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ChemArt Automated Packaging System

Sean Fisher
University of Rhode Island

Jennifer Hart
University of Rhode Island

Emily Tacopina
University of Rhode Island

Alvaro Torrecilla
University of Rhode Island

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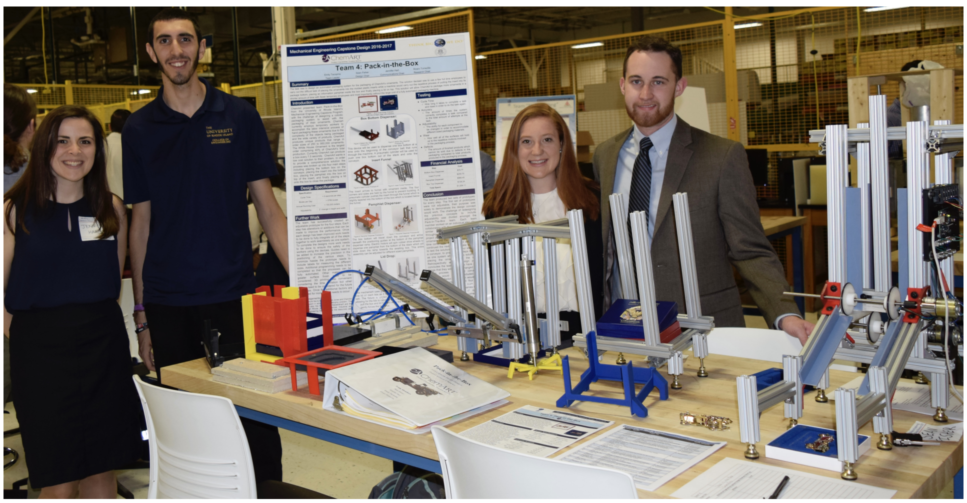
Team 4
Pack-in-the-Box



Team Members:

Sean Fisher - Mechanical Design Engineer

Jennifer Hart - Communications and Design Engineer

Emily Tacopina - Team Leader and Cost Analysis Engineer

Alvaro Torrecilla - Research Engineer

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Faculty Advisor:

Professor Bahram Nassersharif

Department of Mechanical, Industrial, and Systems Engineering

University of Rhode Island

Abstract

ChemArt is a Rhode Island based photochemical etching company that specializes in manufacturing Christmas Ornaments. Each Christmas ornament is handmade in the United States, and at this point in time each and every ornament is packaged by hand as well. Packing the ornaments into their retail boxes is labor intensive and time consuming work. The facility is equipped to make more ornaments than package ornaments at any given time, so packaging becomes a bottleneck in their process. Currently ChemArt hires temporary employees to package the surplus Christmas ornaments that the full time staff cannot package. The project proposed by ChemArt was to create an automatic or semiautomatic packaging system for some or all of the ornaments that ChemArt produces.

During the first semester, the design team set forth to create an automated packaging system for ChemArts ornaments, focusing specifically on the White House ornaments. ChemArt is a custom design shop with customers ordering ornaments in quantities ranging from 250 ornaments to 950,000, with the White House being ChemArts largest customer. Because of the high volume of custom jobs that ChemArt does - making up sixty percent of the companys business - it is difficult to standardize a machine or system of machines. For this portion of the design project the team focuses on finding design solutions using the White House ornament packaging assembly, which makes up the remaining forty percent of ChemArts business.

The second semester was spent focusing specifically on creating adjustable mechanisms that perform the jobs of placing the lid on the conveyor, placing the insert into the box, placing a pamphlet in the box, then sealing the box with the lid. All of these steps were redesigned for adjustability in order to ensure that they would work with any of ChemArts ornament boxes. Once the adjustable designs were created in SolidWorks the team built them and tested them to ensure their adjustability and functionality within the system.

Team Pack-in-the-Boxs Capstone Design Project was a success. The team designed, built, tested, and accordingly modified a set of adjustable machines that accomplish the

goal of packaging ChemArts Christmas ornaments. With minor modifications the modular apparatuses that the team created can be used with a conveyor system in ChemArts Lincoln, Rhode Island facilities on all of the types of boxes that they use to package the ornaments.

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1 Introduction

ChemArt is a leader in the decorative photochemical etching industry. They were founded in 1976 by Richard Beaupre and are located in Lincoln, Rhode Island. Something that makes them extremely unique and their products desirable is that their products are all handmade in the United States. The products begin as solid brass sheets then go through several chemical etching processes each one adding more intricate details. Once the etching process is complete the designs are cut out using a precise laser. Each of the different components of the product are brought to different stations in the factory. In an assembly line manner the product is hand assembled. The intricate details on each product make them vulnerable to scratching and other damage. At the end of the assembly line the employee places the final product in rows into a box which is then transferred into the packaging area.

ChemArt produces several different products, ranging from money clips to ornament keepsakes. The ornament keepsakes are the focus of this capstone project. ChemArt designs two types of ornaments which are the standard ornament and the White House ornament. The White House ornament is constant throughout the year but changes year to year. The standard ornament title covers all other ornaments that are produced. The standard ornament orders vary in quantity, the minimum order being 250 ornaments. They also vary in size and shape which causes the boxes they are packaged into to vary in size.

The design problem that ChemArt wants a solution for concerns the packaging of the ornament keepsakes. Currently all of the ornaments are hand packaged. ChemArt would like a way to eliminate most of the human contact in the packaging system for long term cost savings. The goal is to create a fully automated packaging system that can be operated by a single employee. It currently takes a single person thirty seconds on average to completely package one ornament into the box. ChemArt made the decision that the focus of this project would not include placing the final ornament package into the shipping box. The team along with ChemArt made the decision to not pursue the separating of the inserts and then placing them onto the conveyor; there was not enough time to complete that step in the semester.

The packaging of an ornament consists of several components that are constant for both types of ornaments. Both packages are comprised of a box bottom, lid, insert and the ornament. With the White House ornament there is an additional component of a pamphlet. A large difference between the standard ornament and the White House ornament is the insert that the ornament is placed into. For the standard ornament the insert is universal with a small slit at the top. All of the standard ornaments have a ribbon attached that is ten inches long, the ribbon is placed in the small slit and a piece of tape is placed over the ribbon to attach it to the insert. Unlike the standard ornament the White House ornament insert is form fitted to the ornament. Although the White House ornament changes yearly the outer dimensions of the insert remain the same only the form fit for the different ornament changes. The figures 1 and 2 are examples of the various boxes and their components. [1] [2] [3]

Figure 1: White House ornament box and insert with ornament inside

Figure 2: Standard ornament box and standard ornament

In designing a packaging system the steps to package an ornament had to be considered and compared between the two types of ornaments. When considering the amount of steps for both ornament types the White House ornament had more steps. The extra step was the placing of the pamphlet which some standard boxes can also include but not all. After examining the steps it was determined that there are four main steps consisting of placing the ornament into the insert, insert into the box, pamphlet into the box and lid onto the box. Each of theses steps require that their respective materials be delivered in a controlled manner in order to complete the step. This means that another four designs were necessary to facilitate the task of material handling and dispensing of the inserts, box bottoms, pamphlets, and box lids. In total eight design concepts were required in order to design a machine which can automatically package christmas ornaments.

The varying size of the boxes, inserts as well as the pamphlets created a challenge for designing a universal packaging system. A solution to this was to create adjustable components that can be adjusted based on the dimensions of what is being packaged. Another factor that was considered when designing the system was having each step be independent of the other. The choice to make the steps independent was so ChemArt as a company can automate whichever process they choose, if not the entire process. This also allows for change, as the concepts are tested they can be altered without affecting any of the other steps.

As a team it was decided to focus on proving which concepts would work using the White House ornament package to prove the design concepts would work. This was decided so the main focus was on the concepts themselves rather than their adjustability. Some of the main concerns in creating the designs were to create a high quality, low cost, low maintenance, fully automated and ergonomic system. Once the concepts were proven to work the team altered the concepts to include adjustability. The design were adjustable at least 2 inches in the x,y and z directions. The 2 inch adjustability radius was based on the White House ornament and the standard ornament. At the conclusion of this class the team has produced an adjustable prototype for each step in the packaging process. Currently, all of the steps operate independently of each other a conveyor belt can be added at a later date and would tie all of the systems components together to become the automated packaging system.

2 Project Planning

When initially creating the Project Plan, the first step was to compare the schedule provided by Professor Nassersharif and the schedules of the team members then created a rough draft of the project plan. Some of the important dates used in the preliminary Project Plan included meetings with Professor Nassersharif, due dates for group and individual assignments, and dates when team members would be out of state or unavailable. After creating a preliminary project plan, using Microsoft Project that reflected the course outline as well as the group members schedules, the team contacted ChemArt.

The team coordinated a visit to ChemArts facilities in Lincoln, RI in order to make sure that all of the sponsors needs were being met with the schedule and project plan that the team had decided upon. During the meeting the team was able to tour the facilities and ask for ChemArts specific requests and timelines. The team took note of all of the sponsors suggestions and comments to adapt the Project Plan, and has kept in contact with ChemArt adjusting the Project Plan as new specifications and pieces of information come to light.

After meeting with Professor Nassersharif and ChemArt, the teams approach to solving the design problem - creating an automated packaging system - changed by breaking the system down into components that reflect each step in the packaging process. This changed the Project Plan and the deliverables for the semester, by breaking down the large system into smaller, more manageable steps to be proven separately.

As the semester progressed the team adapted the Project Plan to reflect the various times that the team met over the course of the semester. Each time the team met or made plans to meet at times that were not designated at the beginning of the semester the Project Plan was updated to reflect these changes. This proved to be quite useful when dividing the amount of work for each specific QFD Analysis with different proposed solutions for the same packaging step. Also towards the end of the semester when the design team was working on creating prototypes for the proof of concept the Project Plan was a great tool when coordinating what SolidWorks Models and physical models needed to be created and when.

The Project Plan has proven to be an invaluable tool in detailing the design process and work schedule for the semester. It allows for the team to visually understand the due dates and meeting times over the course of the semester. By using Microsoft Project to organize, create, and maintain the Project Plan over the course of the semester.

Keeping the Project Plan updated proved to be useful again during the second semester. At the very beginning the team was dealing with a too broad problem for the time remaining before completion was due. First things added to the plan once the semester started were meetings with Professor Nassersharif, and with ChemArt after his recommendation was to find out the priorities of the company. This was absolutely helpful, the team visited once again ChemArts facilities and after putting in common the work that had been done and the doubts when approaching the next steps for the problem solution, they gave us feedback and we all agreed in which were the specifications and requirements for the new designs, what should be tested, and what would be the steps to be focused on till the end of the semester.

As the team had 4 different steps to redesign and test the decision was made to assign a problem to each one of the team members. Nevertheless the team was still working together and helping in the other steps when needed. Deadlines for redesigning, ordering materials, testing, and building were set to make sure the main objectives would be completed by the end of the semester.

The team also programmed a Skype meeting with ChemArt to inform the company of the project progress since time was an important factor at that moment of the semester and the teams and ChemArts availabilities were limited.

Taking all of this into account, it is completely accurate to state that a good organization of tasks during time, dividing work, or collaborating depending of the needs, are very important things when facing a big project like this one and to make sure that the goals set at the beginning of it will be fulfilled at the end.

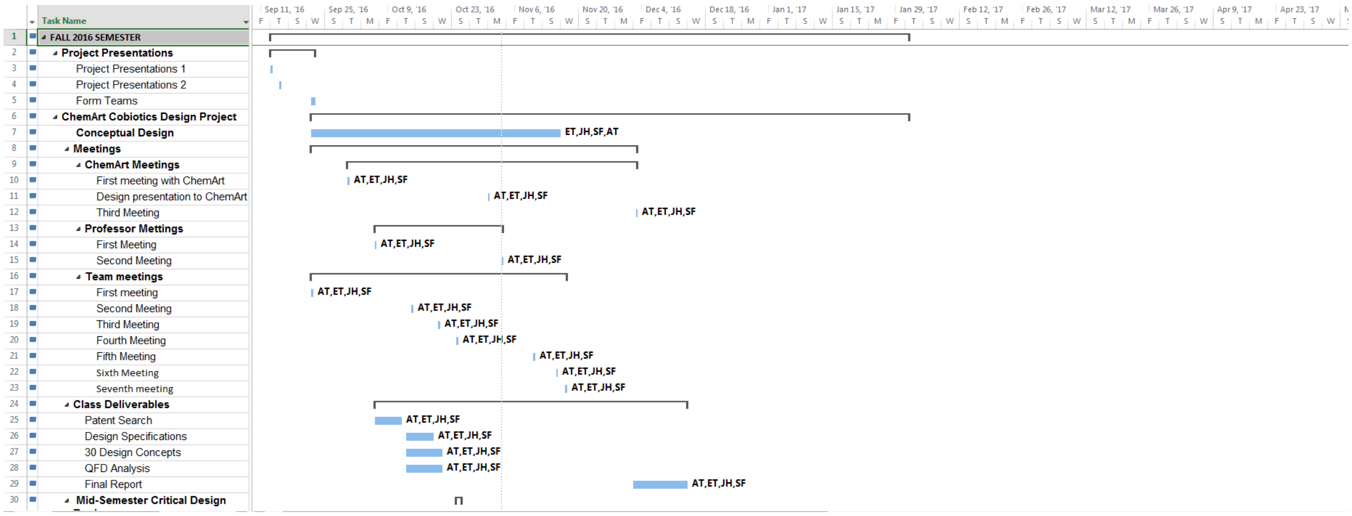


Figure 3: Project Plan View 1

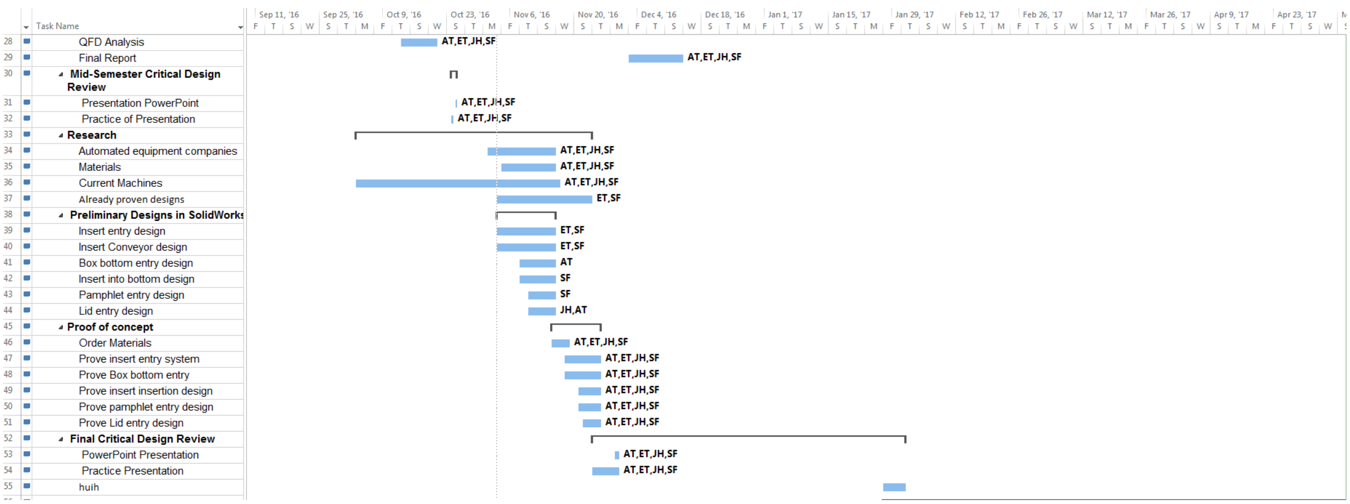


Figure 4: Project Plan View 2

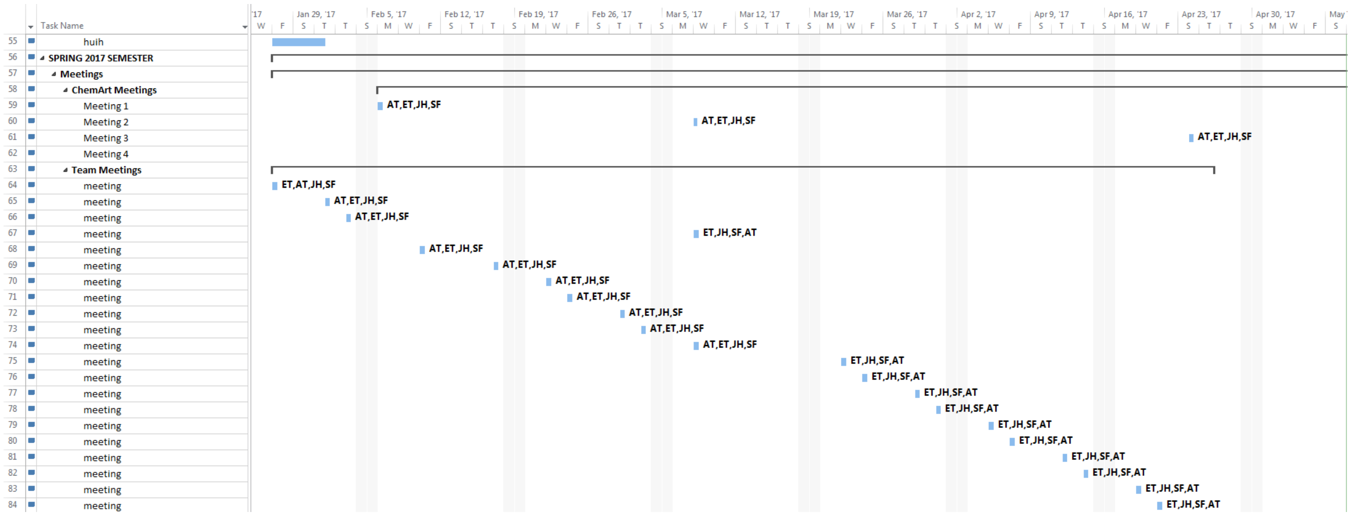


Figure 5: Project Plan View 3

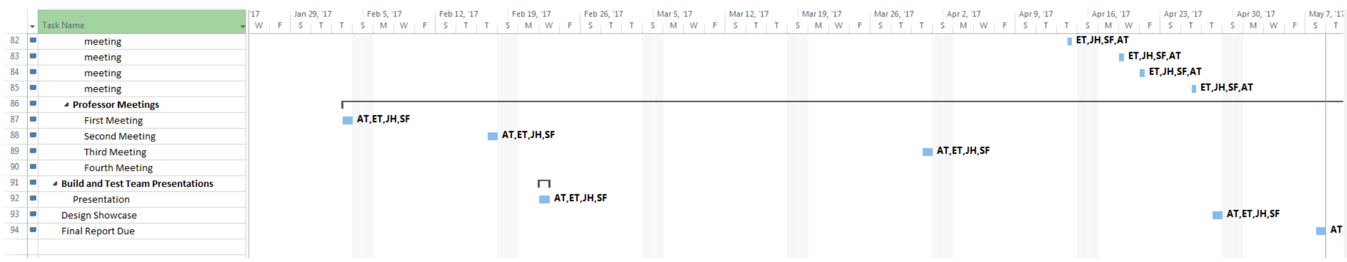


Figure 6: Project Plan View 4

3 Financial Analysis

ChemArt wants an automated packaging system for the ornament keepsakes with little human interaction needed. The current system of hand packaging utilizes eight to ten employees six days a week. The proposed system will utilize one employee to operate the machine. The preliminary packaging system design that was proposed will only be able to package one type of ornament at a time but it will be able to be adjusted for different ornaments. Currently one employee packages a single ornament in thirty seconds. The goal of the new packaging system is to produce a completed ornament every five to six seconds. There are five steps in the proposed design which means it takes an ornament thirty seconds including transition from one step to the next. After further testing of the concepts that have been proposed the time will be analyzed more.

Since the proposed packaging system will only be able to produce one type of an ornament at a time for the cost analysis of the system considers only the White House ornament. The White House ornaments are a constant order size every year whereas the standard ornament order sizes can vary. The White house ornament is 40% of the total production, thus it was it was assumed that 40% of the people packaging are working on the white house ornament. An individual employee that is packaging the ornaments works ten hour days Monday through Friday and works an eight hour day on Saturday. Between 5500 to 7200 boxes are produced a day. Accounting for 40% of those are White House ornaments then approximately 3,299 White House boxes are packaged each day. On average a White House ornament is produced every 10.9 seconds. This number takes into account the 4 employees packaging the White house ornament.

One employee makes $13.50 an hour, thus they make $135.00 in a ten hour workday and $108 in an eight hour work day. Four employees cost $540.00 for a ten hour day and $432.00 for an eight hour day. Adding these costs up four employees cost $3,132.00 a week and $12,528.00 a month. Over the course of a single twelve month year the four employees cost $150,336.00. Creating this packaging system will create long term cost savings. Once the system is installed and paid off there will be these additional funds that can be repurposed for other aspects of the company. The cost analysis for the proof of concept can be found in figure (6).

The goal of the proposed packaging system is to produce a package every five to six seconds. The time it takes for the longest step to be completed will be the regulating factor for the speed at which the ornaments will be produced. If the system can produce the desired ten boxes a minute then six thousand White house boxes will be packaged in a ten hour work day and 4800 will be produce in a eight hour workday. The financial analyses have been conducted for each individual step for the proof of concept prototypes.

3.1 Insert Funnel

The inserts arrive to the ChemArt facility in stacks that are closely packed together. One step in the packaging assembly is to separate the inserts. The concept chosen to pursue for the packaging system is a vacuum with a system used to move it onto the workstation. The vacuum that can be used to remove one insert at a time was found at the company Vacoon. This company makes many different mechanical components including various types of vacuums with different strengths. The vacuum that was found has both a suction aspect and a blowing aspect. [5] These features are important for the pickup and the placement of the inserts. The current vacuum found will cost $300. This product has not yet been purchased so the cost may vary slightly when the final purchase occurs.

Two possible options are available for the movement of the inserts onto the workstations once they have been picked up. There is the opportunity to use two pneumatic cylinders because only two directions of movement are required. The other option is a robot connected to the vacuum. [4] Both options will be further explored in the near future. The two actuators will be $150.00.

Placing the insert into the bottom of the box will be completed using a funnel. The initial prototype for the funnel was made out of PLA filament. The final prototype was made out of 80/20 t-slotted framing. There are two spring loaded L bar arms attached to the bracket that hold up the insert before the actuator will push the insert down into the box. The initial cost of the prototype was $5.00 assuming a quarter of a spool of filament was used. The final prototype cost analysis has been broken down in the table below. The total cost for this prototype was $250.49. This includes all of the components ordered from McMaster Carr, Amazon and the 3D printing plastic used that was supplied by URI.

Table 1: Financial Analysis Insert Funnel

Quantity	Part Number	Description	Unit Cost	Sub Total
2	47065T101	Aluminum T-Slotted Framing Extrusion Single 1" Solid 6ft Length	$19.79	$39.58
1	B00BUA1UW6	Parker 1.06DPSR06.0 Stainless Steel Air Cylinder, Round Body, Double Acting	$18.03	$18.03
2	47065T221	Locking pivot for 1" high single profile aluminum T-slotted Framing extrusion	$18.98	$37.96
16	5537T315	L-Shaped Connector, M5 Thread Size or 1" Aluminum T-Slotted Framing Extrusion	$2.50	$40.00
1	47065T278	Tee, 3" Long for 1" high single Profile aluminum tslotted framing extrusion	$8.83	$8.83
6	47065T341	Swivel leveling Mount with 750lb capacity for 1" aluminum framing	$5.95	$35.70
3	47065T91	End cap for 1" high single aluminum t-slotted framing extrusion	$1.20	$3.60
2	1556A44	Galvanized steel corner Bracket with 2.5" long sides	$1.42	$2.84
2	1613A12	lightweight self-closing spring hinge	$1.96	$3.92
1	8975K596	6061 Aluminum 1/4" thick x 1"wide length 2ft	$5.03	$5.03
1		3D printed parts	$55.00	$55.00

3.2 Box Bottom Dispenser

The box bottom design chosen is a gravity fed loader. The concept consists of a frame that for the prototype was fabricated using PLA plastic filament. This filament is low in cost, an entire spool is $20.00, in the fabrication nothing close to an entire spool was used.

The box bottom required nuts and bolts which cost a total of $15, these were for placing the gate. The gate only allows one box at a time to be pushed out of the machine. An actuator will be used to push one box bottom at a time onto the systems conveyor.Along with an actuator a controller is needed for operation. A single actuator and controller combination will cost around $75.00, this has not been purchased yet but will be in the near future. [6]

Table 2: Financial Analysis Bottom Box Dispenser

Quantity	Part Number	Description	Unit Cost	Sub Total
1	B00BUA1UW6	Parker 1.06DPSR06.0 Stainless Steel Air Cylinder, Round Body, Double Acting	$18.03	$18.03
1	B00HXD2U4Q	Bostitch BTFP72319 Industrial 1/4-Inch Plug with 1/4-Inch NTP Female Thread	$3.99	$3.99
1	B00KHSOCC2	10 Pcs 1/4"NPT Male Thread 6mm Tube Push in to Connect Quick Fittings	$11.59	$11.59
1	B00HG7GXO2	uxcell Pneumatic Quick Fitting 6mm to 6mm Push In Speed Controller Valve 3pcs	$9.54	$9.54
1	B00FH6T7FG	uxcell 10 Pcs Straight Quick Connectors Pneumatic Fittings 6mm x 1/8" PT Male Thread	$10.01	$10.01
1	B008IGHNUI	uxcell 5 Way 2 Position DC 12V 3W 120mA Solenoid Valve 4V210-08	$13.32	$13.32
1	B008MO66FO	uxcell 10M 32.8Ft 6mm x 4mm Pneumatic Polyurethane PU Hose Tube Pipe Blue	$13.29	$13.29
1		3D printed parts	$19.00	$19.00

3.3 Pamphlet Dispenser

The final pamphlet dispenser prototype utilized a combination of purchased and 3D printed parts. Most of the parts were purchased from Mcmaster Carr with a few of the items being purchased from Amazon. As well as ording parts online some of the miscillanious hardware was purchased from the local Home Depot. As for the 3D printed parts some were made from an inexpensive PLA plastic while other parts that required a smoother surface finish were printed with a high quality resin printer. A detailed summery of the cost of the parts used in the pamphlet dispenser is available in tables 3 and 4.

Table 3: Financial Analysis Pamphlet Dispenser

Quantity	Part Number	Description	Unit Cost	Sub Total
2	47065T101	Aluminum T-Slotted Framing Extrusion Single 1” Solid 6ft Length	$19.79	$39.58
1	47065T107	Aluminum T-Slotted Framing Extrusion Doube 1” x 2” Solid 3ft Length	$18.03	$18.03
1	47065T101	Aluminum T-Slotted Framing Extrusion Single 1” Solid 3ft Length	$11.53	$11.53
4	47065T236	Bracket 1” Long for 1” Single Aluminum T-slotted framing Extrusion	$5.79	$23.16
23	47065T216	Brace 1” Long for 1” Single Aluminum T-slotted framing	$5.51	$126.73
2	5537T315	L-Shaped Connector for Aluminum T-slotted Framing	$2.50	$5.00
15	47065T142	Steel End-Feed Fastener for 1” Single Aluminum T-Slotted Framing pack of 4	$2.30	$34.50
1	8632T132	D-Profile Rotary Shaft 1045 Carbon Steel 1/4” Diameter 6” long	$6.64	$6.64
2	5395T111	Set Screw Rigid Shaft Coupling without Keyway for 6mm Diameter Shaft	$2.81	$5.62
4	6294K405	Light Duty Dry-Running Sleeve Bearing for 1/4” Shaft 1/4” long	$1.34	$5.36
3	2471K26	Slim-Tread Drive Roller 2-5/8” Roller for shaft diameter 1/4”	$20.71	$62.13
1	8739K34	White Delrin Acetal Resin Rectangular Bar 1/2” thick 1” Wide 24” long	$13.12	$13.12

Table 4: Financial Analysis Pamphlet Dispenser Continued

Quantity	Part Number	Description	Unit Cost	Sub Total
7	47065T341	Swivel Leveling Mount for 1" High Aluminum T-Slotted Framing	$5.95	$41.65
1	8632T139	D-Profile Rotary Shaft 1045 Carbon Steel 1/4" Diameter 12" long	$9.10	$9.10
2	B01KTXRB90	uxcel DC 12V 200PRM Micro Gear Box Motor Speed Reduction Electric Gearbox	$13.22	$26.44
1	B008GRTSV6	Arduino Uno Microcontroler	$18.82	$18.82
1	B00UHI3NGS	12 Volt DC power supply	$12.99	$12.99
1		3D printed parts	$55.00	$55.00
1		Miscellaneous Hardware	$50.00	$50.00
			Total:	**$565.40**

3.4 Box Lid Loader

The final step in the packaging process is placing the lid onto the box. The apparatus that the team designed to perform this task uses gravity and the force of the conveyor belt to place the lids on the boxes as they pass below the fixture on the conveyor belt. The final revision of the Box Lid Loader is a frame made from 80/20 aluminum framing and various connectors and inserts. The fixture is completely adjustable and fixture cost a total of $128.24 in components. This does not include the cost of labor to assemble the apparatus or the cost of the plastic inserts for the inside of the fixture. The cost breakdown for this component can be found in Table 5.

