

Letter of Transmittal

Team 18 – MECH 4860 – Mechanical Engineering Capstone

University of Manitoba

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Dear Jean-Marc Dequier and Cody Peters,

Team 18 is pleased to present to Elmer's Manufacturing our report for the Grain Cart Mainframe Welding Jig Design. This final design report is considered the main deliverable of this project, which combines all concepts as well as final concept with parts list, standard operating procedure, total cost, bill of materials, CAD model, DXF files, and drawings.

During the term, an exceptional amount of effort has been made to research, investigate, and brainstorm to meet the client's needs and technical specifications. With the help and support from all the industry advisors and academic advisors, our team is extremely thankful for all of opinions and suggestions from Jean-Marc Dequier, Cody Peters, Paul Labossiere, Nishant Balakrishnan, Jaime Ordenez, and Aidan Topping. These advisors greatly helped the team throughout the entire design process to produce the final design of an upside down mainframe assembly jig system.

Team 18 also ensures that the design is wholly their own design, which avoids patent litigation prior to handing it to Elmer's Manufacturing. We are privileged to be a part of the engineering team, as well as feel grateful for all the experience and instruction that we have learned during our time working together with Elmer's Manufacturing.

Sincerely,

Team 18

Thanh Bui

David Josh Kagaoan

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**University
of Manitoba**



Design of Grain Cart Mainframe Welding Jig

MECH 4860

Final Design Report

Price Faculty of Engineering

Department of Mechanical Engineering

Team 18

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Presented to:

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Jean-Marc Dequier, Jig and Tool Team Lead
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Aidan Topping, Technical Communication Instructor

Wednesday, December 8, 2021

Executive Summary

Elmer's Manufacturing is a rapidly growing company, located just north of Altona, MB, that specializes in the production of agricultural equipment such as grain carts, harrows, ditch cutters, and bale processors. Elmer's is looking to increase their manufacturing capacity to produce products that are in high demand. The management team at Elmer's is in the process of physically expanding their facilities while improving the efficiency of their manufacturing processes. Team 18, a group of four mechanical engineering students from the University of Manitoba, has been selected to assist the team at Elmer's Manufacturing with one of their improvement projects. The project is meant to decrease the assembly time required to tack weld grain cart mainframes together by utilizing a jig system that is user-friendly and effective. The goal of this project is to decrease the six-hour assembly time of a mainframe by 30%.

This final design report covers the overall process leading to the final design and outlines content written in the problem definition report and concept definition report. The introduction provides background to the project and an overview of the project definition report, which was used in phase one of the project. The external research section outlines topics that the student design team researched in preparation for the concept development for this project. Concept generation, completed by the team, with assistance from industrial and academic advisors, resulted in a total of 21 conceptual solutions to the project. Through the process of screening and analyzing concepts based on criteria deemed to be important to the success of the project, the team was able to narrow the desirable solutions down to three concepts. The three concepts were further iterated and optimized until only one design was chosen.

After much time in discussion amongst the team and with an engineer from Elmer's Manufacturing, the final design chosen was the upside down assembly variation. Fixtures and jigs were later made for this design to ensure that all parts were located and clamped efficiently. This design is modular to be able to work with all four grain cart mainframe assemblies. Concerning the final design, CAD models, a bill of materials, drawings, DXF files, a standard operating procedure, and a cost analysis are delivered within this report to be presented to Elmer's Manufacturing. In order to prove that this design decreases the six-hour assembly time of a mainframe by 30%, testing and further study will need to be done by workers at Elmer's Manufacturing.

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Glossary

Bill of Materials (BOM): A list of parts or assemblies needed to create the jig system.

Cam Clamps: Clamping tools used attach the base of the jig to the jig table.

Computer Aided Design (CAD) Model: Also known as a 3D model, used to build a realistic computer model of parts and assemblies.

Computer Numerical Control (CNC) Machine: Machine tool that cuts or moves material as programmed by the controller. Used for high tolerance parts.

Degrees of Freedom (DOF): This describes how free an object is to move in three axes (X, Y, and Z).

Downstream: Any other process after the mainframe assembly process.

Drawing Exchange Format (DXF): File used for laser cutting in manufacturing.

Engineering Drawings: Technical drawing to convey information about a component or assembly.

Fixture: A piece of equipment which is used to constrain an object in space.

Hollow Steel Structure (HSS): A metal profile with hollow cross section that holds the structure of the mainframe.

House of Quality (HOQ): House shaped diagram, which shows needs and design parameters of a project.

Intermittent Welding: Commonly referred in industry as stitch welding is a welding process that is not continuous across a welded joint.

Jig System: A set of jigs used to properly define geometric properties of the mainframe.

Jigs: Devices used to guide tools and components to the correct location in the assembly process.

Laser Cut: Utilizes laser beams to heat up and cut specific parts of a material.

Machined: To cut or shape metals using a CNC machine.

Processing Time: The amount of time used to assemble the mainframe.

Rotisserie Stand: Equipment used by Elmer's to rotate the mainframe by $\pm 180^\circ$.

Standard Operating Procedure (SOP): A set of instructions on how to operate the designed jig system.

Sub-assembly: An assembled component to be incorporated with other parts for the final assembly.

Sub-weldments: A pre-welded set of components to be welded for the final weldment.

Tack Welding: A welding process that involves placing small and discontinuous welds to pieces of an assembly before fully welding or intermittently welding those pieces together.

Upstream: Any other process before the mainframe assembly process.

Weighted Decision Matrix (WDM): A tool used to compare different concepts generated with respect to the different criteria as well as their level of importance.

Welding: A fabrication process used to join materials by using heat to melt the parts together.

1 Introduction

Elmer's Manufacturing is working with a team of students from the University of Manitoba to evaluate and improve their current **Tack Welding** process used to manufacture the mainframe for their Row Crop Tandem, small, large, and high capacity Haulmaster grain carts. This section summarizes the company background, project background, problem statement, project objectives, scope, project deliverables, assumptions, project constraints and limitations, client needs and technical specifications, and lastly standard items that Elmer's uses in their facility.

1.1 Company Background

Elmer's Manufacturing Ltd. is a manufacturing company that designs, develops, and manufactures specialized agricultural equipment, with the company being founded in 1978. Their main products include row crop cultivators, edible bean cutters, header and swather transports, Super 7 Harrow, and the Haulmaster grain cart. The Haulmaster grain cart is a high capacity grain cart that is available in a multitude of **Assembly** variations to fit their customer's needs. Grain carts are typically used to move large amounts of harvested material from the combining process to an appropriate mode of transportation, such as a semi-trailer. Figure 1 below shows the process of a crop being transported from the field, into a semi-trailer.



(a) Grey 2000 Bushel Capacity Grain Cart Receiving Crop from a Combine



(b) 1300 Bushel Capacity Grain Cart with Tracks Unloading into a Semi Trailer

Figure 1: Elmer's Haulmaster Transporting Grain from Combine to Transport Semi Trailer [1]

1.2 Project Background and Problem Statement

Elmer's Manufacturing Ltd. manufactures the Haulmaster, which is one of their popular products. The Haulmaster is available in different assemblies such as the row crop tandem, small, large, and high capacity grain carts, shown respectively in Figures 2a , 2b, 2c, and 2d.



(a) Elmer's Row Crop Haulmaster [2]



(b) Elmer's Small Haulmaster [3]



(c) Elmer's Large Haulmaster [2]



(d) Elmer's High Capacity Haulmaster [1]

Figure 2: Four Haulmaster Models

Each grain cart is built with its own specific mainframe, and currently, each mainframe is constructed from the bottom-up in a tack welding process on welding tables. Workers at Elmer's tighten down **Clamps** to hold the mainframe parts in place while it gets tack welded. In Figure 3 on the next page, a view of a completed mainframe is shown. This mainframe is then attached to other the other assemblies, which forms a grain cart as shown on the next page in Figure 4.

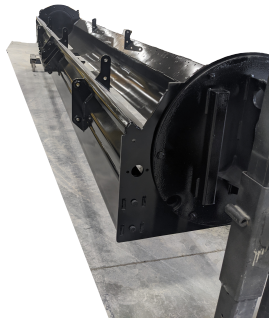


Figure 3: Mainframe Prior to Installation

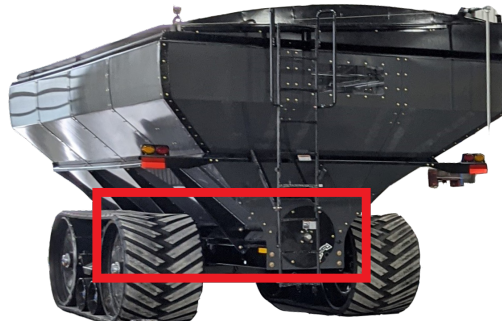


Figure 4: Location of Mainframe Within Grain Cart

Below in Figure 5, a small mainframe table is shown. This table is used in conjunction with two large mainframe tables to assemble large mainframes. Figure 6 on the next page shows the welding process for the large mainframe. After the assembly process on the welding tables is complete, the mainframe is then moved to a **Rotisserie Stand**, where the welding process is completed. Currently the average time it takes to finish the manufacturing process is six hours (360 minutes).



Figure 5: Small Jig Table



Figure 6: Large Mainframe on top of Large Jig Table

The problem that Elmer's is facing is that the current tack welding process used to manufacture the mainframe for their various Haulmaster grain carts is not efficient and requires an overhaul. As shown in Figure 7 below, the clamps used to secure parts of the mainframe assembly are being applied at irregular, and sometimes unstable, angles.



Figure 7: Close-up of Extra Clamps on Mainframe Jig Table

Elmer's workers are forced to use an excessive amount of c-clamps to define the mainframe which increases the amount of time to manufacture its product. This has also led workers to perform extra work on the mainframe assembly by hammering the clamps into place to make parts fit, which is shown below in Figure 8.

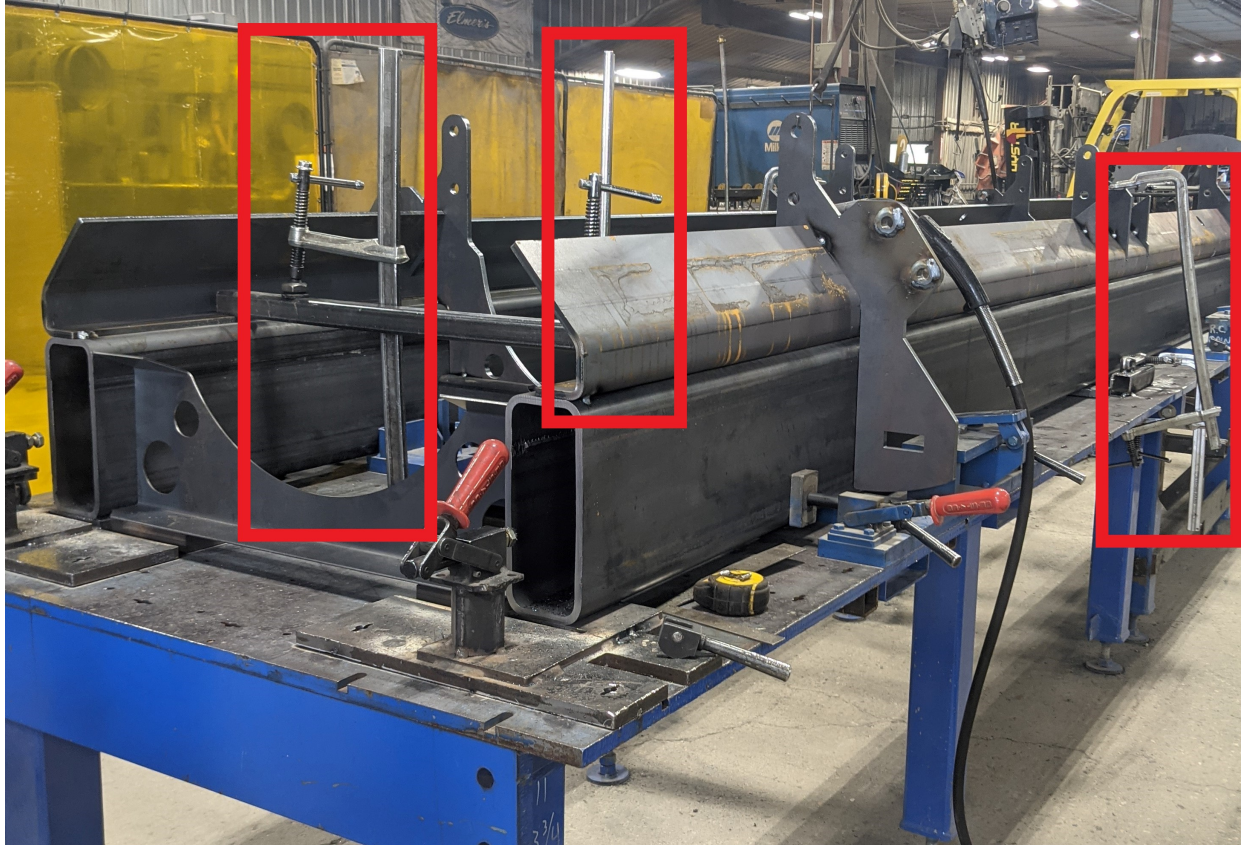


Figure 8: Location of Extra Clamps on Mainframe Jig Table

1.3 Project Objectives

The main objective of this project is to design a modular welding **Jig System** to be used in the assembly of the Row Crop tandem, small, large, and high capacity, grain cart mainframes, which helps to decrease the time needed to weld a mainframe. Currently, the time needed to weld a mainframe is approximately six hours (360 minutes). Elmer's manufacturing has informed Team 18 that the time to manufacture the mainframe should be decreased by at least 30% (108 minutes).

1.4 Scope

The scope of this project includes the following:

1. Final design of the jig system.
2. Accurate **CAD Models** of the design.
3. A standard operating procedure on how to use the jig while assembling mainframes.

4. Cost analysis of the final design.

The following are not considered in the scope of the project:

1. Any manufacturing before and after the tack assembly process.
2. Considerations of warping in the design process.
3. Labour Costs will not be considered in the cost analysis.

1.5 Project Deliverables

By the end of the project, Team 18 plans to deliver the following to Elmer's Manufacturing Ltd.:

Deliverables	
Concept Drawings or Illustrations	For full visualization of the concept ideas during concept selection
CAD Models	For a more refined visualization of the jig and how it interacts with the system
SOP	To show how the jig is used when assembling the various mainframes
BOM	For the construction and operation of the design
Engineering Drawings	For accurate measurements of the parts
DXF Files	For parts that are required to be Laser Cut

1.6 Assumptions

Below is a list of assumptions that Team 18 has made going forward with this project, that was given to the team by Elmer's Manufacturing:

- A cost of \$2/lb of material for laser cut components, including the cost to weld these components.
- A cost of \$4/lb for **Machined** components to produce and machine.
- In house labour cost will be accounted for after the design.
- Processes **Upstream** and downstream of the tack welding are not considered in the design.
- Mild steel is to be used in all jig or **Fixture** components.

1.7 Constraints and Limitations

Any real life project is bound to encounter constraints and limitations such as time, scope, design, and cost. The following illustrates what Team 18 must consider throughout the project:

- **Time**
 - One of the main constraints of this project. The team must submit all project deliverable to the client and advisors by the deadline of this project.

- **Scope**

- Team is solely focusing on redesigning the jigging system, using the current jigging tables. This limits the team's alternatives for significantly changing the welding process.
- The team will be unable to control most welding options such as welding settings, welding wires, treatments, pre-bending options, and welding orders.
- Team 18 also cannot change any upstream or **Downstream** solutions.

- **Design**

- The final's design size must not exceed above and around the current jig table and assembly.

- **Cost**

- As per client's request, the team cannot exceed a budget of \$5,000 for this project. This will cover all the parts, equipment, and tools used for the final design.

1.8 Client Needs and Technical Specifications

Through different meetings with Elmer's Manufacturing Engineering Team and Capstone advisors, the needs and target specifications have been established based on the current constraints, as well as the expected outcome. With a new jig system, the **Processing Time** should be optimized to be at least 30% (108 minutes) less than the previous time of six hours. To determine if Team 18's final design will meet this outcome, Elmer's employees will have to estimate how much time a jig system will save in the assembly process. Reducing processing time will yield lower labour costs and increase tool lifespans. Below, in Table I, the needs of the project are defined, with an importance rating for each need. The importance rating ranges from 1-3, with 1 being least important important and 3 being most.

TABLE I: GENERAL PROJECT NEEDS

Number	Need	Importance
1	The jig lowers assembly time of mainframes by 30% (108 minutes).	3
2	The jig should be able to accommodate for different sizes of mainframe assemblies.	3
3	The jig should fit on the adjustable tables for welding.	3
4	The jig should minimize warping in the mainframes.	3
5	The jig should be safe to use by workers.	3
6	The jig should allow for space around the adjustable tables for welders to weld the assembly.	2
7	The jig should be easy to use by the welders assembling the mainframes.	2
8	The jig should be durable.	2
9	The jig should be easy to maintain.	2
10	The jig should be able to be moved via overhead crane if needed to.	1
11	The jig should be within a budget of \$5000.	1

Needs numbers 1, 2, 3, 4, and 5 have an importance rating of 3 because these needs will have a large influence in the concept generation and design of the jig.

- Need #1: The purpose of the re-designed jig is to lower assembly time therefore, this is the most important need.
- Need #2: The jig must be designed to be used for the 4 different sizes of mainframes.
- Need #3: The current jig table that the client uses is irreplaceable, therefore the jig should be designed within the area of the table.
- Need #4: Warping will cause parts to not fit well with each other; increasing mainframe assembly time.
- Need #5: Considering the safety of the workers is a must.

Needs numbers 6, 7, 8, and 9 have an importance rating of 2 because they are less important compared to the the needs above.

- Need #6: An oversized and awkwardly shaped jig will be an inconvenience to the workers working around the assembly.
- Need #7: The jig should be user friendly for the welders tacking the mainframe.
- Need #8: The jig should be reusable for 5 years and should be able to take frequent hammer blows from workers.
- Need #9: The workers can easily use, find and access the jig when they need it.

Needs number 10 and 11 are the least important needs of the project, but are still a requirement for the project.

- Need #10: The jig needs to be accessible from the top of the production assembly in order to use the overhead crane to position heavy parts.
- Need #11: The design and construction of the jig should be reasonably priced.

Table II below shows the metrics for this project. A metric can correspond to one or more project need based on how the metric is to be accomplished.

TABLE II: PROJECT METRICS

Metric#	Metric	Need#s
1	Reduce mainframe assembly time by a minimum of 108 minutes	1,2,6,7
2	Maximum Jig costs is \$5000	11
3	Jig lifetime is at least 5 years	8,9
4	Jig works with 4 different mainframe sizes	2,7
5	No complex inspection required to use jig (mostly visual test required)	9
6	Welding process will be accomplished on adjustable tables (for various mainframe sizes)	3
7	The welding process will be done manually	6,7
8	Limit as much warping while Welding	1,4,7
9	Jig should not exceed weight able to be carried by crane if needed	10
10	Jig should be safe according to workplace safety standards	5

The **HOQ** from Appendix D aims to rate how important each client need is numerically, and rate how important each parameter (safety, time, cost, user friendliness, and quality) is to the project succeeding. The HOQ clarifies that the top priority of this project is the time parameter. Some of these parameters will be used to help determine the most suited and feasible concepts to accomplish this projects objectives.

1.9 Standard Items

The following items are preferred items that are already on-site at Elmer's Manufacturing. Wherever possible, the team has been requested to implement these readily available goods into the design. Machined parts, where a higher level of tolerance is required is also a viable option, as the client has the capability to CNC mill parts on-site.

Standard Tube Sizes (Inches):

- 2.000 x 2.000 x 0.188
- 4.000 x 4.000 x 0.188
- 8.000 x 4.000 x 0.250

Standard Sheetmetal Thicknesses (Inches):

- 0.25
- 0.375
- 0.5

Standard Clamps (Inches):

- Destaco 650
- Destaco 245-U
- Destaco 341

2 External Research

In manufacturing, manufacturing innovators have come up with different methods concerning producing high quality products to meet high demands of customers. These methods involve making products as fast as possible, which helps save on cost. Methods that sufficiently meet those criteria and also facilitate the ease to manufacture complex products, improve safety, as well as ensure the production standard is kept to a high level are of a high importance within manufacturing. This is most commonly done by applying jig and fixture systems. It should be noted that this project is termed “mainframe welding jig” colloquially, but in the final design, it resembles a fixture more than a jig. In this section, the differences between **Jigs** and fixtures will be shown, as well as other important topics that are relevant to jig and fixture design.

2.1 Jigs and Fixture Differences

To discern between jigs and fixtures, it is important to know the definition of each system. Jigs are commonly used as efficient tools to guide machine parts on a workstation, as well as fix parts together during an assembly process. Depending on the purpose of different applications, jigs help to guide tools for efficient operation and keep parts stationary, especially with assemblies using complex shapes. Unlike jigs, that are mostly used to guide machining tools, fixtures are used solely to constrain a part in a desired location. Fixtures also decrease the loading, unloading, and fixing time of the work piece, making a fixture a critical piece of equipment in regards to saving time and cost in manufacturing. In Table III below, the differences of jigs and fixtures are clearly outlined.

TABLE III: JIGS AND FIXTURES OBSERVATION OF DIFFERENCE

Jigs	Fixtures
Controls and guides the machining tool	Holds and supports the components precisely to be machined or assembled
Offer accuracy, repeatability, and interchangeability	Provide reduction in error by holding a component firmly on a table
Usually on the lighter than fixtures	Bulky, rigid and heavy
Can be put in place and held by hand pressure	Always placed firmly on a machine table
Used for drilling, reaming, tapping, boring are some of the standard	Not limited to just drilling, reaming, tapping, or boring
Cost more than fixtures	Cheaper than jigs
Require intricate design operation	Less complicated operation

Based on the definitions, as well as the advantages and disadvantages, and the differences between jig and fixtures, engineers can apply their knowledge and expertise to brainstorm and decide which method is best for their project.

2.2 Jig and Fixture Construction

For applications that require the need of the operator to clamp or mount work pieces properly as well as guide a welding or machining tool, jigs are to be constructed. As shown in Figure 9 below, this is an example of a table jig that uses holes to locate clamps in any desired orientation. It is designed for locating the work piece on to the surface of the table.



Figure 9: Table Jig [4]

Fixture constructions are used in manufacturing industries involving tasks such as holding work pieces parallel to the machine table, locating components at an angle to the machine table, manipulating odd shaped, heavy or bulky items, or inspecting complicated parts.



Figure 10: Welding Fixture [5]

For example, a welding fixture is shown above in Figure 10. Welding fixtures provide an efficient process of putting together an assembly by using a plate fixture on top of a sturdy table. Elmer's Manufacturing is currently using this type of fixture for their mainframe welding process, which allows a massive weight to be loaded on the table. Toggles clamps, swivel clamps, and c-clamps are often used in the welding fixture which provides an excellent combination of design flexibility, holding capacity and operational speed. It is also not uncommon for other fixtures and and toggle clamps to be welded to the plate fixture on the table.

2.3 Structural Components

The use of structural components during the development of jigs and fixtures needs to be carefully evaluated moving forward since the geometric tolerance of structural components can vary greatly [6]. The benefit of lower cost materials needs to be noted as well, where structural components are much more economically desirable per volume, when compared to high tolerance metal.

Jigs and fixtures are mainly composed of a number of elements such as the body, the clamping devices, locating devices and jig bushing or tool guide. In different designs, production, and assembly processes, these compenets of jigs and fixtures are modified and arranged to meet the needs of increasing throughput, the quality of products, and interchangeability and accuracy.



Figure 11: Elements of Jigs and Fixtures [7]

Shown above in Figure 11 is a set up of a jig with some of its components explained below. Notice that the drill is guided by a hole and bush, making this a jig and not a fixture.

Main Body: the main supportive component of jig systems, is fabricated by slabs or metals, then heat-treated to decrease stress concentrations.

Clamping Devices: used to hold work-pieces tightly in place; must be easy to use and straightforward to achieve high throughput efficiency.

Locating devices: very common in the jigs; used to locate parts onto work holder and is made from hardened steel.

Jig Bushing and Tool Guide: locates the cutting tool to the component properly; used in drilling and boring to resist wearing, improve interchangeable and precision, and is usually made from high grade tool steel for best performance.

2.4 Part Constraining

In regards to constraining parts using jigs and fixtures, it is essential to understand how degrees of freedom work. An object normally has six Degrees **DOF** such as up and down, left and right, forward and backward, and the ability to rotate about three axes (X,Y and Z). Well thought out designs of jig and fixture systems do not over-constrain these freedoms, but adequately restrict these DOF as much as possible to exactly define the assembly or part. Over-constraint occasionally brings up the following problems: the appearing of residual forces, increased cost, wasted time, decreased quality, and creating risks in a work environment. The goal of designing a jig and fixture set requires engineers to deeply understand the definition, concept, function of the tool, as well as know how to design precision equipment. On top of this, a variety of parameters also need to be considered as a constraint of the design, shown below in Table IV

TABLE IV: PART CONSTRAINTS

Key Considerations	Characterization
One-handed Operation	Allow operators to use one hand to hold the fixture and stabilize position workpieces.
Human Assistance Cutoff	No human assistance needed to hold parts
Geometries Optimization	Existence of misalignment error
Adaptation	How a system fits into the overall production workflow
Setup Steps	Minimize number of steps.
Durability	The longevity of part with minimum maintenance
Manufacturability	Ease of manufacturing at low cost

Jigs and fixtures definition limitations are related by the degree of freedom such as up and down, left and right, forward and backward, as well as the ability to rotate 3 different axes and create many constraints for operator. Because of that, different part constraints have been developed to determine if engineers could distinguish between manufacturing processes, and apply this into different industries. The following equipment will outline different methods of constraining work on jigs and fixtures.

2.4.1 Steel Cables



Figure 12: Steel Cables [8]

Steel cables can be used to hold down structural components as shown above in Figure 12. A steel cable is an assembly of metallic strands arranged in a helical form around their respective core and assembled to become one piece. These cables are used to transmit force, movement, and energy in an assembly of mechanical parts. With steel cables it is important to consider the specific alloy in use as steel refers to a grouping of metals with different properties rather than a single element. Stainless steel cables are among the most popular as they offer increased resistance to corrosion and wear even in harsh environments [9].

2.4.2 Ratchet Strap



Figure 13: Ratchet Strap [10]

Ratchet straps, or down straps, are usually used to hold down cargo or equipment during transport. It has a webbing pattern that has a tie down hardware sewn to it, shown above in Figure 13. A ratchet mechanism is used to loosen or tighten the straps. The strap is attached to the area surrounding the equipment, looped over it, and attach to the equipment. It is also used to provide a method of introducing tension to hold an item in place [11].

2.5 Clamps

Clamps are versatile tools that serve to temporarily hold a piece securely in place, and are used for various applications including carpentry, woodworking, furniture making, welding, construction, and metal working. For this section the types of clamps that will be discussed are those that will aid in the concept generation of the report. These clamps will be categorized into two types which are the manual clamps and the pneumatic clamps.

2.5.1 Manual Clamps

Manual Clamps as the name suggests are clamps that are used manually by a user. These are handheld devices where a user will have to use physical force to tighten the clamps down. Below are some examples of manual clamping devices.

Destaco 650



Figure 14: Detasco 650 [12]

Destaco 650, shown above in Figure 14 is a straight action clamp for assembly, welding, and light press work. It is mostly used for heavy-duty push and pull clamping. It locks in both extended and retracted

position with a forged steel base and handle. This clamp can handle a maximum holding capacity of 16,000 lbf. This clamp is one of Elmer's Manufacturing stock held clamps that the company uses in their assembly lines [12].

Destaco 245-U



Figure 15: Detasco 245-U [13]

Another stock held clamp that Elmer's Manufacturing has inventory of is the Destaco 245-U, which is shown above in Figure 15. Destaco 245-U is a low profile, manual horizontal clamp for holding down work pieces. It has a large handle clearance for ease of use and a clamp supplied with a neoprene spindle. This clamp can handle a maximum holding capacity of 1,000 lbf [13].

Destaco 341



Figure 16: Detasco 341 [14]

Destaco 341 is a pull action latch clamp for molding, assembly and closures. It has a thumb control lever for one handed operation with threaded U-hooks for easy adjustment. It is a light clamp that weighs only 1.43 lb and can handle a maximum holding capacity of 2,000 lbf [15]. Elmer's Manufacturing has this clamp in stock readily available for easy access.

Screw Clamps



Figure 17: Screw Clamps [16]

Shown above in Figure 17, screw clamps are one of the simplest and least expensive clamps [citeScrewClamps](#). They are types which use a screw mechanism to adjust the jaws and clamp a workpiece in place [16]. These clamps are commonly referred to in a workplace setting as “c-clamps”.

Quick-Release Clamps



Figure 18: Quick-Release Clamps [16]

Shown above in Figure 18, quick release clamps or one-handed clamps are designed with a mechanism which allows the user to release a work piece in one quick movement [16]. They are commonly used for holding glued wooden parts together and home DIY projects. This type of clamping is mainly used for its versatility and speed to clamp down parts together.

Bar Clamps



Figure 19: Bar Clamps [16]

Bar clamps, shown above in Figure 19, have a long metal bar which holds the two jaws parallel. The extensive bar allows the user to clamp long or wide work pieces effectively for heavy duty work [16]. This type of clamping is typically used for woodworking application and sometimes metalworking [17].

Angle Clamps



Figure 20: Angle Clamps [16]

Shown above in Figure 20, angle clamps also known as corner or mitre clamps and are designed for clamping objects at an angle[16]. This device allows two items to be held at a 90-degree angle, in order to be attached together [18]. These clamps are commonly used in box-like assemblies.

Toggle Clamps



Figure 21: Toggle Clamps [16]

Toggle clamps only have one clamping plate and work in conjunction with a worktop, such as a bench surface, to hold a work piece steady. The clamp is designed to be permanently fixed to the workbench table, by bolting it into place [16]. Toggle clamps function by either being “toggled on” and clamping something down, or “toggled off” with the clamp end retracted. In Figure 21 above, this toggle clamp is shown in the “toggled off” position.

All Purpose Jack



Figure 22: All Purpose Jack [19]

All purpose mechanical jacks are used for lifting, pushing, pulling, and clamping. An all purpose jack is shown above in Figure 22. Mechanical jacks use a physical means to raise or lower a work piece. These are self-locking systems where, when power is removed from the jack, the screw remains in the same position until power is reapplied.

2.5.2 Pneumatic Clamps

Pneumatic Clamps are portable devices that are utilized for quick clamping in repetitive production operations. They use air-actuated cylinders with a toggle mechanism to operate the clamping action. They are used in a wide variety of fields such as the processing and assembly of general machinery [20].

Pneumatic Lever Clamp



Figure 23: Pneumatic Lever Clamp [21]

Pneumatic lever clamps, shown above in Figure 23, are clamps used for light duty welding assembly applications in aerospace, automotive, food and packaging, industrial and consumer goods industries. The lever arm can be positioned left, forward, or right within the same clamp body. It has a consistent clamping force over a range of part thickness. This clamp is engineered for longevity and reliability [21].

Light Duty Pneumatic Toggle Clamp



Figure 24: Light Duty Pneumatic Toggle Clamps [22]

Destaco pneumatic toggle clamps, shown above in Figure 24, includes a toggle-lock safety feature to stay mechanically locked even with a total loss of pressure. Holding capacities are a function of the cylinder/clamp/pressure combination. The units are completely self-contained and require only a pressure source hook-up. Most models are equipped with a magnetic piston ring for end position sensing using optional switches, as well as a remote feature for no contact usage [22].

Heavy-Duty Pneumatic Clamp



Figure 25: Heavy-Duty Pneumatic Clamp [23]

Destaco's heavy duty pneumatic power clamps, shown above in Figure 25, offer exceptional clamping forces and holding capacities, far greater than clamps of similar size. These clamps are generally used in aerospace, automotive, and the food and packaging industries [23].

Pneumatic Power Cylinder



Figure 26: Pneumatic Power Cylinder [24]

Destaco's pneumatic power cylinder, shown above in Figure 26, operates based on a wedge lever principle. It can provide maximum holding capacity of over 13,000 lbf. Equipped with dual cylinders that features two step strokes: a forward stroke to move a certain distance and a power stroke with an amplified force. This clamping system is ideally suited as the power source for tools and devices for clamping, punching, stamping, notching, coining, riveting, pressing and clinching [24].

2.6 Movement Prevention

Further analysis on jigs and fixtures system, knowledge and basic understanding of their construction is quite useful and necessary to engineers in manufacturing. Essentially, jigs and fixtures systems combine an assortment of parts to be assembled in a desired manner using tool bodies.

All the locators, clamps, supports and other parts need a sufficient mounting area that position and grasp the work-piece tightly and keep it stationary. Most common categories of tool bodies are cast, welded, and

built-up. Each category gives a desired result in a specific case. Therefore, choosing an appropriately tool body would optimize the function of a jig or fixture system.



Figure 27: General Categories of Tool Bodies [25]

Shown above in Figure 27 are the three basic forms of tool bodies such as cast, welded and built up. The cast tool bodies material types are diverse and can be made from cast iron, cast aluminum, and cast magnesium. When being investigated, cast tool bodies can be structured meticulous and complex. The cast tool bodies are commonly used as a relatively permanent work holders or work holders not subject to drastic change. Like cast tool bodies, welded tool bodies can be fabricated from many type of materials, especially steel, aluminum, and magnesium. Welded tool bodies offer a variety of benefits like high strength and rigidity, design versatility, ease of modification and short lead time. Although these two provide many advantages, however, the most common form of tool body used is built-up tool bodies constructed with threaded fasteners. It can be formed by steel, precast section, aluminum, magnesium, or even wood. Built-up tool bodies not only yield all of the other two advantages, but are also applicable for the adaptation and use in manufacturing standard parts.

2.7 Y14.5 and ISO Drafting Definitions:

This subsection will introduce common definitions within the previous standard, ASME Y14.5. Based on the drawing deliverable from the client, the team must closely follow ASME Y14.5. While the ASME Y14.5 mainly focus on these listed terms such as: Datum Feature, Datum Identifier, Datum Reference

Frame, Datum Simulator, Datum Target, Degrees of Freedom, Dimension, and Feature, the ISO tolerance terms are defined by: Feature, Boundary, Condition, Limits, Position, Tolerance and Conditions [26]. More information on these definitions are available in Appendix G.

2.8 Lean Manufacturing

Waste is a common element within any manufacturing process; being anything in the manufacturing process that is not needed. Waste can take the form of unnecessary procedure steps, an excess amount of tools, ambiguous and unclear assembly procedures, idle worker or idle equipment, and product defects [27]. Lean manufacturing is a set of principles within manufacturing that aim to cut down on the amount of waste present in a manufacturing process. Applying lean manufacturing within a manufacturing company is an iterative process, and the ideal manufacturing process that has little to no waste is reached over a period of time. As a result of successfully applying lean manufacturing principles, product quality can increase, and a company can save money during the manufacturing process. For the design of the mainframe welding jig system, it is essential to apply lean manufacturing principles during the concept generation process. Waste can be found in the excessive amount of c-clamps that are used during the mainframe assembly process. Therefore, well thought out designs must eliminate this waste by using quicker and more efficient means of clamping mainframe parts down.

2.9 MADESAFE

MADESAFE is a program that regulates safety within manufacturing in Manitoba. Manufacturing can be a dangerous field of work due to hazards created by machines, tools, and heavy objects, which have the potential to cause injuries and fatal accidents to workers. MADESAFE aims to decrease the frequency of workplace accidents by offering valuable safety resources to manufacturing companies such as seminars, inspections, and training [28]. MADESAFE also provides certification to manufacturing companies that pass MADESAFE safety inspection. This certification has many benefits, with one of the benefits being a 15% rebate in Worker's Compensation Board fees for the manufacturing company [28]. Considering this, Team 18's designs must be as safe as possible and try to eliminate hazards wherever possible. In regards to concept generation, safety is an important focus for generated designs. For the final design, safety procedures are outlined for workers in order to keep workers safe, which is in line with MADESAFE principles.

3 Concept Development and Selection

This section will cover Team 18's process during the concept generation phase. This includes concept generation and concept analysis and selection that led to the three designs that were chosen going into the final design phase.

3.1 Concept Generation

Concept generation is integral to the design process. This section will explain the methodology and reasoning behind Team 18's concept generation process. Following this, all concepts will be presented in a table that describes each concept as well as their pros and cons. Currently, all four styles of Haulmaster mainframe have similar assembly procedures. Therefore, the final design will be completed on the large mainframe styles and then retrofitted to the remaining three styles until the final deliverables are submitted to the client.

