# UNIVERSITY OF MANITOBA

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# Ambutech Joiner Operation Design

Presented to: Dr. Paul Labossiere

Date: December 7th, 2016

**Consulting Team 11 – Melet Plastics**

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[MECH 4860] –University of Manitoba – [Mechanical Engineering]

# LETTER OF TRANSMITTAL

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Anna Schappert

Team 11 – Melet Plastics

Team Administration

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December 7th, 2016

Dear Dr. Labossiere,

Please find enclosed the final design report for the Ambutech Joiner Operation from Team 11, which consits of Ahmed Hammad, Connor McKay, Curtis McQuarrie, and Anna Schappert. Ambutech is a division of Melet Plastics which manufactures and sells mobility canes.

The purpose of the enclosed report is to present the design for the joining process within the Ambutech manufacturing cell. The team was tasked with reducing the operator's time spent at the joiner operation of the assembly line. This will allow the operator to spend more time at the tape rolling process, which is creating a bottle neck further down the assembly line. The joiner process takes cut shafts from the previous step in the assembly line, and forces ferrules into the shaft using an actuator. By using a combination of operator input and automation, operator time is expected to be significantly reduced.

The team successfully designed an automated machine which will join ferrules with shafts in the appropriate combinations with the operator time reduced to 50% of machine run time. Please contact me if you have any questions,

Sincerely,

Anna Schappert

Team Administration – Team 11

# EXECUTIVE SUMMARY

Ambutech is a division of Melet Plastics Inc. which manufactures mobility canes. Ambutech provides their customers with a custom product made of aluminum, fiberglass, or graphite. Aluminum and graphite canes make up 93.8% of total sales. The project focused on the joining process for assembling graphite and aluminum canes.

The team analyzed Ambutech's manufacturing process using the 8-step method. Both aluminum and graphite lines are standalone and run in tandem. The takt time for the cane assembly process is 281 [s/cane] for both the aluminum and graphite assembly lines. Currently the only stages of the manufacturing under the takt time are the aluminum press and final assembly stage of both canes. The goal of the project was to reduce operator time needed at the joiner process so that the operator can spend more time at the tape roller, which is the current bottleneck in the assembly line.

With an understanding of the process, concept generation, and concept selection completed, the detailed design could begin. The team separated the machine into three sections: shaft delivery, ferrule delivery, and the joiner. Fatigue analysis was completed on parts which experienced high loads and large cycle counts to extend the life of the machine. The final concepts were: vibratory hoppers for the ferrule delivery system, three shaft hoppers with a capacity of 50 shafts are used for the shaft delivery system, and a shaft rotator with replaceable inserts and an electric linear actuator is used for the joining operation.

Consideration was made to reduce the payback period, maintenance costs, and costs associated with machine downtime.  The machine was designed to be identical between the two manufacturing lines, with only the applied force needing to be changed between the aluminum and graphite lines.  One machine will cost $ 44 564.28 CAD, which includes all materials, components, and labor to assemble the machine, which is within budget.

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# 1. INTRODUCTION

Melet Plastics is a manufacturing company based in Winnipeg, Manitoba, whose core business is the manufacture of injection molded plastics. Ambutech is a division within Melet Plastics, whose mandate is to manufacture high quality mobility canes to their customer's specifications to be delivered within 2 weeks of the order being placed. Ambutech is proud to be the largest supplier of mobility canes in North America and Europe.  As the leading supplier in the mobility cane industry, Ambutech uses a combination of automated and manual assembly processes to achieve the quality their customers are looking for.

For this project, the team was tasked with improving the joiner process within the mobility cane assembly line.  The canes are designed to be folded into sections for ease of storage. For this to be possible, ferrules are needed to align the sections when the cane is in use. Joining the ferrules to the shafts is one of the more involved processes in the can manufacturing process. The joiner process is the second step in the assembly line, which takes a shaft cut to length, and presses three different combinations of ferrules into the appropriate top, middle, or bottom shaft section of the cane.  The team was tasked with improving the joiner process within the Ambutech assembly line.  Figure 1 shows a shaft with both female and male ferrules inserted.
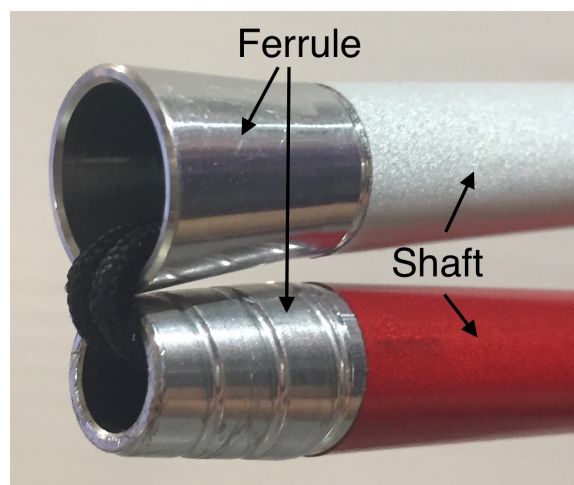


Figure 1 – Ferrules pressed into a complete cane

The background of the report shows how the joiner process works, the sales of each model of cane produced, and how the current process is unable to keep up with the increase in demand.  To further define the problem, a client oriented needs analysis was completed, and technical specification requirements follow. Once the process was understood, concept creation was initiated.  The joiner process was split into three sections, shaft delivery, ferrule, delivery, and joining to simplify the problem and create the best solution. The 48 concepts generated were reduced down to three through screening and scoring, and then confirmed using a sensitivity analysis and client input.

The contents of the detailed design section show a preliminary analysis of how the new joining machine works and how it will improve upon the old pressing method. This comparison between the old and new machines is important as the proposed design is entirely new and does not integrate with the old pressing method. The detailed design covers the selection of common components used, the design of the shaft delivery system, the design of the ferrule delivery system, and the design of the joining system. These sections go in-depth into the material, dimensions, and the operational design of the joining machine.

## 1.1 BACKGROUND

Melet Plastics has tasked our team with improving the joiner process which joins ferrules into each section of the cane, hereafter called shafts.  Ambutech is projected to see a 194% increase in mobility cane sales.  The manufacturing cell is unable to keep up with this increase in demand, and has created a backlog in work and an increase in overtime shifts. To combat this, the manufacturing cell needs to be able to withstand a throughput rate increase from 3,000 to 5,000 canes per month on both the aluminum and graphite assembly lines.

The scope of this project is to design a machine that is capable of joining different combinations of shafts and ferrules with minimal input from the operator.  This process includes the operation of the machine and the movement of material through the machine.

The scope includes the immediate area to the machine within 1 foot in all directions. Any pre-processing and post-processing of the material is considered out of scope. Ladder logic, timers, manufacturing, and testing of a detailed prototype are to be done upon completion of the project by the client.

The current machines used for the joining operation are different between the aluminum and graphite production lines. Ferrules are manually inserted into the shafts, and then shafts are placed into a bed where they are pressed. The operator must attend the machine at all times while this process is in operation. The current machines are shown in Figure 2 and Figure 3.

Summary of steps for the current aluminum joining process:
1. The operator inserts the male and/or female ferrule into the end of the shaft
2. The shaft-ferrule combination is then placed in the vertical bed of the joiner
3. A cover is then manually closed to initiate the hydraulic piston used to the join
4. While piston is pressing, the operator repeats steps 1 and 2 on the next shaft
5. The next shaft is then placed in a parallel bed that shares the same cover
6. Cover is rotated to cause next shaft to be pressed while completed shaft is removed
7. Steps 3 through 6 are then repeated until there are no more shafts to join
8. Completed shafts are inspected for incomplete presses, and if found, are re-pressed in the machine
9. Shafts are then delivered onto the next process

The cover between the two beds creates operator wait time between the first shaft being completed and the second shaft ready for pressing. The aluminum press is shown in Figure 2.
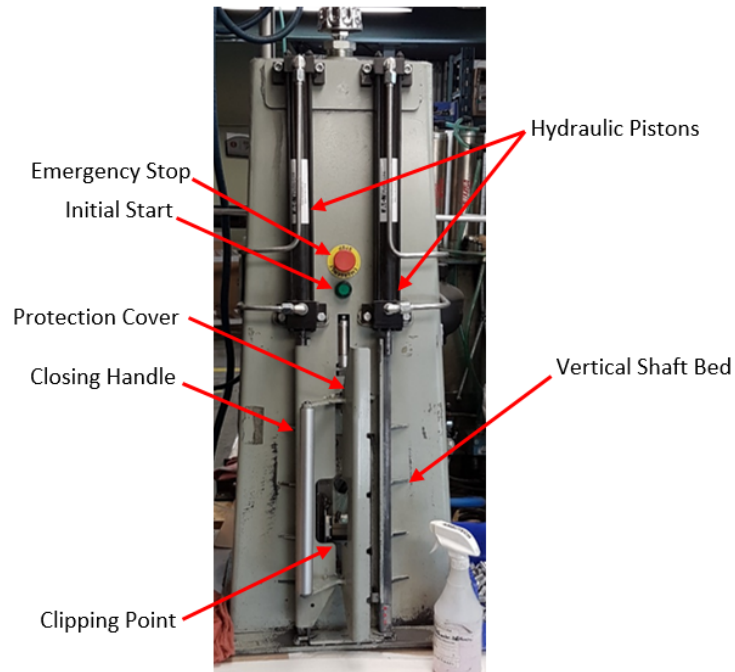
Figure 2 - Aluminum joining machine

The graphite joining process follows a similar process as the aluminum joiner. The difference is the graphite machine can join multiple shafts per one press cycle. The current graphite joining machine has the following steps:

1. The operator inserts male and/or female ferrules into the ends of four shafts
2. The operator adjusts the platform to the closest of the three heights available
3. The shafts are placed in the suitable locations
4. The safety cover is closed
5. The operator holds down two switches which start the joining process
6. The joined shafts are removed and put aside
7. Steps 1 through 4 are repeated until the batch has been completed
8. The completed shafts are checked to ensure the ferrules have been fully inserted into the shaft
9. If a shaft was deemed in need of a repress, steps 4 to 7 are repeated
10. Shafts are then delivered onto the next process

The graphite press is shown in Figure 3.
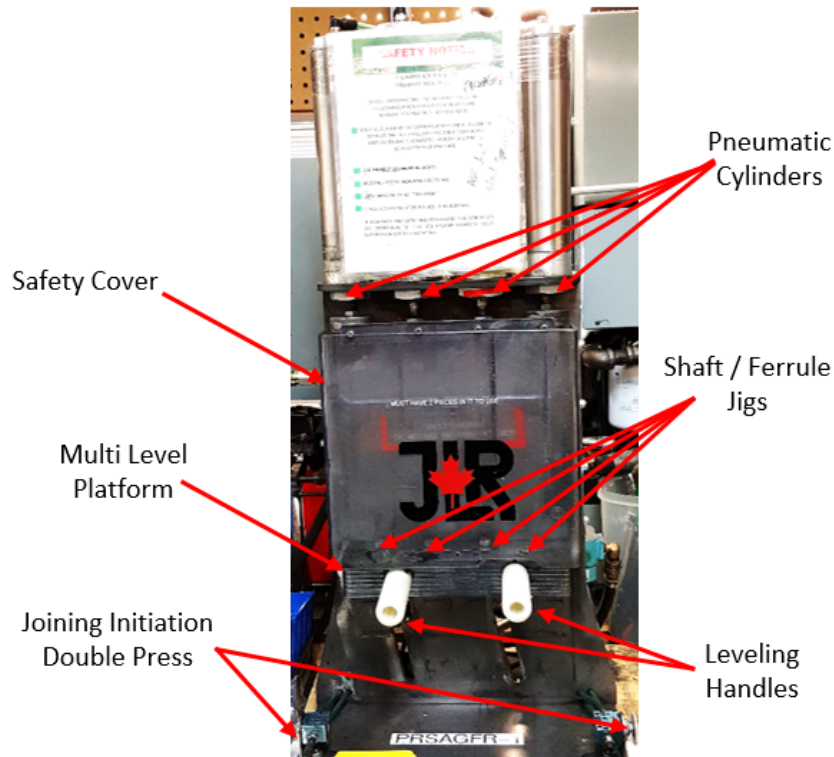
Figure 3 - Graphite pressing machine

There are issues with the current machines.  The safety of these machines is not up to the level which Melet Plastics would like to be operating at.  The graphite joining process often requires re-work on shafts after they have been pressed.  The operator must attend the joining machine while it is in operation, which is time that could be better spent at the tape roller process.

The team determined that the current throughput rate of the joiner process is 78.9 [s/shaft] and the utilization is 18.5%. By improving the joiner process, the utilization rate will improve to 50%, which is expected to increase the throughput rate beyond 10 000 canes per month.

The project focuses on Ambutech's two best selling canes types, aluminum and graphite. These canes currently make up 94% of Ambutech's sales, as seen in Table I. By increasing product throughput rate, Ambutech will be able to meet increasing demands and function

smoothly during peak demand periods. A more in-depth analysis of Melet Plastic's sales can be found in Appendix A.

TABLE I - AVERAGE PERCENTAGE OF CANES SOLD PER MONTH

| Shaft Material | % |
| --- | --- |
| Aluminum | 47.2 |
| Fiberglass | 2.9 |
| Graphite | 46.6 |
| Slimline | 3.2 |

By improving both press operations and eliminating the issues specified below, the project is expected to increase productivity of the equipment, reduce costs related to defects and operator time, and eliminate any safety concerns.

The specific deliverables for this project are:
- o  Solidworks models and a drawing package of the new machine in Appendix F
- o  A process flow diagram and operating instructions for the process in section 2.5
- o  A cost breakdown of implementing the recommended solution in Appendix A
- o  Any additional press related documentation created during the course of the work
- o  A copy of the final report and presentation

## 1.2 CURRENT PROCESS

The cane assembly process steps are as follows: cut the shaft to length, inserting the ferrules into the shaft, roll reflective stickers onto the shaft, connect the shafts together using an elastic cord, attaching the cane tip, and then packaging for shipment. The operation we are focusing on in the assembly process is the insertion of the ferrules into the shafts, hereafter called the "joiner operation".

Table II summarizes the existing process flow by describing the cane manufacturing process owner, key stakeholders, stakeholder concerns, process performers, purpose and outputs, the processes' customers, the suppliers, and inputs. Understanding the needs of the joiner operation customer allows the team to narrow the focus on what is needed out of

the process to satisfy the processes customers. The metrics for validating the customer needs are the throughput rate, as it correlates to the proper quantities of shafts being provided, and the first pass yield, as it correlates to the shafts and ferrules being joined correctly.

TABLE II - PROCESS WORKSHEET

| Process Owner | | |
|---|---|---|
| Laura Hudek – Production Coordinator | | |
| **Key Stakeholders** | **Stakeholder Concerns** | |
| Operators | Easy to use process | |
| Production Coordinator (Laura Hudek) | High capacity/ Low defects | |
| Management (Noel Mattson) | High enough capacity | |
| Engineering (Carl Rogers) | High enough capacity | |
| Maintenance | Easy to maintain | |
| **Process Performers** | **Requirements** | |
| Ambutech Operator | Move raw materials, control press operation and remove finished product | |
| **Purpose** | **Outputs** | |
| To join a shaft and two ferrules. | Shaft joined with two ferrules. | |
| **Customers** | **Customer Needs and Wants** | **Validating Customer Needs** |
| Final Assembly | Desired quantities of completed shafts and ferrules | Throughput rate [s/shaft] and First Pass Yield (FPY) |
| **Suppliers** | **Inputs** | |
| Cutting Station | Shafts Ranging from 4" to 16" in 2" increments | |
| Raw Materials | Male and Female Ferrules | |

The next step in understanding the process flow is mapping the process, which is shown in Figure 4.  It is important to note that the aluminum line and graphite line run in parallel.  The projects scope is highlighted in gold in the process map.

**Inputs**      **Processes**      **Inputs**

Start       Start

| Raw Materials (Aluminium Tube) | Shaft Cutter (Automated) Output - Cut Shaft | Shaft Cutter (Automated) Output - Cut Shaft | Raw Materials (Fiberglass or Graphite Tube) |

**Project Scope**

| Raw Materials (Aluminium Ferrule) | Ferrule-Shaft Joiner (Manual) Output - Joined Ferrule and Shaft | Ferrule-Shaft Joiner (Manual) Output - Joined Ferrule and Shaft | Raw Materials (Plastic Ferrule) |

| Raw Materials (Tape) | | | Raw Materials (Tape) |

| Tape Cutter (Automated) Output - Cut Tape | Tape Roller (Manual) Output - Tape/Shaft Combined | Tape Roller (Manual) Output - Tape/Shaft Combined | Tape Cutter (Automated) Output - Cut Tape |

| Raw Materials (Tape and Grip) | Grip Press (Manual) Output - Grip on Handle Shaft | | Raw Materials (Tape and Grip) |

| Raw Materials (Cord, Tip, packaging, other accesories) | Final Asembly (Manual) Output - Completed Cane | Final Asembly (Manual) Output - Completed Cane | Raw Materials (Cord, Tip, packaging, other accesories) |

Shipping

Figure 4 - Process flow chart

Table III outlines the current and desired target for process performance. This is important for knowing how much the process needs to improve to meet requirements. Currently the process takt time is 281 [s/cane]. The only steps of the process which are under the takt time are the aluminum press and the assembly station for both aluminum and graphite canes. The utilization for all of the processes is low, due to one operator focusing on the shaft cutting, joining and, tape rolling.  This shows that the load balancing between the three process steps needs to be improved.  Fixing the issues highlighted in Table III will allow for load rebalancing between the processes as the operator will be able to do other work when less time is spent working with the joiner.  This rebalancing will increase the tape rolling processes speed since the operator will be working at it more, which will increase the assembly process throughput rate.

TABLE III - PROCESS PERFORMANCE SUMMARY

| Output | Dimensions | Measure | Current Level | Target Level | |
|---|---|---|---|---|---|
| Aluminum Assembled Ferrule and Shafts | Throughput Rate | [s/shaft] | 42.6 | 56.16 | |
| | Quality | FPY (%) | 100 | 100 | |
| | Safety | Number of Concerns | 2 | 0 | |
| | Utilization | % | 13.5 | 13.5 | |
| Graphite Assembled Ferrule and Shafts | Throughput Rate | [s/shaft] | 64.3 | 56.16 | |
| | Quality | FPY (%) | 85 | 98 | |
| | Safety | Number of Concerns | 3 | 0 | |
| | Utilization | % | 14.5 | 14.5 | |
| **Inputs** | **Process Steps** | | | | **Output** |
| | Shaft Cutter | Joiner | Tape Roller | Final Assembly | |
| Throughput Rate [s/cane] | 130.91 | 171.43 | 244.07 | 144 | 690.41 |
| Utilization [%] | 23.6 | 18.50% | 21.60% | 100.00% | |
| Target Condition | Remains Constant | Automated with minimal setup time or operator input | Higher utilization through increase operator input | Increased throughout through extra man power freed up from the Joiner operation | Few defects and little rework needed on canes |
| **Source of Problem** | **Location of Occurrence** | **Impact** | | | |
| Joiner needs an operator to function | At the joiner | Pulls operator away from other steps in the process, this causes the throughput rate to decrease and leads to low equipment utilization | | | |
| Tape roller is slow to operate | At the tape roller | Pulls operator away from other steps in the process, this causes the throughput rate to decrease and leads to low equipment utilization | | | |

Figure 5 is the value stream process summary, which is an overview of all relevant data to the process for easy reference.

**Value Stream: Ambutech Joiner Operation**

**Mission or Purpose:** To increase monthly capacity from 3300 to 6400 per month

**Demand Rate or Volume that flows through the Value Stream?** 4000 canes per month

**What is the Output of the Value Stream?** A cane

| | Stakeholders: | Project Team, Operators, Maintenance | Process Performers: Operators |
|---|---|---|---|
| **Value Stream Owner:** Laura Hudak | | | |

| | Cutting Station | Joiner | Tape Roller | Final Assembly |
|---|---|---|---|---|
| **S – Supplier:** | Stores | Cutting Station and Raw Materials | Joiner and Raw Materials | Tape Roller and Raw Materials |
| **I – Input:** | Raw Materials (Either Graphite or Aluminium Shafts) | Cut to Length Shafts (Cutting Station) Ferrules (Raw Materials) | Joined Shaft/Ferrule Assemblies (Joiner), Cut to Length Tape (Raw Materials) | Tape Covered Shafts (Tape Roller), Handle (Raw Materials), Tip (Raw Materials), Cord (Raw Materials) |
| **P – Process (Value Stream Step):** | Cutting Station | Joiner | Tape Roller | Final Assembly |
| **O – Output:** | Cut to Length Shafts | Joined Shaft and Ferrules | Tape Covered Shafts | Assembled Cane |
| **C – Customer:** | Joiner | Tape Rolling Station | Final Assembly | Shipping |
| **KPI: Throughput Time — Throughput Rate (seconds per Cane)** | Aluminium Assembly Line: 282.4 Graphite Assembly Line: 130.9 | Aluminium Assembly Line: 171.4 Graphite Assembly Line: 144 | Aluminium Assembly Line: 360 Graphite Assembly Line: 244.1 | Aluminium Assembly Line: NA Graphite Assembly Line: 144 |
| **Takt Time (seconds per Cane)** | 219.4 | 219.4 | 219.4 | 219.4 |
| **Challenges and Obstacles:** | Machines need to be frequently replenished and the aluminium saw creates numerous defects (around 30%-40% from first review) | The joiner requires an operator to be there at all times to use and it shares an operator with the saw and the tape roller so utilization is low | The tape roller requires an operator to be there at all times to use and it shares an operator with the saw and the joiner so utilization is low | Assembly is at 100% utilization and is not able to meet demand. |

**Key Requirements:** Proper Throughput Rate
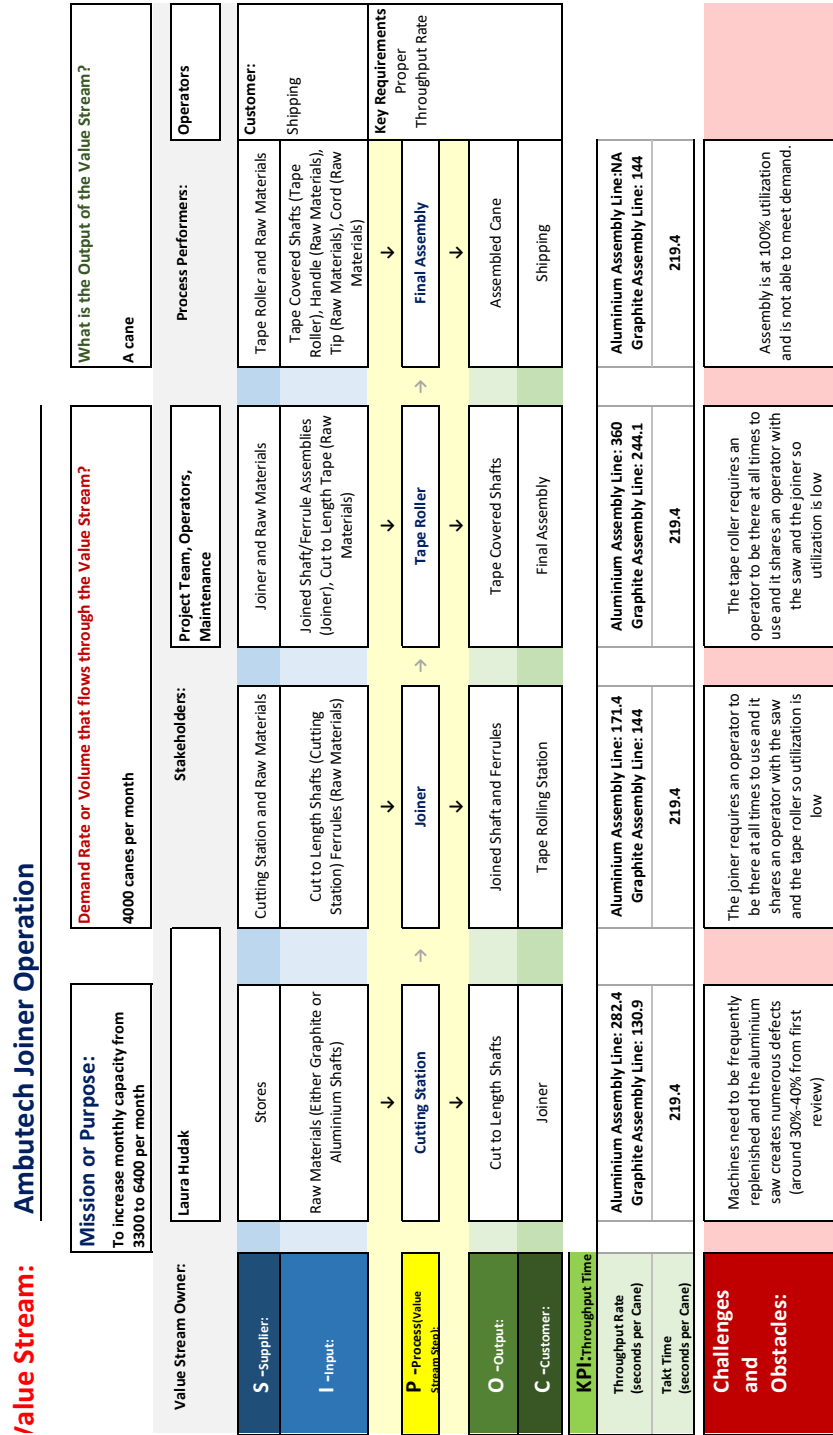
**Customer:** Shipping

Figure 5 - Value stream map

Melet Plastics has tasked us with developing safe and simple to use machines that are capable of efficiently and quickly inserting ferrules into the shafts of canes.  This specific process was given to us because Ambutech is experiencing an increase in demand, and desires an increase in production capacity.  Ambutech can currently produce 6000 canes per month and requires an increase in peak monthly capacity to 10 000 canes to meet the increasing demand.  This productivity lever increase increase needs to be done, while improving the level of safety and reducing the defect rate.

The scope of this project is restricted to the two cane ferrule-shaft joiners in the aluminum and the graphite assembly lines. The joiner process starts after the shaft is cut to length and ends before the tape rolling process.

The current aluminum press has a throughput rate of 42.6 [s/shaft] with a utilization of 13.5%.  The current graphite press has a throughput rate of 64.3 [s/shaft] with a utilization of 14.5%.  This leads to a throughput rate of 213 [s/cane] for the aluminum line and 321 [s/cane] for the graphite line.  The required takt time for the process to meet the increased monthly capacity is 281 [s/cane].  The only processes which meet the required takt time are the aluminum press and the cane assembly process for both lines.

Figure 6 and Figure 7 show the current and proposed operator time and run time. Figure 8 shows the process throughput rates in comparison to the takt time.
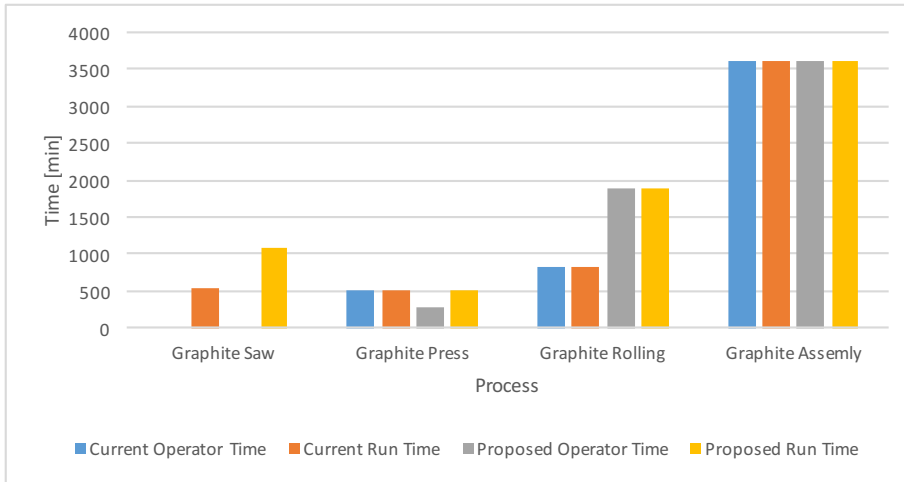
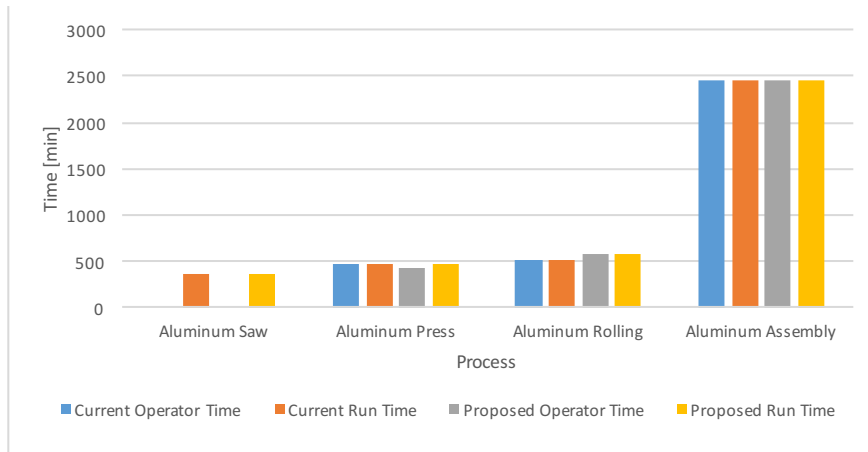Figure 6 – Current and proposed operator and run time comparison: Graphite



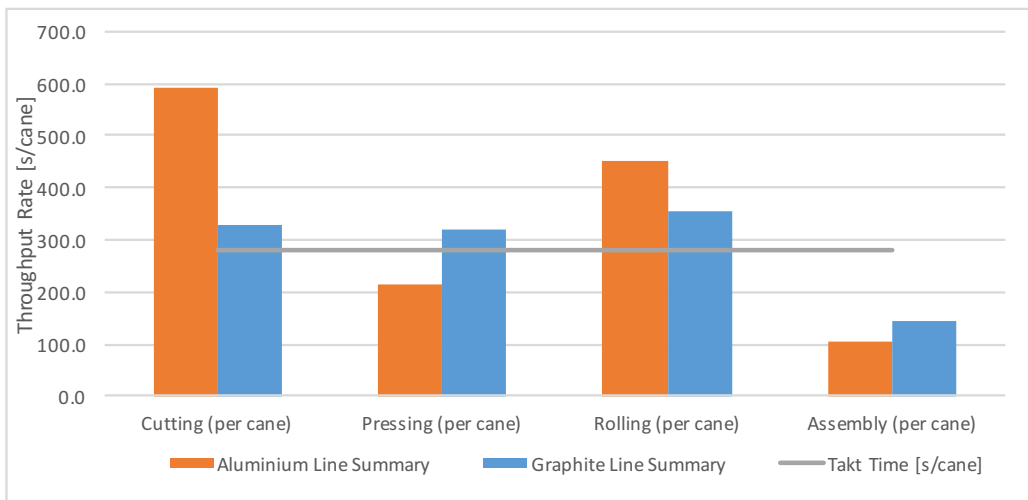Figure 7 – Current and proposed operator and run time comparison: Aluminum



Figure 8 - Takt time summary

## 1.3 NEEDS ANALYSIS

The following section includes a full analysis of our customers' requirements. These requirements were obtained from site visits to Melet Plastics and were further refined by our team to identify exactly what our proposed designs are to accomplish. The top needs were identified as the following:

- o Improved Joiner safety
- o Joiner operation automation
- o The ability to accommodate multiple shaft lengths.

After needs were determined, our team constructed engineering metrics that allowed the team to measure each need. Along with the metrics, the team established target specifications with the input of our clients. Important target values that our customer set were the following:

- o Zero safety concerns
- o A decreased combined operator and setup time to 1.5 s/shaft
- o Joiner ability to accommodate all 7 shaft lengths

A more in-depth analysis can be found in the proceeding pages, and a condensed summary of our findings can be found in the House of Quality, shown in section 1.3.2.

### 1.3.1 CONSTRAINTS AND LIMITATIONS

The existing constraints and limitations were the following:

- o The joiner needs to be as compact as possible
- o The joiner fabrication needs to stay within a budget of $ 90 000
- o The joiner design will need to be completed within 90 days
- o The joiner needs to operate with minimal noise

After the first site visit to Ambutech, the team found that the work area had limited space to accommodate any equipment. The current footprint of the existing joiners is approximately 144 in$^2$. It is possible to move other existing equipment included in the assembly process in order to accommodate a larger joiner and to reduce operator time spent traveling. The layout and foot print of the manufacturing cell can be seen in Figure 6.
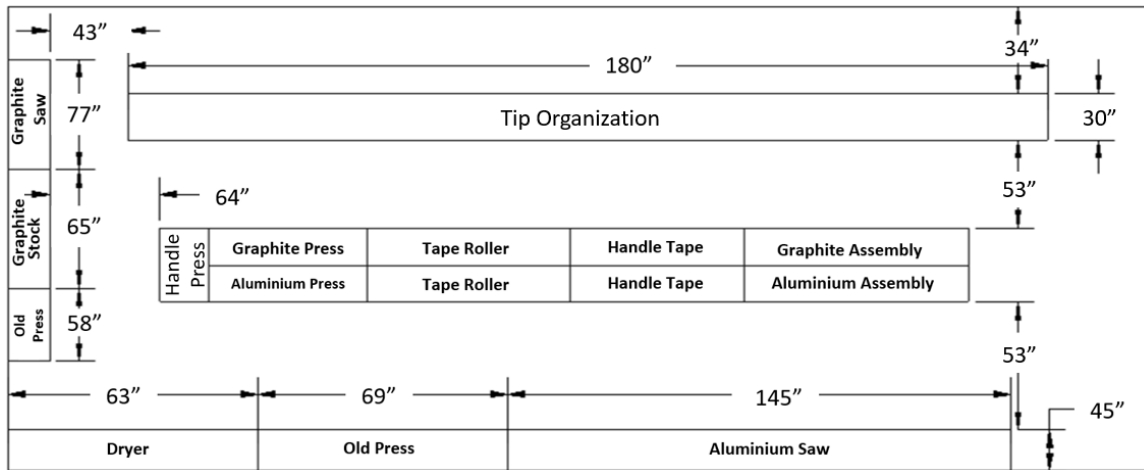


Figure 9 - Ambutech manufacturing cell footprint

The current layout of the manufacturing cell leads to the operator spending large amounts of time walking from station to station. Figure 10 show all the movements one operator completed during a 1-hour period.
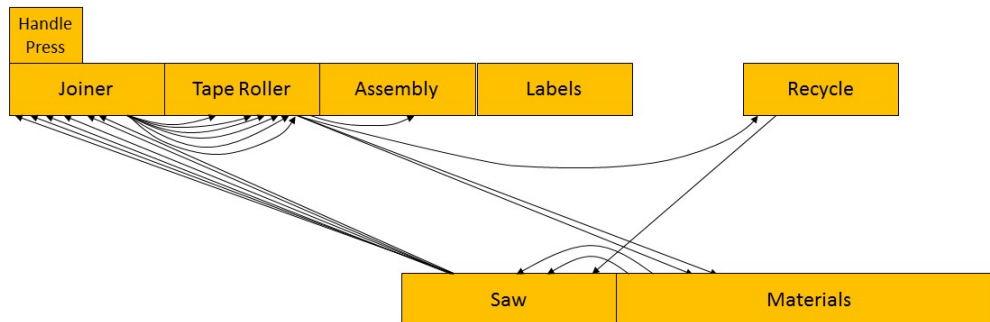


Figure 10 - Aluminum assembly line spaghetti diagram 2

Figure 11 shows all the movements one operator completed during a 15-minute period.
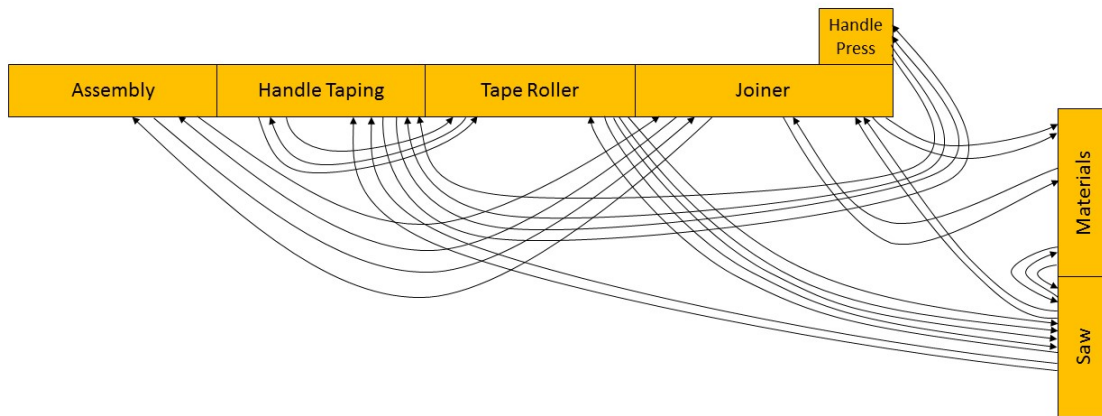


Figure 11 - Graphite assembly line spaghetti diagram

The spaghetti diagrams show the amount of travel involved in manufacturing the canes. The travel time and the operator movement is wasted time and effort that costs money and decreases the quality of work enjoyed by the employees. The new process will greatly reduce the amount of movement the employee must do in a day due to the ability to start the machine and then walk away from it to focus on another task. Figure 12 shows the expected reduced number of movements that the operator will make in a 15-minute period. The spaghetti diagram in Figure 12 is based off of the expected operating and cycle times of all of the machines in the cane production process.
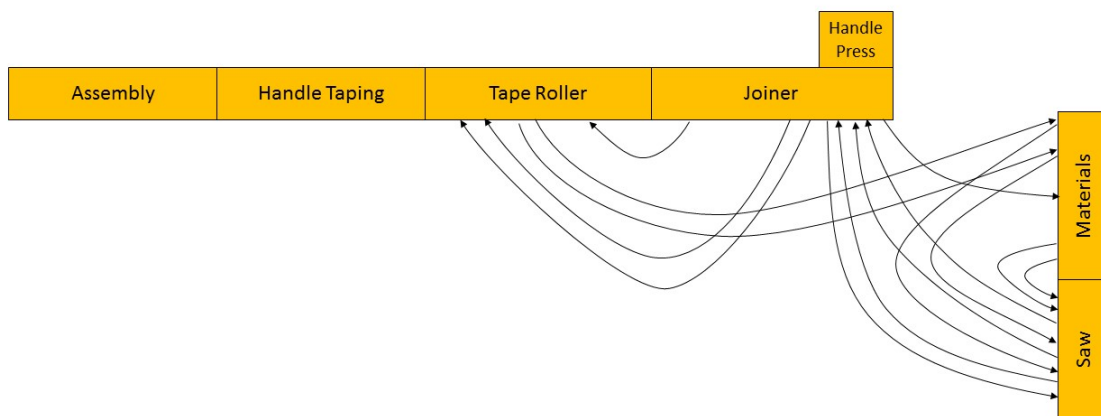


Figure 12 - Expected operator movement spaghetti diagram for a 15-minute time period

For the design of the new joiner process, Melet Plastics has budgeted $90 000 for a solution to be implemented, a full cost breakdown is given in Appendix A. Custom parts will be limited in the design in order to stay below budget because they are commonly more expensive than the off-the-shelf components.

Designing joiners that operate with minimal noise is a requirement for employee health and safety. The employees on the floor already wear hearing protection, however it is important to ensure that the noise level meets the workplace health and safety standards.

## 1.3.2 NEEDS, METRICS, AND SPECIFICATIONS

After meeting with Melet Plastic, the desired needs for the joiner operation was determined and agreed upon. Table IV shows each product need statement with an importance determined by the team and the client, where 5 is high and 1 is low. Table V shows each metric and which need it relates to.

TABLE IV – PRODUCT NEED STATEMENTS AND IMPORTANCE

| ID | Needs | Importance |
|----|-------|------------|
| 1 | Joiner machine is simple | 4 |
| 2 | Joiner process is quick | 3 |
| 3 | Joiner operation need to be reliable | 4 |
| 4 | Joiner operation needs to allow for operator multitasking | 5 |
| 5 | Joiners need to be safe to operate | 5 |
| 6 | Joiners need to be able to handle a variety of shaft lengths | 5 |
| 7 | Joiners need to be able to handle different materials | 2 |
| 8 | Joiners need to be simple to operate | 4 |
| 9 | Joiners need to be easily maintained and serviced | 3 |
| 10 | Joiners need to be standardized | 1 |

TABLE V – RELATION OF METRICS TO CORRESPONDING NEED STATEMENT

| Metrics | ID of Need Metric Relates To |
|---|---|
| First Pass Yield [%] | 1 |
| Sufficient force to join materials [N] | 1, 2 |
| Cycle Time [s/shaft] | 1, 2, 3 |
| Percent custom parts [%] | 3, 9, 10 |
| Down time per shift [min/shift] | 3, 9 |
| Percentage of Similar parts [%] | 3, 6, 7, 8, 9, 10 |
| Setup time [s/shaft] | 4, 8 |
| Operator Time [s/shaft] | 4, 8 |
| Number of Steps to Operate [#] | 4, 8 |
| Number of Safety Concerns [#] | 5 |
| Number of non-ergonomic Operator Motions [#] | 5 |
| Variety of dimensions [#] | 6 |
| Variety of shaft materials [#] | 7 |
| Variety of ferrule materials [#] | 7 |
| Accessibility of Parts [subjective] | 9 |

The joiners must be simple. The metrics related to joiner efficiency are first pass yield, the amount of force applied to join the materials, and the cycle time. These metrics were chosen because the defect rate accurately measures waste in the operation, and the force applied and the cycle time are measures of how power efficient the process is.

The joiner process must be quick. The metrics related to joiner speed are the machine's cycle time and the force required to join the shaft to the ferrule. The metrics were chosen because the joiner's cycle time directly affects the throughput rate of the process.  Having a high cycle time will result in starving processes further down the line.

The joiners must be reliable during operation. The metrics related to joiner reliability are the percentage of the machine made of custom parts, the amount of joiner downtime per shift, and the percentage of similar parts between the two joiners. The metrics were chosen because the number of custom parts and the number of parts that are similar between the

two joiners affect the ease of part replacement during repairs, and the down time per shift reflects the reliability of the machine, which in turn affects throughput.

The joiners must operate in such a way that the operator can do another task while the machine operating. The metrics related to joiner autonomy are the setup time, the operator time required for the joiner to function, the cycle time of the joiner, and the number of steps to operate.  As each of these functions increase, the amount of time operator needs to spend at the machine also increases. These metrics were chosen because the amount of setup time, the amount of time the operator must spend at the joiner, and the number of steps required to operate the joiner, determine how much time the operator can spend away from the joiner.  The cycle time was chosen as it determines how frequently the operator needs to attend to the machine.

The joiners must be safe to operate. The metrics related to safety are the number of safety concerns with the final design and the number of non-ergonomic operator motions.  Safety concerns are considered to be pinch points, sharp edges, raw material projectiles, and un-contained moving parts.  Number of non-ergonomic motions are considered to be the operator bending, twisting, and reaching, because they directly relate to the potential for repetitive motion injuries.

The joiners need to be able to handle a variety of shaft lengths. The metrics related to the joiner's flexibility are the number of discrete lengths that the joiner is capable of processing and the number of similar parts between the two joiners. These metrics were chosen because the shaft length varies in two inch increments from four inches to 16 inches. The number of similar parts between the two joiners is a weak indicator of the joiner's ability to handle a variety of shaft lengths, as both joiners need to be able to manage the various shaft lengths.

The joiners must be able to handle a variety of different materials. The metrics related to the joiner's flexibility are the variety of shaft materials it can handle, the number of ferrule materials the joiner can handle, and the amount of similar parts between the two joiners. The number of materials and number of shafts metrics were chosen becasue they

accurately represent the variety of materials encountered by the joiner. The number of similar parts between the two joiners is a weak indicator of the joiner's ability to handle a variety of shaft materials as both joiners need to be able to manage the various shaft materials.

The joiners must be simple to operate. The metrics related to the joiner's simplicity of operation is the number of steps required to operate the joiner, including setup steps, the amount of setup and operator time, and the percentage of similar parts between the two joiners. These metrics were chosen because the number of operations that it takes to use the joiner, the amount of setup time, and the amount of operator time all correlate to the amount of time that the operator will need to spend with the machine. The percentage of similar parts between the two joiners indicates they will be more likely to have a similar method of operation and reduce the learning curve required to use both joiners.

The joiner must be easy to maintain and service. The metrics related to the joiner's ease of maintenance are the percentage of custom parts, the accessibility of the parts, the amount of down time per shift, and the percentage of similar parts. These metrics were chosen because the percentage of custom parts relates to the ease of acquiring a part if it is needed, the accessibility of the parts affects how easy it is to inspect, remove, and install parts if needed, the amount of similar parts between the two joiners indicates the number of different parts that need to be on hand, and the amount of down time per shift is an indicator of how quickly the joiners can be serviced.

The joiners must be as standardized as possible. The metrics related to the joiner's standardization is the percentage of similar parts between the two joiners and the number of custom parts in each joiner. These metrics were chosen because they directly correlate to how many of the parts are interchangeable.

After meeting with Melet Plastics, the metrics and specifications for the joiner operation were determined and agreed upon. Table VI shows the metrics and specifications with the specifications that define them.

TABLE VI - METRICS AND SPECIFICIATION

| Metric | Target Specification | Marginal Specification |
|---|---|---|
| First Pass Yield[%] | 98.5% | 95% |
| Force to Join Materials [lbf] | Aluminum: 1575 Graphite: 270 | +/- 10% of target force |
| Cycle Time [s/shaft] | <5 | <8 |
| Percent Custom Parts [%] | < 5 | < 15 |
| Downtime per shift [min/shift] | 5 | <10 |
| Setup Time [s/shaft] | <1 | <2 |
| Operator Time [s/shaft] | <0.5 | <1 |
| Number of Safety Concerns [#] | 0 | 2 |
| Variety of Shaft Materials [#] | 4 | 1 to 2 |
| Variety of Ferrule Material [#] | 4 | 1 to 2 |
| Variety of Shaft Lengths [#] | 7 | 7 |
| Number of Steps to Operate [#] | < 5 | < 10 |
| Number of Non-Ergonomic Operator Motions [#] | < 3 | < 7 |
| Accessibility of Parts [subjective] | All parts easy to access | Most parts easy to access |
| Percentage of Similar part [%] | >95 | >85 |

The target specification for the first pass yield is 98.5% was chosen because it is a significant improvement over the observed first pass yield of 85%. This was chosen as a 10-fold improvement over the current defect rate [15,000 defects per million opportunities vs. 150,000 defects per million opportunities] which is an attainable improvement.

The target specification for the cycle time is 5 [s/shaft], which was determined by looking at the required takt time for processing each shaft and the current cycle times of the machines, which are detailed in Appendix B.

The target specification for the required force was chosen as 1575 lbf for an aluminum shaft, and 270 lbf for a graphite shaft. The value was determined experimentally as the minimum force required to press the ferrules in to the shaft plus a safety factor to ensure the ferrule is fully inserted. The most efficient process will be the joiner applying the exact amount of force needed. The results of the testing that the team conducted can be found in Appendix C.

