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Dear Dr. Labossiere,

With great gratification, Team 8 would like to submit the final report for the off-piler design project on December 8, 2021. This report represents the work done by Team 8 for the off-piler project on behalf of Graphic Packaging International (GPI) which is a paper-based manufacturer. The report of the off-piler project includes a 3D CAD model of the final design with justification, detailed design process, FMEA, preliminary engineering drawings and estimated costs as sponsored by the client.

The main purpose of this report is to design a device that can transport different sizes of the carton piles to another pallet to prevent the product mixing. This device will be able to withstand a maximum load of 800 pounds and will be adjustable to accommodate different grooves gaps on the pallet. The final report comprised of the problem statement with specified client needs, the concept generation methodology along with the client input and the analysis of the final design concept. This report includes the manufacturing process to build the off-piler with the engineering drawings specifying the details of the final design.

The team would therefore acknowledge the help received from Dr. Paul Labossiere, the project sponsor Graphic Packaging International, the representatives from Graphic Packaging International, technical communication specialist Aidan Topping, all advisors and teaching assistants, and especially Vern Campbell. Please let us know if you have any concerns or questions.

Yours truly,

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Phase III: Final Project Report
Carton Off-Piler Design

MECH 4860: Engineering Design

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Executive summary

Graphic Packaging International (GPI) has tasked Team 8 with designing a carton off-piler device capable of accommodating varying pallet groove configurations to improve the current carton off-piling process. Pallets with different carton styles are required to be separated to prevent product mixing. The current process utilizes a modified hand truck with fixed loading arm width which limits both the size and weight of carton piles which can be unloaded and offloaded. Therefore, GPI aims to improve the process by accommodating all possible pallet groove configurations while reducing the manual operator input and increasing safety.

Based on team brainstorming and client input, the concept development phase involved generating concepts for four individual design subcomponents of the off-piler design including adjustable width, loading, stability, and lift. Careful consideration was taken towards client recommendations and the possibility of using a commercially available material handling solution as a design base to modify, decreasing cost and complexity.

The final design concept to proceed for Phase 3 consists of a lead thread rod to adjust the off-piler's width from adjustable width concepts, extended caster wheels to support the maximum load and provide frame stability from loading concepts, a clamp mechanism to secure carton piles during transportation from stability concepts, and a manual hydraulic lift to provide clearance between the carton pile and the pallet from the lift concepts. The concepts selected for Phase 3 are compatible with each other and the decisions were made by considering the client needs and input.

The team performed a design development stage where a base model was selected to start with the final design and this base structure was rated for 880 pounds. The further selected components included the threaded rods for the adjustable width, side plate for the loading mechanism with approximate waist height adjust the width of the off-piler arms, the center support bracket to attach the threads in the center of the design, lifting off-piler arm to load the carton piles, the clamp mechanism for the stability and the hydraulic lift which is already attached to the base structure to lift the carton piles. The selected material for the side plate and center support bracket is 7-gauge carbon steel while for the off-piler arms is 0.5" thick alloy steel.

The team performed numerical and analytical analysis to further justify the material selection and making sure that the design can withstand the maximum load of 800 pounds. The critical safety of factor is 1.94 for the ACME screw which is used for the adjustable width. The final off-piler design can be adjusted within 2.50" to 20.00". The manufacturing process is also included along with the engineering drawings to make sure that the off-piler design can be easily manufactured by the client. FMEA analysis was performed to mitigate the risks or failure of the final design. Braking issues for the whole off-piler design has the highest RPN value of 162 which can be reduced by preliminary testing. The approximate total weight of the full assembly is 218.19 lbs. The cost analysis was also performed, and the approximate total design cost is $5,743.53 which is within the provided budget of $25,000.

The final off-piler design meets all the client needs and specifications identified from Phase 1. The off-piler can be operated from the either vertical or the horizontal rods attached at the back of the base structure. The back wheels are the caster wheels which are used to maneuver the design while the front wheels are fixed and will go under the pallet. The handles attached on the side are used to adjust the width of the off-piler arms and are designed to be around the waist level so that the operator does not have to bend to adjust the width. The clamp is designed in such a manner that the operator can adjust the clamp from the vertical rod to move the clamp up and down and the clamp will rest on top of the carton piles. Another key feature for the clamp is that there is threaded rod attached at the plate of the clamp to tighten the clamp on top of the piles to secure the transportation of the load. Moreover, this clamp sub-assembly is also attached to the loading sub-assembly so that the clamp will also be lifted along with the whole carton piles which helps to prevent any damage to the carton piles.

In conclusion, the final off-piler design is safe to operate, robust, and ergonomically friendly.

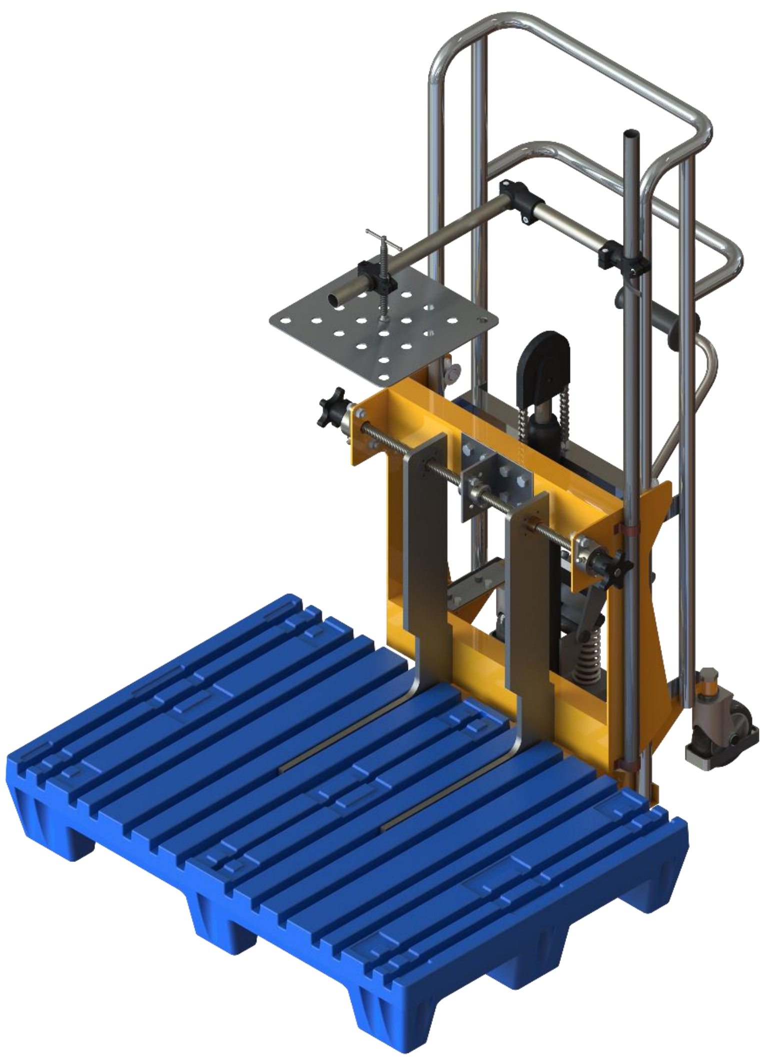

Table of Contents

List of Figures .... **iii**

List of Tables .... **v**

1 Introduction **6**

1.1 Company Background 6
1.2 Project Background 6
1.3 Problem Statement 9

2 Project Description **10**

2.1 Project Objectives 10
2.2 Project Deliverables 10
2.3 Client Needs 11
2.4 Target Specification 12
2.5 Constraints and Limitations 13

3 Design Methodology **14**

3.1 Client Input 14
3.2 Concept Generation 15

4 Design Development **19**

4.1 Base Structure 20
4.2 Adjustable Width 23
4.3 Loading 29
4.3.1 Side plate 29
4.3.2 Upper and Lower Support Tube 30
4.3.3 Center Support Bracket 31
4.3.4 Lifting Arm 32
4.4 Stability 34
4.5 Lift 36

5 Detailed Design **38**

5.1 Analytical Method 38
5.1.1 ACME Screw 40
5.1.2 Off-piler Arms 43
5.1.3 Loading Assembly 44
5.2 Numerical Method 47
5.2.1 ACME Screw 47

5.2.2 Off-Piler Arms 51
5.2.3 Lower Support Tube 54
5.2.4 Upper Support Tube 57
5.2.5 Side Plate 58
5.2.6 Center Support Bracket 62
5.3 Manufacturing Process 64
5.3.1 Off-Piler Arms Manufacturing & Assembly 64
5.3.2 Plate Support Manufacturing & Assembly 65
5.3.3 Clamp Mechanism Manufacturing & Assembly 67
5.4 Failure Modes & Effects Analysis 68

6 Cost Analysis 76

6.1 Purchased Parts Costing Analysis 76
6.2 Sheet Metal Costing Analysis 77
6.3 Labor Costing Analysis 78
6.4 Overall Costing Analysis 78

7 Final Design Summary 79

8 Conclusion and Future Recommendations 82

References 84

Appendix A 89

Table of Contents for Appendix 89

List of Tables in Appendix 89

List of Figures in Appendix 89

A.1– House of Quality Analysis (Target Specifications) 90
A.2 – House of Quality Analysis (Concept Design Components) 92
A.3 – Design Requirements Importance Ranking 94
A.4 – Gantt Chart 95
A.5 – Pallet Design 96
A.6 – Carton Product Example 98
A.7 – Lead Screw Maximum Deflection Analysis 100
A.8 – Detailed Engineering Drawing 100
A.9 – Base Structure Lift Manual 119

List of Figures

Figure 1: Four Different Design Styles on a Sheet 7
Figure 2: Die Cutter Producing Cartons 7
Figure 3: Current Off-Piler Equipment 8
Figure 4: Off-Piler Loading Carton Piles 9
Figure 5: Current Arm Configuration 9
Figure 6: Commercially Available Material Handling Solutions 16
Figure 7: Final Carton Off-Piler Design Concept 17
Figure 8: Final Design Concept Front View 18
Figure 9: Final Design Concept Rear View 19
Figure 10: Final Design Components Overview 20
Figure 11: Base Structure Model 21
Figure 12: Base Structure Model Side View 21
Figure 13: Left Configuration 22
Figure 14: Right Configuration 22
Figure 15: Center Configuration 23
Figure 16: Lead Screw Placement for Adjustable Width 24
Figure 17: Mounted Sealed Ball Bearing with Two-Bolt Flange 25
Figure 18: Dry-Running Mounted Sleeve Bearing with Two-Bolt Flange 25
Figure 19: Adjustable Width Component 26
Figure 20: Centered Off-Piler Pallet Gap Configurations 26
Figure 21: One Sided Offset Off-Piler Pallet Gap Configurations 27
Figure 22: Offset from Center Off-Piler Pallet Gap Configuration 28
Figure 23: Flange, 1.000 – 18 UNS, Steel 28
Figure 24: ACME Threaded Mount Nut, ¾ - 8, RH, Bronze 29
Figure 25: Loading Assembly 29
Figure 26: New Side Plate Shape 30
Figure 27: Bearing Mounting Holes 30
Figure 28: Upper Support Bracket 31
Figure 29: Lower Support Bracket 31
Figure 30: Center Support Bracket 32
Figure 31: Loading Arm Terminology 33
Figure 32: Clamping Assembly Terminology 35
Figure 33: Hydraulic Lift Assembly 36
Figure 34: Lift Mechanism for Base Model 37
Figure 35: Lift and Lowering Control Knob 37

Figure 36: Hydraulic Lift Schematic 38
Figure 37: Maximum Load Free Body Diagram 40
Figure 38: Resulting Force Acting on ACME Screw 41
Figure 39: Maximum Deflection Along a Series of Screw Diameters 43
Figure 40: Arm Blade Dimensions. 44
Figure 41: Forces Acting Though Bottom Tube. 45
Figure 42: Resulting Forces Acting on Top Loading Assembly. 46
Figure 43: ACME Screw Bearing Load Application. 48
Figure 44: ACME Screw Maximum Stress. 49
Figure 45: ACME Screw Deflection Results. 50
Figure 46: Dimensions of The Arm. 52
Figure 47: FEA Simulation Setup of The Arm. 52
Figure 48: Extended Support Section. 52
Figure 49: FEA Result for Stress Across The L-Shaped Part with 400 lbf. Load. 53
Figure 50: FEA Result for Deformation Across The L-Shaped Part with 400 lbf. Load. 54
Figure 51: Lower Support Tube Maximum Stress Results. 55
Figure 52: Lower Support Tube Deflection Results 56
Figure 53: Upper Support Tube Maximum Stress Results. 57
Figure 54: Upper Support Tube Maximum Deflection Results 58
Figure 55: Side Plate Bearing Load Application. 59
Figure 56: Side Plate Maximum Stress Results. 60
Figure 57: Side Plate Maximum Deflection Results. 61
Figure 58: Support Bracket Bearing Load Application. 62
Figure 59: Center Support Bracket Maximum Stress Results. 63
Figure 60: Center Support Bracket Deflection Results. 63
Figure 61: Welded on The Inside (Left) And Outside (Right). 64
Figure 62: Off-Piler Arms Assembly. 65
Figure 63: Loading Assembly Exploded View. 66
Figure 64: Welding Points. 66
Figure 65: Chain Connection to Lower Support Tube. 67
Figure 66: Final Clamp Assembly. 68
Figure 67: Final Off-Piler Design 79
Figure 68: Final Off-Piler Design Components 81
Figure 69: Expanded View of Final Off-Piler Design 82

List of Tables

Table I: Client Deliverables 11
Table II: University of Manitoba Deliverables 11
Table III: Client Needs 12
Table IV: Technical Requirements 12
Table V: Constraints and Limitations 14
Table VI: ACME Screw Material Properties 24
Table VII: Loading Arm Material Properties. 34
Table VIII: Maximum Stress and Deflection at Different Fillet Size. 52
Table IX: Severity Ranking and Definitions. 69
Table X: Occurrence Ranking and Definitions. 70
Table XI: Detection Ranking and Definitions. 71
Table XII: Failure Modes and Effects Analysis. 72
TABLE XIII: Purchased Parts Costing. 76
Table XIV: Sheet Metal Material Costing. 77
Table XV: Laser Cutting Cost for sheet metal. 77
Table XVI: Total cost for fabricating sheet metal parts. 78
Table XVII: Total cost for off-piler design. 78
Table XVIII: Satisfaction of Client Needs. 80

1 Introduction

Graphic Packaging International (GPI) is a paperboard and paper-based packaging manufacturer. Currently, GPI is using a customized off-piler to transport carton piles. The customized off-piler can be seen in Figure 3. This customized off-piler cannot be adjusted to accommodate the different groove widths on their pallets. Moreover, the current off-piler design does not account for the safety of the operator as the operator will have to use their body against the pile to tilt the off-piler upwards for the safe transportation of cartons. The purpose of the project is to design a handling device that is capable of loading, unloading and transporting a pile of cartons from one pallet to another with proper safety, in order to prevent a mixture of product styles from occurring. This report summarizes the project objectives, problem statements, client needs, and design constraints. Furthermore, concept generation and concept selection analysis were performed to finalize the concept for the off-piler design. The final design concept is further analyzed by the team to ensure that the off-piler design will meet all the requirements of the client.

1.1 Company Background

Graphic Packaging International is one of the largest manufacturers of paper-based packaging manufacturers. The vision of the company is inspired packaging to make a world of difference with products are made from renewable, recycled, and recyclable materials. GPI has more than 90 facilities worldwide to provide innovative custom product packaging solutions for customers' needs from folding cartons to food service containers and more. One of their facilities is located in Winnipeg.

1.2 Project Background

Graphic Packaging International designs the cartons according to the customer’s needs. This design varies with the customer as some customers require different styles of packaging solutions. In that case, the design team designs the different styles to be printed on the same sheet as shown in Figure 1, more samples can be seen in Appendix A.6. After the printing is finished, these sheets will go through the die cutters shown in Figure 2 and will be cut down to the specific carton size. These carton sizes will come out on a pallet from the die cutters automatically.

Figure 1: Four Different Design Styles on a Sheet

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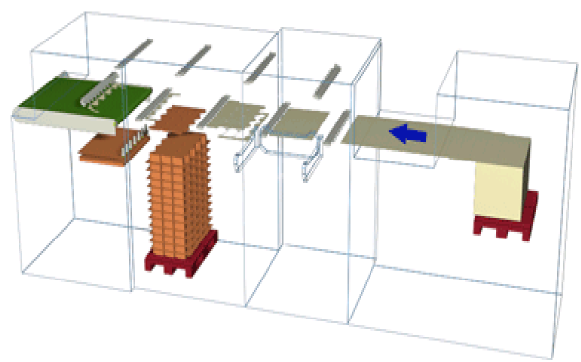

Figure 2: Die Cutter Producing Cartons [1] [2].

If a pallet has multiple styles of cartons, the production worker manually transfers the pile of cartons to a separate pallet to keep the pallet organized with one style. The off-piler in Figure 3 is currently used by the operators to transfer these carton piles as shown in Figure 4. There are no current standards about the usage of this off-piler. The off-piler was developed several years ago as a temporary solution to move carton piles and it is still being used as a solution. This off-piler was bought by GPI from the market and some modifications were made over time to integrate with two of the commonly used pallet groove widths to transfer the carton piles. If the carton piles are not on these specific groove widths which the current off-piler can accommodate, then the operator will have to manually lift the carton piles to transfer them to another pallet.

Since, the current off-piler can only accommodate for two pallet groove widths, it cannot be used for heavy piles which can be approximately the pallet size. The current design is only valid for light loads, possibly up to 200lbs depending on the strength of the operator. Moreover, the off-piler just has the back plexiglass plate for the stability of the piles during the transfer of the cartons. But it does not include any mechanism for the safe operation of lifting the pile. There is also no mechanism to lift the pile. The operator will have to manually tilt the carton pile upwards 10 to 15 degrees while transferring the cartons. This accounts for increased operator fatigue. Also, this off-piler can only be used by the experienced operator. It will be very hard to operate for a new worker. Since this off-piler will have to be tilted by some angle, then it is very hard for the operator to drop the off-piler arms in the pallet grooves during the unloading process. This loading and unloading process is not safe for the operator as the operator will have to use the body as a counterweight against the off-piler to ensure the pile does not tip over.

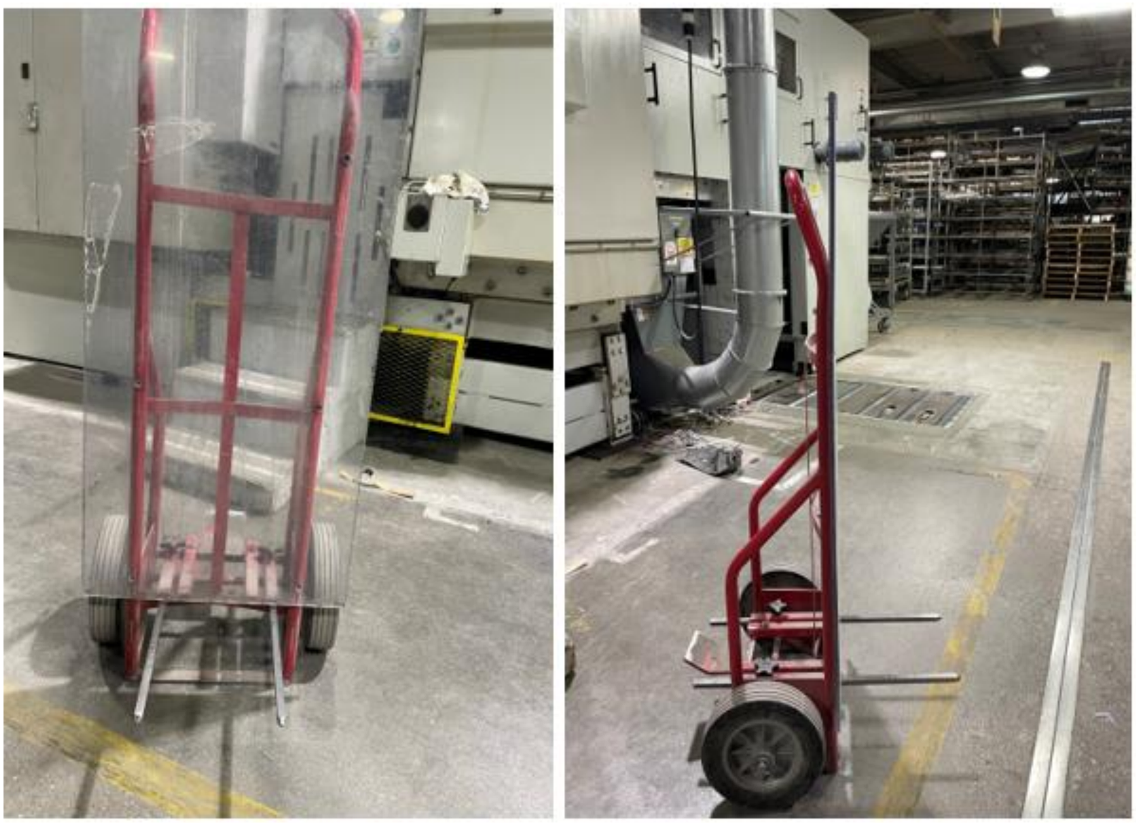

Figure 3: Current Off-Piler Equipment [2].

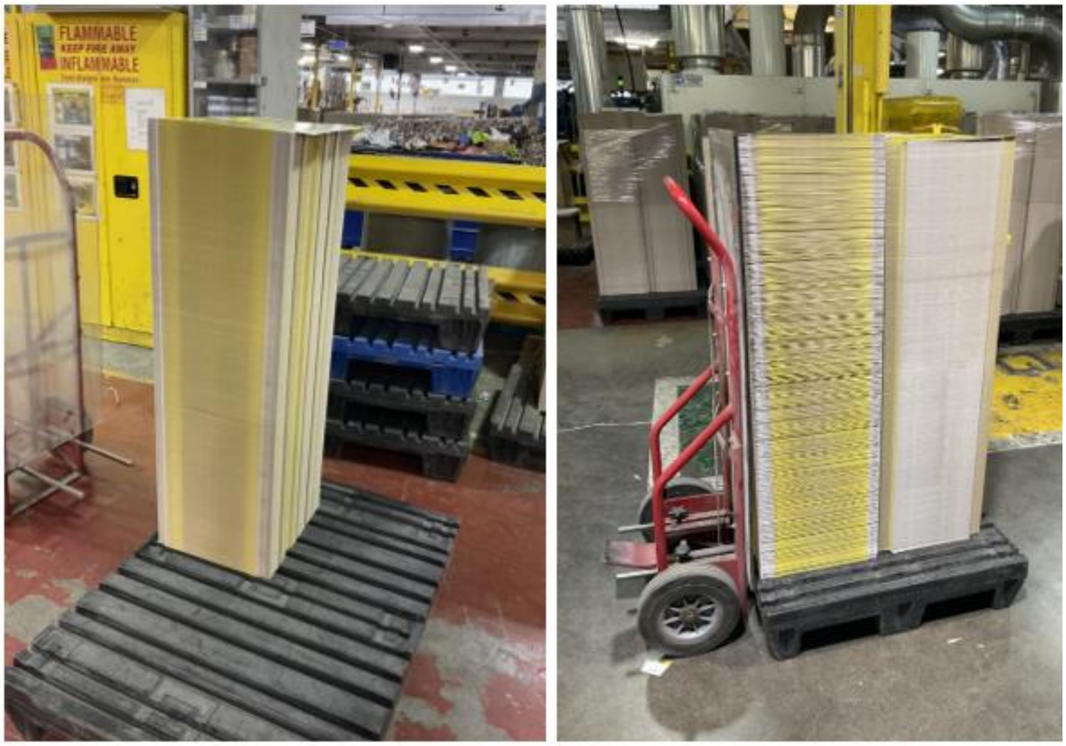

Figure 4: Off-Piler Loading Carton Piles.

1.3 Problem Statement

Figure 5 is the current design to change width of the off-piler arms. This design can only be used to lift piles from the pallet with groove widths of 9.38" and 6.12". These distances are obtained by varying the position of the arm through the squared tube and tested on different distances of the pallet grooves. With only two different distances, that is the limit of this device to lift the pile. Also, when the team collected information from the clients, they mentioned that the off-piler causes physical fatigue for the operator when they are loading or unloading a heavy stack of cartons (usually heavier than 200lbs).

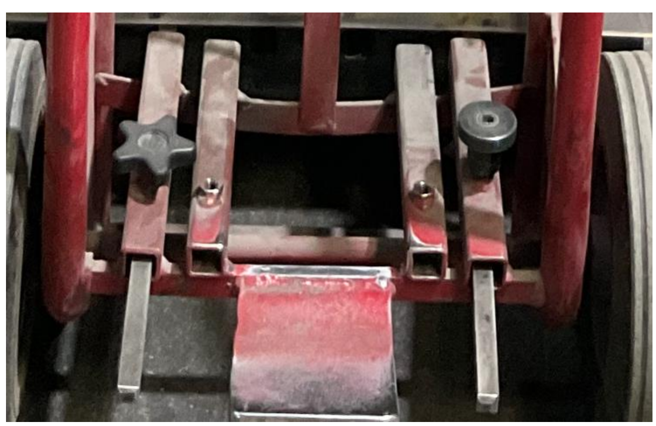

Figure 5: Current Arm Configuration [3].

To accommodate the grooves distances on the pallet, a new mechanism for each arm will be designed to satisfy client requirements. This way, operators can adjust each arm to the desired locations rather than having only two ways to adjust. To reduce the physical fatigue for the operator, a new design will be self-supported and will use a simple lifting mechanism to load and unload a pile of cartons.

2 Project Description

To have a better understanding of the project, the project objectives, deliverables, client needs, and the constraints and limitations of the project are discussed.

2.1 Project Objectives

The objective of this project is to design a material handling device capable of loading, unloading, and transporting a pile of cartons from one pallet to another to prevent product mixing. The device must be able to accommodate a pallet size of 40.5” x 21.5” with groove width of 0.87”, different types of carton sizes and pile configurations, and a weight of up to 800lbs [4]. The project team will maintain close communication with the client to fully analyze the carton off-piling process and to properly develop various concept designs and solutions. The final design will benefit Graphic Packaging International by improving the current work process safety, ergonomics, and efficiency of carton off-piling.

2.2 Project Deliverables

The project requires several deliverables for both the client, and the university. The project deliverables are outlined in Table I and Table II.

Table I: Client Deliverables

Client Deliverables
Detailed Design Processes
Concept Selection Process
Failure Modes and Effects Analysis (FMEA)
Preliminary Engineering Drawings
Estimated Costs
Final Design 3D CAD Model
Final Design Justification

Table II: University of Manitoba Deliverables

University of Manitoba Deliverables		
Due Date	**Phase**	**Deliverable**
Oct. 1, 2021	1	Project Definition Report & Client Evaluation 1
Oct. 4 – 8, 2021	1	Project Oral Presentation
Oct. 8, 2021	1	Self & Peer Assessment 1
Oct. 29, 2021	2	Concept Design Report & Client Evaluation 2
Nov. 1, 2021	2	Self & Peer Assessment 2
Nov. 29, 2021	3	Draft of Final Project Report
Dec. 1, 2021	3	Draft of Final Project Report Feedback
Dec. 8, 2021	3	Final Project Report & Poster
Dec. 9, 2021	3	Final Project Presentation
Dec. 10, 2021	3	Self & Peer Assessment 3

2.3 Client Needs

After conducting a site visit, the verbal information gathered from client meetings along with the project descriptions provided, which can be found in Appendix A.3, were carefully assessed by the team to analyze and determine the client needs. The team ranked the importance of each client needs from 1 to 10, 10 being the most important, and 1 being the least. The resulting client needs were approved by the client and are outlined in Table III.

Table III: Client Needs

Client Needs	Importance
Adjustable width and height	10
Safe	10
Reduce operator fatigue	9
Ergonomically friendly	9
Robust	8
Secured transportation of carton piles	8
Improved loading process	7
Ease to maintenance	6
Easily stored	5
Easily accessible	5
Inexpensive	5

2.4 Target Specification

After identifying the needs of the client, the team compiled a list of technical requirements that are outlined in Table IV. The correlation of each requirement and their relationship with the client needs were analyzed in the House of Quality, which can be found in Appendix A.1, to determine the rank of each based on their relative weight and importance.

Table IV: Technical Requirements

Rank	Technical Requirements	Safety	Cost	Efficiency	Technical
1	Maximum load of 800 lbs.	O			O
2	Movable up to at least 10’ of distance	O			O
3	Transports carton piles up to 42” in height at 1 m/s without instability movement of pile	O			O
4	Accommodates a pallet size of 40.5” x 21.5” with groove width of 0.87” (see pallet design in Appendix A.5)				O
5	Accommodates all pallet groove gap widths between configurations 1 to 4 (see configurations in Appendix A.5)				O
6	Maximum final design cost of $25,000		O		
7	Reduce carton off-piling process time by 25%			O	

As shown in Table IV, the technical requirements were grouped into safety, cost, efficiency and technical categories using the symbol "O" for ease of ranking to support the results of the House of Quality Analysis in Appendix A.1. Safety was prioritized to have the highest importance weighting, and the rest have equal weights. Therefore, requirements that were classified into more than one category were weighted more in the analysis. After completing the analysis, the maximum load of 800 lbs. was ranked first since it targets the client needs of safety and robustness. GPI will occasionally receive orders of carton piles that weigh a maximum of 800 lbs.; therefore, the design must be capable of handling this weight to assure the operator's safety from design failure while carton off-piling. Having a movable design of up to at least 10' of distance was ranked second. Pallets can be far from one another with a distance of at least 10' during the off-piling process, therefore, the design must be moveable to successfully transfer a carton-pile to a new pallet. In rank 3, the design must maximize stability. The carton piles have a maximum height of 42"; therefore, they must be handled by the design with maximum stability while moving at a speed of 1m/s to prioritize the operator's safety during transportation. In rank 4, the design must accommodate a pallet size of 40.5" x 21.5" with groove width of 0.87". This pallet size is universal for GPI, and the only type of pallet used for carton-off piling, and therefore must be accommodated. In rank 5, the design must accommodate all pallet groove gap widths between configurations 1 to 4 as shown in Appendix A.5. Carton pile sizes could vary excessively depending on the customer order. However, they must always fit within the pallet, and having the off-piler arms on any groove gap widths between configurations 1 to 4 should support all carton pile sizes. In rank 6, as stated by the client, the final design has a maximum cost of $25,000 which includes the materials and third-party expenses on manufacturing labor. Ranked last is reducing the carton off-piling process time by 25%. The team has set an initial target of reducing the process time by 25%, however, the main goal is to ensure that the new design process time will not exceed the current time.

2.5 Constraints and Limitations

To properly assess the boundaries and limits of the project, the constraints and limitations are outlined in Table V.

Table V: Constraints and Limitations

Constraints and Limitations	
Constraints and Limitations	**Description**
Budget	The total cost of the design must be under $25,000.
System Footprint	The size of the design must accommodate the carton off-piling design space, and a pallet size of 40.5” x 21.5” with groove width of 0.87”.
Time	The carton off-piling process time of the design must not be greater than 60 seconds.
Quality	The design must be capable of lifting 800 lbs. without failing.
Project Deadline	The project deliverables for both the client and university must be submitted by Dec. 8, 2021.
Study Environment	The project team must adjust to the university’s remote online learning environment.

3 Design Methodology

The methodology used by the team to determine the final design concept involved multiple steps with coordination from both the team and client. The steps are listed below which involved:

1. Site Visit with Client Input and Recommendations
2. Design Component Decomposition
3. Research, Brainstorming, and Concept Generation
4. Development of Preliminary Concept Sketches and Models
5. Client Input and Discussion of Concepts
6. Concept Selection and Integration

3.1 Client Input

Following the project definition phase, the team conducted a site visit to gather further information and search for client inputs and recommendations in preparation for the concept development phase. In addition to a site visit, a series of weekly meetings were also held to update the client with the concept development as well as to request feedback and additional input. The client input and recommendations are listed as follows:

- Maximum Load: Carton pile configuration that reaches the maximum load of 800 lbs. is a rare occurrence, approximately four times a year.
- Extending Wheels Under Pallet: Having wheels under the pallet could limit the functionality and movement of the off-piler design. Therefore, further analysis is required to proceed with any similar concepts.
- Visibility: Operators have difficulties aligning the off-piler arms to the pallet grooves. Therefore, visibility of the arms is important for the design during the off-piling process.
- Lift: Operators are currently rocking and swinging the off-piler device to load and off-load the carton piles. Vertical lift could be beneficial to simplify the work process and prevent these unsafe practices when loading and off-loading.
- Stability: Carton piles could tip over during transportation without proper stability, client recommended to use a clamping style device on top of the carton piles.
- Pinch Points: Safety of the operators is the highest priority. Pinch points are one of the common safety risks and must be considered during concept development.
- Operator Input: Minimize tasks during loading and off-loading of carton pallets to reduce strain on operators.
- Existing Material Handling Solutions: Consider using commercially available structures with the addition of fabricated components to reduce cost and design complexity.

3.2 Concept Generation

For concept generation the team conducted brainstorming sessions, searches for existing lifting devices used within production settings, and patent searches. From patent searches, the team was able to find designs relevant to the lifting process such as hand trucks and pallet jacks, but none relevant to the design requirement of adjustable width. Through broad online searches, the team was able to find commercial applications of manual lift stackers or hand trucks, commonly used for lifting large packages and bins which served as inspiration for generating concepts. Two variations of commercially available material handling solutions are shown in Figure 6.

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Figure 6: Commercially Available Material Handling Solutions [5] [6]

However, the majority our searches found lifting devices that were capable of broad height adjustment without the ability of automatic adjustable arm width. This provided an innovative challenge for the team, as the off-piler design requires both a lifting and adjustable width aspect.

Our concepts can be placed into four differing sub-component categories of the off-piler design based on their working principles. These categories were created when considering the design requirements of the off-piler and insight from our client. They are listed as follows:

1. Adjustable Width: Mechanism to adjust the distance between loading arms and accommodate varying pallet groove configurations.
2. Loading Mechanism: Design to support load transfer from carton piles through the arms to the frame structure.
3. Stability: Component to secure carton piles, ensuring stable unloading, off-loading, and transportation.
4. Lift: Mechanism to provide off-piler arms with clearance to safely remove carton piles from pallet.

A weighted concept selection process was first targeted toward the design of the adjustable width component. This was based on weighted relevance to the customer needs and design requirements. Once the adjustable width mechanism was selected the loading, stability, and lift components of the off-piler could be selected and designed to complement the adjustable width component. Emphasis within the selection process was put on client input and feedback received.

The final design concept consists of the four different design components integrated to complete the Carton-Off Piler Device. Each chosen concept for each design component underwent a thorough analysis and selection process to be ranked as the best and most feasible concept for the team and the client. The four components selected to proceed to final design development are as follows:

1. Adjustable Width: Independent Lead Thread
2. Loading: Extended Caster Wheels Under Pallet
3. Stability: Clamp Mechanism
4. Lift: Manual Hydraulic Lift

A simplified visual of all four components integrated into the full Carton-Off Piler concept is shown in Figure 7 to Figure 9 below. Here each concept selected for the four design components can be seen in Figure 8 and Figure 9.