3.2 Concept Generation Methodology

Team 18 began concept generation by observing the results from external research. Some of the members of Team 18 considered the jigs that they had observed to be used in past co-op work experience, relating to welding and manufacturing jigs. Recounting this past work experience was valuable to the team since it inspired team members ideas to help facilitate concept generation. Some members of the team have also welded before, and explained what processes worked well to constrain parts and assemblies down as they were being welded. SolidWorks models and pictures from the Elmer's Manufacturing facility of the mainframes were also observed and analyzed, to help the team decide which parts of the mainframe needed to be constrained with clamps or fixtures, and which ones did not. With all of this in mind, concept generation could begin.

The concept generation of this project proceeded in phases. Phase one began with initial brainstorming, both together as a team, and separately away from team time. These concepts were then presented to Elmer's Manufacturing. After presenting concepts from phase one of concept generation, the Jig and Tool Team Lead, Jean-Marc Dequier, suggested to Team 18 that while these concepts were interesting and outside the box, they needed to be further refined, and more emphasis needed to be placed on concepts with **Sub-weldments** and fixtures. The same remark was made during a meeting with advisor Nishant Balakrishnan.

After receiving this advice and discussing it amongst the team, Team 18 then began phase two of concept generation. This phase included making more detailed drawings of some concepts, as well as CAD models. Concepts involving different orientations of assembly were also generated, as well as concepts with sub-

weldments. These concepts were then presented to Elmer's Manufacturing during a meeting. Jean-Marc expressed that these concepts were beginning to follow the right track, in terms of approaching a solution that would be user-friendly, and therefore cut down on the assembly time of six hours. From this point, Team 18 decided that enough concepts had been generated, and screening of the concepts could begin.

3.3 Concepts

The initial concepts of this report, known as phase one of the concept generation process, outlined below and on the next page in Tables V and VI, are what resulted from the team brainstorming. Some of these ideas were further refined in phase two of the concept generation process shown on the next page in Table VII. All tables show a brief description of each concept, as well as pros and cons of each concept. Drawings of each concept can be viewed in Appendix H.

TABLE V: CONCEPTS 1-7

Phase 1 Concepts 1-7				
Concept #	Name	Description	Pros	Cons
Concept 1	Adjustable Peg Mounted Clamp System	A system of adjustable clamps that can be placed anywhere on the jig table to clamp parts down during welding.	Clamps are fully adjustable and should be able to reach most places on the mainframe with ease, uses toggle clamps to quickly clamp parts down.	Might be time consuming for welders to constantly adjust the clamps, clamps might not be able to clamp all parts on mainframe and new holes in the table might have to be made.
Concept 2	Adjustable Slot Mounted Pneumatic Clamp System	A system of adjustable pneumatic clamps that can be placed anywhere along the sides of the jig table to clamp parts down during welding.	Clamps are fully adjustable and should be able to reach most places on the mainframe with ease, uses pneumatic toggle clamps to quickly clamp parts down.	Might be time consuming for welders to constantly adjust the clamps, clamps might be difficult to adjust and slide along table, and pneumatic clamps could accidentally close on workers body parts.
Concept 3	Hanging Frame Clamp System	A clamp system that features adjustable toggle clamps that hang from the ceiling.	Clamps are fully adjustable and should be able to reach most places on the mainframe with ease, and is out of the way for the welders during welding.	Might be time consuming for welders to constantly adjust the clamps, could be dangerous and time consuming to install clamping system on ceiling, might interfere with overhead crane, and clamp arms might not be able to clamp down.
Concept 4	Overhead Wheeled Frame Clamp Setup	A clamp system that features adjustable toggle clamps that hang from a wheeled frame.	Clamps are fully adjustable and should be able to reach most places on the mainframe with ease, is out of the way for the welders during welding, and wheeled frame is easy	Might be time consuming for welders to constantly adjust the clamps, might interfere with overhead crane, and clamp arms might not be able to clamp down parts effectively.
Concept 5	Mini Crane Boom Clamp System	A clamp system that uses small crane like designs that can pneumatically clamp parts down.	Crane clamps are easy to move around and can quickly clamp down parts pneumatically.	Might be complex to manufacture and pneumatic clamps could accidentally close on workers body parts.
Concept 6	Replaceable Claw Clamp Fixture	A fixture system that fixes parts on the mainframe by using a clamping force provided by force from bolts connecting the table to each	Provides strong clamping force to clamp down mainframe parts and is a rigid system.	Needs to be refined more as a concept to clamp down all parts on the mainframe and could be time consuming to adjust bolts with a ratchet and socket that control the clamping force of the fixture.
Concept 7	Replaceable Claw Clamp Fixture with Ratchet	A fixture system that fixes parts on the mainframe by using a clamping force provided by a ratchet.	Provides strong clamping force to clamp down mainframe parts, is a rigid system, and is straightforward to clamp parts down using a ratchet.	Needs to be refined more as a concept to clamp down all parts on the mainframe and ratchet system could be difficult to design and implement.

TABLE VI: CONCEPTS 8-14

Phase 1 Concepts 8-14				
Concept #	Name	Description	Pros	Cons
Concept 8	Replaceable Claw Clamp Fixture with Toggle Clamps	A fixture system that fixes parts on the mainframe by using a toggle clamps.	Provides strong clamping force to clamp down mainframe parts and can quickly clamp down parts via toggle clamps.	Needs to be refined more as a concept to clamp down all parts on the mainframe and the toggle clamps might not be trick to implement to hold down the claw
Concept 9	Adjustable Pneumatic Toggle Clamp Arms	A system of adjustable pneumatic clamps that can be placed anywhere along the inside of the jig table to clamp parts down during	Clamps are fully adjustable and should be able to reach most places on the mainframe with ease, uses pneumatic toggle clamps to quickly clamp parts down.	Might be time consuming for welders to constantly adjust the clamps, clamps might be difficult to access in the middle of the table, and pneumatic clamps could accidentally close on workers body parts.
Concept 10	Tree and Plate Fixtures	A system of fixtures used to locate and hold down mainframe parts.	Very simple in design and inexpensive.	None of these fixtures can clamp parts down.
Concept 11	Regular Orientation Assembly Variation	Right-side up variation of assembling mainframes.	Currently being used by Elmer's and mainframe bottom is flat so it safely rests on table.	Not a full concept and more of an idea that is to be used in conjunction with other concepts.
Concept 12	Upside-Down Orientation Assembly Variation	Upside-down variation of assembling mainframes.	Many of the critical parts are located on the top of the mainframe, therefore if the assembly is done upside, these critical parts can be focused on first and constrained	Many more new jigs will have to be designed if this variation of assembly is to be implemented and this is also not a full concept and more of an idea that needs to be used in conjunction with other
Concept 13	Vertical Orientation Assembly Variation	Vertical variation of assembling mainframes.	None	Assembly is too high and could hit ceiling, welders will have to weld on scissor lifts and ladders, assembly needs to be secured so it does not fall over and damage property or injure workers, and not a full concept and more of an idea that needs to be used in conjunction with
Concept 14	Sideways Orientation Assembly Variation	Sideways variation of assembling mainframes.	None	Very little space for welders to weld since many parts will become inaccessible and not a full concept and more of an idea that needs to be used in conjunction with other concepts.

TABLE VII: CONCEPTS 15-21

Phase 2 Concepts				
Concept #	Name	Description	Pros	Cons
Concept 15	Sub-Clamp System	A system of clamp fixtures are used to clamp down all parts on the mainframe during assembly.	Clamp systems are made to fix and clamp every part in the mainframe in a quick and efficient manner and can be used with procedure that Elmer's currently uses.	Clamp fixtures need to be made for all the parts on the mainframe which could be costly.
Concept 16	Ratchet Strap Clamp System	A system that uses ratchet straps and blocks to clamp down parts on the mainframe.	Straps can tightly clamp down parts and would be easy to use by workers.	Is not able to clamp down all parts on mainframe.
Concept 17	Sub-Weldment System	A system that involves manufacturing mainframes into sub-assemblies that are later assembled together to produce a whole mainframe.	Multiple parts of an assembly can be worked on at any moment, increasing throughput and saving time.	Needs multiple tables and could be time consuming to move each sub-assembly.
Concept 18	Fixture Definition Assembly	A system that uses Elmer's current method of mainframe assembly while incorporating more c-clamps, toggle clamps, and bar clamps to clamp down all	Makes use of Elmer's existing assembly method.	Bar clamp and c-clamps will be used, which could increase assembly time.
Concept 19	Fixture System	A refined version of concept 10 that involves more fixtures.	Mainframe parts are located in an efficient yet simple manner and is not overly complex to manufacture.	Does not clamp down any parts, and some of the fixture would be heavy to move and would have to be moved via overhead crane which is time consuming.
Concept 20	Swivel Clamp System	A system that uses pneumatic and manual swivel clamps to clamp down parts of the mainframe.	Clamps are easy to use and would be able to clamp most mainframe parts down on the table.	Slanted and curved parts might be difficult to clamp with swivel clamps and pneumatic clamps might clamp down accidentally on workers body parts.
Concept 21	All Purpose Jack Clamps System	A system of all purpose jacks will be used in conjunction with Elmer's current method of assembly to clamp down	Makes use of Elmer's existing assembly method and clamps would be easy to use by welders.	Slanted and curved parts might be difficult to clamp down.

3.4 Concept Screening and Scoring

This section will screen the concepts generated, and explain the process behind why concepts were chosen and why others were not. The criteria for screening the concepts will also be discussed, and all concepts will be scored with a **WDM**. The three concepts that are selected to move forward with will be chosen in this section.

Frequent meetings were held with Elmer's Manufacturing to discuss concepts, and evaluate the direction for concept generation. Initially, focus by Team 18 was directed towards making a system of adjustable clamps to hold mainframe parts down; that would be faster than the current solution of using c-clamps. However after presenting these concepts to Elmer's Manufacturing, Jig and Tool Team Lead, Jean-Marc, informed Team 18 that more designs focusing on sub-weldments and part fixtures should be generated, as opposed to adjustable clamp concepts. It became apparent to Team 18 that a jig system of adjustable clamps might increase the assembly time of the mainframes due to welders constantly adjusting clamps to constrain parts down. Considering this, Team 18 then began to generate concepts with sub-weldments and part fixtures.

3.5 Selection Criteria

The selection criteria below was chosen based on the most important criteria to the client. The concepts that are most likely to solve the client's issue are used to develop the final deliverables. The importance of each criterion relates to the importance of the needs in the introduction section of this report.

3.5.1 Ease of Use

This criterion outlines the importance of developing a solution which makes the workload of the welders lower than it currently is. The goal of this project is to integrate a system which satisfies both management and shop floor employees that are involved with the manufacturing of the mainframes. Ease of use can be tied to multiple of the other criteria to follow, such as the portability, safety, simplicity, and ease of manufacturing factors of the design. This is the most important criterion since the easier a fixture is to use, the less time that will be spent by the workers trying to use the fixture during mainframe assembly.

3.5.2 Adjustability

The final design will need to satisfy some level of modularity in order to interface with the four types of Haulmaster Graincarts produced by the client. Currently, all four styles of Haulmaster mainframe have similar assembly procedures. Therefore, the final design will be completed on one of the mainframe styles

and then retrofit to the remaining three styles until the final deliverables are submitted to the client. The major difference between the Small Haulmaster Mainframe, used to depict the concepts in this report, and the other three variations, is the overall length and the need for an additional, smaller, welding table. This additional welding table is depicted in Figure 28 below, with a full set of **Engineering Drawings** for this table available in Appendix C. This criterion must be followed in all concepts, but is not as important as the ease of use criterion when rating concepts.

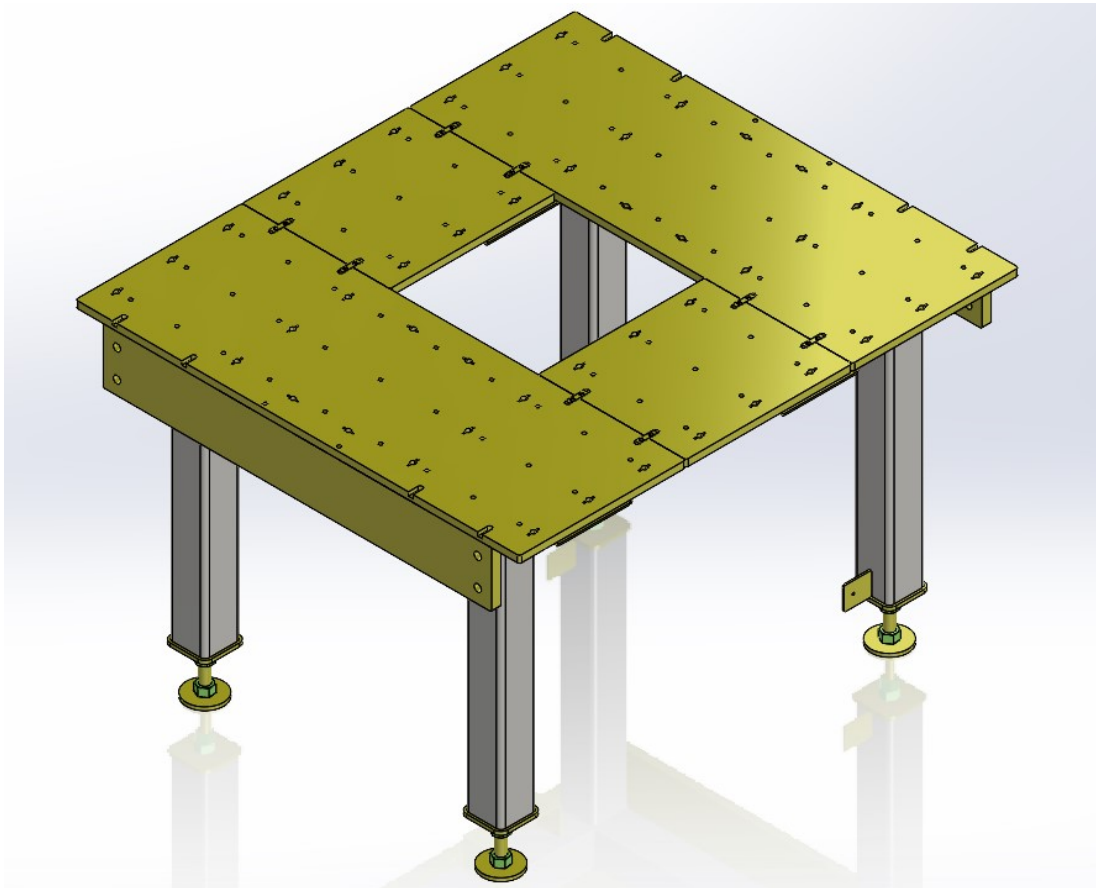


Figure 28: CAD Model of Small Table Weldment

3.5.3 Cost

This project has a budget of \$5,000 which includes the cost of laser cut pieces, any outsourcing costs for value adding processes, the cost of off the shelf components, and any other material or hardware that is included in the bill of materials. It is established that the internal labor cost of implementation, and evaluation, of the design is outside the budget scope for this project. The criterion holds the same importance as the adjustability criterion.

3.5.4 Simplicity

The principle of Occam's Razor suggests that the most simple solution to a problem is likely the best solution [29]. As such, this criteria for concepts is implemented as a good reference to the root problem. Many designs for a problem can be generated through the methods utilized by this team but the most simple design has the highest probability of success upon implementation in the manufacturing process, granted it solves the issue appropriately. This criterion relates strongly to the ease of use criterion.

3.5.5 Portability

The ability to transport the final design is important since the jig system will need be moved from one location to another as the manufacturing line changes to produce other products. Additionally, portions of the final design may need to be manually handled by welders and other employees. In this case, the portions of the design that are likely to be heavy and require manual lifting will score low. In contrast, designs where the portions being manually handled are lightweight, will score higher in this criteria. Compared to other criteria however, this criterion is not as important.

3.5.6 Safety

Each of the concepts will be rated based on the safety of the design with the mainframes. This will evaluate how safe it is for the welders and other workers that will potentially be working with the system, which affects how closely Elmer's Manufacturing follows MADESAFE standards. A large mainframe can weigh over 3,000 pounds, therefore it is essential that any heavy components within the mainframe or jigs and fixtures must be handled properly. This is a very important criterion, and is rated as such, slightly less important than the ease of use criterion.

3.5.7 Ease of Manufacturing

As described by the client representatives, ease of manufacturing should be considered for each of the concepts. The ease of manufacturing criteria ties heavily back to the cost criteria in the sense that an intuitive design, which does not rely on much specialized work, will incur much lower external costs for the client. The team has been informed that sheet metal design should be utilized as much as possible since the client can get lasered components cut and bent for some of the best rates, as these make up a high percentage of the components they already acquire. As previously mentioned, parts that cannot be laser cut or cut from structural components can be machined, but this is at a higher cost and creates more labor for the client. While concepts should not be overly complex, Elmer's Manufacturing has informed Team 18 that

the ease of manufacturing is of low importance.

3.5.8 Durability

A weld shop is not a suitable place for most sensitive components and equipment. With the constant spray of weld splatter, heavy equipment moving frequently, and hammers striking most components that meet the weld table, the design concepts chosen will need to be able to handle harsh conditions. Longevity has been outlined as an important aspect to the client since it would be inconvenient and costly for the client to replace components of the system frequently. The team has been informed that most variations of the final design would experience significant amounts of debris, hammer blows, and other applied forces that may cause damage to components. As such, the team has been provided with a target lifetime for any system of five years. Each of the concepts will be rated based on the relative durability of the system as estimated by the client, academic advisor, and student design team. Lastly, the client has informed the team that sliding components, bolts, nuts, and any other system component that requires movement should be carefully considered and avoided if there is a high probability of over torquing and debris interference. Therefore, this criterion is of average importance.

3.5.9 Concept Screening Result

Concept screening resulted in more thorough and complete concepts, as well as more concepts focusing on sub-weldments and fixtures. Screening was based on analyzation of the concepts from phase one of concept generation, and it was apparent that some of the first concepts were lacking depth and refinement. This helped direct the team's focus to provide a jig system that is very user friendly and efficiently locates as many parts as possible. It is important to note that even the most complete concepts needed further refinement, which would be done once the top three concepts were chosen. The top three concepts were chosen using a WDM, in which all 21 concepts were scored in such a manner.

3.6 Concept Scoring

A WDM was used to score all 21 concepts, and is based off of the criteria explained previously. Each criterion was given a specific weight, which when all criteria was summed together, totalled a value of 1. The weight of each criterion is based roughly from the needs table outlined at the beginning of the design process. A rating for each concept was given, for each criterion, ranging from 0-10, with 0 being worse performance, and 10 being best performance. This rating was multiplied by the criterion weight, and each criterion was rated for each concept. The concept column was then summed, and the result was a value of

out 10 points. The WDM for all concepts is shown below, and on the next page, in Table VIII, Table IX, Table X, Table XI, and Table XII. Based on the results from the WDM, the three concepts to go forward with are concepts 12, 15, and 17.

TABLE VIII: WDM FOR CONCEPTS 1-5

Criteria	Weight	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5
Ease of Use	0.3	4	6	3	3	7
Adjustability	0.1	10	9	10	10	7
Cost	0.1	5	3	3	3	5
Simplicity	0.1	4	5	2	2	5
Portability	0.05	7	7	2	6	8
Safety	0.2	10	5	2	8	5
Ease of Manufacturing	0.05	5	5	3	2	4
Durability	0.1	7	7	7	7	7
Total	1	6.4	5.8	3.75	5.1	6.1

TABLE IX: WDM FOR CONCEPTS 6-10

Criteria	Weight	Concept 6	Concept 7	Concept 8	Concept 9	Concept 10
Ease of Use	0.3	3	6	5	6	7
Adjustability	0.1	2	2	2	8	1
Cost	0.1	6	4	6	3	9
Simplicity	0.1	9	7	7	4	10
Portability	0.05	5	5	5	2	9
Safety	0.2	9	9	9	2	9
Ease of Manufacturing	0.05	9	6	7	4	9
Durability	0.1	9	9	9	5	9
Total	1	6	6.35	6.3	4.5	7.7

TABLE X: WDM FOR CONCEPTS 11-14

Criteria	Weight	Concept 11	Concept 12	Concept 13	Concept 14
Ease of Use	0.3	6	8	1	2
Adjustability	0.1	7	7	1	2
Cost	0.1	9	9	2	2
Simplicity	0.1	9	8	1	1
Portability	0.05	5	5	2	2
Safety	0.2	9	9	1	9
Ease of Manufacturing	0.05	9	9	1	1
Durability	0.1	9	9	8	8
Total	1	7.7	8.2	1.85	3.85

TABLE XI: WDM FOR CONCEPTS 15-18

Criteria	Weight	Concept 15	Concept 16	Concept 17	Concept 18
Ease of Use	0.3	8	6	9	6
Adjustability	0.1	6	8	7	3
Cost	0.1	7	6	9	9
Simplicity	0.1	7	6	8	2
Portability	0.05	7	8	8	2
Safety	0.2	10	8	9	9
Ease of Manufacturing	0.05	6	6	8	2
Durability	0.1	9	8	8	8
Total	1	7.95	6.9	8.5	6

TABLE XII: WDM FOR CONCEPTS 19-21

Criteria	Weight	Concept 19	Concept 20	Concept 21
Ease of Use	0.3	5	6	6
Adjustability	0.1	4	8	2
Cost	0.1	7	7	7
Simplicity	0.1	8	7	6
Portability	0.05	3	9	9
Safety	0.2	9	8	8
Ease of Manufacturing	0.05	9	8	8
Durability	0.1	9	8	8
Total	1	6.7	7.25	6.55

3.7 Concept Scoring Results

From the results of WDM, the concepts chosen were concepts 12, 15, and 17. These concepts were further refined and used to select the final design in phase 3 of the project.

4 Final Design

This section covers specific details of the final design including its CAD models, final design components, BOM, drawings, AutoCAD DXF files, and lastly an SOP for the final design.

4.1 CAD Models

This section discusses the overview of the final design and depicts how each jig works with each other to define the location of the grain cart mainframe. The final design is modular to accommodate the different types of mainframes such as the RC tandem, small, large, and high capacity mainframe. But for simplicity, the team will focus on the Large mainframe assembly, and summarize how it is integrated for the other assemblies.

Shown below in Figure 29 is an isometric view of the final design being used to assemble the large mainframe. In the assembly, the end jigs defines the mainframe axially, the bunny ear jigs and semi-plates establishes the mainframe horizontally, and the top gauge jig fixes the assembly vertically.

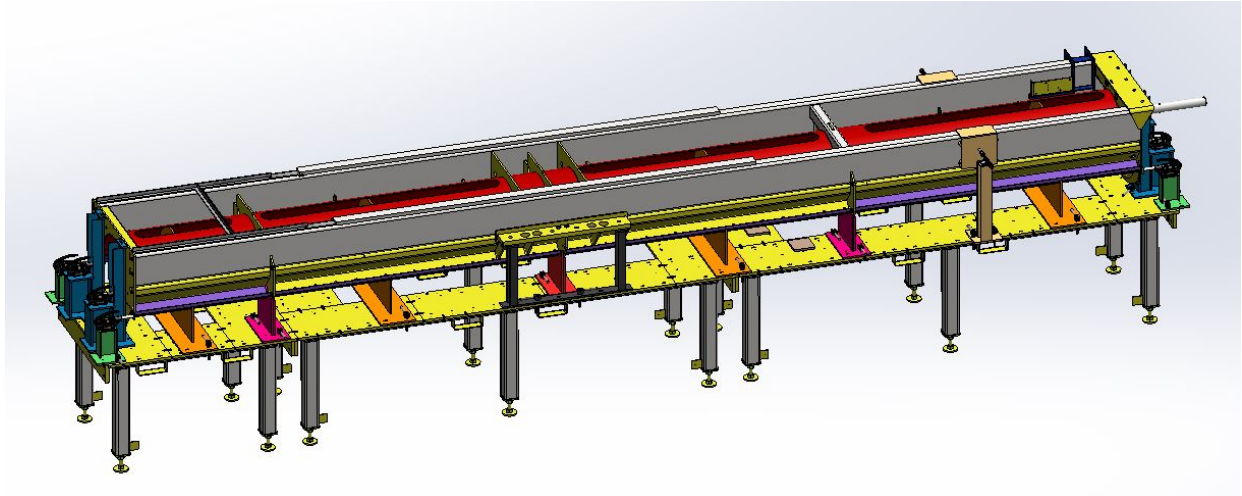


Figure 29: Final Design of Large Mainframe's Jig System Isometric View

Shown below in Figure 30 and Figure 31 is the side and top view of the final design jig system with all of its components on the jig table.

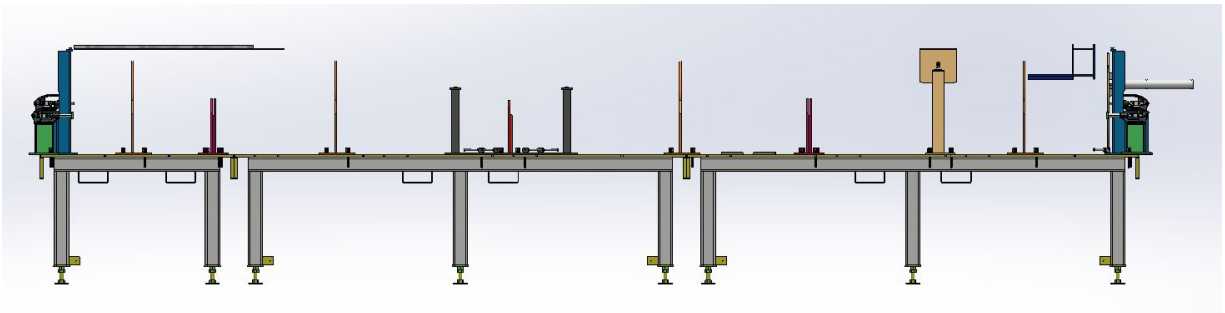


Figure 30: Final Design of Large Mainframe's Jig System Side View

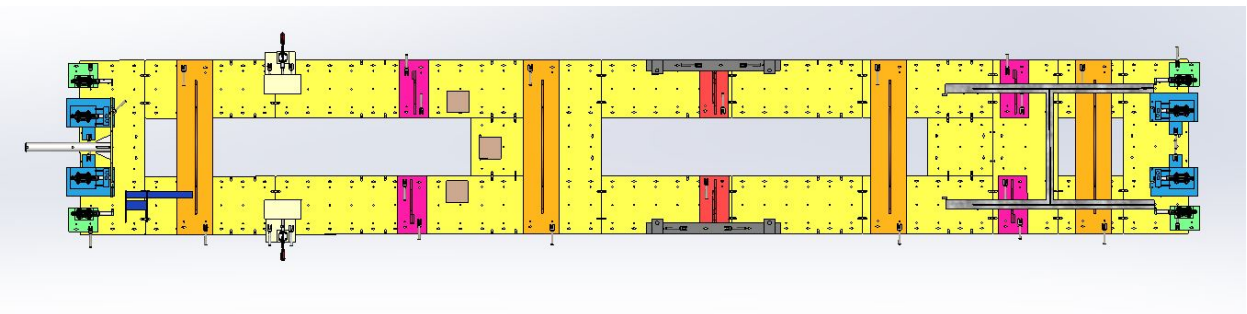


Figure 31: Final Design of Large Mainframe's Jig System Top View

Shown in Figure 32 below depicts the set-up of the final design. For the set-up, the locations for each of the jig is crucial for the accuracy and efficiency of the design. Every jig has a specific hole or holes that lock it into position on the table. Each jig utilizes **Cam Clamps** to connect its base with the jig table for accurate and secure connection.

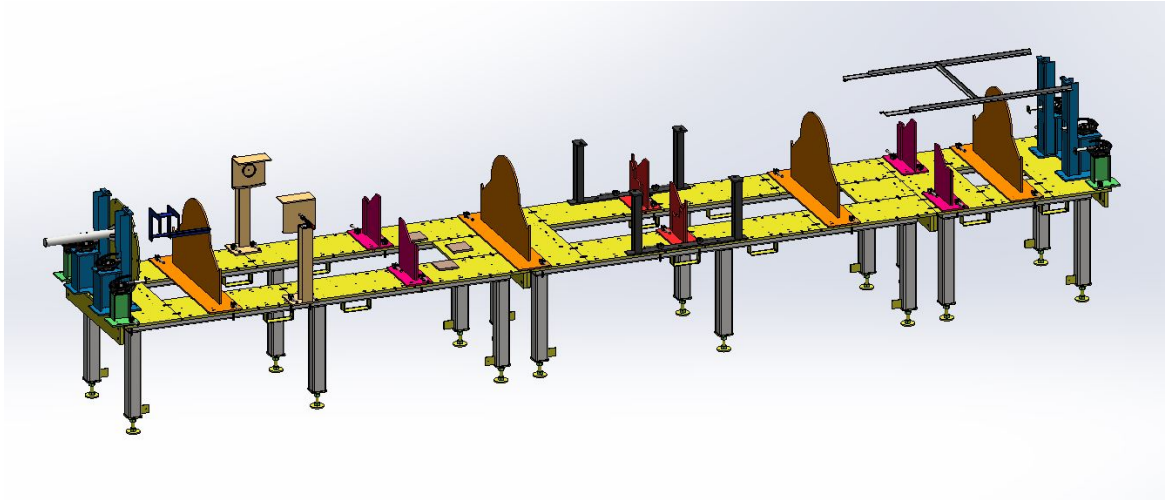


Figure 32: CAD Model of the Final Design

Figure 33 below is the rotisserie stand for the **Sub-assembly** of the design. The rotisserie stand is used to assemble the **HSS** and Z-Plate before it is placed in the final assembly.

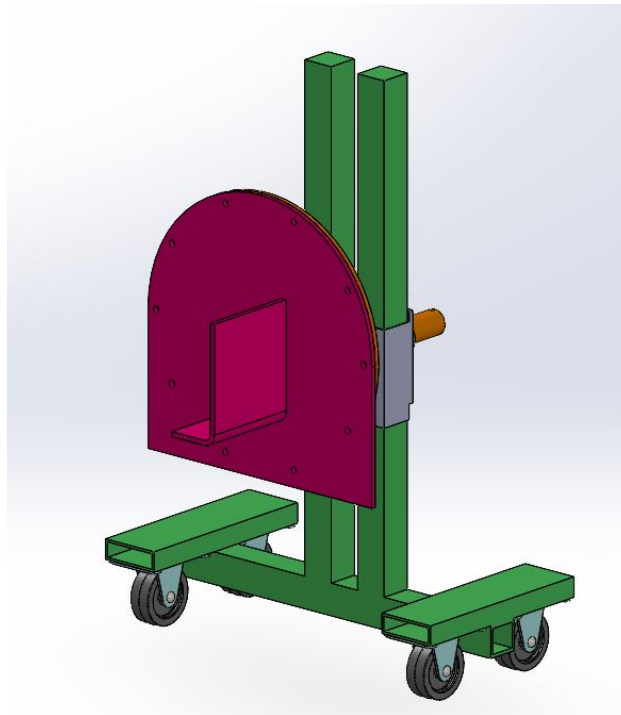


Figure 33: Rotisserie Stand

4.2 Final Design Components

In this subsection, all essential components are mentioned based on their function in the final design, as named accordingly to Grain Cart Mainframe Jig (GCMJ). All the final design components can be manufactured in Elmer's facility without the expense of purchasing finished fixtures from suppliers. These fixtures are mostly made from plain carbon steel (with plate thicknesses of 0.25", 0.375" and 0.5") and are either machined, laser cut, and welded so that each component can easily be replaced and modified in case of bending, broken or upgrading. A table showing the part numbers for the large mainframe is shown in Section 4.5 Furthermore, to ensure that the jigs are placed consistently, cam clamps are utilized.

4.2.1 GCMJ700 - Side Rib Jig

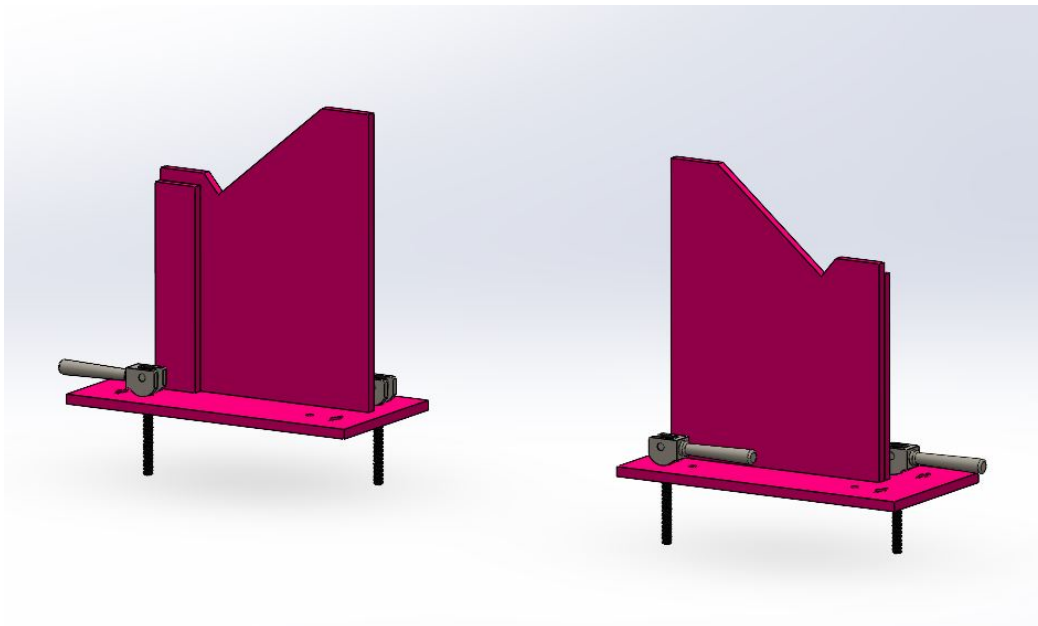


Figure 34: GCMJ700 - Side Rib Supports

Shown above in Figure 34, this fixture is used in the fixing of the Side Rib Supports (parts 31) in place, and also supports the Z Plates (parts 16, 17, 18 and 19). Each fixture on both sides are tasked to support components appropriately and are clamped on to the table using cam clamps.

4.2.2 GCMJ600 - Middle Rib Supports

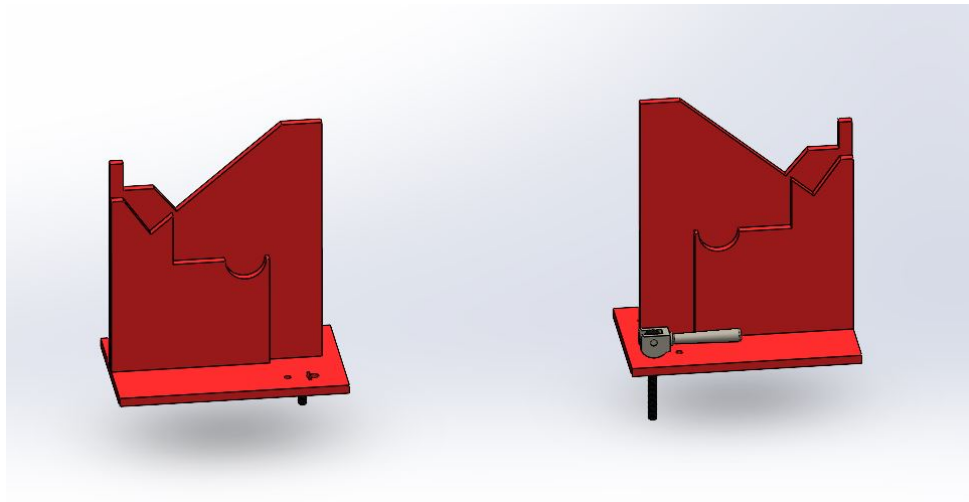


Figure 35: GCMJ600 - Middle Rid Supports

The GCMJ700 parts are shown above in Figure 35. This fixture pair is sufficient to support Middle Ribs (parts 26) and Z Plates (parts 37,38) on each side of the mainframe. The structure of the support is intentionally designed to constrain parts 26, and the base of these fixtures are clamped to the table via cam clamps.

