Novelty Ice Cream Assembly Prototype

Senior Project Report

Prepared for: Keith Zachow of Cool Beans USA

by

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December 5, 2022

Statement of Disclaimer

Abstract

Cool Beans USA is a novelty ice cream startup company founded by Keith Zachow. In winter of 2022, our team began working with Mr. Zachow to develop a machine to automate parts of the production process for his product. This product consists of two hemispherical ice cream cone shell halves filled with soft serve ice cream and pressed together. The assembled pods are around the size and shape of a small walnut and are intended to be sold in stores as a frozen finger food. At the time of project inception, this product was in its early stages and was being assembled in small batches by hand. Our team's task was to design and manufacture a machine that would pick up two shells, orient them appropriately such that they could be filled with soft serve ice-cream, join them cleanly together, and deposit them into a freezer while meeting increased throughput and food safety requirements. Over nine months our team brainstormed and prototyped designs. This project culminated in the manufacture our final prototype assembly machine. In November of 2022, we delivered our completed machine to Mr. Zachow. The final prototype can join shells as intended and can be operated via a simple graphic user interface. We hope that this machine will remove the production bottleneck of joining shells and allow Cool Beans USA to increase their production and sell their product in stores.

Introduction

Our team worked with Keith Zachow, the founder of a novelty ice-cream startup called Cool Beans USA, to design a proof-of-concept piece of assembly equipment to demonstrate scalability of the company's production line. Cool Beans makes soft serve filled ice-cream pods with a shell made of ice-cream cone. At the time of publication, Cool Beans was producing small test batches by having a person pipe the soft serve into shell halves and then press the shell halves together by hand. To scale up production in preparation for selling the product in retail stores Mr. Zachow wanted a machine to automate picking up shell halves, orienting them for filling, joining two filled halves together, and depositing the pods into a freezer tray. This machine is required to meet food safety, product damage, and output requirements identified by our sponsor. Over three academic quarters, our team brainstormed, prototyped, and manufactured this machine. The final machine was delivered to Mr. Zachow in November of 2022 and can produce up to 5,400 joined pods per hour once integrated with other machines in the production line.

This document consists of the four separate reports that were submitted at different milestones throughout the three academic quarters that this project spanned. These reports are as follows:

1. Scope of Work

   This document was submitted part way through the first quarter of work (Winter 2022). This document states our teams understanding of the problem to be solved, clearly states out engineering requirements, defines the scope of this problem our team is responsible for, and presents our teams preliminary research into related products and existing solutions.

2. Preliminary Design Review

   This document was submitted at the end of the first quarter of work. It summarizes our team's ideation, early prototyping, and preliminary testing. This document shows early designs that were not pursued as well as the design direction that evolved into our final product.

3. Critical Design Review

   This document was submitted part way through the second quarter (Spring 2022). It presents our final design prior to beginning manufacturing. The Critical Design Review contains analysis and justification for this design and our plans for manufacturing.

4. Final Design Review

   This document was submitted at the end of the third and final quarter of the project. It details what was built and how our team manufactured it, the results of our testing, and our team's suggestions for the company related to this project. This document contains the final part drawings.

Scope of Work
W23 Novelty Ice Cream Product Assembly

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Date:	2/21/2022	

Abstract

This scope of work document outlines the senior project design challenge being solved by team W23 of the ME 428 Senior Design course at California Polytechnic State University, San Luis Obispo, for project sponsor Keith Zachow of CoolBeans USA™. The project goal is to design, construct, test, and document the development of assembly equipment that can join two halves of a novelty ice cream product consisting of cake cone shell halves and a soft serve ice cream filling. This document serves to organize and present the background research we have conducted for this project to date, as well as the project scope, objectives, and our timeline for completing these goals. The findings of this research indicate that there are no existing solutions to this specific design challenge. There are several similar designs related to food production which we will use as references in our ideation and benchmarking. Aspects of these products can be adapted to our design challenge as we progress to the next phase of the design process. Upon our sponsor's review of this document and the information it contains, we will incorporate feedback into our plan and move on to the next phase of the design process.

Contents

1. Introduction

CoolBeans is a novelty ice cream product consisting of a bite sized pod of soft serve ice cream encased in two “cake batter cone” shells. Each unit is around the size of a walnut and mimics the “last bite” of an ice cream cone. This product is currently assembled by hand at a small scale and is only available in three stores to gauge customer response.

Keith Zachow, entrepreneur and founder of CoolBeans, is scaling up production to make the manufacturing of CoolBeans cost effective. His goal is to automate as much of the process as possible to reduce the cost of labor and increase the rate of production. This process involves manufacturing and coating the shells, filling them with his proprietary ice cream, joining them together, flash freezing the pods, and packaging them.

Mr. Zachow is working with our senior project team to develop a piece of equipment that will accept ice cream filled cone halves, join them together, and deposit them for flash freezing. Ideally, the process will be as automated as possible, rapidly produce joined pods without damaging the cone or the filling and will be easy to manufacture and integrate into an assembly line.

The team working on this project over the next three academic quarters includes Adin Gilman-Cohen, Alvaro Martinez, Logan Williamson, and Mason Sylvester, who are all seniors studying mechanical engineering at California Polytechnic State University, San Luis Obispo.

This document includes background information about the requirements of working with ice cream, current technologies in use for similar challenges, related patents, the project objectives and requirements, and a project management plan that will provide details about how the project will progress.

2. Background

During the first four weeks of this project, we performed stakeholder research, product research, and technical research. This involved multiple interviews with our sponsor, collecting examples of similar processes in use today such as patents and videos, and compiling documentation on standards and practices.

2.1. Stakeholder and Needs

Keith Zachow, the founder of CoolBeans, came to Cal Poly's senior design project with a challenge to design a piece of equipment that can assemble two filled CoolBean halves. Mr. Zachow and his associate Ethan Juhnke will both be overseeing our work and providing information and feedback when needed. From interviews and emails with both Mr. Zachow and Mr. Juhnke, we have determined a set of needs for this piece of equipment as well as a list of possible solutions they have envisioned. The needs expressed in these interviews include being able to join two CoolBean halves with proper alignment, joining 1,200 CoolBeans per hour or 10,000 per day, being able to scale the process to keep up with growing demand, maintaining ice creams properties, minimizing the amount of trapped air, and not damaging the shells. The device must also adhere to all safety and food regulations, be easy to clean and maintain, minimize labor costs, and cost less than $10,000 to develop and $10,000-$20,000 to manufacture. These user needs inspired the engineering specifications tabulated in the objective section.

2.2. Existing Products and Solutions

As of now, the CoolBean team is filling, assembling and packaging their product by hand with a daily output of about 1,800 CoolBeans. Currently there are no commercially available direct solutions to assemble this product. Mr. Zachow described a general vision of two trays of CoolBean halves moving in parallel then tipping up 90° to join the two halves together, though he is open to solutions taking other forms. Through our research, we were able to find a couple of tangentially related solutions that we could take inspiration from when designing our machine. Some of these include conveyor systems like those listed in Table 1:

Table 1: Table of Patents

Item	Citation Number	Patent Description	Patent Number	Application
1	[1]	Food Conveyor Equipment	JP6177974B2	Food conveyor belt meant for use in a freezer. Relevant to transportation of sponsor's product through our process.
2	[2]	Machine for producing filled truffles	DE394994C	Process of adding soft filling to truffles. Provides background on filling process outside of our design scope.
3	[3]	Food Coating and Topping Applicator	US7757836B2	Food production involving dispensing and coating. Provides background on upstream processes and assembly line configuration.

Table 1: Table of Patents (continued)

Item	Citation Number	Patent Description	Patent Number	Application
4	[4]	Sprocket Driven Conveyor Belt Link and Belt Assembly	US10464757B2	Conveyor belts are timed by sprocket and belt assembly. Design is relevant to food processing equipment timing and process control.
5	[5]	Automatic Ice-Cream-Cone Machine	US1369048A	Machine holds and moves ice cream cones automatically. Provides a reference for evaluation of food product moving/manipulating equipment.

In our research for related assembly and alignment systems we looked at footage of other rounded products being assembled, aligned, and moved around. These include items such as sandwich cookies [6], Cadbury Cream Eggs [7], Lindt Truffles [8], Kinder Eggs [9] as shown in Figure 1, Pringles [10], Chocolate Easter Bunnies [11], and hen eggs [12]. This list is far from exhaustive, and throughout the design process we will continue to find other products that we can look at for inspiration. Figure 1 shows the Kinder Egg process of joining two halves of chocolate.

Figure 1. Kinder Joy Egg Assembly Operation Moving Rounded Shells Similar to CoolBeans

2.3. Technical Challenges

The process of assembling CoolBeans brings challenges such as orienting the shell halves correctly, applying the correct amount of pressure on the joined shells, and maintaining the ice cream fillings properties while producing 1,200 pods per hour in a food safe manner. The shell halves are fragile before freezing so some research will have to be done on how much impact they can handle both before and after joining. According to Mr. Zachow, the ice cream used has a high overrun (air content) which can be lost if the ice-cream begins to melt or is subjected to high pressure. This is critical to maintain an acceptable texture. Everything about this machine must be food safe, and our research has included the guidelines to follow in multiple countries. Another component of this challenge is that we do not know in what orientation the shells will arrive from the filling machine, though we have agreed with our sponsor that this is flexible and can be influenced by our design.

3. Project Scope

Based on interviews with our sponsor and the research findings discussed in the Background section of this report, the team has identified the following sponsor needs, wants, expectations, and associated deliverables for this design project. Figure 2 is a rough boundary sketch breaking down individual aspects of the production of our sponsor's product.

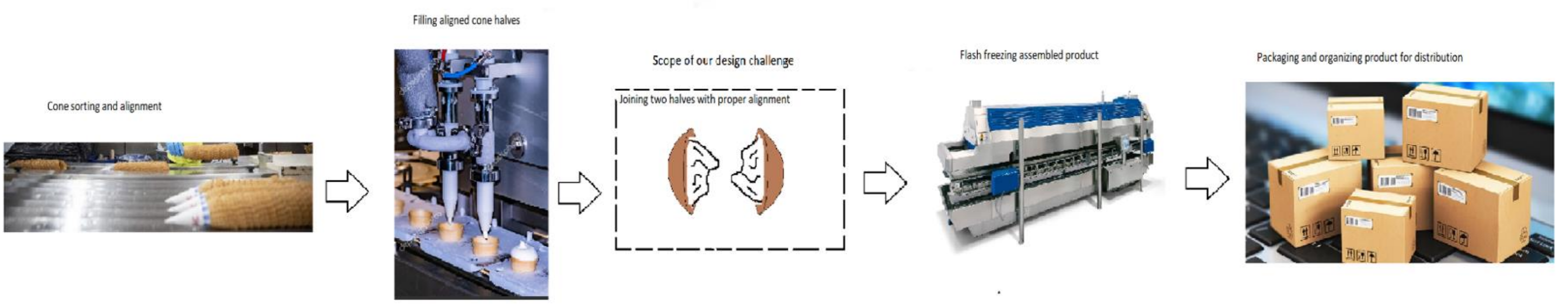

Figure 2. Boundary sketch of the project scope relative to entire production process.

The aspects of this production that will be our team's responsibility are contained within the dashed boundary labelled 'Scope of our design challenge.' These include only the following: receiving the product components from the preceding process, joining of the product halves, and depositing the assembled product into the next piece of processing equipment for flash freezing. Aspects of the production that fall outside of the scope of our design challenge include sorting of shells prior to filling, piping filling into the shells, flash freezing, packaging, and shipping of the finished product. Within the boundaries of our team's project scope, we have identified the primary and additional needs as follows.

The primary need of our sponsor is a solution which can join the two halves of his product, with proper visual alignment, at a high production quantity, while acting as one portion of an automated production line. The additional needs include scalability of this solution, minimization of labor costs associated with operation and maintenance of our solution, and adherence to NSF/ANSI 2&51 and FDA regulations for all materials, manufacturing practices, and operating standards associated with our proposed solution [13-16].

The additional requests of our sponsor include insight into the orientation and location of the product as it leaves the preceding filling process and enters our portion of the production line. Our sponsor has informed us that this aspect of the overall design will be decided by our proposed solution to this design challenge. This information will be used by our sponsor to inform his decision on which upstream equipment to purchase for filling his product prior to the joining step that our design will perform. Given that our design will dictate the orientation and arrangement the product must be in at the beginning of our process, this is not strictly a need of our sponsor;

however, it is important that we exercise foresight and keep in mind our sponsor's options for upstream equipment as we begin working on our design, as it could make selection of related equipment outside the scope of our project easier for our sponsor.

The next step in defining the scope of this project involved decomposition of the design scope into its constituent functions. Together, these functions should be sufficient to address the scope of this design challenge and provide a solution which meets our sponsor's needs. Figure 3 shows the functional decomposition diagram which allows us to identify the main functions of our project scope.

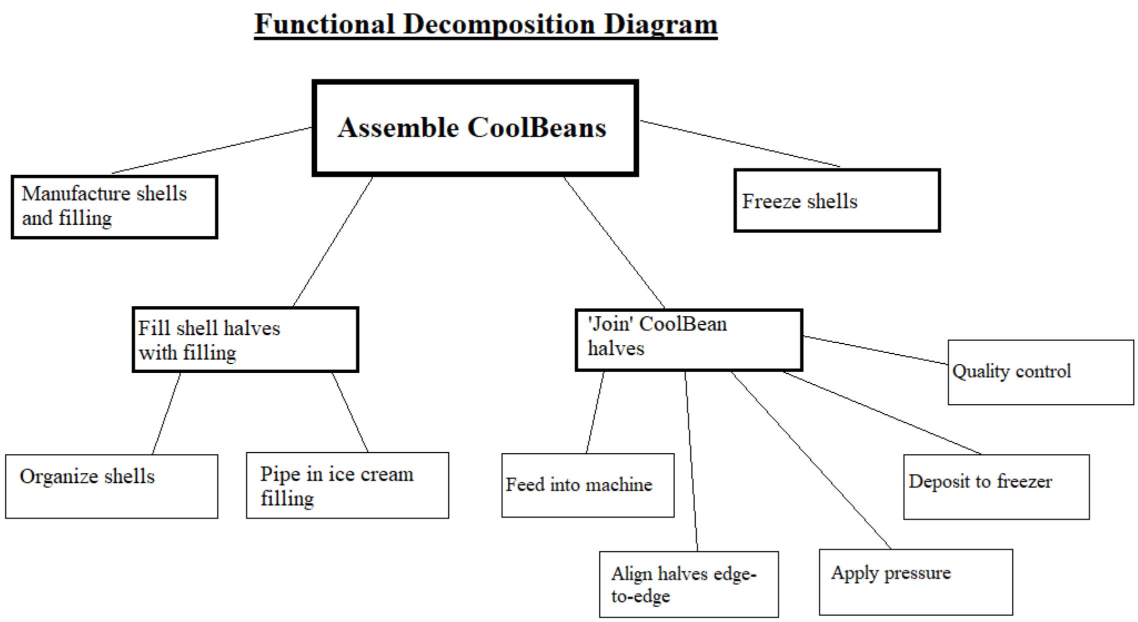

Figure 3. Functional decomposition of the project scope.

Our team has identified four major functions that need to be performed to meet the needs and wants of our sponsor for our portion of production. The halves need to be fed into our part of the overall production process. They must be aligned properly with their mating halves before attempting to join them. Once the halves are aligned, pressure must be applied to join them together. Finally, they must be deposited or passed along to the next part of the production process, flash freezing. Throughout this process, care must be taken to recognize and minimize damage to the product.

At the end of this project, our group plans to deliver a working prototype of the design. Additionally, we will deliver any relevant design drawings, computer-aided design (CAD) files, testing data, and procedures related to testing and manufacturing of our design. Finally, we will deliver instructions for the safe operation and maintenance of our design prototype.

4. Objective

An important part of our scope is to make sure we agree with the sponsor about what the problem is and exactly how we will define a successful solution. This section will present our problem statement, our process for generating engineering specifications, what these specifications are, and how we will test them.

4.1 Problem Statement

Mr. Zachow is a businessman, entrepreneur, and founder of CoolBeans Ice-cream. He needs a way to assemble his product in a way that minimizes labor costs and can be scaled to fit the growth of the company.

4.2 Quality Function Deployment (QFD) Process

To come up with the most important outcomes of the project, we used the Quality Function Deployment process. We created a House of Quality chart, attached in Appendix A, to rank the importance of sponsor wants and how they will relate to engineering specifications. We also generated a target value for each specification and a plan for how we will test if we meet that value, which are listed in section 4.3.

4.3 Engineering Specifications

After the Quality Function Deployment process, we created an engineering specifications table. An engineering specification is a quantitative or measurable criteria that the product is designed to satisfy. Each specification states a description, target value, tolerance, risk, and compliance. The engineering specification table will help to assess how the specifications impact our final design. Table 2 shows the specifications we are working to satisfy.

4.3.1 Engineering Specifications Table

Table 2: Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
1	Materials Are NSF/AINSI/FDA Food Approved	All	Min	L	S
2	Filling Maintains Air Content	Original Air Content	± 3%	M	T
3	Visual Damage Check	Shell Unchipped	TBD Before CDR	M	I
4	Shell Alignment	Cannot See Inside Shell	Min	M	I
5	Machine Output	20/min	Min	H	T
6	Head Count	1 Worker Per Machine	Max	M	T

Table 2: Engineering Specifications Table (continued)

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
7	Service Life	10 Years	Min	M	A
8	Configurable Production Quantity or Variable Speed	Possible to Increase Capacity	Min	L	A
9	Trapped Air	Bean Weight Within Tolerance	± 5%	M	T
10	Budget to Research and Prototype	$10,000	Max	L	I
11	Cost of Manufacturing One Production Model	$15,000	± $5,000	M	A
12	Downtime	2 days/year maintenance, 30 minutes/day cleaning	±1 day/ year, 15 minutes/d ay	L	A

*Risk of meeting specification: (H) High, (M) Medium, (L) Low
**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

4.3.2 Engineering Specifications Description

The following list includes the engineering specifications we need to satisfy. The descriptions are stated along with their requirements or target values and our initial thoughts on how to assess them.

1. Materials Are NSF/AINSI/FDA Food Approved- The materials used to make the machine must be food safe because they will be in contact with the CoolBeans. Our initial thoughts on assessing this specification are to use NSF, AINSI, and FDA guidelines to ensure all materials and geometries meet the requirements to allow contact with food [13].
2. Filling Maintains Air Content- The ice cream's air content should remain the same through the joining process. We can assess this by using overrun calculations to determine the air content in the ice cream before and after it is put through our machine.
3. Visual Damage Check- The outside of the cone shell should remain visually undamaged and retain its original structure. This can be assessed by using damage inspection standards to decide what qualifies as good and what does not meet the requirements. Our sponsor, Mr. Zachow, will ultimately decide what the inspection standards will look like for this criterion. We will also perform drop testing of cones to determine how much impact they can handle without damage.
4. Shell Alignment- The cone shells will need to be oriented correctly so that they are symmetrically aligned and look presentable. We need the inside of the shell to not be visible during a visual inspection.
5. Machine Output- The machine should be able to join 1,200 CoolBeans per hour. This can be tested by running the machine for a measured amount of time and seeing how many units were produced in that time.

6. Head Count- This specification is the number of workers that will need to be assisting or operating the machine for the process to be performed. This can be tested by running the machine and seeing what human processes are required to keep it running.
7. Service Life- The service life is the amount of time that the machine we design will be able to remain in operation with prescribed maintenance. We will assess the service life by performing fatigue analysis for cyclic loading to determine the fatigue life of parts that are likely to wear out.
8. Configurable Production Quantity or Variable Speed- The machine we design must be scalable so that there is a possibility to increase capacity. It should be designed so that multiple machines can be run in parallel, or the speed of the process can be increased.
9. Trapped Air- This is the amount of air trapped inside the CoolBean after the two cone halves have been joined together. If the ice cream does not completely fill the inside of the cone, there will be an empty gap left inside. We can assess this by knowing the weight of a perfectly filled CoolBean and comparing that expected weight to the actual weight of the joined CoolBeans.
10. Cost of Manufacturing One Production Model - This is our budget to design, build, and test our final product. This encompasses any material costs, purchasing of parts, labor costs, testing equipment, etc.
11. Cost of Manufacturing - This is the amount that it will cost if we were to have a company manufacture one machine from our final design. For example, if we have all the CAD files and information sent to a company and ask them to make multiples of the machine for us, the cost of manufacturing is what we should expect to pay them to have each machine made.
12. Downtime - This specification describes the acceptable amount of operating time during which this machine will be inoperable for purposes of cleaning and maintenance. A daily downtime of 30 ± 15 minutes is acceptable, in addition to an annual downtime of 2 ± 1 day for maintenance and repairs.

4.3.3 High Risk Specifications

High risk specifications are those that we anticipate being challenging to meet or those that will have a particularly large impact on the outcome. We feel that the greatest challenge will be achieving the high machine output requested without compromising the other specifications. The machine output is considered high risk because it depends on other specifications for it to be satisfied. For example, the output would be affected by the amount of time it takes to fill the cones and align them correctly or by the machine downtime. Because these other specifications which machine output is dependent on each have their own tolerances, it creates a higher risk.

5. Project Management

The overall design process we will follow is an iterative, multi-step approach to problem solving. Up to this point, our team has been researching and defining the design problem presented to us. After this Scope of Work document has been sent to our sponsor for review, the ideation phase of the design process will begin. This is the phase of the design where our team will investigate a variety of possible approaches to consider, informed by the content in this report and any additional feedback or research findings that come up during this phase. Ideation will include but is not limited to: brainstorming sessions, rough/rapid prototyping of function-specific solutions, and rough CAD models of components and how they interface. Our team will use this information to narrow down our ideas for potential designs until we are left with the best viable option that satisfies each need of our sponsor.

This proposed design will then be peer-reviewed, revised, and presented to our sponsor at the Preliminary Design Review. The Preliminary Design Review will involve a written report, oral presentation, and sharing of a rough concept prototype for our chosen design. This is an opportunity for our team to communicate to our sponsor what design we believe will best meet his needs. Furthermore, it will provide an early opportunity for our sponsor to ask crucial questions, give feedback, and voice concerns about the proposed design direction our team will be working towards for the remainder of this process.

Throughout manufacturing, prototyping, testing and analysis will be done to verify compliance with the specifications described in the objective section of this report. FEA of simple components will be used to verify expected analysis parameters along with preliminary hand analysis of key functions. Upon completion of our prototype, final testing against the project goals will be conducted and the results will be thoroughly documented. This design challenge will conclude with a presentation of our design at the senior design project exposition. Table 3 contains major deliverables our sponsor can expect.

Table 3. Deliverables and Due Dates

Deliverable	Description	Date
Preliminary Design Review Report	First major review of selected approach. In this report we will outline the full design that we believe will work best for assembling CoolBeans.	3/3/2022
Concept prototype	This deliverable will include rough functional models of ideas for the joining, pressure application, alignment, and Bean moving subsystems.	4/21/2022

Table 3. Deliverables and Due Dates

Deliverable	Description	Date
Critical Design Review	Presentation showcasing either (a) fully functional prototypes for each subsystem or (b) a partially functional integrated CoolBeans joining system.	5/3/2022
Senior Project Expo	At the expo, we will present our fully functional, integrated prototype and demonstrate its functionality.	11/18/2022
Final Design Review	This design review will be a formal documentation and presentation of the design presented at the expo, along with evaluation of the design against the criteria set forth in this report.	12/2/2022

6. Conclusion

Over the next year our team will design a piece of assembly equipment to join CoolBean's ice cream filled shells. This document serves to communicate the scope of our team's challenge to our sponsor. It compiles what we will set out to design, how we will define success, what existing products we will draw inspiration from, and how we have organized our project so far. Feedback on our understanding of the challenge is requested, and upon confirmation from our sponsor that this scope of work is appropriate, the team will begin the ideation of solutions. The next major deliverable will be our preliminary design review, which is to be completed no later than March 3, 2022.

7. References

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8. Appendices

Appendix A- QFD House of Quality Diagram

Correlations	
Positive	+
Negative	–
No Correlation	

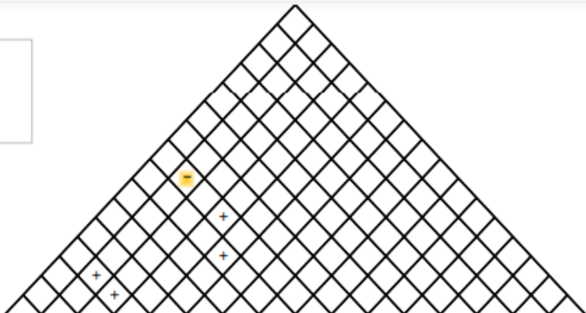
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: W23 Novelty Ice Cream Assembly

Revision Date: January 25, 2022



		WHO: Customers																							NOW: Curr. Products	
							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16			
							Direction of Improvement	◇	▼	◇	▼	▲	▼	▲	◇	▼										
Row #	Weight Chart	Relative Weight	Keith Zachow	Machine Operators	Person Eating Icecream	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Materials are NSF/AINSI/FDA food approved	Filling maintains air content	Visual Damage Check	Shell alignment	Machine output	Head Count	Service life	Configurable production quantity or variable speed	Trapped air	Cost	Cost to manufacture							Current: Manual Assembly	Row #
1	#VALUE!	*	10	0	9	9	Join two filled cone halves			●	●														10	1
2		15%	8	0	0	9	1,200 units per hour			○	○	●	▽	○	●	▽									1	2
3	#VALUE!	*	8	0	7	9	Proper alignment of cone halves				●		▽		○										9	3
4		10%	9	0	0	9	Minimize Labor Cost						●		○										1	4
5		10%	6	0	0	9	Less than $10,000 to develop							○	▽		●								5	5
6	#VALUE!	*	10	10	10	9	Adhere to safety regulations	●																	5	6
7		15%	8	0	0	3	Scalable						○		○										5	7
8	#VALUE!	*	9	0	9	9	Maintain filling properties (air content)		●				●												5	8
9		10%	7	8	0	9	Easy to clean and maintain						○	●	▽										9	9
10		10%	8	0	0	3	$10-20k to manufacture one unit							○	▽										5	10
11		10%	7	0	7	9	minimize air bubbles		○		○				▽	●									10	11
12		15%	7	0	8	9	Minimize damaging shell			●	○				▽										8	12
13																										13
14		0%																								14
15		0%																								15
16		0%																								16

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
HOW MUCH: Target Values	All	± 1%	Shell unchipped	Cannot see inside shell	20/min minimum	<= 1 worker per machine	10 years minimum	Possible to increase capacity	Bean weight within tolerance	Below $10k	10-20k					
Max Relationship	9	9	9	9	9	9	9	9	9	9						
Technical Importance Rating	0	30	180	120	135	180	195	265	105	90	0	0	0	0	0	0
Relative Weight	0%	2%	14%	9%	10%	14%	15%	20%	8%	7%	0%	0%	0%	0%	0%	0%
Curr. Products: Current: Manual Assembly	10	10	8	9	2	NA	NA	1	4							
0																
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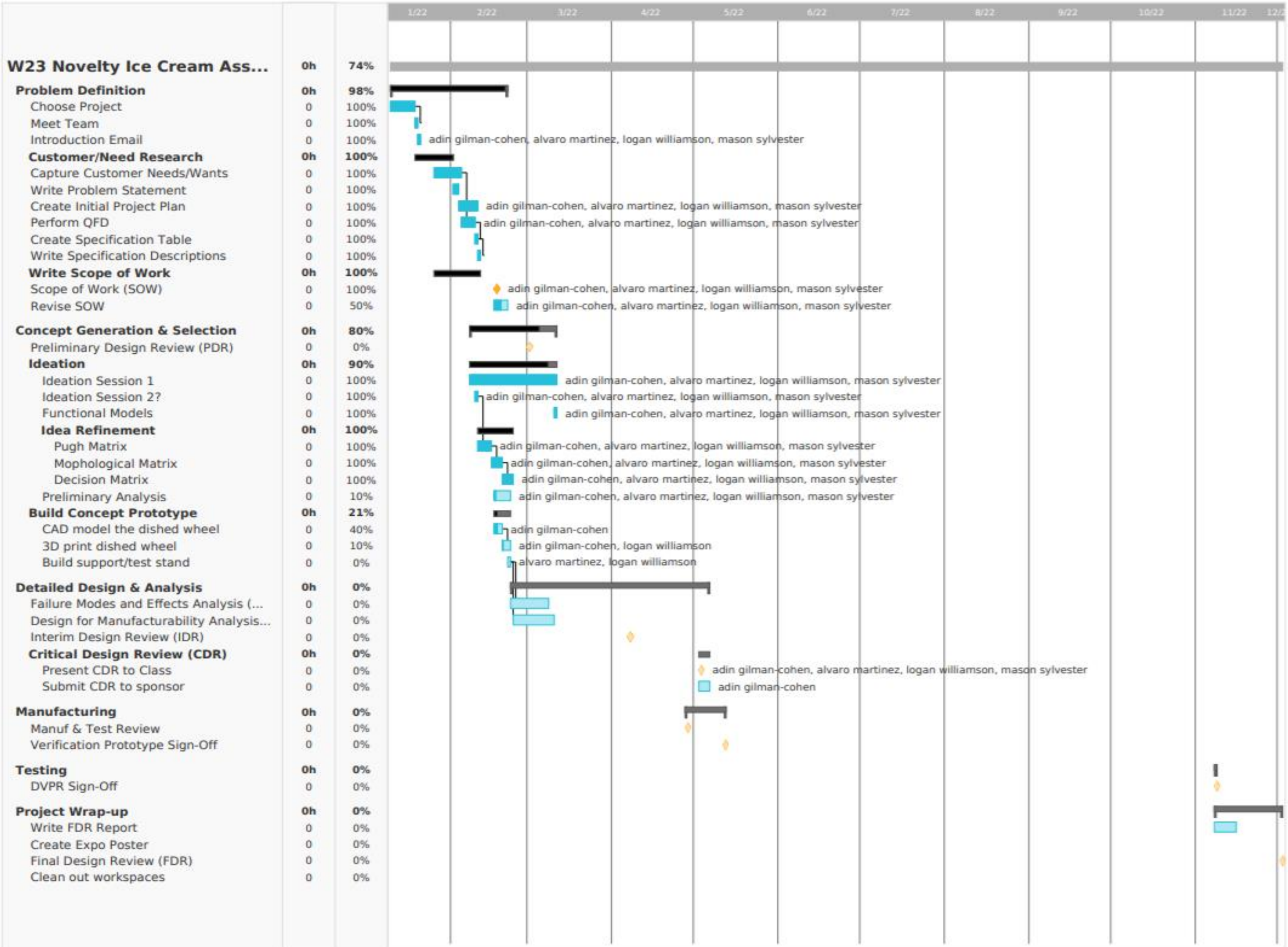
Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B- Gantt Chart



Preliminary Design Review

W23 Novelty Ice Cream Product Assembly

To:	Keith Zachow, Project Sponsor	keith@coolbeansicecream.com
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Date: 3/4/2022

Abstract

This Preliminary Design Review report serves to outline the ideation and concept design selection processes for the CoolBeans assembly system currently being designed by team W23 of the Senior Design course at California Polytechnic State University. This report will discuss the process that was used to generate, select, and integrate ideas for the complete functionality of a system that will automatically assemble the CoolBeans product for our sponsor, Keith Zachow. This process has resulted in the selection of a “Ferris-Wheel” style joining device with integrated peripheral devices for the manipulation, filling, and joining of a novelty ice cream product consisting of hemispherical-ellipsoid cone halves filled with ice cream and pressed together. The selection of this design concept will provide the basis for our team’s prototyping, analysis, and ongoing iterative design of this system. Upon sponsor approval of this design concept, our team will move forward with the selected design and begin extensive detailed design, testing and analysis, and finally acquisition of components and materials for the construction of the fully functional and integrated prototype.

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1. Introduction

Our team is working for the startup company CoolBeans to help them automate the production of their novelty ice-cream product. These ice cream filled shells are currently assembled by hand, and the company's founder, Keith Zachow, has tasked us with designing an automated method of joining them together.

This document presents our selected design direction and supports why this direction is ideal. Since submitting our original Scope of Work document to our sponsor, our project scope has remained the same but a couple of specifications have been added and some existing specifications have been updated as seen in Table 1. We have more accurately distinguished the difference between development cost and production cost clarifying that we have a maximum budget of $10,000 to research and prototype possible designs and that the production design should be $15,000 ± $5,000 to manufacture one machine. We also added a "down time" specification, which describes the acceptable amount of time during which this machine will be inoperable for purposes of cleaning and maintenance. For this specification we will aim for a design that allows for 2 days per year for maintenance and 30 minutes per day of cleaning with a tolerance of ± 1 day per year of 15 minutes per day.

Table 1: Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk*	Compliance**
1	Materials Are NSF/AINSI/FDA Food Approved	All	Min	L	S
2	Filling Maintains Air Content	Original Air Content	± 3%	M	T
3	Visual Damage Check	Shell Unchipped	TBD Before CDR	M	I
4	Shell Alignment	Cannot See Inside Shell	Min	M	I
5	Machine Output	20/min	Min	H	T
6	Head Count	1 Worker Per Machine	Max	M	T
7	Service Life	10 Years	Min	M	A
8	Configurable Production Quantity or Variable Speed	Possible to Increase Capacity	Min	L	A
9	Trapped Air	Bean Weight Within Tolerance	± 5%	M	T
10	Budget to Research and Prototype	$10,000	Max	L	I
11	Cost of Manufacturing One Production Model	$15,000	± $5,000	M	A
12	Downtime	2 days/year maintenance, 30 minutes/day cleaning	±1 day/ year, 15 minutes/day	L	A

*Risk of meeting specification: (H) High, (M) Medium, (L) Low

**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

2. Concept Development

Upon revision of our Scope of Work document, we moved on to the ideation and concept generation phase of the design process. In conducting our project research and defining the scope of this design challenge, we identified the needs of our sponsor that must be addressed by this design and documented these needs in the Scope of Work. Additionally, we generated engineering specifications that would be used to evaluate whether each need of our sponsor had been satisfied by our final design.

Our next step was to generate ideas for sub-functions that our design must perform to meet those needs. We began by brainstorming ideas for the subfunctions we identified in the Scope of Work functional decomposition. Based on further meetings with our project sponsor since delivery of the Scope of Work, we have clarified that the design direction we are pursuing will ideally require us to accommodate filling of the shell halves during the period of product assembly in which the product is being handled by our design. With this additional consideration, we began ideation for the following design functions: feeding the shell-halves of our sponsor's product into our design, receiving filling in the shell halves, properly aligning the filled halves, applying pressure to join the filled halves, and depositing the filled halves for freezing.

Ideas were generated to perform each of these functions in two contexts. First, each member of the team generated several sketches of ideas on their own. Next, the group met and conducted a brainstorming session. In this session, we shared the ideas we had generated on our own, then used those as a jumping off point to produce new ideas that considered the designs each of the team members shared within the group. The results of this process were several different approaches for each function of our design.

Beginning with feeding shell-halves into our design, Figure 1 shows three different ideas for types of tray 'divots' that could be used to support and orient these shell halves. Figure 2 is a rough sketch of a tray consisting of an array of metal fins which would support and orient the shells placed in it.

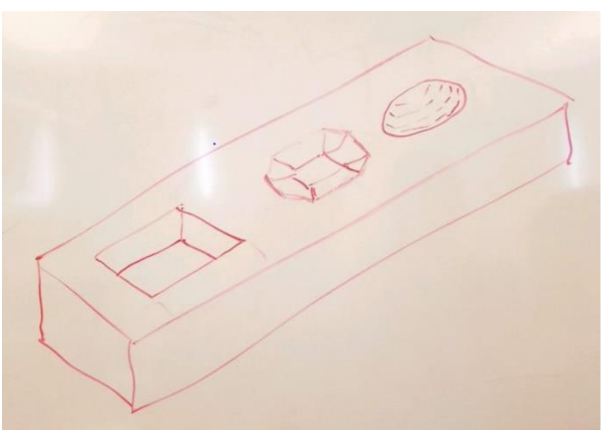


Figure 1: Three different tray divot shapes for orienting and supporting shell halves.

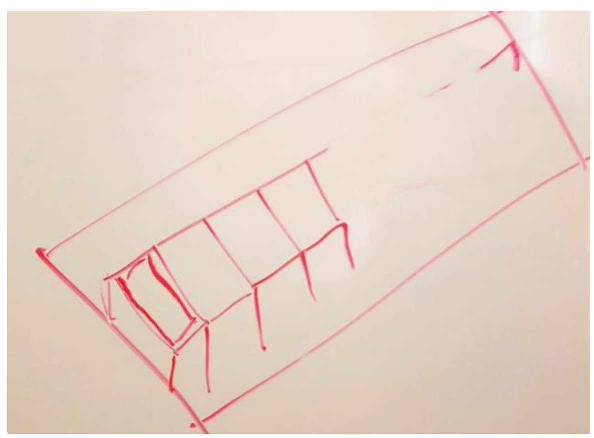


Figure 2: Idea for simply tray made of an array of metal 'fins' for cheap handling of shells.

To better understand how trays of cone halves would be handled in the context of the larger design, ideas were sketched up for how two trays of filled cone halves would be pressed together while still maintaining alignment. Figure 3 shows a system of two trays, connected by a hinge, which would serve to feed shell halves into our design, maintain their proper alignment, and apply pressure to join them once filled. This idea was appealing, as it satisfied three functions with a relatively simple design and was considered into the final stages of our selection process.

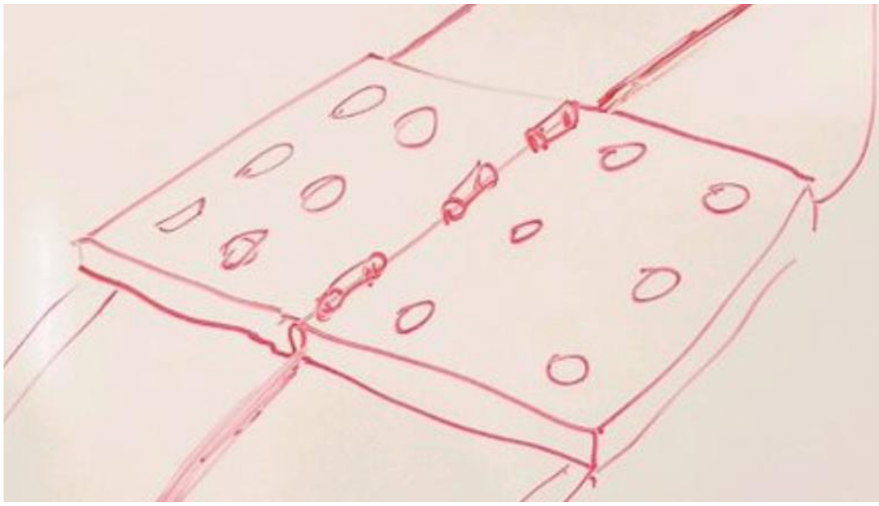


Figure 3: Set of two trays on a hinge for receiving, aligning, and joining of product.

Similar ideas included trays which could be snapped onto receivers on a conveyor belt, or simply placed on a conveyor belt for transportation of cone halves into our design. An idea for this concept is shown in Figure 4. A proposed method by which this concept could be used to apply pressure and join cones is shown in Figure 5. This is essentially an end-to-end configuration of two of these tray-conveyors, such that each tray/row would align with and apply pressure to a matched tray/row on a separate conveyor before dropping the joined halves into some sort of receptacle. This idea was also considered in the final stage of the selection process.

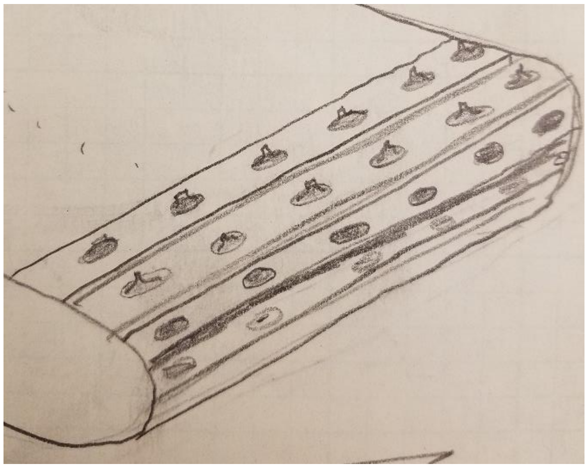


Figure 4: Rough sketch of tray conveyor idea for transportation of shells into our design.

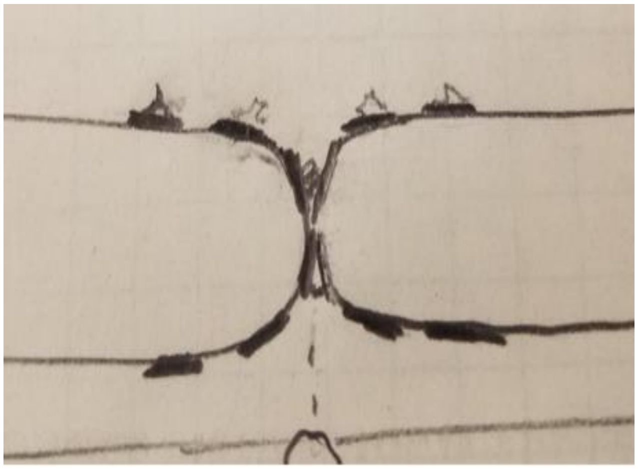


Figure 5: Sideview of how the tray conveyor would apply pressure to join two filled shell halves.

Other ideas for feeding cone halves into our design revolved around the general idea for a hopper feed. This was discussed at length with our sponsor, and potential integration of a vibratory hopper to feed cones into our design is still being researched and considered.

Making this design compatible with receiving the filling is relatively simple. Of all the functions investigated, our team was confident that any of them could be adapted to allow periodic stopping of the movement of the cone halves to allow for an automated piping or filling apparatus to deposit filling at the appropriate intervals. Of the functional designs considered, mechanisms such as a Geneva wheel and driver, depicted below in Figure 6 can be used to mechanically change constant motor input to periodic rotation.

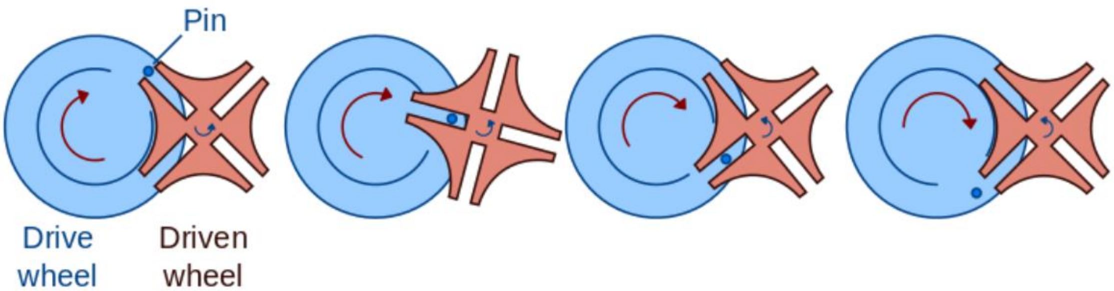


Figure 6: Geneva driver mechanism. Commonly used device for converting constant angular motion of a motor to periodic angular motion of a device.

Alternatively, it would be simple to control the operation of the motor input to any complete design using a program that controls the motor operation. This would also allow for integration with other equipment (such as the timing of the filling equipment) should our sponsor wish to include that functionality as their production expands.

An additional idea that was considered for applying pressure to the product, assuming it was being delivered to our process in trays, was an aligning roller such as the one seen in Figure 7. This device would be placed just above rows of filled CoolBean lower halves, with an upper half loosely dropped on top by a hopper. This roller would then rotate such that it oriented and pressed the top cone half down on the product, completing assembly as they passed under it.

Figure 7: Pressure applicator and alignment roller.

Finally, since submission and revision of the Scope of Work, our sponsor has informed us of his updated plans regarding the freezing of his product after our design has assembled it. At this point in their production, our sponsor believes it will be more economical to simply use a traditional reach-in style industrial freezer for freezing rather than a tunnel flash freezer. As such, the function of depositing the assembled product into the freezing process is very simple: we need to deposit the product such that it is collected on standard sized, rimmed sheet trays without multiple units being stacked on top of each other. This can easily be achieved by having any final design deposit the product onto sheet trays gently by means of a catchment chute and an angled speed rack for holding the receiving trays.

Next, we began rapid prototyping of very simple functional models for each of these functions. These amounted to arts-and-crafts type, three-dimensional models to help visualize and experiment with how our sketched ideas would translate to physical subsystems. This process served to further explore the ideas generated by the team for each function and enable us to begin critically evaluating these ideas. Several of the types of divots for moving shells as well as the folding tray idea were shown to not be feasible at this stage.

From our functional models, the team began evaluating and reducing our ideas down using the Pugh matrices shown in Appendix A. A Pugh matrix is a means of comparing multiple ideas for the same function by evaluation of those ideas against a baseline or benchmark device which performs that function. For example, eight ideas were considered for the function of applying pressure to our sponsor’s product. The baseline against which these ideas were compared was manual assembly of the product, i.e., how well a person can apply pressure to join the beans, as this is how our sponsor is currently assembling his product. Using the sponsor needs outlined in the Scope of Work document, we evaluated how each functional idea compared to this baseline for each category: the same (0), better (+1), or worse (-1). Each idea was then given a score based on the sum-total of ratings for each sponsor need. This process was completed for each function to qualify which functional designs should be incorporated into the final system.

After completing the Pugh matrix analysis, the best-performing ideas within each function were combined in various ways to generate a morphological matrix, as seen in Appendix B. A morphological matrix is a design approach in which the best performing solutions to each function of a design are combined in as many different permutations as possible to generate potential integrated systems. These potential systems are then evaluated based on how easily their constituent parts could be integrated, i.e., how feasible it would be to create a work assembly from the functional designs contained within each. This yielded five feasible designs that incorporated the best functional approaches from the Pugh matrix analysis.

These five designs then had to be narrowed down to one concept design. This was done by means of a weighted decision matrix, which can be found in Appendix C. A weighted decision matrix is a means of evaluating each of these five integrated concept designs against the sponsor needs that were determined in the Scope of Work. Each need was given a weight corresponding to the relative importance of that need to our sponsor. Any score earned by a design in that category will be multiplied by that weight to generate a weighted score for the design in that category. Then, each design is evaluated in each category, relative to the other designs. Finally, the weighted scores for each design in each category are summed to generate a total score for each design.

3. Concept Design

The concept we have chosen to pursue is a "Ferris Wheel" design consisting of two inward rotating wheels as shown in Figure 8. "Cups" cut into the wheels carry shells using negative pressure and press the shells together where the wheels meet. This model does not address all the tasks that our final design must perform. Rather, it demonstrates the feasibility of wheels as a method of joining.

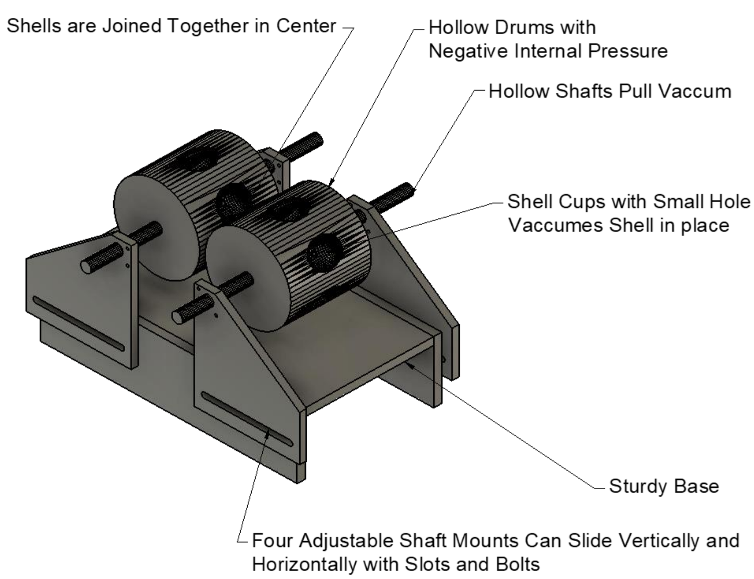


Figure 8: Labeled CAD Isometric of Prototype

Our proof-of-concept prototype consists of two 3D printed plastic wheels with cups printed into their surface as shown in Figure 9. The wheels rotate towards each other on a laser cut plywood frame and carry one cone shell in each of their cups. It is important to note that this prototype is a scale model, and the optimum size of the wheels and frame are still to be determined. The rest of this section will discuss each component of this prototype in more detail.

Figure 9: Laser Cut and 3D Printed Concept Prototype.

3.1 Frame

The base of our concept prototype is a plywood frame that supports the wheels and allows them to spin. The frame design is shown in Figure 10 and was laser cut out of 3/8-inch plywood. The geometry is designed such that it is easy to adjust the position of each wheel independently in the vertical and horizontal directions using slots. This is crucial to be able to test different wheel sizes and fine tune alignment. Exactly how the wheels might be supported in the final design is not yet defined.

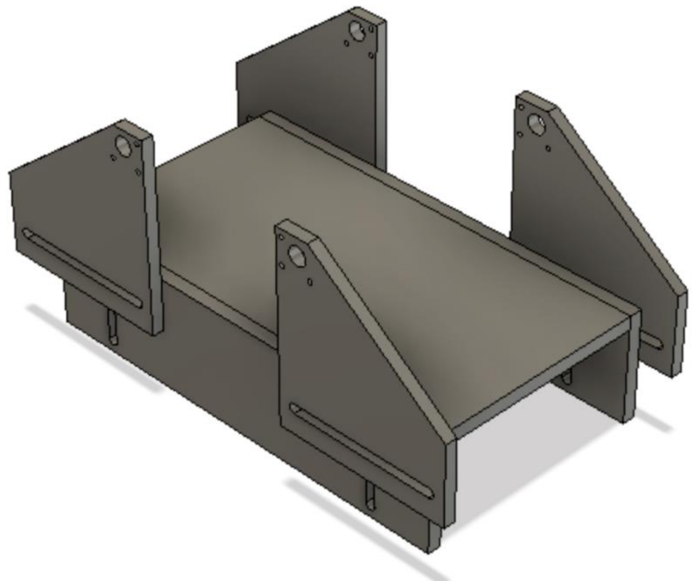


Figure 10: Testing stand for initial prototyping and design evaluation.

3.2 Wheels

The wheels in this design must be able to move shells without them slipping out, apply enough pressure to join filled shells together, and deposit the joined shells for freezing. To hold the shells, we have opted to use an imprint of the shell with a small hole at the bottom through which a vacuum is pulled as shown in Figure 11. Initial tests have shown that this configuration allows the shells to be moved at any angle without falling out. The vacuum also allows the wheel to pick up shells below it. The center of the wheel will be hollow, and the ends capped. A vacuum will be pulled inside of the hollow chamber. The specifics of how this will be done are not yet defined; however, for testing, we will use a vacuum cleaner attached to a hollow shaft. Other wheel designs will also be tested to see if a simpler and easier to manufacture geometry could be successful. The means of spinning the wheels in a synchronized fashion has not yet been defined, but possible ideas include a small motor such as a hand drill with gears connecting the shafts. Manufacturing these wheels could be a challenge. If they are to be made of food safe metal, they may have to be cast or machined on a CNC mill with a rotary table.

Figure 11: CAD model of vacuum wheel design.

3.3 Filling

Ideally, the shells would be filled with ice-cream when they are accepted into the wheel and then they are joined together. Our prototype will test the feasibility of piping ice-cream into each shell with a robot at the top of the wheel. One idea we will test is to spin the wheels with a Geneva drive that will move them in steps with pauses for each shell to be filled. This can easily be tested by hand-piping ice-cream into empty shells at the top.

3.4 Adding Shells

The means of getting the shells into the cups on the wheels is not yet defined; however, this design allows for several options. The shells could be fed underneath the wheels on two conveyer belts and sucked up into the cups using vacuum. If the wheels are moving in increments using a Geneva Drive, a mechanism could be implemented to push each shell up into its cup on a small platform that oscillates up and down. Shells could also be fed in using hopper that orients them and deposits them at the correct rate.

3.5 Removing shells

Once two shells of ice-cream are pressed together, the pod must be removed from the wheels and deposited on a tray for freezing without breaking. This mechanism is not yet defined, but this prototype will test several solutions. These include a small ramp that pushes the pods out of the wheels, a stationary rod inside the wheel that pushes out the shell form the inside at the right position and stopping the vacuum from reaching the hole at the "drop" position.

4. Concept Justification

This section will discuss initial testing, calculations, and analysis that suggest that this design will meet our engineering specifications in a safe manner.

4.1 Testing of Cups

We have performed several initial tests to demonstrate that the vacuum cup model is the best method of holding shells. We modeled shells full of ice-cream by filling the shells with wet paper and hot glue in the absence of the CoolBeans ice-cream mix. These shells were placed in various sizes and shapes cup and tilted to different angles until the shells fell out as shown in Figure 12. The shells stayed in place consistently up to 2 degrees of vertical using the design implemented on the wheels.

Figure 12: Cone-shell form grip retention test.

The shell impression was also printed with a hole at the bottom, onto which we placed a shop-vacuum as shown in Figure 13. This allowed us to tilt the shell fully upside down without it falling out. It also allowed us to pick up shells from the table by bringing the block near and aligning it. The purpose of this test was to check whether we could achieve better cone retention or ‘grip’ of the cone by our transportation apparatus if the shell form shape was insufficient to retain the cone on its own.

Figure 13: Vacuum Retention Test

This vacuum test was repeated with the hollow wheel and axle design and each cup was still able to hold an empty shell when a vacuum was pulled.

4.2 Meeting Specifications

Preliminary testing and calculations have shown that this design can meet our engineering specification for output. Two shells filled with hot glue and rotated in the wheels by hand joined cleanly together and dropped out the bottom as a single unit. This was accomplished without cracking the shells. With the 4-inch diameter wheels on this prototype, the wheels would only have to spin at 3.3 RPM to hit the required output of 1200 per hour as calculated in Figure 14. This speed would be even lower with larger wheels. Output could easily be increased by spinning faster, enlarging wheels, or running wheels in parallel. This design does not require any parts that are particularly expensive, and we are confident that we can hit research and manufacturing budget specifications. The most expensive part may end up being manufacturing the wheels, but we think this will still fall within our budget.

$$\frac{6\ shells}{1\ rotation} \cdot \frac{3.33\ rotations}{1\ minute} \cdot \frac{60\ minutes}{1\ hour} = 1200\ \frac{shells}{minute}$$

Figure 14: Calculation of required wheel RPM

4.3 Hazards

The main hazard that this design presents is that of pinch points due to rotating wheels and gears. The use of vacuum and motors could also create noise hazards. A checklist of all possible hazards in shown in Appendix 8.5. These will be addressed with safety guards and warning labels.

4.3 Concerns

As discussed in Section 3, the largest unknown is how we will feed shells into the wheels. If the possible solutions discussed do not work, the worst-case scenario would be to add shells by hand, which could still meet the engineering specifications of one worker per machine and machine output. There is also a chance that this design will simply not work consistently when run at full speed, such as a backlog of shells getting to the wheels in the wrong orientation or completely causing the shells to get stuck and not feed at all. In which case we would explore some of the other ideas we generated.

5. Project Management

The development plan for the rest of the project will include our planned analysis and early testing of our prototype, planned purchases of materials and equipment, and preliminary plans for building and testing our final design. We will work on building 3D printed models of various design features to get more information on which will work the best. This will also allow us to determine what aspects of our design we need to improve and what will not work under the projected operating conditions. Now that our design direction has been decided, we can focus on making changes to refine our design decisions.

5.1 Planned Analysis & Early Tests

The planned analyses and early testing will begin using a 3D printed model of our prototype. We will 3D print the major components of the device and use nuts and bolts to join components together. This will allow us to have a working prototype that can be used to run tests to inform us of any design flaws. We will need to run tests on the rotating wheels to find out what distance must be between them. The tests will help determine adjustments needed to prevent a gap between the cone halves from the wheels being too far apart, or damage to the cone halves from the wheels being too close together. Once we run these tests, we will be able to analyze and compare the joined beans and see what distance would be ideal considering cosmetic and pressure requirements. We also plan to perform a test to determine what amount of pressure the suction must be set at for the cone halves to be held on without falling. This test will allow us to calibrate the pressure settings for the vacuum for either an empty cone or a full one. With these results, we will be able to determine what equipment we will be needing to buy for the vacuum aspect of the prototype. We must also test what speed the wheels can rotate so that the joining process is possible without any damage to the exiting joined beans. For example, there might be a speed at which the wheels are turning too fast, causing the joined beans to obtain damage from being ejected at too fast a speed.

5.2 Planned Purchases

The purchases that we have planned so far include building materials, ice cream or similar test substances, and components for adding functionality to the existing concept prototype. We will begin making purchases for building materials needed to address the remaining functions of our prototype such as wood, metal rods and plates, and hardware. We also need to make purchases for ice cream or similar substances. Although we would prefer ice cream, we might need to buy products that have a similar consistency or density to facilitate testing. For example, substances such as playdoh, peanut butter, or mayonnaise can be used to simulate ice cream during testing. This will allow us to perform test over a longer period without having to worry about melting of ice cream and its properties changing over the course of our testing procedures. While for testing, we might use a smaller vacuum cleaner, we will need to eventually buy a full-size device to be integrated into our product. We will determine what device will need to be purchased as further testing is done.