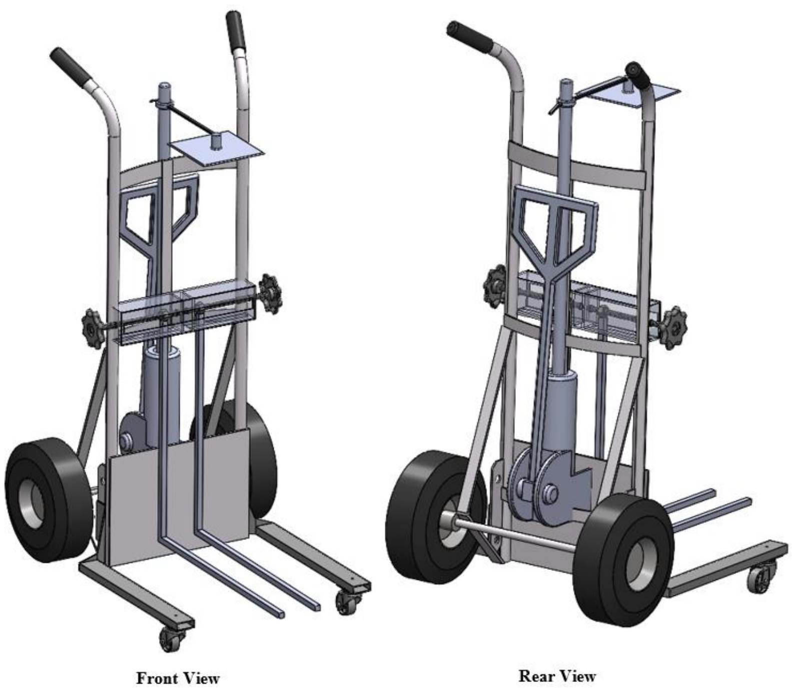

Figure 7: Final Carton Off-Piler Design Concept

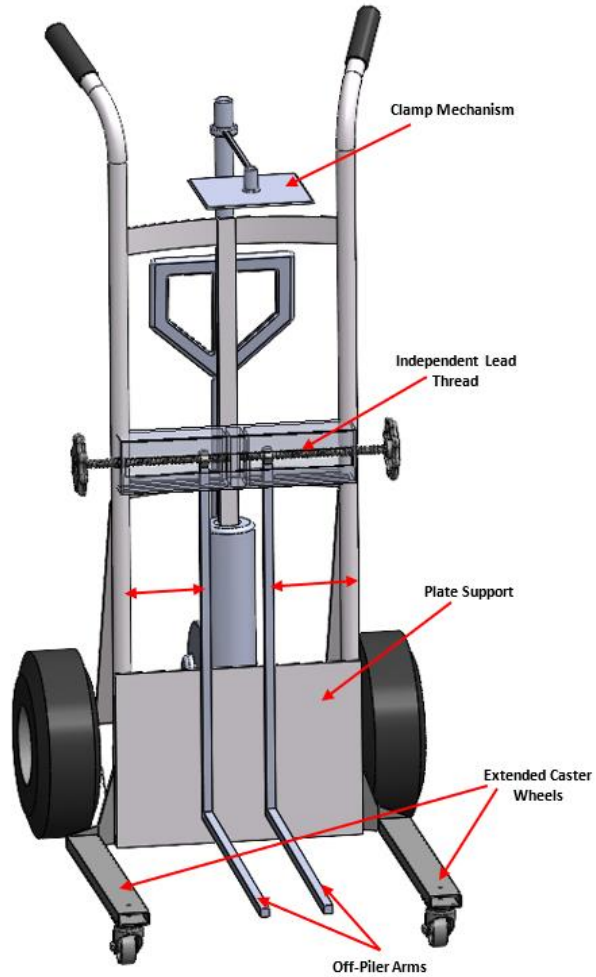

Figure 8: Final Design Concept Front View

Figure 9: Final Design Concept Rear View

As shown from the figures above, all four components are fully compatible with each other to form the off-piler conceptual design. The independent lead screw adjusts the distance between the loading arms that are supported by a plate when loaded. The extended caster wheels will support the whole device when lifting the maximum weight and provide a stable frame. The clamp mechanism keeps the carton piles stable during transportation. The hydraulic manual lift will then lift the plate support which have the off-piler arms, independent lead screws and clamp mechanism attached. This vertical lift will provide a small clearance between the carton pile and the pallet prior to transportation.

4 Design Development

This section provides a step-by-step development in designing the final carton off-piler model and demonstrates how the final concept evolved from a simple generated concept into the final detailed design. The final detailed design consists of five main components, the base structure, adjustable width mechanism, loading assembly, stability, and lift. A simple overview of the final design is shown in Figure 10.

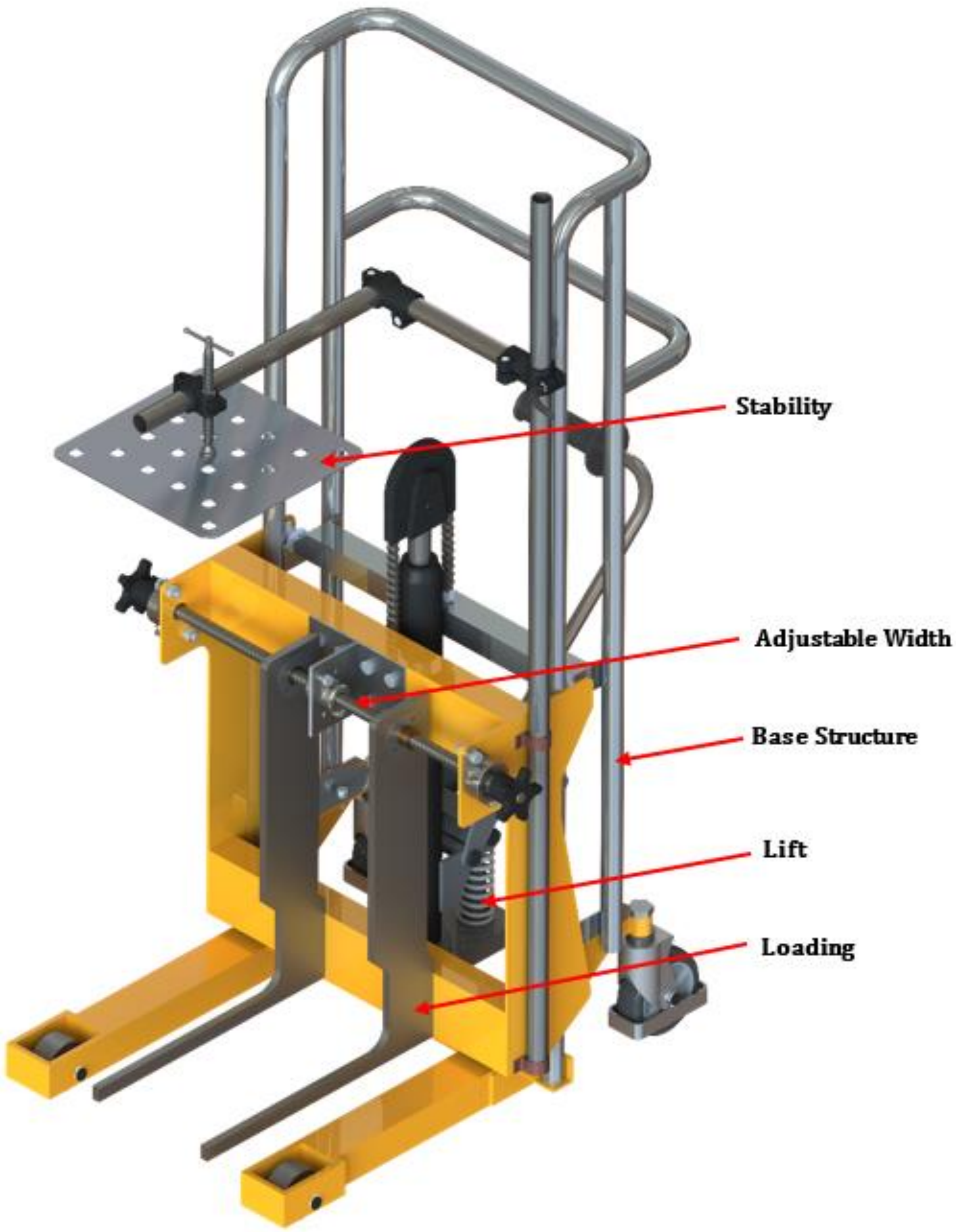

Figure 10: Final Design Components Overview

4.1 Base Structure

Based on the shape of the final design concept from Section 3.2, the team found a base structure that was available on the market from Global Industrial [7]. The shape of the chosen base structure fits with the extended channels and caster wheels concept to counteract the 800 lbs. acting on the model during operation at maximum loading. The base structure is rated for 880 lbs., and therefore exceeds the target specification required for the project. In addition, the base structure has a built in manual hydraulic lift which covers the lift requirement of the off-piling process and will be further discussed in Section 4.4. The wheel base of this structure allows the design to meet the specification of at least 10' of mobility allowing the off-piler to transport carton piles to different departments if required. The selected base structure model is shown in Figure 11 and Figure 12.

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Figure 11: Base Structure Model [7]

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Figure 12: Base Structure Model Side View [7]

The base structure model, as shown in its manual in Appendix A.9, has a width of 22" which fits with the pallet's gap configurations of 1 to 4, which provide a maximum loading width of 22.26" as shown in Appendix A.5. In addition, the 22" width of the base structure model can accommodate GPI’s universal pallet when configured at the left, right, and center of the pallet as shown in Figure 13 to Figure 15.

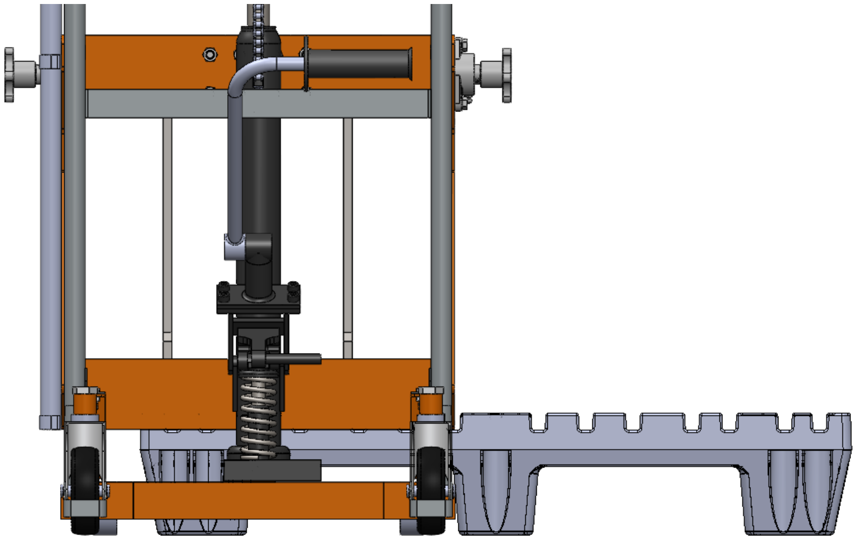

Figure 13: Left Configuration

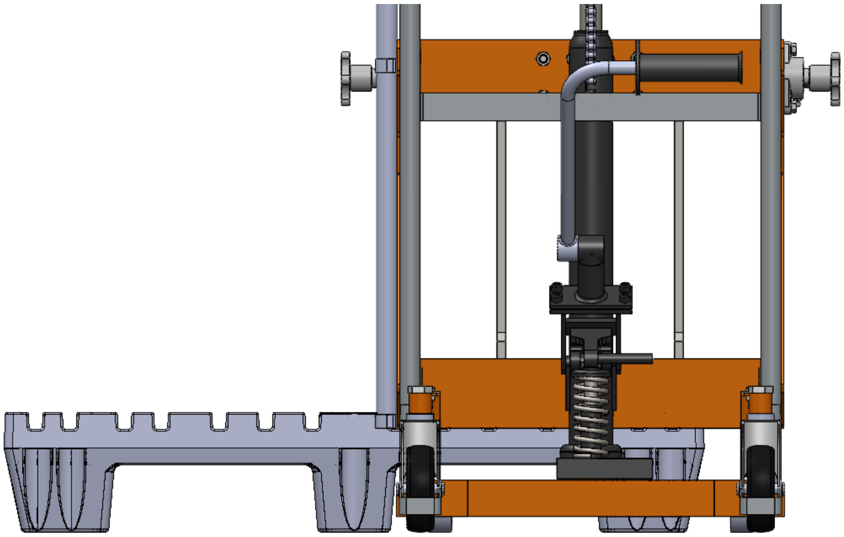

Figure 14: Right Configuration

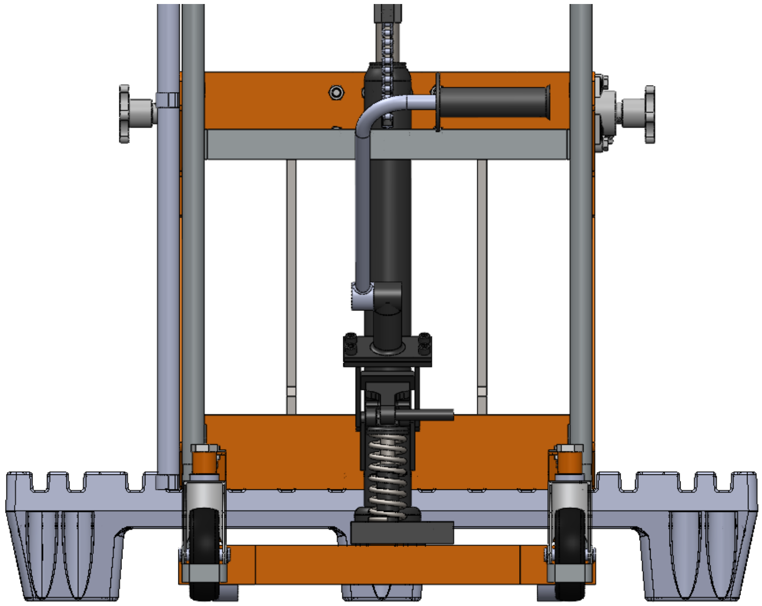

Figure 15: Center Configuration

This base structure will require modifications to meet design requirements and target specifications as detailed in the following sections.

4.2 Adjustable Width

Due to the customers requirement of adjustable loading arm width to accommodate a range of pallet grooves, our team chose the concept of independent lead thread as shown in Figure 8. This allows the loading arms to be off centered with respect to the off-piler, increasing functionality and accommodating slight groove variations between pallets.

Common lead screws used for industrial power transmission and motion control are ACME screws which implement a 29 degree flank angle making them durable, precise, and capable of holding position under axial loading [8]. Since our design requires precise width adjustment relative to the rotational input of the operator, our team considered a screw with a high thread per inch (TPI) value. Increasing TPI decreases axial movement of a meshed nut with constant angular rotation. This ultimately increases resistance to thread rotation under axial loading, increasing safety during transportation. For operator simplicity, the design team has decided to use opposing thread directions for the left and right sides. That way rotation of either knob to the front of the off-piler will always shift the loading arm inwards regardless of the side. The initial structure of the adjustable width system can be seen in Figure 16.

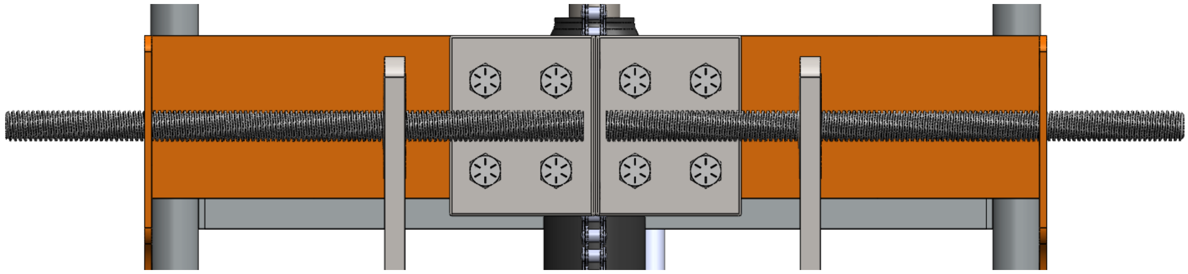

Figure 16: Lead Screw Placement for Adjustable Width

The length of each ACME screw was determined from the selected base model width. As described in Section 4.1, the base structure has a width of 22”. Each thread length will accommodate half the total width while having additional length for rotation knobs which should be easily accessible and operable with one hand. The length of each ACME screw is required to be 14.3” to extend from the center support to the end of the adjustment knobs.

Due to the limited design space and need for increased operator visibility, the material selection considered high strength materials to reduce the diameter required for the lead screws. Since these components are to be sourced, materials available by common retailers such as McMaster-Carr were considered. They are as follows.

Table VI: ACME Screw Material Properties [9], [10], [11].

Material	Yield Strength (N/m^2)	Tensile Strength (N/m^2)	Modulus of Elasticity (N/m^2)	Density (kg/m^3)
Carbon Steel	220,594,000	399,826,000	2.1E+11	7800
Alloy Steel	620,422,000	723,825,600	2.1E+11	7700
Black-Oxide 4140 Alloy Steel	415,000,000	655,000,000	2.1E+11	7850
316 Stainless Steel	515,000,000	485,000,000	2.1E+11	8000

The available ACME screw material with the highest yield strength and tensile strength is alloy steel which is selected for the design. Analysis for the selected thread diameter will be expanded on in Section 5.2.1.

To mount the screws to the off-piler structure, bearings are implemented on the outer ends of each screw to support the load transmitted through them from the loading arms. Additionally, to limit operator input force, reduce wear, and limit noise during adjustment [12]. For this the team selected bearings with mounting flanges for ease of assembly and maintenance. By mounting the outer bearings on the outside face of the loading assembly side plates, adjustable width functionality and range is not limited. For outer bearings, the design team will implement sealed ball bearings with two-bolt flanges and set screws as shown in Figure 17 to limit the threaded screw from axial translation.

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Figure 17: Mounted Sealed Ball Bearing with Two-Bolt Flange [13]

The center bearings are within the adjustable width travel range and would limit total range of motion depending on their thickness. Because of this, the design team implements a low profile, dry-running sleeve bearing with two-bolt flanges. These were selected due to their high load capacity with reduced housing dimensions and weight by having thin-walled sections [14]. The selected center bearings are shown below.

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Figure 18: Dry-Running Mounted Sleeve Bearing with Two-Bolt Flange [15]

Finally, to rotate the lead screws the operator requires a handle or knob which is easily accessible with one hand. For this, a steel knob with setscrew to mount to the outer end of each lead screw is implemented. The adjustable width component of the off-piler design can be seen in Figure 19. The diameter of ACME screw required to safely support the maximum load requirement will be analyzed in Section 5.

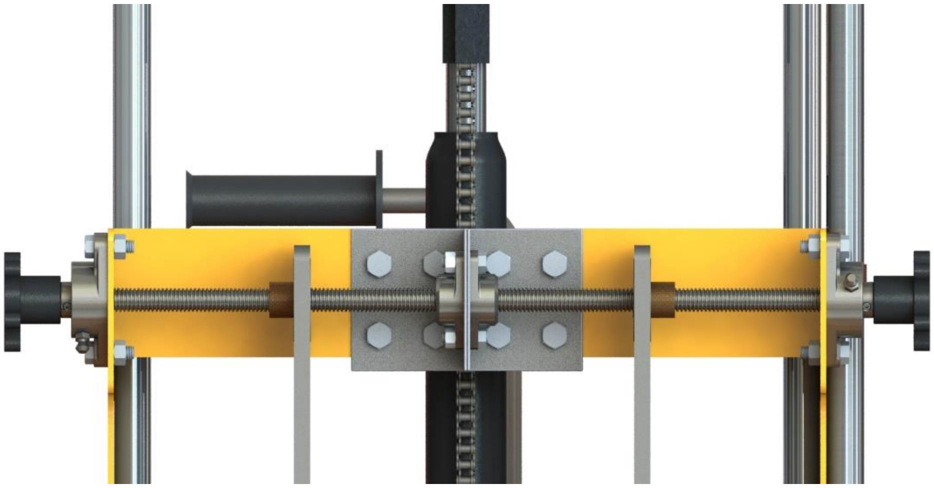


Figure 19: Adjustable Width Component

The feasibility of the adjustable width system accommodating multiple pallet groove configurations is shown through the following series of top view figures.

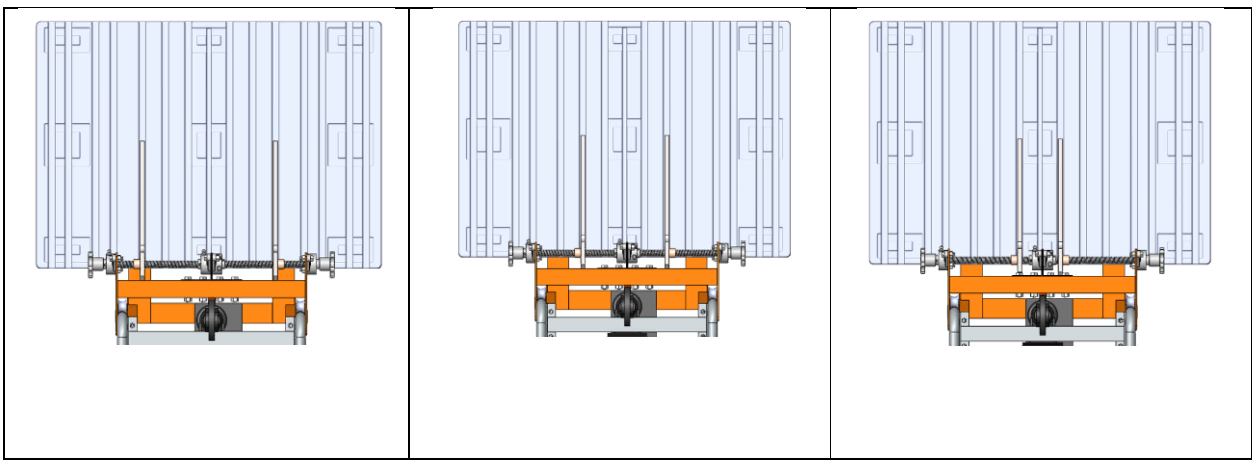


Figure 20: Centered Off-Piler Pallet Gap Configurations

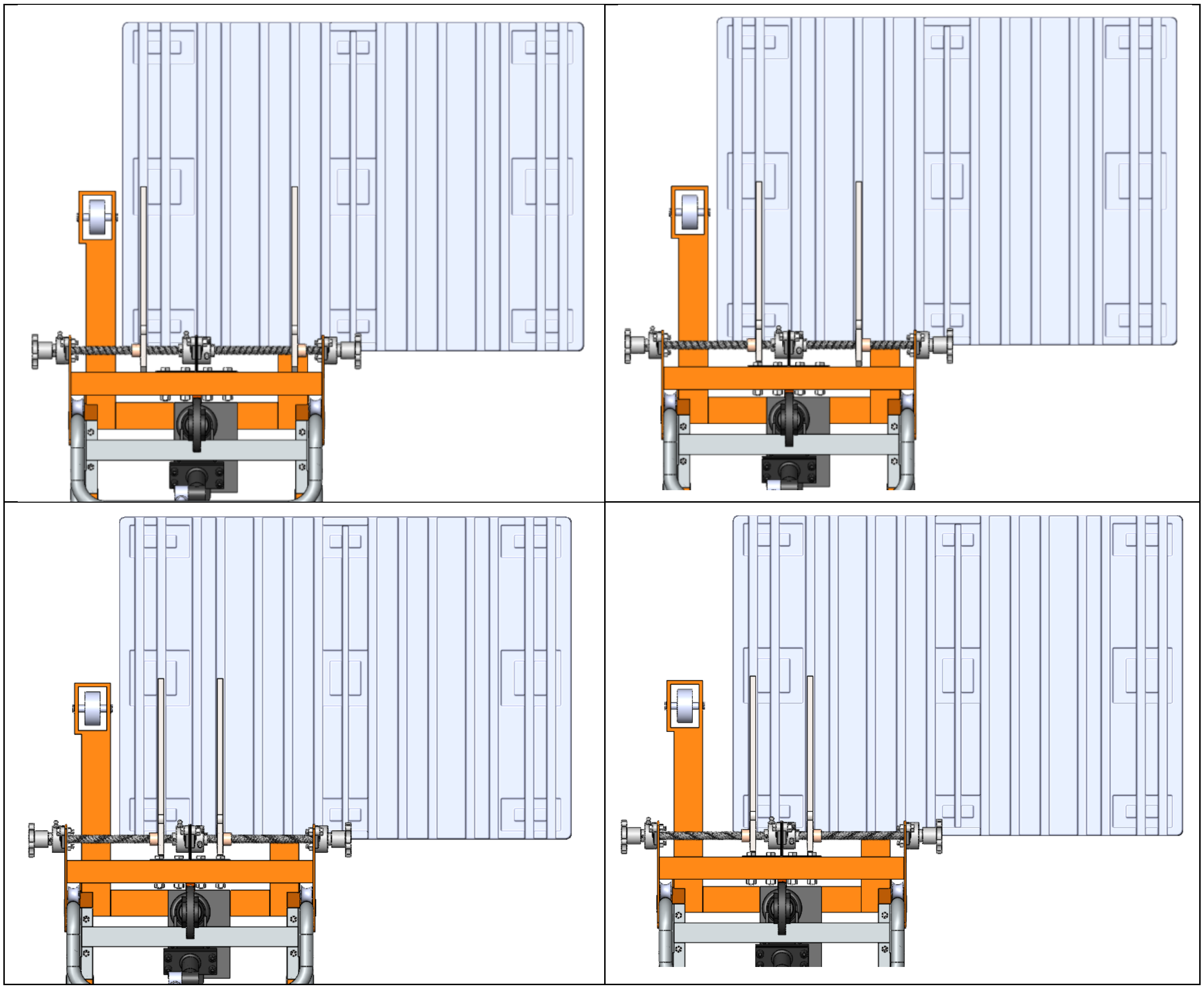
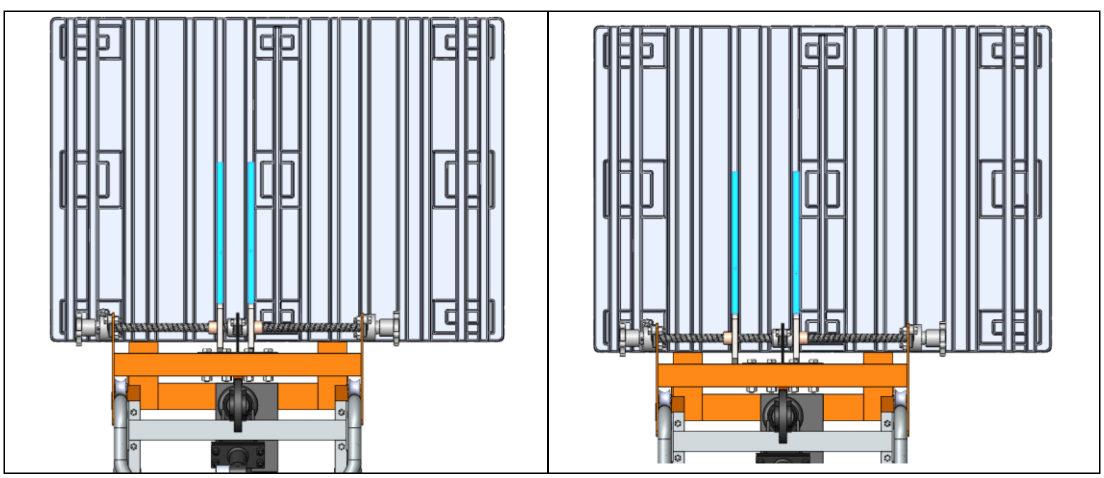


Figure 21: One Sided Offset Off-Piler Pallet Gap Configurations



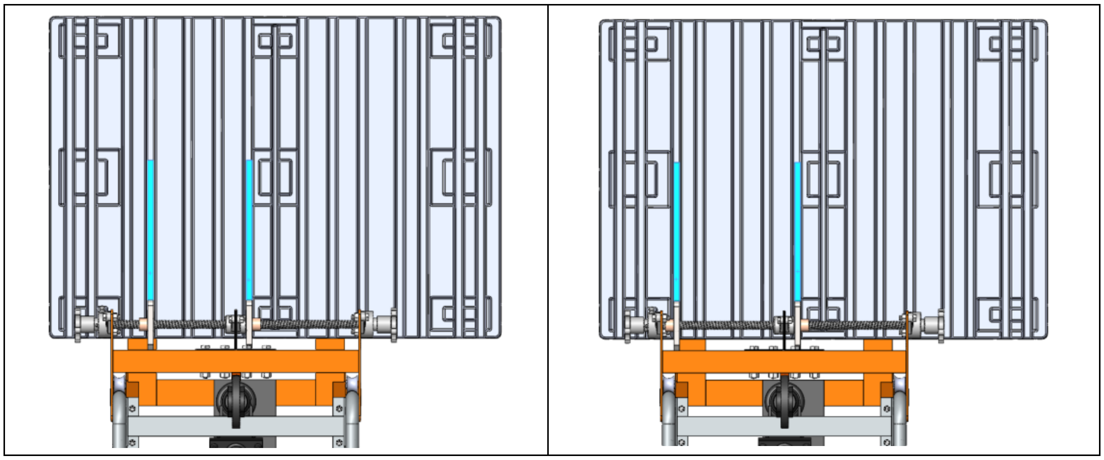


Figure 22: Offset from Center Off-Piler Pallet Gap Configuration

As observed from Figure 20 to Figure 22, the adjustable width mechanism of the off-piler design can accommodate 17 combinations of pallet groove gaps for when the off-piler is positioned at the left, right and center of the pallet. The loading arms range between 2.5” and 20” center to center distances. This tailor’s to the clients requirement of adjustable loading arms to accommodate varying pallet groove gaps, sufficient for common GPI products.

Considering the adjustable width system’s integration with the loading arms, a flange seen in Figure 23 with a threaded mount nut insert shown in Figure 24 will mesh along the ACME screw. This flange will attach to the loading arms as described in Section 5.3.1.

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Figure 23: Flange, 1.000 – 18 UNS, Steel [16]

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Figure 24: ACME Threaded Mount Nut, ¾ - 8, RH, Bronze [17]

4.3 Loading

The loading design includes two mains components which are the loading assembly and lifting arms. The loading assembly is comprised of the structure that will integrate with the base structure, similar to the design of the base structure seen in Section 4.1. These components are discussed in the following sections below. Terminology used for the loading assembly is shown in Figure 25.

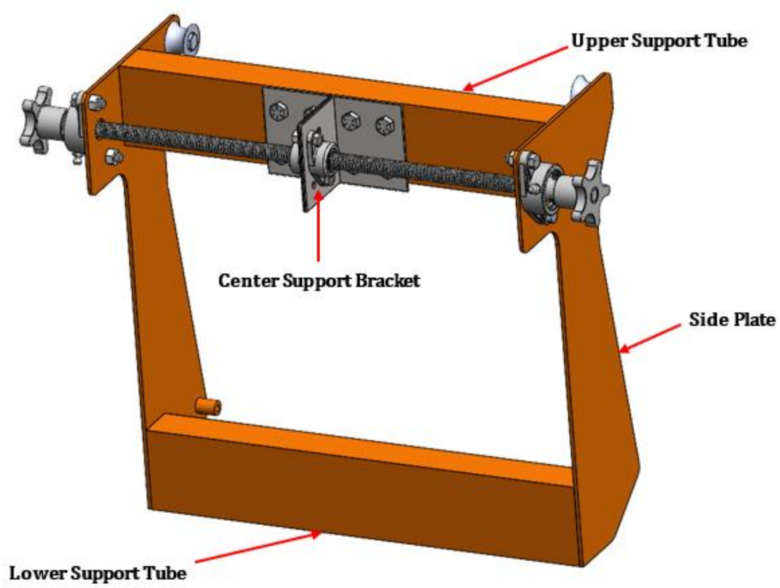

Figure 25: Loading Assembly

4.3.1 Side plate

The height of the side plate that came with the model is approximately 12.6" from the ground when the arm is at the lowest point. This height is not large enough to prevent the operator from bending their back. So, the team will redesign the side plate to a height of 33.46” to help minimize operator physical fatigue. The new height value is derived from simulating the comfortable height between team members when reaching. Figure 26 is a new shape of the side plate which will be designed and analyzed in Section 5.

Figure 26: New Side Plate Shape.

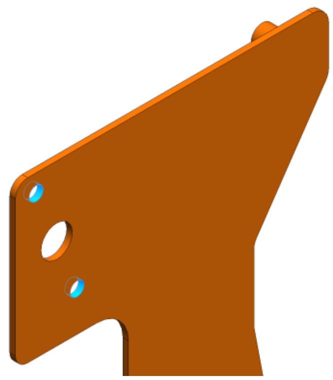

Figure 27: Bearing Mounting Holes

With a new side plate height, the next thing to note is the locations of the mounting holes as shown in Figure 26 to the left. These holes will be used to secure bearings onto the plate as shown in Figure 27 as cyan blue. The other hole is for the ACME screw to pass through.

The material that will be used to manufacture this component is 7-gauge carbon steel sheet metal. Carbon steel is a common material with high strength that is used widely in many applications such as bridges or ships. Also, 7-gauge sheet metal is a standard thickness that is widely available on the market. Therefore, the team will analyze the side plate based on this information to validate the feasibility for manufacturing.

