SunTrac Design Team

Final Proposal

Kadeja Alhossaini

Nathan Firor

Edwin Smith

Ethan Vieane

2019-2020

Project Sponsor: SunTrac USA

Sponsor Mentor: Stu Siebens

Instructor: Sarah Oman

DISCLAIMER

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EXECUTIVE SUMMARY

The purpose of this project is to create a braze welding jig for a company called SunTrac USA which is located in Tempe, Arizona. SunTrac manufactures radiant solar panels that when coupled with variable speed or two speed Air Conditioning systems reduces the energy consumption of the AC system by up to 45 %. The most important component of these solar panels is a copper manifold that must be brazed on both ends and comes in three different sizes, 4 feet, 6 feet, and 8 feet. SunTrac has two jigs in their possession, one for the 6 feet manifold, and the other for the 8 feet, however they would like to have one jig that fits all three sizes. Our capstone team has been tasked to create a design for SunTrac that fits the company's requirements.

To come up with an appropriate design, the team went through a vigorous selection process to make sure the appropriate design is selected. First the team came up with customer requirements (CRs) after speaking with the director of engineering at SunTrac. The most important customer needs are for the jig to be safe to operate, the cost of manufacturing the jig should be within the budget, and it should fit all three sizes of manifolds. Second, engineering requirements (ERs) were created to analyze the customer requirements quantitatively. Both the CRs and ERs were placed in a House of Quality (QFD) and analyzed to know which ER has the most technical importance. Moreover, the team came up with a black box model that developed into a functional decomposition model which details the different functions the design must be able to accomplish. The third step in this process is the team began brainstorming ideas using the Gallery Method. The ideas that worked best together were grouped in a design and put into a pugh chart and a decision matrix where they were weighted against each other. The best design was chosen through this process.

The best design was similar to SunTrac's 8 foot jig but had some major adjustments. It was similar because the jig that holds the pipes in place has a skeleton design and not a solid plate which allow easy access to the welding joints. One major adjustment was that the bars of the jig can elongate on both ends to account for three different sizes of manifolds. Another adjustment is a foot pedal that locks the rotation of the jig. When the foot pedal is pressed, it will release the teeth of the gear which in turn rotates the jig. Finally, the design also provides a stationary place that locks four brass brackets in place which will be welded on either side of the manifold.

To adopt the best design as the final design, some tests and analysis must be conducted. Initially, the final design must adhere to the standards of the industry since SunTrac will be using the jig in their company. Testing procedures will be implemented on the design to ensure these standards are valid and to ensure the ERs have been met. Five testing procedures will be discussed in detail that will be used to accomplish this goal. Moreover, a risk analysis will be implemented on the design. There are two parts to this analysis, the first will analyze the potential critical failures that will occur in the design and the second will deal with the trade-off analysis of the design.

After conducting the prior analysis, the results were considered in finalizing the design. The final design is similar to the best design however, it minimizes the amount of tubes used for the skeleton of the jig from five to three. It also uses a larger gear diameter for the locking mechanism. Moreover, the jig will be at an offset of a 10 degree angle to make sure it stands upright before it is bolted to the ground. Finally, specific calculations of the weight, thermal expansion, and gear force analysis were conducted to make sure the final design is safe and durable.

TABLE OF CONTENTS

1 BACKGROUND

1.1 Introduction

This capstone project consists of redesigning the braze welding jig that is currently in use at SunTrac USA. The objective of this project is to design a new braze welding jig that is compatible with SunTrac's 8', 6', and 4' product variants. This project is important to SunTrac because they are projected to grow exponentially in the next three years and need to be ready for the increase in demand for their products. This product solves issues relating to lean manufacturing and ensures that SunTrac is using floor space efficiently and reducing the time in which machinery is idle.

1.2 Project Description

Following is the original project description provided by the sponsor:

> The director of engineering for SunTrac USA (please see www.suntracusa.com) would like a capstone team to create a system to help with manufacturing. We manufacture a radiant solar panel that when coupled with variable speed or two speed Air Conditioning systems reduces the energy consumption of the AC system by up to 45 %.
>
> One of the key components of our system is a series of (6) 5/8" diameter copper tubes that must be brazed at both ends into a 1-1/8" copper tube. We call this a "copper manifold" and we make it in three different lengths (4 ft, 6 ft, and 8 ft).
>
> What I would like your team to do is design and build a brazing jig that would give us the flexibility to do any of the three lengths on the same jig. The function of the jig is to hold all the copper pipes in place while they are brazed together. SunTrac would provide all the materials at no cost to the students. What we would like is for your team to design the jig and draw up the parts needed to assemble the fixture. We would have the parts made to their drawings and they could assemble the finished product. We would like to extend an invitation to the team that will be working on this project to visit our facility in Tempe AZ. Seeing how we do things now would be a good start for the team to get the wheels turning[1].

2 REQUIREMENTS

The requirements that were set by SunTrac USA are listed in the customer needs and their resulting engineering requirements. These data sets are then further analyzed in a House of Quality to determine correlations in the data as well as ranking the engineering requirements. The highest priority customer requirements are safety, cost, and the ability for the welding jig to be compatible with all three product variants. This section expand further to the data listed above and provide data to support the decisions made in the design selection.

2.1 Customer Requirements (CRs)

The customer needs are listed below with their associated weights.

1.	Safe to Operate	5
2.	Cost within budget	5
3.	Can fit a 4’, 6’, and 8’ copper manifold	5
4.	Machinable parts	4
5.	Fit within a 5’x5’ square	3
6.	Allow easy access to all copper joints	4
7.	Jig can rotate and lock at various angles	3
8.	Durable and Robust design	4
9.	Reliable design	4

The weighting system used for the customer needs included a one to five ranking with five being the most important need for the client. The customer needs and weights were given to us from Suntrac directly. The first customer need is for the system to be safe to operate. This was given a high weight because safety is a priority that is stressed at SunTrac. The second customer need is for the system to be within budget. This was given a weight of five because Suntrac desires this to be a cheap and easily repeatable design. The third customer need is for the braze welding jig to be compatible with SunTracs 4’, 6’, and 8’ product variants. This was given a weight of five because Suntrac wants this system to employ lean manufacturing principles and have multiple functions within the manufacturing facility.

The next set of customer needs were given a ranking of four given their high importance but lower priority than the other needs. These needs include that the system is made with standard parts to keep costs down. Suntrac also desires a braze welding configuration that allows easy access to all copper joints. This customer need specifies that the jig should allow access to the copper joints even from behind the jig. The last two customer needs that are given a weight of four are that the braze welding jig has a durable and robust design while also being reliable. This customer needs details how the jig should be strong enough to complete its designed task and continue to function optimally for many years into the future.

The last set of customer needs are given a weighting of three because they are still important but have the smallest priority. The first customer need in this category is that it fits within a 5’x5’ square footprint. SunTrac specified that they prefer this customer need to be met but will accept designs with a larger footprints if all other needs are met. The last customer need is for the jig to be able to lock in many different configurations. This need was given a weight of three because the braze welding jig is still as functional as the original design as long as two locking positions are permitted.

2.2 *Engineering Requirements (ERs)*

The engineering requirements are listed below along with their target values.

1.	Melting Temperature (degrees Celsius)	1400 ± 300
2.	Force to Rotate (Newtons)	13 ± 3
3.	Cost (dollars)	1500 ± 300
4.	Versatile (number of compatible product variations)	3 ± 0
5.	Standardized Parts (dollars)	1500 ± 300
6.	Footprint (feet^2)	25 ± 5
7.	Degree of Rotation (Radians)	2pi ± 0
8.	Adaptable (Number of locking positions)	8 ± 2
9.	Durable (Years before repair)	20 ± 5
10.	Error (Difference in desired length) (in)	1/16" ± 1/32"

The first engineering requirement is melting temperature. The jig must have a high melting temperature so the braze welding process does not change the physical properties of the jig and therefore increase the error regarding the tolerances. Most mild steels with a melting temperature around 1400C or higher should suffice for this project. The second engineering requirement is for the force to rotate the subassembly to be within a range for ideal safety circumstances. A force approximately 13 ± 3 newtons is ideal because most people can exert that much force without struggle and it won't cause the jig to rotate at an unsafe speed. The third engineering requirement is the cost which has a target value of $1500 ± $300 as per SunTrac's specifications. The fourth requirement is to increase versatility by allowing all three product variations to be compatible with this jig. The requirement is derived directly from the clients needs. The fifth requirement is closely related to costs in that the jig be made of standard parts to keep costs low. Again this requirement states the total cost of the jig be around $1500 with a tolerance of ± $300.

Engineering requirement six states the footprint of the final braze welding jig be 25sqft ± 5sqft. This is not a critical engineering requirement but more so a guideline for the team to follow. Ideally the jig must fit within those dimensions but SunTrac stated that those dimensions could be larger if all customer needs are met. The seventh requirement is to allow a full 360 degree angle of rotation. This requirement quantifies the need for all copper joints to be easily accessible. The eighth engineering requirement detailed that a desirable number of locking positions would be eight or more. Additional locking positions allows the welder at SunTrac to lock the jig at their desired position to maximize production. The ninth requirement is that the jig lasts 20 years with minimal repairs or alterations. This requirement was derived directly from SunTrac's specifications. The last requirement is that the jig can hold each manifold to a tolerance of 1/16" ± 1/32". This requirement ensure all manifolds are consistent and repeatable.

2.3 Functional Decomposition

The process of creating the functional decomposition began during the in-person visit to SunTrac's manufacturing facility. During the visit, the director of engineering at SunTrac gave the team a tour of the facility and detailed the braze welding process within the scope of this capstone project. One of the results of this meeting was the knowledge to create the first draft of the hypothesized functional model for the new braze welding jig. SunTrac explained that the final result of this project must be able to support eight copper pipes and four brass standoffs in the correct orientations while maintaining tolerances during the braze welding process. After minor revisions the final material flows for this process are the components and human for inputs and the completed manifold and human for outputs. The final energy flows for this system include human and thermal input energies while just thermal energy remaining as an output. The signals used in this design include olfactory, visual, and auditory as both input and output flows. These signals are shown in the final functional model as sensory checks to ensure the braze welding process is being done correctly. The main edit from the hypothesized functional model to the final functional model was the subsystem of locking the rotation of the braze welding jig. Due to the simple design there were few locations in the functional model where edits were required.

Notable subsystems that are listed in the final functional include adjust/ lock orientation, import components, position components, secure components, and join components. The scope of this project as detailed from SunTrac is to create a jig that has the capability of changing orientation while also securing all components in place. The other subsystems that detail the process of building a copper manifold fall outside the scope of this project. Due to the large quantity of parts and small degree of tolerance, many different components must be employed to satisfy the one subsystem of Secure Components as seen in the final CAD drawing.