5.3 Preliminary Plans for Construction & Testing Final Design

Once the existing prototype is more developed and more testing has been performed, we will have a better idea of what construction will entail. Once we know what design specifics we will pursue, we plan on working in the campus machine shop to do any material removal or joining required. We then plan on testing the final design by testing each component needed to run the machine individually at first and then running the machine with everything in place and functioning as it should be. This will allow us to make any adjustments that are needed and perfect the final design. The machine will be run long enough to be confident that it consistently meets all of the engineering specifications.

5.4 Development Plan for Rest of Project

In accordance with our Gantt chart, attached in Appendix D, the next step, beginning March 4th of 2022, will be analyzing the failure modes and effects analysis in which we will be discovering any weak points in our concept prototype design. There will be fatigue analysis done on the components to determine timeframes for wear and potential failure. We will analyze the production rate and the effects of suction loss as well. Beginning on March 8th, we will then move onto design for manufacturability analysis. This leads to the interim design review on April 7th. By this point, we will have a completed CAD model of the integrated prototype assembly. Once we have this model finished, we can begin work on our manufacturing plan and reviewing technical drawings during that same timeframe. With a manufacturing plan in place, we will have sufficient information to begin planning out part ordering and cost analysis for final prototype material acquisitions. We hope to begin cost estimation and purchase planning by April 26th. This is followed by the critical design review in which we will be giving a presentation on May 3rd. Once this is done, we can begin the manufacturing and testing review which should result in the approval of the verification prototype on May 12th.

6. Conclusions

Over the next year our team will design a piece of assembly equipment to join CoolBeans ice cream filled shells. After brainstorming ideas, testing concepts with simple prototypes, and analyzing our options Pugh and decision matrices, we feel that our Ferris-Wheel design will be the most likely to meet our engineering specifications. Initial testing of this prototype demonstrates that it is a feasible method of joining shells at a rate of at least 1200 units per hour without damaging shells. While functions like adding, filling, and removing shells are not yet clearly defined, this design presents several options for fulfilling each of these needs. This report outlines our plan for addressing these remaining functions and establishes a timeline for completion of these remaining tasks. Upon approval of this design by our sponsor, we will further develop this prototype to make it fully functional and able to meet all engineering specifications.

7. References

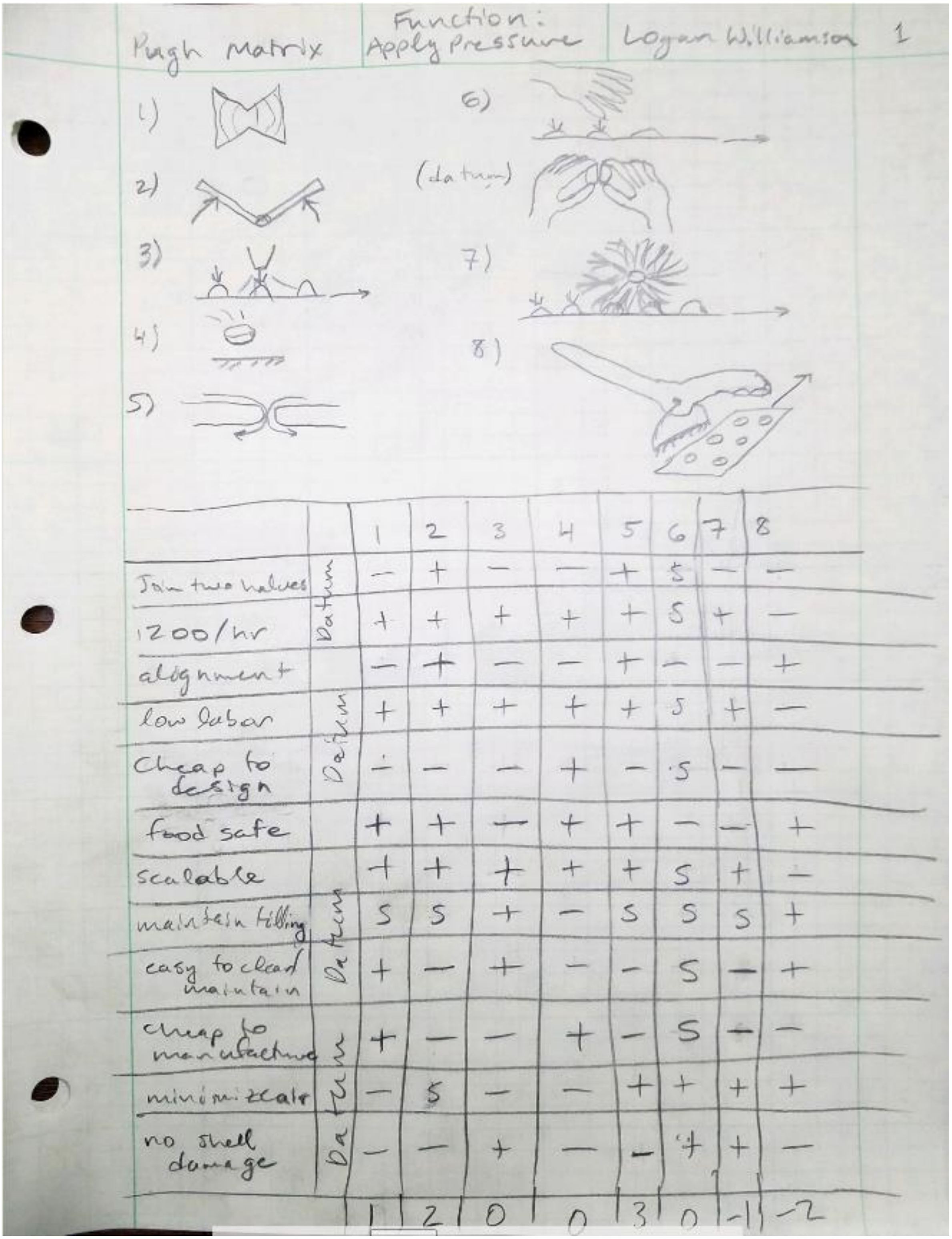
"Geneva Drive." *Wikipedia*, Wikimedia Foundation, 10 Aug. 2021, https://en.wikipedia.org/wiki/Geneva_drive.

"ME Senior Design Project Student Success Guide." Department of Mechanical Engineering, California Polytechnic State University, 2021.

Ullman, D., The Mechanical Design Process, McGraw-Hill, 1997

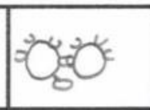
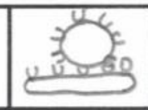
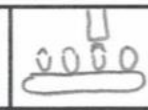
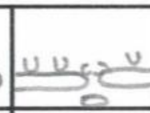
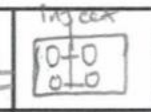
8. Appendices

8.1 Appendix A – Pugh Matrices

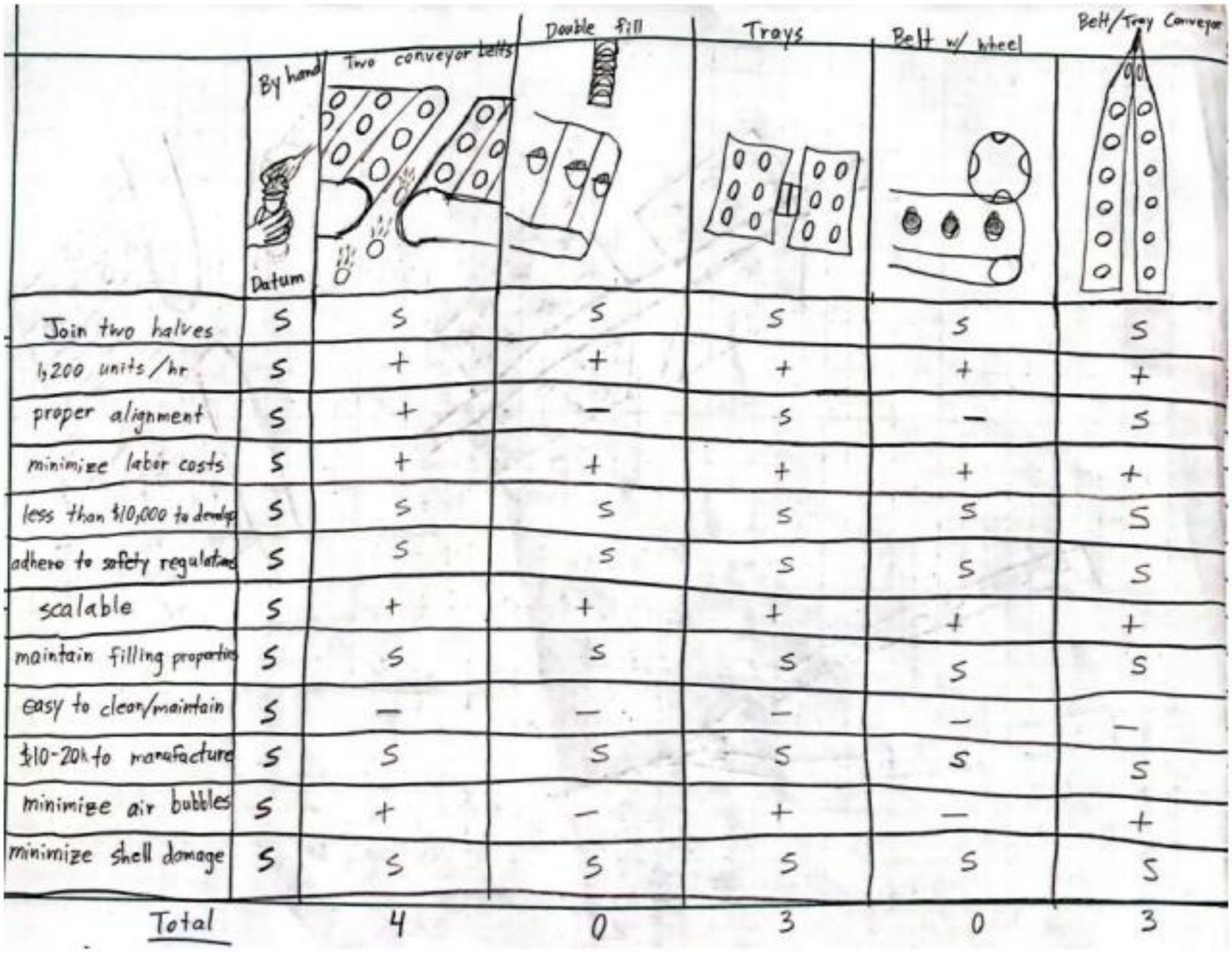


	Datum	1	2	3	4	5	6	7	8
Join two halves	Datum	–	+	–	–	+	S	–	–
1200/hr		+	+	+	+	+	S	+	–
alignment		–	+	–	–	+	–	–	+
low labor	Datum	+	+	+	+	+	S	+	–
Cheap to design		–	–	–	+	–	S	–	–
food safe		+	+	–	+	+	–	–	+
scalable		+	+	+	+	+	S	+	–
maintain filling	Datum	S	S	+	–	S	S	S	+
easy to clean/maintain		+	–	+	–	–	S	–	+
cheap to manufacture	Datum	+	–	–	+	–	S	–	–
minimizcale		–	S	–	–	+	+	+	+
no shell damage	Datum	–	–	+	–	–	+	+	–
		1	2	0	0	3	0	-1	-2

Pugh Matrix for the Function of Applying Pressure

	by hand					
Join two filled cone halves	S	S	S	S	S	S
1,200 units per hour	S	+	+	+	+	+
Proper alignment of cone halves	S	S	S	S	S	S
Minimize Labor cost	S	+	+	+	+	+
Less than $10,000 to develop	S	+	+	+	+	+
Adhere to saftey regulations	S	S	S	S	S	S
Scaleble	S	+	+	+	+	S
Maintain filling properties	S	S	S	+	S	−
Easy to clean and maintain	S	−	−	S	S	−
$10-20k to manufacture 1 unit	S	S	S	S	S	−
Minimize air bubbles	S	S	S	S	S	+
Minimize damaging shells	S	−	−	−	−	−

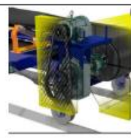
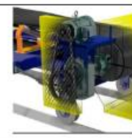
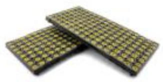
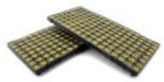
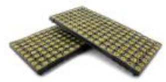
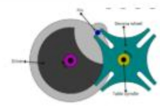
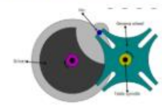
Pugh Matrix for the Function of Joining



	By hand (Datum)	Two conveyor belts	Double fill	Trays	Belt w/ wheel	Belt/Tray Conveyor
Join two halves	S	S	S	S	S	S
1,200 units/hr	S	+	+	+	+	+
proper alignment	S	+	—	S	—	S
minimize labor costs	S	+	+	+	+	+
less than $10,000 to develop	S	S	S	S	S	S
adhere to safety regulations	S	S	S	S	S	S
scalable	S	+	+	+	+	+
maintain filling properties	S	S	S	S	S	S
easy to clean/maintain	S	—	—	—	—	—
$10-20k to manufacture	S	S	S	S	S	S
minimize air bubbles	S	+	—	+	—	+
minimize shell damage	S	S	S	S	S	S
Total		4	0	3	0	3

Pugh Matrix for the Function of Joining

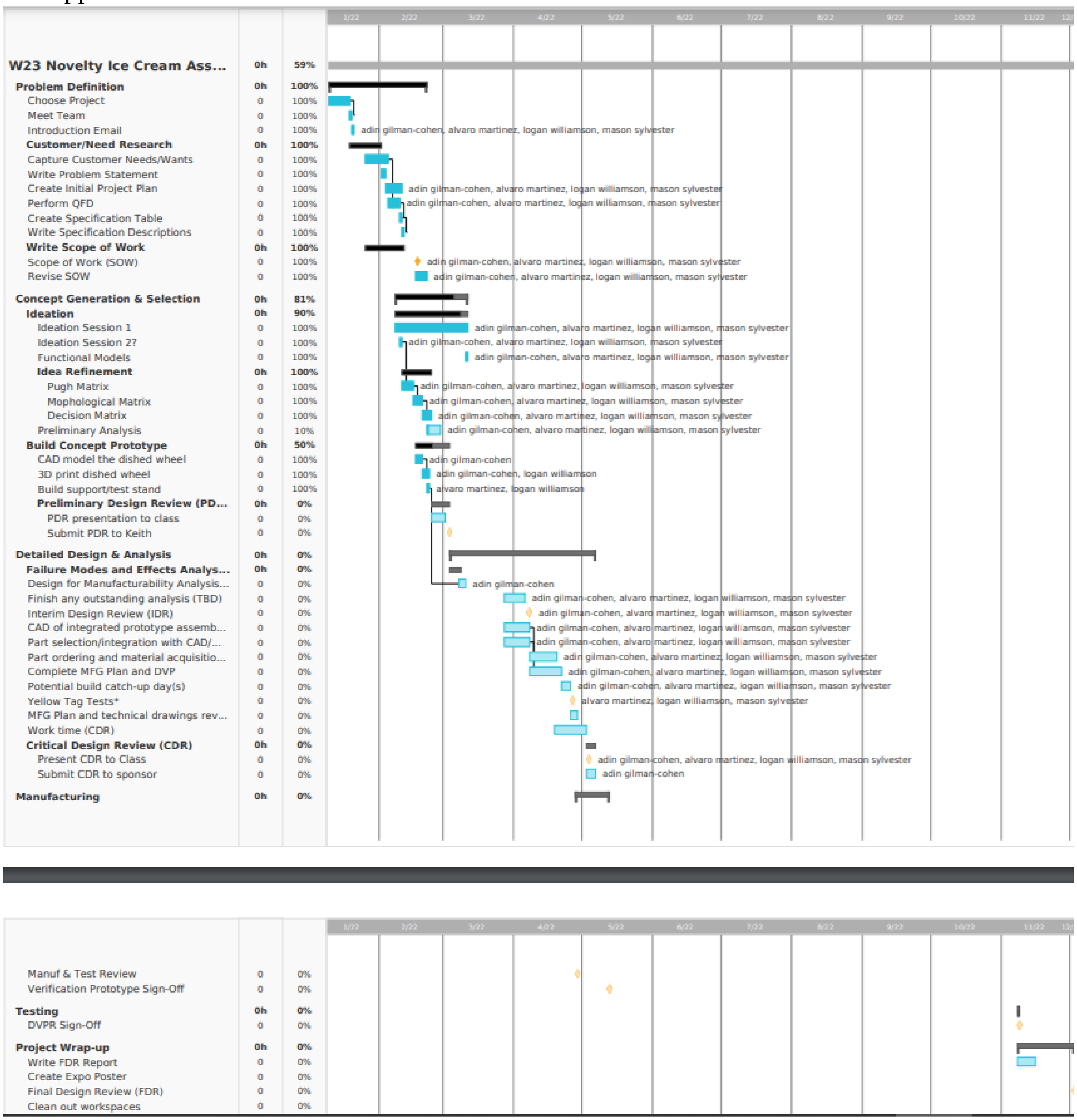
8.2 Appendix B – Morphological Matrix

Function	Dual Conveyor	Convery Single Wheel	Conveyor w/ Hopper	Dual Wheel	Big Wheel
Accept Cones					
Accept Power					
Accept Filling					
User Stop/Start					
Align Shells					
Deposit Beans					
Apply Pressure					

8.3 Appendix C – Weighted Decision Matrix

Criteria	Weight	Design 1		Design 2		Design 3		Design 4		Design 5	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Join two filled cone halves	5	5	25	5	25	5	25	5	25	5	25
1,200 units per hour	4	5	20	5	20	5	20	5	20	4	16
Proper alignment of cone halves	4	5	20	3	12	3	12	5	20	4	16
Minimize labor cost	4	5	20	4	16	4	16	4	16	2	8
Less than $10,000 to develop	3	3	9	3	9	3	9	3	9	5	15
Adhere to saftey regulations	5	5	25	5	25	5	25	5	25	5	25
Scalable	4	5	20	5	20	3	12	5	20	2	8
Maintain filling properties	4	5	20	5	20	5	20	5	20	5	20
Easy to clean and maintain	4	4	16	4	16	3	12	4	16	3	12
$10-20k to manufacture one unit	4	3	12	3	12	3	12	3	12	5	20
Minimize air bubbles	3	5	15	2	6	2	6	5	15	1	3
Minimize damaging shells	4	4	16	4	16	4	16	4	16	2	8
Total		218		197		185		214		176	

8.4 Appendix D – Gantt Chart



8.5 Appendix E – Design Hazard Checklist

Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	N	2. Can any part of the design undergo high accelerations/decelerations?
	N	3. Will the system have any large moving masses or large forces?
	N	4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	N	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
	N	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
Y		14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
Y		16. Is it possible for the system to be used in an unsafe manner?
Y		17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
This design will have a potential pinch-point between two rotating roller-type components.	The rotating components will be covered by a shroud or shielding to prevent accidental placement of limbs/fingers into the pinch point. Additionally, the torque and speed of the rotating components is relatively low. Operational procedures will include removal of any dangling or loose articles of clothing before interaction with the design.	4/22	
Vacuum system may be loud, could require hearing protection	Operating procedures will involve requirement of hearing protection PPE if deemed necessary	10/1	
There will be a potential shear point between the hopper or conveyor mechanism that feeds shells into our system, and our system itself.	Again, improper handling of the system near this location will be prevented with a simple piece of shielding to protect users	4/28	
Operation of the system at higher-than-intended speeds could potentially cause component failures and dangerous runaway of the system rotation.	The system operating speed will be limited via motor selection and either a mechanical driving device or software.	4/25	

Critical Design Review

W23 Novelty Ice Cream Product Assembly

To:	Keith Zachow, Project Sponsor	keith@coolbeansicecream.com
From:	Adin Gilman-Cohen	agilmanc@calpoly.edu
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Date: 5/12/2022

Abstract

Our team is working to design a machine that will automate product assembly for the novelty ice-cream company CoolBeans. This report outlines the prototyping, testing, analysis, and iterative design that our team has done to arrive at our proposed final design, which will be constructed in the form of our Design Verification Prototype (DVP).

Shortly after submission of the Preliminary Design Review report (PDR), our senior project team completed a structural prototype to be used for testing critical design functionality. This prototype was used to test different design concepts and has shown that our two-wheel concept presented in PDR, with some modifications, can consistently retain and join the filled product halves while meeting all required specifications.

A thorough analysis of potential failure modes and their solutions, a manufacturing plan for each component, and a mathematical analysis of each critical module were created to ensure the feasibility of this design. This analysis informed minor changes to the design and motivated the minimization of custom manufacturing in favor of purchasing and modifying prefabricated components. With these analyses complete, a comprehensive computer-aided design (CAD) model representing the proposed prototype was created. This was completed in concert with the generation of a bill of materials (BOM) containing all required hardware to build a physical prototype of the model.

Table of Contents

1. Introduction

Our team has been working with the startup company CoolBeans to help them automate the production of their novelty ice-cream product. Their ice-cream filled shells are currently being assembled by hand, and the company’s founder, Keith Zachow, has tasked our group with designing an automated method of joining two Cool Bean halves together to increase the rate of production.

In this document we will present our final design for the Cool Bean assembly machine and provide justification that this design will meet all our design specifications. In the time that has passed since our Preliminary Design Review (PDR), we have progressed from a Structural Prototype design geared towards rapid prototyping to our final Design Verification Prototype (DVP) design. The core functionality of the design has remained the same throughout this process. However, the testing that was conducted with the structural prototype, in addition to engineering analysis of various design aspects, have informed the changes that have been made since PDR.

All proposed materials are now safe for food contact and able to be washed. The shafts are no longer held by two separate risers but are instead held by a single piece of stainless-steel square tubing bolted to a sturdy baseplate. The wheels and shafts are now removeable for easy washing and are driven by gears and an industrial servo motor. The Geneva drive mechanism used to facilitate the incremental motion design has been replaced with a servo motor to enhance the ease of use of the machine as well as the positioning precision. Perhaps the most significant update to our structural design is extension of the wheel "cups” that hold the shells to the edge of the wheel. This was done to enable shells to be automatically fed into these cups on the joining wheels via our sponsor’s desired conveyor feeding system. This feeding system remains outside the scope of our design work, per the agreement discussed in the Scope of Work (SOW) report.

The design specifications that we presented in the preliminary design review remain unchanged, though some specifications are no longer relevant to the part of the manufacturing process included in our scope, as will be discussed in the “Design Verification Plan” section. The new updated specification table can be seen in Table 1.

Table 1: Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
1	Materials Are NSF/AINSI/FDA Food Approved	All	Min	L	S
2	Filling Maintains Air Content	Original Air Content	± 3%	M	I

Table 1: Engineering Specifications Table (continued)

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
3	Visual Damage Check	Shell Unchipped	Min	M	T
4	Shell Alignment	Cannot See Inside Shell	Min	M	T
5	Machine Output	20/min	Min	H	T
6	Head Count	1 Worker Per Machine	Max	M	I
7	Service Life	10 Years	Min	M	A
8	Configurable Production Quantity or Variable Speed	Possible to Increase Capacity	Min	L	T
9	Trapped Air	Bean Weight Within Tolerance	± 5%	M	I
10	Budget to Research and Prototype	$10,000	Max	L	I
11	Cost of Manufacturing One Production Model	$15,000	± $5,000	M	A
12	Downtime	2 days/year maintenance, 30 minutes/day cleaning	±1 day/ year, 15 minutes/day	L	A

*Risk of meeting specification: (H) High, (M) Medium, (L) Low
**Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

2. System Design

Our most current design employs the same overarching method of assembling the shell halves as the structural prototype design presented in the Preliminary Design Review (PDR) report. This method consists of two counter-rotating wheels that use suction to pick up empty shells at the 6 o'clock position which are then filled at the 12 o'clock position and rotated to be joined between the two wheels. The pressed-together shells are dropped out of a hole in the bottom as shown in Figure 3. Our structural prototype design used four separately adjustable shaft mounts to be able to easily test different wheel sizes and spacings for determination of the best system geometry for joining our sponsor's product, as seen in Figure 1. With these optimal sizes and spacings found through testing this prototype, we have decided to transition the final design to a non-adjustable enclosure to reduce the risk of misalignment when setting up the machine, as seen in Figure 2.

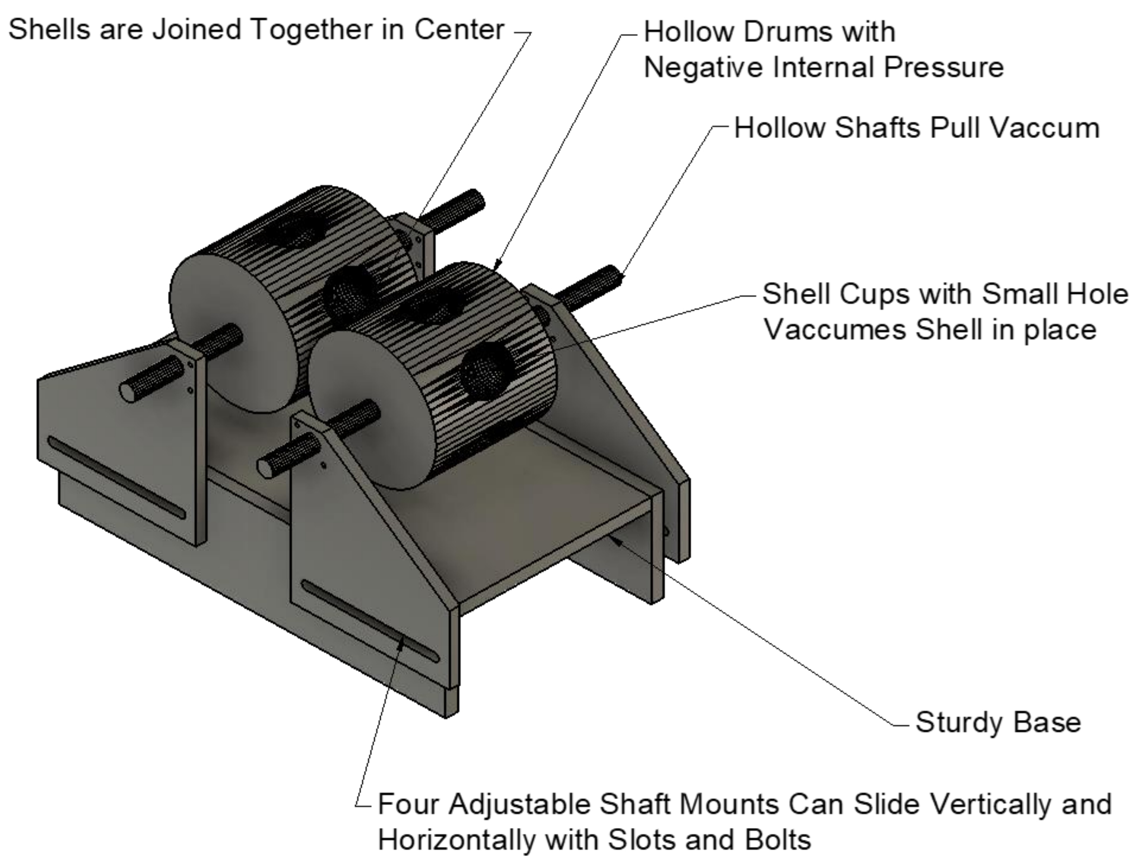


Figure 1: Adjustable structural prototype base design as presented in PDR.

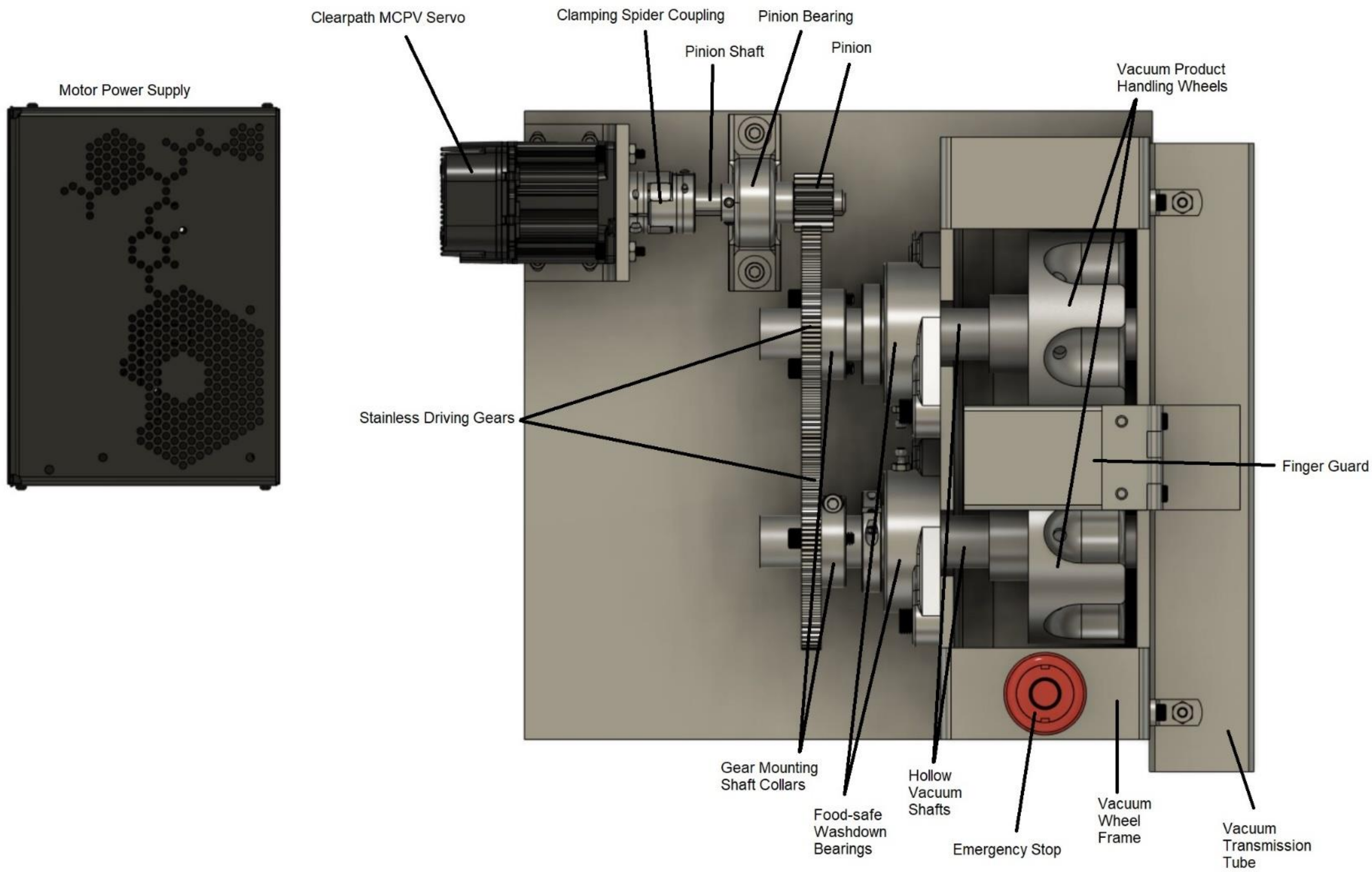


Figure 2: Design Verification Prototype Assembly.

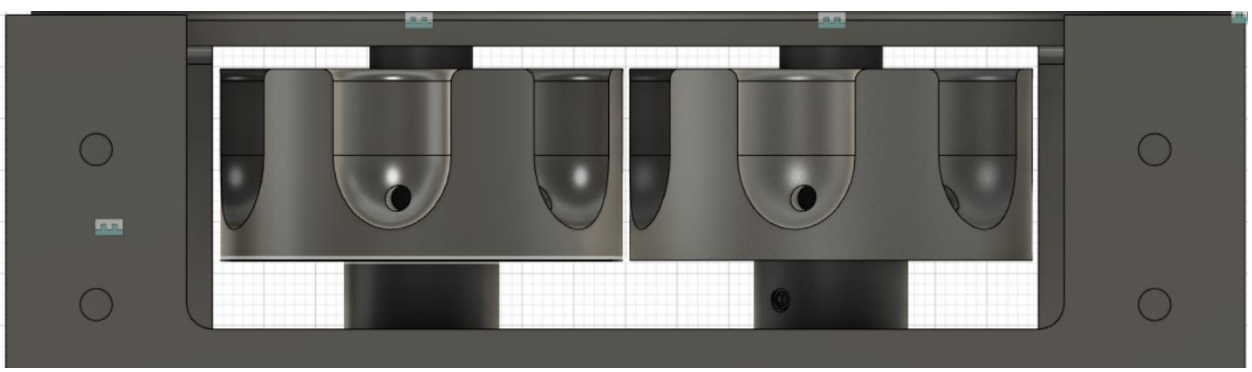


Figure 3: Hole cut in baseplate for completed Cool Beans to be extracted.

2.1 Subassemblies

The Design Verification Prototype design consists of four main subassemblies which are broken down in detail in Appendix B. The price and where we will source all the parts for the DVP can be seen in the bill of materials in Appendix C. Each of these subassemblies and their purpose is expanded upon below. Detailed drawings of every part and the part numbers included in each subassembly are included in Appendix J.

2.1.1 Base and Frame Assembly

The proposed frame will be built on a ¼ inch thick, 12-by-12-inch stainless steel plate. A stainless-steel square tube modified to retain the shaft mounting hardware will be bolted to this plate using slots to allow positional adjustment. This square tube will allow the shafts to be removed for cleaning by unbolting the flange bearings, pulling them back enough to clear the front bushings and then lifting them straight up as shown in Figure 4. Locating pins press fit into the square tube allow for easy alignment of the bearings. The frame will also include slots for a stainless-steel L-beam modified to secure the motor in place to be bolted down to the base plate, as well as a mounting block for the bearing that will support the motor shaft.

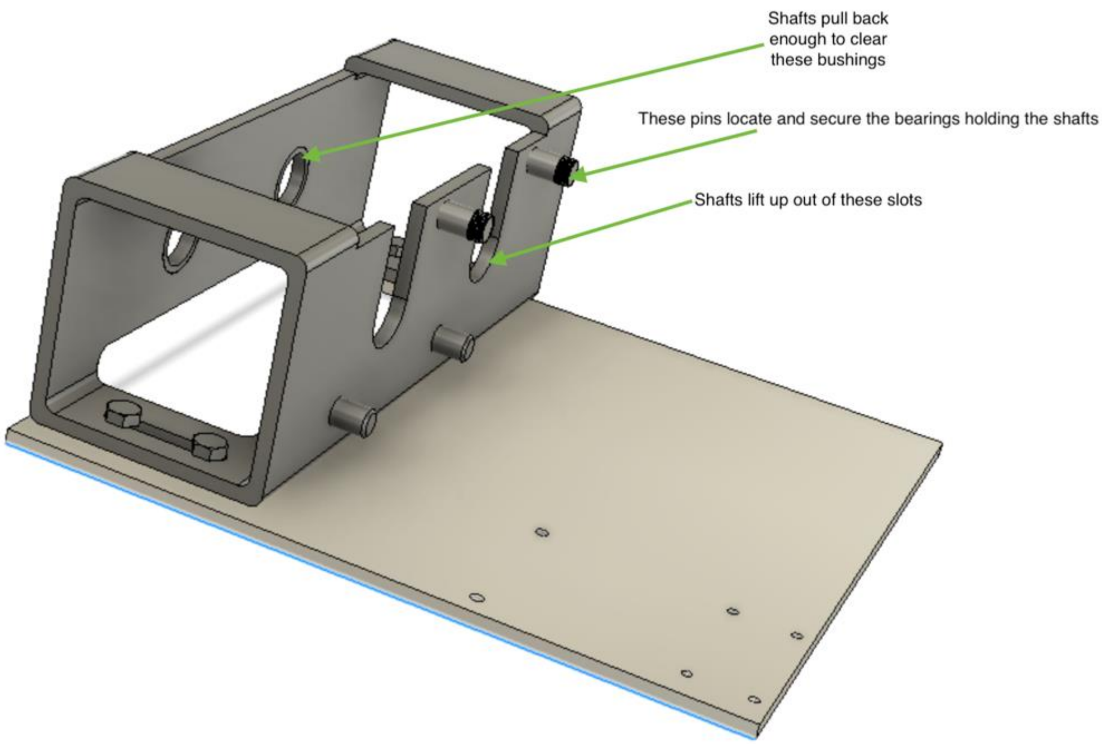


Figure 4: Baseplate and Frame Subassembly

2.1.2 Shaft, Wheel, and Gear Subassembly

Each of the two shafts carries a bearing, a gear, and a hollow vacuum wheel. Vacuum suction is transmitted through two pairs of holes per shaft, with each pair offset by 90° as shown in Figure 5. These holes provide a flow pathway from the holes in the bottom of each wheel slot to the vacuum. The wheels are capped at one end with a steel disk that can be removed for cleaning the inside of the wheel. This disk will be held in place with a simple plastic spacer that sits over the shaft. Holes in the shafts are larger than those in the wheels to prevent crumbs from becoming trapped in the wheels. The suction pulled through the shafts and wheels will deliver the force required for the mechanism to pick up shells from the feed system our sponsor chooses and retain them in their positioning slots as this subassembly rotates. This rotation will be performed in an incremental manner, moving each shell half collected by the wheels to the top position and pausing for filling.

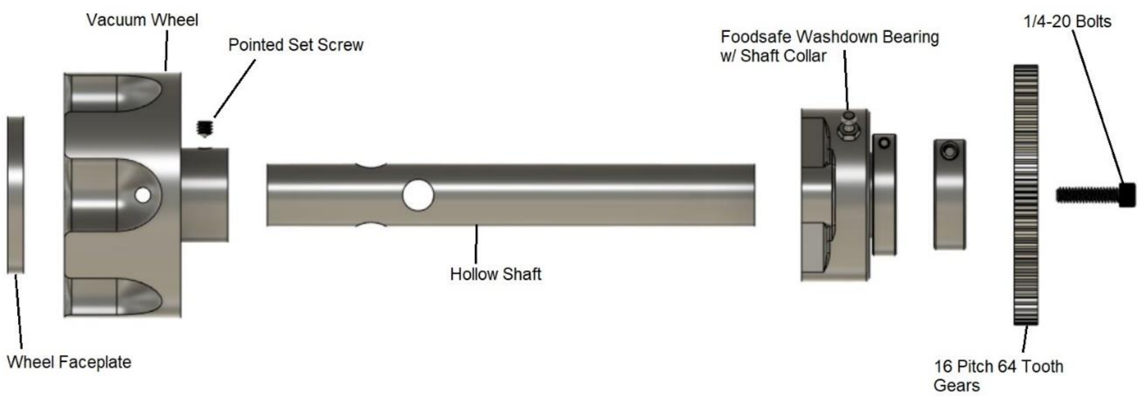


Figure 5: Exploded view of the shaft, wheel, and gear subassembly.

To mount and position this subassembly to the main assembly, there will be a washdown approved, food-safe bearing that is positioned and mounted to each shaft via an integrated shaft collar. Each subassemblies' bearing will in turn be fastened to the modified square tube frame using two precisely sized and located mounting pins. These bearings will retain the axial position and incidental axial loads present on each shaft while locating them at the correct positions for proper meshing of the gears and alignment of the vacuum wheels. The other end of each shaft will be supported radially by a food safe oil impregnated bushing. The drawing package in Appendix J includes specifications for the positioning of these mounting components which will ensure proper manufacturing tolerances are maintained to position the bearings correctly.

By taking this approach, each component that is attached to the shafts will be unable to be repositioned unless the user intends to disassemble a component for replacement. This enables the entire subassembly to be removed as a rigid unit and washed without ever having to remove the wheel, gear, or bearing after initial assembly. The intention behind this design approach is to prevent accidental misalignment of the critically positioned components during daily operation and cleaning of the machine

2.1.3 Vacuum System

To generate suction in the wheels, we will use the impeller from a dust collection system meant for a home woodshop as shown in Figure 6. From initial testing with shop vacuums, we are confident that this impeller will be strong enough to create sufficient suction. We have selected a dust collection system that can be purchased locally and returned if, upon testing, it is found to provide insufficient suction. If this is the case, there are many options for stronger systems, although they are more expensive. This remains one of the major testing aspects that will need to be further investigated during the construction of the DVP. Based on our testing up to this point, in addition to the input of fluid mechanics professor Dr. Hans Mayer, we are confident that there is a viable solution which can be easily integrated with the main assembly. Our goal now is to find the vacuum system that can provide sufficient suction force at the best price point. The dust collection system chosen will be modified to remove unnecessary parts and make it as compact as possible. This will involve removal of the dust collection bag and frame, and any other parts that do not serve the primary purpose of providing high-flow suction.

Figure 6: One option for the dust collection system is the “70 Gallon 2 HP High Flow High Capacity Dust Collector” from Central Machinery

The square tube adaptor connects the dust collection system to the shafts and wheels. The adapter from the dust collector hose to this square tube will be designed after purchase of the system. The square adapter tube bolts to the square tube riser and seals against it with a rubber gasket. The hollow shafts stick into the square tube adapter through two oversized holes. This entire subassembly is food safe and can be removed for cleaning if it needs to be.

The finger guard shown in Figure 7 is attached to the square vacuum tube and can fold down to protect the pinch point between the wheels. It can fold up to allow removal of the shafts.

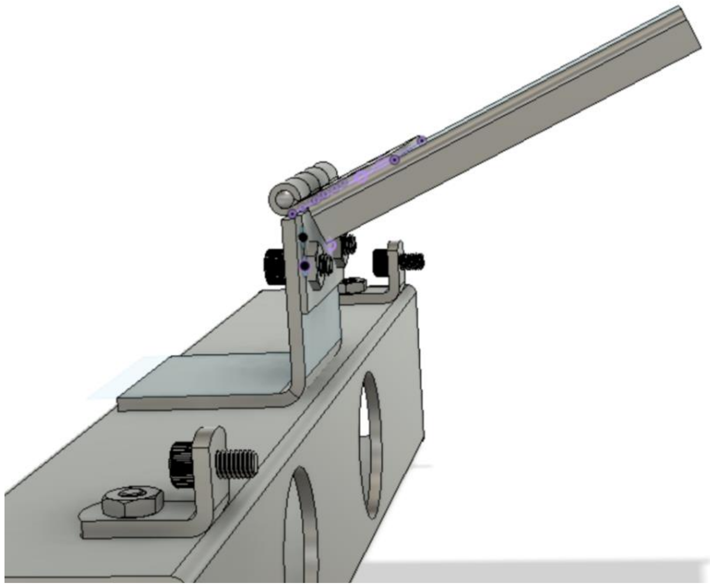


Figure 7: Finger guard pivots on vacuum square tube coupler

2.1.4 Drive and Timing System

The proposed drive and timing subassembly transmits torque to the shafts via a pinion meshed with one of the gears. This will dictate the timing and position control of the system. The sponsor has requested that the design can perform incremental movement of the machine so that he can later incorporate a piece of automated filling equipment to fill the empty shell-halves of his product. Though a Geneva mechanism was used in early design iterations to illustrate the type of motion desired, the sponsor has since requested that the system be driven by an electric motor for reliability and standardization reasons. Additionally, the sponsor has requested that the system user should be able to operate the device both manually, performing one 'step' of motion per user input, as well as in addition to automatic operation. The proposed design of the motor subassembly is shown in Figure 8.

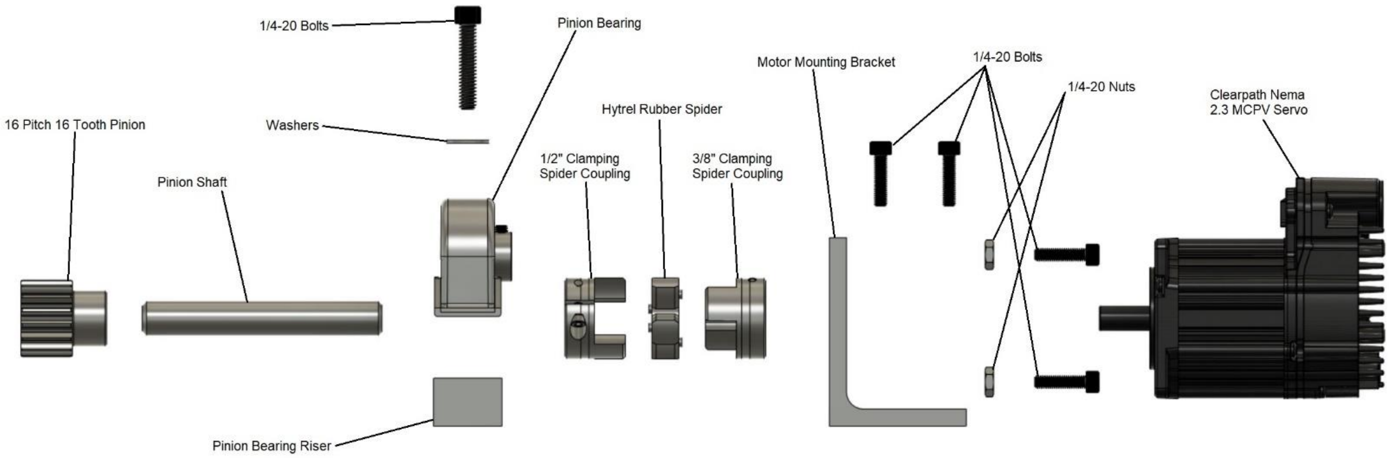


Figure 8: Exploded view of the drive and timing system.

Thorough research was conducted to identify an appropriate motor and control system for achieving this type of motion in a user-friendly manner. Additional considerations were made to seek a motor which will be simple to configure and integrate with the system to ensure that the drive system control can be implemented by the project deadline. Upon speaking with applications engineer Celine Alvarado at Teknic, the sealed-shaft, 800 ticks/revolution, integrated-encoder Clearpath CPM-MCPV-2310S-RLN servo motor was confirmed to be capable of producing the desired motion and positioning resolution. This motor can achieve these important functionalities with minimal need to directly influence its motion. Teknic provides user-friendly software for configuring the operating parameters before installing their motor in our assembly. By configuring and operating the motor in incremental positioning mode, in which the user may set a desired increment in units of encoder ticks, the motor's internal control system can repeatedly actuate the designated rotational distance whenever a 5V logic-high pulse is delivered to the motor input. This is ideal for our application, as it allows the team to focus on integrating a simple Raspberry Pi user interface which will generate the required pulse whenever the system user presses a button. Additionally, a simple clocked push of this pin will be set up to provide automated operation. It is easily capable of achieving the output torques required to actuate the system, an analysis for which is included in Appendix D.

Per Celine's recommendation, this motor is being coupled with the pinion shaft via a clamping spider coupling. This will provide shaft alignment compensation, as well as the damping required by the motor to prevent undesirable vibration in the drive system. The motor will be mounted on a simple L-shaped bracket using four bolts through the designated motor mounting holes and corresponding holes on the bracket. The bracket will be mounted to the base plate through four slots in the bracket base to allow for some adjustability in its mounting position relative to the system as shown in Figure 9.

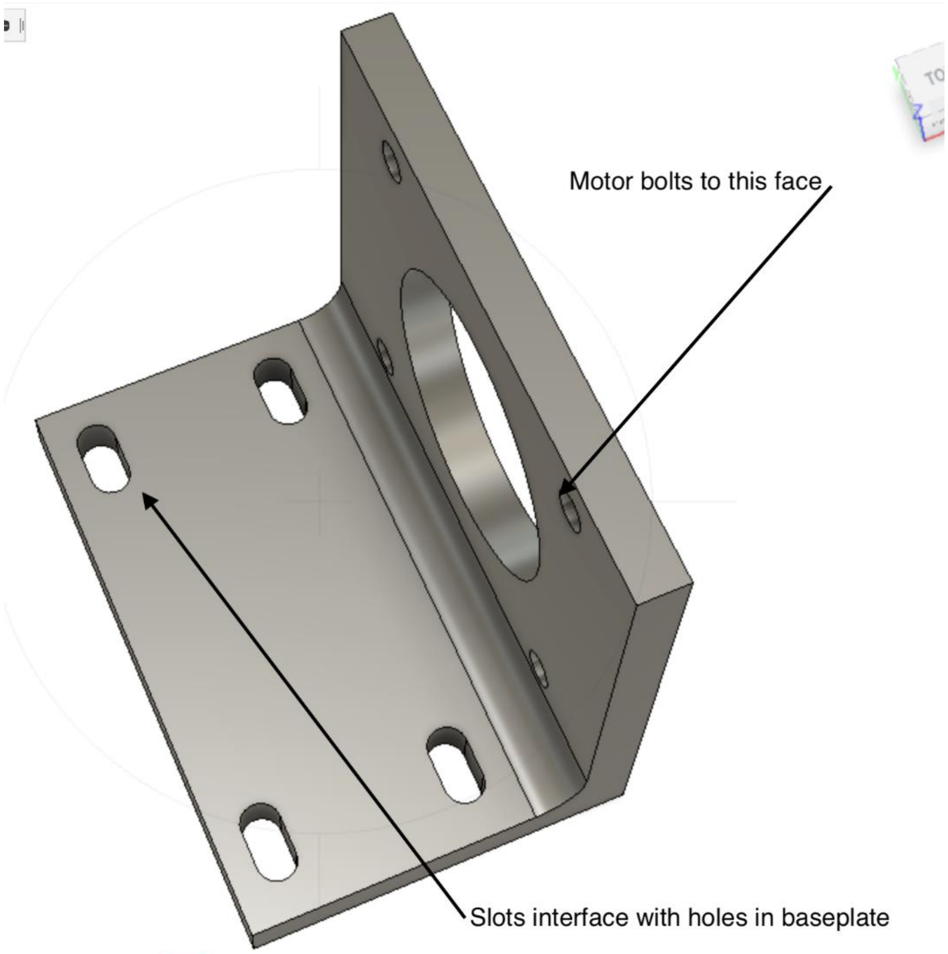


Figure 9: L-bracket mounts motor to base plate

The selected shaft is a ½” diameter shaft designed for mounting components via set screw. It will be supported against radial loads by both the spider coupling, as well as a set screw mounted bearing. The bearing will also provide resistance to the small axial loads that may be experienced by the shaft due to marginal misalignment. This bearing will in turn be fastened to the system baseplate on top of a small riser to position it at the correct height. The mounting holes of the prefabricated bearing will be slot features to allow for adjustability of the driving pinion position relative to its mating gear, similar to the motor mount. Finally, a small 16 pitch, 16 tooth, 1-inch diametral pitch pinion will be press fit onto the shaft to mesh with and drive the 16 pitch, 64 tooth, 4-inch diametral pitch gears as seen in Figure 8. This will provide a gear ratio of 1:4 between the gear and the pinion; in other words, for each full 360° rotation of the pinion, the meshing gears will rotate ¼ of that or 90°. This serves to keep the required motor output torque well below the capabilities of the MCPV by amplifying the motor torque by this ratio when transmitting torque to the shaft, wheel, gears subassembly. This provides the additional benefit of scaling the positioning resolution of the MCPV encoder by a factor of four, per Equation (1) below. This will provide an angular positioning precision of 0.1125° with 0.0075° repeatability.

$$\theta_{res} = \frac{360°\,[pinion]}{800ticks[motor]} * \frac{90°[gear]}{360°[pinion]} \quad (1)$$

The system positioning precision will also be affected by the meshing of the pinion with the gears, and the meshing of the gears with each other. However, proper alignment of these components will produce more than adequate positioning to maintain proper alignment of the product being assembled.

2.2 Cost Breakdown

We will be buying materials and prefabricated parts from multiple suppliers in order to build our prototype. The main supplier we will be ordering from will be McMaster-Carr, as well as Teknic, Kaman Industrial Technologies, and Amazon. The cost breakdown is provided in detail in the Bill of Materials document present in Appendix C and the cost for the entire project can be seen in Appendix A. This document has all the useful information regarding part description and pricing, including links to the supplier's website and item number. The cost will be broken down by subassembly.

First, we have the Base and Frame subassembly. This subassembly consists of a stainless-steel plate, stainless steel square tube, and 2 bronze bushings. These parts and raw materials will be purchased from McMaster-Carr for a total cost of $379.96.

The next subassembly is the Shaft-Wheel-Gear subassembly. This subassembly consists of a stainless-steel tube, stainless steel round stock, stainless steel gears, and food safe washdown bearings. The raw materials will be purchased from McMaster-Carr, while the gears will be purchased from Kaman Industrial Technologies for a total cost of $1492.50.

The Vacuum System subassembly is the next subsystem. It consists of a stainless-steel square tube, a dust collection fan, and prefabricated gaskets. The raw material and gaskets will be purchased from McMaster-Carr while the dust collection fan will be purchased from Harbor Freight, for a total cost of $432.06.

The Motor and Drive Assembly subsystem is one of the more expensive subassemblies. It consists of the servo motor, power supply, motor mount, pinion gear, spider collar, and bearing. The servo motor and power supply will be purchased from Teknic, while the other components are purchased from McMaster-Carr for a total cost of $962.31.

In total, once we combine all the subassemblies and include hardware and any other parts required for the overall system assembly, we come to the total cost of the assembly. The total material cost for the prototype is $3,207.27. The cost breakdown by subassembly can be seen visually represented in a diagram on Figure 8 below. Paying a CNC operator to manufacture the wheels is expected to cost another $500.

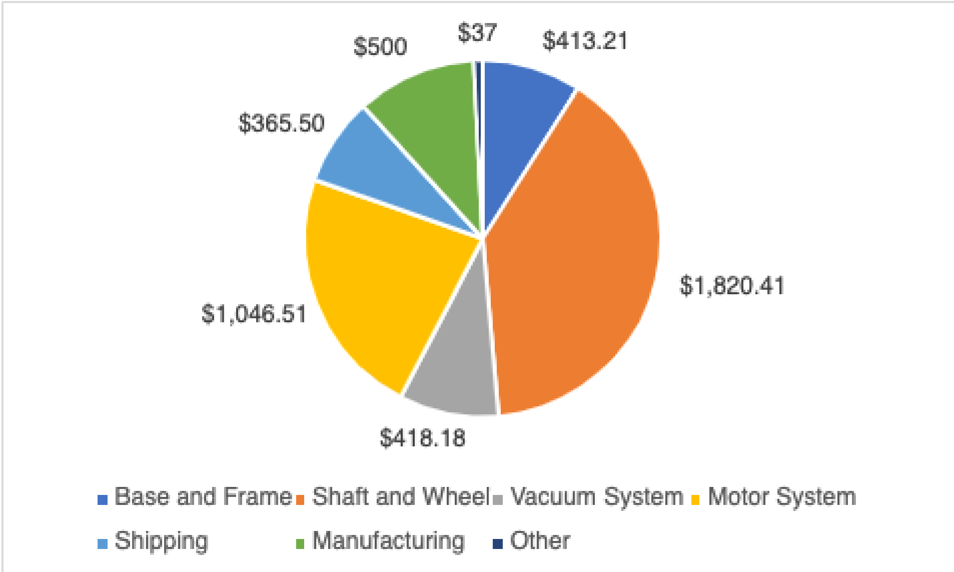


Figure 8: Diagram Showing the Cost Breakdown by Subassembly in US Dollars

3. Design Justification

This section will discuss calculations, FEA analysis, prototype testing, and interviews with food science professionals that were used to ensure this design will meet the required specifications.

3.1 Testing

A prototype was built using a plywood frame and 3D printed wheels and gears that will match the dimensions of the final design. This prototype was used to find the optimal spacing between the wheels and the optimum height of the wheels from the surface below them on which shells are fed in. It is important to note that this distance is set from the inside of the bottom of the "square tube riser" which holds the shafts. In this design, the material where the shells will slide in has been removed to allow a conveyer system of our sponsors choosing to be inserted under the wheels.

If the wheels are too low, the shell cannot fit into its cup. If the wheel is too high, suction is lost, and the shell is not pulled in. We found the optimal height of the wheel to be 0.1 inches from the surface the shell slides on to the largest outer diameter of the wheel. A photo of this prototype is seen below in Figure 9.

Figure 9: Fixed distance structural prototype

If the wheels are too close together, the shells crack when joined. If they are too far apart the shells are not pressed close enough together and a gap remains. The team found the optimal spacing between the wheels to be 0.1 inches between the largest outer diameter of each wheel.

This prototype was also used to test the vacuum system. We demonstrated that a loose-fitting pipe that sits over the ends of the hollow shaft is a simple but effective way to draw vacuum through the shafts. It was found that coupling the vacuum system to the shafts using infinitely rotating couplers such as those used on compressor hoses resulted in too much head loss and a loss of vacuum at the wheel holes. The team found that running two 5 HP shop vacuums in parallel generated enough suction to easily hold the shells in place on the wheels. Optimally, slightly more vacuum would result in the wheels drawing the shells off the feed-in system better, and we will be testing larger fans on the verification prototype.