4.3.2 Upper and Lower Support Tube

Figure 28 on the left is the upper support tube which is the major support for the loading assembly because this tube will be acted on by the force that is transmitted from the center support bracket. To secure the center support bracket, eight holes will be drilled for the bolting connection. Without this tube, there is no other way to indirectly support the force coming from the center support bracket. Figure 29 on the right is the lower support tube. The purpose of this tube is to ensure the stability of the lifting arm. As the load is applied on the arm, without this tube, the arms will tend to slightly swing back and forward which results to an angle with respect to the ground and could lead to unstable loading. The length of the tube is similar to the tube length of the original model. The material used is carbon steel to be consistent with the side plates

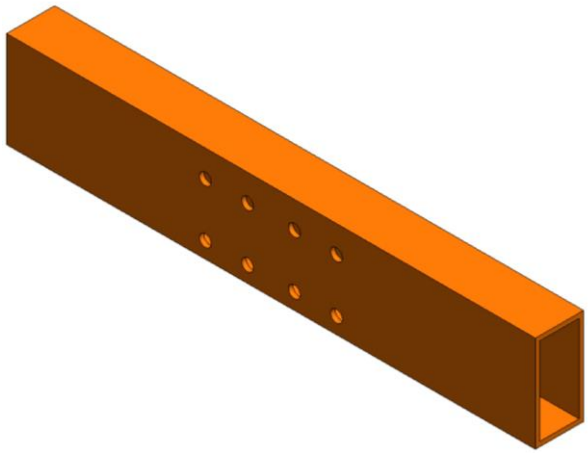

Figure 28: Upper Support Bracket

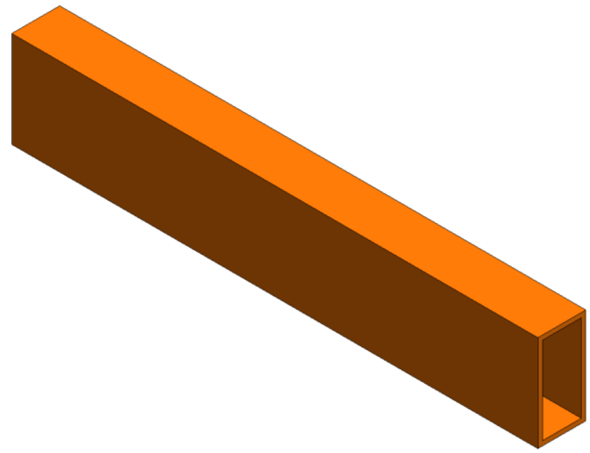

Figure 29: Lower Support Bracket

4.3.3 Center Support Bracket

The center support bracket will support the threads that are used to adjust the lifting arm width. The bracket is one of the main components to make the ACME screws move independently by acting as a divider between the left and right screws to allow adjustable width with asymmetrical configurations along the pallet. The extruded portion of the bracket has a width of 3.61” and a height of 4.43” to align with the extruded section of the side plate and allow the ACME screw to run perpendicular through the center and outer bearings. This portion also has four holes that are custom made to perfectly align the center bearings with the outer bearings mounted from the side plate. In addition, it supports the ACME screw and reduces its effective length by having a portion of it fixed onto the center bearings and into the support bracket to prevent excessive bending during maximum loading. The back support portion has a width of 3.50” and a height of 4.43” to provide sufficient contact surface to properly transmit the force to the upper support tube during maximum loading. This portion also has four 0.5” holes to accommodate hardware. Similar to the side plate, the material that will be used for the center support bracket is carbon steel for ease of manufacture and as it is widely available on the market.

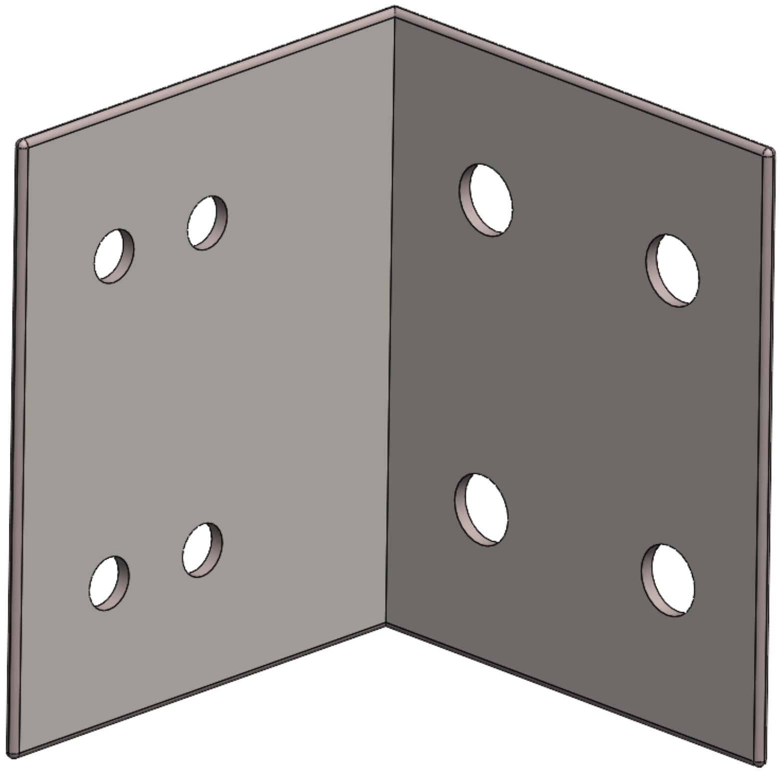

Figure 30: Center Support Bracket

4.3.4 Lifting Arm

The lifting arm will be redesigned to accommodate the narrow groove width and shallow groove height of the pallet. To describe the content effectively, several terms such as tip, blade, shank and heel will be used, as shown in Figure 31.

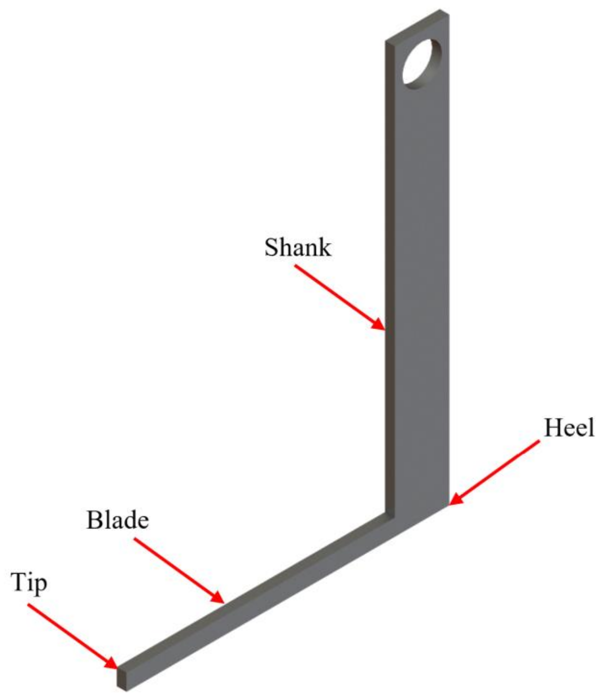

Figure 31: Loading Arm Terminology

To determine the optimal dimension of the blade, the second moment of area will be used in the process to calculate the deformation of the blade under the maximum loading situation to minimize the failure. The second moment of area equation is shown in Section 5.1.

Based on a forklift repair and maintenance shop, a common material used to manufacture forklift arms is AISI 4140 or 4340 Steel [18]. The properties of the material are shown in Table VII. [redacted] Therefore, the material with the highest yield and tensile strength is selected to maximize the safety factor. AISI 4340 Steel (Normalized) is chosen to be the material for the arm. Further analysis will be discussed in Section 5.1.2 and 5.2.2.

Table VII: Loading Arm Material Properties [11].

Material	Yield Strength (MPa)	Tensile Strength (MPa)
AISI 4140 Steel, Annealed	417	655
AISI 4140 Steel, Normalized	655	1020
AISI 4340 Steel, Annealed	470	745
AISI 4340 Steel, Normalized	710	1110

4.4 Stability

The stability component of the final off-piler design used the following considerations derived from design requirements and client feedback:

- Lightweight to reduce operator fatigue during clamp height adjustment
- Quick clamping mechanism for holding height of pad plate
- Slight lateral movement to accommodate adjustable width range of loading arms
- Ease of assembly and disassembly for possible future modifications
- Assuming piles shorter than 2’ do not require the clamp mechanism to provide stability for the pile due to low center of mass, and likelihood of manual removal by die-cutting operator

With the above considerations, the stability component’s integration with the off-piler structure will be through a clamping assembly which can be seen in Figure 32.

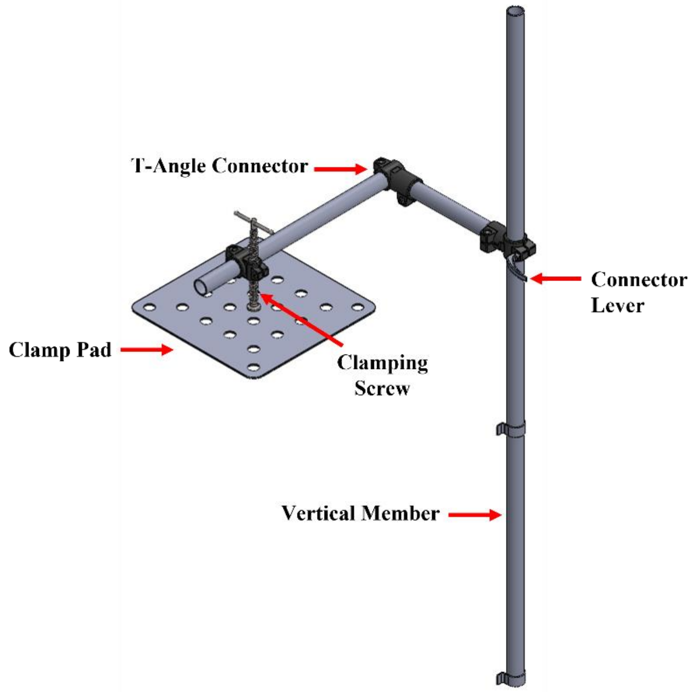

Figure 32: Clamping Assembly Terminology

To function, the clamp pad and supporting members slide vertically along the vertical tube member. By loosening the T-angle connector lever approximately 1/4-1/2 turn while holding a support member, the clamp assembly can be slid down to rest on top of the pile [20]. After tightening the T-angle connector, the clamping screw can be rotated, providing sufficient clamping force through the pad to fix the location of the carton pile. The swivel end of the screw was implemented to reduce the possibility of the pad rotating and damaging product while being forced to clamp the pile.

To limit complexity, this design implements 30mm OD tubing with a 2mm wall thickness, similar to the base model frame. To conserve weight for ease of operator adjustment, the two horizontal members and clamping pad are made of aluminum 6060 alloy material instead of common carbon steel. The T-angle tube connectors are as well made of aluminum alloy for weight reduction [21]. The clamp pad dimensions were based on outer dimension of common 8UP carton piles to cover maximum surface area without overhanging onto different piles. Length and width dimensions of the pad are 12” x 12”.

The maximum carton pile height was provided by our client to be 42”. Considering the carton pile height with the addition of the pallet height, the stability mechanism will accommodate a maximum carton pile height off the ground of 49”. The vertical tube member is then 55” in length which was selected to accommodate the maximum height of carton piles, while providing additional length for the threaded clamp pad adjustment. Fabricated c-clamps are used to mount the clamp mechanism to the off-piler loading assembly; due to the restricted space for fasteners to pass through the side plates.

4.5 Lift

The hydraulic lift system employed by the Global Industrial manual lift stacker will be used for the lift component of the off-piler design. This was decided by the design team to reduce cost, complexity, and time assembling the off-piler. This hydraulic lift system uses a master cylinder to lift a sprocket attached to its rod end, which allows a chain fixed on one end to lift the entire loading sub-assembly vertically. The oil reservoir is contained within a sleeve around the master cylinder [7], as shown in Figure 33.

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Figure 33: Hydraulic Lift Assembly [7]

Manual input is required from the operator by depressing the foot lever shown in Figure 34. This forces hydraulic oil from the reservoir sleeve into the bore end of the cylinder, lifting the off-piler’s loading assembly.

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Figure 34: Lift Mechanism for Base Model [7]

A knob located near the top of the cylinder barrel controls the lifting and lowering cylinder movements and is shown below in Figure 35. By turning the knob counterclockwise, hydraulic pressure is relieved on the bore end of the cylinder which allows the cylinder to be lowered. By turning the knob clockwise, the relieving orifice is closed allowing hydraulic pressure to build when the operator presses the foot pedal, extending the cylinder.

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Figure 35: Lift and Lowering Control Knob [7]

The hydraulic schematic for this lift system can be seen below in Figure 36, with both the lifting cylinder and the operator input cylinder.

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Figure 36: Hydraulic Lift Schematic [7]

In the event the load exceeds it model's maximum rated value of 880lbs, the safety check valve (3) will open when the operator pushes the work cylinder (6), allowing oil to return to the reservoir sleeve without extending the out-pushing cylinder (1). For specified hydraulic oil and lift system maintenance intervals, see the operator's manual in Appendix A.9.

5 Detailed Design

Here the analytical and numerical methods will be discussed in detail. After the results are verified as suitable for the final design, the manufacturing process for the modified parts and the failure modes and effects analysis will be described below.

5.1 Analytical Method

All equations can be found in Shigley's Mechanical Engineering Design [22]. To determine the force reactions along the design, a summation of moments and forces are needed through the static equations as provided in Equation 1.

$$\sum F_X = 0\,, \sum F_y = 0\,, \sum M_{@point} = 0 \tag{1}$$

To find the normal stress due to axial forces, the force, $F\ [N]$ acting on a member is divided into its cross-sectional area, $A\ [m^2]$ as seen in Equation 2.

$$\sigma = \frac{F}{A} \tag{2}$$

To find the bearing stress due to axial loads, the load, F [N] acting on a cylindrical is divided into the bearing's thickness. t [m], and the cylinder's diameter, d [m].

$$\sigma_b = \frac{F}{td} \tag{3}$$

To find the normal stress due to bending, Equation 4 is used where M $[Nm]$ is the moment, c $[m]$ is the distance from the neutral axis, and I $[m^4]$ is the moment of inertia.

$$\sigma = \frac{Mc}{I} \tag{4}$$

The moment of inertia of a cylindrical object can be calculated through its mass *m* [kg], its diameter *d* [m], and its length *L* [m].

$$I = \frac{m}{48}(3d^2 + 4L^2) \tag{5}$$

The maximum deflection due to bending when the load is applied at the center of the beam is determined through the load P [N], length L [m] of the material subjected to the load, the material's modulus of elasticity *E* [Pa], and the material's moment of inertia *I* $[m^4]$.

$$\delta_{maximum} = \frac{PL^3}{48EI} \tag{6}$$

The second moment area is used to determine the used in the calculation of the beam's deflection and the calculation of stress caused by a moment applied to the beam where *b* [m] is the width and *h* [m] is the depth.

$$I = \frac{1}{12}bh^3 \tag{7}$$

The maximum deflection of a beam is calculated using Equation 8. All the variables are identical as described in Equation 6.

$$\delta_{maximum} = \frac{PL^4}{8EI} \tag{8}$$

5.1.1 ACME Screw

This section will determine a viable ACME screw diameter through a series of moment and stress calculations starting with the preliminary bearing stress acting on the ACME screw by the loading arm. The analysis then leads to the maximum deflection when the off-piler arm is configured at the middle of the screw length, to ensure that the chosen screw would not fail by deflection during maximum loading operation. The analysis will start with a force free body diagram, as shown in Figure 37 and Figure 38, to determine the maximum force acting on the thread.

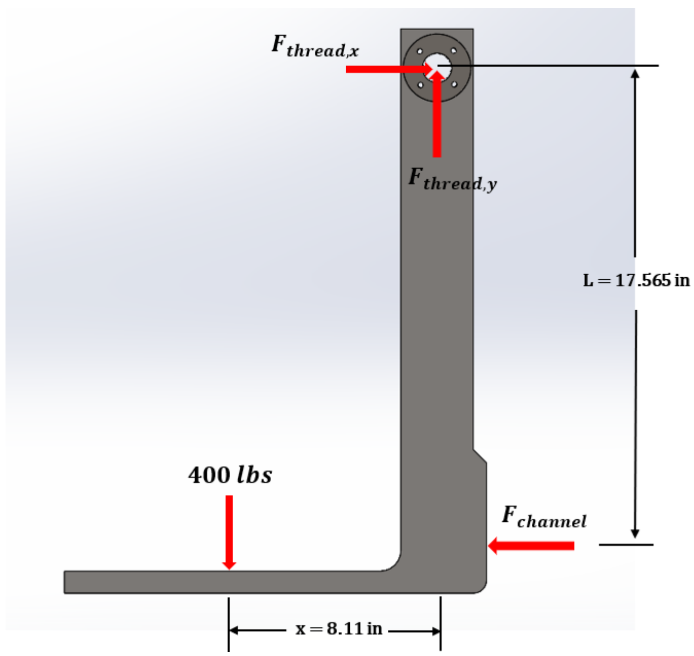

Figure 37: Maximum Load Free Body Diagram

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Figure 38: Resulting Force Acting on ACME Screw

Here we assume the maximum design load of 800 lbs. is distributed evenly between the two arms, leading to a 400 lbs. load per arm. We also assume that the load is evenly distributed along the length of the arm and thus can act as a point load at half the distance as shown in Figure 37. With this, a summation of moments about the adjustable width thread location results in:

$$\sum M_O = 0:\ F(x) - F_{channel}(L) = 0 \Rightarrow F_{channel} = F\left(\frac{x}{L}\right) = 400\left(\frac{8.11}{17.565}\right)$$

$$F_{channel} = 184.69\ lbs$$

After obtaining the force acting on the bottom support tube, both the y-component and x-component of the force acting from the adjustable width thread can be found:

$$\sum F_y = 0:\ -F + F_{thread,y} = 0 \Rightarrow F_{thread,y} = F = 400\ lbs$$

$$\sum F_x = 0:\ -F_{channel} + F_{thread,x} = 0 \Rightarrow F_{thread,x} = F_{channel} = 184.69\ lbs$$

This can be simplified to a resultant force acting at θ degrees from the horizontal axis.

$$F_{thread,resultant} = \sqrt{184.69^2 + 400^2} = 440.58\ lbs$$

$$\theta = \tan^{-1}\left(\frac{F_{thread,y}}{F_{thread,x}}\right) = \tan^{-1}\left(\frac{400}{184.69}\right) = 65.22°$$

The resultant force of 440.58 lbs can then be converted into Newtons:

$$(440.58\ lbs) * \left(0.453592\frac{kg}{lbs}\right) * \left(9.81\frac{m}{s^2}\right) = 1960.47\ N$$

Using the yield strength of the chosen alloy steel material of $\sigma_{yield} = 620{,}422{,}000$ Pa and the mounting nut thickness of t = 1.25” (0.03175 m), Equation 3 can be used to determine the minimum diameter of a lead screw considering bearing stress:

$$d_{minimum} = \frac{F_{thread,resultant}}{t * \sigma_b} = \frac{1960.47}{0.03175 * 620422000} = 9.99x10^{-5}\ m$$

$$d_{minimum} = 0.0999\ mm = 0.003918\ in$$

As observed from the calculations, the minimum diameter was found to be significantly small indicating that the thread will not fail due to bearing stress if nominal sizes are selected. To further analyze, the maximum deflection of the ACME screw will be considered when the off-piler arm is configured at the middle of its adjustable width travel, theoretically resulting in the maximum stress and deflection.

Substituting the calculated thread force of 1960.47 N, screw length of 14.27” (0.362 m), and modulus of elasticity of alloy steel of 2.1×10^{11} Pa into Equation 6, along with the moment of inertia for a cylinder from Equation 5, the screw diameter can be obtained as the remaining variable. The maximum deflection of the ACME screw is plotted along a series of diameters from 0.1” to 2” using the MATLAB code from Appendix A.7 to obtain a range of deflection values as shown in Figure 39.

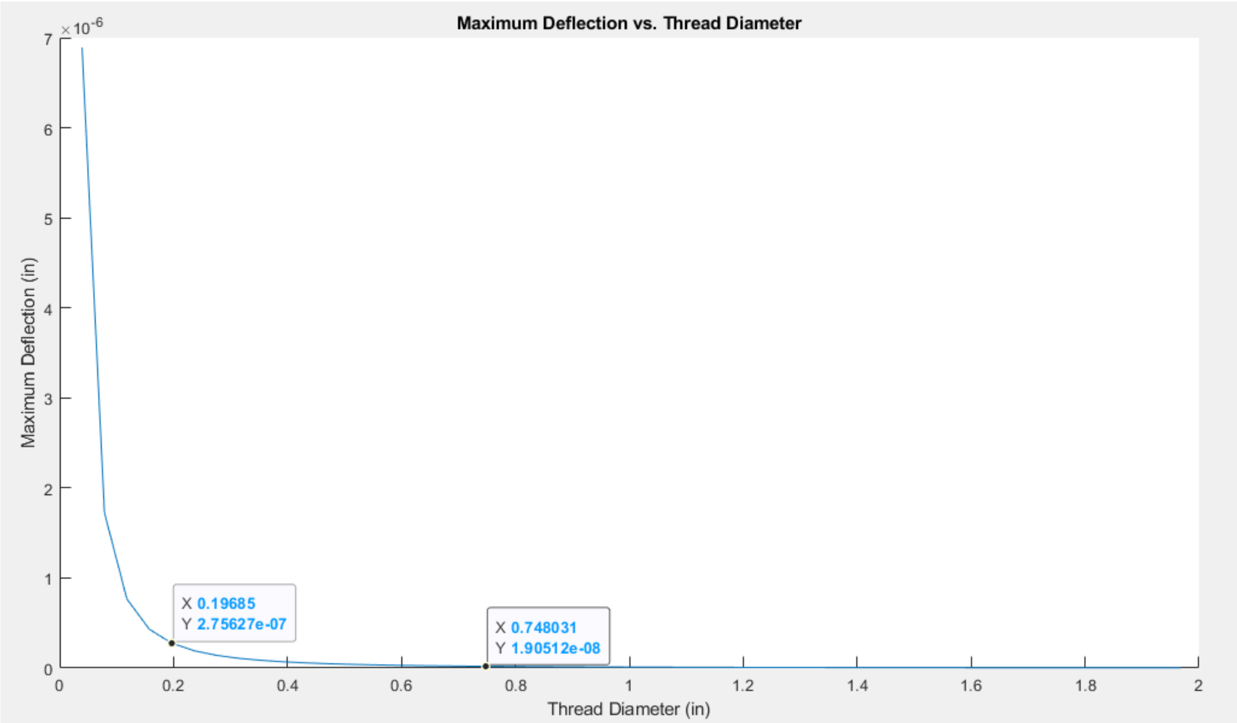


Figure 39: Maximum Deflection Along a Series of Screw Diameters

As observed from the plot in Figure 39, the maximum deflection experienced by the ACME screw during maximum loading conditions is significantly low for diameters greater than 0.60". Due to this, the design team will select an ACME screw diameter of ¾" as it is the next available nominal size with high availability of materials, varying lengths, and high TPI values. Here the analytical results predict approximately 1.9×10^{-8}" of deflection.

The selected threaded rods for the adjustable width component are ¾"-8 Left Hand and Right Hand Alloy Steel ACME screws [23] [24], implying a ¾" O.D. with 8 threads per inch. For further stress and deflection validation, a Finite Element Analysis has been performed in Section 5.2.1 to validate the screws capability of withstanding the maximum load without failure due to deflection.

5.1.2 Off-piler Arms

In Figure 40, the area in cyan blue with width and height of b and h is the dimension of the arm blade. This section will be placed in the groove of the pallet. From Equation 7, the deflection resistance can be maximized due to the cubic exponent of the height. From that, the team concluded the value of the height must be at an optimal length.

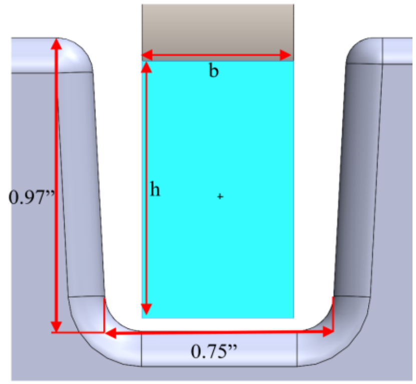


Figure 40: Arm Blade Dimensions.

The optimum width of the blade is 0.5". This width can be neither larger nor smaller than 0.5. Because with a larger value, the height will be smaller due to the contact with the fillet of the groove; and with a small value, the strength of the fork will be poor. Also, to ensure no product will get damaged by sliding the fork blade onto the groove, a clearance of 0.12" is needed. Finally, the blade width and height are selected to be 0.5" and 0.85". The second moment of area and the maximum deflection are:

$$I = \frac{1}{12} bh^3 = \frac{1}{12} \times 0.5 \times 0.85^3 = 0.0256\ in^4 \approx 1.065 \times 10^{-8}\ m^4$$

$$\delta_{maximum} = \frac{PL^4}{8EI} = \frac{1780 \times 0.03272^4}{8 \times 2.05x10^{11} \times 1.065x10^{-8}} = 0.001168\ m = 1.168\ mm = 0.046"$$

The maximum deflection of the arm blade is calculated as 0.046”. This maximum deflection will be validated again with more accurate result, from the simulation shown in Section 5.2.2.

5.1.3 Loading Assembly

This section will consider the maximum loading scenario to determine forces acting on the loading assembly to serves as a base for numerical analysis in Section 5.2.3 to 5.2.6. Since the loading assembly supports the forces acting through the arm from the carton pile weight, the forces resisting movement of the arm by the loading assembly will be analyzed; mainly the bottom tube and side support plates.

As calculated in Section 5.1.1 the force acting on the lower channel from one loading arm is $F_{channel} = 184.69\ lbs$. Since both arms provide a force which acts on the lower channel, the maximum force exerted through the lower channel is expressed in Figure 41.

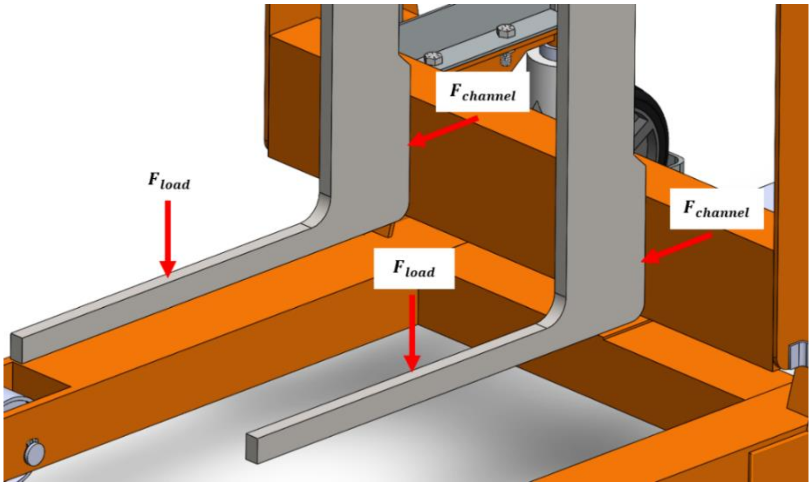


Figure 41: Forces Acting Though Bottom Tube.

This implies the total force acting on the lower tube from the maximum loading conditions is:

$$F_{channel,total} = 2(F_{channel}) = 2(184.69) = 369.38\ lbs$$

This value will be implemented in Section 5.2.3 for numerical analysis of the lower support tube to validate the selected height, width, and wall thickness.

Considering a front view shown in Figure 42, the arm load will be transmitted through the ACME screws to the center support bracket and side plates. A free-body diagram of the resulting forces from the maximum load acting on the top loading assembly is shown below.

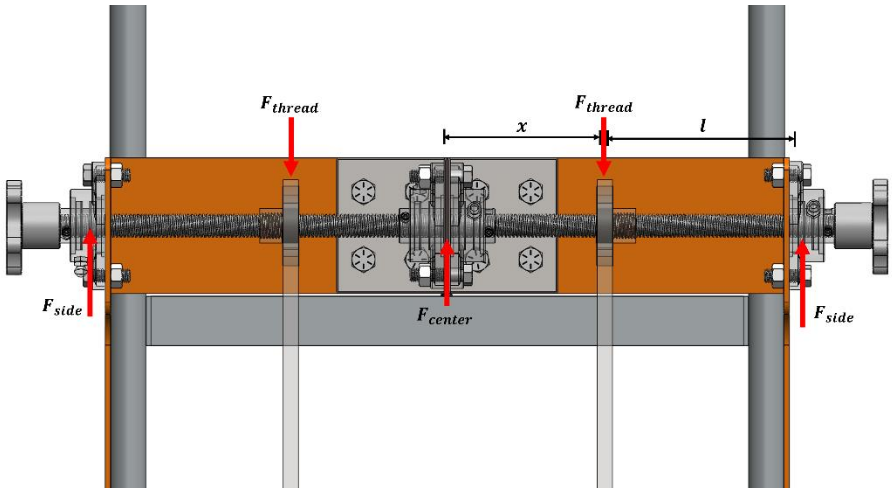


Figure 42: Resulting Forces Acting on Top Loading Assembly.

Similar to the analytical results obtained for the ACME screw, we will consider one half of the loading system, with the loading arm positioned at a distance x from the center support bracket and distance l from the side plate as shown in Figure 42. Here F_{thread} represents the resultant thread force calculated in Section 5.1.1. The following moment balance about the side plate for one loading arm is shown below using Equation 1.

$$\sum M_{side} = 0: -F_{thread}(l) + F_{center}(x+l) = 0 \Rightarrow F_{center} = F_{thread}\left(\frac{l}{x+l}\right) \tag{9}$$

Using Equation 1, a force balance in the positive y-direction can determine the side plate force required to support the loading arm by substituting in Equation 9.

$$\sum F_y = 0: F_{side} - F_{thread} + F_{center} = 0 \Rightarrow F_{side} = F_{thread}\left(1 - \frac{l}{x+l}\right) \tag{10}$$

For maximum loading on the side plate, the team considers the widest pallet groove configuration (Case 1 from Figure 20), which would locate the thread force closest to the side plates. This results in $x = 8.13"$, $l = 2.93"$ with respect to Figure 42. Using Equation 10, the side plate force due to the maximum loading scenario is calculated below.

$$F_{side} = F_{thread}\left(1 - \frac{l}{x+l}\right) = 440.58\left(1 - \frac{2.93}{(2.93 + 8.13)}\right) = 323.86\ lbs$$

For maximum loading on the center support bracket, we will consider the narrowest pallet groove configuration (Case 3 from Figure 20), which would locate the thread force closest to the center bracket. The resulting distances are $x = 2.68"$, $l = 8.24"$. With Equation 9, the center support bracket force can be obtained for the described loading case.

$$F_{center} = F_{thread}\left(\frac{l}{x+l}\right) = 440.58\left(\frac{8.24}{2.68+8.24}\right) = 332.45\ lbs$$

The calculated forces acting on the loading assembly will be used in Section 5.2 to determine stresses acting through each component and validate the chosen parameters.

5.2 Numerical Method

The Finite Element Analysis (FEA) simulation was performed on SolidWorks which is a useful tool that allows the team to further gain confidence in the results obtained from the hand calculations. The stress values obtained through the FEA results will be directly compared to the stress values obtained analytically and discussed. Also, FEA studies could be performed to validate the deformation on the bending case to gain further confidence and control the safety level before failure.

5.2.1 ACME Screw

An FEA simulation was performed on the ACME screw to support the analytical calculations from Section 5.1.1 using the maximum loading condition of 800 lbs. with the loading arms positioned in the center of their adjustable travel width. Both ends are fixed to represent the bearing supports seen in Figure 19. The resultant force acting on one screw was calculated as 440.58 lbs. from Section 5.1.1. To run the simulation, a bearing load resolved in the x and y axis applied at the center as shown in the Figure 43. The center of the thread was extruded as a solid cylinder to simulate its bearing contact with the mounting thread nut and to create a surface to simulate the bearing load. The resolved forces are:

$$F_{thread,y} = 1961 * \sin(65.22°) = 1781\ N$$

$$F_{thread,x} = 1961 * \cos(65.22°) = 822\ N$$

The forces are then applied as bearing loads as shown in the figure below:

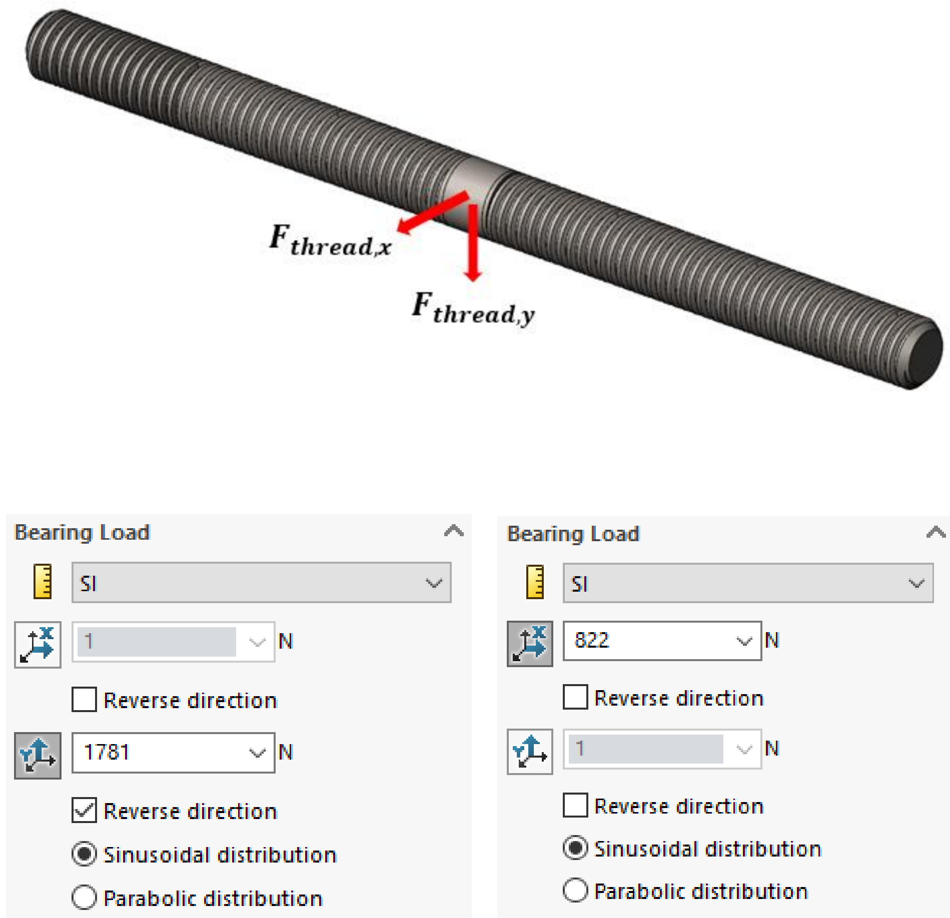


Figure 43: ACME Screw Bearing Load Application.

To guarantee the accuracy of the simulation, a blended curvature-based mesh with fine mesh density was used. The analysis was performed, and both the resulting maximum stress and deflection are shown in the Figure 44 and Figure 45.