2.3.1 Black Box Model

Figure 1. Black Box Model

Figure one clearly shows the black box model for the teams final functional model. Notable features of this figure include that components enter the material flow and completed manifold exit the material flow. This figure is important because it shows the main objective of this project. The black box model also states that "Support Components" is the main function that needs to be accounted for when designing this project. This model helps the team clarify our project by neglecting all subsystems and stating the main purpose of the teams devise. This figure also helps the team refocus our efforts on satisfying the main goal instead of focusing on every minor detail.

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

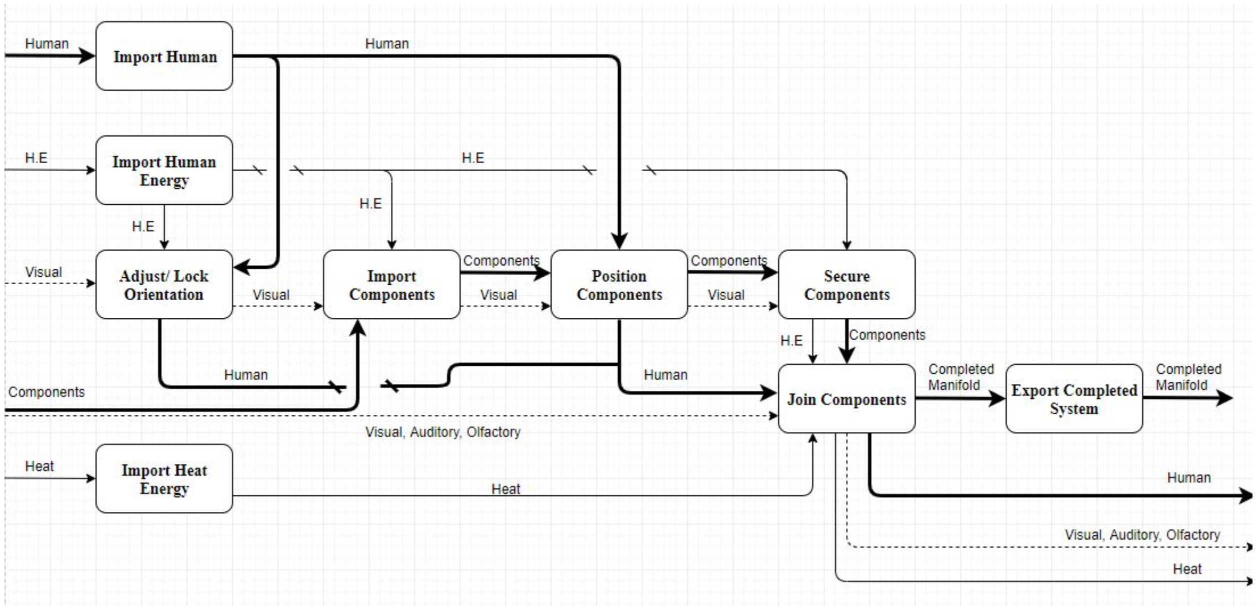

Figure 2. Functional Model Diagram

Figure two displays the teams final functional model for SunTrac's braze welding jig. Edits that were made between the hypothetical and final function models include adding a subsystem of "Lock Jig Orientation" and propagating the "human" material flow throughout the entire model. This model helps visualize the project by detailing every subsystem that our team must articulate into the design. Whereas the black box model states the main function of the design, the final functional model details how that main function is achieved. This figure is important because it ensures every subfunction is accounted for in the design and the scope of the project is fully defined. The design selected closely relates to the final functional model with slight variations to the methods in which subsystems are accomplished that are better expressed in the final CAD package.

2.4 House of Quality (HoQ)

The House of Quality detailed the correlation between the customer needs that were provided from SunTrac USA and the team derived engineering requirements. The completed House of Quality as well as the approvals are listed in appendix A. The House of Quality helps in the design process by determining correlations between the engineering requirements, customer needs, and their associated weights. This helped the team by ensuring that all the customer needs that SunTrac specified were satisfied and quantifiable with related engineering requirements. The absolute and relative technical importance also helped the team by ensuring that all design concepts met the most important engineering requirements as a minimum. The House of Quality also provided a single document that all relevant data populated following the in person meeting at SunTrac's manufacturing facility. The testing procedures listed in the following section encompass all the engineering requirements and will test whether the target engineering requirement values are satisfied.

2.5 Standards, Codes, and Regulations

An important factor to consider when assembling and building the jig is the standards, codes, and regulations. SunTrac will be using the jig to produce internationally manufactured solar panels, therefore it is vital to know these standards. There are many organizations and societies that have specific codes that our design should adhere to. These standards will factor in the decision of the material of the parts, equipment type used, and tests that will be performed on the device. For this project, the team has compiled a set of standards and codes that can be seen in table one. This table lists each code or standard and its relevance to our design creation.

Table 1: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
OSHA 1910-24 [2]	Walking-Working Surfaces- Step Bolts and Manhole steps	Helps decide what step to use if the jig is tall and the user needs assistance accessing it.
ASTM F1554-18 [3]	Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength	Helps when choosing the anchor bolts for the tripod that will be attached to the ground.
ASTM E3052-16 [4]	Standard Practice for Examination of Carbon Steel Welds Using Eddy Current Array	Helps to detect surface-breaking cracks on the joints of the jig where it is welded together.
ANSI/AGMA 1010-F14 [5]	Appearance of Gear Teeth- Terminology of Wear and Failure	This standard classifies the most common types of gear failure which will help us avoid such failures.
ANSI/AGMA 2004-C08 [6]	Gear Materials, Heat Treatment and Processing Manual	Helps choose the gear material that is appropriate with respect to the surrounding environment, weight limitations, and component geometry.
ASME Y14.5-2018 [7]	Dimensioning and Tolerancing	Helps fit the standards for dimensioning and tolerancing in drawings, models and document files.
ASTM A125-96 (2018) [8]	Standard Specification for Steel Springs, Helical, Heat-Treated	Helps choose the appropriate spring for the foot pedal that locks the jig in place.

3 Testing Procedures (TPs)

This section discusses the testing procedures that will be developed to ensure the Engineering Requirements have been satisfied. It is important to have these tests as they will determine if the device is durable and also eliminate the chance of the device breaking any standards, codes, or regulations. For the purpose of this project, the team has created five different testing procedures. First, the objectives of these tests will be discussed and also the details about how these tests will be performed. Next, details about the testing equipment used along with the means of acquiring this equipment will be analyzed. Finally, the schedule needed to perform these tests will be listed.

3.1 Testing Procedure 1: Critical Length Measurement after Centrifugal Force

This test includes measuring the critical length of the jig before and after changing the configuration of the jig and subjecting it to a large centrifugal force. This test will test will prove that the error, versatility, and degree of rotation engineering requirements are satisfied. The general schedule for this test is once the final braze welding jig is completed in March of 2020.

3.1.1 Testing Procedure 1: Objective

There are three objectives for this test. The first objective is to test whether a large centrifugal force will change the critical length of the jig. The second objective is to see if each size copper manifold will fit in the braze welding jig. The third objective is the test if the jig will rotate a full 360 degrees. This test includes taking a length measurement of the jig at the four foot configuration before changing the jig to the eight foot configuration and locking it vertically. The next step is to release the locking mechanism before spinning the jig as fast as the user can manage. Once the jig comes to a stop, the final step is to set the jig back in the four foot configuration and remeasuring the length. This test is conducted because it satisfies all the above objectives into one test. If there are no difference in lengths the Error requirement is satisfied. If all three configurations of copper manifolds fit in the jig the Versatility requirement is satisfied. Finally, if the jig rotates a full 360 degrees the Degree of Rotation requirement is met.

3.1.2 Testing Procedure 1: Resources Required

The required resources for this test include the completed full scale braze welding jig as well as the SunTrac manufacturing facility, the SunTrac team, Stu Siebens, and a tape measure. The completed jig needs to be bolted to the floor and therefore needs the manufacturing facility. The team and Stu Siebens will be there to monitor the experiment and a tape measure will be used to measure the change the critical length of the braze welding jig.

3.1.3 Testing Procedure 1: Schedule

This test will take approximately 15 minutes to conduct and record. If any additional trials are requested it will take an additional 15minutes per trial. This test will likely be run in late March 2020 when the full scale braze welding jig is assembled and installed. This test is dependant on manufacturing space and available free time of Stu Siebens and the SunTrac team and therefore may change date to fit schedules. This will fit into the second semester schedule by ensuring it is added into the gantt chart.

3.2 Testing Procedure 2: Heat Exposure Durability

This test includes measuring the resistance to deformation of the braze welding jig material at various temperatures. This test will test will prove that the melting temperature and durability engineering requirements are satisfied. The general schedule for this test is once the team has access to the braze welding jig in February of 2020.

3.2.1 Testing Procedure 2: Objective

There are two objectives for this test. The first objective is to measure the temperature of the braze welding jig in a worse case scenario. The second objective is to measure how much the metal deforms at different times in the heating process. This test includes taking multiple one inch pieces of the metal square tubes that are used in the face of the braze welding jig and place them on a hard surface. Using a brinell hardness tester the team will then measure the hardness at room temperature. After this test the team will sequentially heat up each piece of metal using an oxy-propane torch and test the hardness every 30 seconds until 300 seconds has elapsed. During this time period a temperature sensor is used to measure the temperature of each piece of metal. If the temperature does not reach the temperature that steel melts the Melting Temperature requirement is satisfied.

3.2.2 Testing Procedure 2: Resources Required

The required resources for this test include 11 one inch pieces of steel square tubing, an oxy-propane torch, brinell hardness tester, calculator, stopwatch, SunTrac team, Stu Siebens, and an available lab location. More personal may be included to this list if SunTrac employees want to watch the test take place.

3.2.3 Testing Procedure 2: Schedule

The required time to conduct this lab is approximately 20 minutes if there are no complications in the data analysis. The schedule for this test is dependant on when the needed material and lab equipment can be procured. The likely date in which this lab will take place is in February on 2020. This will fit into the second semester schedule by ensuring it is added into the gantt chart.

3.3 Testing Procedure 3: Cost of Final Design

This test includes calculating the total cost used in the construction of the braze welding jig and ensuring that standardized parts were used when at all possible. The engineering requirements that are satisfied in this test include the cost requirement and standardized parts requirement. The general schedule for this test is early February of 2020 when parts are being ordered.

3.3.1 Testing Procedure 3: Objective

There are two objectives for this test. The first objective is to ensure that the cost is within the teams budget. The second objective is to avoid using custom parts when at all possible. This test includes looking over the bill of materials and ensuring cost are minimized. The second part of this test is calling the manufacturers to finalize the quotes for material and begin purchasing the supplies. If the final amount quoted is within the allowed budget the Cost engineering requirement is met. If custom parts are minimized in the quoted material the Standardized Part engineering requirement is also met.