Table 5: Financial Analysis Box Lid Loader

Quantity	Part Number	Description	Unit Cost	Sub Total
4	47065T341	T-Slotted Framing Leveling Mounting Foot For 1" High Rail	$5.95	$23.60
8	47065T216	T-Slotted Framing Corner Brace For 1" High Singular Rail	$5.51	$44.08
8	5537T315	T-Slotted Framing L-Shaped Connector	$2.50	$20.00
1	47065T101	4 ft Solid Metal Rail	$14.20	$14.20
1	47065T101	5 ft Solid Metal Rail	$17.75	$17.75
1	91251A541	Black Oxide Alloy Steel Socket Head Screw w/4"-20 Thread Side, 7/8" Long	$8.41	$8.41

3.5 Human Resource Allocation

As a team a significant amount of time was dedicated to this project. The time dedicated can be broken down into several sections fr the fall semester. The team met as a group for a total of 44 hours throughout the entire Fall semester. Team meetings account for a total of 176 man hours between the four team members. Once a month the team had a meeting with ChemArt to keep them up to date on what work has been accomplished. The three meetings with ChemArt throughout the semester added to a total of 6 hours for each of the team members. This adds 24 man hours. Through the course of the fall semester the team met with Dr. Bahram Nassersharif to make sure the project was on track. In the conceptual process the team spent a large amount of their time performing research on current designs in the engineering industry and brainstorming possible solutions to the design problem. Once the conceptual phase completed many hours were allotted to designing the components of the system. The bulk of the hours this semester were spent on research and designing the concepts for prototype. In figures 7 through 9 below they are the breakdown of each team member's time. As a team 616 man hours were spent towards the completion of this project. An average starting salary for a mechanical engineer is $25 an hour. The cost of labor for the team for the Fall semester is $15,400.

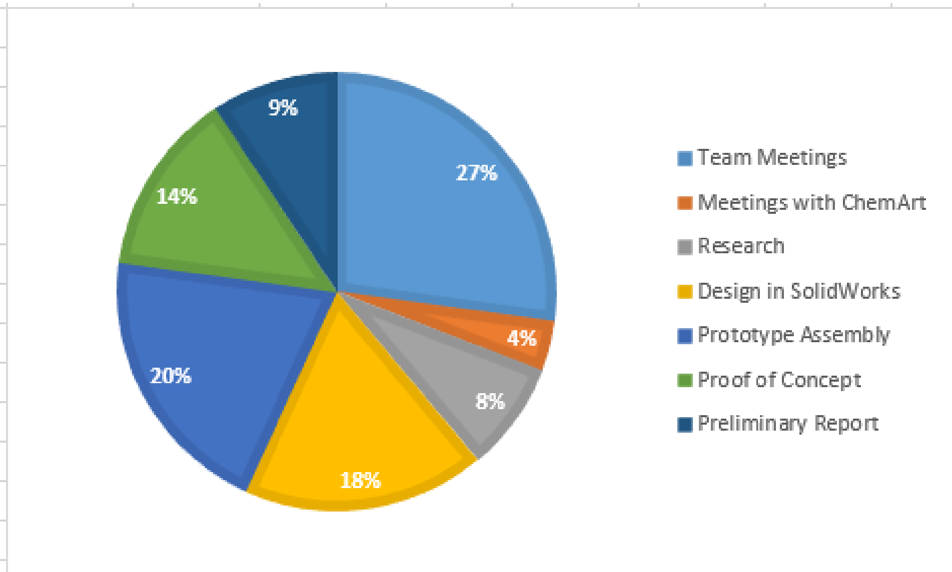


Figure 7: Sean Fisher Time Distribution Fall Semester

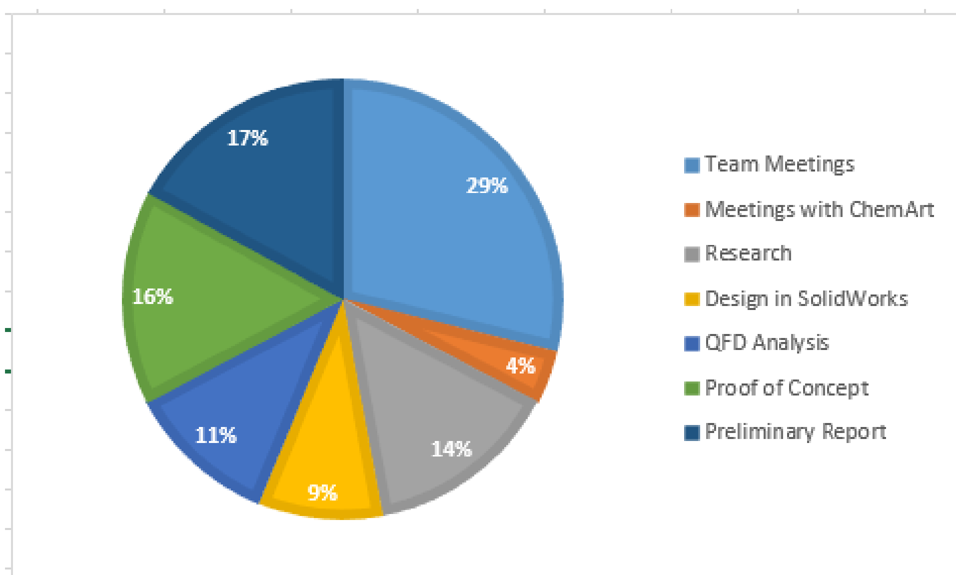


Figure 8: Jennifer Hart Time Distribution Fall Semester

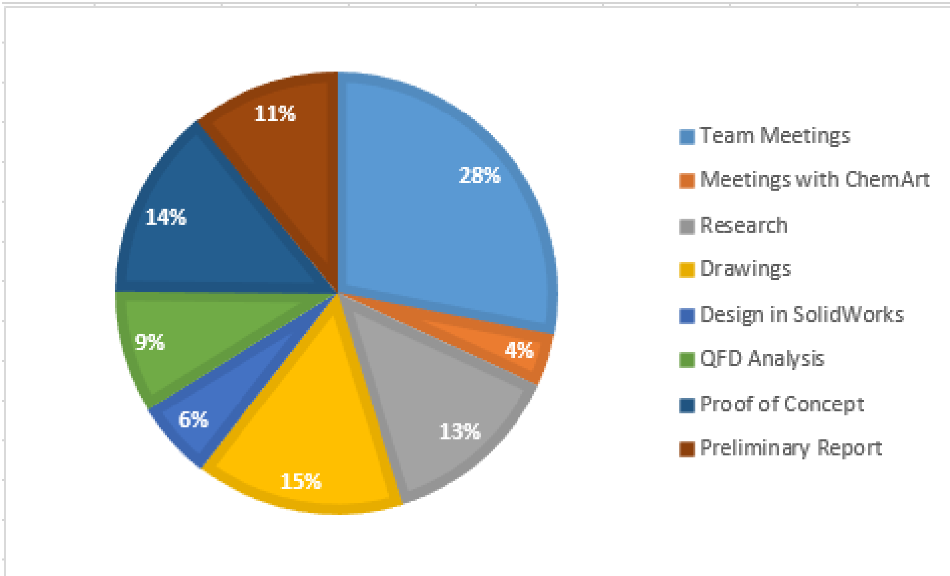


Figure 9: Alvaro Torrecilla Time Distribution Fall Semester

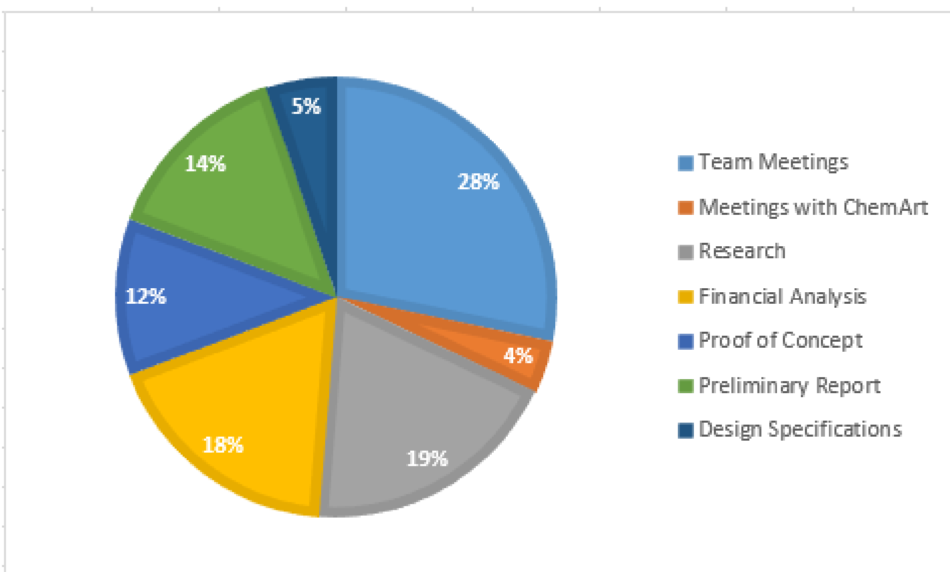


Figure 10: Emily Tacopina Time Distribution Fall Semester

As a team a significant amount of time was dedicated to this project. The time dedicated can be broken down into several sections fr the Spring semester. The team met as a group for a total of 72 hours throughout the entire Fall semester. Team meetings account for a total of288 man hours between the four team members. Once a month the team had a meeting with ChemArt to keep them up to date on what work has been accomplished. The three meetings with ChemArt throughout the Spring semester added to a total of 6 hours for each of the team members. This adds 24 man hours. Through the course of the Spring semester the team met with Dr. Bahram Nassersharif to make sure the project was on track. In the Design process the team spent a large amount of their time using SolidWorks to design each of the different steps. The bulk of the hours this semester were spent on designing, Building and testing the final prototype. The figures 11 through 14 below are the breakdown of each team member's time. As a team 736 man hours were spent towards the completion of this project. An average starting salary for a mechanical engineer is $25 an hour. The cost of labor for the team for the Fall semester is $18,400.

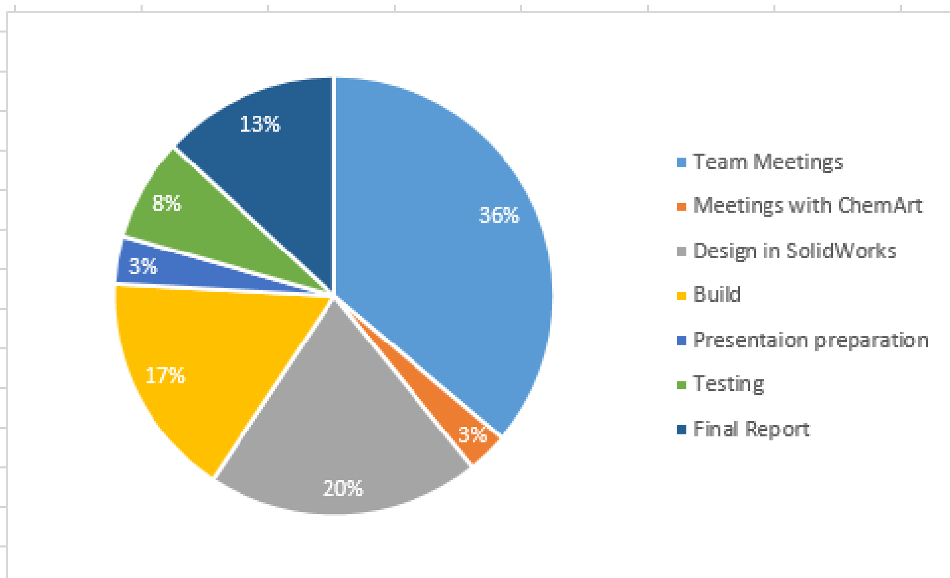


Figure 11: Sean Fisher Time Distribution Spring Semester

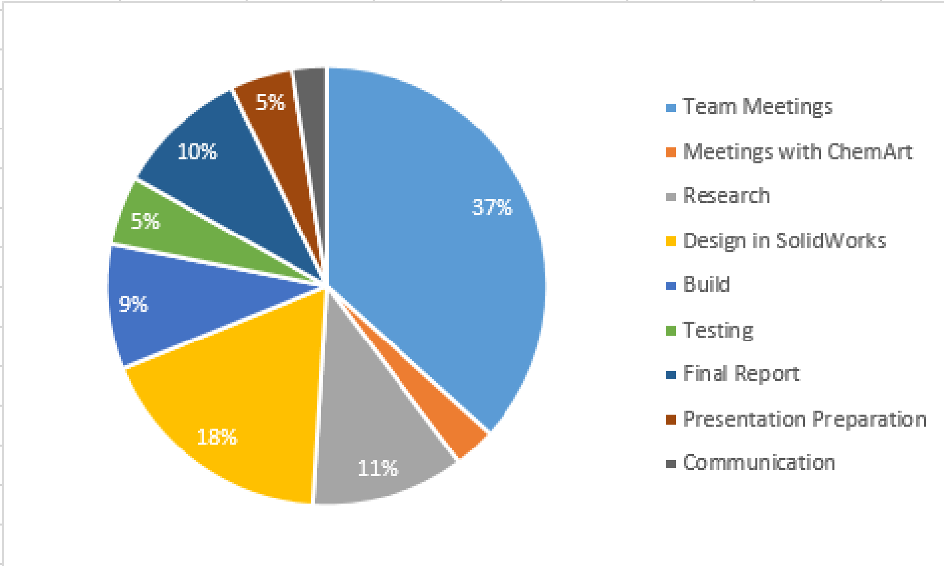


Figure 12: Jen Hart Time Distribution Spring Semester

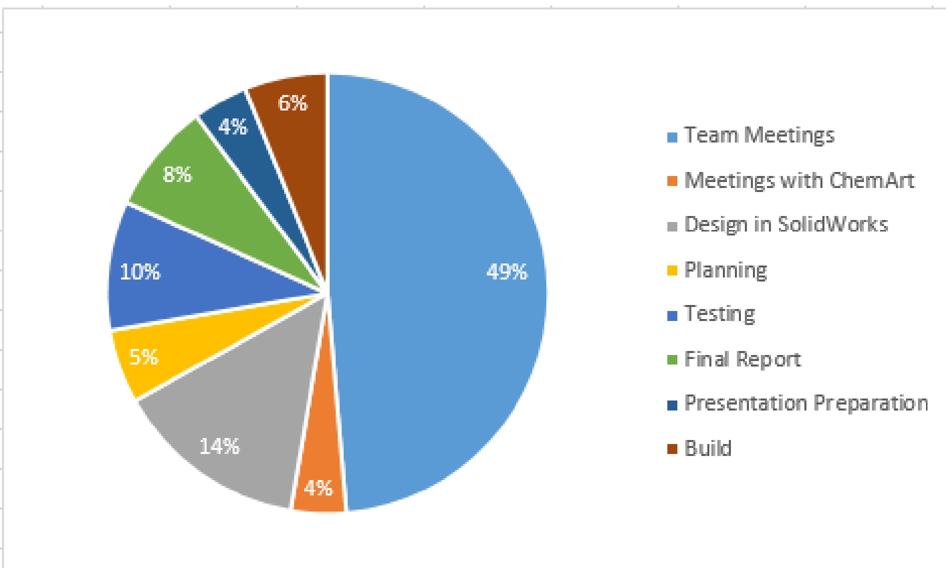


Figure 13: Alvaro Torecilla Time Distribution Spring Semester

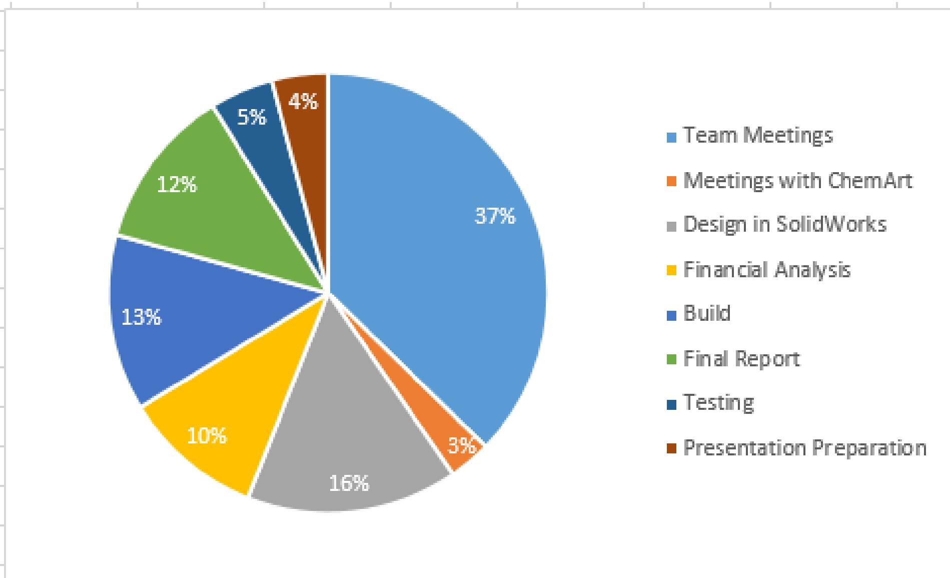


Figure 14: Emily Tacopina Time Distribution Spring Semester

3.6 Machine Components

Aside the individual steps to the system there needs to be a way to connect all of the steps. The proposed solution is to use a series of conveyor belts that will run from one step to the other carrying the main box. As the main box travels down the conveyor the additional components will be added to it until the box is completed. These conveyors will also need a guard that will keep the box in the correct position as it travels down the system. Methods of centering the box are still being looked into and will be factored into the cost of the system. There will be a single conveyor or rollers that will travel down the center of the final assembly work station. The conveyor and motor will cost more than the rollers but the trade off is, the employee will have to use man power to push the box down the line if rollers are put in place. All of the steps will have to have mounting fixtures that they can be placed above the conveyor in their appropriate locations.The conveyor for the length to fit all of the steps will cost approximately $15,000. Guides will add to the cost.

Table 6: Financial Analysis for Proof of Concept

Step	Components	Cost ($)
Placing bottom of box	PLA filament supplied from URI	$5
Placing bottom of box	Nuts and bolts from Home Depot	$15
Insert into bottom of box	PLA filament supplied from URI	$5
Insert into bottom of box	Nuts and bolts from Home Depot	$15
Placing pamphlet	Motor from Amazon	$12.93
Placing pamphlet	Speed controller from Amazon	$8.47
Placing pamphlet	PLA filament supplied from URI	$5
Placing pamphlet	Nuts and Bolts from Home depot	$30
Placing pamphlet	Wheel from Mcmaster Carr	$20.71
Placing lid	PLA filament supplied from URI	$5
	TOTAL:	$122.11

Table 7: Financial Analysis for Final Prototype

Step	Cost ($)
Box Bottom Dispenser	$98.77
Insert Funnel	$250.49
Pamphlet Dispenser	$565.40
Lid Drop	$128.24
TOTAL:	$1,042.90

Table 8: Return on Investment

Component	Cost ($)
Worker Savings One Year	+$122,148.00
Box Bottom Dispenser	-$98.77
Insert Funnel	-$250.49
Pamphlet Dispenser	-$565.40
Lid Drop	-$128.24
Conveyor	-$15,000.00
TOTAL SAVINGS:	$106,105.10

4 Patent Searches

Patent number: 7,591,124

Patent Name:Automated supply system for delivery of products to packaging mechanism

Patent Date: September 22, 2009

Description: This patent is involves an automated system in which products are packaged into the final shipping container. Although the system created by team Pack-in-the-Box no longer includes the shipping step the ideas patented can be used in other parts of the system. The patent mentions having guide rails to make sure the package stays in place. In the system being designed for ChemArt a conveyor system will need to include rails to keep the box in the correct place. If the box were to be altered in orientation the steps following the mishap will be wrong, causing shutdown of the system for reorientation and possible damage if the mishap was not caught early enough. To avoid any potential error guide rails will be implemented alike the patent. This patent also includes a sensor that is able to sense when the correct number of products are stacked, this can be implemented in the proposed packaging system. Sensors can be placed in the desired locations to confirm the products are in the right location for each step. The objectives for the patent is to provide an automated supply system that quickly and efficiently packages products while also decreasing processing times and operating costs and increasing production and productivity. The objective for this project is concurrent with the patent allowing the team to use the patent to assist in brainstorming concept ideas. [7]

Patent number: 6,584,753

Patent Name: Method for including inserts with goods during automated packaging

Patent Date: June 1, 2004

Description: This patent includes an insert delivery system for use with an automated packaging system. For this particular patent is has to do with placing the insert in the product of a sliced loaf of bread. This invention comprises a vacuum system for the placing of the insert, placing sensors in critical locations and the control mechanism. In the system being designed for ChemArt this invention can be related to two of the steps. One of the steps is the removing of the plastic inserts then placing them onto the conveyor. The other step is the placement of the pamphlet into the bottom of the box. The system comprises a vacuum system that picks up the places the insert between the two desired positions. In relation to this project the plastic inserts will need to be picked up in the same location repeatedly then placed in the same position repeatedly. Understanding the programming to do these steps will be crucial in being able to program the system. Further learning about the programming done for this patent will aide in the programming for this projects programming. Including a sensor will benefit the design of the proposed system to minimize errors and to be able to keep track of the box as packaging assembly occurs. Looking at the breakdown of the patent aids the team in comprehending how to go about conceptual design for a system. [7]

Patent Number: 5,041,907

Patent Name: Automated Assembly and Packaging System

Patent Date: August 20, 1991

Description: This patent is for an apparatus and method for picking up and randomly manipulating randomly positioned objects moving on a belt and transferring them to randomly oriented and placed destinations. This seemed very relevant to the ChemArt design project seeing as the entire project is based on placing objects into boxes in an organized fashion. The fact that this system would need some sort of conveyor belt system seemed clear from the beginning of the design process, and this patent provides insight as to how one could use robotics to pick up and place objects while they move on separate conveyor belts. A system such as this one would allow for less human interference in the operation seeing as the system is able to pick up and place objects without specific alignments. This system uses vision windows to identify and locate objects with an image processing unit. The locations of the objects and the destinations for the objects are entered in an output queue that is then transmitted to a first robot motion controller. The robot then picks up and places the objects at their destinations that it can in the time that is available while the object pass by it. This dynamic system is appealing when it comes to finding a fast, efficient, and effective way of packaging a steady flow of ornaments. This patent helped the design team understand the capabilities of robotic components and can be implemented in the separation and organization of inserts as well as placing the ornaments into the inserts. [7]

Patent Number: 6,655,015

Patent Name: DPA automated assembly and packaging machine

Patent Date: December 2, 2003

Description: This patent details a system that automatically assembles, inspects, and packages disposable prophylaxis angles. Although the product varies distinctly from Christmas ornaments, the principles and ideas are applicable to this design project. The machine includes an apparatus that is set up so that objects are fed into it, then inspected, and are ultimately fed into packages. The objects are inspected at stations that are set up in a circular fashion, then once the objects pass inspection they are fed into individual bags which are counted then fed into boxes. Although the packaging of the angles is less sophisticated than the packaging of Christmas ornaments, the process has aspects that relate well to the design challenge. The system gave the design team ideas as to how one may inspect the components of the assembly during the process rather than at the beginning or the end. This system displays a viable method for removing human interaction with the system and cutting down labor costs. This system, when applied to ChemArts design problem, also ensures that the ornaments and components of the packaging assembly are all up to ChemArts standards for quality. Many modifications would need to be made to this system to have it work for ChemArt, but the concepts within the design are transferable and have inspired the design solutions that the team ultimately chose to pursue. [7]

Patent Number: 7,104,029

Patent Name: Method for carrying out a size change over in a packaging machine

Patent Date: September 12, 2006

Description: This patent describes an organized system for transferring a packaging machine from one product size to another. The process described in this patent directly relates to this packaging machine because the intent is to make it adjustable for multiple packaging sizes. Described within the patent is a checklist for all of the items that need to be changed in order for the machine to operate properly with the different sized packaging materials. This patent protects the computer design of a system which uses sensors and operator input to ensure that all requirements of the checklist have been made. This system could be integrated into the design of this packaging machine to ensure that all necessary components have been changed in order to work with the new packaging size. [7]

5 Evaluation of the Competition

The automated packaging design system that is being developed is intended for use by ChemArt, and not intended for commercial retail. Therefore, the primary competition associated with this design is the current system and the proposed design solutions that the team narrowed down from the initial 120 design concepts generated. Quality Function Deployment Analyses performed by the team were used in order to determine which of these competitive ideas the team would choose for the final product.

5.1 Comparison with Current System

The current system that ChemArt uses to package their ornaments is done completely by hand. Workers are at rectangular tables, four workers per table, and they package the ornaments, each worker doing the entire assembly themselves. The workers have stacks of inserts, boxes, and pamphlets on their workstations, and one worker moves around restocking materials and retrieving ornaments from the manufacturing space located in close vicinity to the packaging area. This system produces one box per thirty seconds per worker, therefore a table of four workers produces approximately eight boxes per minute.

The current system is fast and efficient for what it is, but when ChemArt needs to increase the volume of product that they are producing they need to hire temporary employees to keep up with the the demand for this man-powered system. This is extremely inefficient and cost-ineffective. The system has its innate benefits - one of which is that each and every item that leaves ChemArt is hand inspected once more before it leaves the premises, ensuring that only the best quality product leaves the facility.

The goal of the capstone design challenge is to create a fully or semi-automated system which can produce ornaments at the same rate without the need for added temporary labor. The students are faced with creating a system that delicately and quickly assembles the packages in an efficient and timely way. The current system does not meet those specifications and is therefore not up to the standards that have been set for this design project.

5.2 Ornament into the Insert and Insert into the System

Currently the workers take one insert from a tightly stacked pile of inserts then they place the ornament inside of this insert. It is one of the more time consuming steps in the packaging process and involved a wide variety of hand movements and both hands of the worker packaging the ornament. In order to approach finding design solutions for this specific step the team members had to carefully analyze video that was recorded during a visit to ChemArt and brainstorm viable solutions.

The team decided that the best, and safest, method for placing the ornament into the inserts was by having the people who assemble the ornaments place them into the inserts after completing the final touch on the finished product. This allows for the ornaments to be safely placed into the insert without risk of damage to the ornament. ChemArt has exceptionally high standards when it comes to defects on the assembled ornaments and a large part of their product is considered damaged and is then recycled. The concept of having a form of suction attached to a robotic arm was considered, but due to the various shapes, surface areas, and designs that the ornaments that ChemArt makes it would be nearly impossible to program a machine to handle the variety and it would be a constant struggle to maintain.

The process of separating the inserts is one of the more difficult steps to approach from an automation standpoint. The inserts are stacked together tightly and the White House ornament inserts have detailed indentations in order for the White House Ornaments to sit in the box without tape or external adhesives. This trait makes the inserts difficult to separate and the workers currently separate the inserts from the pile upside down so that the smoother surface faces upwards and the indentation faces up so the box is easier to grasp.

Ideas for solving this problem ranged from using a grabbing arm mechanism to having a person separate the inserts one at a time. Their interlocking stacks make it difficult to find a feasible solution for separating them without risk of damage to the product. The competitive idea to solve this problem with was to use suction to separate one insert at a time from the stack, then a robotic arm would place the insert onto a conveyor belt. This idea is closely related to the concept that the team chose. It was the best option because of the proven capability of the mechanism and the ability to reprogram the suction and set it to different levels depending on the insert.

5.3 Box Bottom into the System

Currently the workers take boxes that are already put together and separate the top from the bottom of the box. This is how the boxes arrive from the supplier, and ChemArts employees work around this. The team asked ChemArt if it was possible to have the lids and bottoms shipped separately, not already assembled, and ChemArt was confident that their suppliers would not have an issue with that. Now that the box bottoms will be in their own stack there are a couple solutions as to how the box bottoms can be introduced into the system. The box bottoms do not fit inside of each other and do hot have draft angles that would make them interlock or stack without the assistance of guides and force. Therefore all of the design solutions need to incorporate a way of keeping the box bottoms in a stack that will not fall over, and will allow for one box to be removed at a time from the system.

The first proposed design solution was to have the stack of boxes on a spring loaded mechanism which would raise every time one box was removed from the stack. The boxes would then be pushed onto a conveyor belt using an actuator and probe pushing the box onto a moving conveyor belt. The actuator probe pushes the box and retracts quickly as to not interfere with the box that is rising due to the released force on the spring loaded mechanism at the bottom of the stack of box bottoms.

The second proposed concept was similar to the first and the only major difference was that instead of a spring loaded mechanism, the design would incorporate an elevator for a more precise result and less need to interchange and adjust parts for different boxes.

ChemArt uses a variety of boxes in different weights, shapes and sizes, so the elevator mechanism would be easily adjusted to account for the boxes of varying weights. It also would lower more smoothly when reloading, but requires electricity to function properly - while spring loading does not require power.

The third design, which is the design that most closely resembles the design that the team proved with the proof of concept presentation, uses the actuator but changes the stacking mechanism. The box bottoms are vertically stacked above the level of the conveyor belt and there is space for one box to be exposed to the actuator probe, which moves quickly as the next box drops down. This was the most efficient, adaptable, and conserved energy - therefore it is the design which was chosen.

5.4 Placing Insert into Box Bottom

Placing the insert into the box is the most precise and delicate step in the system. The inserts are flexible to a certain extent, but they fracture under a relatively small amount of pressure. The workers currently take the inserts that already have the ornaments placed in them then they place the insert into the box at an angle, as to only put pressure on two corners at a time. This approach prevents the insert from cracking, and also allows for the insert to smoothly enter the box without having to press down. The fit of the insert in the box is tight, so the insert and ornament do not rattle around.

There are a few design concepts which were contemplated by the group. The first concept is mimicking the current process. A three pronged probe acts as though a hand would guiding the insert into the box bottom then applying the force that would allow for the insert to be firmly placed within the box. The trouble with this is finding the right amount of force and also programming the arm to move with so many degrees of freedom. It would also be time consuming to recalibrate and adjust for other packaging assemblies.