The target specification for the percent of custom parts is < 5% because that has been deemed a negligible percentage of parts by the team and accounts for any required stands and mounting brackets that are unlikely to fail and need replacing.

The target specification for down time per shift is 5 [min/shift], which gives a total of 75 minutes of down time per week on average, so any design created must be easily fixed to return the joiner to service as quickly as possible.

The target specification for the setup time is 1 [s/shaft], because that is the allowable time determined after analysis of the current throughput rate and takt times. The times are measured in [s/shaft] to allow for proper throughput rate calculations and to allow for variable batch sizes to be accurately compared if needed.

The target specification for the operator time is 0.5 [s/shaft], because that is the allowable time determined after analysis of the current throughput rate and takt times. The times are measured in [s/shaft] to allow for proper throughput rate calculations and to allow for variable batch sizes to be accurately compared if needed.

The target specification for the number of safety concerns is zero, because the joiner should have all potential sources of injury guarded, altered to be safe, or removed.

The target specification for the variety of shaft lengths is seven because that is the total number of potential lengths that need to be processed, as the shaft lengths go from four inches to 16 inches in two inch increments.

The target specification for the variety of shaft materials is two because that is the number of different shaft materials to be focused on for cane fabrication.

The target specification for the variety of ferrule materials is two because that is the total number of different ferrule materials used for cane fabrication.

The target specification for the number of steps to operate the joiner is five or fewer because that is fewer or equal to the number of steps that is currently needed to operate the joiner.

The target specification for the number of non-ergonomic operator motions is based on the process requiring two thirds of the required steps to operate.  This is because they can not be entirely eliminated, but should be reduced over the number of operator motions.

The target specification for the accessibility of the parts is subjective.  The specification focuses on if the parts can be reached without needing to remove other parts, through an access door or, how easy it is to manipulate the joiner.

The target specification for the percentage of similar parts is 95% or greater, because it is expected that potential mounts and bases will need to be different, but other parts, such as hardware, can be similar between the two.

Once the needs, metrics, and target specifications were determined, the House of Quality was created. The House of Quality enables one to locate the relationships between needs and metrics at a glance. These relationships help us to determine which metric to focus on to achieve a specification. Strong, medium, and weak relationships can be identified using the symbols in the supplied legend. Needs that have several strong relationships were focused on as a priority.

Through analyzing the House of Quality, our team found that there are certain needs that can be adjusted more easily than others. By utilizing the "correlation strength" column we found that these needs were: operator multitasking, joiner efficiency, and joiner simplicity.

This is important because those customer requirements also happen to have the highest weight of importance.

Correlation strength is only part of the analysis because some metrics are out of scope. The out of scope metrics are illustrated in the bottom row of the House of Quality. Metrics that are out of scope and therefore not testable include the cycle time, downtime, and first pass yield. These metrics can only be tested once a prototype is created, which is beyond the project scope.

The House of Quality is useful because it organizes the target and marginal specifications in a localized section of the table; making it quicker and easier to see. The completed House of Quality is shown in Figure 13.

The right hand side of the House of Quality shows a benchmarking of the top three to four concepts determined in the concept selection phase. This benchmarking allows the concepts to be compared at a glance as the visualization of the rankings makes it easier to see the differences between the concepts.

**Legend**

| Symbol | Relationship | Value |
|---|---|---|
| Θ | Strong Relationship | 9 |
| O | Medium Relationship | 3 |
| ▲ | Weak Relationship | 1 |

**Legend**

| | | | | | |
|---|---|---|---|---|---|
| FH | Ferrule Hopper | SC | Shaft Chute | JG | Gravity Rotation Joiner |
| FS | Slot Fedder | SS | Step Motor | JS | Step Motor Design |
| FM | Removeable Magaize | SH | Hinge Design | JC | Converyor Joiner |
| FC | Contoured Acuator | | | | |

**Engineering Metrics (Columns 1–15)**

1. First Pass Yield [%]
2. Force to Join Materials [N]
3. Cycle Time [s/unit]
4. Percent Custom Parts [%]
5. Downtime per shift [min/shift]
6. Setup Time [s/shaft]
7. Operator Time [s/shaft]
8. Number of Safety Concerns [#]
9. Variety of Shaft Materials [#]
10. Variety of Ferrule Material [#]
11. Variety of Shaft Lengths [#]
12. Number of Steps to Operate [#]
13. Number of Non-Ergonomic Operator Motions [#]
14. Accessibility of Parts [subjective]
15. Percentage of Similar part [#]

**Customer Requirements / Relationship Matrix**

| Row # | Weight of Importance | Customer Requirements | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Correlation Strength |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4 | The equipment needs to efficiently insert the joiners into the shafts | Θ | Θ | ▲ | | | | | | | | | | | | | 0 |
| 2 | 3 | The equipment needs to insert the joiners into the shafts quickly | | O | Θ | | | | | | | | | | | | | 0 |
| 3 | 4 | The equipment needs to be reliable | | | ▲ | | Θ | | ▲ | | | | | | | | ▲ | 0 |
| 4 | 5 | The equipment's operation needs to allow for operator multitasking | | ▲ | | | | O | Θ | | | | | O | | | | 0 |
| 5 | 5 | The equipment needs to have safety features | | | | | | | Θ | | | | | | O | | | 0 |
| 6 | 5 | The equipment needs to accommodate multiple product lengths | | | | | | | | | | | Θ | | | | ▲ | 0 |
| 7 | 2 | The equipment needs to accommodate different product materials | | O | | | | | | | Θ | O | | | | | ▲ | 0 |
| 8 | 4 | The equipment needs to be simple to use | | | | | | ▲ | O | | | | | O | | | ▲ | 0 |
| 9 | 3 | The machine needs to be ergonomic | | | | | | ▲ | ▲ | O | | | | | O | | | 0 |
| 10 | 3 | The equipment needs to be easily maintained/serviced | | | O | O | | | | | | | | | | Θ | O | 0 |
| 11 | 1 | The equipment needs to be standardize relative to each other | | | O | | | | | | | | | | | | Θ | 0 |

**Competitive Analysis (1 = Best, 5 = Worst)**

| Row # | Ferrule Feeder (1–5) | Shaft Delivery (1–5) | Joiner (1–5) |
|---|---|---|---|
| 1 | ------ M --- FH FS FC --- ------ | SC --- SS SH ------ | ------ JG JS - -JC --- ------ |
| 2 | ------ FH FM FS ----FC ------ | SH --- SS SC ------ | ------ JG JS - -JC --- |
| 3 | ------ FC FH ------ FM --- FS --- | ------ SH ---------- SC SS ------ | ------ JC ----JG --- JS ---- ---- |
| 4 | FH --- ------ FC FM ------ FS | ------ SC SS SH -------- | JG ----JS JC ------ ------ |
| 5 | FH ---: FM FS ------ ------ | SC SH ----SS | JG JC JS ----------- |
| 6 | ------ FH FC ----- FS FM | SC SH SS --- -------- | JS JG JC ----- |
| 7 | ------ FC FH FS ---- FM ----- | ------ SC SH SS ----- ------ | JC JG --JS --- ----- ---- |
| 8 | FH --- ------ FC ----FM FS --- | ------ SC SH SS ----- ------ | JC ----JG JS ----- ----- |
| 9 | FH --- ------ FC --- FM FS --- | ------ SC SS SH -------- | JC ----JG JS ------ |
| 10 | ------ ------ FC FM FS --- FH --- | ------ SC ---------- ------ SS SH ------ | ------ ------ JC ---- JS JG ------ |
| 11 | ------ FC FS FC FH ------ ------ | SC --- SS SH ------ | JG ---------- JS JC ------ ------ |

**Target or Ideal Value / Marginal Values / Difficulty of Testing**

| Column | Target or Ideal Value | Marginal Values | Difficulty of Testing (0=Easy to Accomplish, 10=Extremely Difficult) |
|---|---|---|---|
| 1 | 98% | 90% | 8 |
| 2 | Alu: 7000 [N] / Gr.: 1200 [N] | Within 10% of Target Force [N] | 0 |
| 3 | 7 s/shaft | 8 to 11 s/shaft | 10 |
| 4 | < 5% | < 15% | 0 |
| 5 | 5 min/shift | <10 min/shift | 10 |
| 6 | 6 s/shaft | 7 to 10 s/shaft | 6 |
| 7 | 6 s/shaft | 7 to 10 s/shaft | 6 |
| 8 | 0 | 2 | 2 |
| 9 | 2 | 1 | 1 |
| 10 | 2 | 1 | 1 |
| 11 | 7 | 7 | 1 |
| 12 | < 5 | < 10 | 2 |
| 13 | < 3 | < 7 | 2 |
| 14 | All parts easy to access | Most parts easy to access | 3 |
| 15 | 0.05 | 0.15 | 0 |

Figure 13 – House of Quality

## 1.4 CONCEPT SELECTION

The design was separated into three modular sections for better refinement of the design. These sections are the ferrule delivery, shaft delivery, and the joiner. Through the use of research, brainstorming, and decision matrices, 48 concepts were created and reduced down to a final three.

Once a large pool of concepts had been created the team used a comparison screening process, using the current graphite press as the baseline, to eliminate weak concepts and move forward with the stronger concepts.  The stronger concepts were then scored on a scale of one through 10 on their ability to meet the specific criteria.  The three highest scored concepts were presented to the client for review and evaluation.  With the client's approval the team moved forward with the following three concepts:  vibratory ferrule hoppers, the shaft chute design, and the gravity rotation joiner.

To ensure the selection of the concepts was un-affected by differences in opinions, a sensitivity analysis was completed on the top five criteria.  The sensitivity analysis confirmed that the top concepts for the process were significantly affected by changes in their scores. This analysis also showed that the top concepts for the ferrule delivery system were affected by a change in the criteria's weights. The complete concept generation and analysis can be found in Appendix D.  Once the team had finalized the concept selection, the detailed design could begin.

# 2. DETAILED DESIGN

Once the concept was selected, the team could begin the detailed design. The detailed design includes a preliminary analysis for specifying the correct parts needed, and ensuring the lifecycles of the parts would withstand a reasonable lifetime. This section outlines the common parts in the machine, how the three sections of the machine work, how the machine operates, workflow through the machine, a preliminary analysis of the required Boolean logic, a preventative maintenance plan, and a cost overview.

The joining machine, involves nine major components that work together to autonomously interference fit the ferrules into the shaft. The only input from operator will be loading the shafts, loading the ferrules, the starting of the process and removing the completed shafts. Major components of design include; three shaft hoppers, two vibratory hopper ferrule feeders, an electric linear actuator, a shaft selector, a shaft rotator, and a discharge chute. Figure 14 shows the joining machine with the major components labelled. In the figure the electric linear actuator is transparent to show the position the machine. The details of the machine are found in the proceeding sections.
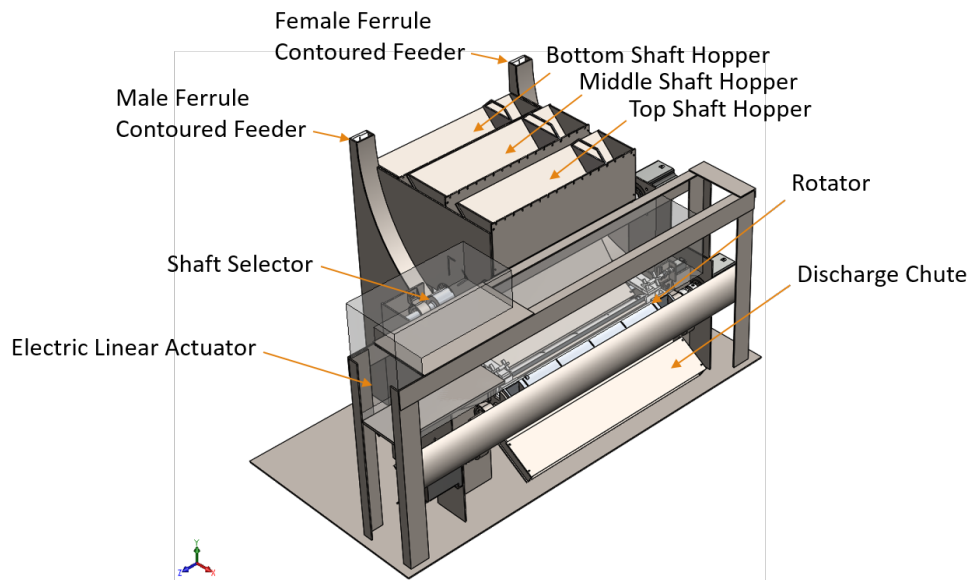


Figure 14 - Joining machine with major components labeled

## 2.1 COMMON PARTS

In order to simplify the design of the joiner machine, improve maintainability, and reduce the number of spare parts that need to be kept in stock, parts of similar function within the machine were deemed to be common parts. These common parts were selected for the worst case scenario, and then other instances of the part were kept the same, even if they were over designed for the specific application. The team determined that there are five common parts in the joiner machine: the bearing shoulders for the shaft rotator and shaft selector, the bearings for all of the shaft connections, the stepper motors and drivers used to drive the rotating parts, the couplings to join the rotating parts to the stepper motors, and the limit switches for detecting machine parts and shaft locations.

### 2.1.1 ANALYSIS OF THE SHAFT ROTATOR BEARING SHOULDER

The bearing shoulder for the shaft rotator and the shaft selector needed to be made from a different material than the main body to make sure that the shoulder was strong enough to last for at least two years. Figure 15 shows the designed bearing shoulder.
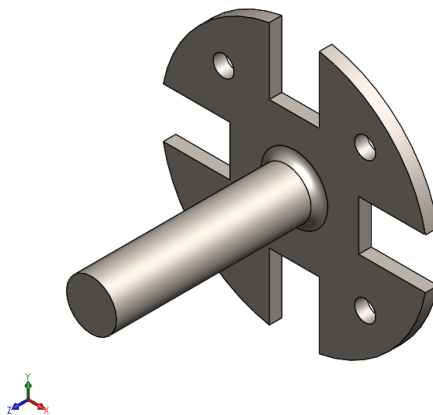


Figure 15 - Isometric view of bearing shoulder

To properly determine the required bearing shoulder diameter for the shaft rotator, a fatigue analysis was performed to ensure that the shaft would last the desired number of cycles. The method used is for shafts in reversed bending with nearly uniform torsion. The required values and the equation used, is given in Table VII and equation 3.1.1 respectively.

TABLE VII - REQUIRED SHAFT DESIGN CRITERIA [1] [2] [3] [4]

| Criteria | Value |
|---|---|
| Design Factor [N] | 2.5 |
| Stress Concentration Factor [$K_t$] | 1.8 |
| Bending Moment [M] (in-lbs) | 853.67 |
| Endurance Strength Limit [$S_n'$] (psi) | 18360 |
| Applied Torque [T] (in-lb) | 3 |
| Yield Strength [$S_y$] (psi) | 57000 |

$$D = [\frac{32\,N}{\pi}\sqrt{\left[\frac{Kt\,M}{Sn'}\right]^2 + \frac{3}{4}\left[\frac{T}{Sy}\right]^2}]^{1/3}$$

Eq. 1 [3]

Equation 3.1.1 is used to determine the required diameter of a shaft in bending and torsion only. The design factor was chosen to be 2.5 due to moderate uncertainty in the material properties. The stress concentration factor was determined based on the bearing hub diameter, the fillet radius between the bearing hub and the body of the shaft rotator, and the diameter on the face of the shaft rotator. The relevant criteria for determining the stress concentration factor, and the determined stress concentration factor, are given in Table VIII. The endurance limit at the required number of cycles for two years of operation (1.2 million cycles), the applied torque, and the yield strength of the material were determined.

TABLE VIII - STRESS CONCENTRATION FACTOR CRITERIA [1]

| Criteria | Value |
|---|---|
| Fillet Radius (in) | 0.125 |
| Bearing Shoulder Diameter (in) | 0.75 |
| Outer Diameter of Fillet (in) | 1 |
| r/d | 0.166 |
| D/d | 1.33 |
| Stress Concentration Factor ($K_t$) | 1.8 |

Using the r/d and D/d values the stress concentration is interpolated from a chart for flat bars with fillets [1]. Further research and the use of a stress concentration factor calculator calculated a stress concentration value of 1.63, which makes the 1.8 value used a much more conservative, and safer estimate [5]. It should be noted that the determination of the stress concentration factor is iterative, in that first a shaft diameter needs to be determined to calculate the stress concentration factor, then the suitability of the shaft needs to be re-evaluated based on the stress concentration determined. The values in Table VIII are for the final bearing hub diameter of 0.75 inches.

The bending moment was determined by finding the deflection due to the distributed load of the weight of the rotator shaft, and then determining what bending moment is necessary to bend the ends of the shaft back into a horizontal position. Figure 16 shows a representation of the distributed load and the bending moments being analyzed.
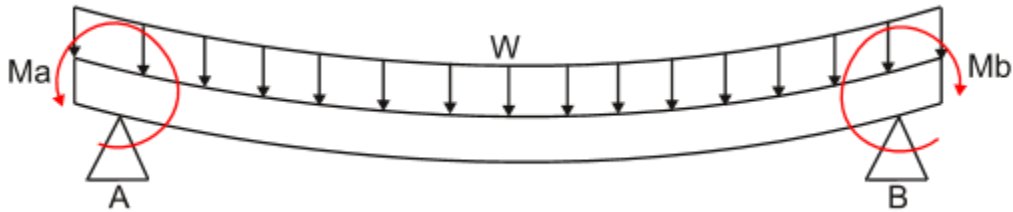


Figure 16 - Representation of  load and moments on the rotator shaft

Due to the distributed load W, the angle of deflection at each end is equal to the following equation.

$$\theta = \frac{WL^3}{24EI}$$

Eq. 2 [1]

The bending moment, Ma or Mb, can then be calculated as the moment required to create the same slope at the end of the beam. When determining this moment, the moment being applied at the other end must also be considered since it will cause bending at the end of the beam. Equation 3.1.3, shows the equation for the slope at the end of the beam due to equal but opposite moments being applied to each end. For the following analysis, only the

bending moment at location A will be solved for since the bending moments will have the same magnitude.

$$\theta = \frac{ML}{6EI} - \frac{ML}{3EI} \qquad \text{Eq. 3 [1]}$$

Equating Equations 3.1.2 and 3.1.3, the bending moment can be solved for. The solved for bending moment is given in equation 3.1.4.

$$M = \frac{(\frac{WL^3}{24EI})}{(-\frac{L}{6EI})} \qquad \text{Eq. 4}$$

## 2.1.2 BEARINGS

Two bearings where chosen to mount the rotating components on, both of them being low profile ball bearings with the difference being the shaft diameter they are suited for. The first bearing is designed for ¾ inch shafts and is used to mount the heavier parts, such as the shaft rotator, the shaft selector, and the discharge chute. The second bearing is much smaller, designed for a ¼ inch shaft, and is used for the male and female ferrule star wheels, which are made of ABS plastic.

The first bearing is designed for a ¾ inch shaft and was chosen for its small size while still being able to handle dynamic radial loads of 962 lbs at a speeds of 5800 rpm. These values are beyond the required loading requirements that the shaft rotator, the largest of the rotating parts, places on the bearing. The bearing is also double sealed to prevent dust from the aluminum and graphite shafts getting into the bearings and comes pre-greased with lithium complex grease [6].

The second bearing is designed for a ¼ inch shaft and was chosen for its small size while still being able to handle dynamic radial loads of 256 lbs at a speeds of 40,000 rpm, which are beyond the required loading requirements that the male and female ferrule star wheels' place on the bearing. The bearing is double sealed to prevent dust from the aluminum and graphite shafts getting into the bearings and comes pre-greased with lithium complex grease [7].

### 2.1.3 STEPPER MOTORS AND DRIVERS

Two stepper motors were chosen for the design, one to power the larger rotating parts and one to power the smaller ones. The decision for having two stepper motors was made due to sizing constraints, power output requirements, and the difference in cost of the motors.

The shaft rotator is the heaviest of the three parts so larger stepper motors must be able rotate the shaft rotator at the desired speed. The same stepper motor type will be used for the selector and delivery chute to reduce the amount of stock replacement parts. If the motor fails, the driver does not need to be replaced.

The rotator shaft needs to rotate $45^{\circ}$ in 0.25 seconds to match the desired overall process time of the joining operation. To calculate the torque, $\mathcal{T}$, required by the motor, the moment of inertia, $I$, of the shaft needs to be multiplied by the angular acceleration, $\boldsymbol{\alpha}$, as shown in the equation below.

$$\mathcal{T} = I\alpha \qquad\qquad \text{Eq. 5}$$

The shaft's moment of inertia is determined by the mass, $m$, and the radius, $r$, using the equation below.

$$I = \frac{mr^2}{2} \qquad\qquad \text{Eq. 6}$$

The angular acceleration depends on the angular velocity, $\omega$, and the time required $t$ using the equation below.

$$\alpha = \omega/t \qquad\qquad \text{Eq. 7}$$

The angular velocity depends on the change of angle over the change in time, $t$, using the following equation.

$$\omega = \frac{\Delta\theta}{\Delta t} \qquad\qquad \text{Eq. 8}$$

By combining the four equations above, we can calculate the minimum torque required to rotate the shaft assuming no friction from the bearings at the ends of the shaft. The mas and radius values are found through the Solidworks model of the design.  Table IX outlines the variables and associated values used for the torque calculation.

TABLE IX - TORQUE APPLIED VARIABLES

| Variable | Value |
|----------|-------|
| m (kg) | 15.88 |
| r (m) | 0.0594 |
| θ (radians) | 0.0785 |
| t(s) | 0.25 |

$$\mathcal{T} = \frac{mr^2 \frac{\Delta\theta}{\Delta t}}{2t}$$

Eq. 9

The torque required is 0.35 Nm and in imperial is 3.10 lb-in. The specified stepper motor has a minimum torque of 4.375 lb-in to allow for a factor of safety, friction from the bearings, the weight of shafts and ferrules when loaded, couplings, screws, steel inserts as well as torque degradation over time from continuous use. The stepper motor chosen to power the larger rotating components, the shaft rotator, shaft selector and, the discharge chute, must overcome the inertia of the shaft rotator, which is 3 in-lbs. Due to shaft sizing requirements for the coupling, the NEMA 34 Position Control DC stepper motor.  This motor has a max torque of 4.375 in-lbs at 720 rpm was chosen [8]. The driver chosen was the suggested driver model for the stepper motor from McMaster-Carr [9].

The stepper motor chosen to power the smaller rotating components, needed to fit within the size constraints where they are mounted.  The smaller rotating components are the male and female ferrules star wheel, and is $523.77 less than the larger [10]. The driver chosen was the suggested driver model for the stepper motor from McMaster-Carr [11].

### 2.1.4 COUPLINGS

There are two sets of couplings needed to connect the stepper motors to the rotating parts in the joiner machine. One coupling is needed to connect a ½ inch shaft to ¾ inch shaft for the larger stepper motor to the rotator shaft, shaft selector, and discharge chute.  A second type of coupling is needed to connect a 0.1574-inch shaft to ¼ inch shaft for the smaller stepper motor to ferrule star wheel connections. Both couplings need to withstand relatively low speeds of 30 rpm or less, with the ½ inch to ¾ inch coupling needing to withstand torques of 4.375 in-lbs and the 0.1574 in to ¼ inch coupling needing to withstand torques of 0.1625 in-lbs [12] [13].

Both couplings are flexible couplings, with an acetal disc flexible core and aluminum hubs with the inner diameter of the connected shafts. These couplings can withstand torques up to 30 in-lbs and rotational velocities up to 4500 rpm which are more than sufficient for the needs of the joining machine. The couplings are installed with the use of set screws to hold the hub to the shaft. The distance between the couplings are adjusted by sliding them along the length of the shaft to properly hold the flexible core between the two hubs.

### 2.1.5 LIMIT SWITCHES

The limit switched required for the joiner machine must be as small as possible, easy to mount, and easy to connect the electrical leads to. A miniature snap acting limit switch from McMaster-Carr, with screw terminals for attaching leads to was chosen in accordance to the needs [14]. The limit switch can handle loads of up to 10 amps at 250 V AC, and is CSA approved. The mounting positions also allow for easy setup and removal if the limit switches need to be replaced.

## 2.2 SHAFT DELIVERY HOPPERS

The first interaction that the operator has with the machine is loading of the different sections of shafts.  There are three different shaft hoppers per machine, which hold the separated sections of shafts before they are to be joiner.  There is an intermediate step after the section hoppers and before the joiner, which is called the delivery chute.  The features of the design are described in detail in the following section.

### 2.2.1 TOP, MIDDLE, AND BOTTOM SHAFT HOPPER

The automation in the manufacturing cell is incapable of separating the different shafts sections, and therefore this must be done by the operator. There are three shaft hoppers, top, middle, and bottom, in which the operator will load the appropriate shaft.  Each hopper is able to accommodate up to 50 shafts, which is equivalent to a batch of 10 canes, assuming that the average number of shafts in one cane is five. The hoppers are shaped in such a way that a single shaft can be transferred at one time. At the bottom of each hopper, there is limit switch that will detect the presence of a shaft. Figure 17 shows the three delivery hoppers in alignment.  The hopper farthest to the right is for the top sections of a cane, the middle hopper is in the center, and the bottom hopper is farthest to the left of the image.
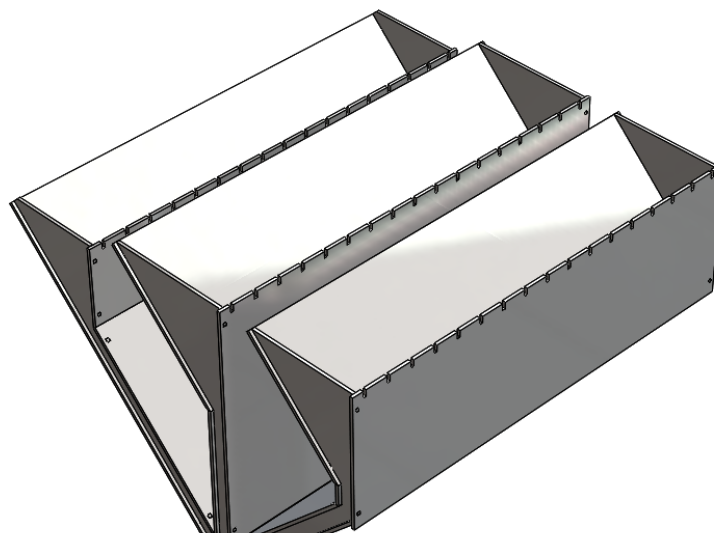


Figure 17 - Top, middle, and bottom shaft delivery hoppers

The shaft hoppers are designed to accommodate shaft lengths from four to 16 inches long. To align the shorter shafts within the large area and to disallow the shafts from becoming misaligned when being placed into the hopper, a guide is put in place.  The guide will be used to push the shafts against the wall opposite the actuator tip.  This also reduces the amount that a shaft will slide along the shaft rotator inserts which reduces wear on the full length of the insert. Figure 18 shows the shaft guide in the shaft hopper.
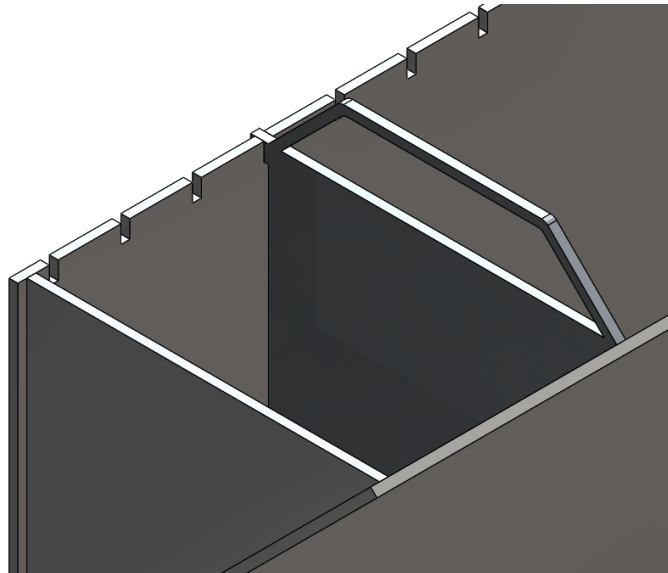


Figure 18 - Shaft guide in shaft hopper

### 2.2.2 SHAFT SELECTOR

The shaft selector functions as a selection device for the three different shafts found in a mobility cane.  Dependent on which shaft the machine will work on, it will rotate to the correct shaft hopper, and allow all shafts from the hopper to drop down into the delivery chute. It is to be made from an aluminum cylinder with ¾ inch cylindrical shoulders, as mentioned in the common parts, that allow it to mount on ball bearings at each end as well as attach to the motor. The shaft has a 16.5-inch x 0.56-inch rectangular cut out through the center to allow the shafts to pass through.  The circular form of the shaft selector acts as a block to the entrances of the other hoppers. The selection occurs between the three hoppers because shafts from each hopper require a different ferrule combination.  Figure 19 shows a top down view of the shaft selector.
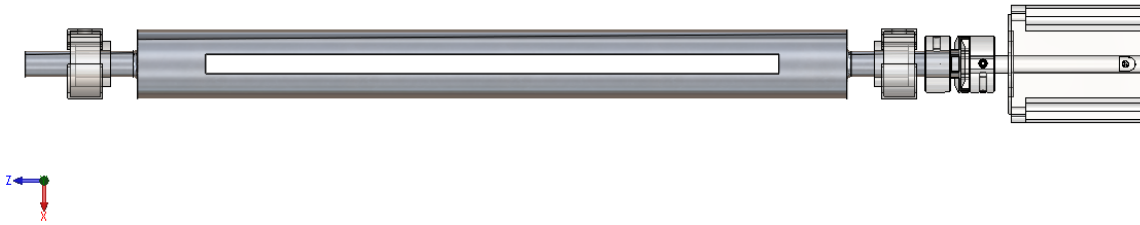
Figure 19 - Top view of shaft selector

### 2.2.3 SHAFT DELIVERY HOOPER

The shaft delivery hopper acts as a path between the shaft selector and the shaft rotator. The hopper allows the shafts to travel one by one into the shaft rotator. It is sized so that shafts can travel through it at their highest tolerance. Moreover, it allows up to five shafts to line up one after the other awaiting the joining operation. The shaft delivery hopper is angled at 30°, so that the shaft movement is driven by gravity. Just before the shaft rotator, is a limit switch to detect the presence of a shaft at the end of the delivery hopper. By having a switch just before the rotator, the machine will continue to press the correct shaft-ferrule combination until there are no shafts in the delivery chute. Figure 20 shows the shaft delivery chute.
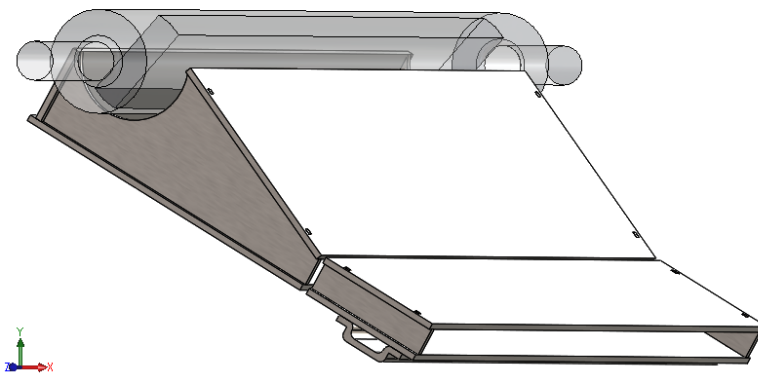


Figure 20 - Shaft delivery chute

## 2.3 FERRULE FEEDERS

The purpose of the ferrule feeder system is to correctly orient and transport the ferrules into their respective shaft rotator inserts one at a time. Our team selected the vibratory hopper and contoured magazine ferrule feeder designs after considering the alternatives and consulting with the client. In addition to the two mentioned designs, there is an independent subsystem of the ferrule feeder system that will individually deliver ferrules into their respective shaft rotator insert. This section introduces the ferrule droppers, star wheel, and limit switch. The star wheel and limit switch will be needed for both ferrule feeder designs.

### 2.3.1 VIBRATORY HOPPER

During our concept design selection, it was determined that the vibratory hopper design would be the most effective at orientating and transporting the ferrules. To accommodate each ferrule style, four vibratory hoppers are needed.  One for each type of ferrule for both the aluminum and graphite shafts.

After a discussion with the customer, it was determined that the vibratory hoppers need to be contracted out to a supplier. Figure 21 shows a vibratory hopper, currently in use in a different assembly cell within Melet Plastics. Parts are dropped down into the hopper and when a part is needed, the vibration is initiated, which pushes the parts up a track.  The track is contoured in a way that will align the part in the correct orientation and can be directed in any way the designer chooses.

With the assistance of our primary contact, Carl Rogers, we were able to obtain a quote from their vibratory hopper suppliers. The supplier determined that creating hoppers for the ferrules is possible but each individual hopper will cost $15,000.
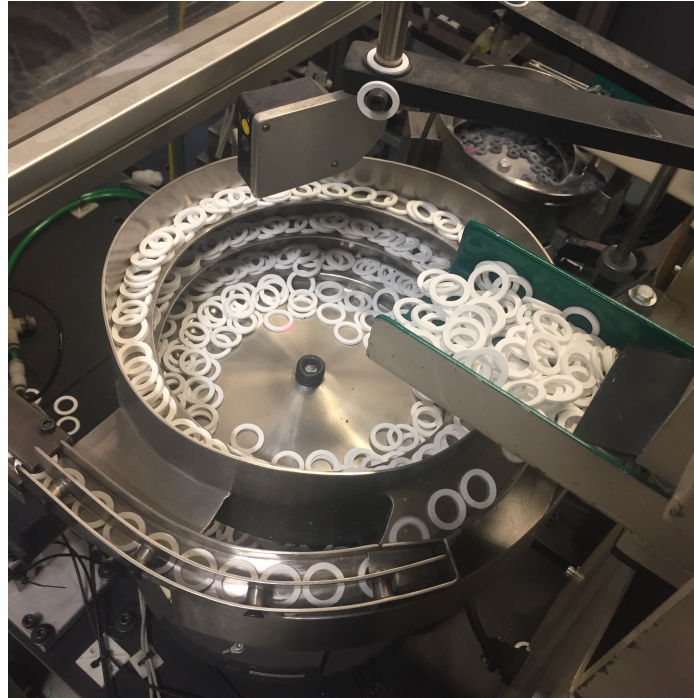
Figure 21 - Sample vibratory hopper [28]

Upon learning this, the customer requested that we consider alternative designs that can act as a nonpermanent interim delivery system. The nonpermanent design would act as a transitional step until the vibratory hoppers can be purchased.

### 2.3.2 CONTOURED MAGAZINE

As mentioned previously, the client requested that we create an alternate design to deliver and orientate the ferrules. The chosen design will act as a transitional step between manufacturing the joiner and obtaining the vibratory hoppers. The contoured magazine was chosen as the ferrule feeding system that will be utilized. This selection was because the contoured magazine ranked second best in our concept selection and the design can be modified to work with the vibratory hoppers. This design consists of a sloped contoured channel where an operator will manually insert ferrules.

For the contoured magazine to act as an intermediate step it needs to hold and deliver several ferrules to the male and female ferrule inserts. To determine how much the magazine should hold we considered the shaft hopper designs which can hold 50 shafts. Our team then calculated that the magazine will need to accommodate at least 60 ferrules to match the demand from the shaft hoppers. Once the model was assembled in *Solidworks*, it was determined by the team that there was a tight space constraint. To deal with the space constraint the contoured magazine was formed into an arc in order to efficiently make use of the space available. This design did not meet the ferrule quantity requirement, however once the vibratory hoppers are installed, more than 60 ferrules will easily be available for the joining operation. The contoured magazine design can be seen below in Figure 22.
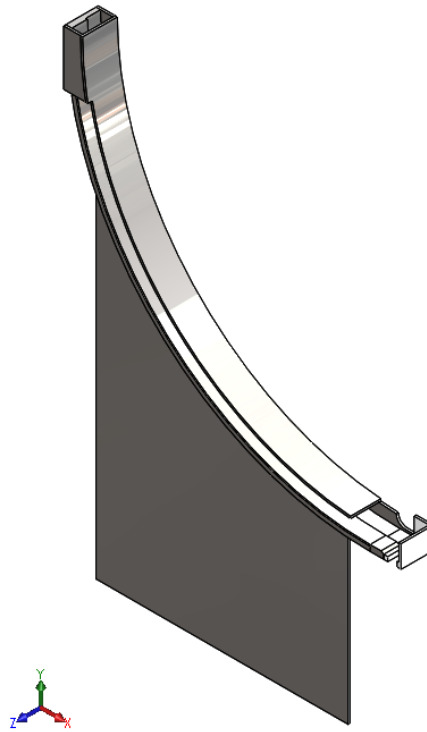


Figure 22 - Isometric view of contoured ferrule magazine

The magazine contour will be made from ABS plastic and the side plates will be 1045 steel plates to keep the joiner frame materials consistent. The steel plates will be laser cut and will be used to support the contoured base. The connection between the steel plates will

be similar to the shaft hoppers where L-beams will be welded to the side plates and bolted to the contoured channel.

Once the vibratory hoppers are obtained, their delivery channels can be connected to the existing contoured magazines. If the client decides that they want to remove the contoured magazine to use only the vibratory hopper, then a channel that does not interfere with the existing components will need to be designed.

### 2.3.3 FERRULE DELIVERY SUBSYSTEM

Transporting and orientating the ferrules is only part of the complete ferrule feeding system. The design also needs to be able to detect whether there are ferrules present and then individually deliver the appropriate ferrule to the ferrule insert. The components of this ferrule delivery subsystem are the female ferrule dropper, the male ferrule dropper, the star wheel, and the limit switch.

Beginning with the female ferrule side, the female ferrules must have a profiled opening at the end of contoured magazine to drop into their shaft rotator insert. The opening will be 3D printed out of ABS plastic and must be the profile of the female ferrule. The female ferrule profiled dropper is positioned directly above the female ferrule insert. Figure 23 shows how this component will look.
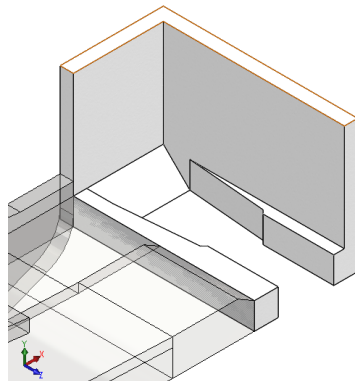


Figure 23 - Female ferrule dropper

Next, the male ferrule dropper will need to also allow for accurate delivery. The design is different from the female counterpart however because it needs to allow for the electric linear actuator to pass through it. The male ferrule dropper will therefore not have the ferrule's profile but instead be a small drop into the male ferrule insert.

For both ferrule sides, there will be a star wheel connected to a stepper motor. The star wheel will be 3D printed out of ABS in the shape of two Xs connected to the star wheel stepper motor. The extended segments of the X are the size of a ferrule with a 0.004-inch tolerance.  Both X's will be the same because of part standardization, and it is unnecessary to have unique star wheels. Figure 24 shows the star wheel in position.
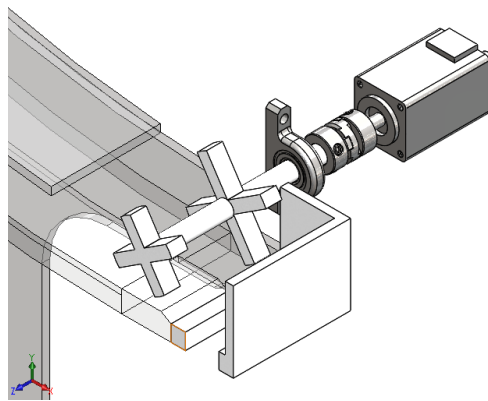


Figure 24 - Ferrule star wheel in position

To detect if a ferrule is at the star wheel, a limit switch will be positioned directly below the star wheel for the male and female ferrule sides. When a ferrule is positioned within the star wheel it will press down the cantilever arm of the limit switch and send an input to the PLC. This input will tell the PLC that there is a ferrule located there.

## 2.4 JOINER MECHANISM

The joiner mechanism is the main component of the joiner machine. It includes four primary components: the shaft rotator, the rotator inserts, the actuator, and the discharge chute. These components were designed based on the life expectancy, cost, functional requirements, and maintenance concerns. The final designs of the components include the use of 6160-T6 aluminum, ABS plastic, and AISI 4130 steel, as these materials are commonly used in industry for the fabrication of parts and have been verified to work for the purposes required for the joiner machine.

### 2.4.1 SHAFT ROTATOR

The shaft rotator is the component which accepts the shafts and ferrules from the delivery chutes, holds the shafts and ferrules during the pressing operation, acts as a door for the delivery chute, and delivers joined shafts to the discharge chute. On the shaft rotator, there are four main features, the bearing shoulders at each end, the male ferrule inserts, the female ferrule inserts, and the shaft inserts. The main body of the shaft rotator which supports these four main features, is made of 6061-T6 aluminum. The male and female ferrules inserts are made out of ABS plastic. The shaft insert is made out of AISI 4130 steel. These four features, along with the shaft rotators rounded exterior, provide the functionality required to properly align and transfer the shafts and ferrules through the process. Figure 25 and Figure 26 show the body shaft rotator with the four main features on it.
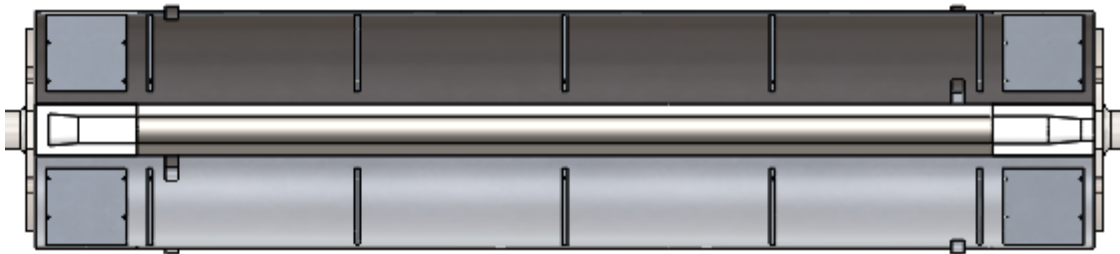


Figure 25 – Top down view of shaft rotator
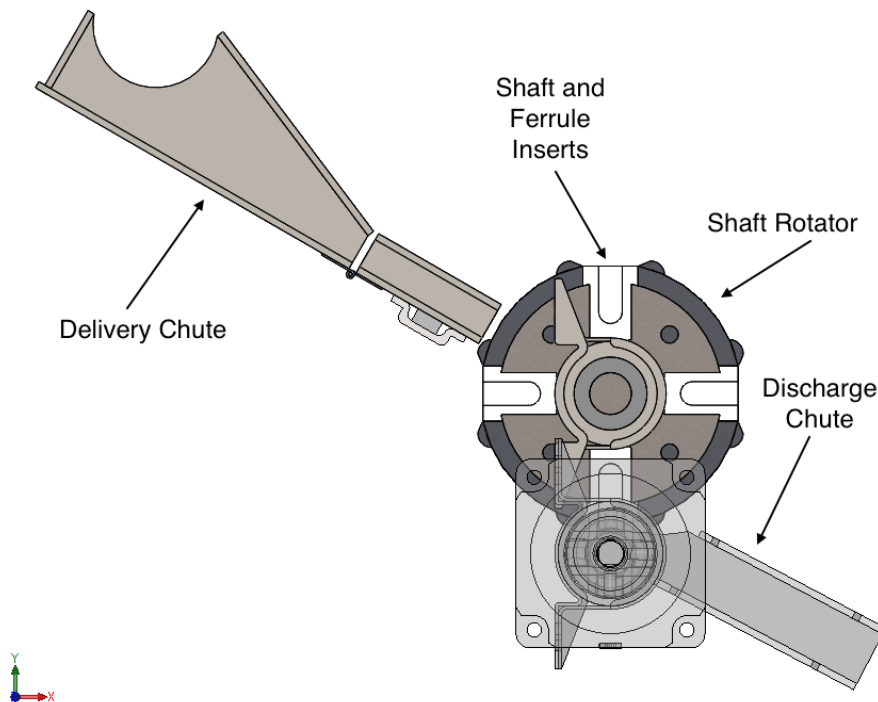
Figure 26 - Side view of delivery chute, shaft rotator, and discharge chute

To turn and support the shaft rotator, a McMaster-Carr NEMA 34 stepper motor, low profile aluminum bearings, and the bearing shoulders are used, as detailed in section 3.1 Common Parts.

### 2.4.2 FERRULE AND SHAFT INSERT

In the shaft rotator there are three styles of inserts, the shaft insert, the female ferrule insert, and the male ferrule insert. These inserts are used to increase the life span of the shaft rotator, and to reduce maintenance costs. These inserts are tightly fitted to the shape of the slot which houses them, to allow for the best possible transmission of forces while the shaft rotator is in motion.  The inserts are held in place with #0 Grade 8 cap screws.

Since the body of the shaft rotator is the most complex part of the joining machine, it is inefficient to replace the entire shaft rotator if any one of the features becomes worn or broken due to the machining and material costs. The inserts aid in increasing the life span

of the shaft rotator by being a simple to replace, wearable part that is made of a material appropriate for the degree of wear each feature is experiencing. To this end, the male and female ferrule inserts are recommended to be made of ABS plastic on a three dimensional printer. This material choice for the male and female ferrule inserts is due to the low forces being exerted on the materials in this area. The only forces are the weight of the ferrules and shafts. The inserts must be within four thousandths of an inch.

For the shaft insert, AISI 4130 chrome-alloy steel was chosen due to its increased hardness over the 6061-T6 aluminum body. AISI 4130 steel has a Brinell hardness of 167 [2] compared to aluminum, which has a Brinell hardness of 96 [15], using the 10 mm ball at 500 kg testing method. The increased hardness for the shaft insert is required to reduce the amount of wear in the contoured pocket holding the shaft due to the abrasive action of the graphite and aluminum shafts moving across it.

### 2.4.3 ACTUATOR AND END EFFECTOR

The actuator is the component of the joining machine that forces the ferrules and shafts together. To complete this task, the actuator must be capable of delivering a load of 1575 lbf of force, so that it can join both the aluminum and graphite shafts, be adjustable down to a 270 lbf force to not break the graphite shafts, and travel 33 inches in under two seconds in order to meet the required cycle times.

Pneumatic pistons, hydraulic pistons, rod-end electric linear actuators, and rod-less electric linear actuators were investigated by the team. The team conducted research on the alternatives to determine the operation speeds, force limitations, size, and life expectancy of the four alternatives. Hydraulic pistons were ruled out as an alternative due to the much slower travel speed of the piston than the other three alternatives.

It was found by the team that pneumatic pistons and rod-end electric linear actuators posed a problem in that the rod size needed to with stand the force for joining the aluminum without buckling would make the shaft to large to fit into the guiding slot. It was

also found by the team that there were no available rod-end electric linear actuators that were built large enough to support the buckling load at the require 16.5 inch stroke length without external supports [16]. With this information, the team looked into rod-less electric linear actuators instead of any type of piston or rod-end electric linear actuators, to both reduce the amount of extra supporting structure needed and to reduce the foot print required for the machine.