3.3.2 Testing Procedure 3: Resources Required

The resources needed to complete this test include the SunTrac team, cell phone, $1500.00 budget, bill of materials, and verbal confirmation from Stu Siebens. Since this test requires the spending of the budgeted money the Director of Engineering at SunTrac USA must approve the bill of materials. Any setting with a WiFi connection will suffice for this test.

3.3.3 Testing Procedure 3: Schedule

The required time to conduct this test will likely be several hours depending on how long it takes to finalize quotes over the phone. This test must be completed before all other tests and therefore must be completed as soon as possible. To ensure the bill of materials if finalized the test will most likely take place in early February at the latest. This will fit into the second semester schedule by ensuring it is added into the gantt chart.

3.4 Testing Procedure 4: Rotation Assessment

This test includes measuring the force to rotate the braze welding jig from a resting state. This test also includes locking the jig at every available locking position to confirm that it stays secure. This test ensures that the engineering requirements of force to rotate and adaptability are satisfied. The general schedule for this test is once the final braze welding jig is completed in March of 2020.

3.4.1 Testing Procedure 4: Objective

There are two objectives that must be met in this test. The first objective is to test if a person of average strength can create a force strong enough to cause the braze welding jig to rotate. The second objective is to test if all available locking positions are free of debris and can successfully secure the jig. This test first includes attaching a force gauge on the bottom left edge of the rotating subassembly of the braze welding and slowly pulling the other edge of the braze welding jig until the jig begins to rotate. The force to overcome the static friction should be displayed on the force gauge. The next portion of this test is locking the jig at every locking position and applying a five pound force perpendicular to the lever arm of the jig. The lock should resist the applied force and keep the jig stationary. If it takes less than 10lbs of force to rotate the jig the Force to Rotate requirement is satisfied.If the jig can resist a 10lb weight while in each locking configuration the Adaptability requirement is also met.

3.4.2 Testing Procedure 4: Resources Required

The required resources for this lab include the SunTrac team, Stu Siebens, the full scale braze welding assembly, force gauge, 10lb weight, and SunTrac's manufacturing facility. The team is needed to conduct the experiment while Mr. SIebens is needed to confirm the results. The completed braze welding jig will be required to conduct the test and it will need to be bolted to the floor of the SunTrac manufacturing facility to resist any shear or moment. More members of SunTrac's executive board may attend if they have the time.

3.4.3 Testing Procedure 4: Schedule

This test will take approximately one hour to conduct and record. This test will likely be run in late March 2020 when the full scale braze welding jig is assembled and installed. This test is dependant on manufacturing space and available free time of Stu Siebens and the SunTrac team and therefore may change date to fit schedules. This will fit into the second semester schedule by ensuring it is added into the gantt chart.

3.5 Testing Procedure 5: Final Dimensions

This test includes taking multiple measurements of the full scale completed braze welding jig including footprint area and height. This test will test will prove that the footprint engineering requirement is satisfied. The general schedule for this test is once the final braze welding jig is completed at the end of March 2020.

3.5.1 Testing Procedure 5: Objective

The objective of this test is to ensure the footprint area is less than a 5' by 5' area. This test includes measuring the area of the triangle created from the three legs of the braze welding jig. If the area is less than $25ft^2$ the Footprint engineering requirement is satisfied.

3.5.2 Testing Procedure 5: Resources Required

The required resources for this lab include the SunTrac team, Stu Siebens, the full scale braze welding assembly, tape measure, calculator, and SunTrac's manufacturing facility. The completed braze welding jig will be required to conduct the test and it will need to be bolted to the floor of the SunTrac manufacturing facility to resist any shear or moment. More members of SunTrac's executive board may attend if they have the time.

3.5.3 Testing Procedure 5: Schedule

This test will take approximately 10 minutes to conduct and record. This test will likely be run in late March 2020 when the full scale braze welding jig is assembled and installed. This test is dependant on manufacturing space and available free time of Stu Siebens and the SunTrac team and therefore may change date to fit schedules. This will fit into the second semester schedule by ensuring it is added into the gantt chart.

4 Risk Analysis and Mitigation

To analyze failure and risk, two Failure Modes and Effects Analysis (FMEA) have been conducted. The first FMEA will be presented in this section of the report, and this entails an analysis of the components which four critical subsystems comprise of. The second analysis is illustrated in appendix D, and consists of the FMEA procedure carried out for each part in the bill of materials while considering all failure modes combined for each part. For the analysis that will be discussed in this section, the failure modes for each part have been isolated and analyzed individually. The subsystems analysed in this process include the pivot mechanism about which the jig face rotates, the foot pedal, and the locking mechanism which the foot pedal is attached to, as well as the sliding tubes which satisfy the variability engineering requirement. To quantify the effects of the failures of each subsystem component, a risk priority number is calculated. During this process many steps are carried out, these include: listing potential failures for each component, list the causes and effects of these failures, develop design control tests to detect failure before production, and provide recommended action. To calculate the risk priority number directly, three values must be generated all on a 1-10 scale. These values being Severity (S) based on how severe the failure is, Occurrence(O) based on how likely this failure is to occur in its application, and Detection (D) being how easily the defect will be detected. This process is outlined in this section below.

4.1 Critical Failures

A shortened version of the FMEA has been conducted to illustrate in the report the top ten most considerable risks, that is the ten risks with the greatest risk priority number; this can be seen below in Table 2.

Table 2. Shortened FMEA

Product Name - Brazing Jig System Name - Manifold Production		Development Team: Edwin, Ethan, Kadijah, Nathan			Page No 1 of 1 FMEA Number 1 Date: 11/14/2019	
Subsystem Name	Part #	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Pivot Mechanism	12) Gear	Bending Fatigue	Inability to Lock, Uncontollable Jig Face, Flying Debris	Poor Operation, Poor Design, Overstressing	54	Ensure Proper Material And Dimension Specification, Provide a user guidline
Pivot Mechanism	2) Large Sliding Tube	Ductile Fracture	Structural Failure, Flying Debris	Poor Material Selection, Overstressing,	54	Optimize Material Stress Strain Curve
Pivot Mechanism	3) Small Sliding Tube	Ductile Fracture	Structural Failure, Flying Debris	Poor Material Selection, Overstressing,	54	Optimize Material Stress Strain Curve
Pivot Mechanism	2) Large Sliding Tube	Abrasive Wear	Weaken Mechanism Integrity	Assembly Error	48	Increase Material Hardness
Pivot Mechanism	3) Small Sliding Tube	Abrasive Wear	Weaken Mechanism Integrity	Assembly Error	48	Increase Material Hardness
Pivot Mechanism	2) Large Sliding Tube	High Cycle Fatigue	Weaken Mechanism Integrity,	Poor Maintenance	48	Design Material to Optimize Stress-Life Curve
Pivot Mechanism	3) Small Sliding Tube	High Cycle Fatigue	Weaken Mechanism Integrity,	Poor Maintenance	48	Design Material to Optimize Stress-Life Curve
Pivot Mechanism	11) Ball Bearing	Spalling	Flying Debris, Erratic operation, Structural Failure	Overloading, Poor Mainenance	48	Optimize Geometry to Reduce Contact Stresses
Locking Mechanism	15) Rod	Impact Wear	Weaken Mechanism Integrity, Noise	Overstressing, Poor Operation, Assembly Errors	48	Increase Material Hardness
Foot Pedal	9) Aluminum Sheet Metal	Ductile Fracture	Inability To Lock	Overstressing, Assembly Error	48	Ensure Proper Material Specification

This shortened FMEA disregards a few critical elements of the full FMEA process which can be seen in appendix B. These top ten failure modes are broken down and analyzed in terms of cause, effect, and recommended action in the sections below.

4.1.1 Potential Critical Failure 1: Gear Tooth Bending Fatigue (RPN 54)

To actuate the locking of the jig face, a rod is mechanical positioned between the teeth of a gear as a part of the pivoting subsystem. The repeated impact between these two components if not performed properly will subject an excessive bending stress onto the gears teeth. Once these stresses exceed the local fatigue strength, a local fatigue crack propagates at the tooth base. The effect of this failure is a loss of the locking mechanism functionality, and perhaps flying gear tooth debris. This failure will be mitigated through performing gear tooth analysis to ensure proper material specification, these specs will be outlined in the performance instructions

4.1.2 Potential Critical Failure 2: Large Sliding Steel Tube Ductile Fracture (RPN 54)

When minimizing cost, a soft metal may be considered for the sliding tubes on the jig face. This is considered in terms of failure as ductile fracture. If this material is repeatedly loaded in the plastic deformation region, ductile fracture can be experienced. This failure will cause complete structural failure, and perhaps flying metal debris. For this reason this failure mode is rated a 9 on the 1-10 severity scale, and consequently is tied for the most significant failure mode. To minimize the chance of this happening, a comprehensive dynamic load analysis will be conducted to ensure that the yield strength of the material won't be exceeded during the life time of the jig.

4.1.3 Potential Critical Failure 3: Small Sliding Steel Tube Ductile Fracture (RPN 54)

This failure mode is remarkably similar to failure mode 2. There are two sliding tube elements on the jig face to allow for a full 4 foot extension. The failure mode of the smaller tube has all of the same causes and effects of the larger tube. Although, for mitigating action the dimensions and forces of the dynamic loading analysis will be different, resulting in a different risk of failure.

4.1.4 Potential Critical Failure 4: Large Sliding Tube Abrasive Wear (RPN 48)

For the variability engineering requirement to be satisfied, the variable sliding tubes hold great weighting in their complete and accurate use. A failure consideration is the wear of these tubes when repeatedly sliding causing physical abrasion between them. After numerous operations and sliding iterations these tubes will wear and scrape off particles, causing a small margin of tolerance stack up as the accurate fitting of these tubes are mandatory. This will also create a safety hazard as particulates will be breathed in by workers. This failure will be mitigated by conducting research on a cost effective and situationally accurate lubricating material that is fire resistant and abide by engineering requirement restrictions.

4.1.5 Potential Critical Failure 5: Small Sliding Tube Abrasive Wear (RPN 48)

This failure mode is comparable to that of the large sliding steel tube abrasive wear more-so than other failures that are shared between the sliding tubes. As ideally, the material analysis regarding project restrictions will determine a lubricant which can be applied across both materials. Although this mitigating action may be contingent on another as if the analysis which will determine the sliding tube material results in separate materials, a lubricant will be chosen specific to each. Other than this variation, the other factors of this failure such as cause and effect are the same for each.

4.1.6 Potential Critical Failure 6: Large Sliding Steel Tube High Cycle Fatigue (RPN 48)

A considerable failure mode for the large sliding steel tube is the fatigue due to small elastic strains under a high amount of loading cycles. The sliding steel tubes will undergo many cyclic loadings as the jig face configuration varies from 4' to 6' to 8'. it will also experience this repeated loading as the jg face is rotated about an axis and the load is applied to the structural support under different conditions. The effects of this occurrence is eventual, yet noticeable, failure as the material slowly reaches its fatigue limit. This can cause complete loss of primary function, as well as potential flying debris, thus the severity is high, although its ability to be detected and occurrence counteract the severity. A material analysis will be conducted to determine a material that can withstand the weight of the jig face and 8' copper manifold under different configurations.