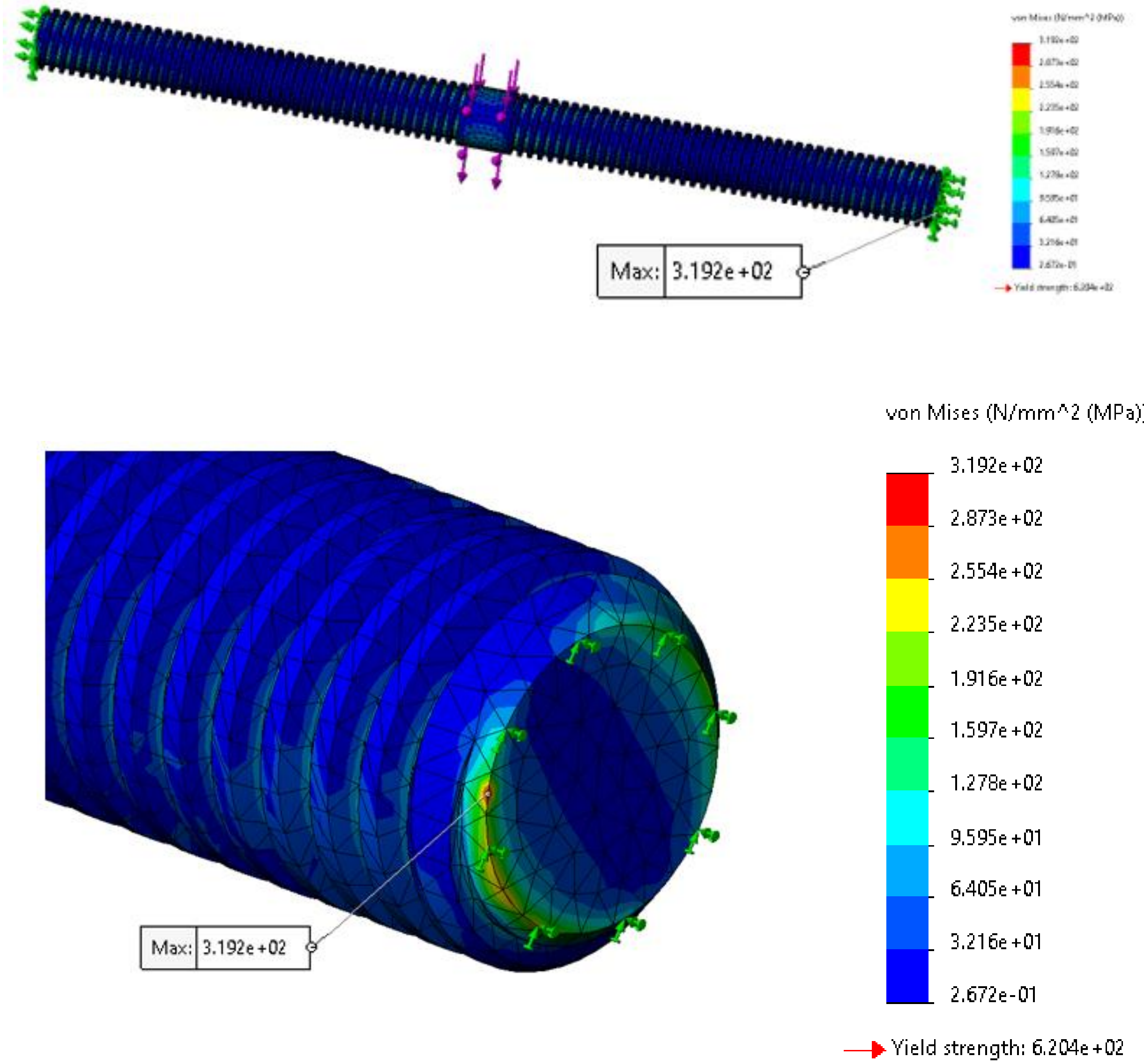


Figure 44: ACME Screw Maximum Stress.

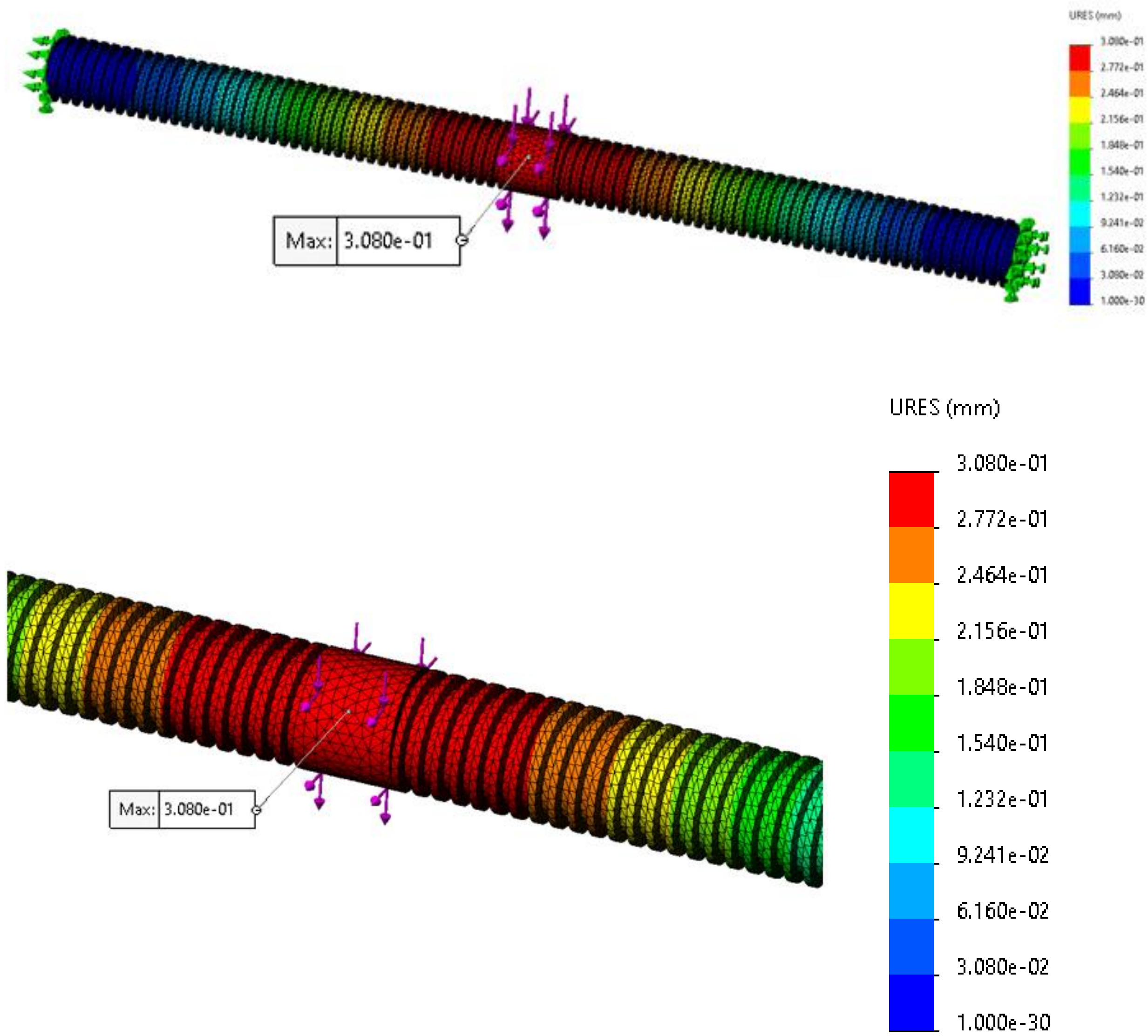


Figure 45: ACME Screw Deflection Results.

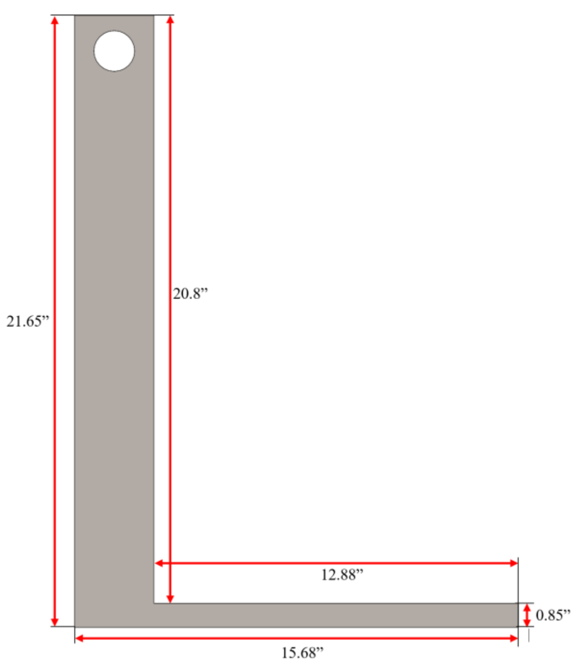
As observed from the finite element analysis results from Figure 44 and Figure 45, the maximum stress observed was 319.2 MPa and was concentrated at the fixed end of the thread, and the maximum deflection was 0.308 mm and was observed at the center of the thread. The maximum stress states a lower value than the alloy steel's yield strength indicating it is safe from yielding with a minimum factor of safety of 1.944. The maximum deflection is significantly low and can be classified as negligible.

After performing the analytical and numerical analysis, it has been shown that the stress and deflection due to the maximum load is negligible for the chosen thread size of ¾”-8 which is safe from failure due to yielding or deflection.

5.2.2 Off-Piler Arms

The stress calculation of the off-piler arms cannot be performed in the analytical method as the geometry is not suitable and the stress concentration factor (K_t) is not able to be found. Hence, FEA simulation will be used to validate the stress concentration and maximum deformation when the load is applied.

One arm is used to simplify the simulation. Then the force applied on an arm will be half of the 800 lbs. maximum load. To set up the FEA, a simple L-shaped part was modelled using SolidWorks software with the dimensions shown in Figure 46. The arm blade with a length of 12.88” was applied to a distributed force of 400 lbf. Two different fixtures were used which are slider and fixed geometry. The slider fixture and the fixed geometry were applied to the location where the arm will move sideways when it is adjusted, the back of the arm area where it will be supported by the lower support tube that is shown in Figure 25. Figure 47 shows the distributed load as illustrated by the pink arrows and the two fixtures by the green arrow. The mesh type that was used is the blended curvature-based mesh with fine mesh density. This mesh combined different types of mesh, and the fine density will increase the accuracy of the simulation.



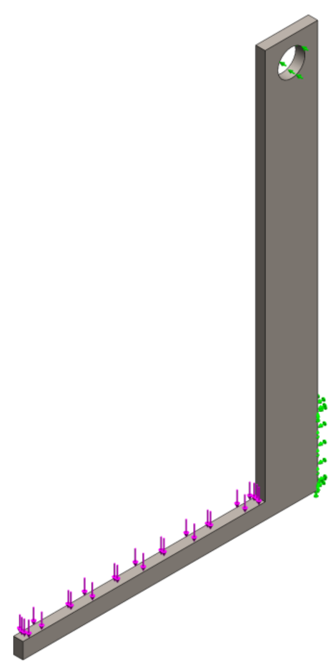


Figure 46: Dimensions of The Arm.

Figure 47: FEA Simulation Setup of The Arm.

Since the stress at the corner between the blade and the shank is high (~ 437.3MPa) for AISI 4340, the team added a fillet to reduce the stress. Different fillet radius dimensions will be tested to optimize the stress and the deformation of the arm. Table VIII shows the result of stress and the deformation with different fillet dimensions. As the fillet increases the deformation is greater, but the incremental change is not significant.

Table VIII: Maximum Stress and Deflection at Different Fillet Size.

Fillet Radius Dimension (mm)	**Maximum Stress (MPa)**	**Deflection (mm)**
N/A	437.3	4.203
10	414.8	4.461
20	366.8	4.671
30	347.6	4.861

For further optimization, two extended portions from the front and back of the arm are indicated as cyan blue area shown in Figure 48. The front extension is used as a support to the back of the load so that the bottom of the product will not be damaged by hitting the curvature of the fillet. The back extension prevents the swinging motion when the arm is loaded.

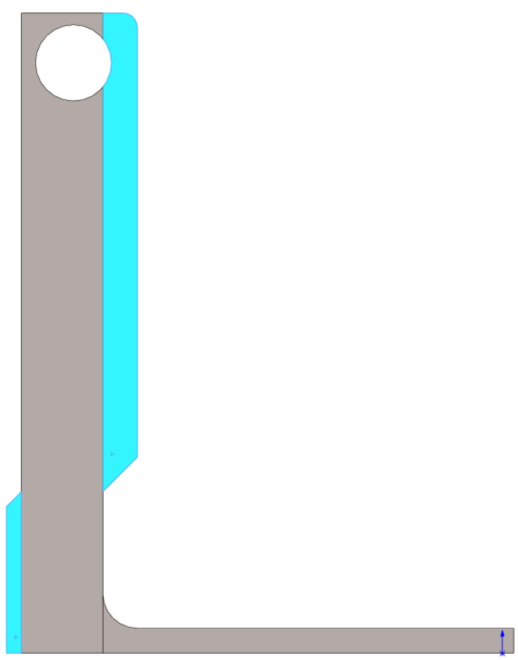


Figure 48: Extended Support Section.

According to the FEA study, the maximum stress at the load of 400lbf was found to be 347.9 MPa which is under 710 MPa yield strength of the AISI 4340 Steel (normalized). Hence, the part is not expected to yield. The safety factor of 2.04 is calculated by using the yield stress divided by the maximum stress. The area that experienced the highest stress is the location of the fillet where the blade and the shank intersect. Figures 49 and 50 illustrate the maximum stress and maximum deformation of the 400 lbs. load.

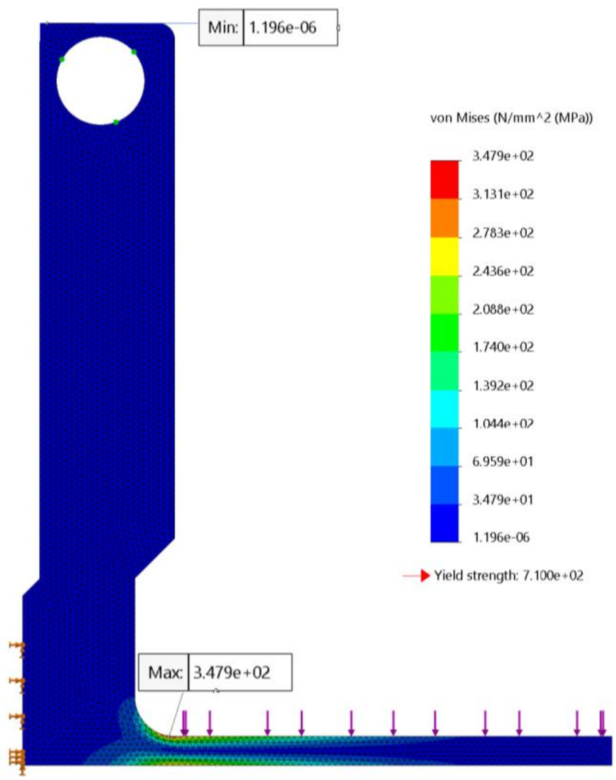


Figure 49: FEA Result for Stress Across The L-Shaped Part with 400 lbf. Load.

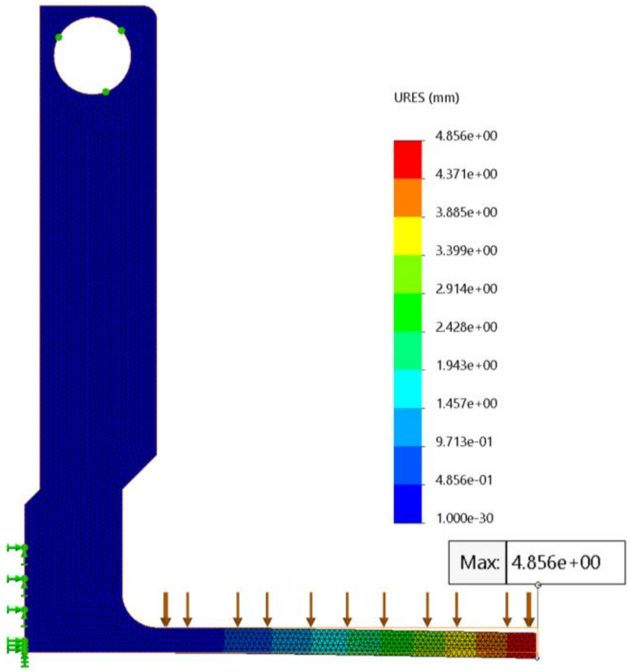


Figure 50: FEA Result for Deformation Across The L-Shaped Part with 400 lbf. Load.

5.2.3 Lower Support Tube

A finite element analysis using SolidWorks was performed to validate the strength capacity of the lower support tube when a distributed load of 184.69 lbs., as analytically calculated from section 5.1.3, is acting on it. Both ends of the lower support tube have been fixed in the simulation, and the distributed load of 184.69 lbs. is applied to the off-piler arm contact sections as shown in Figures 51 and 52 below. To increase the accuracy of the results, a curvature blended mesh with a fine mesh density was used in the analysis. Here the maximum stress and deflection results are then summarized.

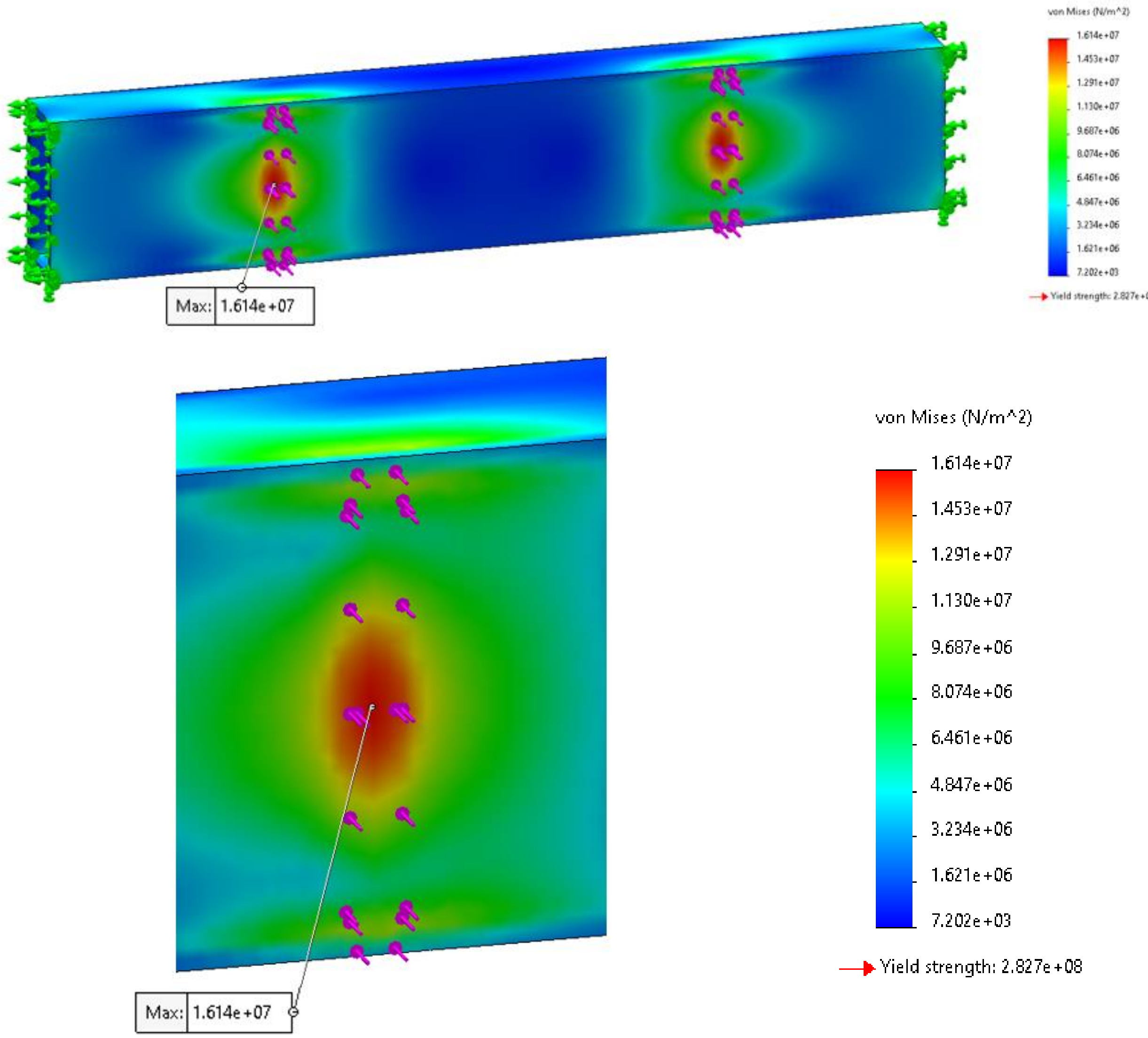


Figure 51: Lower Support Tube Maximum Stress Results.

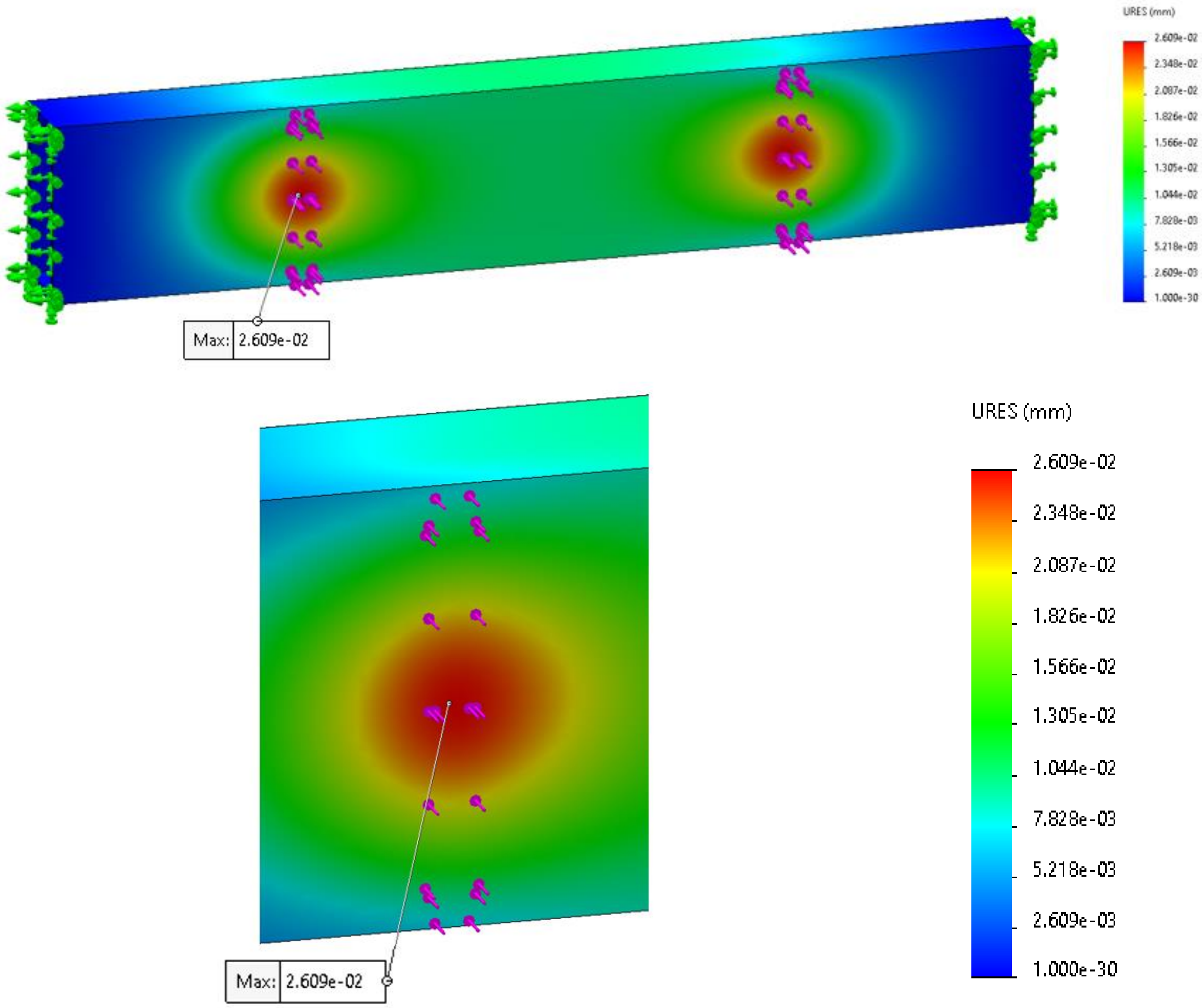


Figure 52: Lower Support Tube Deflection Results

As observed from Figure 51, the maximum stress is concentrated on the center location of the distributed load, which is the off-piler arm contacts the tube. However, the maximum stress experienced by the lower support tube due to the distributed load of 16.14 MPa is significantly smaller than the yield strength of carbon steel of 282.7 MPa. In addition, the maximum deflection of 0.02609 mm, as observed from Figure 52, is concentrated at the same location as the maximum stress. However, the maximum deflection of 0.02609 mm is negligible and significantly below yielding conditions. Therefore, it will not affect the off-piling process and is not of a concern for failure. The model’s minimum factor of safety is 17.51, which is a significantly high value. With these results, the lower support tube is safe from failures due to stress and deflection during maximum loading operation.

5.2.4 Upper Support Tube

Similar to the lower support tube, a finite element analysis has been performed on the upper support tube to validate its safety and strength capacity during the maximum loading operation. By fixing both ends of the tube as fixed structures, a doubled force of 1480 N, as calculated from section 5.1.2, is applied on the center of the tube to act as the force transmitted from the center support bracket during maximum loading. Using a fine blended curvature mesh and a fine mesh density, the simulation was performed to calculate the maximum stress and maximum displacement as shown in the figures below.

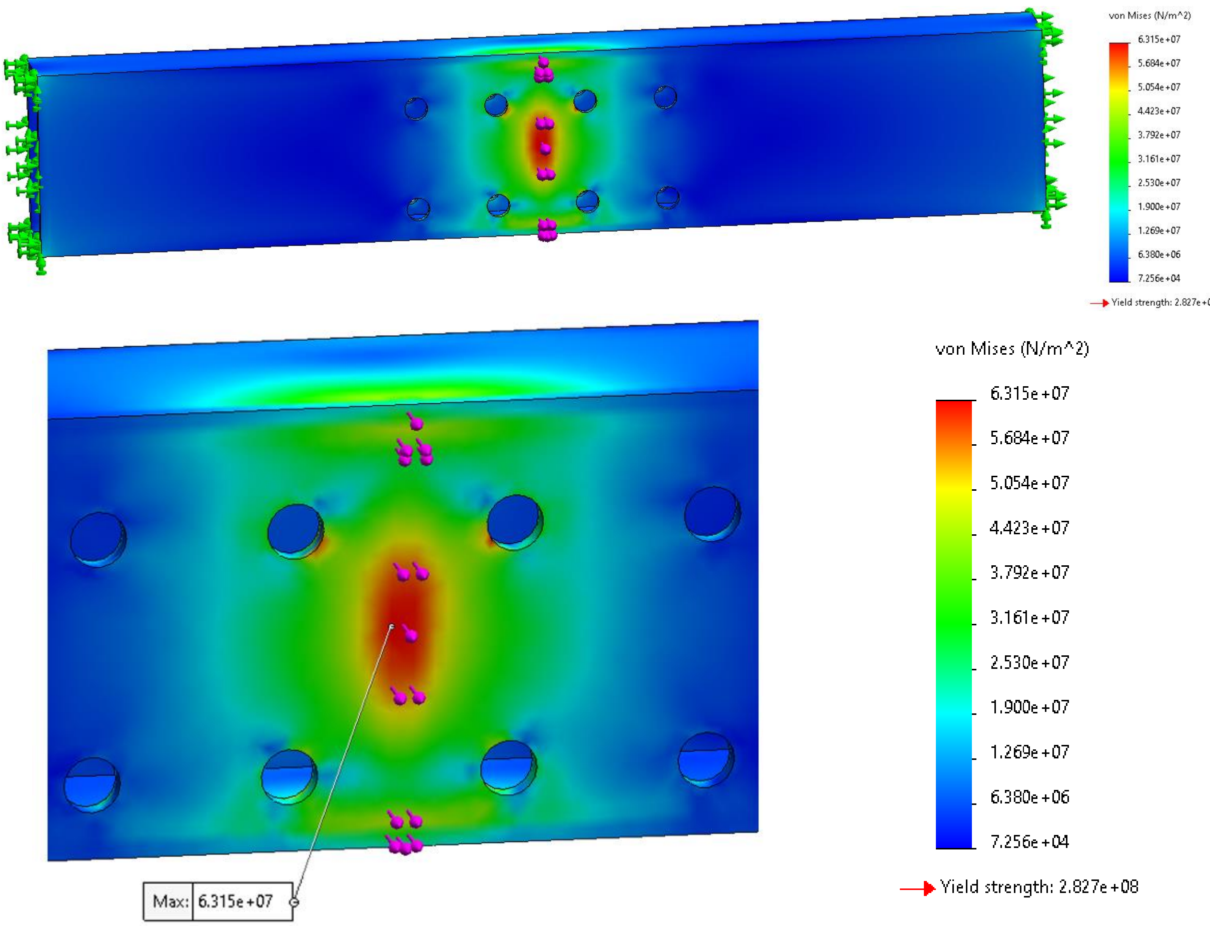


Figure 53: Upper Support Tube Maximum Stress Results.

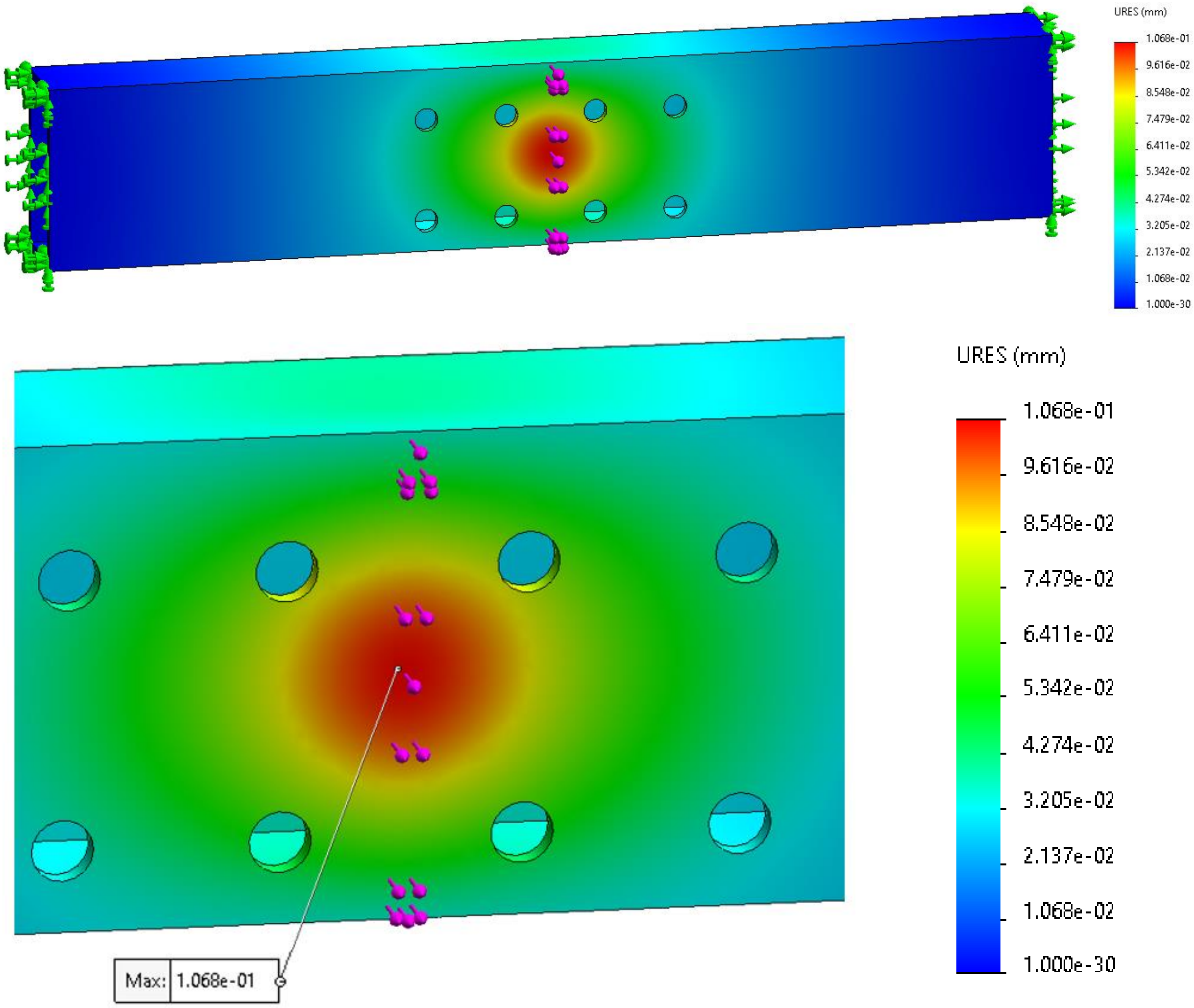


Figure 54: Upper Support Tube Maximum Deflection Results

As observed from Figure 53, the maximum stress experienced by the upper support tube is 63.15 MPa which is significantly lower than carbon steel's yield strength of 282.7 MPa which results in a minimum factor of safety of 4.476. The maximum deflection resulted in 0.1068 mm and was found to be concentrated at the center of the support tube as shown in Figure 54. With these results, and similar to the lower support tube, the upper support tube of the lifting assembly is safe from failures due to stress and deflection during maximum loading operation.

5.2.5 Side Plate

A finite element analysis using SolidWorks was performed to validate the strength capacity of the side plate when a load of 323.86 lbs, as analytically calculated from Section 5.1.3, is evenly distributed on the two bearing mounting holes acting as a coupling force. For each mounting hole, the 323.86 lbs load is halved into 161.93 lbs to act as the magnitude of the bearing load during maximum loading. Surfaces on both upper and lower sections of the plate were simulated as fixed structures to represent the upper and lower support tube connections.

To apply the bearing loads on the model, the 721 N force was resolved into forces in the x and y axis using the angular direction of the force of 65.22°, as calculated from the thread's force free body diagram in section 5.1.1. The resolved forces are:

$$F_{bearing,y} = 721 * \sin(65.22°) = 655\ N$$

$$F_{bearing,x} = 721 * \cos(65.22°) = 303\ N$$

The forces are then applied as bearing loads as shown in the Figures 55:

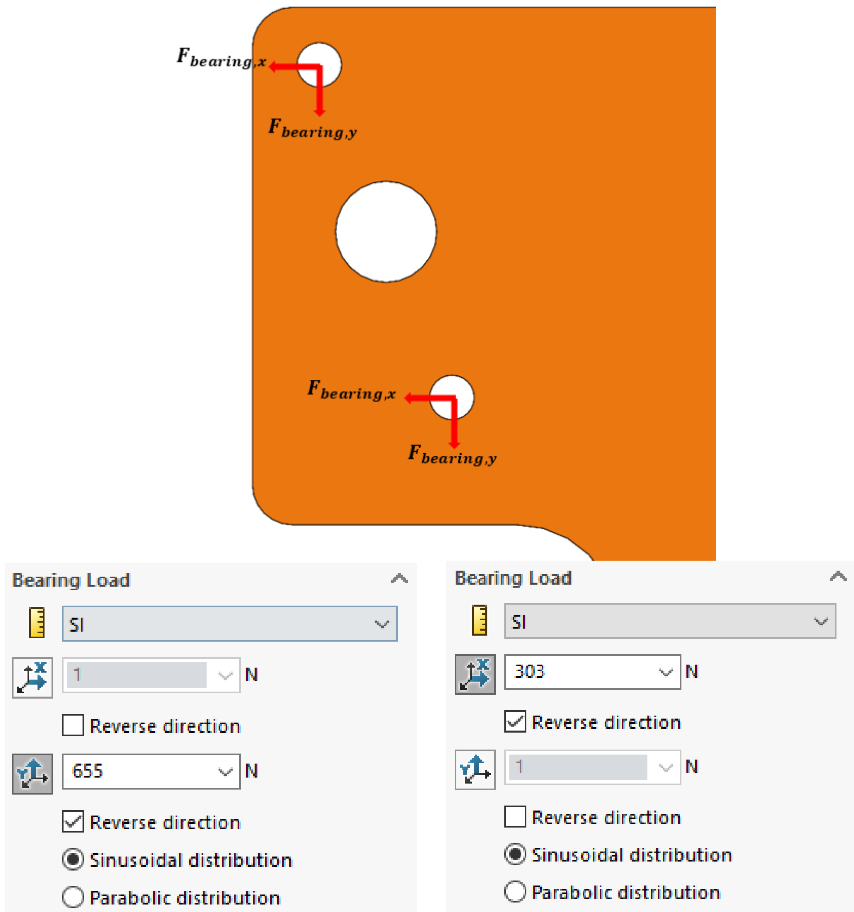


Figure 55: Side Plate Bearing Load Application.