Another design concept that the team looked into was using two conveyor belts of different heights then feeding the insert from the top conveyor into the box on the bottom conveyor belt using a robotic arm and a low ceiling to press the insert into the box. The robotic arm would have two arms instead of three and would push the insert into the box at an angle then push down onto the insert forcing it into the box. Again, this system seemed troublesome and the team was unsure of how the right amount of force would be to prevent fracture in the insert, but still ensure that the insert made it into the box. The team did think that the low or tapered ceiling could be a good mechanism to force the insert into the box and level the insert inside of the box.

Lastly, the third design was one which incorporated the low tapered ceiling from the previous design, but instead of using a robotic arm it uses a funnel mechanism. The shape of the inserts allow for the corners to be larger than the box itself so if one were to try to place the insert into the box from directly above the insert would break. With this in mind the funnel mechanism pinches the corners of the insert and then a force from above pushes the insert through the funnel and into the box. When done properly and when the tolerances are correct this proves to work well with a very low rate of defects. It also involves the least sophisticated robotic component, therefore it is easier to maintain.

5.5 Pamphlet into the System

Currently the process for introducing the pamphlet into the system and assembly is very straightforward. On the workstation there is a pile of pamphlets and the worker takes one pamphlet and places it on top of the box with the ornament and insert in it. Then afterwards the worker places the lid on the box and moves it to the pile of completed boxes. It is a relatively simple motion for a person to perform, but it is a fairly intricate step to automate. The size and shape of the pamphlets vary from customer to customer and the pages can separate or rip if there is a jam in the system. The pamphlets are an important aspect, especially for the collectible White House ornaments that are meant to be keepsakes for years to come.

The first proposed idea was to stack the pamphlets in a cage of sorts above the conveyor belt, then a gate or set of mechanical teeth would release one pamphlet onto the box below as it passes by. The system is relatively simple, but there are a few parts that worried the designers. The teeth could allow for papers to get jammed within the cage. If the teeth did not retract fast enough or became out of sync through wear the pamphlets could release in too few or too great of quantities from the cage above.

The next proposed idea was similar to the concept was to have a stack of pamphlets on a spring loaded platform and an L-shaped probe would push one insert onto the box assembly at a time. The L-shaped probe seemed like a great solution for only allowing one pamphlet to be put on the box assembly at a time. The probe would reach between the pamphlets and would push one forward onto the box and a stopper on the other side of the conveyor belt would prevent the pamphlet from moving too far. This design seemed viable, but the recalibration to account for different sized pamphlets proved to be a difficult challenge to design around using this mechanism. The spring loading would have to be altered each time the materials were changed and the work to upkeep this system seemed too great.

The final proposed idea was the idea that the group most closely replicated for the proof of concept. The design involved a vertical stack of pamphlets and a slot at the bottom of the stack that would allow for one pamphlet to be released at a time. The pamphlets are forced out from the bottom of the stack by means of a roller wheel. The wheel is powered by a motor and turns off and on forcing one pamphlet out at a time. This mechanism had less likelihood of paper jams and failure than the other options proposed. It is also an easily adjusted design, and can be adapted for multiple different types of pamphlets, leaflets, and cards.

5.6 Box Lid into the System

As stated before the boxes are currently introduced to the system as fully assembled boxes without the contents inside of them, so the workers have to separate them, place the contents inside, then close the boxes. The box tops and bottoms will be introduced to the new packaging system as separate parts in their own stacks which do not interlock. The team came up with a couple solutions for how to get the lid onto the box. The two parts fit together well, which makes the automated process difficult to design.

The first proposed concept was to use a robotic arm - similar to a crane mechanism - to pick up one box at a time from the box of lids then place it on the assembly. A positive trait for this specific design is that the lids would not have to be removed from the box in which they were shipped by a person. One of the downsides is that it would take a great deal of highly precise programming and calibration to make this a feasible design which leaves a lot of room for error. If this were to fail the system would have to be completely shut down and recalibrated costing ChemArt time, money, and skilled labor to fix the problem.

The second proposed solution was to have a vertical stack of lids above the conveyor belt and at the bottom a gate with retractable teeth lets one lid go at a time over the assembled box. This design required precise timing and exact placement of boxes on the conveyor belt which is difficult to ensure in a fast moving system. This design, although relatively simple, seemed difficult to create and ensure its adjustability and precision.

The last proposed design solution was a gravity driven angled box release which would involve no electrical mechanism to release one box at a time. The angle of the drop allows for one lid to fall at a time, and the conveyor belt pulls the lid onto the box and allows for the next lid to fall. This design, although relatively simple, won in terms of the standards which were set in the QFD analyses. Its robust design and ability to allow for different sized boxes were selling points as well as its need for less maintenance than the other designs.

6 Conceptual Design

In order to begin the conceptual design phase of this project the individual steps required to package the product needed to be decided upon. The final package is made up of a box bottom and lid, the ornament, a plastic insert that the ornament is placed into, as well as an information pamphlet which describes the ornament inside. With these materials in mind the steps to package the ornament could be decided upon. The process was broken down into four main steps including ornament into insert, insert into box, pamphlet into box, and lid onto box. Each of theses steps require that their respective materials be delivered in a controllable manner in order to complete the step. This means that another four designs were necessary to facilitate the task of material handling and dispensing of the inserts, box bottoms, pamphlets, and box lids. In total eight design concepts were required in order to design a machine which can automatically package Christmas ornaments.

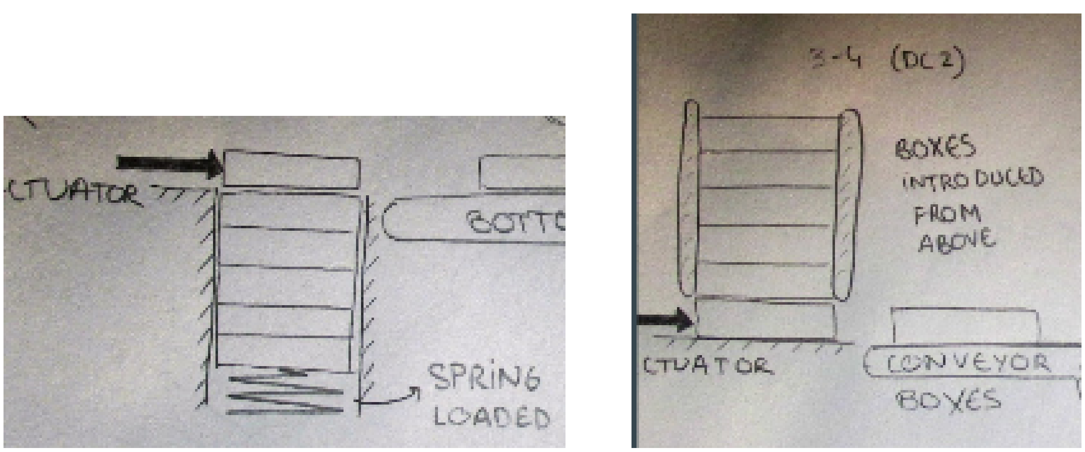
Each student was given the responsibility of creating 30 design concepts to accomplish the eight different processes required to package the ornaments. The students were encouraged to create ideas for each design challenge however they were allowed to create more designs for the problems that they had more solutions to. With four students creating 30 concepts each a total of 120 design concepts were created to provide solutions to the various challenges presented by this design problem.

Some addition design concepts were also created to solve other problems not directly related to the packing of the ornament. Several ideas were developed for ways automatically place the finished ornament packing into its shipping box. Also designs were created for methods of transferring those full boxes from the packaging area to the shipping department. Finally concepts were created for how to better manage the flow of materials in the factory. After meeting with the sponsor it was decided that it would be better to focus on the packaging of the ornament and these other design considerations could be brought up in the future to help improve the work flow in the factory.

Once the design concepts had been created and they had been narrowed down to the challenges that would be focused on for this project it was time to consolidate them down to one or two designs that could be prototyped. In order to help with this process all the concepts for each challenge were compared to each other and evaluated for the effectiveness at completing the task. The design that won was the one that was mechanically the simplest, was the most repeatable, and had the highest level of automation. In the following sub sections each design concept will be explored in further detail.

6.1 Box Bottom

The challenge of getting the bottom of the box into the system was by far the simplest. Since the box bottom is comprised of a simple rectangular shape it is easy to create rectangular guides to hold a stack of boxes in place. Two main design concepts were created to transfer one box bottom at a time out of a stack and into the packaging system. The first design concept relied on a spring or actuator to push a stack of boxes up towards a pneumatic cylinder which would push the top box off the stack into the system fig.15a. The second design concept was very similar however it relies on the force of gravity to allow the stack of boxes to move down once the bottom box is pushed out by an actuator fig. 15b.



(a) Spring loaded bottom feed design

(b) Gravity top feed design

Figure 15: Conceptual designs for box bottom dispenser

Other design concepts were created for ways in which to load stacks of boxes into the mechanism that deposits one box at a time. The ability to have a mechanism to load additional stacks of boxes into the system will increase the amount of time the machine can continue running without having to be reloaded.

6.2 Insert

The inserts currently arrive at the factory in stacks of inserts nested inside one another. This has proven to be a difficult challenge to solve because it is very hard to separate one insert from the stack of inserts. It was decided that the best method to accomplish this would be to use a suction system in combination with a robotic arm in order to transfer the inserts from the stack to the conveyor belt fig. 16. In addition to this, grippers would be needed to hold the lower part of the stack while the top insert is being pulled off. These grippers would ensure that only the top insert is removed from the stack. Once the insert has been removed from the stack it will be transferred onto a conveyor where it will travel to the assembly workers where the ornament will be placed inside.

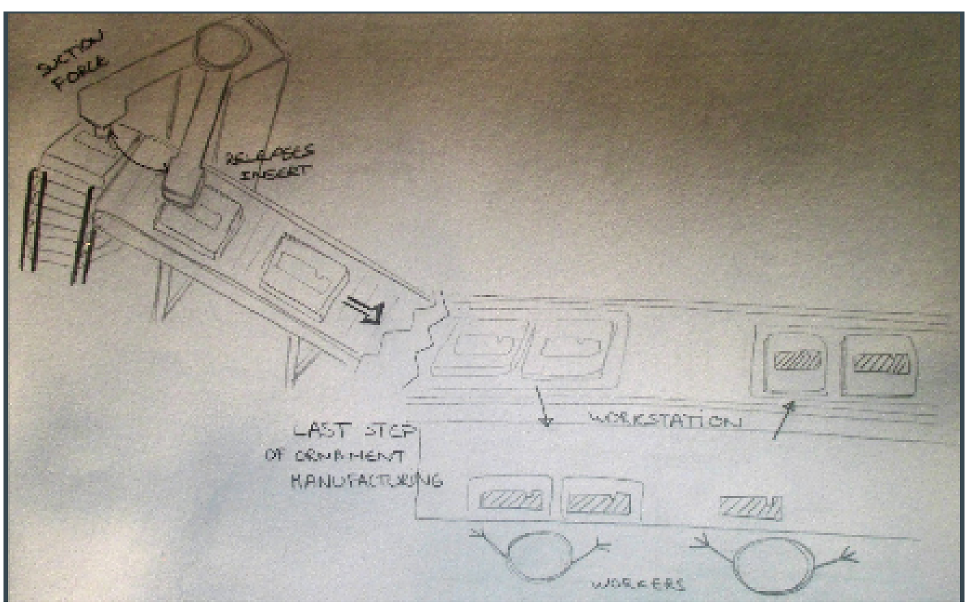


Figure 16: Conceptual design for getting the inserts into the system

6.2.1 Ornament into insert

Placing the ornament into the insert is a very complicated task. This is due to the irregular shape of the ornament as well as the way in which the ornament currently arrives at the packaging department. Since this process is so difficult there is only one design concept that would be effective. This concept would include a robotic arm with a high degree of accuracy to transfer the ornaments to the insert. This robotic arm would also need to be equipped with an imaging system to ensure the arm was picking up the correct ornament placing it into the insert in the correct orientation. Finally custom holding trays would be required to provide a way to transfer the ornaments from assembly to packaging in an orderly manner. This solution would have an extremely large cost and would require a lot of reprogramming with each change in ornaments. Since this solution has such a high cost a simpler less automate solution has been agreed upon. The inserts will now travel on a conveyor belt in front of the workers assembling the ornaments. As the workers complete the last step in assembling the ornament they will place the ornament into the insert on the belt in front of them. This belt will then be transferred down the line of assemblers and towards the packaging machine.

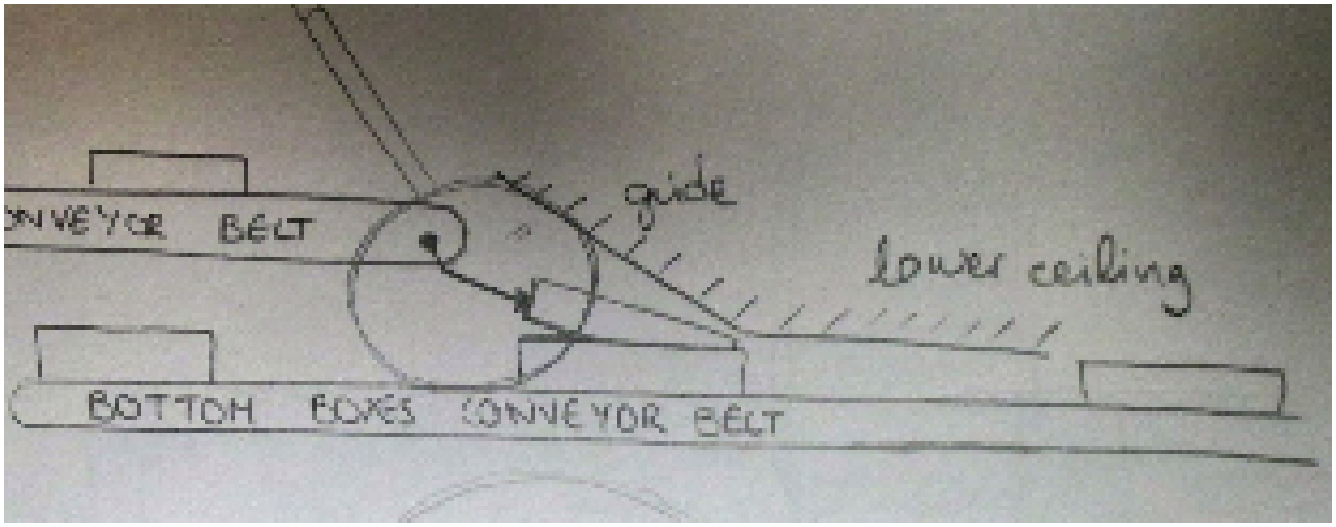
6.2.2 Insert into box bottom

Placing the insert into the box has proven to be another difficult challenge that needs to be solved in order to complete the packaging of the ornament. Currently the workers place the insert into the bottom box on an angle and apply pressure while pushing the insert down into the box. The have to apply pressure in order to squeeze the insert into the box bottom which is slightly smaller than the insert. The reason for the size difference is so that the insert stays secure in the box bottom even if it is tipped upside down.

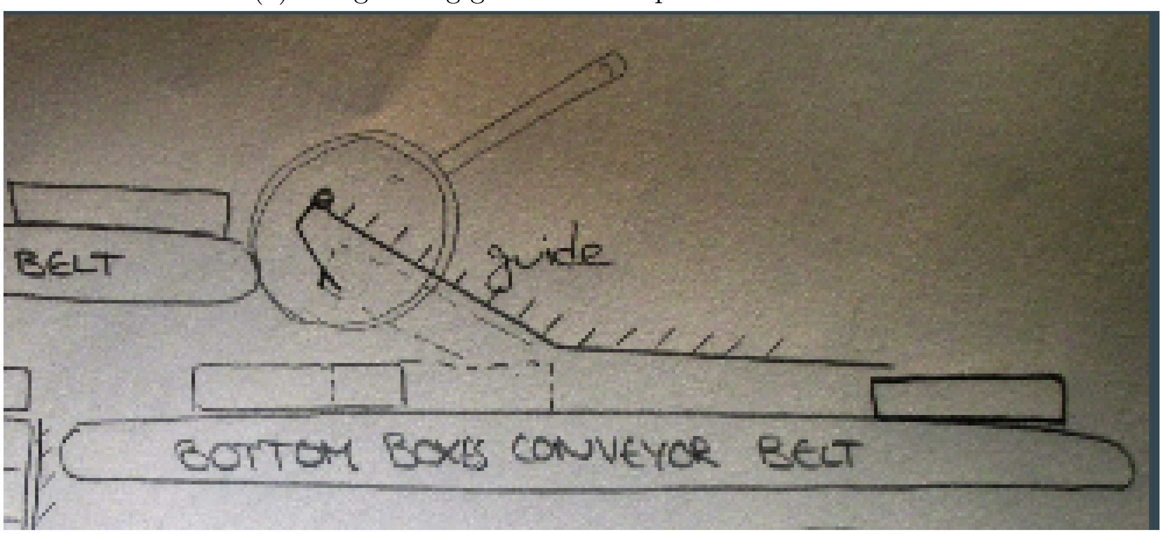
The first design concept aims to mimic this behavior by using guide arms to push the insert off of one conveyor and into the box bottom which is on a lower conveyor fig. 17a. While this method is proven to work it would be very difficult to replicate with mechanical arms.

Another design concept is to have a conveyor belt with fins attached to it. The idea behind this concept is that as the insert reached the end of the belt it would begin to fall into the box bottom which is waiting on the lower conveyor belt. As the fin came around the end of the belt it would begin to push down onto the insert to force it into the box. This concept can is better illustrated in fig. 17b. While this concept provides a very simple, streamlined solution to the problem the issue of repeatability made it not a viable option.

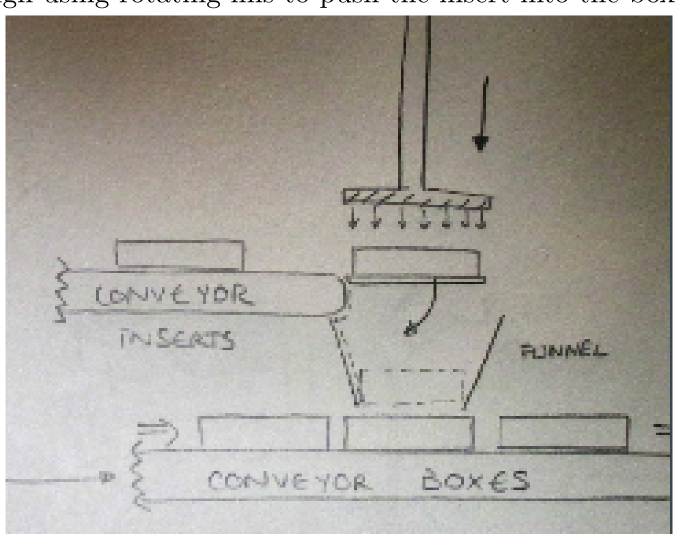
The final concept that was evaluated was to have the insert pushed through a funnel into the box bottom fig. 17c. The purpose of the funnel is to compress the sides of the insert equally just enough for it to fit inside the box. The idea behind this concept is that the insert would ride off the end of the first conveyor into the funnel. Inside the funnel would be spring loaded arms that would hold the insert in position until the box bottom was in position below the funnel. Once the box bottom is ready a pneumatic cylinder would be used to push the insert through the funnel and into the box bottom. This design was chosen because it provided the simplest solution to the problem at hand. This concept performs a complicated task with one motion it a manner that is very repeatable as well as easy to adjust.



(a) Design using guide arms to push insert into box



(b) Design using rotating fins to push the insert into the box bottom



(c) Design using actuator to push insert through funnel into box bottom

Figure 17: Conceptual designs for placing insert into box bottom

6.3 Pamphlet

In order to place the insert into the box a system needed to be design that could dispense one pamphlet at a time. One solution to this problem was to have two vertical belts with teeth that would grip one pamphlet at a time fig. 18. The belts would advance down towards the belt carrying the box bottom with the insert. Once a box was below the device and was ready for an insert to be dispensed the belt would advance and the bottom set of teeth would be released allowing one pamphlet to fall into the box. The problem with this solution is that it would be very difficult to ensure that only one pamphlet was in each set of teeth.

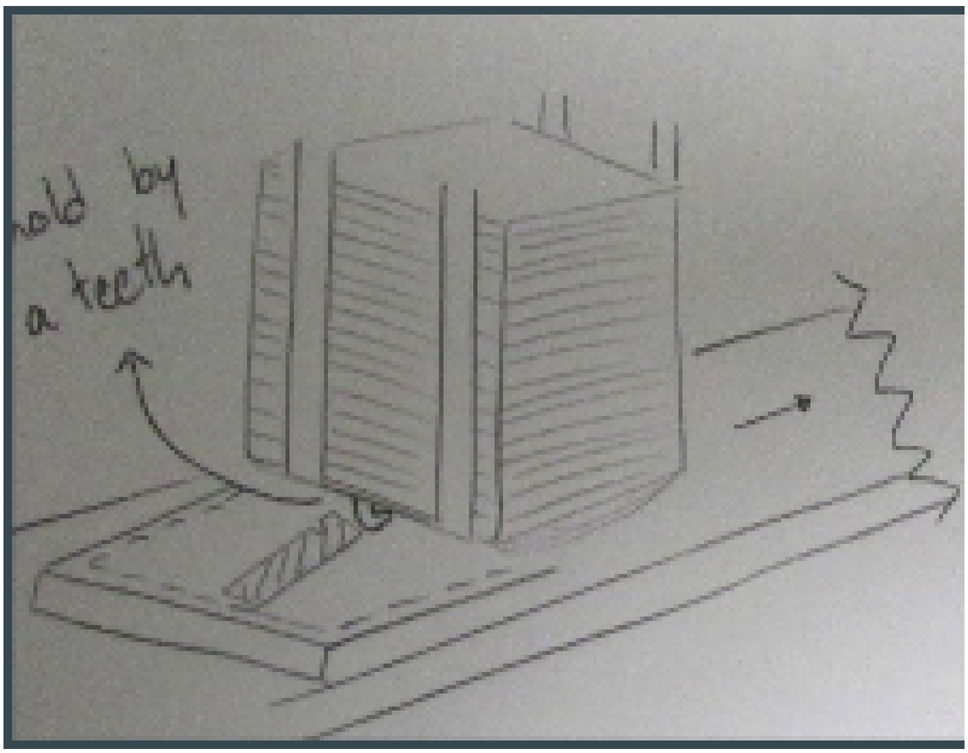


Figure 18: Conceptual design for dispensing a pamphlet using a belt with teeth

Another design concept was to have a stack of pamphlets contained above a rubber drive wheel fig. 19. This drive wheel could be activated to dispense the bottom pamphlet from the stack. This design is superior because it can be easily adapted to different size/ thickness pamphlets. Also it is easy to reload because it is gravity fed therefor a worker could simply just add more pamphlets to the top of the pile as the stack got low.

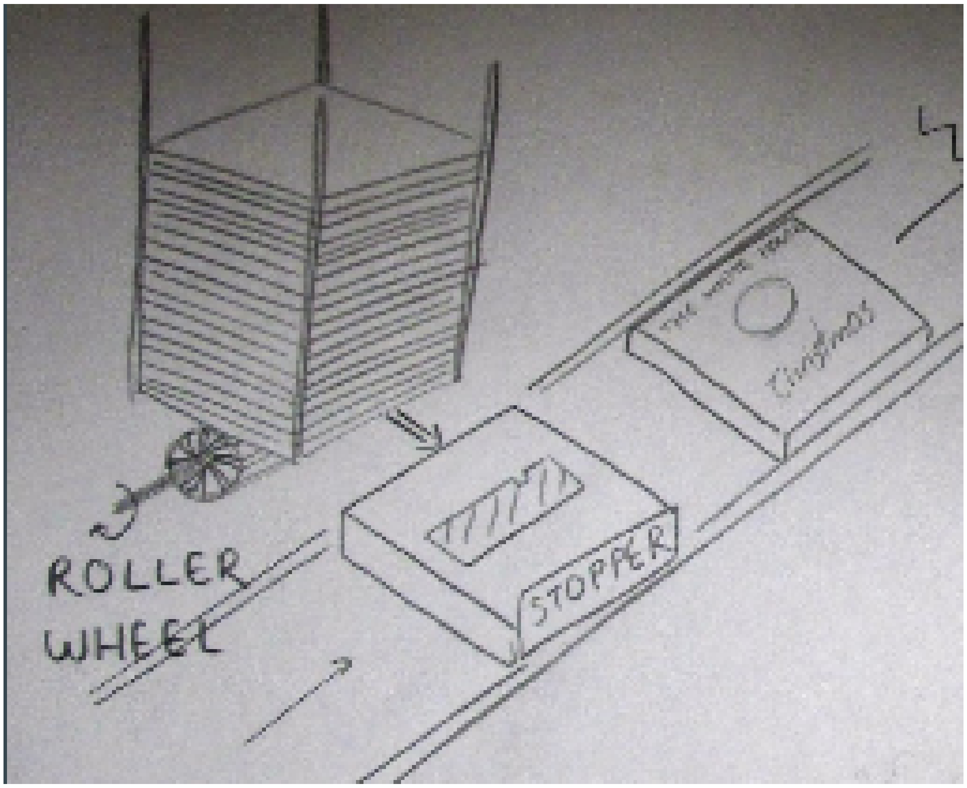
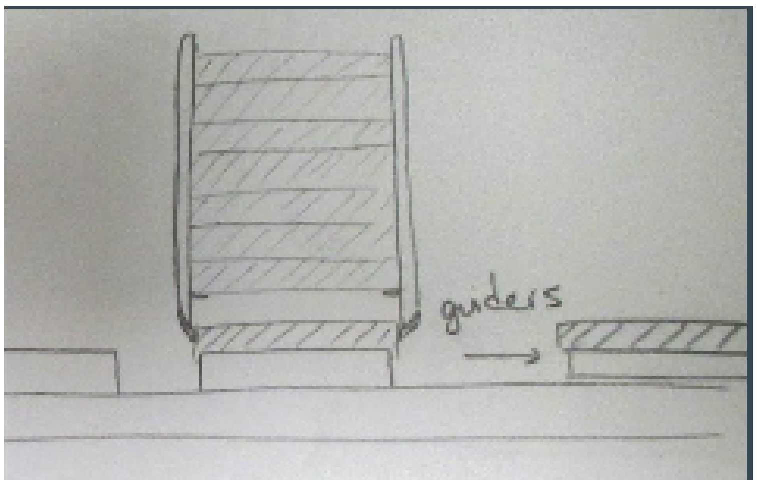


Figure 19: Conceptual design for dispensing one pamphlet at a time using a spinning wheel

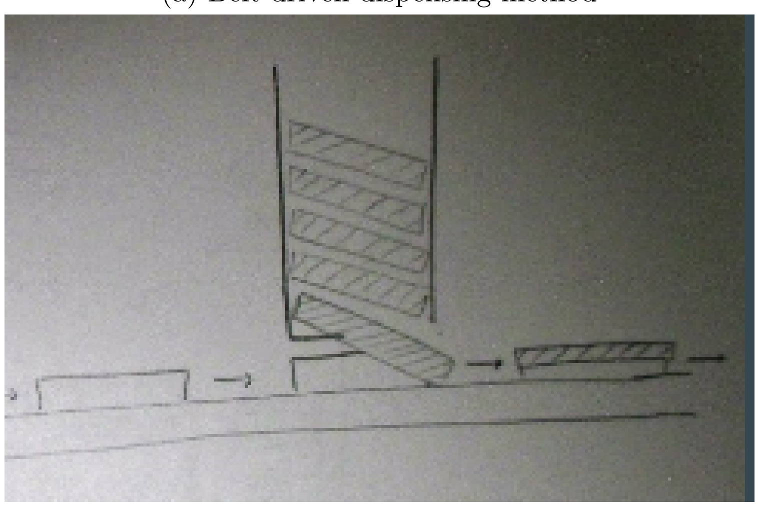
6.4 Box Lid

The final step in the process of packaging this ornament is to place the lid on the box. One concept for accomplishing this task was similar to the first concept for placing the pamphlets in that two vertical belts would be used to move the stack of lids down toward the conveyor belt. As the box lids traveled down the vertical belts they would reach the end of the belts just above the box bottom on the lower conveyor fig. 20a. As the vertical belts began curving out to travel back to the top of the stack they would lose their grip on the lowest box. This would cause one box to drop down from the vertical belts onto the box bottom below. This method would be a very good way of dispensing one box lid at a time into the system however it would not be very accurate in dropping the box and it may not be perfectly aligned with the box bottom below.

Another design concept is to have the box lids held at a slight angle just above the lower conveyor carrying the box bottoms fig. 20b. As the box bottoms ride along the conveyor they would be pushed into the box lid causing it to slide out of its holder. Once the box lid was completely released from its holder the back side of the lid would fall down over the back side of the box bottom. An idler wheel would be positioned to ensure the lid is fully seated onto the box bottom. This method is far superior because the conveyor belt would be able to be continuously moving for this step. Also it does not have any moving parts which will break and need to be replaced.



(a) Belt driven dispensing method



(b) Gravity feed box lid dispenser

Figure 20: Conceptual designs for dispensing box lids

7 QFD

QFD, that stands for Quality Function Deployment, is a method to help transform customer needs into engineering characteristics for a product or service. The team took every ChemArt demands referring the possible solution and the quality characteristics, concerning how the problem would be solved, and put them together in a house of quality. This is one of the main tools used in QFD analysis, where relationships between different proposed solutions and comparisons among competence or opposite solutions are established.