4.2.3 GCMJ800 - Semi Plate

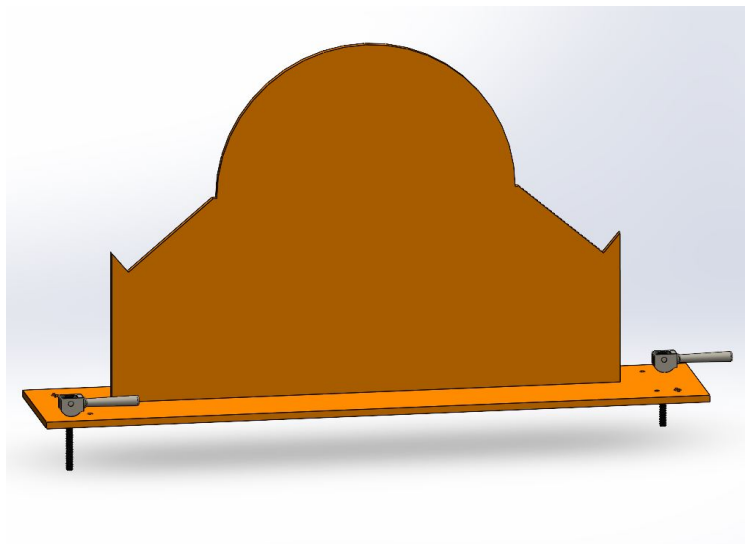


Figure 36: GCMJ800 - Semi Plate

The Semi Plate Fixture (GCMJ800) shown above in Figure 36, is designed to support the curved plates (Parts 10, 11) and all the Z plates (Part 16, 17, 18, 19, 37 and 38) of the mainframe. Due to this fixtures large size, it will need to be loaded onto the table by means of an overhead crane. Cam clamps are used to clamp this fixture on to the table.

4.2.4 GCMJ200 - Weight Scale Locators

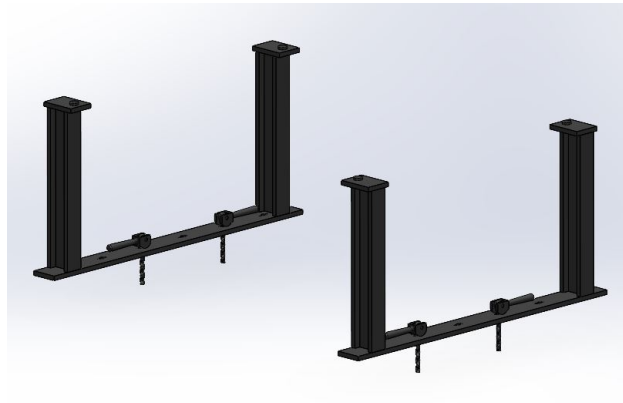


Figure 37: GCMJ200 - Weight Scale Locators

This fixture, shown above in Figure 37, is used to locate one of the most crucial large mainframe's components being the "weight scale parts". The jig has two beams welded at the end of the base. The top of the beams consists of plates that have been machined to produce a plate with a circular pin that fits into holes on the weight scale parts. The fixtures are attached to the table via cam clamps.

4.2.5 GCMJ500 - Computer Part Fixture

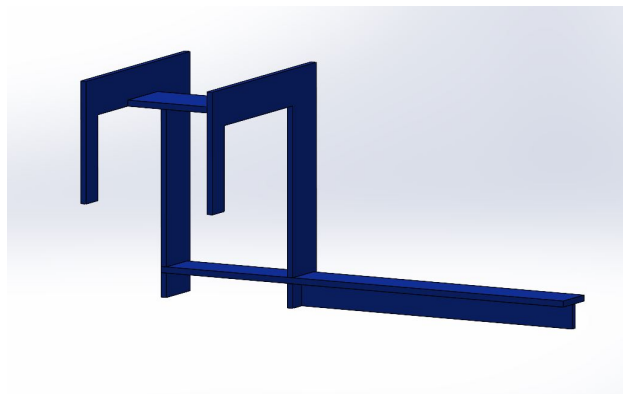


Figure 38: GCMJ500 - Computer Part Jig

To repeatably locate the computer part, the fixture shown above in Figure 38 was constructed. This fixture does not require any clamp to constrain parts but instead acts as a gauge to located the computer part. It is made of sheet metal of thickness of 0.25" and can be easily manufactured and welded.

4.2.6 GCMJ400 - Peg Hitch Fixture

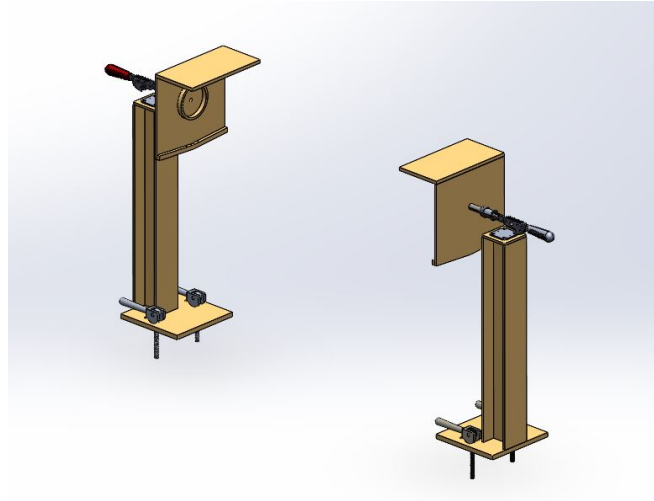


Figure 39: GCMJ400 - Peg Hitch Fixtures

To weld a component on the mainframe attached on the HSS tubes, the team has designed the Peg Hitch Jig (GCMJ400) shown above in Figure 39, which uses toggle clamps to horizontally place the Peg Hitch (part 7) into place.

4.2.7 GCMJ1111 - Top Gauge Jig

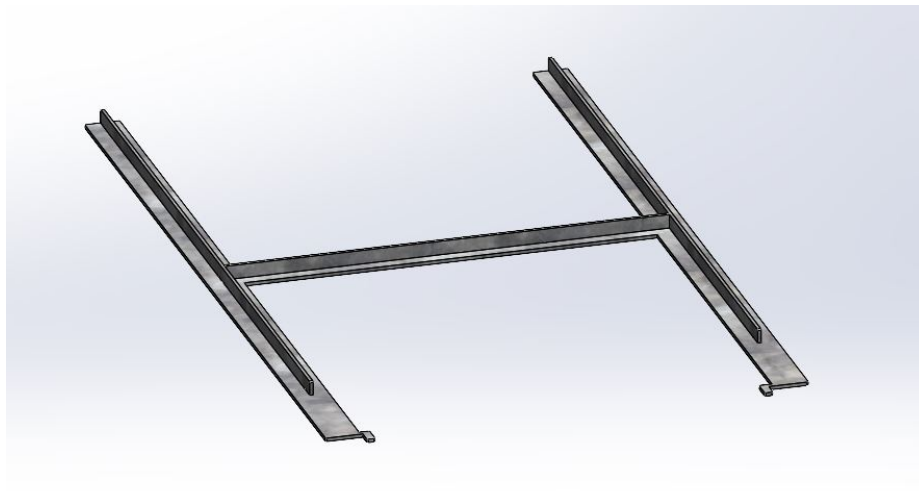


Figure 40: GCMJ111 - Top Gauge Fixture

To position the flat stock (part 6) onto the HSS, Team 18 developed the design of the Top Gauge Fixture (GCMJ111), which is shown above in Figure 40. After the flat stock has been welded, the fixture can be comfortably removed out of the mainframe manually by welders, without the use of equipment. The material used is 0.25" sheet metal.

4.2.8 GCMJ100 - End Plate Mounts

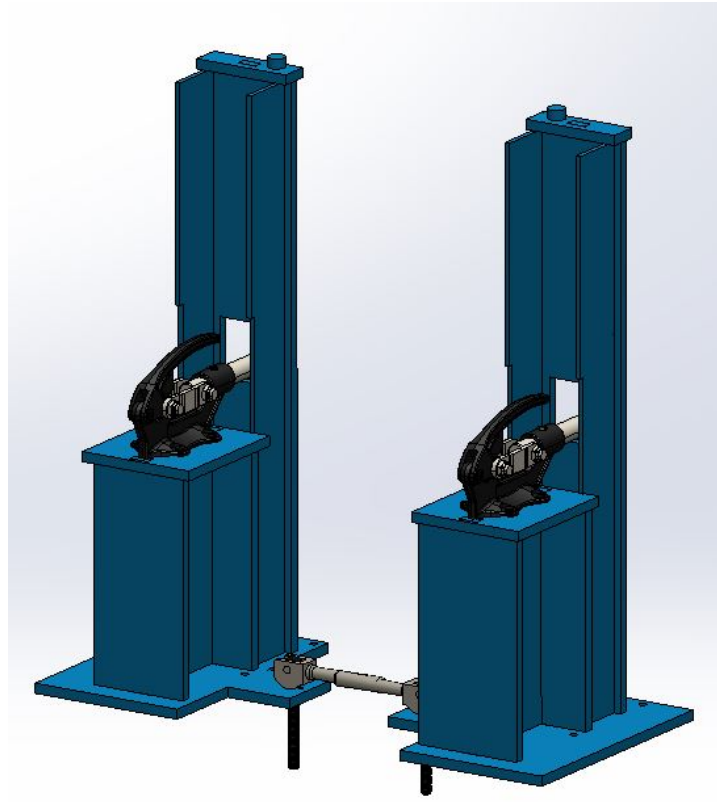


Figure 41: GCMJ100 - End Plate Mounts

At the end of process, the welders have to find a way to weld the end plates (parts 32 and 34), therefore, the End Plate Mounts (GCMJ100), shown above in Figure 41, have been constructed to allocate the end plates position onto the mainframe. There is an additional base on top of jig where is beneficially fix the V-plate (part 33) for welding. This design uses Destaco 650 clamps to clamp the end plates. The fixture is clamped to the table via cam clamps.

4.2.9 GCMJ300 - Purple Clamp Jigs

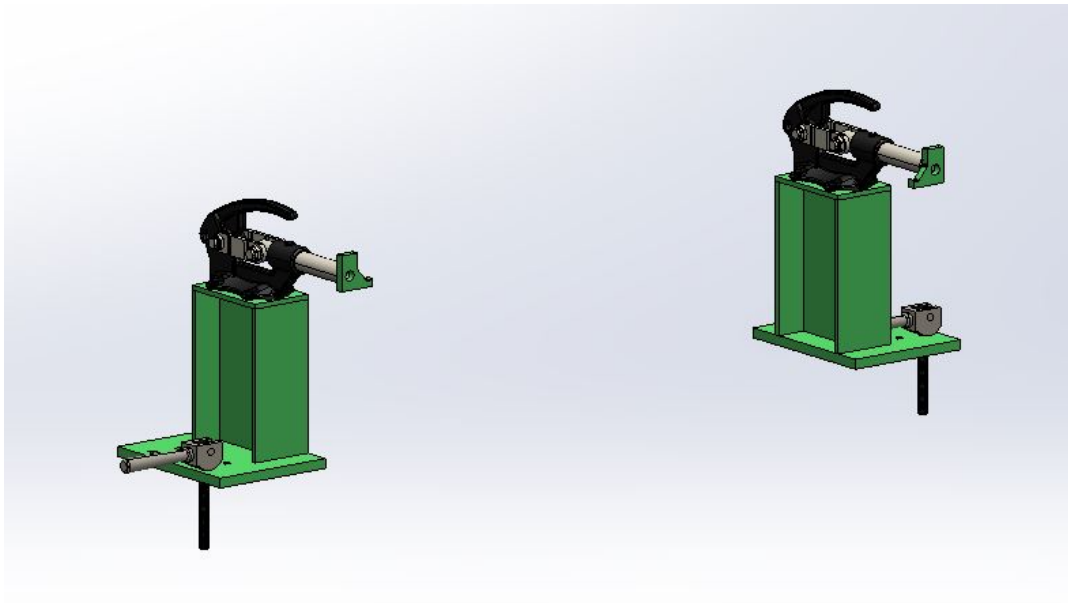


Figure 42: GCMJ300 - Purple Clamp Fixtures

Similar to the GCMJ100, these fixtures use Destaco 220 clamps with laser cut steel plate ends that are welded to the end of the clamps. These fixtures are shown above in Figure 42. The laser cut steel plate ends contact the Z Plates (part 16, 17, 18 and 19), and help fix the mainframe axially at each end in order to avoid any misalignment of the final product, meaning that four fixtures are need for one mainframe. Cam clamps are used to clamp these fixtures to the table.

4.3 DXF Files

DXF files are specific files format in a CAD modelling software that gives a 2D outline of a part. DXF files are used by tools and machines such CNC router and CNC laser cutters to produce 2 dimensional design into flat pieces of material such as wood or metal. Due to time constraints in the project, DXF files were not obtained but can be created by Elmer's by using the available CAD models.

4.4 Clamp Safety

Clamps are handheld devices to hold two pieces of material together. Operating a clamp is straightforward but a wrong action while using a clamp can cause injuries to its user and the surrounding people. Clamps are commonly used when welding, so some general safety tips for clamp and welding in a manufacturing setting include:

- Wearing proper safety equipment while operating a clamp, which includes :
 - Safety Glasses or a Welding Helmet (when welding).
 - Flame-resistant Gloves.
 - Steel-toed Boots.
 - Earplugs (when using loud pneumatic and hydraulic clamps).
 - Flame-resistant Shirts (when welding).
 - Flame-resistant Pants (when welding).
- Selecting the proper clamp style and size for the job.
- Dispose any broken clamps.
- Ensuring that the two work pieces used for the clamps are in full contact before tightening.
- Keeping clamps lightly oiled to prevent rust and seizing.

4.5 SOP

The following section covers the operating procedure for the Large Mainframe (Drawing #13351600) jig setup. The changes needed for the small mainframe, the row crop mainframe, and the high capacity mainframe are summarized below. A summary of the parts and their description for the Large Mainframe is shown below in Table XIII.

TABLE XIII: SUMMARY OF LARGE MAINFRAME ASSEMBLY PARTS

Drawing #13351600		20	0.750 Plate - 83.106 x 6.750, Mild Steel
Part #	Part Description	21	0.250 Plate - 28.000 x 6.678, Mild Steel
1	0.250 Plate - 1.519 x 0.507, Mild Steel	22	0.188 Plate - 2.697 x 1.740, Mild Steel
2	Weld Nut, H-Pilot, Gr 5, 3/8 UNC, Plain	23	0.134 Plate - 28.000 x 13.241, Mild Steel
3	Weld Nut, H-Pilot, Gr 5, 1/2 UNC, Plain	24	0.375 Plate - 37.500 x 3.625, Mild Steel
4	Weld Nut, H-Pilot, Gr 5, 1/4 UNC, Plain	25	See Assembly BOM
5	Weld Nut, H-Pilot, Gr 5, 5/16 UNC, Plain	26	0.500 Plate - 45.750 x 22.745, Mild Steel
6	Bar-Flat - 3.000 x 1.000 - A36	27	0.500 Plate - 45.750 x 17.629, Mild Steel
7	See Assembly BOM	28	0.500 Plate - 13.455 x 10.254, Mild Steel
8	Bar-Rd - 1.000 - 44W - Hot Rolled	29	HSS - Rect - 4.000 x 3.000 x 0.250
9	See Assembly BOM	30	DOM - 1.250 x 0.781 x 0.235
10	0.188 Plate - 131.313 x 35.691, Mild Steel	31	0.500 Plate - 41.500 x 22.745, Mild Steel
11	0.188 Plate - 156.063 x 35.691, Mild Steel	32	0.375 Plate - 36.750 x 28.625, Mild Steel
12	0.375 Plate - 155.938 x 9.550, Mild Steel	33	0.500 Plate - 47.211 x 7.000, Mild Steel
13	0.375 Plate - 131.188 x 9.613, Mild Steel	34	0.375 Plate - 36.750 x 28.812, Mild Steel
14	0.375 Plate - 131.188 x 9.613, Mild Steel	35	HSS - Rect - 10.000 x 4.000 x 0.375
15	0.375 Plate - 155.938 x 9.613, Mild Steel	36	0.134 Plate - 17.575 x 4.000, Mild Steel
16	0.188 Plate - 121.875 x 9.872, Mild Steel	37	0.188 Plate - 82.813 x 9.872, Mild Steel
17	0.188 Plate - 82.875 x 9.872, Mild Steel	38	0.188 Plate - 82.813 x 9.872, Mild Steel
18	0.188 Plate - 121.875 x 9.872, Mild Steel	39	0.134 Plate - 11.326 x 4.852, Mild Steel
19	0.188 Plate - 82.875 x 9.872, Mild Steel	40	0.134 Plate - 6.500 x 6.257, Mild Steel

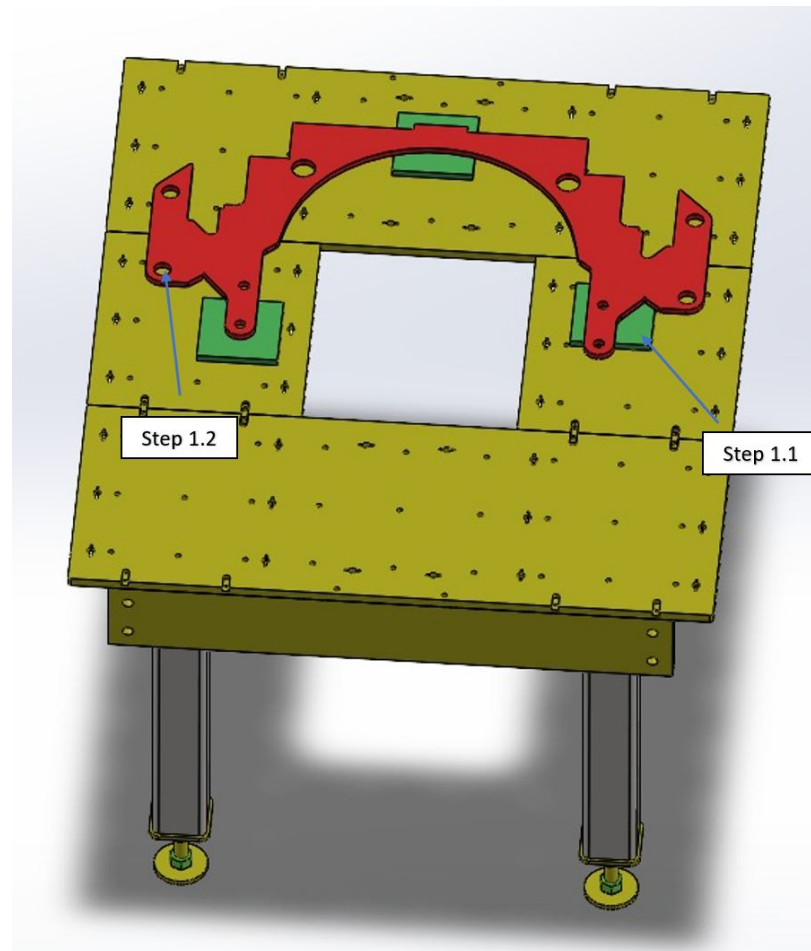
Step 1: Welding the Bushings and Setting Up Mainframe Jigs

Figure 43: Bushing Jig

1.1 Start by placing part 26 on the table, and placing bushing jig (part 31) on top of the bushing jig plate (part 26), as shown in Figure 43.

1.2 Next, press the bushings into place and locate the holes in parts 26 and 31.

1.3 Tack the bushings into place, and then flip part 26 (or 31) around to tack the bushings on the other side.

1.4 Then weld fully along the edge of the bushing (on both sides of part 26/31).

1.5 Repeat for the rest of parts 26 (x1) and 31 (x2).

*Please note that cam clamps will be utilized to secure all jigs to the welding table.

Step 2: Sub-Assembly of Part 35

2.1 Remove the plates used for the bushing jig once all bushings have all been welded to parts 26 and 31.

2.2 Next, locate each one of the jigs shown in Figure 44

2.3 Jigs that are too heavy to lift into place will have to be put into place using a crane or forklift.

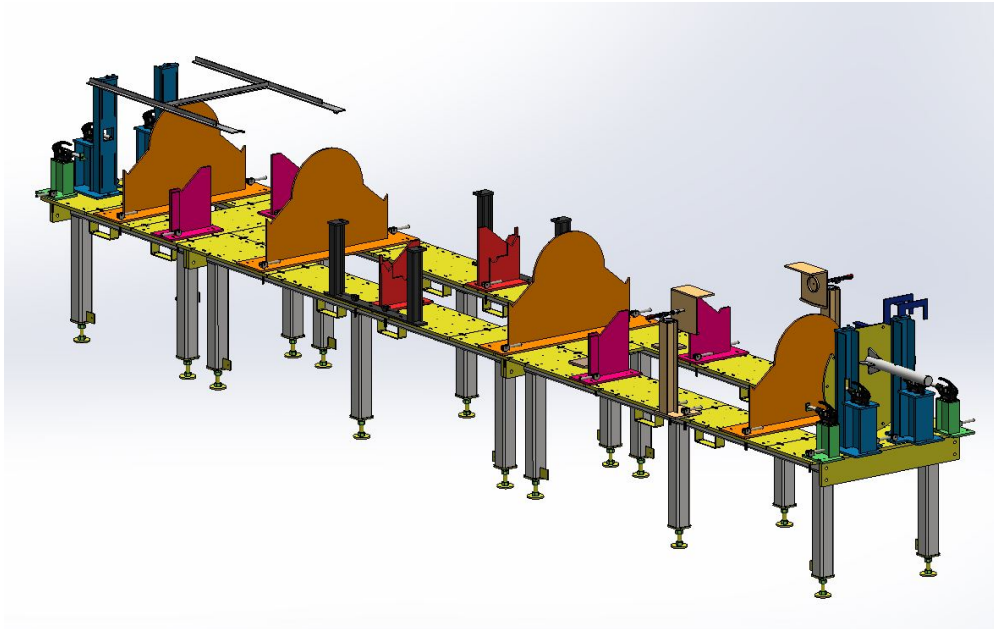


Figure 44: Setting Up Mainframe Jigs

2.4 Using a crane, lower part 35 onto the rotisserie jigs as shown in Figure 46.

2.5 Then, lower parts 14 and 15 (12 and 13 are the equivalent parts, just mirrored) into place on top of part 35.

2.6 With parts 14 and 15 clamped and located on part 35, tack weld as shown in Figure 46.

2.7 After tack welding, run several **Intermittent Welds** along parts 14 and 15 (on both sides).

2.8 Then tack parts 1 to this assembly.

2.9 Using a crane, pick up this assembly of parts 14, 15, and 35, and place on the ground.

2.10 Repeat these steps for the second part 35, 12, and 13 (Tacked in the same way as 46, but mirrored).

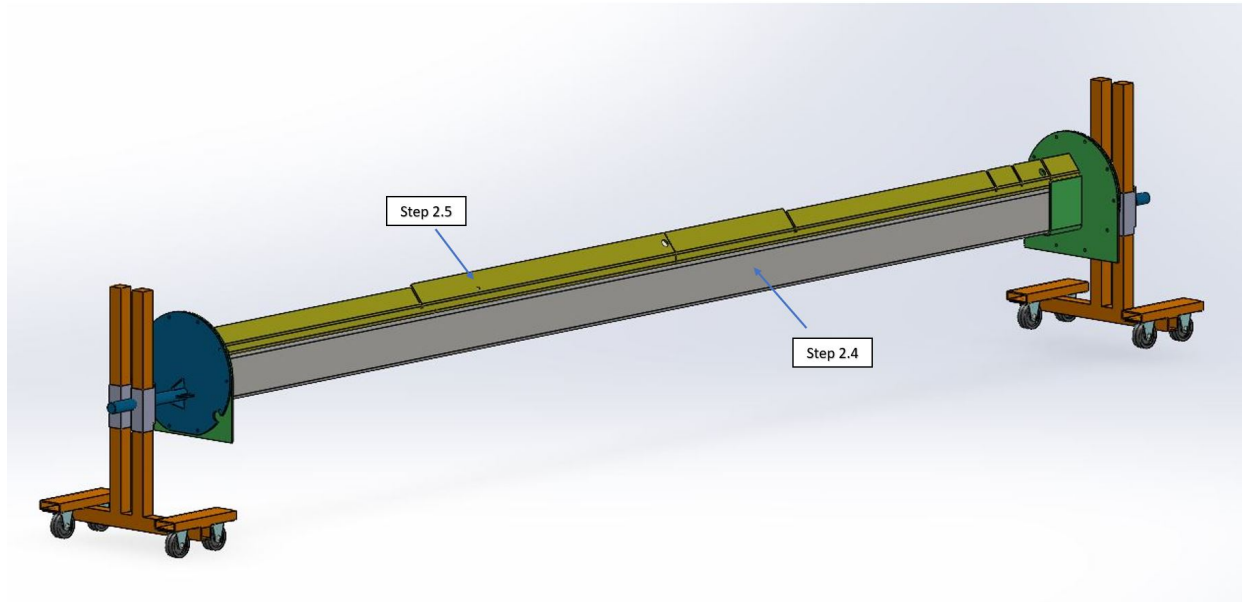


Figure 45: Welding HSS to Z-bar Jig

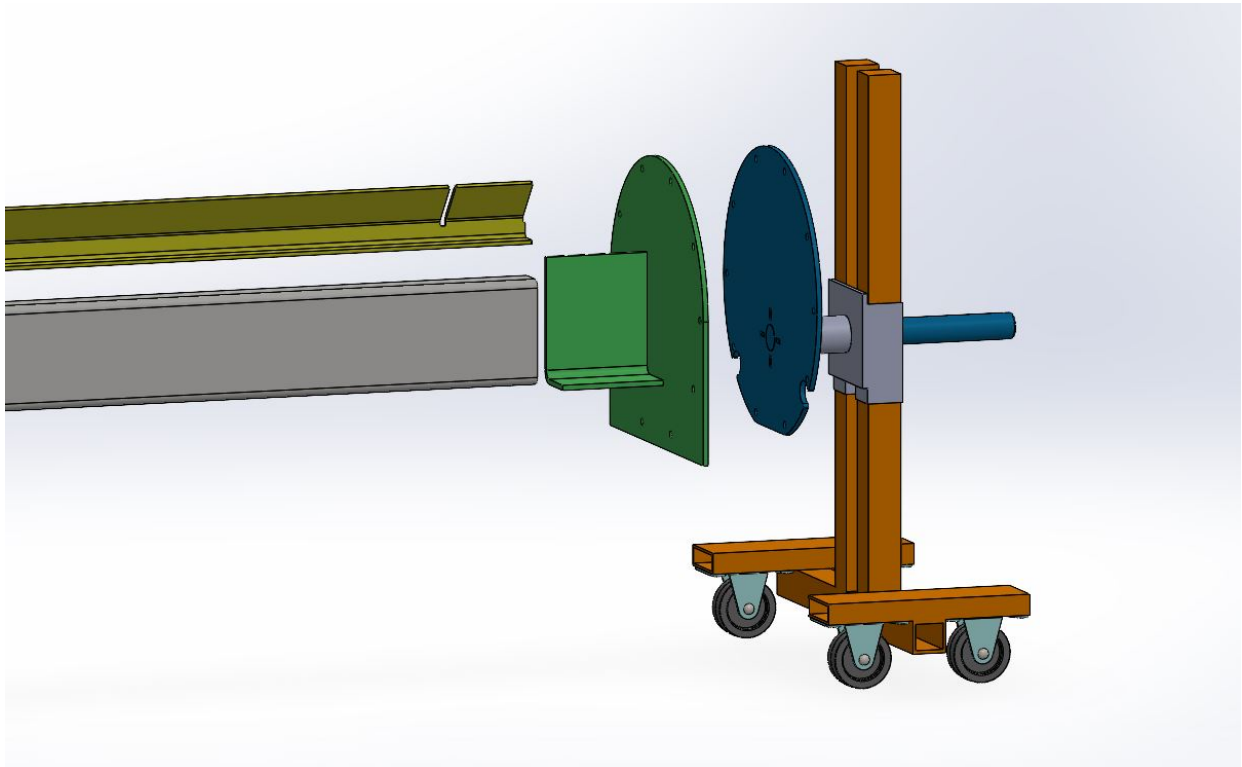


Figure 46: Welding HSS to Z-bar Components

Step 3: Welding Parts 16, 17, 18, 19, 20, 37, and 38

3.1 Begin by opening the clamps for each jig.

3.2 Then, place parts 16, 17, 18, 19, 37 and 38 with crane onto the plate jigs as shown in Figure 47.

3.3 Close the clamps to lock parts 16, 17, 18, 19, 37 and 38 into correct orientation.

3.4 Then, place four part 20s onto parts 16, 17, 18, 19, 37, and 38.

3.5 Do this in such a manner that the square holes align with each other, as shown in Figure 48.

3.6 Tack the part 20's to parts 16, 17, 18, 19, 37 and 38, and then do intermittent Welds all here as well.

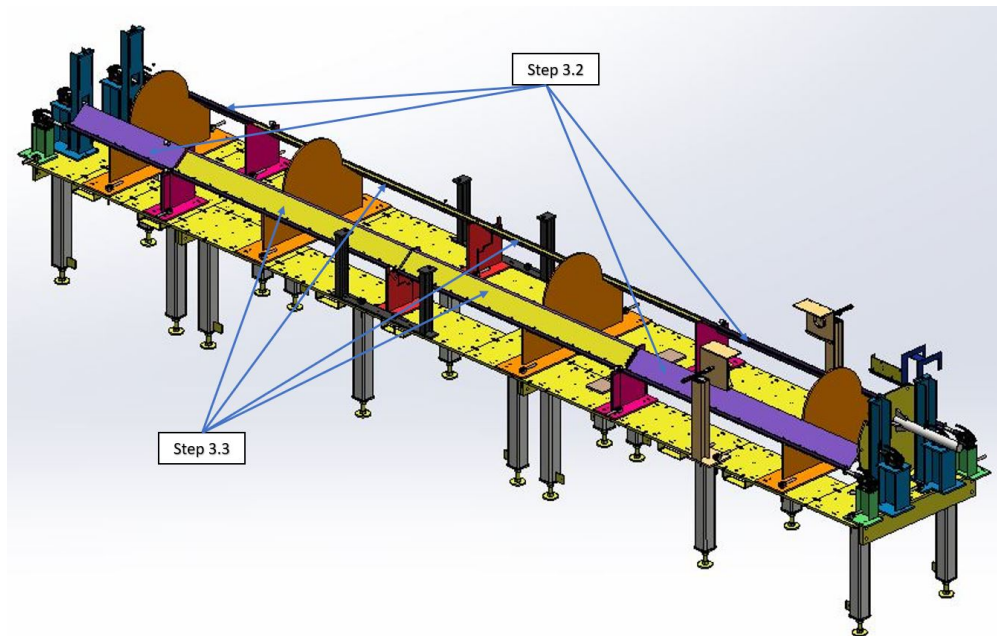


Figure 47: Preliminary Parts in Jig

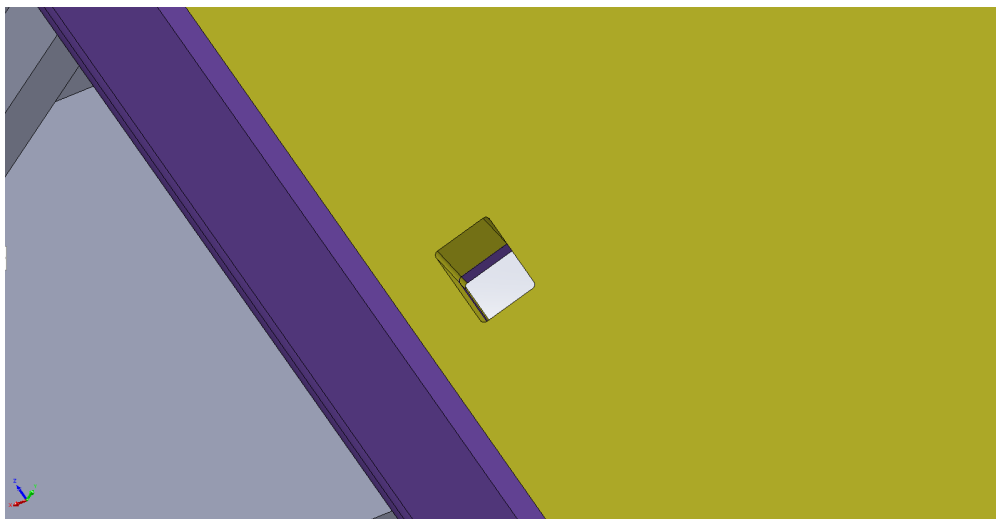


Figure 48: Alignment of Carriage Holes

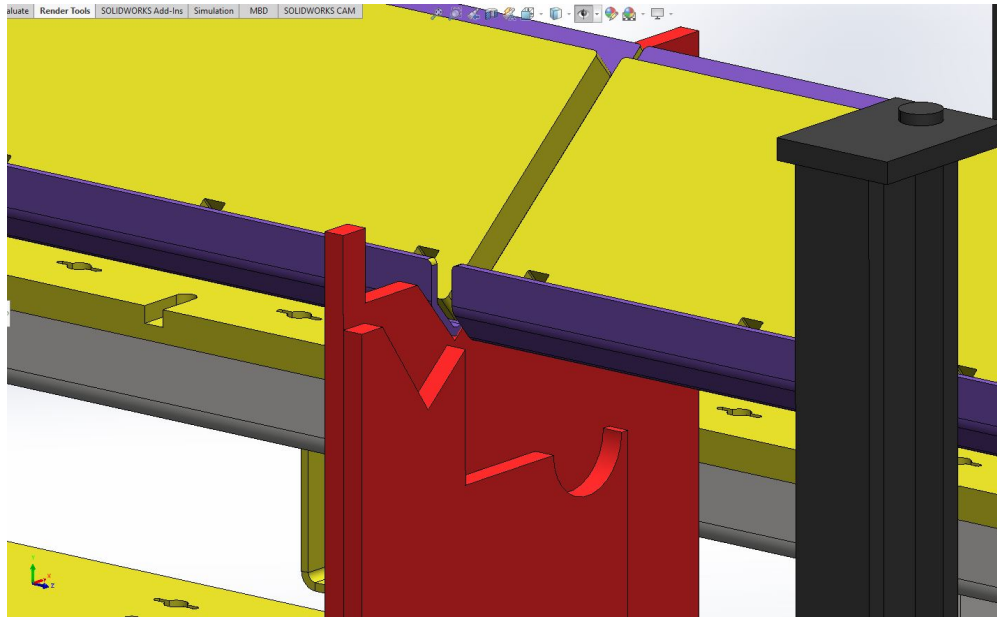


Figure 49: View of Bent Structural Components Resting on Jig System

Step 4: Welding Parts 10, 11, and 22

- 4.1 Begin by lowering parts 10 and 11 into place via crane, as shown in Figure 50.
- 4.2 Ensure that parts 10 and 11 are aligned in such a manner that they are flush with the parts from the previous step, shown in Figure 51.
- 4.3 Tack weld parts 10 and 11 along where these parts meet with the parts from the previous step, shown in Figure 52.
- 4.4 Then, intermittent weld this same area. This is done for both sides.
- 4.5 Then, weld the multiple part 22's into place, shown in Figure 53.