For the rod-less style of electric linear actuators, the team found two potential options offered from Tolomatic that could withstand the forces required by the aluminum shafts. The two potential actuator models are the B3S20 and MXE63 rod-less actuators, that use a ball style lead screw for motion, which allows for higher possible applied forces and for a longer life. A wrap around style platform is used to improve the bending moment resistance of the actuator for both models. The primary deciding factor between the two actuators is the life expectancy. The B3S20 has a life expectancy of 5,000,000 linear inches of travel, which equates to 6 months if integrated within the joining machine [17]. The MXE63 has a life expectancy of 22,000,000 linear inches, which equates to 26 months of life if integrated within the joining machine [18]. Due to the expected cost difference, the team decided to use the MXE63, the details of which are shown in Figure 27, Table X, and Figure 28.
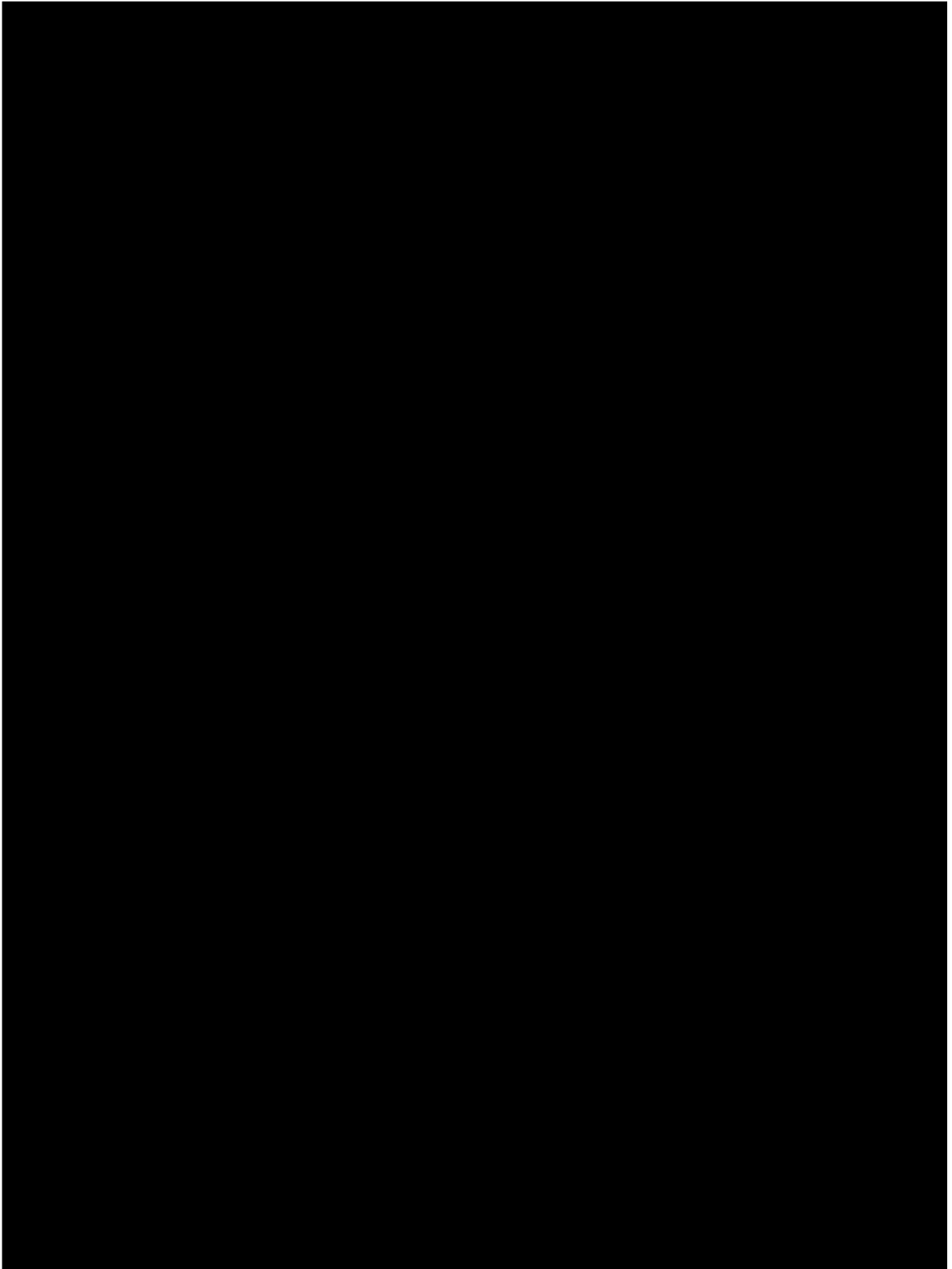
Figure 27 - Diagram of Tolomatic MXE63 electric linear actuator

| | |
|---|---|
| B | 8.51 |
| C | 1.88 |
| N | 12.11 |
| P | 3.00 |
| Q | 1.50 |
| R | 3/8-16 |
| S | 3/8-16 |
| T | 3/8-16 |
| U | 3.25 |
| Y | 0/ 3.01 |
| Z | 0.5 |
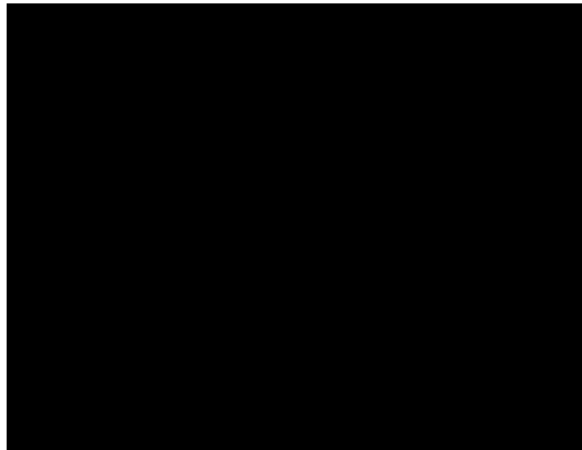


Figure 28 - MXE63 Life expectancy graph [18]

Table X gives the dimensions of the mounting plate to which the end effector must be mounted. Using the hole pattern shown for the mounting plate, the end effector was designed to mount to the plate, support the load of the aluminum shaft, and fit through the end of the male ferrule insert. All of the support structure for the end effector is made up of ¼ inch AISI 1045 mild steel with the portion of the end effector that guides the ferrule into the shaft being made up of ABS plastic. Figure 29 shows the end effector along with the support structure. Figure 30 shows a close up of the end effector where it contacts the ferrule.
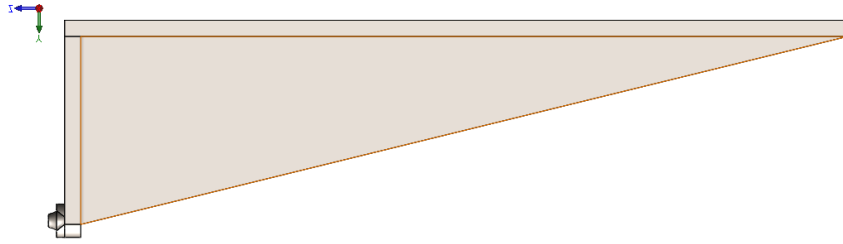
Figure 29 - Side view of the end effector
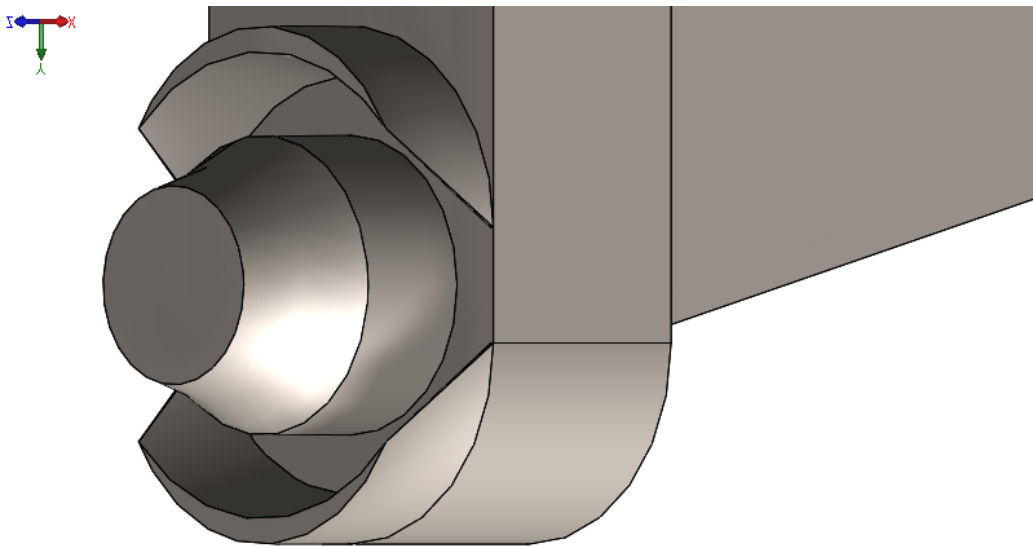


Figure 30 - Detailed view of end effector

### 2.4.4 DISCHARGE CHUTE

After the shafts have been joined in the shaft rotator, they are delivered to the discharge
chute, which directs the shafts to one of three bins for collection by the operator. The
discharge chute is controlled by a step motor to move to one of three locations, each
corresponding to one of the shaft types. When the collection bin is full, or when the
operator needs more shafts, the operator will replace the bin with completed shafts with an
empty bin while the machine is in operation. Figure 31 shows the discharge chute with the
step motor.
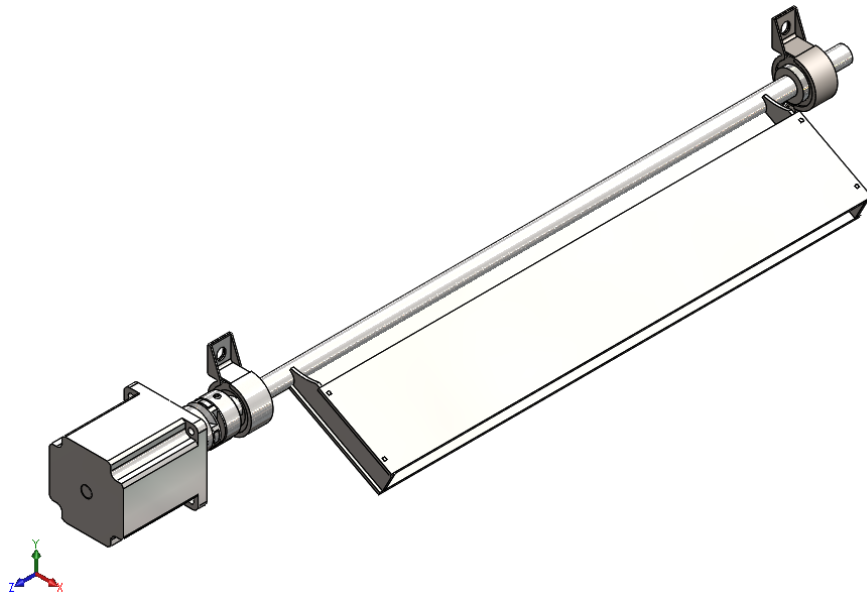


Figure 31 - Discharge chute with step motor

## 2.5 OPERATION OF THE MACHINE

To improve the throughput of shafts in the mobility cane assembly line, it was determined
that operator time at the joiner process needed to be reduced so operator time could be
focused on the tape rolling process.  Currently the operator places the appropriate ferrule
into the shaft to be joined, one at a time by hand. Once the ferrules have been fitted into
the shafts, the shafts are placed vertically in a press.  Due to the ferrule interference fit and

shaft material, the graphite and aluminum line require different pressing forces. This has resulted in having two different joining machines.

On the aluminum assembly line, the pressing process can be done in parallel with the ferrule-shaft preassembly. Though this does make efficient use of the operator's time, the operator still needs to pre-assemble the ferrules into the shafts and attend to the pressing machine during machine operation.

On the graphite assembly line multiple shafts are pre-assembled and then placed into the pressing area. For the graphite pressing operation to be initiated, the operator must take both hands and hold down two buttons until the pressing process is completed. Though the process of pre-assembling the shafts and ferrules manually takes two seconds per shaft, having the operator hold down the operation buttons is time that could be better utilized at the tape rolling process.

The key to the proposed solution is a reduced number of steps that the operator performs. This is achieved by introducing automation into the delivery and pressing steps. The proposed solution, hereafter called the joiner machine, completes the processes mentioned above in the following order: concurrent delivery of ferrules and shafts, joining, and then discharge.

There are four steps which the operator needs to complete for the ferrules and shafts to joined in this process. First, the operator loads the female and male ferrules into their respective vibratory hoppers. Second, the operator adjusts the shaft guide to the appropriate location and loads the designated top, middle, and bottom shafts into their respective hoppers. Third, the operator must close the safety case. The fourth task, is to turn the machine on for the joining process to begin. By having the operator place a large amount of ferrules and shafts into hoppers, which will align the products in their correct orientation, the operator can then take the time spent aligning and placing products correctly and work at the tape rolling process.

For shaft joining priority, the machine first completes the top sections, followed by the bottom sections, and finishes by completing the middle sections.  By completing tops, bottoms, and then finishing with middles, the operator can take the completed top and bottom sections to the next stage of assembly while the machine finishes the middle sections.

For every cane, there is only one top section and one bottom section.  The average amount of middle sections found in a cane is three sections.  By completing the top and bottom sections before the middle sections, the operator, if working on a batch of 10 canes, can then begin the next assembly step on the top and bottom sections, while the joiner machine is completing the cycle by pressing the joining the remaining middle sections.

 Before starting the joining operation, the machine first checks for ferrules at the ferrule dropper, and if ferrules are present, the machine will move onto the next step. If there are no ferrules present the machine will run the vibratory hoppers for a period of time so that ferrules can be delivered to the ferrule drop.  The machine will then check the top hopper for shafts, if shafts are present in the hopper the joining process will begin, if no shafts are present the machine will move onto the next step, the bottom section.

The joining process is defined as the operation of pressing the appropriate ferrule combination into the respective shaft.  The shaft rotator will begin at the home position, which is labelled at "H" in Figure 32.  Once the machine has been initiated and shafts are detected at the delivery chute, the shaft rotator will rotate 45° to accept a shaft.  Once the shaft has been accepted the shaft rotator will rotate another 45° and align with the actuator.  Once the shaft rotator and actuator are aligned the ferrules will drop into place on either side of the shaft and the actuator will then begin the pressing operation.  Once the actuator has forced the ferrules into the shaft and retracted back into the "Home" position. The shaft rotator will rotate another 45° to accept another new shaft, and the process will begin again.  The recently completed shaft will be discharged once the shaft rotator reaches the "Home" position to press in the new shaft. Figure 32 shows the shaft rotator in an instance where three shafts are accepted, pressed, and discharged, with the rotator beginning in the "Home" position.  The rotation angle was chosen as 45° due to the

efficiency it provided to the machine, the ability to integrate with the shaft rotator, and simplicity of the driving stepper motor rotating the same angle.
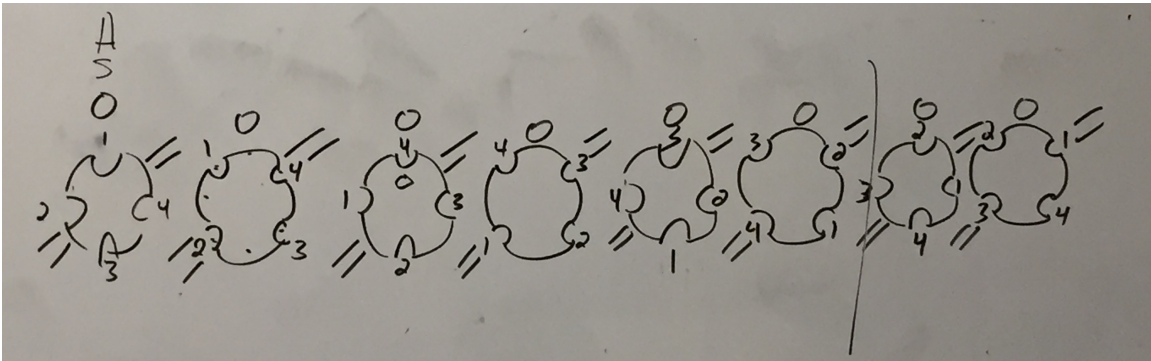


Figure 32 - Shaft rotator cycle

Once the joiner machine has completed pressing the top shafts, the joiner machine will then check the bottom hopper for shafts.  If shafts are present in the hopper, then the joining process will begin. If no shafts are present the machine will move onto the next step, the middle hopper.  The machine will then check the middle hopper for shafts and if shafts are present in the hopper, the joining process will begin. If no shafts are present, the machine will end the process. Once completed, all shafts are discharged into a bucket, with three buckets for tops, middles, and bottoms for the operator to easily discern which shaft is which at the next stage of the assembly line. Shown in Figure 33 is a flow chart outlining the ideal machine operation.
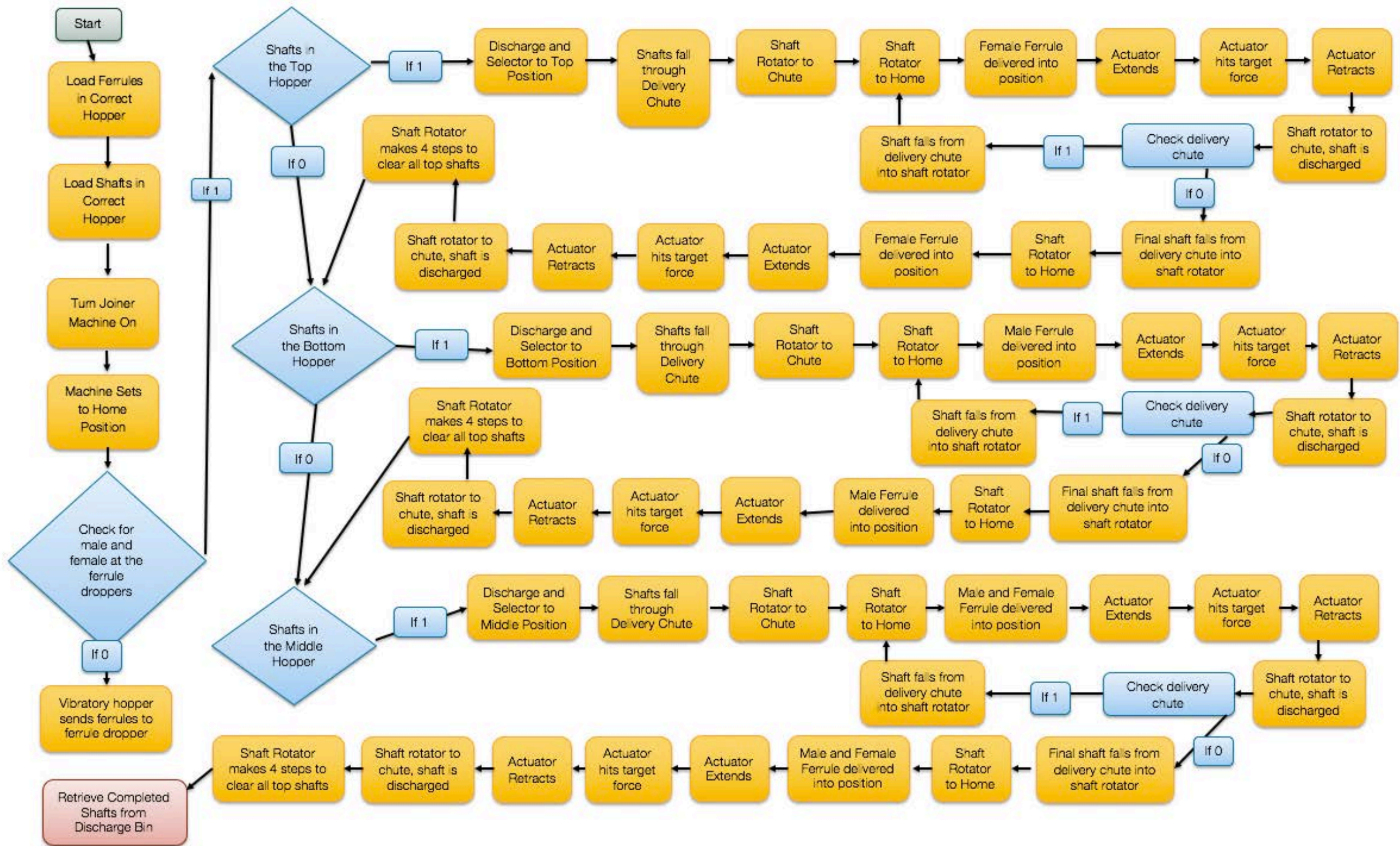
Figure 34 – Joiner operation process flow chart

The machine was designed with the ability to work in the aluminum or graphite lines to create redundancy in the process and similarity of parts between the two machines.  For the machine to work on any line, only the target force needs to be adjusted to press at the appropriate force for the shaft material being pressed.  By having two similar machines, the appropriate adjustments can be made in the event that if one machine becomes unusable, the joining process can still be completed, and high quality products can still be delivered in a timely manner.

Along with a reduction in operator time spent at the machine, there will also be a reduction in defective products from the joining operation.  During the design of the machine, careful attention was paid not only to operator time, but also to reducing the potential for error.  Though no empirical data was recorded for the different types of defects found in the shafts, the common types of defects found in both incomplete and completed canes were discussed with the client.  These defects are shafts buckling and ferrules pressed to much or to little into the shaft.

The first action taken to account for these defects, before any concepts were generated, was force testing on the different ferrule and shaft combinations, as found in Appendix C.  From this testing, the team was able to select an appropriate actuator which will press in the ferrules at the force needed and also ensure that buckling of the shaft will not occur.  As a secondary precaution we created the design to support the shaft in all directions to minimize the chance of buckling.  This was done by orienting the shaft pressing motion in the horizontal direction, as opposed to the vertical direction.

The machine is expected to significantly reduce operator interactions, and increase the throughput rate of shafts which will free up the operator to focus on the bottle neck of the process, and to provide a steady stream of shafts when other steps in the assembly are improved.

## 2.6 MACHINE LOGIC

To achieve the minimum operator input required, the machine must be automated. A preliminary analysis was completed to determine the basic logic for the machine to operate using a programmable logic control, hereafter called a PLC. By using a combination of operator controlled inputs and detection sensors, the machine logic can be determined by using Boolean Table and a truth table. Table XI outlines each input and output to determine the machine logic.

TABLE XI - INPUTS AND OUTPUTS

| Input | Label | Output | Label |
|---|---|---|---|
| On/Off Switch | O | Rotator Step Motor | R |
| Emergency Off | E | Female Ferrule Step Motor | $M_S$ |
| Case Lock | CL | Male Ferrule Step Motor | $M_F$ |
| Reset Switch | $R_S$ | Piston | P |
| Top Hopper | $T_H$ | Delivery Selector Top | $D_T$ |
| Middle Hopper | $M_H$ | Delivery Selector Middle | $D_M$ |
| Bottom Hopper | $B_H$ | Delivery Selector Bottom | $D_B$ |
| Delivery Chute Hopper | $D_H$ | | |
| Female Ferrule Sensor | $F_F$ | | |
| Male Ferrule Sensor | $F_M$ | | |
| Piston Retracted | $P_R$ | | |
| Shaft Rotator Home | $R_H$ | | |
| Shaft Rotator Chute | $R_C$ | | |
| Selector Top Position | $P_T$ | | |
| Selector Middle Position | $P_M$ | | |
| Selector Bottom Position | $P_B$ | | |
| Selector Home Position | H | | |

### 2.6.1 INPUTS

There are 17 different digital inputs which control the joiner machine operation. These 17 inputs can be grouped according to which part of the machine they are related to. These groups are power control, shaft hoppers, ferrule sensors, piston sensors, selector position, and shaft rotator position. These groups and how they work are described in more detail in the following section.

The on/off switch is an operator controlled switch, which turns on the machine and begins the process. An output of 1 designates the switch turned on and and output of 0 designates that the switch turned off. The emergency off is a button which will stop the process in the event of an emergency. The emergency switch will output a 1 when pressed and a 0 when not pressed. The case lock is a switch which can detect when the safety case is open. If the case is open and exposing the moving parts of the machine, the case lock input will read 0. Until the switch reads 1, the machine will not turn on or continue working. The reset switch is an operator controlled switch which allows the operator, to reset the machine components back to all their respective home positions. Each of the above variables were compounded into one intermediate variable, power control, to simplify the logic. If either the emergency stop and/or the reset become 1then the machine will shut of. The machine will only turn on when both the on/off switch reads 1 and the case lock is reads 1.

There are four hoppers: the top hopper, the middle hopper, the bottom hopper, and the delivery hopper. The top, middle, and bottom hoppers correspond to the type of cane section found in the cane. It is important to separate the three sections due to the ferrule-shaft combinations. These three hoppers can hold up to 50 shafts each, which will allow the manufacturing cell to process up to a batch of 10 canes at a time. The delivery hopper connects the three shaft type hoppers at the shaft rotator. Each hopper has a sensor at the mouth where the shaft selector or rotator is located. These sensors detect if there is a shaft in the hopper. As shown in the process flow chart, the machine completes the top sections, followed by the bottom sections, and finishes with completing all the middle sections. If there are no shafts sensed in the top hopper and the delivery chute, then the

machine will move onto the bottom sections.  Once there are no sections in the bottom hopper and the delivery chute, the machine will move onto the middle sections.  The machine will continue operation until there are no more shafts sensed in both the middle hopper and the delivery chute.

The male and female ferrules are separated in different vibratory hoppers. Before they are delivered to the ferrule droppers, a switch will sense if there is one in place at the star wheel.  These switches are named female ferrule sensor and male ferrule sensor.  If there is a ferrule at the switch, the switch will output a value of 1.  If there is no ferrule at the switch, the output value will be zero.  For simplicity an intermediate variable, FE was introduced.  Before the machine will sense any shafts in the hoppers, the machine must detect if there are ferrules ready to be dropped into place.  For the operation to work, there must be both female and male ferrules ready, even if the first shaft to be pressed is a top shaft, which will only need a female ferrule.

There is one piston position input which detects if the piston is retracted.  This sensor was chosen because if the piston is not retracted, then no other components in the machine should be moving. When the piston is retracted the sensor will output a value of 1.  At any point that the piston is extended, the sensor will output a value of 0.  To control the piston, an intermediate variable is introduced to measure the voltage value.  As the pushback force from the ferrules being pushed into the shafts increases, the voltage to run the actuator increases.  The intermediate variable will switch once the voltage proportional to the target force is reached, and trigger the actuator retraction.

There are four inputs which can detect the position of the shaft selector.  Since the PLC is unable to store any memory of where the shaft selector is at any moment in time, physical sensors are used to tell the PLC where the shaft selector is.  The four sensors are: selector top position, selector middle position, selector bottom position, and selector home position.  If any of the three sensors input a 1 to the PLC, the selector is in that respective position.  For example, if the selector middle position is to return a 1, the selector is delivering middle shafts to the delivery chute.

There are two inputs which return what position the shaft rotator is at: shaft rotator home and shaft rotator chute.  As mentioned above, when the shaft rotator is at the home position, from a side view the rotator looks like a "+". When the shaft rotator is at the chute, the side view of the shaft rotator will look like an "x".  As with the shaft selector position, the PLC is unable to record any memory of where the shaft rotator is, which is why these sensors are necessary.  The alignment of the home position in relation to the piston needs to be very precise and the alignment of the chute position needs to be in line with the delivery chute for shafts to be efficiently dropped into the rotator.  For this reasoning, these sensors are very important to the implementation of the design.

## 2.6.2 OUTPUTS

There are 7 different outputs which determine how the shafts flow through the process. They are listed in Table XI and are described in detail in the following section.

The output to the rotator step motor is a pulse that is sent to the step motor driver, to will tell the step motor to rotate 45°. A 45° rotation was determined in conjunction with the design of the joiner process for simplicity of automation and efficiency of shaft flow through the process.

The female ferrule step motor and male ferrule step motor outputs send a signal to the step motors which delivers the respective ferrules by rotating 90°. The rotation will drop the required ferrule into the shaft selector for friction fitting.

The piston output sends a signal to the actuator which will start the pressing process.  The pressing process will only end and begin retracting to the home position once the target force has been achieved by the actuator.

The delivery selector top, delivery selector middle, and delivery selector bottom outputs designate which angle the shaft selector should be at for delivery of the appropriate shafts.

### 2.6.3 PROGRAMMABLE LOGIC CONTROLLER

Each machine is designed to be a standalone system.  One programmable logic controller is needed for each machine. A PLC is the most stable system for machine control, and is most commonly used in industrial applications.  The PLC must be able to accommodate all the inputs and outputs of the machine.

The PLC selected for use is the Click C0-00AR-D.  The base model has eight inputs and six outputs.  As the machine needs 17 inputs and 7 outputs for use, the PLC selected needs more ports for inputs and outputs.  To accommodate for this issue, modules are available for the PLC which expand the input and output ports.  One module has four inputs and four outputs.  For the needs of the project, each PLC will need an additional three modules. This PLC comes with free software for programming the ladder logic with lots of documentation for troubleshooting.  One PLC will cost $450, which includes all additional modules, the CPU, and power requirements [19].

### 2.6.4 BOOLEAN METHODOLOGY

The section below presents the preliminary Boolean logic to be implemented in the automation of the machine. After determining the inputs and outputs of the system, they were grouped together into different families, and new intermediate variables were created. This creation of intermediate variables was done to reduce the number of lines required in the final truth table to fully describe the actions of the joiner machine. The different family groupings and their associated intermediate variables are given in Table XII.

TABLE XII - INPUT AND ASSOCIATED INTERMEDIATE VARIABLES

| Intermediate Variable | Associated Input Variables |
|---|---|
| PC | O, E, R, CL |
| FE | Ff, Fm |
| B | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |
| M | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |
| T | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |

After the intermediate variables were defined, they were used to create the final truth table consisting of 8 inputs and 7 outputs. The inputs and outputs for the final truth table are given in Table XIII.

TABLE XIII - FINAL TRUTH TABLE INPUTS AND OUTPUTS

| Inputs | Outputs |
|--------|---------|
| PC | R |
| Pr | Sf |
| Rh | Sm |
| Rc | P |
| FE | Dt |
| T | Dm |
| M | Db |
| B | |

The truth tables for all intermediate variables, as well as the final truth table, are shown in Appendix VII. The reduction of the logic equations generated by the truth tables are also given in Appendix E, with the final logic equation for each output variable given in Table XIV. It should be noted that the equations below need to have the intermediate variables substituted with the original input variables that were used to create them to get the final equations for each output.

TABLE XIV - FINAL TRUTH TABLE OUTPUTS WITH EQUATIONS

| Output Variable | Equation |
|-----------------|----------|
| R | (PC•Pr)•(Rh•Rc'+Rh'•Rc)•(T•M'•B' + T'•M•B' + T'•M'•B) |
| Sf | (PC•Pr•Rh•Rc')•(T•M'•B' + T'•M•B') |
| Sm | (PC•Pr•Rh•Rc^)•(T'•M•B' + T'•M'•B) |
| P | (PC•Pr•Rh•Rc')•(T•M'•B' + T'•M•B' + T'•M'•B) |
| Dt | PC•(T•M'•B' + T'•M'•B')•(Pr•(Rh' + Rc') + Pr'•(Rh•Rc)) |
| Dm | PC•(Pr•(Rh•Rc'+Rh'•Rc+Rh'•Rc')+Pr'•(Rh•Rc'))•T'•M•B' |
| Db | PC•(Pr•(Rh•Rc'+Rh'•Rc+Rh'•Rc')+Pr'•(Rh•Rc'))•T'•M'•B |

## 2.7 PREVENTATIVE MAINTENANCE

A preventative maintenance plan is an important part of the design process for any piece of equipment that is intended to have a long service life. From the failure modes and effects analysis completed below, it was determined that the joining process portion of the machine that has a higher number of potentially severe defect possibilities, so the preventative maintenance plan created, which will focus on that portion of the machine.

To create the preventative maintenance plan, a failure mode and effect analysis (FMEA) was completed. The FMEA performed in this report is done in two steps, the cause and effect analysis which leads into the Risk Priority Number (RPN) analysis. The cause and effect analysis breaks down the process to the different steps that could fail and their causes are then compared against the effects. The scoring is on a 0,1,3 and 9 scale where 9 represents high impact and 0 is no impact. The values are then multiplied by a customer rating from 0 to 10. 10 represents a high priority and 0 is a low priority. Table XV summarizes the cause effect analysis of the design.

TABLE XV - CAUSE AND EFFECT TABLE

| | Customer Rating | 5 | 5 | 7 | 8 | 3 | 5 | 10 | 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Output | Process Delay | Damaged Shaft | Broken Step Motor | Broken Rotator | Broken Sizing Handle | Wrong Shaft-Ferrule Combination | Broken ELA | Incomplete /Incorrect parts | |
| Process Step | Process Input | | | | | | | | | Total |
| Loading | Load ferrules in wrong hopper | 9 | 0 | 3 | 0 | 0 | 9 | 0 | 3 | 126 |
| Loading | Load shafts in wrong hopper | 9 | 0 | 0 | 0 | 0 | 9 | 0 | 9 | 135 |
| Loading | Shaft out of plane | 9 | 3 | 9 | 1 | 1 | 0 | 1 | 9 | 189 |
| Loading | Move shaft sizing while still partially loaded | 1 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 14 |
| Loading | Shaft jams in delivary chute | 9 | 3 | 3 | 1 | 0 | 0 | 1 | 3 | 114 |
| Loading | Ferrule backwards | 9 | 0 | 3 | 0 | 0 | 3 | 0 | 9 | 126 |
| Loading | Stepper motor failing | 9 | 1 | 9 | 0 | 0 | 3 | 0 | 3 | 143 |
| Joining | Stepper motor failing | 9 | 1 | 9 | 3 | 0 | 1 | 3 | 3 | 187 |
| Joining | Rotator jamming | 9 | 3 | 9 | 3 | 0 | 0 | 3 | 0 | 177 |
| Joining | Ferrule jamming | 9 | 3 | 3 | 3 | 0 | 3 | 3 | 9 | 195 |
| Joining | Build up of shavings | 3 | 3 | 0 | 1 | 0 | 0 | 1 | 3 | 63 |
| Joining | ELA force degrading | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 40 |

Table XV indicates that the joining process contains the highest number of severe issues such as ferrule jamming. Due to the joiner being a higher risk area, the team chose to perform a Risk Priority Number analysis on this section of the machine.

In the RPN matrix, the items and functions being analyzed are ranked based on the level of severity (SEV) of a failure, the failures level of occurrence (OCR), and the ability to detect (DET) a failure. The team assigned a value from 1 (best) to 10 (worst) for each of the three categories and are detailed in Table XVI, Table XVII, and Table XVIII for severity, occurrence, and detectability, respectively.

TABLE XVI - FMEA SEVERITY BREAKDOWN [20]

| Effect | Severity | Value |
|---|---|---|
| Very High | Causes system failure without warning and possible injuries | 10 |
| | Causes system failure with warning and possible non compliance issues | 9 |
| High | Destructive failure without compromising safety and system at halt | 8 |
| | System at halt with equipment damage | 7 |
| Moderate | System inoperable with minor damage | 6 |
| | System inoperable without damage | 5 |
| | System operates with significant degradation of performance | 4 |
| Minor | System operates with some performance degradation | 3 |
| Low | System operates with minimal interference | 2 |
| Minor | No effect | 1 |

TABLE XVII - FMEA OCCURENCE BREAKDOWN [20]

| Frequency | Frequency Rate | Value |
|---|---|---|
| Very High | >1 in2 | 10 |
| Very High | 1 in 8 | 9 |
| High | 1 in 20 | 8 |
| High | 1 in 40 | 7 |
| Moderate | 1 in 80 | 6 |
| Moderate | 1 in 400 | 5 |
| Moderate | 1 in 1,000 | 4 |
| Low | 1 in 4,000 | 3 |
| Very Low | 1 in 20,000 | 2 |
| Remote | <1 in 20,000 | 1 |

TABLE XVIII - FMEA DETECTION BREAKDOWN [20]

| Detection | Chance of Detection | Ranking |
|---|---|---|
| Absolute Uncertainty | Design control cannot detect potential problems | 10 |
| Very Low | Design control very remotely detects potential problems | 9 |
| Low | Design control remotley detects potential problems | 8 |
| Low | Very low chance for the design control to detect potential problems | 7 |
| Moderate | Low chance for the design control to detect potential problems | 6 |
| Moderate | Moderate chance for the design control to detect potential problems | 5 |
| High | Moderately high chance for the design control to detect potential problems | 4 |
| High | High chance for the design control to detect potential problems | 3 |
| Very High | Very High chance for the design control to detect potential problems | 2 |
| Very High | Design control will detect potential problems | 1 |

Table XIX shows the scoring for the severity, occurrence, and detectability of each item or function. The RPN value is then calculated by multiply each of the three scores together.

TABLE XIX - RISK PRIORITY NUMBER EVALUATION

| Item / Function | Potential Failure Mode | Potential Effect | SEV | Potential Causes | OCR | Current Design Controls | DET | RPN |
|---|---|---|---|---|---|---|---|---|
| Stepper Motors | Burns out | Production halt | 6 | Operating while a part is jammed | 1 | None | 7 | 42 |
| Rotator | Jams | Production halts, rotator is damaged due to ELA movement | 6 | Bearing seizes, shaft misaligned | 2 | Long life bearing specified | 6 | 72 |
| Ferrule Joiner | Jams | Shafts with less ferrules than required | 2 | Misaligned ferrule | 1 | Ferrule shaped jig | 10 | 20 |
| Rotator | Buildup of shavings in channels | Ferrule & shaft misalignment | 2 | Continuous usage without cleaning | 3 | None | 3 | 18 |
| Electric Linear Actuator | Force degradation | Incomplete ferrule joining with the shaft | 2 | Usage beyond recommended life | 1 | Over specified ELA | 8 | 16 |

Table XIX shows that the stepper motor burning out and the rotator jamming have the highest RPN, so potential actions will be concentrated on these items. Table XIX shows that in every item or function the detectability of the failure mode is the worst scored criteria. This trend meant that the teams efforts were put towards improving the detectability of the items, so a preventative maintenance plan was created to accomplish this.

Four primary items in the joining process were identified as having a potential for failure, the stepper motor, the shaft rotator, the ferrule joiner, and the electric linear actuator. These parts of the machine are in constant use and see the most wear. To help prevent these parts from failure the following preventative maintenance plan shown in Table XX, or a derivative of it, should be implemented.

TABLE XX - PREVENTATIVE MAINTENANCE PLAN

| Part | Inspection Frequency | Inspection Task | Inspection Performed By |
|---|---|---|---|
| Stepper Motor | Daily | Check exterior of stepper motor and attached wires for damage | Operator |
| Stepper Motor | Monthly | Inspect coupler from servo the rotator shaft for wear | Maintenance |
| Stepper Motor | Quarterly | Check step motor voltage and amperage draw on step motors for potential wear and problems | Maintenance |
| Rotator | Daily | Check all inserts for wear and built up debris | Operator |
| Rotator | Monthly | Check bearings and bearing shoulders for wear | Maintenance |
| Rotator | Quarterly | Replace ferrule dropper contour and ferrule inserts | Maintenance |
| Rotator | Annually | Replace bearings and shaft insert | Maintenance |
| Ferrule Dropper | Daily | Check dropper contour for wear | Operator |
| Electric Linear Actuator | Daily | Check end effector tip for wear | Operator |
| Electric Linear Actuator | Daily | Check for alignment issues during travel, ensure that end effector is not rubbing on the shaft inserts | Operator |
| Electric Linear Actuator | Monthly | Replace end effector tip | Maintenance |
| Electric Linear Actuator | Quarterly | Check voltage and amperage draw to ensure there are no issues | Maintenance |
| Electric Linear Actuator | Annually | Evaluate travel speed accuracy to determine if a replacement is needed | Maintenance |

This plan focuses on the early detection of wear and the routine replacement of wearable parts. The current replacement periods for the ferrule dropper, the ferrule inserts, bearings, and end effector tip are suggestions based on replacement periods for similar parts that the team members have experience with performing maintenance on from other projects. The exact replacement periods should be evaluated during operation based on the operator inspections of the wear each part is experiencing.

It should also be noted that based on the forces involved, the electric linear actuator as a life expectancy of 22,000,000 linear inches, which corresponds to a life expectancy of approximately 26 months, if 5000 canes are processed per month[13]. The annual

inspection of the travel speed accuracy of the electric linear actuator is to help verify this life expectancy as the purchase and replacement of the actuator is one of the more expensive tasks that the joining machine will need to under go for to remain properly maintained.

## 2.8 COST OVERVIEW

The total cost of one machine comes at $44,564.28 which is under the budget of $45000 however, due to the fluctuations in the Canadian dollar. Parts that were sourced from the United States were subjected to a 1.35 conversion from USD to CAD [19]. Also, the costing was subjected to taxes in Canada and Manitoba, 5% GST and 8% PST [20]. All sheet metal parts can be done on two 4'x 8'x1/8" sheet metal at a flat rate [22].  A categorized cost of the machine is shown in Table XXI, and a complete bill of materials is shown in Appendix A.

TABLE XXI - TOTAL COST OF ONE JOINER MACHINE

| Description | Cost ($) |
|:---:|:---:|
| Material | 579.65 |
| Components | 42936.63 |
| Labor | 1048.00 |
| Total Cost | 44564.28 |

### 2.8.1 PAYBACK PERIOD OVERVIEW

To validate the decision to purchase the joiner machines, it was decided to calculate the payback period of the joiner machines for both the graphite and aluminum sides of production for 3000, 4000, and 5000 shafts every month. The purpose is to see what levels of production are required to make the fabrication of the joiner machine viable. Table XXII summarizes the results of the payback period analysis.

TABLE XXII - SUMMARY OF PAYBACK PERIOD ANALYSIS

| Shaft Type | Production Level (Canes/Month) | Payback Period (Month) |
|---|---|---|
| Aluminum | 3000 | 29.39 |
| Aluminum | 4000 | 5.19 |
| Aluminum | 5000 | 2.84 |
| Graphite | 3000 | 3131.17 |
| Graphite | 4000 | 18.01 |
| Graphite | 5000 | 9.75 |

From the data shown in Table XXII, the payback period for the graphite shaft production at a production level of 3000 canes per month, 3131.17 months, is not a viable payback period. Also, in all cases the aluminum shafts production is a better investment, as the amount of overtime saved is always higher due to the extra amount of time the operator can spend at the rolling station or on other products. The full analysis of the payback period is given in Appendix A.

# 3. CONCLUSION

Having completed the preliminary design of an entirely new joiner machine, the team has prepared a number of recommendations that would help to further improve the process, as well as the lessons learned from the design process. These two topics as well as a comparison of the target and marginal specifications to the expected performance of the joiner machine are given in the following sections.

## 3.1 DESIGN SYNTHESIS

The design of the joiner machine began with obtaining the input of the operators, maintenance, engineering, and management at Melet Plastics. This input was distilled into a number of need statements, metrics, and specifications to be met by the design process. This user oriented approach was integral to the success of the project since the team knew precisely what the expectations for the project were.

Going into the concept developments stage the team created 48 different concepts across three different categories: shaft delivery system, ferrule delivery system, and the joiner system. The separation of concept categories made it easier for the team to combine the best ideas together once selected. Once again, meeting with the primary contact at Melet Plastics was a central part of the team's advancement, as the input from Melet Plastics was invaluable in determining what concepts would help accomplish the project's goal the best.

In the detailed design stage, the team created a draft model of the machine and presented it to Melet Plastics for approval and revision prior to advancing into a second draft. The first draft of a fully assembled model in the detailed design stage helped to point out problems and gave both the team and the client an overview of the final layout. This overview helped determine a number of changes to be made, which were included in the final detailed design of the joiner machine.

Due to customer oriented process the team followed, the expected performance levels were obtained in almost all cases, as shown in Table XXIII. The one case where the expected performance level was worse than the marginal specification is for the percentage of custom parts in the joiner machine due to the unique requirements of the process.

TABLE XXIII - SUMMARY OF EXPECTED PERFORMANCE COMPARED TO THE TARGET AND MARGINAL SPECIFICATIONS

| Metric | Target Specification | Marginal Specification | Expected Performance Level |
|---|---|---|---|
| First Pass Yield[%] | 98% | 95% | 98% |
| Force to Join Materials [lbf] | Aluminum: 1575 Graphite: 270 | +/- 10% of Target Force | Aluminum: 1575 Graphite: 270 |
| Cycle Time [s/shaft] | <5 | <8 | 1.5 |
| Percent Custom Parts [%] | <5 | <15 | 39 |
| Downtime per shift [min/shift] | 5 | <10 | 8.25 |
| Setup Time [s/shaft] | <1 | <2 | 0.8 |
| Operator Time [s/shaft] | <0.5 | <1 | 0.4-0.5 |
| Number of Safety Concerns [#] | 0 | 2 | 0 |
| Variety of Shaft Materials [#] | 2 | 1 to 2 | 2 |
| Variety of Ferrule Material [#] | 2 | 1 to 2 | 2 |
| Variety of Shaft Lengths [#] | 7 | 7 | 7 |
| Number of Steps to Operate [#] | < 5 | < 10 | 3 |
| Number of Non-Ergonomic Operator Motions [#] | < 3 | < 7 | 3 |
| Accessibility of Parts [subjective] | All parts easy to access | Most parts easy to access | Most parts easy to access |
| Percentage of Similar part [#] | 95 | 85 | 95 |

All of the expected performance levels listed in Table XXIII are determined for steady state operation. At machine start up and during changes from top to bottom to middle shafts there is a delay as the machine empties of one type of shaft and then fills with another. This delay will increase the amount of time taken to see the next shaft, but was included in the

cycle time calculation so it is accounted for. In regards to metric percentage of custom parts not meeting the marginal specification, the team deemed it an acceptable lapse in order to make sure that the performance specifications were met. This acceptance was based on being able to meet more important specifications such as decrease operator involvement, improved safety, and better quality of work for the operators. The reasoning behind all of the expected performance levels is summarized in Table XXIV.