Using a curvature blended mesh with a fine mesh density, the analysis was performed, and the resulting maximum stress and deflection are shown in the figures below.

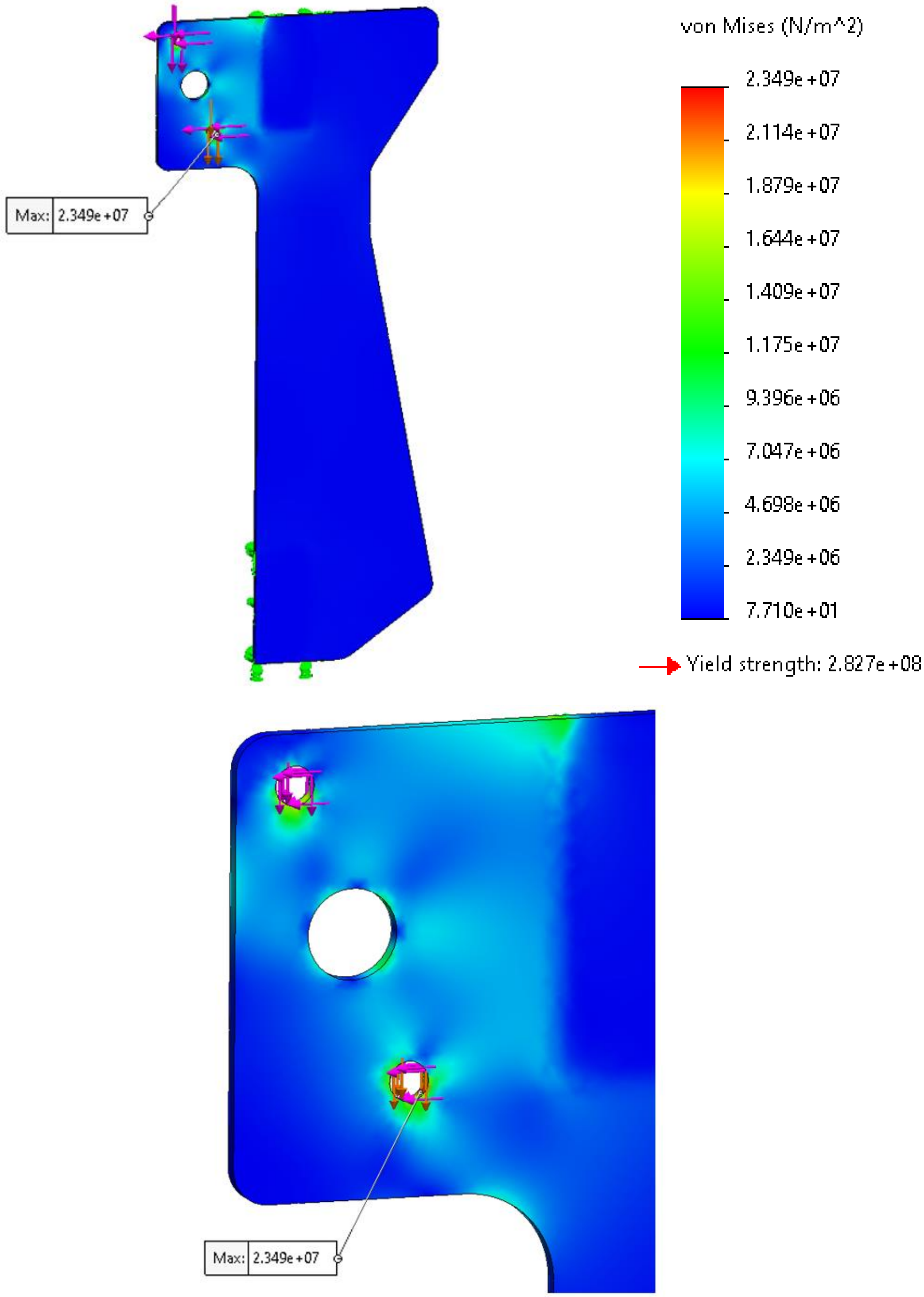


Figure 56: Side Plate Maximum Stress Results.

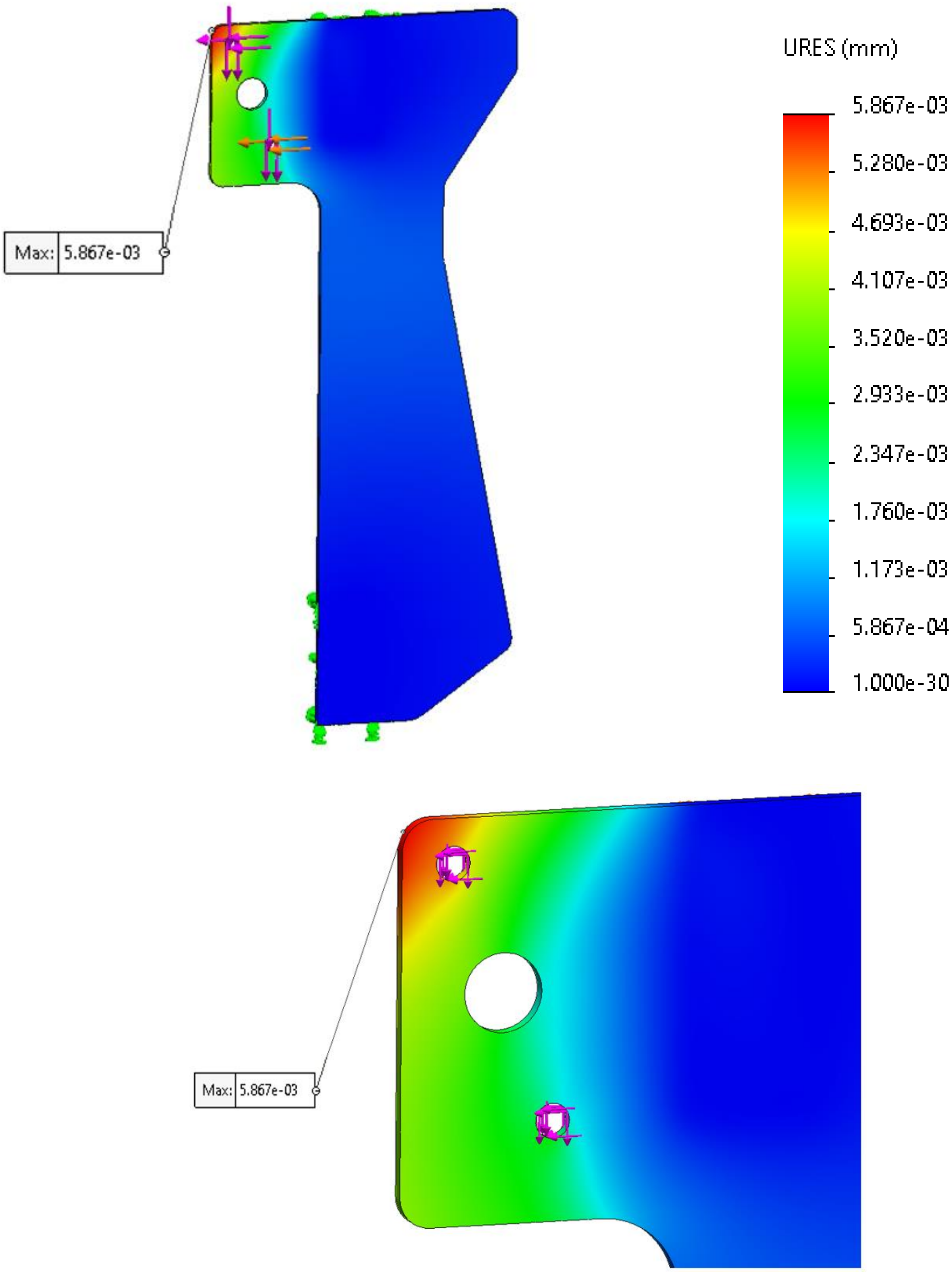


Figure 57: Side Plate Maximum Deflection Results.

As observed from the finite element analysis results from Figures 56 and 57, the maximum stress was 23.49 MPa and the maximum deflection was 0.005867 mm. In addition, the minimum factor of safety was 12.03. The maximum stress states a significantly lower value than the carbon steel's yield strength indicating the component will not fail due to yielding under normal operation. As well the maximum deflection is significantly low and can be classified as negligible, therefore validating the side plate's strength capacity and safety during the maximum loading operation.

5.2.6 Center Support Bracket

To properly align the ACME threads to the side plates of the loading assembly, a center support bracket will be designed and custom manufactured to mount the bearing that will allow the ACME threads to rotate freely when adjusting the off-piler's width. Prior to finalizing the support bracket's dimensions, a finite element analysis will be performed to validate its safety and strength capacity when a center load of 1480 N, as calculated from Section 5.1.3, acting on it as a coupled force. The coupled force is evenly distributed on both mounting bearing holes, therefore resulting into a halved force of 740 N for each bearing mounting hole. To run the analysis, both rear ends of the support were simulated as sliding supports to represent their surface contact to the upper support tube and to the other support bracket. The resolved forces are:

$$F_{bearing,y} = 740 * \sin(65.22°) = 672\ N$$

$$F_{bearing,x} = 740 * \cos(65.22°) = 311\ N$$

The forces are then applied as bearing loads as shown in Figure 58 below.

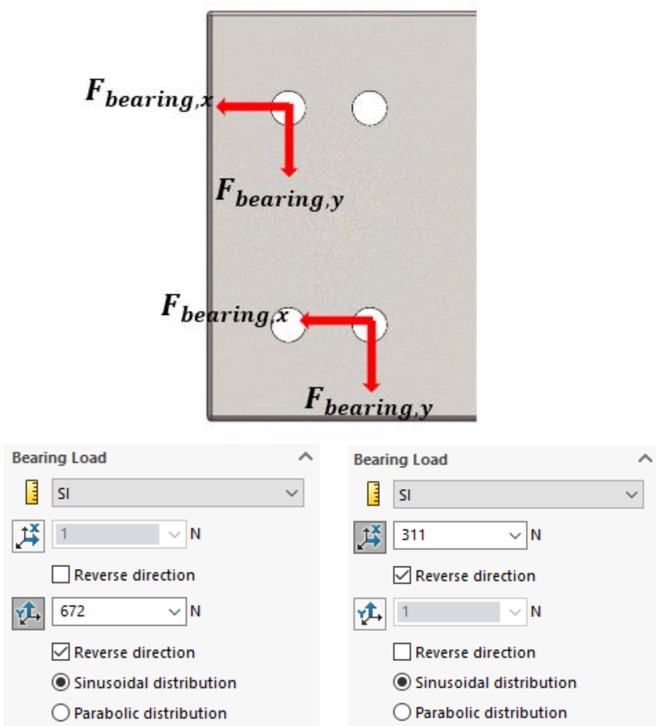


Figure 58: Support Bracket Bearing Load Application.

Using a curvature blended mesh with a fine mesh density, the resulting maximum stress and deflection are shown in Figures 59 and 60 below.

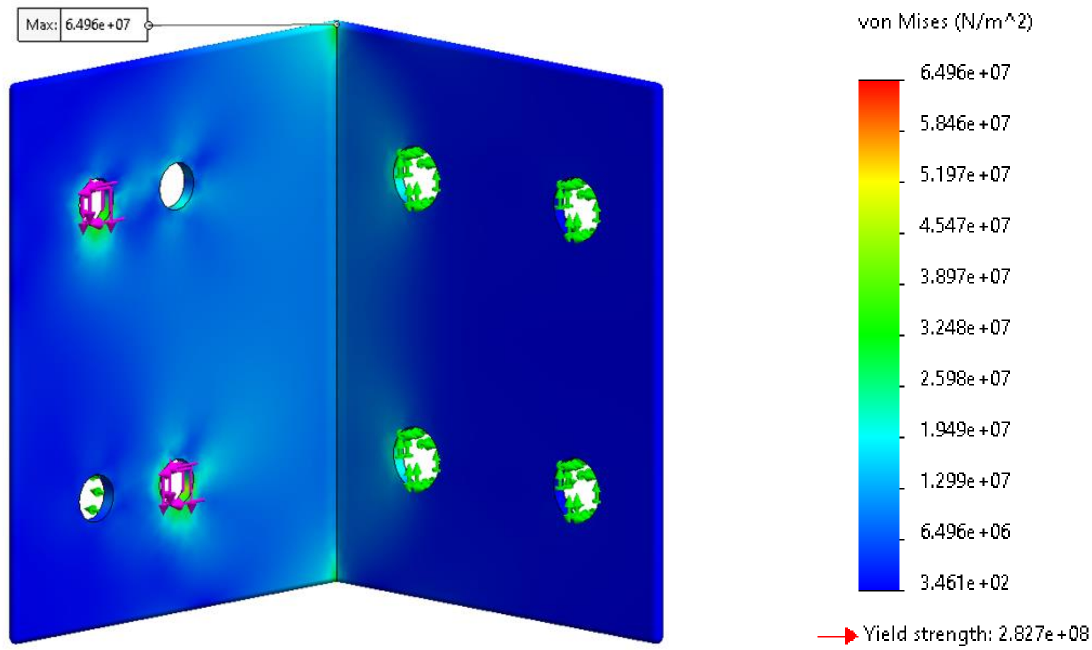


Figure 59: Center Support Bracket Maximum Stress Results.

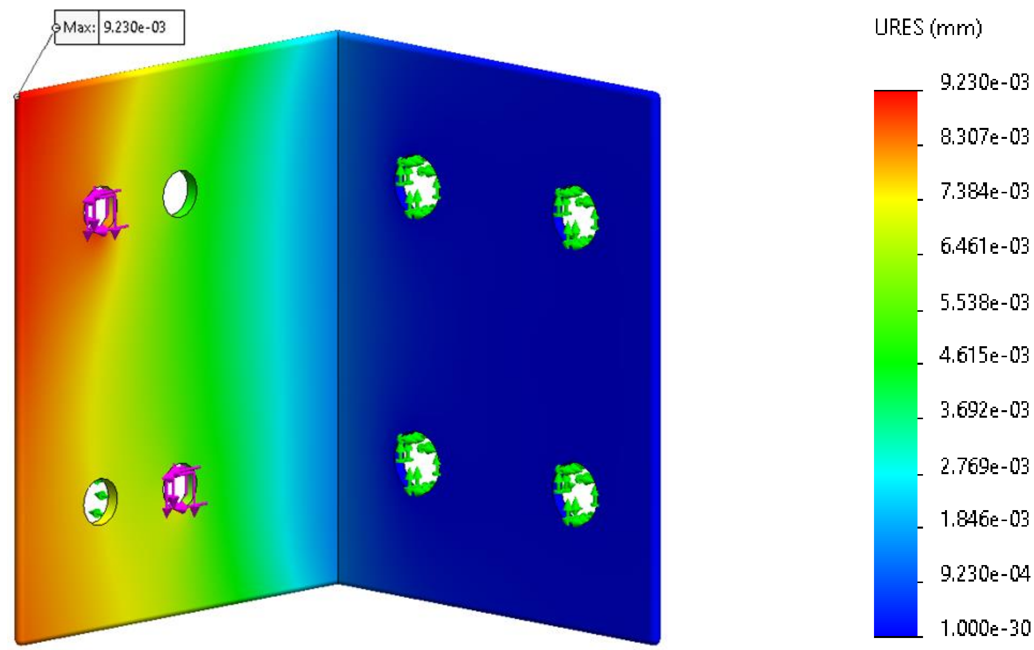


Figure 60: Center Support Bracket Deflection Results.

As observed from the FEA results in Figures 59 and 60, the maximum stress experienced by the support bracket is 64.96 MPa and the maximum deflection is 0.00923 mm at the upper left corner of the bracket. In addition, the minimum factor of safety is 4.352. The maximum stress is significantly lower than carbon steel's yield strength which indicates of source of its high factor of safety. In addition, the maximum displacement is negligible. With these results, the dimensions and material of the center support bracket are safe from yielding and deflection during maximum loading operation.

5.3 Manufacturing Process

This section describes how each subassembly will be manufactured and assembled in detail. Engineering drawings for both individual components and assemblies are included in Appendix A.8.

5.3.1 Off-Piler Arms Manufacturing & Assembly

The loading arms will be laser cut from a 0.5" thick sheet of AISI 4340 Steel Normalized. Cutting material from the sheet ensures the component will have a uniform shape. This eliminates the need to weld the shank and blade components together, and therefore reduces the chances of failure. The ACME flange will be welded onto the off-piler arm, the welding will be performed on both sides to make it more secure as shown in Figure 61. Then the thread will be inserted into the ACME flange. Figure 62 shows the off-piler arms assembly and how the components interact.

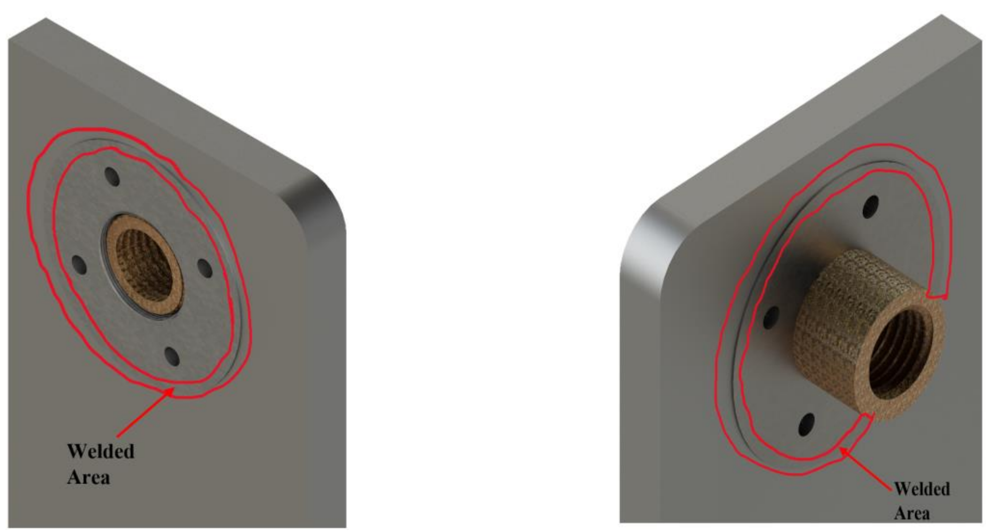


Figure 61: Welded on The Inside (Left) And Outside (Right).

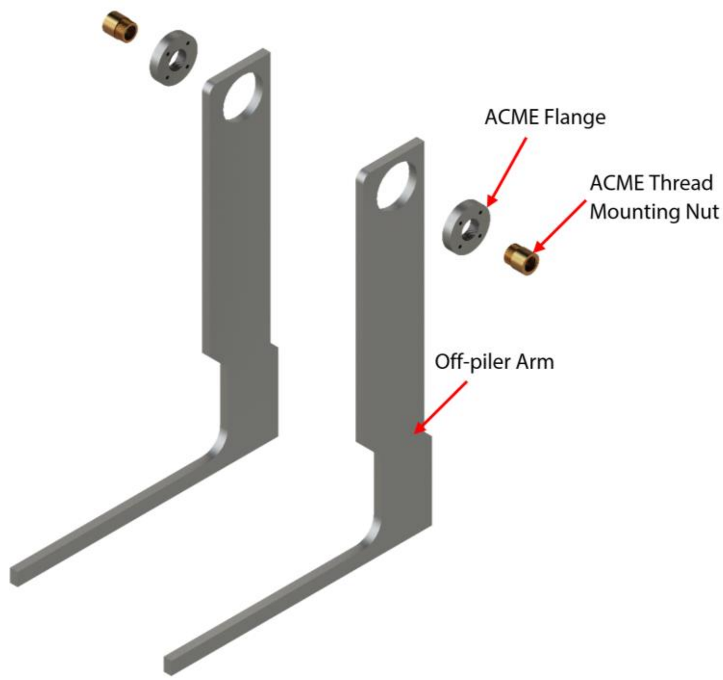


Figure 62: Off-Piler Arms Assembly.

5.3.2 Plate Support Manufacturing & Assembly

The main components of the loading assembly are the side plate, upper and lower support tubes, and the center support bracket as shown in Figure 63. These components require custom manufacturing and are all made of carbon steel. The side plates and the center support brackets are fabricated through laser cutting. The center support bracket will undergo bending to generate its bracket form. The upper and lower support tubes are made of 2” x 4” hollow carbon steel tubes that with 0.188” walls. They will be cut to their specific lengths of 21.945”, as shown in the engineering drawings in Appendix A.8, to fit the sourced base structure’s roller system from Section 4.1.

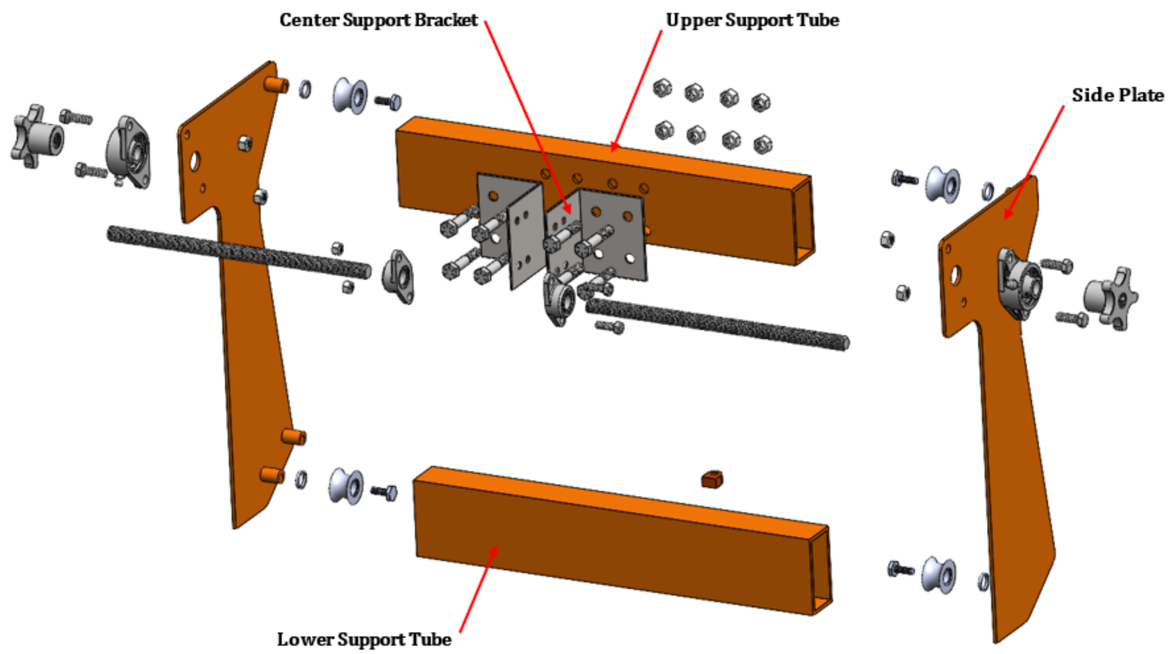


Figure 63: Loading Assembly Exploded View.

After manufacturing the components, both ends of the upper and lower support tubes will be welded on to the side plates as shown in Figure 64. The center support bracket will be bolted on to the upper support tube.

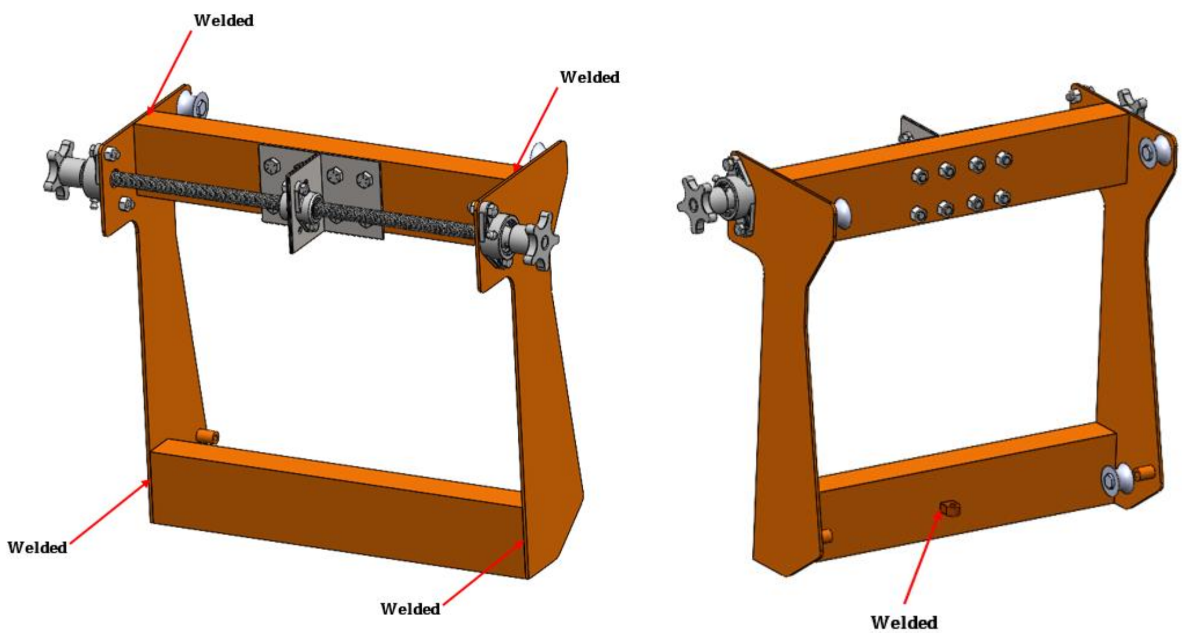


Figure 64: Welding Points.

In addition, a chain lock connection piece will also be welded to the back of the lower support tube to connect with chain built with the base structure, as shown in Figure 65, to connect the loading assembly to the hydraulic lift system.

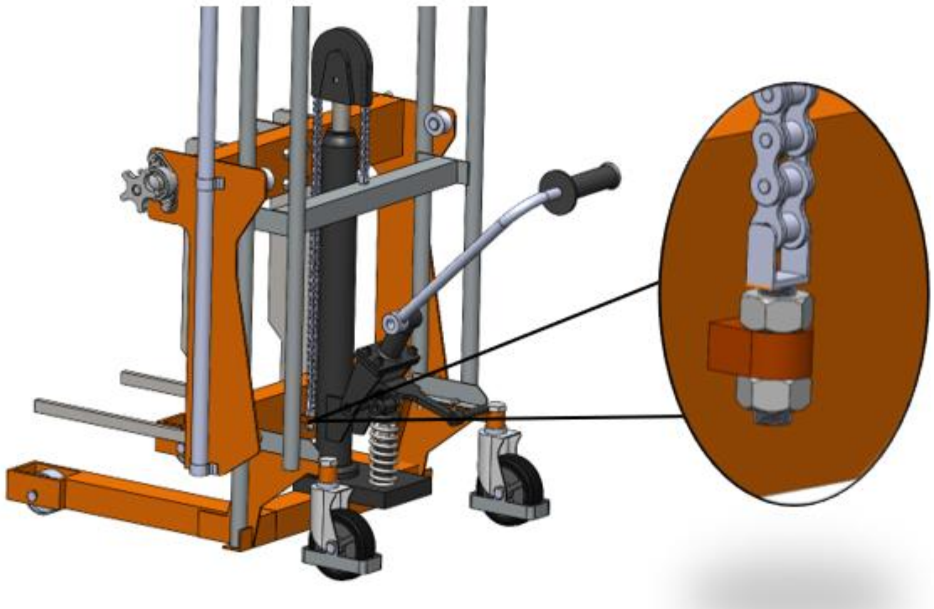


Figure 65: Chain Connection to Lower Support Tube.

Preliminary drawings for each manufactured component in the assembly can be found in Appendix A.8.

5.3.3 Clamp Mechanism Manufacturing & Assembly

The tube members will be cut from Aluminum 6060 Alloy tube stock with 2 mm wall thickness. The vertical member will be cut from 1018 Carbon Steel round tube stock with 3 mm wall thickness. Both the clamp pad and c-clamp weldments will be laser cut, and the weldments will be bent to their final shape.

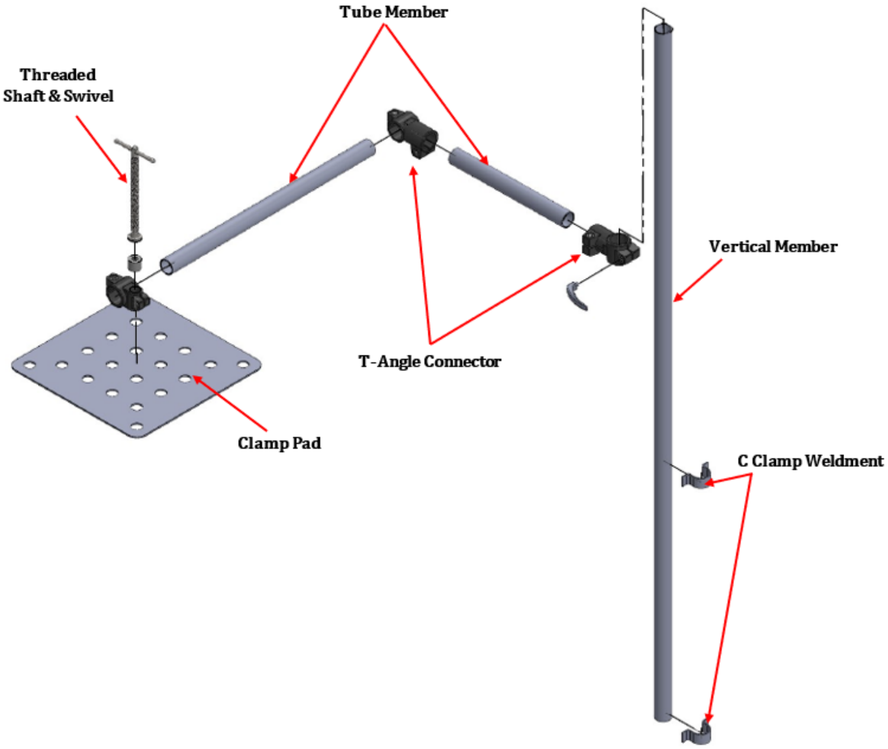


Figure 66: Final Clamp Assembly.

As shown from Figure 66, the c-clamp weldments will be welded to both the vertical tube and loading assembly side plate. Each tube member requires assembly with a T-angle connector clamp. The T-angle connector which slides along the vertical tube requires a connector lever for quick height adjustment of the clamp pad. The threaded shaft and swivel are re-purposed from a C-clamp [25], with the swivel end welded to the center of the clamp pad. Preliminary drawings for each manufactured component in the assembly can be found in Appendix A.8.

5.4 Failure Modes & Effects Analysis

Failure Modes and Effects Analysis (FMEA) is used to identify different possibilities of failure in the design, in order to mitigate or eliminate the risks of these failures. The failure of a design comes from components, assemblies, design systems, or human usage. The FMEA uses Risk Priority Numbers (RPN) to determine how urgent the failure will need interventions to reduce future risk. RPN is calculated by multiplying the severity, occurrence and detection ranking.

Severity ranking describes the consequences of the failure when it happened. Occurrence ranking is used to rank the severity of each failure that may happen. Detection ranking is used to describe the chance of a failure being detected before it occurs. Table IX, Table X and Table XI show the definitions and ranking of each.

Table IX: Severity Ranking and Definitions.

Severity of Effect		**Ranking**
Minor	Unreasonable to expect that the minor nature of this failure would cause any substantial effect on system performance or on a subsequent process or service operation. Customer is unlikely to either notice or care about the failure.	1
Low	Low severity ranking due to nature of failure causing only a slight customer annoyance. Customer will probably notice only a minor degradation of the service performance, or a slight impact on a subsequent action; i.e., some quick, minor rework.	2, 3
Moderate	Failure causes some customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. Customer will experience some very noticeable inconvenience or performance degradation. May cause either delay due to rework or irreversible damage.	4, 5, 6
High	High degree of customer dissatisfaction due to negative impact of the failure such as an inaccurate payroll run, loss of vital data or an inoperable convenience system. Does not involve safety or noncompliance to government regulations. May cause serious disruption to subsequent processing; may require major rework or loss to customer and/or create significant financial hardship.	7, 8
Very high	Failure mode involves serious personal safety hazards, potential for civil litigation or noncompliance with government regulations.	9, 10

Table X: Occurrence Ranking and Definitions.

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

Table XI: Detection Ranking and Definitions.

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

Table XII: Failure Modes and Effects Analysis.