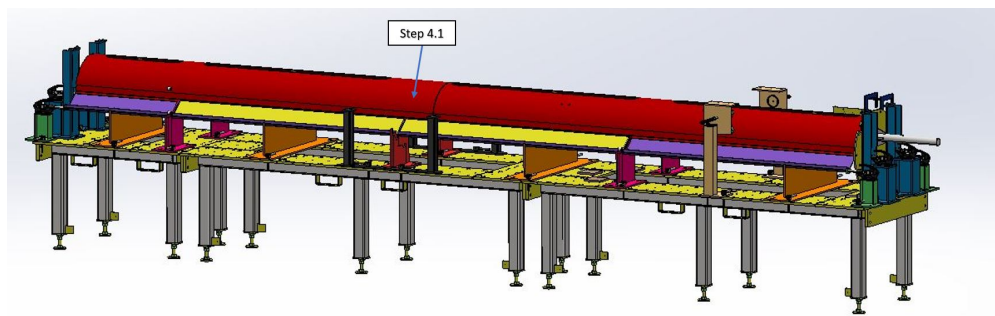


Figure 50: Inserting Parts 10 and 11

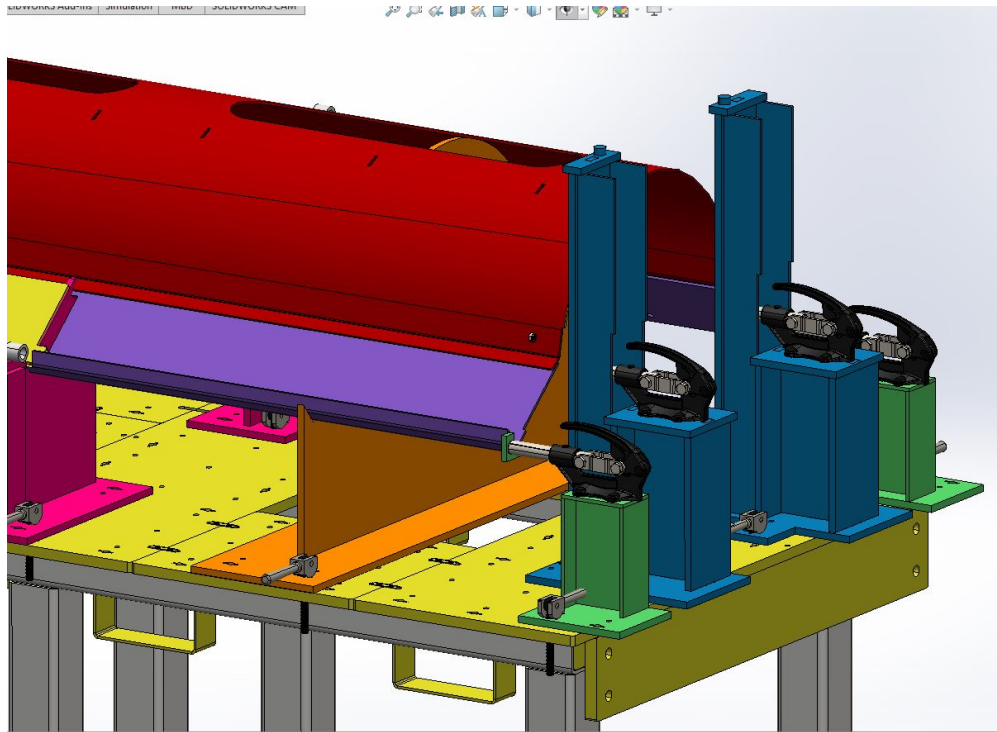


Figure 51: Overlap of Components

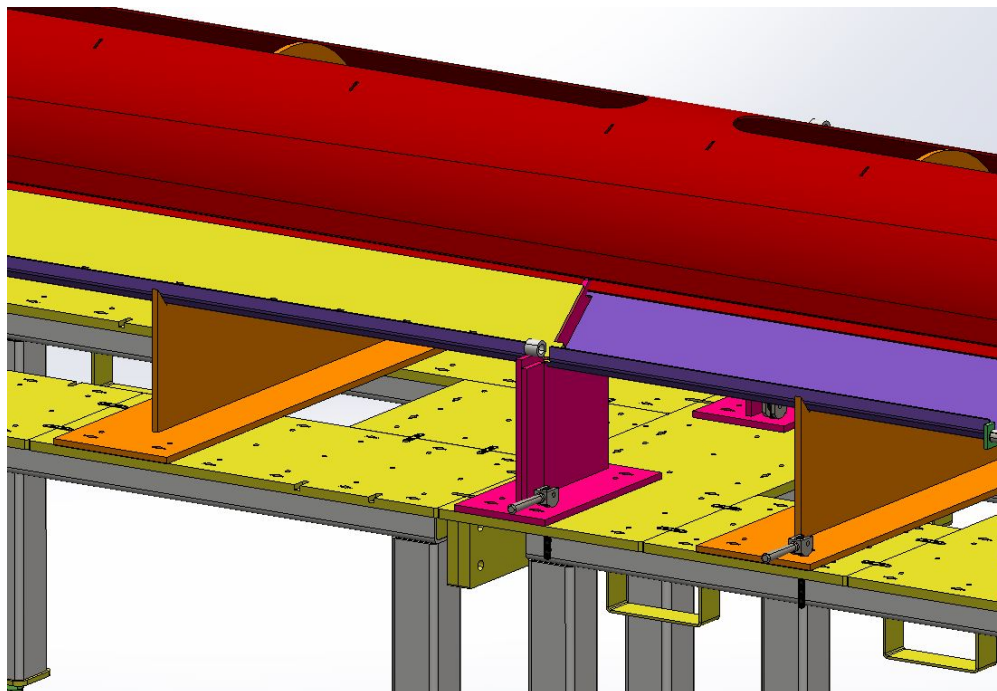


Figure 52: Tack Welding Parts 10 and 11

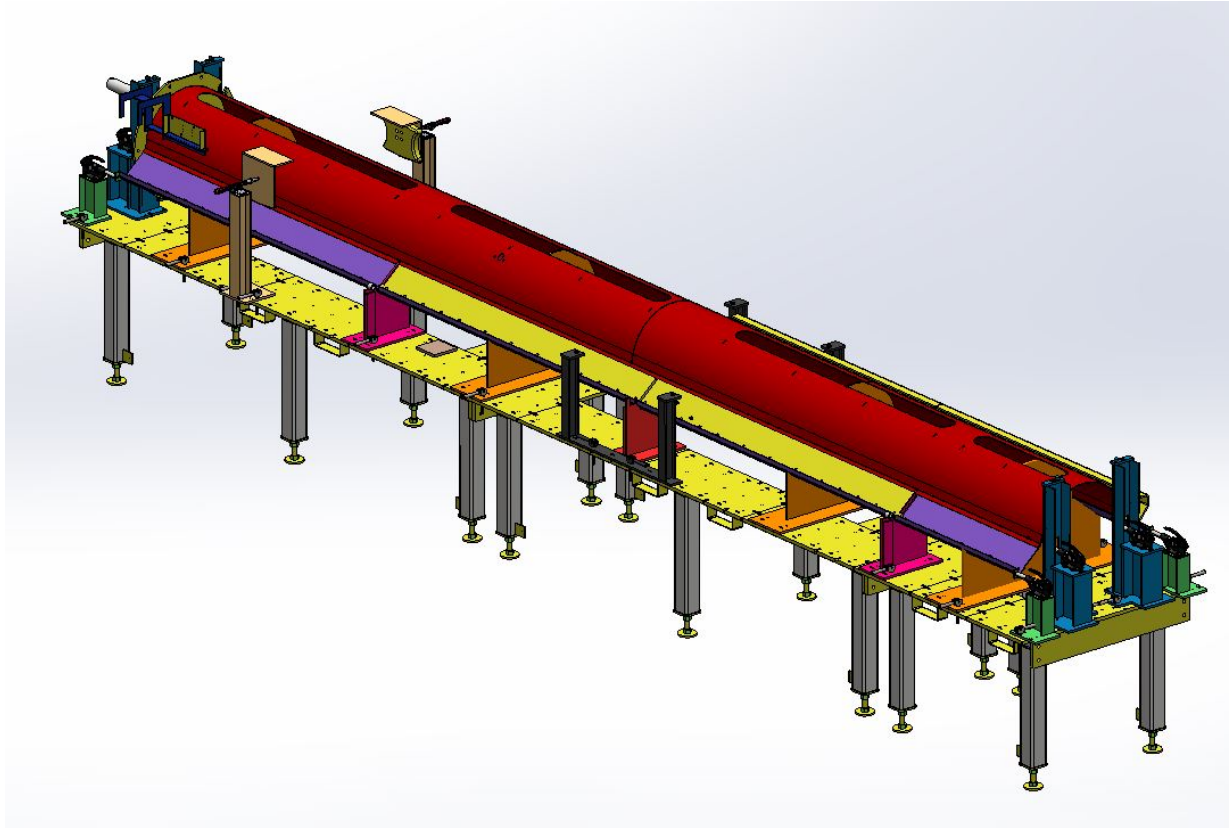


Figure 53: Part 22s Welding onto Parts 10 and 11

Step 5: Welding Parts 2, 28, 26, 27, and 31

- 5.1 Begin by loading parts 26, 27, and 31 into place via crane as shown in Figure 54.
- 5.2 Ensure that all of these parts are perpendicular to table. Parts 26 and 31 will fit into the jigs shown in Figure 11, 12, and 13.
- 5.3 Tack weld (on both sides) along parts 26, 27, and 31 as shown in Figure 10.
- 5.4 Then, intermittent weld these same locations.
- 5.5 Then, weld all of parts 2 into the required locations (bushings that go into the holes of 26 and 31)

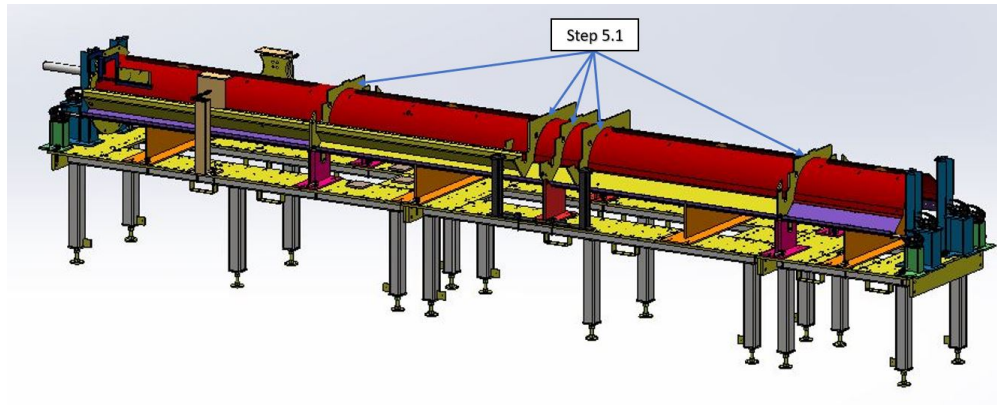


Figure 54: Parts 26, 27, and 31 in Place on Assembly

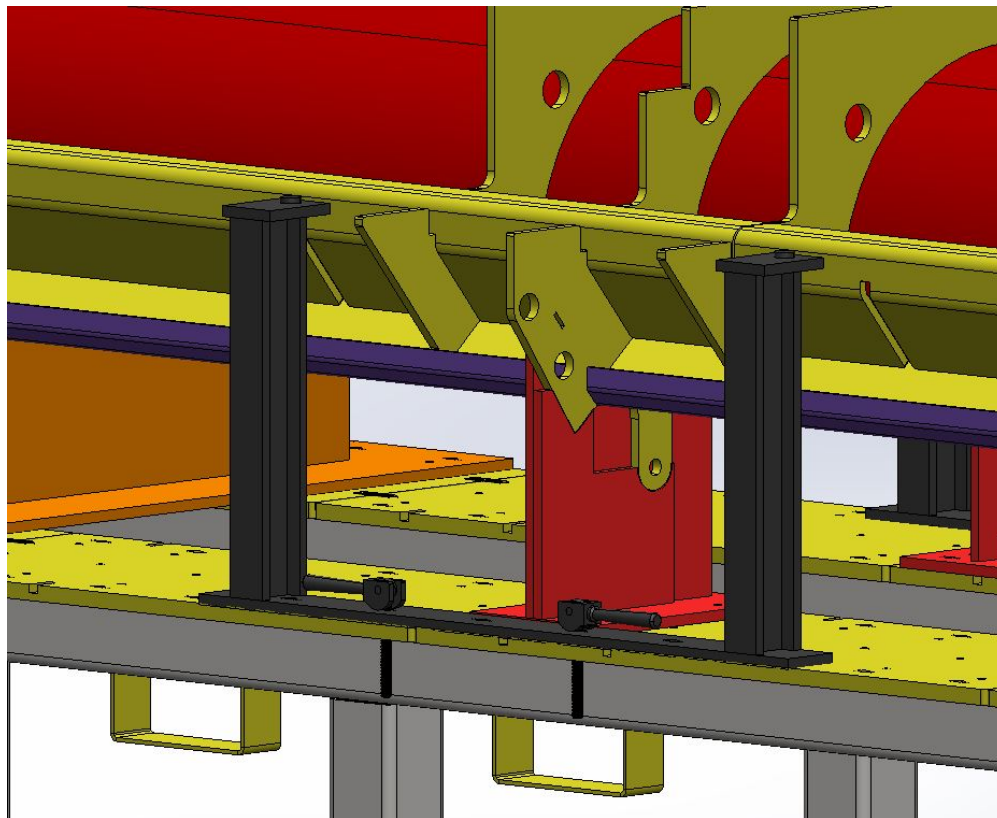


Figure 55: Part 26

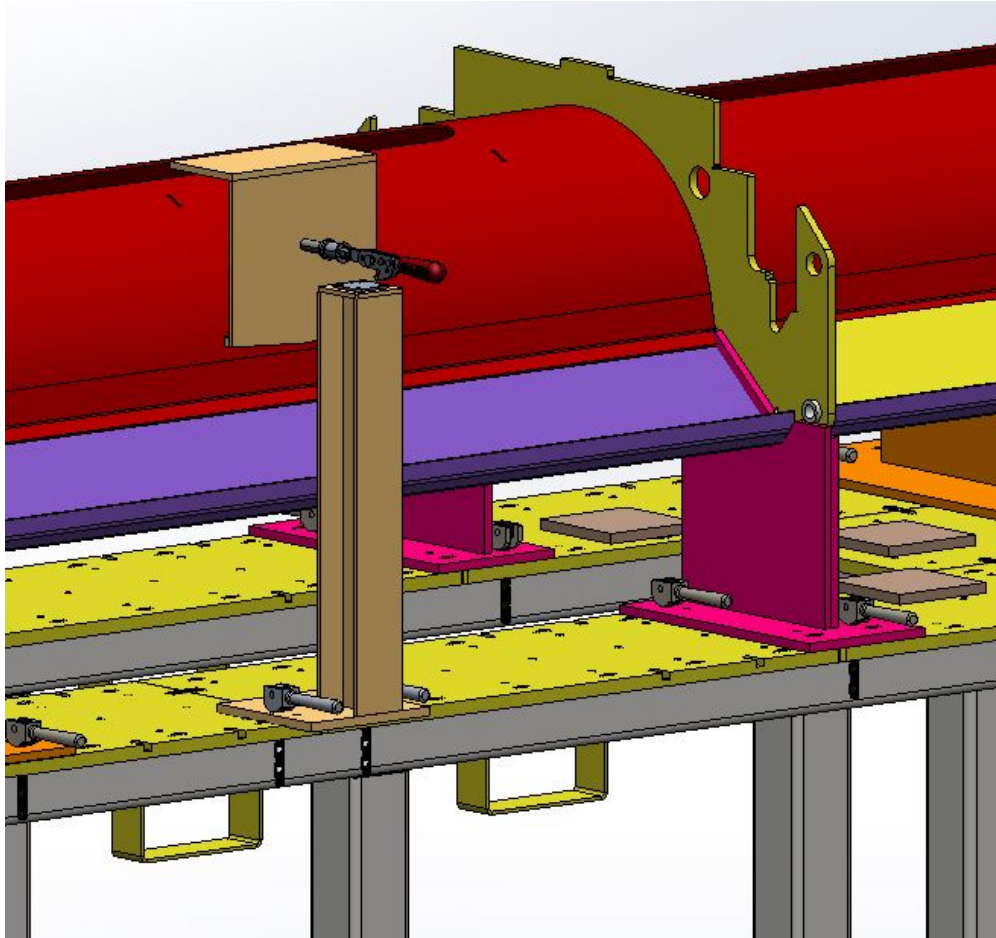


Figure 56: Part 31

Step 6: Placing Parts 12, 13, 14, 15, and 35 Assembly (from Step 2) Onto Main Assembly, and Weld

- 6.1 Lift the assembly from step 2 and drop into place as shown in Figure 57.
- 6.2 Ensure that the ends of part 35 are flush with the rest of the assembly's ends (using a speed square).
- 6.3 First, tack weld along the areas shown in Figure 16, then intermittent weld.
- 6.4 Repeat this for the other step 2 assembly, shown in Figure 58.

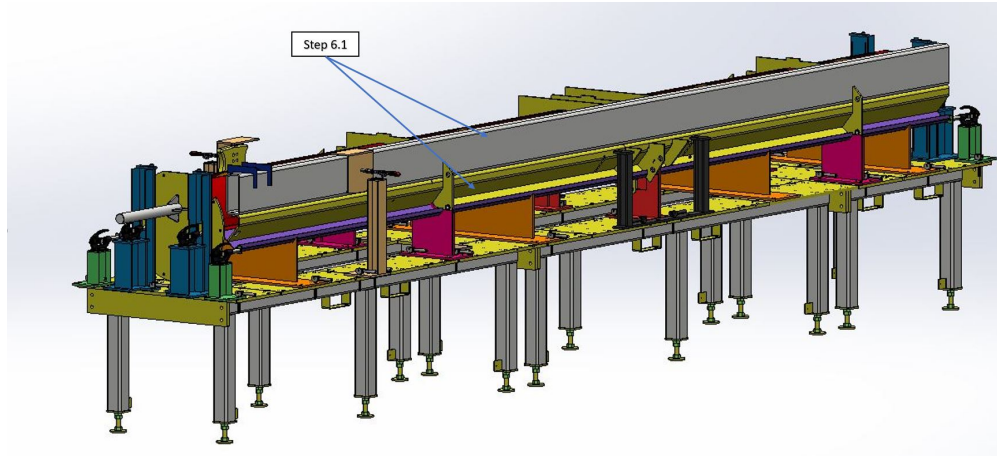


Figure 57: Step 6 Assembly in Place

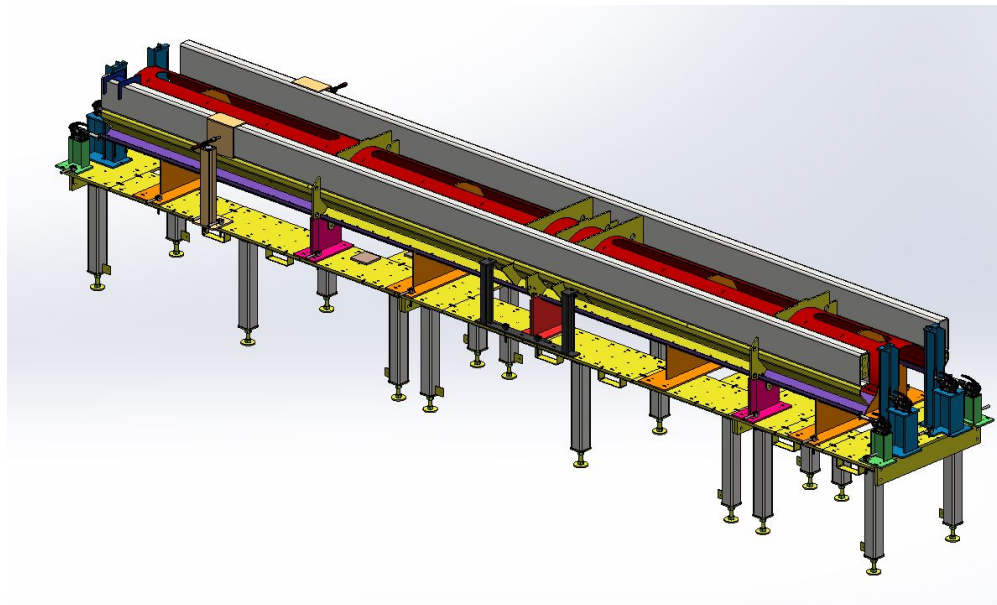


Figure 58: Repeat of Step 6 Assembly, Other Side

Step 7: Welding of part 7

- 7.1 End Clamps in Figure 58, is used to constrain part 7 into place.
- 7.2 Open toggle clamp shown in Figure 18, and insert part 7 into place, then close clamp.
- 7.3 The result should look like Figure 60.
- 7.4 Tack along the edge of part 7, and then do a continuous weld along part 7.
- 7.5 Repeat this for the other part 7, on the other side.

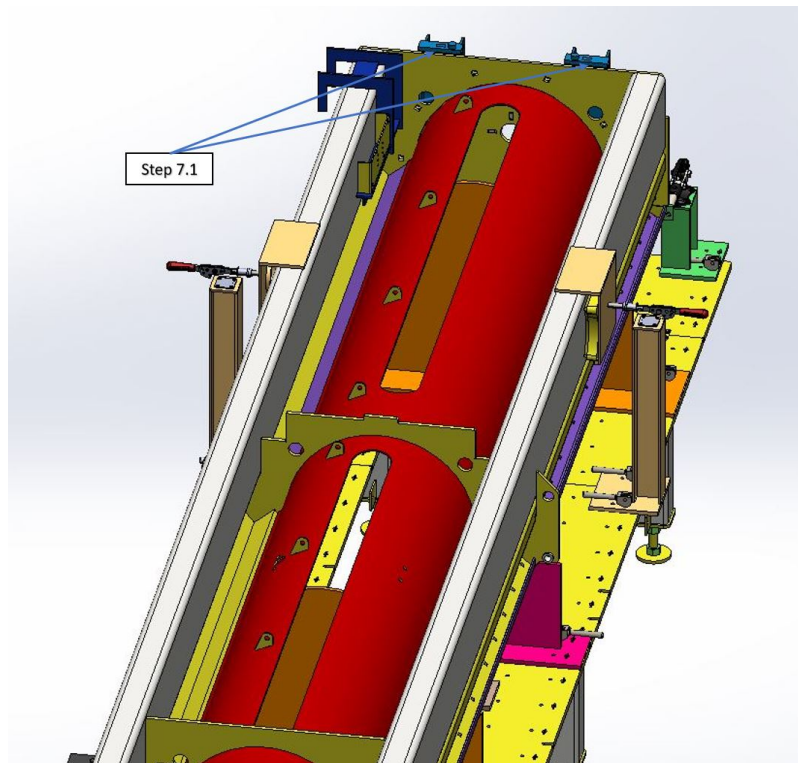


Figure 59: Clamp End for Part 7

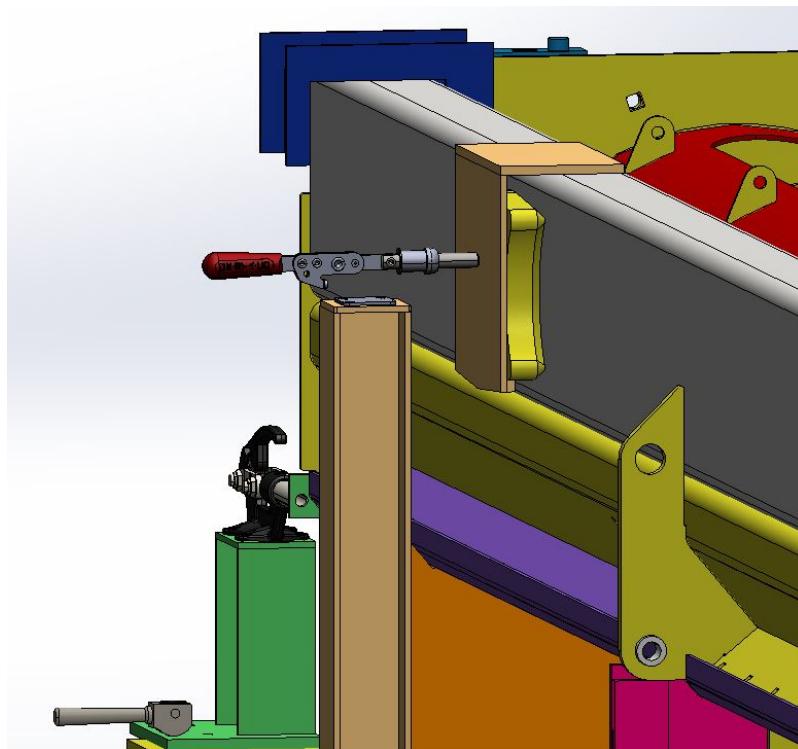


Figure 60: Clamping Part 7

Step 8: Welding Parts 24 and 25

- 8.1 First put, part 24 into place as shown in Figure 20.
- 8.2 Tack weld along the edges, and then do a continuous weld along part 24.
- 8.3 Then, put part 25 into place onto locating fixture, shown in Figure 61.
- 8.4 Tack and weld part 25 into place, and then do a continuous weld along part 25.
- 8.5 Repeat this for the other side.

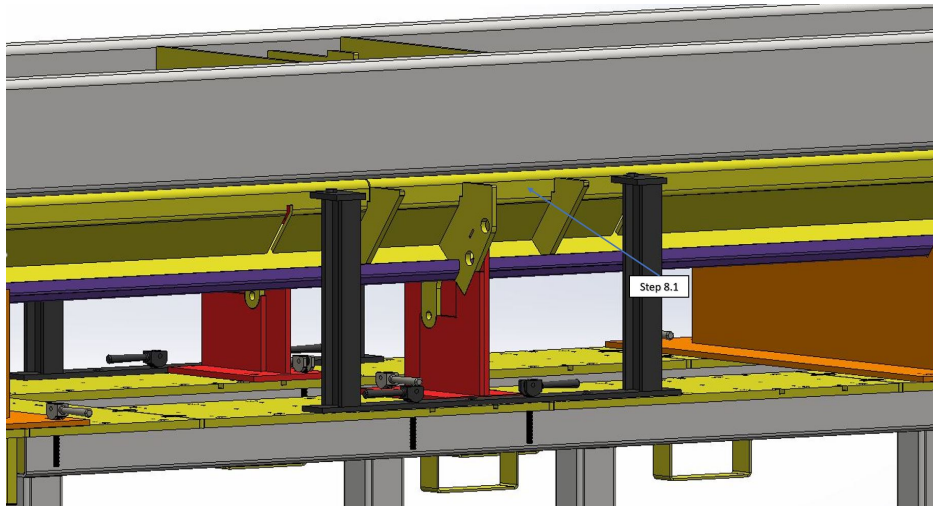


Figure 61: Placing Part 24 into Place

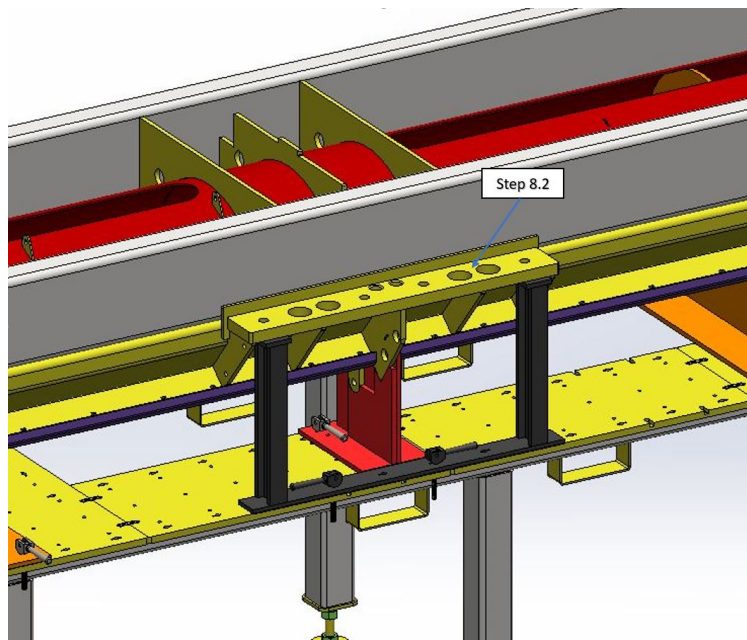


Figure 62: Placing Part 25 onto Jig

Step 9: Welding and Assembling Parts 3, 5, 9, 32, and 34

9.1 Shown in Figure 63, assemble as shown.

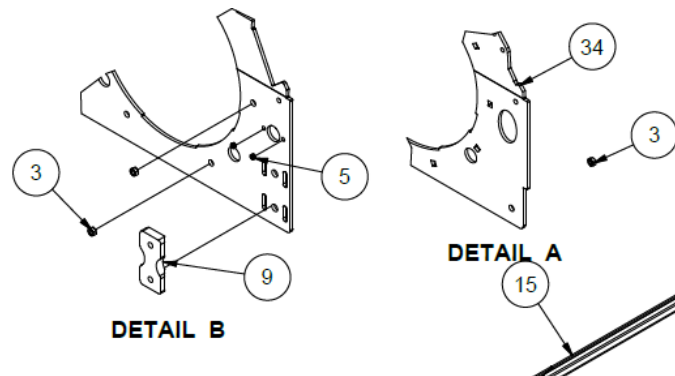


Figure 63: Tacking Parts 3, 5, and 9 to Parts 32 and 34.

Step 10: Welding Parts 32, 33, and 34 to Main Assembly

10.1 Clamp parts 32 and 34 to rotisserie stands as shown in Figure 64 and 65, respectively.

10.2 Tack to main assembly, then do a continuous weld.

10.3 Then, place part 33 onto jig as shown in Figure 66.

10.4 Tack part 33 to main assembly and then do a continuous weld.

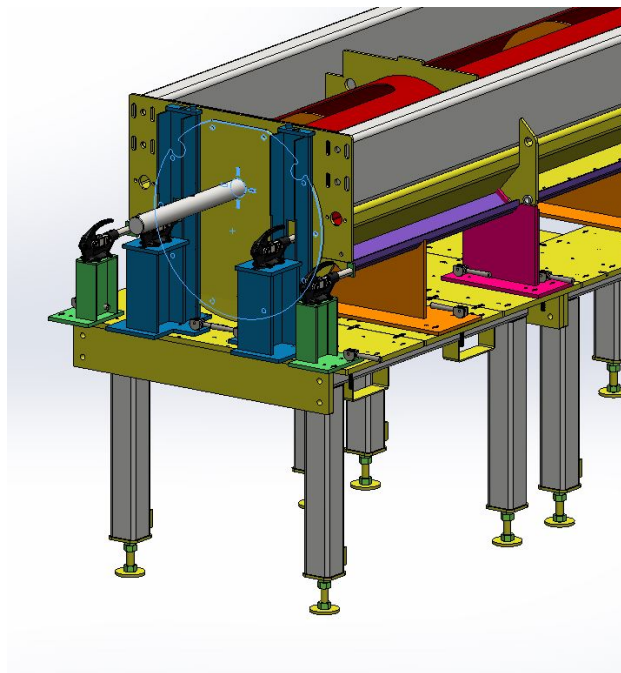


Figure 64: Clamping Part 32 using Rotisserie

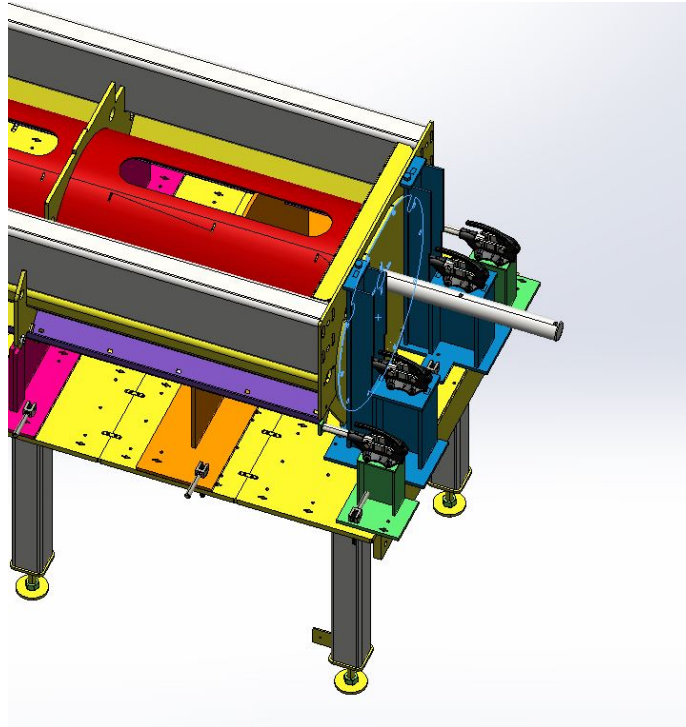


Figure 65: Clamping Part 34 using Rotisserie

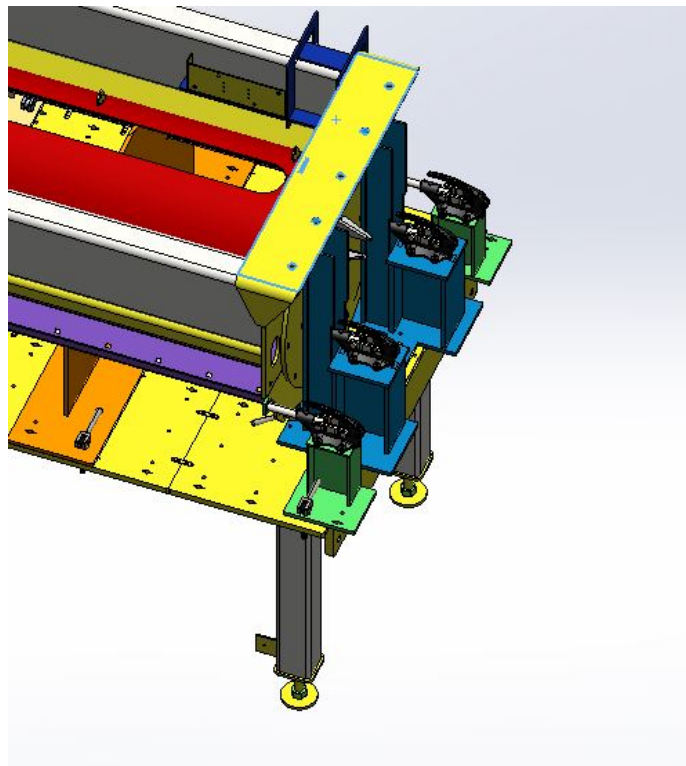


Figure 66: Placing Part 33 into Place, with Jig

Step 11: Weld the rest of the assembly (parts 6, 15, 21, 23, 29, 39, and 40)

11.1 Place parts 29 into place, as shown in Figure 67 and tack weld them to the main assembly.

11.2 Then, place part 15 into place and locate it using the jig shown in Figure 68.

11.3 Tack weld part 15 into place.

11.4 Place parts 6 into place atop parts 35, shown in Figure 67.

11.5 Tack weld parts 6 into place and produce a continuous weld here. Finally, place parts 21 and 33 into place, shown in Figure 69.

11.6 Tack weld into place, and then produce a continuous weld.

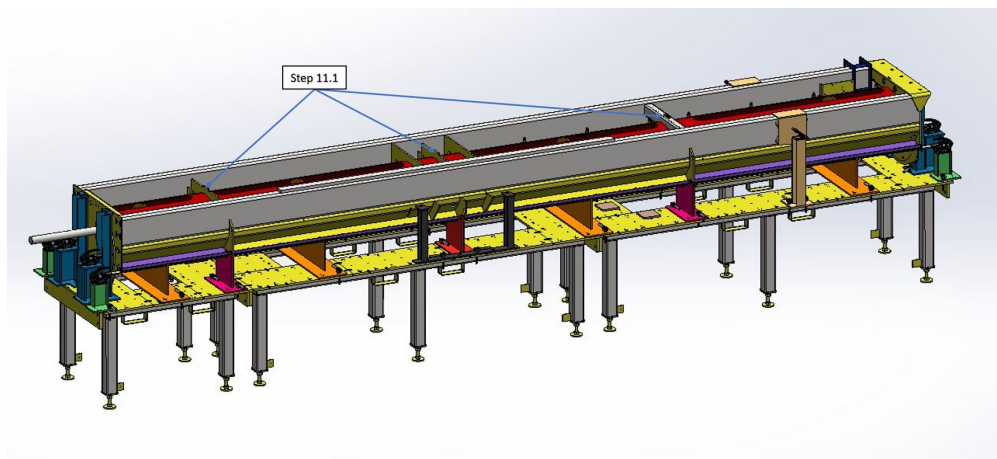


Figure 67: Load Cell Location Completed

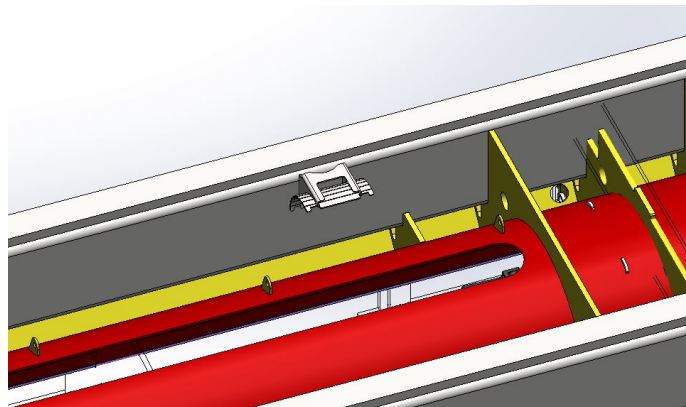


Figure 68: Hitch End Completed

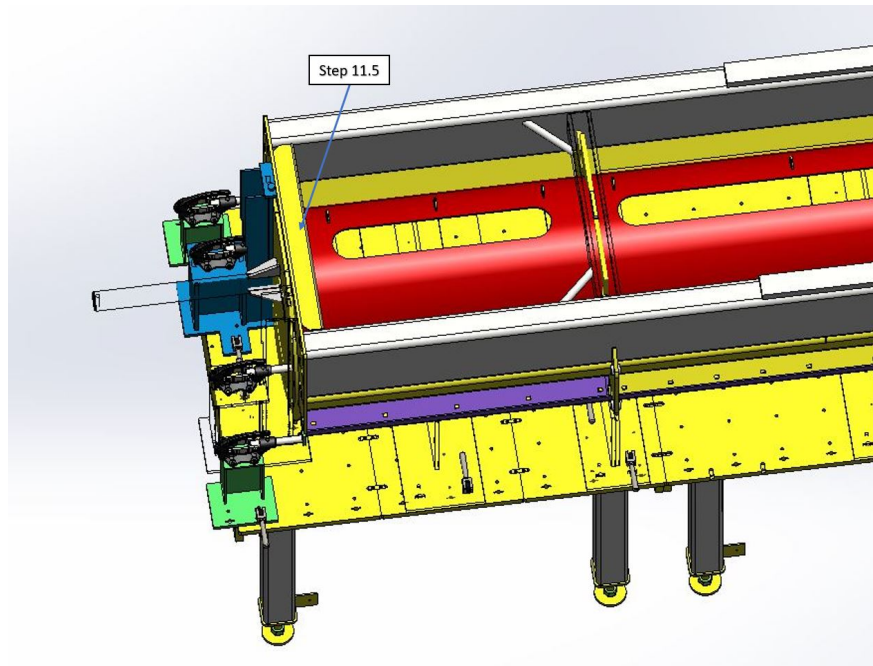


Figure 69: Tail End Completed (Parts 21 or 33)

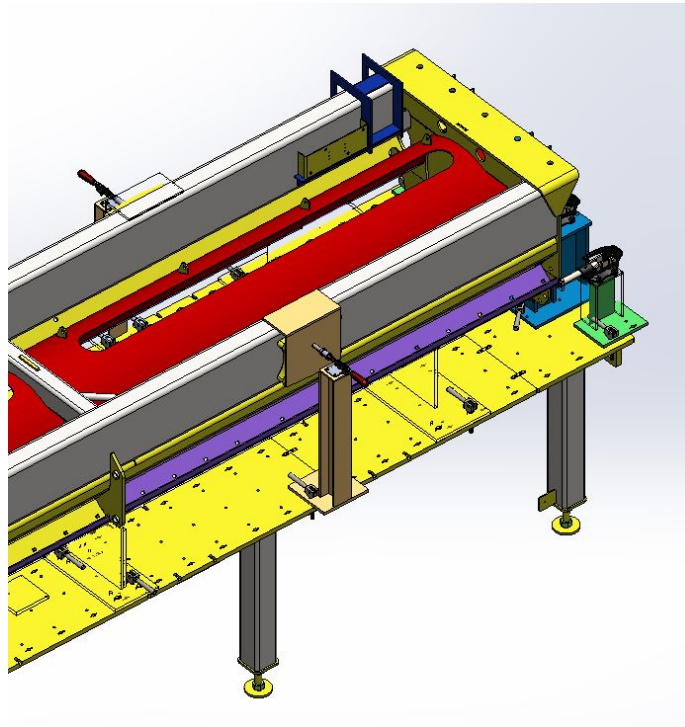


Figure 70: Final Assembly

5 Cost Analysis

This section discusses the associated cost of each jig for the grain cart mainframe assembly. This includes the raw materials and manufacturing cost for each jig. Plain Carbon Steel is the material that is going to be used to manufacture each part of the jig. As per client, laser cut parts will cost \$2 per pound and machined parts will cost \$4 per pound, this cost also includes any bending of the parts. A more detailed information for each part of the jig are listed in Appendix I. Appendix I lists its part number, number of parts, manufacturing technique, cost/lb, mass and part cost for each individual part. The labour and maintenance cost are not considered in the cost breakdown as it is not part of the scope for this project. All costs provided are in Canadian Dollars. TABLE XIV below shows the cost summary for each of the jig, as well as its total number of parts and total mass.