3.2 Interview on Cleaning

We interviewed a Cal Poly dairy science professor Dr. Vincent Yeung to get more information on best practices for food safety when working with ice-cream. We learned that the only “food contact surface” in the system is the cups that hold the shells, and that these will need to be sanitized at the end of every shift. Any surface that contacts “food waste” (food that will not end up being eaten) will need to be cleaned at less regular intervals, maybe around once a week. This includes the inside of the vacuum shafts.

Dr. Yeung told us that, while parts could conceivably be cleaned in place, the best practice would be to put any part that needs to be cleaned in a sink. This is what inspired our design to have removeable shafts that can be placed in a sink and submerged. This is also what inspired every component on the shaft, including the bearings, to be completely wash-down safe. The end caps will need to be removed from the wheels and their insides cleaned, which is why the entire square tube cannot lift out as one unit for cleaning.

Every surface on the frame is safe for food contact up until the motor assembly, and every part can be wiped down with disinfectant.

Dr. Yeung made it clear that our sponsor will need to hire a professional food industry expert to develop a cleaning schedule for all the equipment in the assembly line. The specifics of how this machine is cleaned will be up to them, and we sought to design a system that will give our sponsor as many options as possible when it comes to cleaning.

3.3 Analysis

Mathematical analysis was used to verify that our gears will be strong enough to last for infinite fatigue life. A dynamic analysis on the wheels was performed to find our max theoretical acceleration and the amount of torque needed to reach this level of acceleration, which can be seen in detail in Appendix D. We performed a gear wear/contact stress and bending stress analysis using the calculated torque from the dynamic analysis, which can be seen in detail in Appendix E. Finally, fatigue, stress and deflection analyses will be performed on the shaft to ensure that they will not break or bend enough to impact use.

3.3.1 Dynamic Analysis

To quantify the dynamics governing the system motion, kinetic and kinematic analyses were conducted as seen in Appendix D. This involved establishing assumptions regarding the resolved vacuum force that will be transmitted to the product during operation. Based on this estimation, a simple kinematic analysis was conducted to approximate the maximum operating speed of the system. The result was a far higher operating speed than is necessary to achieve the throughput required of the system. With this contextual information, the system kinematics were characterized by breaking down the incremental motion of the device. One increment of motion was evaluated, assuming a constant step acceleration and equal/opposite step deceleration each occur over half the motion regime of one incremental movement. The motor operates based on acceleration ramp outputs; however, this analysis provides an adequate approximation. Further analysis was conducted for a minimum net rotational speed of 3.33RPM, as well as a maximum of 10RPM, with an assumed pause/filling period of 0.5 seconds per incremental movement. Integrating the acceleration required to produce 10 RPM net rotation speed over one incremental movement period yielded a maximum operating speed far below the estimated maximum evaluated for context. The resulting angular accelerations were used in a kinetic analysis of the system to evaluate the torque required to produce this acceleration. This resulted in a maximum torque of 86.4 oz-in, which is approximately 1/3 of the torque the MCPV motor can output at these low operating speeds, as seen in Figure 9.

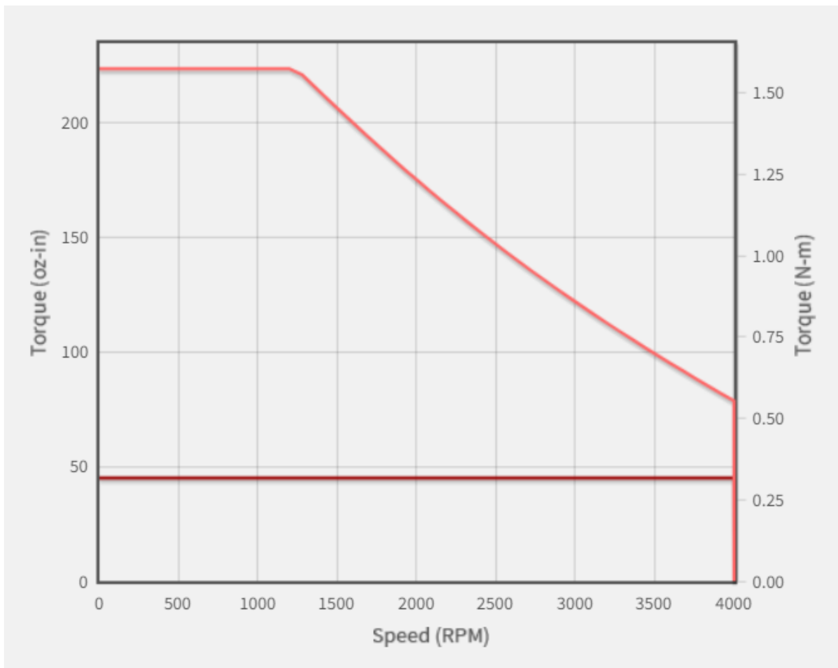


Figure 9: Torque-Speed Curve, Clearpath MCPV 2310S servo motor.

3.3.2 Gear Stress Analysis

Our gear stress analysis started with the 86.4 oz-in torque determined from the dynamic analysis. This is a low torque application since our motor choice can easily handle 2.5x the amount of torque that we need to actuate the system.

The stresses were calculated using the AGMA contact/wear stress equation and AGMA gear bending stress equations from Shigley's Mechanical Engineering Design textbook. In these calculations we conducted the analysis on the 1" pitch diameter pinion since it would be the weak link in the gear train. As for the values used in the calculation, we assumed a worst-case scenario which gave us an overestimation in our stress calculations giving us a calculated contact stress of 32,129 PSI. This is significantly less than yield strength of the 1020 steel the gear is made of, resulting in a factor of safety of 6.54. The in-depth calculations and reasoning behind the overestimations can be seen in Appendix E. Additionally, we calculated a bending stress of 1,487 PSI which is extremely low, demonstrating that the gear would not fail from bending stress. To confirm the accuracy of these calculations we ran a finite element analysis study in Fusion360, as seen in Figure 10, which supplied remarkably similar results for bending stress. This is further indication that our calculations for contact stress are also correct.

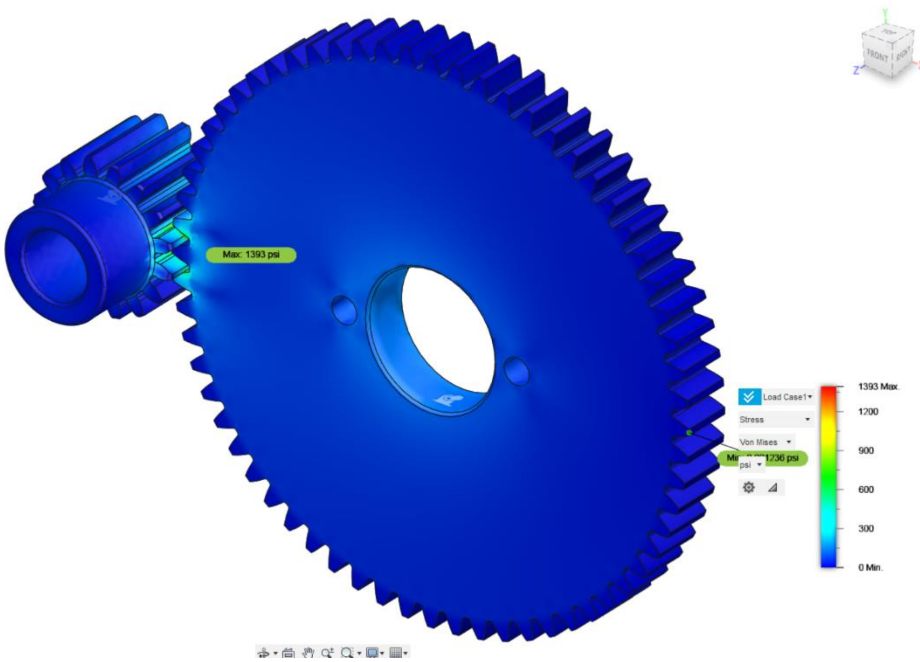


Figure 10: Fusion360 FEA study on gear and pinion assembly.

3.4 Safety and Reliability

Several potential failure points and associated failure modes were identified in this system. These are outlined in the Failure Modes and Effects Analysis (FMEA) in Appendix F. Most of these line items are planned to be addressed through inspection and testing of the final prototype. Stress and deformation analysis of the gears has been completed, as discussed in section 3.3.2. Shaft deflection and fatigue analysis is currently in progress and should be completed by 5/14/2022, but issues are not expected. If shaft fatigue is found to be a problem, it is a simple matter to use thicker walled shafts.

Additionally, a design hazard checklist contained in Appendix G outlines the functional hazards associated with this design. The primary danger associated with this machine is the pinch point created between the wheels. This has been addressed with a hinged finger guard which folds up when removing the shafts. The gears may be shrouded with a simple cage depending on how and where the machine is mounted. The electrical system will be wired to an emergency stop button within reach of an operator feeding or filling the machine. The vacuum system may be loud and require hearing protection for those in its vicinity for extended periods.

4. Manufacturing Plan

Manufacturing of the final design will begin during week eight of spring quarter and continue until the final design report at the end of fall quarter. A breakdown of the proposed manufacturing timeline can be seen on the Gantt chart in Appendix H. All requisite materials are listed on the bill of materials attached in Appendix C. Most materials will be ordered online by our sponsor from the websites provided and shipped to Cal Poly. Certain materials, such as select nuts and bolts and the vacuum system, will be purchased by the team at local hardware stores.

Most parts that need to be manufactured or modified will be produced by our team at Cal Poly's student machine shop. This includes the base plate, the square tube riser, the shafts, the gears, the motor mount, the motor shaft mount, the finger guard, and the vacuum tube. The Manufacturing Plan for each of these parts is shown in Appendix I. The machine will be assembled as four sub-assemblies, also discussed in the attached Manufacturing Plan. This project presents a large manufacturing challenge. However, one of our team members is employed at the machine shop, meaning we will be able to utilize these facilities outside of standard hours, speeding up this process. If manufacturing begins to overrun the current schedule, we will discuss with our sponsor the possibility of paying shop-technicians on campus to help machine parts.

Currently, the only parts that will be outsourced for manufacturing are the wheels. These will be partially machined by the team in the machine shops, and then Dakota Hollingsworth, a CNC certified shop technician, will be hired to machine the cups into the outside of the wheels. The part has been discussed with Mr. Hollingsworth and will cost an estimated $300-$500 in labor. Manufacturing this part will be our highest priority as we expect it to take the longest.

5. Design Verification Plan

Our PDR report outlined 12 engineering requirements for our final design. This section will outline how we plan to test the success of each requirement, or why we no longer feel that we need to or are able to. Table 2 below shows the specifications that will be tested, along with their specification number, requirements, tolerance, and risk. The description of the test being performed for each specification as well as the expected date of testing is described in the Design Verification Path and Report located in Appendix B. The measurements that will be taken are also shown here. The accepted criteria are stated so that there is a firm requirement to meet for the test to result in success. Any special parts needed to perform the test are noted.

Table 2: Engineering Specifications Being Tested

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
3	Visual Damage Check	Shell Unchipped	Min	M	T
4	Shell Alignment	Cannot See Inside Shell	Min	M	T
5	Machine Output	20/min	Min	H	T
8	Configurable Production Quantity or Variable Speed	Possible to Increase Capacity	Min	L	T

The first specification we will be testing is for visual damage to the shells. The size of chip that will be counted as damaged and the acceptable frequency is still being decided by our sponsor. Because an automated filling and feeding system does not yet exist, we will perform this test in two parts. First, we will visually inspect the shells before they are fed into the wheels for any imperfections that were already present so that we do not fault our machine. Then, we will perform a test in which empty shells with no ice-cream will be fed in by hand at the base of the wheel, rotated through, and inspected. The second test will load ice-cream filled shells in at the 8’Oclock position and join them. These shells will then be inspected for damage.

We will also conduct a visual test for shell alignment. The requirement for this specification is that the inside of the joined shell cannot be seen. To test for alignment, the shells filled with ice-cream will be loaded in from the side of the wheel. Then the wheels will be rotated through the joining cycle and inspected afterward to look for any gaps or misalignment. The quantity of unacceptable joined shells in a joining cycle will be measured.

The machine output specification requires that at least 20 joined beans per minute. To test this specification, the machine will run with the motor and without the shells for half an hour. The number of joined shells will be counted in that period and compared to the target speed. The quantity of “joined shells” will be counted to see if the goal of 20 joined shells per minute is met.

The next specification is the service life of the machine. This has been done analytically and is discussed in the “Design Justification” section.

The last specification that we need to test for is the configurability of production quantity or variable speed. The requirement for this specification is that the possibility exist to increase production capacity. To test for this, we will run the machine at different motor speeds to see if the shells are joined similar in quality to normal operating speeds. We can see if there are any new problems encountered from variable speeds. We can visually inspect the joined shells to ensure that damage and alignment aspects still meet the requirements as well as there being no issue with picking up or releasing shells. We can count the machine output quantity to ensure that it can vary its output depending on different speeds.

All these tests will require a working verification prototype, a power source, and either an ice-cream machine or a local source of soft serve.

The remaining specifications include air content, down time, and head count. We feel that these all depend heavily on elements outside of our scope and cannot be meaningfully tested with just our verification prototype. The air content will primarily be influenced by the filling method, which is outside of our scope. The time to disassemble the machine can be measured, but the time to clean the parts will depend on our sponsor's cleaning procedure which we will help inform. The head count for each machine will depend on the level of filling automation and the feed system our sponsor chooses.

6. Conclusions

Every part of our final design has drawings, required materials, and a manufacturing plan. While small changes will inevitably be made throughout the manufacturing process, the overarching design has been decided upon and validated. The only undefined part of the design is the vacuum system, which depends on testing that must be done with the final prototype. If this design is approved by our sponsor, we are prepared to order material and begin manufacturing. After this point, any changes will be run past our sponsor before they are made.

References

Budynas, Richard G, J K. Nisbett, and Joseph E. Shigley. Shigley's Mechanical Engineering Design. 11th ed., New York: McGraw-Hill, 2019. Print.

Gilman-Cohen, Adin, and Vincent Yeung. “Dairy Manufacturing Cleaning Protocol.” 14 Apr. 2022.

“ME Senior Design Project Student Success Guide.” Department of Mechanical Engineering, California Polytechnic State University, 2021.

Ullman, D., The Mechanical Design Process, McGraw-Hill, 1997

Appendices

Appendix A: Project Budget

Materials Budget for Senior Project

Title of Senior Project: W23 Novelty Ice Cream Product Assembly
Team members: Adin, Alvaro, Logan, Mason
Designated Team Treasurer Mason Sylvester
Faculty Advisor: Eileen Rossman
Sponsor: Keith Zachow
Quarter and year project be Winter 2022

Materials budget given for **$10,000.00**

Description	Vendor	Vendor's Part No.	Purchase Link	Design Part No.	Material Price	Estimated Tax	Estimated Shipping	Purchase Method	Purchase Date
Base and Frame:				11100					
Assembly baseplate	McMaster-Carr	8983K361	8983K361	11110	$ 97.02	$ 8.49	$ 20.00	Sponsor	5/17/2022
Riser Tubing	McMaster-Carr	89825K481	89825K48	11120	$ 244.43	$ 21.39	$ 50.00	Sponsor	5/17/2022
Bronze Bushing	McMaster-Carr	7095K48	7095K48	11130	$ 20.82	$ 1.82	$ 4.00	Sponsor	5/17/2022
Locating Pins	McMaster-Carr	89535K15	89535K15	11140	$ 5.85	$ 0.51	$ 2.00	Sponsor	5/17/2022
Nuts	McMaster-Carr	90389A218	90389A218	11150	$ 11.84	$ 1.04	$ 2.00	Sponsor	5/17/2022
Shaft-Wheels-Gear:				11200					
Shaft Tubing	McMaster-Carr	89495K64	89495K64	11210	$ 74.38	$ 6.51	$ 5.00	Sponsor	5/17/2022
Vacuum Wheels	McMaster-Carr	89535K83	89535K83	11220	$ 549.10	$ 48.05	$ 200.00	Sponsor	5/17/2022
Bearings	McMaster-Carr	7363N27	7363N27	11230	$ 504.10	$ 44.11	$ 20.00	Sponsor	5/17/2022
Rubber Plugs	McMaster-Carr	9545K118	9545K118	11240	$ 5.90	$ 0.52	$ 5.00	Sponsor	5/17/2022
Wheel Cap	McMaster-Carr	9208K12	9208K12	11250	$ 44.16	$ 3.86	$ 5.00	Sponsor	5/17/2022
Set Screw	McMaster-Carr	92785A433	92785A433	11260	$ 6.40	$ 0.56	$ 0.50	Sponsor	5/17/2022
Gears	McMaster-Carr	F16S20-64	F16S20-64	11270	$ 401.48	$ 35.13		Sponsor	5/17/2022
Bolts - Shaft Collars	McMaster-Carr	92196A542	92196A542	11280	$ 30.52	$ 2.67	$ 2.00	Sponsor	5/17/2022
Shaft Collars	McMaster-Carr	5631T16	5631T16	11290	$ 57.90	$ 5.07	$ 3.00	Sponsor	5/17/2022
Vacuum System:				11300					
Dust Collector Fan	Harbor Freight	97869	9786997869	11310	$ 249.99	$ 21.87		Reimbursem	5/17/2022
Square Tubing	McMaster-Carr	2937K17	2937K17	11320	$ 42.69	$ 3.74	$ 30.00	Sponsor	5/17/2022
Vacuum Tube Caps	McMaster-Carr	88885K74	88885K74	11330	$ 26.55	$ 2.32	$ 2.00	Sponsor	5/17/2022
Gasket	McMaster-Carr	5025T172	5025T172	11340	$ 40.24	$ 3.52	$ 2.00	Sponsor	5/17/2022
L-brackets	McMaster-Carr	1556A65	1556A65	11350	$ 5.18	$ 0.45	$ 3.00	Sponsor	5/17/2022
Bolts - 10-32 UNF	McMaster-Carr	92196A267	92196A267	11360	$ 14.53	$ 1.27	$ 2.00	Sponsor	5/17/2022
Bolts - 10-32 x 3/8	McMaster-Carr	91841A195	91841A195	11370	$ 5.35	$ 0.47	$ 2.00	Sponsor	5/17/2022
Finger Guard				11380					
U Channel	McMaster-Carr	1262T392	1262T392	11381	$ 22.00	$ 1.93	$ 5.00	Sponsor	5/17/2022
Corner Machine Bracket	McMaster-Carr	2313N14	2313N14	11382	$ 13.78	$ 1.21	$ 3.00	Sponsor	5/17/2022
Surface-mount Hinges	McMaster-Carr	1586A24	1586A24	11383	$ 12.74	$ 1.11	$ 3.00	Sponsor	5/17/2022
Hardware:				11400					
Bolts- Frame Mounting	McMaster-Carr	92240A301	92240A301	11410	$ 5.98	$ 0.52	$ 2.00	Sponsor	5/17/2022
Drive/Timing System:				11500					
Emergency Stop Switch	McMaster-Carr	7480T12	7480T12	11510	$ 30.18	$ 2.64	$ 5.00	Sponsor	5/17/2022
Clearpath NEMA 3.4 Servo	Teknic	CPM-MCPV-2310D-RLN	CPM-MCPV-2310	11520	$ 344.00	$ 30.10	$ 20.00	Sponsor	5/17/2022
IPC-5 Power Supply	Teknic	IPC-5	IPC-5IPC-5IPC-5	11530	$ 248.00	$ 21.70	$ 10.00	Sponsor	5/17/2022
Motor Mount	McMaster-Carr	8993K72-8993K729	8993K72-8993K7	11540	$ 26.52	$ 2.32	$ 5.00	Sponsor	5/17/2022
IPC35-CABLE110	Teknic	IPC35-CABLE110	IPC35-CABLE110	11550	$ 14.00	$ 1.23	$ 2.00	Sponsor	5/17/2022
User Interface:				11560					
Display	ELECROW	8595698868	8595698868	11561	$ 56.99	$ 4.99	$ 5.00	Reimbursem	5/17/2022
Level Shifter	Amazon	8541740602	8541740602	11562	$ 7.49	$ 0.66	$ 3.00	Reimbursem	5/17/2022
Raspberry Pi	Charlie Refvem			11563	$ -	$ -			
Rpi Power Supply	CanaKit	DCAR-RSP-PI	DCAR-RSP-PI	11564	$ 22.94	$ 2.01	$ 2.00	Reimbursem	5/17/2022
Motor Shaft Coupling:				11570					
Spider Collar 3/8" ID	McMaster-Carr	2401K15-2401K153	2401K15-2401K1	11571	$ 35.75	$ 3.13	$ 5.00	Sponsor	5/17/2022
Spider Collar 1/2" ID	McMaster-Carr	2401K15-2401K154	2401K15-2401K1	11572	$ 35.75	$ 3.13	$ 5.00	Sponsor	5/17/2022
Spider Hub	McMaster-Carr	2401K84	2401K84	11573	$ 13.67	$ 1.20	$ 2.00	Sponsor	5/17/2022
Pinion Subassembly:				11590					
Pinion	McMaster-Carr	5172T21	5172T21	11591	$ 27.57	$ 2.41	$ 6.00	Sponsor	5/17/2022
Pinion Bearing	McMaster-Carr	5913K61	5913K61	11592	$ 10.95	$ 0.96	$ 3.00	Sponsor	5/17/2022
Bolts - 10-32 UNF	McMaster-Carr	92196a272	92196a272	11593	$ 19.56	$ 1.71	$ 2.00	Sponsor	5/17/2022
Pinion Shaft	McMaster-Carr	8632T134	8632T134	11594	$ 7.81	$ 0.68	$ 6.00	Sponsor	5/17/2022
Pinion Bearing Riser	McMaster-Carr	8992K132-8992K434	8992K132-8992K	11595	$ 25.32	$ 2.22	$ 3.00	Sponsor	5/17/2022
Bolts - Bearing Mount	McMaster-Carr	92196A544	92196A544	11596	$ 17.51	$ 1.53	$ 2.00	Sponsor	5/17/2022
Nuts - 10-32 UNF	McMaster-Carr	96537A160	96537A160	11597	$ 8.29	$ 0.73	$ 2.00	Sponsor	5/17/2022
Washers - 1/4-20	McMaster-Carr	90107A029	90107A029	11598	$ 10.01	$ 0.88	$ 2.00	Sponsor	5/17/2022
Manufacturing Tools:									
Drill Bit	McMaster-Carr	29315A164	29315A164		$ 33.93	$ 2.97	$ 3.00	Sponsor	5/17/2022
							$ 465.50		

Total expenses: $ 4,725.47

Budget	$ 10,000.00
Materials Cost	$ 4,725.47
Manufacturing Cost	$ 500.00
Total Cost	$ 5,225.47
remaining balance:	$ 4,774.53

Appendix B: Design Verification Plan and Report

DVP&R - Design Verification Plan (& Report)

Project: W23 Novelty Ice Cream Product Assembly | Sponsor: Keith Zachow

TEST PLAN

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipm	Parts Needed	Responsibility	TIMI Start date
1	3	Shells will be fed in by hand at the base of the wheel and fed through without icecream. The shells will be inspected before and after for chips and cracks.	The frequency of shells damaged beyond an accpetable point for sale	Awaiting Sponser Decision	N/A	Prototype (With focus on wheels)	Adin	9/27/2022
2	3	Shells filled with ice-cream will be loaded in at the side of the wheel and roated through joining. The joined assembly will be inspected for chips and cracks.	The frequency of shells damaged beyond an accpetable point for sale	Awaiting Sponser Decision	Ice-cream machine or source of soft serve.	Prototype (With focus on wheels)	Alvaro	9/27/2022
3	4	Shells filled with ice-cream will be loaded in at the side of the wheel and roated through joining. The joined shells will be inspected for chips and cracks.	The alignment of the joined shells will be inspected. The frequnecy of unnaceptable joining will be measured.	Can not see inside of shells. Acceptable frequency awaitng sponser decision	Ice-cream machine or source of soft serve.	Prototype (With focus on wheels)	Logan	9/27/2022
4	5	The machine will be run with the motor and wihtout shells for half an hour. The number of "shells joined" will be counted and compared to the target speed.	The quantity of beans that would be joined if fully running.	20 joined beans per minute.	Power source to power the motor	Prototype with motor assembly and power source.	Mason	10/20/2022
5	7	Perform dynamic calculations in order to calculate torque required by the motor to contribute to service life calculations.	Perform a conservative calculation that gives a measurement of torque in in-lbs.	A torque value lower than the maximum torque output by the motor.	N/A	Motor specifications sheet provided from motor manufacturer.	Logan	5/5/2022
6	7	Perform dynamic calculations in order to calculate stresses on gears to contribute to service life calculations.	Perform a conservative calculation that gives a measurement of stress in psi.	A stress value low enough to allow for a safety factor of 3.	N/A	Gear specifications sheet provided from gear manufacturer along with known load values	Mason	5/5/2022
7	8	Run the machine at different motor speeds in order to see if the shells are joined similar to normal operating speeds or if there are any new problems encountered from variable speeds.	Visually inspect to ensure that damage and alignment still meet requirements as well as no problems with picking up or releasing of shells. Count machine output to ensure that it can vary	Count the machine output of acceptable quality joined beans to see if capacity is able to be incresed.	N/A	Fully functioning protoype	Aidan	10/20/2022

Appendix C: Bill of Materials

CoolBeans Automated Assembler

Indented Bill of Material (iBOM)

Assy Level	Part Number	Descriptive Part Name Lvl0	Lvl1	Lvl2	Lvl3	Lvl4	Qty	Part Cost	Total Cost	Source	URL	More Info
0	10000	**Final Assy**										
1	11000		**Top Assembly**									
2	11100			**Base and Frame**								
3	11110				Baseplate		1	$ 97.02	$ 97.02	McMaster	8983K361	12x12x1/4 inch
3	11120				Riser Tubing		1	$ 244.43	$ 244.43	McMaster	89825K48	4x4x1/4 inch
3	11130				Bronze Bushings		2	$ 10.41	$ 20.82	McMaster	7095K48	FDA approved food safe for incidental contact
3	11140				Locating Pins		1	$ 5.85	$ 5.85	McMaster	89535K15	1/2"x 1" Diameter
3	11150				Nuts		1	$ 11.84	$ 11.84	McMaster	90389A218	1/2-20 18-8 Stainless for locating pin
2	11200			**Shaft-Wheel-Gear Subassy**								
3	11210				Shaft Tubing		1	$ 74.38	$ 74.38	McMaster		2 ft section
3	11220				Vacuum Wheels		1	$ 367.66	$ 367.66	McMaster	89535K83	Round Stock, 1 ft section
3	11230				Bearings		2	$ 252.05	$ 504.10	McMaster	7363N27	Item 7363N27
3	11240				Rubber Plugs		1	$ 5.90	$ 5.90	McMaster	9545K118	Item 9545K118 without holes
3	11250				Vacuum Wheel Cap		2	$ 22.08	$ 44.16	McMaster	9208K12	2-1/2"ODx1/4"
3	11260				Set Screw		1	$ 6.40	$ 6.40	McMaster	92785A433	1/4" length, 1/4"-20 box of 25
3	11270				Gears		2	$ 200.74	$ 401.48	Kaman Industrial	F16S20-64	64 tooth 4" Pitch Dia., 16 Pitch, 3/8 Face wd., 303 Stainless
3	11280				Bolts - Shaft Collars		1	$ 30.52	$ 30.52	McMaster	92196A542	1/4"-20 Thread Size, 1" Long pack of 50
3	11290				Shaft Collars		2	$ 28.95	$ 57.90	McMaster	5631T16	Item 5631T16
2	11300			**Vacuum System**								
3	11310				Dust collector Fan		1	$ 249.00	$ 249.00	Harbor Freight	Harbor Freig	Pricing reflects maximum
3	11320				Square Tubing		1	$ 42.69	$ 42.69	McMaster	2937K17	Item 2937K17 - 1 foot section
3	11330				Vacuum Tube Caps		1	$ 26.55	$ 26.55	McMaster	88885K74	Item 88885K74
3	11340				Gasket		1	$ 40.24	$ 40.24	McMaster	5025T172	1'x1'x0.325" sheet, to be cut to form
3	11350				L-brackets		2	$ 2.59	$ 5.18	McMaster	1556A65	11/16" x 1" x 1/2" stainless, holes to be drilled out, for mounting vacuum tube
3	11360				10-32 UNF Bolts		1	$ 14.53	$ 14.53	McMaster	92196A267	Pack of 100
3	11370				10-32x3/8 Nuts		1	$ 5.35	$ 5.35	McMaster	91841A195	Pack of 100
3	11380				**Finger Guard**							
4	11381					Stainless Steel U Channel	1	$ 22.00	$ 22.00	McMaster	1262T392	6 inches
4	11382					Corner Machine Bracket	1	$ 13.78	$ 13.78	McMaster	2313N14	To hold finger guard
4	11383					Surface-Mount Hinges	1	$ 12.74	$ 12.74	McMaster	1586A24	
2	11400			**Hardware**								
3	11410				Bolts - Frame Mounting		1	$ 9.38	$ 9.38	McMaster	97646A252	Item 97646A252 - 5/16"-18 x 1/2" full thread
2	11500			**Drive/Timing System**								
3	11510				Emergency Stop Switch		1	$ 30.18	$ 30.18	McMaster	7480T12	Item 7480T12
3	11520				Clearpath NEMA 3.4 Servo		1	$ 344.00	$ 344.00	Teknic	CPM-MCPV-:	0.375", sealed-shaft model. Configured in incremental positioning mode
3	11530				IPC-5 Power Supply		1	$ 248.00	$ 248.00	Teknic	IPC-5	MUST be a non-switching supply, 75VDC
3	11540				Motor Mount		1	$ 26.52	$ 26.52	McMaster	8993K72-89!	1/4" Wall Thickness, 3" High x 3" Wide Outside
3	11550				IPC35-CABLE110		1	$ 14.00	$ 14.00	Teknic	IPC35	
3	11560				**User Interface**							
4	11561					Display	1	$ 56.99	$ 56.99	ELECROW	ELECROW ca	Comes with HDMI and power
4	11562					Level Shifter	1	$ 7.49	$ 7.49	Amazon	8541740602	Multipack (15) need (1)
4	11563					Raspberry Pi 2	1	$ -	$ -	Charlie Refvem		Already acquired
4	11564					RPi Power Supply	1	$ 22.94	$ 22.94	CanaKit	DCAR-RSP-PI	5.1V 2.5A
3	11570				**Motor Shaft Coupling**							
4	11571					3/8" ID Spider Collar	1	$ 35.75	$ 35.75	McMaster	2401K15-24(	Compression coupling collar, 0.25" ID
4	11572					1/2" ID Spider Collar	1	$ 35.75	$ 35.75	McMaster	2401K15-24(	Compression coupling collar, 0.5" ID
4	11573					Spider Hub	1	$ 13.67	$ 13.67	McMaster	2401K84	1° misalignment compensation, damping
3	11590				**Pinion Subassy**							
4	11591					Pinion	1	$ 27.57	$ 27.57	McMaster	5172T21	16 Pitch, 1" Pitch Dia, 16 teeth
4	11592					Pinion Bearing	1	$ 10.95	$ 10.95	McMaster	5913K61	Set screw to shaft
4	11593					10-32 UNF Bolts	1	$ 19.56	$ 19.56	McMaster	92196a272	10-32x3/4" Multipack (100) need (8)
4	11594					Pinion Shaft	1	$ 7.81	$ 7.81	McMaster	8632T134	1/2" Dia with set screw flat
4	11595					Pinion Bearing Riser	1	$ 25.32	$ 25.32	McMaster	8992K132-8!	3/4"x1" stock, 1/2ft section
4	11596					Bearing Mount Bolts	1	$ 17.51	$ 17.51	McMaster	92196A544	Multipack (25) need (2)
4	11597					10-32 UNF Nuts	1	$ 8.29	$ 8.29	McMaster	96537A160	Multipack (100) need (4)
4	11598					1/4-20 Washers	1	$ 10.01	$ 10.01	McMaster	90107A029	Multipack (100) need (4)
	Total Items						**51**		**$3,207.27**			

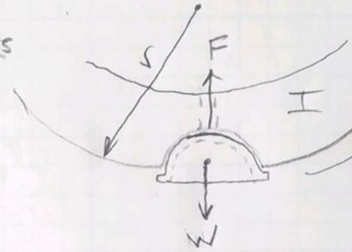
Appendix D: Dynamic Analysis Hand Calculations

ME 429-01	W23 - Cool Beans Motor Settings Analysis	Logan Williamson	1

Problem: We need to identify the maximum motor torque (and by extension, acceleration) that will not cause the CoolBeans empty shell halves to be thrown from the device during one rotational "step" of the operation.

Known parameters

$\rho_i = 0.54\,g/mL$
$V_i = 10\,mL$
$r = 0.0508\,m$
$m_c = 0.698\,g$



$I_w = 0.0103\,kgm^2$
$I_g = 0.0079\,kgm^2$

Assume: 1) Perfectly tuned vacuum such that the weight of a filled, assembled Bean barely overcomes the vacuum suction force at 30° from the joining location between the wheels.

2) Every step movement starts with zero initial conditions

3) The most likely shell position to lose suction is the bottom position.

4) All wheel positions experience equal suction/retaining force

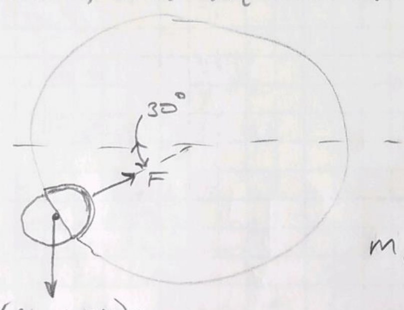
5) The density of CoolBeans ice cream is equal to the minimum standard density for high overrun ice cream, $\rho_i = 0.54\,g/mL$ (American Chemical Society)

6) Weight of product is negligible compared to weight of a wheel.

7) Negligible bearing/bushing friction

8) Moments of inertia of pinion, and shafts are negligible.

Analysis: We start by using the weight of a filled, assembled Bean to calculate the resolved suction force, F, on each occupied wheel position. Letting W be the weight of one cone half, and W_i the weight of filling, we get:



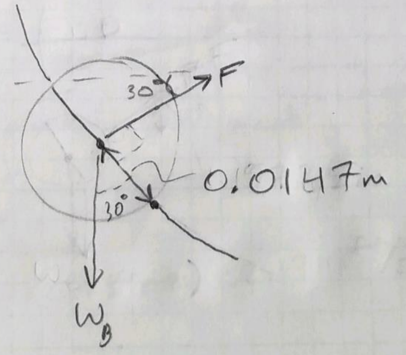
$$W_B = (2m_c + m_i)g$$

$$m_i = (\rho_i)(V_i)$$
$$= (0.54\,g/mL)(10\,mL)$$
$$m_i = 5.4\,g$$

Plugging in the known mass of one shell and known volume of filling in one bean, we get a resolved weight of W_B

$$W_B = [2m_c + m_i]g$$
$$= [2(0.698g) + 5.4g]\left(\frac{1kg}{1000g}\right)\left(9.81\frac{m}{s^2}\right)$$
$$W_B = 0.067\,N$$

Now, the component of suction force which resists the Bean falling can be found via free body diagram (FBD) and used to calculate the required maximum suction force, F.



If we assume that the only force keeping a filled Bean in its divot is the suction force the required suction force can be found by:

$$F\sin(30°) = W_B$$

$$F = \frac{0.067N}{\sin(30°)}$$

$$F = 0.134N$$

This result neglects any motion effects, and may need to be adjusted after further testing. However, if we assume this is an accurate working force on each Bean, we can use this to determine the maximum acceleration a Bean being picked up (at the bottom position) can withstand without being flung free of the wheel. The centripetal force acting on a shell cannot exceed the vacuum force minus the weight of the shell, or

$$F_{c,max} = (0.134N) - (0.0068N) = 0.127N$$

Solving for the corresponding centripetal force on a shell yields:

$$F_{c,max} = \frac{m_c V^2}{r}$$

$$0.127N = \frac{(6.98 \times 10^{-4} kg)(V^2)}{0.0508m}$$

$$V = 3.04 m/s$$

This is the maximum linear velocity of a shell such that the centripetal force acting on it wont overcome the suction force of the vacuum. Converting this to angular speed, we get

$$V = \omega_{max} r$$

$$3.04 m/s = \omega_{max}(0.0508m)$$

$$\omega_{max} = 59.9 \text{ rad/s}$$

This is the maximum constant speed that the wheels can turn without ejecting shells.

4

Due to the nature of this device, constant speed operation is not practical. However, this ω_{max} indicates that under ideal, constant conditions, the risk of ejecting shells is very low at the desired operating speeds. Now to account for the periodic motion our application requires, we will do a proper dynamic analysis and examine the forces on the shell due to acceleration of the device.

To begin, we desire to offer a range of net operating speeds from 3.3 RPM to 10 RPM. If we assume it takes 0.5 seconds for each shell to be filled, there will be 3 seconds of filling time in which the wheels are not rotating per revolution. To achieve 3.33 RPM, there will be

$$\left(\frac{3\,sec}{rev}\right)\left(\frac{3.33\,rev}{min}\right) \approx 10\,s/min$$

of filling time per minute of operation. For 10 RPM, there will be 30 seconds of fill time per minute of operation. The acceleration will therefore have to be greater during the movement phase of the cycle to account for the increasing proportion of operating time devoted to filling.

For the 3.33 minimum RPM case, this leaves us with 50 seconds to accelerate and decelerate the wheel motion the required number of times to produce 3.33 revolutions, or 20 'steps' from position-to-position. In other words, for one given increment of the wheel position, the wheel must be actuated 60° in 1/20 of 50 seconds, or 60°/2.5 seconds, or 0.4189 radians/s

For the 10 RPM maximum case we will have 30 seconds to accelerate and decelerate the wheel through 60 'steps'. In other words, the one incremental motion must be carried out by actuating 60° in 1/60 of 30 seconds, or 2.094 rad/s

5

We need to determine the acceleration required to perform half of one increment, since acceleration will become negative halfway through the cycle (equal/opposite)

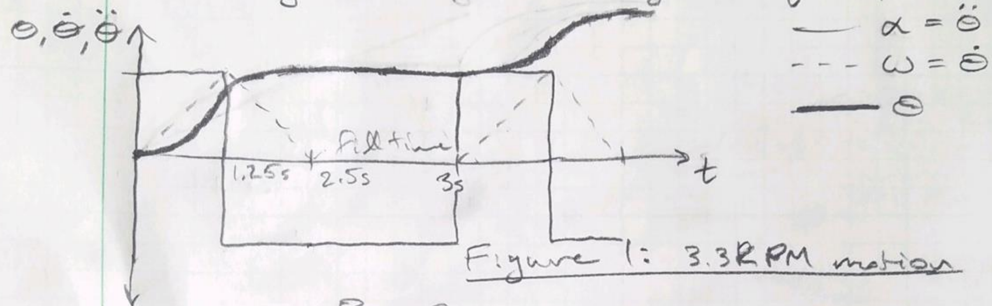


Figure 1: 3.3RPM motion

$$\theta = \theta_0 + \omega_0 t + \tfrac{1}{2}\alpha t^2$$

$$30^\circ = \tfrac{1}{2}\alpha(1.25s)^2$$

$$\boxed{\alpha = 0.67\ rad/s^2}$$

$$\omega = \omega_0 + \alpha t^2$$

For the 10 RPM case, we make a similar timing diagram using the single step motion constraints for this case

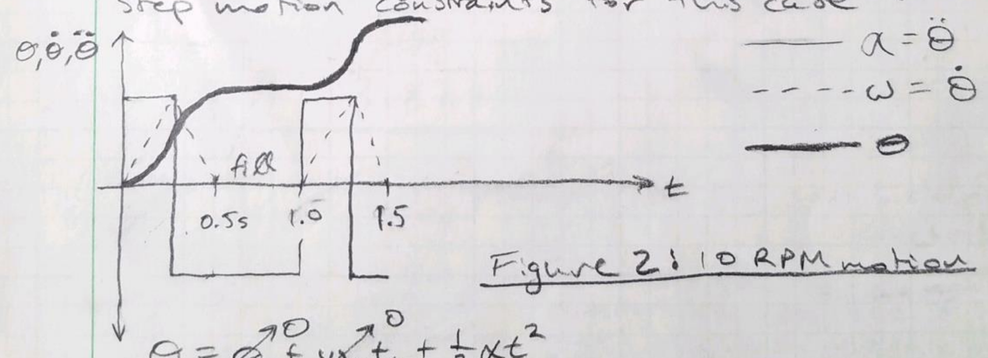


Figure 2: 10 RPM motion

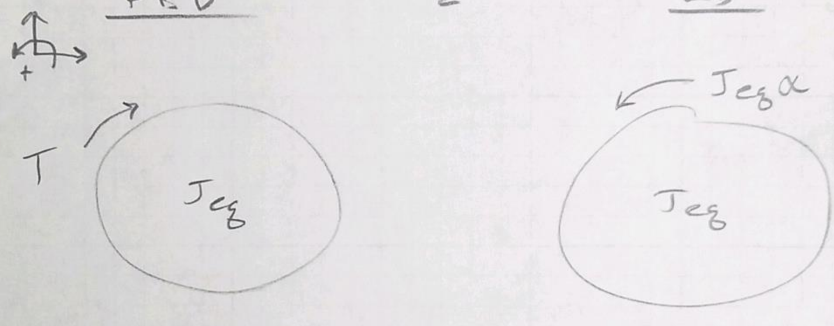
$$\theta = \theta_0 + \omega_0 t + \tfrac{1}{2}\alpha t^2$$

$$30^\circ = \tfrac{1}{2}\alpha(0.25s)^2$$

$$\boxed{\alpha = 16.76\ rad/s^2}$$

Using the maximum angular acceleration of $\alpha = 16.76 \, rad/s^2$, we can now calculate
(i) Maximum torque
(ii) Maximum linear shell speed

(i) To calculate maximum torque, we must solve for the torque required to accelerate the two wheel-shaft-gear subassemblies to the maximum angular velocity required for 10RPM net running speed.



$$T = 2\left[(0.0103 + 0.0079)\, kgm^2\right](16.76\, rad/s^2)$$

$$\boxed{\begin{aligned} T &= 0.610 \text{ Nm} \\ T &= 86.4 \text{ oz-in} \end{aligned}}$$

This torque is well within the capabilities of our motor

Next, we must evaluate the maximum speed at 10RPM operation to see if this will exceed our vacuum retaining force on a single shell.

$$\omega = \int_0^{0.5s} (16.67\, rad/s)\, dt$$

$$= 16.67t \Big|_0^{0.5}$$

$$\omega = 8.335\, rad/s$$

$$V = r\omega = (0.0508\, m)(8.335\, rad/s)$$

$$\boxed{V = 0.423\, m/s}$$ ✓

Appendix E: Gear Stress Hand Calculations

ME 429 | | Mason Sylvester | ①

GEAR STRESS ANALYSIS

Using LOGAN's Calculated Torque of 86.4 oz-in for the wheels turning at 10 RPM.

The Pinion will be the Limiting gear so anaysis will only need to be Performed on it.

KNOWN PROPERTIES:

$T = 86.4$ oz-in

$n_{wheel} = 10$ RPM

$d_p = 1$ in

$\phi = 20°$

$P = 16$ TEETH/IN

ANALYSIS:

FIRST ANALYSIS WILL BE THE AGMA CONTACT STRESS / WEAR EQUATION WITCH IS:

$$\sigma_c = C_p \sqrt{W_t K_o K_v K_s \frac{K_m}{d_p F} \frac{C_f}{I}}$$

WHERE

C_p - ELASTIC COEFFICIENT

W_t - TRANSMITTED LOAD

K_o - OVERLOAD FACTOR

K_v - DYNAMIC FACTOR

K_s - SIZE FACTOR

K_m - LOAD DISTRIBUTION FACTOR

d_p - PINION PITCH DIAMETER

F - PINION FACE WIDTH

C_f - SURFACE CONDITION FACTOR

I - GEOMETRY FACTOR

FIND VALUES from Tables & GRAPHS:

C_p for 1020 CARBON STEEL FROM SHIGLEY'S TABLE 14-8

$$C_p = 2300$$

W_t is CALCULATED USING SHIGLEY'S FIGURE 13-29 B

$$\omega_t = 2T / d_p$$

$$\omega_t = \frac{2\,(86.4\ oz\text{-}in)\left(\frac{1\ lbf}{16\ oz}\right)}{1\ in}$$

$$\omega_t = 10.8\ Lbf$$

K_o IS DETERMINED BY USING FIGURE 14-17 FROM SHIGLEY'S

ASSUMING WORST CASE SCENARIO WHERE THERE IS MODERATE SHOCK.

$$K_o = 1.5$$

K_v IS DETERMINED BY USING FIGURE 14-9 FROM SHIGLEY'S USING THE FOLLOWING PARAMETERS:

$V = \pi d_p n_p / 12$ AGMA QUALITY = 9

$V = \pi (1 in)(10 RPM)\left(\frac{4}{1}\right) / 12$

$V = 10.5$ ft/min

$$K_v = 1.0$$

K_s IS DETERMINED USING SHIGLEYS EQUATION 14-29

$$K_s = 1.192 \left(\frac{F\sqrt{Y}}{P}\right)^{0.0535}$$

$$K_s = 1.192 \left(\frac{0.75\ in\ \sqrt{0.296}}{16}\right)^{0.0535}$$

$$K_s = 0.980$$

WHERE Y IS LEWIS FORM FACTOR FROM SHIGLEYS TABLE 14-2

K_m IS CALCULATED USING SHIGLEYS EQUATION 14-30

$$K_m = 1 + C_{mc}(C_{pf}C_{pm} + C_{ma}C_e)$$

WHERE $C_{mc} = 1$ FOR UNCROWNED TEETH

$C_{PF} = 0.047$ FOR A FACE WIDTH OF 1IN.

$C_{PM} = 1$ FOR STRADDLE MOUNTED

$C_{MA} = 0.1388$ FOR COMMERCIAL GEARING

$C_e = 1$ FOR FACTORY FINISH

$K_m = 1.186$

C_F IS EQUAL TO 1 SINCE THE GEARS WILL BE NEW AND OF FACTORY FINISH.

I IS CALCULATED USING SHIGLEYS EQUATION 14-23

$$I = \frac{\cos\phi \sin\phi}{2m_n} + \frac{m_G}{m_G+1}$$

WHERE $m_n = 1$ FOR SPUR GEARS

AND $m_G = 4$ FOR THE SPEED RATIO

$I = 0.129$

FROM ALL OF THESE VALUES THE CONTACT STRESS CAN BE CALCULATED

$$\sigma_c = 2300\sqrt{(10.8\,LBF)(1.5)(1.0)(0.980)\frac{1.186}{(1in)(0.75in)}\frac{1}{0.129}}$$

$$\boxed{\sigma_c = 32129\ PSI}$$

THIS IS VERY LOW STRESS SINCE FROM SHIGLEY'S TABLE A-20 THE YIELD STRENGTH FOR 1020 STEEL IS 210,000 PSI WHICH GIVES A FACTOR OF SAFETY OF:

$$FOS = \frac{210{,}000\ PSI}{32{,}129\ PSI} = 6.54$$

A GEAR WILL ALMOST ALWAYS FAIL FROM CONTACT STRESS BUT THE BENDING STRESS CAN ALSO BE CALCULATED USING THE AGMA BENDING STRESS EQUATION:

$$\sigma_b = W_t K_o K_v K_s \frac{P}{F} \frac{K_m K_B}{J}$$

WHERE W_t, K_o, K_v, K_s, F, and K_m ARE THE SAME AS BEFORE

AND
- P - DIAMETRIAL PITCH
- K_B - RIM THICKNESS FACTOR
- J - BENDING STRENGTH GEOMETRY FACTOR

K_B IS CALCULATED USING SHIGLEY'S FIGURE 14-16

$$K_B = 1$$

J IS CALCULATED USING SHIGLEY'S FIGURE 14-6

$$J = 0.27$$

NOW THE BENDING STRESS CAN BE CALCULATED

$$\sigma_b = (10.8\ lbf)(1.5)(1.0)(0.980) \frac{16}{0.75in} \frac{(1.186)(1)}{0.27}$$

$$\boxed{\sigma_b = 1487\ PSI}$$

FROM THIS WE SEE $\sigma_c \ggg \sigma_b$ SO THE PINION IS MUCH MORE LIKELY TO FAIL FROM CONTACT STRESS THAN BENDING STRESS.

Appendix F: Failure Mode & Effects Analysis

Design Failure Mode and Effects Analysis

Product: ____________________________ Prepared by: ________

Team: ____________________________ Date

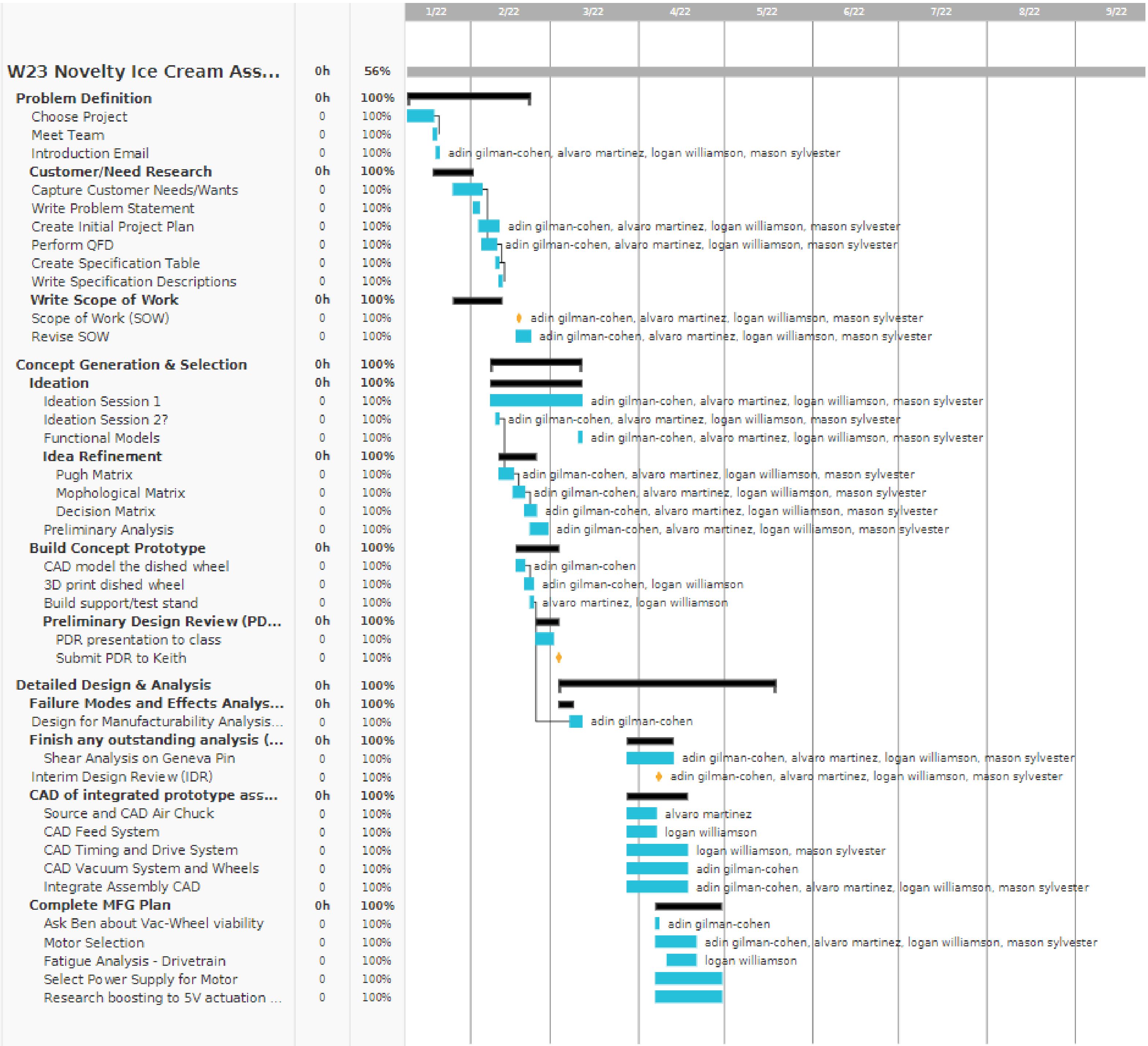
												Action Results				
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**RPN**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Detection**	**RPN**
Wheel Fasteners	Set screw breaks or deforms	Loss of wheel suction Wheel misalignment	8	Set screw backs out	None	1	Inspection	1	8	Installation with torque wrench	FDR					
Wheel End Seals (1 fixed one removable)	Too much vacuum leaks Is hard for user to remove Does not transmit torque	Shells fall out of cups Cleaning time increases Wheels do not rotate	8	Gasket or O ring breaks End seal isn't installed correctly	None	4	Inspection	2	64	Clamping pressure analysis of gasket (depends on design) Gasket selection	FDR					
wheel cups	Cups get dirty	Machine is not food safe Shells are damaged or fall out	9	Ice-cream melts and drips cup base is too thin	Making the holes in the shaft larger than the holes in the wheels to evacuate any debris that fall in	6	Inspection	3	162	Keeping a smooth surface finish so debris fall off the surface of the wheels	FDR					
wheel holes	Holes get filled with debris	Loss of suction on shells Not food safe	7	Shells break from too much pressure or prior damage holes are too small Cones come damaged from manufactuer	None	4	Inspection	3	84	Oversize shaft holes	FDR					
vaccum compressor	Compressor overheats	Loss of suction Fire	7	Line gets kinked or clogged Improper compressor used for desired requirements	None	2	Inspection	4	56	Research vacuum with saftey features Prevent clogging	FDR					
motor power supply	Power supply overheats	Electrical fire Power supply failure	9	Incorrect ventilation, placement Incorrect supplied power	None	1	None	4	36	Proper placement specifications None,addressed by plug type	FDR					
motor	Motor overheats (stall)	Burns up the motor	9	Gears or wheels get stuck and can't turn Motor is incapable of required speeds and power	None	4	None	3	108	Motor system analysis with load Add electrical saftey system Endurance Testing	FDR					
Wheel Axles	Deform too much Yield Get clogged	Wheel alignment changes and shells don't join Shells fall out/not food safe	6	Wheels are too heavy for shaft Wrong material used Whirl effects from non-symmetry	None	5	None	3	90	Deformation Analysis Stress Analysis Fatigue Analysis Testing	CDR					
bearings	Bearing seizes Bearing breaks from overloading	Shaft seizes Shaft drops/misaligns	7	Bearing isn't serviced Bearing is overloaded	Buying serviceable bearings	2	None	3	42	bearing analysis schedualed mainteneance	FDR					
Gears	Tooth Failure Too loud Get lubricant on food	Misalignment of wheels Operator hearing damage Lost product/customer injury	7	Incorrect gear analysis incorrect material improper lubrication delivery	None	3	None	3	63	gear stress/fatigue analysis	CDR					