Relative Weight	Weight / Importance	Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Fully Automated Packaging	Semi Automated Packaging	Reduce Personel/Box	Linear Process	Circular Process	Reorganization of Space	Improve Workstations	High Skilled Workers	Safeguards for machines	Protection for Operators	Easy Access Emergency Stop	Accessible Replacable components	Interchangable Components	Adjustable components	Implement Roller System
15.2	5.0	Increase Automation	⊙	⊙	○	○	▲	▲	▲	○	▲	▲	▲	○	⊙	⊙	○
6.1	2.0	Reduce Process Cost (Long Term)	⊙	⊙	⊙	○	▲	○	○	○	▲	○	▲	⊙	⊙	⊙	⊙
9.1	3.0	Use Space Efficiently	○	○	⊙	⊙	▲	⊙	⊙	▲	▲	▲	○	⊙	▲	○	⊙
12.1	4.0	Produce a Package Every 5 Seconds	○	○	▲	○	▲	▲	○	○	▲	▲	▲	▲	▲	▲	○
3.0	1.0	Reduce Process Cost (Short Term)	▲	○	⊙	○	▲	○	⊙	▲	▲	○	▲	▲	○	⊙	⊙
3.0	1.0	Reduce Defect Rate	▲	▲	▲	○	▲	○	⊙	⊙	▲	▲	○	○	○	○	▲
15.2	5.0	High Safety	○	○	○	▲	▲	○	⊙	○	⊙	⊙	⊙	○	○	○	▲
12.1	4.0	Low Maintenance	▲	○	○	○	▲	○	⊙	○	▲	▲	○	⊙	⊙	⊙	○
15.2	5.0	Adaptability and Adjustabiliy (for various components)	○	○	▲	▲	▲	○	▲	▲	○	▲	▲	⊙	⊙	⊙	▲
9.1	3.0	Ergonomic	▲	○	▲	○	▲	○	⊙	▲	○	○	○	⊙	○	○	⊙

Figure 21: QFD analysis, "Whats" vs "Hows".

The team decided that increasing the automation level, with adjustability options for machines and safety being primordial requirements, was the aim of our final process, and so the maximum weight in the chart was set for those three customer requirements. Oppositely, reducing the cost of process in short term had the lowest weight for our project, as a system offering good quality with high efficiency improvement, able to add upgrades in the future is being pursued, and the necessary technological investment in machines will be quite large.

A comparison between the current process, a complete automation process, and an automation process where the placing insert into box step would be obliterated, was also performed. The obtained graphs showed the team that the fully automated solution worked best for our objectives, as it only scored a bad punctuation when talking about a short term decrease of the process, that as mentioned before, would not be the aim of the project.

	Current process	Complete Automation	No Automation for insert			
Increase Automation	1	5	1			
Reduce Process Cost (Long Term)	2	4	1			
Use Space Efficiently	1	4	0			
Produce a Package Every 5 Seconds	0	4	1			
Reduce Process Cost (Short Term)	4	0	3			
Reduce Defect Rate	3	3	3			
High Safety	3	4	3			
Low Maintenance	3	2	4			
Adaptability and Adjustabiliy (for various components)	2	5	3			
Ergonomic	1	4	2			

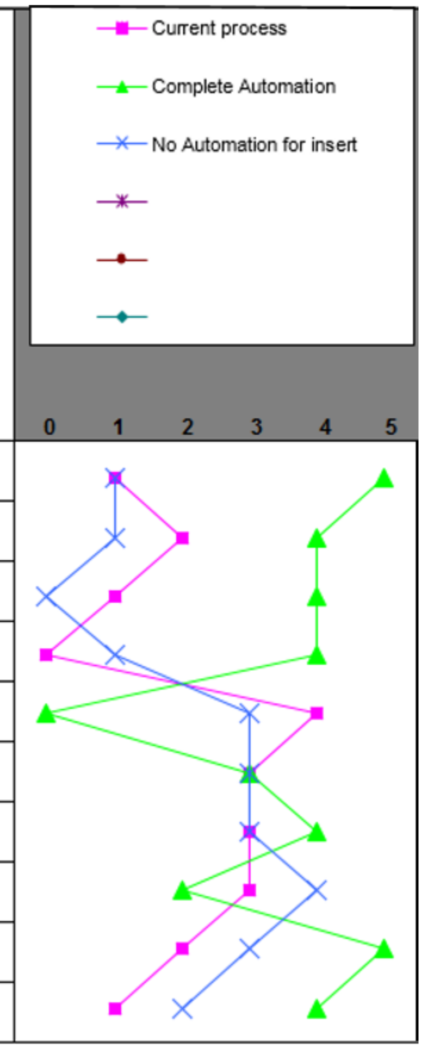


Figure 22: QFD analysis, comparison among solutions.

Team also studied the correlation that some of the possible solutions had, categorizing them as strong positive, positive, negative, or strong negative correlations. Using this method we can see clearly that a linear process would help us to achieve several objectives, such as achieving a better floor distribution, and reorganize the space increasing efficiency, or being able to access the replaceable components of machines, emergency stops easily as well as performing maintenance operations without much difficulties. Implementing a roller system is one of the solutions that would show a strong positive correlation when trying to work with a linear process for example. Obviously, the ideas that are completely opposite to the ones selected, like the circular process, are directly discarded.

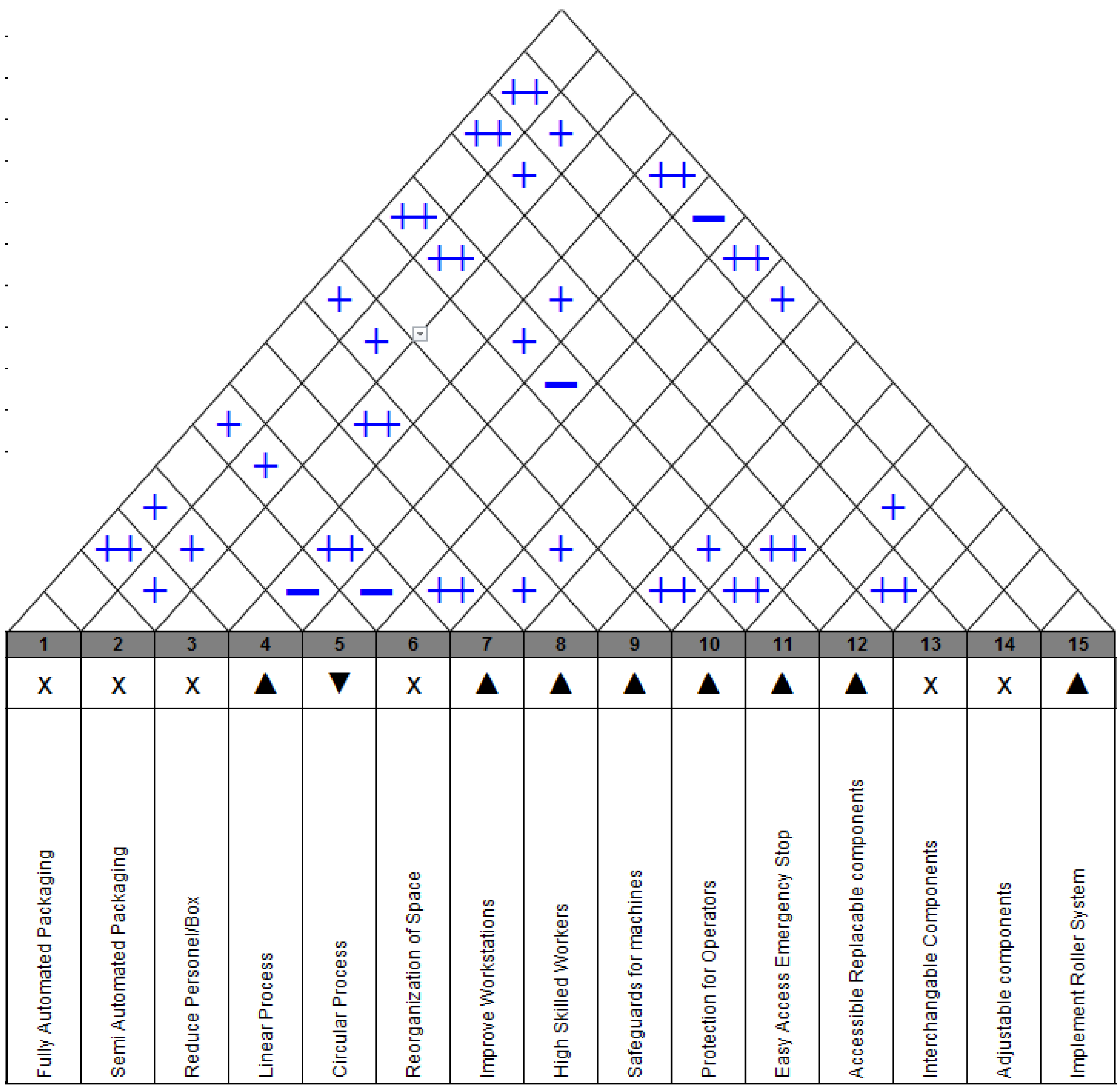


Figure 23: QFD analysis, correlation of different options.

8 Design for X

This section will be used to describe the ways in which this packaging machine will be designed to accomplish specific tasks. When designing a complicated machine like this packaging machine there are many design aspects which need to be taken into account. The major design concerns which have to be considered are design for safety, quality, cost, as well as adjustability,

8.1 Design for Safety

Safety is a big concern when working with automated packaging equipment, there can be rotating belts and actuators moving back and forth as well as electrical shock hazards. In the process of designing this automated packaging machine safety will be the number one concern above all others. Safeguards will be designed into each and every element of this machine to ensure the safety of the everyday workers as well as the maintenance workers who will service the machine. Two main types of protection will be used to facilitate the task of safety.

The first type of protection that will be used on this machine are physical guards that protect workers from any and all moving parts. Examples of this would be belt guards around rotating pulleys and belts to ensure that nothing and no one could be injured by getting caught in rotating equipment. Also Guards would be place around all sliding actuators to ensure that the path of the actuator is clear. Also guards will be placed around all critical sensors to ensure that a worker could not displace a sensor enough to disable the safety features built into the machine programming. Another form of guards would be placed around all cable paths and control panels to ensure that workers are not exposed to any electric shock hazards due to the voltage traveling to the machine components. A final line of safety to protect workers could be a safety fence around the whole machine that only allows the machine to run if the gate is closed. This safety measure would ensure that no one could just walk right up to the machine while it was in operation and possibly be injured. With this safety fence in place all of the raw materials needed to package the ornament could be feed from outside the fence and travel through the fence into the dangerous area. This would ensure the safety of the workers feeding the machine because they would not be directly exposed to any moving parts.

The second form of protection that could be used to protect workers could be in the programming of the machine. First off emergency stop buttons could be placed at every workstation and at all critical machine components. The precise placement of the emergency stop buttons will ensure that if for some reason a person would get caught in the machine it would be easy to shut the entire machine down from multiple locations. Also light curtain sensors could be used to make sure no foreign objects are placed within the machine's work envelope. A final set of sensors could be used to measure that each step has been carried out correctly. If a step has not been completed correctly the machine will shut down before the problem can escalate to the point where a worker might get hurt.

8.2 Design for Quality

When designing an automated packaging system quality is a major factor in the design. The quality of the product that the system turns out and the quality of the components which make up the system are equally important. ChemArt prides itself in the high quality handcrafted products that they create and sell, and packaging the products for sale is an important part of that process. The quality of the machine is highly intertwined with the quality of the products that are sold, because each and every package that leaves this system for the White House is then shipped and sold in retail where a damaged package will not be acceptable. If the ornament is beautiful but the packaging is damaged, it reflects negatively on ChemArt and their product. In order to design for quality several measures were taken. First the components which make up the system will be made of high quality materials so that the replacement of these components is infrequent and the system is built to last.

Second, the timing of each step and the rate at which the conveyor belt moves is done so in order to allow for minimal errors in the system, every time it is stopped is time wasted and money is lost. The precise movement of the components and boxes is what drives the packaging system, and if one step is off then they will all be out of sync. Third the system must be easily re-calibrated and tested to ensure that the steps are precise and the package comes out perfectly each and every time the machine is running. Then finally the system needs to be easily maintained and cleaned in order to ensure the end product is perfect. Without easy access and the ability to clean the system the machine can stop functioning properly, losing more time than it would take to service regularly.

Since the system that currently takes place is all done by hand, ChemArt has the ability to make sure that the end product - the package - is always up to their standards when it comes to quality. When designing to maintain this quality the team needs to account for ChemArts customary in person inspection of each and every step and product that leaves their facility, and the team needs to design the system keeping this in mind. This has been accounted for in the fact that a person will be managing the end product and will be placing the finished packages into a box. This person can ensure the quality of the products and see them before ChemArt ships the products to their customers. Ultimately designing for quality involves looking at the whole system and the components that make up the system and ensuring that everything is the best it can be.

8.3 Design for Cost

The purpose of creating the automated packaging system for ChemArt was to save on cost long term. In every step of the design process the team considered the cost. In the QFD analysis low cost was weighted heavily in order for the team to emphasize the importance of cost in the system. The team used the QFD analysis to determine which concepts to continue to pursue for the proof of concept through to the final design. The conceptual steps that were chosen to prototype do not have a large number of components which minimizes the cost. The concept analyses also looked at the cost to manufacture each of the steps for the assembly.

Placing the ornament into the insert would need a high precision instrument that could pick up and place different ornaments. The team looked into the cost for one of these machines and compared it to the cost to have an employee place the ornament. The cost difference was large, the lower cost option was having the employee pick up and place the ornament in the insert. In the team's design the employee who completes the last step of the ornament assembly will place the ornament into the insert. This employee is already in the facilitys assembly line, the only difference is where the employee places the completed ornament. An extra step was eliminated thus decreasing cost.

All of the steps in the packaging process could be completed by highly automated robotic arms but that would be high in cost, and would take time to re-calibrate at least once a week if not once a day which is a time consuming, therefore costly process. The design for placing the bottom of the box is gravity fed with a block attached to an actuator. The most expensive part of the design is the actuator. The actuator only needs the horizontal motion, more axes of motion would increase the cost. The placement of the lid is also gravity fed. The lid catches onto the box as the box bottom assembly moves on the conveyor. This design requires no additional moving parts except the conveyor which is being used for all of the steps.

The second step in the assembly process in placing the insert into the box bottom. This step could have easily used more automated aspects but the design chosen is low cost. An actuator which is the only aspect that needs to be programmed pushes the insert into the box. A gate that is spring loaded hold the box level so the actuator can push the box down evenly. The spring is a low cost mechanism. The third step in the assembly process uses two sets of motorized wheels to push out one pamphlet onto the bottom box at a time. The two motors and speed controllers are the only programmable automated parts. The design also includes a pusher that is gravity controlled. As the pamphlet pile decreases the pusher lowers. The simple automation allows for a low cost design.

A major factor of the system designed for ChemArt is adjustability. Accounting for adjustability increased the cost. The 1080 aluminum extrusion used in the prototype is inexpensive and easily adjustable. Because it had to be adjustable the design could not be machined as one part which is where the majority of the increase cost comes from. The automated aspects of the design are factored into the cost with or without the adjustability. Looking into the future of this project materials other than 3D printed plastics need to be considered to increase the surface finish. The material cost along with the material strength was and will need to continue to be taken into consideration when choosing the materials used in manufacturing the system. Changing materials will alter the cost but in the long run a better material will last longer making the long term cost the same. The initial cost and long term value of the materials and assemblies was taken into account. This production line is an investment for ChemArt that is intended to pay for itself after continued use.

8.4 Design for Maintenance

If the designs are analyzed from the point of view of a comfortable and simple maintenance we can observe several advantages. When the first sketches of the system were done, the Pack-in-the-box team took into account that it had an easy access to favor the exchange of components (to adapt or adjust the mechanisms, and also for repair and maintenance operations), to ensure rapidity when making an emergency stop, and to achieve a better distribution of the space of the floor plant in general.

The team aspires to a system that does not require too many maintenance operations, and that when it needs them does not produce a long term stop in the production. When looking at the different parts of the system, leaving aside the work that the conveyors would require, the only mechanisms with a greater need for supervision would be the pamphlet dispenser and the pneumatic arm with the vacuum mechanism attached to it, the rest of elements are basically cages where the function of feeding material is performed by gravity and will not suffer from wear. The metallic actuators will not suffer deformations either when working with the plastic and the cardboard that compose the ornaments boxes.

Besides all of this, different pieces used for each solution are very inexpensive and easily interchangeable, saving money and time when maintenance, reparations, or replacement operations are needed.

Taking all this information into account can be said that the team has achieved an optimum design in terms of maintenance.

8.5 Design for Adjustablitiy

Adjustability is a really important factor for the project. ChemArt currently works with different sizes of boxes, this does not suppose a problem when speaking about handmade production, but is becomes a big concern when trying to automate the system. Every small change that is done to one of the products will affect the parameters machines have to match.

At the moment up to 40 percent of ChemArt production consists in the White House ornament and the other sixty percent would be standard ornaments, this includes every other ornament produced, that can have size and shape variations, affecting box dimensions. Clearly, first aim of the project is to automate the process for the White House as it is the larger order the company has to deal with and is the one that needs extra temporal workers to be hired, increasing the manufacturing process cost. However, not every step of the process remains the same from one year to another when speaking about the White House, in the case of the pamphlet dispenser it should be designed taking into account that sometimes only one pamphlet is added to the ornament box, but some others it consists of a single paper, a card, or several papers.

Looking into the future, the perfect scenario for the fully automated packaging process would require the adjustability of every single mechanism in each step so it can be modified for different specifications such as inserts characteristics, boxes size, lids dimensions, and the addition if needed of pamphlets, cards or papers. Due to this, team had to think in all the possible modifications that the packaging system would have to suffer in the different steps to make sure that process could be adjustable and meet requirements. This has resulted in the design of prototypes that can be easily modified for example, performing a cut in the mechanism and attaching guides to it with a measurement tool so it can allow all of the different dimensions required to work with.

Thanks to the redesign of the models, implementing T aluminum frame extrusions for the funnel, pamphlet and lid drop steps, the team has achieved fully adjustable models. The final model for the bottom box dispenser is also adjustable for all the standard sizes that ChemArt uses at the moment thanks to the addition of slots and holes in the 3D printed model. In case this measures change, using foam or another deformable material in the inferior piece and a metal finger in the upper one would be an easy way of making it fully adjustable. Also the divider could be easily moved back and forth to hold the boxes at the desired position.

Adjustability of each one of the steps has been without any doubts the most challenging issue the team has solved throughout the second semester, but also one of the company priorities as stated before, so it is very satisfactory for the team to be able to say that a high level of adjustability has been achieved.

9 Project Specific Details and Analysis

The current packaging process at ChemArt is completely done by hand. Workers are at large tables of four which are set up with four individual work spaces. The workers each perform the entire packaging process and do not implement an assembly line set up. There is a fifth individual who is tasked with the job of making sure all of the packaging stations are well stocked. This person moves from the ornament manufacturing space to the supply space and back frequently throughout the day moving materials. This is a relatively inefficient use of resources and time is lost in the constant shuffling of resources.

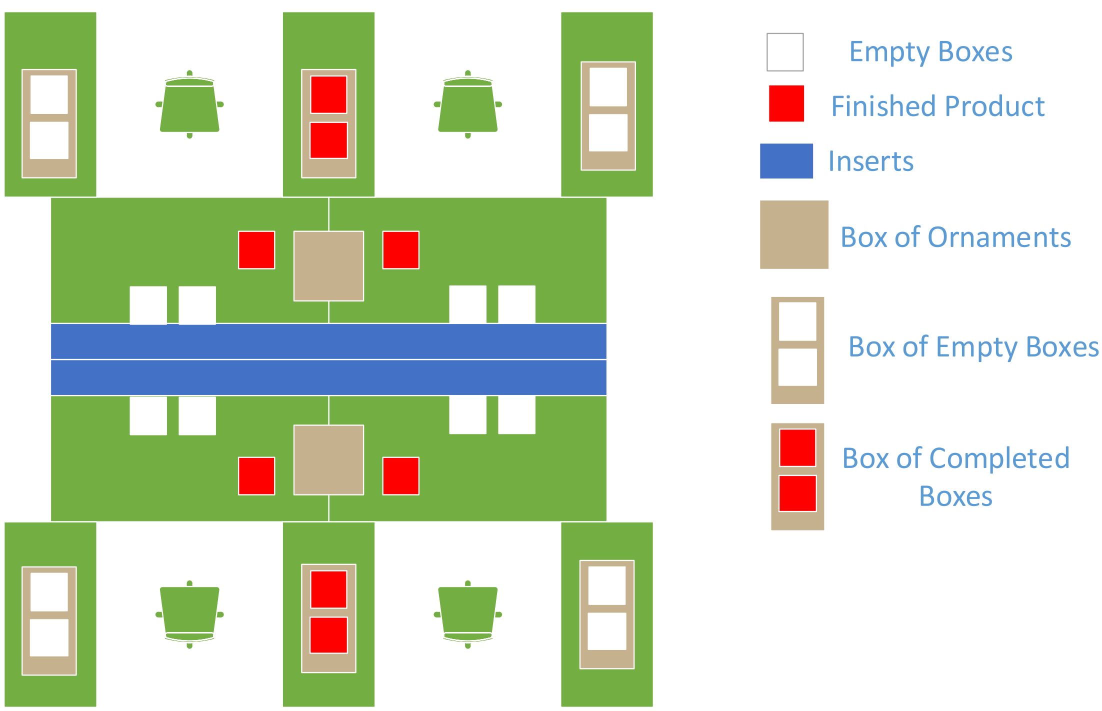


Figure 24: Current Process Floor Plan

In Figure 24, one packaging station is mapped out, when the team has visited ChemArt two to three of these tables of four have been set up and functioning to the fullest capacity. As seen in figures. 25 and 26 the workstations are typically more crowded than what is depicted in the schematic, and the workers have limited table space, which they are accustomed to. There are many items on the workstations which makes it difficult for the workers to keep all of the components of the packaging assembly organized. When items need replacing or replenishing on the workstations progress comes to a halt because it takes more than one person to maneuver the boxes of unpacked ornaments and the boxes of empty ornament boxes.

Figure 25: Manufacturing section at ChemArt facilities

Figure 26: Packaging section at ChemArt facilities

The average time for boxing one ornament is thirty seconds. This value was found during extensive time studies that were performed by ChemArt specifically focusing on the packaging process. The 30 second average time includes the time lost to restocking stations, replenishing supplies, the actual physical packaging time is less than this. The automated packaging system will allow for restocking and packaging to occur simultaneously or in a much faster manner which will allow for more packages per minute. The constant start and stop of the process allows for a decrease in momentum that the workers have when assembling the same type of package throughout the day.

The current solution for an increase in productivity is to hire more temporary employees to keep up with the supply created by the people fabricating the ornaments. The packaging process is labor intensive and one employee can work on one package at a time, it is not a process that can produce more than one unit at a time. The process is efficient for the setup in which it is configured, and the time is also relatively efficient. ChemArts goal in this design challenge is to find a way to produce packages at the same rate, or a better rate, while using their workforce and resources efficiently.

10 Detailed Product Design

10.1 Future Floor Plan

In order to successfully implement the automated packaging system, the workspace layout in ChemArts manufacturing facility needs to be reconfigured. Below in Figure 27 the proposed design for the space is detailed. This is a suggested layout that the team decided would incorporate all of the components necessary to creating a fully automated packaging system. The diagram was created using Microsoft Visio and details the method and order in which the steps will be combined. Packaging an ornament requires several steps which need to occur in a specific order precisely in order to get an acceptable finished product.

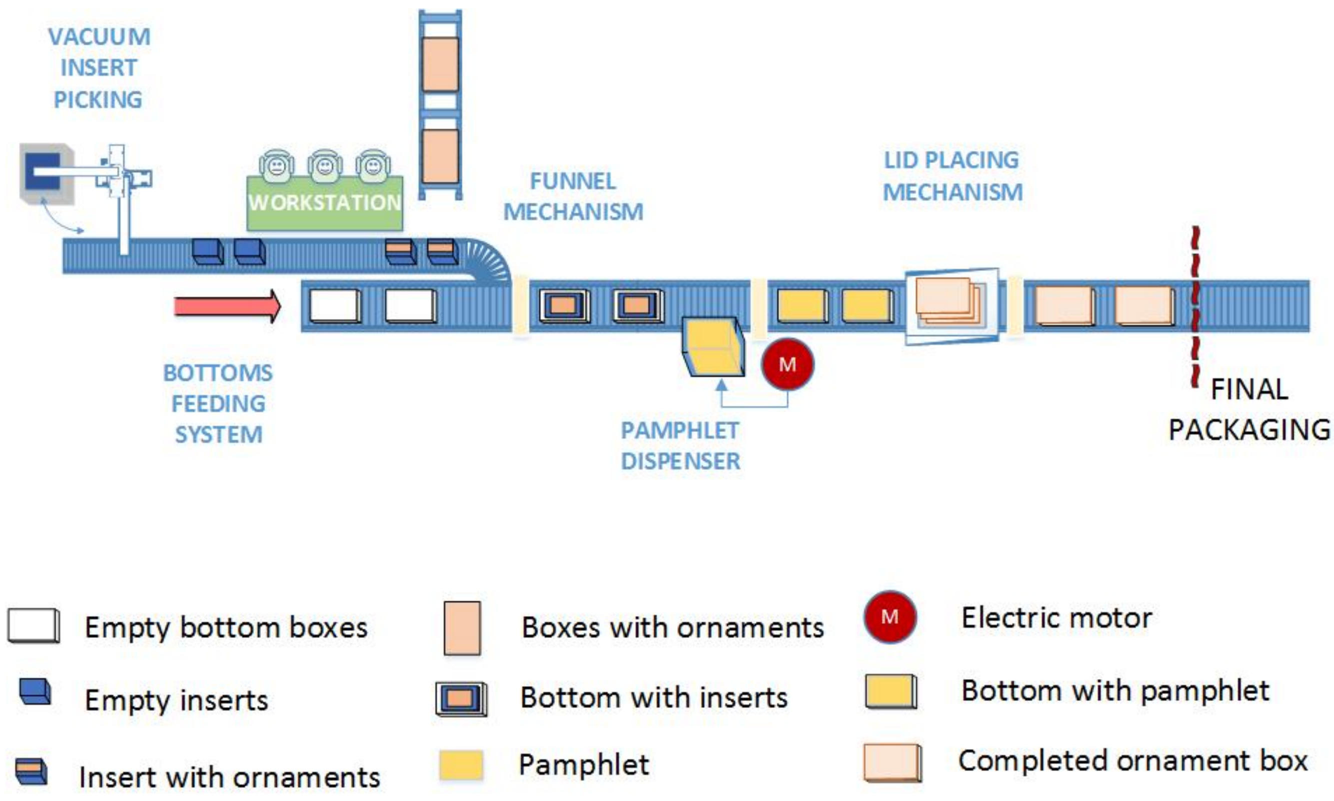


Figure 27: Possible System Layout

To the far left in Figure 27 there is a robotic arm separating the inserts by means of suction or pneumatic cylinders then the inserts are placed onto a conveyor which routes the inserts through the manufacturing area and the people completing the ornaments then place the ornaments into the plastic inserts. On a separate conveyor box bottoms are released into the system using an actuator. The inserts with the ornaments placed inside of them are then fed into the main conveyor belt where a funnel mechanism is used to introduce the inserts into the box bottoms. Then, the boxes with the inserts and ornaments are fed past the mechanism which spits one pamphlet, leaflet, or piece of paper onto the assembly. Next the box lids are placed onto the boxes through a gravity fed system, then finally the boxes are packaged for shipment by a worker.

This design is meant to optimize the space that ChemArt as available, and having employees work efficiently within the space. This design can be reconfigured or changed to suit the space and to increase productivity as ChemArt sees fit. The conveyor belts are a means of uniting the individual steps and components necessary for assembling a completed product. All of the conveyor belts will be a costly investment for ChemArt, but their value will be obvious as soon as they are implemented.

10.2 Box Bottom Loader

10.2.1 Initial Prototype

The design of the box bottom loader was a fairly straightforward one. The process began by measuring the outside dimensions of the box bottoms. Average dimensions for the length width and height were measured to be 5.825 inches, 5.16 inches, and 0.87 inches respectively. With these dimensions a holder could be designed to guide the stack of boxes down towards the actuator. Tolerances for the sizes of the material holders had to be determined and agreed upon. It was determined that a tolerance of 0.125 inches larger than the length or width was appropriate to allow for the boxes to slide easily within their holder while not allowing the stack to fall out of alignment. In designing this holder and all other custom parts in this project the dimensions of the 3D printer had to be taken into consideration because for prototyping purposes the intent is to print all of the necessary parts on the University of Rhode Islands 3D printer. The design for the holder uses four L-shaped supports in the four corners of the box. This design is effective because it provides ample support for the stack of boxes in every corner while allowing it to be easily adjustable by sliding the corner supports inward or outward for different sized boxes.

A sturdy base was required to attach these corner supports to as well as the other components which will be discussed later. After experimenting with the 3D printer a thickness of 0.375 inches was agreed upon for all mounting plates/fixtures. This is because it provides a strong base that could not be easily deformed as well as enough room to countersink size M6 or 0.25 inch socket head cap screws which will be used to assemble the various components of this machine. The base of this component was also designed with puzzle piece like connectors to attach other components to it in the future. The reason for this is due to the print size limitation on the 3D printer as well as the fact that those additional components have not yet been designed. The ability to design components in the future which will lock into those shapes on this base will allow for a very versatile design which can be adapted at any time. Another key feature of the base is a large circle of material which has been removed from this base. The purpose of removing this material is to reduce the material and time required to fabricate this part as well as to reduce the weight of the component. These design features can be seen in fig. 28.