TABLE XIV: COST ANALYSIS OF JIGS

Cost Summary of each Jig for Final Design Assembly				
Jig Name	Jig Number	# of Parts	Total Mass (lb)	Jig Cost (\$)
End Plate Mounts (2 Pairs)	GCMJ100	18	72.51	639.84
Weight Scale Locators	GCMJ200	16	22.1	194.6
Purple Clamp Jig (2 Pairs)	GCMJ300	12	18.87	118.96
Peg Hitch Bottom Plate	GCMJ400	12	41.55	202.92
Computer Jig	GCMJ500	5	6.44	17.48
Part 26 Jig	GCMJ600	6	47.76	191.04
Part 31 Jig(2 Pairs)	GCMJ700	6	42.62	340.96
Semi-Plate Jig	GCMJ800	8	158.03	1264.24
HSS and Z-Plate Jig	GCMJ900	4	117.47	469.88
Part 26 Bushing Jig	GCMJ000	3	5.71	34.26
Top Gauge Jig	GCMJ110	4	36.06	79.28
			Total Jig Cost:	\$3553.46

The team's final design also incorporates clamps to some of the jig. Specifically, the end plate mounts (GCMJ100) and the purple clamp jig (GCMJ300) integrates the use of the Destaco-650: Straight Line Action Clamps, then the peg hitch clamp (GCMJ400) uses the Destaco-620: Straight Line Action Clamp. These clamps have an associated costs of \$126 and \$137 which would bring the total cost for the final design to be **\$4,331.46**, which is within the budget for this project at \$5,000.

6 Conclusion

In this project, the design team was tasked with improving Elmer's process on their current mainframes jig system which currently uses an excessive amount of c-clamps to locate components in place. The goal of the design was to improve the whole tack welding process and decrease the total assembly time by at least 30% in manufacturing for four different variations of mainframe which include large, small, Row Crop tandem and high-capacity mainframes.

From advice from the Elmer's engineering team and advisor Nishant Balakrishnan, Team 18 was able to come up with a final design that meets most of the objectives outlined in the project. The total cost of the jig system is \$4,331.46 which does not exceed the proposed budget of \$5,000. The design consists of 94 different components that make up 11 different jigs in the jig system. The construction of these jigs can be completed at the Elmer's Facility with standard sheet metal sizes and toggle clamps, making the final design easier to construct. CAD models are provided for each jig, and DXFs can be sourced from these CAD models for Elmer's to laser cut jig components if Elmer's plans on using this design in the future. Lastly, a preliminary version of a SOP has also been completed for the large mainframe, which will help the engineers at Elmer's understand how to assemble a large mainframe via Team 18's jig system.

Additionally, in this process designed by Team 18, the design does not use any c-clamps. Therefore, a large amount of time will be saved by welders during the mainframe assembly process since excessive clamping using c-clamps was used in Elmer's previous process of mainframe assembly. Destaco toggle clamps are used on jigs in the final design to quickly and efficiently clamp parts down, which saves a lot of time. Since more jigs are used than in Elmer's previous design, all parts in the mainframe assembly can be properly constrained and located. This helps improve the quality of each mainframe because there is less room for errors produced by mainframe parts being located improperly. The final design has also been adapted to the client's needs of being modular to accommodate all four different mainframes sizes. Lastly, the final design is safe and does not present any extreme hazards or safety issues.

Finally, the main goal of this project, that the design should cut 30% of the current mainframe assembly time of 6 hours, can be verified by further research by Elmer's employees.

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Appendices

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A - Elmer's Small Mainframe Drawing



B - Elmer's Large Table Weldment Drawing



C - Elmer's Small Table Weldment Drawing

Permission Pending

D - House of Quality



Figure D.1 Project House of Quality [30]

E - Team 18 MS Project Gantt Chart From Phase One

The Gantt chart show in Figure E.1 depicts the initial timeline that the student design team has presented to the client. The CDR outlines the deviations between this timeline and the most recent timeline that the team has presented to the client. The phase one Gantt chart is to be used as a baseline going forward, comparisons from this chart to the updated one will be referenced by the student moving forward. Any deviations from the phase two Gantt chart will be evaluated by the team and accounted for through the use of additional work sessions and meetings with academic and industrial advisors.

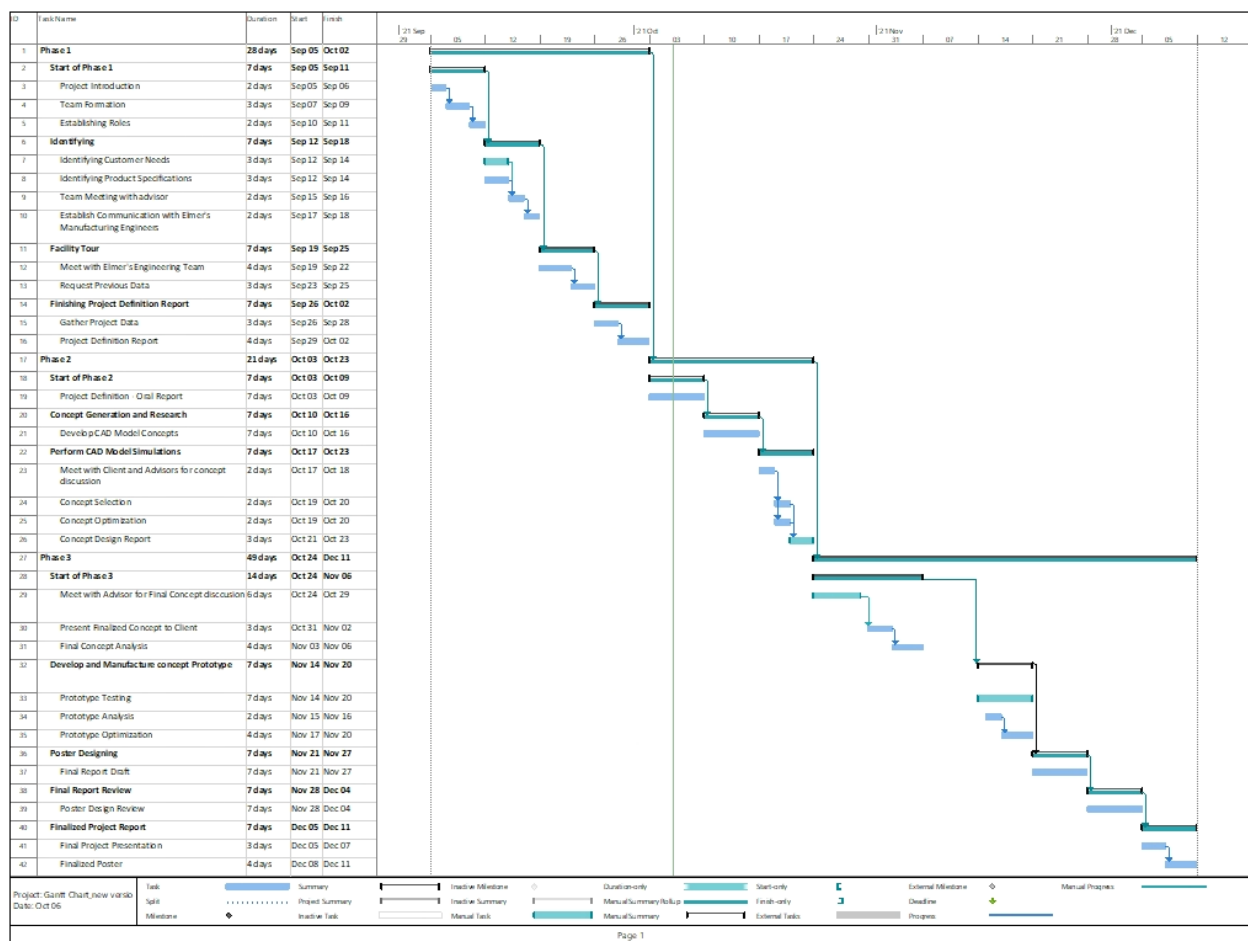


Figure E.1: Phase 1 Project Gantt Chart used by Team 18

F - Geometric Dimensioning & Tolerancing



Figure F.1: ASME Y14.5 Geometric Control Symbols



Figure F.2: ANSI and ISO Orthographic Projections

G - Y14.5 and ISO Drafting Definitions



Figure G.1: Datum Feature Symbol



Figure G.2: Feature Control Frame and Datum Order of Precedence



Figure G.3: Tolerance Query on a 3D CAD System Compliant with ASME Y14.41-2003

H - Concept Figures and Sketches

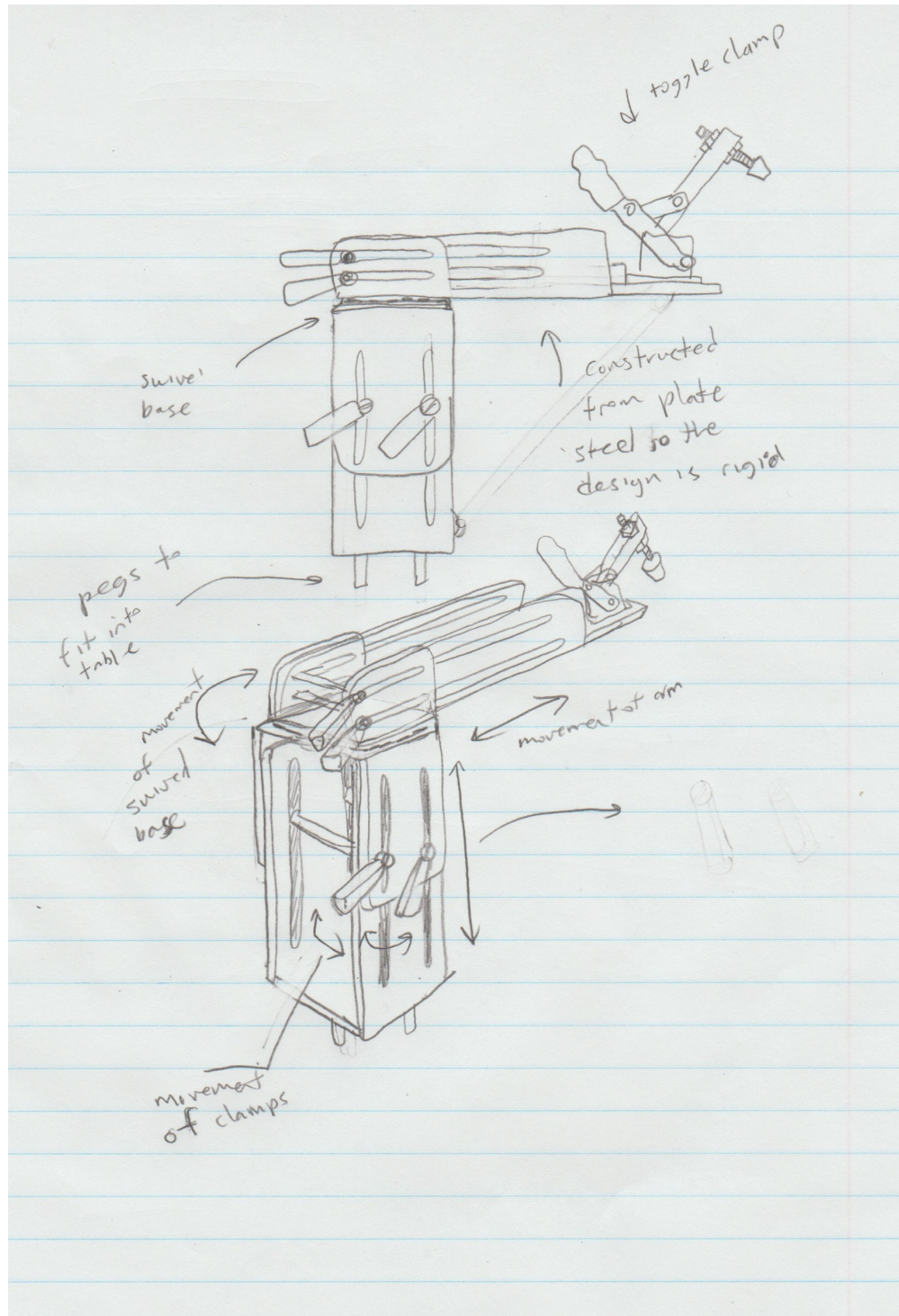


Figure H.1: Drawing of the Adjustable Peg Mounted Clamp System (Concept 1)

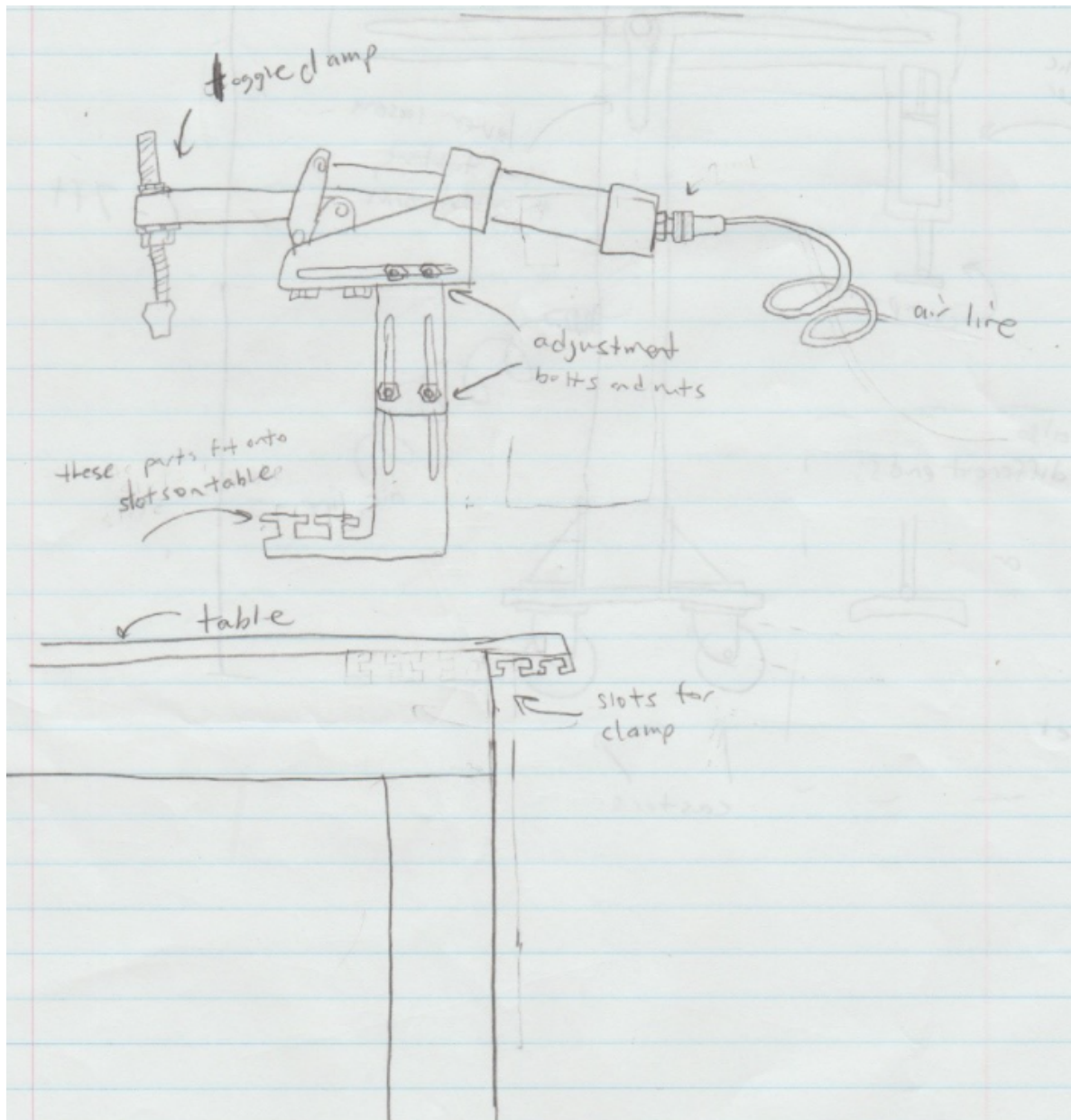


Figure H.2: Drawing of the Adjustable Slot Mounted Pneumatic Clamp System (Concept 2)

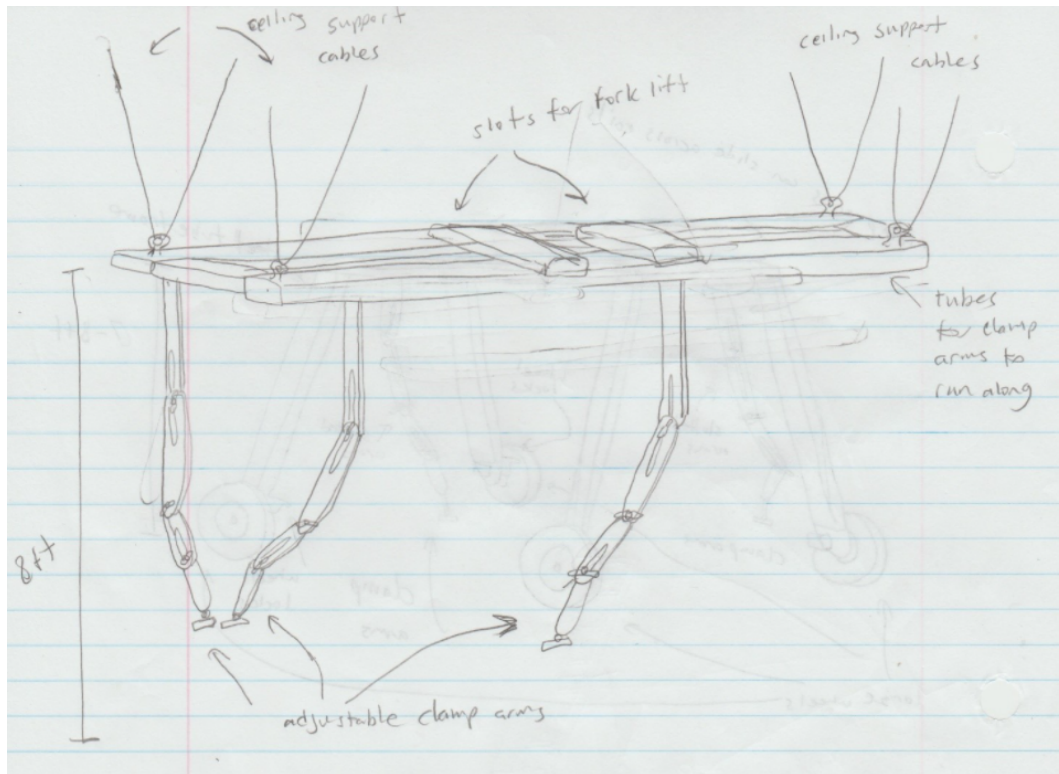


Figure H.3: Drawing of the Hanging Frame Clamp System (Concept 3)

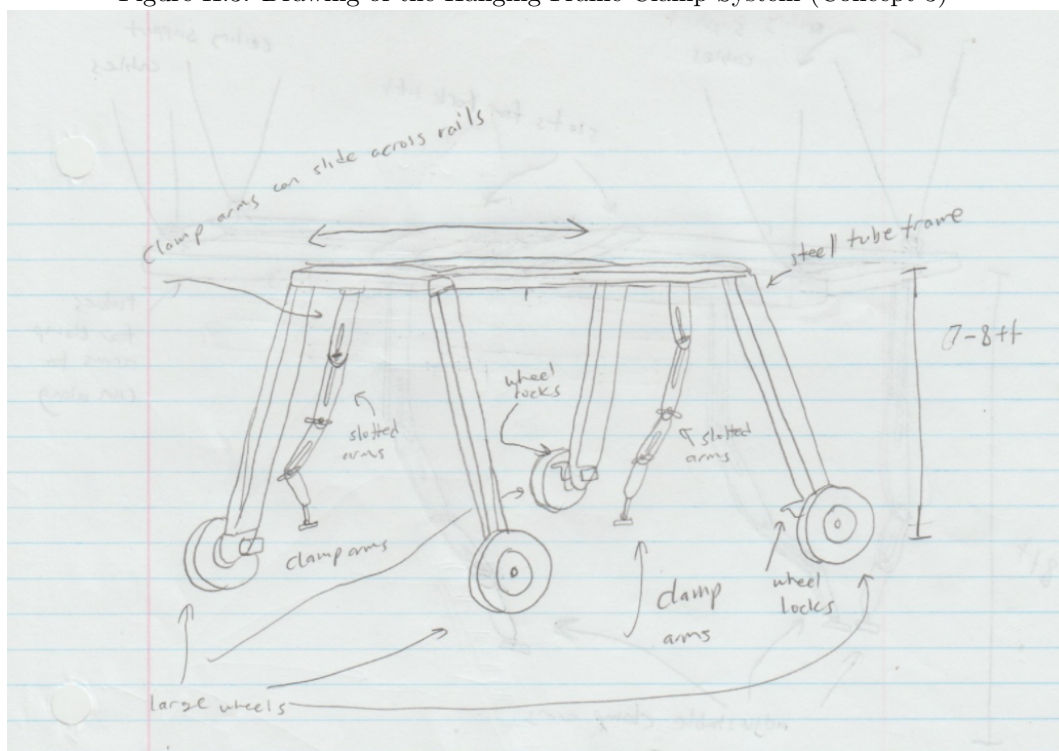


Figure H.4: Drawing of the Overhead Wheeled Frame Clamp System (Concept 4)

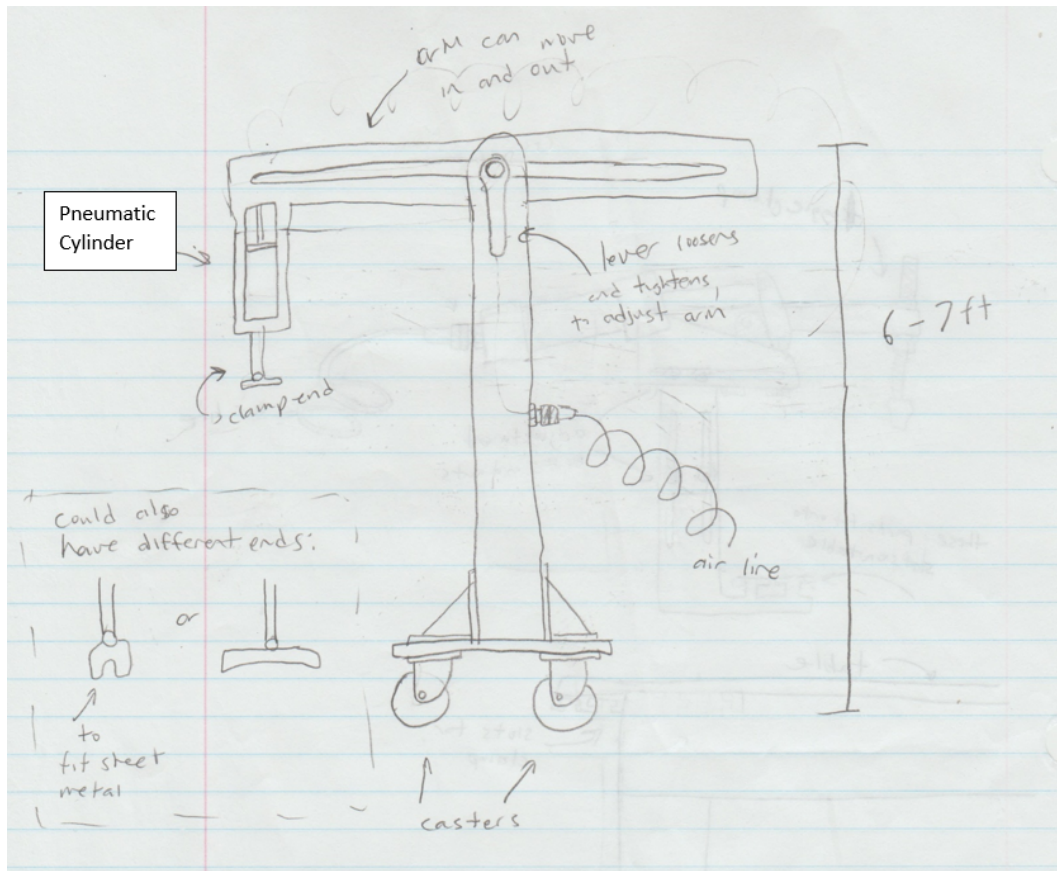


Figure H.5: Drawing of the Mini Crane Boom Clamp System (Concept 5)

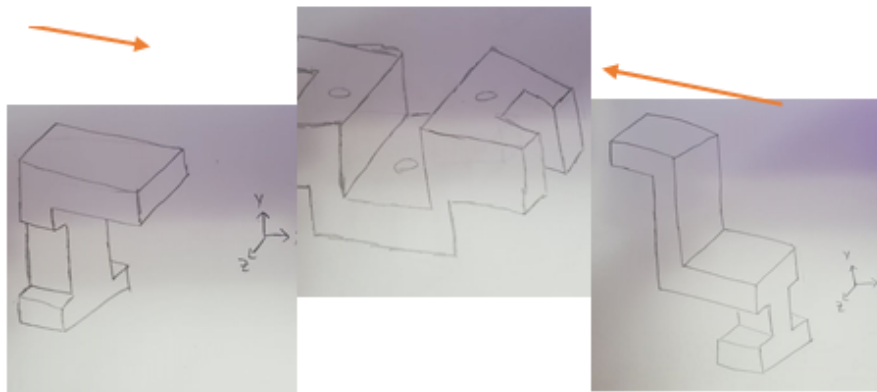
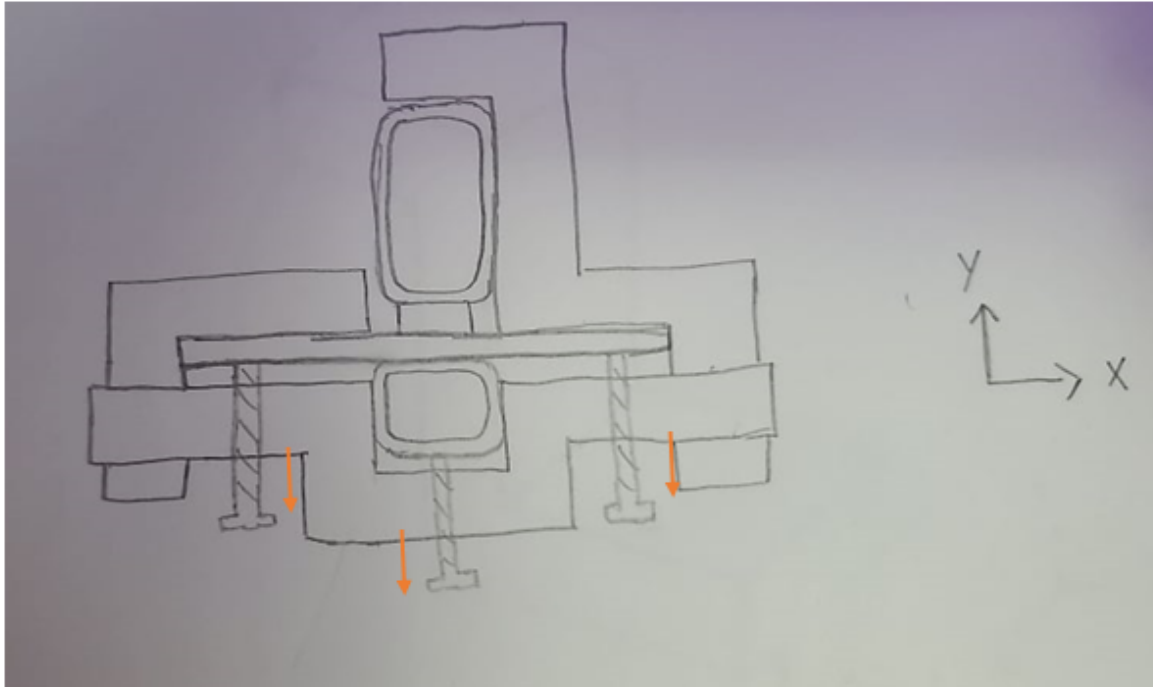


Figure H.6: Drawings of the Replaceable Claw Clamp System Jig (Concept 6)

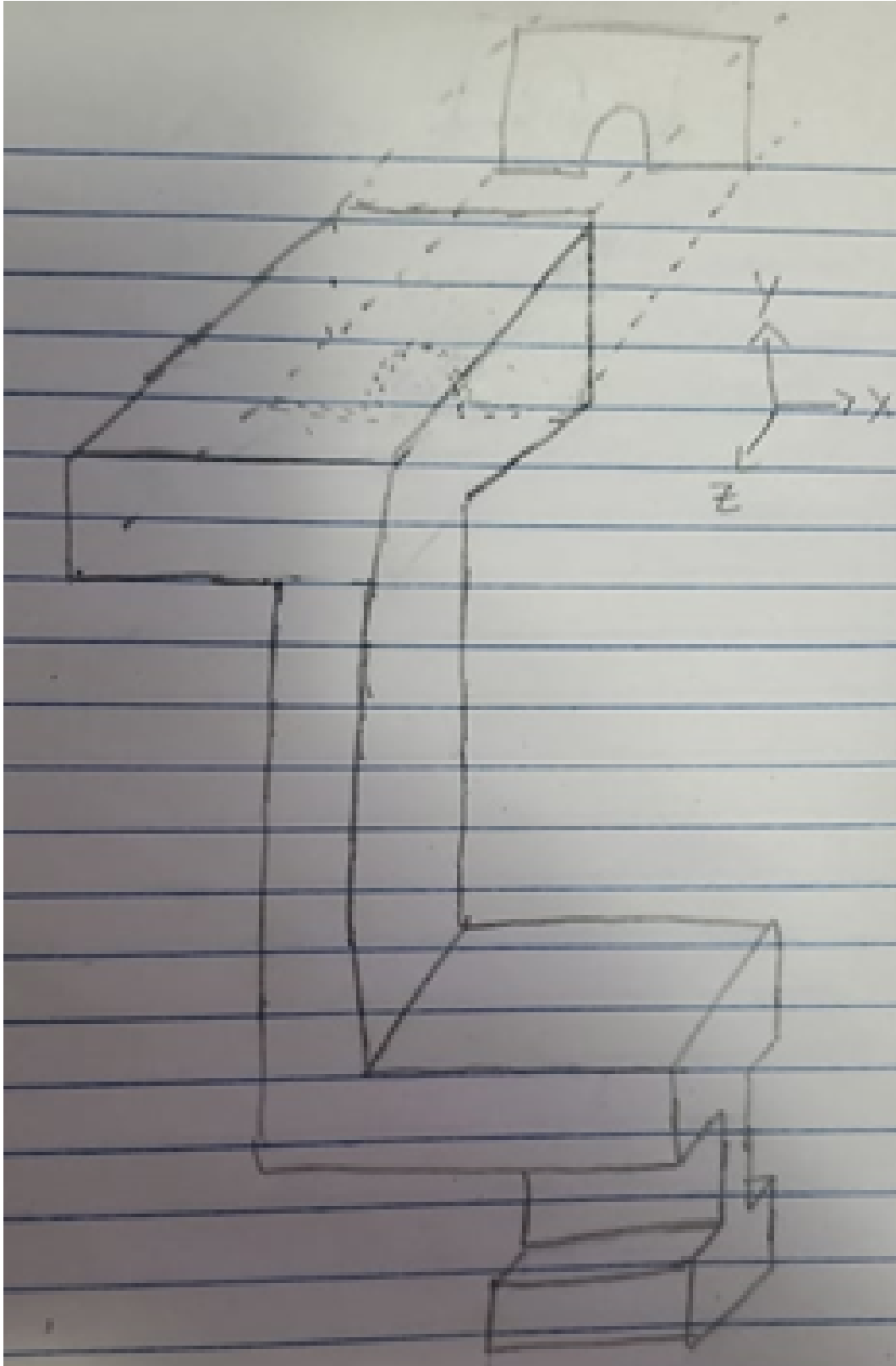


Figure H.7: Drawing of the Flange Claw Clamp (Concept 6)

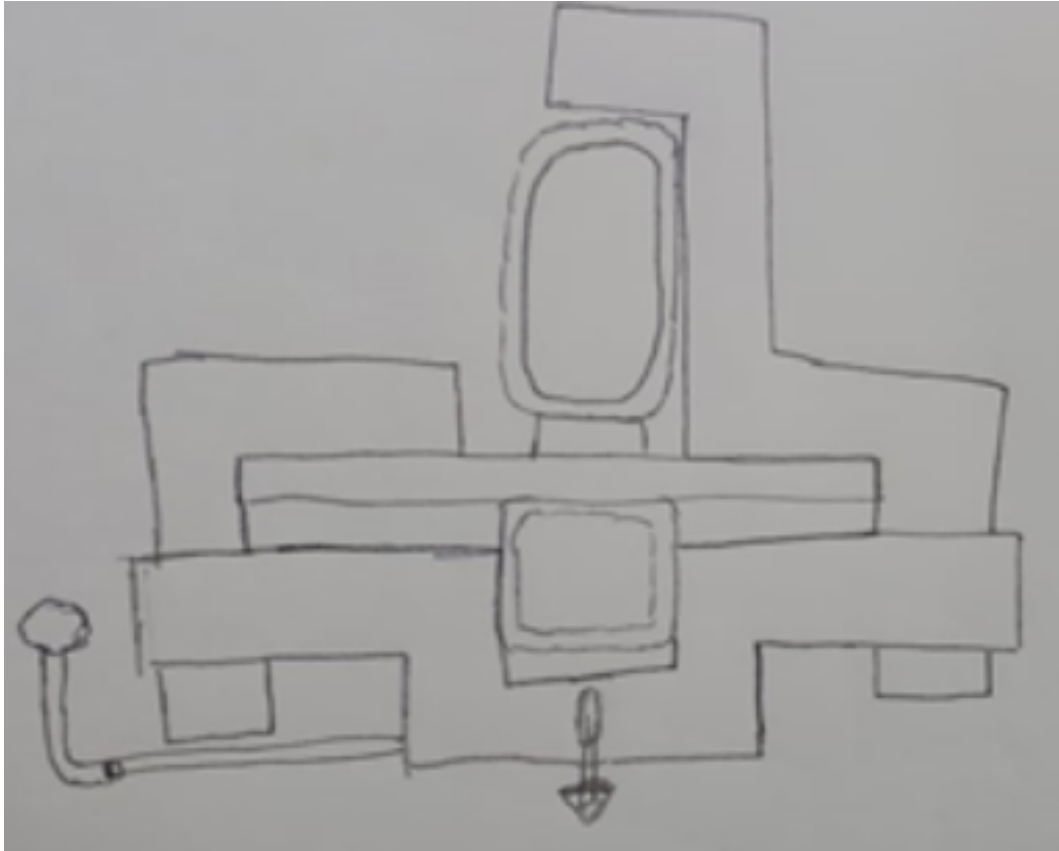


Figure H.8: Drawing of the Replaceable Claw Clamp System Jig with Ratchet (Concept 7)