TABLE XXIV - SUMMARY OF REASONING FOR EXPECTED PERFORMANCE LEVELS

| Metric | Reasoning |
|---|---|
| First Pass Yield[%] | • Tight tolerances and a voltage controlled actuator make mis-presses very unlikely (less than 1% chance)<br>• Daily inspections and easy to replace inserts make repairing defect causing problems fast (take less than 15 minutes to replace an insert) |
| Force to Join Materials [N] | • Voltage controlled actuator will press until the required force is met, and then immediately stop |
| Cycle Time [s/unit] | • This was calculated by finding the first part time and the time required between each consecutive part, then averaged |
| Percent Custom Parts [%] | • This was calculated as the number of custom parts divided by the total number of parts |
| Downtime per shift [min/shift] | • This was calculated from best estimates by the team, with the down time per shift being over a two-year average to account for the replacement of every part at least once, with an additional 50% added for unexpected downtime. This estimate includes all routine inspection, including daily inspections by the operators. |
| Setup Time [s/shaft] | • This was determined experimentally with the use of the samples given to the team by Melet and the prototype produced. |
| Operator Time [s/shaft] | • This is the estimated time required to set all three shaft length guides, as well as press the on button. |
| Number of Safety Concerns [#] | • This was determined by the team after a thorough look at all of the parts during creation to find potential safety problems. It was determined that there are no safety concerns to the team. |
| Variety of Shaft Materials [#] | • The designed machine can accommodate both the aluminum and graphite shafts |
| Variety of Ferrule Material [#] | • The designed machine can accommodate the ferrules for both the aluminum and graphite shafts |
| Variety of Shaft Lengths [#] | • The machine can accommodate all length of shafts within the range specified by Melet |
| Number of Steps to Operate [#] | • As shown in section 3.5, operation of the machine |
| Number of Non-Ergonomic Operator Motions [#] | • The only non-ergonomic motions the team is aware of are for the placement of the shaft length guide. This amounts to three motions per use of the machine. |
| Accessibility of Parts [subjective] | • Due to the placement of panels and fiberglass doors, the team determined that most parts are easy to access, and need few to no other parts removed before they can be worked on. |
| Percentage of Similar part [#] | • The only differences between the two machines are the vibratory hopper systems. |

## 3.2 RECOMMENDATIONS

Throughout the project, the team developed a number of recommendations for improving the quality and speed of the cane production. These recommendations fall into two categories: recommendations for further improving the joining process, and recommendations for improving other processes outside of the scope of the project.

The following recommendations are for improving the joining process. The recommendations focus around potential alterations to the machine, recommended performance tests, and methods for reducing cost while keeping quality the same.

- The positioning of the hoppers should be evaluated to see if it is ergonomic, and changed as needed by altering the heights and rotations of the hoppers to improve the operator's quality of work. This evaluation will require the joining machine to be in place, and tested over a period of days to ensure that the operators have enough exposure to give meaningful feedback.
- The cycle time of the machine could be increased to reduce wear on the actuator, end effector, ferrule inserts, and shaft inserts. Currently the joining machine can cycle at 1.5 seconds per shaft on average. Since the rolling process has a cycle time of at least 13 seconds the joiner cycle time could be increased to as much as seven or eight seconds per shaft and not impact the product flow.
- Force testing should be done before implementing the electric linear actuator. This force testing should focus on determining the required voltage across either a voltage meter or a piezoelectric load cell to determine the exact voltage at which the actuator will be pressing at the required load. The results of this test will help create the proper control logic to ensure that the shafts and ferrules are not damaged during the pressing operation, and that wear will be lower than if a higher than necessary load is applied.
- When specifying the components, the team decided to pursue standardization with common components in the machine over having a lower initial cost so that there are fewer spare parts to keep stored in stock. However, some of the components such as the stepper motors and couplings are over designed for the application they are being

used in and using a more appropriately designed components would reduce the initial purchase cost.

- Investigation into the amount of wear on the shaft insert. It may be better to have the shaft come through the hopper on the male side to make the shaft insert wear uniform.

Throughout the joiner project for Ambutech, the team came across a few items outside of the project scope. The team suggests the following recommendations for consideration in for improving other processes within the Ambutech manufacturing cell.

- The cutting saws for both graphite and aluminum should be made more accurate. The manufacturing tolerance of the saws are large enough such that there is a very significant waste of material and operator time spent accounting for the errors.
- There is excessive worker movement along both sides of the assembly, and it is recommended that streamlining the layout would lead to significant improvement in operator time spent assembling canes as opposed to walking from station to station.
- The tape rolling process should be evaluated and made faster as it is the next bottle neck in the process that needs to be improved to improve the speed of the cane production process.

## 3.3 SUMMARY

The design team has created a preliminary joining machine design. The main components of the design are the shaft delivery system, which is composed of an arrangement of hoppers with a rotating shaft for selection of shaft type, the ferrule delivery system, which is composed of vibratory hoppers feeding a magazine tray on the machine, and the joining mechanism, which is composed of a rotating aluminum shaft with AISI 4130 steel and ABS plastic inserts that hold the parts while an actuator presses them together.

This design is expected to meet all but one of the marginal requirements, with most of the metrics meeting the target specifications designed for them. This level of performance will allow for a reduction in operator time spent performing the manually dexterous work required of the current process, increase the throughput of the system, reduce the number of safety and ergonomic concerns, and improve the quality of work the operators experience due to a reduced amount of travel time expected as a result of the new system. The cost for the machine is also expected to be within budget, with a payback period of 2.87 to 10.65 months depending on the shaft type for the desired throughput of 5000 canes per shaft type per month.

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# APPENDIX A - FINANCIAL ANALYSIS

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## A1.1 ANALYSIS OF SALES DATA AND OPERATION EXPENDITURE

To better determine the viability, payback period and cost of the joiner project, Melet has given the team sufficient data to do an estimate of the current situation to compare to the eventual proposed solution. The data given includes the number of units sold in the period of October 2015 to September 2016, the amount of overtime being worked currently, and an hourly rate to use for operator cost estimates [1] [2]. The overtime being worked amounts to one 8 hour shift every second weekend by four operators, and the hourly rate

for the operators is $17/hour. Figure 1 and Table I summarize the sales data given to the

Figure A1 - Ambutech division cane sales data
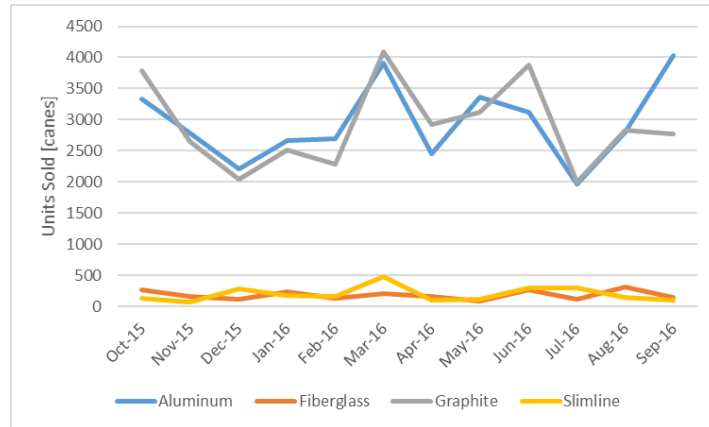


team.

TABLE AI - AMBUTECH CANE SALES

|  | Monthly Average [units] | Percent of Sales [%] |
|---|---|---|
| Aluminum | 2945 | 47.2 |
| Fiberglass | 184 | 2.9 |
| Graphite | 2907 | 46.6 |
| Slimline | 198 | 3.2 |

With the sales data it was determined that for the aluminum and graphite production lines a production capacity of at least 5000 canes per month was needed. Also, from Table A 1 it can be seen that the fiberglass and Slimline products are a small portion of the total product sales, equaling only 6.1% of all the product produced. Due to this low level of demand it was decided to only focus the project on the aluminum and graphite canes in order to invest in the products earning the most money.

The project is also being undertaken to reduce the amount of overtime being used to meet the current demand for the canes. Currently, four operators work every second Saturday at an overtime rate of approximately $25.50/hour. For an eight hour shift this amounts to $816 in operator expenses along with the additional cost of operating the equipment. With the planned increase in capacity of both the aluminum and graphite production lines this expense will be eliminated.

# A1.2 PRELIMINARY ESTIMATE OF EXPECTED JOINER UPGRADE COSTS

The preliminary estimate for the manufacture of a single joiner machine is given below in Table A3. The total cost of the machine is $44,564, with the major components being the vibratory hoppers costing $15,000 each, and the actuator which has a budgetary estimate of $6,000.

| # | Part | Qty | Mat. | Type | Source | Cost | Shipping/ Machining | Sub Total |
|---|---|---|---|---|---|---|---|---|
| 1 | Female Ferrule Insert | 4 | | | | | | |
| 2 | Male Ferrule Insert | 4 | | | | | | |
| 3 | Female Contour Magazine | 1 | | | | | | |
| 4 | Star Wheel | 2 | 1.75mm ABS | 3D Printed | Matterhackers / White ABS Filament | 23.67 | In House | 71.15 |
| 5 | Male Contour Magazine | 1 | | | | | | |
| 6 | Ferrule Dropper | 1 | | | | | | |
| 7 | End Effector | 1 | | | | | | |
| 8 | 70 in-oz Position Control DC Motor | 3 | Multiple | | McMaster-Carr / 6627T570 | 214.99 | | 969.33 |
| 9 | 70 inoz Motor Driver | 3 | Multiple | | McMaster-Carr / 6627T62 | 487.7 | | 2,198.89 |
| 10 | 1/2" - 3/4" Sotted Disc Flexible Coupling Start | 3 | Plastic | | McMaster-Carr / 59985K250 | 27.3 | | 123.09 |
| 11 | 1/2" - 3/4" Slotted Disc Flexible Coupling Mid | 3 | Plastic | | McMaster-Carr / 59985K650 | 9.62 | | 43.37 |
| 12 | 1/2" - 3/4" Slotted Disc Flexible Coupling End | 3 | Plastic | Purchased Part | McMaster-Carr / 59985K125 | 27.3 | TBD | 123.09 |
| 13 | 3/4" Low-Profile Mounted Ball Bearing | 6 | 52100 Steel | | McMaster-Carr / 5913K630 | 11.78 | | 106.22 |
| 14 | Chute Hinge | 1 | Unfinished Steel | | McMaster-Carr / 15665A477 | 1.4 | | 2.10 |
| 15 | 1.6 in-oz Position Control DC Motor | 3 | Multiple | | McMaster-Carr / 6627T330 | 79.5 | | 358.44 |
| 16 | 1.6 in-oz Motor Driver | 3 | Multiple | | McMaster-Carr / 6627T41 | 99.43 | | 448.30 |
| 17 | .16" - 1/4" Slotted Disc Flexible Coupling Start | 3 | Plastic | | McMaster-Carr / 59985K102 | 10.54 | | 47.52 |
| 18 | .16" - 1/4" Slotted Disc Flexible Coupling Mid | 3 | Plastic | | McMaster-Carr / 59985K130 | 10.54 | | 47.52 |
| 19 | .16" - 1/4" Slotted Disc Flexible Coupling End | 3 | Plastic | | McMaster-Carr / 59985K610 | 2.32 | | 10.46 |

| # | Part | Qty | Mat. | Type | Source | Cost | Shipping/ Machining | Sub Total |
|---|------|-----|------|------|--------|------|---------------------|-----------|
| 20 | 1/2" Low Profile mounted ball bearing | 3 | 52100 Steel | | McMaster-Carr / 8600N300 | 15.14 | | 68.26 |
| 21 | Dicharge Hopper Rod | 1 | 1045 Carbon Steel | | McMaster-Carr / 1886K43 | 21.5 | | 32.31 |
| 22 | #0 Bolts pack | 15 | Black-Oxide Alloy Steel | | McMaster-Carr / 91253A026 | 6.34 | TBD | 142.93 |
| 23 | #8 Bolts pack | 1 | Zinc-Plated Alloy Steel | | McMaster-Carr / 91263A524 | 6.67 | | 10.02 |
| 24 | 5/16" Bolts pack | 1 | Zinc-Plated Alloy Steel | | McMaster-Carr / 91306A385 | 7.21 | | 10.84 |
| 25 | Miniature Snap-Acting Switch | 10 | Multiple | Purchased Part | McMaster-Carr / 7779K13 | 4.45 | | 66.88 |
| 26 | Electric Linear Actuator | 1 | Multiple | | Tolomatic / MXE-63 | 6000 | 0 | 6,000.00 |
| 27 | Outer Casing | 5 | Plexiglass | | Homedepot / 1000126445 | 124 | Pick Up | 700.60 |
| 28 | Connections Wire | 20 | Copper | | Homedepot / 205001906 | 2.74 | Pick Up | 82.36 |
| 29 | Vibrating Hopper | 2 | Multiple | | Crown Automated Feeders Inc. / Custom | 15000 | 0 | 30,000.00 |
| 30 | PLC | 1 | Multiple | | Automationdirect / C0-00AR-D, C0-008CDR, C0-00AC | 167 | 0 | 250.98 |
| 31 | Rotor | 1 | 5" dia - 2 ft Aluminium 6061-T6 | | McMaster-Carr / 8974K98 | 251.4 | 300 | 677.83 |
| 32 | Rotor Shoulder | 2 | 2" dia - 1ft 4130 Alloy | Purchased / Machined | McMaster-Carr / 6673T34 | 51.65 | 50 | 127.62 |
| 33 | Shaft Insert | 4 | 1"x"1" - 4130 Alloy | | Industrialmetalsales / 4130SQ1x12 | 30.19 | 50 | 231.49 |
| 34 | Selector | 1 | 2" dia - 2ft Aluminium 6061-T6 | | Metalsdeport / R312 | 4.1 | 50 | 56.16 |

| # | Part | Qty | Mat. | Type | Source | Cost | Shipping/ Machining | Sub Total |
|---|---|---|---|---|---|---|---|---|
| 35 | Delivery Hopper Side Plate | 2 | | | | | | |
| 36 | Delivery Hopper Back Plate | 1 | | | | | | |
| 37 | Delivery Hopper Lower Plate | 1 | | | | | | |
| 38 | Delivery Hopper Top Plate | 1 | | | | | | |
| 39 | Delivery Chute Side Plate | 2 | | | | | | |
| 40 | Delivery Chute Lower Plate | 2 | | | | | | |
| 41 | Delivery Handle Brace | 1 | | | | | | |
| 42 | Top Hopper Side Plate | 2 | | | | | | |
| 43 | Top Hopper Chute Upper Plate | 1 | | | | | | |
| 44 | Top Hopper Lower Plate | 1 | | | | | | |
| 45 | Top Hopper Upper Plate | 1 | | | | | | |
| 46 | Top Hopper Slider | 1 | | | | | | |
| 47 | Middle Hopper Side Plate | 2 | 1/8" 1045 Steel | Sheet Metal | Special Laser Tech Inc. Ernie Matichu | $450 | Pick Up | 508.50 |
| 48 | Middle Hopper Chute Plate | 1 | | | | | | |
| 49 | Middle Hopper Lower Plate | 1 | | | | | | |
| 50 | Middle Hopper Upper Plate | 1 | | | | | | |
| 51 | Middle Hopper Slider | 1 | | | | | | |
| 52 | Bottom Hopper Side Plate | 2 | | | | | | |
| 53 | Bottom Hopper Chute Upper Plate | 1 | | | | | | |
| 54 | Bottom Hopper Chute Lower Plate | 1 | | | | | | |
| 55 | Bottom Hopper Chute Vertical Plate | 1 | | | | | | |
| 56 | Bottom Hopper Upper Plate | 1 | | | | | | |
| 57 | Bottom Hopper Lower Plate | 1 | | | | | | |
| 58 | Bottom Hopper Slider | 1 | | | | | | |
| 59 | Ferrule Feeder Support | 2 | | | | | | |
| 60 | Ferrule Feeder Top Support | 2 | | | | | | |
| 61 | Ferrule Feeder Support Cover | 2 | | | | | | |
| 62 | Top Hopper Support | 2 | | | | | | |
| 63 | L Beam Duct | 6 | | | | | | |
| 64 | Hopper Supports | 2 | | | | | | |
| 65 | L Beam Duct Support Longest | 2 | | | | | | |
| 66 | L Beam Duct Support | 2 | | | | | | |

| # | Part | Qty | Mat. | Type | Source | Cost | Shipping/ Machining | Sub Total |
|---|------|-----|------|------|--------|------|----------|-----------|
| 67 | Servo Supports Female | 1 | | | | | | |
| 68 | Bearing Support 001 | 1 | | | | | | |
| 69 | Bearing Support 002 | 2 | | | | | | |
| 70 | Bearing Support 003 | 2 | | | | | | |
| 71 | Bearing Support 004 | 2 | | | | | | |
| 72 | Bearing Support Male | 1 | | | | | | |
| 73 | Servo Supports Male | 1 | 1/8" 1045 Steel | Sheet Metal | Special Laser Tech Inc. Ernie Matichu | $450 cont. | Pick Up | 508.5 cont. |
| 74 | Dicharge Hopper Lower Plate | 1 | | | | | | |
| 75 | Dicharge Hopper Side Plate | 2 | | | | | | |
| 76 | Dicharge Hopper Top Plate | 1 | | | | | | |
| 77 | Bearing Support 005 | 1 | | | | | | |
| 78 | Base | 1 | | | | | | |
| 79 | Delivery Bar | 1 | | | | | | |
| 80 | ELA Support Vertical | 4 | | | | | | |
| 81 | ELA Support Horizontal | 2 | | | | | | |
| 82 | ELA Top Base | 1 | | | | | | |
| 83 | ELA Support Horizontal 3 | 1 | | | | | | |
| 84 | Rotator Guard | 1 | | | | | | |
| 85 | Assembly & Wiring | 24 | n/a | Labour | Ambutech | 17 | N/A | 408.00 |
| 86 | Welding | 16 | | | TBD | 40 | N/A | 640.00 |

# A1.3 Preliminary Payback Period Estimation

Due to the size of the investment involved in upgrading to the new joiner machine, the payback period has been calculated to inform the decision on whether to proceed with the investment. This payback period is a preliminary estimate based on pricing costs from vendors for individual parts as opposed to a single contracted fabrication. Also, many of the delivery costs for these parts are still to be decided, and the machining and labour costs are budgetary estimates. The payback period calculations are done with a month as the unit of time being examined, so all costs are converted to monthly costs for the comparison. Also, the time value of money was not considered in the following, so the results will differ than if am interest rate had been used.

Tables A 3 gives the throughput rates used in the payback period for determining the amount of operator time needed to produce the requisite number of canes and the amount of overtime required. The current throughput rates are based on the tape rolling stations throughput rate and the proposed throughput rate is based on the cutting process for the graphite shafts, and the tape roller for the aluminum shafts as the joining process is faster than these other processes.

TABLE AIII - THROUGHPUT RATES USED FOR PAYBACK PERIOD CALCULATION

| Shaft Type | Current (s/cane) | Proposed (s/cane) |
|---|---|---|
| Aluminum | 450 | 278 |
| Graphite | 352 | 327 |

Table AIV gives the defect rates used in the payback period and the costs associated with them, as well as the time available on a per month basis to complete the work within regular time hours. The monthly available time was calculated as 6.5 working hours per shift x 3 shifts per day x 20 working days per month, and then converted to seconds to more easily work with the throughput rates.

TABLE AIV - DEFECT COSTS AND AVAILABLE TIME

| | Proposed | Current |
|---|---|---|
| Hourly Rate ($/hr) | 17 | 17 |
| Discard Defect Rate (%) | 0.01 | 0.03 |
| Rework Defect Rate (%) | 0.01 | 0.12 |
| Discard Defect Cost ($) | 1 | 1 |
| Available Time (s) | 1,404,000 | 1,404,000 |

Table AIV shows the total cost, life time, replacement periods, and calculated monthly costs of all the replaceable parts in the new joiner process. Other than defect rate costs, these are the only costs considered in the payback period analysis. The maintenance of the current process was not considered as is in this analysis.

TABLE AV - PART REPLACEMENT COSTS FOR NEW JOINER AS A MONTHLY COST

| Item | Cost ($) | Life Time (months) | To Replace (#) | Cost/month ($) |
|---|---|---|---|---|
| Actuator (replace every 18 months) | 6000.00 | 26.67 | 1.00 | 225.00 |
| 3D printed parts | 71.15 | 3.00 | 1.00 | 23.72 |
| Shaft Rotator (5" dia. 2ft Rotor) | 321.00 | 24.00 | 4.00 | 53.50 |
| 1" x 1", 2ft Rotor Shaft Insert | 11.00 | 12.00 | 1.00 | 0.92 |
| 2" dia. 2ft, Selector | 53.00 | 24.00 | 1.00 | 2.21 |
| 70 in-oz Stepper Motors | 487.00 | 24.00 | 3.00 | 60.88 |
| 1/2"-3/4" Coupling | 64.22 | 12.00 | 3.00 | 16.06 |
| 3/4" Ball Bearing | 11.78 | 12.00 | 6.00 | 5.89 |
| 1.6 in-on Motor | 79.50 | 24.00 | 2.00 | 6.63 |
| .16"-1/4" coupling | 23.40 | 12.00 | 2.00 | 3.90 |
| 1/2" bearing | 15.14 | 12.00 | 2.00 | 2.52 |
| Limit switch | 4.45 | 6.00 | 5.00 | 3.71 |
| Bearing Shoulder | 185.00 | 24.00 | 4.00 | 30.83 |
| Shaft insert | 115.00 | 24.00 | 4.00 | 19.17 |

Table AVI and Table AVII show the monthly costs of throw away defects and overtime for the current process and the proposed process respectively. The overtime costs are a combination of rework defect time and time needed to complete the required work load for the month.

TABLE A VI - CURRENT PROCESS MONTHLY NON-MAINTENANCE COSTS

|  | Graphite | | | Aluminum | | |
|---|---|---|---|---|---|---|
|  | 3000 Canes | 4000 Canes | 5000 Canes | 3000 Canes | 4000 Canes | 5000 Canes |
| Thrown Away (#) | 90 | 120 | 150 | 90 | 120 | 150 |
| Reworked (#) | 360 | 480 | 600 | 360 | 480 | 600 |
| Throw Away Costs ($) | 90 | 120 | 150 | 90 | 120 | 150 |
| Overtime Costs ($) | 0 | 2,570.26 | 8,035.33 | 1,530 | 8,670 | 15,810 |

TABLE AVII - PROPOSED PROCESS EXPECTED MONTHLY DEFECT COSTS

|  | Graphite | | | Aluminum | | |
|---|---|---|---|---|---|---|
|  | 3000 Canes | 4000 Canes | 5000 Canes | 3000 Canes | 4000 Canes | 5000 Canes |
| Thrown Away (#) | 30 | 40 | 50 | 30 | 40 | 50 |
| Reworked (#) | 30 | 40 | 50 | 30 | 40 | 50 |
| Throw Away Costs ($) | 30 | 40 | 50 | 30 | 40 | 50 |
| Overtime Costs ($) | 0 | 0 | 3,504.13 | 0 | 0 | 0 |

Table AVIII shows the monthly savings and the expected payback period for the joiner machine by the style of shaft it is designed to produce. Most of the monthly savings is in overtime costs, as the payback period analysis assumed that the level of production was the same between the proposed and old process. This assumption led to the current process having more overtime costs than regular time cost on a monthly basis to keep up with demand.

TABLE A VIII - MONTLY SAVINGS AND PAYBACK PERIOD

| Shaft Type | Production Level (Canes/Month) | Saved Monthly ($) | Payback Period (Month) |
|---|---|---|---|
| Aluminum | 3000 | 1,135.08 | 39.2 |
| | 4000 | 8,295.08 | 5.36 |
| | 5000 | 15,455.08 | 2.87 |
| Graphite | 3000 | 0 | Never |
| | 4000 | 2,075.34 | 21.44 |
| | 5000 | 4,176.29 | 10.65 |

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# APPENDIX B - TIMING STUDY ANALYSIS

## LIST OF TABLES

To determine the current state of the cane assembly process, and to determine how much the process needed to improve, the team took timing data of the process across a number of site visits. After taking the time study data at each of the stations, the following values were calculated: the cycle time (s/shaft or s/cane), the throughput rate (s/unit), and utilization (%). The results of the calculations are tabulated in Table BI through Table BVIII.

TABLE BI - ALUMINUM SAW DATA SUMMARIZED

| | |
|---|---|
| Total Shafts | 61.0 |
| Total Time | 752.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 12.3 |
| **Throughput Rate [s/shaft]** | 118.0 |
| **Utilization (%)** | 10.4 |

TABLE BII - GRAPHITE SAW DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 110.0 |
| Total Time | 1083.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 9.8 |
| **Throughput Rate [s/shaft]** | 65.5 |
| **Utilization (%)** | 15.0 |

TABLE BIII - ALUMINUM PRESS DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 169.0 |
| Total Time | 970.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 5.7 |
| **Throughput Rate [s/shaft]** | 42.6 |
| **Utilization (%)** | 13.5 |

TABLE BIV - GRAPHITE PRESS DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 112.0 |
| Total Time | 1046.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 9.3 |
| **Throughput Rate [s/shaft]** | 64.3 |
| **Utilization (%)** | 14.5 |

TABLE BV - ALUMINUM ROLLING DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 80.0 |
| Total Time | 1040.1 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 13.0 |
| **Throughput Rate [s/shaft]** | 90.0 |
| **Utilization (%)** | 14.4 |

TABLE BVI - GRAPHITE ROLLING DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 102.0 |
| Total Time | 1660.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 16.3 |
| **Throughput Rate [s/shaft]** | 70.6 |
| **Utilization (%)** | 23.1 |

TABLE BVII - ALUMINUM ASSEMBLY DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 69.0 |
| Total Time | 4932.0 |
| **Total Timing Period [s]** | 7200.0 |
| **Cycle Time [s/shaft]** | 71.5 |
| **Throughput Rate [s/shaft]** | 104.3 |
| **Utilization (%)** | 68.5 |

TABLE BVIII - GRAPHITE ASSEMBLY DATA SUMMARIZED

| | |
|---|---|
| Total Tubes | 25.0 |
| Total Time | 3600.0 |
| **Total Timing Period [s]** | 3600.0 |
| **Cycle Time [s/shaft]** | 144.0 |
| **Throughput Rate [s/shaft]** | 144.0 |
| **Utilization (%)** | 100.0 |

From the data, the team created a summary of the aluminum process and the graphite process. These summaries are in Table BIX and Table BX respectively. The time to process does not include time spent waiting.

TABLE BIX - GRAPHITE PROCESS SUMMARY

| [canes are 5 segment canes] | Throughput Rate [s/unit] |
|---|---|
| | |
| Cutting (per cane) | 327.3 |
| Pressing (per cane) | 321.4 |
| Rolling (per cane) | 352.9 |
| Assembly (per cane) | 144.0 |
| | |
| Total | 1145.6 |

TABLE BX  - ALUMINUM PROCESS SUMMARY

| [canes are 5 segment canes] | Throughput Rate [s/unit] |
|---|---|
| | |
| Cutting (per cane) | 590.2 |
| Pressing (per cane) | 213.0 |
| Rolling (per cane) | 450.0 |
| Assembly (per cane) | 104.3 |
| | |
| Total | 1357.5 |

Once all of the throughput rates were determined, the team decided to compare it to the takt time of the process. To determine the takt time, the team discussed with the company what the desired throughput of canes was at peak capacity and what the useable hours in each shift was. The results of this discussion are summarized in Table BXI.

TABLE BXI - TAKT TIME SUMMARY

| | |
|---|---|
| Shifts per Day | 3.0 |
| Used Hours Per shift | 6.5 |
| Seconds/Hour | 3600.0 |
| Useable days per month | 20.0 |
| Product Per Month | 5000.0 |

| | |
|---|---|
| Takt Time [s/cane] | 280.8 |
| Takt Time [min/cane] | 4.7 |
| Takt Time [s/shaft] | 70.2 |
| Takt Time [min/shaft] | 1.2 |

In comparing the takt time to the summarized aluminum and graphite timing data, it can be seen that tape rolling stations are a larger problem than the pressing stations. In fact, the aluminum press is actually below the required Takt time of the system. With this knowledge the team determined that the proposed joining operation must free up enough operator time to allow for the tape rolling times to improve until they are below the Takt time, as well as be able to run without the operator to improve utilization so that the joiner throughput time improves as well.

To determine the operator time required at the press to reduce the tape roller throughput rate below the required takt time, the team compared the current and a proposed operator involvement times at the joiner and determined how much time would be saved per hour at the joiner. The saved time was then utilized to complete more rolling operations, with 10% of the saved time assumed to be lost due to travel, refocusing on another task by the operator or some other form of waste. The proposed times are just low enough to ensure that the throughput time of the tape roll is below the Takt time. Tables BXII and BXIII summarize the calculations.

TABLE BXII - SUMMARY OF GRAPHITE PROCESS OPERATOR INVOLVEMENT CALCULATION

| | | |
|---|---|---|
| **Graphite Press** | Shafts per Hour | 56.00 |
| | Current Operator Involvement Time [s] | 9.30 |
| | Proposed Operator Involvement Time [s] | 5.00 |
| | Time Saved per shaft | 4.30 |
| | Total Time Saved | 240.80 |
| | | |
| **Tape Roller** | Current Rolls per hour | 51 |
| | Roll time per shaft | 16.27 |
| | Extra Shafts Rollable | 13.32 |
| | New Rolls per hour | 64.32 |
| | | |
| **Tape Roller Throughput Comparison** | Current Throughput Rate [s/cane] | 352.94 |
| | New Throughput Rate [s/cane] | 279.87 |
| | % improvement | 26.11 |

TABLE BXIII - SUMMARY OF ALUMINUM PROCESS OPERATOR INVOLVEMENT CALCULATION

| | | |
|---|---|---|
| **Aluminum Press** | Shafts per Hour | 84.50 |
| | Current Operator Involvement Time [s] | 5.70 |
| | Proposed Operator Involvement Time [s] | 1.50 |
| | Time Saved per shaft | 4.20 |
| | Total Time Saved | 354.90 |
| | | |
| **Tape Roller** | Current Rolls per hour | 40 |
| | Roll time per shaft | 13.00 |
| | Extra Shafts Rollable | 24.57 |
| | New Rolls per hour | 64.57 |
| | | |
| **Tape Roller Throughput Comparison** | Current Throughput Rate [s/cane] | 450.00 |
| | New Throughput Rate [s/cane] | 278.78 |
| | % improvement | 61.42 |

Given the difference in the proposed operator involvement times at the joiner required to reduce both the aluminum and graphite tape rolling process throughput rate to below the takt time, the team chose the lower of the two involvement times, the 1.5s from the aluminum calculation, to be the target specification. This was done to support the goal of standardizing the process between the two assembly lines and to give greater improvements in the graphite line to allow for more operator time to be spent elsewhere.

# APPENDIX C – FORCE ANALYSIS

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# AIV.1 – FORCE TEST BACKGROUND AND PROCEDURE

As a part of determining the appropriate actuators for the joining process, Team 11 conducted a series of tests using the aluminum and graphite cane shaft segments, and the male and female ferrules that are pressed into them. The tests were conducted to determine both the force required to fully join the ferrules to the shafts and, the force required to make the shaft segments catastrophically fail.  The test was conducted using an MTS Insight compression and tensile testing machine, and Test Works software. During the test, the MTS Insight testing machine was used to apply a compressive load to a shaft held between a support plate at the bottom and the loading plate at the top. The Test Works software was used to read the information being transmitted from the load cell in the loading plate and generate a set of time dependent data. The test machine with a sample prepared for testing is shown in Figure C1 below.



Figure C1 - Test Apparatus

The tests conducted covered the six possible shaft material and ferrule type combinations that are possible to have when making one of the canes. The possible combinations of shaft and ferrule types, along with the sample sizes tested, are listed in Table C1.

TABLE CI -SHAFT AND FERRULE COMBINATIONS

| Combination Name | Shaft Type | Male Ferrule | Female Ferrule | Tip Adapter | Number of Samples |
|---|---|---|---|---|---|
| Aluminum Cane Bottom Shaft | Aluminum | Used | Not Used | Not Used | 10 |
| Aluminum Cane Middle Shaft | Aluminum | Used | Used | Not Used | 20 |
| Aluminum Cane Top Shaft | Aluminum | Not Used | Used | Not Used | 10 |
| Graphite Cane Bottom Shaft | Graphite | Not Used | Not Used | Used | 10 |
| Graphite Cane Middle Shaft | Graphite | Used | Used | Not Used | 20* |
| Graphite Cane Top Shaft | Graphite | Not Used | Used | Not Used | 9 |

*Some of the graphite middle shafts where tested with only the male ferrule, but plotted with the others to illustrate the difference in between pressing with one or two ferrules in the shaft.

The procedure for conducting the test involved the following steps:

1. Each shaft is paired with an appropriate ferrule. For middle shafts, each end is paired with either a male or female ferrule.
2. The internal diameter of the shaft and the outer diameter of the ferrule knurl section are measured. For the middle shafts, the inner diameters at both ends are measured. For the graphite bottom shaft, the outer diameter of the shaft and inner diameter of the tip adapter are measured.
3. The ferrules are mated with the shaft end they are paired with.
4. The ferrule-shaft assemblies are placed into the testing machine and held in place by the operator.
5. The test software is activated, which causes a load to be applied at a constant rate. Once the loading plate contacts the ferrule-shaft assembly the operator releases the shaft.
6. The test loading is applied until the operator turns off the test cycle.
7. With the cycle complete, the data is saved into a text file for future analysis

During the tests, the operator recorded any observations they had about the test sample's response.

# AIV.2 – SUMMARY OF TEST DATA

Using the test data, six force-time charts were made to compare the test results for each ferrule-shaft combination.  A force-interference chart was also made for the aluminum shafts and the graphite shafts. The graphite bottom and the aluminum top combinations were excluded from the force-interference analysis due to having either an insignificant amount of force required to fully join the tip adapter to the shaft or for having no force plateau, respectively.

From the force-time charts, Team 11 determined that the shaft material was the most significant factor in the amount of force needed to fully join the ferrule to the shaft, so only two forces, one for aluminum shafts and one for graphite shafts, needed to be determined. It was also determined that the plastic tip adapters have such a low force required to break the tip adapter that it may not be feasible to press these adapters on with a machine. Also, due to the uniformity of the force-time charts it was possible to visually determine the force required to join the ferrules to the shafts without breaking the shaft.

The force-interference data was used to extrapolate the force required to join the ferrules to the shafts under the worst case circumstances, i.e. where the shaft's inner diameter is as small as the tolerances will allow and the ferrule's outer diameter is as large as the tolerances allow. In the case of the middle combinations, the highest interference of the two sides was used, as it would require the higher force of the two ferrules being joined to the shaft.

From the force-interference charts, Team 11 determined that the spread of the results is large enough that the numeric relation derived from the data is not useful in determining the amount of force required vs the interference of the knurl and the shaft. This conclusion was drawn due to the aluminum shaft relation having a coefficient of determination of 0.021 and the graphite shaft relation having a coefficient of determination of 0.449. This lack of predictability is most likely due to the fact that measurements were only taken at the end of the shafts, and that the interior of the shafts is not perfectly uniform in either diameter or surface roughness.

Table II below summarizes the test's conclusions. Following Table II are the force-time and force vs interference charts, and the team's interpretation of the data they contain, used to determine the results.

TABLE CII - SUMMARY OF FORCE TESTING RESULTS

| Shaft Type | Force Required For Joining (N) | Force-Interference Relationship |
|------------|-------------------------------|--------------------------------|
| Aluminum | 7000 | none |
| Graphite | 1200 | none |
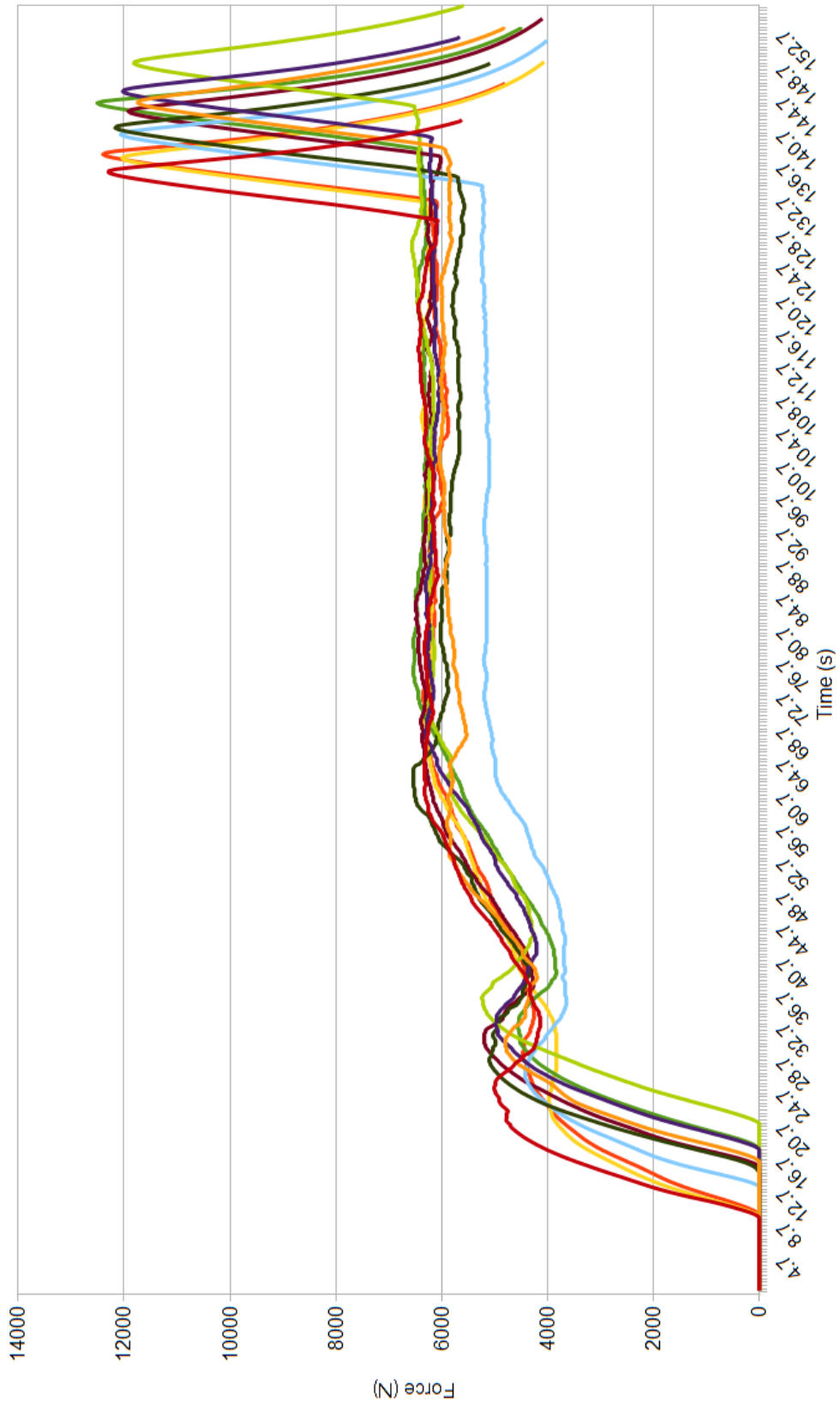
Figure C2 - Aluminum Cane Bottom Shaft Force Trend
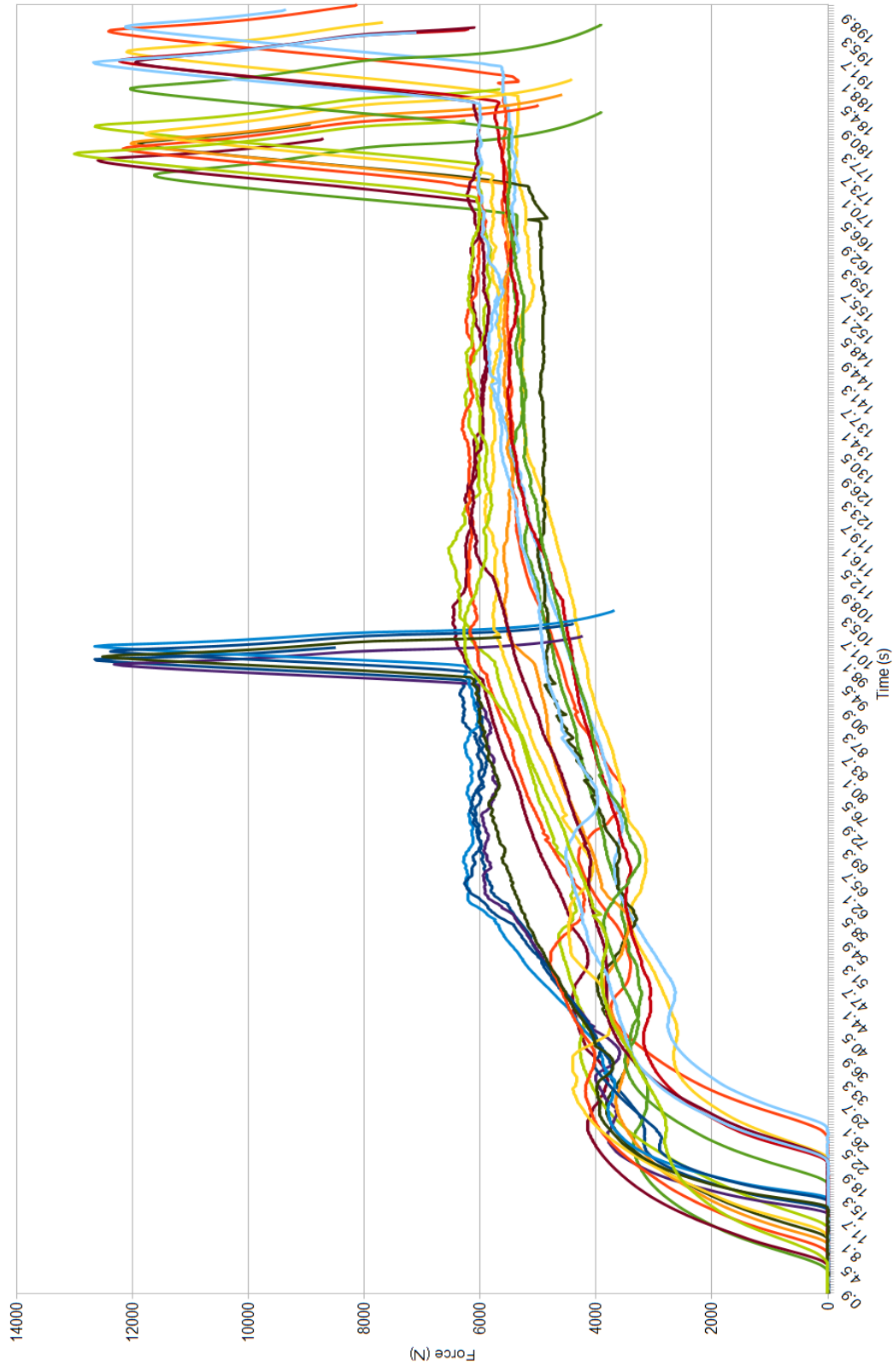
Figure C3 - Aluminum Cane Middle Shaft Force Trend
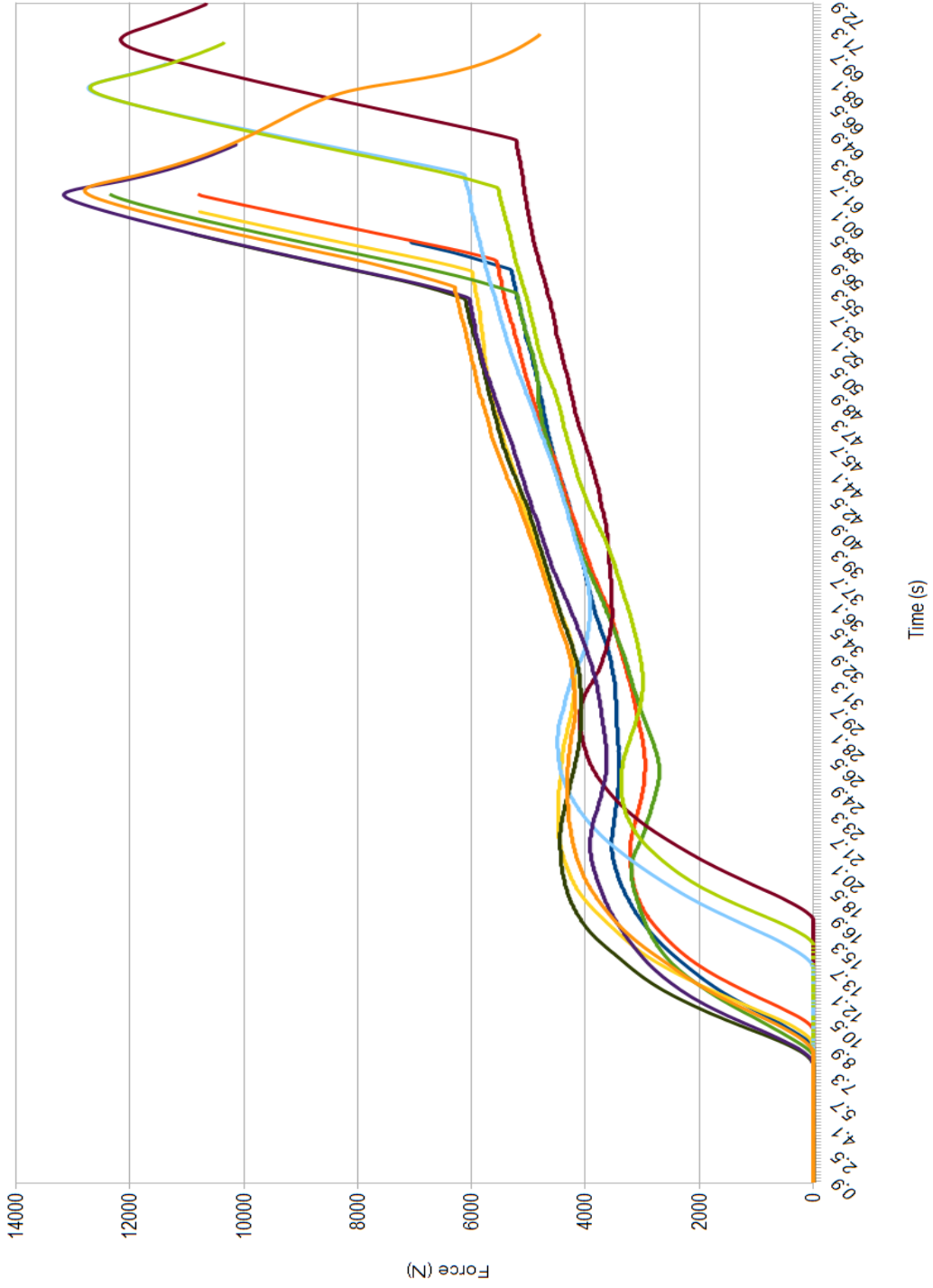
Figure C4 - Aluminum Cane Top Shaft Force Trend
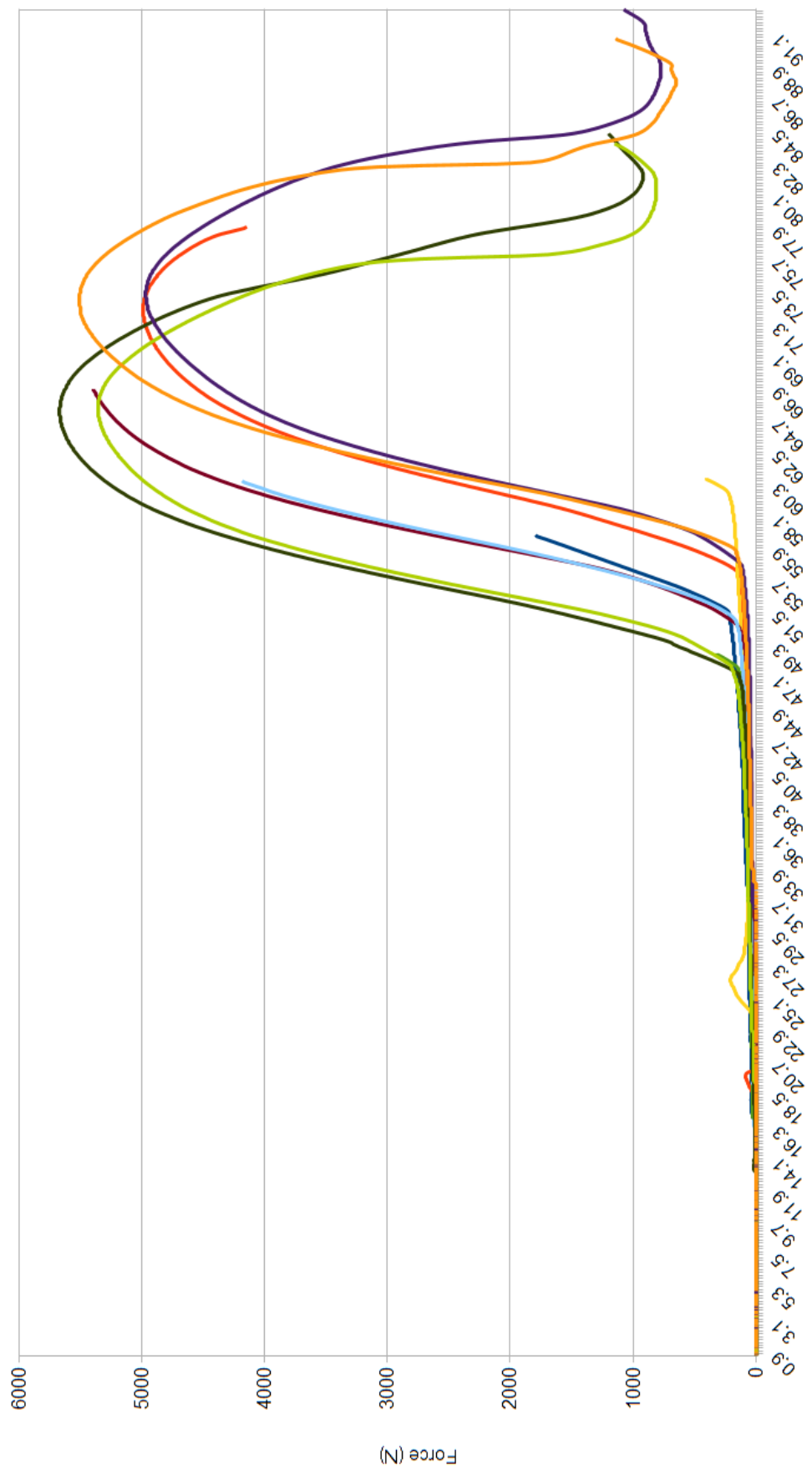
Figure C5 - Graphite Cane Bottom Shaft Force Trend
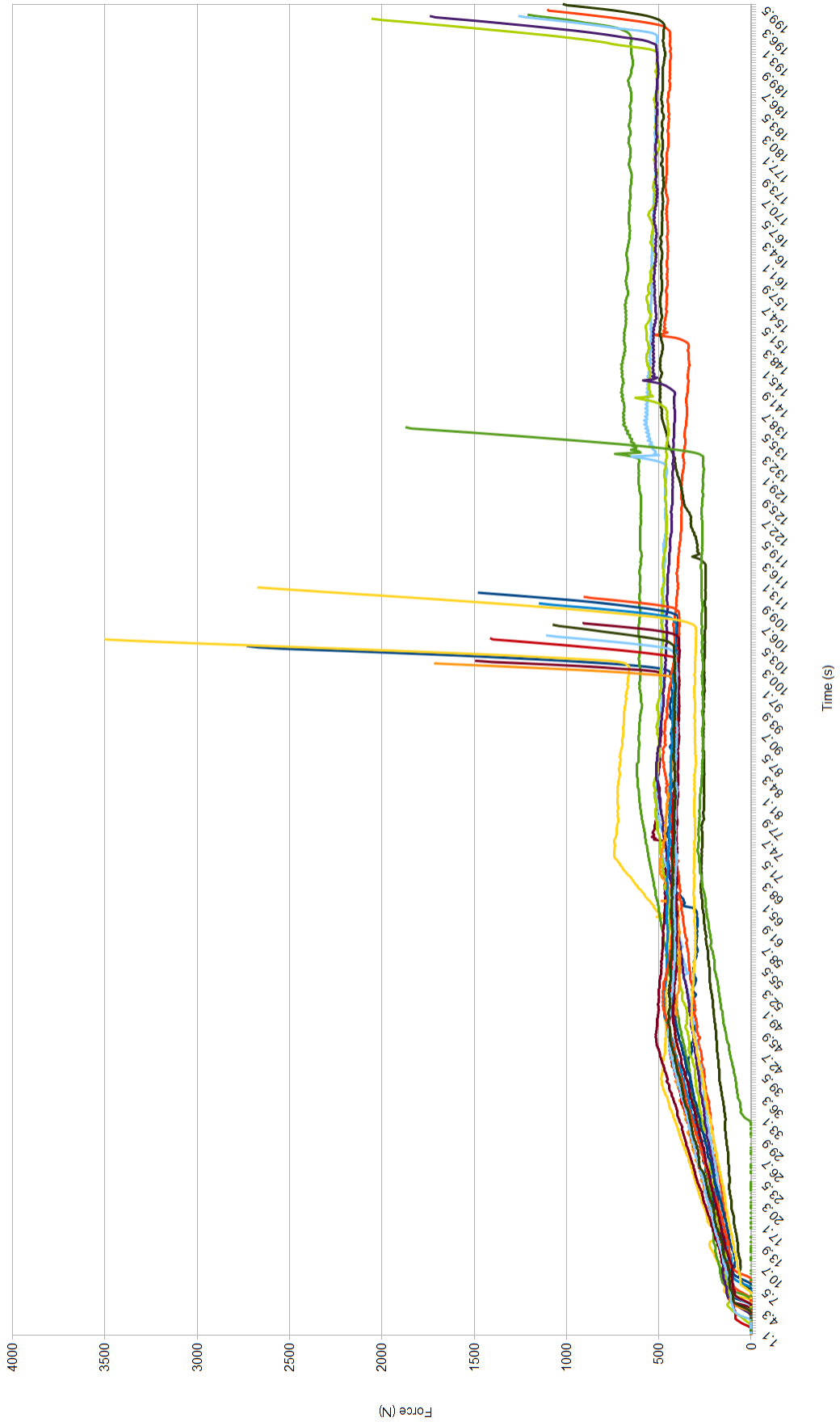
Figure C6 - Graphite Cane Middle Shaft Force Trend