4.1.7 Potential Critical Failure 7: Small Sliding Steel Tube High Cycle Fatigue (RPN 48)

The dynamic loading of the various copper manifolds in different orientations affects both the large and small sliding tubes. Perhaps one more than the other, although this will be determined in a dynamic loading analysis. the causes and effects of the larger sliding tube carry over to the smaller, although the smaller is less severe by a small margin as this failure contains less mass to be potential flying debris. A material analysis will be conducted that is similar to that of the larger tubes, although different dimension and load applications will be considered.

4.1.8 Potential Critical Failure 8: Ball Bearing Spalling (RPN 48)

The pivot mechanism is a critical subsystem of the brazing jig as it allows the primary function to be carried out, If the Jig face couldn't rotate, the top of the copper manifold wouldn't be reachable. Although this contains much risk, as this is the second critical failure exclusive to the ball bearing. The bearring is susceptible to three types of spalling: Geometric Stress Concentration (GSC), Point Surface Origin (PSO), and Inclusion Origin Spalling. Inclusion Origin Spalling is negligible in this case as this failure mode requires millions of cycles. This application focuses on the intensity of few cycle amounts. The other two failure modes are triggered through localized stress regions, which is a heavy consideration for the pivot mechanism application as the ball bearing will be inclined in a tilted plane, causing a localized stress region from the heavy jig face weight near the back of the bearing inner diameter. An analysis on this loading setup will be conducted to better inform the team members of this potential failure mode, and to ensure that proper bearing material specification and size is concluded.

4.1.9 Potential Critical Failure 9: Rod Impact Wear (RPN 48)

The locking mechanisms interacting dynamic components involve great reactionary forces. Just as this force exchange between rod and gear can result in bending fatigue on the teeth of the gear, this can result in impact wear on the rod. The severity of this failure mode is not as high as bending fatigue as there will be notice of failure before severity reaches great proportions. For example the rough contact interface will create minor erratic locking operation as well as distinct noise. To mitigate this failure a material analysis and dimension analysis will be carried out in which proper hardness will be found in which this issue will not arise during the lifetime of the jig or maintenance periods.

4.1.10 Potential Critical Failure 10: Foot Pedal Aluminum Sheet Fracture (RPN 48)

The foot pedal; which actuates the locking mechanism will be constructed out of an aluminum sheet, hinge and spring. As this mechanism will be in use multiple times during each operation it is critical to consider the effects of repeated use. The most prominent failure here is the ductile fracture of the aluminum sheet if its yield strength is repeatedly exceeded. The aluminum sheet will be pivoted about the hinge and spring to apply tension to the locking mechanism wire. If ductile fracture were to occur, this locking mechanism would fail and the jig face would be free to rotate. The current system used by Suntrac USA is a free rotation controlled by the hand, so this concept is not unfamiliar and consequently doesn't entail complete severity. To reduce this failure risk, a dynamic loading analysis will be carried out to determine the average operating specs. A material will be tailored to these specs and an operating guideline will be constructed.

4.2 Risks and Trade-offs Analysis

To analyze critical risks and how they relate to each other, the design team took a quantitative approach. Scenarios were devised which beneficially impact respective engineering requirements. These scenarios were then analyzed regarding how they influence engineering requirements as well as risk. To do this, the effect(s) of each scenario on its respective engineering requirement were stated, then each effect was assigned an engineering requirement which it impacts positively (+) or negatively (-). The weighting of impact was determined by the criterion weighting of the decision matrix. If an effect has a positive influence on the engineering requirement, it was assigned a positive value equal to the decision matrix weight for that particular criteria, if the influence is negative this same value would become negative. Two other factors to accurately weigh the impact of these scenarios are the weight of the engineering requirement which the actions is positively affecting, as well as the risk factor. The risk factor is determined through listing all of the potential risks of the action. For example, when considering reducing the jig face structural member count from six to three, this entails increased susceptibility to yielding, high cycle fatigue, and abrasive wear as the forces of operation are concentrated across less area. The severity, detection, and occurrence ratings were considered in creating a risk priority number for each of these scenarios, then this number was divided by ten to create a zero to one relative weighing scale to match the rest of the analysis. The risk factor, engineering requirement weight, and summation of effect impacts were combined in creating a total rating. The total ratings of all of the engineering requirement benefiting actions were taken to solve for a relative rating. An excerpt of this process is outlined in table 3 below.

Table 3.Shortened Risk Trade Off Analysis

Risk Trade Off Analysis								
Engineering Requirement (ER) Improving Actions	Risk Factor	Risk Description	Impact	Impacted Criteria	Criteria Weight	Impact	Total Rating	Relative Rating
1) Reduce Force to Rotate					**0.07**			
1a) Replace end beam with sheet metal	0.4	Increase susceptability to force induced deformation						
Reduces moment of inertia			+	Force to Rotate	0.07	0.07	0.056	0.08
Lessens material mass			+	Cost	0.17	0.17		
Decreases rigidity of jig face			-	Durability Error	0.11 0.11	-0.22		
1b) Decrease number of face beams	0.6	Enahnce effects and possibility of yielding, high cycle fatigue, abrasive wear						
Decreases moment of inertia			+	Force to Rotate	0.07	0.07	0.084	0.12
Decrease part count			+	Cost	0.17	0.17		
Decrease structural support/rigidity			-	Durability Error	0.11 0.11	-0.22		
2) Reduce Cost					**0.17**			

The table above illustrates this process for a single engineering requirement with two benefitting actions, the entire process is outlined in appendix D. The conclusions which can be drawn from this process are listed in table 4 below.

Table 4. Risk Analysis Results

Risk Scenario	Relative Impact
2c) Implement manual locking	1
5a) Replace steel tube material with low-carbon	0.65
2a) Reduce to three face beams	0.2
5a) Strengthen pin material	0.22
1a) Replace end beam with sheet metal	-0.01
3a) Reduce tripod leg angle from vertical	-0.28
4a) Increase number of structural members	-0.78

Given the way that these relations were solved for result in a non objective scaling of influence regarding engineering requirements and risk. An action with a rating of 1 is the best action which can be currently taken to benefit engineering requirements with regard to its impact on other engineering requirements while also considering risk. If the value is positive there is a net positive impact regarding engineering requirements and risk, if the value is negative the action is detrimental in regard to these considerations. So it can be concluded from this analysis that implementing manual locking is the most beneficial action to currently take. This is significant as if this is carried out, the design will revert back to the original design currently used in Suntrac USA's brazing process, and a new method to satisfy the adaptability sub-function will be required. Although this result is quantitatively justified, this action may not be taken as the current theoretical mechanically actuated locking system may be worth the negative cost influence. This concern will be brought to the project client Stu Siebens and he will have the final decision on whether or not this action will be carried out.

5 *DESIGN SELECTED – First Semester*

This section contains a description of the final design. First, the preliminaries and fundamental components of it are detailed in depth. Design changes are discussed regarding how the design changed since the previous report publication. Why these changes were made are discussed on a qualitative basis. Furthermore, engineering principles are substantiated with some mathematical calculations.

5.1 Design Description

The final design of the jig utilizes rotation about an axis similar to what SunTrac currently uses. The jig rotates on a 10 degree offset from the vertical plane where the pivot point is supported by a tripod which stands near 72 inches tall with a 5.4 square foot footprint. The jig in it's 8 foot configuration swings to a height of 10.8 feet from the base off the tripod. The operational component of the jig is made from three sets of square telescoping tubes that allow it to change configuration sizes. These tubes have holes for pins where a pin can be removed, adjusted to a new configuration size, and reinserted to lock it in place for another manifold size. Vertical copper pipes are supported by two standoffs which are L- beams with u-shaped holes cut into them. The horizontal pipes are mounted with power screw clamps attached to each end of the jig. There is a gear rigidly mounted to the back of the jig which rotates with it. This gear is coupled with a spring, an interlocking wedge, and a cable which connects it to the foot pedal at the base of the tripod. When the foot pedal is pressed it actuates the wedge out of place allowing the jig to swing freely. Then when the foot pedal is released, this wedge reinserts and the jig gets locked back in place.

5.1.1 Design Preliminaries and Changes Made

The requirements that SunTrac laid out for us were heavily considered in the design. Considerable changes were made since the preliminary report. Most of the design features were implemented for safety reasons. The jig is offset at a 10 degree angle so it can stand upright before being bolted into the floor. The foot pedal and gear locking mechanism allows the operator to work more comfortably and safely. Power screws ensure a rigid grasp onto the manifold to prevent it from falling out. Additionally, one leg of the tripod is facing in front instead of two to avoid it being a tripping hazard.

A significant change made is the amount of telescoping tube sets were reduced. Originally there were to be five sets of tubes, but since one row of vertical pipe standoffs are now a single part, there is no need to have as many individual sets of tubes as there are vertical pipes to accompany each standoff. Each individual standoff becoming a solid piece greatly increases rigidity. Additionally, less tube sets indicates less locking pins, so there is a shorter time to reconfigure the jig for another manifold size. So not only does this design change functionally work but also reduces raw material and manufacturing costs.

The gear used for the locking mechanism was increased from a 2 inch diameter to a 4 inch diameter. Initial calculations showed that the smaller gear would yield with a 108.7 lbf load at the end of the jig. This force could be easily achieved with a simple accident like a cart collision. Thus the gear size was increased make it stronger.

5.1.2 Engineering Calculations

Some engineering calculations were conducted to substantiate some of the design changes. With less telescoping tubes, the jig becomes easier to maneuver, but there is a potential for it to deflect more since there isn't as much reinforcing material. How much weight is removed and how much axial stress the new design may endure is conducted in two analyses. Then, a new force that the larger gear can withstand is calculated.

5.1.2.1 Reduced Weight Analysis

This analysis is to examine how the reduced amount of collapsible tubes will affect the weight of the jig. For this, first the dimensions of one set of telescoping tubes will be considered. The density of carbon steel is 0.284 lb/in^3. The weights of each tube are as follows.