Appendix G: Design Hazard Checklist

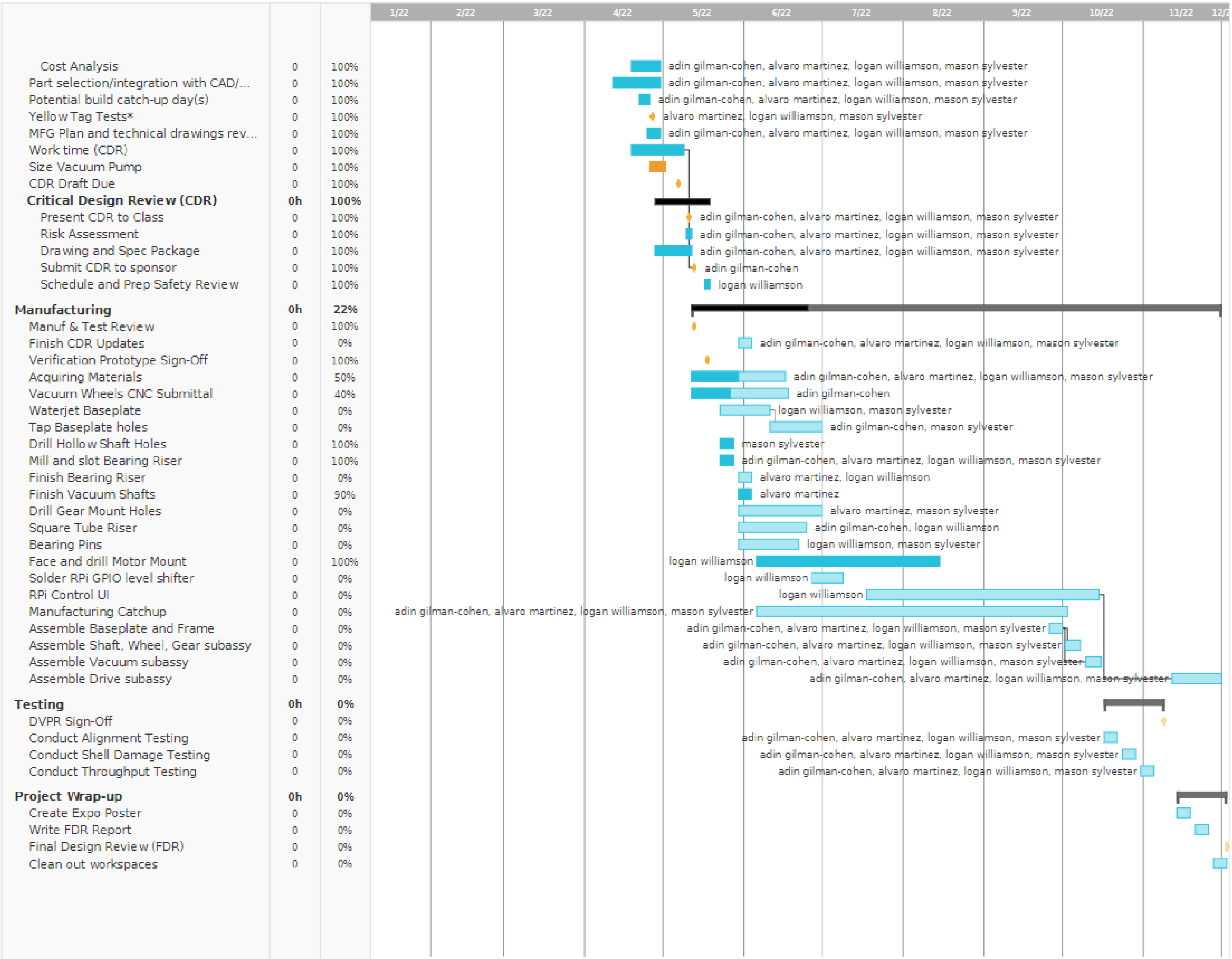
Y	N	
Y		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
	N	2. Can any part of the design undergo high accelerations/decelerations?
	N	3. Will the system have any large moving masses or large forces?
	N	4. Will the system produce a projectile?
	N	5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	N	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
Y		9. Will there be any large batteries or electrical voltage in the system above 40 V?
	N	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	N	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
Y		14. Can the system generate high levels of noise?
	N	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
Y		16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
This design will have a potential pinch-point between two rotating roller-type components.	The rotating components will be covered by a shroud or shielding to prevent accidental placement of limbs/fingers into the pinch point. Additionally, the torque and speed of the rotating components is relatively low. Operational procedures will include removal of any dangling or loose articles of clothing before interaction with the design.	10/1	
Vacuum system may be loud, could require hearing protection	Operating procedures will involve requirement of hearing protection PPE if deemed necessary	10/1	
There will be a potential shear point between the hopper or conveyor mechanism that feeds shells into our system, and our system itself.	Again, improper handling of the system near this location will be prevented with a simple piece of shielding to protect users	10/1	
There will be a 75V DC power supply supplying motor power.	This component is the recommended supply for this specified motor and includes many standard safety features. Specifications for mounting proximity and wiring routing to the device will be provided upon delivery of the device to ensure it does not interfere with the operator or moving assembly components.	10/18	

Appendix H: Gantt Chart



Gantt Chart (continued)



Appendix I: Manufacturing Plan

Subsystem	Component	Purchase (P) Modify (M) Build (B)	Raw Materials Needed to make/modify the part (only M & B)	Where/how procured?	Equipment and Operations anticipate using to make the component	Key limitations of this operation places on any parts made from it
Base and Frame	Baseplate	M	12"x 12"x .25" 304 Stainless Steel Sheet	McMaster-Carr Item 8983K361	Drill holes to accomodate the 5/16"-24x1/2"	N/A
	Riser Tubing	M	4" High x 4" Wide 0.25" Thick 304 Stainless Steel Square Tubing	McMaster-Carr Item 89825K48	1. Drill holes to fit 1" shafts through 2. Cut out slot to accomodate feeding of the shells. 3. Drill holes to accomodate 5/16" bolts mounting frame to base	N/A
	Locating Pins	M	1/2" x 1" OD Stainless Steel Rod	McMaster-Carr Item 89535K15	1. Cut out slots to mount bearings 2. Drill holes to accomodate 5/16 bolts mounting frame to base	N/A
	Bronze Bushing	P	N/A	McMaster-Carr Item 7095K48	N/A	N/A
Wheels and Shafts	Shaft Tubing	M	0.083" Thick, 1" O.D. 304 Stainless Steel Tube	McMaster-Carr Item 89495K64	1. Cut tube in half to create two shaft 2. Drill holes in shaft to allow for airflow into wheels.	N/A
	Vacuum Wheels	M	4" Diameter 304 Stainless Steel Rod	McMaster-Carr Item 89535K83	1. Mount flat-sides vertical and mill the interior thru hole 2. Same mounting, mill the inset rim 3. Flip mounting 180° and perform operation #2 on opposite side 4. Mount vertically (round surface up) and use descending sizes of ball-nose endmills to CNC mill a single pocket until smooth 5. Drill vacuum transmission orifice in the bottom of the pocket 6. Rotate mounting 60° and repeat operation #5 an additional 5 times, creating a total of 6 pockets	Manufacturing this component will be very time intensive and require an authorized CNC operator. The lead time on this component will be large, and must be accounted for to leave time for subsequent fitting and testing.
	Rubber Plugs	P	Rubber Plugs Without Holes	McMaster-Carr Item 9545K118	N/A	N/A
	Vacuum Wheel Caps	P	2-1/2" OD x 1/4" Stainless Steel	McMaster-Carr 88885K74	N/A	N/A
	Bearings	P	N/A	McMaster-Carr Item 7363N27	N/A	N/A
Vacuum System	Motor & Impeller	P	N/A	N/A	N/A	N/A
	Square Tubing	M	2" x 2" x 0.25" Thick 316 Stainless Steel Rectangular Tube	McMaster-Carr Item 2937K24	Drill holes to allow for the shaft ends to enter the center of the square tubing.	N/A
	Vacuum Tube Caps	M	6" x 6" x 0.06" Thick 316 Stainless Steel Sheet	McMaster-Carr Item 88885K74	Cut 2" x 2" pieces to attach to ends of square tube, acting as caps	N/A
	Gasket	P	N/A	McMaster-Carr Item 5025T172	N/A	N/A
Hardware	Frame Mounting Bolts	P	N/A	Home Depot Item 92240A619	N/A	N/A
	Shaft Collar Bolts	P	N/A	McMaster-Carr Item 92196A533	N/A	N/A
Drive/Timing System	Clearview NEMA 3.4 Servo	P	N/A	Teknic Item CPM-MCPV-2310D-RLN	N/A	N/A
	DC Power Supply	P	N/A	Teknic Item IPC-5	N/A	N/A
	AC Power Supply Cable	P	N/A	Teknic IPC35-CABLE110	N/A	N/A
	Display	P	N/A	ELECROW Item 8595698868	N/A	N/A
	Level Shifter	P	N/A	Amazon Item 8541740602	N/A	N/A
	Raspberry Pi 2	P	N/A	Already Acquired	N/A	N/A
	Raspberry Pi Power Supply	P	N/A	CanaKit	N/A	N/A
	Motor Shaft Coupling Collars	P	N/A	McMaster-Carr Item 2401K13	N/A	N/A
	Motor Shaft Coupling Spider Hub	P	N/A	McMaster-Carr Item 2401K84	N/A	N/A
	Gears	P	N/A	McMaster-Carr Item 8983K222	N/A	N/A
	Shaft Collars	P	N/A	McMaster-Carr Item 5631T16	N/A	N/A

Manufacturing Plan

1) Riser (Assembly 11100)
    a) Square tube
        i) Clamp square tube in a vice on a mill with flange bearing side up
        ii) Find x and y datums with edge finder
        iii) Plunge holes for locating pins according to drawing
        iv) Plunge holes for shaft slots with an extra long drill bit, and drill all the way to far side to also drill the bushing holes in one operation
        v) Pull drill bit depth up and mill the slots on the flange bearing side
    b) Bushings
        i) Clamp bushing in lathe and cut to length with parting tool
    c) Locating pins
        i) Clamp round stock in lathe
        ii) Turn to diameter
        iii) Chamfer end
        iv) For the threaded pins, use a die to thread to given depth
        v) Cut to length with a parting tool
    d) Base plate
        i) Waterjet from DXF file
        ii) Tap mounting holes as shown in drawing
        iii) Break any sharp edges around edge
    e) Assembly
        i) Press fit bushings into square tube riser
        ii) Press fit locating pins into square tube riser

2) Shaft Assembly (Assembly 11200)
    a) Wheels
        i) Use horizontal bandsaw to cut off 2.5 inches of steel from the 4" diameter rod
        ii) Clamp part in lathe and drill a 1 inch through hole
            (1) Begin with center drill, then step up to ½ inch morse taper drill and then 1" morse taper drill in tail stock
        iii) Create the hollow interior of the wheel
            (1) Drill out the front opening to the largest available drill size
            (2) Use a boring bar to bring to the final internal diameter and to square the bottom of the hole
            (3) Use a facing tool to add the ridge for the wheel cap to sit on
        iv) Remove the piece and flip the jaws of the chuck to grip the inside of the wheel. Clamp the wheel facing the other way
        v) Use a facing tool to add the rear hub for the set screw
        vi) Clamp with large V-blocks on a mill and drill the set screw hole

        vii) Tap set screw hole
        viii) Pass to CNC operator to machine in cups
    b) Shafts
        i) Cut shafts to length on small horizontal band saw
        ii) Put on lathe and scribe lines at edge of where wheel, bearing, and shaft collar will sit
        iii) Scribe one line axially down shaft to serve as bearing and wheel index
        iv) Clamp on mill using V-blocks
        v) Find datum at end of tube and edges with edge finder
        vi) In center of tube, drill the vacuum holes
    c) Gears
        i) Clamp gear on mill with toe clamp
        ii) Find center with center finder and drill through hole to shaft size
        iii) Locate and drill shaft collar holes
        iv) Scribe a fine line from the tip of one tooth to the center
    d) Assembly
        i) Slide on gear shaft collar to mark and tighten
        ii) Slide on Gear, align scribed tooth line with scribed axial line, secure to shaft collar with two bolts
        iii) Slide on bearing to its marking and tighten onto shaft
        iv) Slide on wheel to its marking and tighten set screw to align with axially scribed line
3) Motor Assembly (Part 11500)
    a) Motor Mount
        i) Clamp L-bracket in mill
        ii) Find datums with edge finder
        iii) Mill slots
        iv) Rotate to clamp other side of "L" and repeat
    b) Bearing mount
        i) Cut block near size with band saw
        ii) Square on mill
        iii) Drill two mounting holes
    c) Shaft
        i) Press fit pinion onto shaft
        ii) Assembly spider coupler using given instructions
    d) Assembly
        i) Bolt motor to the motor mount
        ii) Slide shaft through bearing into motor and attatch with spider coupler
4) Vacuum Assembly (Part 11300)
    a) Square tube
        i) Clamp in vice on mill
        ii) Find datums with edge finder
        iii) Drill two large holes for shafts as shown on drawing
        iv) Rotate 90 degrees and find datums again

v) Drill slots for L brackets

b) Finger Guard

i) Cut U-channel to length with band saw

ii) Clamp u-channel in mill and remove material from the top until it meets drawing height

iii) Clamp L-bracket in vice on mill

iv) Find datums and mill two slots as shown on drawing

v) TIG weld the hinge to the U-bracket

vi) Bolt the other side of the hinge to the L-bracket

c) Assembly

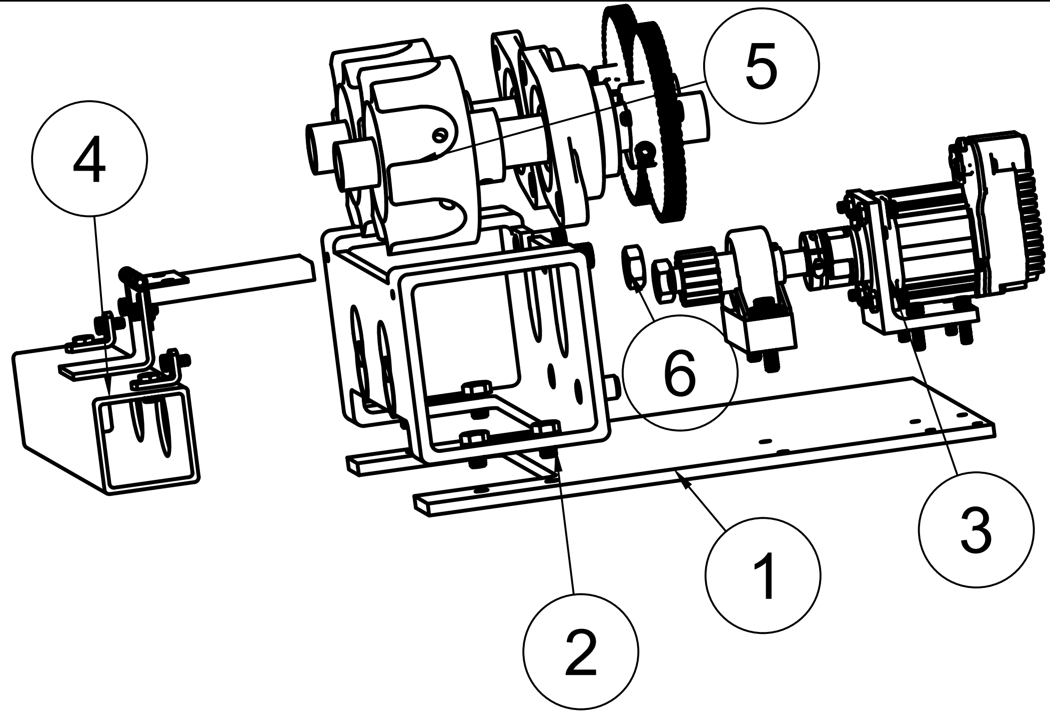
i) TIG weld the other side of the L-bracket to the center of the square tube

ii) Bolt the small L-brackets to the slots on the end of the square tube

Final Assembly

1. Frame
    a. Bolt riser to respective holes on the base plate
    b. Bolt motor assembly to base plate
    c. Bolt vacuum coupler to front riser
    d. Lower the first shaft into place, slide shaft into bushing, and bolt bearing to rear riser
    e. Lower the second shaft into place, rotate until the gears align, and bolt bearing to rear riser

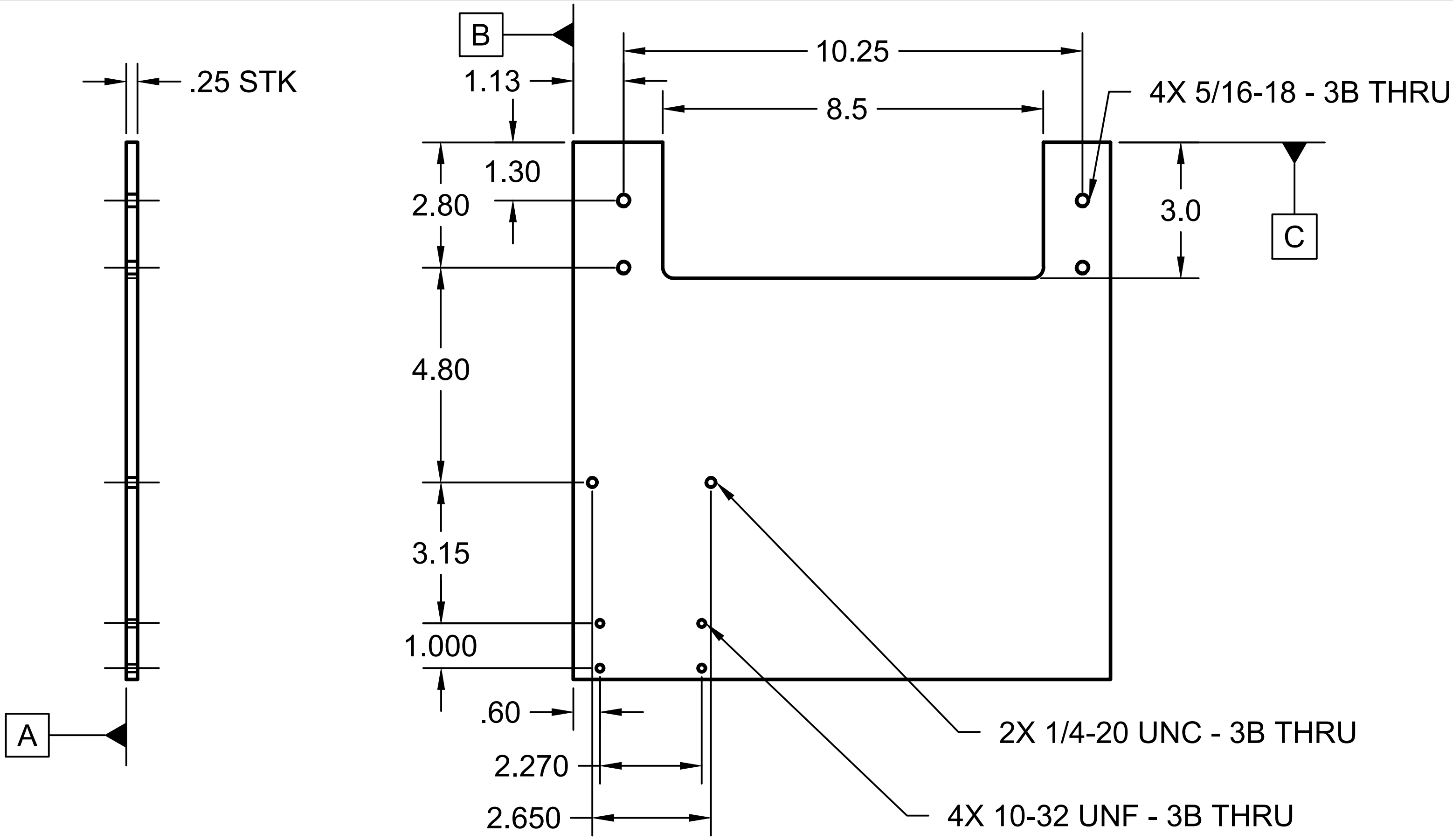
Appendix J: Drawing & Spec Package



ALL PARTS POSITION
ADJUSTED FOR
PROPER MESHING
USING SLOTS

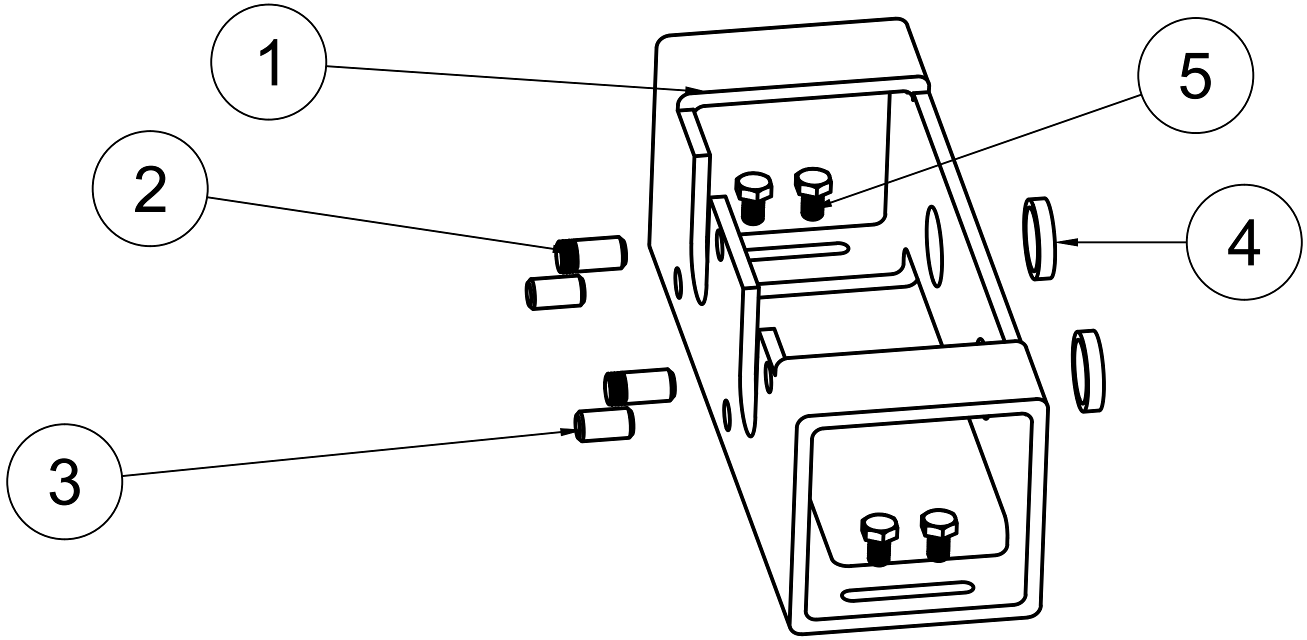
ITEM	QTY	PART #	DESCRIPTION	MATERIAL
1	1	11110	BASE PLATE	304 STAINLESS STEEL
2	1	11120	RISER SUBASSEMBLY	N/A
3	1	11500	MOTOR ASSEMBLY	N/A
4	1	11300	VACUUM ADAPTER SUBASSEMBLY	N/A
5	2	11200	SHAFT SUBASSEMBLY	N/A
6	2	11150	1/2-20 NUTS	18-8 STAINLESS STEEL

NEXT ASB:	FILE NAME: FULL ASSEMBLY
DWG #: 10000E	
CHECKED: ME STAFF	SCALE: SCALE
DRAWN: Adin Gilman-Cohen	5/10/22



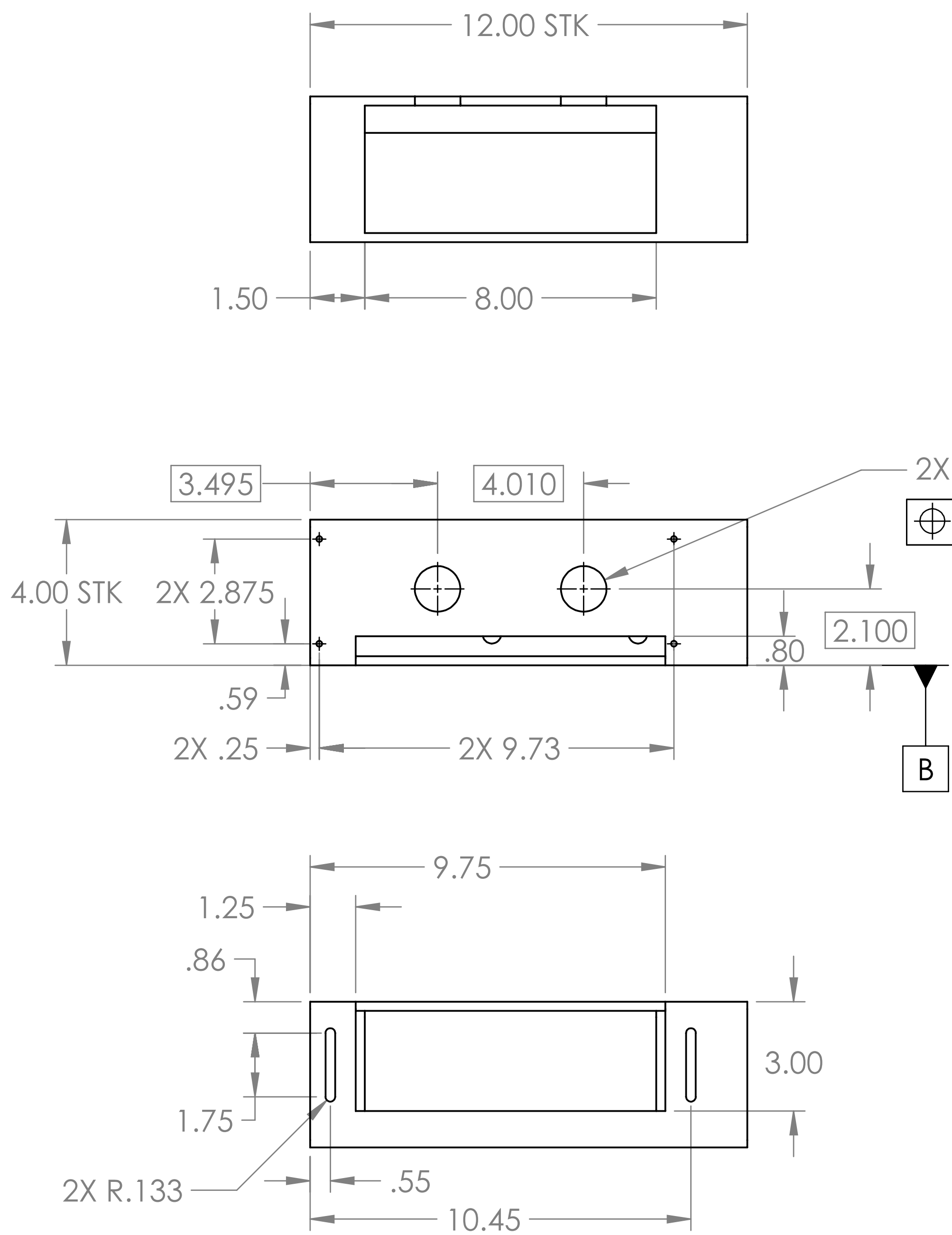
NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .01
X.XXX = ± .005

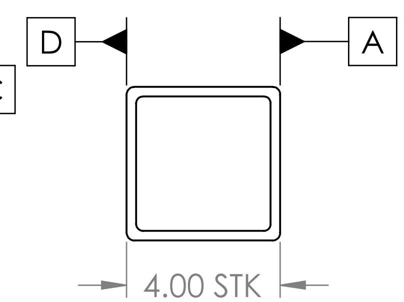
MATERIAL: 304 STAINLESS	FILE NAME: Baseplate	
DWG #: 11110		
CHECKED: ME STAFF	SCALE: 1:4	DRAWN: Logan Williamson 5/9/2022

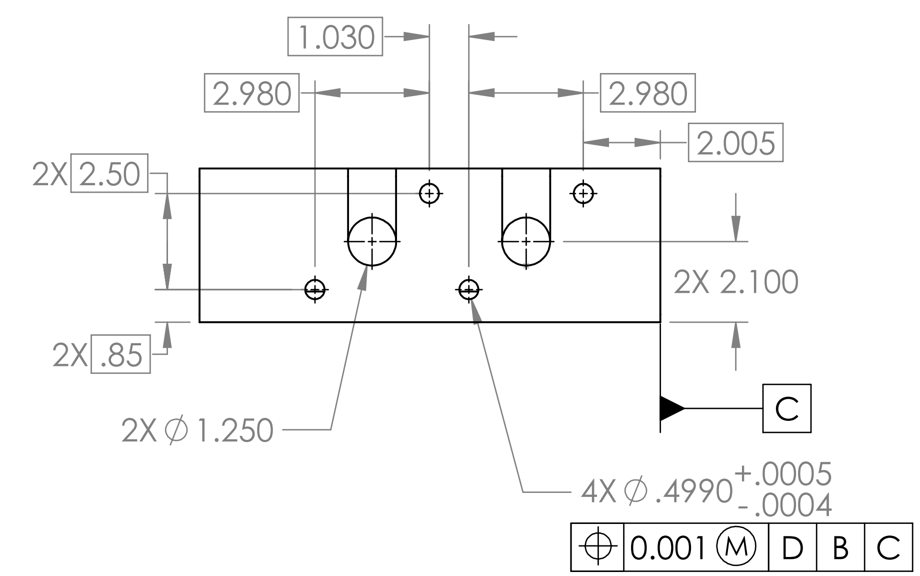


ITEM	QTY	PART #	DESCRIPTION	MATERIAL
1	1	11120	RISER TUBE	304 STAINLESS STEEL
2	2	11140	THREADED LOCATING PINS	304 STAINLESS STEEL
3	2	11140	LOCATING PINS	304 STAINLESS STEEL
4	2	11130	BUSHINGS	BRONZE
5	4	11410	5/16-18 BOLTS	18-8 STAINLESS STEEL

NEXT ASB:	FILE NAME: SQUARE TUBE RISER	
DWG #: 11100E		
CHECKED: ME STAFF	SCALE: SCALE	DRAWN: Adin Gilman-Cohen 5/11/22







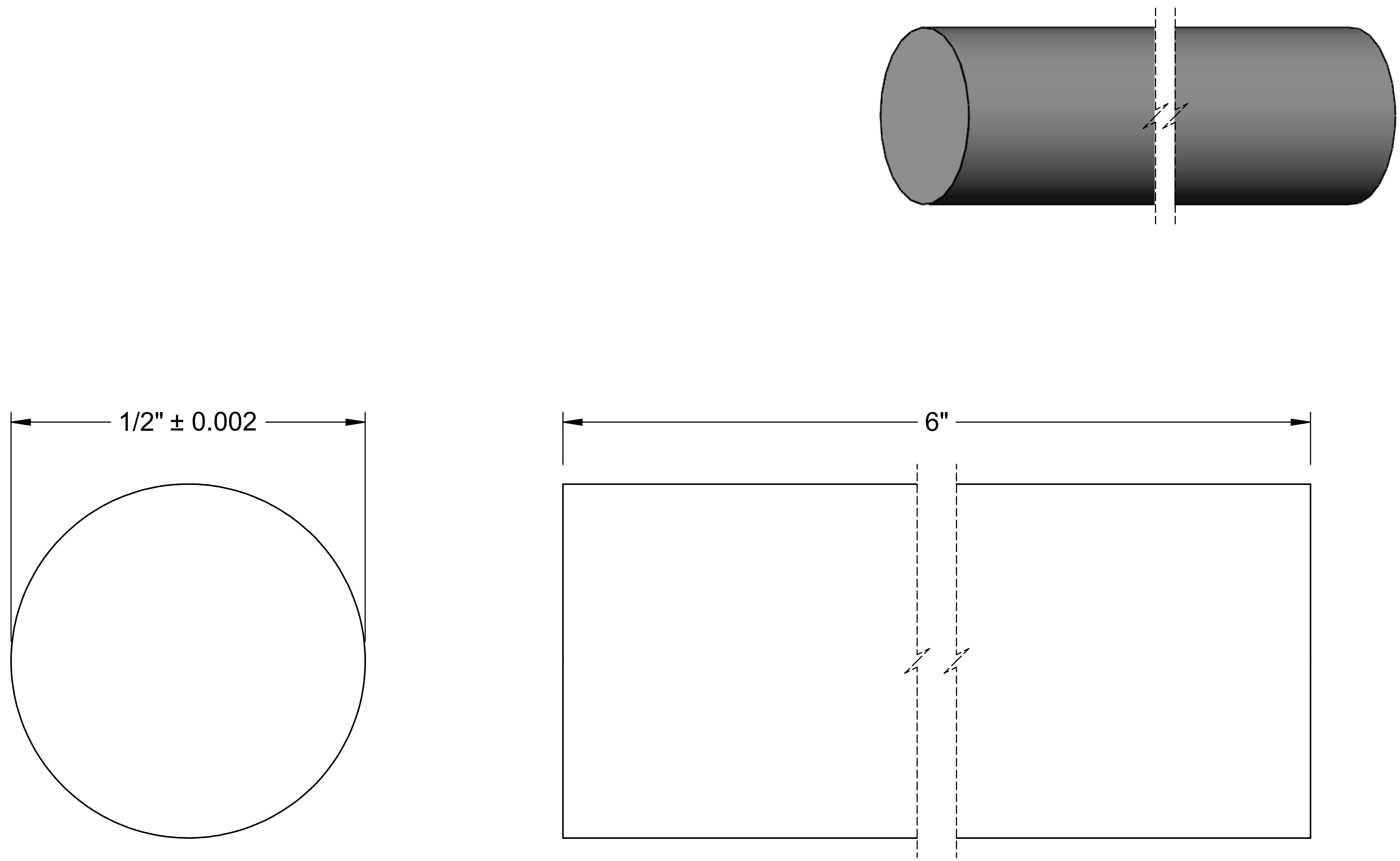
NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = .1
X.XX = .01
X.XXX = .001
FOUR HOLE PATTERN IN RIGHT VIEW
ALL ANSI FN2 FORCE FIT
TWO HOLES IN LEFT VIEW ARE
ANSI FN5 FORCE FIT

	NAME	DATE
DRAWN	LOGAN WILLIAMSON	6/4/2022
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

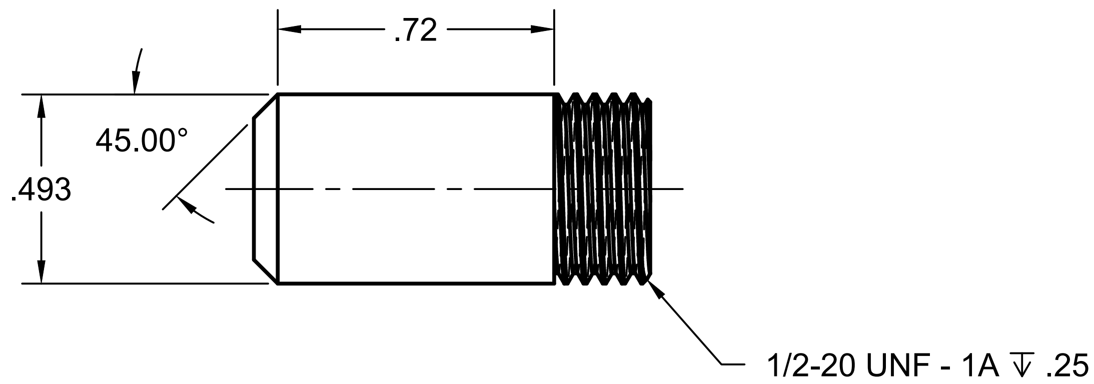
Riser for CNC v7

SIZE	DWG. NO.	REV
B		
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

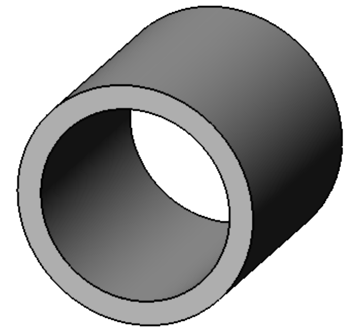


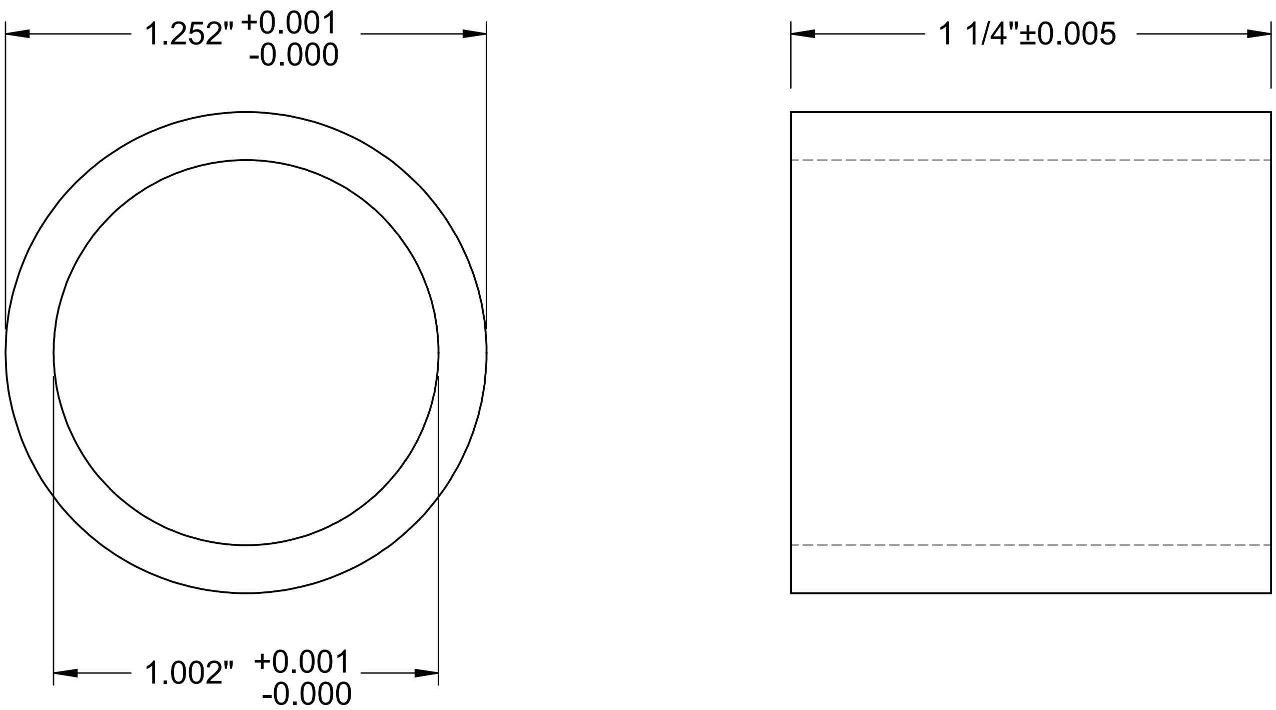
McMASTER-CARR® CAD	PART NUMBER	89535K151	
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company	Multipurpose 304/304L Stainless Steel Rod		
Information in this drawing is provided for reference only.			

NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .01
X.XXX = ± .002

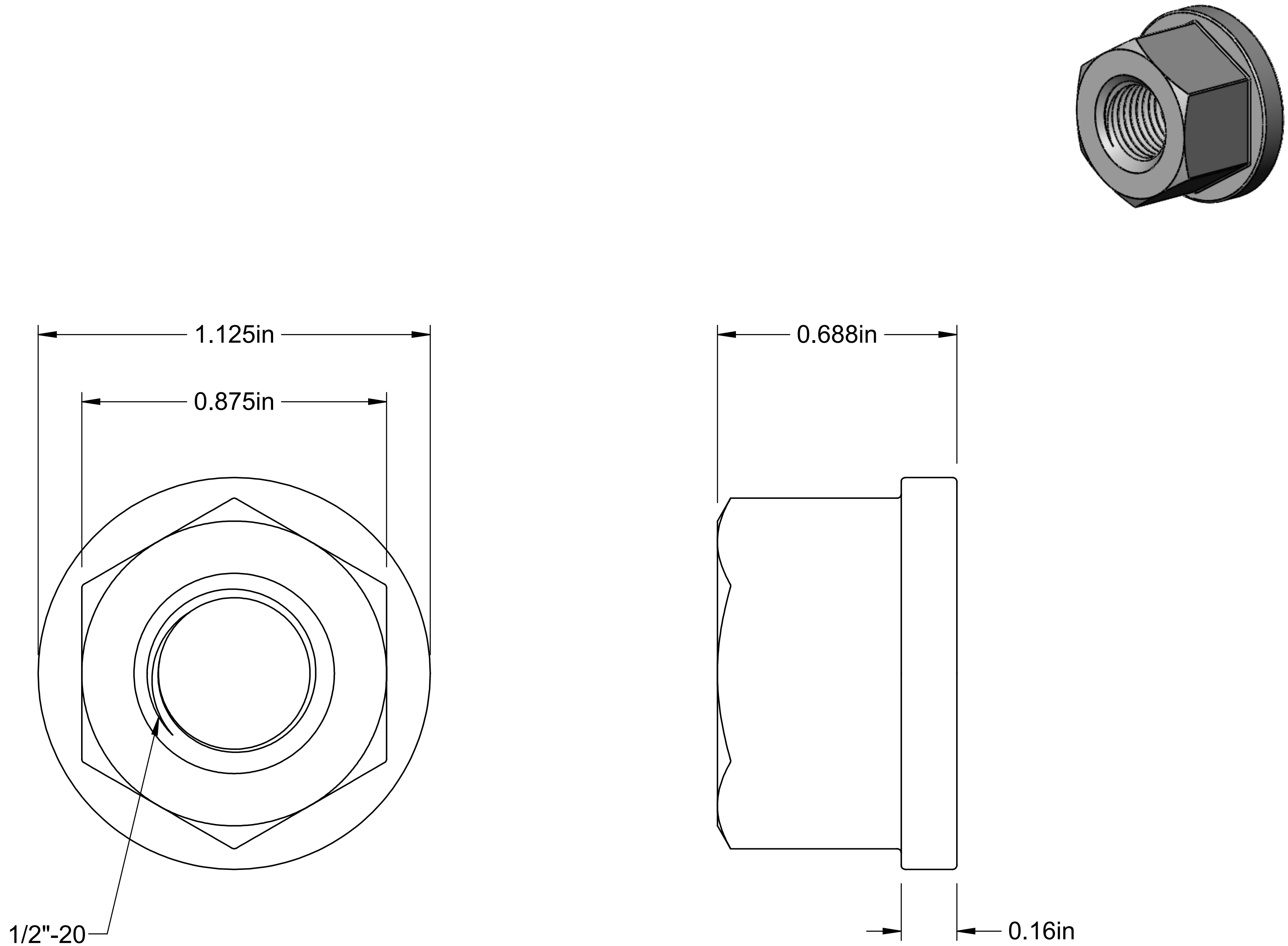


NEXT ASB:	FILE NAME: Bearing Locating Pin	
DWG #: 11140		
CHECKED: ME STAFF	SCALE: 2:1	DRAWN: Logan Williamson 5/7/2022

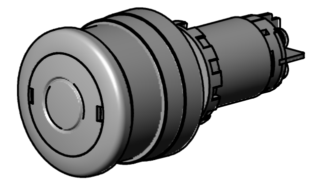


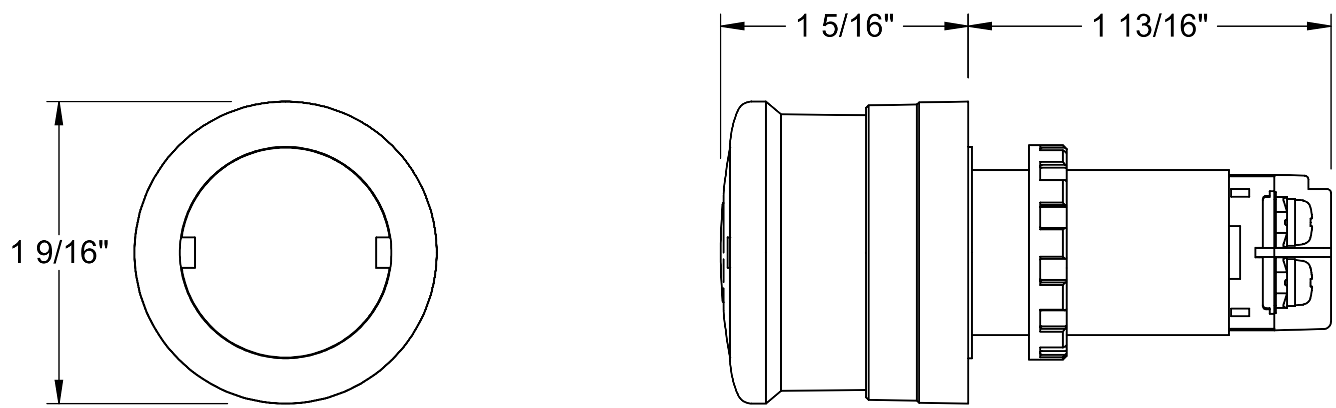


McMASTER-CARR® CAD	PART NUMBER	7095K48
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Food Industry Oil-Embedded Sleeve Bearing	

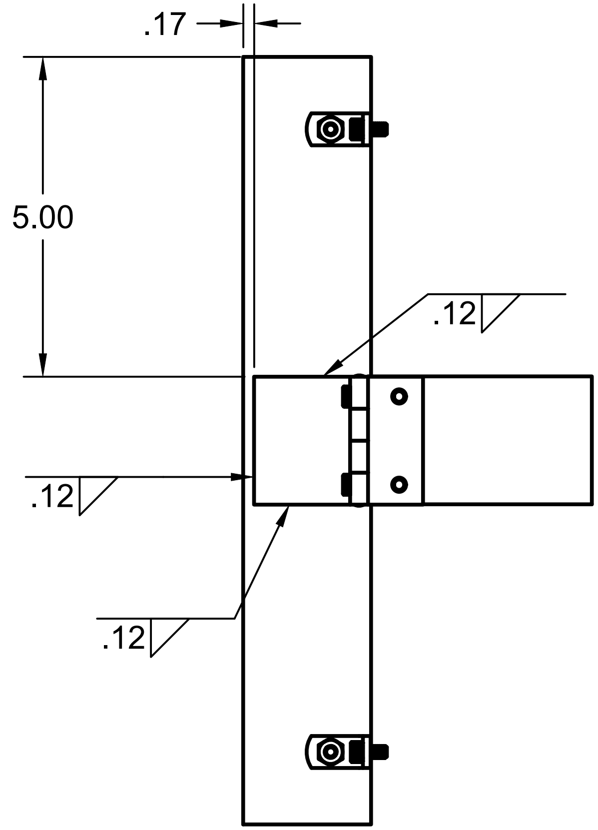


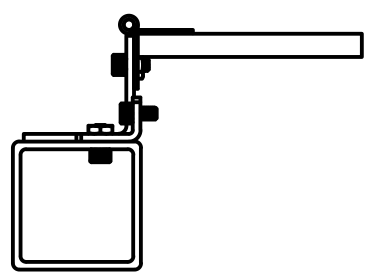
MCMASTER-CARR® CAD	PART NUMBER 90389A218
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company	316 Stainless Steel Flange Nut
Information in this drawing is provided for reference only.	



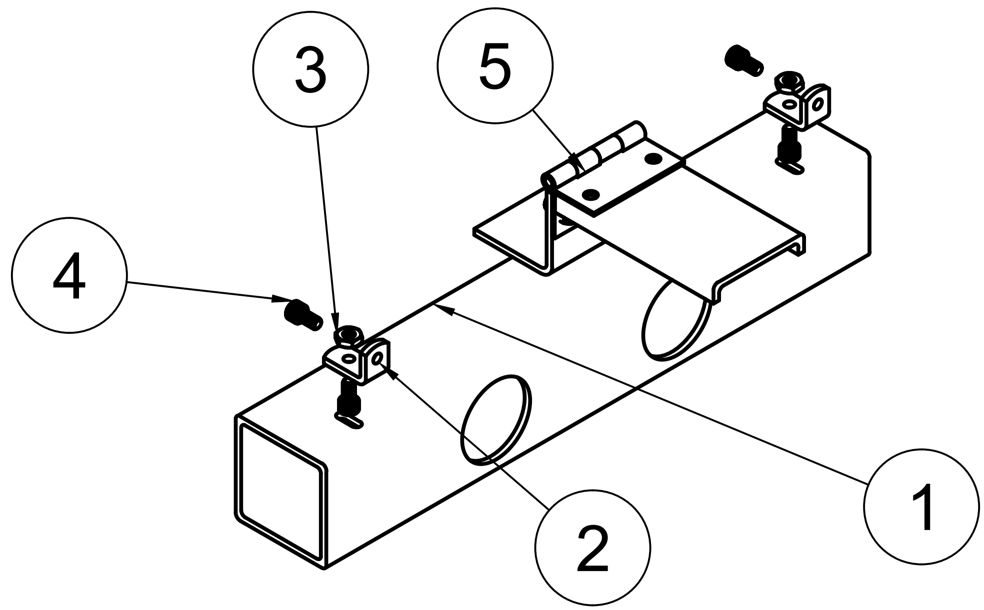


McMASTER-CARR® CAD		PART NUMBER	7480T12
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.		22 mm Emergency Stop Panel-Mount Switch	



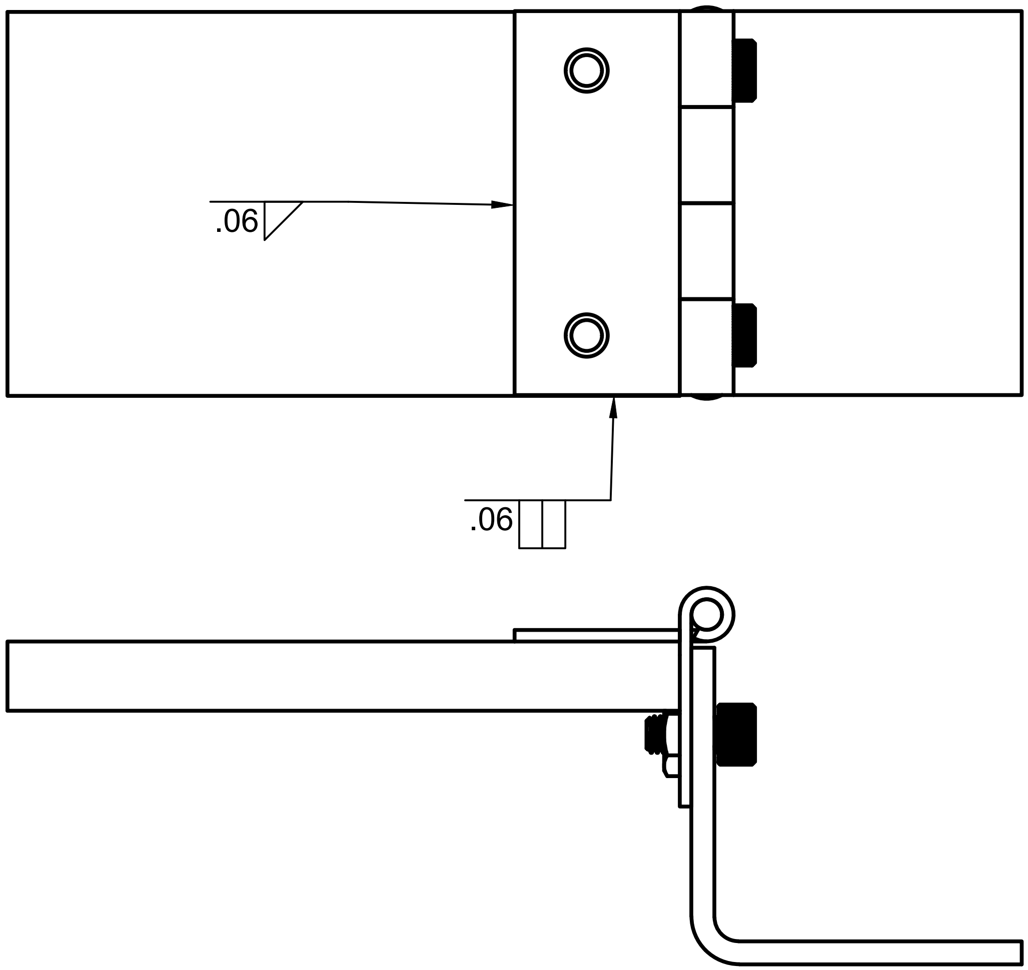


MATERIAL: VARIOUS	FILE NAME: Vacuum Adapter		
DWG #: 11300			
CHECKED: ME STAFF	SCALE: 1:3	DRAWN: Logan Williamson	5/10/2022

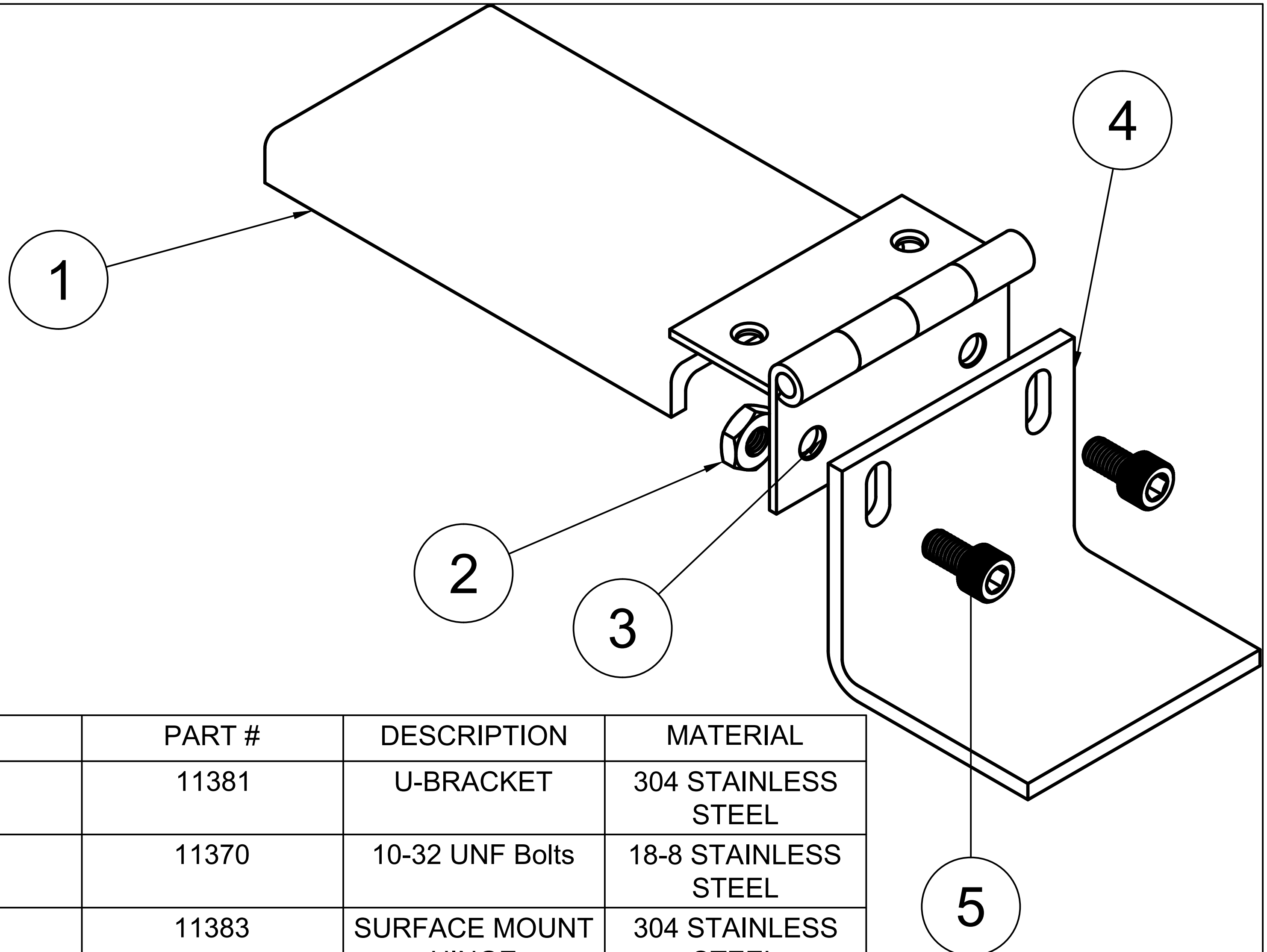


ITEM	QTY	PART #	DESCRIPTION	MATERIAL
1	1	11320	SQUARE TUBE	316 STAINLESS STEEL
2	2	11350	L-BRACKET	304 STAINLESS STEEL
3	2	11370	10-32x3/8 Nuts	18-8 STAINLESS STEEL
4	4	11360	10-32 UNF Bolts	18-8 STAINLESS STEEL
5	5	11380	Finger Guard	N/A

NEXT ASB:	FILE NAME: VACUUM ADAPTER	
DWG #: 11300 E		
CHECKED: ME STAFF	SCALE: 1:3	DRAWN: Adin Gilman-Cohen 5/10/22



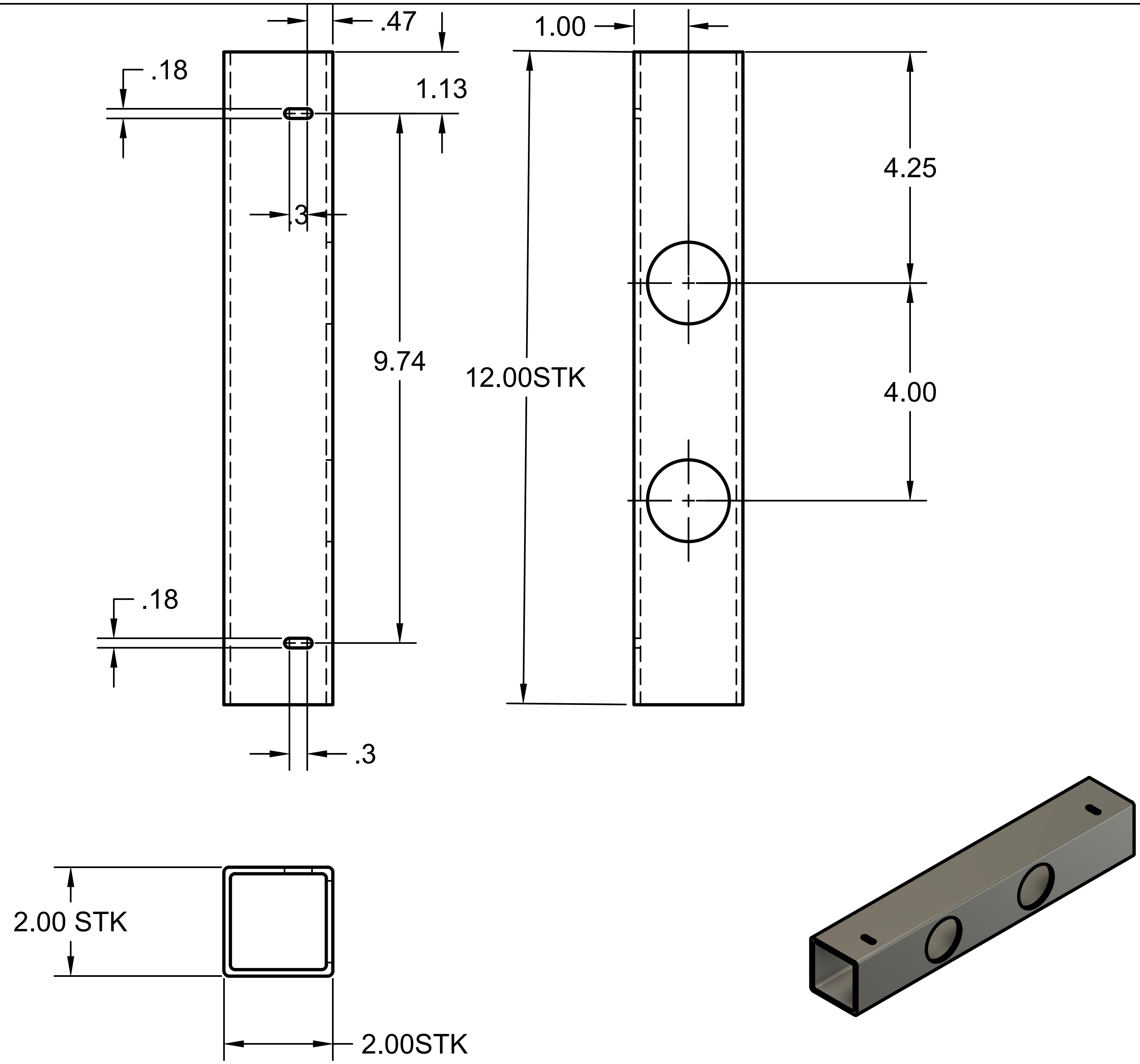
MATERIAL: VARIOUS	FILE NAME: FINGER GUARD		
DWG #: 11380			
CHECKED: ME STAFF	SCALE: SCALE	DRAWN: Logan Williamson	5/10/2022