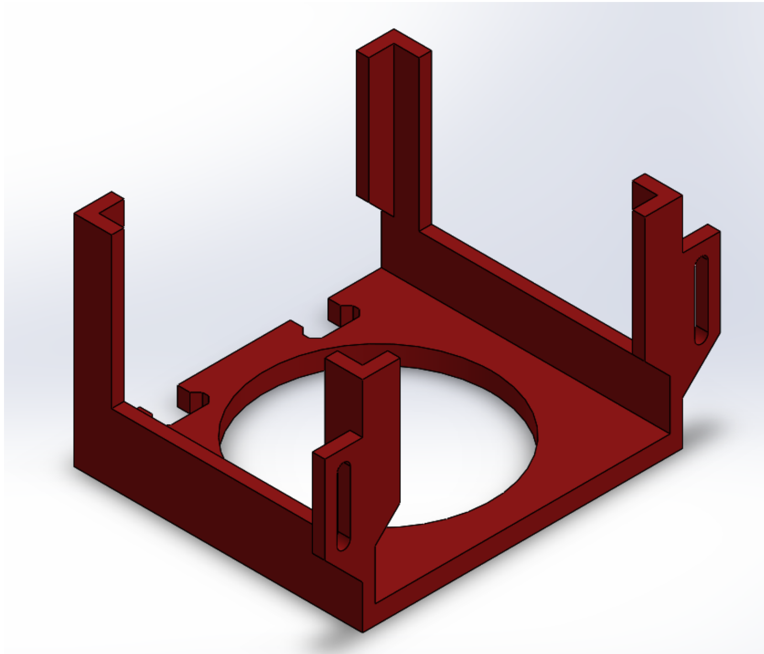


Figure 28: Holder for box bottoms

Another important part of this design is an adjustable gate pictured in fig. 29 which allows for different height boxes to be pushed out of this single design. The adjustable gate is positioned just above the height of the box being packaged. This positioning allows only the bottom box to be pushed out from the stack because the gate is holding the higher boxes in the stack. In order to make this gate adjustable mounting slots were designed into the support corners on the side of the device that the box bottom comes out of as seen in fig. 28. The Slots allow for one inch of vertical travel centered on the median box height which is the White House ornament. The adjustability of the corner supports as well as the gate height will allow this one component to be used to deposit all of the box bottoms currently used by ChemArt.

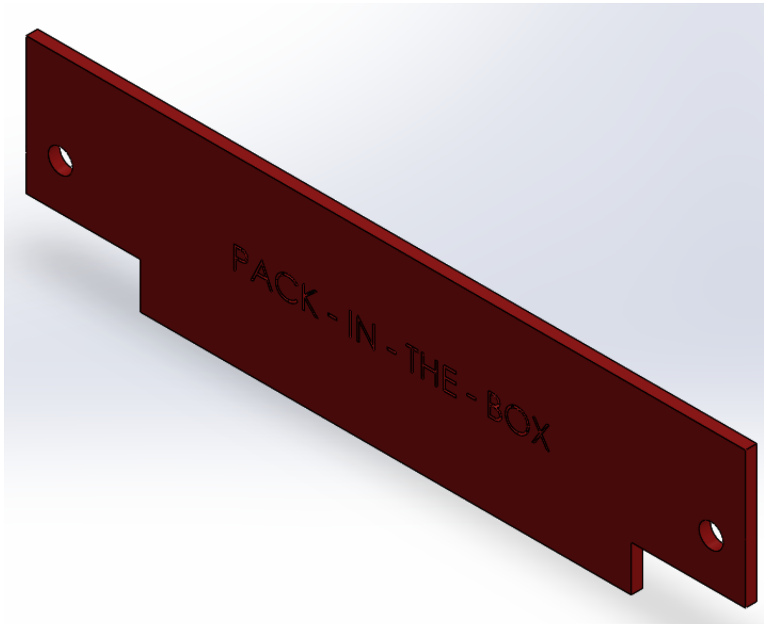


Figure 29: Adjustable gate for box bottom loader

The final part required to dispense a box bottom is a pneumatic actuator to push the bottom box out of the stack and onto the conveyor belt. A lot of time was spent to research a reliable dealer for the components of this machine that would need to be purchased. The team has agreed that the best one stop shop for all of our machine components such as actuators, switches, indicator lights, and electronics is Automation Direct industrial equipment wholesalers [10]. Looking through this company's website an appropriately sized actuator has been sourced to accomplish this task. The actuator that will be used in this design is a double acting cylinder with a 6 inch stroke. This type of cylinder was chosen because the cylinder needs to be able to advance at least 5.825 inches to push the box bottom out of the holder. The double acting quality of this cylinder will be used to separately control the speed of actuation and retraction in order fine tune the machine's operation. Holders for this cylinder will be designed to lock into the puzzle piece shapes in the base of the holder as discussed before. Having the cylinder attached to the holder will create a rigid assembly that can withstand the forces of the actuator pushing the cylinder out of the holder.

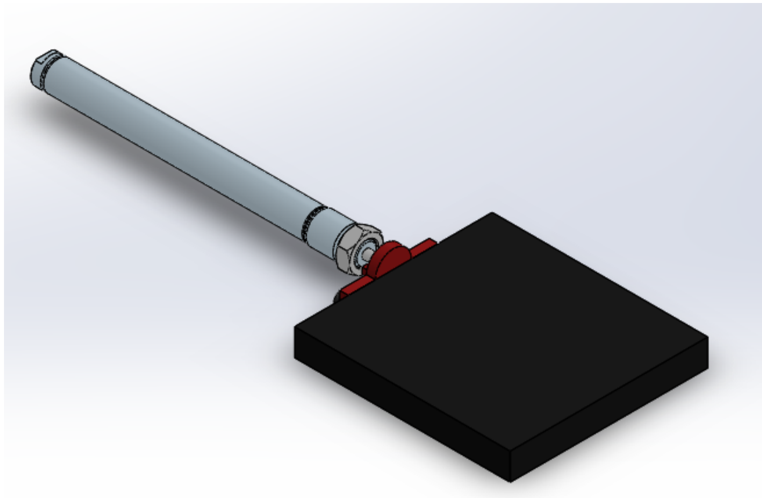


Figure 30: Device to push out the bottom box in the stack

With all of these components assembled together a device has been created which can automatically dispense one box bottom on command. An image of the final assembly can be viewed in figure 31 and all drawings of individual components can be viewed in the appendix.

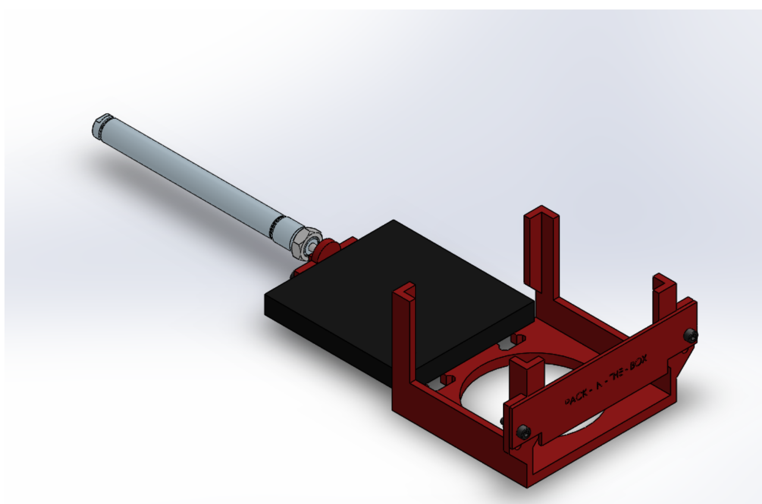


Figure 31: Assembly of all box bottom loader components

10.2.2 Proof of Concept

For this proof of concept the designs for the box bottom holder and the box bottom pusher were 3D printed using PLA Plastic. Once the parts were printed their operation could be thoroughly evaluated. The first design flaw that was examined was that there was too much clearance on the box sides and therefore the boxes could come out of alignment and nest inside one another. If the boxes were to become nested inside one another it would cause a jam in the system because there is only enough space for one box bottom to push out at a time. In order to solve this problem tape was added to the holder to decrease the tolerance around the boxes. Decreasing the tolerance around the boxes leaves less space for the boxes to twist and rotate inside the holder. Tape was added one layer at a time until the bottoms no longer came out of alignment and were still able to slide easily. The final adjustment of the box bottom holder with box bottoms inside can be seen in fig. 32.

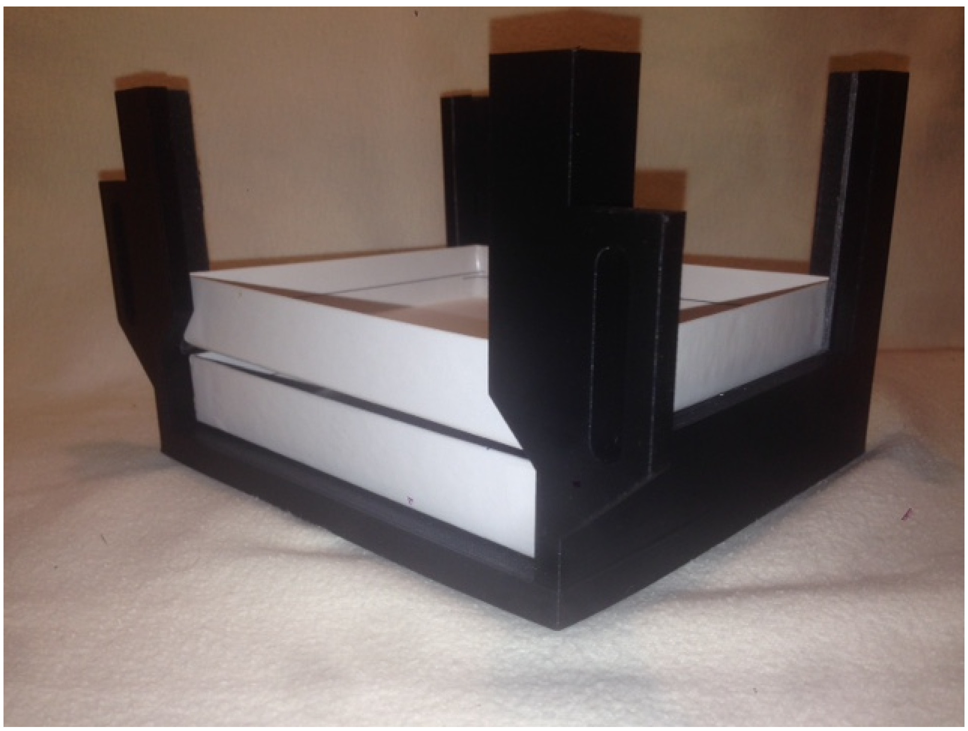


Figure 32: Box bottom loader with box bottoms inside

Now that the boxes were sitting properly in the holder it was time to test the pusher. Since there was not enough time to purchase an actuator the actuation of the pusher was done by hand. The pusher proved to be an effective means of pushing the bottom box bottom out of the stack easily and reliably. On the in stroke of the pusher the bottom box pushed out of the holder while the next box in the stack came down on top of the pusher as designed. Fig. 33 shows the pusher in stoke as it is half way complete. On the out stroke the box bottom that was resting on the pusher drops down as the pusher is removed completely from the holder. Now that the pusher mechanism has proven to be effective the process can be automated with the use of a pneumatic cylinder and the actuator attachment.

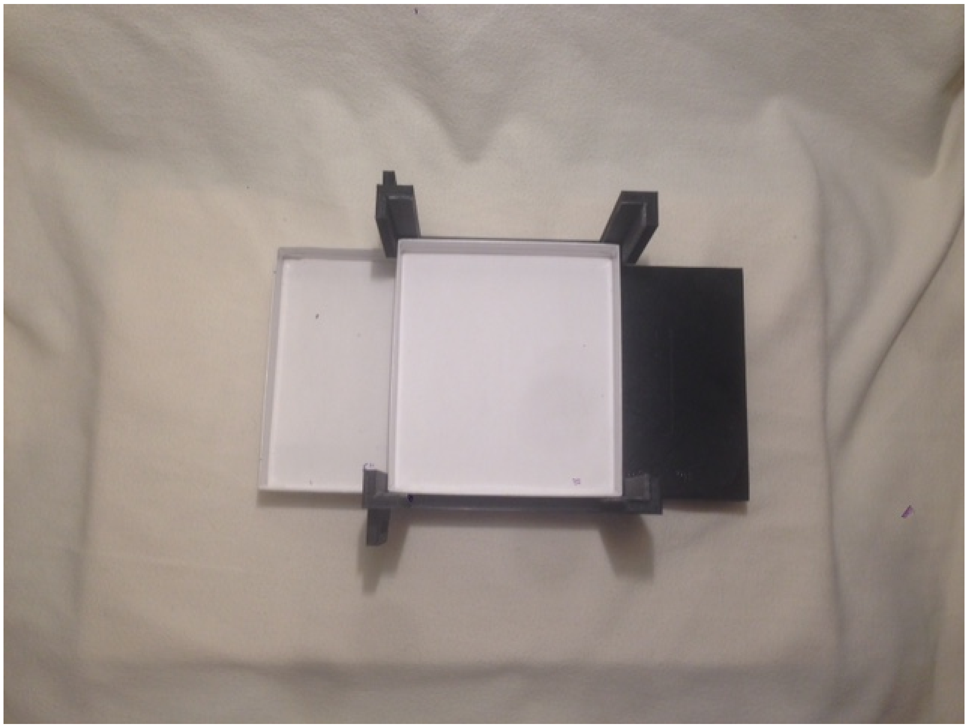


Figure 33: Box bottom loader half way through dispensing cycle

10.2.3 Redesign

Once that the first prototype was built and the team had been able to prove its workability the next step was to redesign the bottom box dispenser mechanism so it would be adjustable for different sizes of boxes (the standard ones and the White House boxes).

Different steps were taken when the team first started thinking about how to improve the bottom box dispenser. Efficiency was already achieved in a satisfactory way, using a plastic piece attached to the end of the actuator that is box-shaped and would hold still the bottom boxes above the one it is pushed onto the conveyor belt while it is moving forward and letting them go down when it is fully retracted.

Then it was need to achieve the other two goals that were set by ChemArt: adjustability of course, and do not forget about cycle times. Several new designs were considered, such as a 4-pieces model where a corner could be subtracted, and another corner would rotate the workers to place the new stack of boxes, then rotate it back to its position and close the model, starting again the actuator sequence, sending bottom boxes to the system. As it can be observed, re-stacking the mechanism with more boxes was considered when redesigning, cause it will affect our total time for a complete process, and thus the cycle time of the operation. Finally, a two pieces model that could be easily separated was chosen as the best option.

For achieving adjustability two slots on each side of the 3D printed model were created, so a divider can be slided through any of them and hold the boxes no matter the size in the stack. Also, circular holes have been placed at the lower piece so the model can be adapted to different widths.

10.2.4 Final Prototype

The final prototype for the bottom box dispenser uses the same idea than the first model the team built. A cage (now adjustable for different sizes and with highly improved tolerances) that is divided in two main pieces and a separator, where the worker would place the bottom boxes, and an actuator fixed to the ground at the perfect height so the plastic rectangle that pushes the boxes lands in the 3D model so it just slides in a horizontal move forward and backwards.

This prototype was also quite cheap to build, which is an advantage, the cost of the parts that form the total bill was below $100. Figure 34 shows an ISO view of the final assembly for all three parts in SolidWorks.

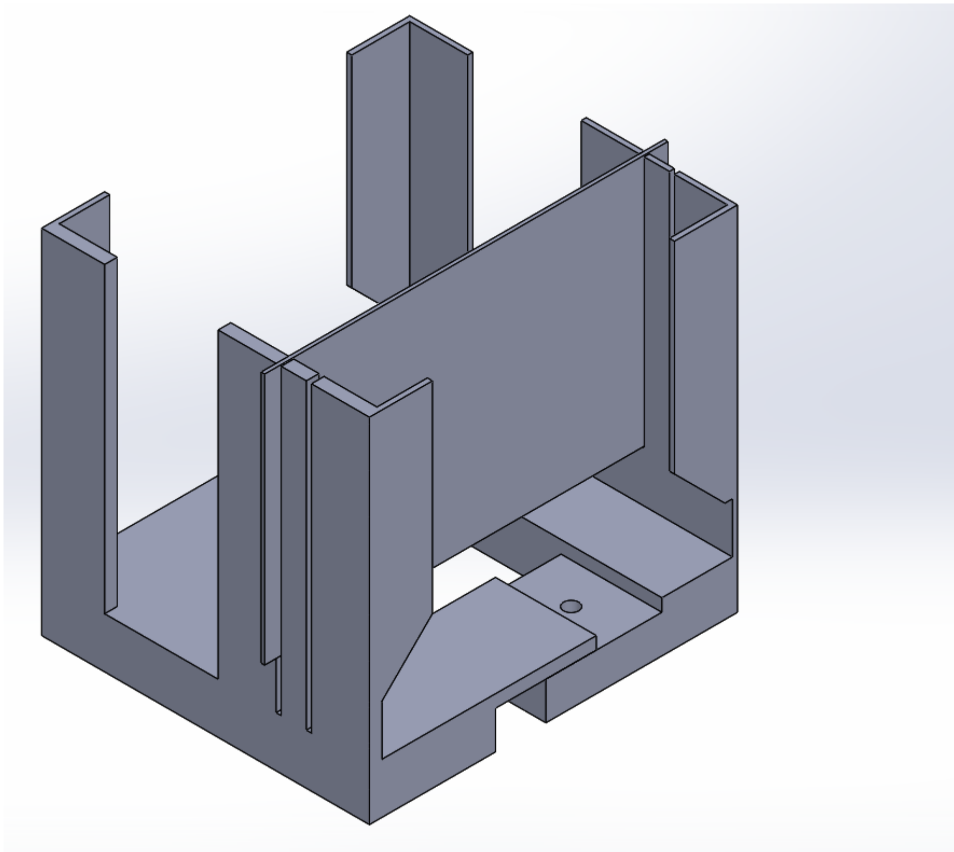


Figure 34: ISO view of the Final Bottom Box Dispenser Prototype Design

10.3 Insert Funnel

10.3.1 Initial Prototype

The insert funnel was the first component to be designed as its ability to carry out the task was questionable. The design process began by taking careful measurements of both the box bottom and the insert. Since both the box bottom as well as the insert are constructed from pliable materials several instances of each component were measured. The average insert size was determined to be 5.625 inches in length and 4.94 inches in width. The average box bottom inside dimension was determined to be 5.625 inches in length and 5 inches in width. These numbers prove the challenge at hand in that the dimensions of both the insert and the box bottom are almost identical. This means that the insert needs to be compressed evenly in all directions to fit within the box bottom. To provide a solution to this problem a funnel was designed to apply even pressure on all sides of the insert as it was pushed down into the box. After several trials using hand pressure it was determined that by compressing the insert by one sixteenth of an inch on all sides allowed the insert to press into the box bottom with minimal force. It was also determined that if too much pressure was applied the thin sides of the insert would buckle making it impossible to fit inside the box bottom. Now that some baseline dimensions had been determined from these initial tests a prototype funnel could be designed. The bottom of the funnel has dimensions which are one sixteenth of an inch smaller than the box bottom on all sides making it a total of one eighth of an inch smaller in length and width. The final dimension for the bottom of the funnel was set at 5.5 inches in length and 4.875 inches in width. Next the top dimension of the funnel needed to be determined to allow for the insert to easily fit inside while not creating too steep of a draft angle. An increase in size from the bottom dimension of one half an inch was decided upon to allow for extra room for inserts which have been made slightly larger. With the top of the funnel being one half inch larger than the bottom of the funnel which is one eighth of an inch smaller than the insert the total clearance allowed for variances in insert size is three eighths of an inch in the length and width. Rather than being a completely solid funnel it was decided to remove material from all four sides of the funnel to reduce material for the 3-D printing process. It was also decided to leave a single fin in the center of each funnel side to help prevent the buckling of the insert sides described before. Also these holes will give access to retractable arms which will be used to hold the insert at the top of the funnel until the box bottom is in position below. These arms were left out of this design as it was simply a proof of concept to ensure that this would work. The final design for this proof of concept can be viewed in fig. 35.

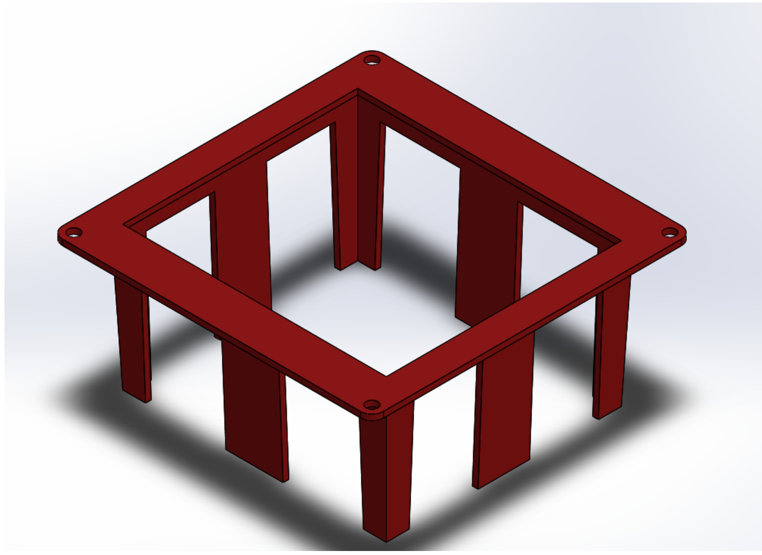


Figure 35: Initial Funnel Design

In the future this design will be improved upon to allow for the adjustability of its size for different size inserts. Also a pneumatic pusher similar to the one in fig. 30 will need to be designed to push the insert through the funnel and into the box bottom waiting below. Also attachments will need to be designed which will elevate this funnel mechanism above the conveyor carrying the box bottoms through the machine.

10.3.2 Proof of Concept

Like the box bottom loader the insert funnel was also 3D printed using PLA plastic. After printing the part was tested by pushing the inserts through the funnel and into a box bottom. An initial flaw that was identified is that the sided of the funnel were too rough from the layers of PLA plastic left over from the 3D printing process. The roughness of the funnel walls was causing damage to the inserts by curling over the bottom edge of the insert. In order to solve this problem the funnel walls were sanded to help smooth the surface. Another method used to smooth the surface was to rub the surface with nail polish remover which dissolves the plastic enough for it to be smoothed. Once the sides were smoothed the inserts slid through much nicer and there was no longer any damage to the inserts. Another issue with testing this prototype was aligning the funnel above the box bottom. In the final design of this machine there will be guides on all sides of the box bottom to hold it directly under the center of the funnel. However for this proof of concept there was only enough time to 3D print the funnel so the box bottom needed to be held under the funnel. Holding the funnel by hand often caused the insert to be misaligned with the box bottom. On the other hand when the funnel was aligned properly the insert slid directly into the box bottom with very minimal effort. Since the funnel did work when the box was in the proper position it was decided that this was an effective proof of concept and more work needed to be done to ensure the centering of the box bottom below the funnel. An image of the insert part way through the funnel can be seen in fig. 36.

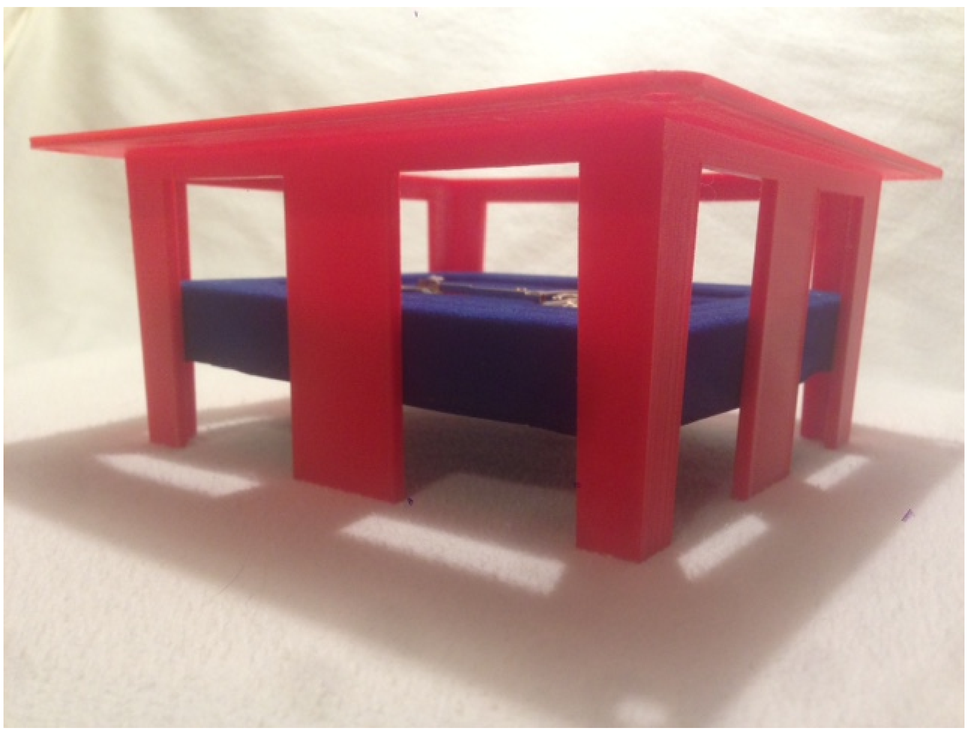


Figure 36: Insert loader funnel with insert part way through the funnel

10.3.3 Redesign for Adjustability

The initial prototype was to prove the design concept. One of the design specifications given to team Pack-in-the-Box was that the automated packaging system had to be adjustable to account for the different size boxes being packaged. The initial concept needed to be redesigned to still adhere to the authenticity of the concept but include adjustable features. The team brainstormed different materials that could make the steps adjustable. As a team to keep the system uniform it was decided to make the framework out of 80/20 aluminum extrusion. The extrusion was 1" by 1". This framework is made out of strong but lightweight aluminum that have a slot running the length of its four sides allowing for special "T-Shaped" fasteners to be slid in and tightened at any point along the length of the extrusion. This material can easily be adjusted by loosening fasteners, altering the dimensions and then tightening the fasteners. Nothing actually has to be taken apart and then rebuilt.

The frame of the funnel is held together by the T shape at the top of the design. Two shorter rails of 80/20 are attached at the bottom of the T to make the shape be a capital I. Now that the top frame was established the rails that will turn this design into a funnel had to be placed. There are three 80/20 rails that would hang down from the top horizontal part of the T. There is one rail that hangs vertically from the center of the T. One rail hangs vertically from each of the two shorter horizontal pieces at the bottom of the T (Figure 78. This capital i shape allows adjustability in the width of the inserts. Each of the six rails that hang vertically allow for adjustability in the lengths of the inserts. Each of the vertical rails has swivel feet that they are mounted to. The feet can be adjusted for different height boxes. The frame of the funnel is completely adjustable in the x, y, and z directions. The Frame is also adjustable up to 2 inches in every direction, which was part of our design specifications. Now that the adjustable frame has been established the prototype in its entirety will be explained in the following section.

10.3.4 Final Prototype

The frame consists of six vertical rails of 80/20. Keeping with the same concept as the initial prototype each of those six rails make up the funnel. The four corners have a 3D printed tapered corner that will funnel the insert corners into the box. The frame was set up so that the funnel is symmetrical. Three of the rails are symmetrical to the other three rails. Only three funnel pieces were designed, each piece was used on two rails. The funnel design has four corners. Each of the corners begin wide and taper to be smaller. The two designs for the corners have the same dimensions the only difference is the placement of the T so the piece can be slid into the t-slotted framing. The corner designs and the assemblies can be found in figures 70, 71' 72, and 73. The sides of the insert also have tapered effects. The two remaining vertical rails have a piece called the side wall that prevents the sides of the ornament insert from buckling. The drawings for the side wall can be seen in figures 74 and 75.

The design for this insert funnel also includes a ramp feature so the ornament insert can easily glide into the system. The ramp is made out of two "80/20" rails that are 12 inches long. The two rails are connected to two of the vertical rails using a locking pivot. The locking pivot is adjustable for different angles allowing the ramp to be used for different size ornament inserts. The ramp is composed of the two rails and two 3D printed slides that fit into the rails. The slide is the contact that the insert rests on when sliding into the center of the funnel. The drawings and dimensions for the slide can be seen in figure 77, 76.

The ornament insert needs to be parallel to the conveyor where the bottom of the box awaits. The slide would get the ornament insert into the funnel but it would not be parallel. Gates had to be designed so the insert will sit evenly parallel until the bottom of the box is in the right place and the actuator pushes the insert into the bottom of the box. The gate is composed of several different parts. The first part is a bracket that holds the two rows of vertical rails in place (Figure 67). The bracket consists of two slots where fasteners are placed so the bracket is attached to the rails. The bracket is used to sturdy the vertical rails and keep them in place. The slots were created to allow for adjustability. The drawing for the bracket can be seen in figure 79. The bracket also has two holes for the spring loaded hinge to be attached. The L bracket is attached to the top of the hinge so the hinge cannot open more than 90 degrees. The L bracket is what this design uses as the gate, when the

L bracket is pushed the spring bends to close and the ornament insert can now be pushed down the funnel without the excess force of the gate.