Large Tube

$$V_L = L(A_{LO} - A_{LI}) = 48\,in\,((2.5\,in * 2.5\,in) - (2.29\,in * 2.29\,in)) = 48.28\,in^3$$
$$W_L = V * \rho = 48.28\,in^3 * 0.284\,lb/in^3 = 13.71\,lb$$

Medium Tube

$$V_M = L(A_{MO} - A_{MI}) = 12\,in\,((2.25\,in * 2.25\,in) - (2.04\,in * 2.04\,in)) = 10.81\,in^3$$
$$W_M = V * \rho = 10.81\,in^3 * 0.284\,lb/in^3 = 3.07\,lb$$

Small Tube

$$V_S = L(A_{SO} - A_{SI}) = 12\,in\,((2.0\,in * 2.0\,in) - (1.79\,in * 1.79\,in)) = 9.55\,in^3$$
$$W_S = V * \rho = 9.55\,in^3 * 0.284\,lb/in^3 = 2.71\,lb$$

Total Weight Reduced

There is 1 large tube, 2 medium and small tubes per set, so the weight of each set is.

$$W_{Set} = W_L + 2 * W_M + 2 * W_S = 13.71\ lb + 2 * 3.07\ lb + 2 * 2.71\ lb = 25.28\ lb\ per\ set$$

Thus, with two removed sets, there is a 50.58 lb weight reduction.

5.1.2.2 Thermal Expansion Maximum Axial Stress

When the copper tubes are heated up thermal expansion will occur in both the axial and radial directions. Depending on what the pipes are coincident with, this may induce very high stresses on the pipes and/or the pipe surroundings [Mech Mat]. How much stress is induced in the jig frame can be found from this. Thermal expansion in the axial is calculated to provide some insight on this phenomenon.

$$_{axial} = \Delta T()(L) = 1375F(9.4 * 10^{-6} in/in * F)(8ft * 12in/ft) = 1.24\ in$$

There are assumptions built into this computation. This assumes that the pipe uniformly heats up to the maximum temperature during brazing; but this is not highly unrealistic given copper has excellent thermal conductivity. It also assumes that the expansion is unrestricted. The axial force can be found as such.

$$F = E * \alpha * \Delta T * A_C = (17 * 10^6 psi) * (9.4 * 10^{-6} in/in * F) * 1375F * (0.1104\text{in}^2) = 24{,}257\ \text{lbf}$$

The copper pipes are brazed one at a time, and there are three sets to restrain this thermal expansion, each with a minimal cross- sectional area of

$$A_C = ((2.0\ in * 2.0\ in) - (1.79\ in * 1.79\ in)) = 0.796 in^2 * 3\ sets = 2.39\ in^2$$

The induced axial stress is

$$\sigma = F/A_C = 24,257\ lbf / 2.39\ in^2 = 10,150\ psi$$

Some considerations to this calculation. It assumes that the thermal expansion is uniform which gives the largest expansion, and that the steel remains rigid, which induces the highest stresses. So with this conservative modeling, a factor of safety of 7 is maintained, which indicates the design is robust and will last.

5.1.2.3 Gear Force Analysis

How much force would it take to break the gear if a force was applied at the bottom of the jig?
The manufactured gear selected is 4.0 inches in pitch diameter, has 48 triangular teeth, is 0.88 inches wide,is a spur gear with a 20 degree pressure angle, and is made of 1020 carbon steel. These next set of equations came from *Shigley's Mechanical Engineering Design* [17] to evaluate the spur gear.

$$P = TPI\ (Threads\ Per\ Inch)$$

$$n = number\ of\ teeth$$

$$t = half\ tooth\ thickness$$

$$P = n/d = 48 teeth/4 in = 12\ TPI$$

$$t = /(2 * P) = /(2 * 12TPI) = 0.1309\ in$$

$$A_C = t * w = 0.1309\ in * 0.88\ in = 0.115\ in^2$$

This portion of the analysis was to determine the cross-sectional area of the tooth. for the rest of the analysis, halfway up the triangular tooth is called the pitch diameter, the distance between the tooth tip and the root. The cross-sectional area of this part of the gear tooth may be used in transmitted force modeling for it is commonly a contact point at a 20 degree pressure angle gear. Next, the moment net sum about the pivot point is found to solve for the reaction force that the gear needs to give in order to maintain equilibrium, and this reaction force is found by dividing the yield strength of stainless steel (72,800 psi) [16] by the cross-sectional area of the half tooth thickness multiplied by the cos of the tooth angle.

$$\sum M = 0 = F * L - F_R * R_{gear} ==> F * L - A_c \sigma_y * cos(20) * R_{gear}$$

$$0 = F * 48\ in - 0.115\ in^2\ (72,800\ Psi) * cos(20) * 2\ in$$

$$Solving\ for\ F\ gives\ F\ =\ 327.8\ lbf$$

So this shows that when the jig is in its eight foot long manifold configuration then if one were to apply 327.8 pounds of force then they would yield the gear. This larger gear size shows near 3 times the strength than the smaller gear.

5.1.3 First Prototype

A 1/4 scale model prototype was constructed to not only demonstrate the design concept but to also allow the team to evaluate flaws and potential changes. The Prototype doesn't utilize all of the mechanical components that are detailed for the final design. for example, does not have working power screws, the foot pedal gear stop, or the locking pins. Given the resources available, these components would have been difficult to not only make, but have functional.

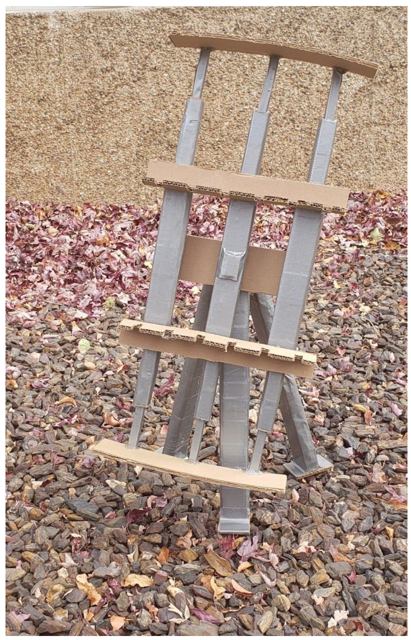

Figure 3. 1/4th Scale Prototype of Complete Jig

It was during the construction of the prototype at the team got the idea to reduce the amount of tube sets from five to three. The two other sets seemed intuitively unnecessary. Tt was determined that at least three are needed so one could be the center and attached to the bearing, while the other two are for guidance and rigidity. The other idea found during construction was to make the one tripod leg in front instead of two. One leg placed directly under the jig would be less of a tripping hazard than two extending along the sides of it. This also allows attaching the foot pedal to this one leg and have the cable it's coupled with be directed by the leg instead of it being in the open.

5.2 Implementation Plan

The section details the team's current plan in order to implement the design. This includes putting the design into effect through constructing an operational scale prototype, needed resources to accomplish this goal, and a schedule to abide by. Given in the project description, one of the final deliverables is to deliver a 1/4th scale model to SunTrac. The team anticipates this being the first step of implementation. The plan is to fabricate it entirely out of aluminum, have each dimension completely to scale, and be able to demonstrate each dynamic and mechanical features. Since it will be made of aluminum, it won't be able to withstand the excessive temperature from braze welding a copper manifold. However, this wasn't designated to be a requirement, as constructing a miniature scale copper manifold proves no use to SunTrac.

5.2.1 Needed Resources

The bill of materials (Appendix C) details all of the raw materials and their costs that need to be purchased for the full scale jig assembly. The final CAD package and drawings detail which piece from the bill of materials corresponds to each component. For the 1/4th scale prototype, Suntrac's partnered machine shop shall be in charge of fabricating each component. Initially the team will request quotes to determine how expensive the scale model components will cost. The components will be requested through SunTrac because SunTrac receives regular customer discounts from this machine shop. The individual pieces will be shipped to the team for assembly. SunTrac will cover the expenses of fabrication and shipping. Should modifications be required due to some unprecedented error, they will be made at our own expense with our own resources and the NAU machine shop. Then, alterations to the CAD package will be made accordingly.

A similar process shall be conducted with the full-scale final product. SunTrac will submit the team's detailed drawings to the machine shop and receive quotes. The team will thoroughly revise the drawings looking for possibilities and/or following recommendations to utilize DFMA guidelines to reduce costs and increase manufacturability. With the final submission of the drawings, machine shop will fabricate these parts and send them to the SunTrac facility in Tempe to store them. The team will make a trip down to SunTrac to assemble the jig.

5.2.2 Implementation Schedule

The second half of the Gantt chart details the team's current plan for the second semester of Capstone. This chart includes Capstone specific submission dates for assignments and when they are to begin. Per the team charter, each team assignment is intended to be finished 24 hours before the submission time. The chart can be seen in figure 4.

Fall Semester	Start Date	End Date	Timeline	Authors	Status
SunTrac Team	12-4-2019	5-31-2020			
Post Mortem	12-4-2019	1-14-2020		All	Upcoming
Self Learning	12-4-2019	1-21-2020		All	Upcoming
HR1 Summary	12-4-2019	2-11-2020		Ethan	Upcoming
Peer Eval 1	1-13-2020	2-11-2020		All	Upcoming
Website Check	12-4-2019	2-18-2020		Kadeja	Upcoming
Midpoint Report	12-4-2019	3-3-2020		All	Upcoming
Individual Analysis II	12-4-2019	3-10-2020		All	Upcoming
Device Summary	12-4-2019	3-24-2020		Ethan	Upcoming
Peer Eval 2	2-11-2020	3-24-2020		All	Upcoming
Poster Drafts	12-4-2019	3-31-2020		All	Upcoming
Testing Proof	12-4-2019	4-7-2020		Edwin	Upcoming
Final Poster/ Operational Manual	12-4-2019	4-14-2020		All	Upcoming
Final Presentation	12-4-2019	4-14-2020		All	Upcoming
Final Report	12-4-2019	4-28-2020		All	Upcoming
CAD Package	12-4-2019	4-28-2020		Nathan	Upcoming
Final Website	12-4-2019	5-5-2020		Kadeja	Upcoming
Peer Eval 3	3-24-2020	5-5-2020		All	Upcoming

Figure 4. Current Plan For Implementation

The plan structure for the next semester is a bit rudimentary. Many of the Capstone assignments have yet to have further details explained and submission dates designated. Nonetheless, the current work structure of this portion is intended to span from December 4th 2019 to May 5th, 2020. Contacts/ meetings with SunTrac, trips made to the facility, requesting machine shop quotes, reviews, fabrication time, and prototype assembly are not detailed in the chart. The team's current plan follows as such in table 5.

Table 5. Rough Dates for SunTrac and Machine Shop Proceedings

Activity	Anticipated Date
Submit Prototype Drawings and Package	December 16, 2019
Review Machine Shop Prototype Quotes	January 4, 2020
Intended Resubmission of Prototype Package	January 13, 2020
Prototype Fabrication/ Assembly	January 13, 2020 - January 31,2020
SunTrac Trips	January 11, 2020, 5th, and 10th Week of Semester
Final CAD Drawings and Package Submission	February 10, 2020
Review Machine Shop Quotes	February 17, 2020
Intended Resubmission of CAD Package	March 1st, 2020

The first submission of prototype parts occurs at the end of first semester. This is because of the Capstone final CAD package assignment. Since the CAD package will be done to completion by then with all the associated drawings, the team wanted to send those in before winter break started so then a portion of winter break could be used as waiting time for receiving feedback from the machine shop. Should the CAD package need revisions those will be done over winter break and resubmitted. Before second semester begins, we intend to convene in Phoenix and meet with SunTrac before returning to Flagstaff. This meeting should be to address the current state of our design, to receive input, and to possibly use that time for assembly should the machine shop deliver the components ahead of the schedule. Other meetings with SunTrac are scheduled for later in the semester. The team anticipates on submitting the final CAD package around the Monday of February 10th.