C10
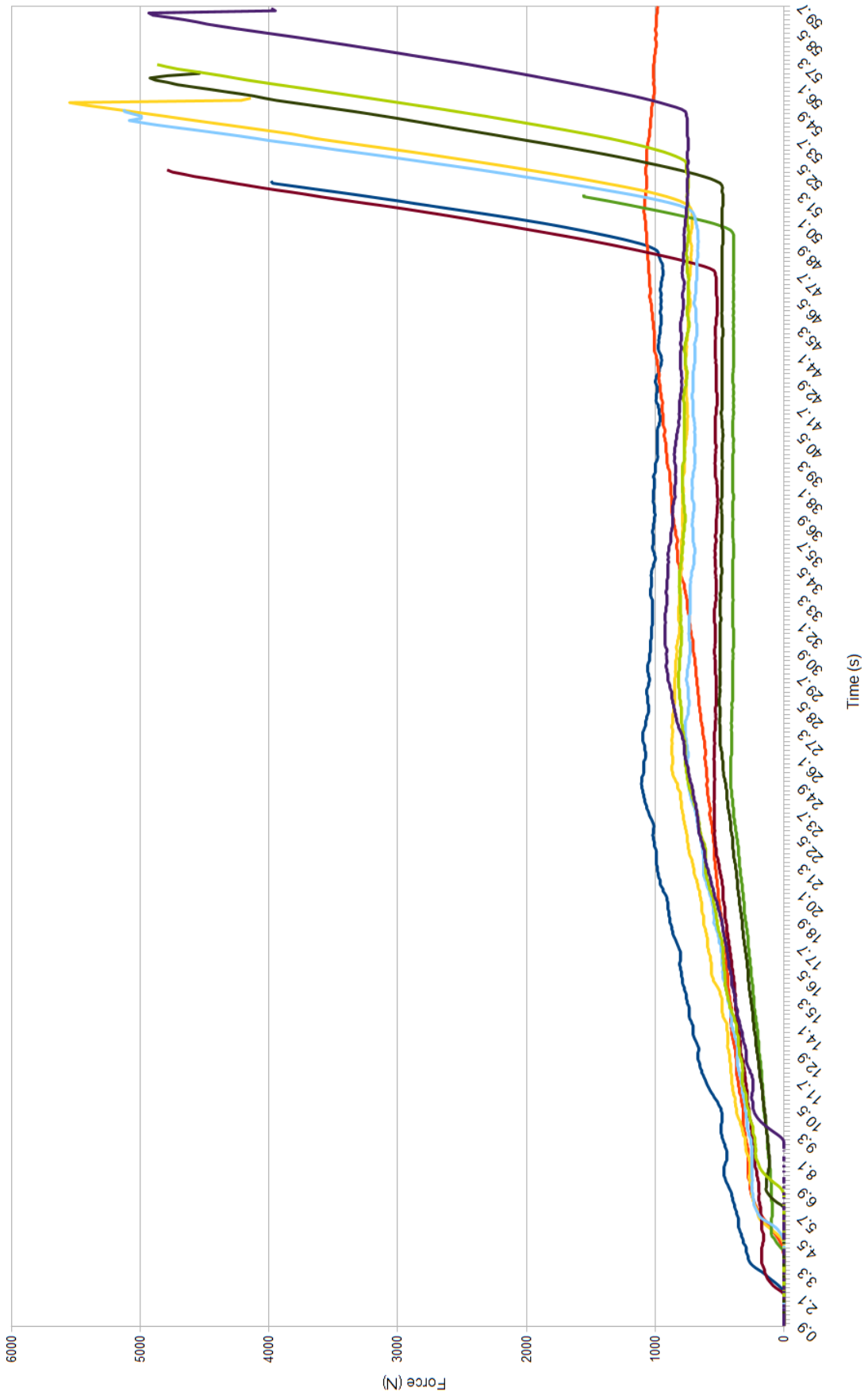
Figure C7 - Graphite Cane Top Shaft Force Trend

C11

In Figure C2 and C3, the amount of force required for the joining is given by the plateaued section in the center of the chart. Notably, the amount of force required during the operation is relatively steady once the initial ramp up is complete, which allows the team to more easily choose an adequate joining force. Also, the gap between the joining force and the peak force at the right of the chart, which is the force required to break the specimen, is large enough that a force 10-20% larger than required does minimally risks damaging the product.

In Figure C4, the same general trend for the aluminum shafts can be seen as above in Figures C2 and C3, though there is no significant plateau to determine the average joining force, the largest required joining force is seen at the point of inflection where the pressing stage in the center of the chart changes into the rapidly climbing peaks at the right of the chart. This largest joining force is consistent with the joining forces in the other aluminum shafts.

In Figure C5, the amount of force required to join the plastic tip adapter to the graphite cane shaft can be seen to be very low, in the range of 400 N or less. Due to this lack of strength, the tip adapters may not be a viable candidate for any automated joining operations since the actuators available may not be able to stop pressing fast enough to avoid damaging the adapters.

In Figure C6 and C7, the same plateauing and peaking of the joining force can be seen in the graphite shaft-ferrule assemblies as in the aluminum shaft-ferrule assemblies. The only significant difference between the two shaft types is the magnitude of the force being exerted. Unfortunately, the amount of force required to damage the graphite shafts, as seen in the peaking in Figure 7, is low enough that the same joining force could not be used on both the aluminum and graphite shafts.

In Figures C8 and C9, the lack of significant relationship between the amount of interference and the amount of force applied can be seen. The large spread of points around the trend lines leads to a low amount of confidence in any estimates that the numeric relations would produce, and this is best shown in the aluminum shaft relation

having a coefficient of determination of 0.021 and the graphite shaft relation having a coefficient of determination of 0.449. Both of these coefficients of determination are very low, with the graphite coefficient giving approximately a 44% chance of accurately estimating the required force for a given amount of interference.
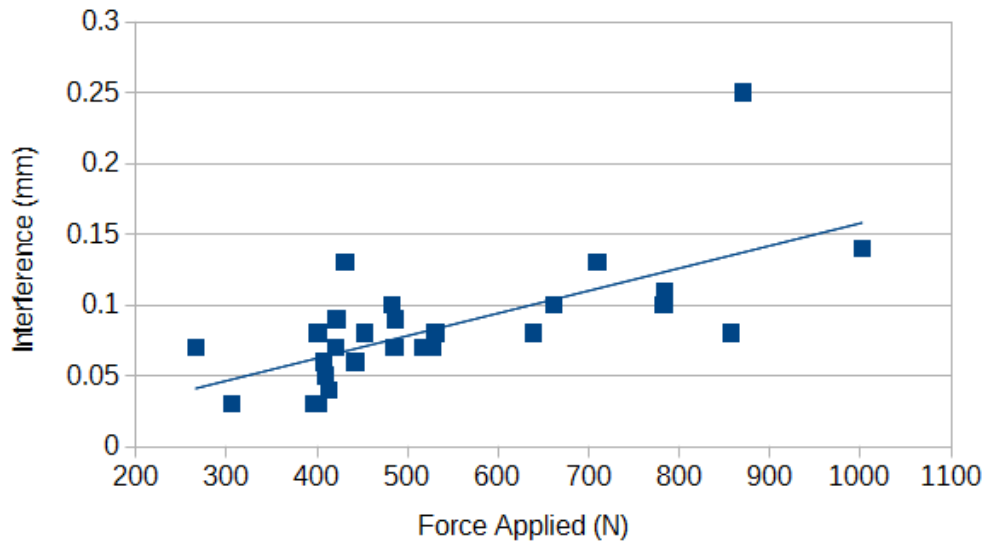


Figure C 9 - Graphite Shaft Force Interference Trend
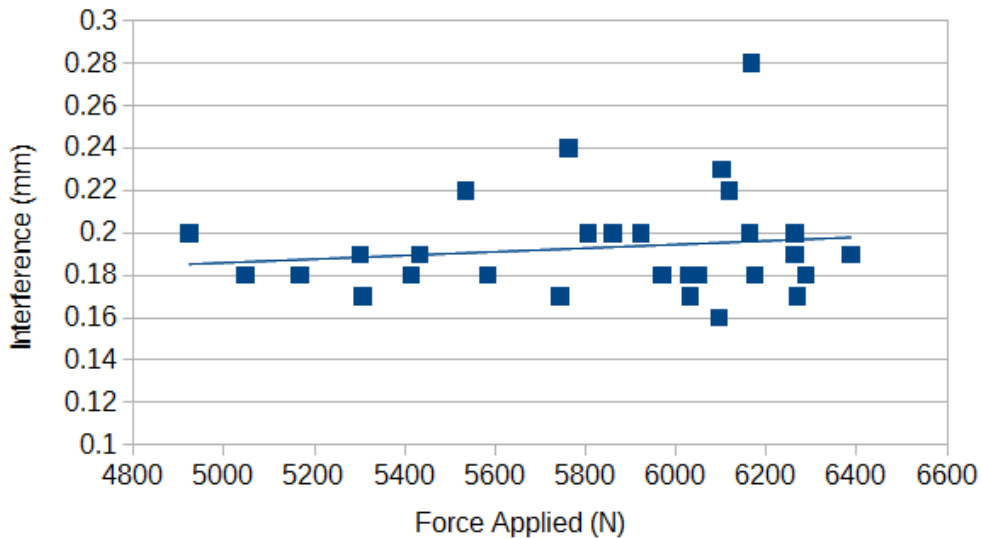


Figure C 8 - Aluminum Shaft Force Interference Trend

C13

# APPENDIX D – CONCEPT SELECTION

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# LIST OF TABLES

## D.1 INTRODUCTION

The team performed multiple iterations of concept generation and utilized screening methods to obtain a final design. After multiple site visits to understand the process, each team member was asked to brainstorm 2 to 3 preliminary concepts to discuss later as a team. During that meeting, our team used the SCAMPER method to reduce and refine the concepts. Team members were then assigned to pick one concept and further develop it. Once developed, these the designs were gathered and evaluated on a Pugh chart.

 Upon examination of the designs, our team decided to break down the Joiner into three different categories. The three categories of concepts are: ferrule delivery system, shaft delivery system and the Joiner system. These designs can be found in the secondary concepts section and were evaluated on a Pugh chart to select the top designs. Afterwards, a matrix was created to calculate the weighing of each criteria and show the top concepts. The weighting was constructing from customer feedback and our observations of the process.

The final design screening process involved performing a sensitivity analysis on the results of the weighted matrix. This analysis allowed us to closer examine the top concepts. Lastly, the concepts were then discussed with Melet Plastics for feedback based on their experience.  A decision on which concepts to pursue in the detailed design portion of the project was received.

## D.1.1 EXTERNAL RESEARCH

To inform the concept generation, the team researched patents available through Google Patents. The team used keyword searches to determine what types of patents would be displayed, collected the results, and grouped the patents to more easily compare them to the concepts the team generated.

For the keyword search, the terms joiner, press, ferrule, tube, shaft, pipe, press fit, friction fit, interference fit, and autonomous press were used as the search terms. A sample of what patents the keyword search produced and brief descriptions of the patents are given in Table DI.

The patents in Table DI all pertain to other industries, and either perform singular pressing operations or modify the material as it is being pressed in an automated process. Notably, the pressing operations found in the search are all more similar to the original pressing operation that Melet is using now than to the new concepts being developed to improve the joiner process.
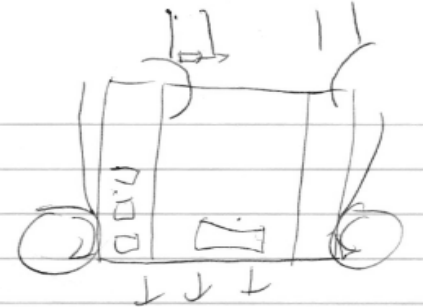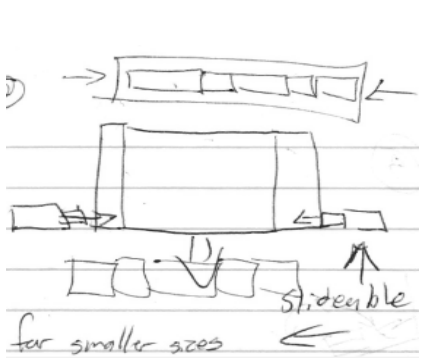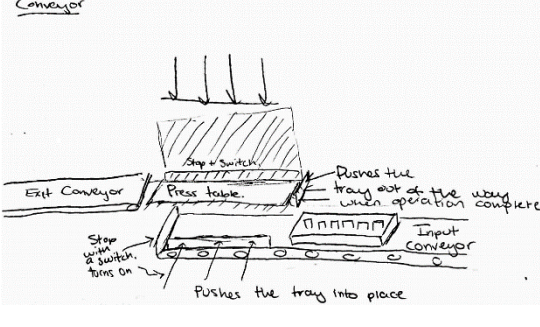
TABLE DI - PATENT RESEARCH SUMMARY
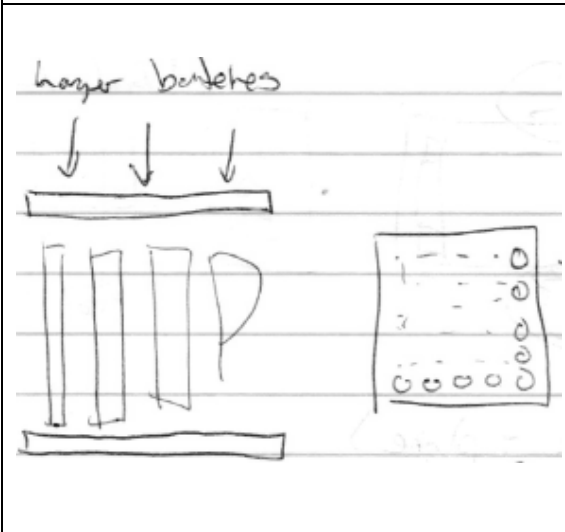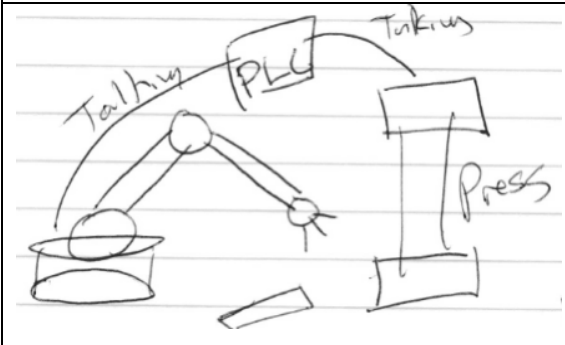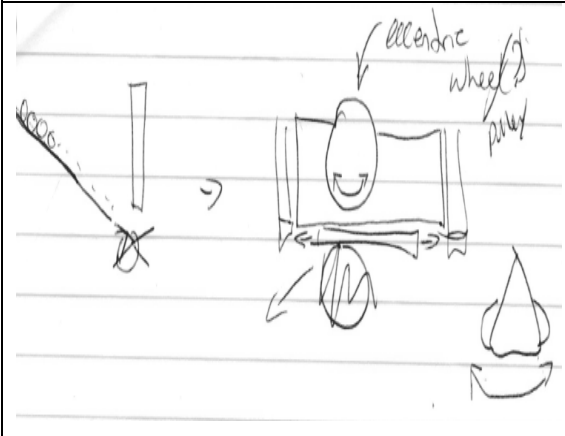
| Patents Found | Description |
|---|---|
| US3470725 | This patent is about the press drawing process of the material for a metal gold club shaft. The operation of the press involves multiple pressing cycles happening in close succession due to an automated pressing process. [1] |
| US7017252B2 | Single shaft press intended to mate golf club heads and shafts by application of force at one end of the shaft while supporting the head at the other end. [2] |
| US3159876A | High pressure press that surrounds entire entity being pressed and presses it volumetrically [3] |
| US5339729A | Single shaft press for pressing and piece of fruit over a screen to juice it [4] |
| US4391358A | Hardware press and punch apparatus for punching hardware and fasteners onto sheet metal or other product [5] |
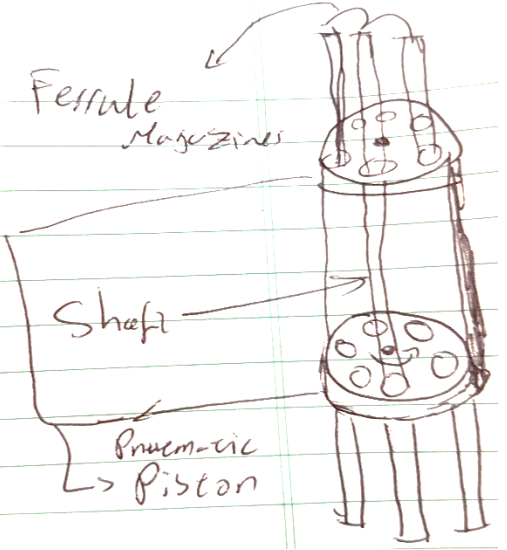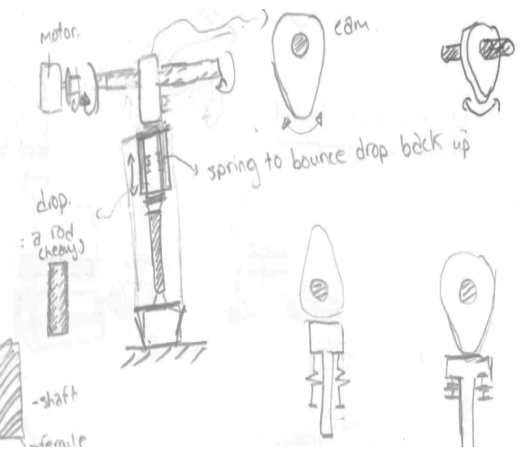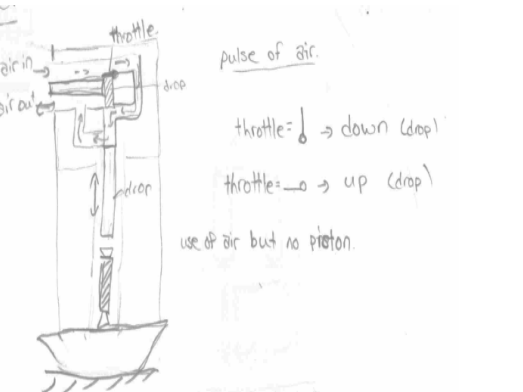
# D.2.2 PRELIMINARY CONCEPTS
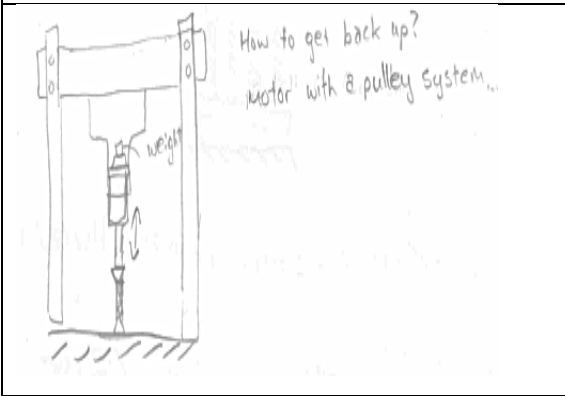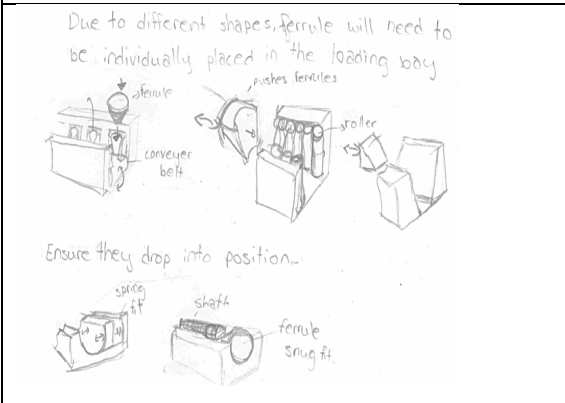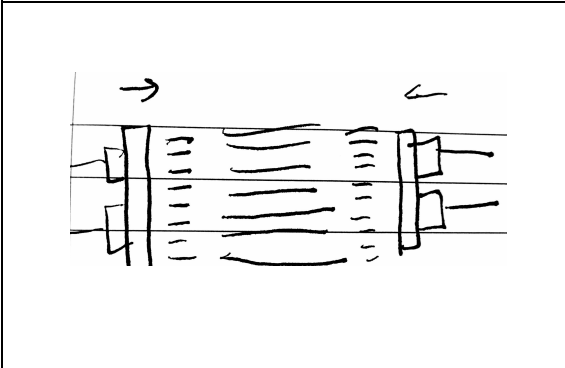
The starting point for developing design concepts is to come up with as many as possible to explore every alternative. The team's first concept generation did not focus on a specific function of the Joiner, but was instead an all-encompassing attempt to fabricate ideas. Table DII contains rough drawings of all 13 original designs ideas the team developed, along with descriptions and a list of their pros and cons. It is important to note that the description incorporated in the sketches are re-iterated in the description column.

TABLE DII - PRELIMINARY CONCEPTS

| Drawing | Description | Advantages | Disadvantages |
|---------|-------------|------------|---------------|
|  | The ferrules and shafts are placed in a tray that moves along a base by means of spinning disks. The disks will eventually converge and press them together. | • No compressed air.<br>• No hydraulics.<br>• No linearly moving parts.<br>• Low complexity. | • Cannot accommodate different shaft lengths.<br>• Requires manual steps.<br>• Potential to exert too much force. |
|  | Dual pistons will press-fit the ferrules into the shafts. The pistons have a set arm displacement but are adjustable for varying lengths. | • Can fit different shaft lengths.<br>• Piston press fit is a proven method.<br>• Pistons are quick. | • Time required to adjust piston position.<br>• Complexity of method to adjust piston position.<br>• Tolerances will be difficult to account for. |
|  | The shafts and ferrules are carried in a tray to a location where pistons will actuate to press them together. The assembled units will be sent to an exit conveyer. | • Ensures proper alignment before joining.<br>• Partially automated. | • Manual tray loading.<br>• Can only press one length at a time. |

| Drawing | Description | Advantages | Disadvantages |
|---|---|---|---|
|  | Shafts will be inserted into holds to allow for easy alignment for the Joiner operation. | • Can join batches at a time. | • It is a manual method.<br>• Need for shaft length organization.<br>• Less efficient than current method. |
|  | A robot arm will pick up and align the shafts and ferrules into a Joiner machine. | • Completely automated.<br>• Correctly orientates ferrules. | • Expensive.<br>• Large footprint. |
|  | A shaft will be loaded between two eccentric disks that will rotate back and forth to press fit the stationary ferrules into the shaft end. | • No linearly moving parts.<br>• Compact. | • Cannot accommodate multiple shaft dimensions.<br>• Difficult to account for tolerances.<br>• Potential for exerting too much force. |

D5
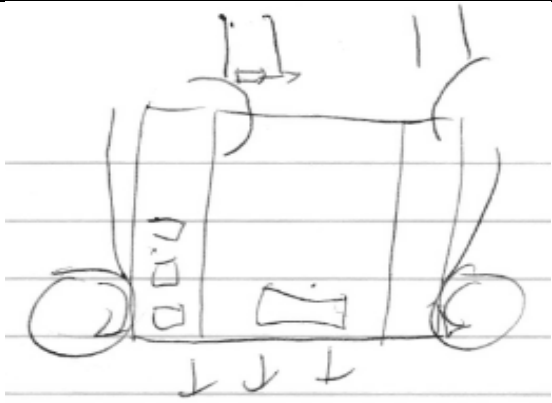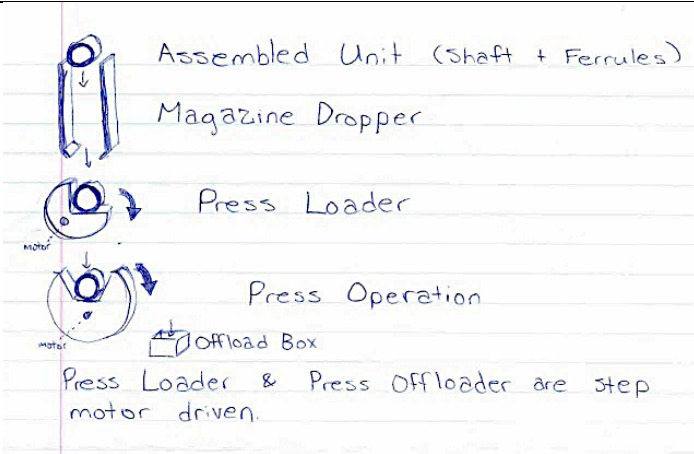
| Drawing | Description | Advantages | Disadvantages |
|---|---|---|---|
|  | Shafts will be loaded into a circular holder along with the ferrules. Once components are in the circular holder, it will rotate them to a piston which will press fit them together. | • An automated system.<br>• Piston press fit is a proven method. | • Cannot accommodate multiple shaft dimensions.<br>• Complication of circular holder. |
|  | Shafts are pre-fit with ferrules and are fed into the into the Joiner. The Joiner will operate by means of an eccentric disk which will push down on a spring reacting joining end. | • Simple press mechanism.<br>• Pre-fitting ferrules eliminates need for ferrule orientating. | • Cannot accommodate various shaft dimensions.<br>• Potential for exerting to much force.<br>• May include a manual step. |
|  | A shaft that is pre-fit with the ferrules will be inserted into a holder. The Joiner press fits them together by the same method a jack hammer works. | • Quick method of inserting the ferrules into the shaft.<br>• Operates via compressed air which is already available. | • Potential for sudden and violent presses.<br>• Poses a danger to operator hearing.<br>• Need for precise throttle manipulation.<br>• Includes a manual loading step. |

| Drawing | Description | Advantages | Disadvantages |
|---|---|---|---|
|  How to get back up? Motor with a pulley system... weight | A shaft that is pre-fit with the ferrules will be inserted into a holder. Once loaded a calibrated weight will drop to join the pieces together. | • Simple method of joining.<br>• Can be calibrated to accommodate multiple materials. | • May include manual step of loading shafts.<br>• Need for calibrating the dropped weight.<br>• Free-fall weight creates a potential safety hazard. |
|  feed by gravity shaft input piston | Shafts are loaded into the Joiner by means of a gravity fed magazine. Ferrules are appropriately aligned, Joiner will fit the pieces together with a piston. | • Simple shaft feed system.<br>• Piston press fit is a proven method.<br>• Partially automated system. | • Alignment of ferrules are not considered.<br>• Cannot accommodate multiple shaft diameters. |
|  Due to different shapes, ferrule will need to be individually placed in the loading bay ferrule pushes ferrules roller conveyer belt Ensure they drop into position... spring fit shaft ferrule snug fit | Ferrules are loaded into a contoured channel and will then be pushed into position for the Joiner process. | • Partially automated system.<br>• Can be adapted for different ferrules.<br>• | • Ferrules require a specialized contoured channel. |
|  | Shafts and ferrules are loaded in the Joiner and a multi-piston system joins them. | • Presses multiple units together at a time.<br>• Potential for full automation. | • Expensive.<br>• Manual loading may be required.<br>• Large footprint. |

Upon collecting and organizing our initial concepts, we then used our engineering intuition to determine which ideas were most reasonable. These more reasonable designs were then further elaborated upon and compared. Specifically, the designs that we decided to expand upon included components with piston actuation, gravity fed loading, and conveyer trays.

After combining some designs, reconsidering some of the alternatives, and thinking rationally about them, we identified four designs that we wished to compare. These designs are shown in Table DIII.

TABLE DIII – PRELIMINARY CONCEPTS TAKEN FARTHER

| Name | Drawing | Description |
|---|---|---|
| Cam Conveyor Tray |  | The ferrules and shafts are placed in a tray and move horizontally along a base by means of spinning disks which would eventually press them together. |
| Step Motor |  | The shaft is gravity fed to a holder which rotates and drops it using a step motor, into the Joiner location. A piston presses the components together and then a step motor rotates to offload the shaft. |

| Name | Drawing | Description |
|---|---|---|
| Roller |  | Shafts and ferrules are loaded in the Joiner via some means and a multi-piston system joins them. |
| Vertical Tray Conveyer |  | The ferrules and shafts are place in a tray and move vertically along a guide by means of spinning disks which would eventually press them together. |

Our team then applied a Pugh chart analysis to compare these designs with each other. The Pugh chart applies a rating for each of the designs in terms of a reference design which enable our team to uncover any design pitfalls. The reference design used in this case was the existing graphite joiner. Ratings are made with respect to how well a design satisfied the corresponding metric.

The Pugh chart comparison is done by adding the pros and subtracting the cons to reach a quantifiable design strength. A plus (+) symbol means that the design in that column is better at meeting the metric in the corresponding row compared to the reference. A minus (–) symbol denotes that the design is weaker and a 0 denotes that it has the same ability to meet the need. Table DIV is the described PUGH Chart applied to our chosen preliminary designs.

TABLE DIV – PRELIMINARY CONCEPT PUGH CHART

| Preliminary Designs Pugh Chart | Graphite | Aluminum | Cam Conveyor Tray | Step Motor Idea | Roller | Vertical Tray Conveyor |
|---|---|---|---|---|---|---|
| Efficiently Joins Ferrules | 0 | + | + | + | 0 | 0 |
| Inserts Ferrule Quickly | 0 | 0 | 0 | 0 | + | 0 |
| Reliable | 0 | + | + | + | - | 0 |
| Allows Operator Multitasking | 0 | 0 | + | + | + | + |
| Safe | 0 | - | + | + | + | - |
| Allows Multiple Lengths | 0 | + | + | + | + | 0 |
| Allows Multiple Materials | 0 | - | + | 0 | 0 | 0 |
| Simple to Use | 0 | + | 0 | + | 0 | + |
| Easy to Maintain | 0 | - | 0 | - | - | 0 |
| Standardized | 0 | 0 | + | 0 | 0 | 0 |
| Foot print | 0 | 0 | - | 0 | - | - |
| Budget | 0 | - | 0 | - | - | 0 |
| Noise level | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | |
| Positive | 0 | 4 | 7 | 6 | 4 | 2 |
| Zero | 13 | 5 | 5 | 5 | 5 | 9 |
| Negative | 0 | 4 | 1 | 2 | 4 | 2 |
| Net | 0 | 0 | 6 | 4 | 0 | 0 |

From this chart our team learnt that strongest ideas were the step motor design and the cam conveyor tray. Determining that these two designs had the most potential, the team chose to improve the designs by adding more functions to them.

It is important to note that new designs were considered moving forward but the findings from this Pugh chart pointed out issues with current ideas. The specific issues were with the maintenance, footprint, and budget.

# D.3 SECONDARY CONCEPTS

It was decided to breakdown the concepts into three sections to refine and focus on each process better. These section are: ferrule delivery, shaft delivery, and joiner methods. The final design will consist of the strongest combination of each section.

## D.3.1 FERRULE DELIVERY CONCEPTS
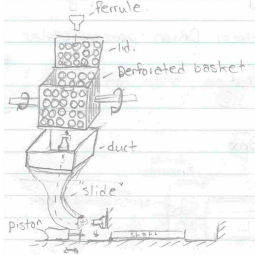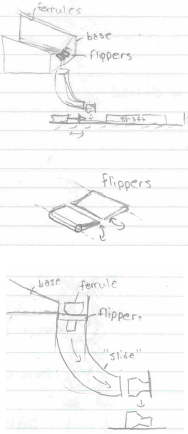
Table DV contains all secondary concepts relating to the ferrule delivery system.

TABLE DV – FERRULE DELIVERY CONCEPTS

| Name | Concepts | Description | Advantages | Disadvantages |
|------|----------|-------------|------------|---------------|
| Slot Feeder |  | Slot Feeder slides back and forth allowing one ferrule to fall through at a time. | • Cheap.<br>• Simple.<br>• Small. | • Chance of jamming.<br>• Manually loaded.<br>• Hard to maintain. |
| Upwards Feeding Ferrule Feeder |  | The ferrules are stacked horizontally on top of each other on an angle with a spring at the bottom of the magazine like holder and it pushes them up to the opening where an arm pushes the ferrule to the next step. | • Can be preloaded. | • Requires more loading time than current method.<br>• Prone to jamming. |
| Spring Fed Ferrule Feeder |  | The ferrules are stacked edge to edge vertically in a magazine like fashion with a spring on top the pushes them down an angled opening that allows one ferrule to exit at a time. An arm moves down to push the ferrules out from the edge. | • Can contain more ferrules | • Very prone to jamming.<br>• Hard and slow to load |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Ferrule Rod Feeder |  | The ferrules are loaded on a rod one after the other vertically then they the rod bends on an angle and a star wheel pushes one ferrule into a separated second rod that moves down to the next step. | • Lines up the asymmetrical ferrules. | • Slow loading time.<br>• Hard to maintain. |
| Ferrule Tray |  | Ferrules come pre-assembled in a tray from the manufacturer. | • Simple | • Continuous cost.<br>• Insignificant improvement |
| Fixed Magazine |  | A ferrule magazine, fixed to the operation, which is loaded by the operator for a large amount of ferrules. It delivers ferrules to the process, by allowing the press to go through the magazine. | • Can be preloaded. | • Hard to maintain.<br>• Prone to jamming. |
| Removable Magazine |  | A magazine, which could be loaded by the operator, or the ferrule distributor, which the operator can attach to the ferrule delivery system, or directly to the press. | • Can be preloaded. | • Prone to jamming<br>• Slow to load. |
| Removable Packaging |  | Ferrules come pre-packaged from the manufacturer as 10 ferrules attached by an easily removable packaging once pressed. A compression fit into the ends of the ferrules, which still allows for pressing into the shaft. | • Faster than picking ferrules from a bag.<br>• Pre-lined up to match shafts | • Continuous cost. |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Sloped Run with Contured Actuator Ferrule Feeder |  | Ferrules slide down feed and onto sloped run. Sloped actuator end effector guides a ferrule into the shaft and sets it up. Contouring the end effector will provide an effective solution to different combinations. | • Simple.<br>• Efficient.<br>• Allows for more multi-tasking. | • Manually loaded.<br>• Struggles with multiple materials.<br>• Large footprint |
| Tray Feeder |  | Servo and gravity driven conveyors allowing magazines to fallout slowly into the joiner system. | • Can be preloaded.<br>• Systematic. | • Prone to jamming.<br>• Cannot handle multiple materials and lengths. |
| Variable Slope with Actuator Ferrule Feeder |  | Ferrules are put into the feeder then fall out onto a sloped run. The slope sets the ferrules onto the shaft and a light force actuator "sets" it prior to the joining. | • Allows for operator multitasking. | • Does not handle multiple materials. |
| Wheel fed actuator Ferrule Feeder |  | Ferrules fall down the feed chute and a wheel pushes them forward. A light force actuator "sets" the ferrules in the shaft prior to the joining process. | • Quick.<br>• Improves multi-tasking.<br>• Simple. | • Does not handle multiple materials.<br>• Hard to maintain.<br>• Large. |
| Ferrule Hopper Design |  | The operators drops the ferrules on the hopper which vibrates drives the ferrules to a profiled hole that orients the ferrule on a slide to the next stage. | • Allows for operator. multi-tasking<br>• Orients parts correctly. | • Expensive<br>• Complicated |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Ferrule Rolling Basket |  | The ferrules are put into a perforated basket where the wholes are a specific size that allows the ferrules to exit in a specific manner by rotating them. Then they slide out to the next stage. | • Orients parts<br>• Simple to use | • Very prone to jamming<br>• Inconsistent<br>• Slow<br>• Many moving parts |
| Ferrule Flipper |  | This design has a vibrating base that leads the ferrules to a flipper that opens when a ferrule is needed and sends it down a duct to the next stage. | • Quick<br>• Allows multi-tasking | • Large<br>• Noisy<br>• Hard to maintain |

The team was assigned to rank all the concepts in a Pugh chart independently then the team met to discuss the results and come up with a combined Pugh chart as seen in Table DVI.

TABLE DVI - FERRULE FEEDER PUGH CHART
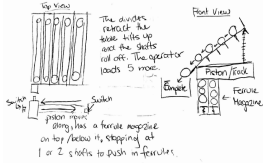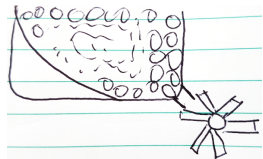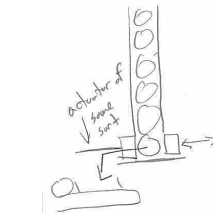
| Ferrule Feeder Pugh Chart | Graphite | Aluminium | Ferrule of Shaft Slot Feeder | Ferrule Rod Feeder | Ferrule Tray | Fixed Magazine | Removable Magazine | Removable Packaging | Sloped Run With Contoured Actuator | Spring Fed Frrule Feeder | Tray Feeder | Upwards Feeding Ferrule Feeder | Variable Slop With Actuator Ferrule | Wheel Fed Actuator Ferrule Feeder | Ferrule Hopper Design | Ferrule Rolling Basket Design | Ferrule Flipper Design |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Efficiently Joins Ferrules | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | + | x | 0 | x | 0 | 0 | 0 | 0 | + |
| Inserts Ferrule Quickly | 0 | 0 | + | + | + | + | + | x | - | x | 0 | x | 0 | + | + | 0 | + |
| Reliable | 0 | 0 | - | - | + | - | - | x | 0 | x | 0 | x | 0 | 0 | 0 | - | 0 |
| Allows Operator multitasking | 0 | 0 | + | + | + | + | + | x | + | x | + | x | + | + | + | + | + |
| Safe | 0 | 0 | + | + | 0 | 0 | 0 | x | + | x | 0 | x | 0 | 0 | + | 0 | 0 |
| Allows Multiple Lengths | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | x | 0 | x | 0 | 0 | 0 | 0 | 0 |
| Allows Multiple Materials | 0 | 0 | - | 0 | 0 | - | - | x | - | x | + | x | - | - | - | - | - |
| Simple To Use | 0 | 0 | + | + | + | + | + | x | + | x | + | x | + | + | + | + | + |
| Easy To Maintain | 0 | 0 | - | 0 | 0 | - | - | x | 0 | x | - | x | - | - | 0 | - | - |
| Standardized | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | x | 0 | x | 0 | 0 | 0 | 0 | 0 |
| Foot Print | 0 | 0 | + | + | 0 | + | + | x | - | x | - | x | - | - | - | - | - |
| Noise Level | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | x | - | x | 0 | 0 | - | - | - |
| Positive | 0 | 0 | 5 | 5 | 4 | 4 | 4 | 0 | 4 | 0 | 3 | 0 | 2 | 3 | 4 | 2 | 4 |
| Zero | 12 | 12 | 4 | 6 | 8 | 5 | 5 | 0 | 5 | 0 | 6 | 0 | 7 | 6 | 5 | 5 | 4 |
| Negative | 0 | 0 | 3 | 1 | 0 | 3 | 3 | 0 | 3 | 0 | 3 | 0 | 3 | 3 | 3 | 5 | 4 |
| Net | 0 | 0 | 2 | 4 | 4 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | -1 | 0 | 1 | -3 | 0 |
| Ranking | 4 | 4 | 2 | 1 | 1 | 3 | 3 | DQ | 3 | DQ | 4 | DQ | 5 | 4 | 3 | 6 | 4 |
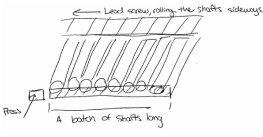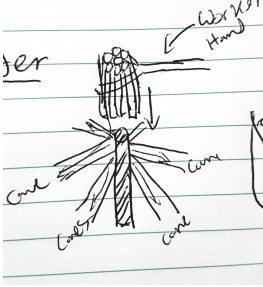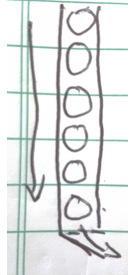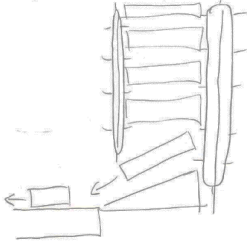
From the Pugh chart we can see the top ranking concepts for the ferrule delivery and how some concepts tied for 1st place and 3rd place. The top concepts are the ferrule slot feeder and the ferrule rod feeder.  The removable packaging, spring fed ferrule feeder and the upwards feeding ferrule feeder were disqualified due to close similarity to other concepts.
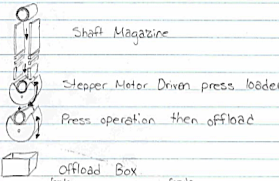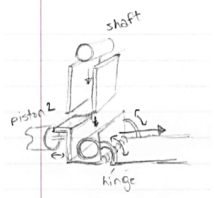
## D.3.2 SHAFT DELIVERY CONCEPTS

This section discusses the shaft delivery concepts generated and their advantages and disadvantages. All concepts are then compared to the current methods in a Pugh chart. The top three methods of shaft delivery are then moved forward into more rigorous concept selection methods.