Design Component or Process	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Process Control Prevention	Process Control Detection	DET	RPN
A. Base Structure	1. Braking issues	Operator unable to stop when moving, causing harm or injuries	9	Built up momentum when moving the off-piler	2	Preliminary testing	Physically unable to stop the device	9	**162**
	2. Maneuverability	Operator unable to maneuver device, takes longer time to transfer carton pile to new pallet	6	Rolling over small objects (nuts, bolts, debris)	2	Precautionary scan of transportation path	Visual confirmation from operator	2	24
B. Adjustable Width	1. Pinch points on ACME thread	Hand or finger injury	10	Operator has their hand on the loading arm when adjusting	1	Installing guards over the ACME threads	Operator injury	2	20
	2. Adjustment knob became loose	Unable to rotate ACME thread	2	Set screw loosens	3	Regularly tighten set screws	Physical confirmation from operator	3	18
	3. Thread damage	Increased wear on ACME nut and bearings, possibly unable to adjust forks	7	Poor system design	2	Avoid loading in excess of maximum load	Visual confirmation from operator	4	56
	4. ACME Screws will not rotate	Damage rotation knob set screw	3	Adjusting arm location during loading	4	Avoid width adjustment while forks are loaded	Unable to rotate handles	4	48

Table XII: Failure Modes and Effects Analysis (con't)

Design Component or Process	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Process Control Prevention	Process Control Detection	DET	RPN
C. Loading	1. Component welding failure	Dropping carton pile load	10	Fatigue stress	1	Preliminary testing	Inspection interval	5	50
	2. Unbalanced loading	Carton pile falling over	8	Carton piles loaded unevenly on fork arms	4	Properly balance off-piler before loading	Visual confirmation from operator	2	64
	3. Lifting beyond maximum design load	Carton pile tips causing harm or injury	8	Neglect safety hazard	2	Warning labels and SOP	Visual confirmation from operator	2	32
D. Stability	1. Clamp arm unexpected rotation	Clamp arm or pad contacts operator	6	Erratic movement with connector clamp loosened	3	Ensure connector is tightly fastened before lifting	Visual confirmation from operator	3	54
	2. Clamp pad leaves markings on top carton	Damaged product	4	High clamping force with rough surface finish	4	Preliminary testing	Visual confirmation from operator	6	96
	3. T-angle connectors slip when force applied	Unstable transportation of carton piles	7	Poor system design	5	Preliminary testing	T-angle connector sliding while forcing clamp pad	4	140

Table XII: Failure Modes and Effects Analysis (con't)

Design Component or Process	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Process Control Prevention	Process Control Detection	DET	RPN
E. Lift	1. Oil leak from hydraulic cylinder	Slipping hazard	7	Production model defects	1	Routine inspection interval	Visual confirmation from operator	7	49
	2. Lifting chain binding	Unable to lift or drop carton pile	7	Neglecting regular maintenance	2	Regular maintenance intervals for chain and sprocket	Inspection interval	4	56
	3. Cylinder retracts unexpectedly during operation	Damage to product or equipment	8	Production model defects	1	Routine inspection interval	Hydraulic orifice damage	8	64
	4. Excessive lifting past required clearance	Falling object hazard	8	Neglecting safety hazard	2	Warning labels and SOP	Visual confirmation from operator	4	64
	5. Operator trips over foot lever	Tripping hazard	5	Storage latch is neglected	5	Warning labels and SOP	Visual confirmation from operator	3	75
F. Full Assembly	1. Loosened fasteners	Sub-component failure	8	Excessive use without inspection	3	Regular inspection intervals	Visual confirmation from operator	2	48
	2. Unable to support 800 lbs load	Sub-component failure	8	Poor system design	3	Preliminary testing	Visual confirmation from operator	3	72

Referring to Table XII, the failure mode with the highest RPN equal to 162 (A.1) would occur if the braking system from the base structure supplied by Global Industrial could not sufficiently stop the off-piler from movement when loaded. This is due to the high severity rate of 9 and high detection rate of 9. Since the base structured would be an externally sourced component, analysis of the system is out of scope by the design team. This failure mode could lead to operator harm or injury, which is also hard to detect as the operator would become aware of insufficient braking force only when braking fails to stop the off-piler. Preliminary testing of the base structure is recommended to reduce the severity rating to 1 by ensuring the braking system is sufficient for GPI's heaviest carton piles. Another failure mode with significant consideration is the T-angle connector slipping when forcing the clamp pad, with a RPN equal to 140 (D.3). Preliminary testing of the mechanism is again recommended to determine the required force to clamp carton piles without damaging the clamp system or GPI product. Implementing standard operating procedures until operators gain experience with the device would decrease the occurrence rating lower than the current value of 5. For the remaining failure modes, the RPN does not exceed 100 and both monitoring and awareness during operation should be sufficient.

6 Cost Analysis

This section will cover the total cost required to build the off-piler design. The calculated overall cost will be an estimate which is required to build this design. This section will also evaluate if the final cost is within the provided budget of $25,000 from Graphic Packaging International.

6.1 Purchased Parts Costing Analysis

This section will cover the cost of the purchased parts which are required to build this final design.

TABLE XIII: Purchased Parts Costing.

Description	Quantity	Cost
Base Structure [26]	1	$1,173.61
Alloy Steel ACME Lead Screw, LH [23]	1	$77.49
Alloy Steel ACME Lead Screw, RH [24]	1	$78.04
ACME Mounting Flange [27]	2	$87.22
ACME Threaded Mount Nut [28]	2	$69.54
Channel for Lifting Mechanism [29]	2	$113.14
Adjustable Width Handle [30]	2	$38.80
Center Bearings [31]	2	$60.62
Outer Bearings [32]	2	$136.74
GN 192 Connector Clamp [33]	2	$60.32
GN 133 Connector Clamp [34]	1	$29.39
C-Clamp Shaft and Swivel - 3/8"-16 [25]	1	$17.95
ACME Sleeve Nut [35]	1	$23.84
Clamp Handle [36]	2	$43.04
Clamp Bolt [37]	1	$9.15
Clamp Nut [38]	1	8.21
Clamp Arm [39]	1	$123.46
Clamp Vertical Mounting Pipe [40]	1	$157.00
Bolts for Off-piler Arm Bracket [41]	8	$21.72
Bolts for Outer Bearings [42]	4	$11.78
Bolts for Center Bearings [43]	2	$14.10
Nuts for Bearing Bolts [44]	4	$19.44
Nuts for Center Bearing [45]	2	$14.75
Nuts for Chain Connection to Plate [46]	2	$12.71
Nuts for Off-piler Arm Bracket [47]	8	$13.41
	Total Cost	**$2,415.47**

Table XIII provides the parts required to purchase for the final off-piler design along with the quantity and the cost associated with these parts in Canadian dollars. All these parts listed above are easily available to purchase online. The total cost for the purchased parts is $2415.47.

6.2 Sheet Metal Costing Analysis

This section will cover the costs associated with the sheet metal parts that are required to laser cut from the sheet metal with different thicknesses.

Table XIV: Sheet Metal Material Costing.

Description	Quantity	Cost
0.5" Carbon Steel Plate Hot Rolled [48]	1	$1,672.26
60" X 120" Hot Rolled Steel Sheet (7ga) [49]	1	$1,024.50
1’ x 2’ Aluminum (8 ga) [50]	1	$57.37
	Total Cost	**$2,754.13**

Table XIV describes the cost of the sheet metals required to build the sheet metal parts using the laser cut. The total material cost for the required sheet metal is $2754.13.

Table XV: Laser Cutting Cost for sheet metal.

Description	Quantity	Perimeter	Cost
Sheet Metal Plate for Lifting Mechanism	2	75.36	$21.10
Off-piler arms	2	88.52	$24.79
Sheet Metal part attached to the chain	1	5.57	$0.78
Off-piler Arm bracket	2	45.54	$12.75
Clamp Mounting Bracket	2	19.04	$5.33
Clamp Plate	1	150.46	$21.06
		Total Cost for laser cutting	**$39.93**

Table XV shows the cost for laser cutting the parts. This cost was calculated using the perimeter of each part required to laser cut. The laser cutting cost associated was $0.14 per inch [51]. Thus, the analysis was performed by multiplying the perimeter of each part with the $0.14 and the quantity required for each part. After the calculations, the total laser cutting cost is $39.93.

Table XVI: Total cost for fabricating sheet metal parts.

Description	Cost
Material Cost	$2,754.13
Laser Cutting Cost	$39.93
File Processing Fees	$75.00
Minimum Order Fee	$50.00
Total Cost	**$2,919.06**

Table XVI describes the total cost required to purchase the material and laser cut the sheet metal parts along with service fees and minimum order fees. The total cost for the sheet metal parts is $2,919.06.

6.3 Labor Costing Analysis

This section will cover the labor cost analysis required to assemble the full design. Firstly, the parts will need to be disassembled from the base structure. After that, it will require welding of the parts as listed in the manufacturing processes section along with the assembling of some parts using bolts and nuts. The team estimated the time required for the whole assembly process will be around 8 hours with 2 people. The general labor cost is $25 per hour [52]. By calculating, the total labor cost is $400.

6.4 Overall Costing Analysis

This section covers the total overall cost of the project. The total cost is calculated by adding the purchasing cost, sheet metal parts cost and the labor cost.

Table XVII: Total cost for off-piler design.

Description	Cost
Purchasing Cost	$2,415.47
Sheet Metal Cost	$2,919.06
Labor Cost	$400.00
Total	**$5,734.53**

From Table XVII, the overall total cost for the off-piler design is $5743.53. It is clear from the analysis that this design is under the budget of $25000 provided by GPI.

7 Final Design Summary

This section summarizes the whole design of the off-piler. Initially, the team divided the concept generation section into four parts; adjustable width, lift, loading and stability. One concept was chosen from each of the four sections and the team proceeded with the final design. The base structure was found online by the team and was modified to get the final design. The loading mechanism, clamp mechanism, and off-piler arms sub-assembly was added to the base structure. The team performed analysis on each sub-assembly numerically and analytically to make sure that the final design meets the client specifications.

Figure 67: Final Off-Piler Design

Figure 67 shows the final assembly of the off-piler design. The operator can handle the off-piler from either vertical or the horizontal tubes attached at the back of the base structure. The back wheels are caster wheels which are used to maneuver the design while the front wheels are fixed and will go under the pallet during loading. The knobs attached on the side are used to adjust the width of the off-piler arms and are designed to be around the waist level so the operator does not have to bend over to adjust the width. The clamp is designed in such a manner that the operator can adjust the clamp from the vertical tube to move the clamp pad up and down until it is resting on top of the carton piles. Another key feature for the clamp is that there is a threaded screw attached at the clamp pad to apply pressure on top of the piles for secured transportation of the load. Moreover, this clamp sub-assembly is also attached to the loading sub-assembly so the clamp will also be lifted along with the whole carton piles which helps to prevent any damage to the carton piles.

Table XVIII: Satisfaction of Client Needs.

Client Needs	**Meets Requirement**
Adjustable width and height	Yes
Safe	Yes
Reduce operator fatigue	Yes
Ergonomically friendly	Yes
Robust	Yes
Secured transportation of carton piles	Yes
Improved loading process	Yes
Ease of maintenance	Yes
Easily stored	Yes
Easily accessible	Yes
Inexpensive	Yes

Table XVIII describes the client needs and if the final design for the off-piler meets each client need. The off-piler arms can be adjusted very easily using the knobs attached on the side and can be lifted very easily using the manual hydraulic lift. This design is safe to operate as the team designed to reduce the pinch points where possible and the team also performed FMEA analysis on each component of the design to consider the safety of the operator. The adjustable knobs are attached at the waist level to reduce the operator fatigue as in the current design, the operator needs to bend down to adjust the width. The clamp mechanism is used to secure the transportation of the carton piles. This design can be easily stored as the front wheels can go under the pallet minimizing the device footprint when not in use. Cost analysis is also performed, and the final design cost is less than the budget provided by the client.

This design is simple and easy to make. Most of the parts are available online to purchase. Some parts are required to be custom made which are the sheet metal parts. But these parts will be fabricated easily as it just requires laser cutting sheet metal and some press braking. The team also divided the full assembly process into smaller sub-assemblies to make the assembly process easier and faster. The engineering drawings in Appendix A.8 will show the details of the whole assembly process. The total approximate weight of the full assembly is 218.19 lbs.

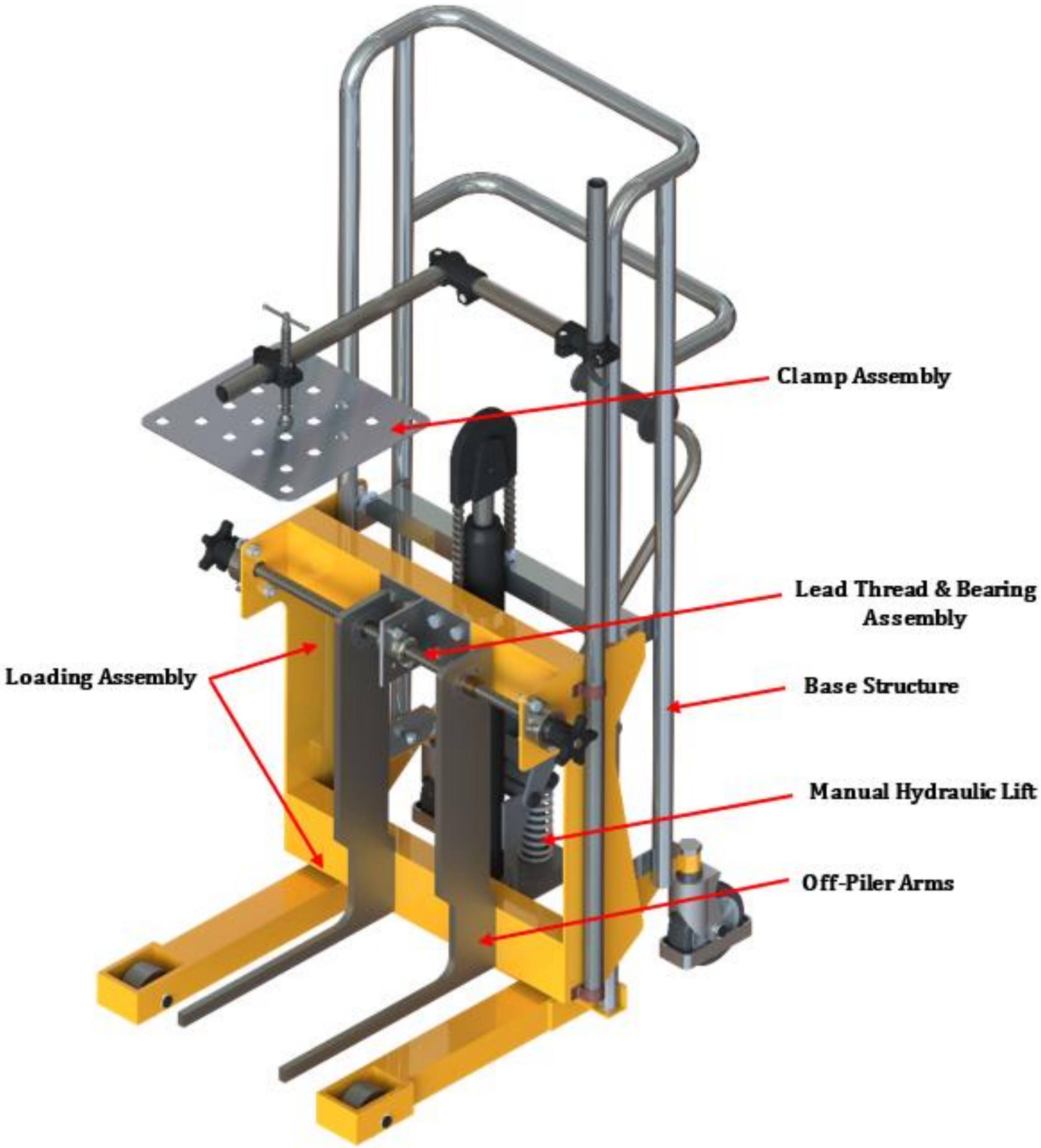


Figure 68: Final Off-Piler Design Components

Figure 69: Expanded View of Final Off-Piler Design

8 Conclusion and Future Recommendations

Graphic Packaging International (GPI) is a paper-based packaging company. The company prints carton sheets according to their customer's order and cuts them off through the die cutter machine. The pallet coming out of the die cutter may include different printed carton styles. To transfer the cartons to a different pallet, the operators use an off-piler, which is not a safe solution. The team will need to design a new device which is capable to handle a maximum weight of 800 lbs. This device should be safe and ergonomically friendly. The objective of the project is to design an adjustable device to accommodate the different groove widths for a 40.5" x 21.5" pallet to transfer the cartons to a separate pallet. Project deliverables, client needs and target specifications were identified by the team and verified with the client.

The team divided the concept generation of the off-piler device into four subcomponents to develop the concepts individually for each component. These four components are adjustable width, loading, stability and lift. The team used a selection criteria matrix for each component and weighted decision matrix to come up with the number one concept for each. The team also used feedback from the client for concept screening. The final design concept involves independent movement of two lead screws for the adjustable loading arm width, extended wheels under the pallet for loading, a clamp mechanism at the top for stability and finally, hydraulic lift for the lifting mechanism.

The team chose the base structure which is available online to purchase and performed numerical and analytical analysis on all the modifications required to update the base structure. These modifications include the loading sub-assembly, clamp sub-assembly and the off-piler arms sub-assembly. The total approximate weight of the final design is 218.19 lbs. The team also included the manufacturing process of each sub-assembly along with the manufacturing process of the final design. Failures Mode and Effects Analysis was also performed on the final off-piler design to mitigate the risks associated with the final design. The cost analysis was also performed, and the final design cost was estimated to be $5,743.53 which is less than the provided budget of $25,000 by GPI.

Recommendations

- Replace the hydraulic cylinder of the sourced structure model for a shorter cylinder to increase operator visibility. Since the off-piling process only requires up to approximately 3" of clearance to load the carton piles. Possible solution to modify the base frame by fixing a weldment to vertical height adjustment tubes to limit lifting range.
- Adjust the length of off-piler arms to accommodate for longer carton piles if required.
- Consider changing the material of the bottom tube support which contacts the loading arms. Likely to a low friction material, to reduce wear, noise, and force required to adjust the loading arm positions.
- Consider optimizing loading arms for higher safety factor (2-3) if the maximum load was a frequent occurrence. Since discussing with our client, the 800 lbs. load would rarely be required.
- Addition of clear guards to cover the ACME screws from the adjustable width mechanism to reduce risk of pinch points.

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Appendix A

Table of Contents for Appendix

A.1– House of Quality Analysis (Target Specifications) 90
A.2 – House of Quality Analysis (Concept Design Components).. 92
A.3 – Design Requirements Importance Ranking 94
A.4 – Gantt Chart.. 95
A.5 – Pallet Design 96
A.6 – Carton Product Example 98
A.7 – Lead Screw Maximum Deflection Analysis 100
A.8 – Detailed Engineering Drawing.. 100
A.9 – Base Structure Lift Manual 119

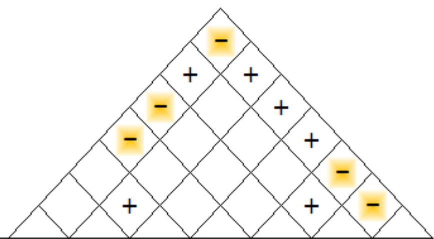
List of Tables in Appendix

Table A-3: Design Requirements.. 94
Table A-5: Pallet Groove Gap Width Sizes 97

List of Figures in Appendix

Figure A-5.1: 3D Model of a Pallet of 40.5” x 21.5” with Groove Width of 2.2 cm 96
Figure A-5.2: Detailed Drawing of a Pallet of 40.5” x 21.5” with Groove Width of 2.2 cm....... 96
Figure A-5.3: Pallet Groove Gap Width Configurations 97

A.1– House of Quality Analysis (Target Specifications)



					Column #	1	2	3	4	5	6	7
					Direction of Improvement	▼	◇	◇	▲	▲	▼	▲
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Technical Requirements / Client Needs	Cost	Pallet Size Accomodation	Groove Gap Width Accomodation	Able to Lift Max Load	Movable	Process Time	Stable
1		12%	10	9	Adjustable width and height		●	●				
2		9%	7	9	Improved loading process		○	○			●	
3		10%	8	9	Secured transportation of carton piles				○	○		●
5		11%	9	9	Reduce operator fatigue				●	●		○
6		11%	9	9	Ergonomically friendly				●	○		○
7		7%	6	9	Easy to maintenance	●				●		
8		6%	5	9	Easily Stored					●		
9		6%	5	9	Easily Accessible					●		
10		10%	8	9	Robust				●			○
11		12%	10	9	Safe				●			●
12		6%	5	9	Inexpensive	●						
					Target	Under $25,000	Pallet Size of 40.5" x 21.5" with groove width of 2.2 cm	All Groove Gap Widths Between Configurations 1 to 4	>800 lbs	>10'	Reduce by 25%	Handle atmost 4 ft high of carton piles at 1m/s
					Max Relationship	9	9	9	9	9	9	9
					Technical Importance Rating	120.7	135.4	135.4	424.4	336.6	76.83	292.7
					Relative Weight	8%	9%	9%	28%	22%	5%	19%
					Weight Chart							

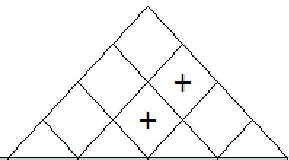
Correlations	
Positive	+
Negative	−
No Correlation	
Relationships	
Strong	●
Moderate	○
Weak	▽
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

The House of Quality Analysis in Appendix A.1 shows the relationships between the client needs and technical requirements of the project. The technical requirement metrics are listed as follows:

1. Cost: The total cost of the final design as provided by the client must be under $25,000. (Minimize)
2. Pallet Size Accommodation: The final design must accommodate the universal pallet for the off-piling process with a size of 40.5” x 21.5” and a groove width of 2.2 cm. (Target)
3. Groove Gap Width Accommodation: The final design must accommodate all groove gap widths between configurations 1 to 4 (see Appendix A.5) of the pallet to accommodate for all types of carton products. (Target)
4. Able to Lift Max Load: The final design must be capable of lifting a maximum load of 800 lbs. (Maximize)
5. Movable: The final design must be movable up to at least 10’ of distance to successfully transport the carton piles from one pallet to another. (Maximize)
6. Process Time: The team have set an initial target of reducing the off-piling process time by 25%. (Minimize)
7. Stable: The final design must handle at most 42” high of carton piles while moving at 1m/s with maximum stability. (Maximize)

The client needs and the technical requirement metrics are scored with solid hits (•) to show a strong relationship, a hollow hit (○) for moderate, and an inverted triangle (▽) for a weak relationship. The total scoring is then calculated to provide the technical importance rating and relative weight of each technical requirement in the bottom rows of the House of Quality. The maximum load, movability, stability, and adjustability (pallet size and groove gap accommodations) scored the highest numeric values, and therefore will be crucial to the concept development and concept selection for the final design.

A.2 – House of Quality Analysis (Concept Design Components)



					Column #	1	2	3	4
					Direction of Improvement	◇	◇	◇	◇
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Design Components / Target Specifications & Client Needs	Adjustable Width	Loading	Stability	Lift
1		14%	9	9	Max Load of 800 lbs		●	○	●
2		14%	9	9	Movable up to atleast 10' of Distance		●	○	
3		14%	9	9	Handles up to at most 4' high			●	
5		16%	10	9	Pallet Size Accomodation	●			
6		16%	10	9	Pallet Groove Gaps	●			
7		16%	10	9	Safety	○	●	●	●
8		11%	7	9	Process Time	●			
					Max Relationship	9	9	9	9
					Technical Importance Rating	426.6	393.8	351.6	267.2
					Relative Weight	30%	27%	24%	19%
					Weight Chart				

Correlations	
Positive	+
Negative	−
No Correlation	
Relationships	
Strong	●
Moderate	○
Weak	▽
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

The House of Quality Analysis in Appendix A.2 relates the concept design components with the technical requirements and client needs of the project from phase 1, as well as to analyze their relationship with each other. The concept design components are listed as follows:

1. Adjustable Width: Mechanism to adjust distance between arms and accommodate varying pallet groove configurations (Target)
2. Loading Mechanism: Design to support load transfer through the arms to the frame of the off-piler from the carton piles (Target)
3. Stability: Component to secure carton piles, ensuring stable unloading, offloading, and transportation (Target)
4. Lift: Mechanism to provide off-piler arms with clearance to remove carton piles from pallet (Target)

The concept design concept design components are scored with solid hits (•) to show a strong relationship, a hollow hit (○) for moderate, and an inverted triangle (▽) for a weak relationship. The total scoring is then calculated to provide the technical importance rating and relative weight of each design component in the bottom rows of the House of Quality. The adjustable width scored the highest numeric value, and therefore will be used as a reference for compatibility with the rest of the components for the concept selection process of the project.

A.3 – Design Requirements Importance Ranking

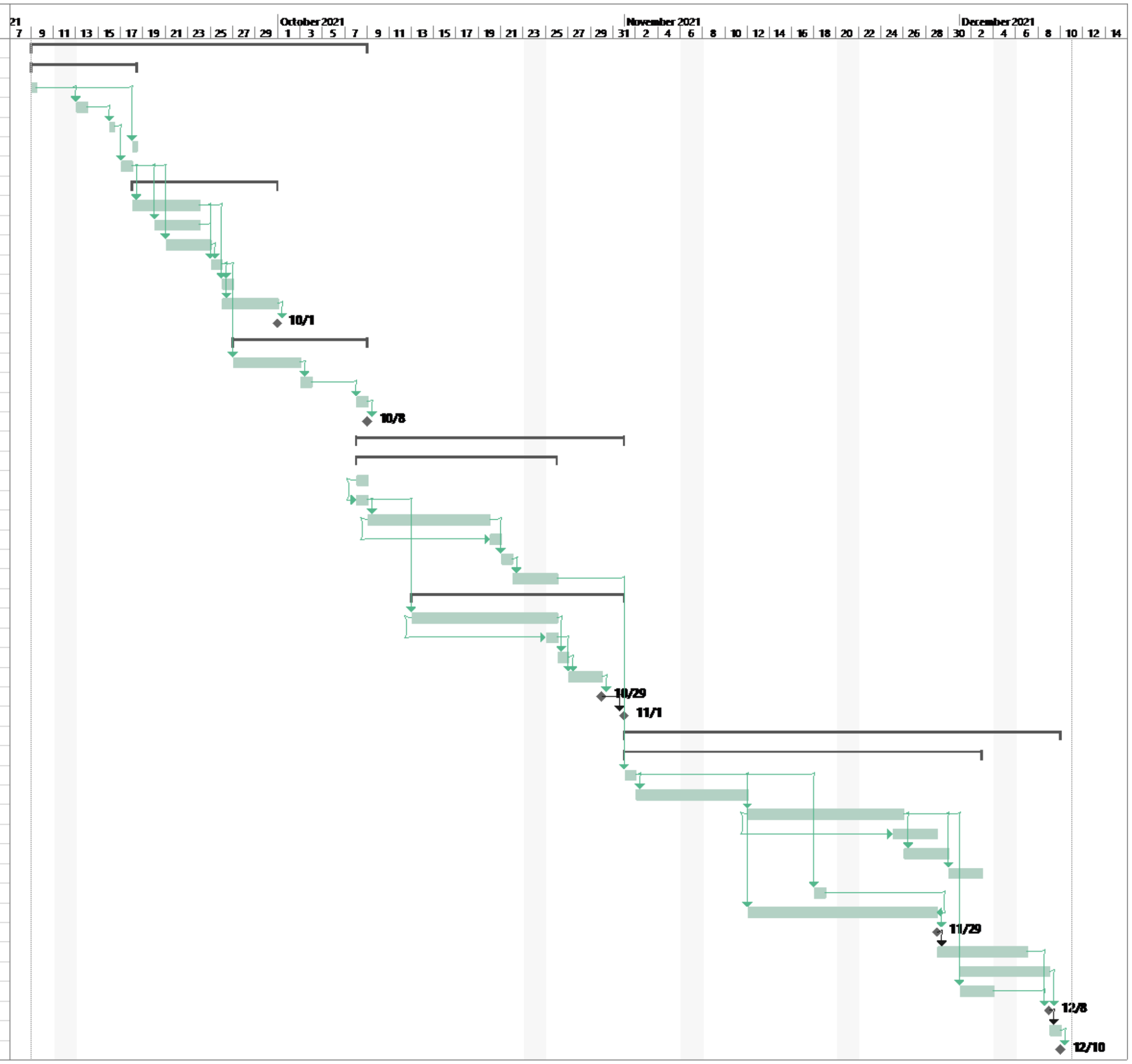
Table A-3: Design Requirements [4]

<table>
<tr><th>Design Requirement</th><th>Analysis</th><th>Importance</th></tr>
<tr><td>The design needs to transport a pile of cartons from one pallet to another.</td><td>Movable</td><td>7</td></tr>
<tr><td>The design must be able to accommodate pallet size of 40.5" x 21.5" with groove width of 0.87”. (See detailed drawing of pallet in Appendix A.5)</td><td rowspan="3">Adjustable</td><td rowspan="3">10</td></tr>
<tr><td>The design must be compatible with all the pallet groove gap widths between configurations 1 to 4. (See configurations in Appendix A.5)</td></tr>
<tr><td>The design must be compatible with various carton sizes.</td></tr>
<tr><td rowspan="2">The design must support the load to prevent from falling from the sides.</td><td>Load Support</td><td>7</td></tr>
<tr><td>Safe</td><td>10</td></tr>
<tr><td>The design must be able to lift pile of cartons up to 800 lbs.</td><td>Lift a Load of Up to 800 lbs</td><td>8</td></tr>
<tr><td>The design must be ergonomically friendly.</td><td>Ergonomic</td><td>9</td></tr>
<tr><td>The design must prevent the operator from any risk of potential injury during operation.</td><td>User Safe and User Friendly</td><td>10</td></tr>
</table>

A.4 – Gantt Chart

The following project schedule was implemented to ensure the team met both internal and external deadlines required for project completion. The team finished on schedule for the final design report and presentation, including all requested client deliverables.

ID	Task Name	Duration	Start	Finish
1	**Phase 1**	**27 days**	**9/9/21**	**10/8/21**
2	**Project Initiation**	**7.13 days**	**9/9/21**	**9/18/21**
3	Team Introduction Meeting	1 hr	9/9/21	9/9/21
4	Generate Questions for Client	1 day	9/13/21	9/13/21
5	Introduction Meeting with Client	1 hr	9/16/21	9/16/21
6	Introduction Meeting with Advisor	1 hr	9/18/21	9/18/21
7	First Site Visit	1 day	9/17/21	9/17/21
8	**Project Definition Report**	**12 days**	**9/18/21**	**10/1/21**
9	Identify Customer Needs, Constraints and Specification	5 days	9/18/21	9/23/21
10	Generate WBS	4 days	9/20/21	9/23/21
11	Generate Gantt Chart	4 days	9/21/21	9/24/21
12	Advisor to Review Preliminary Draft	1 day	9/25/21	9/25/21
13	Generate House of Quality	1 day	9/26/21	9/26/21
14	Implement Feedback, Edit and Report Submission	5 days	9/26/21	9/30/21
15	Phase 1 Project Definition Report Due	0 days	10/1/21	10/1/21
16	**Oral Presentation 1**	**12 days**	**9/27/21**	**10/8/21**
17	Create Presentation Slides	6 days	9/27/21	10/2/21
18	Reherse Presentation	1 day	10/3/21	10/3/21
19	Oral Presentations	1 day	10/8/21	10/8/21
20	Self/Peer Assessment 1 Due	0 days	10/8/21	10/8/21
21	**Phase 2**	**17 days**	**10/8/21**	**11/1/21**
22	**Concept Generation**	**13 days**	**10/8/21**	**10/25/21**
23	Site Visit	1 day	10/8/21	10/8/21
24	Concept Brainstorming Session	1 day	10/8/21	10/8/21
25	Generate List of Concepts	8 days	10/9/21	10/19/21
26	Concept Refinement and Additional Brainstorming	1 day	10/20/21	10/20/21
27	Client Input and Discussion	1 day	10/21/21	10/21/21
28	Finalize WDM for Concept Selection	2 days	10/22/21	10/25/21
29	**Concept Design Report**	**13 days**	**10/13/21**	**11/1/21**
30	Prepare Preliminary Draft	9 days	10/13/21	10/25/21
31	Submit Draft Report for Technical Review	1 day	10/25/21	10/25/21
32	Submit for Review with Advisor	1 day	10/26/21	10/26/21
33	Implement Feedback, Edit and Submission	3 days	10/27/21	10/29/21
34	Phase 2 Concept Design Report Due	0 days	10/29/21	10/29/21
35	Self/Peer Assessment 2 Due	0 days	11/1/21	11/1/21
36	**Phase 3**	**30 days**	**11/1/21**	**12/10/21**
37	**Final Design Deliverables**	**25 days**	**11/1/21**	**12/2/21**
38	Selection of Final Concept	1 day	11/1/21	11/1/21
39	Develop Technical Specifications	8 days	11/2/21	11/11/21
40	Complete Detailed Design CAD Model	10 days	11/12/21	11/25/21
41	FMEA Analysis of Final Design	3 days	11/25/21	11/28/21
42	Cost Analysis of Final Design Components	3 days	11/26/21	11/29/21
43	Generate Standard Operating Procedure	3 days	11/30/21	12/2/21
44	Client Input and Discussion	1 day	11/18/21	11/18/21
45	Prepare Preliminary Draft	12 days	11/12/21	11/28/21
46	Draft Report Due	0 days	11/29/21	11/29/21
47	Implement Feedback, Final Editing and Submission	6 days	11/29/21	12/6/21
48	Develop and Rehearse Verbal Presentation	6 days	12/1/21	12/8/21
49	Develop Poster	3 days	12/1/21	12/3/21
50	Final Project, Presentation and Report Due	0 days	12/8/21	12/8/21
51	Final Poster Presentations	1 day	12/9/21	12/9/21
52	Self/Peer Assessment 3 Due	0 days	12/10/21	12/10/21



A.5 – Pallet Design

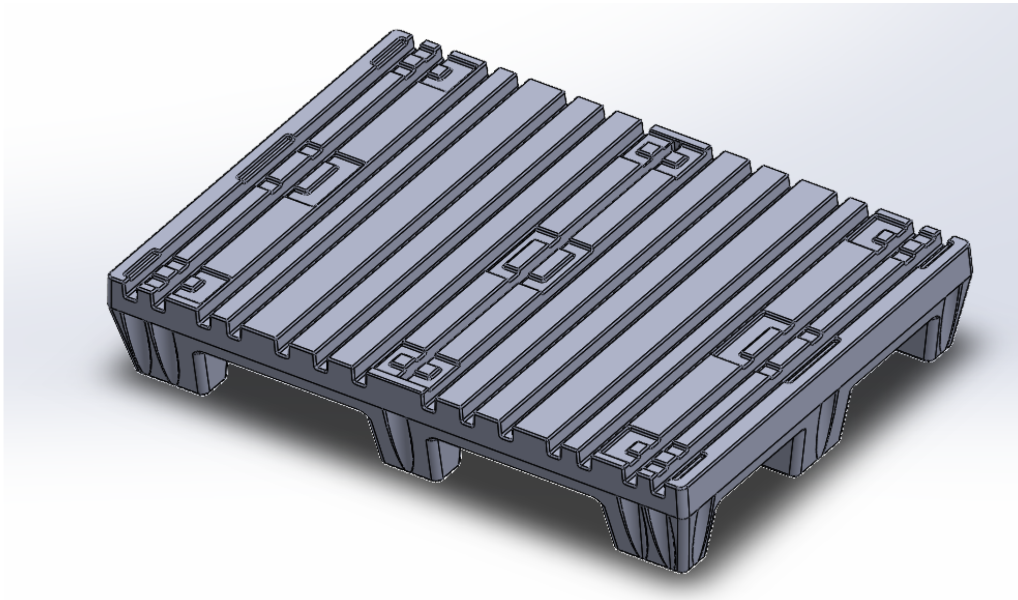


Figure A-5.1: 3D Model of a Pallet of 40.5” x 21.5” with Groove Width of 2.2 cm

This item has been removed due to copyright issues. To view it, refer to its source.