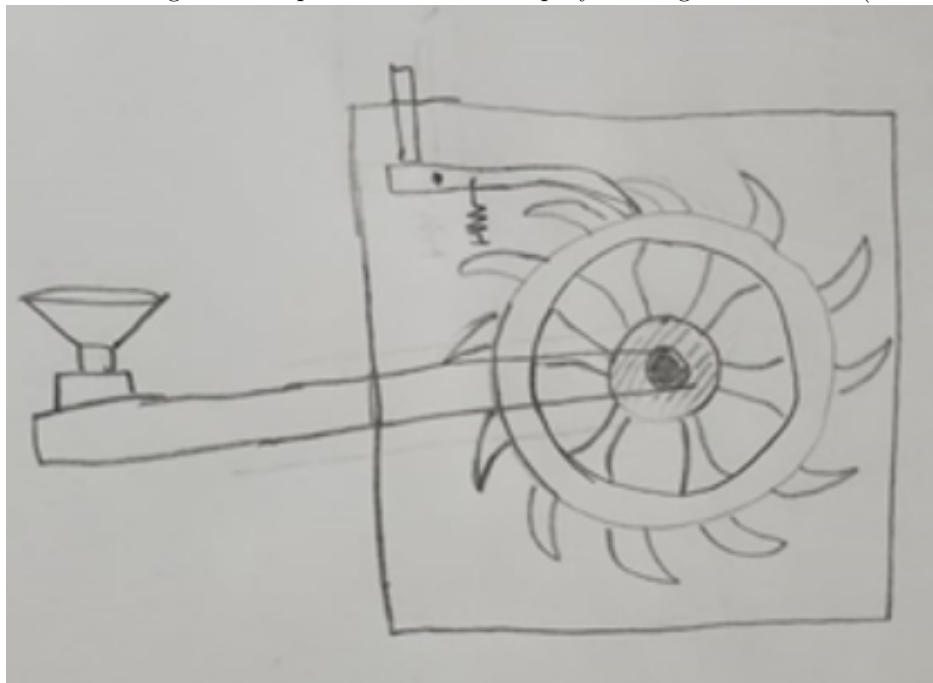


Figure H.9: Drawing of the Ratchet System (Concept 7)

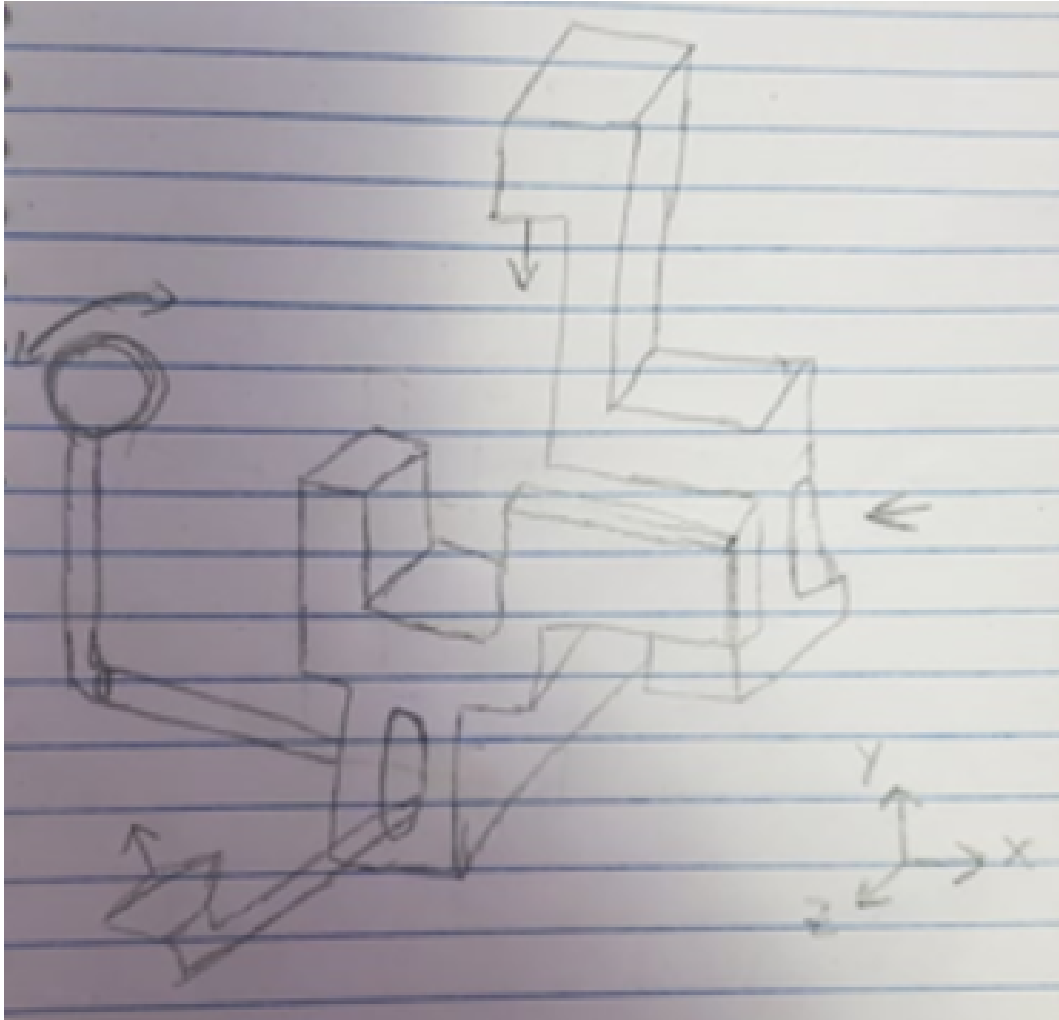


Figure H.10: Isometric Drawing of the Replaceable Claw Clamp System Jig with Ratchet (Concept 7)

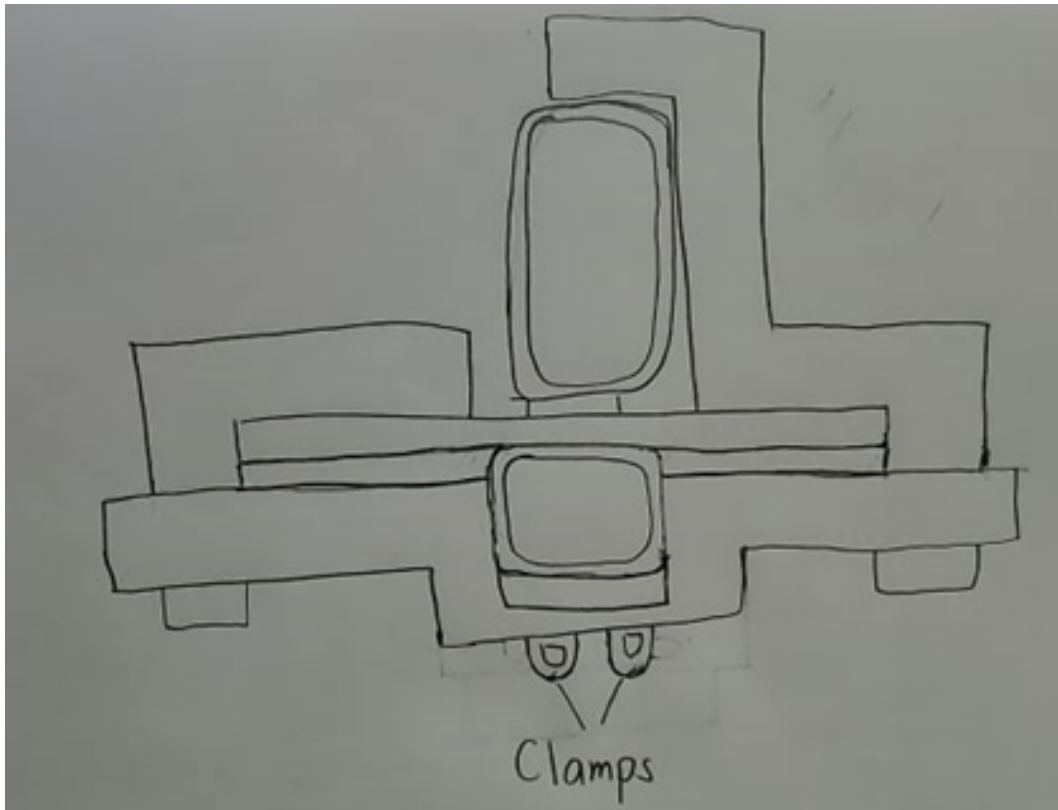


Figure H.11: Drawing of the Replaceable Claw Clamp Jig with Toggle Clamps (Concept 8)

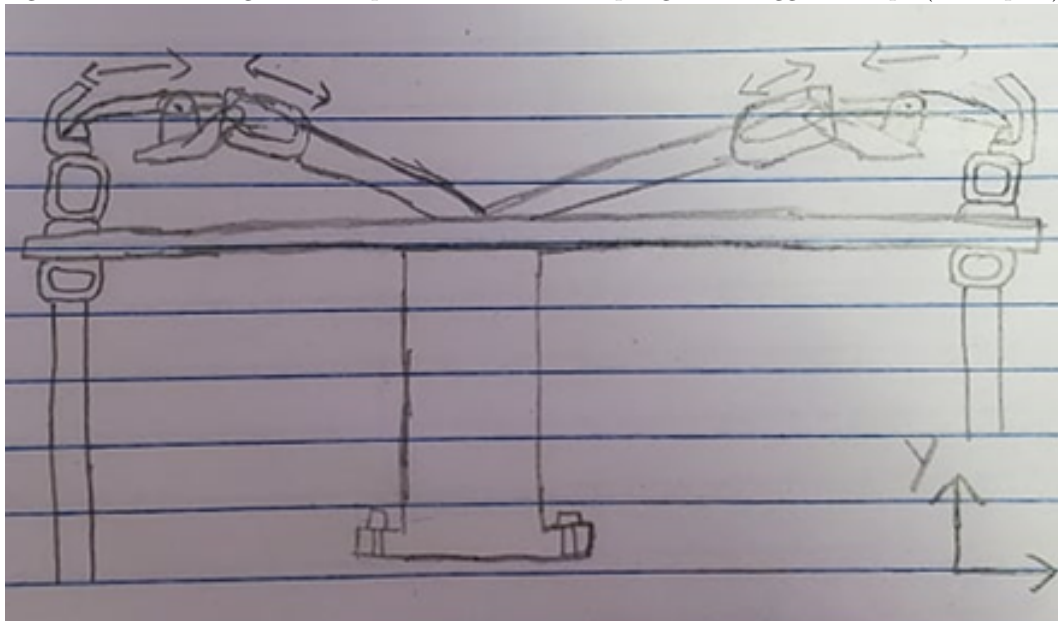


Figure H.12: Drawing of the Adjustable Pneumatic Toggle Clamp Arm (Concept 9)

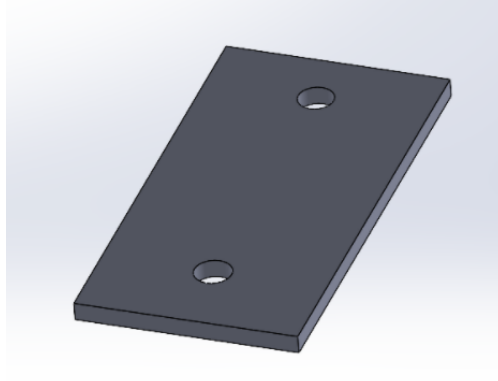


Figure H.13: CAD Model of the Tree Fixture (Concept 10)

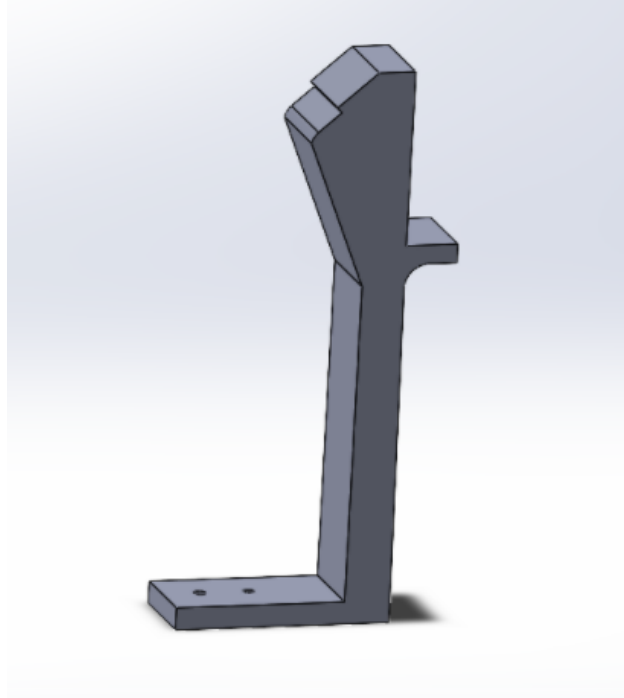


Figure H.14: CAD Model of the Plate Fixture (Concept 10)

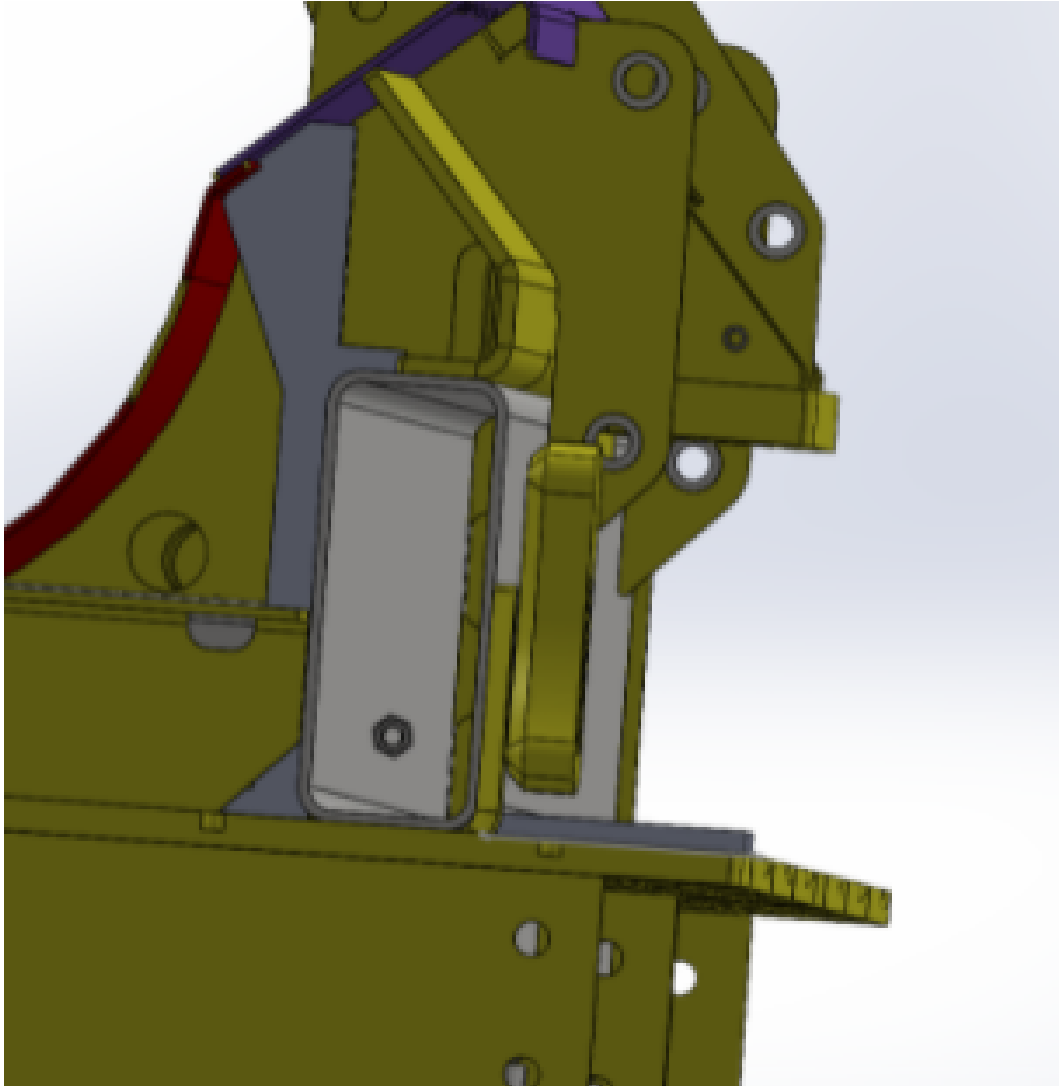


Figure H.15: CAD Model of the Tree Fixture Implemented in the Mainframe (Concept 10)

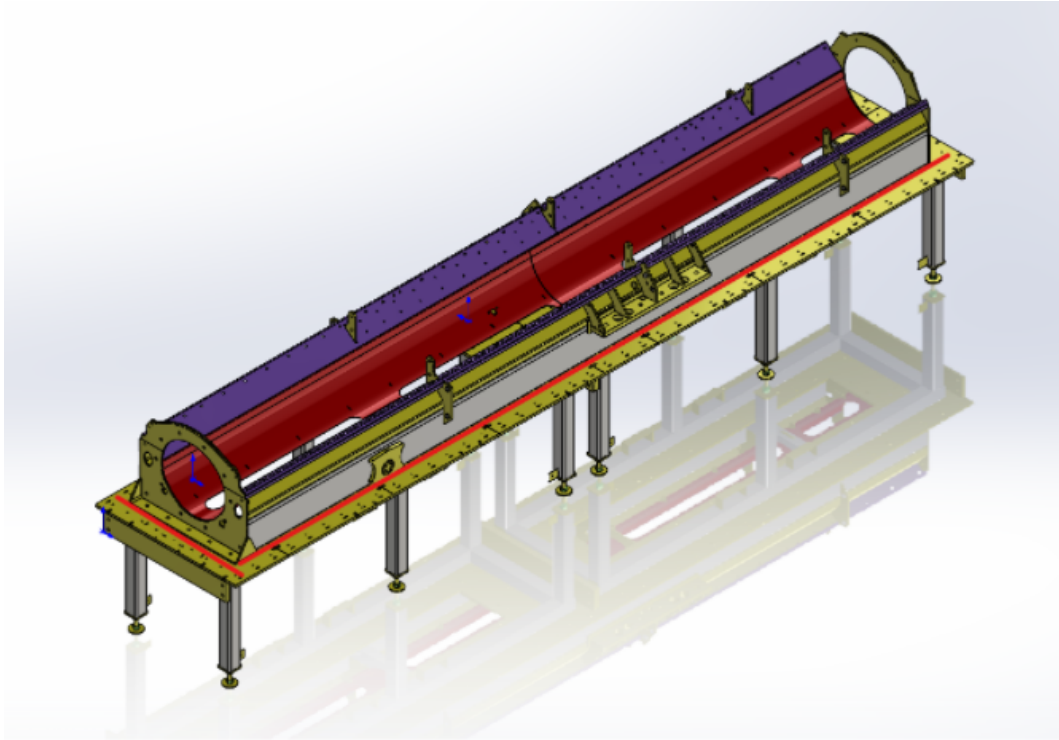


Figure H.16: CAD Model of Regular Orientation Assembly (Concept 11)

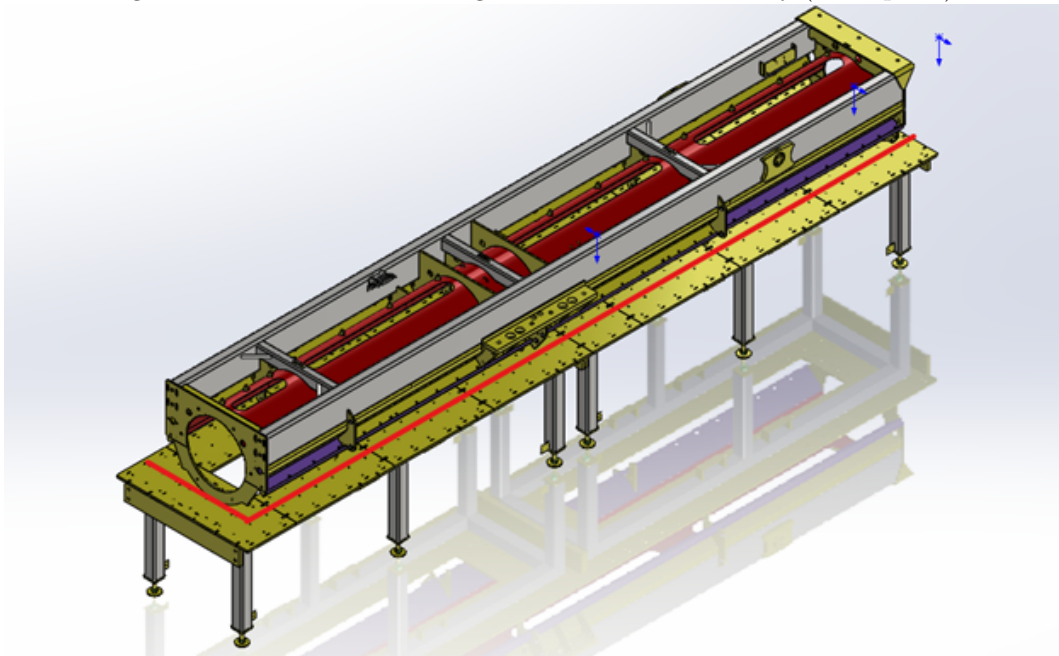


Figure H.17: CAD Model of Upside-down Assembly (Concept 12)

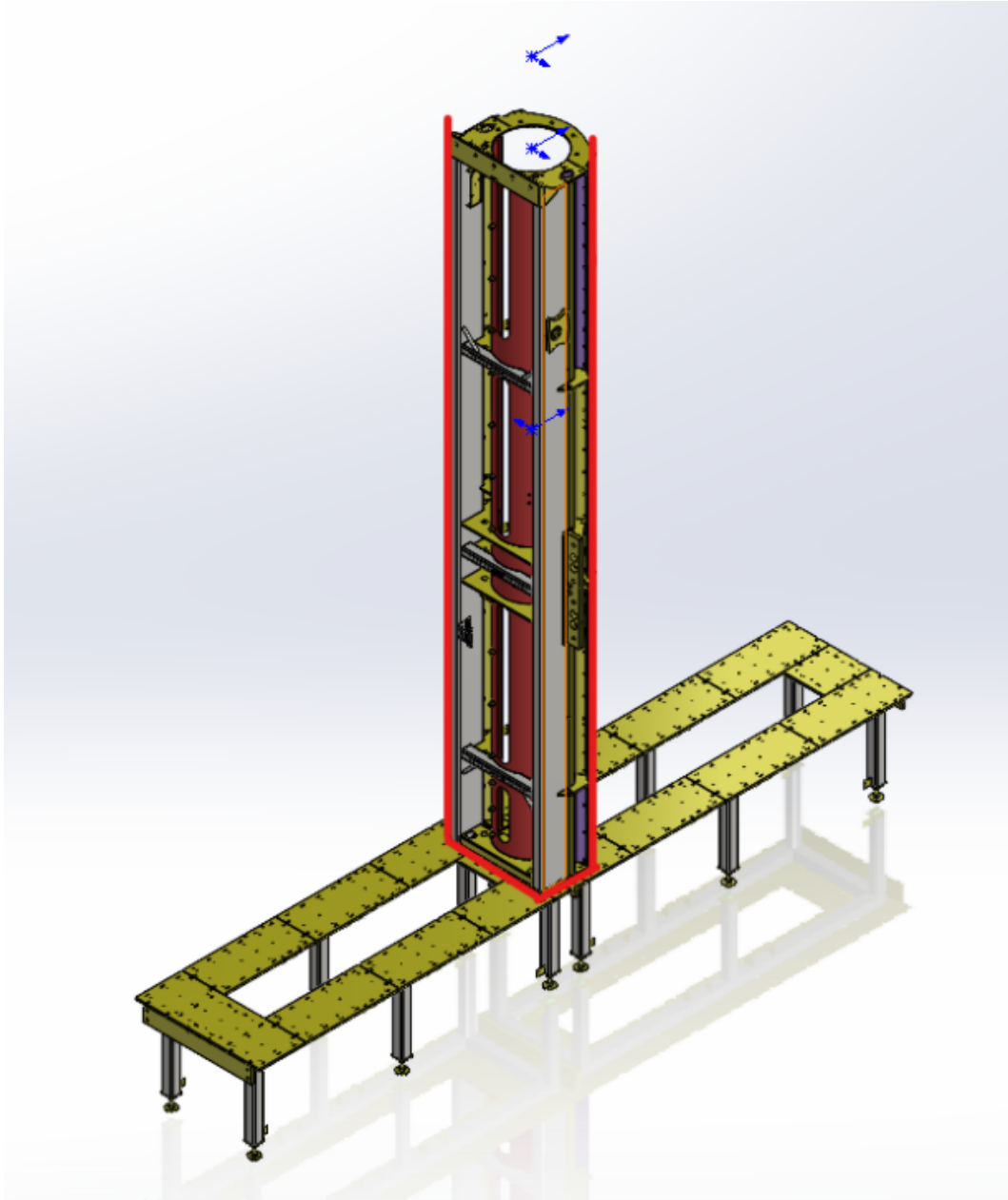


Figure H.18: CAD Model of Vertical Assembly (Concept 13)

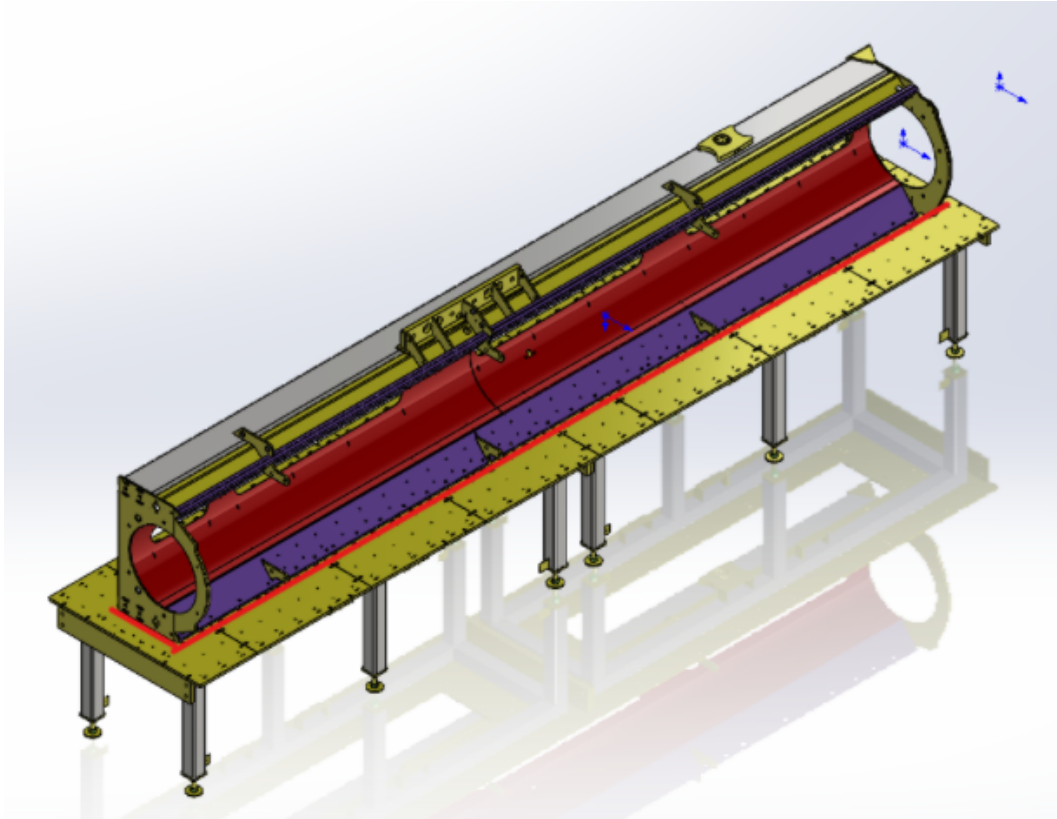


Figure H.19: CAD Model of Side Assembly (Concept 14)

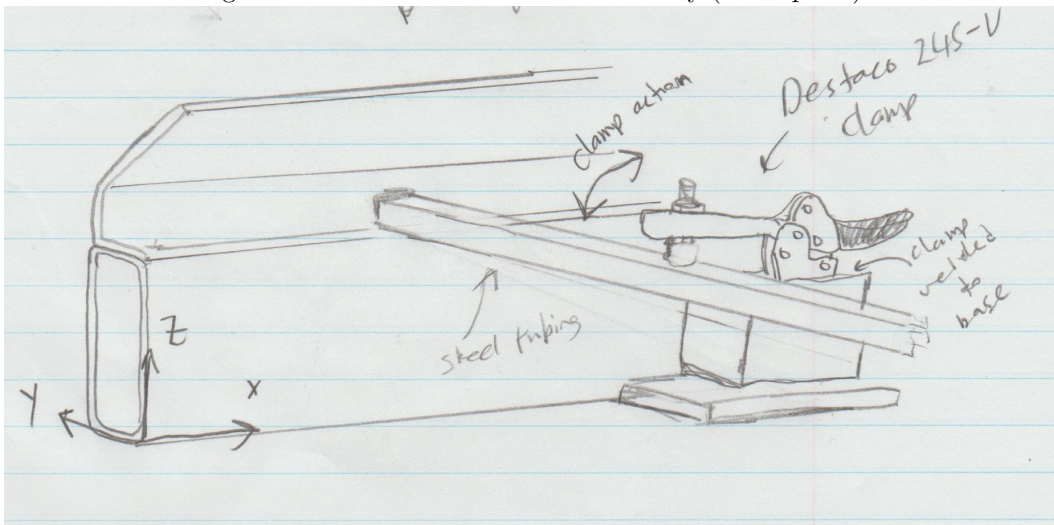


Figure H.20: Drawing of the Double Clamp Sub-Weldment (Concept 15)

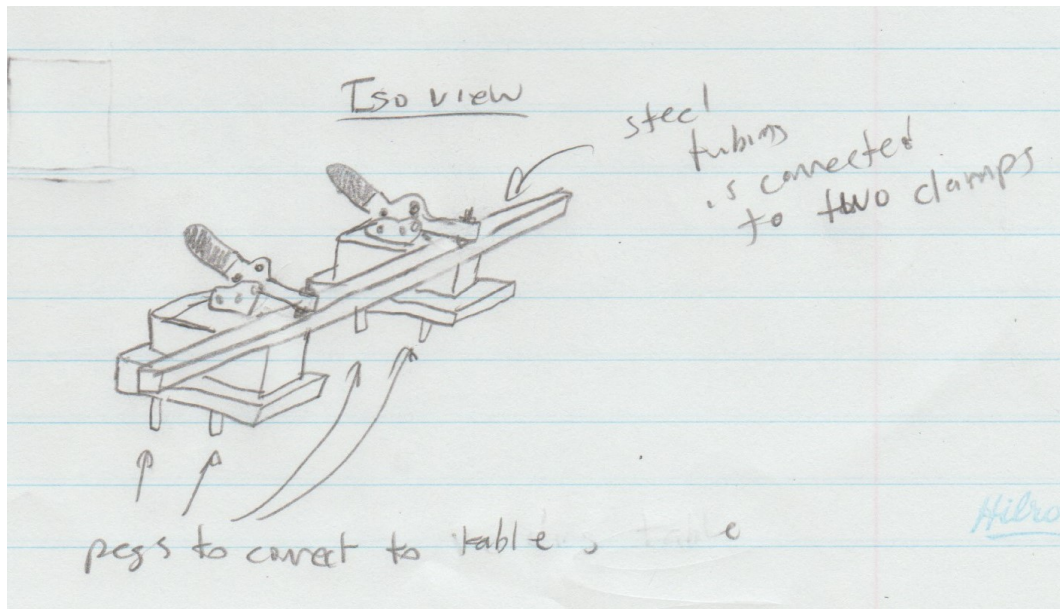


Figure H.21: Isometric Drawing of the Double Clamp Sub-Weldment (Concept 15)

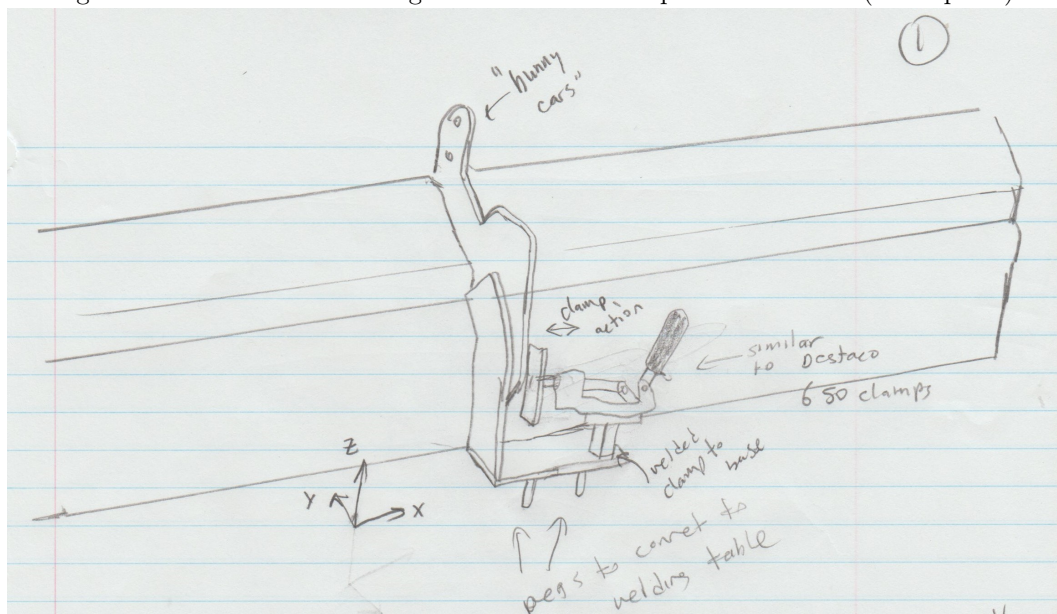


Figure H.22: Drawing of the Flange Sub-Weldment (Concept 15)

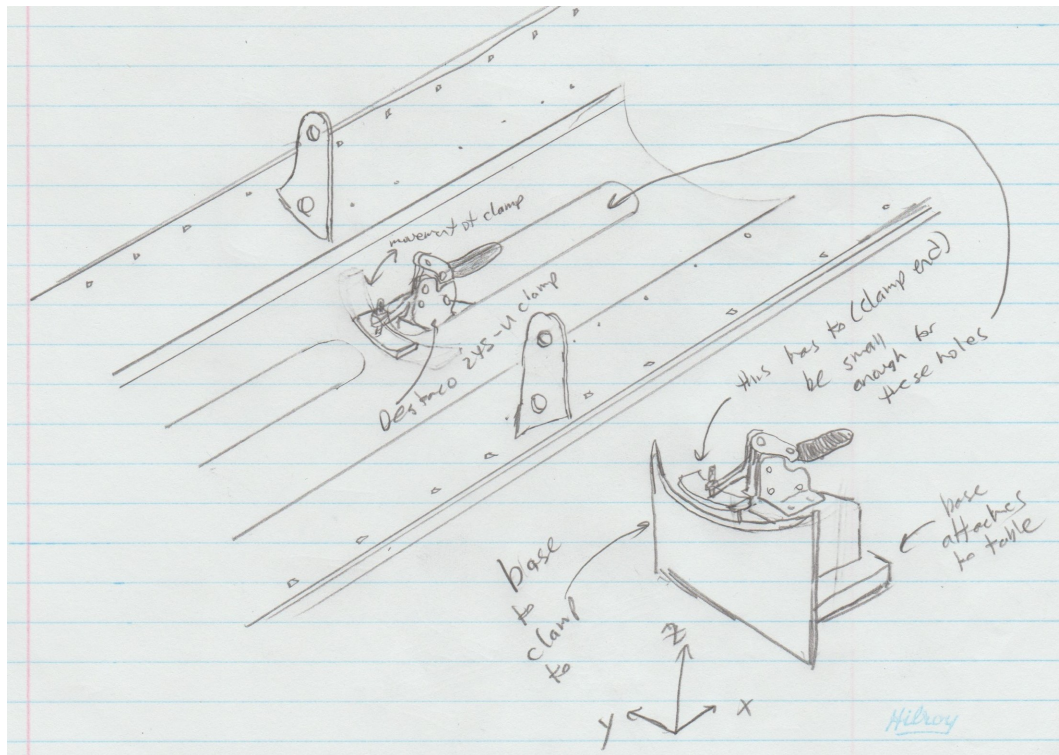


Figure H.23: Drawing of the Trough Sub-Weldment (Concept 15)