5.2.3 CAD Model Views

This section contains figures and explanations on the current state of the jig design. The individual parts and 3D assembly were constructed in SolidWorks. Future revisions are intended to take place as well as the addition of a few components. This is contingent on Suntrac's opinion of the design. The exploded view of the assembly can be seen in figure 5.

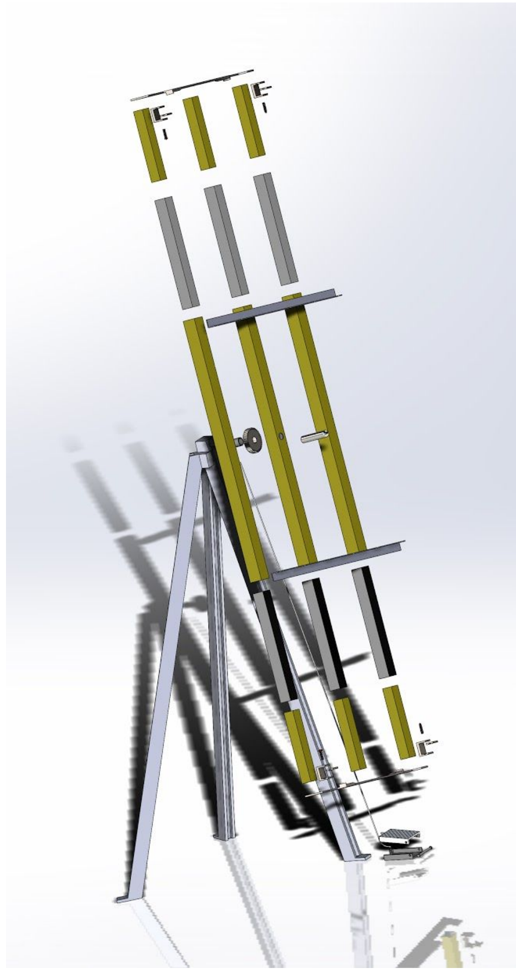

Figure 5. CAD of the Most Finalized State of the Design

There are 40 components in total here. The tripod has holes in each of the feet so it can be bolted to the floor. The top of the tripod contains a housing which fits the bearing to support the shaft and the gear. The gear has an interlocking wedge that is held up with a small arm and spring. This arm is attached to the cable which is attached to the foot pedal. The gear is fused to the center large telescoping tube and the shaft so that it is only free to rotate on the bearing. The L- beam standoffs are welded at each end to the large telescoping tubes. The small telescoping tubes are welded to the end plate, which are welded to the power screws and their housings. The assembly can be seen in figure 6.

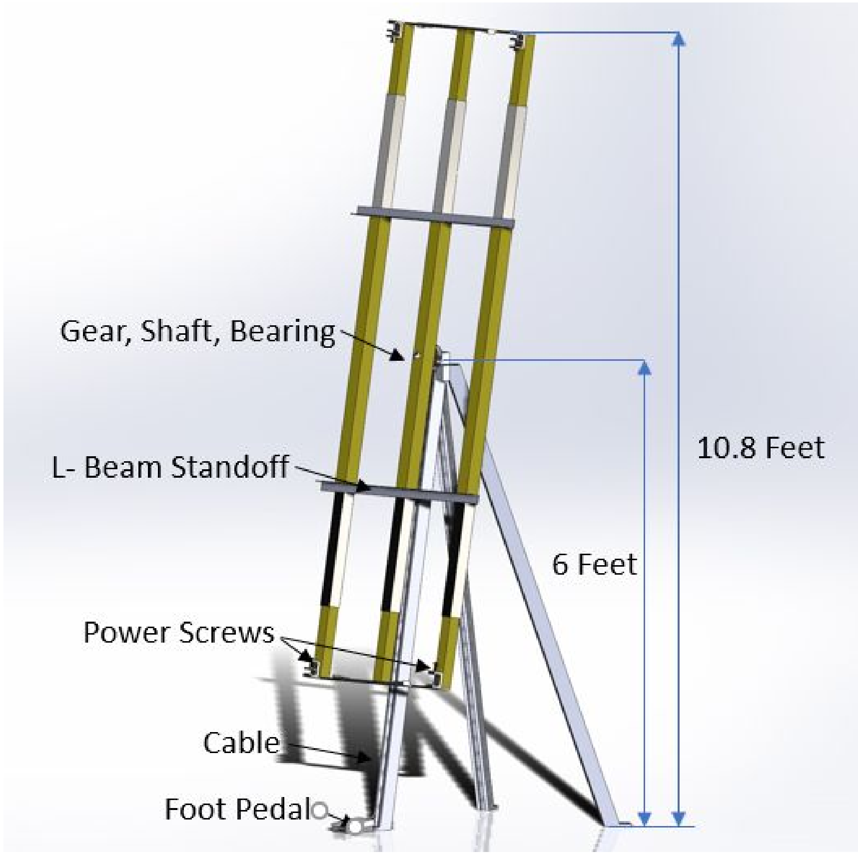

Figure 6. Jig CAD Assembly with Annotations

The tripod stands 72 inches (6 feet) tall by itself and the gear positioned behind the middle set of telescoping tubes is 4 inches in diameter and 0.88 inches thick. The largest tubes measure 2.5 in x 2.5 in x 48 in and are spaced 14 inches apart from each surface. The medium tubes are 2.25 in x 2.25 in x 12 in and the smallest tubes are 2.0 in x 2.0 in x 12 in. The u- standoffs are 40 inches wide, made from the 1.5 in x 1.5 in L beams. The centers from each of the u- cutouts are 7.625 inches apart per the dimensions Suntrac uses.

6 CONCLUSIONS

The goal of this project is to design a braze welding jig for SunTrac. The jig must fit three sizes of manifolds, 4 feet, 6 feet, and 8 feet. In addition, the jig should be within a 5'x5' square footprint space and be safe to operate. The cost of creating this design must be within the budget. To come up with the first design, the team created a black box model and a functional decomposition model to trace the subsystems needed and then brainstormed ideas that were grouped into design alternatives that were weighted in a pugh chart and decision matrix. The best design was chosen through this process. Next, test procedures for the final design were discussed and risk analysis and mitigation was implemented to produce the best possible final design. The final design uses a jig that rotates at a 10 degree offset from the vertical plane where the pivot is supported by the base. There are three square tubes that make up the skeleton of the jig which holds the vertical copper pipes in place. These tubes will elongate on either side to account for the three sizes of manifolds which have designated holes in them for pins to lock the tubes in place. The back of the jig has a gear that rotates 360 degrees and a foot pedal that utilizes a spring locks the gear in place. Releasing the foot pedal in turn releases the gear which rotates the jig. Calculations were conducted to ensure the final design meets the safety requirements and is deemed durable.

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8 APPENDICES

8.1 Appendix A: House of Quality

House of Quality (HoQ)

Customer Requirement	Weight	Engineering Requirement	Melting Temperature (degrees Celsius)	Force to Rotate (Newtons)	Cost (dollars)	Versatile (number of compatible product variations)	Standardized Parts (dollars)	Footprint (meters^2)	Degree of Rotation (Radians)	Adaptable (Number of locking positions)	Durable (Years before repair)	Error (Difference in desired length) (in)
Desired Direction			^	v	v	^	v	v	^	^	^	v
1. Safe to Operate	5		9	9	9				1	1	3	
2. Cost within budget	5		1	1	9	3	9			1	9	9
3. Can fit a 4', 6', and 8' copper manifold	5				3	9		9	3			3
4. Machinable parts	4				9		9					
5. Fit within a 5'x5' square	3					1		9	3			
6. Allow easy access to all copper joints	4			1		3		1	9	9		
7. Jig can rotate and lock at various angles	3			3	1	9			9	9		3
8. Durable and Robust design	4		3	1	3	1	3				9	
9. Reliable design	4		3		3	1	1		1		3	9
Absolute Technical Importance (ATI)			74	67	168	110	97	76	96	73	108	105
Relative Technical Importance (RTI)			8	10	1	2	5	7	6	9	3	4
Target ER values			1400	13	1500	3	1500	2.32	2*pi	8	20	1/16"
Tolerances of Ers			300	3	500	0	500	0.5	0	2	5	1/32"
			0.08	0.07	0.17	0.11	0.10	0.08	0.10	0.07	0.11	0.11

Approval (print name, sign, and date):

Team member 1: Edwin Smith 09/13/19

Team member 2: Ethan Vieane 09/13/19

Team member 3: Kadeja Alhossaini 09/13/19

Team member 4: Nathan Fior 09/13/19

Client Approval: Stu Siebens 09/14/19

8.2 *Appendix B: Full Subsystem FMEA*

Product Name - Brazing Jig	Development Team: Edwin, Ethan, Kadijah, Nathan	Page No 1 of 1	
System Name - Manifold Production		FMEA Number 1	
Subsystem Name		Date 11/14/2019	
Component Name			

Subsystem Name	Part #	Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Locking Mechanism	6) Metal Wire	Connect the foot pedal to the spring	High Cycle Fatigue	Inability To Activate Spring, Uncontrollable Jig Face	5	Poor Maintenance	2	Dynamic Loading / Multi-Material Fatigue Analysis	2	20	Design Material to Optimize Stress-Life Curve
			Abrasive Wear	Weaken Mechanism Integrity, Noise	5	Assembly Error	3	Material Science Analysis (Hardness)	2	30	Increase Material Hardness
			Heat Damage	Disconnect Foot Pedal	6	Poor Maintence	2	Thermal Endurance Analysis	2	24	Design Material to Optimize Operating Temp
			Stretching	Inability To Activate Spring, Uncontrollable Jig Face	5	Design Error	2	Material Science Analysis (Tensile Strength)	2	20	Optimize Material Stress Strain Curve
	13) Spring	Lock the jig in place	Abrasive Wear	Inability To Activate Rod, Uncontrollable Jig Face	4	Assembly Error	3	Material Science Analysis (Hardness)	2	24	Increase Material Hardness
			Low Temperaure Fatigue	Weaken Mechanism Integrity,	5	Poor Maintence	3	Thermal Endurance Analysis	2	30	Design Material to Optimize Operating Temp
			Overload	Inability To Activate Rod, Uncontrollable Jig Face	4	Overstressing, Impact Loading	3	Material Configuration / Dynamic Loading Analysis	2	24	Specify Operating Load Conditions
			High Cycle Fatigue	Weaken Mechanism Integrity,	5	Poor Maintence	3	Dynamic Loading / Multi-Material Fatigue Analysis	2	30	Design Material to Optimize Stress-Life Curve
	15) Rod	Stops rotation of gear	Abrasive Wear	Weaken Mechanism Integrity	5	Assembly Error	3	Material Science Analysis (Hardness)	2	30	Increase Material Hardness
			Bending	Uncontrollable Jig Face, Damage Gear Teeth	7	Poor Design, Overstressing	3	Stress Strain / Bending Limit Analysis	2	42	Ensure Poper Proper Part Dimensions and Material Specification
			Impact Wear	Weaken Mechanism Integrity, Noise	8	Overstressing, Poor Operation, Assembly Errors	3	Material Science Analysis (Hardness)	2	48	Increase Material Hardness
			Creep Buckling	Uncontrollable Jig Face, Damage Gear Teeth	6	Poor Design, Overstressing	2	Material Configuration / Dynamic Loading Analysis	2	24	Optimize Material Melting Point, Increase Grain Size, Use Alloying