TABLE DVII - SHAFT DELIVERY CONCEPTS

| Name | Concepts | Description | Pros | Cons |
|------|----------|-------------|------|------|
| Angled Table |  | A table with dividers and a press pushes the shafts magazines along the table. At the end a switch causes the table to rotate and the dividers retract and allow the shafts to roll down to the next stage. | • Quick.<br>• Simple<br>• Allows operator multi-tasking. | • Hard to maintain.<br>• Large.<br>• Noisy. |
| Bin with star wheel feeder |  | A slanted bin with a slot opening at the corner that allows for many shafts to be stacked and feeds into a slotted wheel that can take one rod at a time. The wheel then carries each shaft to the next stage. | • Can load high quantities. | • Prone to jamming.<br>• Does not handle multiple materials. |
| Shaft Slotting Feeder |  | Slot Feeder slides back and forth allowing one shaft to fall through at a time. | • Cheap.<br>• Simple.<br>• Small. | • Chance of jamming.<br>• Manually loaded.<br>• Hard to maintain. |

| Name | Concepts | Description | Advantages | Disadvantages |
|------|----------|-------------|------------|---------------|
| Lead Screw |  | A "lead screw" rotates the shafts along a table until they come up to a press. The table is a "batch" of shafts long, allowing the operator to put down all of the shafts that need to be pressed. | • Systematic. | • Prone to jamming.<br>• Slow. |
| Shaft Bundle Delivery System |  | The employee grabs a stack of shafts and slides it over a rod that will reject the center shaft while allowing the other shafts to follow a path to the next station. | • Simple. | • Requires more operator time than currently.<br>• Not efficient. |
| Shaft Chute |  | Vertical shaft loader where shafts are stacked on top of each other and there is a door at the bottom that opens to allow one shaft to roll out at time then it closes. The shafts are enclosed in a casing that only allows one shaft horizontally. A different casing will be needed for different shafts outer diameter. | • Small.<br>• Efficient.<br>• Simple. | • Not automated. |
| Tray Feeder |  | Servo and gravity driven conveyors allowing magazines to fallout slowly into the joiner system. | • Can be preloaded.<br>• Systematic. | • Prone to jamming.<br>• Cannot handle multiple materials and lengths. |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Step Motor Design |  Shaft Magazine / Stepper Motor Driven press loader / Press operation then offload / Offload Box | The shafts are dropped into a magazine which then feeds into a step motor driven guide roller that is able to intake one shaft at a time to the offload box. | • Efficient. | • Hard to maintain. |
| Hinge Design |  shaft / piston 2 / hinge | The shafts are dropped in a magazine that then feeds into a hinge slot which is able to intake one shaft at a time. | • Small. | • Hard to maintain. |

The designs were subjected to a Pugh chart concept selection with multiple metrics. They were compared to the current graphite press as shown in Table DVIII.

| Shaft Feeder Pugh Chart | Graphite | Aluminum | Angled table | Bin with Star Wheel Feeder | Ferrule or Shaft Slotting Feeder | Lead Screw | Shaft Bundle Delivery System | Shaft Chute | Tray Feeder | Step Motor Design | Hinge Design |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Efficiently Joins Ferrules | 0 | 0 | 0 | 0 | 0 | 0 | - | + | + | + | 0 |
| Inserts Ferrule Quickly | 0 | 0 | + | + | + | 0 | 0 | 0 | + | + | + |
| Reliable | 0 | 0 | 0 | - | 0 | 0 | - | 0 | 0 | 0 | 0 |
| Allows Operator multitasking | 0 | 0 | + | + | + | + | 0 | + | 0 | + | + |
| Safe | 0 | 0 | + | + | + | 0 | 0 | + | 0 | + | + |
| Allows Multiple Lengths | 0 | 0 | 0 | - | 0 | - | - | 0 | 0 | 0 | 0 |
| Allows Multiple Materials | 0 | 0 | 0 | - | 0 | - | 0 | 0 | + | 0 | 0 |
| Simple To Use | 0 | 0 | + | + | + | + | - | + | + | + | + |
| Easy To Maintain | 0 | 0 | - | - | - | - | 0 | 0 | - | - | - |
| Standardized | 0 | 0 | 0 | 0 | 0 | - | - | 0 | 0 | 0 | 0 |
| Foot Print | 0 | 0 | - | - | - | - | - | 0 | - | - | - |
| Noise Level | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Positive | 0 | 0 | 4 | 4 | 4 | 2 | 0 | 4 | 4 | 5 | 4 |
| Zero | 12 | 12 | 5 | 3 | 6 | 5 | 6 | 8 | 6 | 5 | 6 |
| Negative | 0 | 0 | 3 | 5 | 2 | 5 | 6 | 0 | 2 | 2 | 2 |
| Net | 0 | 0 | 1 | -1 | 2 | -3 | -6 | 4 | 2 | 3 | 2 |
| Ranking | 5 | 5 | 4 | 6 | 3 | 7 | 8 | 1 | 3 | 2 | 3 |
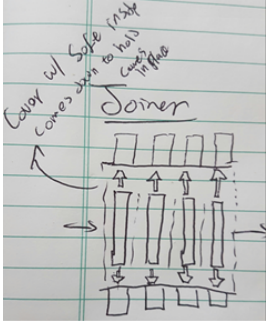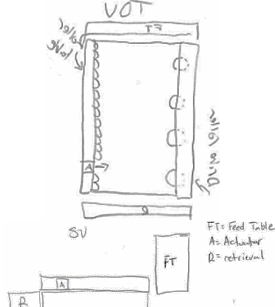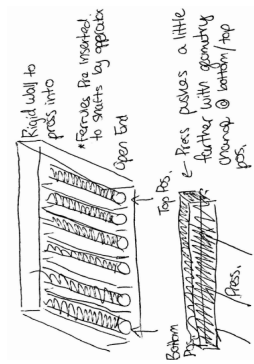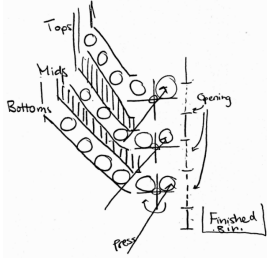
The Pugh chart concludes that the shaft chute is the strongest idea. The concepts are compared to the current graphite machine. Only the shaft feeding operation of the current machine is used for comparison, which is considered as hand fed.
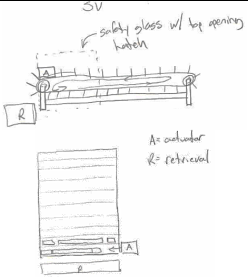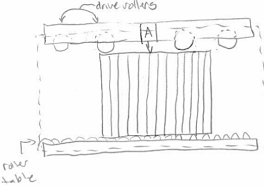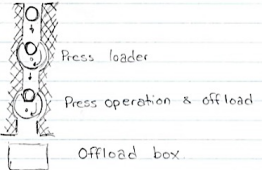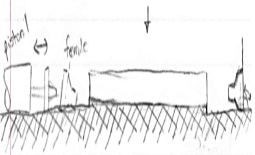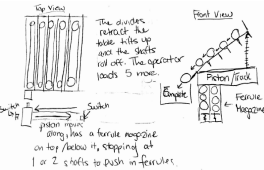
## D.3.3 JOINER CONCEPTS

This section compares the different joining process concepts generated and their advantages and disadvantages. After the concepts are introduced, they are compared to the current method graphite joining method in a Pugh chart. This helps determine the top three strongest concepts.

TABLE DIX - JOINER PROCESS CONEPTS

| Name | Concepts | Description | Pros | Cons |
|---|---|---|---|---|
| Adjustable Table with Belt |  | A belt is on the bottom, which rolls shafts along. There is a removable table on top holding the shafts in position. There is a different table for each type of material and shaft diameter. The shafts are rolled along, until the lead one hits a switch. A door will close not letting in any other shafts, the belt will stop moving. Once the press operation is complete, the 2 stop doors will open, the completed shaft will roll into a bin, and a fresh shaft will roll into place. | • Efficient.<br>• Reliable. | • Hard to maintain.<br>• Many moving parts. |
| Star Joiner |  | The shafts are loaded into a star shaped wheel that turns a certain a certain amount after each press. It is powered by a pneumatic piston that stops when a pre-assigned force is reached. The ferrules have a similar wheel on each side of the shaft wheel. | • Simple. | • Hard to maintain.<br>• Hard to handle multiple materials.<br>• Hard to handle multiple lengths. |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Multi Piston Joiner |  | The shafts and ferrules move horizontally along each other on a conveyer belt then they are pressed via pistons on each side that are powered pneumatically. The conveyer belts have spacers that line up the ferrules and shafts. A cover is placed on top at each press for safety. | • Efficient.<br>• Quick.<br>• Simple.<br>• Reliable. | • Hard to maintain.<br>• Large. |
| Horizontal wheel fed joiner |  | Horizontal wheels slide the magazine forward and align an actuator to join the shafts. A hinged, interlocking lid provides safe, covered operation. | • Allows multi-tasking.<br>• Allows multiple lengths.<br>• Simple. | • Hard to maintain.<br>• Large.<br>• Many moving parts.<br>• Complex. |
| Horizontal Tray |  | A horizontal tray, set up with ferrules on the back side of the tray. The operator would fit the shafts into the ferrules, and then the remaining ferrules for the middles into the open end of the tray. Alternative: Ferrules are already pre inserted by the operator. The operator would prepare batch trays. | • Improves multi-tasking. | • Inefficient.<br>• Many moving parts. |
| Gravity Rotation |  | Three gravity fed funnels which the operator just loads the bare shafts into their respective slot feed into a rotation device. It rotates to the pressing operation and then rotates again to drop into the finished parts bin. | • Can take multiple sections at a time.<br>• Quick.<br>• Simple.<br>• Efficient.<br>• Reliable. | • Large. |

| Name | Concepts | Description | Advantages | Disadvantages |
|---|---|---|---|---|
| Conveyor Joiner |  | A conveyor belt delivers shafts and ferrules to the actuator that presses them. Safety glass surrounds the pressing operation to increase the safety of the machine. | • Efficient.<br>• Reliable.<br>• Allows multi-tasking. | • Hard to maintain.<br>• Many moving parts.<br>• Large. |
| Vertical Wheel Fed Joiner |  | Vertical tray feeder with an actuator to push the ferrules into the shaft. Rollers drive the tray forward. There is a hinged lid that acts as a safety interlock. | • Simple.<br>• Allows multi-tasking.<br>• Efficient.<br>• Reliable. | • Large.<br>• Many moving parts. |
| Step Motor Design |  | The shafts and ferrules fall into press loaders which are a cylinder with a cut in the size of the shaft and ferrule. The cylinder then rotates to drop into another cylinder for a piston to perform the pressing operation then the cylinder offloads to a box. | • Simple.<br>• Quick.<br>• Allows multi-tasking.<br>• Efficient.<br>• Reliable. | • Many moving parts.<br>• Complex.<br>• Hard to access the interior. |
| Hinge Design |  | The piston tip pushes into the ferrule and guides it into the shaft, which then pushes the shaft and ferrule to the end ferrule that sits on a spring. | • Simple.<br>• Quick.<br>• Allows multi-tasking.<br>• Efficient.<br>• Reliable. | • Ferrule misalignment could happen. |
| Angled Table |  | A table with dividers and a press pushes the shafts magazines along the table. At the end a switch causes the table to rotate and the dividers retract and allow the shafts to roll down to the next stage. | • Efficient.<br>• Reliable. | • Large.<br>• Noisy. |

The different joining methods were put in a Pugh chart to compare against the current graphite press at Melet Plastics on the product needs, which is found in Table DX.

TABLE DX - JOINER PUGH CHART

| Joiner Pugh Chart | Graphite | Aluminum | Adjustable Table with Belt | Conveyor Joiner | Gravity Rotation Joiner | Horizontal Tray | Horizontal Wheel fed Joiner | Multi piston Joiner | Star Joiner | Vertical Wheel fed Joiner | Step Motor Design | Hinge Design | Angled Table |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Efficiently Joins Ferrules | 0 | 0 | + | + | + | 0 | 0 | 0 | x | + | + | + | 0 |
| Inserts Ferrule Quickly | 0 | 0 | 0 | 0 | + | 0 | 0 | + | x | 0 | + | + | + |
| Reliable | 0 | + | + | + | + | 0 | + | + | x | 0 | 0 | 0 | 0 |
| Allows Operator multitasking | 0 | 0 | + | + | + | + | + | + | x | + | + | + | + |
| Safe | 0 | 0 | + | + | + | 0 | + | + | x | + | + | + | + |
| Allows Multiple Lengths | 0 | + | 0 | 0 | + | - | + | 0 | x | 0 | 0 | 0 | 0 |
| Allows Multiple Materials | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | x | 0 | 0 | 0 | 0 |
| Simple To Use | 0 | 0 | + | + | + | 0 | + | + | x | + | + | + | + |
| Easy To Maintain | 0 | - | - | - | - | 0 | - | - | x | - | 0 | 0 | 0 |
| Standardized | 0 | 0 | + | + | + | + | + | + | x | + | + | + | + |
| Foot Print | 0 | 0 | - | - | - | 0 | - | - | x | - | 0 | 0 | - |
| Noise Level | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 | x | 0 | 0 | 0 | - |
| Positive | 0 | 2 | 6 | 6 | 8 | 2 | 6 | 6 | 0 | 5 | 6 | 6 | 5 |
| Zero | 12 | 8 | 4 | 4 | 1 | 9 | 4 | 4 | 0 | 5 | 6 | 6 | 5 |
| Negative | 0 | 2 | 2 | 2 | 3 | 1 | 2 | 2 | 0 | 2 | 0 | 0 | 2 |
| Net | 0 | 0 | 4 | 4 | 5 | 1 | 4 | 4 | 0 | 3 | 6 | 6 | 3 |
| Ranking | 6 | 6 | 3 | 3 | 2 | 5 | 3 | 3 | DQ | 4 | 1 | 1 | 4 |

The step motor and hinge designs scored top place in the ranking with 2nd and 3rd place concepts not placing too far with a difference of 1 and 2 points respectively. The top designs received no negative points.

# D.4 Concept Scoring

The following section details the process that Team 11 used to determine the criteria to use in the scoring, the weights of the criteria, the scoring process, and the sensitivity analysis. All of the content of this section is on the mechanical process behind generating all of the data for comparison, and does not delve into the final selection of each component of the joiner, which is discussing section D.6, Concept Selection.

The first step in the scoring process is to determine the criteria and the weight each criteria holds in the scoring system. The determination of criteria was done with the client to ensure that the criteria chosen were valuable. The weighting of each criteria was done internally.

Next, the criteria and weights are taken and used to judge the top three tiers of concepts from the ferrule feeder, shaft feeder, and joiner concept sections. Each criterion was given a grade out of 10, which was multiplied by the weight to give the score for each criteria. The individual scores from each criterion were summed to get a final score out of 100 for each concept. This process was done internally and then presented to the client for discussion and selection of the concepts.

The final part of concept scoring is conducting a sensitivity analysis to determine how subjective the final results were relative to the teams scoring and weighting systems. This was done in a systematic manner to ensure the validity of the testing and the final results of the scoring process.

# D.4.1 WEIGHTED MATRIX

The first part in the concept scoring process is determining what criteria are going to be used and the weight each criteria will have in the scoring process. In choosing the criteria, the team reviewed the criteria used in the screening process and with the input of the client chose the criteria listed in Table DXI.

TABLE DXI - WEIGHTED MATRIX CRITERIA

| Criteria | Description |
|---|---|
| Efficiency | Based on the number of steps the machine must take to complete its job |
| Quickly | The speed at which the machine does it job |
| Chance of breaking the shaft/ferrule | How likely the machine is to break either a shaft or ferrule (includes jamming) |
| Correcting the error of a broken shaft/ferrule | How easy it is to fix a broken shaft/ferrule issue (includes jamming) |
| Allows operator multitasking | How easy the operator can do other work while the machine is operating |
| Safe | How safe the machine is |
| Allows multiple lengths | How easily the machine allows for multiple shaft lengths |
| Allows multiple materials | How easily the machine allows for multiple materials to be processed |
| Operator time required | The amount of time the operator must spend at the machine |
| Number of steps to operate | How many unique steps the machine requires from the operator |
| Easy to maintain | How easy the machine is to maintain or fix is broken |
| Standardized | How similar the machine will be to other machine working on different shaft types |
| Foot print | How much floor space the machine |
| Budget | How costly the initial expenditure is for the machine |
| Noise level | How much noise the machine produces |

With the criteria decided upon, the team then did a one to one comparison of each criteria to determine how important each one was compared to the other. The number of times each criterion was better than another was recorded and divided by the total number of comparisons to get a weight. Table DXII, shows the comparison of each criterion to one another and which of the two was more important. The bottom of the table shows the number of hits, the percent weight and, the ranking of importance of each criterion. It is the weights shown that are used in the final scoring matrices.

| | | Efficiently joins ferrules | Inserts ferrule quickly | Chance of breaking of the shaft | Correcting the error of a broken shaft | Allows operator multitasking | Safe | Allows multiple lengths | Allows multiple materials | Operator time required | Number of steps to operate | Easy to maintain | Standardized | Foot print | Budget | Noise level |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** | **O** |
| Efficiently joins ferrules | **A** | | A | A | A | E | F | G | A | I | J | K | A | A | A | A |
| Inserts ferrule quickly | **B** | | | C | D | E | F | G | H | I | J | K | L | B | B | B |
| Chance of breaking of the shaft | **C** | | | | C | E | F | G | C | I | J | K | C | C | C | C |
| Correcting the error of a broken shaft | **D** | | | | | E | F | G | D | D | D | D | D | D | D | D |
| Allows operator multitasking | **E** | | | | | | F | G | E | E | E | E | E | E | E | E |
| Safe | **F** | | | | | | | F | F | F | F | F | F | F | F | F |
| Allows multiple lengths | **G** | | | | | | | | G | G | G | G | G | G | G | G |
| Allows multiple materials | **H** | | | | | | | | | I | J | K | L | M | N | O |
| Operator time required | **I** | | | | | | | | | | I | I | I | I | I | I |
| Number of steps to operate | **J** | | | | | | | | | | | J | L | J | J | J |
| Easy to maintain | **K** | | | | | | | | | | | | L | K | K | O |
| Standardized | **L** | | | | | | | | | | | | | L | N | L |
| Foot print | **M** | | | | | | | | | | | | | | N | O |
| Budget | **N** | | | | | | | | | | | | | | | N |
| Noise level | **O** | | | | | | | | | | | | | | | |
| | | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O |
| Sum of hits | | 8 | 3 | 7 | 9 | 12 | 14 | 13 | 1 | 10 | 8 | 6 | 6 | 1 | 4 | 3 |
| Percent weight | | 7.62 | 2.86 | 6.67 | 8.57 | 11.43 | 13.33 | 12.38 | 0.95 | 9.52 | 7.62 | 5.71 | 5.71 | 0.95 | 3.81 | 2.86 |
| Place | | 6 | 12 | 8 | 5 | 3 | 1 | 2 | 14 | 4 | 6 | 9 | 9 | 14 | 11 | 12 |

## D.4.2 FERRULE CONCEPT SCORING

Taking the criteria and weights shown in Table DXII, the top three tiers of ferrule feeder concepts from the secondary concept scoring in Table DV, were graded and their scores calculated as shown in Table DXIII, with the green, yellow and red highlighted scores being first, second and third strongest respectively.

TABLE DXIII - FERRULE FEEDER CONCEPT SCORING MATRIX

| | Weight | Ferrule of shaft slot feeder | | ferrule rod feeder | | ferrule tray | | fixed magazine | | removable magazine | | sloped run with contoured actuator ferrule feeder | | Ferrule Hopper Design | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grade | Score | Grade | Score | Grade | Score | Grade | Score | Grade | Score | Grade | Score | Grade | Score |
| Efficiently delivers ferrules | 7.62 | 5 | 38 | 6 | 46 | 3 | 23 | 7 | 53 | 7 | 53 | 5 | 38 | 5 | 38 |
| Delivers ferrule quickly | 2.86 | 7 | 20 | 7 | 20 | 3 | 8.6 | 7 | 20 | 7 | 20 | 5 | 14 | 7 | 20 |
| Chance of breaking/jamming the ferrule | 6.67 | 5 | 33 | 5 | 33 | 9 | 60 | 3 | 20 | 3 | 20 | 7 | 47 | 5 | 33 |
| Correcting the error of a broken/jammed ferrule | 8.57 | 3 | 26 | 4 | 34 | 9 | 77 | 1 | 8.6 | 5 | 43 | 7 | 60 | 7 | 60 |
| Allows operator multitasking | 11.43 | 7 | 80 | 5 | 57 | 1 | 11 | 4 | 46 | 5 | 57 | 5 | 57 | 9 | 103 |
| Safe | 13.33 | 7 | 93 | 6 | 80 | 7 | 93 | 7 | 93 | 7 | 93 | 7 | 93 | 9 | 120 |
| Allows multiple lengths | 12.38 | 5 | 62 | 5 | 62 | 1 | 12 | 5 | 62 | 5 | 62 | 7 | 87 | 7 | 87 |
| Allows multiple materials | 0.95 | 7 | 6.7 | 7 | 6.7 | 1 | 1 | 5 | 4.8 | 5 | 4.8 | 7 | 6.7 | 7 | 6.7 |
| Operator time required | 9.52 | 5 | 48 | 5 | 48 | 3 | 29 | 3 | 29 | 5 | 48 | 5 | 48 | 9 | 86 |
| Number of steps to operate | 7.62 | 4 | 30 | 7 | 53 | 5 | 38 | 5 | 38 | 5 | 38 | 6 | 46 | 9 | 69 |
| Easy to maintain | 5.71 | 5 | 29 | 4 | 23 | 9 | 51 | 5 | 29 | 5 | 29 | 5 | 29 | 3 | 17 |
| Standardized | 5.71 | 7 | 40 | 7 | 40 | 9 | 51 | 7 | 40 | 7 | 40 | 7 | 40 | 6 | 34 |
| Foot print | 0.95 | 9 | 8.6 | 7 | 6.7 | 9 | 8.6 | 9 | 8.6 | 7 | 6.7 | 4 | 3.8 | 5 | 4.8 |
| Budget | 3.81 | 7 | 27 | 6 | 23 | 3 | 11 | 7 | 27 | 7 | 27 | 5 | 19 | 1 | 3.8 |
| Noise level | 2.86 | 7 | 20 | 8 | 23 | 7 | 20 | 7 | 20 | 7 | 20 | 7 | 20 | 5 | 14 |
| Final Score | | 560.95 | | 555.24 | | 496.19 | | 498.10 | | 560.95 | | 607.62 | | 696.19 | |

From Table DXIII, it can be seen that the ferrule hopper design ranks as the option with the most potential for giving the best design. This first place ranking is notable as the ferrule hopper design was in the third tier of concepts in the screening process, but performed much better in the areas of highest importance than the other concepts did.

## D.4.3 SHAFT DELIVERY CONCEPT SCORING

Applying the criteria and weights from Table DXII and the shaft feeder concepts from Table DVII, the concepts were graded and their scores calculated. Table DXIV shows the results

of the grading, with the first, second and third place concepts highlighted in green, yellow and, red respectively.

TABLE DXIV - SHAFT FEEDER CONCEPT SCORING MATRIX

| | Weight | ferrule or shaft slotting feeder | | shaft chute | | tray feeder | | Step Motor Design | | Hinge Design | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Grade | Score | Grade | Score | Grade | Score | Grade | Score | Grade | Score |
| Efficiently delivers shaft | 7.62 | 7 | 53 | 9 | 69 | 5 | 38 | 8 | 61 | 8 | 61 |
| Places shaft quickly | 2.86 | 6 | 17 | 7 | 20 | 7 | 20 | 8 | 23 | 9 | 26 |
| Chance of breaking/jamming of the shaft | 6.67 | 5 | 33 | 9 | 60 | 9 | 60 | 7 | 47 | 7 | 47 |
| Correcting the error of a broken/jammed shaft | 8.57 | 3 | 26 | 3 | 26 | 3 | 26 | 3 | 26 | 6 | 51 |
| Allows operator multitasking | 11.43 | 7 | 80 | 7 | 80 | 7 | 80 | 7 | 80 | 7 | 80 |
| Safe | 13.33 | 7 | 93 | 9 | 120 | 7 | 93 | 9 | 120 | 6 | 80 |
| Allows multiple lengths | 12.38 | 7 | 87 | 7 | 87 | 7 | 87 | 7 | 87 | 7 | 87 |
| Allows multiple materials | 0.95 | 6 | 5.7 | 7 | 6.7 | 7 | 6.7 | 8 | 7.6 | 7 | 6.7 |
| Operator time required | 9.52 | 7 | 67 | 7 | 67 | 3 | 29 | 6 | 57 | 7 | 67 |
| Number of steps  to operate | 7.62 | 7 | 53 | 7 | 53 | 3 | 23 | 7 | 53 | 7 | 53 |
| Easy to maintain | 5.71 | 5 | 29 | 8 | 46 | 4 | 23 | 3 | 17 | 5 | 29 |
| Standardized | 5.71 | 7 | 40 | 9 | 51 | 9 | 51 | 7 | 40 | 7 | 40 |
| Foot print | 0.95 | 9 | 8.6 | 9 | 8.6 | 3 | 2.9 | 8 | 7.6 | 6 | 5.7 |
| Budget | 3.81 | 7 | 27 | 7 | 27 | 4 | 15 | 7 | 27 | 7 | 27 |
| Noise level | 2.86 | 7 | 20 | 7 | 20 | 5 | 14 | 7 | 20 | 7 | 20 |
| Final Score | | 639.05 | | 740.00 | | 568.57 | | 672.38 | | 679.05 | |

From Table DXIV, it can be seen that the shaft chute ranks as the option most likely to give the best solution. However, the second and third place options are physically very similar, with the main difference between the top three concepts being the delivery mechanism at the bottom of the chute, and the team believes that the shaft chute rated this highly mainly for its simplicity.

## D.4.4 JOINER CONCEPT SCORING

With the criteria and weights from Table DXI the top three tiers of joiner concepts shown in Table DIX were graded and their scores determined. Table DXV below shows the resulting scores, with the first, second, and third best concepts highlighted in green, yellow, and red respectively.

| | Weight | Adjustable table with belt Grade | Score | conveyor joiner Grade | Score | gravity rotation joiner Grade | Score | horizontal wheel fed joiner Grade | Score | multi piston joiner Grade | Score | Step Motor Design Grade | Score | Hinge Design Grade | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Efficiently joins ferrules | 7.62 | 5 | 38 | 5 | 38 | 7 | 53 | 5 | 38 | 7 | 53 | 7 | 53 | 6 | 46 |
| Joins ferrule quickly | 2.86 | 5 | 14 | 6 | 17 | 7 | 20 | 6 | 17 | 6 | 17 | 7 | 20 | 7 | 20 |
| Chance of breaking/jamming a shaft/ferrule | 6.67 | 5 | 33 | 4 | 27 | 6 | 40 | 5 | 33 | 7 | 47 | 5 | 33 | 7 | 47 |
| orrecting the error of a broken/jammed shaft/ferrule | 8.57 | 3 | 26 | 9 | 77 | 2 | 17 | 7 | 60 | 7 | 60 | 4 | 34 | 4 | 34 |
| Allows operator multitasking | 11.43 | 7 | 80 | 7 | 80 | 8 | 91 | 5 | 57 | 5 | 57 | 7 | 80 | 7 | 80 |
| Safe | 13.33 | 7 | 93 | 9 | 120 | 9 | 120 | 8 | 107 | 7 | 93 | 9 | 120 | 5 | 67 |
| Allows multiple lengths | 12.38 | 3 | 37 | 7 | 87 | 7 | 87 | 6 | 74 | 6 | 74 | 7 | 87 | 6 | 74 |
| Allows multiple materials | 0.95 | 5 | 4.8 | 7 | 6.7 | 7 | 6.7 | 7 | 6.7 | 6 | 5.7 | 5 | 4.8 | 7 | 6.7 |
| Operator time required | 9.52 | 6 | 57 | 7 | 67 | 7 | 67 | 5 | 48 | 6 | 57 | 7 | 67 | 7 | 67 |
| Number of steps to operate | 7.62 | 7 | 53 | 9 | 69 | 7 | 53 | 3 | 23 | 7 | 53 | 8 | 61 | 7 | 53 |
| Easy to maintain | 5.71 | 3 | 17 | 5 | 29 | 3 | 17 | 3 | 17 | 4 | 23 | 3 | 17 | 3 | 17 |
| Standardized | 5.71 | 5 | 29 | 7 | 40 | 7 | 40 | 7 | 40 | 7 | 40 | 7 | 40 | 7 | 40 |
| Foot print | 0.95 | 5 | 4.8 | 5 | 4.8 | 4 | 3.8 | 3 | 2.9 | 3 | 2.9 | 7 | 6.7 | 7 | 6.7 |
| Budget | 3.81 | 3 | 11 | 5 | 19 | 5 | 19 | 3 | 11 | 3 | 11 | 5 | 19 | 5 | 19 |
| Noise level | 2.86 | 5 | 14 | 5 | 14 | 7 | 20 | 5 | 14 | 4 | 11 | 7 | 20 | 6 | 17 |
| Final Score | | 513.33 | | 694.29 | | 655.24 | | 549.52 | | 606.67 | | 662.86 | | 594.29 | |

From Table DXV, it can be seen that the conveyor joiner is the best scored concept. However, the spread of scoring among the top three concepts is only 39.05 points. This gap in score can be over come by simply changing two to four of the scores by a point or two, so the conveyor joiner is not necessarily clearly the best concept.

## D.5 SENSITIVITY ANALYSIS

Taking the top three scored concepts from each of the sections, a sensitivity analysis was done to the weights for each set of concepts, and for the grading of the top three joiner concepts. These sensitivity analyses were useful in validating the rankings of the scoring process.

For the weight sensitivity analysis, only the top five most important criteria: safety, allows multiple shaft lengths, allows for operator multitasking, amount of operator time required, and ease of correcting a broken shaft or ferrule, were tested. The decision to only do a

sensitivity test based on these five criteria was made due to their importance to the client and they compose of 55.23% of the total weight of all the criteria.

During the weight sensitivity analysis, the weight of the criterion being tested was changed in increments of one percent, and ranged from ten below to ten above the weight used in the scoring process. This range was selected as it gives a reasonable view of the relationship between the weight of the criterion and the score, so that any trends in the rankings and scores would be easily visible.

The scores of the five concepts are generally insensitive to the changes in weight of the criteria, with the highest ranked concept either remaining in the lead by the same amount of points as in the original or pulling further ahead. However, there are a few exceptions to this behavior.  The shaft feeder concept scores during the analysis of the 'ease of fixing a broken shaft' criterion, the joiner concept scores during the analysis of the 'ease of fixing a broken shaft' criterion and, the joiner concept scores during the analysis of the 'allows operator to multitask' criterion.

In the first and third exceptions, the highest scored concept never changes in the range of weights tested, but at least one other concept does begin to improve relative to the highest scored concept at a point where the weight is non-zero. In both cases, this improvement would happen after an increase of the weights importance by at least 300%. This required increase in weight of the criterion for the lower scored concepts to improve to the level of the best scored concept is not feasible though due to the criterion then having 25% or more of the total weight of all the criteria being taken into consideration, so the results of these tests show that the results of the scoring are effectively insensitive to weight changes.

The second exception, that of the joiner concept scores during the analysis of the 'ease of fixing a broken shaft' criterion, show the best scored concept becoming the worst scored concept of the three highest scored concepts when the 'ease of fixing a broken shaft' criterion its weight reduced from 8.57% to about 2%. Due to the current importance of this criterion, the reduction in its weight to 2% is unlikely regardless of how the weights are

determined due to the criterion being a leading indicator of how much potential down time the machine will have, and if maintenance will be required to fix the machine instead of an operator. Because of this reason and the fact that the concepts are insensitive to change in the other criteria, even though the joiner concept scores are sensitive to the weighting of the 'ease of fixing a broken shaft' criterion, the team has decided to leave the weights how they are.

Moving from the weight sensitivity analysis to the sensitivity analysis of the grading of the joiner concepts, it was decided by the team that to keep the tests reasonable two constraints needed to be created. The first constraint is that no more than two grading for any concept can be changed at one time. The second constraint is that no grading can be adjusted upwards or downwards by more than two points. These constraints keep the grading nearly identical to the original grading that the concept were given to make the comparison more valid and to show the effect of small changes in grading on the final scores.

Using the constraints, five tests were devised to check for the level of sensitivity of the final scores relative to the grading. These test change either the better graded or worst graded criteria for the concepts, to highlight changes made in places where the concept may have been graded too high or too low in a given criterion. The weight of the criteria change was not considered other than to make sure that the team was not simply targeting high weighted criterion for grading changes without a good reason. Table DXIV summarizes the methodology of the five tests.

TABLE DXVI - GRADE CHANGES FOR SENSITIVITY ANALYSIS TESTS

| Test | Change to Best Concept | Change to All Other Concepts |
|------|------------------------|------------------------------|
| 1 | None | Two of their best grades are adjusted up by one point each |
| 2 | None | Two of their worst grades are adjusted up by two points each |
| 3 | Best grade is adjusted down by one point | One of their best grades is adjusted up by one point each |
| 4 | Two of the best grades are adjusted down by one point each | One of their best grades is adjusted up by one point each |
| 5 | Two of the best grades are adjusted down by one point each | Two of their worst grades are adjusted up by two points each |

From this analysis, the team determined that the ranking of the top three joiner concepts is sensitive to the grading given, and that the three are effectively scored the same since very small changes in the grading made the final scores of the concepts have a spread of only seven to twenty points depending on the grading, and that the best scored concept could become the worst scored concept.

## D.6 CONCEPT SELECTION

After the concepts were scored, the team presented the top three scored concepts from each category to the client, and the merits of each were discussed.  A final decision was made to pursue the ferrule hopper feeder concept, the shaft chute concept, and the gravity rotation joiner concept in the detailed design phase of the project. These concepts were chosen for a variety of reasons, including the scores given in the scoring process, the cost to benefit ratio of each concept, and intangible benefits such as quality of work of the joiner operators. The reasoning behind the selection of each concept is given below.

The ferrule hopper feeder design was chosen as the ferrule feeder concept with the greatest potential to meet the project goals as it reduces the amount of operator input time to fractions of a second per ferrule being inserted, as opposed to the operator taking a

second to handle each single ferrule. The other key reason behind using the ferrule hopper concept is that it improves the quality of work of the employees by an immeasurable value, due to not having to manually insert the ferrules into the shafts of the canes.  This is a time consuming and tedious process. However, the ferrule hopper design is expected to be the most expensive of the ferrule delivery techniques, with the current estimate being around $15,000 per feeder [6]. This higher cost was noted by the client in a meeting with the team, and was considered an acceptable expense for the benefits given.

The shaft chute concept was chosen due to the amount of flexibility provided during the detailed design phase of the project, as well as due to receiving the highest score in the scoring process.  Flexibility is desired is for ease of integration with the joiner and ferrule feeder concepts. Also, an important point about the shaft feeder concepts is that the top three scored concepts were very similar in how they held the shafts, with the main difference being in the delivery system that placed the shaft on the joiner. The shaft delivery system is the section that the joiner needs the most flexibility in, so any of these delivery mechanism may end up being used based on constraints created in the joiner design.

The rotational gravity joiner was the joiner concept chosen over the better scored conveyor joiner and step motor concept due to how well it handled the need to keep operator time to a minimum and removed the need for the operator to setup the appropriate ferrule-shaft combinations. This second advantage greatly reduced the amount of repetitive manually dexterous work required by operator from having to individually place shafts in the press to only needing to drop a bundle of like sized shafts into the appropriate destination, which was considered a large improvement in the quality of work being done by the operators by both the team and the clients at Melet. Another contributing factor was the grading sensitivity analysis done showing that the top three concepts were close enough in score to be considered equally viable, so any reservations of having chosen this concept as opposed to a numerically 'superior' concept were eliminated.

With all of the above reasoning for the selections in mind, the team has made sure to note what the unchosen concepts did well in order to make use of these ideas in the detailed design stage.

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# APPENDIX E – BOOLEAN LOGIC

## LIST OF TABLES

To make the joiner machine operate without the operator overseeing every operation of the machine, the machine must be automated to function properly. To facilitate this, the team performed a preliminary analysis on the Boolean logic required to make the machine operate. In this analysis, the use of timers, counters, and other ladder logic elements has been neglected with the focus being on truth table analysis to get the basic equations needed. Table E 1 shows all of the inputs and outputs that were identified as needed in the system.

TABLE EI - INPUTS AND OUTPUTS

| Input | Label | Output | Label |
|---|---|---|---|
| On/Off Switch | O | Rotator Step Motor | R |
| Emergency Off | E | Female Ferrule Step Motor | $S_f$ |
| Case Lock | CL | Male Ferrule Step Motor | $S_m$ |
| Reset Switch | $R_S$ | Piston | P |
| Top Hopper | $T_H$ | Delivery Selector Top | $D_T$ |
| Middle Hopper | $M_H$ | Delivery Selector Middle | $D_M$ |
| Bottom Hopper | $B_H$ | Delivery Selector Bottom | $D_B$ |
| Delivery Chute Hopper | $D_H$ | | |
| Female Ferrule Sensor | $F_F$ | | |
| Male Ferrule Sensor | $F_M$ | | |
| Piston Retracted | $P_R$ | | |
| Shaft Rotator Home | $R_H$ | | |
| Shaft Rotator Chute | $R_C$ | | |
| Selector Top Position | $P_T$ | | |
| Selector Middle Position | $P_M$ | | |
| Selector Bottom Position | $P_B$ | | |
| Selector Home Position | H | | |

Due to the number of input variables involved in the system, the team decided to combine some of them into intermediate variables in order to simplify the final truth table. The intermediate variables along with their associated inputs are given in Table E 2.

TABLE EII - INTERMEDIATE VARIABLE AND ASSOCIATED INPUTS

| Intermediate Variable | Associated Input Variables |
|---|---|
| PC | O, E, R, CL |
| F' | Ff, Fm |
| B | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |
| M | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |
| T | Th, Mh, Bh, Dh, Pt, Pm, Pb, H |

With the intermediate variables associated with inputs the team then determined the equation for each intermediate variable. Tables EIII, EIV, and EV show the lines of the truth tables where the intermediate variable would be active, along with the equations for those lines of the truth tables. In the team's signage convention, the '^' symbol represents a negative variable.

TABLE EIII - POWER CONTROL INTERMEDIATE VARIABLE SOLUTION

| Inputs | | | | Intermediate Variable | Equation Associated with the Line |
|---|---|---|---|---|---|
| O | E | R | CL | PC | |
| 1 | 0 | 0 | 1 | 1 | O   E^   R   CL |

TABLE EIV - FERRULE INTERMEDIATE VARIABLE SOLUTION

| Inputs | | Intermediate Variable | Equation Associated with the Line |
|---|---|---|---|
| Ff | Fm | F' | |
| 1 | 1 | 1 | Ff   Fm |

TABLE EV - TOP, MIDDLE, AND BOTTOM INTERMEDIATE VARIABLE SOLUTION

| Selector | Hopper | | | | Selector | | | Intermediate Variable | | | Equation Associated with the Line |
|---|---|---|---|---|---|---|---|---|---|---|---|
| H | Th | Mh | Bh | Dh | Pt | Pm | Pb | T | M | B | |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H   Th   Mh   Bh   Dh^   Pt^   Pm^   Pb^ |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H   Th   Mh   Bh^   Dh^   Pt^   Pm^   Pb^ |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H   Th   Mh^   Bh   Dh^   Pt^   Pm^   Pb^ |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | H   Th   Mh^   Bh^   Dh^   Pt^   Pm^   Pb^ |
| 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | H   Th^   Mh   Bh   Dh^   Pt^   Pm^   Pb^ |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | H   Th^   Mh   Bh^   Dh^   Pt^   Pm^   Pb^ |
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | H   Th^   Mh^   Bh   Dh^   Pt^   Pm^   Pb^ |
| 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^   Th   Mh   Bh   Dh   Pt   Pm^   Pb^ |
| 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^   Th   Mh   Bh   Dh   Pt^   Pm   Pb^ |
| 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^   Th   Mh   Bh   Dh   Pt^   Pm^   Pb |
| 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | H^   Th   Mh   Bh   Dh^   Pt   Pm^   Pb^ |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh | Bh | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh | Bh | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh | Bh^ | Dh | Pt | Pm^ | Pb^ |
| 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh | Bh^ | Dh | Pt^ | Pm | Pb^ |
| 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh | Bh^ | Dh | Pt^ | Pm^ | Pb |
| 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh | Bh^ | Dh^ | Pt | Pm^ | Pb^ |
| 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh | Bh^ | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh | Bh^ | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh^ | Bh | Dh | Pt | Pm^ | Pb^ |
| 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh^ | Bh | Dh | Pt^ | Pm | Pb^ |
| 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh^ | Bh | Dh | Pt^ | Pm^ | Pb |
| 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh^ | Bh | Dh^ | Pt | Pm^ | Pb^ |
| 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh^ | Bh | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh^ | Bh | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh^ | Bh^ | Dh | Pt | Pm^ | Pb^ |
| 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh^ | Bh^ | Dh | Pt^ | Pm | Pb^ |
| 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh^ | Bh^ | Dh | Pt^ | Pm^ | Pb |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th | Mh^ | Bh^ | Dh^ | Pt | Pm^ | Pb^ |
| 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th | Mh^ | Bh^ | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th | Mh^ | Bh^ | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th^ | Mh | Bh | Dh | Pt | Pm^ | Pb^ |
| 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th^ | Mh | Bh | Dh | Pt^ | Pm | Pb^ |
| 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh | Dh | Pt^ | Pm^ | Pb |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh | Dh^ | Pt | Pm^ | Pb^ |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th^ | Mh | Bh | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th^ | Mh | Bh^ | Dh | Pt | Pm^ | Pb^ |
| 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th^ | Mh | Bh^ | Dh | Pt^ | Pm | Pb^ |
| 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh^ | Dh | Pt^ | Pm^ | Pb |
| 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh^ | Dh^ | Pt | Pm^ | Pb^ |
| 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | H^ | Th^ | Mh | Bh^ | Dh^ | Pt^ | Pm | Pb^ |
| 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | H^ | Th^ | Mh | Bh^ | Dh^ | Pt^ | Pm^ | Pb |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | H^ | Th^ | Mh^ | Bh | Dh | Pt | Pm^ | Pb^ |
| 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | H^ | Th^ | Mh^ | Bh | Dh | Pt^ | Pm | Pb^ |
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | H^ | Th^ | Mh^ | Bh | Dh | Pt^ | Pm^ | Pb |

Taking the equations in the "Equations Associated with the Line" column in Tables EIII, EIV, and EV combining them together with an OR statement, the team created the logic

equations for each intermediate variable. The simplified versions of the logic equations for the intermediate variables are in Table EVI.

TABLE EVI - SIMPLIFIED INTERMEDIATE VARIABLE EXPRESSIONS

| Intermediate Variable | Equation |
|---|---|
| PC | O*E^*R^*CL |
| F' | Ff*Fm |
| B | H*Th^*Bh*Dh^*Pt^*Pm^*Pb^ + H^*(Th*Pt^*Pm^*Pb + Th^*(Bh*Dh+Mh*(Bh*Dh^+Bh^*Dh) + Mh*Bh*Dh^*Pt*Pm^*Pb^)) |
| M | H*Th^*Mh*Bh^*Dh^*Pt^*Pm^*Pb^ + H^*(Pt^*Pm*Pb^*(Th + ((Mh^+Bh*Dh)+(Mh*(Bh^+Dh^)) + Th^*Mh*Bh^*Dh^*(Pt^*Pm^*Pb + Pt*Pm^*Pb^) |
| T | H*Th*Dh^*Pt^*Pm*Pb^ + H^*Th*Pt*Pm^*Pb^ + H^*Th^*(Mh+Bh)*Dh |

The intermediate variables and the remaining inputs were then used in a final truth table to determine the equations for the output variables. The inputs and outputs used in the final truth table are summarized in Table EVII and the final truth table is in Table EVIII. Table EVIII only shows the active lines of the final truth table, not any lines where there are no active elements.

TABLE E VII - INPUTS AND OUTPUTS FOR FINAL TRUTH TABLE

| Inputs | Outputs |
|---|---|
| PC | R |
| Pr | Sf |
| Rh | Sm |
| Rc | P |
| F' | Dt |
| T | Dm |
| M | Db |
| B | |

TABLE EVIII - FINAL TRUTH TABLE

| Inputs | | | | | | | | Outputs | | | | | | | Equation Associated with the Line | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PC | Pr | Rh | Rc | F' | T | M | B | R | Sf | Sm | P | Dt | Dm | Db | | | | | | | | |
| 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | PC | Pr | Rh | Rc^ | F' | T | M^ | B^ |
| 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | PC | Pr | Rh | Rc^ | F' | T^ | M | B^ |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | PC | Pr | Rh | Rc^ | F' | T^ | M^ | B |
| 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh | Rc^ | F' | T^ | M^ | B^ |
| 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | PC | Pr | Rh | Rc^ | F'^ | T | M^ | B^ |
| 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | PC | Pr | Rh | Rc^ | F'^ | T^ | M | B^ |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | PC | Pr | Rh | Rc^ | F'^ | T^ | M^ | B |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh | Rc^ | F'^ | T^ | M^ | B^ |
| 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc | F' | T | M^ | B^ |
| 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr | Rh^ | Rc | F' | T^ | M | B^ |
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr | Rh^ | Rc | F' | T^ | M^ | B |
| 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc | F' | T^ | M^ | B^ |
| 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc | F'^ | T | M^ | B^ |
| 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr | Rh^ | Rc | F'^ | T^ | M | B^ |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr | Rh^ | Rc | F'^ | T^ | M^ | B |
| 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc | F'^ | T^ | M^ | B^ |
| 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc^ | F' | T | M^ | B^ |
| 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr | Rh^ | Rc^ | F' | T^ | M | B^ |
| 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr | Rh^ | Rc^ | F' | T^ | M^ | B |
| 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc^ | F' | T^ | M^ | B^ |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc^ | F'^ | T | M^ | B^ |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr | Rh^ | Rc^ | F'^ | T^ | M | B^ |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr | Rh^ | Rc^ | F'^ | T^ | M^ | B |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr | Rh^ | Rc^ | F'^ | T^ | M^ | B^ |
| 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr^ | Rh | Rc^ | F' | T | M^ | B^ |
| 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr^ | Rh | Rc^ | F' | T^ | M | B^ |
| 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr^ | Rh | Rc^ | F' | T^ | M^ | B |
| 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr^ | Rh | Rc^ | F' | T^ | M^ | B^ |
| 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr^ | Rh | Rc^ | F'^ | T | M^ | B^ |
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | PC | Pr^ | Rh | Rc^ | F'^ | T^ | M | B^ |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | PC | Pr^ | Rh | Rc^ | F'^ | T^ | M^ | B |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | PC | Pr^ | Rh | Rc^ | F'^ | T^ | M^ | B^ |

Taking the "Equation Associated with the Line" column in Table EVIII and matching them to the relevant positive outputs, the preliminary logic equations that will run each machine for each output were created. These final equations are given in Table EIV.