The moving part that is pushing the insert into the bottom of the box is a pneumatic cylinder. The pneumatic cylinder provides the force to push the insert but an attachment had to be designed so the force would be evenly distributed. The attachment is an "X" shape at the end points of the "X" there is a cylinder which is what touches the corner of the insert to push it into the box. The attachment also has adjustable features, there is a horizontal bar through the center of the "X". This bar has two slots. The slots are for the L shaped attachment, which is what pushes down the spring loaded gate. The L slots are longer than the cylinders on the "X" that way they push down the gate before the cylinders begin to push down the corners of the insert. The idea is that no force from the spring will be exerted onto the insert. The insert is very fragile so any excess force will break it. The drawings of the actuator attachment can be seen in figures 80, 81, and 82

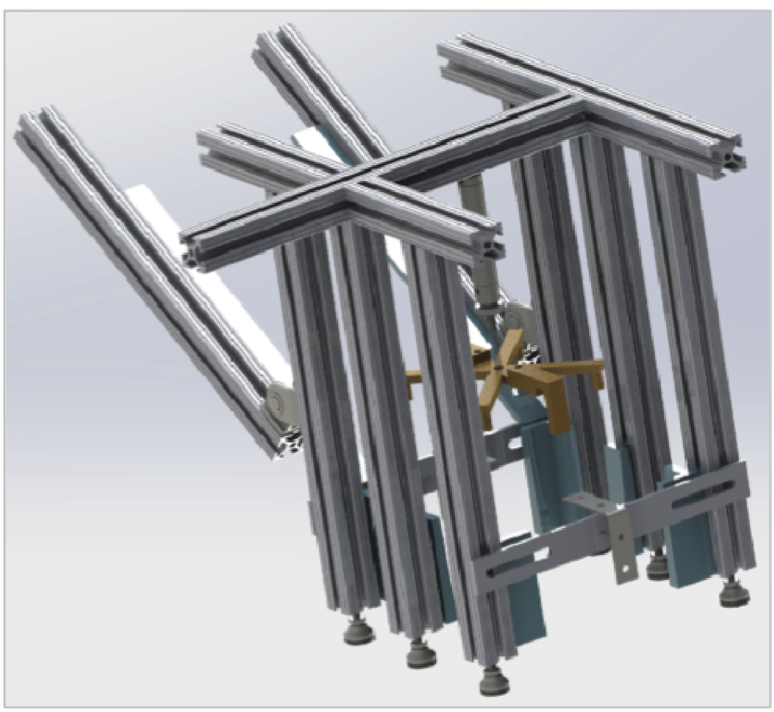


Figure 37: Rendering of Final Insert Funnel

Figure 37 shows the overall final prototype design. The figure shows the design from the back left corner. The two angled rails are the slides. The yellow spider looking part in the center is the actuator attachment. The cylinder hanging from the center is the pneumatic cylinder. The horizontal metal bars with the two slots are the brackets. Aside the two short rails that are 6 inches all of the other t-slotted framing is 12 inches long.

10.4 Pamphlet Dispenser

10.4.1 Initial Prototype

The pamphlet dispenser was the most involved design for this machine since it involved the most adjustablity in the parts in order to fine tune the machine to get it to work effectively. The first component of this assembly to be designed was the pamphlet holder itself. This component needed to hold the stack of pamphlets in alignment while providing a location for the spinning wheel to push against the bottom pamphlet in the stack. This holder also included locations to mount an adjustable gate fig. 38 as described in the box bottom dispenser to adjust the exit height of the mechanism. Also mounting holes were located which would be used to support this platform above the motor and spinning wheel. All of these features can be seen in fig. 39.

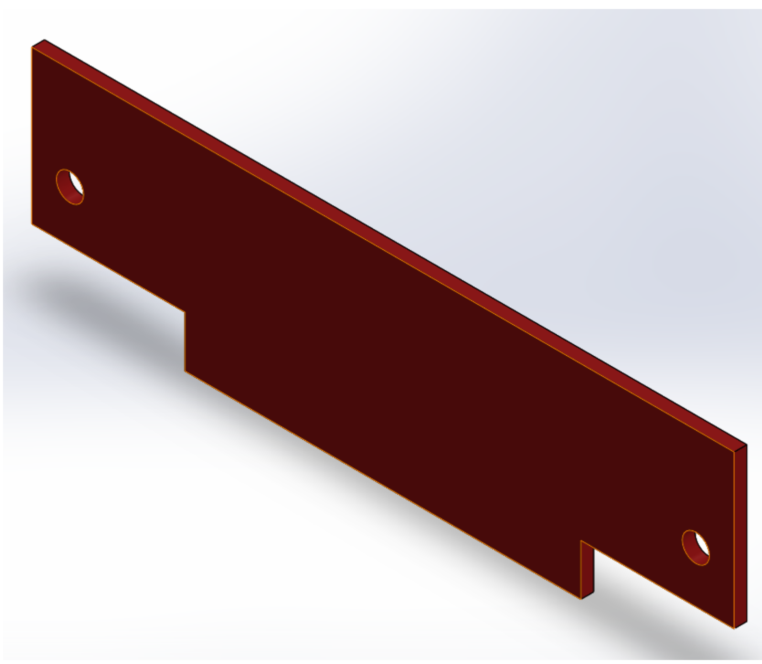


Figure 38: Part used to adjust the output height to allow for fine tuning of device

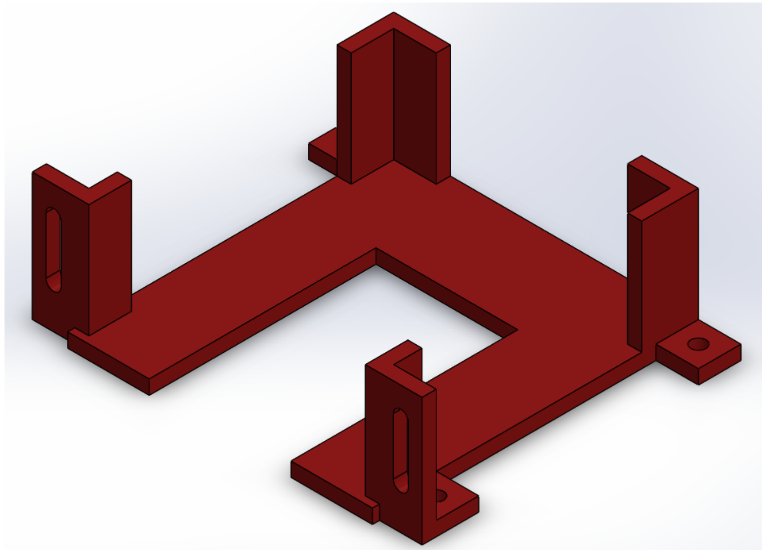


Figure 39: Pamphlet holder used to hold the stack of pamphlets above the spinning wheel

This pamphlet holder was designed to offer one eighth of an inch of clearance for the length and width of the pamphlet. Also the slots for the mounting of the pamphlet gate allow for half an inch of vertical travel to adjust fro different size pamphlets of papers. Also the hole for the spinning wheel was left intentionally large to allow for the adjustment of the front to back position of the spinning wheel.

Since the pamphlet holder is intended to be suspended above a motor a sturdy base was required to provide a mounting location for the support rods which hold up the pamphlet holder as well as mounting locations for a motor holder which will be discussed later. The base which can be seen in fig. 38 has a hole in each corner for a M6 bolt which will be used to adjust the position of the pamphlet holder relative to the spinning wheel. The holes in the pamphlet holder will slide over the support bolts and rest on nuts which can be adjusted along the height of the bolt to adjust the height of the platform. Another set of nuts will be placed above the pamphlet holder to sandwich the holder in between the two nuts on each support rod. The purpose of this is to prevent the platform from rising up due to the force of the spinning wheel as well as to prevent the loosening of the lower nuts causing the platform to fall closer to the spinning wheel. The base plate also features two holes for the motor holder to attach to in order to provide a rigid connection between all components. All holes in the base are countersunk on the bottom side to fit a M6 socket head cap screw to allow the base plate to sit securely on whatever base it is resting on. The locations of these holes and the overall design of the base plate are visible in fig. 40.

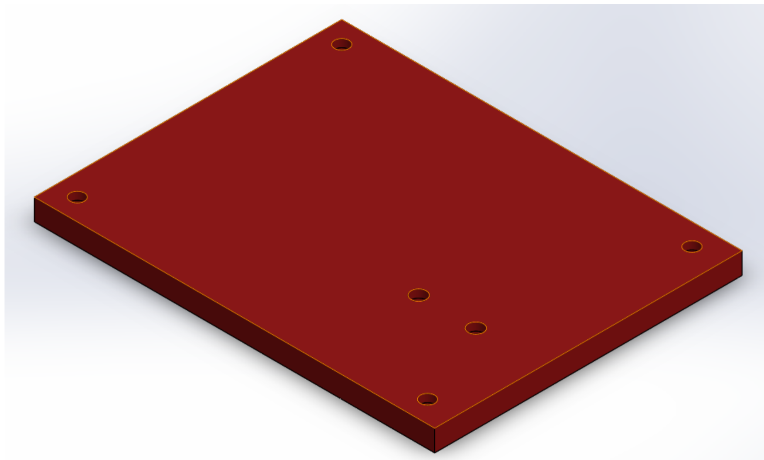


Figure 40: Mounting platform for pamphlet dispenser components

Once the pamphlet Holder had been designed an appropriately sized motor and drive wheel needed to selected for this operation. An initial search of McMaster Carr's [8] extensive product catalog produced a drive wheel specializing in the task of pushing paper products. The drive wheel is three inches in diameter and is primarily made of delrin with a rubber O ring around the circumference of the wheel to act as a gripper to push paper products. This product was selected for its extremely grippy surface as well as its narrow design as that would apply more force to a specific area rather than a small force across a larger surface area. The selected drive wheel had a quarter inch shaft therefor an appropriate motor needed to be selected to drive the spinning wheel. McMaster Carr did not supply any motors small enough for this operation therefor an internet search was performed to find a appropriate motor. Amazon.com [9] had a large selection of 12 volt dc motors, once the search was narrowed down to the appropriate shaft size the only variable remaining to select the motor was speed at which it spins. A 200 revolution per minute motor was selected for this operation, the details about this selection will be further outlined in the engineering analysis section. Now that a motor and wheel had be selected a motor holder needed to be designed which would hold the motor securely in the correct position below the pamphlet holder while allowing its position to be adjusted. Critical diminsions for the motor were taken from the web page it was purchased from. Based on those dimensions a holder was created that the front side of the motor could be screwed to as well as a support for the back end of the motor to rest upon. The dimension of the bolt holes was given to be 3M however the bolt circle in which the holes were located was not given. It is for that reason that slots were design rather than holes for the mounting of the motor. The slots allowed for a quarter inch variance in the bolt circle diameter. The height of the bolt circle was determined based on the radius of the spinning wheel with a quarter of an inch taken into consideration for clearance between the wheel and the base. The hole in the center of the bolt circle was left large to allow for the variance in the position of the shaft. The final element added to the motor holder are the slots at the base which allow for one inch of travel to adjust the position of the motor below the stack of pamphlets. All of these design considerations can be viewed in fig. 41 below.

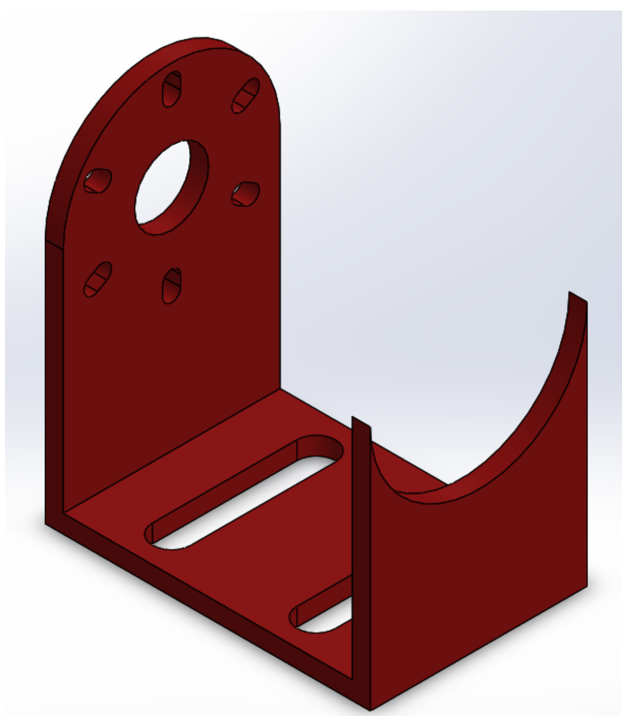


Figure 41: Part used to hold the motor in position below the stack of pamphlets

Now that all the components for the pamphlet holder have been designed it is time to assemble all the components. Two M6 by 12 socket head cap screws as well as two M6 nuts were used to attach the motor holder to the base. Two M6 by 18 socket head cap screws and nuts were used to attache the pamphlet gate to the pamphlet holder. Finally four M6 by 110 socket head cap screws and eight M6 nuts were used to adjust the position of the pamphlet holder above the spinning wheel. All of these components came together seamlessly into the assembly seen in fig. 42.

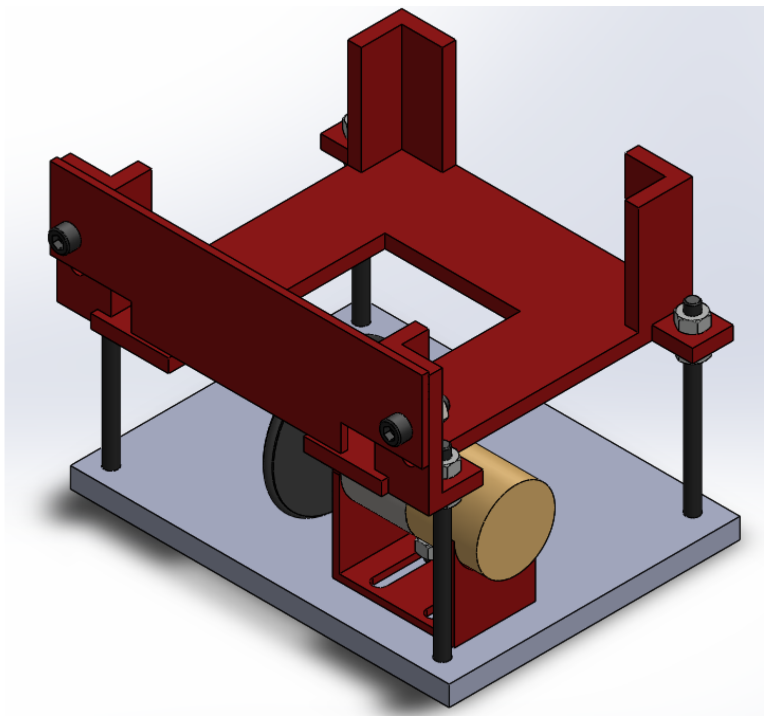


Figure 42: Final assembly of all Pamphlet dispenser components

10.4.2 Proof of Concept

For the proof of concept of the pamphlet dispenser the designs for the pamphlet base , Pamphlet holder, pamphlet gate, and motor holder were 3D printed using PLA plastic. A rubber drive wheel was purchase from McMaster carr to act as a pushing device for the paper. A 12 volt electric motor also needed to be purchase from Amazon.com to power the rubber drive wheel. Once all the components were printed and delivered they were assembled using M6 and M3 socket head cap screws. An image of the final assembly of the pamphlet loader with pamphlets in the holder can be seen in fig. 43.

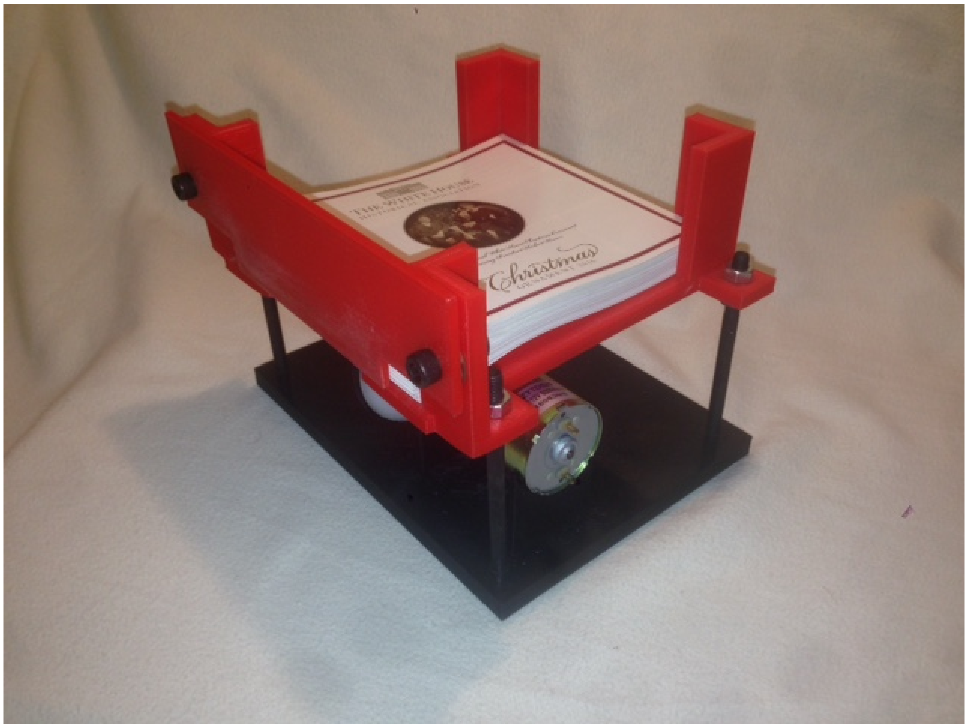


Figure 43: Pamphlet dispenser proof of concept assembly

All of the components of this assembly were designed with to make it easier to fine tune the operation of the device. After adjusting the gate height the holder height and the motor position a combination was determined that offered the best result. The pamphlet gate needs to be approximately one and a half pamphlets height. This gives a little clearance for the bottom pamphlet to be pushed out while still holding the second pamphlet inside the holder. The motor worked best in a mid position as if it were too close to the gate it would push the above the gate opening not allowing the pamphlets to exit. Also if the motor was too far away from the gate the pamphlets would simply arch over the wheel and the wheel was not able to grip the pamphlets to push them out. In the mid position the pamphlets sat on top of the wheel and then arched back down to fit under the gate. The final adjustment was the height of the pamphlet holder above the rubber drive wheel. After some experimentation it was decided that the device functioned best with the holder in its lowest position to force the pamphlets down onto the rubber wheel. In this orientation the pamphlets are arched up over the rubber wheel slightly which gives a larger contact area to apply the pushing force to. The arch in the pamphlets as well as the locations of the motor holder and the pamphlet gate can be seen in fig. 44.

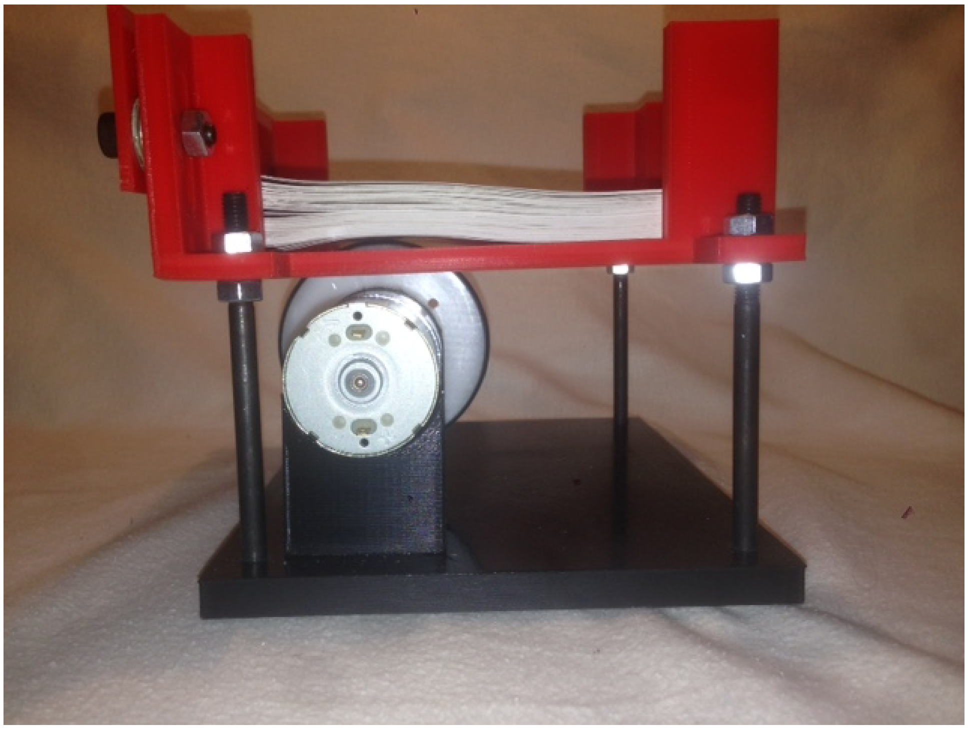


Figure 44: Side view of pamphlet dispenser

Through all of these adjustments a major design flaw became apparent. The initial concept was that this dispenser would push one pamphlet completely out of the holder. However since the motor does not have enough time to get up to full speed the pamphlet is not moving fast enough when it is out of grip of the wheel to propel it completely out of the holder. As a result of this the pamphlet is only pushed half way out of the holder as in fig. 45. This however can be fixed by trying to increase the speed of the motor which may be able to shut the pamphlet out at a faster speed, or by adding another spinning wheel just outside of the holder that is constantly spinning. The purpose of this second wheel would be to grab the pamphlet as soon as it roughly one inch outside the pamphlet gate and pull it out of the holder and speed it up fast enough to shoot the pamphlet into the box bottom. With all of these adjustments optimized and accepting the fact that the pamphlet only pushes half way out of the holder the dispenser functioned effectively 95 percent of the time with the occasional pamphlet jam. In the future this design will be optimized to reduce the amount of pamphlet jams.

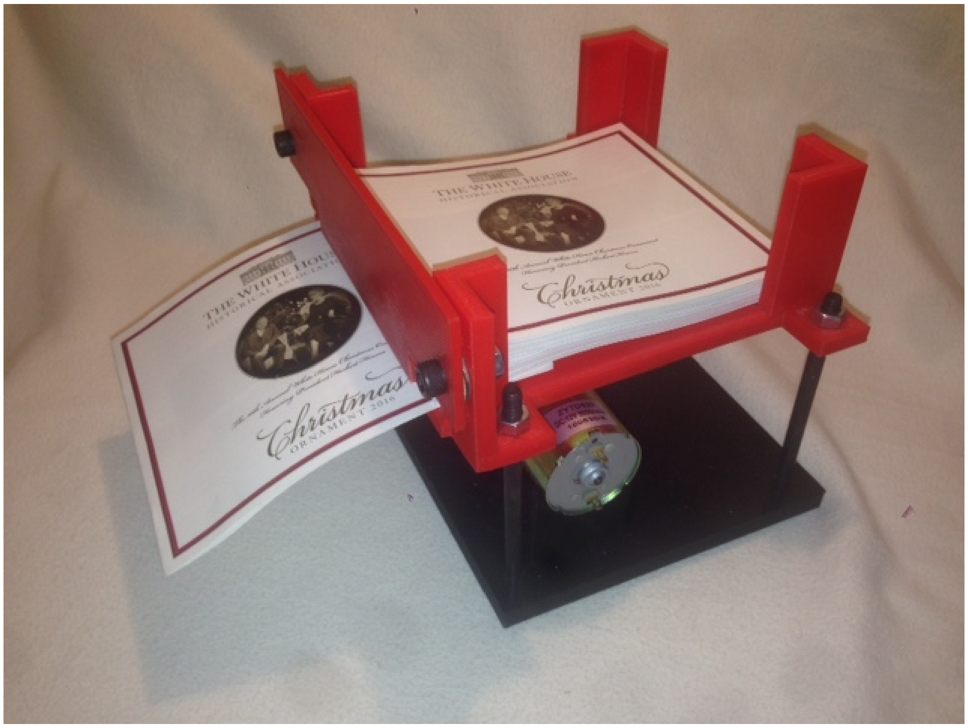


Figure 45: Pamphlet dispenser with pamphlet dispensed

10.4.3 Redesign for Adjustability

Now that the initial prototype had be constructed and put through its proof of concept tests it was time to redesign the dispenser using materials that would allow it to be adjusted for different sized pamphlets. In order to achieve complete adjustability it was decided to construct the dispensers framework out of aluminum extrusion framework also referred to as "80/20". This framework is made out of strong but lightweight aluminum that features a slot running the length of its four sides allowing for special "T-Shaped" fasteners to be slid in and tightened at any point along the length of the extrusion. The use of this material will make it easy for anyone to simply loosen the fasteners holding a particular frame member in place in order to adjust it for different sized products. At first the thought was to use an ”X” shaped framework that the four corners of the pamphlet holder would slide out on equally from a center position which would never change. After playing around with that design in solid works it was determined that it would be too complicated and that the most important part was the front of the pamphlet holder where the pamphlets would be dispensed. Also, with the X design the motor position would have to be changed whenever the pamphlets size was changed. It is for those reasons that a new ”T” shaped design was created. With this design the motor would be placed at the front of the pamphlet holder located at the base of the T and this part would always be stationary. The back corners of the pamphlet holder would be attached to the adjustable cross section of the T allowing for adjustment for different length and width pamphlets. The pamphlets will be held into the holder using four columns attached to the ”T” shaped frame along with some 3D printed guides that slide into the 80/20 extrusion to provide a smooth L shape to guide to pamphlets down towards the drive wheels. The drive wheels can also be adjusted as they are mounted on there own cross section that is free to slide along the length of the T shape. Once the pamphlet has been dispensed another mechanism is required to ensure the accurate placement of the pamphlet into the box. Using more 80/20 an angled framework was designed to allow the pamphlets to slide down along additional 3D printed guides towards positioning guides mounted on 80/20 rails that allow for the adjustment of the length of the pamphlets. This additional framework would be mounted to vertical pamphlet holder columns meaning they will already be positioned correctly for the width of the pamphlets. Now that the basis for the redesign had been formulated it could be translated to the final design which is discussed further in the next section.

10.4.4 Final Prototype

Using the design principles discussed in the previous section the final prototype could be finalized using adjustable materials. Most of the framework for the pamphlet dispenser was constructed from one inch by one inch aluminum extrusion which was joined together using various 90 degree angle brackets and braces. The only differing framework is the front columns of the pamphlet holder which were made from one inch by two inch framework which has a notch to allow for the motor to positioned anywhere beneath the pamphlet. The reason for this is because the DC motor powering the drive wheels is wider than 1 inch and needs to be able to be positioned directly beneath the front edge of the pamphlet. Drawings for all of the parts used to construct the final pamphlet dispenser prototype are available in the appendix in figures 88 through 109. Also included in the drawing set is the bill of materials in fig. 90 which show every part in the pamphlet dispenser as well as the quantity and where it was purchased from. The framework design is visible in a rending of the final CAD model shown in figure 46. An additional adjustable framework was attached to the top of the columns to provide more stability as well as a mounting location for sliding plunger which keeps constant down force on the pamphlets in the holder.

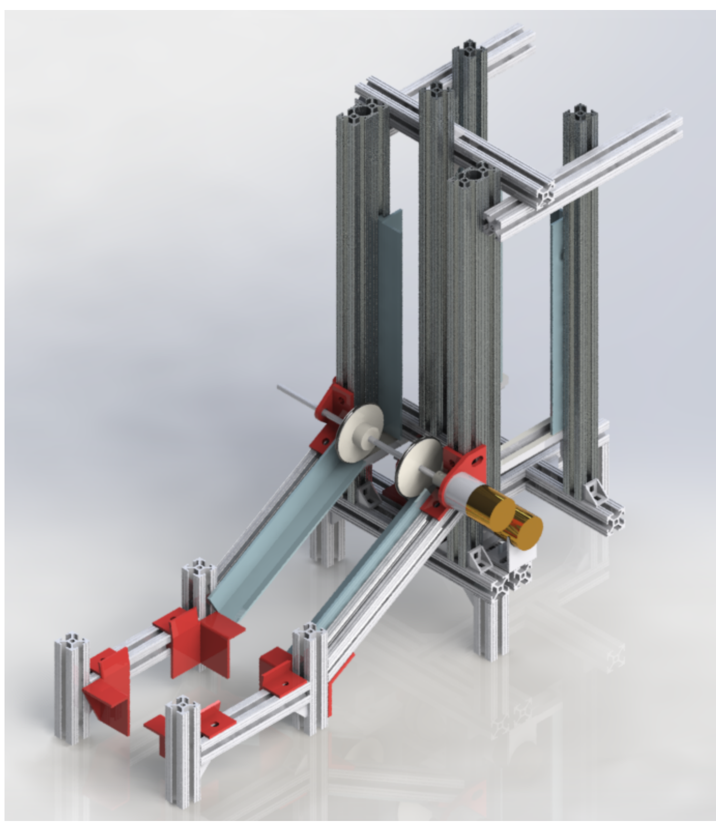


Figure 46: Rendering of Final Pamphlet Dispenser Prototype Design (Isometric View)

Also visible in figure 46 are the pamphlet guides which appear as the light blue colored L shaped brackets around the pamphlet holder and along the ramp. These brackets were designed to be one inch by one inch by one eighth inch thick L brackets that feature a T shaped extrusion on the back which slides into the 80/20 columns. In order to obtain the correct measurements for the T shape a test piece was printed based on rough measurements from the 80/20 extrusion and the design was further refined until an appropriate fit was achieved. Rather than spending a lot of time to machine all of these parts and to achieve the best surface finish it was decided to print these parts using the University of Rhode Island's 3D resin printer. Another important aspect of the design of these component is that they are designed to be symmetrical that way each part could be flipped over to be used on the opposite side of the dispenser. Doing this is important because it reduces the amount of different parts that need to be fabricated and reduces the amount of spare parts that need to be kept on hand in case one should break. Drawings for the pamphlet corner support as well as the ramp support can be found in figure 101 and 102 located in the appendix.