Variable Manifold Sliding System	2) Large steel tube (square)	Slides in part # 1 to allow for manifold variation	Yielding	Operation Tolarance failure,	8	Overstressing, Poor Operation, Assembly Errors	3	Material / Configuration Dynamic Loading Analysis	2	48	Ensure Proper Material And Dimension Specification
			Ductile Fracture	Structural Failure, Flying Debris	9	Poor Material Selection, Overstressing,	3	Stress Strain / Deformation Limit Analysis	2	54	Optimize Material Stress Strain Curve
			Overload	Operation Tolarance failure,	8	Assembly Error, Oversressing	3	Material Configuration / Dynamic Loading Analysis	2	48	Specify Operating Load Conditions
			Temperature Induced Deformation	Operation Tolarance failure,	7	Poor Assembly, Poor Maintenance	2	Thermal Endurance Analysis	2	28	Design Material to Optimize Operating Temp
			High Temperature Fatigue	Transformations of the material structure, Operation Tolarance failure,	7	Diffusion Processes, Aging, Dislocation Restructuring	2	Thermal Endurance Analysis	2	28	Design Material to Optimize Operating Temp
			High Cycle Fatigue	Weaken Mechanism Integrity,	8	Poor Maintenance	3	Dynamic Loading / Multi-Material Fatigue Analysis	2	48	Design Material to Optimize Stress-Life Curve
			Creep	Operation Tolarance failure, Flying Debris	8	Poor Maintenance, Poor Assembly	2	Material Configuration / Dynamic Loading Analysis	2	32	Optimize Material Melting Point, Increase Grain Size, Use Alloying
			Buckling	Inability to Slide, Lose Variation Fuction,	8	Poor Maintenance, Poor Assembly, Poor Design	2	Stress Strain / Deformation Limit Analysis, Dynamic Loading Analysis	2	32	Ensure Poper Proper Part Dimensions and Material Specification
			Abrasive Wear	Weaken Mechanism Integrity	8	Assembly Error	3	Material Science Analysis (Hardness)	2	48	Increase Material Hardness

	3) Small steel tube (square)	Slides in part # 2 to allow for manifold variation	Yielding	Operation Tolarance failure, Structural Failure, Flying Debris	8	Overstressing, Poor Operation, Assembly Errors	3	Material / Configuration Dynamic Loading Analysis	2	48	Ensure Proper Material And Dimension Specification
			Dutile Fracture	Structural Failure, Flying Debris	9	Repeated Overstressing	3	Stress Strain / Deformation Limit Analysis	2	54	Optimize Material Stress Strain Curve
			Temperature Induced Deformation	Operation Tolarance failure,	7	Poor Maintenance, Overheating	3	Thermal Endurance Analysis	2	42	Design Material to Optimize Operating Temp
			High Cycle Fatigue	Weaken Mechanism Integrity,	8	Poor Maintenance	3	Dynamic Loading / Multi-Material Fatigue Analysis	2	48	Design Material to Optimize Stress-Life Curve
			Creep	Operation Tolarance failure, Flying Debris	8	Poor Maintenance, Poor Assembly	3	Material Configuration / Dynamic Loading Analysis	2	48	Optimize Material Melting Point, Increase Grain Size, Use Alloying
			High Temperature Fatigue	Transformations of the material structure, Operation Tolarance failure,	7	Diffusion Processes, Aging, Dislocation Restructuring	3	Thermal Endurance Analysis	2	42	Design Material to Optimize Operating Temp
			Overload	Operation Tolarance failure,	8	Overstressing	3	Material Configuration / Dynamic Loading Analysis	2	48	Specify Operating Load Conditions
			Creep Buckling	Operation Tolarance failure, Lose Variation Function	8	Poor Material Selection, Poor Mainenance,	3	Material Configuration / Dynamic Loading Analysis	2	48	Optimize Material Melting Point, Increase Grain Size, Use Alloying
			Abrasive Wear	Weaken Mechanism Integrity	8	Assembly Error	3	Material Science Analysis (Hardness)	2	48	Increase Material Hardness
	15) Pin	Secures sliding tube location	Abrasive Wear	Weaken Mechanism Integrity	4	Assembly Error	3	Material Science Analysis (Hardness)	2	24	Increase Material Hardness
			Bending	Lock in place, require forced removal, Temporary loss of variation ER,	5	Overstressing, Poor Assembly, Impact Loading	2	Stress Strain / Bending Limit Analysis	2	20	Ensure Poper Proper Part Dimensions and Material Specification
			Impact Wear	Weaken Mechanism Integrity,	5	Overstressing, Poor Assembly, Impact Loading	3	Material Science Analysis (Hardness)	2	30	Increase Material Hardness
			Creep Buckling	Operation Tolarance failure, Flying Debris	5	Poor Maintenance, Poor Assembly	2	Stress Strain / Deformation Limit Analysis	2	20	Optimize Material Melting Point, Increase Grain Size, Use Alloying
Foot Pedal	9) Aluminum Sheet Metal	Toggle jig locking mechanism	Ductile Fracture	Inability To Lock	8	Overstressing, Assembly Error	3	Material / Configuration Dynamic Loading Analysis	2	48	Ensure Proper Material Specification
			High Cycle Fatigue	Weaken Mechanism Integrity, Inability to Effectively Activate Spring	7	Poor Maintenance	2	Dynamic Loading / Multi-Material Fatigue Analysis	2	28	Design Material to Optimize Stress-Life Curve
			Abrasive Wear	Weaken Mechanism Integrity	7	Assembly Error	3	Material Science Analysis (Hardness)	2	42	Increase Material Hardness
			Forced Induced Deformation	Weaken Mechanism Integrity, Inability to Effectively Activate Spring	7	Impact Loading, Poor Operation,	3	Stress Strain / Deformation Limit Analysis	2	42	Ensure Poper Proper Part Dimensions and Material Specification
	10) Hinge	Allow foot pedal rotation	Abrasive Wear	Inability To Lock	6	Assembly Error	3	Material Science Analysis (Hardness)	2	36	Increase Material Hardness
			High Cycle Fatigue	Weaken Mechanism Integrity, Inability to Effectively Activate Spring	6	Poor Maintenance	2	Dynamic Loading / Multi-Material Fatigue Analysis	2	24	Design Material to Optimize Stress-Life Curve

	13) Spring	Lock the jig in place	Abrasive Wear	Inability To Lock Eratic Operation	6	Overstressing, Assembly Error	3	Material Science Analysis (Hardness)	2	36	Increase Material Hardness
			Low Temperaure Fatigue	Weaken Mechanism Integrity,	7	Poor Maintenance	2	Thermal Endurance Analysis	2	28	Design Material to Optimize Operating Temp
			Overload	Inability to Activate Epper Locking Mechanism,	7	Overstressing	2	Material Configuration / Dynamic Loading Analysis	2	28	Specify Operating Load Conditions
			High Cycle Fatigue	Weaken Mechanism Integrity, Inability to Effectively Activate Rod	6	Poor Maintenance	2	Material Configuration / Dynamic Loading Analysis	2	24	Design Material to Optimize Stress-Life Curve
Pivot Mechanism	11) Ball Bearing	Allows rotation of skeleton frame	Abrasive Wear	Structural Failure, Flying Debris	7	Poor Maintenance, Assembly Errors	3	Material Science Analysis (Hardness)	2	42	Increase Material Hardness
			Flaking	Flying Debris, Erratic operation, Structural Failure	7	Assembly error, Rusting, Over-loading, Poor Shaft Accuracy	2	Rolling Fatigue Failure Analysis	2	28	Optimize Geometry to Reduce Contact Stresses
			Temperature Induced Deformation	Erratic operation, Noise, Structural Failure	8		2	Thermal Endurance Analysis	2	32	Design Material to Optimize Operating Temp
			Skew	Increase Temperature and Susceptibility to Temp Deformation, Erratic Operation, Vibration	8	Assembly Error, Poor Maintenance	2	Material Propertie and Loading Analysis	2	32	Improve rigidity of shaft and housing, Ensure adequate clearance
			Creep	Structural Failure, Flying Debris	7	Poor Maintenance	2	Material Configuration / Dynamic Loading Analysis	2	28	Optimize Material Melting Point, Increase Grain Size, Use Alloying
			Corrosion Wear	Erratic operation, Noise, Structural Failure	8	Poor Maintenance	2	Material Properties Given Conditions Analysis	2	32	Ensure Non-Corroive Metals
			Spalling	Flying Debris, Erratic operation, Structural Failure	8	Overloading, Poor Mainenance	3	Sub-Surface Rolling Fatigue Failure Analysis	2	48	Optimize Geometry to Reduce Contact Stresses
	12) Gear	Attached to ball bearing to allow for locking by part # 13	Surface Fatigue Wear,	Structural Failure, Flying Debris	8	Poor Maintenance, Assembly Errors	2	Part Dynamic Loading Analysis	2	32	Ensure Proper Material And Dimension Specification
			Pitting	Noise, Vibration, Increase in Temperature	9	Impact Loading, Poor Maintenance	2	Rolling Fatigue Failure Analysis	2	36	Optimize Geometry to Reduce Contact Stresses
			Temperature Induced Deformation	Erratic operation, Noise, Structural Failure	9		2	Thermal Endurance Analysis	2	36	Design Material to Optimize Operating Temp
			Bending Fatigue	Inability to Lock, Uncontollable Jig Face, Flying Debris	9	Poor Operation, Poor Design, Overstressing	3	Stress Strain / Bending Limit Analysis	2	54	Ensure Proper Material And Dimension Specification, Provide a user guidline
			Impact Wear	Weaken Mechanism Integrity, Erratic Operation	8	Overstressing, Assembly Error	3	Material Science Analysis (Hardness)	2	48	Increase Material Hardness