TABLE EIX - PRELIMINARY LOGIC EQUATIONS

| Output Variable | Equation |
|---|---|
| R | (PC*Pr)*(Rh*Rc^+Rh^*Rc)*(T*M^*B^ + T^*M*B^ + T^*M^*B) |
| Sf | (PC*Pr*Rh*Rc^)*(T*M^*B^ + T^*M*B^) |
| Sm | (PC*Pr*Rh*Rc^)*(T^*M*B^ + T^*M^*B) |
| P | (PC*Pr*Rh*Rc^)*(T*M^*B^ + T^*M*B^ + T^*M^*B) |
| Dt | PC*(T*M^*B^ + T^*M^*B^)*(Pr*(Rh^ + Rc^) + Pr^*(Rh*Rc)) |
| Dm | PC*(Pr*(Rh*Rc^+Rh^*Rc+Rh^*Rc^)+Pr^*(Rh*Rc^))*T^*M*B^ |
| Db | PC*(Pr*(Rh*Rc^+Rh^*Rc+Rh^*Rc^)+Pr^*(Rh*Rc^))*T^*M^*B |

# APPENDIX F – DRAWING PACKAGE

| TIER 1 | DWG | TIER 2 | DWG | TIER 3 | DWG | TIER 4 | DWG | TIER 5 | DWG |
|---|---|---|---|---|---|---|---|---|---|
| Final Assembly | A001 | Major Sub Assembly | A002 | Hoppers Sub Assembly | A004 | DELIVERY SUB ASSEMBLY | A008 | DELIVERY HOPPER SIDE PLATE | P029 |
| | | | | | | | | DELIVERY HOPPER BACK PLATE | P030 |
| | | | | | | | | DELIVERY HOPPER LOWER PLATE | P031 |
| | | | | | | | | DELIVERY HOPPER TOP PLATE | P032 |
| | | | | | | | | DELIVERY CHUTE LOWER PLATE | P033 |
| | | | | | | | | DELIVERY CHUTE SIDE PLATE | P034 |
| | | | | | | | | DELIVERY HANDLE BRACE | P035 |
| | | | | | | | | HINGE - MCMASTER-CARR 15665A477 | |
| | | | | | | TOP HOPPER SUB ASSEMBLY | A009 | TOP HOPPER SIDE PLATE | P036 |
| | | | | | | | | TOP HOPPER CHUTE PLATE | P037 |
| | | | | | | | | TOP HOPPER UPPER PLATE | P038 |
| | | | | | | | | TOP HOPPER LOWER PLATE | P039 |
| | | | | | | MIDDLE HOPPER SUB ASSEMBLY | A010 | MIDDLE HOPPER SIDE PLATE | P040 |
| | | | | | | | | MIDDLE HOPPER CHUTE PLATE | P041 |
| | | | | | | | | MIDDLE HOPPER LOWER PLATE | P042 |
| | | | | | | | | MIDDLE HOPPER UPPER PLATE | P043 |
| | | | | | | BOTTOM HOPPER SUB ASSEMBLY | A011 | BOTTOM HOPPER SIDE PLATE | P044 |
| | | | | | | | | BOTTOM HOPPER CHUTE UPPER PLATE | P045 |
| | | | | | | | | BOTTOM HOPPER CHUTE LOWER PLATE | P046 |
| | | | | | | | | BOTTOM HOPPER CHUTE VERTICAL PLATE | P047 |
| | | | | | | | | BOTTOM HOPPER UPPER PLATE | P048 |
| | | | | | | | | BOTTOM HOPPER LOWER PLATE | P049 |
| | | | | | | HOPPER MAIN SUPPORTS SUB ASSEMBLY | A012 | TOP HOPPER SUPPORTS | P050 |
| | | | | | | | | L BEAM DUCT SUPPORT | P051 |
| | | | | | | HOPPER SECONDARY SUPPORTS SUB ASSEMBL | A013 | HOPPER SUPPORTS | P052 |
| | | | | | | | | L BEAM DUCT SUPPORT | P051 |
| | | | | | | | | L BEAM DUCT SUPPORT LONGEST | P054 |
| | | | | | | TOP HOPPER SLIDER | P012 | | |
| | | | | | | MIDDLE HOPPER SLIDER | P013 | | |
| | | | | | | BOTTOM HOPPER SLIDER | P014 | | |
| | | | | | | L BEAM DUCT | P015 | | |
| | | | | | Rotator Sub Assembly | A005 | LARGE SERVO SUB ASSEMBLY | A014 | 70 INOZ MOTOR - MCMASTER-CARR 6627T62 | |
| | | | | | | | | 1/2" - 3/4" COUPLING START - MCMASTER-CARR 59985K250 | |
| | | | | | | | | 1/2" - 3/4" COUPLING MID - MCMASTER-CARR 59985K650 | |
| | | | | | | | | 1/2" - 3/4" COUPLING END -MCMASTER-CARR 59985K125 | |
| | | | | | | SMALL SERVO SUB ASSEMBLY | A015 | 1.6 IN-OZ MOTOR - MCMASTER-CARR 6627T41 | |
| | | | | | | | | .16" - 1/4" COUPLING START - MCMASTER-CARR 59985K102 | |
| | | | | | | | | .16" - 1/4" COUPLING MID - MCMASTER-CARR 59985K130 | |
| | | | | | | | | .16" - 1/4" COUPLING END - MCMASTER-CARR 59985K610 | |
| | | | | | | ROTATOR INSERTS SUB ASSEMBLY | A016 | ROTATOR | P055 |
| | | | | | | | | ROTATOR SHOULDER | P056 |
| | | | | | | | | FEMALE FERRULE INSERT | P057 |
| | | | | | | | | MALE FERRULE INSERT | P058 |
| | | | | | | | | SHAFT INSERT | P059 |
| | | | | | | | | BOLT #0 - MCMASTER-CARR 91253A026 | |
| | | | | | | | | 5/16" BOLT - MCMASTER-CARR 91306A385 | |
| | | | | | | BEARING - MCMASTER-CARR 5913K630 | | | |
| | | | | | | STAR WHEEL | P016 | | |
| | | | | | | SERVO FEMALE SUPPORT | P017 | | |
| | | | | | | BEARING SUPPORT 001 | P018 | | |
| | | | | | | BEARING SUPPORT 002 | P019 | | |
| | | | | | | BEARING SUPPORT 003 | P020 | | |
| | | | | | | BEARING SUPPORT 004 | P021 | | |
| | | | | | | BEARING SUPPORT 005 | P022 | | |
| | | | | | | BEARING - MCMASTER-CARR 8600N300 | | | |
| | | | | | | BASE | P023 | | |
| | | | | | | DISCHARGE CHUTE SUB ASSEMBLY | A017 | DISCHARGE HOPPER LOWER PLATE | P060 |
| | | | | | | | | DISCHARGE HOPPER SIDE PLATE | P061 |
| | | | | | | | | DISCHARGE HOPPER TOP PLATE | P062 |
| | | | | | | | | DISCHARGE HOPPER ROD - MCMASTER-CARR 1886K43 | |
| | | | | | | BOLTS - MCMASTER-CARR 91263A524 | | | |
| | | | | | | BOLTS - MCMASTER-CARR 91253A026 | | | |
| | | | | | Female Ferrule Feeder | A006 | FERRULE FEEDER SUPPORT | P024 | | |
| | | | | | | | FERRULE FEEDER SUPPORT COVER | P025 | | |
| | | | | | | | FERRULE FEDER TOP SUPPORT | P026 | | |
| | | | | | | | FEMALE CONTOUR MAGAZINE | P027 | | |
| | | | | | Male Ferrule Feeder | A007 | FERRULE FEEDER SUPPORT | P024 | | |
| | | | | | | | FERRULE FEEDER SUPPORT COVER | P025 | | |
| | | | | | | | FERRULE FEDER TOP SUPPORT | P026 | | |
| | | | | | | | MALE CONTOUR MAGAZINE | P028 | | |
| | | | | | | | Selector | P002 | | |
| | | | | | | | BEARING - MCMASTER-CARR 5913K630 | - | | |
| | | | | | | | FERRULE DROPPER | P003 | | |
| | | | | | | | DELIVERY BAR | P004 | | |
| | | | | | | | MALE SERVO SUPPORT | P005 | | |
| | | | | | | | BEARING SUPPORT 001 MALE | P006 | | |
| | | | | | | | SCREWS - MCMASTER-CARR 91306A385 | - | | |
| | | ELA SUB ASSEMBLY | A003 | | | | | ACTUATOR | |
| | | | | | | | | ELA SUPPORT VERTICAL | P007 |
| | | | | | | | | ELA SUPPORT HORIZONTAL | P008 |
| | | | | | | | | ELA TOP BASE | P009 |
| | | | | | | | | ELA SUPPORT HORIZONTAL 3 | P010 |
| | | | | | | | | END EFFECTOR | P011 |
| | | Rotator Guard | P001 | | | | | | |

NOTE:
-FOR PRELIMINARY USE ONLY
-PLEXIGLASS CASING TO BE INSTALLED
AROUND THE MACHINE FOR SAFETY

| ITEM# | PART# | DESC. | QTY |
|---|---|---|---|
| 1 | A002 | MAJOR SUB ASSEMBLY | 1 |
| 2 | A003 | ELA SUB ASSEMBLY | 1 |
| 3 | P001 | ROTATOR GUARD | 1 |
| 4 | N/A | WELD | A/R |



**AMBUTECH JOINER OPERATION**

DWG: A001

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
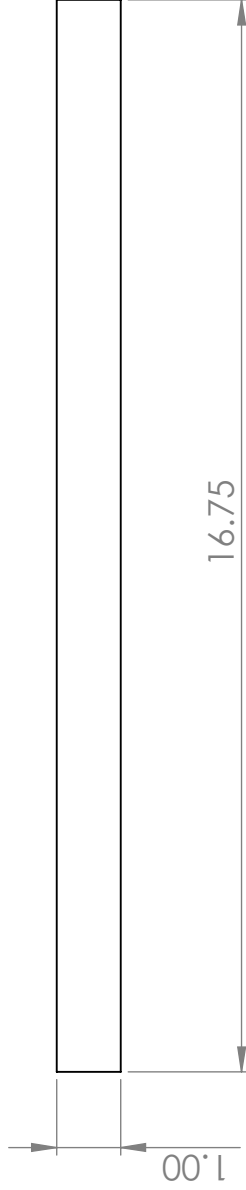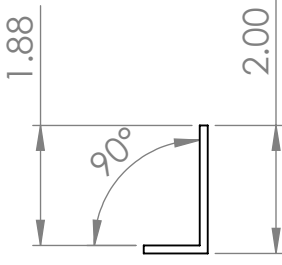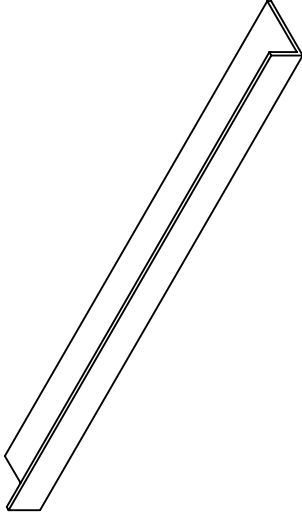USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| MATERIAL | N/A | | |
| | DRAWN | AH | DEC-04-16 |
| FINISH | N/A | | |
| | CHECKED | | |

DO NOT SCALE DRAWING

TITLE:

**FINAL ASSEMBLY**

| SIZE | REV |
|---|---|
| **A** | **0** |

SCALE: 1:10   UNIVERSITY OF MANITOBA   SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | A004 | HOPPERS SUB ASSEMBLY | 1 |
| 2 | A005 | ROTATOR SUB ASSEMBLY | 1 |
| 3 | A006 | MALE FERRULE FEEDER | 1 |
| 4 | A007 | FEMALE FERRULE FEEDER | 1 |
| 5 | P002 | SELECTOR | 1 |
| 6 | 5913K630 | BEARING - MCMASTER-CARR | 2 |
| 7 | P003 | FERRULE DROPPER | 1 |
| 8 | P004 | DELIVERY BAR | 1 |
| 9 | P005 | MALE SERVO SUPPORT | 1 |
| 10 | P006 | BEARING SUPPORT 001 | 1 |
| 11 | N/A | WELD | A/R |
| 12 | 91306A385 | SCREWS - MCMASTER-CARR | A/R |
| 13 | N/A | PLASTICS GLUE | A/R |

NOTE:
-FOR PRELIMINARY USE ONLY

AMBUTECH JOINER OPERATION    DWG: A002

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

TITLE:
**MAJOR SUB ASSEMBLY**

SIZE **A**

REV **0**

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-04-16 |
| MATERIAL N/A | | |
| DRAWN | AH | |
| FINISH N/A | | |
| CHECKED | | |

DO NOT SCALE DRAWING

SCALE: 1:20   UNIVERSITY OF MANITOBA   SHEET 1 OF 1

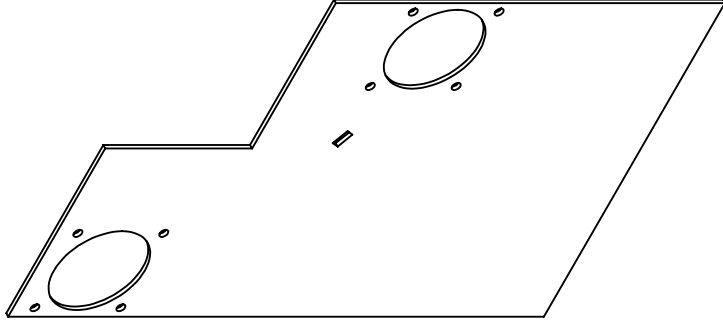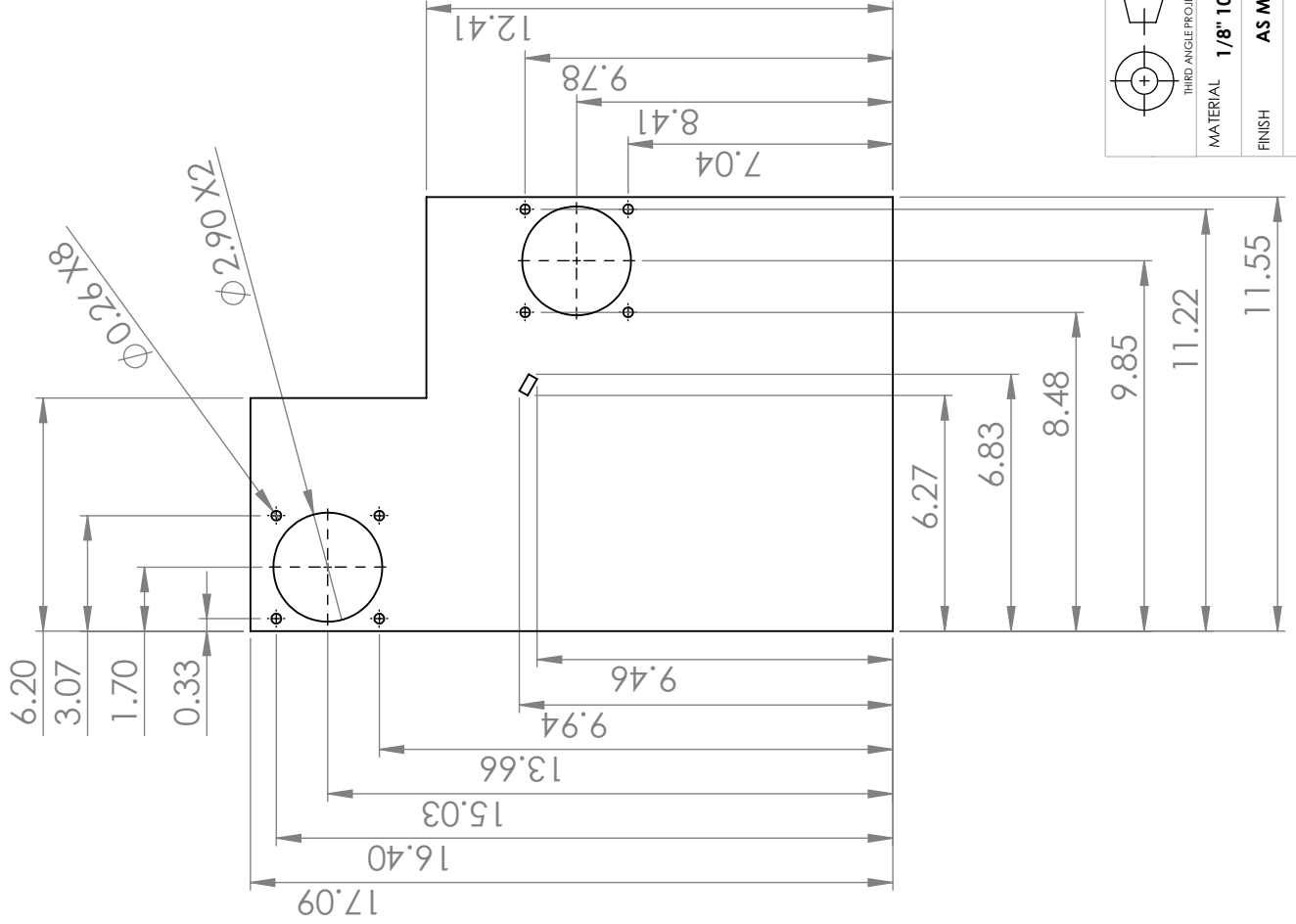| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | MXE-63 | ACTUATOR - TOLOMATIC | 1 |
| 2 | P007 | ELA SUPPORT VERTICAL | 4 |
| 3 | P008 | ELA SUPPORT HORIZONTAL | 2 |
| 4 | P009 | ELA TOP BASE | 1 |
| 5 | P010 | ELA SUPPORT HORIZONTAL 3 | 1 |
| 6 | P011 | END EFFECTOR | 1 |
| 7 | N/A | WELD | A/R |
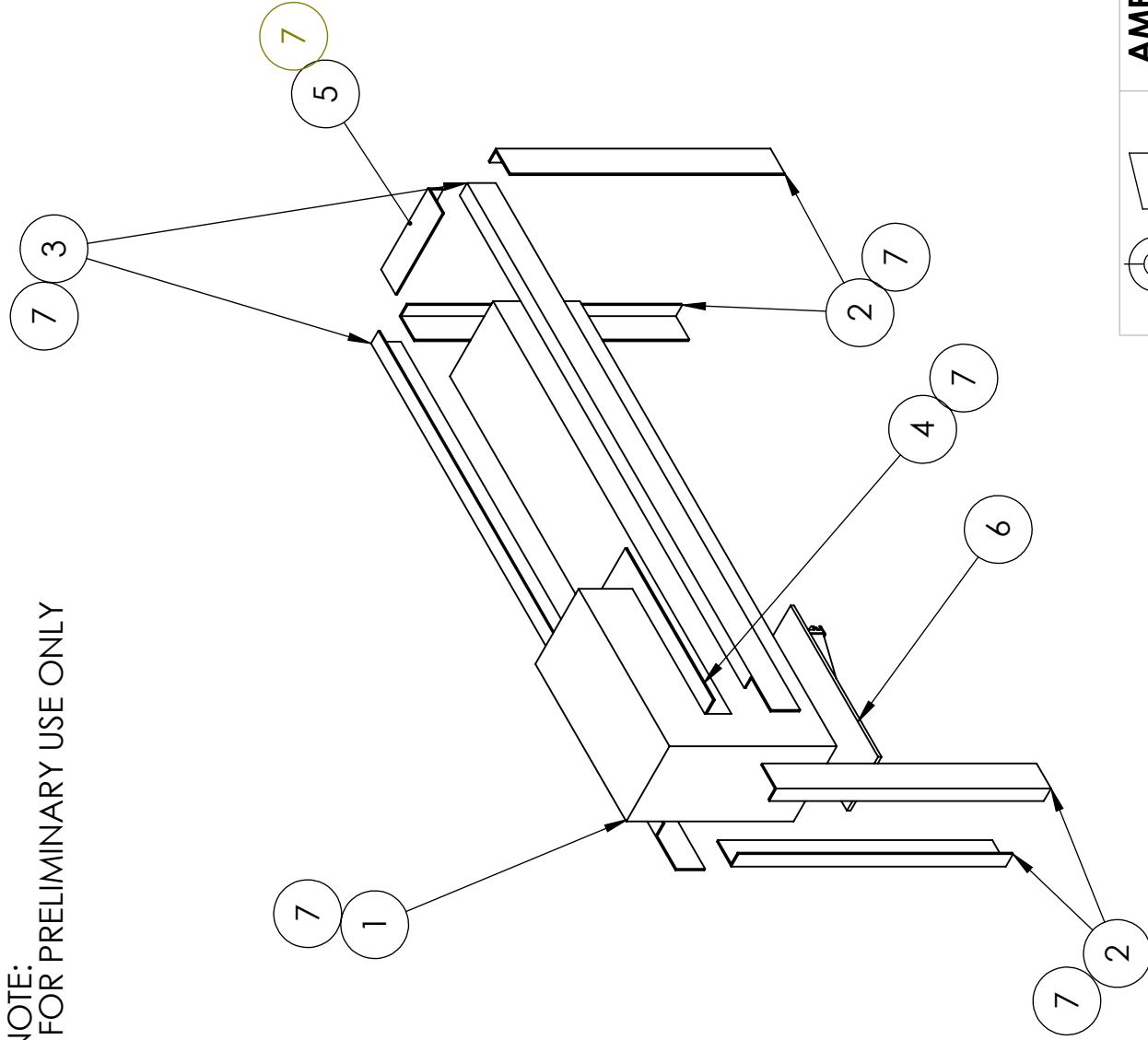


AMBUTECH JOINER OPERATION

DWG: A003

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| | | | |
|---|---|---|---|
| MATERIAL | N/A | | |
| FINISH | N/A | | |
| | | MECH 4860 | NAME | DATE |
| | | DRAWN | AH | DEC-06-16 |
| | | CHECKED | | |

DO NOT SCALE DRAWING

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

TITLE:

ELA SUB ASSEMBLY

SIZE

A

REV

0

SCALE: 1:10  UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | A008 | DELIVERY SUB ASSEMBLY | 1 |
| 2 | A009 | TOP HOPPER SUB ASSEMBLY | 1 |
| 3 | A010 | MIDDLE HOPPER SUB ASSEMBLY | 1 |
| 4 | A011 | BOTTOM HOPPER SUB ASSEMBLY | 1 |
| 5 | A012 | HOPPER MAIN SUPPORTS SUB ASSEMBLY | 1 |
| 6 | A013 | HOPPER SECONDARY SUPPORTS SUB ASSEMBLY | 1 |
| 7 | P012 | L BEAM DUCT | 3 |
| 8 | P013 | TOP HOPPER SLIDER | 1 |
| 9 | P014 | MIDDLE HOPPER SLIDER | 1 |
| 10 | P015 | BOTTOM HOPPER SLIDER | 1 |
| 11 | N/A | WELD | A/R |



AMBUTECH JOINER OPERATION

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMAL PLACES
USE ±0.005 FOR THREE DECIMAL PLACES

THIRD ANGLE PROJECTIONS

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-04-16 |
| DRAWN | AH | |
| CHECKED | | |

MATERIAL    N/A
FINISH    N/A

DO NOT SCALE DRAWING

TITLE:
**HOPPERS SUB ASSEMBLY**

SIZE **A**

DWG: A004

REV **0**

SCALE: 1:10    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

| ITEM# | PART# | PART NAME | QTY |
|-------|-------|-----------|-----|
| 1 | A014 | LARGE SERVO SUB ASSEMBLY | 3 |
| 2 | A015 | SMALL SERVO SUB ASSEMBLY | 2 |
| 3 | A016 | ROTATOR INSERTS SUB ASSEMBLY | 1 |
| 4 | 5913K630 | BEARING - MCMASTER-CARR | 4 |
| 5 | P016 | STAR WHEEL | 2 |
| 6 | P017 | SERVO FEMALE SUPPORT | 1 |
| 7 | P018 | BEARING SUPPORT 001 | 1 |
| 8 | P019 | BEARING SUPPORT 002 | 1 |
| 9 | P020 | BEARING SUPPORT 003 | 1 |
| 10 | P021 | BEARING SUPPORT 004 | 1 |
| 11 | P022 | BEARING SUPPORT 005 | 1 |
| 12 | 8600N300 | BEARING - MCMASTER-CARR | 2 |
| 13 | P023 | BASE | 1 |
| 14 | A017 | DISCHARGE CHUTE SUB ASSEMBLY | 1 |
| 15 | 91263A524 | BOLTS - MCMASTER-CARR | A/R |
| 16 | N/A | WELD | A/R |
| 17 | 91253A026 | BOLTS - MCMASTER-CARR | A/R |
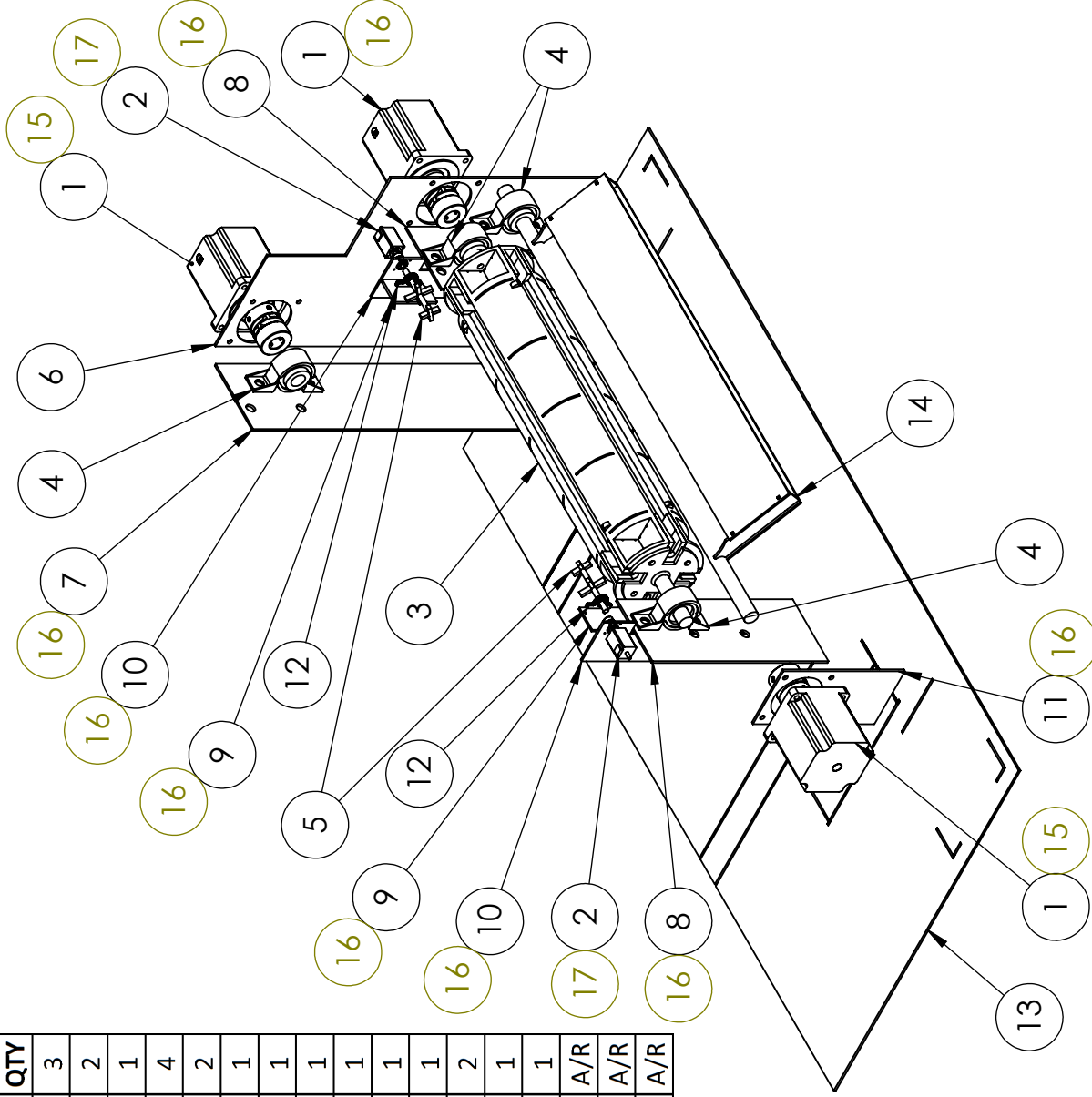
NOTE:
- FOR PRELIMINARY USE ONLY



AMBUTECH JOINER OPERATION    DWG: A005

TITLE:
ROTATOR SUB ASSEMBLY

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

MATERIAL    N/A
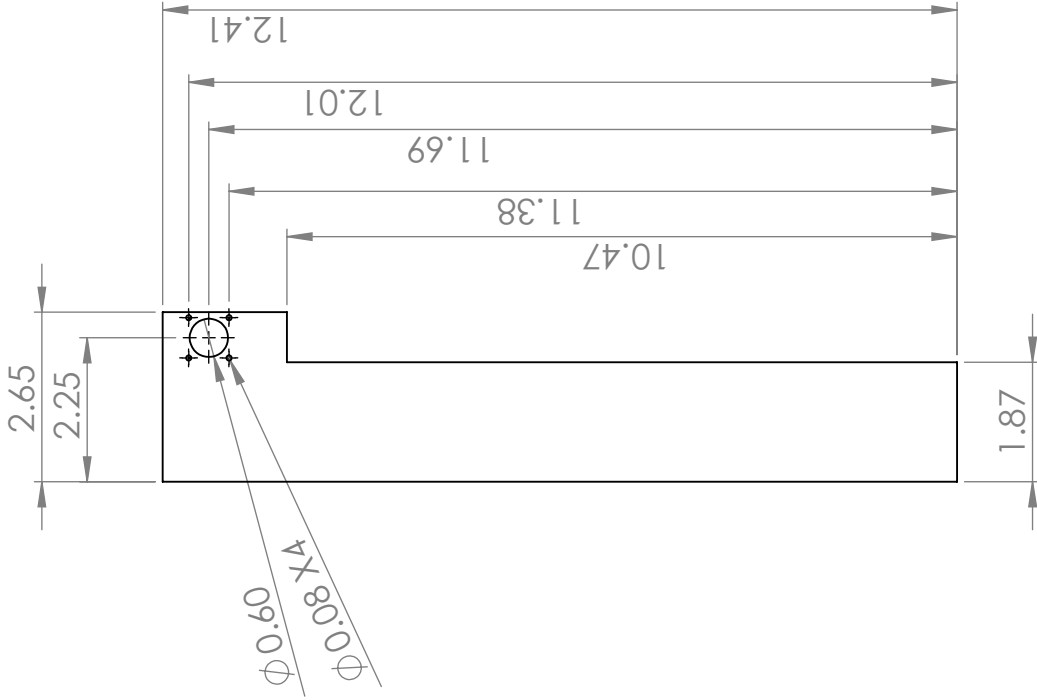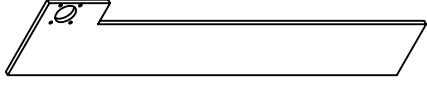FINISH    N/A

MECH 4860

| | NAME | DATE |
|---|------|------|
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

DO NOT SCALE DRAWING

SIZE  A

SCALE: 1:8.5 UNIVERSITY of MANITOBA

REV
0

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P024 | FERRULE FEEDER SUPPORT | 1 |
| 2 | P025 | FERRULE FEEDER SUPPORT COVER | 1 |
| 3 | P026 | FERRULE FEDER TOP SUPPORT | 1 |
| 4 | P027 | FEMALE CONTOUR MAGAZINE | 1 |
| 5 | N/A | WELD | A/R |
| 6 | N/A | METAL–PLASTIC GLUE | A/R |



**AMBUTECH JOINER OPERATION**

DWG: A006

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-05-16 |
| DRAWN | AH | |
| CHECKED | | |

| MATERIAL | N/A |
|---|---|
| FINISH | N/A |

DO NOT SCALE DRAWING

TITLE:
**FEMALE FERRULE FEEDER**

SIZE **A**

SCALE: 1:5    UNIVERSITY OF MANITOBA

REV **0**

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P024 | FERRULE FEEDER SUPPORT | 1 |
| 2 | P025 | FERRULE FEEDER SUPPORT COVER | 1 |
| 3 | P026 | FERRULE FEDER TOP SUPPORT | 1 |
| 4 | P028 | MALE CONTOUR MAGAZINE | 1 |
| 5 | N/A | WELD | A/R |
| 6 | N/A | METAL-PLASTIC GLUE | A/R |



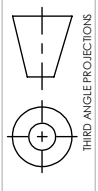**AMBUTECH JOINER OPERATION**

DWG: A007

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

TITLE: **MALE FERRULE FEEDER**

REV **0**

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | |
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

MATERIAL N/A
FINISH N/A

DO NOT SCALE DRAWING

SIZE **A**

SCALE: 1:5   UNIVERSITY OF MANITOBA

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY
- WELD AT NUBS

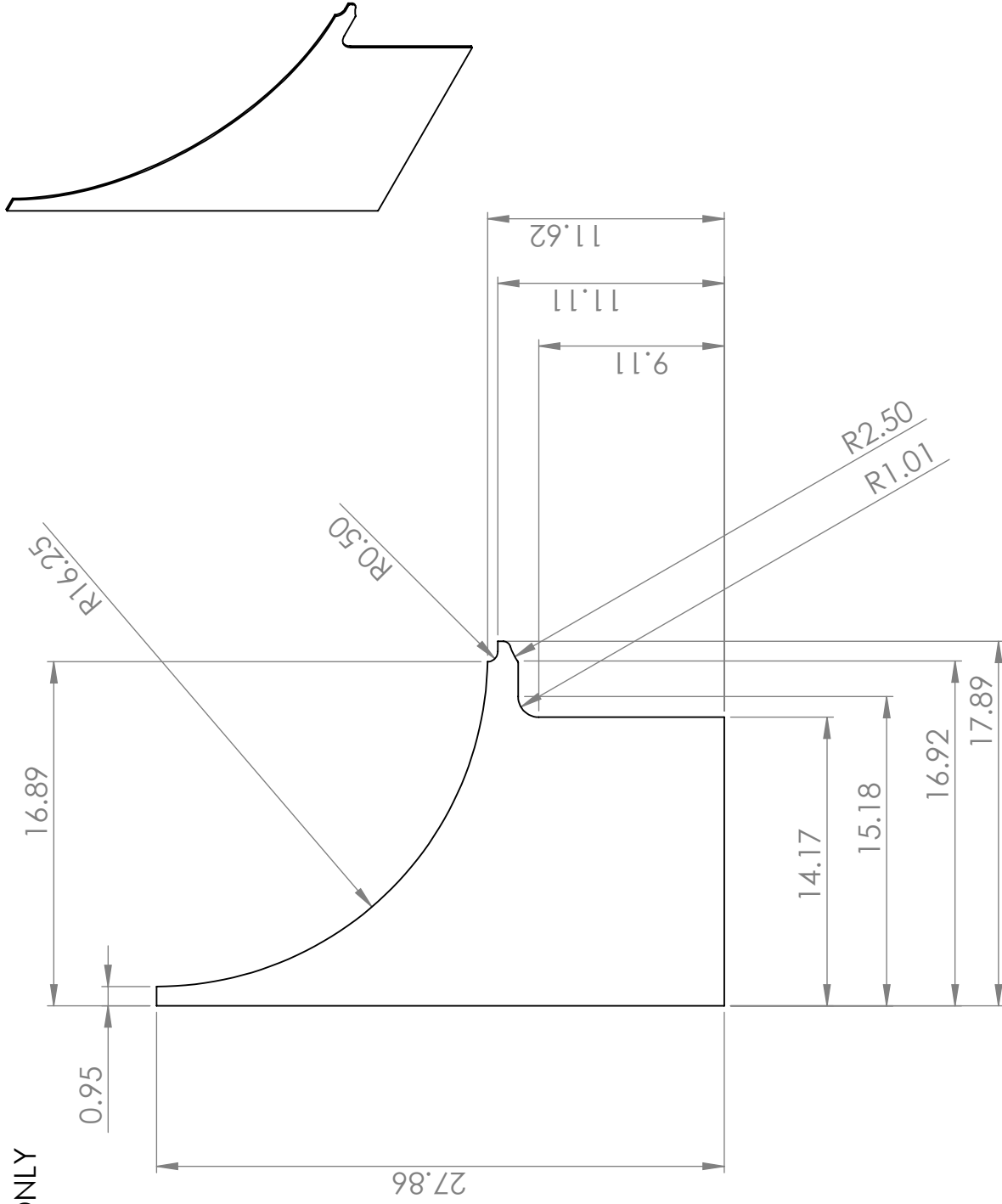| ITEM# | PART# | PART NAME | QTY |
|-------|-------|-----------|-----|
| 1 | P029 | DELIVERY HOPPER SIDE PLATE | 2 |
| 2 | P030 | DELIVERY HOPPER BACK PLATE | 1 |
| 3 | P031 | DELIVERY HOPPER LOWER PLATE | 1 |
| 4 | P032 | DELIVERY HOPPER TOP PLATE | 1 |
| 5 | P033 | DELIVERY CHUTE LOWER PLATE | 2 |
| 6 | P034 | DELIVERY CHUTE SIDE PLATE | 2 |
| 7 | P035 | DELIVERY HANDLE BRACE | 1 |
| 8 | 15665A477 | HINGE - MCMASTER-CARR 15665A477 | 1 |
| 9 | N/A | WELD | A/R |



AMBUTECH JOINER OPERATION

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| | | NAME | DATE |
|---|---|------|------|
| MATERIAL | N/A | | |
| | MECH 4860 | | DEC-05-16 |
| | DRAWN | AH | |
| FINISH | N/A | | |
| | CHECKED | | |
| DO NOT SCALE DRAWING | | | |

TITLE:
DELIVERY SUB ASSEMBLY

DWG: A008

SIZE A

SCALE: 1:5

REV 0

SHEET 1 OF 1

UNIVERSITY OF MANITOBA

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P036 | TOP HOPPER SIDE PLATE | 2 |
| 2 | P037 | TOP HOPPER CHUTE PLATE | 1 |
| 3 | P038 | TOP HOPPER UPPER PLATE | 1 |
| 4 | P039 | TOP HOPPER LOWER PLATE | 1 |
| 5 | N/A | WELD | A/R |

NOTE:
- FOR PRELIMINARY USE ONLY
- WELD PARTS AT NUBS

**AMBUTECH JOINER OPERATION**

DWG: A009

TITLE:

**TOP HOPPER
SUB ASSEMBLY**

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| MATERIAL | N/A | NAME | DATE | SIZE | REV |
|---|---|---|---|---|---|
| | | | | **A** | **0** |
| FINISH | N/A | | | | |
| | MECH 4860 | AH | DEC-05-16 | | |
| | DRAWN | | | | |
| | CHECKED | | | SCALE:1:5 | SHEET 1 OF 1 |

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P040 | MIDDLE HOPPER SIDE PLATE | 2 |
| 2 | P041 | MIDDLE HOPPER CHUTE PLATE | 1 |
| 3 | P042 | MIDDLE HOPPER LOWER PLATE | 1 |
| 4 | P043 | MIDDLE HOPPER UPPER PLATE | 1 |
| 5 | N/A | WELD | A/R |

NOTE:
- FOR PRELIMINARY USE ONLY
- WELD PARTS AT NUBS



**AMBUTECH JOINER OPERATION**  **DWG: A010**

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

TITLE:

| | NAME | DATE |
|---|---|---|
| MECH 4860 | AH | DEC-05-16 |
| DRAWN | | |
| CHECKED | | |

| MATERIAL | N/A |
|---|---|
| FINISH | N/A |

DO NOT SCALE DRAWING

**MIDDLE HOPPER SUB ASSEMBLY**

| SIZE | REV |
|---|---|
| **A** | **0** |

SCALE:1:5    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P044 | BOTTOM HOPPER SIDE PLATE | 2 |
| 2 | P045 | BOTTOM HOPPER CHUTE UPPER PLATE | 1 |
| 3 | P046 | BOTTOM HOPPER CHUTE LOWER PLATE | 1 |
| 4 | P047 | BOTTOM HOPPER CHUTE VERTICAL PLATE | 1 |
| 5 | P048 | BOTTOM HOPPER UPPER PLATE | 1 |
| 6 | P049 | BOTTOM HOPPER LOWER PLATE | 1 |
| 7 | N/A | WELD | A/R |

NOTE:
- FOR PRELIMINARY USE ONLY
- WELD PARTS AT NUBS



AMBUTECH JOINER OPERATION

DWG: A011

TITLE: BOTTOM HOPPER SUB ASSEMBLY

| | | | |
|---|---|---|---|
| UNLESS OTHERWISE SPECIFIED: USE ±0.01 IN FOR TWO DECIMEAL PLACES USE ±0.005 FOR THREE DECIMEAL PLACES | | | |
| | MECH 4860 | NAME | DATE |
| | DRAWN | AH | DEC-05-16 |
| | CHECKED | | |

THIRD ANGLE PROJECTIONS

| MATERIAL | N/A |
|---|---|
| FINISH | N/A |

DO NOT SCALE DRAWING

SIZE **A**

SCALE:1:5

UNIVERSITY OF MANITOBA

REV **0**

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

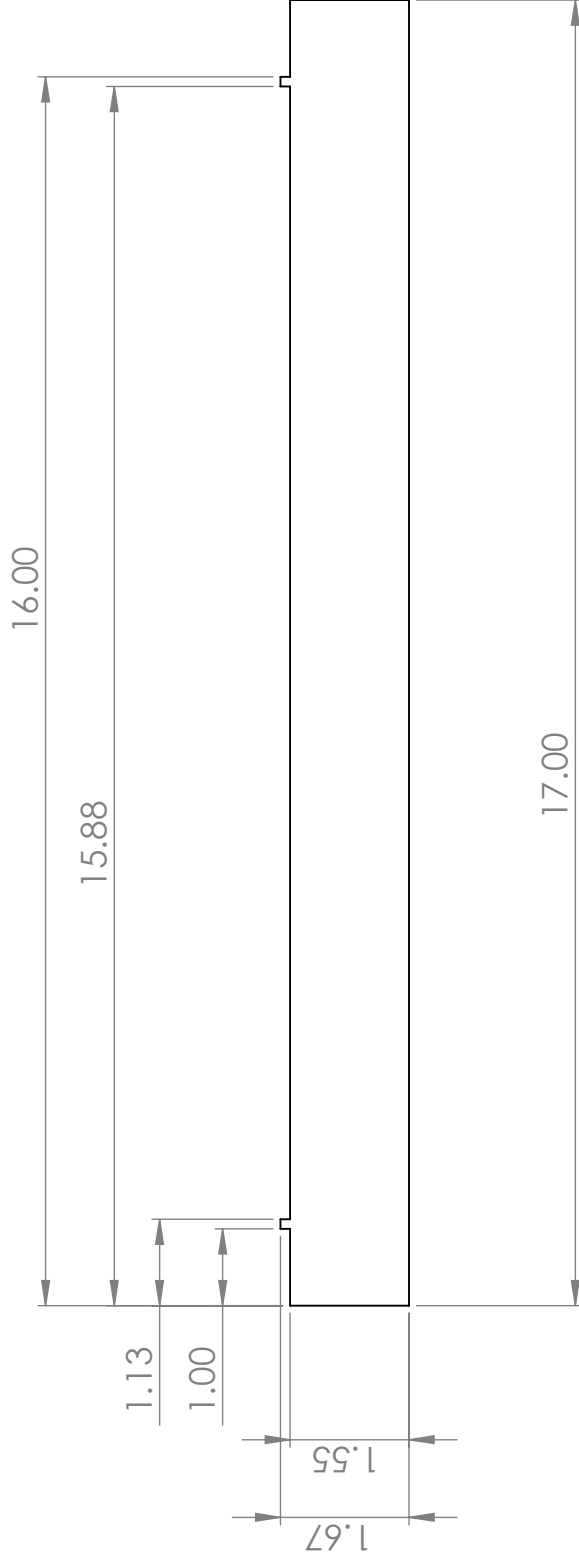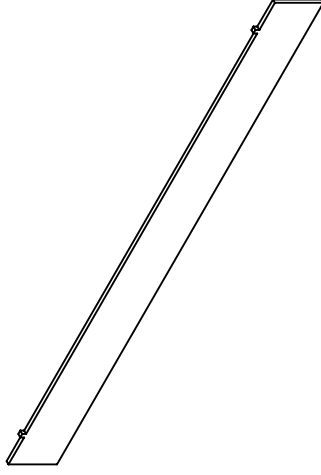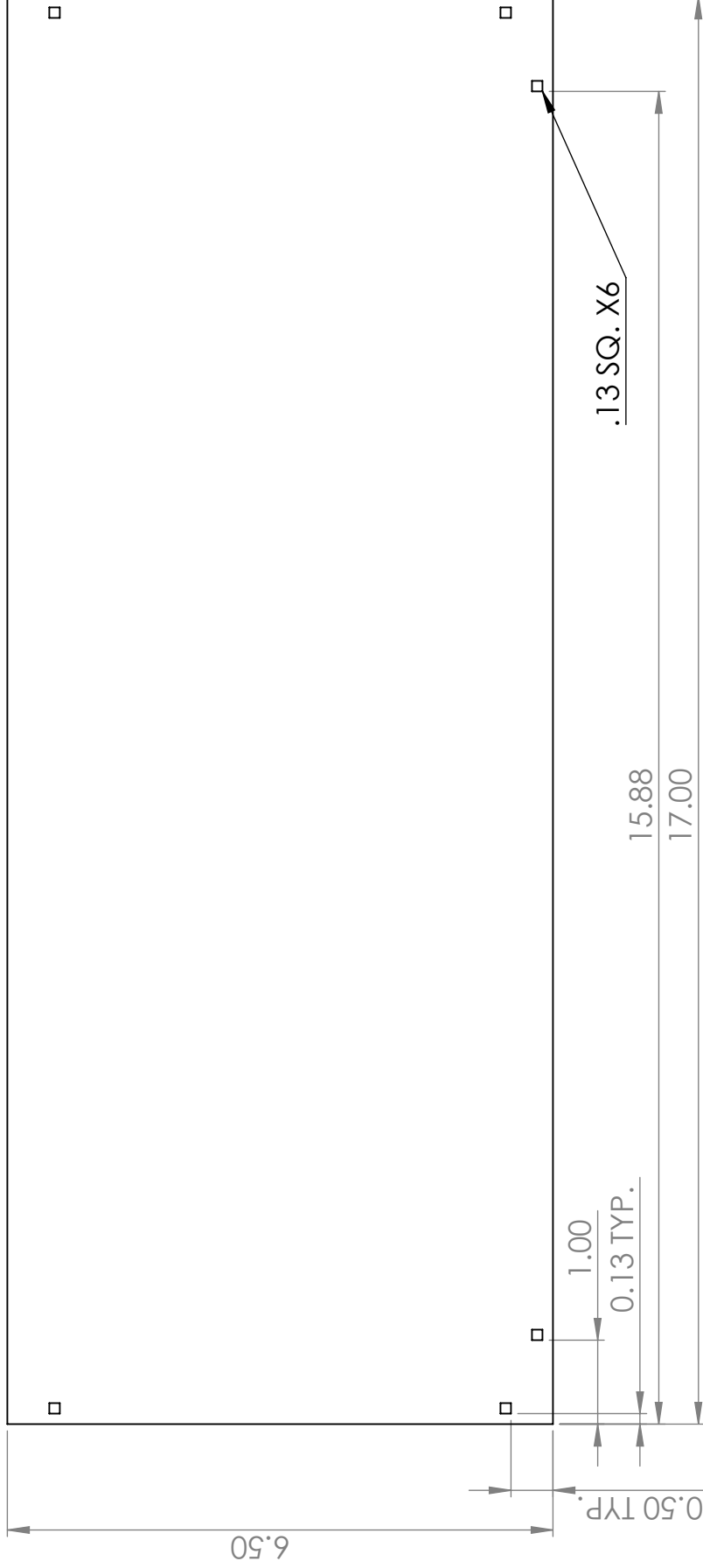| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P050 | TOP HOPPER SUPPORTS | 2 |
| 2 | P051 | L BEAM DUCT SUPPORT | 3 |
| 3 | N/A | WELD | A/R |

