
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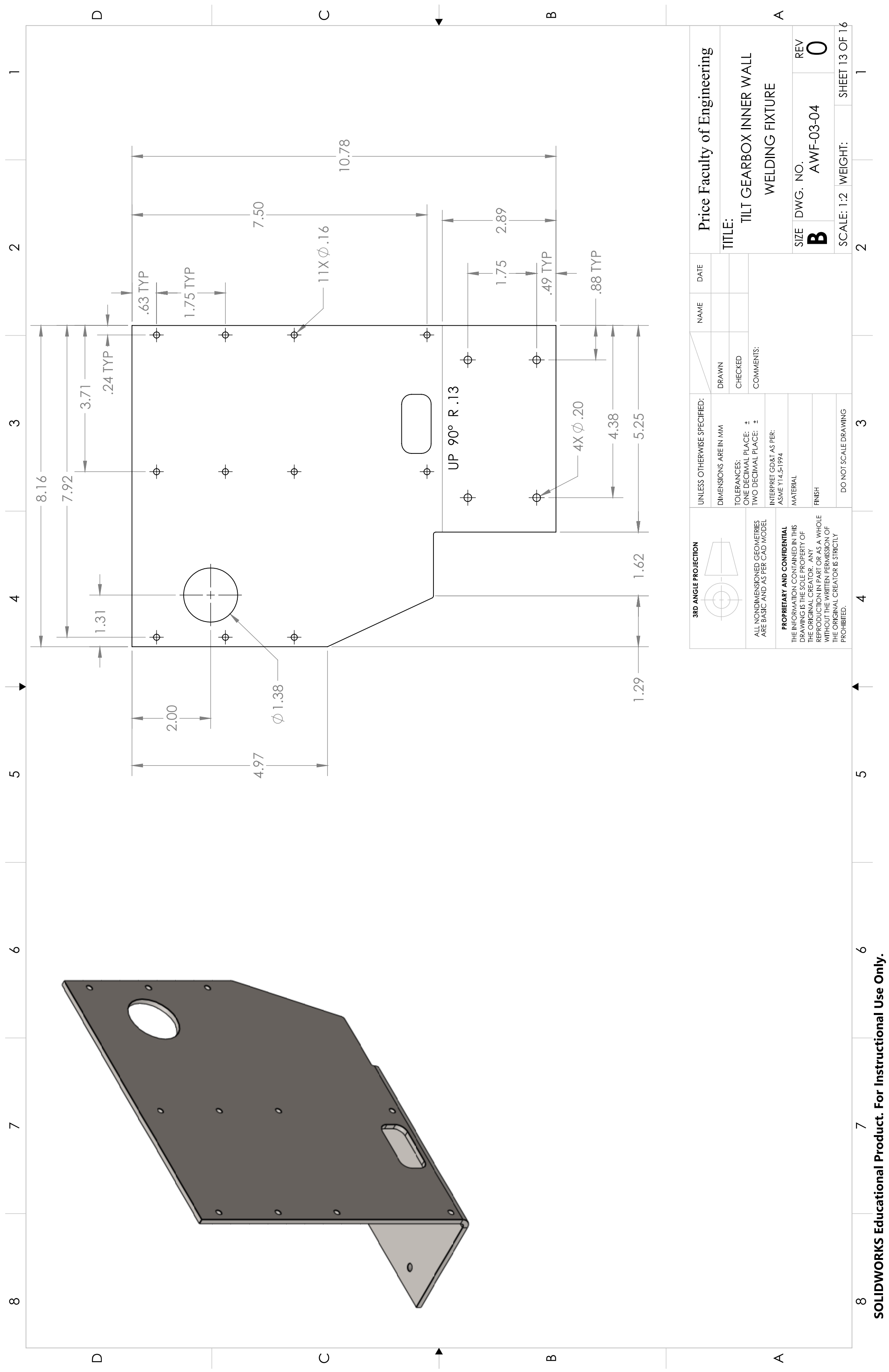
Price Faculty of Engineering
TITLE:
TILT GEARBOX INNER WALL
WELDING FIXTURE
SIZE B
DWG. NO. AWF-03-04
REV 0
SCALE: 1:2
WEIGHT:
SHEET 13 OF 16
UP 90° R .13
11X ⌀.16
4X ⌀.20
⌀1.38
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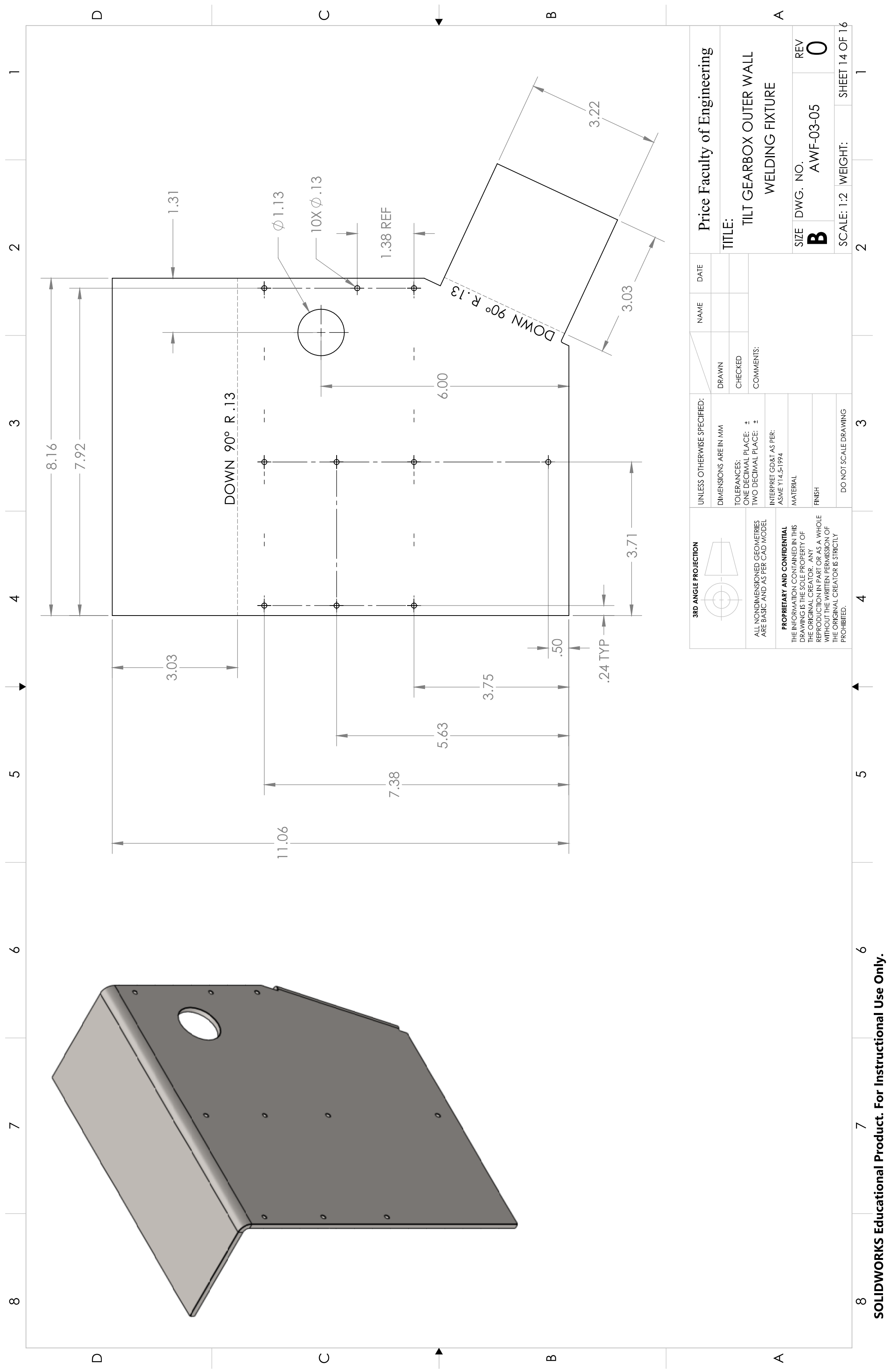
Price Faculty of Engineering
TITLE:
TILT GEARBOX OUTER WALL
WELDING FIXTURE
SIZE B
DWG. NO. AWF-03-05
REV 0
SCALE: 1:2
WEIGHT:
SHEET 14 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER:
ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
COMMENTS:
NAME
DATE
3RD ANGLE PROJECTION
ALL NONDIMENSIONED GEOMETRIES ARE BASIC AND AS PER CAD MODEL
PROPRIETARY AND CONFIDENTIAL
DOWN 90° R .13
Ø1.13
10X Ø.13
1.38 REF
1.31
3.22
3.03
6.00
8.16
7.92
3.71
.50
.24 TYP
3.75
5.63
7.38
11.06
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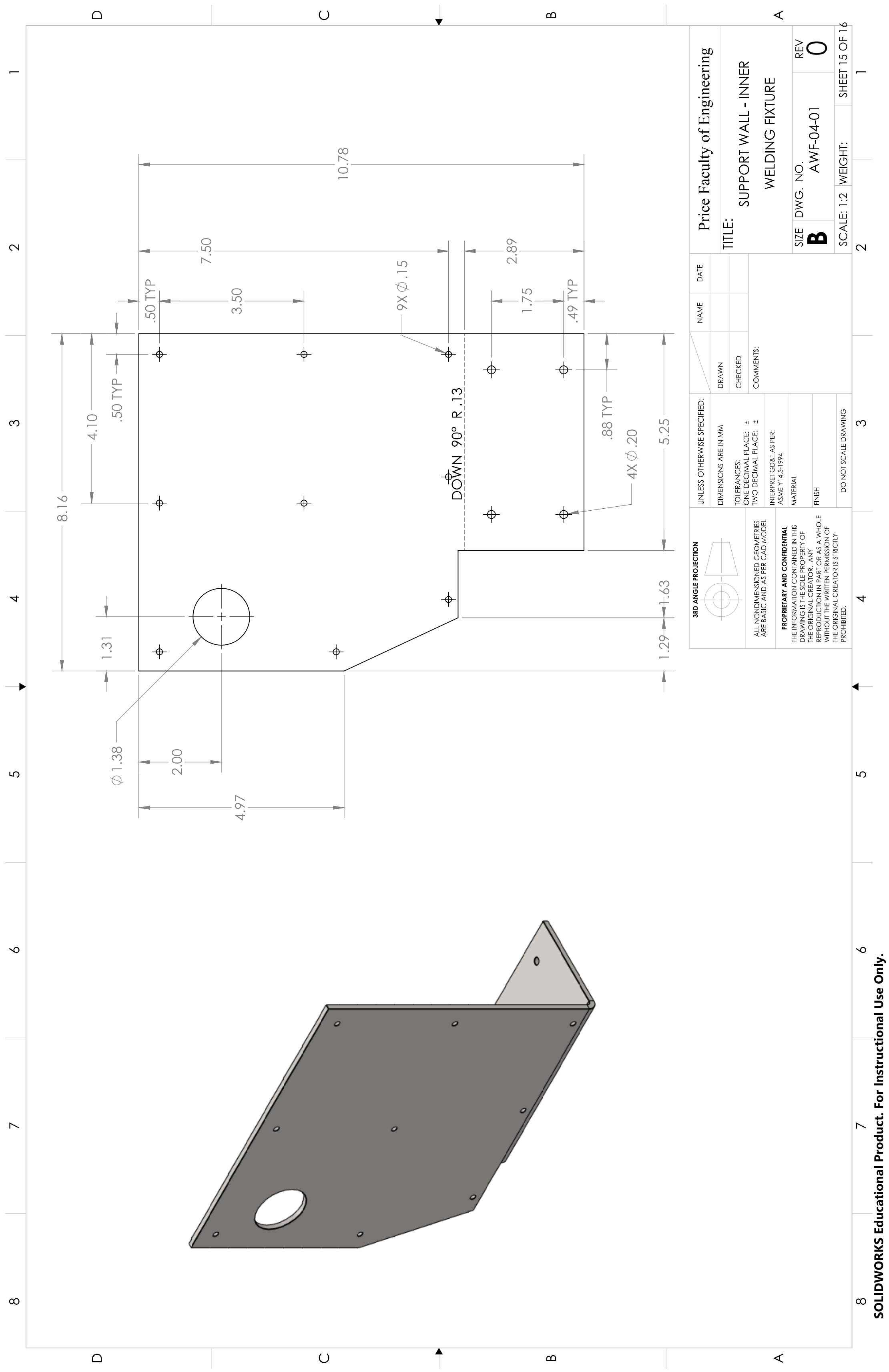
10.78
7.50
2.89
.50 TYP
3.50
9X ⌀.15
1.75
.49 TYP
8.16