The pamphlet corner supports as well as the pamphlets themselves needed a sturdy yet slippery surface to sit on. It was decided to use Delrin for this application due to its high strength and durability. In order to attach the Delrin to the 80/20 columns aluminum L brackets were used in combination with socket head cap screws which were countersunk into the surface of the Delrin to provide a smooth surface for the pamphlets to slide on. In order to still allow the dispenser to be adjustable the screws at the front of the holder were simply installed in countersunk holes since that side doesn't need to move but the screws in the back of the dispenser were installed in counterbored slots. This allows the back columns to be slid in or out to adjust the length of the holder while both side columns could be slid in or out to adjust the width. A drawing of this part is available in fig. 100 in the appendix. The slots within the Delrin are also visible in the top view of the pamphlet dispenser shown in fig. 47.

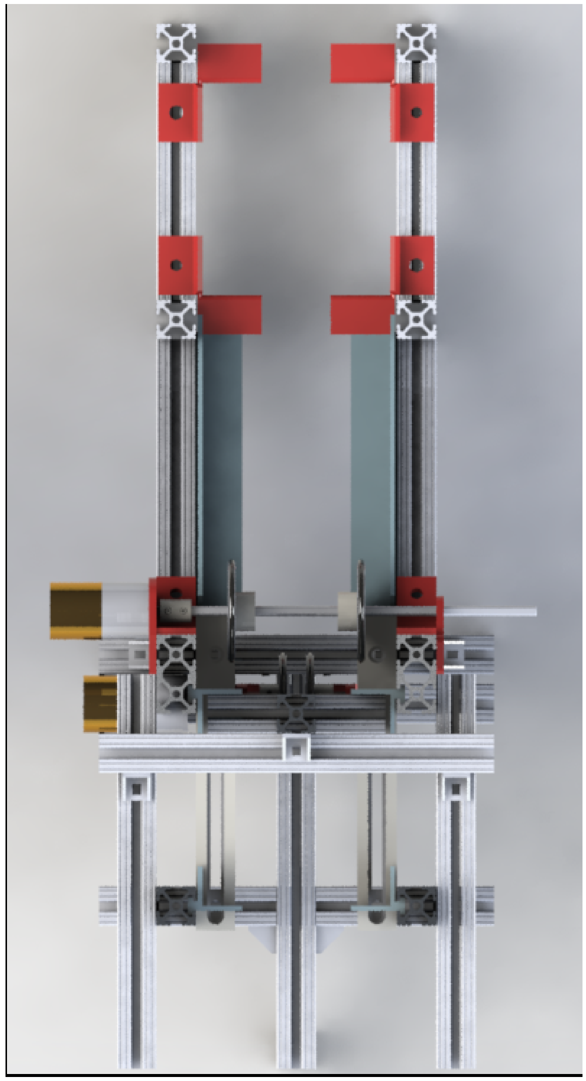


Figure 47: Rendering of Final Pamphlet Dispenser Prototype Design (Top View)

In order to support the drive wheels and their motors it was necessary to design several different motor and axle holders. Eventually all of these supports would be fabricated from metal to ensure they are strong enough to not flex under the torque of the motor but for now these parts were simply 3D printed. As the semester was drawing to a close and 3D printed availability was getting scarce it meant that the front motor and axle holder needed to be fabricated from simple plywood. Switching to this weaker material combined with the lack of accuracy when fabricating caused some issues which will be further discussed in the redesign section. As well as motor and axle supports, brackets also needed to be fabricated to support the ramp at its 30 degree angle. Also parts were designed to act a positioning guides for the pamphlets at the base of the ramp. These parts also utilized the T shaped extrusion to hold the parts onto the 80/20 rail while incorporating a screw hole to lock the guide in place. Unfortunately due to time constrains and 3D printer availability those parts were not able to be printed. Drawings for all of these components can be found in figures 103 through 109 in the appendix.

Figure 48 is a cutaway of the pamphlet dispenser which helps to depict how it will function. The stack of pamphlets will be held within the guides on the right of the image above the lower drive wheel. When a signal is given to dispense the lower motor will turn on until a sensor detects that the pamphlet has reached the second drive wheel at which point the lower motor will shut off. The upper motor is always active so that when the pamphlet makes contact it pulls the pamphlet out from the stack and dispenses it down the ramp towards the positioning guides.

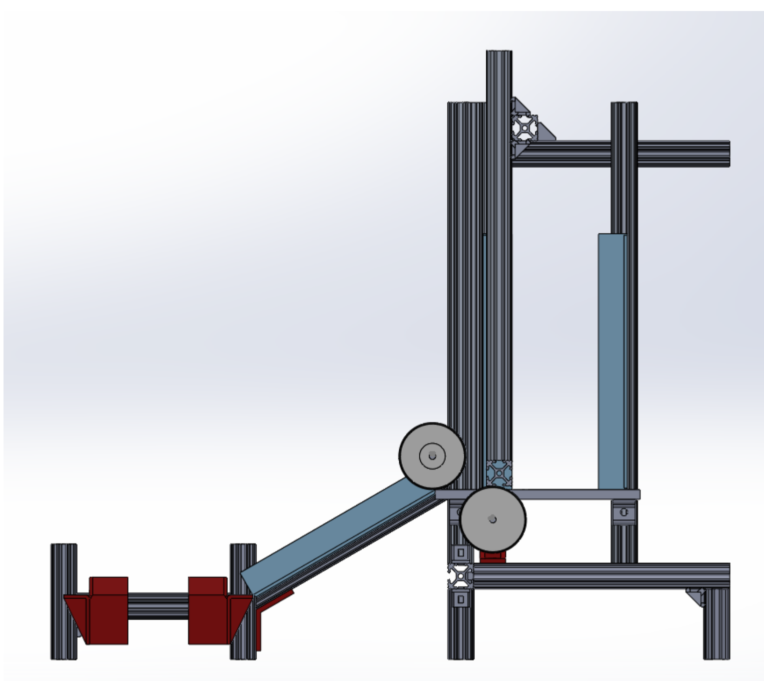


Figure 48: Rendering of Final Pamphlet Dispenser Prototype Design (cutaway View)

10.5 Box Lid Loader

10.5.1 Initial Prototype

Placing the lid on the box assembly is the final step in completing the product. The first step in designing an apparatus for the box lid loader was to take the dimensions of the White House Ornament box lid, $6in. \times 4.25in. \times 0.56in.$ with a wall thickness of 0.078 in. Once these dimensions were found one of the design engineers created a model rectangle of the same size in SolidWorks, to use as a reference and to visualize the tolerances. This model also allows for the engineering team to stack and orient the boxes in different ways then build geometries around them. This methodology allows for less rapid prototyping and saves time and resources in the design process.

The design team decided on a gravity fed and angled design for the box lid loader so that no external mechanical components besides the actual frame would need to be used to place the lid onto the box. The concept for this mechanism is simple, seeing as there is only one true component to the system excluding the stand on which it will be oriented on above the conveyor belt which unites the entire process. Although the design is simple there are factors which need to be taken into account such as the number of lids that can be fed into the loader at a time, how high the lid loader will be off of the conveyor belt, and how the lids are loaded into the apparatus.

For the first design of the Box Lid Loader, the team decided to leave the bottom of the apparatus angled and have the top of the apparatus configured vertically. Using a box bottom, a protractor, and a lid the team decided that an angle between ten degrees and thirty degrees seemed reasonable for the angle between the lid and the conveyor belt below. For the prototype which is shown in Figure 49 the angle of twenty degrees above the horizontal was chosen. This model was created and checked by the design engineers then it was physically created by means of the 3D printer.

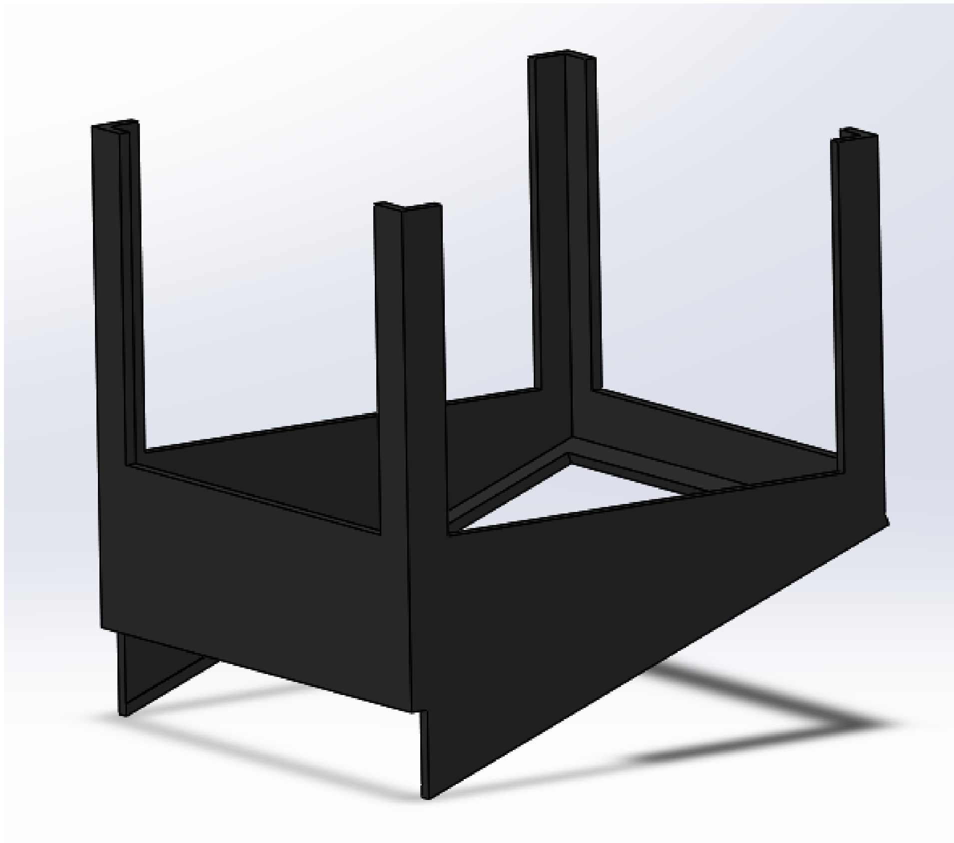


Figure 49: Box Lid Drop Mechanism First Prototype

This model, once created was used test actual box lids and the team learned many things from this model. The first issue that the team found was that the twenty degree angle was a bit too large for this application, and therefore decided that in the next model the angle would be reduced to ten degrees. The L-bracket style corners of the mechanism were too flexible and a bit feeble, so the design team decided to make the wall thickness for the next model greater. The last, and largest issue the design team found was that because of the vertical stacking mechanism the lids were falling into each other and jamming the system.

These issues were addressed and corrected by creating an entirely new model which is depicted in Figure 50 and Figure 51. The wall thickness was increased in order to create a more robust prototype. Once the actual material is chosen for this component the model will be adjusted to reflect the final materials strength and wall thickness. For the prototype the wall thickness was increased in order to ensure durability during testing and to make up for the brittle properties of the PLA. The angle from the horizontal was adjusted to be ten degrees. The stacking mechanism for the box lids was the greatest adjustment in this design. Instead of having an angled bottom with vertical sides the team decided to angle the entire cage that the lids are stacked within so they sit one on top of the other and avoid falling into each other. This angle is maintained by means of legs which hold the stacking mechanism up at a specific height above the conveyor belt. In the future these legs can be modified so that the apparatus can be adjusted for various sizes of boxes and lids.

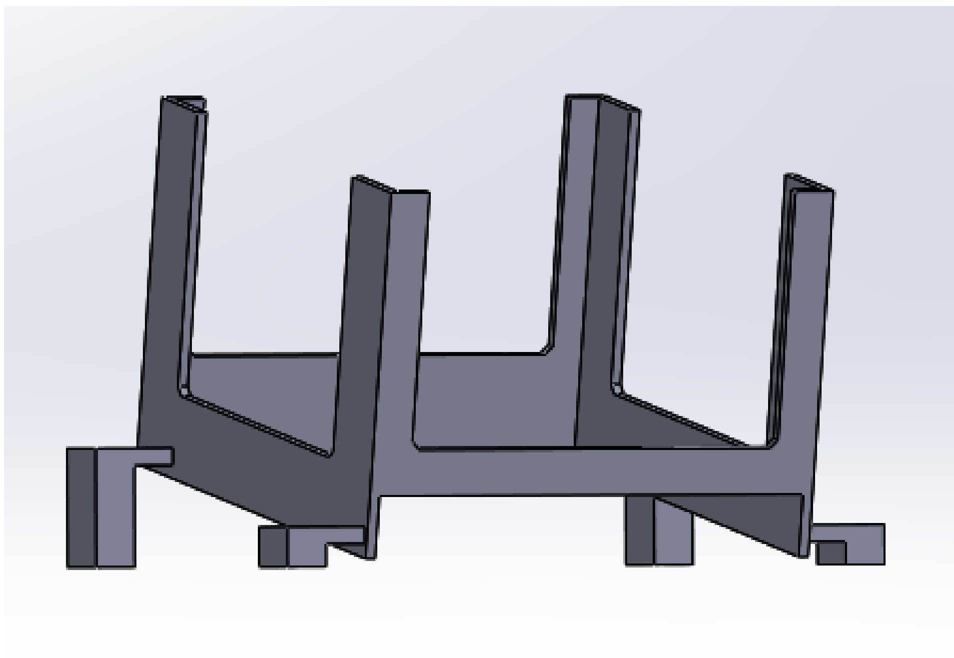


Figure 50: Box Lid Drop Mechanism View 1

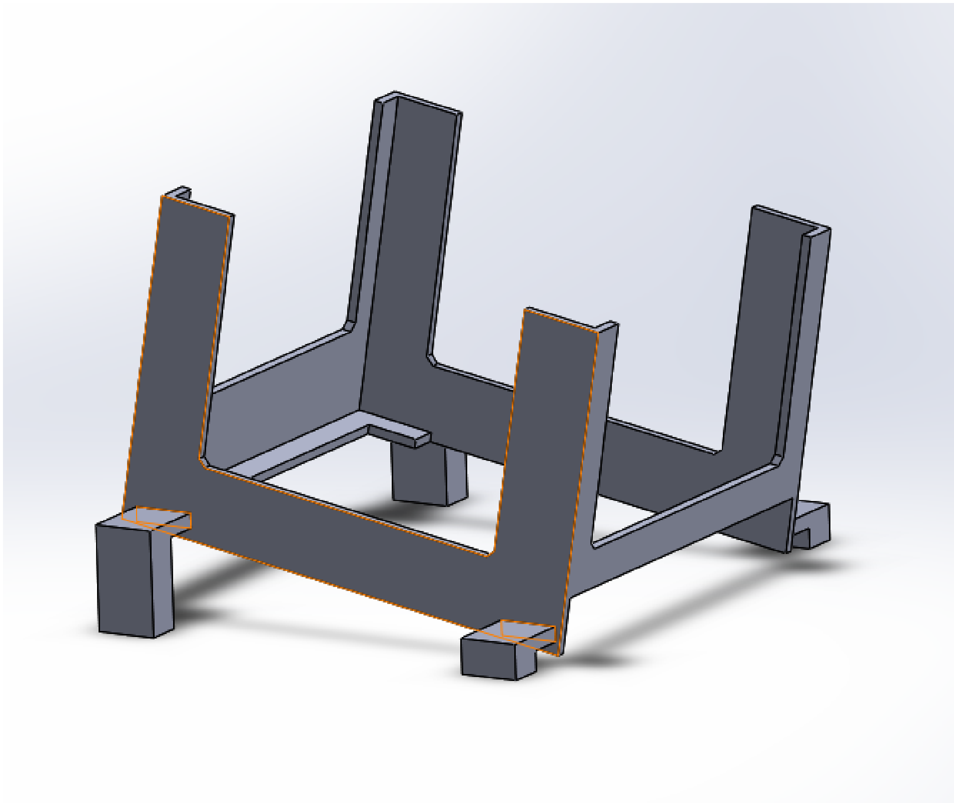


Figure 51: Box Lid Drop Mechanism View 2

The models in Figure 50 and Figure 51 best reflect the design which the group created at the end of the Fall Semester. The team is confident in the changes made to the initial design and will continue to learn from the design to improve upon the final product. Due to time constraints the team was unable to 3D print this model and will continue with the design in the spring semester. The Box Lid Loader is an efficient design, and with fine tuning and testing the design will be functioning to its fullest capacity early in the Spring Semester.

10.5.2 Proof of Concept

The Box Lid loader is a mechanism intended to place the lis of the box on the completed assembly. This step completes the packaging process and is the final automated step in the process before the boxes are inspected and shipped to the customers. For the Box Lid Loader, the design teams proof of concept was the first 3D printed prototype of the box lid loader. The design team had already designed and sent the second iteration out for 3D printing at the time of the Proof of Concept presentation, but the second version had not been printed. This first prototype was the team's mechanism for understanding what needed to be changed in order to make this part the best it could be.

For the proof of concept the design team demonstrated how the first model worked, and discussed the changes made to the second model. The first model was already missing a leg at this point due to the wall thickness that was initially determined for the part. This model, although a work-in-progress, proved that this type of apparatus will work for accomplishing this step in the packaging process. After fine-tuning the part and figuring out the timing with the conveyor belt this step will function properly without external automation.

Both the first and second design for this part showcased the team's ability to accomplish this step in the packaging process without a motor or some sort of arm. The lack of sophisticated electronics in this part allows for lower cost, higher durability, and less maintenance over time. The model will be changed in the future once materials for the parts have been chosen. The design is fluid, but for the purpose of the proof of concept the design proved that this step in the packaging process can be completed using the mechanisms that the team designed.

10.5.3 Redesign for Adjustability

After the initial 3D printed prototypes proved that the design concept would work, the team started to focus on making the apparatus adjustable for different size boxes that ChemArt uses to package the various size ornaments. The Box Lid Loader is a relatively simple design, which made it difficult to translate into something bulky and adjustable while still maintaining the integrity of the original design. The Lid Loader requires that the front end of the apparatus is close to the surface of the conveyor and no parts of the apparatus interfere with the contact between the box bottom and the lid. The team brainstormed many different adjustable possibilities for this apparatus, but most of them were difficult to build and time consuming to adjust. The team finally settled upon creating an external frame from 1 inch × 1 inch, 80/20 aluminum extrusions. This frame is held together using L-Shaped fasteners and brackets that can easily be moved in all directions using a couple Metric allen wrenches. The feet that hold the apparatus up at the correct angle are mounted to the sides of the basic frame. The feet are made from 2 inch segments of the aluminum extrusion, and the hole through the extrusion is threaded so the leveling feet can be adjusted. The fasteners used allow for the feet to pivot and be tightened at exactly the right angle and then adjustable leveling feet were added to the 2 inch long aluminum extrusions so the heights can be precise for each specific box used.

The internal framework of the apparatus was created to secure the lids in place within the frame. The frame itself allows for the system to hold at the correct angle and height, but does not hold the box lids in place, or keep them from collapsing into each other, which was a major concern in the design process. Inside the fixture various extrusions made using the 3D printer are placed strategically to hold the lids in place. The extrusions have a smooth surface finish so that they do not damage the boxes, while still providing integral support within the apparatus. The bottom two inserts were added to ensure that the boxes did not fall directly onto the conveyor belt immediately. The extrusions hold the back of the bottom box lid up over the conveyor belt at the set angle so that the front of the box bottom and the inside of the front end of the box lid come in contact with each other. The corner inserts were added to hold the lids in the stack without them buckling and collapsing into each other, rather they rest atop each other at a determined angle.

The frame is completely adjustable in the X, Y, and Z directions, the feet can be adjusted up to 1 inch up and down and the angle that the feet are positioned at can be changed using an allen wrench. The whole frame can be taken apart and reassembled easily with little to no training or instruction. It is a simple design that can be maneuvered so that the frame works for every Christmas ornament that ChemArt packages.

10.5.4 Final Prototype

The final prototype for the Box Lid Loader is a combination of everything that was learned from the previous design iterations. The adjustable frame was incorporated, while the stacking mechanism and drop angle were kept from tests done on initial prototypes. The goal of the final prototype was to prove that the concepts that had been designed and tested could all come together in a cohesive design that functions and can be easily adjusted. The frame of the final prototype consists of twelve segments of 80/20 aluminum extrusions. Four 10-inch segments of the 80//20 aluminum extrusion were used to construct the bottom rectangle of the frame. Four 12-inch segments were used in the corners for the corner inserts to hold the box lids in place in a neat stack. Four two inch segments were cut and then threaded for the leveling feet, so that they could be mounted to the external sides of the bottom frame to hold the fixture at the correct drop angle. The 80/20 aluminum extrusions were fastened together using connectors and brackets, the 3D printed extrusions slid into place, and the feet were mounted on the external sides of the frame using drop in fasteners.

The bottom frame was constructed using 10-inch segments of extrusion because this allows for the frame to be adjusted for all of ChemArts box sizes. One of the main challenges with this project was for the fixture to work for all of the different shape boxes. The 12-inch segments were chosen for ease of use in testing - this height was easy to work with during testing and allowed for a tall enough stack of lids to be added to see if there would be an issue with the lids collapsing into each other. For the actual fixture that would be used in ChemArts packaging facility this height could be increased so that the workers would not have to reload the device as frequently. The height of the 2-inch segments was chosen because the legs needed to be at least this high to function properly in the set up, and with the addition of the leveling feet it allowed for a range of motion in these heights.

Figure 52: Box Lid Drop Mechanism View 2

Figure 52 shows the final prototype assembly. The top four vertical extrusions are held in place using L-shaped connectors which can be moved after loosening the screws in them using an allen wrench then they can be tightened in any configuration along the horizontal bars that they rest on. The horizontal bars are held in place using the corner brackets which can be adjusted and readjusted in the same way that the L-shaped connectors can. The brackets were chosen for this connection because the directions of the channels in the extrusions are perpendicular and these connectors allowed for this connection to be made. They are also robust, which is important because this bottom rectangular frame bears the weight in the system. The feet were fastened onto the sides of the fixture using drop in fasteners. In order to use these fasteners holes were drilled through the 2-inch segments of extrusion and longer screws were used to mount the feet to the sides. This method of fastening allows for the feet to be moved along the horizontal bar and the angle at which they are set to be adjusted with ease.

The internal inserts of the frame are what make the fixture effective and hold the lids in place within the frame which dictates the angle of the stack and the height that it rests at above the conveyor. The bottom and corner inserts were designed to slide into the channels in the 80/20 extrusion with enough resistance for the extrusions to hold themselves in place. Stoppers can be added to secure the bottom inserts because they will be load bearing, and if they slide it may affect the way the box lids come in contact with the box passing underneath the fixture on the conveyor belt. The way that the lid and the box come into contact is crucial to this step being successful. The corner extrusions were designed to hold the lids in a stack without them collapsing into each other, which was an issue with the first 3D printed prototype. These inserts were made using the same tolerancing as the bottom ones with the same material and surface finish.

The final design incorporates the intrinsic qualities of the earlier prototypes while still achieving the goal of adjustability. The 80/20 aluminum extrusions allow for precise adjustments so that the fixture fits the specific lid shape perfectly for each variation of box lid. The leveling feet allow for the angle that the fixture sits above the horizontal to be adjusted for each box variation. All of the components in this step are completely adjustable and can be fine-tuned to fit each box that ChemArt uses.

11 Engineering Analysis

11.1 Box Bottom Loader

The main piece of engineering analysis which needed to be conducted to complete this part of the machine is to determine an appropriate tolerance which will allow the box lids to slide easily in their holder while not allowing them to get out of alignment or to fall inside one another. In order to perform this engineering analysis the box bottom loader was initial designed and fabricated with an eighth of an inch of clearance along the length and width of the box bottom. This larger size would ensure plenty of clearance for the boxes to slide down when the lower box was removed however it allowed too much room for the boxes to move around and fall inside one another. In order to determine an appropriate clearance for these box bottoms tape was applied to the sides of the guides until the boxes would slide easily downward without begin able to nest inside one another. Once the results of this test was satisfactory measurements of the new length and width sizes were taken and the length and width of the box bottom was subtracted respectively to obtain the new values of clearance which will be used in future designs.

After solving the clearances issue the only thing left to fix in the new design besides choosing the correct height for the actuator, was to test the different speeds of the actuator pushing the box and during its retraction. The team selected different speeds modifying the amount of air entering into the acuators system. The tests gave the team positive feedback as even high velocities (when pushing) were working for the device. Even so, a medium speed was chosen for the continuous testing as it is one of the teams priorities not to damage the boxes in the process. For the retraction movement of the actuator a slower speed was chosen as we want to avoid boxes falling onto each other when a too fast retraction. This has not occurred during all of the testing process but still it was a pre-emptive decision the team made as there is not a problem in obtaining the desired cycle time under 5 seconds per box.

11.2 Insert Funnel

When designing the funnel the main design consideration was how much pressure needed to be applied to the sides of the insert to force it into the box bottom. Initially experiments were conducted by hand to determine how far the inserts needed to be deflected in order for them to fit within the box bottoms. It was determined that a deflection of one sixteenth of an inch on all four sides was enough for the insert to fit inside the box bottom. It is for this reason the bottom of the funnel was designed to be one eighth of an inch smaller in length and width than the box bottom to force the pamphlet into place. The angle of the funnel was determined based on the fact that their needed to be plenty of clearance for the insert to fit inside the top of the funnel. In the end a draft angle of 9.5 degrees was created based on the fact that the funnel decreases in size by half an inch along the three-inch depth of the funnel. The same dimensions were kept for both the initial prototype and the adjustable prototype.

For the adjustable prototype the force of the spring for the gate compared to the force the actuator could handle was compared. The spring requires 3 pounds of force to close the spring completely. The actuator was rated for 25 pounds. The force of the pneumatic cylinder can be adjusted based on the air pressure. Tests were run to see the different force of the actuator to adjust it appropriately. The actuator needed to push the 3 pound spring on either side along with the insert itself. The actuator had an attachment that was adjustable to touch the spring before touching the insert. The actuator attachment had to be able to distribute the force from the pneumatic cylinder evenly through the attachment and then still be able to push down the spring. The attachment adjuster aspect was made thick so it coud withstand the force being distributed through it. The main x shape attachment was thick, the shape and the thickness were chosen to evenly distribute the force. The actuator assembly was chosen to minimize the stress.

11.3 Pamphlet Dispenser

Most of the components in the pamphlet dispenser were made adjustable so that the operation of the device could be fine tuned to optimize its performance. The one variable which needed to be decided upon at the time of purchase of the motor was the speed at which it rotates. The total step time for the operation of placing the pamphlet into the box needs to be less than 5 seconds therefore the pamphlet needs to be dispensed as quickly as possible. Allowing for any time that the pamphlet would need to travel from the dispenser to the box as well as allowing time for any alignment devices to make sure the pamphlet is correctly placed in the box a realistic time of one second or less to dispense the pamphlet has been agreed upon. Also the faster that this step is completed will allow more time to be used by the other steps to keep the total packing time within the design specification. Based on the circumference of the wheel being roughly 9.5 inches the wheel would have to travel at least one half revolution for the pamphlet to be dispensed. In order for the pamphlet to be dispensed in under 1 seconds the motor would need to spin at at least 30 revolutions per minute. Rather than purchase a 30 revolution per minute motor it was decided to purchase a faster motor along with a speed controller so the speed of the motor could be optimized. A speed of 200 revolutions was chosen as any speed above that would have a negligible effect on the speed of dispensing. What this means is that if the 200 RPM motor could dispense six pamphlets in one second therefor a motor any faster would be pointless. Having this 200 Revolution per minute motor will allow the machine to be fine tuned for dispensing times from less than one per second to more than five per second. Also having a faster motor will accommodate for the fact that the motor will need to speed up as it receives a signal that the machine is ready for a pamphlet.

11.4 Box Lid Loader

Throughout the process of designing the Box Lid Loader the team has focused on trying to make the part work without the use of actuators and external automation. The design was created so that gravity and the conveyor belt would work in harmony to place one lid on each box as it passes below the fixture on the conveyor belt and once that lid clears one falls into its place. Initially the team designed in SolidWorks and 3D printed models to ensure that the concept of a rigid, inflexible and unadjustable, fixture would work and successfully place the lids on the boxes as they travel under the conveyor belt. The angle of ten degrees above the horizontal was settled upon for the White House Ornament box after a series of tests and adjustments were made. The stacking mechanism for the lid loader reflects this ten degree offset to prevent the boxes from collapsing into each other as was seen with the first prototype. The angle that the fixture was set above the conveyor and the stacking mechanism, once altered, ultimately proved that the fixture did not require an actuator.

The goal of the system was to get each step to take about 5 seconds to complete, this steps timing is completely reliant on the speed at which the conveyor belt is set. The steps function performed well in testing when the box was pushed under the fixture manually at a variety of speeds to see if it failed when the belt was moving quickly. Through the testing performed the team is confident that ultimately this step will be successful in a timed conveyor system.

Once the concept was solidified in the rigid form the task of redesigning for adjustability became the first priority. After many brainstorming sessions and redesigns the ultimate end fixture was created from 80/20 aluminum extrusions and various connectors that hold the fixture together. The feet that hold up the fixture are 2-inches tall and the adjustable leveling feet that are threaded inside of them allow for the heights to be altered. The heights of these feet were decided upon through testing performed on the 3D printed models. The maximum size lid that can be used using this frame is 9 in $\times$ 9 in which is larger than ChemArts largest box, but makes the fixture easy to maneuver and adjust. The height of the stack is currently set at 1 foot, but this can easily be changed by using different length extrusions and inserts.

12 Build

12.1 Box Bottom Loader

Oppositely to the other prototypes built for this project, full 3D printed were composing the body of the design, instead of the T-slotted Aluminum framing. The model was provided with holes and slots that allow the model to fit in different size boxes simply by adjusting the two 3D printed pieces, and putting a divider in its desired position.

This prototype can be separated in two main parts: the 3D printed body, and the pneumatic actuator.