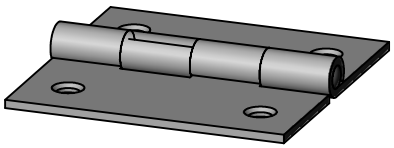
ITEM	QTY	PART #	DESCRIPTION	MATERIAL
1	1	11381	U-BRACKET	304 STAINLESS STEEL
2	2	11370	10-32 UNF Bolts	18-8 STAINLESS STEEL
3	1	11383	SURFACE MOUNT HINGE	304 STAINLESS STEEL
4	1	11382	L-BRACKET	316 STAINLESS STEEL
5	2	11360	10-32 UNF Bolts	18-8 STAINLESS STEEL

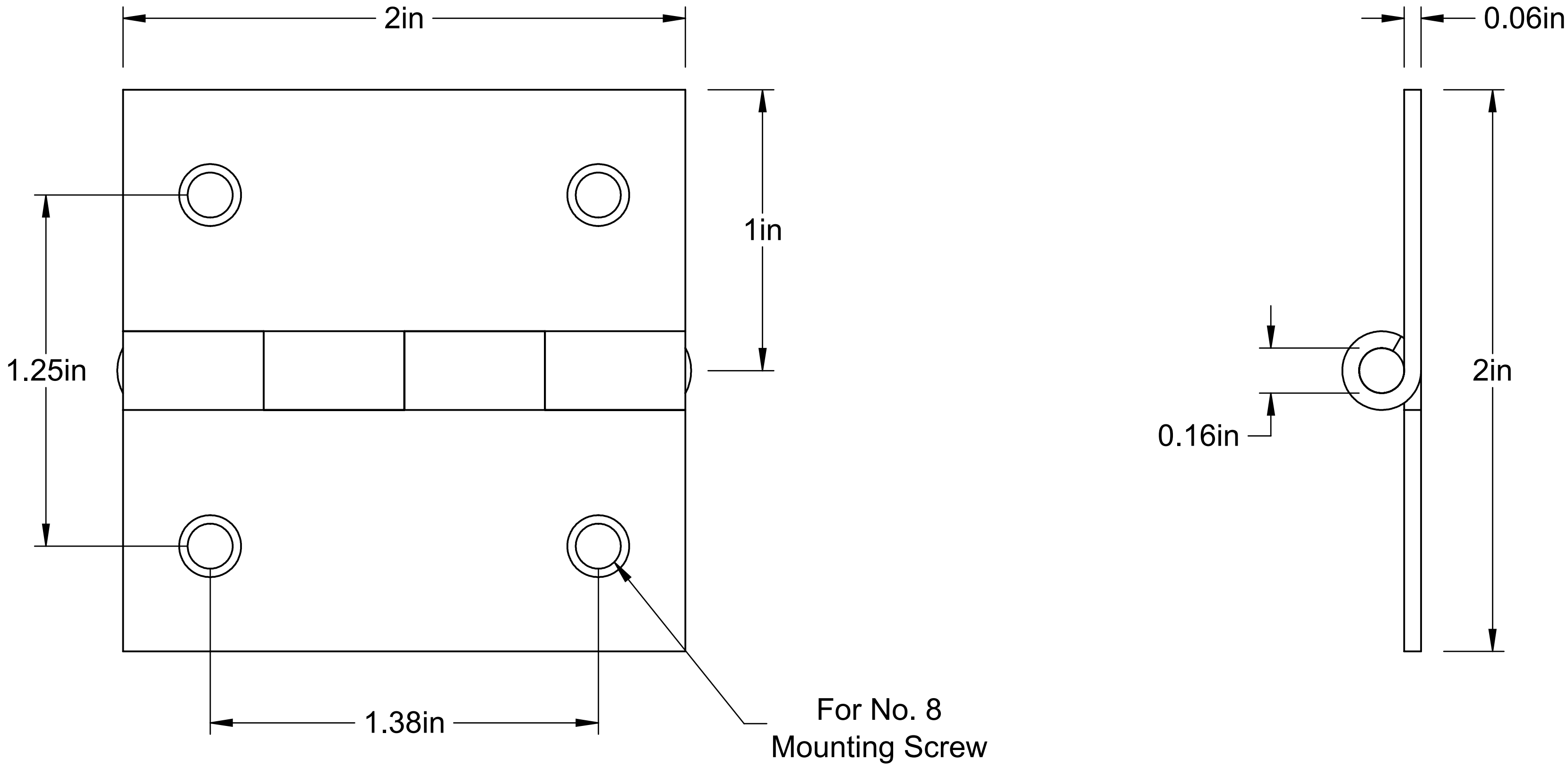
NEXT ASB:	FILE NAME: FINGER GUARD	
DWG #: 11380E		
CHECKED: ME STAFF	SCALE: 1:1	DRAWN: Adin Gilman-Cohen 5/10/22

x.xx ±..05
x.x ±..1

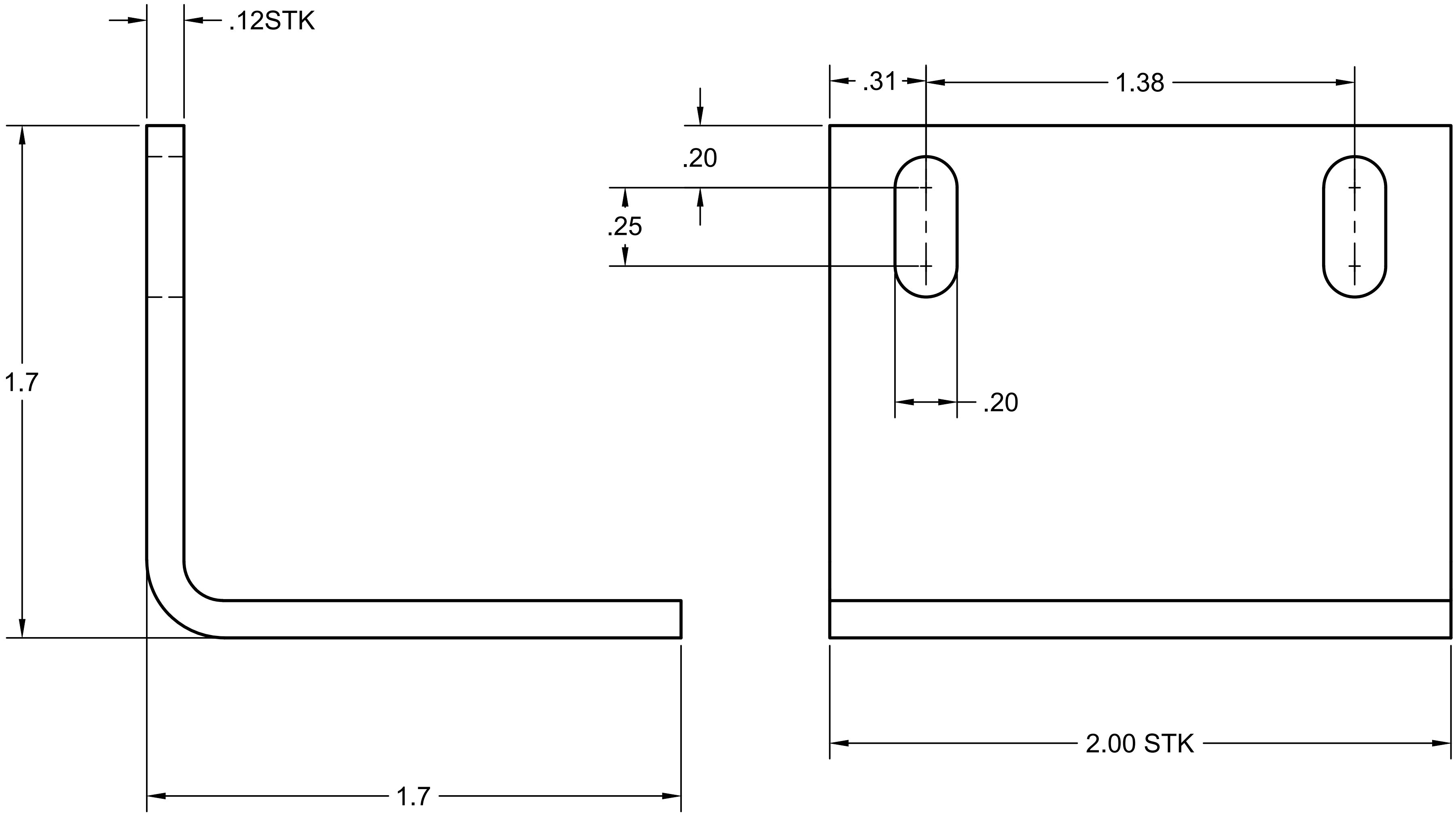


MATERIAL: 316 STAINLESS	FILE NAME: VACUUM ADPTER SQUARE TUBE	
DWG #: 11320		
CHECKED: ME STAFF	SCALE: SCALE	DRAWN: Logan Williamson 5/10/2022



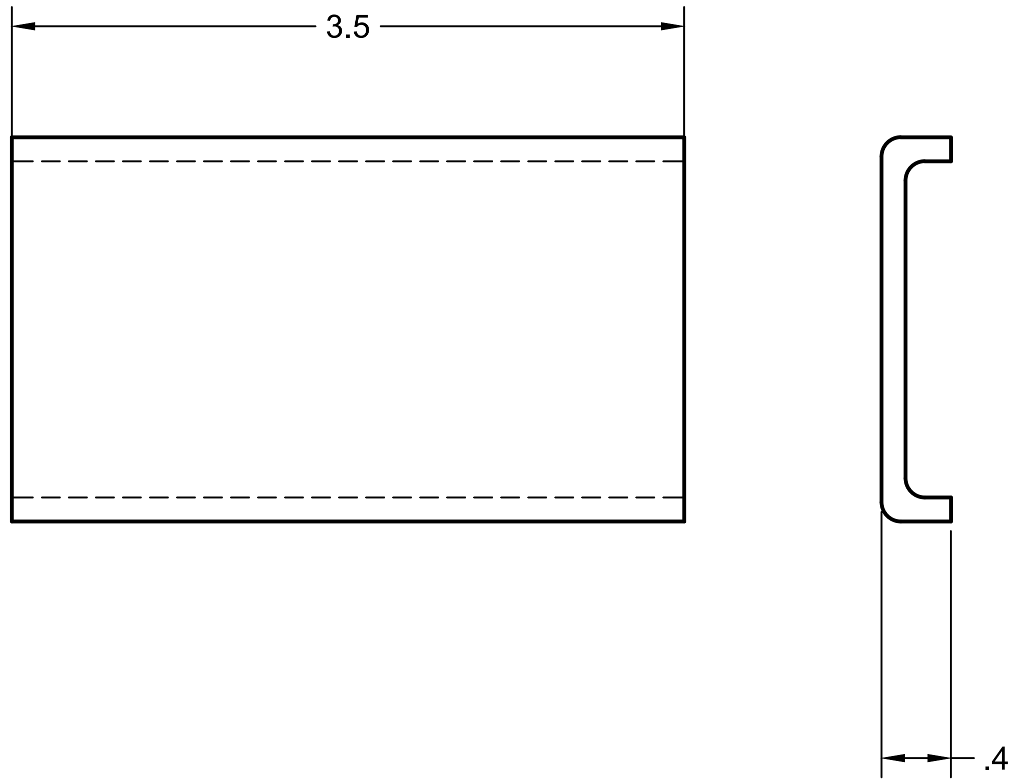


McMASTER-CARR® CAD	PART NUMBER	1586A24
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Surface-Mount Hinge with Holes	



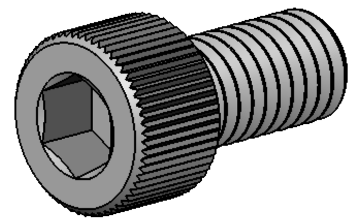
NOTES:
UNLESS OTHERWISE SPECIFIED
MATERIAL 316 STAINLESS STEEL
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .01

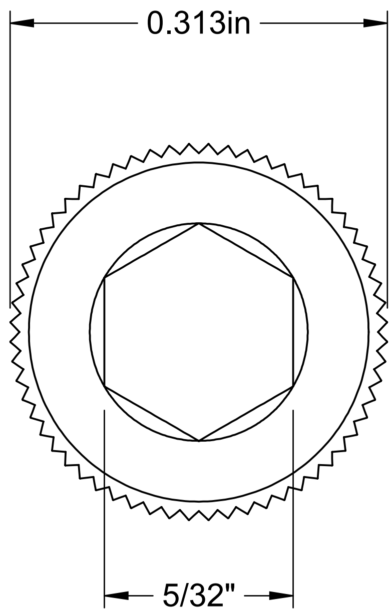
MATERIAL: 316 STAINLESS	FILE NAME: L-BRACKET	
DWG #: 11382		
CHECKED: ME STAFF	SCALE: 2:1	DRAWN: Logan Williamson 5/9/2022

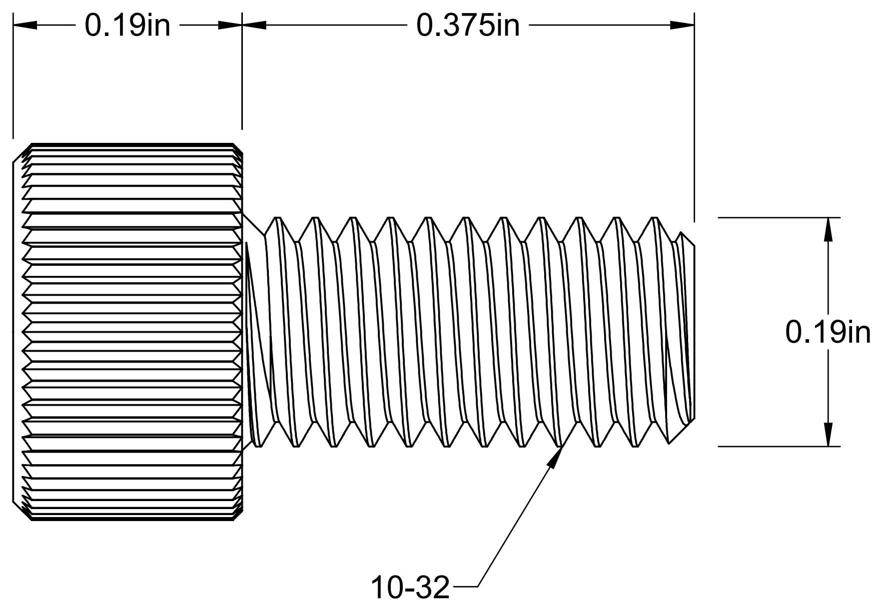


NOTES:
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
ALL OTHER DIMESNIONS STOCK

MATERIAL: 304 STAINLESS	FILE NAME: U-CHANNEL		
DWG #: 11381			
CHECKED: ME STAFF	SCALE: 1:1	DRAWN: Logan Williamson	5/10/2022







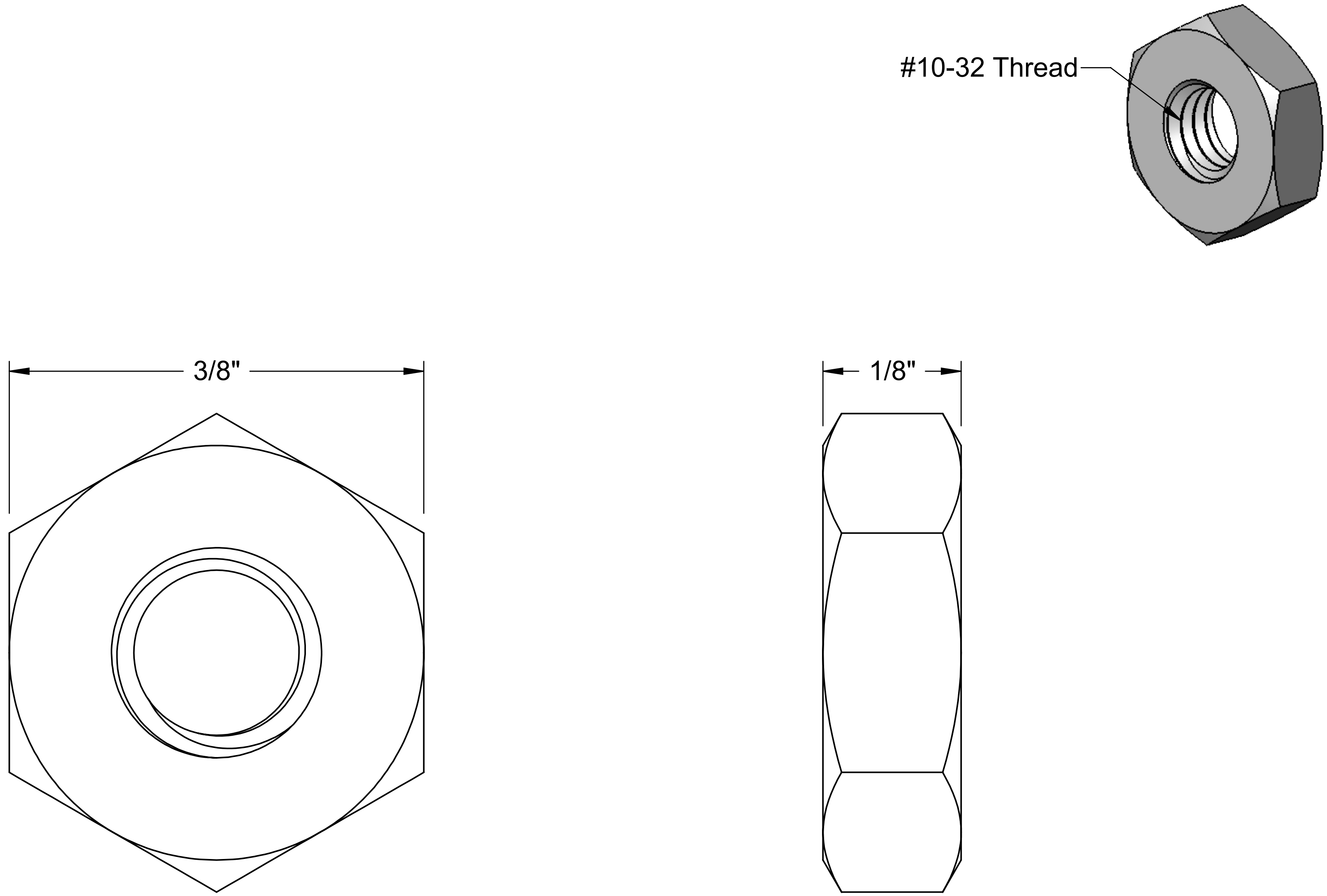
Thread Direction: Right Hand

McMASTER-CARR® CAD

http://www.mcmaster.com

PART NUMBER **92196A267**

18-8 Stainless Steel Socket Head Screw



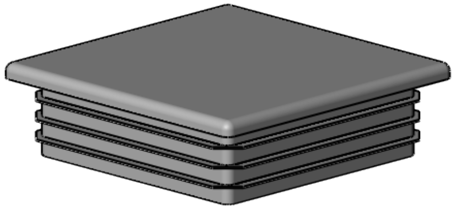
McMASTER-CARR® CAD

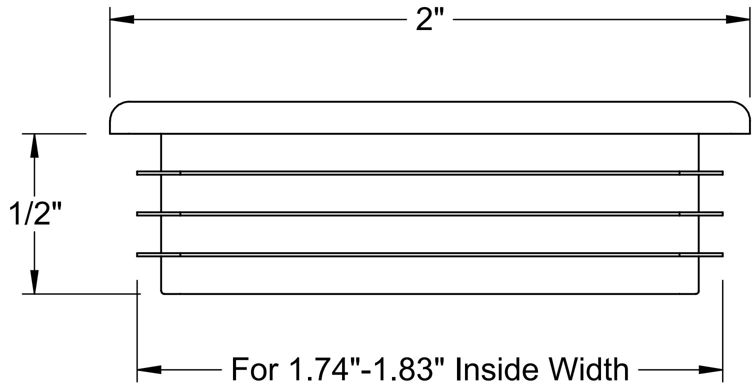
PART NUMBER 91841A195

http://www.mcmaster.com

Information in this drawing is provided for reference only.

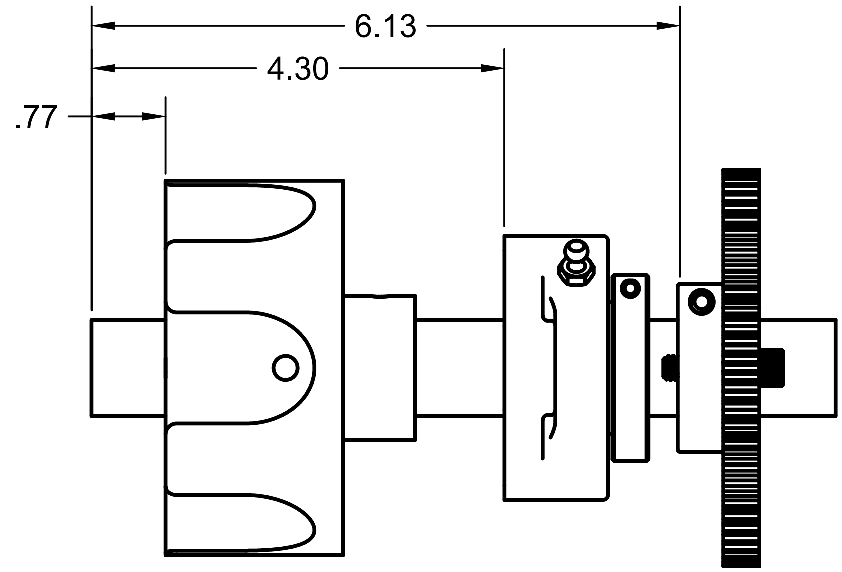
18-8 Stainless Steel Hex Nut



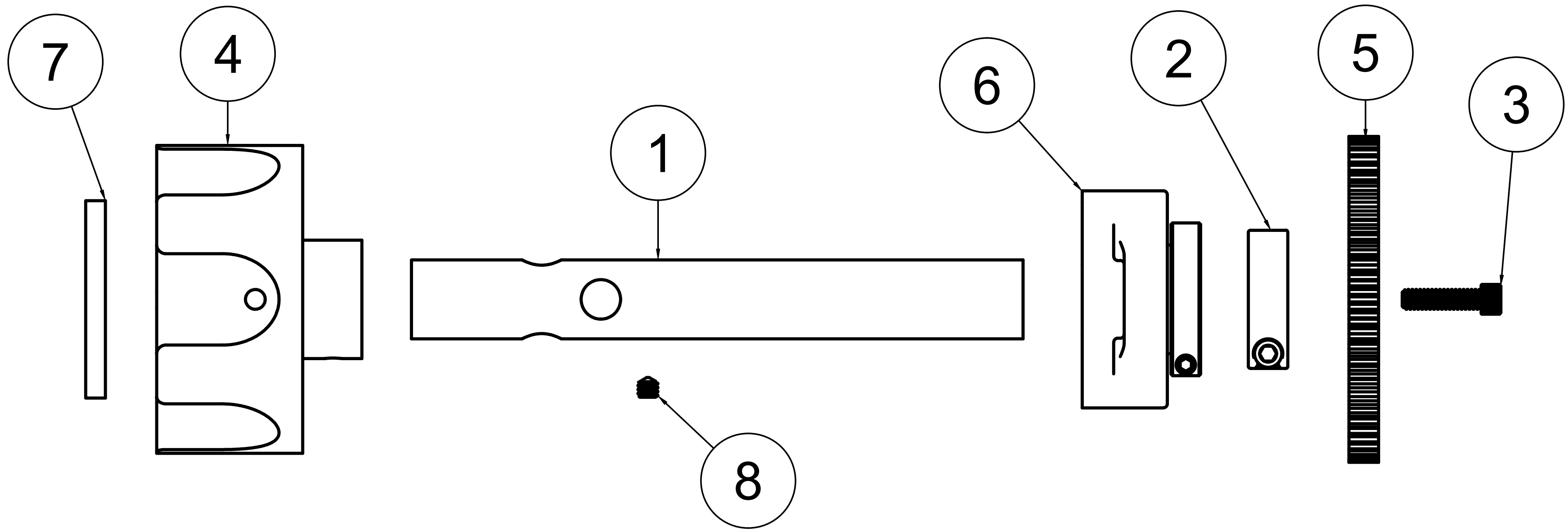


McMASTER-CARR CAD	PART NUMBER	9565K38
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Polyethylene Square Plug	

NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
ALL COMPONENTS MOUNTED WITH HARDWARE THAT ALLOWS FOR ADJUSTMENT.
REQUIRED ADJUSTMENTS TO BE SHOWN IN DRAWING REVISION UPON INITIAL ASSEMBLY AND TESTING.

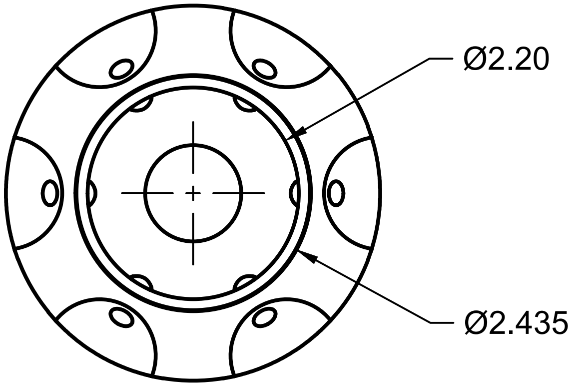


MATERIAL: VARIOUS	FILE NAME: Shaft Wheel Gear Subassembly
DWG #: 11200	
CHECKED: ME STAFF	SCALE: 1:2 — DRAWN: Logan Williamson — 5/9/2022

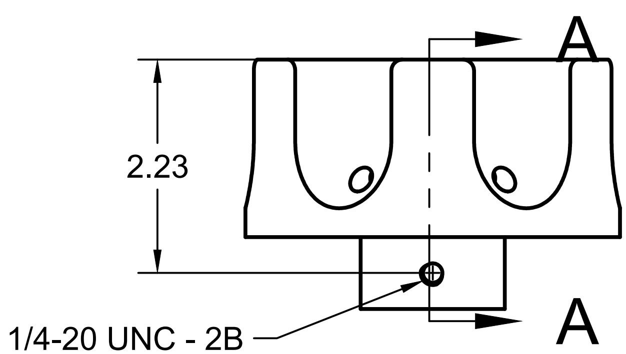


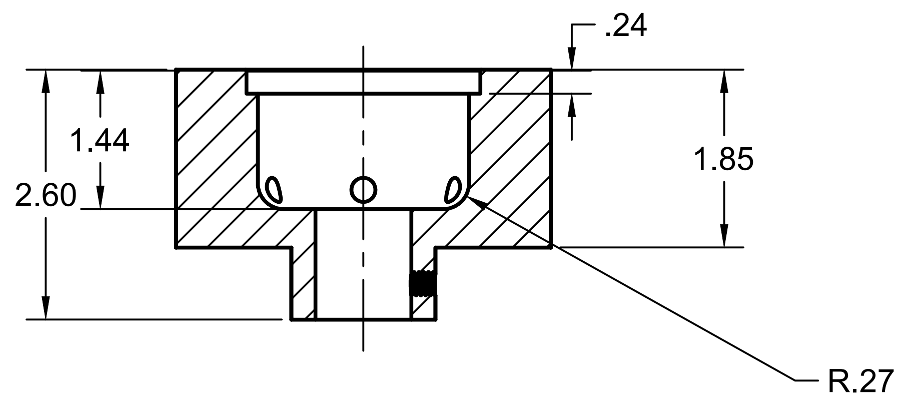
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	2	11210	VACUUM SHAFT	304 STAINLESS
2	2	11290	CLAMPING SHAFT COLLAR	303 STAINLESS
3	4	11280	1/4-20 UNC SHAFT COLLAR BOLT	18-8 STAINLESS
4	2	11220	VACUUM PRODUCT HANDLING WHEEL	304 STAINLESS
5	2	11270	64 TOOTH 16 PITCH GEAR	303 STAINLESS
6	2	11230	WASHDOWN BEARING	STEEL
7	2	11250	WHEEL END CAP	304 STAINLESS
8	2	11260	WHEEL SET SCREW	18-8 STAINLESS

NEXT ASB:	FILE NAME: Shaft Wheel Gear Subassembly	
DWG #: 11200E		
CHECKED: ME STAFF	SCALE: 1:2	DRAWN: Logan Williamson 5/9/2022

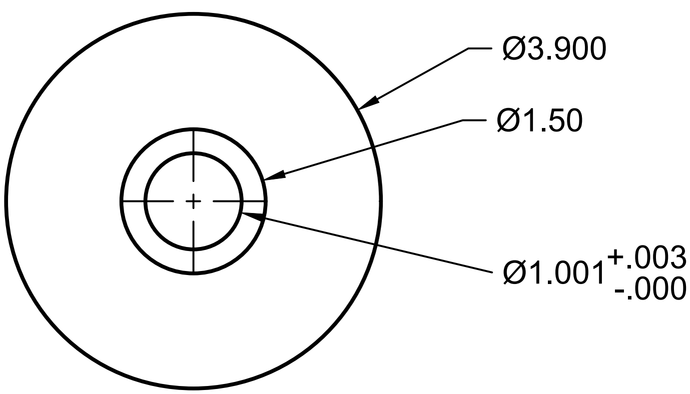


NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .05
X.XXX = ± .005
PARTS TO BE MADE ON 5-AXIS CNC
ANGULAR LOCATION OF SET SCREW HOLE
UNIMPORTANT

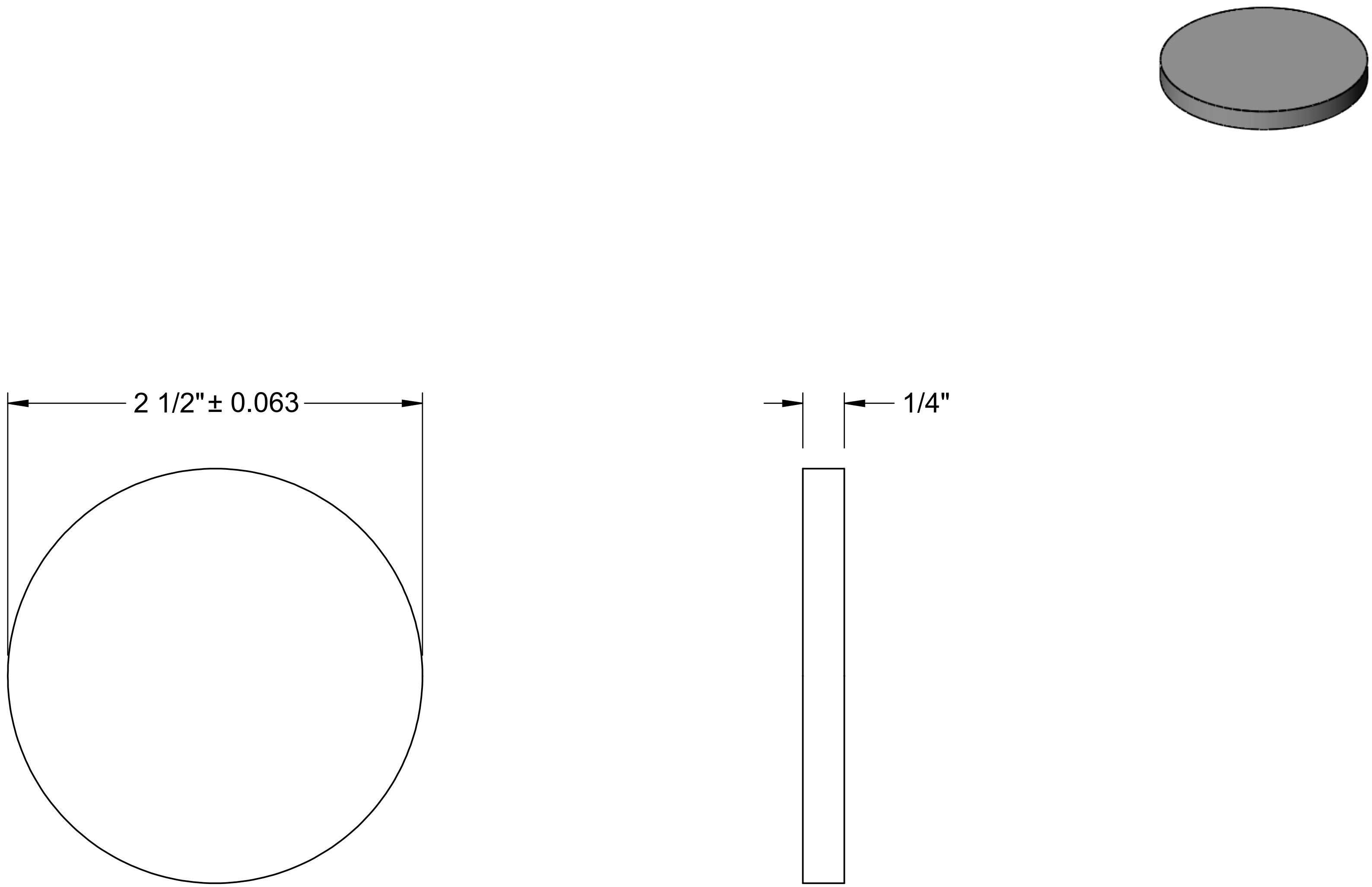




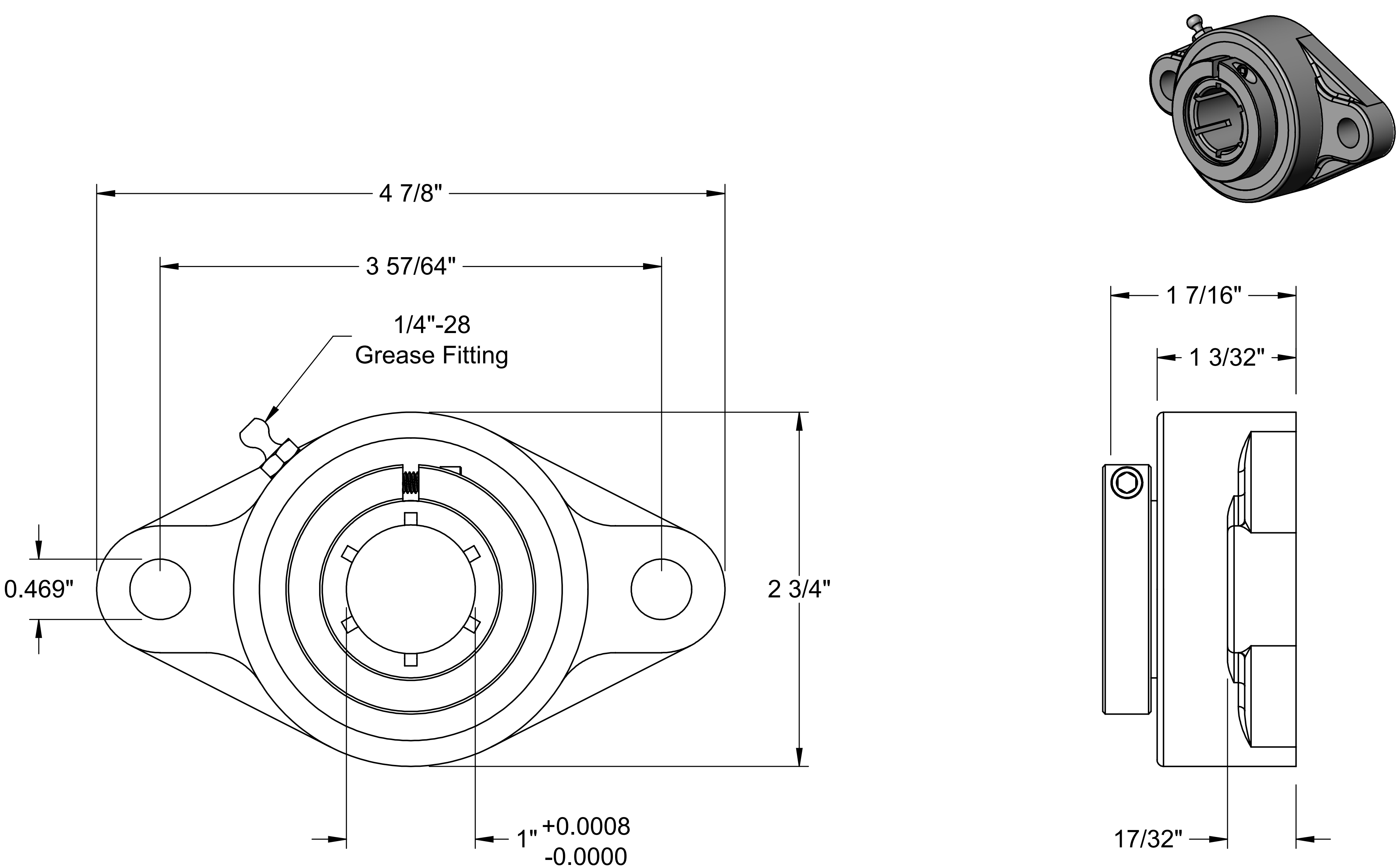
SECTION A-A
SCALE 1:2



MATERIAL: 304 STAINLESS	FILE NAME: Vacuum Product Handling Wheels	
DWG #: 11220		
CHECKED: ME STAFF	SCALE: 1:2	DRAWN: Logan Williamson 4/28/2022



McMASTER-CARR® CAD	PART NUMBER	9208K121
http://www.mcmaster.com 	Multipurpose 304 Stainless Steel Disc	



McMASTER-CARR® CAD

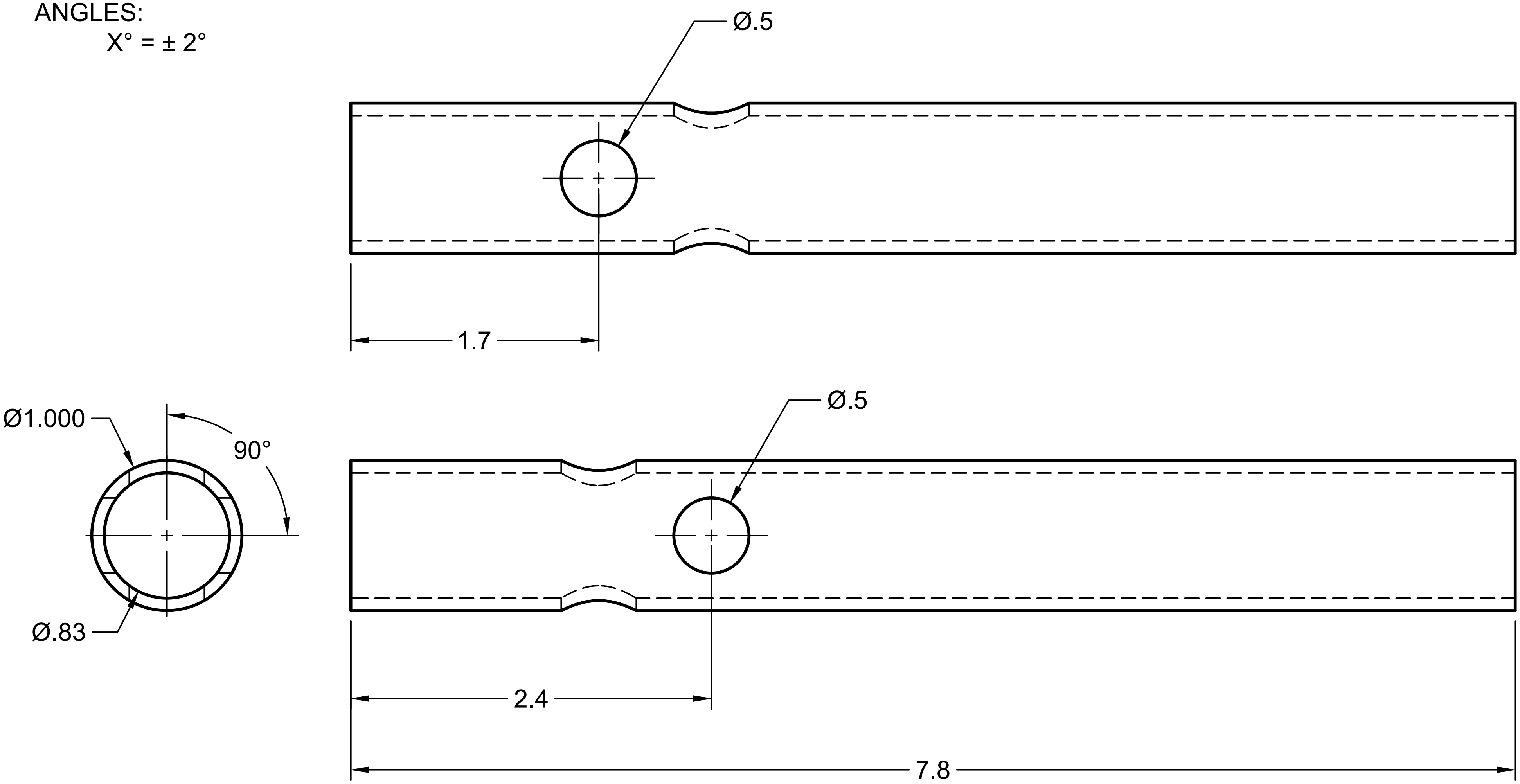
PART NUMBER **7363N27**

http://www.mcmaster.com

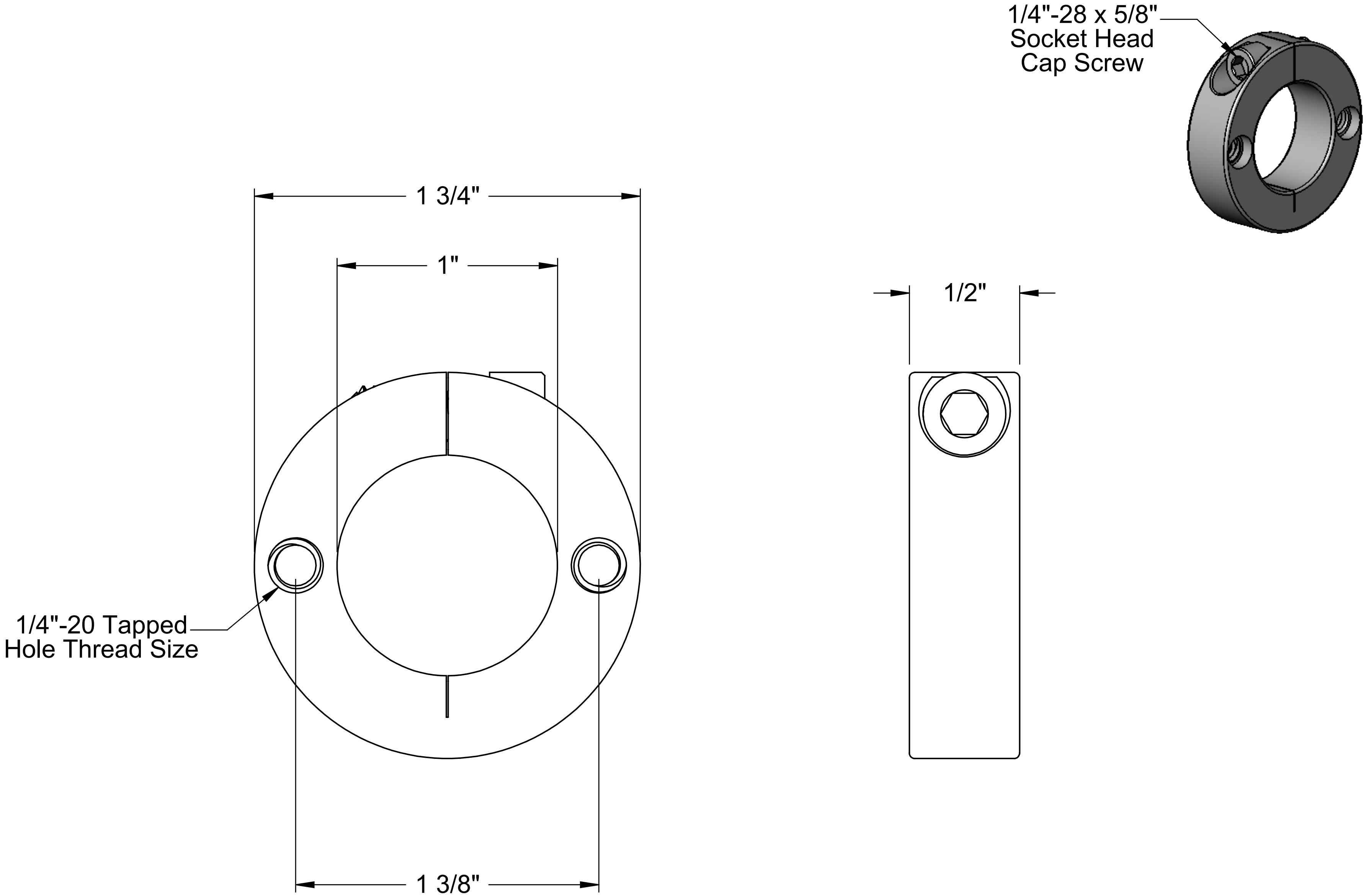
Information in this drawing is provided for reference only.

Washdown Mounted Ball Bearing with Two-Bolt Flange

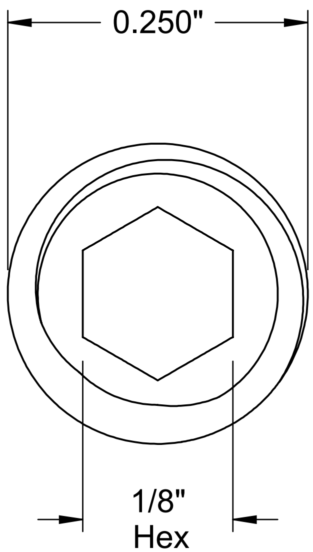
NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .01
X.XXX ± .005
ANGLES:
X° = ± 2°

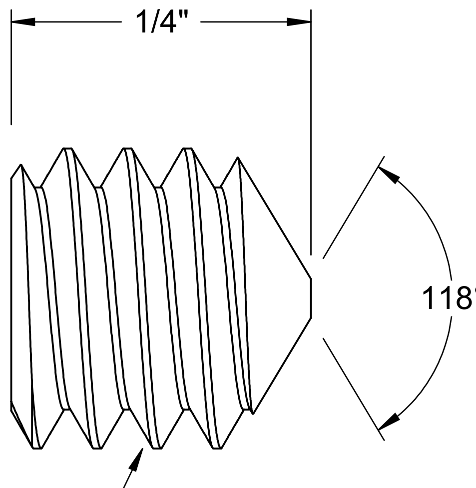


MAERIAL: 304 STAINLESS	FILE NAME: Hollow Shaft		
DWG #: 11210			
CHECKED: ME STAFF	SCALE: 1:1	DRAWN: Logan Williamson	4/28/2022

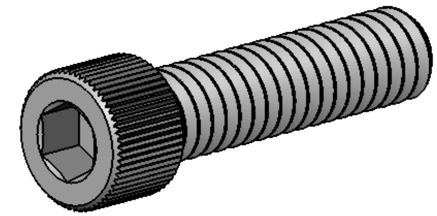


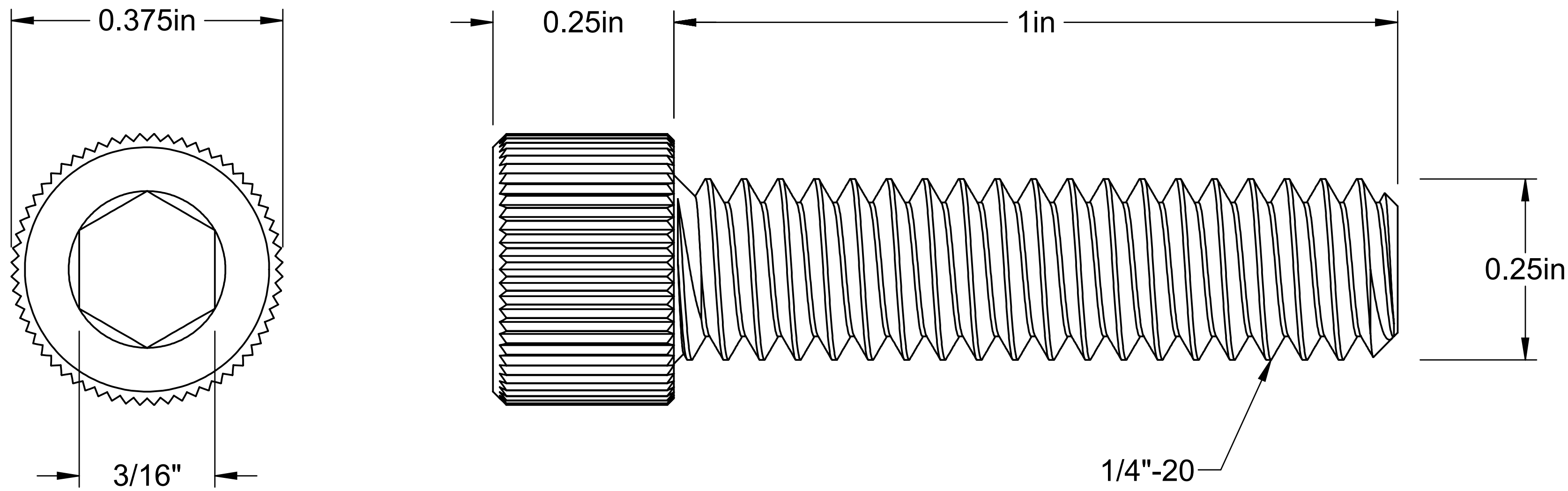
McMASTER-CARR® CAD	PART NUMBER	5631T16
http://www.mcmaster.com 	Face-Mount Shaft Collar	





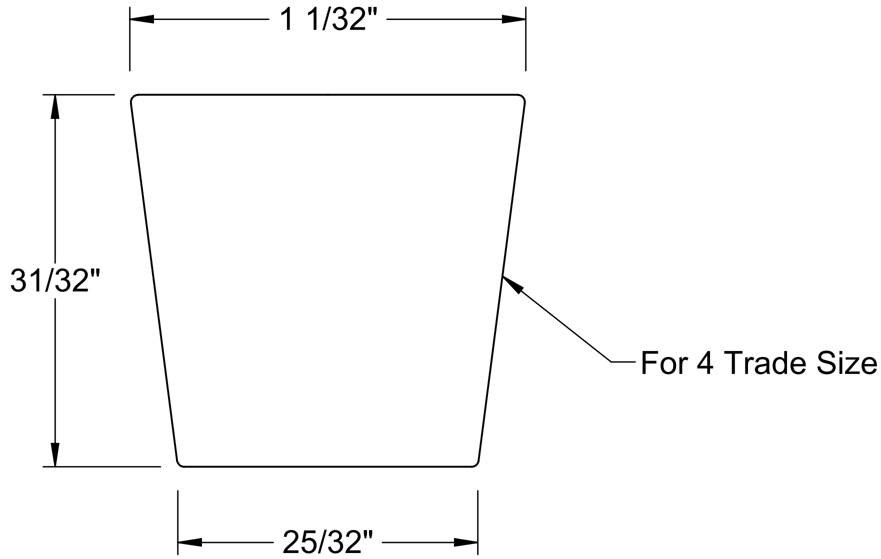
McMASTER-CARR® CAD	PART NUMBER	92785A433
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	18-8 Stainless Steel Cone-Point Set Screws	





Thread Direction: Right Hand

McMASTER-CARR® CAD	PART NUMBER	92196A542
http://www.mcmaster.com © 2022 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	18-8 Stainless Steel Socket Head Screw	



McMASTER-CARR® CAD

PART NUMBER 9545K16

http://www.mcmaster.com

Information in this drawing is provided for reference only.

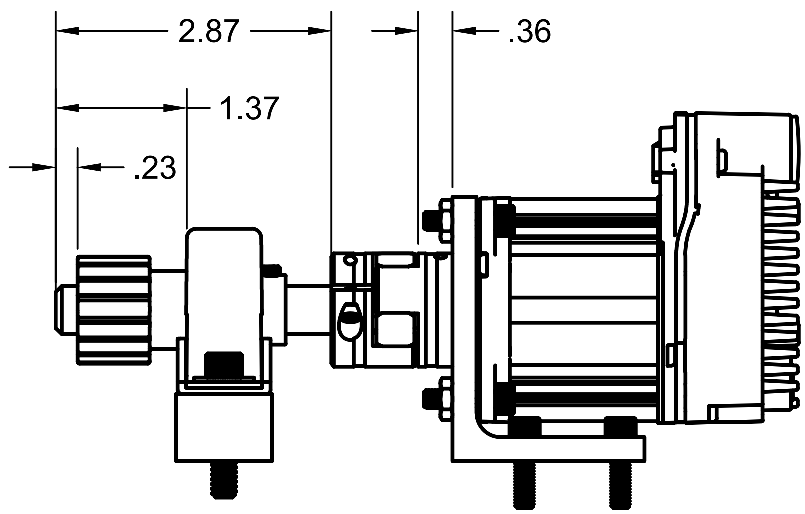
SBR Rubber Tapered Plug

NOTES:

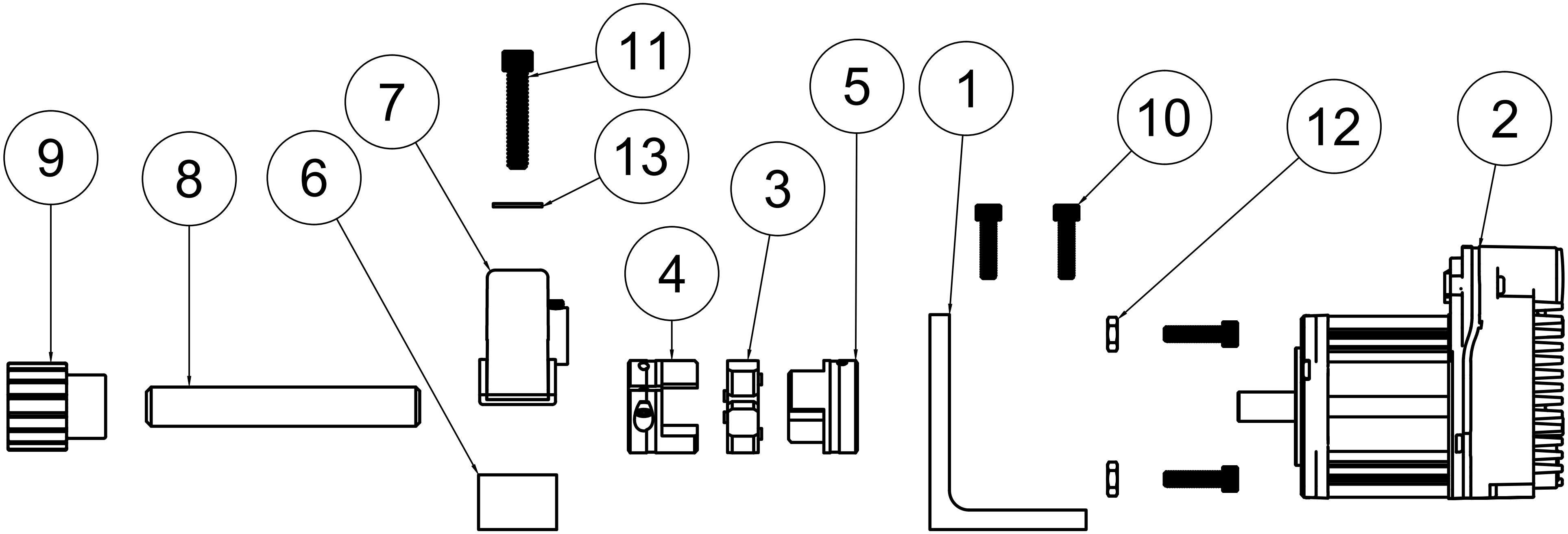
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:

X.X = ± .1
X.XX = ± .05

RELATIVE POSITIONS OF ALL COMPONENTS ON THE PINION SHAFT ARE CRITICAL . POSITION OF THE SHAFT BEARING AND MOTOR-SHAFT COUPLING ARE ADJUSTABLE VIA SET SCREW. SUBASSEMBLY POSITION RELATIVE TO MAIN ASSEMBLY HAS SOME ADJUSTABILITY AND IS CONTROLLED BY MOUNTING FEATURE POSITIONS OF THE MAIN ASSEMBLY BASEPLATE.