8.3 *Appendix C: Bill of Materials*

Team SunTrac										
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost ($)	Link to Cost estimate	Part ID	Unit Price
1	Steel tube	3	4 foot center	Comprises of the stationary middle skeleton structure	Carbon Steel	2.5" x 2.5" x 4'	$96.48	https://www.mcmaster.com/steel-tubing	4931 T146	32.16
2	Steel tube	1	Variable length	Slides in part # 1 to allow for manifold variation	Carbon Steel	2.25" x 2.25" x 8'	$62.62	https://www.mcmaster.com/steel-tubing	4931 T145	62.62
3	Steel tube	1	Variable length	Slides in part # 2 to allow for manifold variation	Carbon Steel	2" x 2" x 8 '	$50.93	https://www.mcmaster.com/steel-tubing	4931 T144	50.93
4	Carbon Steel Strip	2	6' piece of low carbon strip	Bind all three variable length tubes together	Carbon Steel	2.0" x 1/8" x 6'	$54.82	https://www.mcmaster.com/steel-strips	6511 K511	27.41
5	Steel beam	3	Tripod	Holds welding jig upright	Carbon Steel	2.5" x 2.5" x 8'	$187.86	https://www.mcmaster.com/steel-tubing	4931 T146	62.62
6	Angle Iron	2	Vertical Pipe Supports	Positions the Vertical Copper Pipes	Low-Carbon Steel	1.5" x 1.5" x 6'	$33.90	https://www.mcmaster.com/angle-iron	9017 K484	16.95
7	Ball Bearing	1	Rotational Ball Bearing	Allow rotation	Mild Steel	2.5" x 2.5" x 1" x 52"	$110.62	https://www.mcmaster.com/ball-bearings	8828 T221	110.62
8	Pipe Clamp	4	Bolt tightening pipe clamp	Secure horizontal pipes	Galvanized Iron	33mm OD for pipe size of 1.0"	$92.76	https://www.mcmaster.com/pipe-clamps	8868 T63	23.19
9	Aluminum Sheet Metal	1	sheet metal used for foot pedal	Used to toggle jig locking mechanism	Multipurpose 6061 Aluminum Sheet	8" x 8"	$16.95	https://www.mcmaster.com/aluminum-sheets	8901 5K239	13.86
10	Hinge	1	Hinge used in foot pedal assembly	Allow foot pedal rotation	5052 Aluminum	6" x 1.5" x 0.05"	$4.97	https://www.mcmaster.com/hinges	1586 A36	4.97
11	Metal Wire	1	Stainless Steel Wire	Connect the foot pedal to the spring	Multipurpose 304 Stainless Steel Wire	0.162" x 14'	$12.06	https://www.mcmaster.com/metal-wire	8860 K24	12.06
12	Spring	1	Foot Pedal Assembly Spring	Lock the jig in place	301 Stainless Steel	0.5" x 1.5"	$7.13	https://www.mcmaster.com/springs	1986 K264	7.13
13	Gear	1	Locking Mechanism	Allows rotation of skeleton	1020 Carbon	OD = 4", 48 teeth	$84.49	https://www.mcmaster.com/gears	5172 T36	84.49

				frame	Steel					
14	Pin	6	Locking Mechanism	Secures position of sliding tubes	18-8 Stainless Steel	3" 3/32"	$36.36	https://www.mcmaster.com/pins	94563A571	36.36
15	Pin	1	Locking Mechanism	Stops rotation of gear	4140 Alloy Steel	3/32"	$10.00	https://www.mcmaster.com/pins	98381A121	10
Total Cost Estimate:							$861.95			

8.4 Appendix D: Full Risk Trade Off Analysis

Risk Trade Off Analysis								
Engineering Requirement (ER) Improving Actions	Risk Factor	Risk Description	Impact	Impacted Criteria	Criteria Weight	Impact	Total Rating	Relative Rating
1) Reduce Force to Rotate					**0.07**			
1a) Replace end beam with sheet metal	0.4	Increase susceptability to force induced deformation						
Reduces moment of inertia			+	Force to Rotate	0.07	0.07	-0.0056	-0.01
Lessens material mass			+	Cost	0.17	0.17		
Decreases rigidity of jig face			-	Durability Error	0.11 0.11	-0.242		
1b) Reduce to three face beams	0.6	Enhance effects and possibility of yielding, high cycle fatigue,						
Decreases moment of inertia			+	Force to Rotate	0.07	0.07	0.084	0.14
Decrease part count			+	Cost	0.17	0.17		
Decrease structural support/rigidity			-	Durability Error	0.11 0.11	-0.22		
2) Reduce Cost					**0.17**			
2a) Decrease number of face beams	0.6	Enahnce effects and possibility of yielding, high cycle fatigue,						
Decreases moment of inertia			+	Force to Rotate	0.07	0.07	0.204	0.33
Decrease part count			+	Cost	0.17	0.17		
Decrease structural support/rigidity			-	Durability Error	0.11 0.11	-0.22		
2b) Decrease beam yield strength (low-carbon steel)	0.6	Increase susceptability to yielding, high cycle fatigue, surface fatigue wear, buckling						
Decrease yield strength/hardness			-	Durability	0.11	-0.11	0.612	1.00
Save on material costs			+	Cost	0.17	0.17		
2c) Implement manual locking	0.3	Small increase in risk of user injury (current						
Decrease number of locking positions			-	Adaptability	0.07	-0.07	0.51	0.83
Decrease part count			+	Cost	0.17	0.17		
3) Decrease Footprint					**0.08**			
3a) Reduce tripod leg angle from vertical	0.4	Increase resistance to buckling and brittle						
Decrease stability			-	Durability	0.11	-0.11	-0.144	-0.24
Decrease required floor space			+	Footprint	0.08	0.08		
4) Increase Durability					**0.11**			
4a) Increase number of structural member	0.4	Decrease susceptability to yielding, high cycle fatigue, surface fatigue wear, buckling						
Increase part count			-	Cost	0.17	-0.17	-0.396	-0.65
Increase structural support			+	Durability	0.11	0.11		
5) Decrease Error					**0.11**			
5a) Strengthen pin material	0.2	Decrease susceptability to yielding, surface fatigue wear, buckling, abrasive wear						
Increase cost			-	Cost	0.17	-0.17	0.11	0.18
Increase rigidity			+	Durability	0.11	0.11		
Decrease tolerance			+	Error	0.11	0.11		
5a) Increase yield strength (4130 alloy steel tube material)	0.6	Decrease susceptability to yielding, high cycle fatigue, surface fatigue wear, buckling						
Increase cost			-	Cost	0.17	-0.17	0.33	0.54
Increase rigidity			+	Durability	0.11	0.11		
Decrease tolerance			+	Error	0.11	0.11		

8.5 *Appendix E: Full Component FMEA*

Product Name - Brazing Jig	Development Team: Edwin, Ethan, Kadijah, Nathan	Page No 1 of 1
System Name - Manifold Production		FMEA Number 1
Subsystem Name		Date 11/06/2019
Component Name		

Part #	Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1) Steel tube (square)	Comrpises of the stationary middle skeleton structure	High Cycle Fatigue	Operation tolarance failure	7	Overstressing	1	Material / Configuration Dynamic Loading Analysis	2	14	Ensure Proper Material And Dimension Specification
2) Steel tube (square)	Slides in part # 1 to allow for manifold variation	Yielding, Brittle Fracture, High Cycle Fatigue, Creep, Creep Buckling, Abrasive Wear	Operation Tolarance failure, Structural Failure, Flying Debris	9	Overstressing, Poor Operation, Assembly Errors	2	Material / Configuration Dynamic Loading Analysis	2	36	Ensure Proper Material And Dimension Specification
3) Steel tube (square)	Slides in part # 2 to allow for manifold variation	Yielding, Brittle Fracture, High Cycle Fatigue, Creep, Creep Buckling, Abrasive Wear	Operation Tolarance failure, Structural Failure, Flying Debris	9	Overstressing, Poor Operation, Assembly Errors	2	Material / Configuration Dynamic Loading Analysis	2	36	Ensure Proper Material And Dimension Specification
4) Carbon Steel Strip	Bind all three varaible length tubes together	Temperature induced deformation, High, Cycle Fatigue	Negative Effects On Error ER, Jiyg Face Deformation, Decrease in Durabilit	6	Overstressing, Poor Material design, Assembly Error	2	Material / Configuration Dynamic Loading Analysis	2	24	Ensure Proper Material And Dimension Specification
5) Steel beam	Holds welding jig upright	Yielding, Brittle Fracture, Creep, Creep Buckling	Structural Failure, Flying Debris	10	Overstressing, Poor Operation, Assembly Errors	1	Material / Configuration Dynamic Loading Analysis	2	20	Ensure Proper Material And Dimension Specification
6) Metal Wire	Connect the foot pedal to the spring	High Cycle Fatigue, Streething	Inability To Lock	5	Overstressing, Assembly Error	1	Static Loading Analysis	2	10	Ensure Poper Material Specification
7) Angle Iron	Secure vertical pipes	Temperature induced deformation	Operational Tolerance Failure, Bond Manifold To Bracket	6	Excessive Use	2	Thermal Expansion Analysis	2	24	Ensure Proper Material Specification
8) Pipe Clamp	Secure horizontal pipes	Temperature induced deformation, Abrasive Wear	Operational Tolerance Failure,	4	Excessive Use	3	Thermal Expansion Analysis	2	24	Ensure Proper Material Specification
9) Aluminum Sheet Metal	Toggle jig locking mechanism	Ductile Fracture, High Cycle Fatigue, Forced Induced Deformation	Inability To Lock	4	Overstressing, Assembly Error	2	Material / Configuration Dynamic Loading Analysis	2	16	Ensure Proper Material Specification
10) Hinge	Allow foot pedal rotation	Abrasive Wear, High Cycle Fatigue,	Inability To Lock	4	Overstressing, Assembly Error	2	Material / Configuration Dynamic Loading Analysis	2	16	Ensure Proper Material Specification
11) Ball Bearing	Allows rotation of skeleton frame	Abrasive Wear, Spalling	Structural Failure, Flying Debris	7	Poor Maintenance, Assembly Errors	2	Part Dynamic Loading Analysis	2	28	Ensure Proper Material And Dimension Specification
12) Gear	Attached to ball bearing to allow for locking by part # 13	Surface Fatigure Wear, Impact Wear	Structural Failure, Flying Debris	7	Poor Maintenance, Assembly Errors	2	Part Dynamic Loading Analysis	2	28	Ensure Proper Material And Dimension Specification
13) Spring	Lock the jig in place	Abrasive Wear, High Cycle Fatigue,	Inability To Lock	4	Overstressing, Assembly Error	2	Material / Configuration Dynamic Loading Analysis	2	16	Ensure Proper Material Specification