NOTE:
- FOR PRELIMINARY USE ONLY



**AMBUTECH JOINER OPERATION**

**DWG: A012**

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

TITLE:

**HOPPER MAIN SUPPORTS SUB ASSEMBLY**

REV

**0**

| | NAME | DATE |
|---|---|---|
| **MECH 4860** | | |
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

| MATERIAL | N/A |
|---|---|
| FINISH | N/A |

DO NOT SCALE DRAWING

SIZE **A**

SCALE: 1:5

UNIVERSITY OF MANITOBA

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

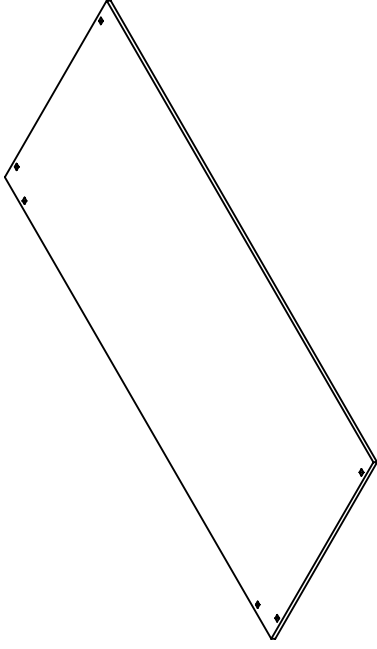| ITEM# | PART# | PART NAME | QTY |
|-------|-------|-----------|-----|
| 1 | P052 | HOPPER SUPPORTS | 2 |
| 2 | P053 | L BEAM DUCT SUPPORT | 2 |
| 3 | P054 | L BEAM DUCT SUPPORT LONGEST | 2 |
| 4 | N/A | WELD | A/R |
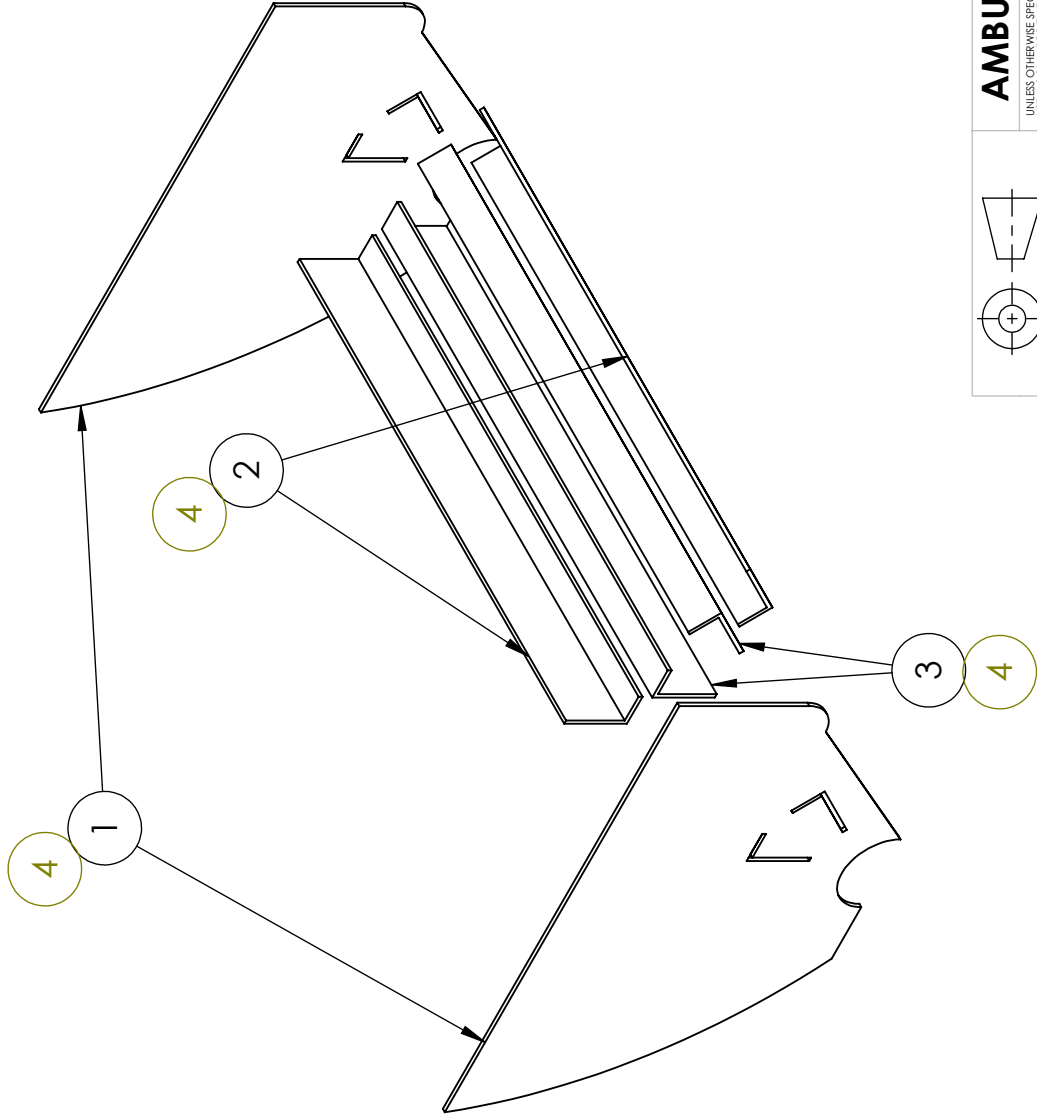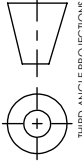


**AMBUTECH JOINER OPERATION**  DWG: A013

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

| | | NAME | DATE |
|---|---|---|---|
| MATERIAL | N/A | MECH 4860 | DEC-05-16 |
| FINISH | N/A | DRAWN | AH |
| DO NOT SCALE DRAWING | | CHECKED | |

TITLE:
**HOPPER SECONDARY SUPPORTS SUB ASSEMBLY**

SIZE **A**

SCALE: 1:5   UNIVERSITY OF MANITOBA   SHEET 1 OF 1

REV **0**

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART NAME | QTY |
|---|---|---|
| 1 | 70 INOZ MOTOR - MCMASTER-CARR 6627T62 | 1 |
| 2 | 1/2" - 3/4" COUPLING START - MCMASTER-CARR 59985K250 | 1 |
| 3 | 1/2" - 3/4" COUPLING MID - MCMASTER-CARR 59985K650 | 1 |
| 4 | 1/2" - 3/4" COUPLING END - MCMASTER-CARR 59985K125 | 1 |



AMBUTECH JOINER OPERATION

DWG: A014

TITLE: **LARGE SERVO SUB ASSEMBLY**

SIZE **A**

REV **0**

SCALE: 1:2     UNIVERSITY OF MANITOBA     SHEET 1 OF 1

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | |
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

MATERIAL     N/A

FINISH     N/A

DO NOT SCALE DRAWING

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

| ITEM# | PART NAME | QTY |
|---|---|---|
| 1 | 1.6 IN-OZ MOTOR - MCMASTER-CARR 6627T41 | 1 |
| 2 | .16" - 1/4" COUPLING START - MCMASTER-CARR 59985K102 | 1 |
| 3 | .16" - 1/4" COUPLING MID - MCMASTER-CARR 59985K130 | 1 |
| 4 | .16" - 1/4" COUPLING END - MCMASTER-CARR 59985K610 | 1 |

NOTE:
- FOR PRELIMINARY USE ONLY

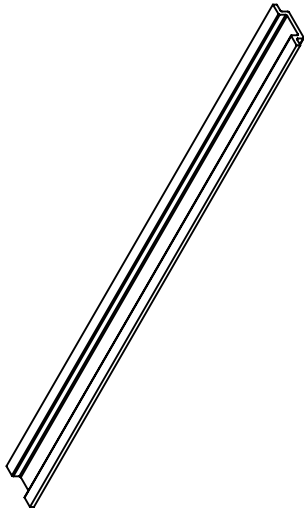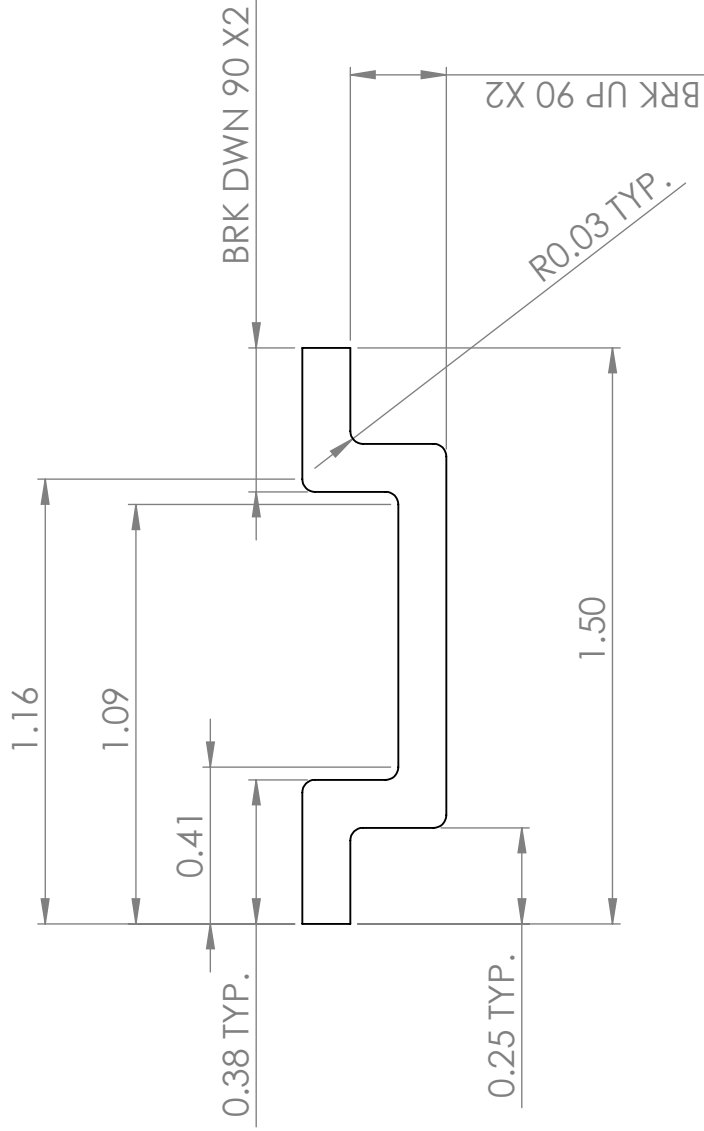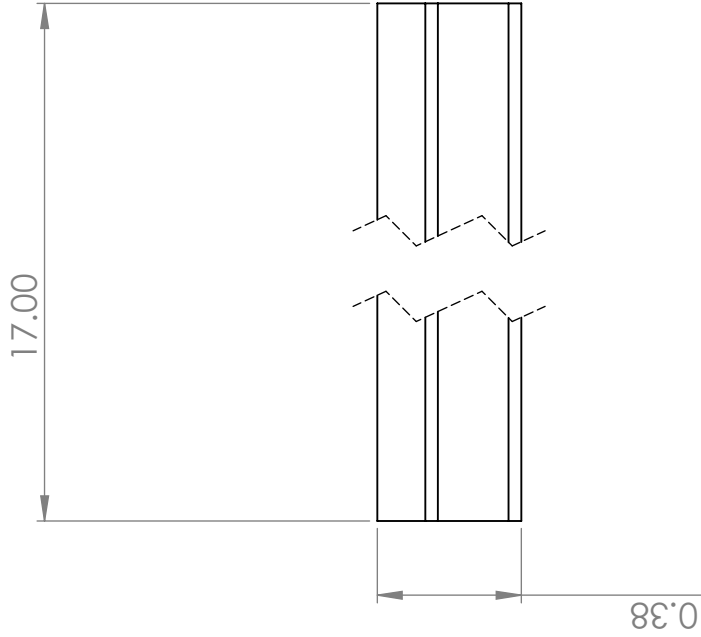| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P055 | ROTATOR | 1 |
| 2 | P056 | ROTATOR SHOULDER | 2 |
| 3 | P057 | FEMALE FERRULE INSERT | 4 |
| 4 | P058 | MALE FERRULE INSERT | 4 |
| 5 | P059 | SHAFT INSERT | 4 |
| 6 | 91253A026 | BOLT #0 - MCMASTER-CARR | A/R |
| 7 | 91306A385 | 5/16" BOLT - MCMASTER-CARR | A/R |
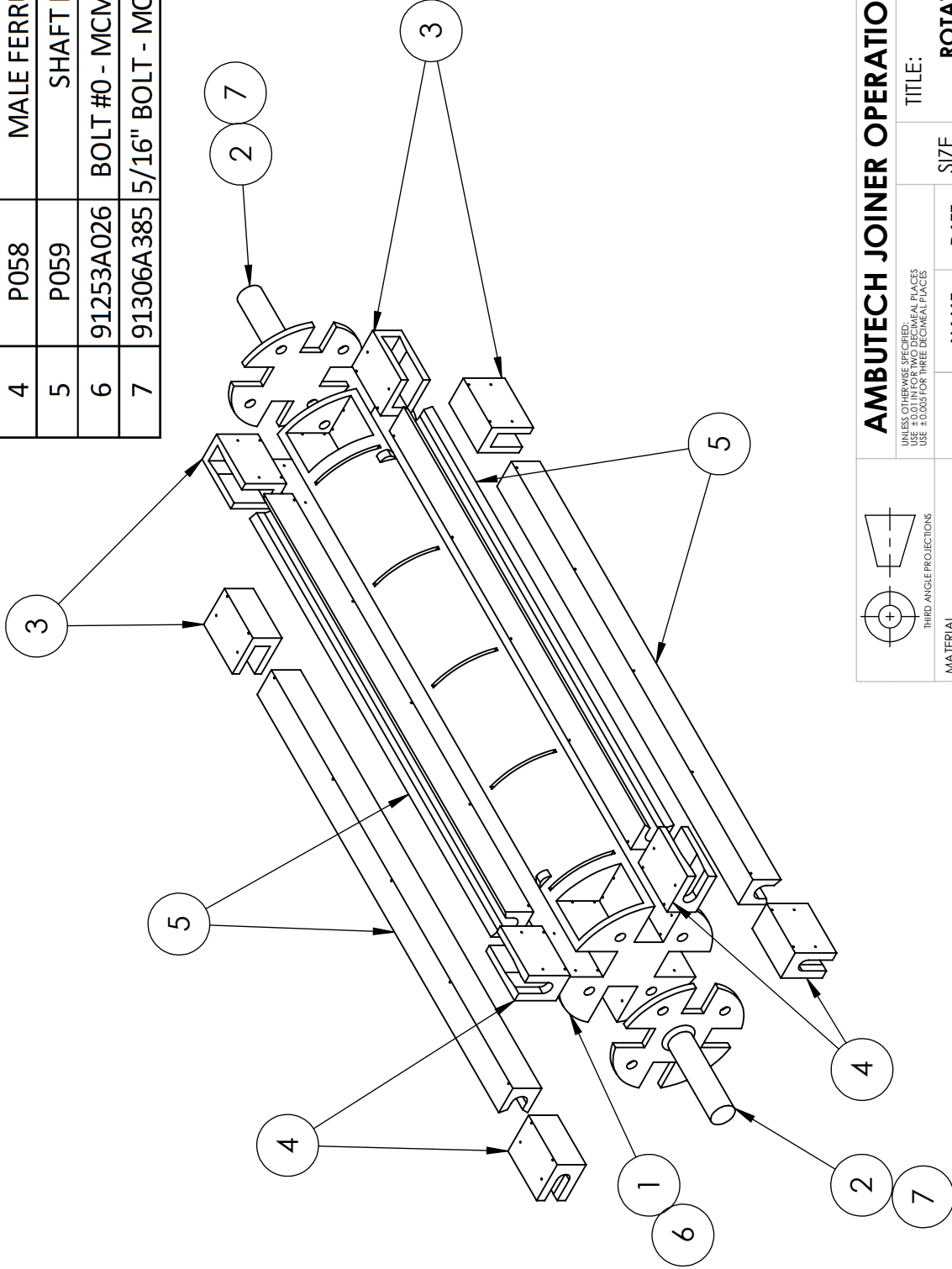


AMBUTECH JOINER OPERATION DWG: A016

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | NAME | DATE |
|---|---|---|
| MECH 4860 | AH | DEC-05-16 |
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

MATERIAL N/A
FINISH N/A
DO NOT SCALE DRAWING

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

TITLE:
ROTATOR INSERT
SUB ASSEMBLY

SIZE **A**

REV **0**

SCALE: 1:4.5 UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| ITEM# | PART# | PART NAME | QTY |
|---|---|---|---|
| 1 | P060 | DISCHARGE HOPPER LOWER PLATE | 1 |
| 2 | P061 | DISCHARGE HOPPER SIDE PLATE | 1 |
| 3 | P062 | DISCHARGE HOPPER TOP PLATE | 1 |
| 4 | P063 | DISCHARGE HOPPER ROD - MCMASTER-CARR | 1 |
| 5 | N/A | WELD | A/R |

NOTE:
- FOR PRELIMINARY USE ONLY
- WELD PARTS AT NUBS

NOTE:
- FOR PRELIMINARY USE ONLY

R2.50

R2.40

41.89

1.18

4.18

NOTE:
- FOR PRELIMINARY USE ONLY
- PREFERRED STOCK MATERIAL: METALSDEPOT - R312

16.5X.56 SLOT

R0.13

Ø2.00 TYP.

Ø1.00 TYP.

Ø0.75 TYP.

2.00
1.50
1.38
0.63
0.50

26.87

23.77

23.64

21.69

5.19

3.23

3.11

NOTE:
- FOR PRELIMINARY USE ONLY

1.25

1.83

0.25

DETAIL A
SCALE 2 : 1

44.20°
4.93°

A

A

A

A

1.46

1.71

0.22
0.75
0.85
0.97

C

SECTION A-A

DETAIL C
SCALE 2 : 1

45°

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| MATERIAL | | MECH 4860 | NAME | DATE |
| ABS | AS MATERIAL | DRAWN | AH | DEC-06-16 |
| FINISH | | CHECKED | | |
| | DO NOT SCALE DRAWING | | | |

**AMBUTECH JOINER OPERATION**

TITLE:

**FINAL ASSEMBLY**

SIZE **A**

DWG: P003

REV **0**

SCALE: 1:1    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

36.00

0.50

NOTE:
- FOR PRELIMINARY USE ONLY

17.09

6.62

9.68

8.54

6.40

5.96

5.77

5.40

8.96

9.46

9.94

A

DETAIL A
SCALE 2 : 5

0.26

R0.51

0.51

R1.01

0.51

NOTE:
- FOR PRELIMINARY USE ONLY

Ø 0.50 X2

16.53

13.53

3.05

4.48

17.09

NOTE:
- FOR PRELIMINARY USE ONLY

2.00

19.01

90°

1.00

AMBUTECH JOINER OPERATION

DWG: P007

TITLE:

ELA SUPPORT
VERTICAL

| | NAME | DATE |
|---|---|---|
| MECH 4860 | AH | DEC-06-16 |
| DRAWN | | |
| CHECKED | | |

MATERIAL    1/8" 1045 STEEL

FINISH    AS MATERIAL

DO NOT SCALE DRAWING

SIZE
A

SCALE: 1:3    UNIVERSITY OF MANITOBA

REV
0

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

2.00

42.14

2.75

90°

1.00

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| MATERIAL | 1/8" 1045 STEEL | MECH 4860 | NAME | DATE |
|---|---|---|---|---|
| FINISH | AS MATERIAL | DRAWN | AH | DEC-06-16 |
| | | CHECKED | | |

**AMBUTECH JOINER OPERATION**    DWG: P008

TITLE:

**ELA SUPPORT HORIZONTAL**

| SIZE **A** | REV **0** |
|---|---|

SCALE: 1:5    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

12.15

6.50

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

2.00

6.50

1.00

90°

THIRD ANGLE PROJECTIONS

| | | | |
|---|---|---|---|
| MATERIAL | 1/8" 1045 STEEL | | |
| FINISH | AS MATERIAL | | |

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-06-16 |
| DRAWN | AH | |
| CHECKED | | |

DO NOT SCALE DRAWING

**AMBUTECH JOINER OPERATION**    DWG: P010

TITLE:

ELA SUPPORT
HORIZONTAL 3

| SIZE | | REV |
|---|---|---|
| **A** | | **0** |

SCALE: 1:2   UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

0.25

13.74°

12.11

0.55
0.25

B

0.25

0.20

0.40

3.35

A

4.30

DETAIL B
SCALE 1 : 1

0.23
0.20

11.77°
80°
25.84°

Ø0.17
Ø0.30
R0.20
R0.44
R0.31
R0.26

DETAIL A
SCALE 1 : 1

THIRD ANGLE PROJECTIONS

AMBUTECH JOINER OPERATION        DRW: P011

| | MECH 4860 | NAME | DATE | TITLE: | | |
|---|---|---|---|---|---|---|
| MATERIAL | | DRAWN | AH | DEC-06-16 | **END EFFECTOR** | |
| | **ABS** | CHECKED | | | SIZE | REV |
| FINISH | **AS MATERIAL** | | | | **A** | **0** |
| | DO NOT SCALE DRAWING | | | | | |

SCALE: 1:2    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY



4.73
3.65
3.56
2.38
2.07
1.90
45° TYP.
3.01
2.84
0.59
4.77
4.90

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

THIRD ANGLE PROJECTIONS

| MATERIAL | 1/8" 1045 STEEL | | |
|----------|-----------------|--|--|
| | AS MATERIAL | | |
| FINISH | | | |

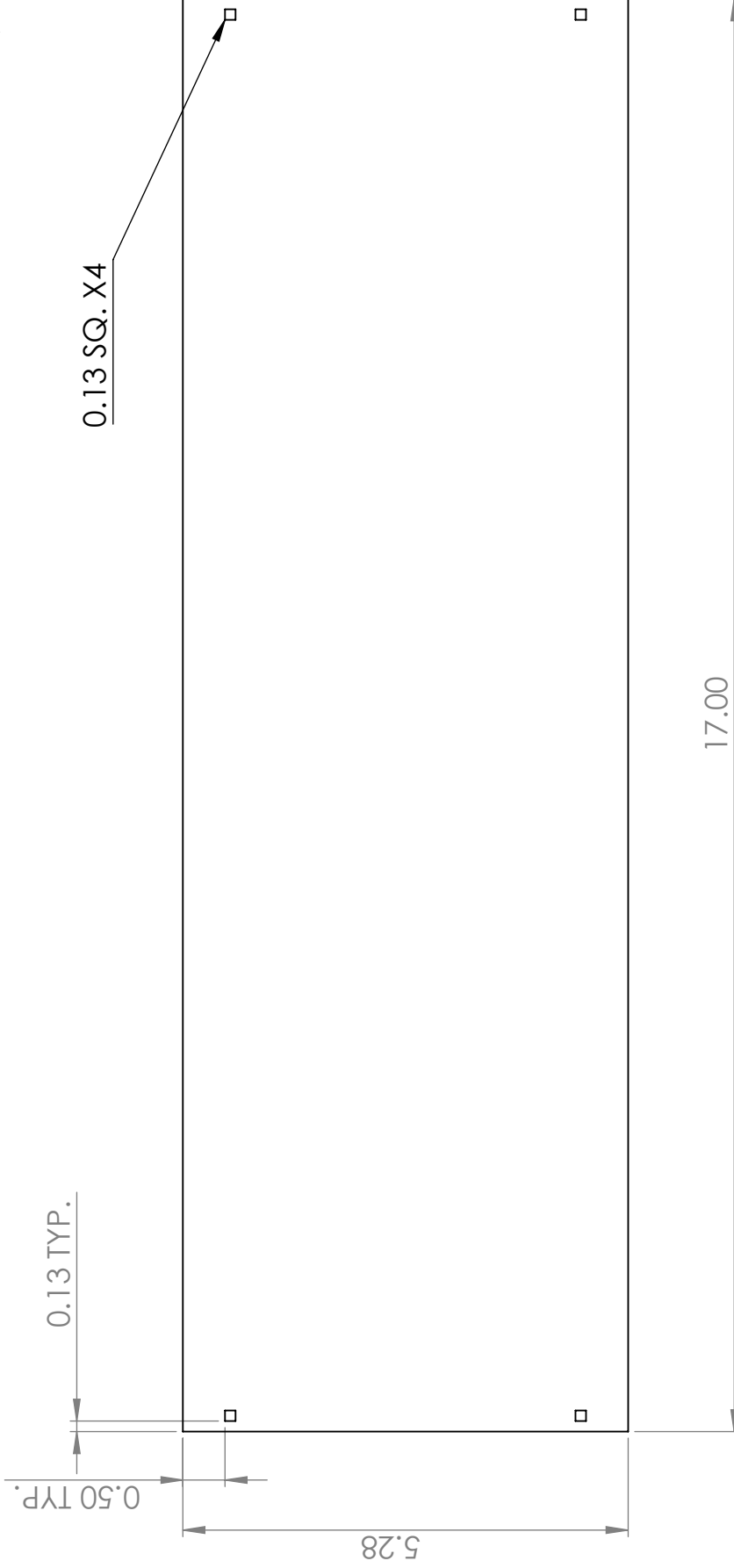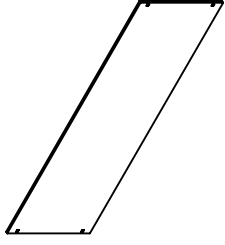**AMBUTECH JOINER OPERATION**  DWG: P012

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMAL PLACES
USE ±0.005 FOR THREE DECIMAL PLACES

| | MECH 4860 | NAME | DATE |
|--|-----------|------|------|
| | DRAWN | AH | DEC-05-16 |
| | CHECKED | | |

TITLE:

**TOP HOPPER SLIDER**

| SIZE | **A** |
|------|-------|

SCALE: 1:1.5  UNIVERSITY OF MANITOBA

REV  **0**

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

45° TYP.

R0.13

5.12
4.94
4.10
4.02
1.35
1.27
0.43

0.25
0.97

3.90
4.15
5.02
5.15

NOTE:
- FOR PRELIMINARY USE ONLY



3.60
3.51
1.35
1.27
4.61
4.45
3.61
3.36
0.25
1.00
4.43
4.61

NOTE:
- FOR PRELIMINARY USE ONLY

1.88

2.00

90°

16.75

1.00

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

MATERIAL    1/8" 1045 STEEL

FINISH    AS MATERIAL

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

AMBUTECH JOINER OPERATION

| | MECH 4860 | NAME | DATE |
|---|-----------|------|------|
| DRAWN | | AH | DEC-05-16 |
| CHECKED | | | |

TITLE:

L BEAM DUCT

SIZE
A

DWG: P015

REV
0

SCALE: 1:3    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

Ø 0.25

3.05

1.55

1.30

0.25

0.99

1.39

90°

R0.50 X4

R0.69 X4

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

THIRD ANGLE PROJECTIONS

**AMBUTECH JOINER OPERATION**

TITLE:

**STARWHEEL**

| MATERIAL | | **MECH 4860** | **NAME** | **DATE** |
|---|---|---|---|---|
| | **ABS** | DRAWN | AH | DEC-06-16 |
| FINISH | **AS MATERIAL** | CHECKED | | |

SIZE **A**

SCALE: 1:1

DWG: P016

REV **0**

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

UNIVERSITY OF MANITOBA

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

Ø 0.26 X8
Ø 2.90 X2

6.20
3.07
1.70
0.33

9.46
9.94
13.66
15.03
16.40
17.09

6.27
6.83
8.48
9.85
11.22
11.55

12.41
9.78
8.41
7.04

NOTE:
- FOR PRELIMINARY USE ONLY

Ø 0.50 X2

16.53

13.53

3.05

4.48

17.09

NOTE:
- FOR PRELIMINARY USE ONLY

Ø0.50 X4

7.04

2.37

1.20

4.26

4.04

6.91

10.47

THIRD ANGLE PROJECTIONS

AMBUTECH JOINER OPERATION

DWG: P019

TITLE:

BEARING SUPPOT
002

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| MECH 4860 | NAME | DATE | SIZE | REV |
|---|---|---|---|---|
| | | | A | 0 |
| DRAWN | AH | DEC-06-16 | | |
| CHECKED | | | | |

MATERIAL    1/8" 1045 STEEL

FINISH    AS MATERIAL

DO NOT SCALE DRAWING

SCALE: 1:2.5  UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

Ø0.13 X2

R0.25

0.35

0.95

1.20

1.54

0.25

1.22

2.34

2.50

**AMBUTECH JOINER OPERATION**

DWG: P020

TITLE: **BEARING SUPPORT**

**003**

| | | | |
|---|---|---|---|
| | SIZE **A** | | REV **0** |

SCALE: 1.5:1 UNIVERSITY OF MANITOBA | SHEET 1 OF 1

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-06-16 |
| DRAWN | AH | DEC-06-16 |
| CHECKED | | |

MATERIAL **1/8" 1045 STEEL**

FINISH **AS MATERIAL**

DO NOT SCALE DRAWING

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY



12.41
12.01
11.69
11.38
10.47
2.65
2.25
1.87

Ø0.60
Ø0.08 X4

NOTE:
- FOR PRELIMINARY USE ONLY

$\phi$0.26 X4
$\phi$2.75

3.64
3.19
1.82
0.45

4.16
5.53
6.90
7.23

NOTE:
- FOR PRELIMINARY USE ONLY

Dimensions: 22.00, 21.32, 19.98, 17.19, 17.07, 16.07, 15.19, 15.07, 14.17, 13.49, 9.03, 8.90, 8.34

1.14, 3.14, 4.83, 4.95, 7.56, 7.68, 9.21

11.39, 11.27, 9.56, 9.44

30.32, 31.85, 31.97, 34.58, 34.70, 41.28, 43.28

44.15, 35.96, 35.84, 30.09, 29.97, 28.27, 28.14

8.78, 16.37, 17.32

NOTE:
- FOR PRELIMINARY USE ONLY



11.62

11.11

9.11

R2.50

R1.01

R0.50

R16.25

16.89

14.17

15.18

16.92

17.89

0.95

27.86

NOTE:
- FOR PRELIMINARY USE ONLY

R16.25

R16.12

14.94

16.19

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| MATERIAL | 1/8" 1045 STEEL | AS MATERIAL | | |
|---|---|---|---|---|
| FINISH | | | | |

AMBUTECH JOINER OPERATION

DWG: P025

TITLE:

**FERRULE FEEDER SUPPORT COVER**

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| | DRAWN | AH | DEC-05-16 |
| | CHECKED | | |

DO NOT SCALE DRAWING

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |
| | | | |
| | | | |

SIZE **A**

REV **0**

SCALE: 1:10   UNIVERSITY OF MANITOBA   SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

R 16.25

0.95

1.25

3.09

NOTE:
- FOR PRELIMINARY USE ONLY

17.12

17.89

0.34

0.34

R16.78
R16.87
R17.12

A

1.70

0.25

0.82

0.09

0.89

DETAIL A
SCALE 1 : 2

0.16

0.34

0.09

NOTE:
- FOR PRELIMINARY USE ONLY

17.12

1.70

17.89

0.34

R16.78
R16.87
R17.12

A

0.25
0.09
0.89

0.82

DETAIL A
SCALE 1 : 2

0.09

0.16

0.34

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| MATERIAL | | | | |
|---|---|---|---|---|
| | **ABS** | | **MECH 4860** | **NAME** | **DATE** |

| MATERIAL | **ABS** | | **MECH 4860** | **NAME** | **DATE** |
|---|---|---|---|---|---|
| | **AS MATERIAL** | DRAWN | | AH | DEC-06-16 |
| FINISH | | CHECKED | | | |

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

**AMBUTECH JOINER OPERATION**

DWG: P028

TITLE:

**MALE CONTOUR MAGAZINE**

SIZE **A**

REV **0**

SCALE: 1:5    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY



1.04
1.00
0.69
0.13

6.25
5.84
5.72
2.74
2.62
2.12

R1.13

2.44
1.67

0.38
0.25

NOTE:
- FOR PRELIMINARY USE ONLY

16.00

15.88

17.00

1.13

1.00

1.55

1.67

NOTE:
- FOR PRELIMINARY USE ONLY

.13 SQ. X6

15.88

17.00

1.00

0.13 TYP.

6.50

0.50 TYP.

NOTE:
- FOR PRELIMINARY USE ONLY

4.49

17.00

.13 SQ X4

0.13 TYP.

0.50 TYP.

| MATERIAL | 1/8" 1045 STEEL | | | |
| --- | --- | --- | --- | --- |
| | | | MECH 4860 | NAME | DATE |
| FINISH | AS MATERIAL | | DRAWN | AH | DEC-05-16 |
| | | | CHECKED | | |
| DO NOT SCALE DRAWING | | | | | |

| REV | DESCRIPTION | DATE | BY |
| --- | --- | --- | --- |
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

**AMBUTECH JOINER OPERATION**

DWG: P032

TITLE:

**DELIVERY HOPPER TOP PLATE**

SIZE **A**

REV **0**

SCALE: 1:5    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY



0.13 SQ. X4

17.00

0.13 TYP.

2.54

0.38 TYP.

THIRD ANGLE PROJECTIONS

MATERIAL  **1/8" 1045 STEEL**

FINISH  **AS MATERIAL**

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | NAME | DATE |
|---|---|---|
| **MECH 4860** | | **DEC-05-16** |
| DRAWN | AH | |
| CHECKED | | |

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

**AMBUTECH JOINER OPERATION**   DWG: P033

TITLE:

**DELIVERY CHUTE
LOWER PLATE**

SIZE **A**

SCALE: 1:2   UNIVERSITY OF MANITOBA

REV **0**

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

2.54

2.17

2.04

0.50

0.38

0.13

0.69

0.81

**AMBUTECH JOINER OPERATION**

**DWG: P034**

TITLE:

**DELIVERY CHUTE
SIDE PLATE**

| SIZE | REV |
|------|-----|
| **A** | **0** |

SCALE: 2:1 | UNIVERSITY OF MANITOBA | SHEET 1 OF 1

| MECH 4860 | NAME | DATE |
|-----------|------|------|
| DRAWN | AH | DEC-05-16 |
| CHECKED | | |

| MATERIAL | 1/8" 1045 STEEL | | |
|----------|------------------|--|--|
| | **AS MATERIAL** | | |
| FINISH | | | |
| | DO NOT SCALE DRAWING | | |

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

BRK DWN 90 X2

BRK UP 90 X2

R0.03 TYP.

1.16

1.09

1.50

0.41

0.38 TYP.

0.25 TYP.

17.00

0.38

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

**AMBUTECH JOINER OPERATION**

**DWG: P035**

TITLE:

**DELIVERY HANDLE BRACE**

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| MATERIAL | **1/8" 1045 STEEL** | | |
| | **AS MATERIAL** | DRAWN | AH | DEC-05-16 |
| FINISH | | CHECKED | | |
| | DO NOT SCALE DRAWING | | |

SIZE **A**

SCALE: 2:1

REV **0**

UNIVERSITY OF MANITOBA

SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY



0.81
0.13
0.69
0.50
0.63
8.09
8.17
7.20
9.63
9.72
7.32
10.16
12.18
12.31
12.81
0.38
3.02

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

0.13 TYP.

0.50 TYP.

7.82

17.00

NOTE:
- FOR PRELIMINARY USE ONLY

0.50 TYP.

0.13 TYP.

17.00

1.36

0.88 TYP.

0.49

0.36

0.13 SQ. X4

3.18

3.31

GRIND 45°

THIRD ANGLE PROJECTIONS

MATERIAL | 1/8" 1045 STEEL

FINISH | AS MATERIAL

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

AMBUTECH JOINER OPERATION

DWG: P038

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| DRAWN | | AH | DEC-05-16 |
| CHECKED | | | |

TITLE:

TOP HOPPER
UPPER PLATE

SIZE
A

REV
0

SCALE: 1:2    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X6

17.00

0.50

7.20

12.18
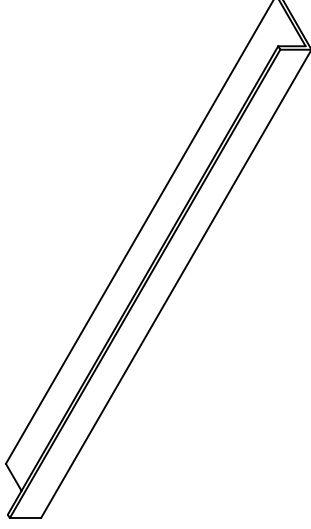
12.81

0.13 TYP.

NOTE:
- FOR PRELIMINARY USE ONLY



4.11
4.02
0.53
0.44
0.50
0.63
5.06
135°
4.87
5.00
9.03
9.15
9.65
4.79
4.70
1.22
1.13
0.81
0.69
0.13

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

0.13 TYP.

0.50 TYP.

5.28

17.00

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

0.88 TYP.
0.57
0.44

9.65

0.50 TYP.

0.13 TYP.

17.00

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

17.00

6.18

0.13 TYP.

0.50 TYP.

NOTE:
- FOR PRELIMINARY USE ONLY



5.75
4.91
4.82
0.48
0.39

9.76
9.32
9.23
5.05
4.96
4.34
4.22
3.60
3.51

9.89
9.81
5.46
5.37
4.93
4.73
4.61

0.53
0.44

0.50
0.63

0.13
4.55

THIRD ANGLE PROJECTIONS

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

**AMBUTECH JOINER OPERATION**

| MATERIAL | 1/8" 1045 STEEL | | MECH 4860 | NAME | DATE | TITLE: | **BOTTOM HOPPER UPPER PLATE** | DWG: P044 |
|---|---|---|---|---|---|---|---|---|
| | AS MATERIAL | DRAWN | AH | DEC-05-16 | SIZE **A** | | REV **0** |
| FINISH | | CHECKED | | | | | | |
| | DO NOT SCALE DRAWING | | | | SCALE: 1:3 | UNIVERSITY OF MANITOBA | SHEET 1 OF 1 |

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

0.13 TYP.

0.50 TYP.

17.00

7.16

7.04

| | | | MECH 4860 | NAME | DATE |
|---|---|---|---|---|---|
| | | | DRAWN | AH | DEC-05-16 |
| | | | CHECKED | | |

AMBUTECH JOINER OPERATION   DWG: P045

TITLE:

BOTTOM HOPPER CHUTE UPPER PLATE

SIZE **A**

REV **0**

SCALE: 1:2.5 UNIVERSITY OF MANITOBA    SHEET 1 OF 1

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY

7.39

7.27

0.13 SQ. X4

17.00

0.13 TYP.

0.50 TYP.

NOTE:
- FOR PRELIMINARY USE ONLY

0.36 TYP.

0.13 TYP.

17.00

0.13 SQ. X2

0.84

NOTE:
- FOR PRELIMINARY USE ONLY

0.13 SQ. X4

5.46

5.34

17.00

0.13 TYP.

0.50 TYP.

NOTE:
- FOR PRELIMINARY USE ONLY

0.88 TYP.

0.56

0.44

0.13 SQ. X4

17.00

5.23

NOTE:
- FOR PRELIMINARY USE ONLY

16.61
13.90
10.65
7.89
13.51
A
11.20
12.20
16.20
17.62
20.17
21.58
24.50

DETAIL A
SCALE 2 : 5

1.00 TYP.
0.88 TYP.
2.00 TYP.
1.88 TYP.

THIRD ANGLE PROJECTIONS

| MATERIAL | 1/8" 1045 STEEL | | |
|---|---|---|---|
| FINISH | AS MATERIAL | | |
| | DO NOT SCALE DRAWING | | |

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

**AMBUTECH JOINER OPERATION**

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

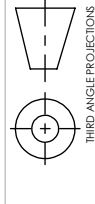| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-05-16 |
| DRAWN | AH | |
| CHECKED | | |

**DWG: P050**

TITLE:
**TOP HOPPER SUPPORT**

SIZE **A**

SCALE: 1:5

REV **0**

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

1.88

90°

2.00

17.00

1.00

THIRD ANGLE PROJECTIONS

MATERIAL **1/8" 1045 STEEL**

FINISH **AS MATERIAL**

| REV | DESCRIPTION | DATE | BY |
|-----|-------------|------|-----|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

**AMBUTECH JOINER OPERATION**

DWG: P051

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

| | MECH 4860 | NAME | DATE |
|---|-----------|------|------|
| | DRAWN | AH | DEC-06-16 |
| | CHECKED | | |

TITLE:

**L BEAM DUCT SUPPORT**

SIZE **A**

SCALE: 1:3

UNIVERSITY OF MANITOBA

REV **0**

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

DETAIL A
SCALE 2 : 3

2.00
1.00
0.88
1.88

R 16.25

9.51
4.51
2.51

14.96
5.71
4.71
4.65
3.15
0.96

R1.25
9.30
6.16
4.91
1.89
4.01
4.36
5.36
R1.00

A

NOTE:
- FOR PRELIMINARY USE ONLY

1.88

90°

2.00

17.25

1.00

**AMBUTECH JOINER OPERATION**

DWG: P054

| | | MECH 4860 | NAME | DATE | TITLE: | |
|---|---|---|---|---|---|---|
| MATERIAL | 1/8" 1045 STEEL | DRAWN | AH | DEC-05-16 | **L BEAM DUCT SUPPORT LONGEST** | |
| FINISH | AS MATERIAL | CHECKED | | | | |

SIZE **A**

REV **0**

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

DO NOT SCALE DRAWING

SCALE: 1:3  UNIVERSITY OF MANITOBA  SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY
- PREFERRED STOCK MATERIAL: MCMASTER-CARR 8974K98

Ø0.05 X10A

1.47X.10 SLOT X40

4.58

0.99

0.20 TYP.

1.76 TYP.

20.41

18.16

14.16

10.16

6.16

2.16

2.75 TYP.

2.50 TYP.

1.54 TYP.

0.07 TYP.

1.54

1.41

1.23 TYP.

0.56 TYP.

Ø0.31 X8

R0.25 WELD NUB X8

<table>
<tr><td>REV</td><td>DESCRIPTION</td><td>DATE</td><td>BY</td></tr>
<tr><td>0</td><td>INITIAL RELEASE</td><td>DEC-05-16</td><td>AH</td></tr>
</table>

THIRD ANGLE PROJECTIONS

MATERIAL **Aluminium 6061-T6**

AS MATERIAL

FINISH

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

DO NOT SCALE DRAWING

AMBUTECH JOINER OPERATION

DWG: P055

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| | | AH | DEC-06-16 |
| | DRAWN | | |
| | CHECKED | | |

TITLE:

**ROTATOR**

SIZE
**A**

REV
**0**

SCALE: 1:3.5 UNIVERSITY OF MANITOBA

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY
- PREFERRED STOCK MATERIAL: MCMASTER-CARR 6673T34



Ø 3.93

0.19

3.23

2.92

R0.13 FILLET

Ø 0.75

1.00 TYP.

0.75 TYP.

0.90 TYP.

0.69 TYP.

Ø 0.13 X4

1.41
0.64
1.96
0.25
4.76°

8 x ⌀ 0.05 ⧨ 0.18
0-80 UNF ⧨ 0.12

4.76°
1.71
1.14
0.24
0.75
0.99
0.80
0.19
0.81
0.06
R.31 LOFT
0.33

NOTE:
- FOR PRELIMINARY USE ONLY

| | | | | |
|---|---|---|---|---|
| REV | DESCRIPTION | DATE | BY | |
| 0 | INITIAL RELEASE | DEC-05-16 | AH | |

THIRD ANGLE PROJECTIONS

| | | MECH 4860 | NAME | DATE |
|---|---|---|---|---|
| MATERIAL | ABS | DRAWN | AH | DEC-06-16 |
| FINISH | AS MATERIAL | CHECKED | | |
| | DO NOT SCALE DRAWING | | | |

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

**AMBUTECH JOINER OPERATION**  DWG: P057

TITLE:  **FEMALE FERRULE INSERT**

SIZE **A**

SCALE: 1.25  UNIVERSITY OF MANITOBA

REV **0**

SHEET 1 OF 1

NOTE:
- FOR PRELIMINARY USE ONLY

0.66 ARC LENGTH LOFT

$\phi$ 0-80 UNF $\downarrow$ 0.05 $\downarrow$ 0.18

5°

1.96
1.71
0.25
0.38
0.33
0.59

1.71
1.08
5°
0.23
0.76

0.81
0.06
0.99
0.71
0.28
1.41
R0.27

THIRD ANGLE PROJECTIONS

| | | |
|---|---|---|
| MATERIAL | ABS | AS MATERIAL |
| FINISH | | DO NOT SCALE DRAWING |

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-05-16 | AH |

UNLESS OTHERWISE SPECIFIED:
USE ±0.01 IN FOR TWO DECIMEAL PLACES
USE ±0.005 FOR THREE DECIMEAL PLACES

**AMBUTECH JOINER OPERATION**   DWG: P058

| | MECH 4860 | NAME | DATE |
|---|---|---|---|
| | DRAWN | AH | DEC-06-16 |
| | CHECKED | | |

TITLE:
**MALE FERRULE INSERT**

SIZE **A**

SCALE: 1:1

REV **0**

SHEET 1 OF 1

UNIVERSITY OF MANITOBA

NOTE:
- FOR PRELIMINARY USE ONLY
- PREFERRED STOCK MATERIAL: INDUSTRIALMETALSALES - 4130SQ1x12

0.06 TYP.

16.25

12.25

Ø 0.05 X10

8.25

16.50

0.25

4.25

0.97

0.24

0.99

DETAIL A
SCALE 1 : 1

R0.26

118.01°

0.13

0.38

NOTE:
- FOR PRELIMINARY USE ONLY

.13 SQ. X4

0.13 TYP.

1.00

3.88

4.75

22.00

| | NAME | DATE |
|---|---|---|
| MECH 4860 | | DEC-06-16 |
| DRAWN | AH | |
| CHECKED | | |

AMBUTECH JOINER OPERATION    DWG: P060

TITLE:

DISCHARGE HOPPER
LOWER PLATE

SIZE
A

SCALE: 1:5    UNIVERSITY OF MANITOBA    SHEET 1 OF 1

REV
0

| REV | DESCRIPTION | DATE | BY |
|---|---|---|---|
| 0 | INITIAL RELEASE | DEC-06-16 | AH |

NOTE:
- FOR PRELIMINARY USE ONLY



R2.43
R.38

4.50
4.38
1.63
1.50
1.04
1.25
0.50
0.61
1.13
0.38

1.25
1.13
0.13
5.00
4.25
4.13
1.38

NOTE:
- FOR PRELIMINARY USE ONLY

17.00

4.49

0.51 TYP.

0.13 TYP.

0.13 SQ. X4