NEXT ASB:	FILE NAME: DRIVE/TIMING SYSTEM		
DWG #: 11500			
CHECKED: ME STAFF	SCALE: 1:2	DRAWN: Logan Williamson	5/11/2022



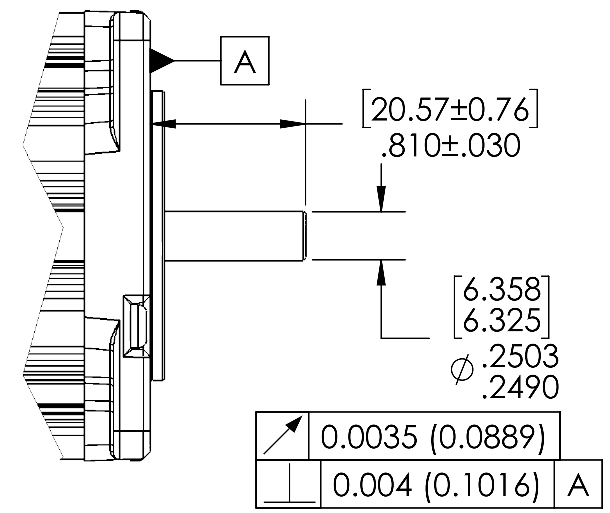
ITEM	QTY	PART NUMBER	DESCRIPTION	MATERIAL
1	1	11540	Motor Mount	304 Stainless
2	1	11520	Clearpath MCPV-s Servo	Various, Plastic
3	1	11573	Damping Motor Coupling Spider	Hytrel Rubber
4	1	11572	$\frac{1}{2}$ in Clamping Shaft Coupling	6062 Aluminum
5	1	11571	$\frac{3}{8}$ in Clamping Motor Coupling	6062 Aluminum
6	1	11595	Pinion Bearing Riser	304 Stainless
7	1	11592	Pinion Bearing	Steel
8	1	11594	Pinion Shaft	1045 Carbon Steel
9	1	11591	Pinion	1020 Carbon Steel
10	8	11593	10-32 UNF Bolts	18-8 Stainless
11	2	11596	1/4-20 UNC Bolts	18-8 Stainless
12	4	11597	10-32 UNF Nuts	18-8 Stainless
13	2	11598	1/4-20 Washers	18-8 Stainless

NEXT ASB:	FILE NAME: Drive System Subassy
DWG #: 11500E	
CHECKED: ME STAFF	SCALE: 1:2
DRAWN: Logan Williamson	5/8/2022

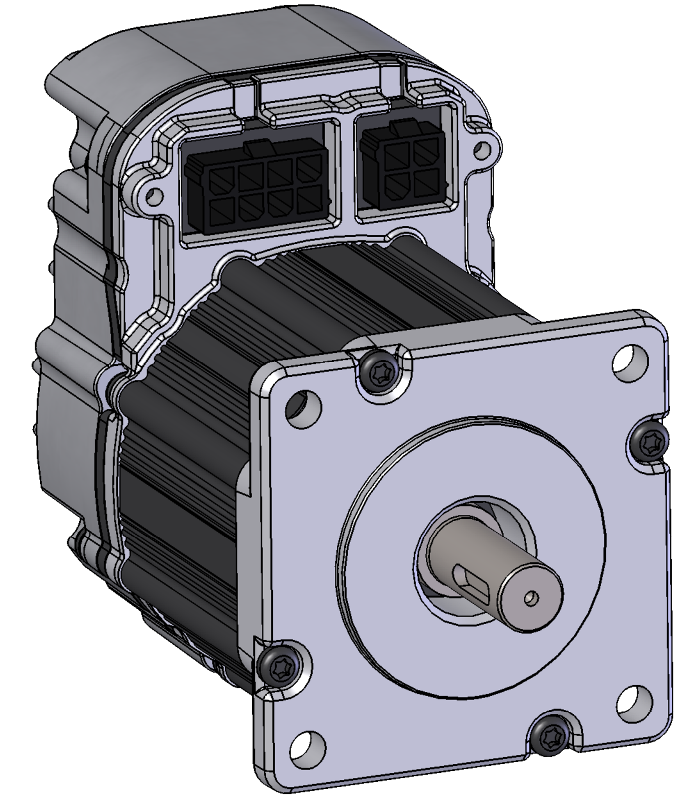
Teknic ClearPath®
Fractional HP, DC Input
NEMA 23

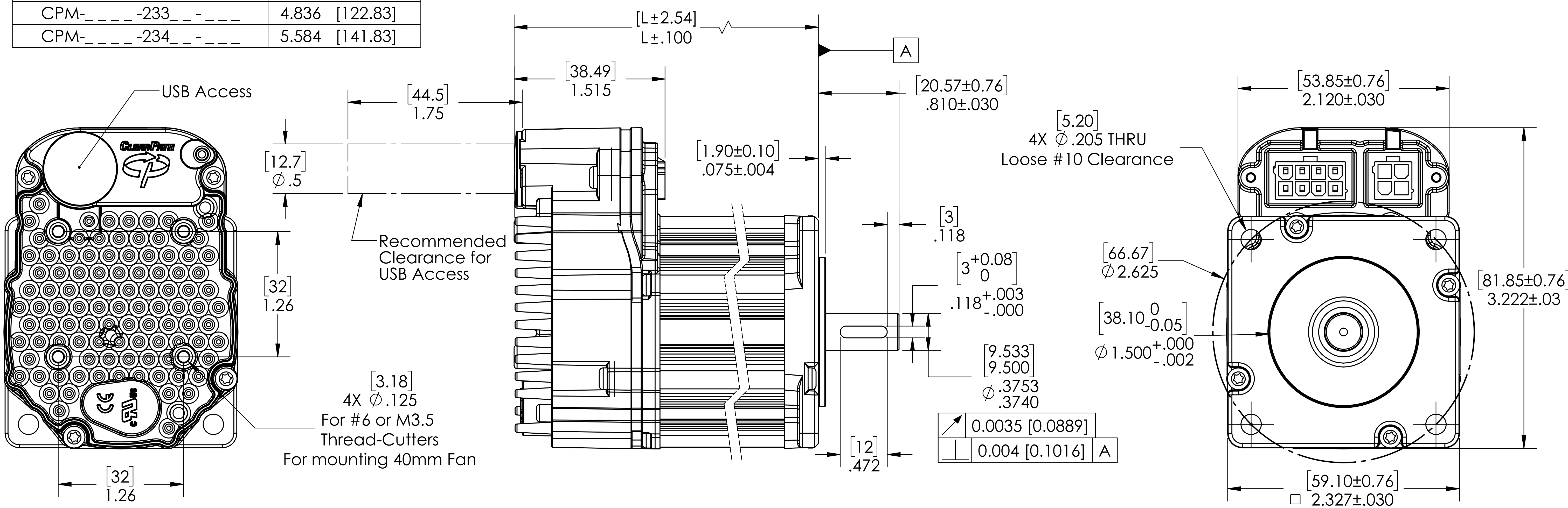
- All dimensions are in inch [mm] unless otherwise noted.
- Sheet Scale 1:1
- Undimensioned features are per 3D file for model of interest for reference use.
- Unless otherwise specified untoleranced dimensions are nonbasic and default to:
  - **X.XX: ± .010" [0.25mm]**
  - **X.XXX: ± .005" [0.125mm]**
  - **Angles: ± 1°**

Model Number	L
CPM-_ _ _ _-231_ _ -_ _ _	3.339 [84.81]
CPM-_ _ _ _-232_ _ -_ _ _	4.088 [103.83]
CPM-_ _ _ _-233_ _ -_ _ _	4.836 [122.83]
CPM-_ _ _ _-234_ _ -_ _ _	5.584 [141.83]



Optional 1/4" Full Round Shaft (No keyway)
Available for 231 and 232 Models





DWG. NO./REV D1171/I

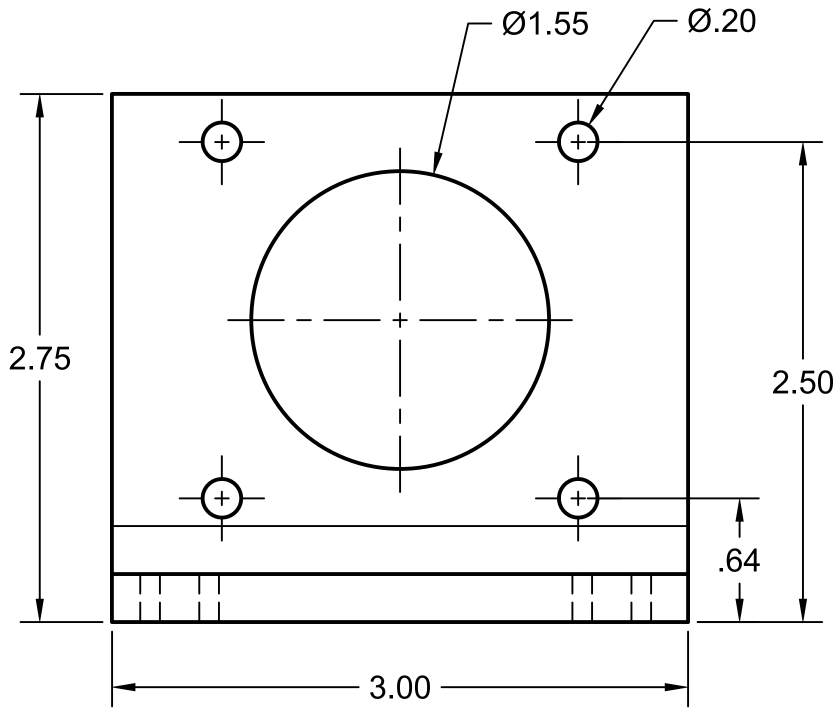
TITLE: 23XX ClearPath Motor Family

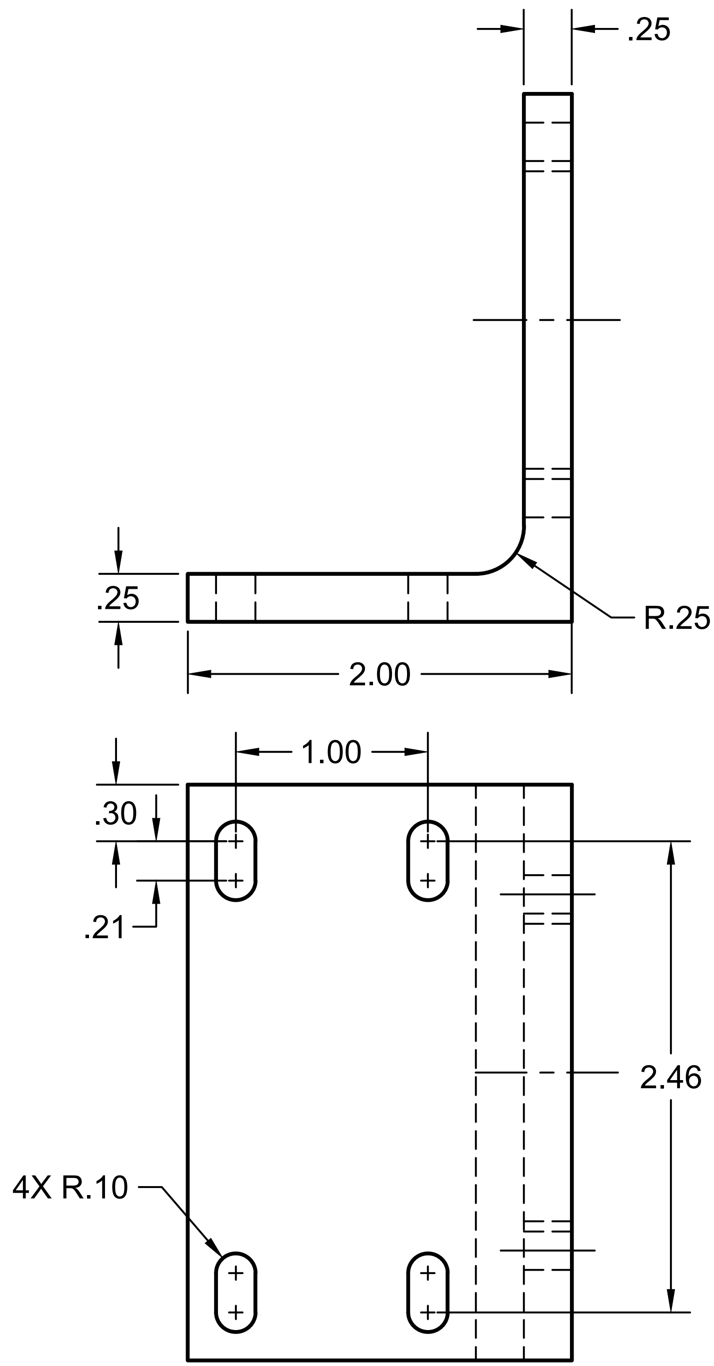
Teknic, Incorporated
Victor, NY 14564 USA

Third-Angle Projection

Interpret Geometric Tolerances per ANSI/ASME Y14.5 (2009)

Additional documentation including product specifications, up-to-date compliance information, and manuals can be downloaded from Teknic's website. Visit https://www.teknic.com/ to access that documentation.

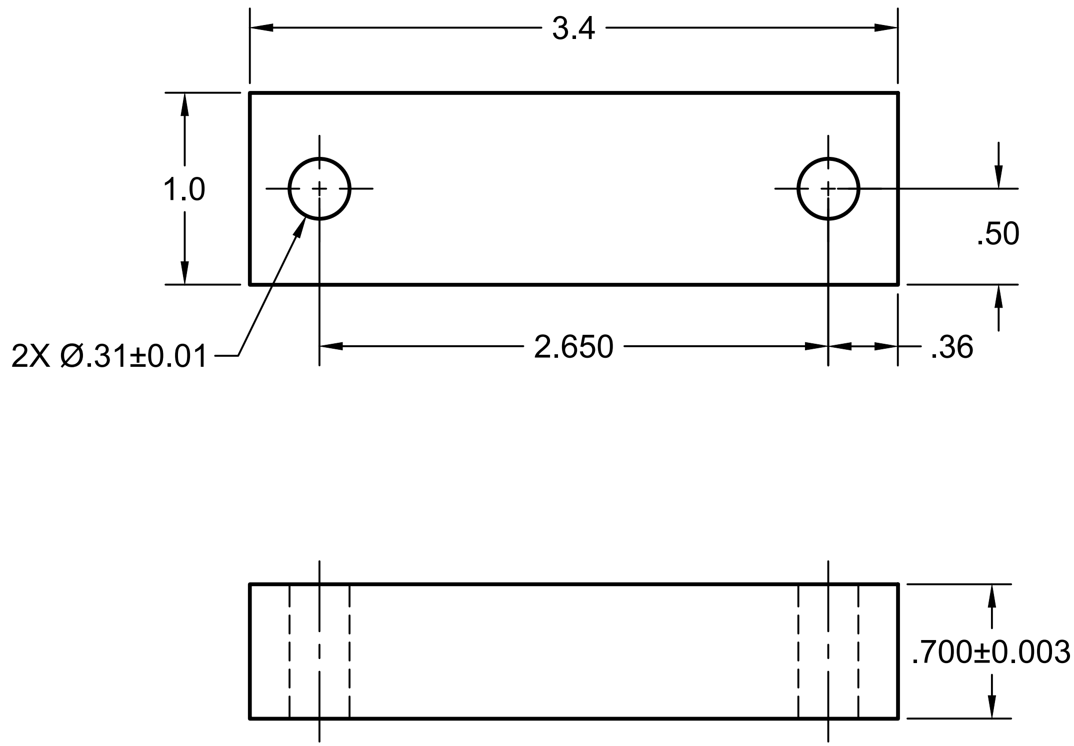




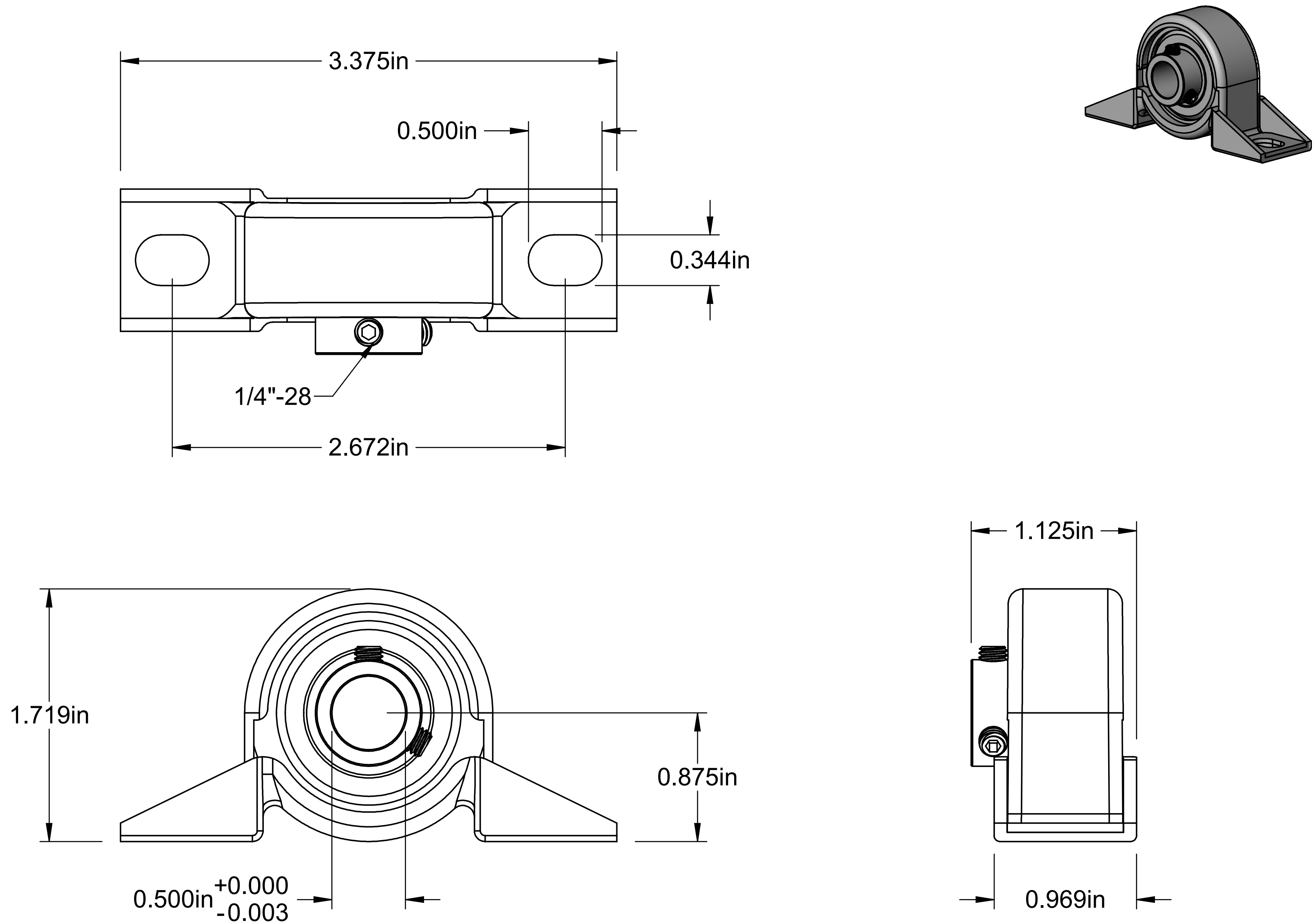
NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .01

MATERIAL: 304 STAINLESS	FILE NAME: Motor Mount	
DWG #: 11540		
CHECKED: ME STAFF	SCALE: 1:2	DRAWN: Logan Williamson 5/6/2022

NOTES:
UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ±0.1
X.XX = ±0.05
X.XXX = ±0.005



MATERIAL: 304 STAINLESS	FILE NAME: Pinion Shaft Mount		
DWG #: 11595			
CHECKED: ME STAFF	SCALE: 1:1	DRAWN: Logan Williamson	5/9/2022

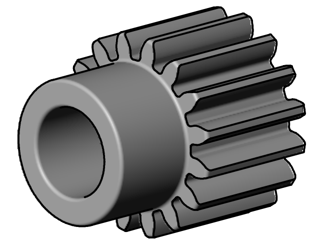


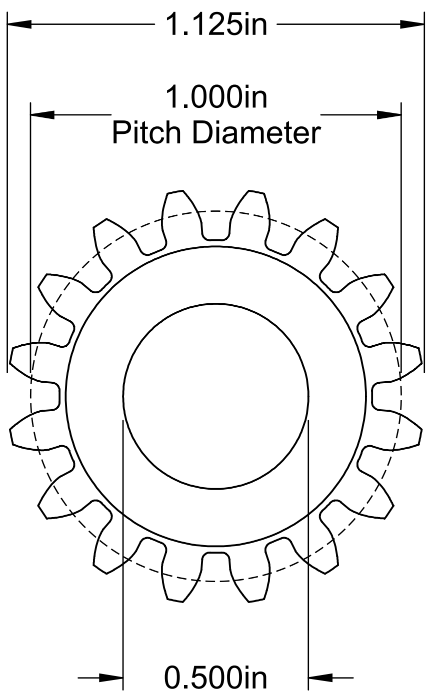
McMASTER-CARR® CAD

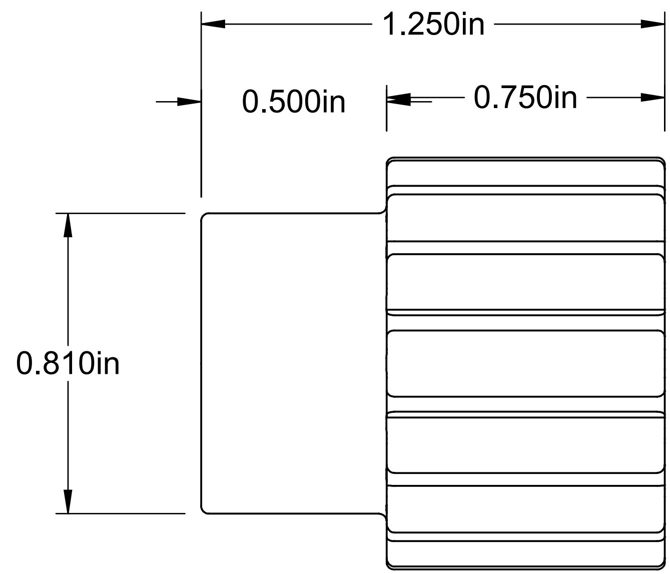
PART NUMBER **5913K61**

http://www.mcmaster.com

Low-Profile Mounted Sealed Steel Ball Bearing

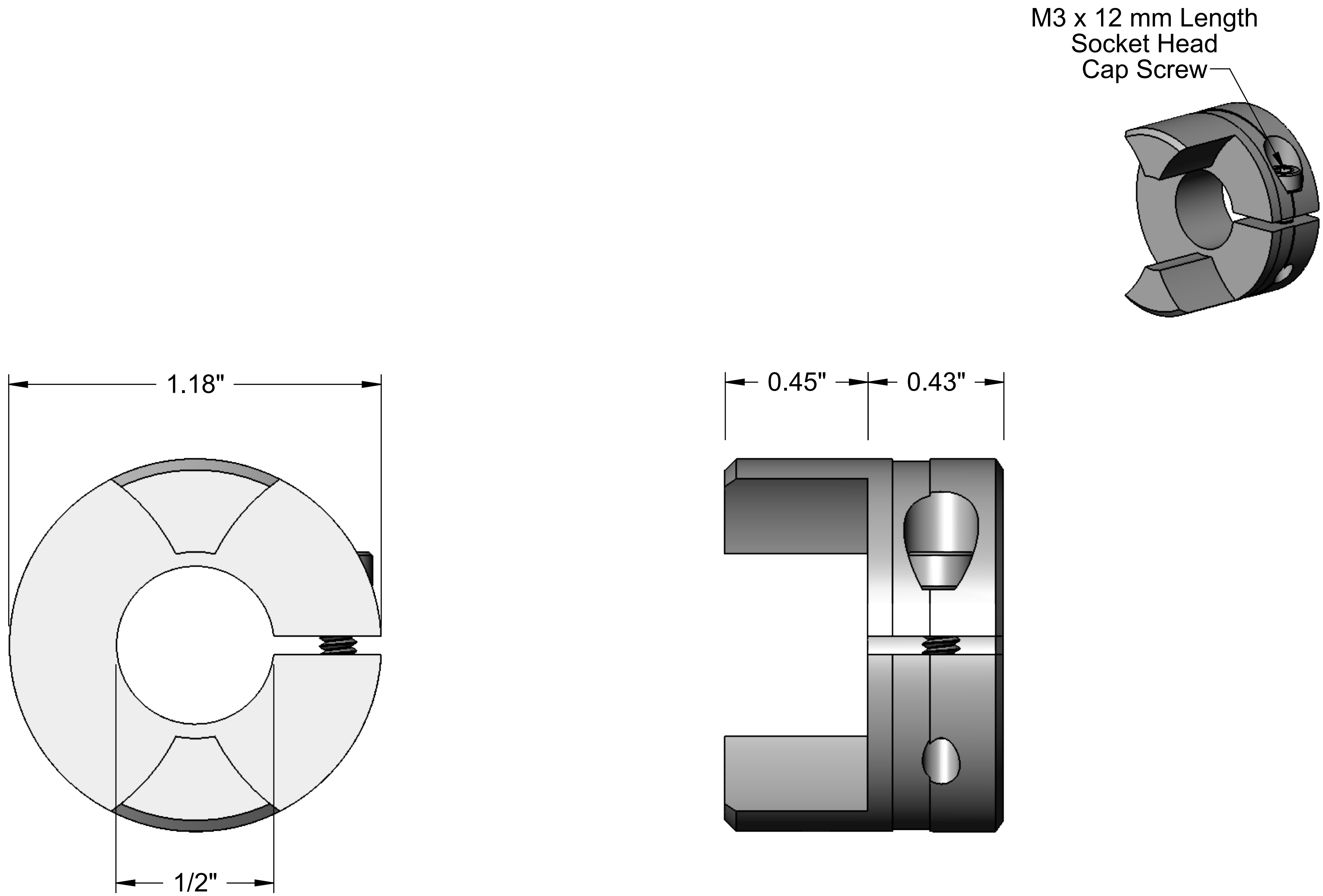






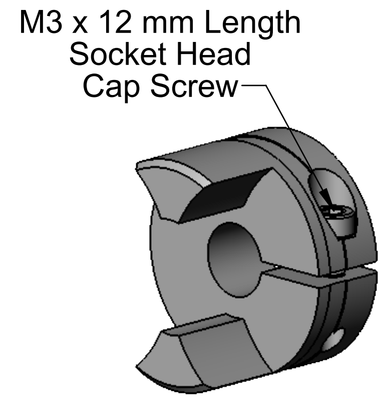
Pressure Angle: 20°
Gear Pitch: 16
Number of Teeth: 16

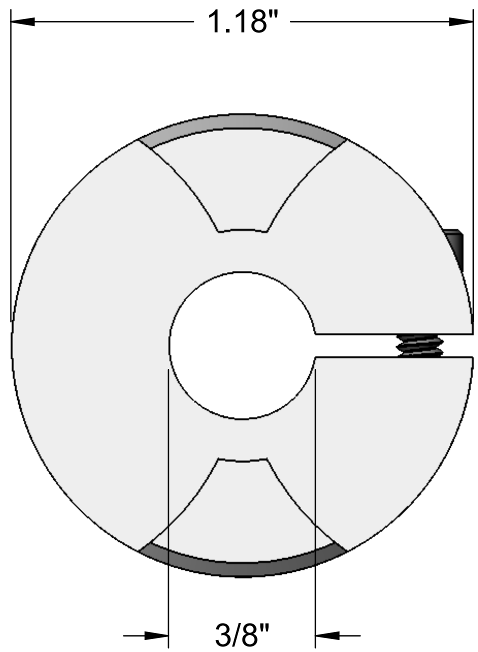
McMASTER-CARR® CAD	PART NUMBER	5172T21
http://www.mcmaster.com © 2022 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Metal Gear - 20 Degree Pressure Angle	

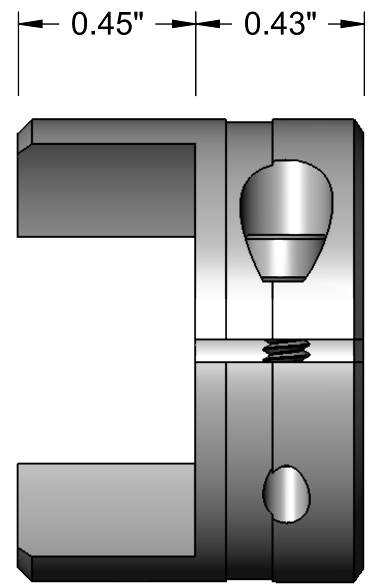


Complete Coupling (Two Hubs and One Spider) Overall Length ERROR!:Overall Length1.38"

McMASTER-CARR® CAD		PART NUMBER	2401K154
http://www.mcmaster.com		Clamping Flexible Shaft Coupling Hub	

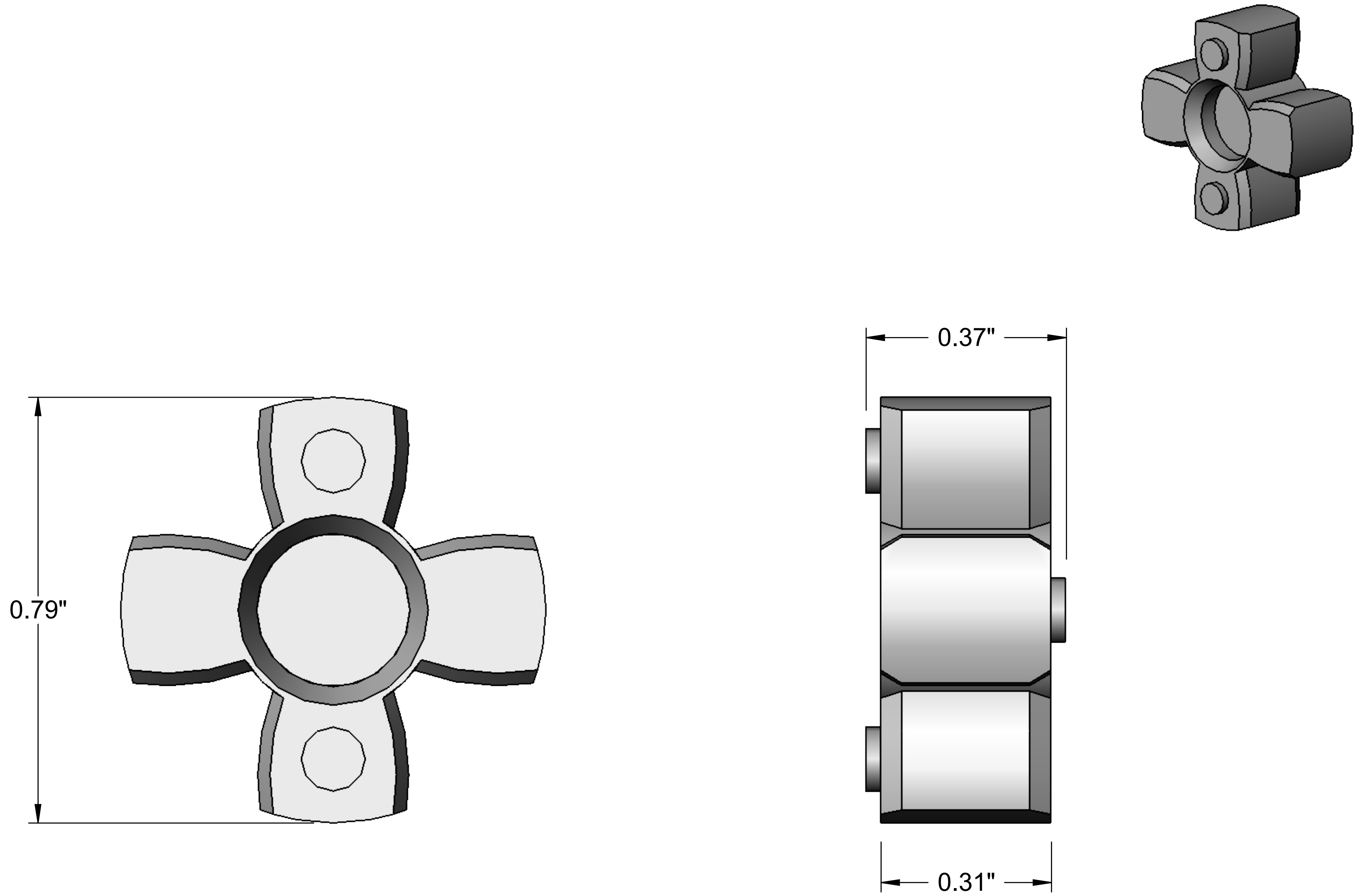






Complete Coupling (Two Hubs and One Spider) Overall Length ERROR!:Overall Length1.38

McMASTER-CARR® CAD	PART NUMBER	2401K153
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Clamping Flexible Shaft Coupling Hub	



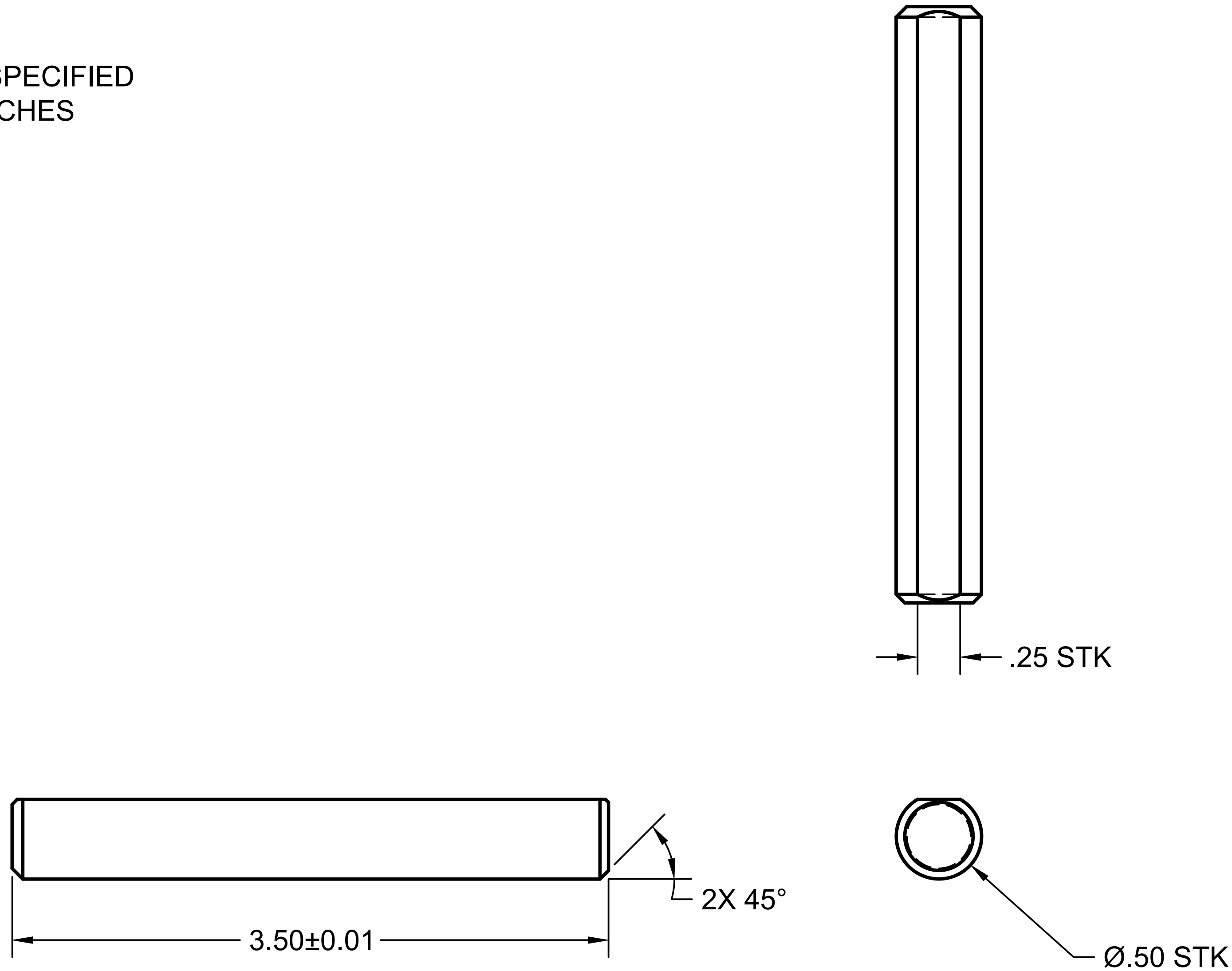
McMASTER-CARR® CAD

PART NUMBER **2401K84**

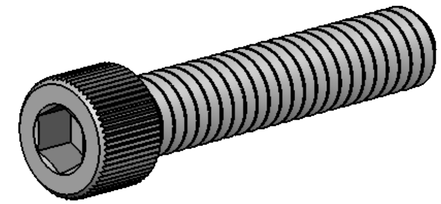
http://www.mcmaster.com

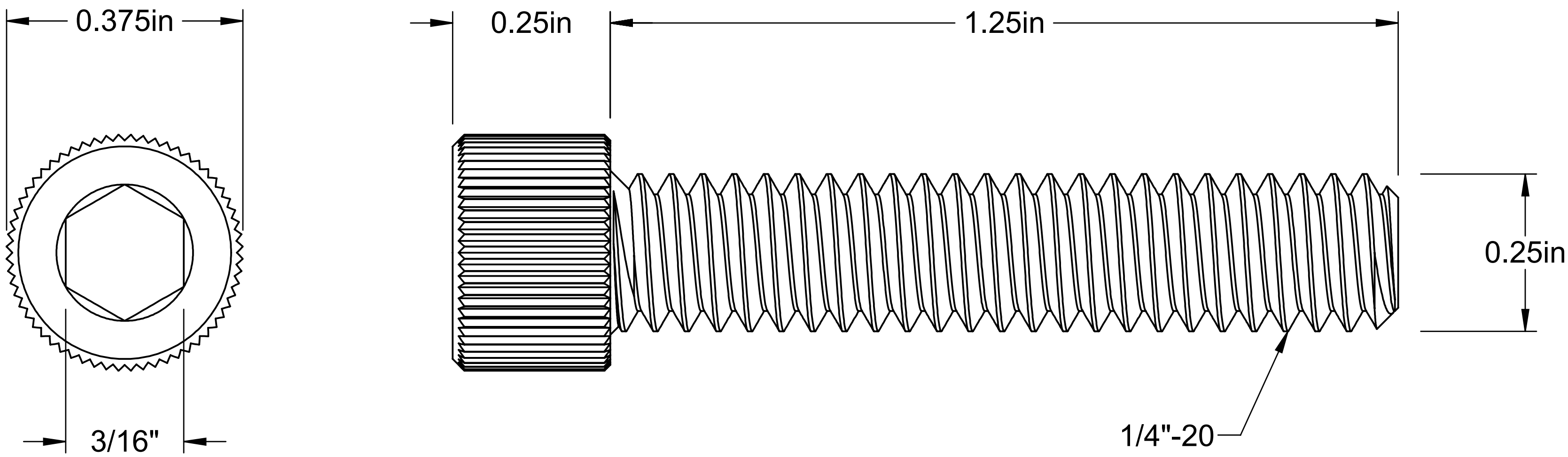
19000 rpm Hytrel Rubber Spider for 51/64" OD Clamping Flexible Shaft Coupling Hub

NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.X = ± .1
X.XX = ± .05
ANGLES:
X° = ± 2°



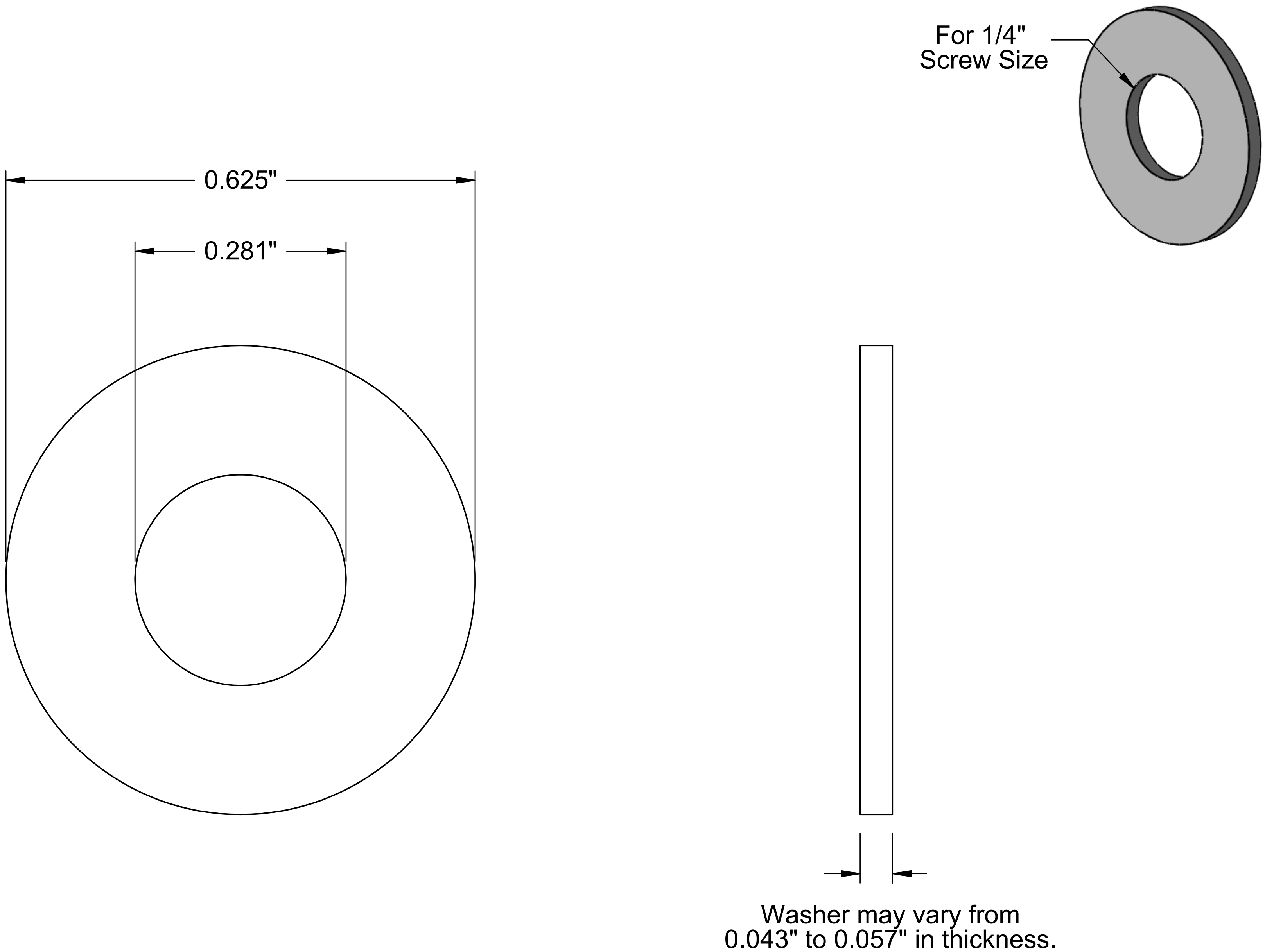
NEXT ASB:	FILE NAME: Pinion Shaft		
DWG #: 11594			
CHECKED: ME STAFF	SCALE: 1:1	DRAWN: Logan Williamson	5/9/2022



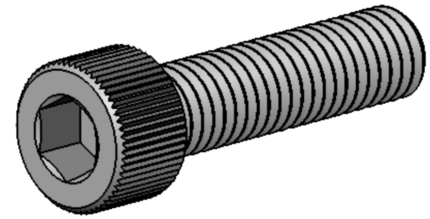


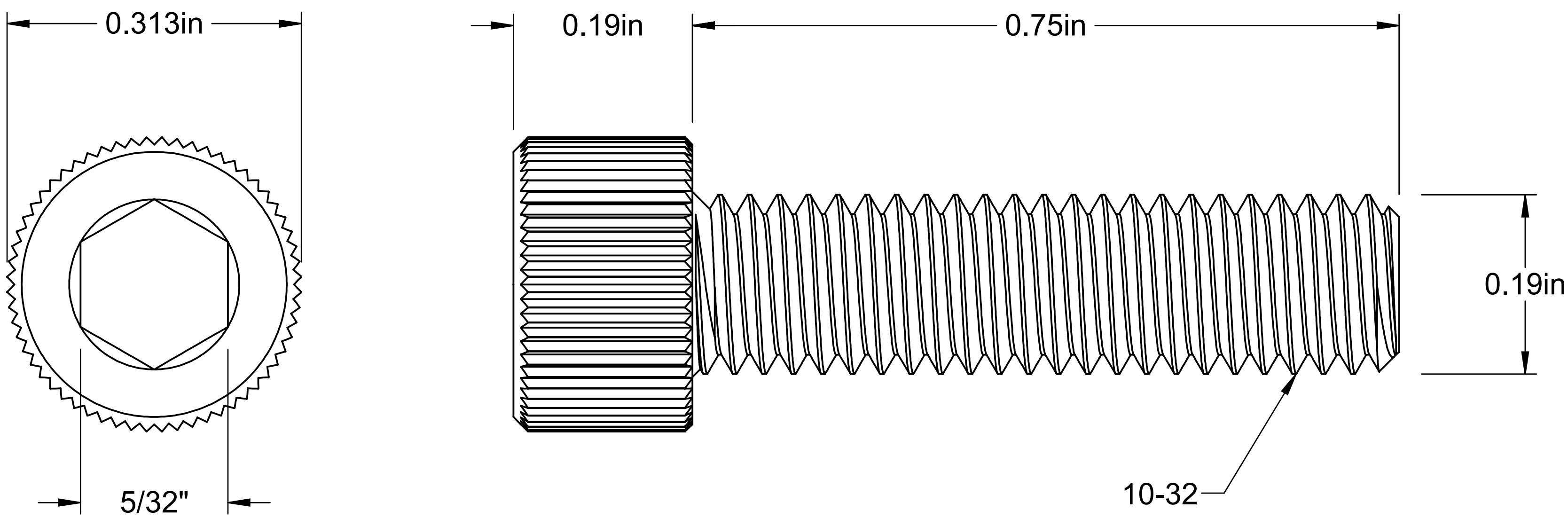
Thread Direction: Right Hand

McMASTER-CARR® CAD	PART NUMBER	92196A544
http://www.mcmaster.com © 2022 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	18-8 Stainless Steel Socket Head Screw	



McMASTER-CARR® CAD	PART NUMBER 90107A029
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	316 Stainless Steel Washer





Thread Direction: Right Hand

McMASTER-CARR® CAD	PART NUMBER	92196A272
http://www.mcmaster.com © 2022 McMaster-Carr Supply Company	18-8 Stainless Steel Socket Head Screw	
Information in this drawing is provided for reference only.		

FDR - Final Design Review

W23 Novelty Ice Cream Product Assembly

To:	Keith Zachow, Project Sponsor	keith@coolbeansicecream.com
From:	Adin Gilman-Cohen	agilmanc@calpoly.edu
	Alvaro Martinez	amart280@calpoly.edu
	Logan Williamson	lwilli47@calpoly.edu
	Mason Sylvester	mssylves@calpoly.edu
Date:	12/5/2022	

Table of Contents

1. Design Updates

Several minor changes were made to our design since the Critical Design Review (CDR). To receive safety approval for the Senior Project Expo, we were required to enclose all moving components of our prototype within a shroud, rather than just the gears. To achieve this, two pieces of shielding were manufactured. The first is a laser cut ¼” acrylic shroud which covers the top of the machine and surrounds the gears and pinion. Two holes are cut in this shroud to allow the filling device our sponsor will select to access the product at the top (12 o’clock) position of the wheels. The second component is a set of two endcaps which fit into the ends of the square tube riser, to prevent the user from reaching into the machine from either side. Finally, the emergency stop we selected is functionally identical to the emergency stop specified in our CDR; however, it is a table-mounted design to remove the need for cutting a mounting hole in the square tube riser. Finally, our sponsor requested that we alter the movement scheme for the device such that it executes two, 30° movements for every motion signal sent to the motor, rather than one 60° movement. This change was easily implemented in the program for the device but does introduce a more-rapid onset of positional error stack-up due to the inherent error in the motor encoder. Since every 60° movement now requires two separate movements, the position of the prototype drifts from the selected setpoint position twice as quickly. This means that the user will need to manually adjust the system position every ~300 units produced, rather than every 600 units as determined by testing.

2. Manufacturing

Manufacturing of our prototype began on schedule during week eight of Spring quarter. A breakdown of the updated manufacturing timeline can be seen on the Gantt chart attached as Appendix A. Most materials were acquired prior to or during the manufacturing that occurred during weeks eight, nine and ten of Spring quarter. Additional purchases, such as the dust collection system and minor hardware purchases, were made during September and October as we progressed through the manufacturing phase and neared completion of our prototype construction.

1. Motor Mount
    - Major Operations

The first component our team manufactured was the mounting bracket for our motor. During the final weeks of Spring quarter, the stock for this component was cut to size from a 6” piece of stainless-steel L-bracket stock using a horizontal bandsaw. The surface was re-finished using a facing endmill on the manual mill in the Cal Poly machine shop. Mounting holes for the motor were then drilled. A plunging endmill was used to cut ¼”-20 bolt clearance slots into the base of the bracket for fastening it to the baseplate. The final operation for this component was to drill a pilot hole in the vertical mounting face of the bracket, then bore it to the correct diameter to accommodate the protruded face of our motor. This final operation was completed in September.

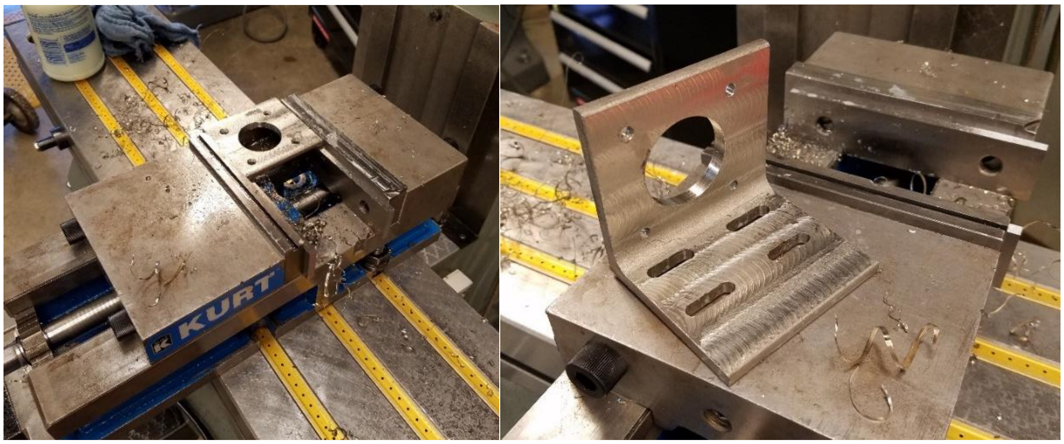


Figure 1. Motor mounting bracket manufacturing

- Challenges

During this slotting operation, the slot features were unfortunately dimensioned from the opposite edge of the component rather than the dimension reference datum due to fixturing the component upside-down. This was easily remedied by extending the slots towards the datum edge, which resulted in longer slots than specified in the drawing. This change remedied the manufacturing error and maintained the functionality of the component without having to use additional stock. Drilling of the pilot hole for the motor shaft was initially started with a step drill. This proved to be a poor choice of tooling, as the collet used to hold this drill bit was unable to transmit sufficient torque once the step drill diameter of 3/4” was reached; at this tool diameter, the step drill bit seized while the mill spindle continued to spin. We needed the pilot hole to be at least 31/32” for the boring head to be used to widen it to the final 1.55” diameter. This was achieved with a 1” drill bit before boring of the hole was conducted.

- Recommendations

The manufacturing of this component would be simplified by making two long slots across the width of the mount base. Having to machine four separate features was unnecessary and added to our manufacturing time due to the additional measurements required. We recommend milling two slots with 1/2" edge-edge distance between each edge of the slot and the corresponding edge of the mount base. This would save time in the manufacturing of the component (at the cost of minor additional tool wear). Drilling the pilot hole for the motor mount could be improved by starting with a 1/4" drill bit and increasing the bit diameter by 1/4" until the hole is 1” diameter. Boring this feature to its final size was relatively easy and resulted in an excellent final surface.

2. Shafts

- Major Operations

The second component, started shortly after were the two shafts that our wheels, bumpers, bearings, and gears would later go on to. From a 2-foot section of 304 stainless steel we cut two pieces down closer to final size on the horizontal bandsaw. Once we had two more manageable sized pieces, we put them in the lathe and faced them down to the final length and added chamfers to both ends on the inner and outer diameters. Once the shafts were the correct length we put the shafts on the mill with V-blocks and spot drilled the two of the holes for vacuum to be pulled through the wheels, then proceeded to drill them larger until the final ½” diameter holes were made. Once the holes were made, we turned the shaft 90° then and repeated the same process for the other two holes.

Figure 2. Shafts ready to be deburred

- Challenges

The main challenge that we encountered when manufacturing the shafts were drilling the vacuum holes. The problem that we were having was that we were using too large of increments when stepping up in drill bit size on the first two holes so drilling them was extremely hard was causing the metal to work harden. Since this was one of the first parts that we manufactured we did not know how difficult machining stainless steel would be.

- Recommendations

Make sure not to cantilever section of shaft being drilled and use a step drill to produce clean small increments in the hole size.

3. Shaft Bumpers
   - Major Operations

   The shaft bumpers were one of the final parts that we manufactured. Starting with a 1-foot section of Delrin round stock, the first operation was to cut off a piece closer to the final size using the miter saw. Once a smaller piece was cut, we put it on the lathe then drilled a 1/4" hole in the middle so a live center could be used as a support. Once supported the lager outside diameter was turned down once to size using a ¾" drill bit the center bore was started then a boring bar was used to take the hole to final size and to make the recess that covers the shaft collars. The piece was then turned around in the chuck and the smaller of the outside diameters was turned to size then parted to length. This same process was then repeated for the second bumper.

   - Challenges

   The manufacture of the shaft bumpers was straightforward the only challenge was with the first attempt at making the bumper we turned down the smaller of the outer diameters first then drilled the shaft bore which left very thin material to hold on to when we flipped the part around which led to the tools moving the part in the lathe chuck.

   - Recommendations

   When manufacturing using plastic allow for the plastic to cool before taking measurements or test fitting. This is because the heat generated when cutting is enough to make the shaft bore expand enough to fit over the shaft directly after cutting but shrink to an interference fit once cooled making it difficult to install and remove later.

4. Finger Guard
   - Major Operations

   The Finger Guard assembly consists of two separate parts that were manufactured and joined together by a hinge. The first part that was manufactured was the finger guard riser. The riser was made from a piece of 316 stainless steel corner bracket. The original stock was 3" long, so the first thing that was done was cutting the stock to length. The metal cut-off saw was used to cut the bracket down from 3" to 2 1/2". This was done to reduce the amount of material that would need to be removed using the mill, and thus reducing the time for machining. Once the bracket had been cut down, we used an endmill to machine the length of the riser to 2". Then, the height and width of the riser were each machined down to 1.7". Lastly, there were two holes made to allow for the mounting bolts to go through. The holes were made using the drill press. The holes were positioned by placing the hinge in place and center drilling the correct position based on the hinge hole spacing.

   The next part that was manufactured was the finger guard cover. This part was made using a 304 stainless steel U channel. The first thing that was done was cut the stock down from 6" to just longer than 3.5'' using the cut-off saw to reduce the amount of material that would need to be removed using the mill. Then, using an endmill, we machined down the length of the U channel to 3.5". The walls of the U channel were 1" high, so the first thing that had to be done was machine the walls down to 0.4’’. We used an endmill to remove the excess material from the walls of the U channel from 1” to 0.4”. The next thing that needed to be done was make two holes to allow for the mounting bolts to go through. The holes were made using the drill press. The holes were positioned by placing the hinge in place and center drilling the correct position based on the hinge holes.