4.10
.50 TYP
DOWN 90° R .13
.88 TYP
4X ⌀.20
5.25
1.31
1.63
1.29
⌀1.38
2.00
4.97
Price Faculty of Engineering
TITLE:
SUPPORT WALL - INNER
WELDING FIXTURE
SIZE B
DWG. NO. AWF-04-01
REV 0
SCALE: 1:2
WEIGHT:
SHEET 15 OF 16
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
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COMMENTS:
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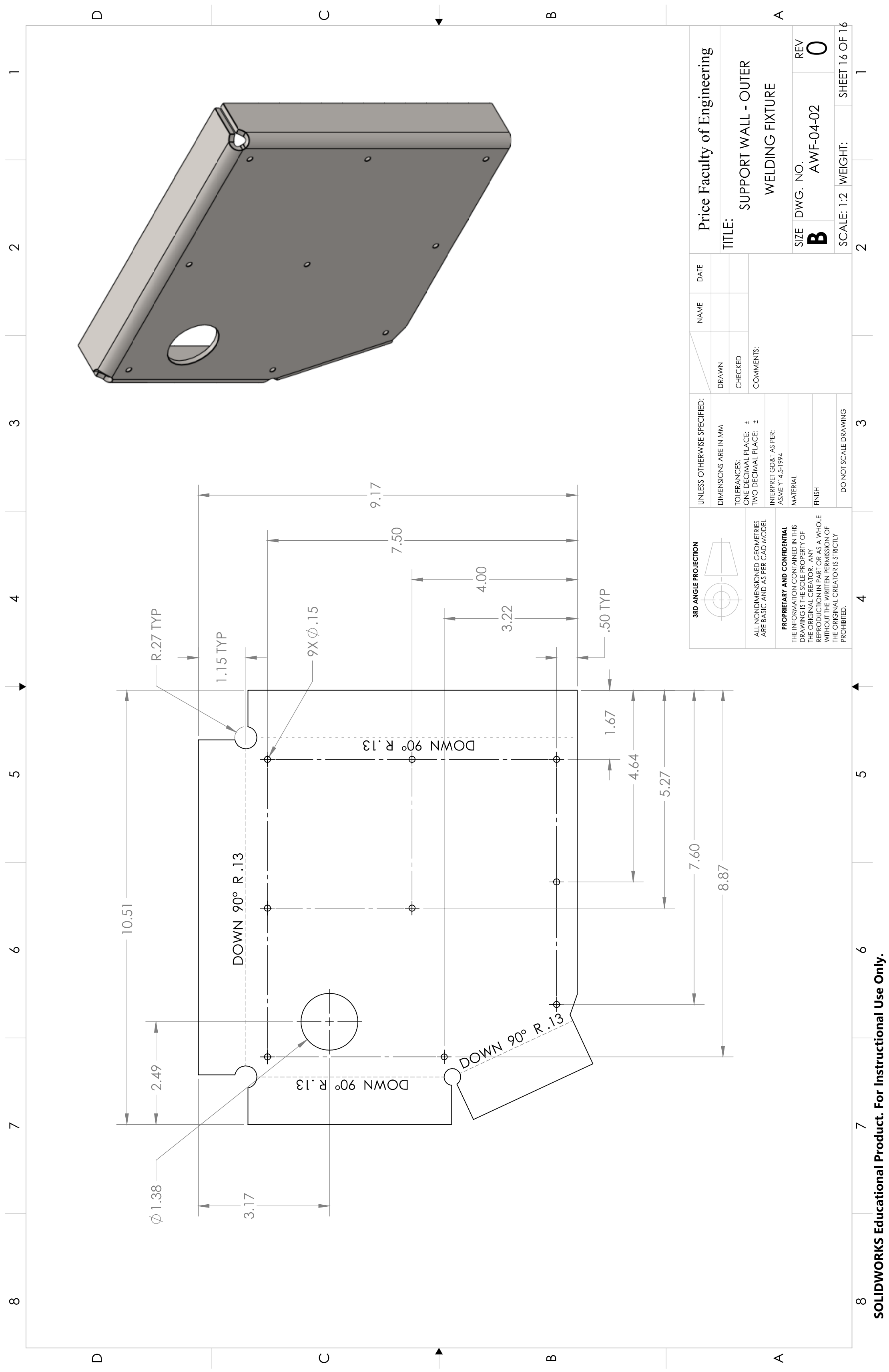
Price Faculty of Engineering
TITLE:
SUPPORT WALL - OUTER
WELDING FIXTURE
SIZE B
DWG. NO. AWF-04-02
REV 0
SCALE: 1:2
WEIGHT:
SHEET 16 OF 16
DRAWN
CHECKED
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MM
TOLERANCES:
ONE DECIMAL PLACE: ±
TWO DECIMAL PLACE: ±
INTERPRET GD&T AS PER: ASME Y14.5-1994
MATERIAL
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9.17
7.50
4.00
3.22
.50 TYP
R.27 TYP
1.15 TYP
9X ⌀.15
DOWN 90° R.13
DOWN 90° R.13
DOWN 90° R.13
DOWN 90° R.13
1.67
4.64
5.27
7.60
8.87
10.51
2.49
⌀1.38
3.17
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