Figure A-5.2: Detailed Drawing of a Pallet of 40.5” x 21.5” with Groove Width of 2.2 cm [2]

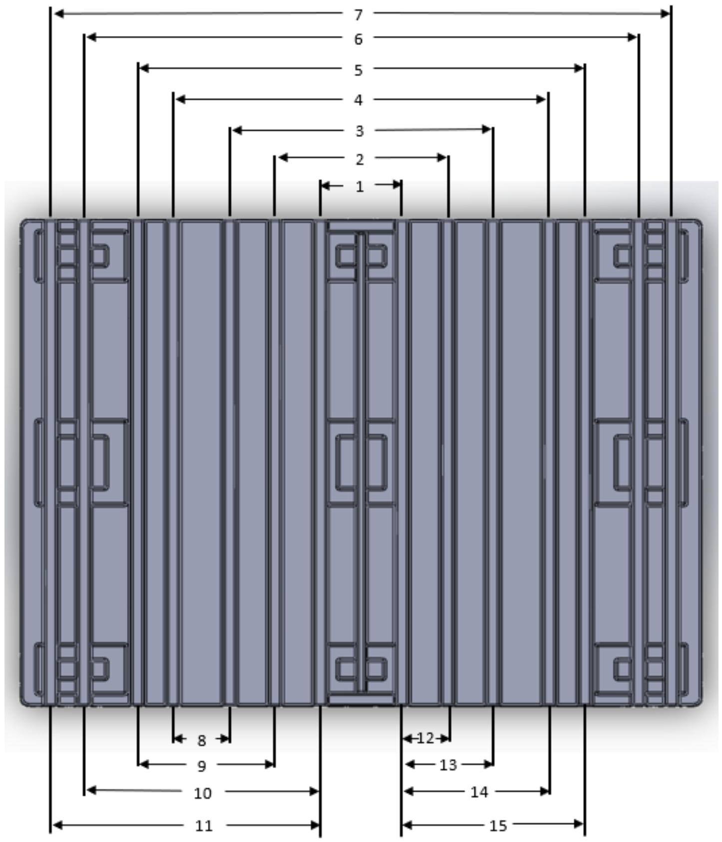


Figure A-5.3: Pallet Groove Gap Width Configurations

Table A-5: Pallet Groove Gap Width Sizes

Number	Pallet Groove Gap Width Sizes	
	inch	cm
1	4.83	12.27
2	10.20	25.91
3	15.57	39.55
4	22.26	56.54
5	26.48	67.26
6	32.81	83.34
7	36.72	93.27
8	3.35	8.51
9	8.14	20.68
10	13.99	35.53
11	15.94	40.49
12	2.68	6.81
13	5.37	13.64
14	8.71	22.12
15	10.82	27.48

A.6 – Carton Product Example

<table>
<tr><th>Carton Pile Configuration</th><th>Example</th></tr>
<tr><td>4 Up with 2 Designs [2]</td><td>
</td></tr>
<tr><td>4 Up with 3 Designs [2]</td><td>
</td></tr>
</table>

4 Up (Stack Height of 4’) [2]	
25 Up with 2 Designs [2]	

A.7 – Lead Screw Maximum Deflection Analysis

The following MATLAB script was implemented to determine the defection within a rod for varying radii. With material properties and the moment of inertia equation for a cylindrical cross section, a plot is produced for deflection vs. rod diameter.

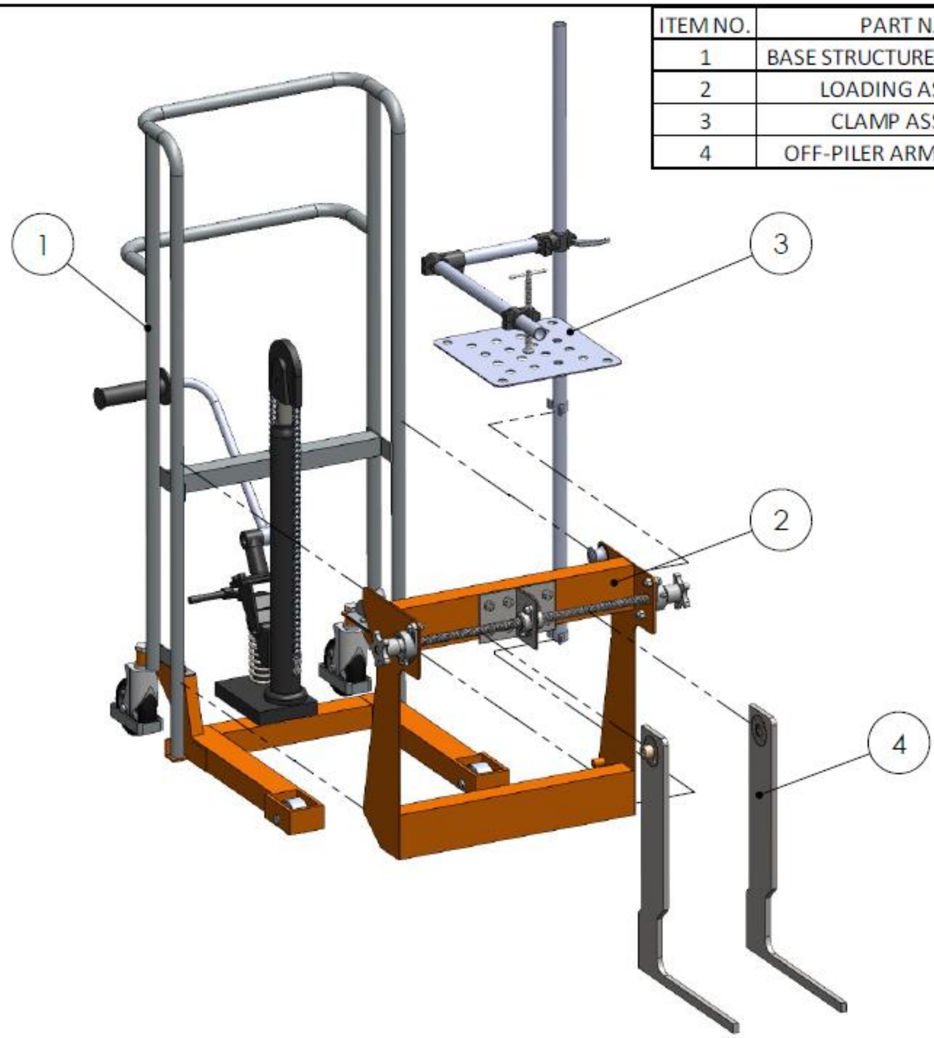
```
Ys = 620422000; % Yield Strength [Pa]
E = 2.1E11; % Modulus of Elasticity [Pa]
M = 199.84*(0.453592); % Mass in lbs x 0.453592kg/lbs [kg]
g = 9.81; % Gravity Acceleration Constant [m/s^2]
F = M*g; % Force Applied on Lead Thread [N]
rho = 7700; % Alloy Steel Density [kg/m^3]
d = 0:0.001:0.0254*2; % Diameter of Lead Thread from 0 to 2 inches [m]
dInch = d.*(1/0.0254);
l = 14.27*(0.0254); % Length of Lead Thread [m]
m_thread = pi.*(d.^2).*l.*rho./4; % Mass of Lead Thread for varying diameter
[kg]
Iz = m_thread.*(3.*(d.^2)+4*l^2)/48; % Moment of Inertia of Lead Thread
MaxDeflection = (F*l^3)./(48*E.*Iz); % Maximum Deflection [m]
MaxDefInch = MaxDeflection.*(1/0.0254); % Maximum Deflection [Inches]

figure(1)
hold on
plot(dInch,MaxDefInch)
title('Maximum Deflection vs. Thread Diameter')
xlabel('Thread Diameter (in)')
ylabel('Maximum Deflection (in)')
hold off
```

A.8 – Detailed Engineering Drawing

This section provides the engineering drawings for both individual components and assemblies of the final off-piler design to provide guidance with the manufacturing and assembling process of the full prototype. The drawings are included in the following pages.

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	BASE STRUCTURE MANUAL LIFT	RATED FOR 880 LBS	1
2	LOADING ASSEMBLY		1
3	CLAMP ASSEMBLY		1
4	OFF-PILER ARMS ASSEMBLY		1



UofM MECHANICAL ENGINEERING

TITLE: CARTON OFF-PILER DESIGN

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL

FINISH

	NAME	DATE
DRAWN	TEAM 8	2021-12-01
CHECKED		2021-12-03
NUMBER		

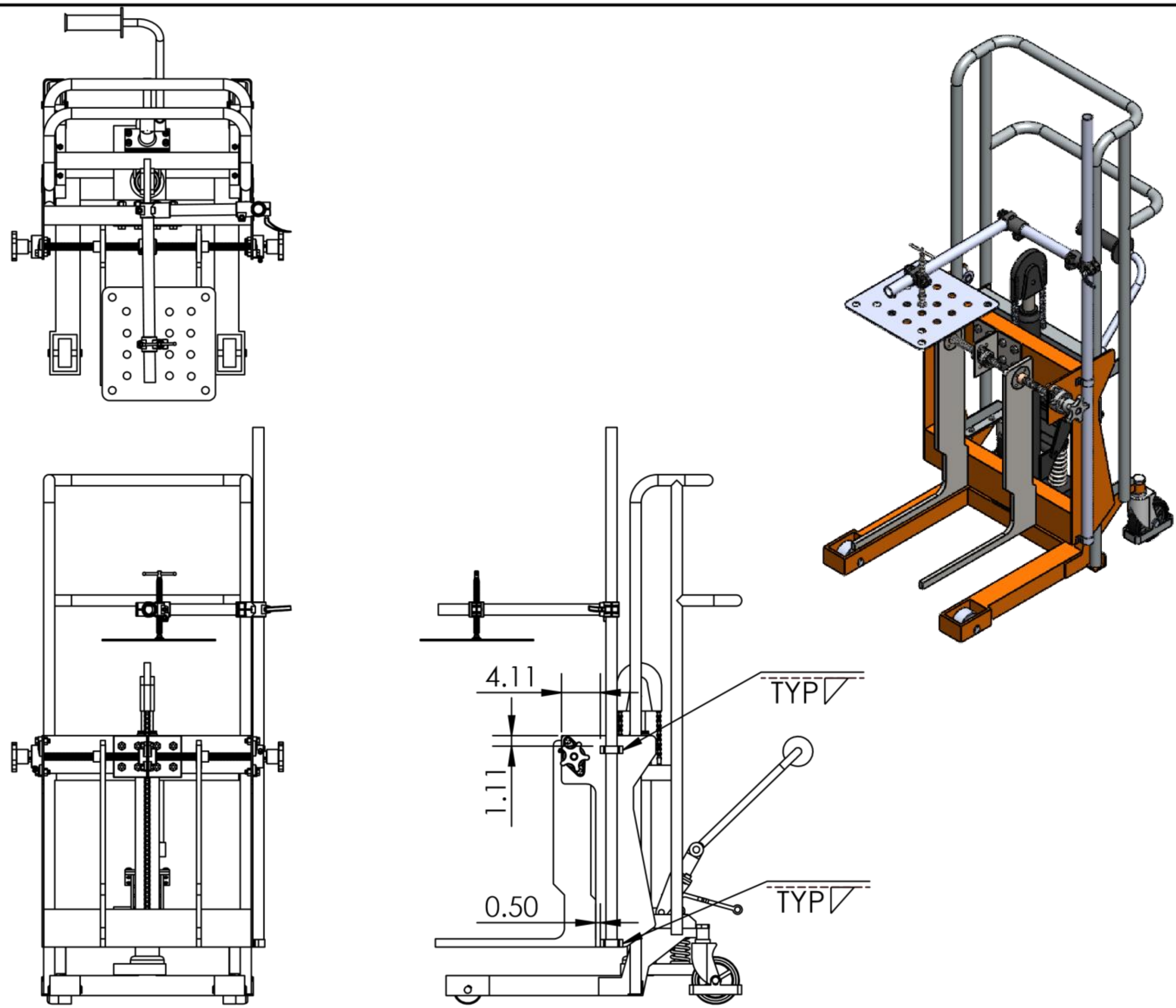
SIZE: A

DESCRIPTION: FULL ASSEMBLY

REV: ANY

SCALE: 1:13 WEIGHT: SHEET 1 OF 1

3 2 1



SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING	TITLE: CARTON OFF-PILER DESIGN	
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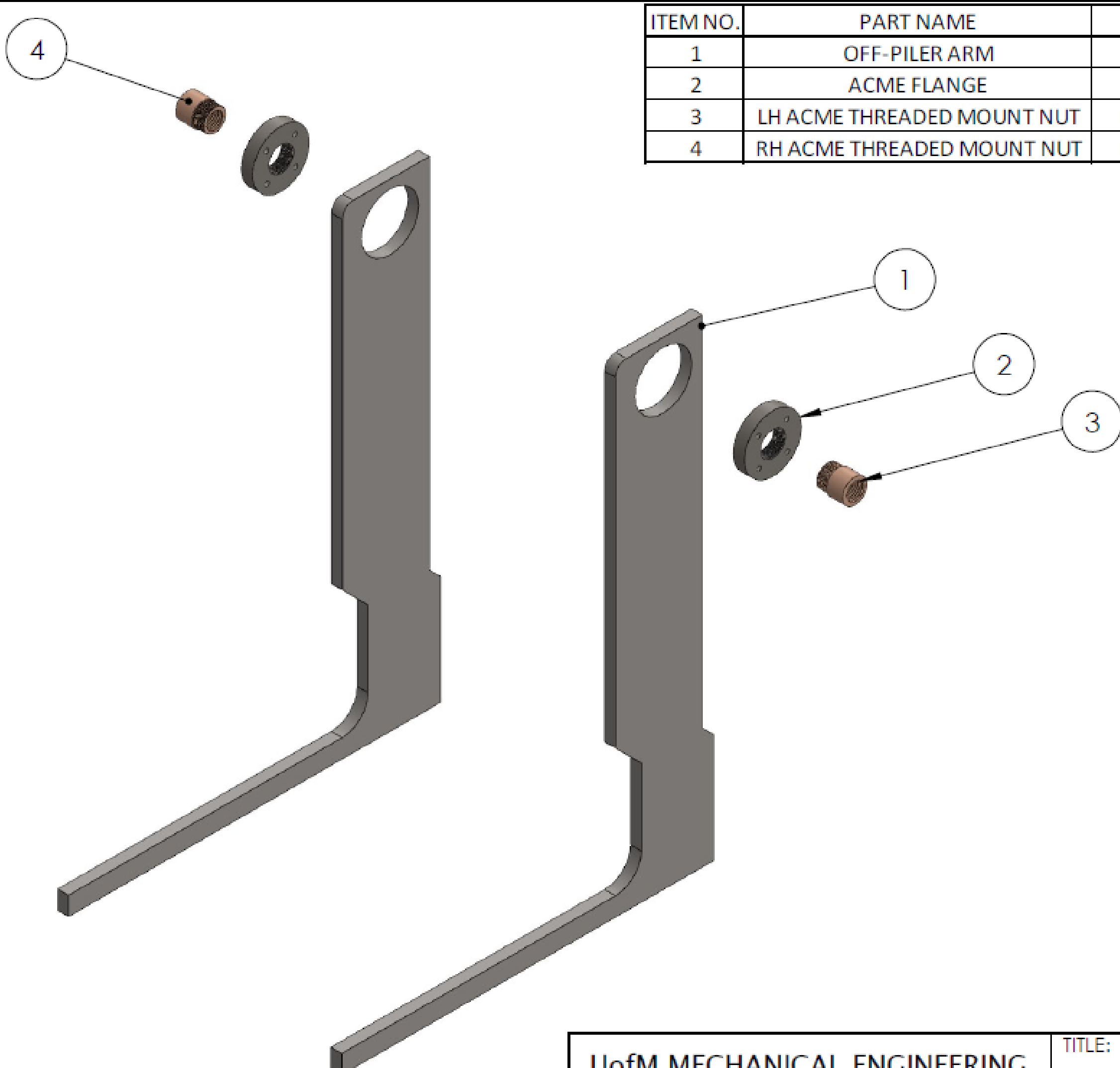
			DO NOT SCALE DRAWING | DRAWN | TEAM 8 | 2021-12-03		
			MATERIAL | CHECKED | | 2021-12-05		
			FINISH | NUMBER	SCALE: 1:16	WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	OFF-PILER ARM		2
2	ACME FLANGE	STEEL, 1.000 - 18 UNS	2
3	LH ACME THREADED MOUNT NUT	BRONZE, 3/4"-8 THREAD SIZE	1
4	RH ACME THREADED MOUNT NUT	BRONZE, 3/4"-8 THREAD SIZE	1



UofM MECHANICAL ENGINEERING

TITLE: OFF-PILER ARMS ASSEMBLY

MECH 4860

UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER:	ANSI Y14. 5M-1994	NAME	DATE
DO NOT SCALE DRAWING	DRAWN	TEAM 8	2021-12-01
MATERIAL	CHECKED		2021-12-03
FINISH	NUMBER		

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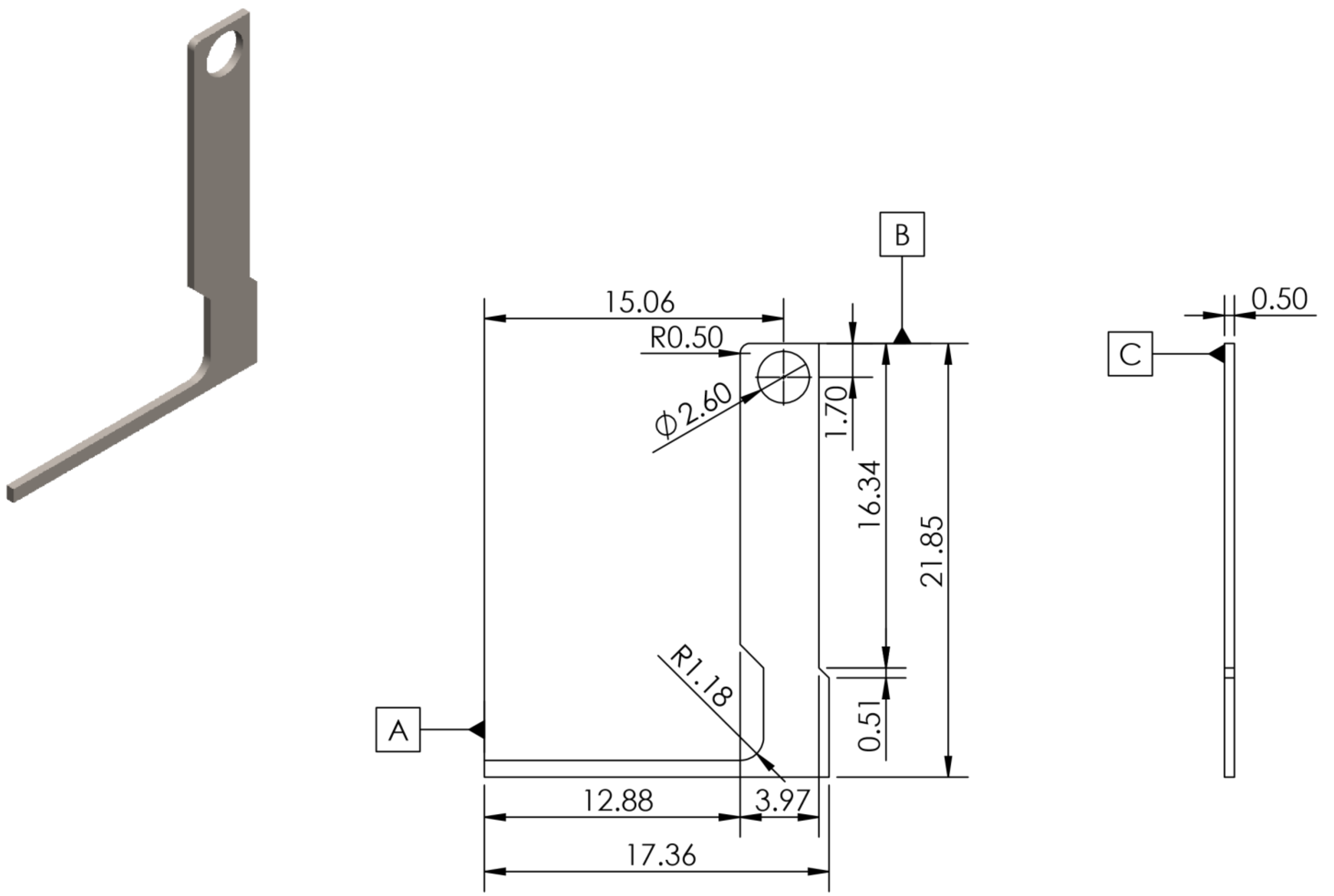

UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

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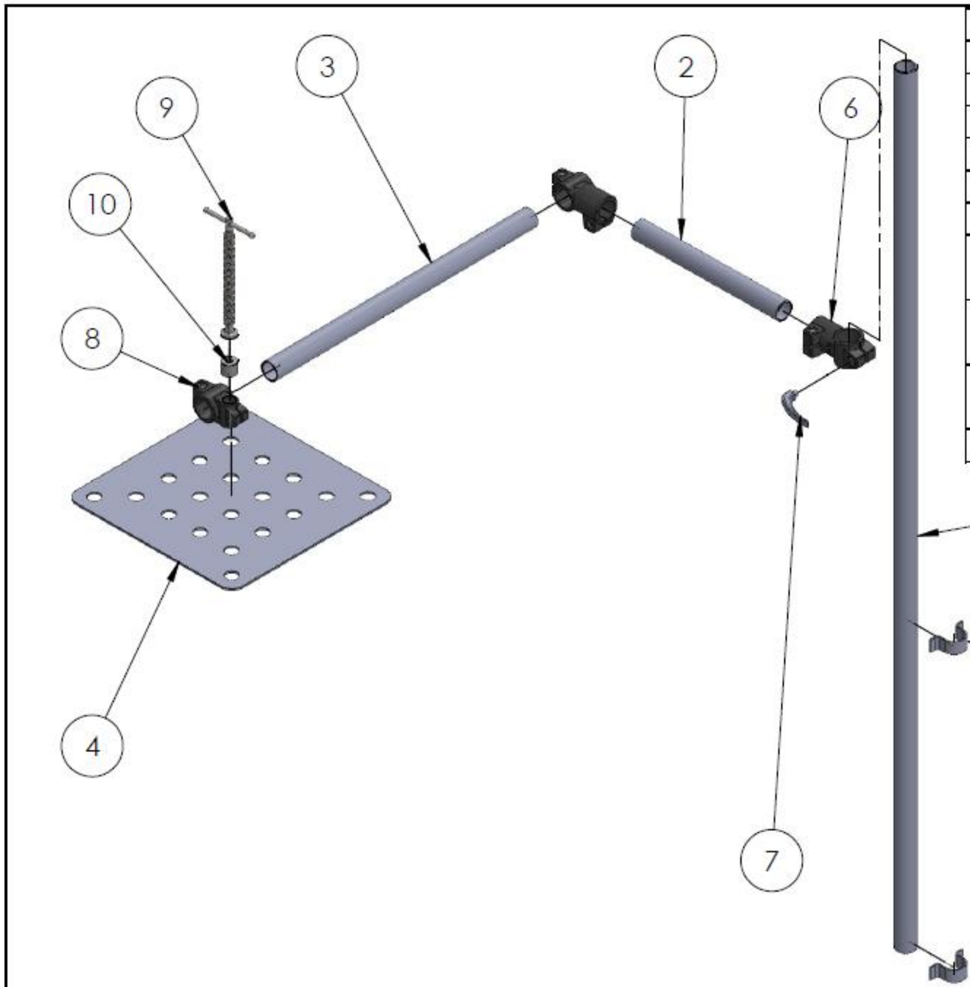
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Team 8	01-Dec-2021
MATERIAL AISI 4340 Steel, normalized	CHECKED		05-Dec-2021
FINISH AS NOTED	NUMBER		

SIZE	DISCRIPTION:	REV
A	Lifting Arm	10

SCALE: 1:8 | WEIGHT: 12.64 | SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	CLAMP TUBE	55" LENGTH	1
2	TUBE MEMBER 1	10.34" LENGTH	1
3	TUBE MEMBER 2	19" LENGTH	1
4	CLAMP PAD		1
5	C CLAMP WELDMENT	TO BE WELDED	2
6	T-ANGLE CONNECTOR		2
7	T-ANGLE CONNECTOR HANDLE		1
8	TWO-WAY CONNECTOR		1
9	THREADED SHAFT & SWIVEL	3/8"-16 ACME THREAD SIZE	1
10	ACME ROUNDED NUT		1

UofM MECHANICAL ENGINEERING

TITLE: CLAMP ASSEMBLY

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

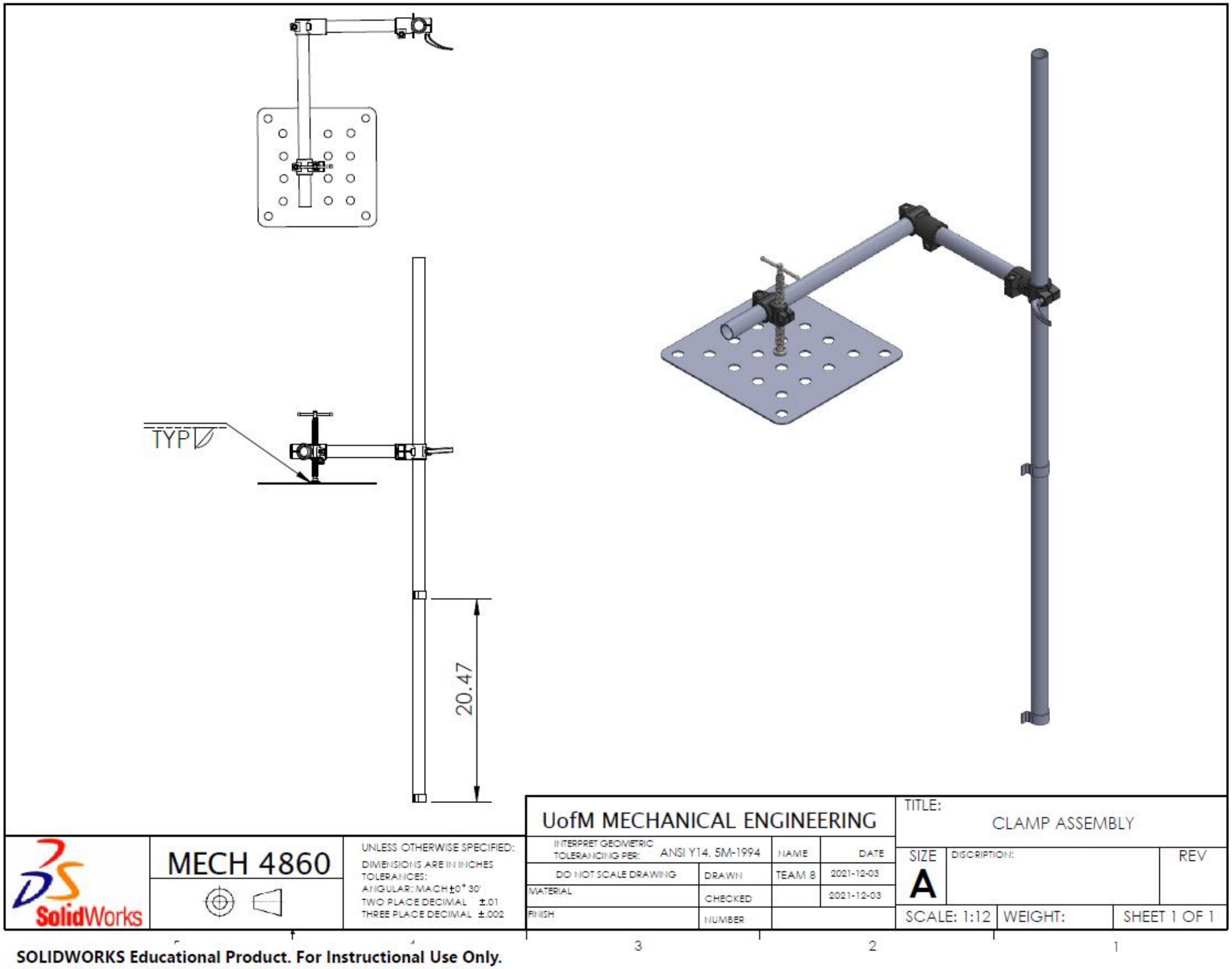
		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	TEAM 8	2021-12-03
MATERIAL	CHECKED		2021-12-04
FINISH	NUMBER		

SIZE A | DESCRIPTION: | REV

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

SolidWorks

SOLIDWORKS Educational Product. For Instructional Use Only.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UofM MECHANICAL ENGINEERING
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CLAMP ASSEMBLY
MECH 4860
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TOLERANCES:
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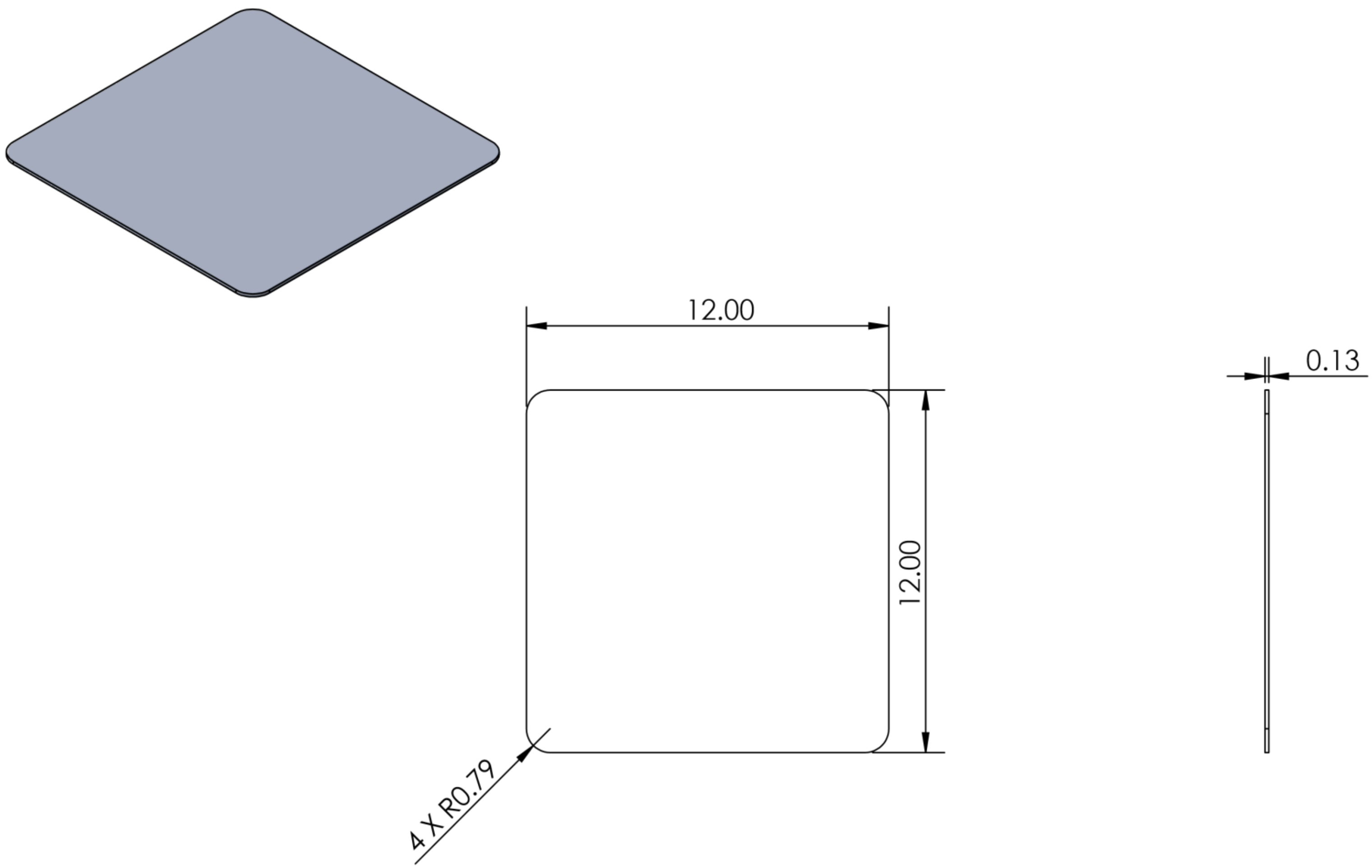
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
NAME
DATE
DO NOT SCALE DRAWING
DRAWN
TEAM 8
2021-12-03
MATERIAL
CHECKED
2021-12-03
FINISH
NUMBER
SIZE
A
DESCRIPTION:
REV
SCALE: 1:12
WEIGHT:
SHEET 1 OF 1
3
2
1
SolidWorks
SOLIDWORKS Educational Product. For Instructional Use Only.



UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

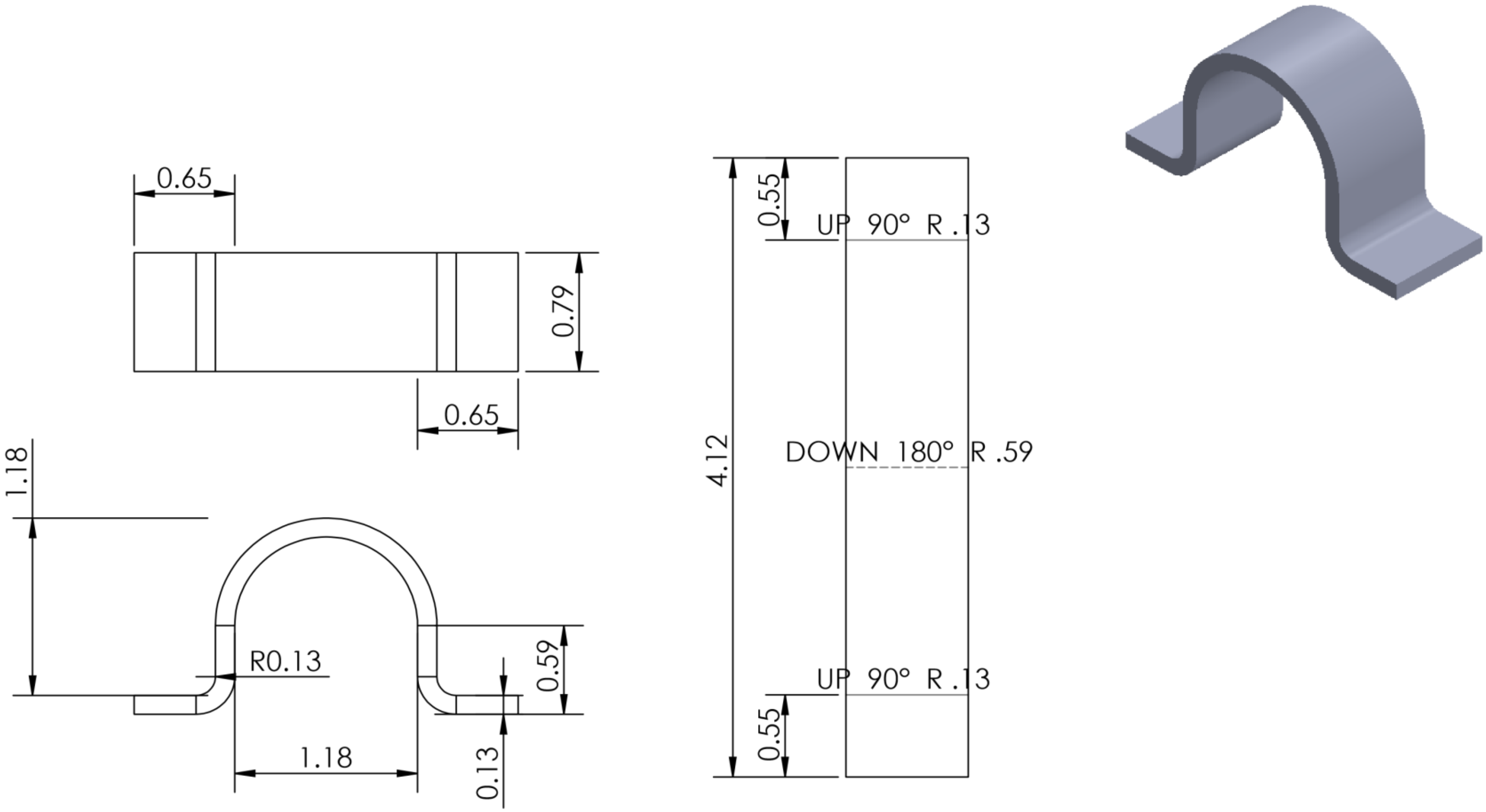
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	T.N.V	03-Dec-2021
MATERIAL 6061-O (SS)	CHECKED		05-Dec-2021
FINISH AS NOTED	NUMBER		

SIZE	DISCRIPTION:	REV
A	Clamp Pad	0

SCALE: 1:5 | WEIGHT: 1.75 | SHEET 1 OF 1

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

MATERIAL: 14. Ga. Hot Rolled Steel Sheet

FINISH

	NAME	DATE
DRAWN	Team 8	12/1/2021
CHECKED		12/4/2021
NUMBER		

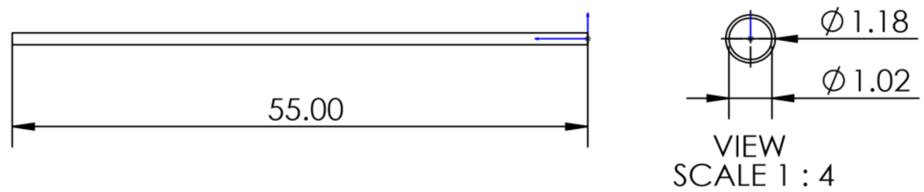
SIZE: A

DISCRIPTION: C-Clamp Weldment

REV

SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



UofM MECHANICAL ENGINEERING

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

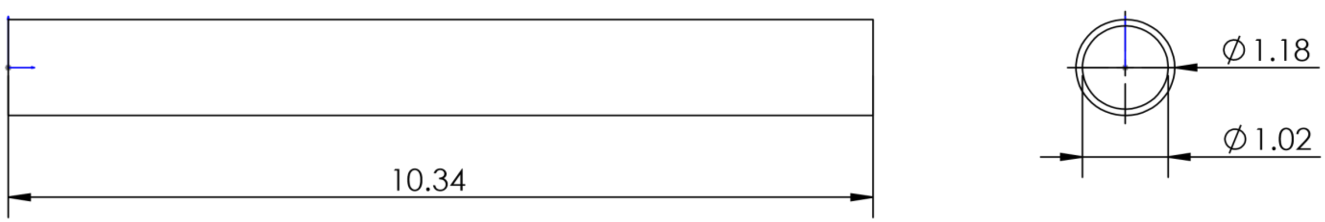
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Team 8	12/1/2021
MATERIAL	CHECKED		12/4/2021
FINISH	NUMBER		

TITLE: **Clamp Tube**

SIZE	DISCRIPTION:	REV
A	Vertical Clamp Tube	

SCALE: 1:16 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Team 8	12/1/2021
CHECKED		12/4/2021
NUMBER		

MATERIAL: 6060 Aluminum

FINISH

SIZE: A

DISCRIPTION: Tube Member 1

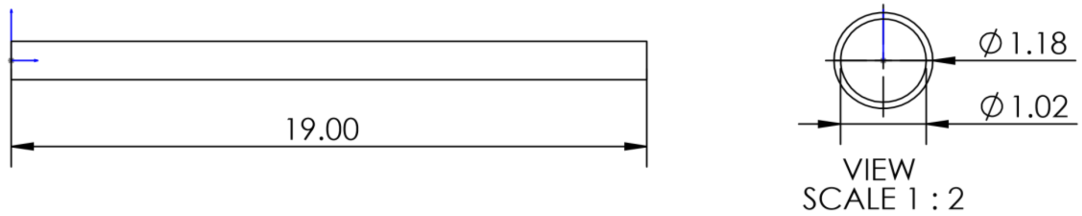
REV

SCALE: 1:2

WEIGHT:

SHEET 1 OF 1

5 4 3 2 1



MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

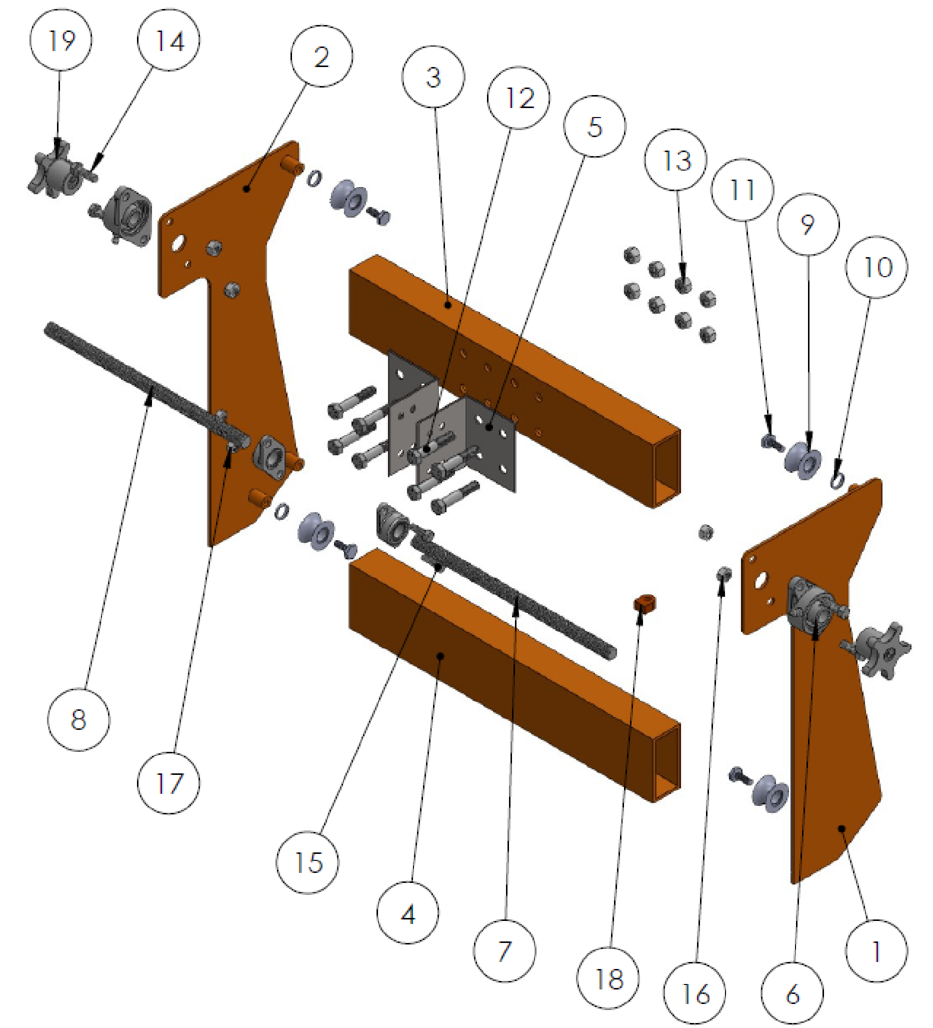
UofM MECHANICAL ENGINEERING

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Team 8	12/1/2021
MATERIAL 6060 Aluminum	CHECKED		12/4/2021
FINISH	NUMBER		

TITLE: **Off-piler Project**

SIZE A	DISCRIPTION: Tube Member 2	REV
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	SIDE PLATE LH		1
2	SIDE PLATE RH		1
3	UPPER SUPPORT TUBE		1
4	LOWER SUPPORT TUBE		1
5	CENTER SUPPORT BRACKET		2
6	MOUNTED BALL BEARINGS WITH TWO BOLT FLANGE	3/4" SHAFT DIAMETER	4
7	ACME LEAD THREAD LH	ALLOY STEEL, 3/4"-8 THREAD SIZE	1
8	ACME LEAD THREAD RH	ALLOY STEEL, 3/4"-8 THREAD SIZE	1
9	ROLLERS	INCLUDED IN BASE STRUCTURE	4
10	WASHER	INCLUDED IN BASE STRUCTURE	4
11	BOLT FOR ROLLERS	INCLUDED IN BASE STRUCTURE	4
12	BOLT FOR CENTER SUPPORT BRACKET	1/2"-13 THREAD SIZE, 2-5/8" LENGTH	8
13	NUT FOR CENTER SUPPORT BRACKET	1/2"-13 THREAD SIZE, 7/16" HEIGHT	8
14	BOLT FOR OUTER BEARINGS	7/16"-14 THREAD SIZE, 1-1/4" LENGTH	4
15	BOLT FOR INNER BEARINGS	3/8"-16 THREAD SIZE, 1-1/8" LENGTH	2
16	NUT FOR OUTER BEARINGS	7/16"-14 THREAD SIZE, 3/8" HEIGHT	4
17	NUT FOR INNER BEARINGS	3/8"-16 THREAD SIZE, 21-64" HEIGHT	2
18	CHAIN CONNECTION		1
19	IRON KNOB	3/4" SHAFT DIAMETER, TO BE WELDED	2

UofM MECHANICAL ENGINEERING

TITLE: LOADING ASSEMBLY

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994
DO NOT SCALE DRAWING
MATERIAL
FINISH

	NAME	DATE
DRAWN	TEAM 8	2021-12-02
CHECKED		2021-12-03
NUMBER		

SIZE A
DESCRIPTION:
REV

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

3 2 1

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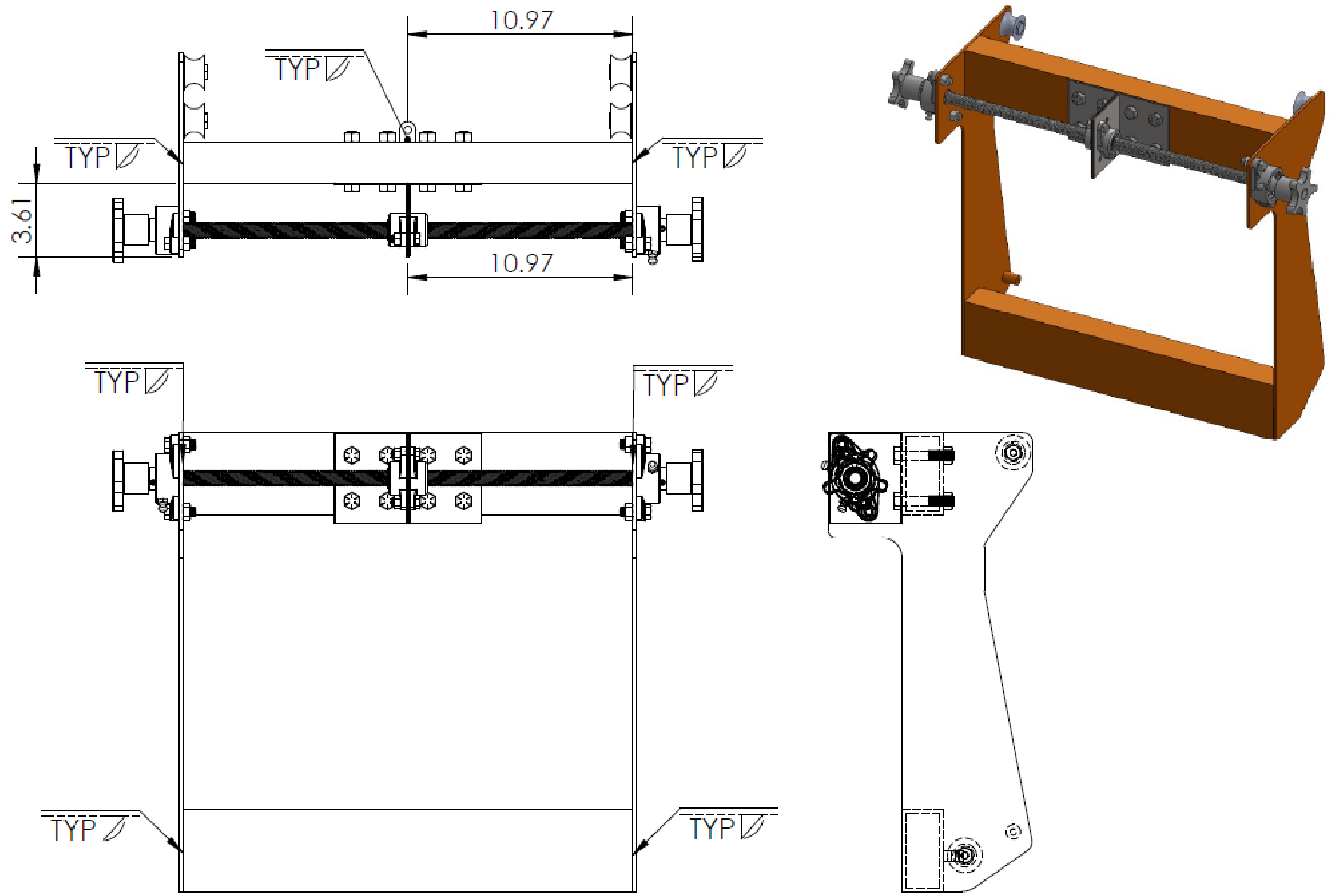
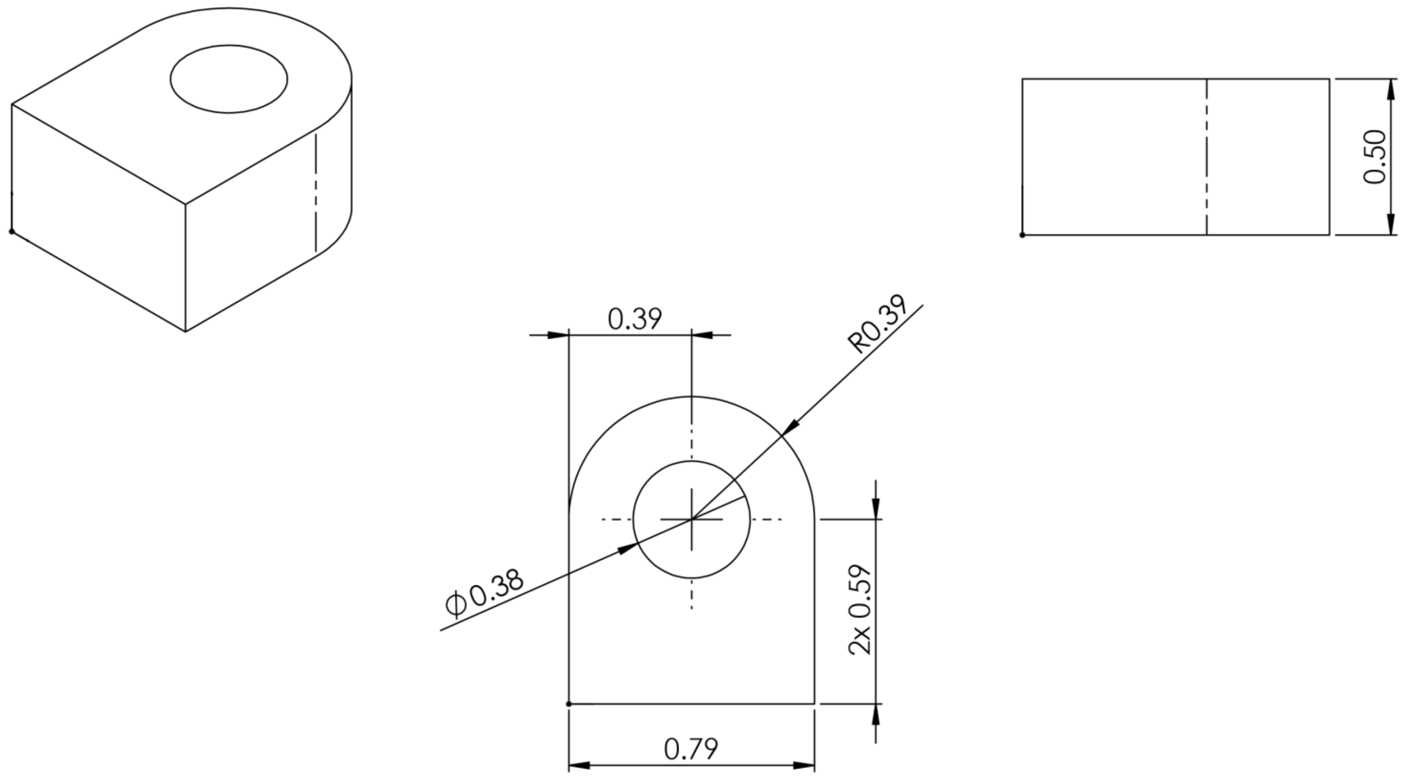


MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: LOADING ASSEMBLY
		INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A
		DO NOT SCALE DRAWING	DRAWN TEAM 8	2021-12-03	DISCRIPTION:
		MATERIAL	CHECKED	2021-12-03	REV
		FINISH	NUMBER		SCALE: 1:7 WEIGHT: SHEET 1 OF 1

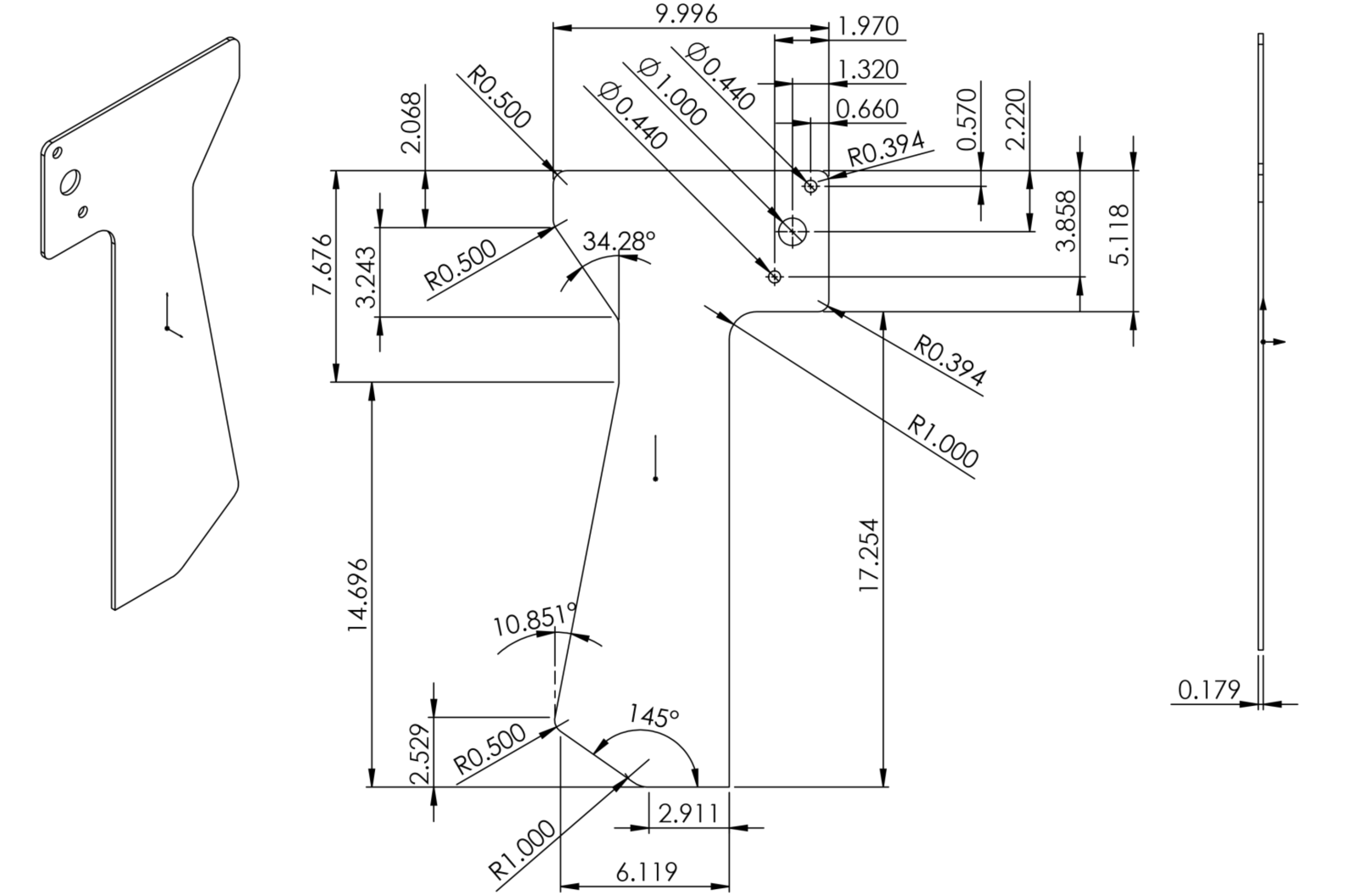
SolidWorks

3 2 1



SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING			TITLE: **Off-piler Project**
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE	SIZE A / DISCRIPTION: Chain Lock Connection / REV 0
			DO NOT SCALE DRAWING	DRAWN Team 8	2021-12-02	
			MATERIAL 0.5" Alloy Steel Plate 4340 Annealed	CHECKED	2021-12-06	
			FINISH	NUMBER		SCALE: 2:1 / WEIGHT: 0.011 / SHEET 1 OF 1

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

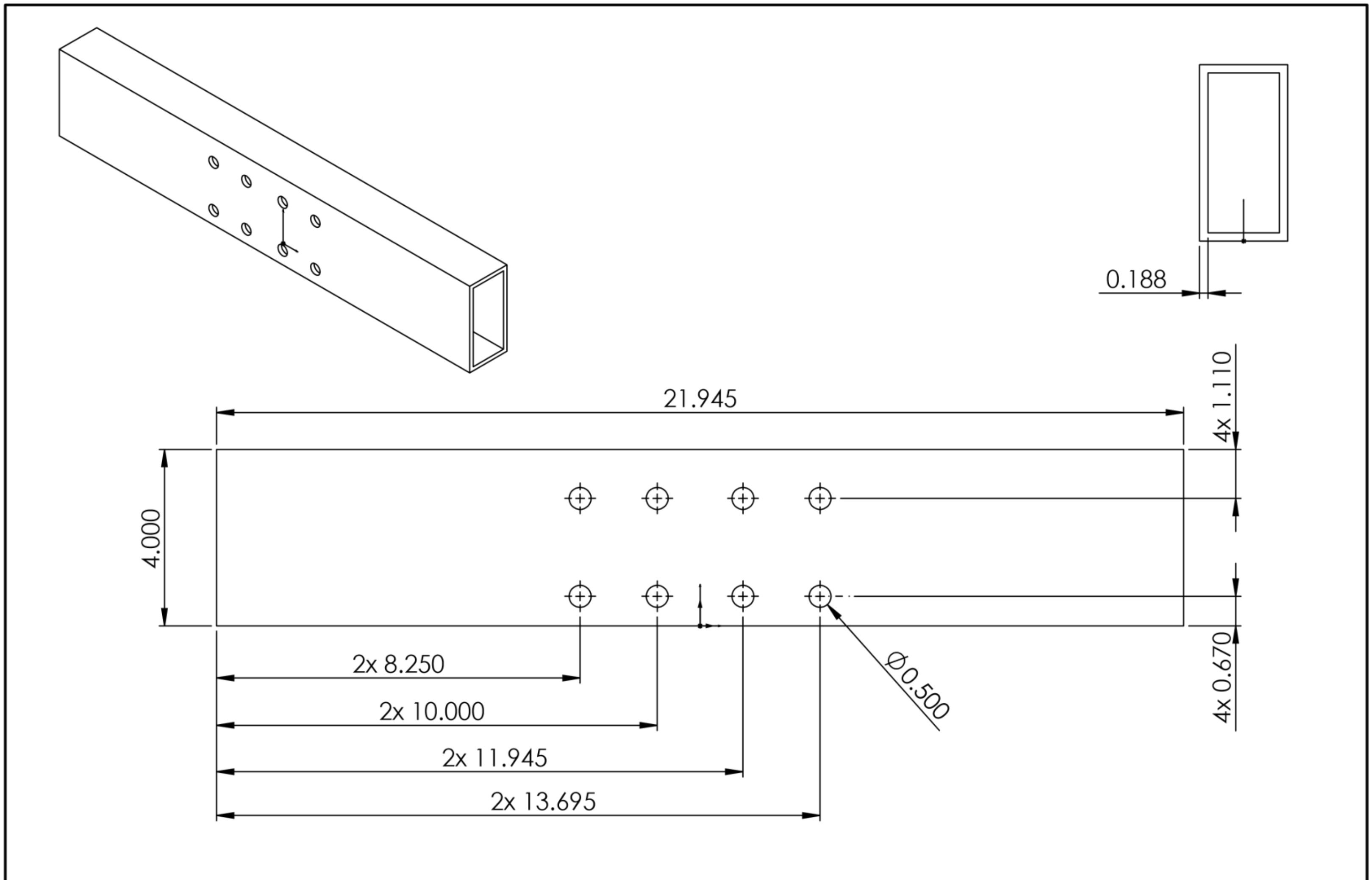
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994	NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Team 8	2021-12-02
MATERIAL 7 Ga. Hot Rolled Steel Sheet	CHECKED		2021-12-06
FINISH	NUMBER		

SIZE	DISCRIPTION:	REV
A	Lift Plate	0

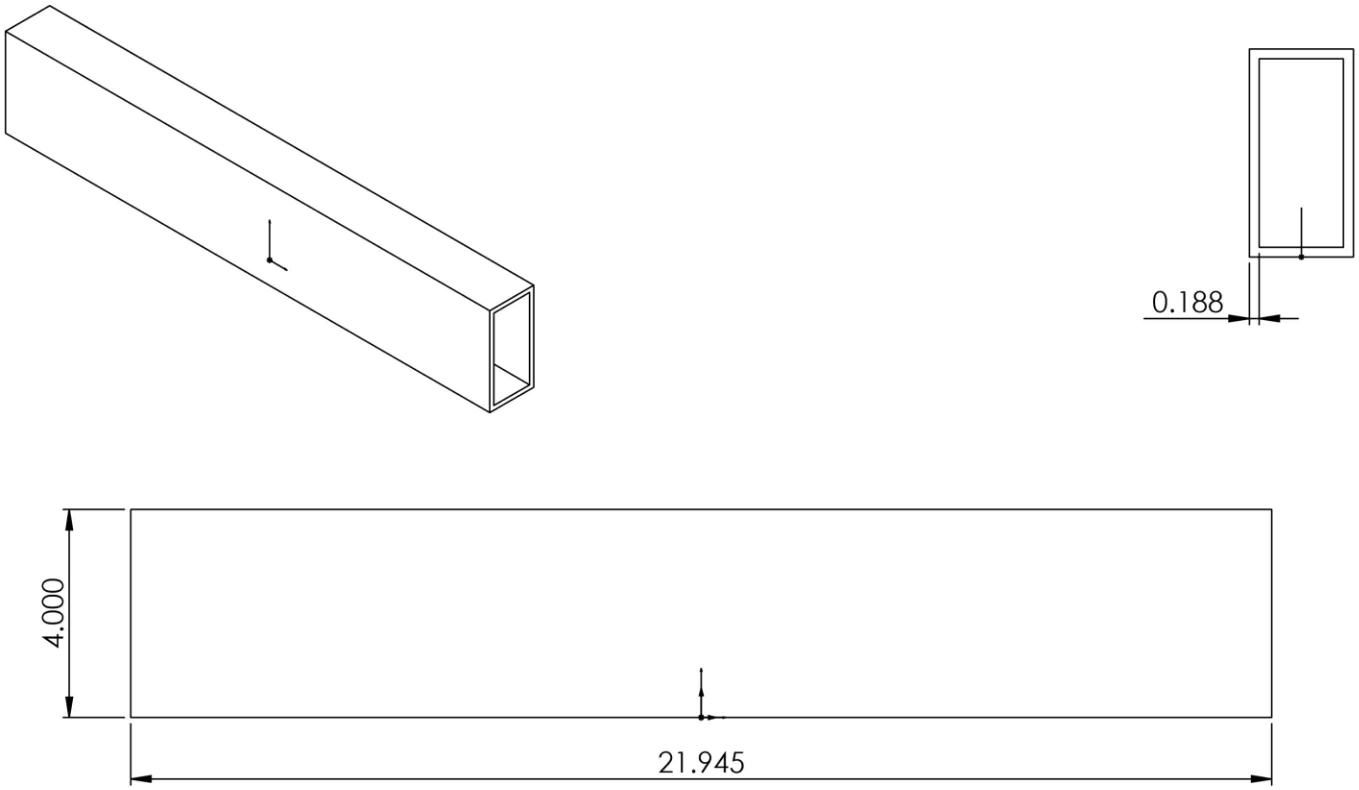
SCALE: 1:5 | WEIGHT: 0.857 | SHEET 1 OF 1

5 4 3 2 1



SolidWorks	MECH 4860	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: ANGULAR: MACH ±0° 30' TWO PLACE DECIMAL ±.01 THREE PLACE DECIMAL ±.002	UofM MECHANICAL ENGINEERING	TITLE: **Off-piler Project**
			INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994 / NAME / DATE	SIZE A
			DO NOT SCALE DRAWING / DRAWN / Team 8 / 2021-12-02	DISCRIPTION: Top Side Bar
			MATERIAL 2" x 4" Rectangular Steel Tube / CHECKED / / 2021-12-06	REV 0
			FINISH / NUMBER	SCALE: 1:3 / WEIGHT: 1.655 / SHEET 1 OF 1

5 4 3 2 1



UofM MECHANICAL ENGINEERING

TITLE: **Off-piler Project**

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

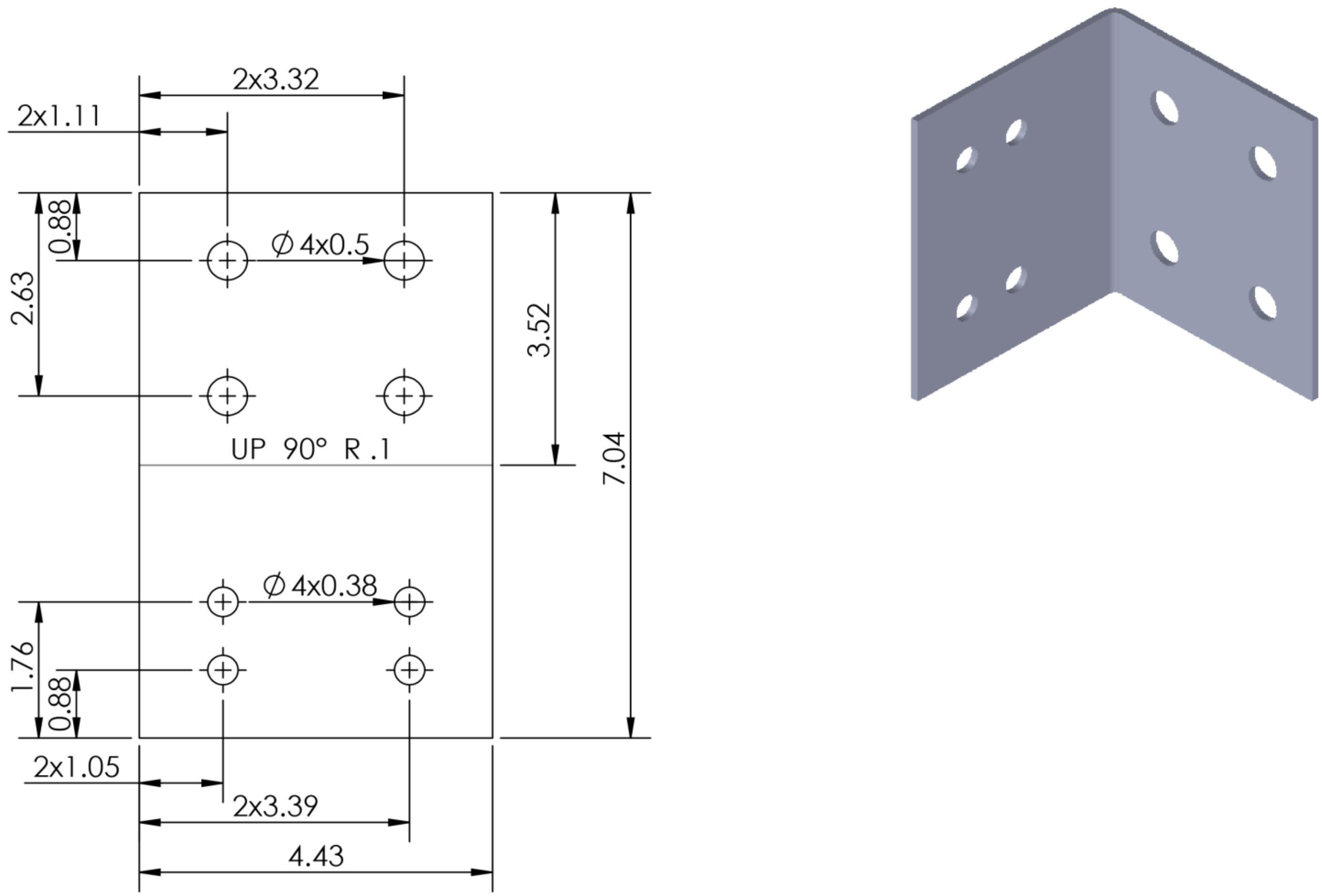
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994		NAME	DATE
DO NOT SCALE DRAWING	DRAWN	Team 8	2021-12-02
MATERIAL 2" x 4" Rectangular Steel Tube	CHECKED		2021-12-06
FINISH	NUMBER		

SIZE	DISCRIPTION:	REV
A	Bottom Side Bar	0

SCALE: 1:3 | WEIGHT: 1.676 | SHEET 1 OF 1

SolidWorks

5 4 3 2 1



SolidWorks

MECH 4860

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
ANGULAR: MACH ±0° 30'
TWO PLACE DECIMAL ±.01
THREE PLACE DECIMAL ±.002

UofM MECHANICAL ENGINEERING

		NAME	DATE
INTERPRET GEOMETRIC TOLERANCING PER: ANSI Y14. 5M-1994			
DO NOT SCALE DRAWING	DRAWN	Team 8	12/4/2021
MATERIAL 12 Ga. Hot Rolled Steel Sheet	CHECKED		12/4/2021
FINISH	NUMBER		

TITLE: **Off-piler Project**

SIZE A

DISCRIPTION: Center Support Bracket

REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1

A.9 – Base Structure Lift Manual [7]

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