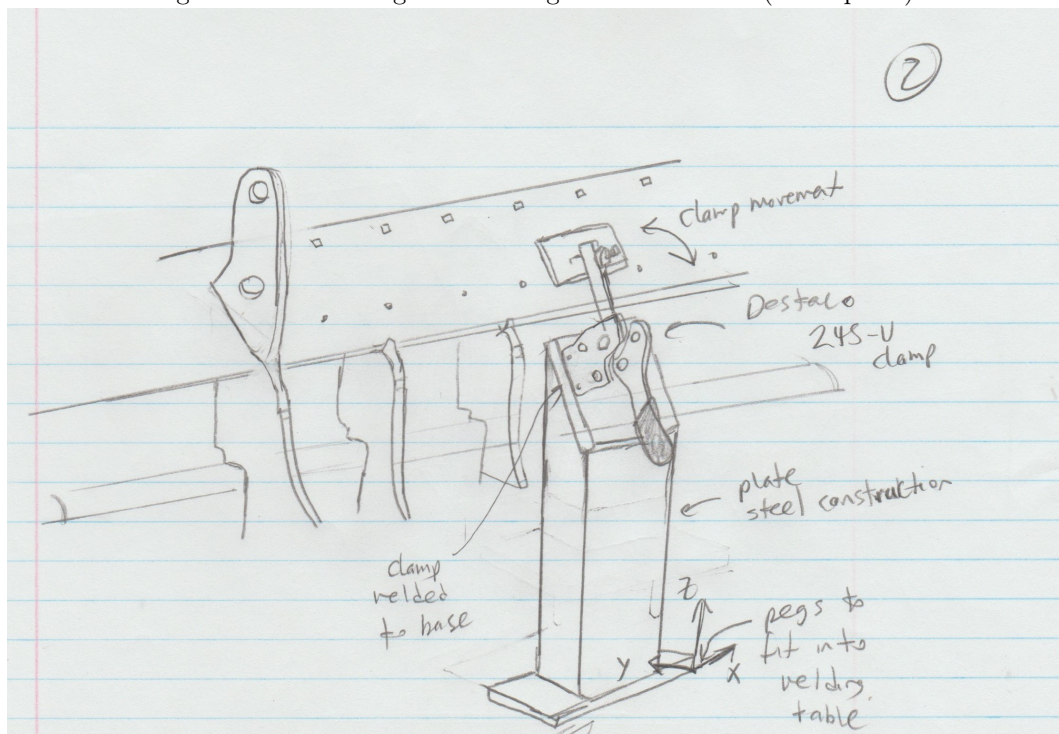


Figure H.24: Drawing of the Trough Skirting Sub-Weldment (Concept 15)

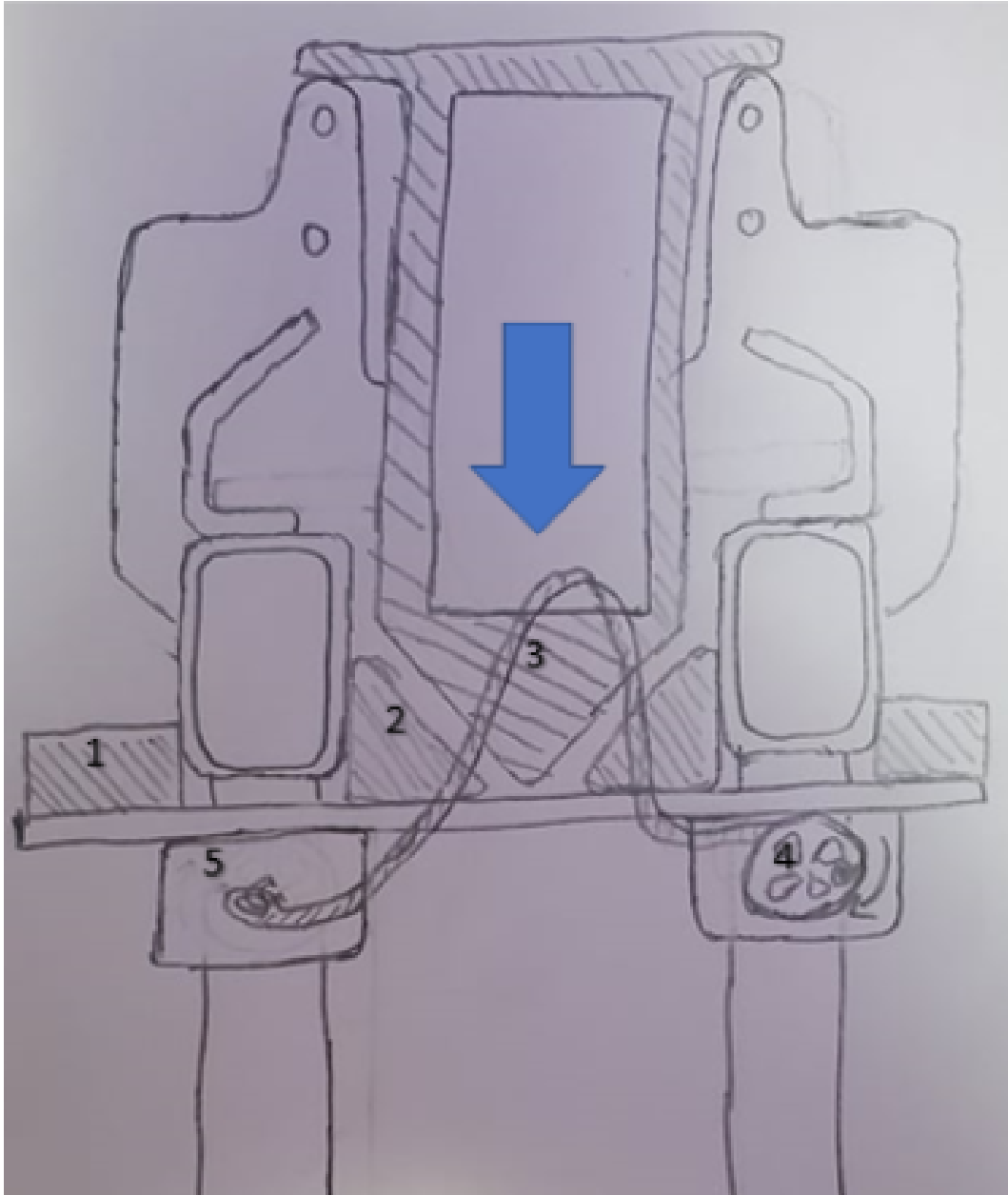


Figure H.25: Drawing of Ratchet Strap Clamp Concept (Concept 16)

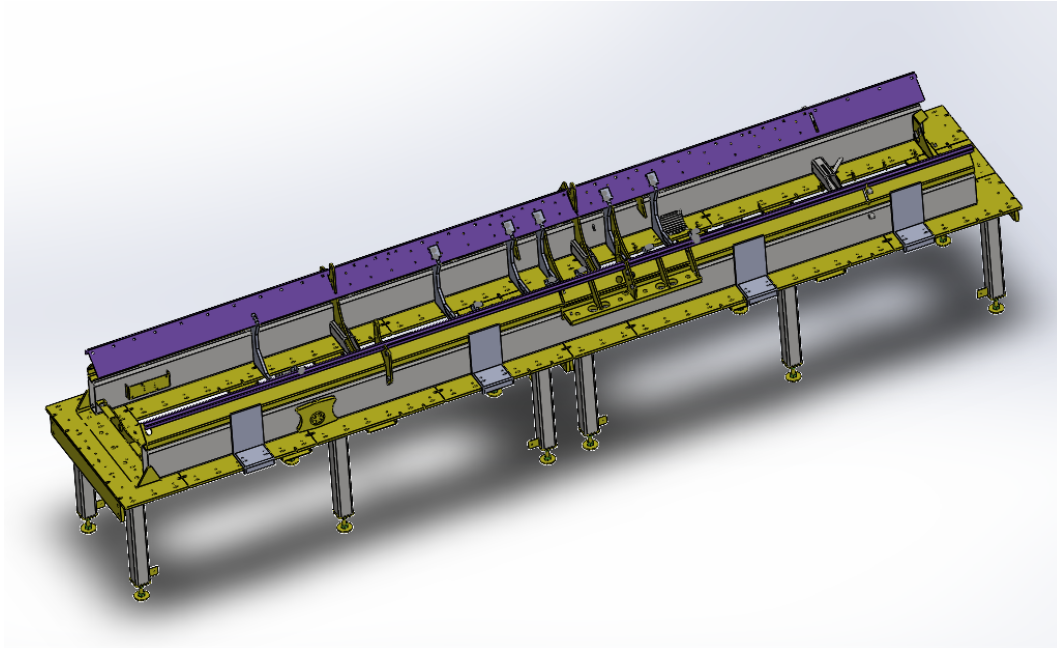


Figure H.26: CAD Model of Fixture System within Mainframe (Concept 19)

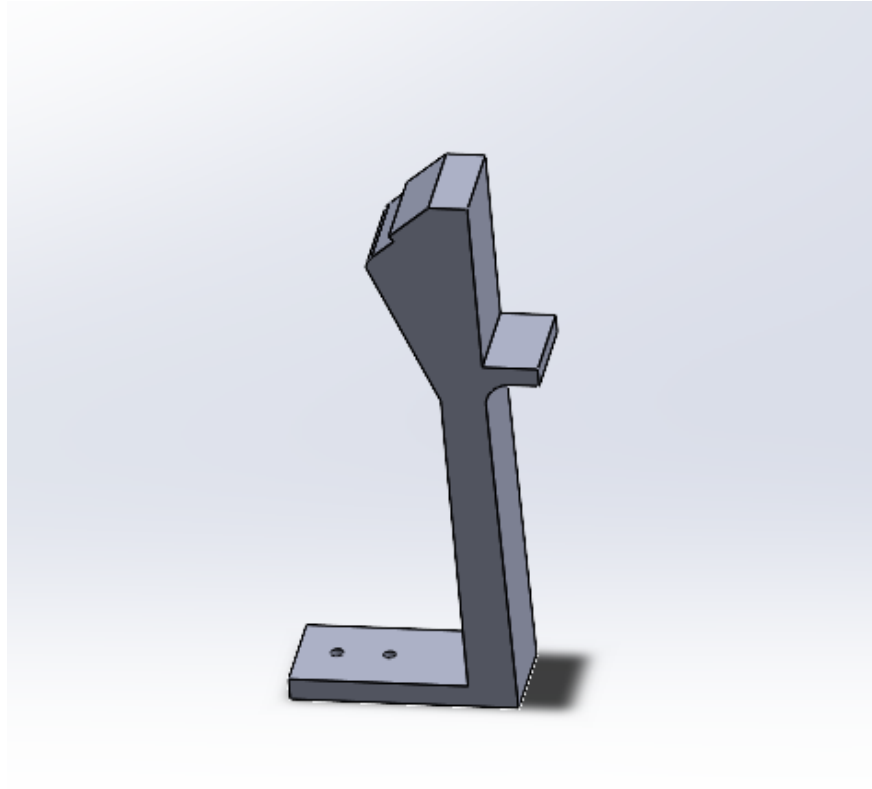


Figure H.27: CAD Model of the Tree Fixture (Concept 19)

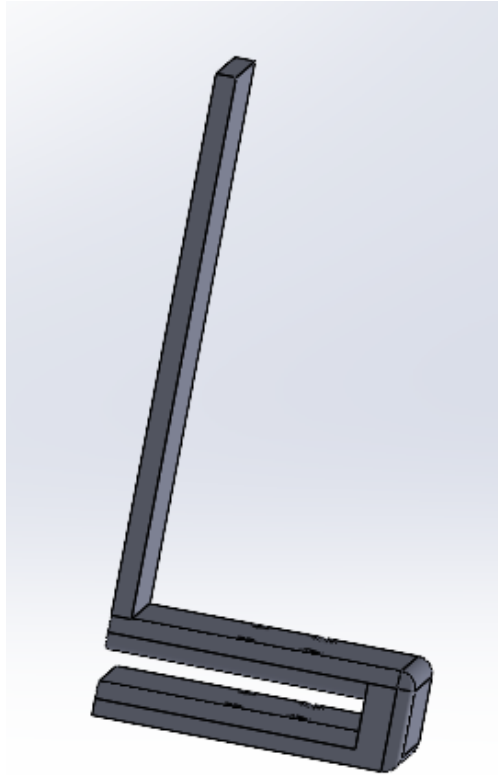


Figure H.28: CAD Model of the Plate System Fixture (Concept 19)

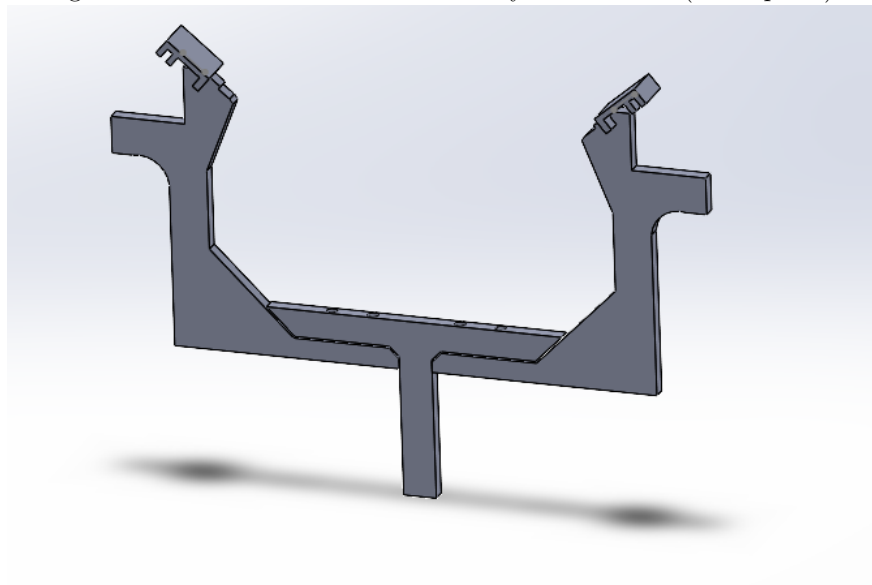


Figure H.29: CAD Model of Inner U-Shaped Plate Fixture (Concept 19)

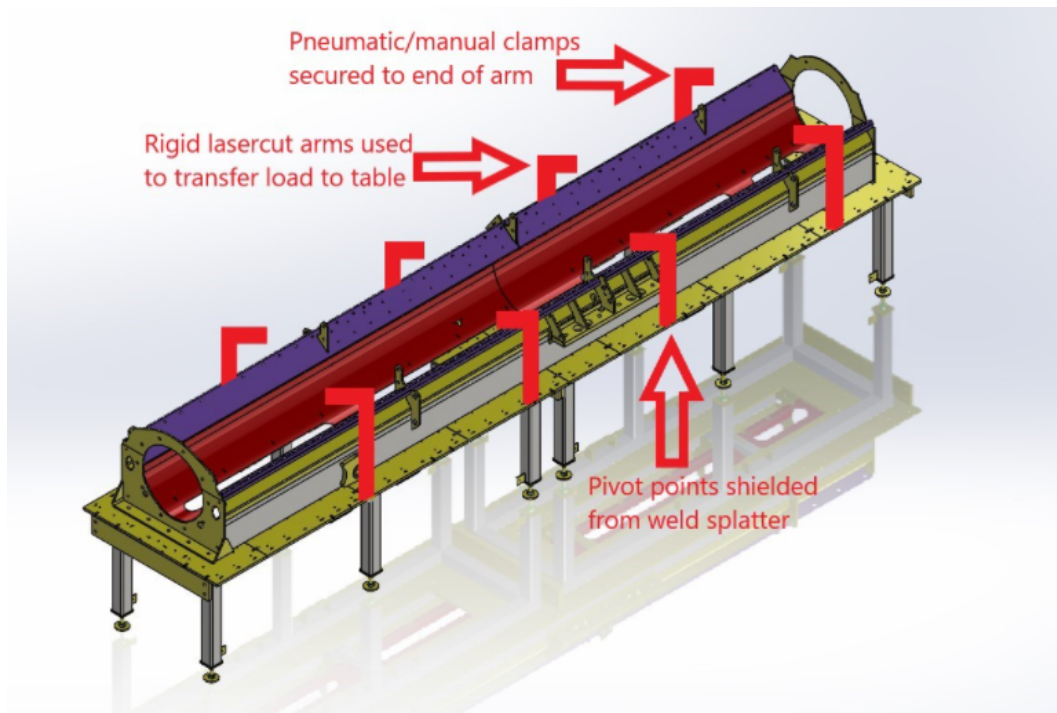


Figure H.30: CAD Model of Swivel Clamp System with Mainframe (Concept 20)

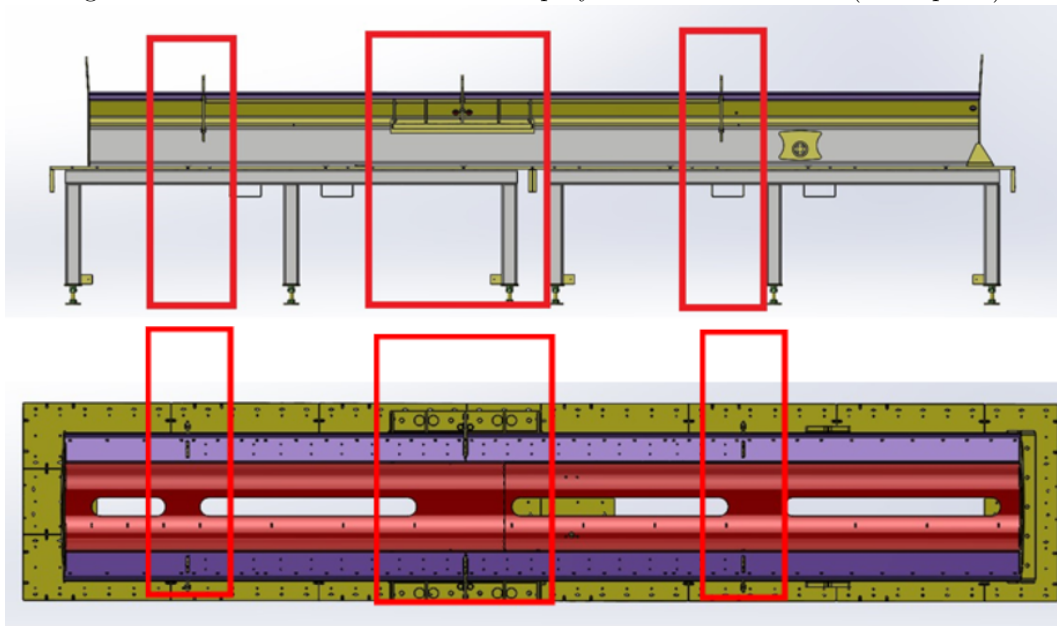


Figure H.31: CAD Model of Locations of Jack Clamps on Mainframe (Concept 21)

I - Cost Analysis Calculation

	A	B	C	D	E	F	G	H	I	J	K
1	Part	Manufacturing Technique	Number of Parts	Part Number	\$Cost per lb	Mass (lb)	Cost of Part	Clamp Used	Number of Clamps	Cost Per Clamp	Clamp Cost:
2	End-Plate-Mounts (2 Pairs)		GCMJ100					Destaco 650	2	126	252
3	I-Beam-Plate	Laser Cut	6	GCMJ101		2	8.67				
4	Clamp-Base	Laser Cut	2	GCMJ102		2	5.63				
5	Base_Right-End-plate-mounts	Laser Cut	1	GCMJ103		2	16.11				
6	Base_Left-End-plate-mounts	Laser Cut	1	GCMJ104		2	16.11				
7	V-plate_mount_supports	Laser Cut	4	GCMJ105		2	6.24				
8	V_plate_mount	Laser Cut	2	GCMJ106		2	17.61				
9	V_plate_top_mount-R	CNC Machined	1	GCMJ107		4	1.07				
10	V_plate_top_mount-L	CNC Machined	1	GCMJ108		4	1.07				
11			18		Total:	72.51	639.84				
12	Weight Scale Locators		GCMJ200								
13	Weight Scale Locators_Base	Laser Cut	2	GCMJ201		2	15.41				
14	Weight Scale Locators_I_Beams	Laser Cut	12	GCMJ202		2	4.96				
15	Weight Scale Locator_Top	CNC Machined	2	GCMJ203		4	1.74				
16			16		Total:	22.11	194.6				
17											
18	Purple Clamp Jig (2 Pairs)		GCMJ300					Destaco 650	2	126	252
19	L-Base	Laser Cut	1	GCMJ301		2	7.44				
20	R-Base	Laser Cut	1	GCMJ302		2	7.44				
21	I-Beam-plate	Laser Cut	6	GCMJ303		2	1.83				
22	Clamp_base	Laser Cut	2	GCMJ304		2	1.72				
23	L-Purple Part Jig Locator	Laser Cut	1	GCMJ305		2	0.22				
24	R-Purple Part Jig Locator	Laser Cut	1	GCMJ306		2	0.22				
25			12		Total:	18.87	118.96				
26	Peg Hitch Bottom Plate		GCMJ400		Total			Destaco 620	2	137	274
27	L-Base	Laser Cut	1	GCMJ401		2	9.08				
28	R-Base	Laser Cut	1	GCMJ402		2	9.08				
29	Peg Middle Plate	Laser Cut	2	GCMJ403		2	4.41				
30	Peg End Plate	Laser Cut	4	GCMJ404		2	5.21				
31	Clamp Plate	Laser Cut	2	GCMJ405		2	0.72				
32	Peg Hitch Plate	CNC Machined	2	GCMJ406		4	13.05				
33			12		Total:	41.55	202.92				

Figure I.1 Cost Analysis 1

	A	B	C	D	E	F	G
34	Computer Part Jig			GCMJ500			
35	Computer Part Base	Laser Cut	1	GCMJ501	2	2.28	4.56
36	Computer Part Bracket	Laser Cut	2	GCMJ502	2	2.3	9.2
37	Computer Part Spacer	Laser Cut	1	GCMJ503	2	0.98	1.96
38	Computer Part Rib	Laser Cut	1	GCMJ504	2	0.88	1.76
39			5		Total:	6.44	17.48
40	Middle Bunny Ear			GCMJ600			
41	Base	Laser Cut	2	GCMJ601	2	17.79	71.16
42	BigPlate	Laser Cut	2	GCMJ602	2	20.6	82.4
43	SmallPlate	Laser Cut	2	GCMJ603	2	9.37	37.48
44							
45							
46			6		Total:	47.76	191.04
47	Side Bunny Ear (2 Pairs)			GCMJ700			
48	Base	Laser Cut	2	GCMJ701	2	17.79	71.16
49	BigPlate	Laser Cut	2	GCMJ702	2	21.28	85.12
50	SmallPlate	Laser Cut	2	GCMJ703	2	3.55	14.2
51							
52							
53			6		Total:	42.62	340.96
54	Semi Plate Jig			GCMJ800			
55	Base	Laser Cut	4	GCMJ801	2	67.38	539.04
56	Plate	Laser Cut	4	GCMJ802	2	90.65	725.2
57			8		Total:	158.03	1264.24
58							
59	HSS and Z Plate Jig			GCMJ900			
60	Base	Laser Cut	2	GCMJ901	2	94.47	377.88
61	BendingPlate	Laser Cut	2	GCMJ902	2	23	92
62	Rotisserie Support	NA	1	GCMJ903	*Stocked in house		
63	Rotisserie Holder	NA	2	GCMJ904	*Stocked in house		
64	Cart Wheel	NA	8	GCMJ905	*Stocked in house		
65			15		Total:	117.47	469.88

Figure I.2 Cost Analysis 2

	A	B	C	D	E	F	G	H	I
66	Bunny Ear Bushing Jig							GCMJ000	
67	Base	Laser Cut	3	GCMJ001	2	5.71	34.26		
68									
69									
70	Top Gauge Jig			GCMJ111					
71	Top Gauge	Laser Cut	1	GCMJ112	2	24.42	48.84		
72	Rib 1	Laser Cut	2	GCMJ113	2	3.58	14.32		
73	Rib 2	Laser Cut	1	GCMJ114	2	8.06	16.12		
74			4		Total:	36.06	79.28		
75									
76	TOTAL COST (\$):		4331.46	* This is not accounting for manual labor cost of internal processes at Elmer's Manufacturing					

Figure I.3 Cost Analysis 3

J - Bill of Materials

In the manufacturing industry, any design that needs to be fabricated is required to have a BOM. The BOM provides various information of the product such as material used, sub-assemblies, parts, manufacturing process and tolerances. The BOM helps the engineer and manufacturer communicate the procedure to prototype the final product properly. There are three typical BOM that are used in manufacturing, which includes single-level BOM, indented BOM and modular BOM.

In this section, the single-level BOM of two main assemblies are investigated which include: Large Mainframe Assembly, Parts 14,15 and 35 sub-assembly.

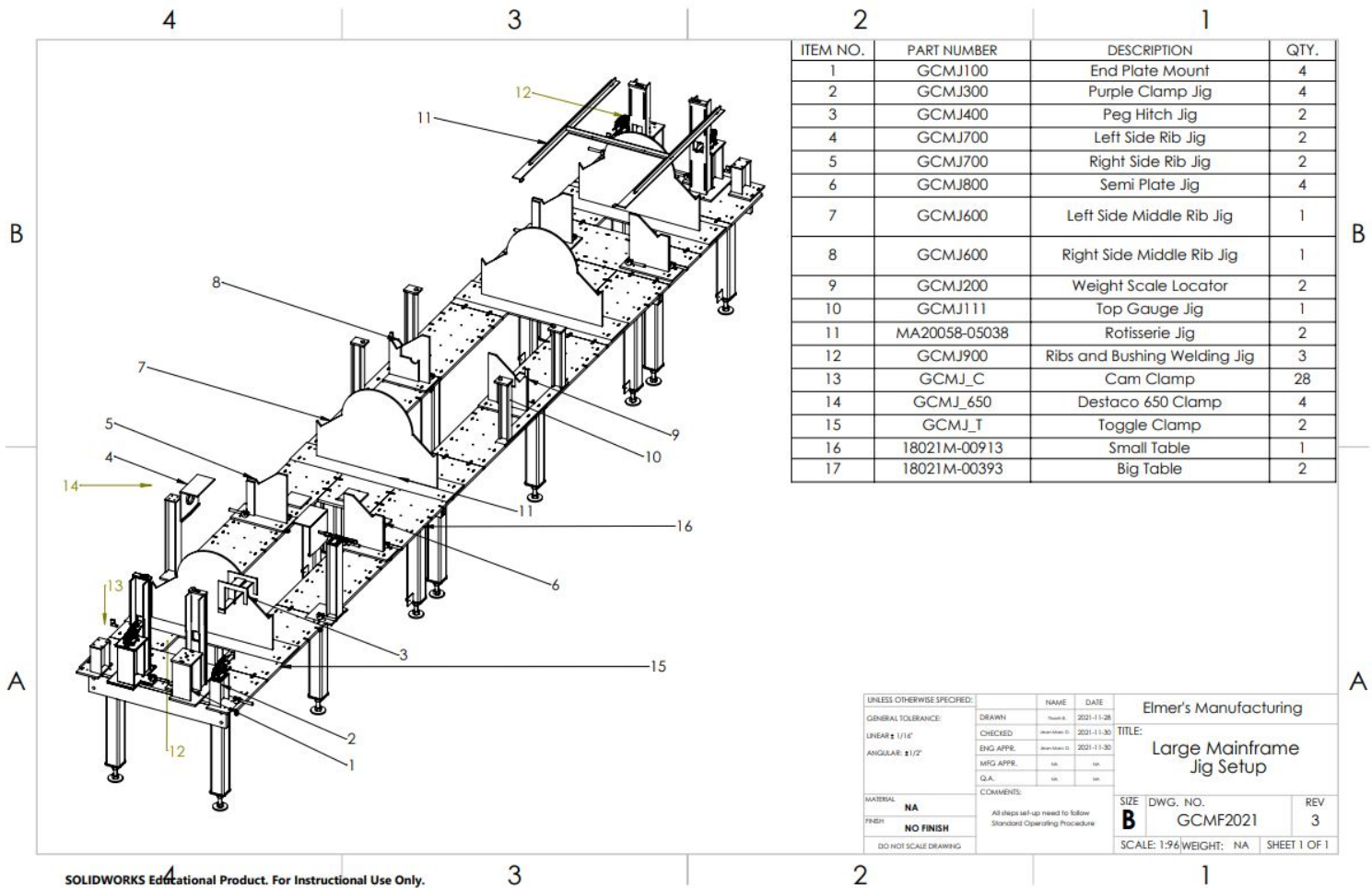


Figure J.1 GCMJ2021- Large Mainframe Setup

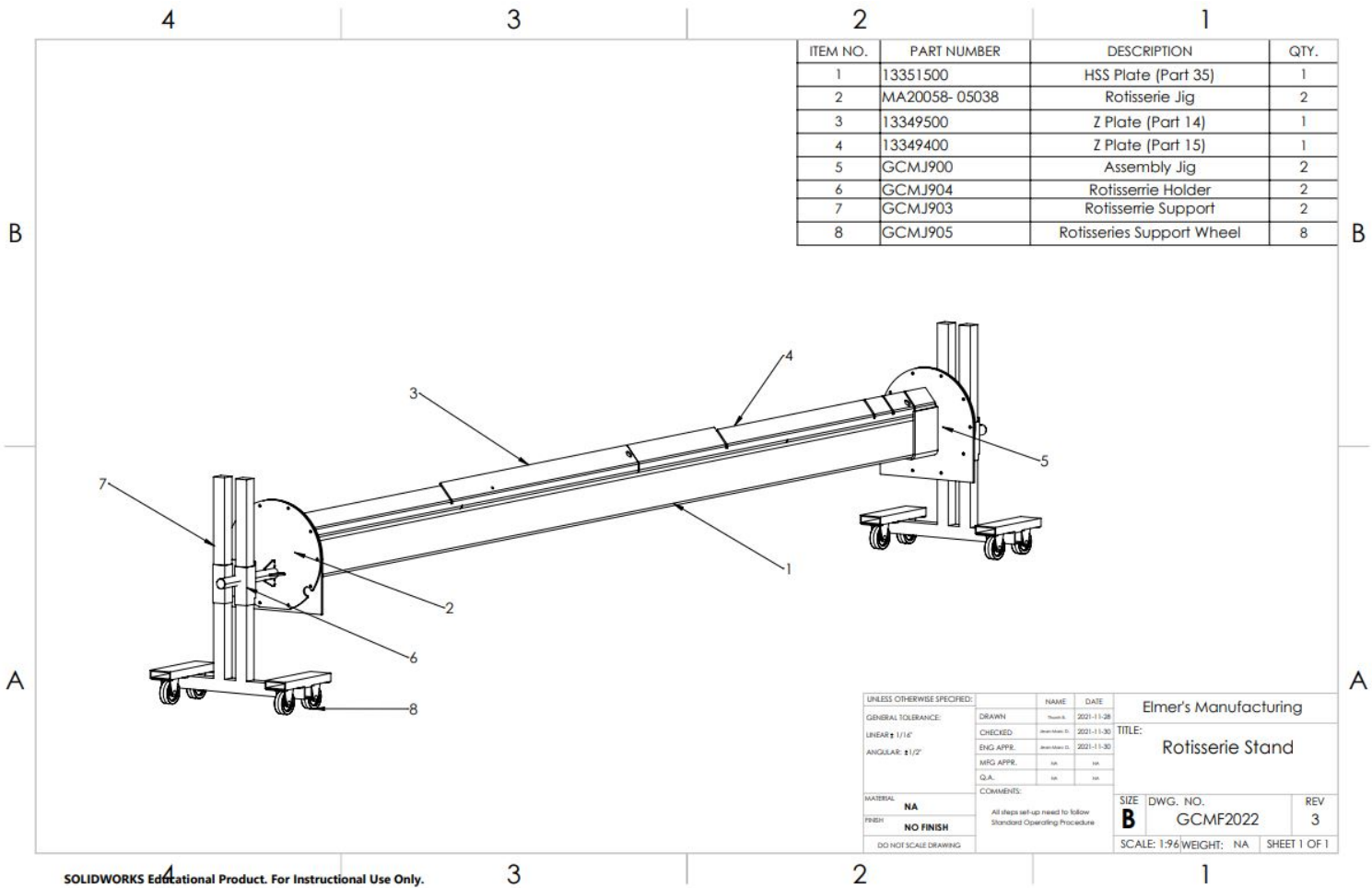


Figure J.2 GCMJ2022- Rotisserie Stand

As shown in the Figure J.1, all the items with descriptions that need to be manufactured for the final design are listed in the BOM table. There are a total of 18 parts that are essential to be lined up as shown in the figure.

Similarly, Figure J.2 also reveals information of needed parts for the sub-assembly of parts 14, 15 and 35. This sub-assembly consists of eight components.

K - Engineering Drawings

Along with the BOM of the final design, the engineering drawing provides additional details for the dimensioning of each component. An adequate drawing document needs to show the component title name, material used, finishing, drawing name or number, and notes if applicable. Different orientations of a component can be viewed in isotropic, front/back, top/bottom and side perspectives. The designer who creates these drawing images need to be competent and familiar with drawing standards in order to outline pertinent features of the design to the manufacturer. This section depicts engineering drawings which are used to accurately portray the designs measurements as well as show its manufacturability.

These drawings are a guide to the manufacturers to accurately and precision manufacture each of the jigs.

Here are the listings of all design components for the final assembly of the jig system. Respectively, those are the End Plate Jig (GCMJ100), the Top Gauge Jig (GCMJ111), the Weight Scale Jig (GCMJ200), the Purple Clamp Jig (GCMJ300), the Peg Hitch Jig (GCMJ400), the Computer Part Jig (GCMJ500), the Middle Rib Jig (GMCJ600), the Side Rib Jigs (GMCJ700), the Semi Plates Jig (GMCJ800), and the Parts 14,15 and 35 Assembly Jig (GCMJ900).