Once we had the two parts made, the hinge was attached to the riser using the 2 mounting bolts and nuts. Then, the finger guard cover was attached to the hinge using the 2 mounting bolts and nuts. Once the assembly was together, the assembly was welded onto the vacuum tube.

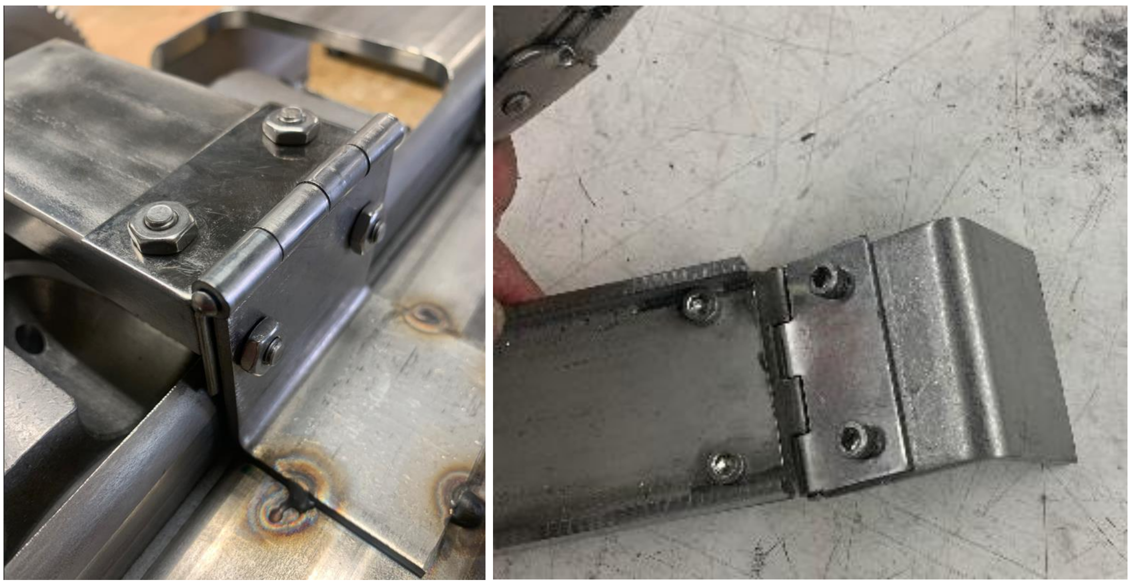


Figure 3. Assembled finger guard components (right). Finger guard welded to vacuum tubing (left).

- Challenges

One of the challenges that we encountered was that the hinge was not to precisely made, so we had to put the hinge in its correct position and then use a centering drill bit to accurately position the holes. A slight misalignment of the center drill caused the hinge to be mounted slightly off center, but there is no noticeable effect. Also, the mounting nut would hit the sides of the finger guard cover if inserted from the bottom, so they need to be mounted to the hinge from the top.

- Recommendations

When making the holes on the drill press, make sure that the parts are tightly secured because a slight movement of the part when center drilling can cause the holes to be misaligned. The mounting nut hits the sides of the finger guard cover on the bottom so make sure to place on top side of the guard or use an endmill to remove material to allow for the mounting nut to fit on the bottom as well.

5. Gear Modification

- Major Operations

The gears used to drive our mechanism were acquired during the summer. These components needed to be modified from their original 3/4" diameter bore to accommodate the 1” shafts we mounted them to. This was done by placing each gear on two 1-2-3 blocks and using toe clamps to fasten them to the mill table. A coaxial indicator was mounted in the spindle of the mill and used to adjust the mill’s x- and y-coordinate zeros such that the spindle axis was colinear with the existing bore axis of the gear. This ensured our new 1” bore would not be eccentric from the axis of the gear, which could prevent proper mesh of the gear teeth. A center drill was then used to locate the two holes on either side of the bore which the clamping shaft collar hardware mounts through. These were then drilled to the proper clearance for the ¼”-20 hardware. Returning the mill table to the coaxial home location, a step drill was then used to widen the bore to 3/4”, followed by a boring head to expand the hole to our specified 1.010” diameter.

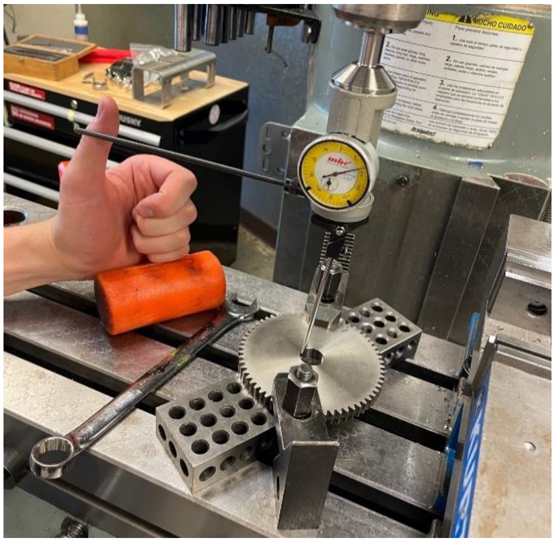


Figure 4. Gear modification fixturing and coaxial alignment with mill spindle

- Challenges

During our manufacturing of the gears, we encountered one issue. Drilling the new bore caused the clearance holes for the shaft collar mounting screws to deform slightly, which made it difficult to pass the mounting hardware through these holes. We were able to place the hardware with some force, but the resulting holes are not proper clearance holes and repeatedly removing the shaft collars from the gears may prematurely wear the threading on these bolts.

- Recommendations

With a professionally maintained mill or CNC, the repeatability of the machine would be improved over the Cal Poly machine shop mills. This enables the operator to bore out the gear prior to drilling the clearance holes for the shaft collar hardware without risking the critical locating positions of the clearance holes. This should prevent the deformation issue we encountered. An even better solution would be ordering custom gears with 1” nominal transition fit bore diameters and keying the gear to the shaft. This approach was cost prohibitive for our prototype, as custom gears were quoted at nearly $2000 for two and would have prevented us from maintaining the gear position adjustability we designed into our mounting solution. For a later model of this design, however, this would be a more-permanent solution.

6. Vacuum Tube

- Major Operations

The vacuum tube needed several hole features drilled into it for mounting and accommodation of the shaft ends for vacuum transmission. To begin, the stock was already an appropriate length as specified in our design. We deburred the open ends and fixed it in a vise to drill holes for the vacuum shafts. Since this stock had a 1/8” wall thickness, we were able to use the step drill to make these hole features without issue. Turning the stock 90° in the fixture, we then drilled two holes through both the top and bottom walls of the component for the mounting hardware. This maintained the alignment of each pair of top and bottom mounting holes, while requiring only two operations and no re-fixturing, rather than drilling all four mounting holes independently.

Figure 5. Assembly of vacuum tube with prototype frame

- Challenges

Upon mounting the vacuum tube to the prototype frame, we realized that there was a small interference between the shafts and the vacuum tube holes they protrude through. To address this, we used a 3/4" endmill to elongate the holes 1/2" towards the lower wall of the vacuum tube, providing sufficient clearance for the shafts. This resulted in a rounded-square shape to the holes but restored functionality of the vacuum tube.

- Recommendations

We are not entirely certain why the interference between the shafts and the vacuum tube arose. It may have been due to another instance of the team member who machined the vacuum holes using the opposite edge of the tube as a datum from the team member who drilled the mounting holes. This could be remedied in several ways. Clear marking and communication of the part datum would have avoided this issue. Moving the mounting holes on the prototype frame down 1/4", such that the holes for the shafts are centered on the clamped face of the vacuum tube would be another solution. Specifying these features as slots, such as those we modified into the final as-built prototype, would prevent this issue as well.

7. Pinion Shaft

- Major Operations

The pinion shaft was a surprisingly challenging component to manufacture. Using the mini lathe, the diameter was turned down to produce a 0.002” interference with the pinion bore, as measured with a gage pin and micrometer. The ends of the shaft were then chamfered for the press fit operation, and to produce a proper contact surface between the motor coupling spider and the end of the shaft clamped in the coupling. The shaft was then chilled in a freezer before being press-fit into the pinion using a hydraulic press. A tap guide was used to provide rotational constraint on the shaft during this operation.

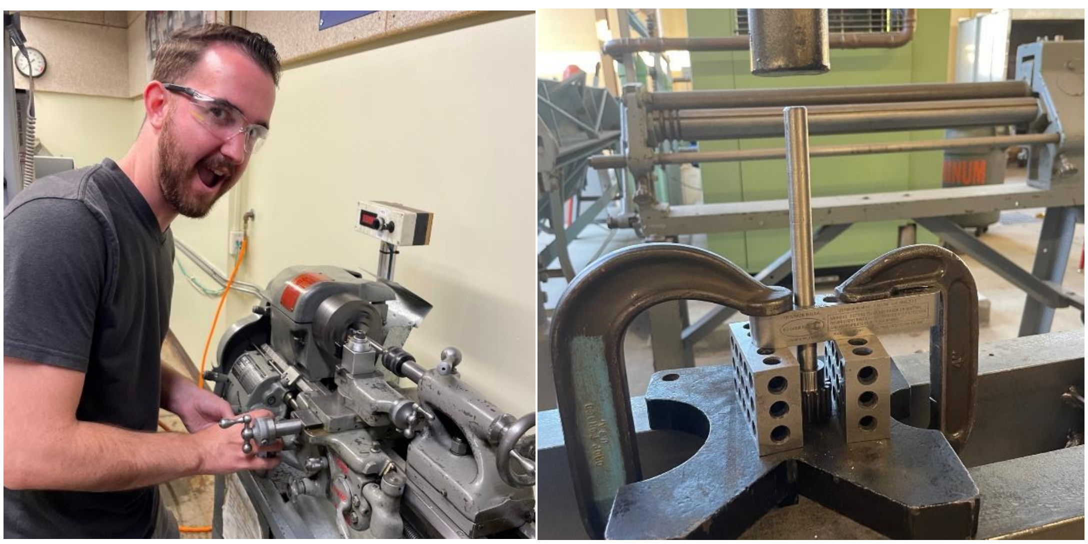


Figure 6. Turning pinion shaft (left) and press fit fixture for mounting pinion to completed shaft (right)

- Challenges

While turning the shaft, we encountered deflection issues at stick outs of ~3” or greater. This was addressed by simply center drilling the shaft and using a live center to support the end opposite the lathe chuck. Unfortunately, the repeatability of the mini lathe is on the order of 0.005”. This made it very difficult to accurately turn down the shaft diameter, even after fixing the deflection issue. We worked around this issue by taking careful measurements with a micrometer after every pass on the lathe, to ensure we did not undersize the shaft diameter for our desired press fit interference. The pinion shaft bearing was slightly undersized, so the portion of the shaft not engaged with the pinion was turned down an additional 0.010” to produce a sliding fit with the bearing.

- Recommendations

We ended up with a custom shaft that is difficult to reproduce due to our part selection. If we were to redesign the pinion shaft, the best place to start would be ensuring that the selected pinion and bearing have appropriate bore tolerances to guarantee a sliding fit with the bearing and interference fit with the pinion. Our final dimensions deviated significantly from our drawing specifications to adjust for this lack of foresight and will need to be updated meticulously if this manufacturing process is to be reproduced.

8. CNC Parts- Wheels and Square Tube Riser

Our team contracted the manufacturing of three parts, the two wheels and one square tube riser, to a CNC machinist. The wheels clearly had to be produced on a CNC mill due to their shape of the rounded handling slots. The Square tube riser could technically be produced on a manual mill, but we did not feel we had the machining skills to do this given the tight tolerances and large amounts of material to remove.

- Major Operations

The stock for both parts was prepped to go into the CNC vice. The round stock for the wheels was cut to length, faced on a mill, and had a ridge cut into the bottom for a vice to clamp on. A custom negative was milled to clamp the irregular surface of the wheels while milling off this ridge in later operations. The square tube had its end flattened by turning it on a lathe with a four-jaw chuck and a custom 3D printed plug to support the hanging end.

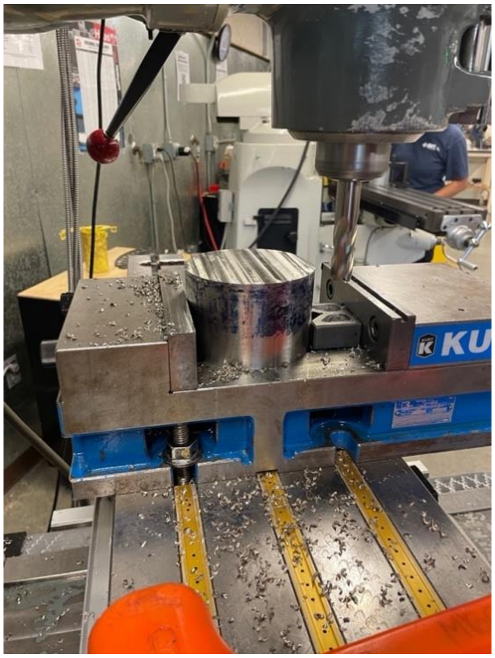


Figure 7. The round stock is face milled on manual mill to be fixtured in CNC mill

Figure 8. Wheel Fixtured in CNC mill

Figure 9. The finished wheel has too large of a hole for the shaft to pass through.

Figure 10. The square tube fixtured in the CNC mill

Figure 11. The square tube having its ends faced on the lathe before being fixtured in CNC mill

- Challenges

These parts presented many challenges. The main issue was that the parts were delayed multiple times and were finished months later than initially agreed upon. This was due to school machines being upgraded and replaced, the schedules of our machinists, and the operations taking longer than expected. The first version of the square tube riser was machined from an old version that did not have important dimensional updates and had to be remade at the machinist's expense. The wheels were made with a shaft hole that was oversized by about 0.05" due to an error on our team's part in the CAD sent to the machinist. This was rectified with a piece of shim tube placed between the wheel and the shaft.

- Recommendations

If making these parts again, we would have a more formal communication pathway with our machinists involving a written contract at the beginning clarifying the expectations, price, and contingency plan if things don't go as planned. The fact that we started this part so early compared to our other parts was good planning, because the parts were finished just in time after the delays.

9. Bronze Bushings

- Major Operations

The bronze bushings from McMaster were clamped in the lathe and a parting tool was used to cut ¼ inch slices off the end. Then the edges were cleaned with a deburring tool. The slices were press fit into the square tube riser by supporting the inside of the square tube riser with a machinist's screw and pressing on an aluminum flat plate placed over the bushing to evenly distribute the load.

Figure 12. Bronze bushings cut to size and chamfered

Figure 13. A parting tool us used on a lathe to cut a ¼ inch slice off of a bronze bushing.

Figure 14. Press fitting the bushings into the square tube with hydraulic press. Black machinist screws keep the square tube from deflecting.

- Challenges

The inner diameter of the bushing decreased when it was press fit such that the shafts no longer slid through it. To fix this, we turned down the diameter of the tip of each shaft until it fit into the bushing.

- Recommendations

If the interference of the press fit were reduced slightly (larger holes on square tube riser), the bushings may not have contracted as much.

10. Locating Pins

- Major Operations

A piece of ½” round stock was fixtured in the lathe. The end was faced, turned down the 0.47 inches and chamfered. Then the pin was cut off with a horizontal band saw and the 0.47” diameter end was clamped in the lathe. The 0.5” diameter part was faced, turned down slightly, and chamfered. Then the pin was held in a vice and tapped with a hand die. The inside of the square tube was supported with machinist’s screws that held an aluminum plate against the inside of the holes for these pins. Then the pins were press-fit in using the hydraulic press.

Figure 15. A finished unthreaded pin. The threaded pin is slightly longer.

- Challenges

The calculations for the press fits of the locating pins had an error and the holes in the square tube were 0.491” instead of the 0.498” inches needed for a press fit. We had to fix this by turning the stock 0.5” diameter round stock down to 0.492”. After being press-fit in, our bearings did not slide over our locating pins. We had to clamp the pins in a vice and bend them slightly towards each other to get them to fit into the bearings.

- Recommendations

If made again, the holes in the riser would be the right size and the stock diameter of the pin could be used for the press fit. It would have been better to make all of the locating pins the same length instead of making the threaded pins longer. This would make it easier to slide on the bearing strait and not at an angle. There are only three threads on the threaded pins because of space restraints. More layout work could be done to potentially allow the pins to be longer while still having clearance for the shafts to pull back and up. Making the with a slightly smaller diameter on the part that supports the bearings would make it easier to slide the bearings on and off.

11. Bearing Riser

- Major Operations

A steel rectangle was clamped on the mill and the top and bottom were faced. Then a plunging endmill was used to cut two slots on either side.

- Challenges

The block was slightly too tall when the machine was assembled, and the height had to be reduced with more facing. This may be due to the motor shaft not sitting perfectly parallel to the base plate.

- Recommendations

None

12. Base Plate

- Major Operations

The base plate was the final part that we manufactured this was because we wanted to make sure all the measurements from our CAD were going to work. Once measurements were confirmed we started by removing the section of material that is directly below the wheels. This started by using the vertical bandsaw to make three cuts so the width would be closer to the final dimension and for fixturing reasons. Once fixtured on the mill on top of a piece of ½” plywood a ¼” endmill was used to remove most of the material at the back of the section. To remove the rest of the material an angle grinder was used to cut through the remaining material. Once most of the material was removed, we fixtured the baseplate on the mill in a vise and milled the under-wheel section to final size using a ½” endmill. Then using a #7 drill bit we drilled ten pilot holes that were then tapped with ¼”-20 threads that will be used to mount the frame, motor mount, and pinion bearing to the base plate.

Figure 16. Milling the under-wheel section of the base plate

Figure 17. Adin using the angle grinder on the base plate to cut out the slot

- Challenges

The challenge that we ran into when making the base plate was fixturing the plate on top of the piece of plywood since when we were milling out the back of the under-wheel section it was just pushing the thin layer of metal into the coolant soaked wood below rather than cutting it which got it very hot work hardening the strip of metal which is why we used the angle grinder to cut the remaining strip of material.

- Recommendations

To ease the manufacturing of the base plate a majority of the material could be cut out of the under-wheel section using the vertical bandsaw and angle grinder prior to putting it on the mill to take the section to final size. Another tip would be to fix it in the vise rather than to the table on top of plywood.

3. Design Verification

Our earlier reports outlined 12 engineering requirements for our final design. This section will outline how we tested the success of each requirement. Table 1 below shows the specifications that were tested, along with their specification number, requirements, tolerance, and risk. The description of the test performed for each specification as well as the dates testing was performed, numerical results, and any notes taken during testing is described in the Design Verification Plan and Report located in Appendix B. The acceptance criteria are stated so that there is a firm requirement to meet for the test to result in success. Any special parts needed to perform the test are also noted. For all tests that required the use of a filling marshmallow fluff was used as a stand in for ice cream because of its air content and its ability to stick to itself. We came to this decision through testing other mediums such as peanut butter, mayonnaise, cool whip, etc. and compared the outcomes to what our sponsor has told us about their company's proprietary ice-cream.

Table 1: Engineering Specifications Tested

Spec. #	Specification Description	Requirement or Target (units)	Tolerance	Risk *	Compliance **
3	Visual Damage Check	Shell Unchipped	Min	M	T
4	Shell Alignment	Cannot See Inside Shell	Min	M	T
5	Machine Output	20/min	Min	H	T
8	Configurable Production Quantity or Variable Speed	Possible to Increase Capacity	Min	L	T

The first specification we tested for is visual damage to the shells. In this test we took 50 cool bean shells that were mostly undamaged from shipping from the shell manufacturer and filled each half with marshmallow fluff. Once all shells were filled each half was manually loaded into the top of the wheels, as seen in Figure 1 below, then using the control software they were joined then set aside. Once all 25 beans were complete all were inspected to any damage that was not already present before passing through the machine. In this test we found that none of the 25 beans were chipped or damaged.

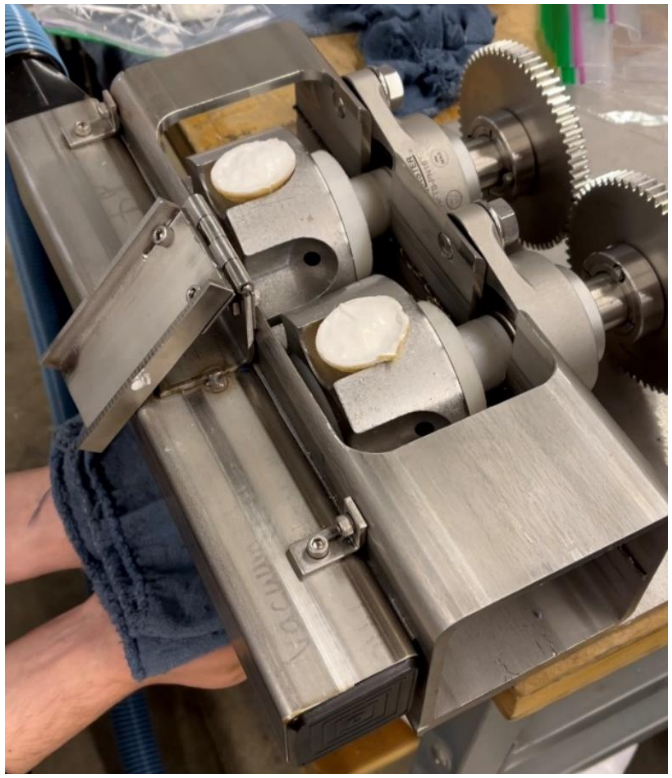


Figure 18: Handloading of shells for damage and alignment testing.

During the same test we conducted a visual test for shell alignment. The requirement for this specification was that the inside of the joined shell cannot be seen. During this test we found that all shells that were not overfilled had perfect alignment. The problem with over filling caused the shells to the spring back once pressed together leaving a gap that allowed for the filling to be seen from the side profile. Out of the 25 beans 10 were selected, the two worst being cherry picked and the rest randomly selected, to send as a sample to our sponsor to see if the alignment was satisfactory. The pictures we sent can be seen in Figures 2 and 3 below. Our sponsor then confirmed that the first two were borderline acceptable, but this misalignment issue would be solved if the shells were not over filled.

Figure 19: Completed cool beans as sent to sponsor.

Figure 20: Completed cool beans as sent to sponsor.

The machine output specification required that at least 20 beans are joined per minute. This specification seeks to enable our project sponsor to produce at least 9,600 units in one standard production shift. To test this specification, we set up our machine's automatic operating mode and allowed the system to run for one hour. This process was repeated three times. The resulting average throughput was 1161 units per hour when the 1200 units per hour throughput setpoint was selected. The discrepancy between the specification and testing results is due to the Python `time.delay()` method used to ensure that the logic-high control signals being sent to the motor controller persist for 25 milliseconds as prescribed by the motor manufacturer, Teknic. The system user interface seen in Figures 4 and 5 is currently configured to allow selection of setpoints from 600-5400 units per hour. This range was tested thoroughly via five-minute tests at 2400, and 5400 unit per hour setpoints. This testing demonstrated that the difference between the setpoint values and the actual throughputs scales linearly with throughput quantity. All available throughput selections produce desirable prototype behavior, and our sponsor has confirmed that the 3.25% discrepancy between setpoint and actual production throughput was acceptable. Additionally, the sum of the delay times has been subtracted from the scheduled control signal events to further reduce this discrepancy; however, this was done since testing and has not been numerically confirmed. To further improve the usability of the prototype, a counter was added to the graphic user interface to retain an accurate count of the units made in each production run.

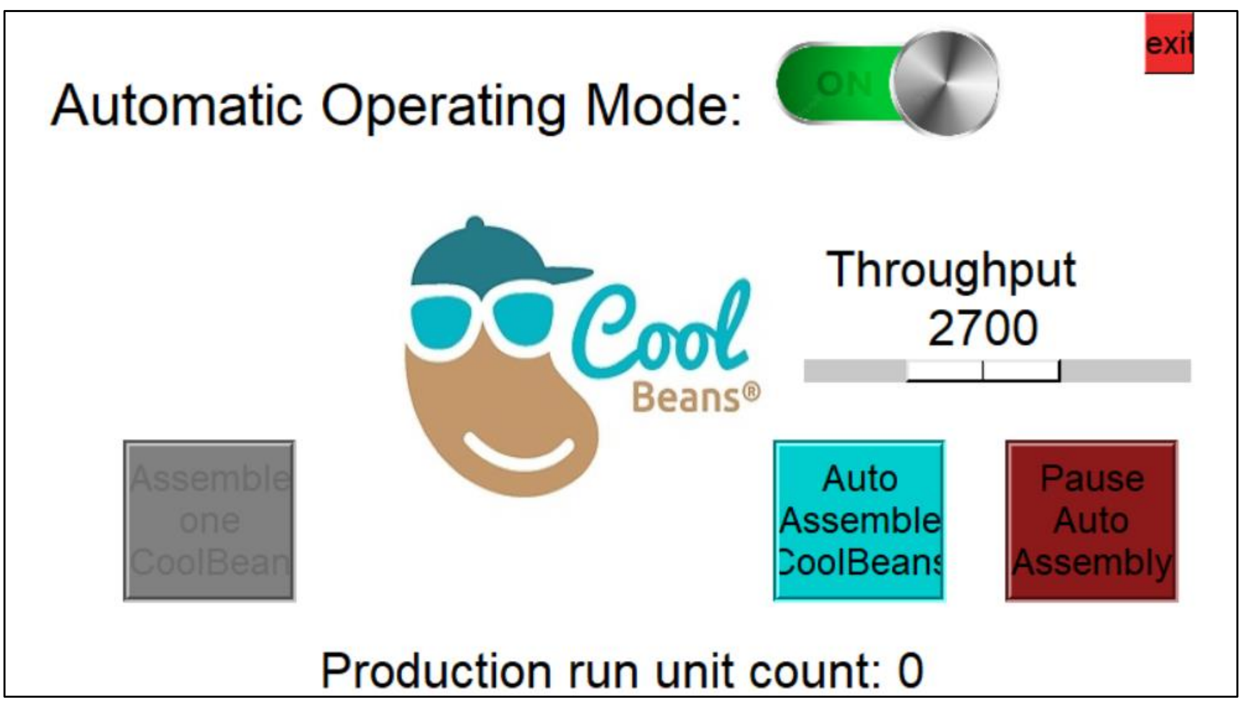


Figure 21: CoolBeans Graphic User Interface final iteration. This highlights the adjustable throughput selection and counter for recording production quantity.

Configurable production quantity is related to the machine output specification, as described above. The current iteration of the graphic user interface allows the user to select any throughput setpoint from 600-5400 units per hour in increments of 60. This is done using a simple slider widget generated in Python's standard `tkinter` library. Additionally, the user can manually actuate the device one increment at a time. The motor motion (i.e. the acceleration ramps) is/are entirely controlled by the Teknic control firmware installed on the motor control board. As such, the acceleration and deceleration behavior of the system is determined only by the motor settings, not by the user interface or throughput setpoint. The user-configurable throughput simply determines the amount of time that elapses between automatic control signal outputs from the Raspberry Pi hosting the interface. Therefore, concerns regarding differences in joining capability due to various production rates are not relevant to the actual operation of the prototype. The limits on the configurable production quantity were selected such that there is at least 1/2 second of stationary time between each movement. This should accommodate any filling equipment our sponsor selects for this prototype. Should our sponsor identify a need for altering the acceleration ramp profile of the motor, this can be done by connecting a PC with ClearPath MSP 2.0 software installed to the motor. This will open a Teknic user interface that allows the operator to adjust and test a new set of acceleration ramp parameters to produce the motion profile they desire.

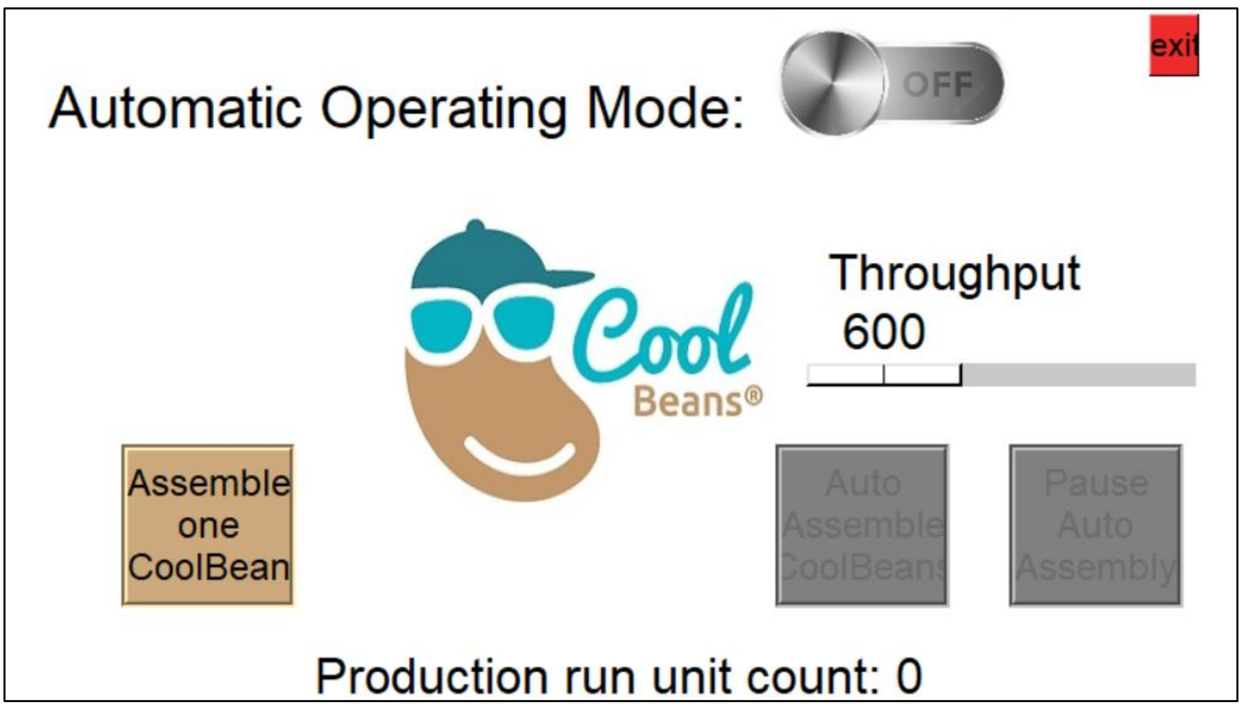


Figure 22: Manual operating mode of graphic user interface.

For our error propagation and uncertainty analysis, the relative positions of the two joining subsystems are indexed to each other, and therefore are not affected by the uncertainty in our motor positioning system. However, the 12 o'clock "filling" position of the device is. Using the manufacturer provided positioning resolution of 0.057° and repeatability of 0.03°, we determined that each movement of the device results in a positional uncertainty of 0.003315° in our prototype. This means that for a full production run of 10,000 units, the device will need to disabled with the emergency stop, adjusted, and re-enabled several times to ensure the filling position of the cones has not drifted from the desired position.

The remaining specifications include air content, down time, and head count. We have determined that these all depend heavily on elements outside of our scope and could not be meaningfully tested with just our verification prototype. The air content will primarily be influenced by the filling method, which is outside of our scope. The time to disassemble the machine can be measured, but the time to clean the parts will depend on our sponsor's cleaning procedure. Based on the cleaning procedure described in our user manual, daily cleaning downtime of the device should take approximately 30 minutes for partial disassembly, cleaning, and reassembly (excluding air-drying time). This was determined by simply following the cleaning procedure once using the wash basin in the Mustang ’60 machine shops. The head count for each machine will depend on the level of filling automation and the feed system our sponsor chooses. However, the prototype was easily operated by a single operator during various tests. Automatic testing was conducted with an operator on standby but did not require ongoing observation of the device. After additional integration of their peripheral filling and feeding equipment, and testing with these systems with the prototype, our sponsor should be able to achieve fully automated operation of the device requiring only one operator to refill the peripheral equipment and make minor adjustments to the system position every 15-25 minutes.

4. Discussion and Recommendations

We recommend reverting the motion control to the previous 60° per actuation signal scheme to prevent position drift in the final operation. Alternatively, having new wheels manufactured with four slots rather than six would enable more-precise locating without having to round the desired angular position tick count of the wheels when converting the desired actuation angle to motor encoder ticks. Finally, upgrading the motor to the premium 6400 tick encoder would provide much better positioning resolution; Teknic should be willing to trade out the current motor for the enhanced encoder option for minimal additional cost.

The current wheels have caps made of Delrin plastic that are snuggly pressed into the wheels. We recommend that a small handle is placed in each plastic cap, such as a nut and bolt passing through, so that they are easier to remove for cleaning.

The machine currently can either pick up shells but not drop them or drop shells but not pick them up depending how much vacuum is used. Depending on the final feed in and feed out systems, we recommend investigation the possibility of a mechanical “finger” that can remove joined shells so that the vacuum can be increased enough to draw shells in.

5. Conclusions

The machine delivered has room for many modifications and improvements. However, it is ready to be used directly in an assembly line for preliminary testing of the scalability of producing our sponsor's product. To function, this machine must be coupled with a device to feed shells in, a device to feed ice-cream in, and a means to transport shells from the assembly machine wheels to a freezer. Once these pieces of peripheral equipment are integrated, and the machine vacuum level is tuned to our sponsor's product, this machine should satisfy the original engineering requirements.

If we were to redo this project, we would not recommend using a folded square tube for the frame because it contains internal stresses due to the folding process used to manufacture it. These stresses cause deflection of the material when sections of the square tube are cut away. This release of internal stress causes the metal to spring back and not be a perfect square. This raised the cost of manufacturing significantly. Our recommendation would be to use two L-shaped billets and bolt them together to avoid this issue.

References

Gilman-Cohen, Adin, and Vincent Yeung. “Dairy Manufacturing Cleaning Protocol.” 14 Apr. 2022.

“ME Senior Design Project Student Success Guide.” Department of Mechanical Engineering, California Polytechnic State University, 2021.

Appendices

Appendix A: Final Project Budget

Materials Budget for Senior Project

Title of Senior Project:	W23 Novelty Ice Cream Product Assembly
Team members:	Adin, Alvaro, Logan, Mason
Designated Team Treasurer	Mason Sylvester
Faculty Advisor:	Eileen Rossman
Sponsor:	Keith Zachow
Quarter and year project be	Winter 2022

Materials budget given for **$10,000.00**

Description	Vendor	Vendor's Part No.	Purchase Link	Design Part No.	Material Price	Estimated Tax	Estimated Shipping	Purchase Method	Purchase Date
Base and Frame:				11100					
Assembly baseplate	McMaster-Carr	8983K361	8983K361	11110	$ 97.02	$ 8.49	$ 20.00	Sponsor	5/17/2022
Riser Tubing	McMaster-Carr	89825K481	89825K48	11120	$ 244.43	$ 21.39	$ 50.00	Sponsor	5/17/2022
Bronze Bushing	McMaster-Carr	7095K48	7095K48	11130	$ 20.82	$ 1.82	$ 4.00	Sponsor	5/17/2022
Locating Pins	McMaster-Carr	89535K15	89535K15	11140	$ 5.85	$ 0.51	$ 2.00	Sponsor	5/17/2022
Nuts	McMaster-Carr	90389A218	90389A218	11150	$ 11.84	$ 1.04	$ 2.00	Sponsor	5/17/2022
Shaft-Wheels-Gear:				11200					
Shaft Tubing	McMaster-Carr	89495K64	89495K64	11210	$ 74.38	$ 6.51	$ 5.00	Sponsor	5/17/2022
Vacuum Wheels	McMaster-Carr	89535K83	89535K83	11220	$ 549.10	$ 48.05	$ 100.00	Sponsor	5/17/2022
Bearings	McMaster-Carr	7363N27	7363N27	11230	$ 504.10	$ 44.11	$ 20.00	Sponsor	5/17/2022
Rubber Plugs	McMaster-Carr	9545K118	9545K118	11240	$ 5.90	$ 0.52	$ 5.00	Sponsor	5/17/2022
Wheel Cap	McMaster-Carr	9208K12	9208K12	11250	$ 44.16	$ 3.86	$ 5.00	Sponsor	5/17/2022
Set Screw	McMaster-Carr	92785A433	92785A433	11260	$ 6.40	$ 0.56	$ 0.50	Sponsor	5/17/2022
Gears	McMaster-Carr	F16S20-64	F16S20-64	11270	$ 401.48	$ 35.13		Sponsor	5/17/2022
Bolts - Shaft Collars	McMaster-Carr	92196A542	92196A542	11280	$ 30.52	$ 2.67	$ 2.00	Sponsor	5/17/2022
Shaft Collars	McMaster-Carr	5631T16	5631T16	11290	$ 57.90	$ 5.07	$ 3.00	Sponsor	5/17/2022
Vacuum System:				11300					
Dust Collector Fan	Harbor Freight	97869	9786997869	11310	$ 249.99	$ 21.87		Reinbursem	5/17/2022
Square Tubing	McMaster-Carr	2937K17	2937K17	11320	$ 42.69	$ 3.74	$ 30.00	Sponsor	5/17/2022
Vacuum Tube Caps	McMaster-Carr	88885K74	88885K74	11330	$ 26.55	$ 2.32	$ 2.00	Sponsor	5/17/2022
Gasket	McMaster-Carr	5025T172	5025T172	11340	$ 40.24	$ 3.52	$ 2.00	Sponsor	5/17/2022
L-brackets	McMaster-Carr	1556A65	1556A65	11350	$ 5.18	$ 0.45	$ 3.00	Sponsor	5/17/2022
Bolts - 10-32 UNF	McMaster-Carr	92196A267	92196A267	11360	$ 14.53	$ 1.27	$ 2.00	Sponsor	5/17/2022
Bolts - 10-32 x 3/8	McMaster-Carr	91841A195	91841A195	11370	$ 5.35	$ 0.47	$ 2.00	Sponsor	5/17/2022
Finger Guard				11380					
U Channel	McMaster-Carr	1262T392	1262T392	11381	$ 22.00	$ 1.93	$ 5.00	Sponsor	5/17/2022
Corner Machine Bracket	McMaster-Carr	2313N14	2313N14	11382	$ 13.78	$ 1.21	$ 3.00	Sponsor	5/17/2022
Surface-mount Hinges	McMaster-Carr	1586A24	1586A24	11383	$ 12.74	$ 1.11	$ 3.00	Sponsor	5/17/2022
Hardware:				11400					
Bolts- Frame Mounting	McMaster-Carr	92240A301	92240A301	11410	$ 5.98	$ 0.52	$ 2.00	Sponsor	5/17/2022
Drive/Timing System:				11500					
Emergency Stop Switch	Amazon	7480T12	7480T12	11510	$ 30.18	$ 2.64	$ -	Sponsor	5/17/2022
Clearpath NEMA 3.4 Servo	Teknic	CPM-MCPV-2310D-RLN	CPM-MCPV-2310	11520	$ 344.00	$ 30.10	$ 20.00	Sponsor	5/17/2022
IPC-5 Power Supply	Teknic	IPC-5	IPC-5IPC-5IPC-5	11530	$ 248.00	$ 21.70	$ 10.00	Sponsor	5/17/2022
Motor Mount	McMaster-Carr	8993K72-8993K729	8993K72-8993K7	11540	$ 26.52	$ 2.32	$ 5.00	Sponsor	5/17/2022
IPC35-CABLE110	Teknic	IPC35-CABLE110	IPC35-CABLE110	11550	$ 14.00	$ 1.23	$ 2.00	Sponsor	5/17/2022
User Interface:				11560					
Display	ELECROW	8595698868	8595698868	11561	$ 56.99	$ 4.99	$ 5.00	Reimbursen	5/17/2022
Level Shifter	Amazon	8541740602	8541740602	11562	$ 7.49	$ 0.66	$ 3.00	Reimbursen	5/17/2022
Raspberry Pi	Charlie Refvem			11563	$ -	$ -			
Rpi Power Supply	CanaKit	DCAR-RSP-PI	DCAR-RSP-PI	11564	$ 22.94	$ 2.01	$ 2.00	Reimbursen	5/17/2022
Motor Shaft Coupling:				11570					
Spider Collar 3/8" ID	McMaster-Carr	2401K15-2401K153	2401K15-2401K1	11571	$ 35.75	$ 3.13	$ 5.00	Sponsor	5/17/2022
Spider Collar 1/2" ID	McMaster-Carr	2401K15-2401K154	2401K15-2401K1	11572	$ 35.75	$ 3.13	$ 5.00	Sponsor	5/17/2022
Spider Hub	McMaster-Carr	2401K84	2401K84	11573	$ 13.67	$ 1.20	$ 2.00	Sponsor	5/17/2022
Pinion Subassembly:				11590					
Pinion	McMaster-Carr	5172T21	5172T21	11591	$ 27.57	$ 2.41	$ 6.00	Sponsor	5/17/2022
Pinion Bearing	McMaster-Carr	5913K61	5913K61	11592	$ 10.95	$ 0.96	$ 3.00	Sponsor	5/17/2022
Bolts - 10-32 UNF	McMaster-Carr	92196a272	92196a272	11593	$ 19.56	$ 1.71	$ 2.00	Sponsor	5/17/2022
Pinion Shaft	McMaster-Carr	8632T134	8632T134	11594	$ 7.81	$ 0.68	$ 6.00	Sponsor	5/17/2022
Pinion Bearing Riser	McMaster-Carr	8992K132-8992K434	8992K132-8992K	11595	$ 25.32	$ 2.22	$ 3.00	Sponsor	5/17/2022
Bolts - Bearing Mount	McMaster-Carr	92196A544	92196A544	11596	$ 17.51	$ 1.53	$ 2.00	Sponsor	5/17/2022
Nuts - 10-32 UNF	McMaster-Carr	96537A160	96537A160	11597	$ 8.29	$ 0.73	$ 2.00	Sponsor	5/17/2022
Washers - 1/4-20	McMaster-Carr	90107A029	90107A029	11598	$ 10.01	$ 0.88	$ 2.00	Sponsor	5/17/2022
Manufacturing Tools:									
CNC tooling	McMaster-Carr	Various		N/A	$ 350.00	$ 30.63	$ 20.00	Sponsor	5/17/2022
Miscellaneous:									
Adhesives	Amazon	N/A	N/A	N/A	$ 20.00	$ 1.75	$ -		11/16/2022

Budget	$ 10,000.00
Materials Cost	$ 4,537.45
Manufacturing Cost	$ 2,300.00
Total Cost	$ 6,837.45
remaining balance:	$ 3,162.55

Appendix B: Design Verification Plan and Report

DVP&R - Design Verification Plan (& Report)

Project: W23 Novelty Ice Cream Product Assembly | Sponsor: Keith Zachow | Edit Date: 10/12/2022

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING: Start date	TIMING: Finish date	Numerical Results	Notes on Testing
	TEST PLAN									TEST RESULTS	
1	3	Shells will be fed in by hand at the base of the wheel and fed through without icecream. The shells will be inspected before and after for chips and cracks.	The frequency of shells damaged beyond an accpetable point for sale	Awaiting Sponser Decision	N/A	Prototype (With focus on wheels)	Adin	10/21/2022	10/28/2022	Out of all the samples made only 5% had a small misalignment issue due to being overfiled. Accouding to sponsor the worst were on the borderline but still acceptable	Shells seemed to come out perfect if not overfilled. If they were overfilled with the marshmellow fluff they would be pressed together and spring back leaving a gap between the shells.
2	3	Shells filled with ice-cream will be loaded in at the side of the wheel and roated through joining. The joined assembly will be inspected for chips and cracks.	The frequency of shells damaged beyond an accpetable point for sale	Awaiting Sponser Decision	Ice-cream machine or source of soft serve.	Prototype (With focus on wheels)	Alvaro	10/24/2022	11/4/2022	0 Shells were damaged during testing.	Shells came out without any damage when only ran through the machine once. Once ran through multiple times small amounts of chipping would occur.
3	4	Shells filled with ice-cream will be loaded in at the side of the wheel and roated through joining. The joined shells will be inspected for chips and cracks.	The alignment of the joined shells will be inspected. The frequnecy of unnaceptable joining will be measured.	Can not see inside of shells. Acceptable frequency awaitng sponser decision	Ice-cream machine or source of soft serve.	Prototype (With focus on wheels)	Logan	10/24/2022	11/4/2022	Out of all the samples made only 5% had a small misalignment issue due to being overfiled. Accouding to sponsor the worst were on the borderline but still acceptable.	Sometimes the shells would stick to the machine rather than drop free causing the non supported half of the shell to sling making them slightly misaligned.
4	5	The machine will be run with the motor and without shells for half an hour. The number of "shells joined" will be counted and compared to the target speed.	The quantity of beans that would be joined if fully running.	20 joined beans per minute.	Power source to power the motor	Prototype with motor assembly and power source.	Mason	10/20/2022	10/28/2022	When targeting 20 beans per minute the actual output we got was 19.35.	This difference scaled linearly for our higher output rates. We contacted our sponsor about this slight discrepancy on output and he said it was fine.
5	7	Perform dynamic calculations in order to calculate torque required by the motor to contribute to service life calculations.	Perform a conservative calculation that gives a measurement of torque in in-lbs.	A torque value lower than the maximum torque output by the motor.	N/A	Motor specifications sheet provided from motor manufacturer.	Logan	5/5/2022	5/11/2022	Required motor torque due to inertial load is expected to be ~87oz-in.	
6	7	Perform dynamic calculations in order to calculate stresses on gears to contribute to service life calculations.	Perform a conservative calculation that gives a measurement of stress in psi.	A stress value low enough to allow for a safety factor of 3.	N/A	Gear specifications sheet provided from gear manufacturer along with known load values.	Mason	5/5/2022	5/11/2022	Analysis of the gears indicates that they will never experience tooth failure or fatigue issues beyond standard wear.	

DVP&R - Design Verification Plan (& Report)

Project: W23 Novelty Ice Cream Product Assembly | Sponsor: Keith Zachow | Edit Date: 10/12/2022

Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING: Start date	TIMING: Finish date	Numerical Results	Notes on Testing
		TEST PLAN								**TEST RESULTS**	
7	8	Run the machine at different motor speeds in order to see if the shells are joined similar to normal operating speeds or if there are any new problems encountered from variable speeds.	Visually inspect to ensure that damage and alignment still meet requirements as well as no problems with picking up or releasing of shells. Count machine output to ensure that it can vary depending on speeds.	Count the machine output of acceptable quality joined beans to see if capacity is able to be incresed.	N/A	Fully functioning protoype	Alvaro	10/24/2022	11/4/2022	The output scaled linearly with out desired output rates. The actual output was slightly lower then what the desired was. For 20 beans per min the actual was 19.35, for 40 beans per min the actual was 38.70, and for 60 beans per minute the actual was 58.05.	In the tests wht amount that were actually joined were slightly off to fix this we can just go in the sofware and target slightly higher values to offset the difference.

Appendix C: Risk Assessment

designsafe Report

Application:	W23 Ice Cream Assembly	Analyst Name(s):	Aidan, Alvaro, Logan, Mason
Description:	Senior Project	Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	operator normal operation	mechanical : crushing Hands or arm getting caught between parts.	Serious Unlikely	Medium	Added a finger gaurd to area prone to crushing.	Serious Unlikely	Medium	In-process Aidan
1-1-2	operator normal operation	mechanical : drawing-in / trapping / entanglement Something hanging gets caught in between rotating parts	Moderate Unlikely	Low	Added a finger gaurd to area prone to drawing-in/entanglment.	Moderate Unlikely	Low	In-process Aidan
1-1-3	operator normal operation	mechanical : pinch point Hands or arm getting caught between parts	Moderate Unlikely	Low	Added a finger gaurd to area prone to pinch points.	Moderate Unlikely	Low	In-process Aidan
1-1-4	operator normal operation	slips / trips / falls : falling material / object Objects are thrown outward by improper setting	Minor Remote	Negligible	Stand back while machine is running in case of falling objects.	Minor Remote	Negligible	Action Item [9/27/2022] Aidan
1-1-5	operator normal operation	noise / vibration : noise / sound levels > 80 dBA Moving parts (gears, motor & wheels) emit noise	Minor Likely	Low	Wear earplug if work area noise levels are too high	Minor Remote	Negligible	Action Item [10/20/2022] Aidan
1-2	operator clean up	<None>						

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-1	maintenance technician parts replacement	mechanical : pinch point Hands or arm getting caught between parts	Moderate Unlikely	Low	Unplug power source before making any part replacements.	Moderate Remote	Negligible	Action Item [10/20/2022] Alvaro
2-1-2	maintenance technician parts replacement	electrical / electronic : energized equipment / live parts Improper handling of energized equipment	Serious Unlikely	Medium	Unplug power source before making any part replacements.	Serious Remote	Low	Action Item [10/20/2022] Alvaro
2-1-3	maintenance technician parts replacement	ergonomics / human factors : lifting / bending / twisting Carrying heavy parts or carrying them improperly	Moderate Unlikely	Low	Team lift if moving heavy or difficult to handle parts/equipment.	Moderate Remote	Negligible	Action Item [9/27/2022] Alvaro
2-2-1	maintenance technician adjust controls / settings / alignment	mechanical : pinch point Hands or arm getting caught between parts	Moderate Unlikely	Low	Added a finger gaurd to area prone to pinch points.	Moderate Unlikely	Low	In-process Alvaro
2-3-1	maintenance technician periodic maintenance	mechanical : crushing Hands or arm getting caught between parts	Serious Unlikely	Medium	Unplug power source before performing periodic maintenance.	Serious Remote	Low	Action Item [10/20/2022] Alvaro
2-3-2	maintenance technician periodic maintenance	mechanical : pinch point Hands or arm getting caught between parts	Moderate Unlikely	Low	Unplug power source before performing periodic maintenance.	Moderate Remote	Negligible	Action Item [9/27/2022] Logan
3-1-1	passer by / non-user work next to / near machinery	noise / vibration : noise / sound levels > 80 dBA Moving parts (gears, motor & wheels) emit noise	Minor Likely	Low	Wear earplug if work area noise levels are too high	Minor Remote	Negligible	Action Item [9/27/2022] Logan
3-2-1	passer by / non-user walk near machinery	noise / vibration : noise / sound levels > 80 dBA Moving parts (gears, motor & wheels) emit noise	Minor Likely	Low	Wear earplug if work area noise levels are too high	Minor Remote	Negligible	Action Item [9/27/2022] Logan

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
4-1-1	Team Common Tasks	mechanical : crushing Hands or arm getting caught between parts	Serious Unlikely	Medium	Added a finger gaurd to area prone to crushing.	Serious Unlikely	Medium	In-process Logan
4-1-2	Team Common Tasks	mechanical : cutting / severing Person is cut by sharp or improperly machined parts	Serious Unlikely	Medium	Remove any sharp edges or potential cutting hazards during manufacturing.	Serious Remote	Low	In-process Logan
4-1-3	Team Common Tasks	mechanical : drawing-in / trapping / entanglement Something hanging gets caught in between rotating parts	Moderate Unlikely	Low	Added a finger gaurd to area prone to drawing-in/entanglment.	Moderate Unlikely	Low	In-process Mason
4-1-4	Team Common Tasks	mechanical : pinch point Hands or arm getting caught between parts	Serious Unlikely	Medium	Added a finger gaurd to area prone to pinch points.	Serious Unlikely	Medium	In-process Mason
4-1-5	Team Common Tasks	mechanical : unexpected start Improper wiring or electrical issues	Moderate Remote	Negligible	Emergency stop switch is readily available in case immmediate halt of movement is rewuired.	Moderate Remote	Negligible	In-process Mason
4-1-6	Team Common Tasks	electrical / electronic : energized equipment / live parts Improper handling of energized equipment	Serious Unlikely	Medium	Inform and add warning labels to keep hands away from energized equipment and electrical wiring.	Serious Remote	Low	In-process Mason
4-1-7	Team Common Tasks	noise / vibration : noise / sound levels > 80 dBA Moving parts (gears, motor & wheels) emit noise	Minor Likely	Low	Wear earplug if work area noise levels are too high	Minor Remote	Negligible	Action Item [9/27/2022] Mason