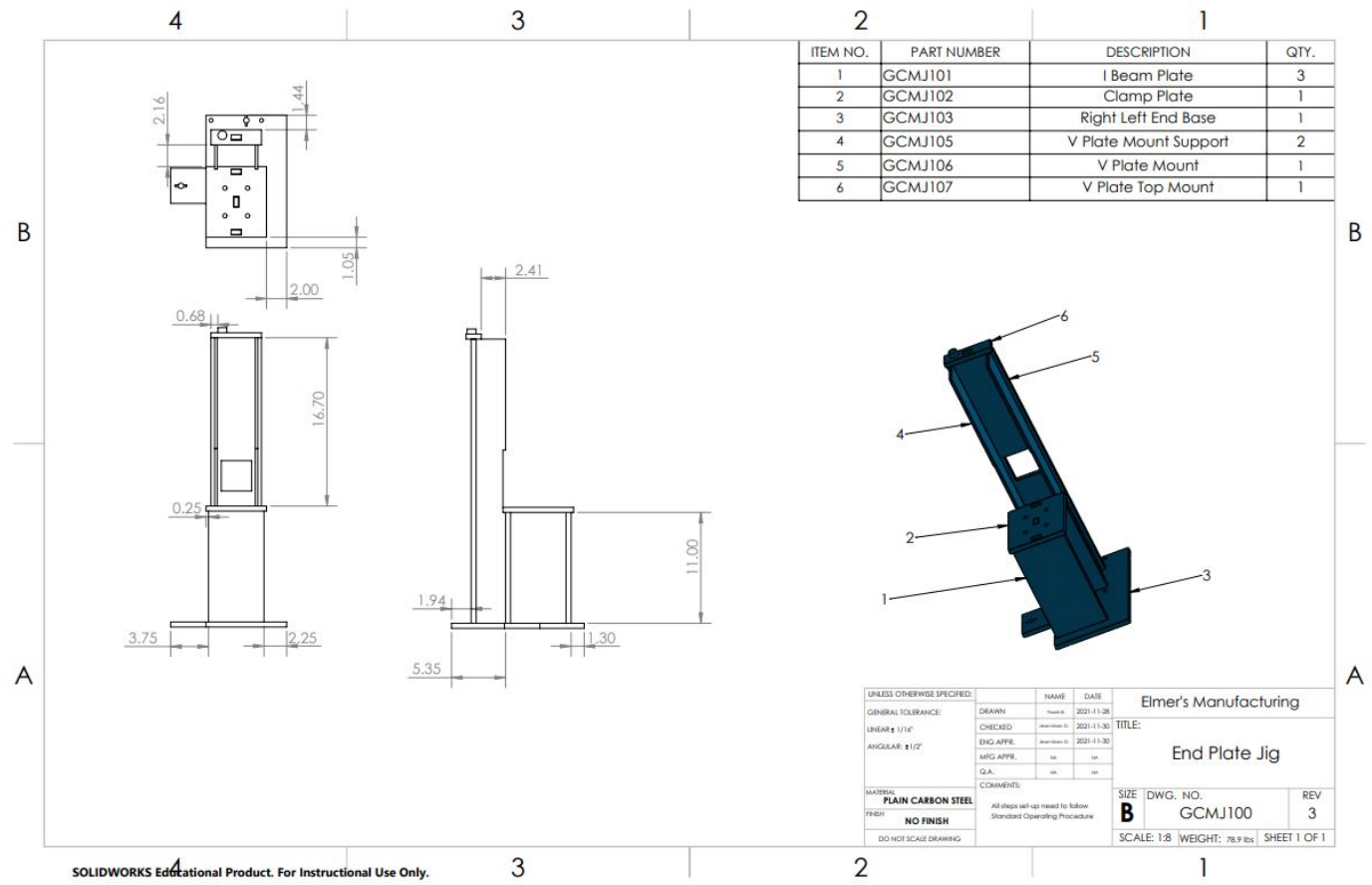


Figure K.1: GCMJ100 - End Plate Jig

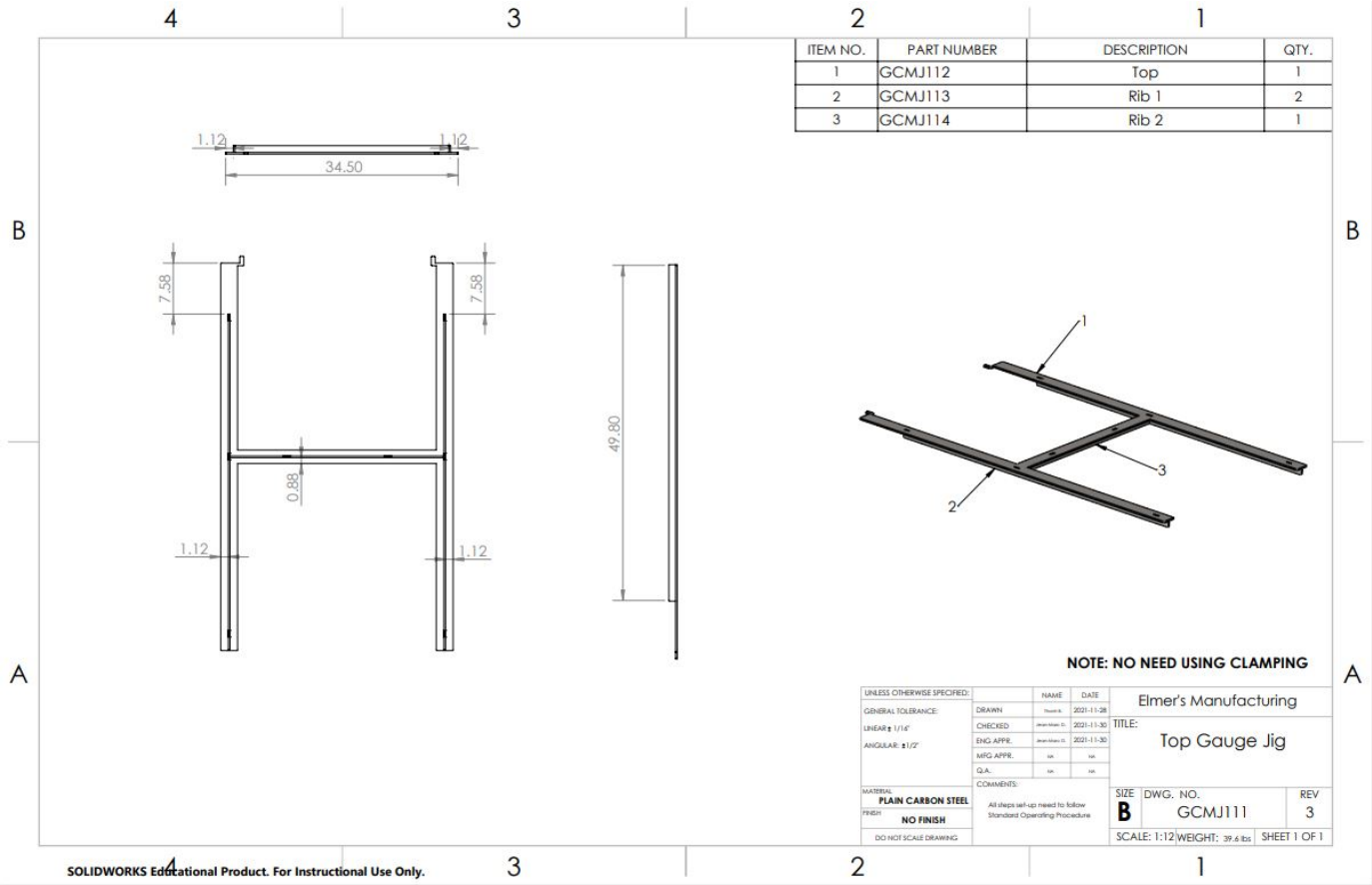


Figure K.2: GCMJ111 - Top Gauge Jig

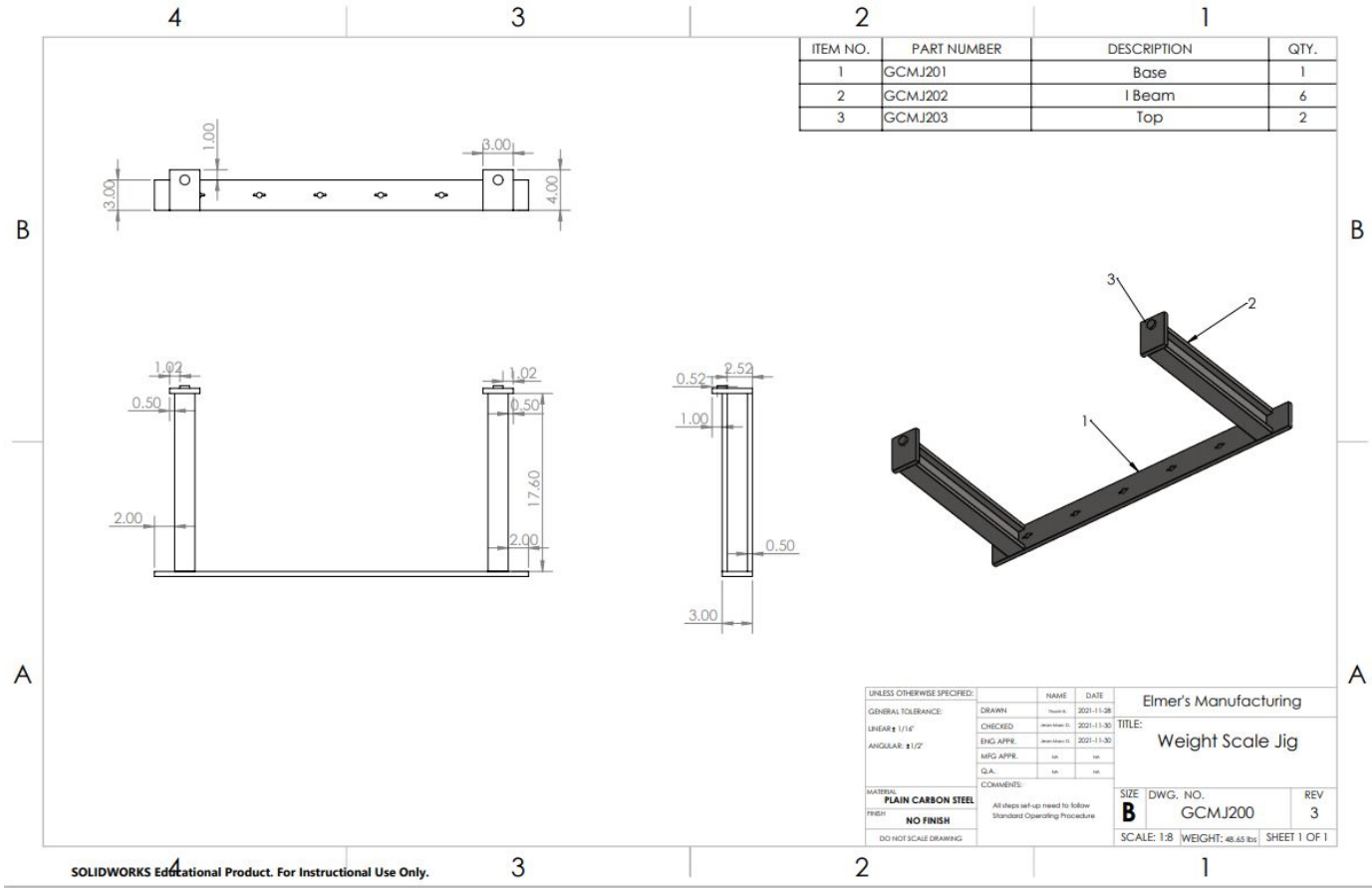


Figure K.3: GCMJ200 - Weight Scale Jig

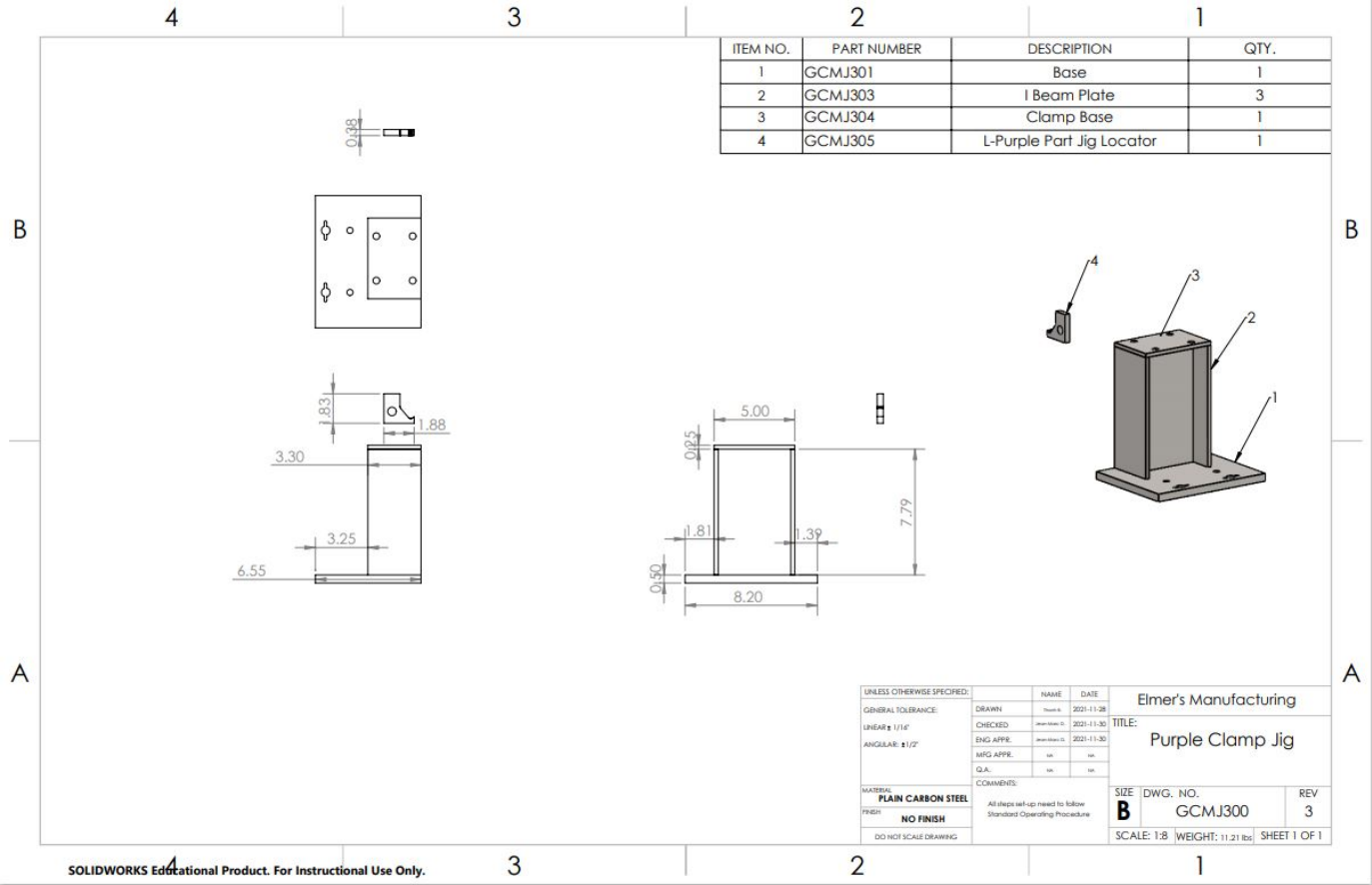


Figure K.4: GCMJ300 - Purple Clamp Jig

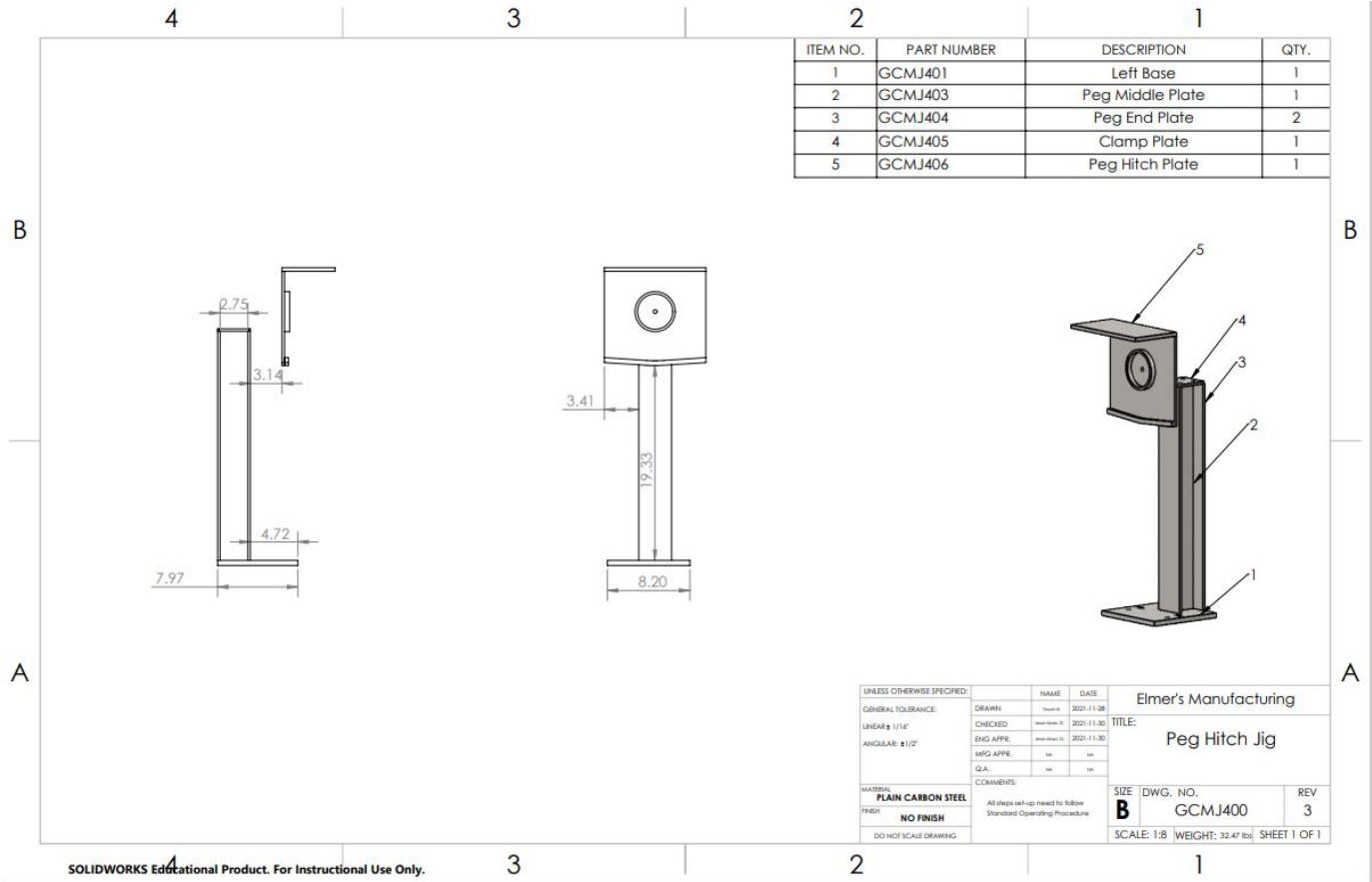


Figure K.5: GCMJ400 - Peg Hitch Jig

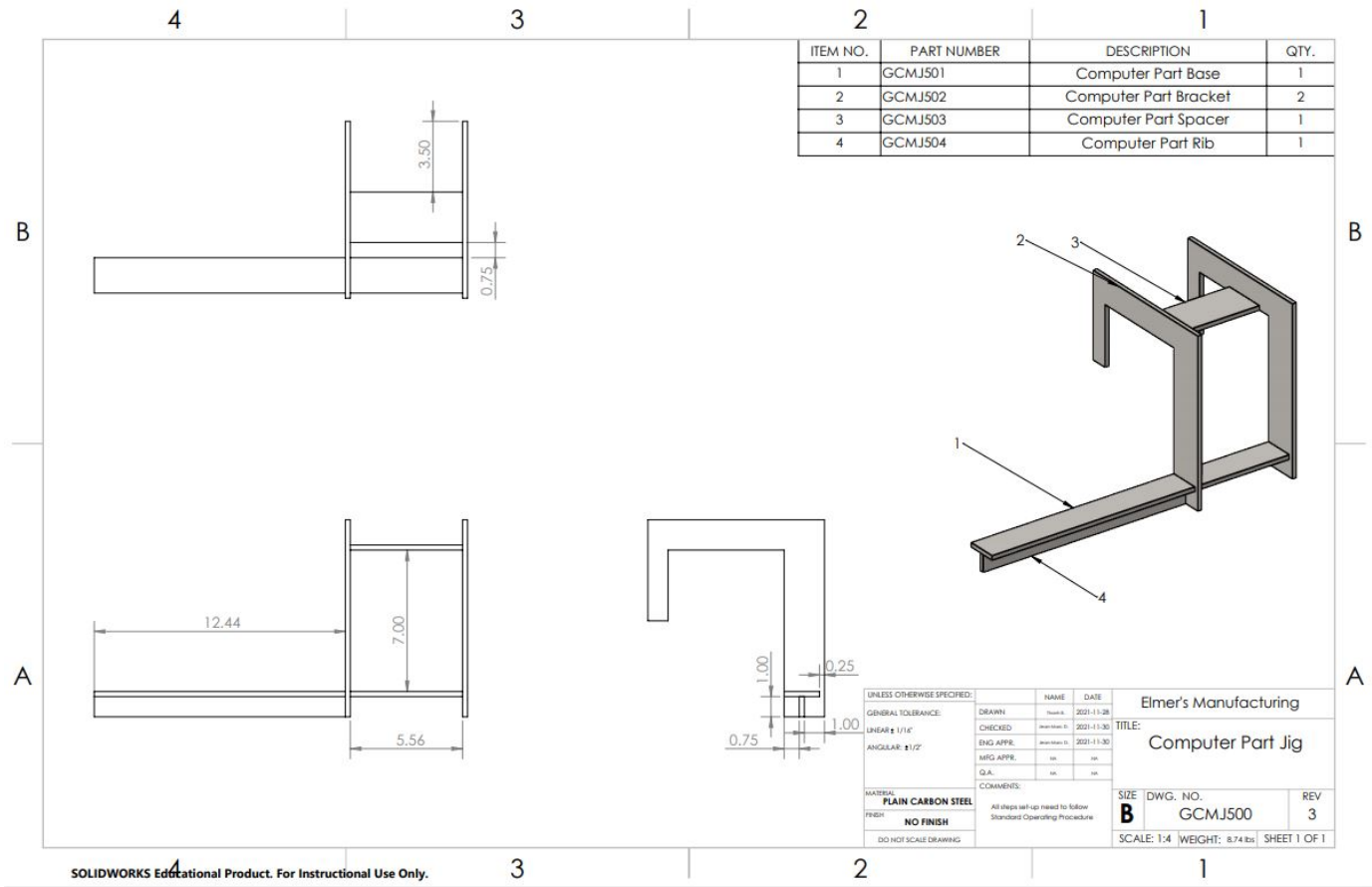


Figure K.6: GCMJ500 - Computer Part Jig

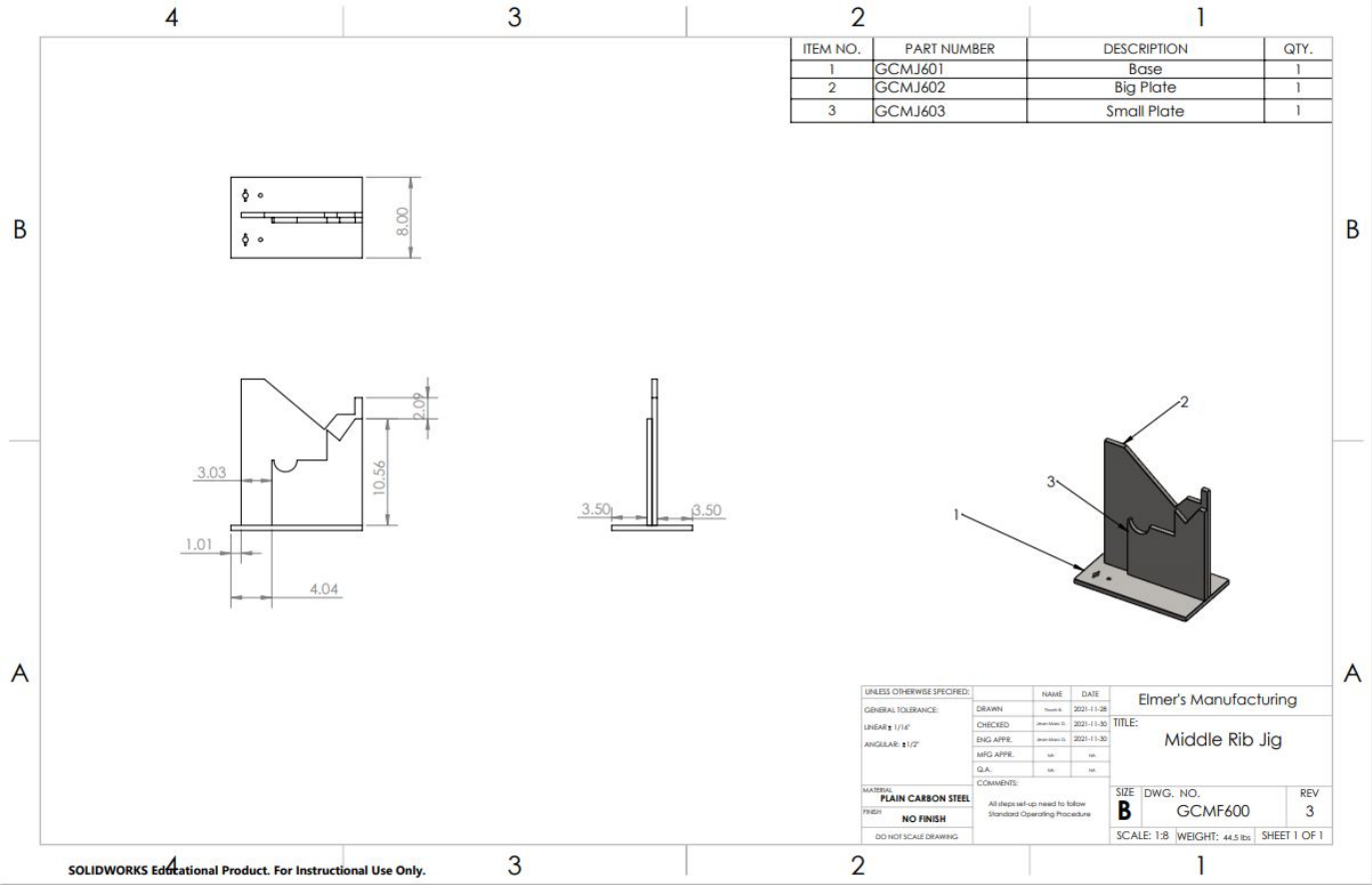


Figure K.7: GCMJ600- Middle Rib Jig

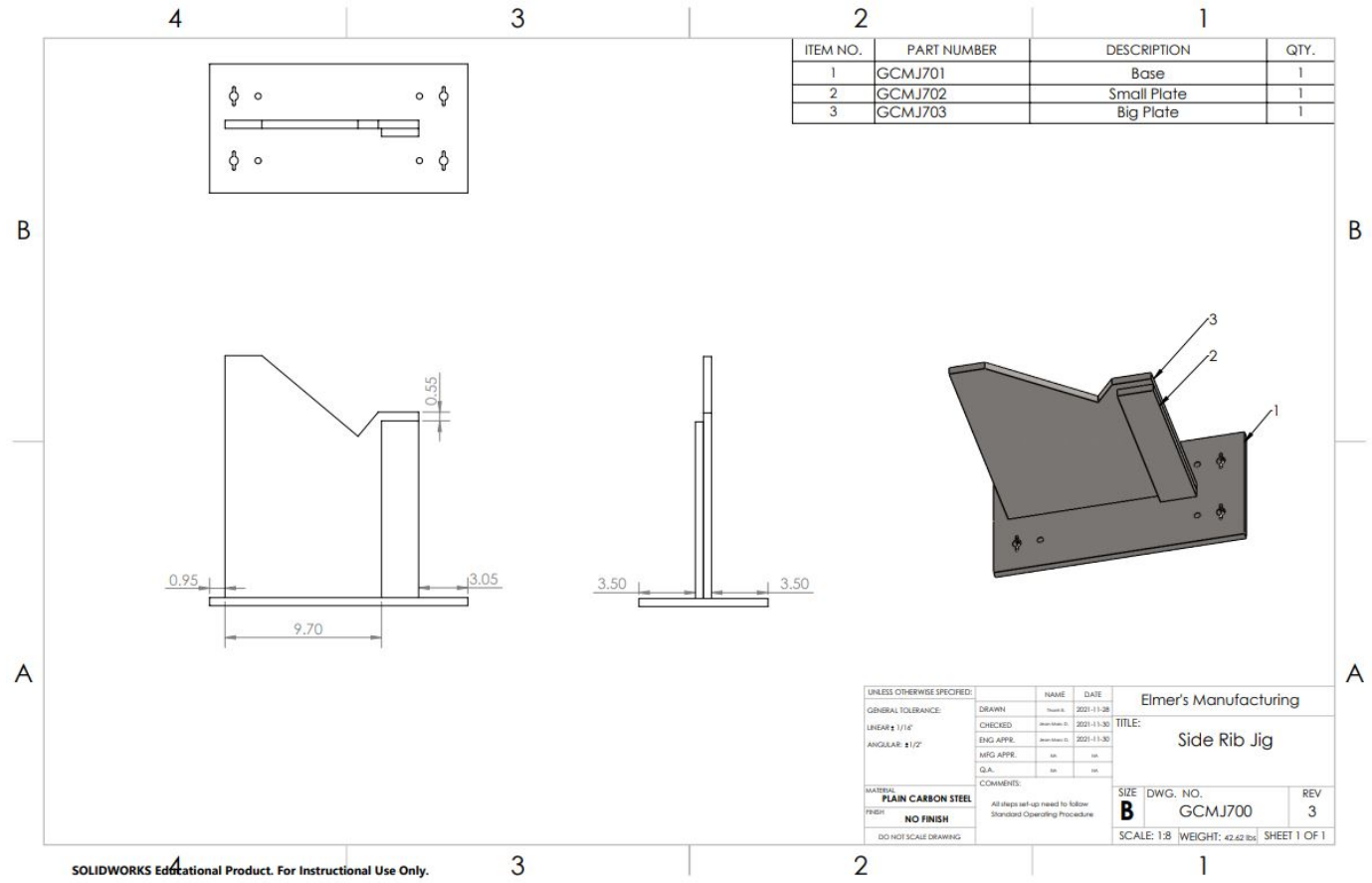


Figure K.8: GCMJ700- Side Rib Jig

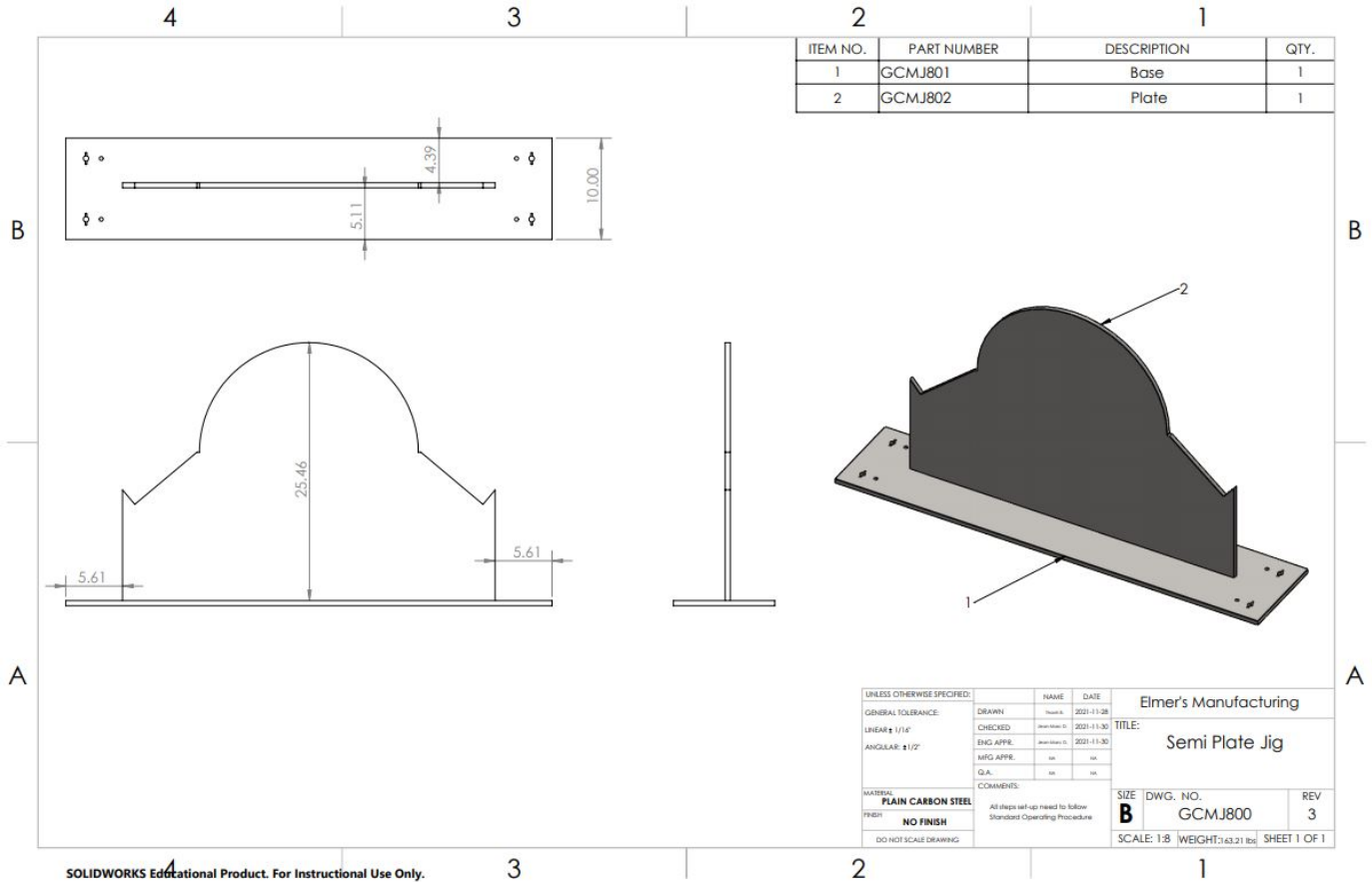


Figure K.9: GCMJ800- Semi Plate Jig

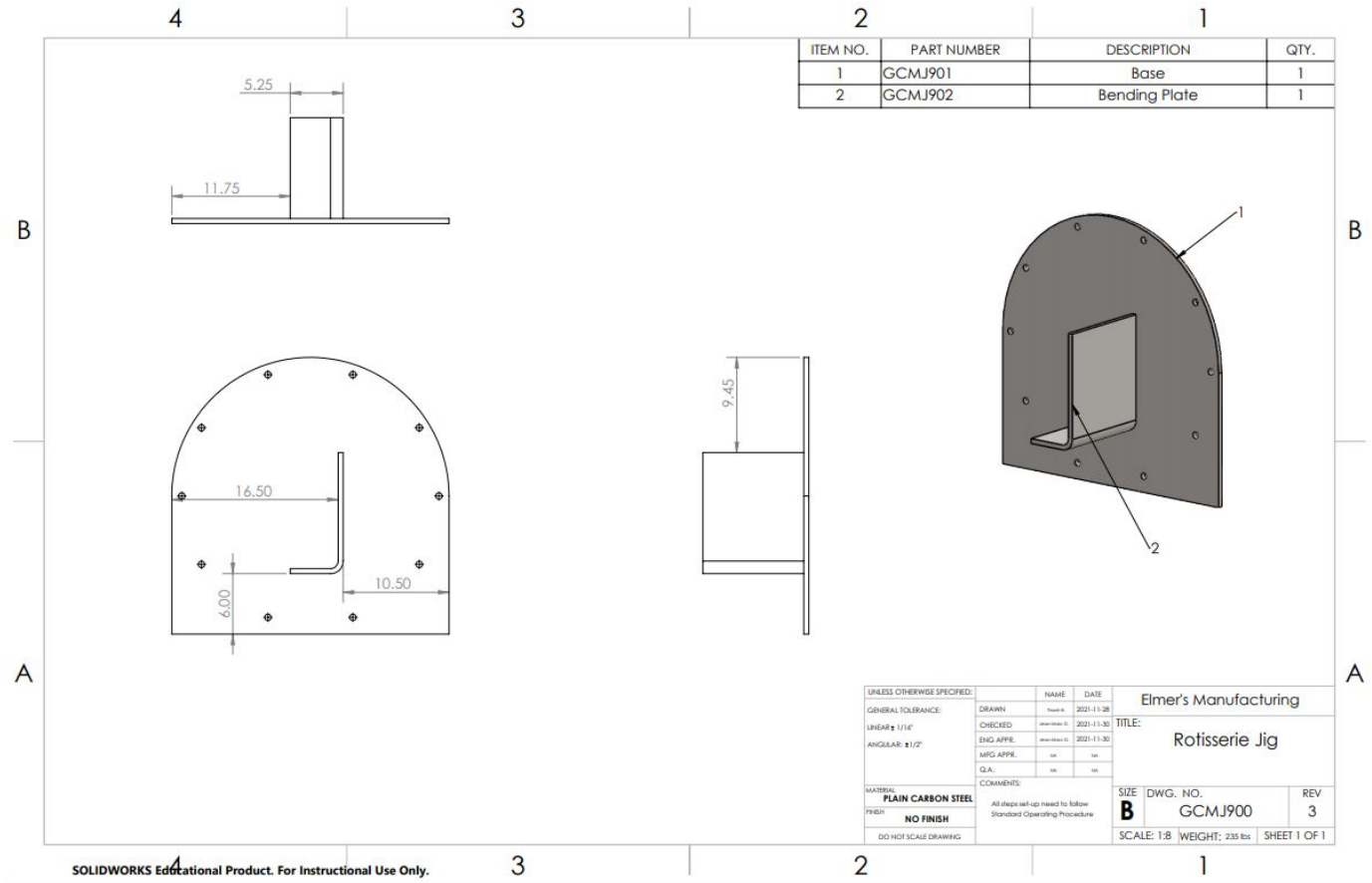


Figure K.10: GCMJ900- Rotisserie Jig