Appendix D: Source Code

```
#!/usr/bin/python3
'''!@file      CoolBeans_GUI_doublestep.py
    @brief     User interface and Raspberry Pi GPIO controller for prototype
                CoolBeans assembly machine
    @details   This file generates a class-based tkinter graphic user interface
                (GUI) which can be used to control
               the GPIO outputs of a Raspberry Pi 2. This enables the user to
               generate simple control rising-edge actuation signals for a
               ClearPath MCPV Nema 2.3 motor configured in Incremental
               Positioning Mode.
    @author    Logan B. Williamson
    @date      11/5/2022
    @copyright Copyright (C) 2022 Keith Zachow, CoolBeans LLC.
                All Rights Reserved.
    @version   1.0.6
'''


import RPi.GPIO as GPIO
import time
import math
from tkinter import *
from PIL import ImageTk,Image

class CoolBeans_UI(Frame):

    def __init__(self,master=None):
    ''' This is the initializer for the CoolBeans prototype assembly machine
        graphic user interface
        @param auto_mode:           Flag variable used for controlling
                                    appearance of mode_slider, auto_button,
                                    auto_pause, and single_button.
        @param delay:               Delay interval in seconds for logic high
                                    motor actuation signal.
        @param count:               Running production count, incremented every
                                    time a GPIO output is sent.
        @param throughput:          User-desired production rate of the device
                                    being controlled by this GUI. Used to
                                    calculate the number of control signals to
                                    send per unit time when the auto_button is
                                    pressed. Can be updated by selecting values
                                    available in the thru_drop dropdown menu
                                    widget at any time.
        @param EN_GPIO:             Raspberry Pi GPIO.BOARD pin number 11.
                                    Used to output an Enable (high) enable
                                    signal.
        @param motor_GPIO:          Raspberry Pi GPIO.BOARD pin number 12.
                                    Used to output an rising edge control
                                    signal for actuating the attached motor.
        @param master:              The master tkinter.Frame object comprising
                                    the window where the GUI is generated.
```

```
    @param logo:                CoolBeans LLC company logo image asset.
                                Used to generate GUI window background.
    @param onswitch:            Public, iOS-style slider button image.
                                Used to indicate and change the current
                                operating mode.
    @param offswitch:           Public, iOS-style slider button image. Used
                                to indicate and change the current
                                operating mode.
    @param exit_button_bg:      tkinter color code used for exit button.
    @param auto_button_bg:      tkinter color code used for automatic
                                assembly button.
    @param auto_button_active:  tkinter color code used for automatic
                                assembly button.
    @param auto_pause_bg:       tkinter color code used for automatic
                                assembly pause button.
    @param single_button_bg:    tkinter color code used for manual assembly
                                button.
    @param wallpaper:           Label widget used to display logo asset as
                                background.
    @param mode_label:          Static text label used to indicate purpose
                                of mode_slider.
    @param count_label:         Dynamic text label ued to indicate the
                                current run's production count.
    @param exit_button:         Button widget used to call close() method.
    @param mode_slider:         Button widget used to call switch_mode()
                                method.
    @param options1:            Dropdown list menu options list.
    @param clicked:             Type handler for dropdown menu options, for
                                use within the thru_drop widget.
    @param thru_drop:           Throughput selection OptionMenu widget.
                                Used to call update_throughput() method.
    @param single_button:       Button widget used to call single() method.
    @param auto_button:         Button widget used to call auto() method.
    @param auto_pause:          Button widget used to call pause() method.
'''
##Prepare backend
    #Prepare working variable attributes
    self.auto_mode = False
    self.delay = 0.03
    self.count = 0
    self.slider_floor = 600
    self.slider_ceiling = 5400
    self.throughput = self.slider_floor

    #Prepare GPIO
    GPIO.setmode(GPIO.BOARD)
    self.EN_GPIO = 11
    GPIO.setup(self.EN_GPIO,GPIO.OUT)
    GPIO.output(self.EN_GPIO,GPIO.HIGH)
    self.motorGPIO = 12 #Signal A+ pin
    self.motorGPIO = 16 #testing pin
    GPIO.setup(self.motorGPIO,GPIO.OUT)
    GPIO.output(self.motorGPIO,GPIO.LOW)

##Create graphical user interface
```

```
        #Create and label root window
        Frame.__init__(self,master)
        self.master = master
        self.pack(fill=BOTH,expand=1)
        root.title("CoolBeans Assembly Controller")

        #Load assets
        self.logo = 
ImageTk.PhotoImage(Image.open('/home/coolbeans/Desktop/CoolBeans/CB_logo.jpg'))
        self.onswitch = 
ImageTk.PhotoImage(Image.open('/home/coolbeans/Desktop/CoolBeans/on_switch.png'))
        self.offswitch = 
ImageTk.PhotoImage(Image.open('/home/coolbeans/Desktop/CoolBeans/off_switch.png'))

        #Define widget colors
        self.exit_button_bg = "firebrick2"
        self.auto_button_bg = "cyan3"
        self.auto_button_active = "DeepSkyBlue4"
        self.auto_pause_bg = "firebrick4"
        self.single_button_bg = "burlywood3"

        #Create root window appearance
        self.wallpaper = Label(self, image=self.logo)
        self.wallpaper.place(x=0,y=0)

        ##Create widgets
        #Create static operating mode label describing operating mode slider
        self.mode_label = Label(self,
                                text="Automatic Operating Mode:",
                                fg="black",
                                bg="white",
                                font=("Arial",28))
        self.mode_label.place(x=30,y=40)

        #Create dynamic production count label
        self.count_label = Label(self,
                                 text=f"Production run unit count: {self.count}",
                                 fg="black",
                                 bg="white",
                                 font=("Arial",24))
        self.count_label.pack(side=BOTTOM)

        #Create Exit button
        self.exit_button = Button(root,
                                  text="exit",
                                  font=("Arial",16),
                                  height=1,
                                  width=2,
                                  bg=self.exit_button_bg,
                                  activebackground=self.exit_button_bg,
                                  bd=1,
                                  command=self.close)
        self.exit_button.place(x=740,y=4)

        #Create operating mode slider button
```

```
        self.mode_slider = Button(root,
                                  image=self.offswitch,
                                  height=100,
                                  width=150,
                                  bg="white",
                                  activebackground="white",
                                  borderwidth=0,
                                  highlightthickness=0,
                                  command=self.switch_mode)
        self.mode_slider.place(x=500,y=0)

        #Create dropdown menu with production throughput selections
#         self.options1 = ['1200/hr','1800/hr','2400/hr']
#         self.clicked = StringVar()
#         self.clicked.set(self.options1[0])
#         self.thru_drop = OptionMenu(self,
#                                     self.clicked,
#                                     *self.options1,
#                                     command=self.dropdown_throughput)
#         self.thru_drop.config(font=("Arial",24))
#         self.thru_drop.place(x=570,y=150)

        #Create a throughput slider to control production throughput selections
        self.thru_slider = Scale(root,
                                 label='Throughput',
                                 font=("Arial",24),
                                 from_=self.slider_floor,
                                 to=self.slider_ceiling,
                                 resolution=60,
                                 length=250,
                                 sliderlength=100,
                                 bg='white',
                                 orient='horizontal',
                                 borderwidth=0,
                                 highlightthickness=0,
                                 command=self.slider_throughput)
        self.thru_slider.place(x=520,y=150)

        #Create user input button for motor actuation
        self.single_button = Button(root,
                                    text="Assemble one CoolBean",
                                    font=("Arial",18),
                                    fg="black",
                                    activebackground=self.single_button_bg,
                                    bg=self.single_button_bg,
                                    wraplength=120,
                                    height=3,
                                    width=7,
                                    bd=4,
                                    relief=GROOVE,
                                    command=self.single)
        self.single_button.place(x=80,y=280)

        #Create automatic assembly mode start button
        self.auto_button = Button(root,
```

```
                                     state=DISABLED,
                                     text="Auto Assemble CoolBeans",
                                     font=("Arial",18),
                                     fg="black",
                                     bg="grey",
                                     activebackground=self.auto_button_bg,
                                     wraplength=120,
                                     height=3,
                                     width=7,
                                     bd=4,
                                     relief=GROOVE,
                                     command=self.auto)
        self.auto_button.place(x=500,y=280)

        #Create user automatic assembly mode pause button
        self.auto_pause = Button(root,
                                    state=DISABLED,
                                    text="Pause Auto Assembly",
                                    font=("Arial",18),
                                    fg="black",
                                    activebackground=self.auto_pause_bg,
                                    bg="grey",
                                    wraplength=120,
                                    height=3,
                                    width=7,
                                    bd=4,
                                    relief=GROOVE,
                                    command=self.stop)
        self.auto_pause.place(x=650,y=280)

    def dropdown_throughput(self,event):
        ''' @brief      Production throughput update callback function for
                        dropdown widget.
            @details    This method is called when the thru_drop dropdown menu
                        becomes active, and updates the throughput parameter
                        based on the newly-selected entry from the options1
                        dropdown list displayed in the thru_drop widget. The
                        dropdown is currently commented out in favor of the
                        adjustment slider
        '''
        self.throughput = int(self.clicked.get()[0:4])

    def slider_throughput(self,event):
        ''' @brief      Production throughput update callback function for
                        slider widget.
            @details    This method is called when the thru_slider Scale widget
                        becomes active, and updates the throughput parameter
                        based on the retrieved value of the slider.
        '''
        self.throughput = self.thru_slider.get()

    def update_count(self):
        ''' @brief      Production count Label update function
            @details    This method updates the label describing the production
                        count.
```

```
        '''
        self.count+=1
        self.count_label.config(text=f"Production run unit count: {self.count}")

    def switch_mode(self):
        ''' @brief      Operating mode switch button command.
            @details    This method acts at the command function for the
                        mode_slider widget. It evaluates what the current
                        operating mode of the GUI class and determines the
                        appropriate image to place on the mode_slider Button.
                        It then decides which state (DISABLED or NORMAL) to
                        switch the control Button widgets to. If automatic
                        operation is the current state, it will update the
                        current state to manual and reconfigure all automatic
                        assembly Button widgets to DISABLED state and the
                        manual assembly Button to NORMAL state. It will then
                        call the cancel_auto_appt() method to cancel any
                        scheduled control signal GPIO outputs. If manual
                        operating is the current state, it will reconfigure all
                        automatic assembly Button widgets to the NORMAL state
                        and the manual assembly Button to the DISABLED state.
        '''
        if self.auto_mode:
            self.auto_mode = False
            self.mode_slider.config(image=self.offswitch)
            self.auto_pause.config(state=DISABLED,bg="grey")
            self.auto_button.config(state=DISABLED,bg="grey")
            self.single_button.config(state=NORMAL,bg=self.single_button_bg)
            self.cancel_auto_appt()
        elif not self.auto_mode:
            self.auto_mode = True
            self.mode_slider.config(image=self.onswitch)
            self.auto_pause.config(state=NORMAL,bg=self.auto_pause_bg)
            self.auto_button.config(state=NORMAL,bg=self.auto_button_bg)
            self.single_button.config(state=DISABLED,bg="grey")

    def single(self):
        ''' @brief      Single GPIO output button command.
            @details    This method acts as the command function for the
                        single_button widget. Upon pressing the single_button
                        widget, it uses the RPi GPIO library to send a logic
                        high pulse of 100ms duration through the RPi GPIO.BOARD
                        pin assigned to the motorGPIO parameter. It then
                        increments the count parameter.
        '''
        GPIO.output(self.motorGPIO,GPIO.HIGH)
        time.sleep(self.delay)
        GPIO.output(self.motorGPIO,GPIO.LOW)
        time.sleep(2*self.delay)
        GPIO.output(self.motorGPIO,GPIO.HIGH)
        time.sleep(self.delay)
        GPIO.output(self.motorGPIO,GPIO.LOW)
        self.update_count()

    def auto(self):
```

```
        ''' @brief      Repeating GPIO output button command.
            @details    This method acts as the command function for the
                        auto_button widget. Upon pressing the auto_button
                        widget, it sets the auto_button state to DISABLED to
                        prevent stackup of multiple delayed signals. It then
                        uses the RPi GPIO library to send a logic high pulse
                        of 100ms duration through the RPi GPIO.BOARD pin
                        assigned to the motorGPIO parameter. It then increments
                        the count parameter. Finally, this method schedules a
                        new_time appointment object of the Tk.after method
                        which calls the function again in a number of
                        milliseconds determined by the currently selected
                        throughput attribute.
        '''
        self.auto_button.config(state=DISABLED,bg=self.auto_button_active)
        self.single()
        self.new_time =
self.auto_button.after(int(math.ceil(3600000/self.throughput)-
4*1000*self.delay),self.auto)

    def stop(self):
        ''' @brief      Automatic assembly pause command.
            @details    This method acts as the command function for the
                        auto_pause widget. Upon pressing the auto_pause widget,
                        this method calls the cancel_auto_appt method to to
                        cancel any scheduled control signal GPIO outputs. If
                        the current operating state is automatic operation, it
                        resets the auto_button widget and returns its state to
                        NORMAL so that automatic operation may be resumed. It
                        then sets the motorGPIO output to LOW to ensure that
                        the output has been reset and is not stuck in a HIGH
                        output state.
        '''
        self.cancel_auto_appt()
        if self.auto_mode:
            self.auto_button.config(state=NORMAL,bg=self.auto_button_bg)
        GPIO.output(self.motorGPIO,GPIO.LOW)

    def cancel_auto_appt(self):
        ''' @brief      Automatic assembly appointment cancelling method.
            @details    This method is called by any Button widget state
                        toggling methods which require the cancellation of
                        scheduled output signals. To prevent AttributeError
                        warnings, this is formatted as try: except: block with
                        a custom error message describing the failed scheduled
                        cancellation reason.
        '''
        try:
            self.auto_button.after_cancel(self.new_time)
        except:
            print("Auto Assembly has not been run. Nothing to cancel")

    def close(self):
        ''' @brief      User interface close button.
            @details    This method disables the EN_GPIO enable signal, prints
```

```
                the count from the current session, and closes the GUI.
        '''
        GPIO.cleanup()
        root.destroy()

#Create instance of CoolBeans_UI class and run the tkinter mainloop()
root = Tk()
app = CoolBeans_UI(root)
root.wm_title=("CoolBeans Assembly Controller")
root.geometry("800x450")
root.mainloop()
```

Appendix E: Test Procedures

Test Procedure 1

Test Name: Visual Damage Check
Purpose: Determine if operation of machine can press two ice-cream filled shells together without damaging the shells.
Scope: The function that this experiment will test is the visual damage of joined shells.
Equipment:

- 120 Volt Outlet
- A Bag of Undamaged CoolBeans Shells
- Supply of Ice-Cream from Soft Serve Machine
- Working Prototype of Machine

Hazards: A hazard would be toward fingers near pinch point in the wheels while loading and removing shells. Another hazard during this test is that there could be exposure to load noise.
PPE Requirements: Safety glasses should be worn to protect us from any objects that might be thrown outward from the spinning wheels.
Facility: The test will take place inside the Mustang '60 shop.
Procedure:

1) Verify all test participants are wearing proper safety equipment. These include closed toed shoes, long pants, and safety glasses.
2) Place the joining machine on a sturdy level surface and plug in
3) Prefill several shell halves with ice cream (enough that they will not melt while waiting to be tested)
4) Start the machine's vacuum system
5) Depress the E-stop so the machine cannot turn on
6) Load one filled shell into each wheel at the 12 o'clock position.
7) Turn off the E-stop and run the motor of the machine until the shells are joined and dropout the bottom
8) Stop the motor of the machine and depress the E-stop
9) Remove the joined pod
10) Have a second group member inspect the joined shell for cracks or missing chunks. Measure the size of any cracks or missing chunks and record them for each shell. Record in Table 1. More trials may be run and recorded on Excel.
11) Photograph any damaged shells
12) Repeat for the next set of shells, stopping the motor to load them and starting it to join them

Table 1: Damage Observed in Joined Shells

Test Number	Damage Present (Y/N)	Defect 1 (Type & Size)	Defect 2 (Type & Size)	Defect 3 (Type & Size)
1	N	N/A	N/A	N/A
2	N	N/A	N/A	N/A
3	N	N/A	N/A	N/A
4	N	N/A	N/A	N/A
5	N	N/A	N/A	N/A
6	N	N/A	N/A	N/A
7	N	N/A	N/A	N/A
8	N	N/A	N/A	N/A
9	N	N/A	N/A	N/A
10	N	N/A	N/A	N/A

Results: The results will be either damage being present or not. If there is damage present, then an additional result will be the measurement of any cracks or missing chunks from the shell.
Performed By: Adin

Test Procedure 2

Test Name: Shell Alignment

Purpose: The purpose is to outline the experimental procedure for determining whether running operation of the CoolBeans assembly design produces acceptable alignment of the product halves. This test will produce tabulated data representing the proportion of shells that pass inspection.

Scope: The function that this experiment will test is the alignment of joined shells.

Equipment:

- One standard 120V outlet to power the equipment
- Two standard icing piping bags
- Sponsor provided CoolBeans shell halves
- Approximately one gallon of soft serve ice cream
- 18” x 24” rimmed tray
- Working prototype of machine

Hazards: Two main pinch points – between the two gears, and between the joining wheels.

PPE Requirements: Safety glasses must be worn as the test will be conducted in the machine shop.

Facility: Test will be best conducted on a table inside the Mustang ’60 machine shop.

Procedure:

1) Ensure proper safety equipment is being utilized according to “PPE requirements”
2) Acquire and organize the prototype and all testing materials on the testing workbench.
3) Install the shroud and lower the finger guard to operating position
4) Plug the motor power supply in
5) Test the motor operation and wheel alignment by manually actuating the system through three full cycles (18 steps)
6) Place the collection tray below the prototype output and fill both piping bags with soft serve
7) Begin feeding cones into the prototype and actuating the device after position is occupied
8) Once the 12 o’clock position of each wheel is occupied with a shell, two team members will each pipe a shell full of 5 milliliters of soft serve ice cream
9) Once an assembled ‘bean’ is dropped out of the machine, a third team member will inspect it for visual alignment and record the bean number, and whether the bean has passed inspection. The encoder position of the motor will also be recorded at this time. This will be used for uncertainty propagation analysis.

10) Repeat steps 6 through 8 until fifty CoolBeans have been assembled. Uncertainty analysis will be conducted to determine how the 0.03° repeatability uncertainty of the position increment operating mode propagates to the final product alignment.

11) Calculate and record proportion of CoolBeans that pass or fail inspection.

Test Number	Inspection Results (Pass/Fail)
1	Pass
2	Pass
3	Pass
4	Pass
5	Pass
6	Pass
7	Pass
8	Pass
9	Pass
10	Pass

Results: Results will be recorded for 100 samples and will be Pass/Fail tests. The absolute position of the motor will be recorded and compared to the alignment to determine propagation of positioning uncertainty.
Performed By: Logan

Test Procedure 3

Test Name: Machine Output
Purpose: The purpose of this test is to determine if the settings being sent to the motor is capable of reaching our sponsors 20 beans per minute output rate.
Scope: The function that this experiment will test is the output rate of joined shells.
Equipment:

- Working Prototype of Machine
- Stopwatch
- Paper and Pencil

Hazards: A hazard is the pinch point between the wheels. Another is the pinch point between the gears on the back of the machine.
PPE Requirements: Safety glasses should be worn as the test will be conducted in the machine shop.
Facility: The test will be conducted inside the Mustang '60 shop.
Procedure:

1) Ensure proper safety equipment is being utilized according to "PPE requirements"
2) Power on machine.
3) Send parameters to the motor.
4) Test to make sure motor is clocking at a constant rate.
5) Start stopwatch and count how many times the wheels clock in 30 minutes.
6) Turn off the machine.
7) Calculate average output rate.

Test Number	Target Wheel Rotations in 1 Hour	Wheel Rotations in 1 Hour	Average Output Rate (Beans/minute)
1	1200	1161	19.35
2	2400	2322	38.70
3	3600	3483	58.05

Results:
Pass Criteria- Wheels clock at a rate of at least 20 times per minute.
Fail Criteria- Wheels clock at a rate lower than 20 times per minute.

Performed By: Mason

Test Procedure 4

Test Name: Configurable Production Quantity or Variable Speed
Purpose: The purpose of this test is to determine whether it is possible to increase capacity or vary the speed of production by changing the speed of the motor.
Scope: The function that this test is for would be the joining process. The joining process determines whether the amount of joined shells can vary.
Equipment:

- Two piping bags
- Cone shell halves
- A gallon of ice cream
- A 120 Volt power outlet
- A container for joined Cool Beans
- Working Prototype of Machine

Hazards: A hazard associated with the test might be cone shells getting thrown around due to high rotational speeds. This is only under certain circumstances since testing at low speeds wouldn't be an issue. At high speeds however, there is a possibility for shells to get thrown outward.
PPE Requirements: Safety glasses should be worn in order to protect us from any objects that might be thrown outward from the spinning wheels.
Facility: The test will occur inside the Mustang 60 shop.
Procedure:

1) Ensure proper safety equipment is being utilized according to "PPE requirements"
2) We will run the motor at a set speed
3) We will operate the machine as it would during normal operation for 10 minutes
4) We will count the filled shells that meet acceptable conditions
5) We will repeat the test for varying motor speeds
6) We will compare the quantity of filled shells to the motor speeds to see if the output is able to change either increasing or decreasing the quantity of production with the change of motor speeds.

Test Number	Target Beans Per Minute	Percent of Acceptable Filled Shells
1	20	100
2	40	95
3	60	95

Results: The results will either pass or fail. We will set a certain goal of production quantity and see if the motor can be adjusted to accommodate that.
Performed By: Alvaro

Appendix F: User Manual

1. Safety Hazards and Operator Personal Protection Equipment (PPE)

When operating this prototype for an entire eight (8) hour production shift, the user must wear hearing protection. The dust collection impeller system used in this system generates approximately 80dB of constant noise, which can cause progressive hearing damage during exposure periods of this length. Shorter durations of operation do not require this PPE per workplace standards, and it is therefore left to the discretion of the operator. However, hearing protection is always highly encouraged when using this prototype for any duration longer than one (1) hour.

As identified in the Risk Assessment presented during the Critical Design Review of this prototype, there exist two potential pinch points in this design. These are located at the interface between the driving gears, and between the food handling rollers. Either of these mechanical pinch points have the potential to cut and/or crush the operator’s appendages, which can cause severe bodily injury. These high-risk locations on the device can catch loose articles of clothing, hair, jewelry, and other objects on the operator’s person, which could subsequently pull them further into the pinch point. Additionally, there are several locations where rotating machinery can entangle loose clothing, hair, and appendages. Protective guards have been added to the prototype to minimize operational exposure to these dangerous components. Proper operating procedures have been outlined in section (2) part (a) describing the appropriate protocol for interacting with this prototype in a production environment.

The following steps must be taken to avoid personal injury during operation of the prototype:

- Never wear gloves when operating this machine.
- Remove all rings, bracelets, watches, dangling earrings, and other wearable jewelry prior to operating this machine.
- Roll up long sleeves; do not simply slide them above your elbows.
- Hoodie sweatshirts with drawstrings should have the drawstrings cut off or tucked into the inside of the apparel.
- Tie up long hair into a bun or tuck it inside of a tight-fitting hat; do not tie it into a ponytail.
- Do not operate this prototype if your alertness, cognitive function, or motor skills are impaired.
- Be aware that in certain operating modes the ClearPath motor is designed to spin as soon as the DC bus power is applied. The Incremental Position operating mode that the device is currently configured in *should* not exhibit this behavior; however, reconfiguration of the motor could result in active-startup behavior as described here. Always expect the prototype to begin moving immediately after applying power.

- Always understand how to use a mode of operation and its associated controls before attempting to operate the ClearPath motor.
- Before applying DC power, ensure that the ClearPath motor and all loads it is driving are properly mounted to a stable, solid work surface and that all appropriate guards are installed around the motor shaft, and any connect loads it is driving.
- Install and test all emergency stop devices and controls at a low operating speed before using this prototype.
- Ensure there is appropriate space around the motor and the loads it is driving for ventilation and cable clearances.
- Do not allow loose cables or other items to drape over or rest near rotating components of the prototype.
- The ClearPath motor installed in this prototype requires that a path exist between the motor chassis and the Protective Earth (PE) connection of the machine to which it is affixed. The PE connection is often satisfied by simply bolting the motor to the machine; however, it is the user's responsibility to verify the PE connection. If an external grounding wire is required, use the same or larger wire gauge as used between the DC power supply and the motor. Confirm that a protective ground has been established before supplying power to the ClearPath motor.
- The power must be removed before the Protective Earth ground conductor is disconnected. Never remove the motor from its mount or remove the external grounding wire without first disconnecting the motor from the DC power bus. Always mount the motor properly and reconnect the Protective Earth ground conductor connection (if required for your configuration), then confirm the Protective Earth connection is secure prior to reconnecting the DC power bus.
- When the ClearPath motor is mounted in an application where the shaft end is higher than the electrical connection end of the motor, the USB connector plug provided by Teknic must be installed. The USB plug in these installations becomes an element to prevent the spread of fire per EN 61010-1 section 9.3.2 part c.
- Do not open the ClearPath motor enclosure. There are no user serviceable parts inside.

2. Operating
    a. Operational Safety
        i. When operating this prototype, the user should never place any part of their person near any rotating components while the 75V DC power supply is energized. **Unexpected movement of the device while handling the rotating components can crush, sever, deglove, and otherwise maim the operator’s hands or person.** To properly de-energize the 75V DC power supply, the user must remove AC power to the power supply by either unplugging the AC power cable from the wall outlet it is drawing power from, or by installing an appropriately rated emergency stop (E-stop) by splicing it into the live wire of this AC power cable. After power has been cut to the 75V power supply, the user should

wait at least thirty (30) seconds before handling any rotating components to allow the power supply to shut down fully. **An AC power bus emergency stop is NOT currently installed on this prototype.** Therefore, the user must ensure that the power supply is disconnected from AC power prior to handling any rotating components of this prototype.

ii. For the purposes of testing and prototype validation, a DC emergency stop has been installed between the microcontroller managing the control signals that actuate this device and the Enable motor I/O input (Molex connector port, channel 4). This emergency stop serves to sever the Enable input to the motor to protect the motor in the event that the device becomes jammed, seized, or is producing unexpected motion and/or noises. The Enable connection to the motor controls power input to the motor coils. Per the Teknic ClearPath user manual, "When a ClearPath is powered up and the Enable Input is asserted (i.e. 5–24VDC is present at the Enable Input) the motor windings energize and ClearPath is able to respond to control signals at [actuation] Inputs A and B. When Enable is deasserted power to the motor coils is removed and the motor cannot respond to user inputs. **The Enable Input is not designed for safety compliance use. Main power must be removed to ensure safety.**"[1] The emergency stop button that is installed should NOT be relied upon for prevention of bodily injury, and as such, the operator should never place their body near moving components in the prototype without first disconnecting the power supply from main power or from the motor. After clearing the obstruction, main power can then be restored, followed by releasing the installed emergency stop by turning it counter-clockwise.

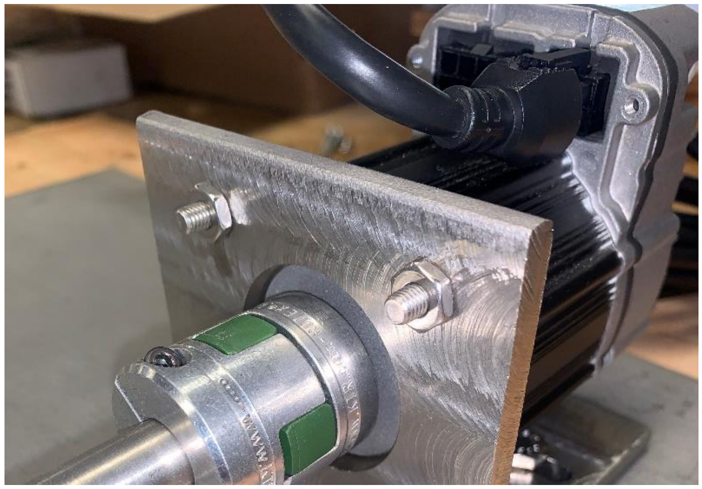
b. Typical Operating Procedure

i. Typical operation of the device during one production shift will start with confirming the cleanliness of the prototype Cool Beans assembly machine. All food contact surfaces should be cleaned of any food debris, maintenance lubricants, and other potential food contaminants that were not removed properly when the device was cleaned at the end of the previous production cycle. If the device is not properly cleaned, follow the cleaning procedure outlined in Section (2)(b)(iv) of this operating manual.

ii. Ensure that the workspace around the assembly prototype is clear.

iii. If the four-pin Molex DC power bus is not connected between the motor and the power supply, connect it to the appropriate four-pin Molex ports on each, respectively. Ensure that the cable is secured such that it does not rest on or near the motor coupling or shaft.

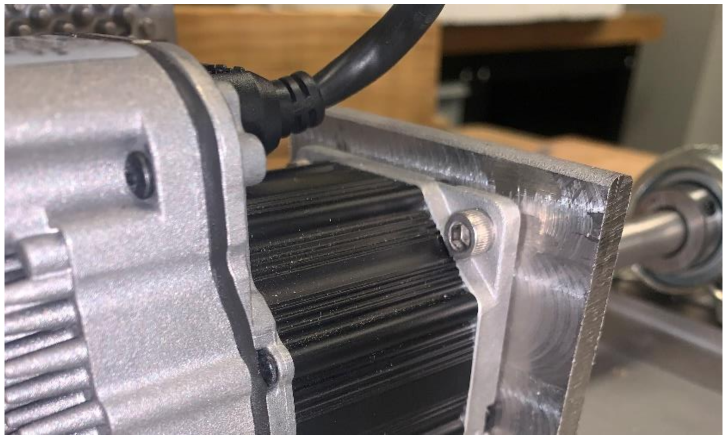
[1] "ClearPath User Manual." Teknic, Inc., 15 Mar. 2022.



iv. Restore power to the motor power supply by plugging the AC power bus into a US standard 120V outlet.

v. The motor is now energized. Do not touch any rotating components of the device until main power has been removed.
vi. Ensure that the touchscreen display is connected to the Raspberry pi by a standard HDMI cable and a standard USB to micro-USB connector. The micro-USB side plugs into the touchscreen (either port) and the USB side can connect to any of the four USB ports on the Raspberry Pi.
vii. If you'd like, you can also connect a standard or wireless USB mouse and/or keyboard to the USB ports on the Raspberry Pi.
viii. Supply power to the Raspberry Pi by plugging it into a US standard 120V outlet using the provided Raspberry Pi power adaptor. The micro-USB port on the Raspberry Pi is the power port. Do not use any other AC to micro-USB adaptor.

ix. Once the Raspberry Pi and motor power supply are both running, connect the digital I/O wiring harness from the Raspberry Pi level shifter to the eight-pin Molex port on the motor. Ensure the wiring harness is clear of the motor shaft and coupling.



x. At the time of prototype delivery to our sponsor, the ClearPath motor is configured in Incremental Positioning mode with a move increment of 533/800 encoder ticks assigned to I/O input A+ (Molex I/O connector port, channel 3). This means that a digital pulse produced by the Raspberry Pi controller will cause the motor to actuate 533/800th of one revolution. In turn, the Shaft Assemblies that the driving pinion is geared to will rotate approximately 59.96°, i.e. one increment.

xi. Test the status of the controller and motor. This can be done by opening the Cool Beans_GUI.py script on the Desktop of the Raspberry Pi Linux OS and pressing the Run button. This will boot the controller graphic user interface (GUI) and present the virtual controller interface.

xii. Press the button labelled “Assemble one CoolBean” to manually actuate the motor through one increment. Repeat this action at least six times to ensure that the motor and controller are working properly.

1. If the system seizes, screeches, shakes, or produces any undesirable behavior, press the emergency stop to disable the motor. Be aware that if you have changed the motor configuration to a run-on-startup mode, the enable disconnect will not stop the motor.
2. If the system is behaving incorrectly, disconnect the eight-pin Molex I/O connector from the motor and begin diagnosing the issue. The simplest fix is to re-calibrate the motor to the load, which may be necessary if the motor mount, shaft collar, or pinion mount have been moved since the previous calibration.
3. To re-calibrate the motor’s onboard control system, install the ClearPath MSP software provided to you and connect to the motor via the USB to micro-USB port under the white plastic cover on

the back. The software will recognize the motor and walk you through steps to recalibrate it.

xiii. Once the system is confirmed to be working properly, you can begin to automatically assemble Cool Beans. Connect the vacuum system hose to the adaptor on the Vacuum Tube Assembly and turn on the vacuum system.

xiv. Press the Auto Mode slider button at the top of the GUI to enable the automatic production mode. Alternatively, you can conduct manual assembly as described above.

xv. Select the Cool Beans production rate you would like to execute for this production cycle; the rate can be changed at any time by selecting a new rate from the three options in the dropdown menu at the left side of the GUI. The production quantity will be recorded and printed in the Thonny window at the end of your session.

xvi. Press the "Automatically Assemble" button to begin automated assembly of Cool Beans.

xvii. Press the STOP button at any time to pause automatic assembly. Always pause automatic assembly before switching back to manual operation.

xviii. To turn off the system at the end of production run, you can simply unplug the power supply, then remove the digital I/O wiring harness from the eight-pin Molex connector on the motor.

xix. If you would like to power down the Raspberry Pi, there is unfortunately no button or switch for doing so. It is best practice to plug a keyboard into a Raspberry Pi USB port, start a terminal window by clicking the black terminal icon in the top left corner of the screen, then typing sudo shutdown -h now into the command line. Similarly, the device can be restarted by typing sudo reboot into the command line. Alternatively, you can turn it off by unplugging it, but be sure to unplug it in one swift motion; accidentally touching the cable to the power port after unplugging it can cause issues as the device attempts to reboot on "browned out" power input. It is also fine to just leave it running, as it should enter a sleep mode after a few minutes of idling.

xx. At the end of a production cycle, the device should be cleaned in preparation for the following production cycle. All food contact and incidental food contact components in this prototype can be washed with soap and water, standard no-rinse sanitizer solution, or bleach solution of no more than one tablespoon per one gallon of water.

   1. Ensure that main power has been removed from the motor by disconnecting the AC power bus from the wall outlet it was connected to during operation.
   2. Remove the Shaft Assemblies by following the disassembly steps described in Section 3 of this user manual.

3. Bring each shaft assembly to a cleaning sink and remove the Delrin endcaps covering the open face of each food handling roller.
4. Ensure that the plastic bearing refill port covers are properly fitted over the refill ports.

5. Using an approved cleaning solution, the holes in the bottom of each of the six food-handling depressions on each of the rollers should be brushed with a ½” diameter, soft bristled plastic brush.
6. The shafts should be cleaned similarly, using a 1” diameter, soft bristled plastic brush long enough to push through the entire shaft length (16”).
7. All other surfaces can be cleaned with an abrasive pad. Clean the interior of each roller wheel thoroughly, and wipe all exterior surfaces, moving the Delrin bumpers towards the washdown bearings to remove any incidental food spillage that may have entered the gap where it contacts the roller wheel.
8. Each Shaft Assembly can then be rinsed by submerging it entirely in clean water, or by running it under clean water until all cleaning solutions are removed.
9. The Shaft Assemblies can then be air-dried or wiped dry with a clean dish towel.
10. While the Shaft Assemblies are drying, disassemble the Vacuum Tube Assembly per the directions in Section 3 of this manual.
11. Using a 2” diameter soft bristled plastic brush and cleaning solution, clean the interior of the vacuum tube.
12. Wipe down the exterior of Vacuum Tube Assembly with an abrasive pad and cleaning solution.

13. Rinse the Vacuum Tube Assembly by submerging it in clean water or running it under clean water until all cleaning solutions are removed.
14. Place the Vacuum Tube Assembly on a rack to dry.
15. Use a kitchen towel with cleaning solution to wipe down the interior of the mounting frame.
16. The motor shaft and driving pinion (small gear) should not be washed in the same manner; if incidental food contact has occurred with these components, they should be wiped clean with no-rinse sanitizer solution, thoroughly dried with a clean kitchen towel or paper towels, and the pinion should be lightly lubricated with food grade mineral oil.
17. Take special care not to get cleaning solutions or water on the motor. While the housing is water resistant and the shaft is sealed, it is not intended to be used in a washdown environment and will be damaged if any liquid gets into the windings or ports. Do not carry wet components or assemblies over the motor, power supply, or controller.
18. Once dry, replace the endcaps on the rollers and reassemble these components in the frame in accordance with the procedure described in Section 4 of this operating manual.
19. Once dry, reassemble the Vacuum Tube Assembly in accordance with the procedure described in Section 4 of this operating manual.

3. Disassembly
    a. Removal of Shaft Assembly for cleaning
        i. The two shaft assemblies, shown in Figure 1 below, which include the cylindrical wheels, bearings, gears, bumpers, and the hollow tubes on which these items sit, can be easily removed from the frame for cleaning in a sink or sanitizer.

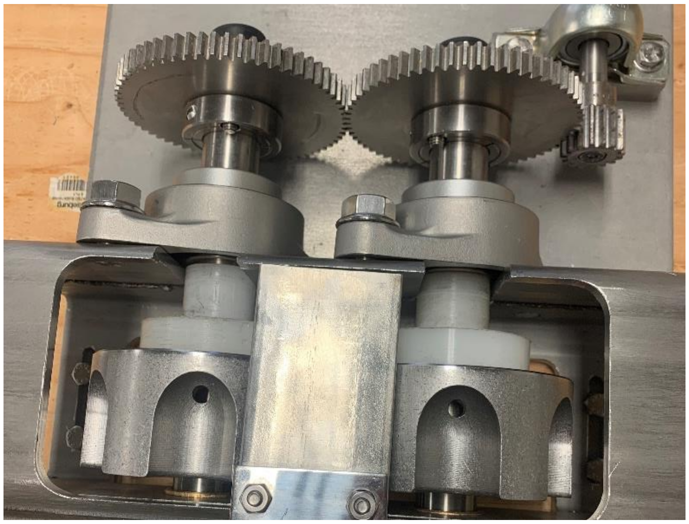


Figure 1: Shaft Assemblies in Place With all Components Installed

        ii. To remove the shafts, follow these steps:
            1. If present, lift finger guard out of the way and remove any filling machinery in the way, as shown in Figure 2 below.

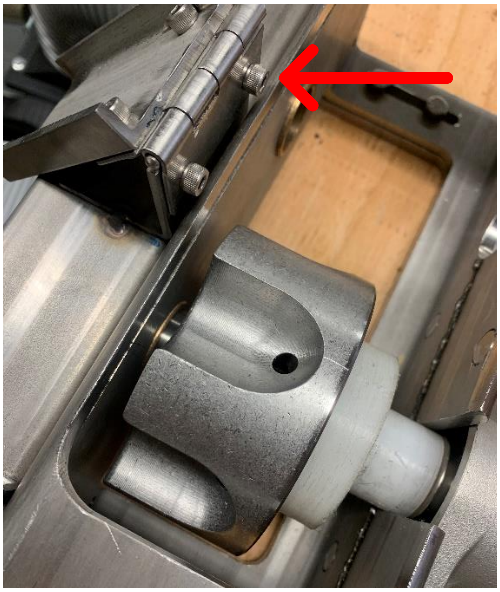


Figure 2: Image showing the finger guard lifted out of the way

2. Use a 3/4‘’ wrench to remove the two nuts holding the bearing onto the locating pins. The nuts that need to be removed can be seen in Figure 3 below.

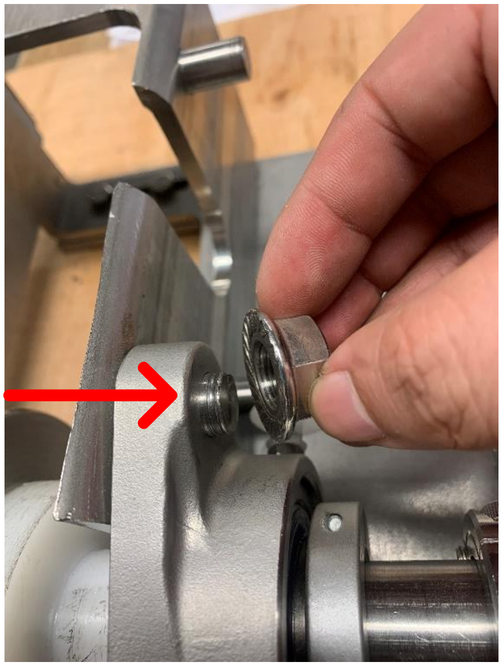


Figure 3: Nuts Holding the Bearings onto the Locating Pins

3. One at a time, slide the shaft backwards (towards the motor) by holding the wheel and pulling. Be careful not to pinch fingers when the shaft slides backwards. The bearing should clear the pins in order to allow for it to be lifted up. This is shown in Figure 4 below.

Figure 4: Bearing clearing the pins after shaft is slid backwards

4. Lift the shaft assembly straight up until it is clear of the machine.
5. Pry out the plastic wheel lids, shown in Figure 5 below, to access inside of wheel. At this point, the shafts and frame can be sanitized using the methods specified by the user's industry.

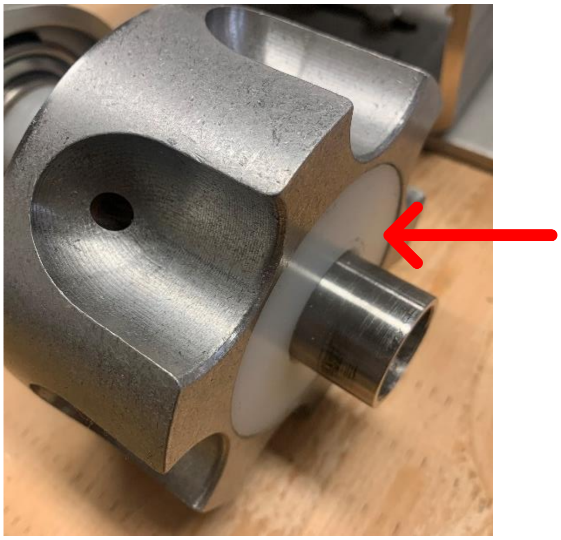


Figure 5: White plastic caps that can be removed from wheel for cleaning.

b. Further disassembling of the shafts
   i. The shaft assembly can be removed and washed without needing to remove the wheel, bearing, bumper, or gear from the shaft. However, these components can be removed if repairs or replacements need to be made.
      1. Use a 3/16 Allen key to loosen the shaft collar from the gear and slide it off of the shaft. The bolt that needs to be loosened is shown in Figure 6 below.

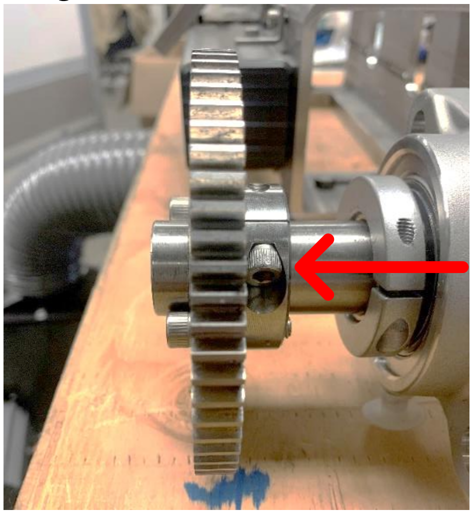


Figure 6: Bolt that needs to be loosened to remove the gear from the shaft

2. Use a T20 torx key to loosen the shaft collar from the bearing and slide if off the shaft. The bolt that needs to be loosened is shown in Figure 7 below.

Figure 7: Bolt that needs to be loosened to remove bearing from shaft.

3. Slide the plastic bumper, shown in Figure 8 below, off of the shaft.

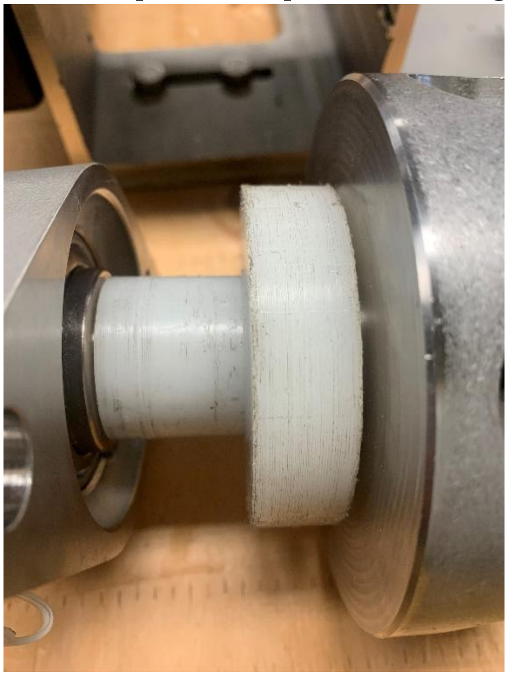


Figure 8: Plastic bumper that can be removed from shaft

4. Use a 1/8 inch Allen key to loosen the set screw on the wheel and slide it off (this may require some force)
5. Slide the plastic spacer ring that sits under the wheel set screw off the shaft if it has not come off with the wheel

c. Removal of Frame components

The frame components include the square tube riser, the bearing riser, and the motor mount. These components are all bolted into threaded holes in the base plate and are not meant to be removed for cleaning or normal operation. However, they can be removed for replacement or repair by simply removing the shafts and unscrewing each bolt.

4. Assembly
   a. Installation of the square tube riser.
      i. The square tube riser components include the square tube riser and the vacuum tube. When installing these components make sure not to torque the fasteners past the recommended torque spec of 5 lb-ft as to not damage the threads on the base plate. The square tube riser can be seen in Figure 9 below.

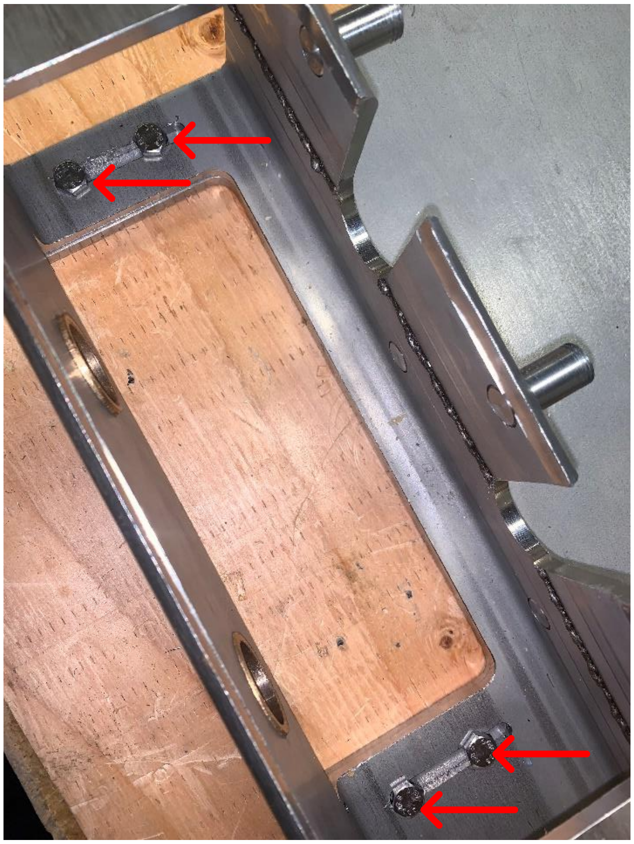


Figure 9: Square Tube Riser and the Mounting Bolts

1. Align the square tube riser with the four bolt holes on the base plate.
2. Start threading the four bolts by hand.

3. Square the front face of the square tube riser to the front edge of the baseplate.
4. Using a 7/16 inch wrench tighten the four bolts in the square tube riser

b. Installing the vacuum tube
    1. Align the vacuum tube with the four bolt holes on the square tube riser. The aligned vacuum tube is shown in Figure 10 below.
    2. Start threading the bolts by hand
    3. Using a hex key, tighten the four bolts onto the square tube riser

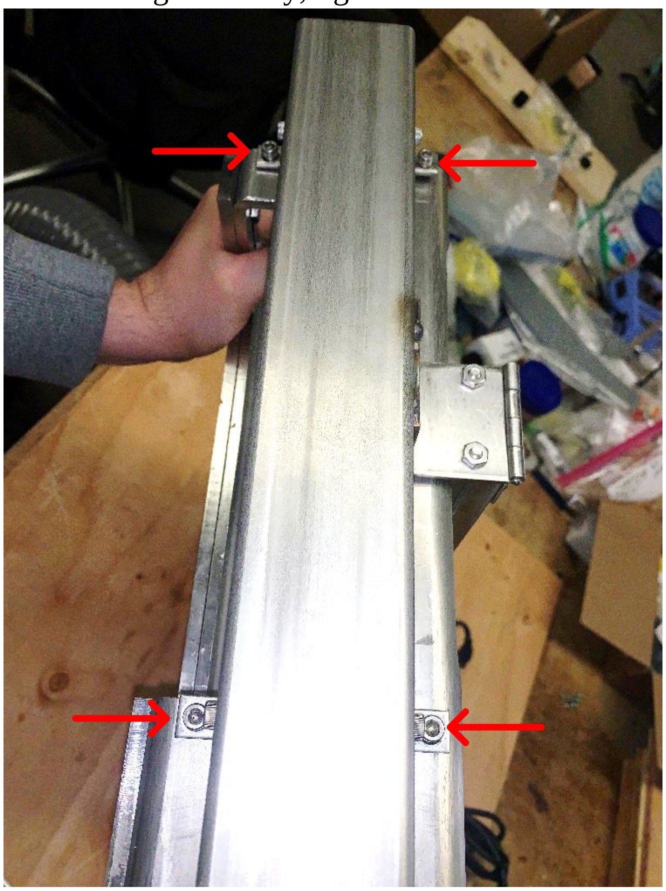


Figure 10: Vacuum tube mounted onto square tube riser with four mounting bolts.

c. Assembly of the shaft assemblies.

The two shaft assemblies include the cylindrical wheels, bearings, gears, bumpers, and the hollow shafts.

1. Slide the cylindrical wheels on to the hollow shaft.
2. Once in place use a 1/8 inch Allen wrench to tighten the set screw.
3. Slide the wheel cap over the front of the shaft and press into the front of the cylindrical wheels.

4. Slide the shaft bumper over the hub on the back of the cylindrical wheel.
5. Slide the bearing on to the back of the hollow shafts but do not tighten collar until installed in frame.
6. Slide gear assembly on to the back of the shaft with the collar facing the bearing until the face of the gear is flush with the back of the shaft
7. Snug the bolt in the collars but do not torque until assembly is installed in the frame assembly

d. Installing shaft assemblies into the frame
   i. When installing the shaft assemblies into the frame always start by installing the shaft closest to the motor.
      1. With the shaft above the frame slowly lower the shaft into the frame until the shaft and front bushings are aligned. This placement is shown in Figure 11 below.

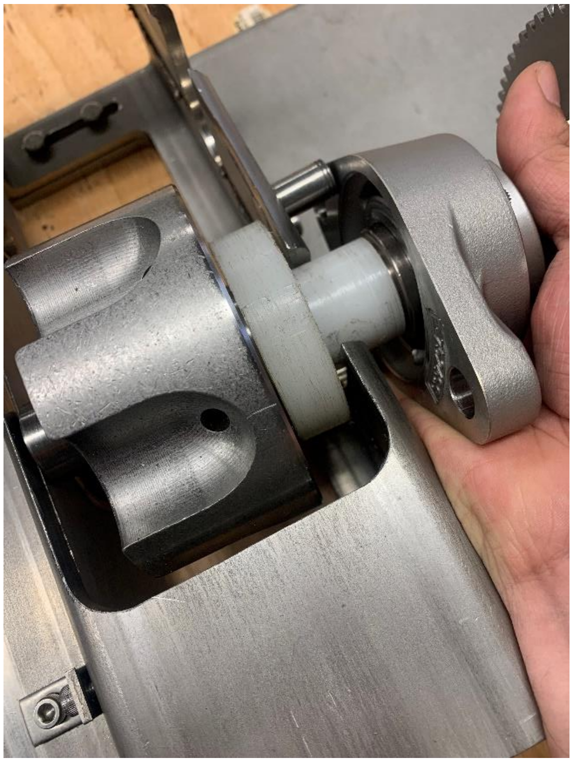


Figure 11: Shaft being lowered into place

      2. Once aligned slide the shaft into the bushing making sure the holes in the bearing slide over their pins.
      3. Using a ¾ inch wrench tighten the nut on the top pin. This nut is pointed out in figure 12 below.

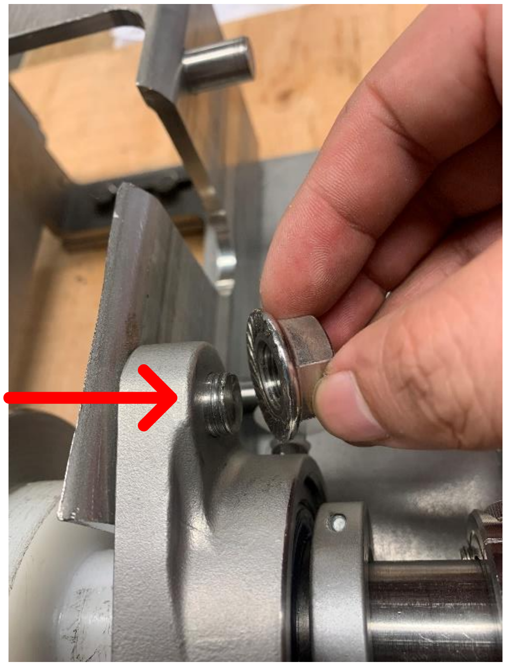


Figure 12: Nuts that needs to be tightened once bearing is aligned.

4. Using a T20 Torx wrench tighten the collar on the bearing. This bolt is pointed out in Figure 13 below.

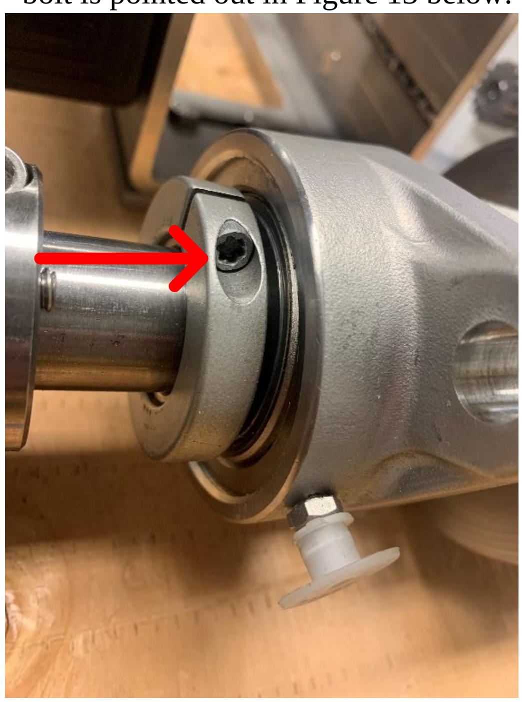


Figure 13: Bolt that needs to be tightened to attach bearing to shaft

5. Install the second shaft repeating the same steps.

e. Timing the shaft assemblies.
    i. Timing the shaft assemblies is very critical to ensure completed Cool Beans are aligned properly.
        1. Turn the shaft assembly until one of the shell cups is between the two wheels and one of the edges is parallel to the base plate.
        2. Torque the bolt on the collar for the gear down. The bolt that needs to be adjusted in these steps is pointed out in Figure 14 below.

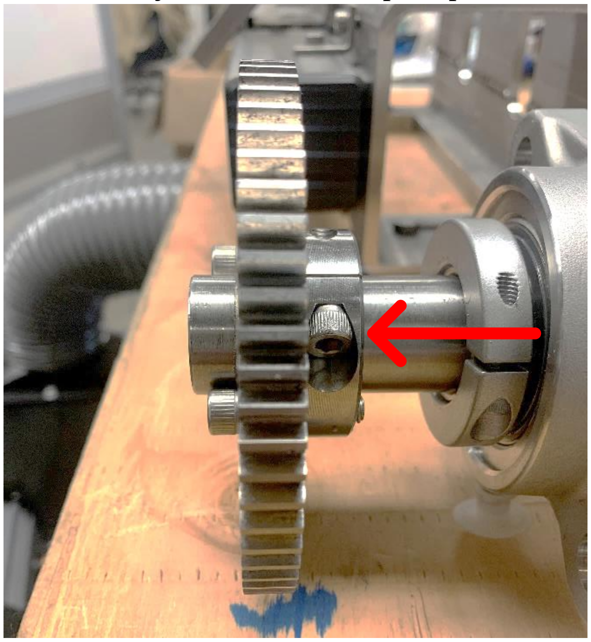


Figure 14: Bolt on gear shaft collar that needs to be adjusted

        3. Loosen the bolt on the collar for the other gear until the shaft moves independent of the gear and line up the edge of the shell cup with the same edge on the other wheel.
        4. Torque down the bolt on the collar for the other gear.

f. Installation of the motor assembly.
    i. The shaft should not be removed from the motor unless absolutely necessary to avoid stripping the head of the small Allen screw that clamps the shaft in place.
        1. Line up the motor mount with the four mounting holes on the base plate. The mounting bolts and positioning of the motor mount can be seen in Figure 15 below.

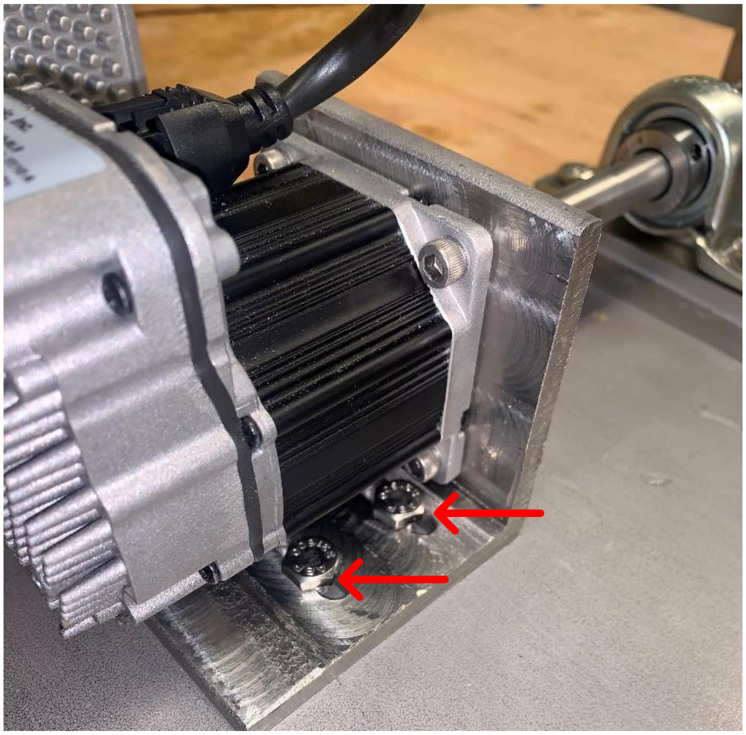


Figure 15: Four mounting bolts (two on other side) used to mount motor mount onto base plate

2. Thread the bolts in by hand loosely so that the mount can still move side to side.
3. Using the small cap head screw and 10 mm nuts install the motor to the motor mount. These four mounting bolts are shown in Figure 16 below.

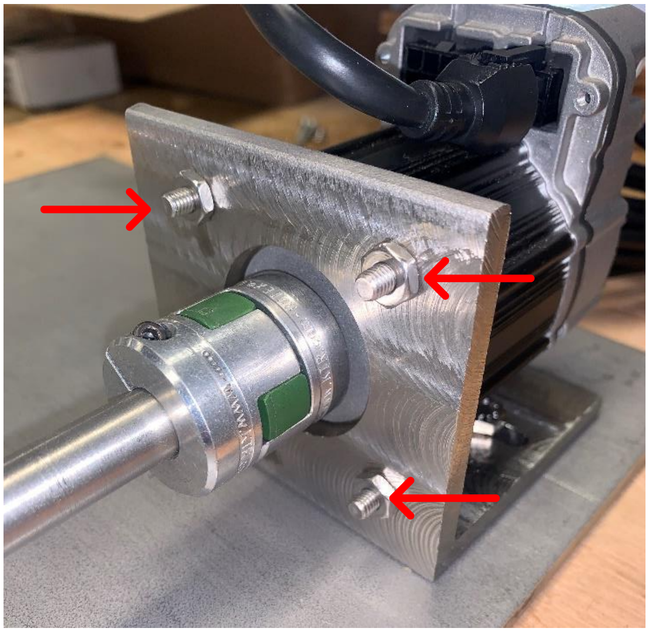


Figure 16: Motor mounted onto motor mount using four bolts

4. Slide the pinion and shaft assembly into the hub on the motor
5. Tighten the hub using a 3 mm Allen wrench.
6. Slide the bearing riser under the bearing on the shaft lining the holes up with the hole in the base plate.
7. Hand thread the bolts into the holes on the base plate so it can move side to side. The bearing riser aligned on the base plate is shown in Figure 17 below.

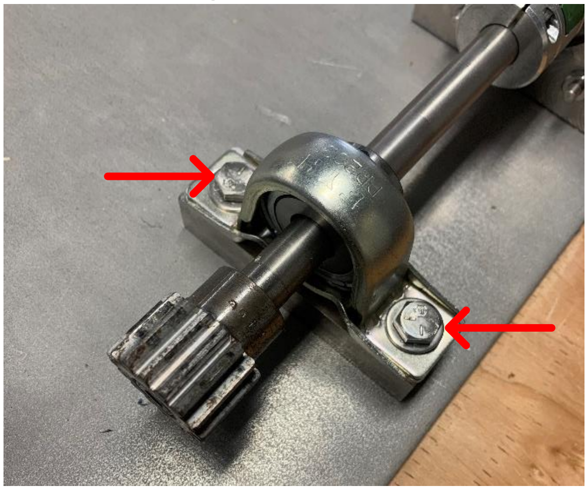


Figure 17: Bearing riser mounted to base plate using two bolts

8. Slide the whole motor mount and bearing riser towards the gears on the back of the shaft until a good gear mesh is achieved.
9. Using a 7/16 inch wrench tighten the bolts on the bearing riser and the motor mount to the base plate.