It is important that the height of the box that is going to be pushed into the system is aligned with the plastic rectangle attached to the actuator. This rectangle is a 3D printed body with the shape of a box that will hold the stack at the same time it goes forward and moves the first box bottom, it has been drilled so the actuator head can go through it, and get the body fixed using a couple of nuts. After measuring the height of the first box in the cage and the head of the actuator, a piece of wood has been cut and placed under the actuator so both things are at the exact same level. Two aluminum clamps and screws are used to fasten the actuator in its correct position, and the wooden frame it attached to a bigger cut piece of wood that has both the 3D printed model and the actuator on it so everything is fixed for when the air controller system of the actuator is pushed, none of the parts will be able to move except for the box bottoms.

The whole model and its performance can be observed in the next series of figures (53 , 54 ,and 55)

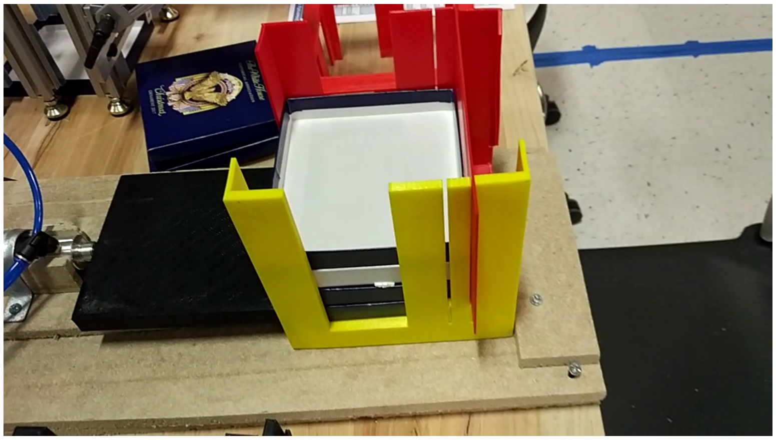


Figure 53: Full model with a stack of bottom boxes

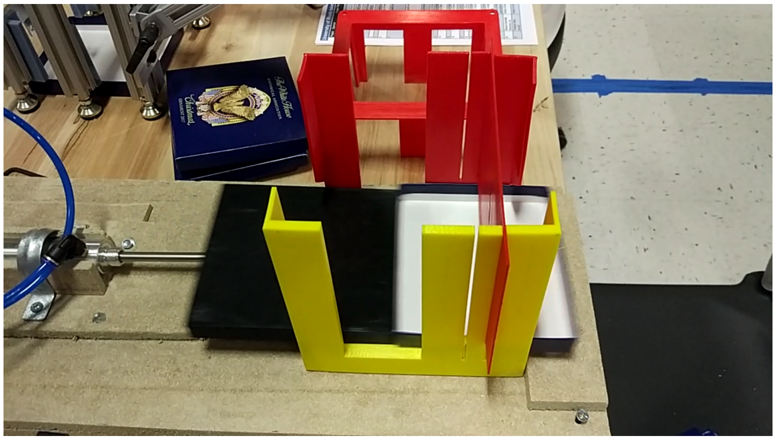


Figure 54: Actuator dispensing last bottom box half through

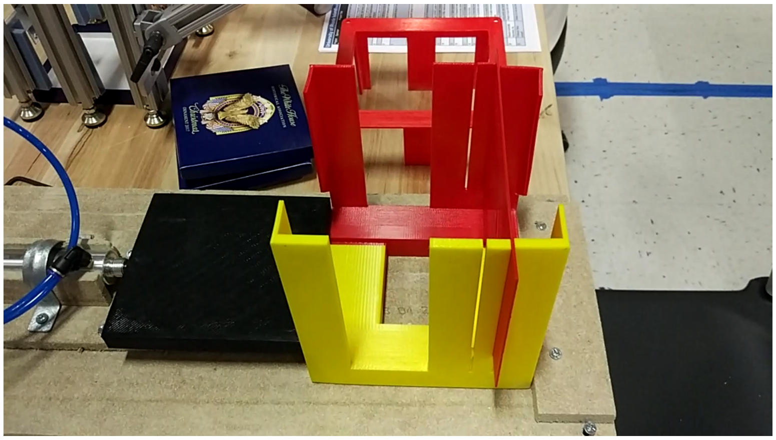


Figure 55: Empty model ready for re-stacking after process

12.2 Insert Funnel

To make the funnel adjustable a frame that was light and could be easily altered was needed. Aluminum T-slotted framing was used for the framework. The 80/20 t-slotted framing was ordered in 6 foot lengths. Two of the 6 ft extrusion segments were ordered and then cut into 12 inch pieces using the horizontal bandsaw. One of the 12 inch pieces was cut again into two 5.5 inch pieces. The framing was assembled using many of the L-shaped connectors and one Tee connector. There are two L-shaped connectors on every vertical piece of the aluminum framing. Two connectors were used to increase the sturdiness. The connectors are attached by sliding them into the slots of the framing and then using an allen wrench to tighten the connector in place. Once the framing was completed the two angled framing for the slide was installed. A hole had to be drilled in the bottom of each of the two segments being attached and then the hole was tapped so that it could be attached to the locking pivot which was attached to the main frame.

The next step of the build was to 3D print all the necessary inserts for the funnel. There are four corner inserts and two side inserts that were 3D printed using the resin printer. There are also two slides for the insert to slide into the funnel center. While the building of the framework was taking place the various inserts were being printed. Once the resin parts were done printing a water jet was used to take off the support material. The water jet was on a high table which caused difficulties while using it. The closet where the water jet was stored needs to be set up more ergonomically. The parts that were 3D printed were too wide so they did not slide smoothly into the T-slotted framing like it was supposed to. The parts were adjusted accordingly since then and fit correctly.

Following the completion of the frame the extra components needed to be added to complete the entire design. A bracket was placed on either side of the design. The bracket began as inch thick by 1 wide aluminum. The aluminum piece came in a 2-foot length. The piece had to be machined to become two 1 foot lengths. For these pieces to become a bracket two horizontal slots had to be machined into the piece. A slight difficulty occurred while machining these slots, the aluminum began to melt and not cut cleanly. If the machining were to be repeated longer breaks in time would be taken and less material for each swipe for the slot. The brackets were attached on either side of the machine to provide stability. They were attached with screws to the t-slotted framing. Hinges with torsional springs inside were attached to the brackets. First two holes were drilled then the holes were taped to create the ridges to hold in the screws. A L bracket was attached to the spring to make the spring rest state be 90 degrees instead of 180 degrees. The L bracket also acted as the gate to hold up the insert parallel to the conveyor. The L bracket had two holes drilled into it. One hole was for the screw to attach the hinge to the L bracket. The other hole was to allow the screw that stuck out to long to not hit the L bracket allowing it to move freely. The screws that were to long were filled down so there was no sharp point.

The actuator needed an attachment so that it could push the insert down and have an even distribution of force. The attachment was 3D printed using PLA plastic. While the final parts were being assembled to the frame the actuator attachment was being 3D printed. The 3D printer failed while printing one of the attachment components so one of the adjusters that allow the actuator to push down any size box was not able to be attached. Once the entire design was finished being built testing began.

12.3 Pamphlet Dispenser

Like the other prototypes in this project the pamphlet dispenser prototype was mainly constructed from aluminum T slotted framing which needed to be cut to length and assembled into the framework. The 80/20 was ordered in 6ft lengths to reduce cost while keeping the length of material manageable. The horizontal band saw was used to cut the pieces into various lengths from 3 to 18 inches. Once all the pieces had been cut they were arranged along with there fasteners before assembly as seen in fig. 56

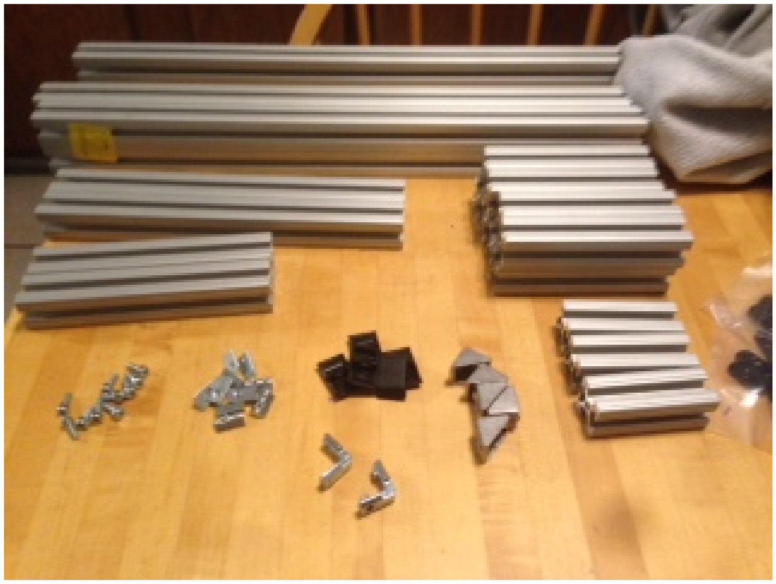


Figure 56: Pamphlet Dispenser Framework before Assembly

While the framework was being constructed the 3D printed parts were simultaneously being printed in order to save building time. After the framework was complete the next task was to machine the Delrin supports in order to attach them to the framework. Machining the Delrin caused some challenges due to the length of the slot it became difficult to clamp the workpiece in the vise without deforming it. In the future if the parts were to be made again the wider part of the counterbored slot should be machined first before cutting all the way through Delrin eliminating its lateral stability. While the finished pieces were not that aesthetically pleasing they were sufficient enough to be used on the dispenser.

After the Delrin supports were added the rest of the 3D printed components could be added to the dispenser. The motor holders required the motors to be attached to them with m3 screws before they were installed. Before the Axle holder parts could be added a quarter inch sleeve bearing needed to be press fit within the axle opening to provide a wear resistant surface for the axle to rotate within. The build up to this point can be seen in fig. 57.

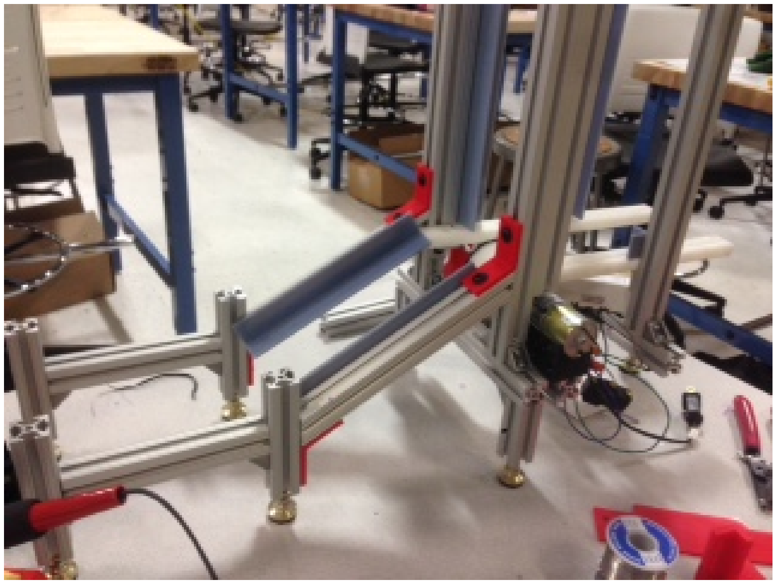


Figure 57: Pamphlet Dispenser Assembly (without front drive wheels)

Initially the design was to only have a single drive motor beneath the dispenser but after much testing and fine tuning it was decided that a second drive motor was going to be needed. The reason for the second motor is described in more detail in the testing section. Having to add the second drive motor and drive wheels at the last minute meant that there holders needed to be fabricated from plywood instead of 3D printed PLA. In order to fabricate the complex holders a scale drawing of the parts was printed and glued onto the plywood which was cut out on the band saw and the hole were drilled using the appropriate sized bits. Unfortunately the rush to fabricate these parts caused a lot of chipping of the plywood on the back sides of the drilled holes. Also going off a paper template can only be so accurate. These in-accuracies in the fabrication of these parts lead to some issues that will be further discussed in the redesign section.

This prototype was also used as part of a mechatronics project to control a real life system. Because of that there was a microcontroller, switches, relays, and a computer program that had be previously designed to control the initial prototype. Once all of the components of the mechanical system were complete work began to integrate the electrical control of this system. Three switches were added, one to monitor if the system was out of pamphlets, one to turn on the motor when a box was ready for pamphlets, and finally one to turn off the motor when a pamphlet had been dispensed. All of these signals were processed using an arduino microcontroller and relayed back to a graphical user interface which would let the operator know if there were any errors that needed attention.

Once all the components were added it took a long time to test and fine tune the assembly to get it to the point where it was functioning at its best. The testing will be described further in the next section.

12.4 Box Lid Loader

The final, adjustable, Box Lid Loader prototype was made out of 80-20 T-slotted Aluminum framing, various connectors that can all be fastened and unfastened using a basic metric set of allen wrenches. All of the parts for the frame were ordered from McMaster-Carr. A 4-foot and 5-foot extrusion were ordered and were cut using a horizontal band saw. The resulting segments were four 1-foot segments, four 10-inch segments, and four 2-inch segments. These segments were used to construct the frame that dictates the shape of the fixture. The four corner inserts and the two bottom inserts were created in SolidWorks then 3D printed with a fine surface finish so that the lids of the boxes would not be damaged in the process of being placed on top of the box with the insert, ornament, and pamphlet in it.

The four 2-inch segments are used for the legs that hold up the fixture. A hole was drilled through each of the 2-inch segments half an inch from the top of the segment. These holes are in place so that the legs can be mounted to the external sides of the bottom rectangle of the frame. The internal hole in the T-slotted framing was threaded using a tap so that the leveling feet could be screwed into the legs and adjusted so that the height of the fixture would be perfect for every type of box. These legs were then mounted on two of the 10-inch segments using drop in fasteners and inch long steel socket head screws. This method for mounting the legs allowed for the legs to be mobile forward and backward along the rail, but also the angle that the legs are at can be changed easily as well.

The bottom rectangle of the frame is constructed out of the four ten inch segments of t-slotted framing. The two bars with the feet mounted to them are on the sides and they are the lower bars in the frame at an angle of ten degrees - the team used a protractor to ensure this measurement was accurate. The 3D printed inserts for the bottom of the frame that hold the lids in place were then inserted into the side bars that have the feet attached to them. The inserts slide into the T-slots on the bars and hold in place. The front and back bar are mounted on top of the bars with the feet mounted to them. This allows for a window in the front of the apparatus for the completed assembly to travel through. The frame is held together using corner braces for 1-inch high single rails - these were chosen because the slots in the framing were perpendicular and these connectors allowed for the bars to be joined with the ability to adjust the position. The corner braces were secured in place using an allen wrench.

The four vertical bars are held in place using L-shaped connectors that fit into the T-slotted framing of the vertical bars and the front and back horizontal bars. These connectors can be adjusted to allow for the frame to expand and contract to fit each type of box that ChemArt uses. The connectors require the use of an allen wrench and hold the vertical bars in place. The corner inserts are then slid into place. These inserts allow for the stack of boxes to stay securely in place and the do not allow for the lids to collapse into each other.

Once all of the components are secured in place the system is tested using a few boxes to make sure that all necessary adjustments are made so that the system can be made before it is exposed to continual use. This step makes sure that the defect rate is as low as possible and allows for the most effective version of the apparatus to be used for each individual type of box.

13 Testing

13.1 Box Bottom Loader

First thing the bottom box dispenser had to accomplish in order to meet the requirements was to be fully adjustable for the desired box sizes (both standard and White House). Several designs were made until the team got to the possible solution of a model with slots and holes that would work simply changing the position of the two matching parts, or/and moving the divider.

After achieving adjustability the team had to make sure that the allowances were still correct, which did not happen for the second 3D printed model and had to be fixed and improved to ensure the process workability.

Once the tolerances were correct the team had to start running tests with different speeds of traction and retraction of the actuator (by regulating the amount of air entering and exiting the valves of the controller) to check that the efficiency, effectiveness, and time cycles were meeting the teams objectives.

At the beginning of the testing, the first time the team built the full model with a wooden piece where the actuator and the 3D printed assembly were fixed, all of the trials with different speeds were successful, which was a really good indicator that the solution chosen was functioning. Bad news, the day after that one when the team tried the model again and the plastic pusher attached to the actuator hit the model instead of the box, obviously it was not correctly aligned anymore, and the team observed that it is something that has to be prevented to avoid a failure in the process.

When the team realized the importance of the actuator being perfectly lined up with the cage and the boxes, the model was put together one more time and built again, taking special care of the position of the mechanism, obtaining really good numbers and satisfactory performances during the next tests ran. It achieved a one hundred percent efficacy and the fantastic cycle time of 1.5 seconds per box (three times better than the desired cycle time of 5 seconds for each step that would improve the current mark). This does not take into account the re-stacking process but it was undoubtedly a great result for the testing of a non-final mechanism that can still be improved.

In the fig. 58 it can be observed the different outcomes for the tests performed in each of the three prototypes the team built during the time of the project with positive results marked in green, and negative in red, choosing yellow when the team was unable to perform any test.

Bottom Box Dispenser Test Matrix

	Efficacy	Adjustability	Tolerance	Time cycle (<6s)	Notes
First model	Y	N	Y	N/A	Solution works. Need to make it adjustable.
Second model	N	Y	N	Y	Achieved adjustability. Boxes can fall onto each other.
Final model	Y	Y	Y	Y	Tolerances and stacking fixed. Satisfactory performance.

Figure 58: Test Matrix for Bottom Box Dispenser (comparison between all of the prototypes)

13.2 Insert Funnel

For the insert funnel the first objective of the testing was the adjustability. If the step failed for adjustability it would not pass any of the other tests that needed to be performed. The adjustability test was to make sure the funnel could be adjusted at least 2 inches in every direction to adhere to the design specifications. For the test performed a larger range was used to ensure the funnel could be used for boxes that ChemArt may use in the future. The funnel was adjustable for a minimum of 4” x 4” to a maximum of 7.5” x 9” in the width and length. The adjustability range exceeded that necessary thus the test for adjustability passed.

The next test was the test for damage. The goal was to have zero damage on the insert, as any damage that occurs is a package that does not pass inspection. Packages that do not meet the high standards cause a loss in revenue. When testing for the damage it was noted that the lip of the insert would get caught slightly on the 3D printed funnel guides. The first prototype had the same issue with getting stuck on the 3D printed PLA plastic. The second prototype used a 3D printed resin which was supposed to give it a higher surface finish but the same problem occurred. This can be fixed easily by machining a metal or using another material. Once the material is changed no damage should occur.

The last thing that was scheduled to be tested was the cycle time and the reliability. The attachment for the actuator did not 3D print correctly; therefore it was not able to be assembled and attached to the actuator. If the attachment is reprinted correctly the cycle time can be tested. The pneumatic cylinder itself was tested and will be able to produce the necessary amount of force in the required time of 5 seconds. Knowing the actuator is reliable, the team is confident the funnel step will meet the required time limit. Reliability was 0% because the insert funnel was not completed to perform the overall desired test. Reliability can be tested for once the actuator attachment is printed.

A large part of the testing was trial and error to figure out the best way to test certain things as well as the placement. Figuring out the right placement for each corner guide as well as the sides of the funnel took a lot of adjusting until everything fell into place. Once the actuator is up and running the step can continued to be tested until it complies with all of the target results.

Insert Funnel Test Matrix				
Condition Being Tested	**Target Result**	**Actual Result**	**Pass/ Fail?**	**Notes**
Adjustability (width):	4" to 6"	4" to 7.5"	Pass	The insert funnel can be adjusted well beyond the target range.
Adjustability (length):	4" to 6"	4" to 9"	Pass	
Damage	No Damage	Lip of insert gets stuck	Fail	Insert gets stuck on the 3D printed guides of the funnel. This can be fixed by machining the funnel guides instead of using the 3D printed material.
Cycle Time	5 Sec	Unable to test for cycle time	TBD	The actuator attachment was not 3D printed correctly thus the cycle time could not be tested. Confident the actuator will meet cycle time once the attachment is correct.
Reliability	100%	0%	Fail	The funnel did not complete a cycle to be able to test for reliability when the action is repeated.

Table 9: Insert Funnel Test Matrix

13.3 Pamphlet Dispenser

The main objective when it came to testing this pamphlet dispenser was to ensure that it was functioning to the best of its ability. At first the design featured a single drive motor located beneath the stack of pamphlets to dispense a single pamphlet. As soon as the building was complete testing of this design began. Since the entire design was made adjustable it took a long time to adjust the prototype. The main challenge was in not knowing what to adjust to improve the performance therefore there was a lot of trial and error to see what combination produced the best results. After finally locking in all of the framework in a way that produced the best dispensing performance a new problem arose. Originally the thought was that an amount of time could be determined that the motor would have to run to dispense one pamphlet. Unfortunately due to the varying amounts of friction on the different pamphlets a set time could not be used. The best results were produced with an motor on time of 110 Milli-seconds which, would work reliably most of the time however would occasionally be not enough or too much time causing the dispenser to get out of its cycle. For example sometimes a pamphlet would come out very quickly causing the drive wheel to engage with the next pamphlet causing that one to be dispensed half way. Now that the dispenser was out of cycle the motor on time of 110 Milli-seconds would cause the dispenser to dispense two pamphlets instead of one. While this result was unfortunate it was something the team was prepared for in that a solution to this problem had been designed in but had not been purchased with hopes that it was not needed.

After the first round of testing revealed that the first solution would not work the necessary parts were ordered for the second solution. The second solution utilized a second motor and pair of drive wheels located outside of the pamphlet holder to pull the pamphlets out of dispenser after the first motor pushed the pamphlet out only a inch or so. In order to know when to turn off the first motor as well as to monitor weather or not a pamphlet was jammed a micro switch was added at the point where the pamphlet comes into contact with the second drive wheel. This switch turns off the first motor once the pamphlet has been pushed into the second wheel. After adding the second motor and drive wheels the system was much more reliable and would dispense a pamphlet almost every time. The issue which caused the pamphlets to sometimes not be dispensed will be discussed in further detail in the redesign section.

Along with testing for the overall functionality of the device tests were also conducted to test for the adjustability of the device, as well as the cycle time, and the damage on the pamphlets. The results of this testing can be seen in table 10. In order to measure for adjustability, the dispenser holder size was measured after the dispenser had been adjusted to its smallest and largest position. The cycle time was evaluated by video tapping the dispenser and timing one cycle while watching it back in slow motion. Finally the damage to the pamphlets was assessed by running the pamphlets through upside down so that the clean side was in contact with the drive wheels.

Pamphlet Dispenser Test Matrix				
Condition Being Tested	**Target Result**	**Actual Result**	**Pass/ Fail?**	**Notes**
Adjustability (width):	3” to 6”	2.5” to 7”	Pass	Pamphlet dispenser is easy to adjust to any given pamphlet size.
Adjustability (length):	3” to 6”	2.5” to 7”	Pass	
Cycle Time	5 Sec	2 Sec	Pass	Pamphlet Dispenser easily meets the 5 second cycle time criteria even if the pamphlet gets jammed for a second or two.
Damage	No marks	Marks if pamphlet gets jammed	Pass	More adjustments could be made to decrease the amount of pressure the rollers are putting on the pamphlets thereby reducing the chance of leaving marks on them.
Reliability	100%	97%	Fail	The dispenser works reliably almost all of the time except for an occasional problem where the pamphlets get jammed in the secondary drive wheels.

Table 10: Pamphlet Dispenser Test Matrix

13.4 Box Lid Loader

When testing the Box Lid Loader the teams primary focus was that the apparatus would function properly using only the conveyor belt and gravity to ensure that the lids would fasten onto the boxes. Most of the teams best and most useful findings were found through the process of designing and redesigning the fixture over the course of the year. The original design incorporated a 20 degree drop angle and a vertical stacking mechanism, which did not succeed. From this first design the team learned that the stacking mechanism needed to be offset from the vertical at the same degree that the bottom face of the fixture was set away from the conveyor belt surface. The resultant best angle, which was found by testing the original designs 3D printed prototype was 10 degrees.

Once the stacking mechanism and angle were set the team started to design a fully adjustable prototype. The goal in creating this prototype would be that the apparatus would conform to the shape of any one of ChemArts many ornament box sizes. The original prototypes were all configured around the White House ornament boxes, meanwhile those only make up 40% of the ornaments that ChemArt manufactures and packages each year. The other 60% are packaged in different size boxes that have different sized lids. The adjustable prototype allowed for a real example for the team to run tests that were more in depth than checking to see if a concept in SolidWorks worked in a real scenario.

The first test that the team performed on the prototype was for adjustability. The fixture was designed to meet these criteria and it met the requirements for length and width and even exceeded the requirements. The length and width that the box lids can be was set to range between 4 inches and 6 inches. This fixture can adjust from 4 inches to 8 inches.

After testing for adjustability, the team tested for damage. In the tests that the team was able to run without the use of a conveyor belt, the apparatus did not damage the lids or the boxes below. This is only partially accurate because the added element of a conveyor belt may change these results. The team thinks that padding could be added to the front face of the lid loader so as the box lid seals it does not make repeated contact with a hard metal surface.

The tests that the team was able to perform for Cycle Time and Reliability were limited due to the absence of a conveyor belt to truly test the system. Since the Lid Loader requires a conveyor belt to function the tests that the team performed in this area were incomplete. From what the team could observe by simply pushing boxes underneath the fixture the Cycle Time should be 5 seconds if the conveyor belt is properly timed. The team could also tell that they system was reliable, but the speeds at which the boxes were run under the fixture were inconsistent due to human hands pushing the box under the Lid Loader.

Lid Loader Test Matrix				
Condition Being Tested	**Target Result**	**Actual Result**	**Pass/ Fail?**	**Notes**
Adjustability (width):	4” to 6”	4” to 8”	Pass	The box lid loader has a greater range of adjustability than required.
Adjustability (length):	4” to 6”	4” to 8”	Pass	
Damage	No Damage	No damage, padding could be added	Pass	The fixture did not damage the lids or the box when tested, but padding could be added to the front face to ensure no future damage would occur.
Cycle Time	5 Sec	Unable to test for cycle time	TBD	The cycle time with this fixture is based on the timing of the conveyor belt. Without a functioning conveyor this test cannot be performed.
Reliability	100%	50%	Fail	The tests that could be performed without the conveyor were positive, but without a conveyor belt the results are only partially accurate.

Table 11: Lid Loader Test Matrix

14 Redesign

14.1 Box Bottom Loader

The design built by the team at the end of the second semester worked correctly and it fulfills the expectations and objectives set. Even so, certain changes would improve the final design. First of all, after running several tests with the same bottom boxes, using them, putting weight on them, transporting them all together with other models and metal pieces ended up damaging the boxes so the dimensions varied. But, having brand new boxes at the packaging chain system, would allow the team to use even tighter allowances to make sure none of the boxes would fall onto each other even with a much higher pile.

Besides the tolerances there are a couple of changes that could improve the workability of the model. First of all, adding a salience at one side of the 3D printed pieces as shown in fig. 59 so the pusher attached to the actuator can lie onto it, letting more space to the box that is falling after the actuator finishes its retraction movement, and making sure that the height of the actuator is always the correct one.

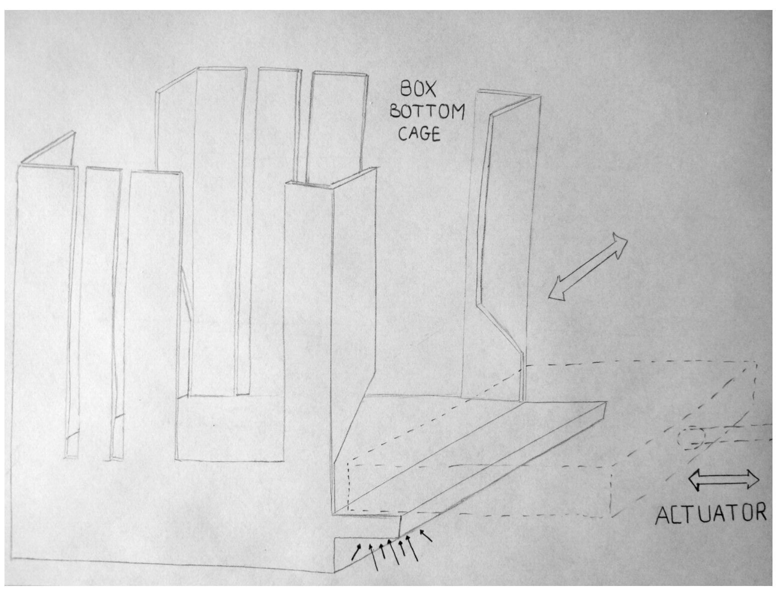


Figure 59: Redesign for Bottom Box Dispenser

The next improvement does not have to do with the model itself but with the process of re-stacking, and how to improve the continuous process of the mechanism, allowing it to run non-stop even when it dispenses the last bottom box hold in the "cage". As it has been shown before, producing one of this 3D printed cages is both easy and inexpensive, so it would be a good idea to have two or three of them in parallel in a moving platform so when one of them runs out of boxes, the one besides it (that is already loaded) can be placed in front of the actuator automatically and keep on feeding the system.

14.2 Insert Funnel

The final design created at the end of the semester has several changes and additions that would make the machine run smoother. The frame was too wobbly. This can be easily fixed by adding 80/20 low on the vertical rails so the rails are fixed in place from the top and also from the bottom. Increasing the stability of the frame will also increase the accuracy of the placement of the insert. The two rails that provide the slide into the center of the funnel also need to increase stability. 80/20 rails can also be placed on the side of the slide so the angle wont change once in place. The issue that came about with the locking pivot was that due to the weight of the slide and rails the pivot didnt hold the correct angle. The pivot would give a little; with added support the pivot will hold the angle.

The funnel corners and the slide were 3D printed using a resin. The surface finish was not great enough for the lip of the insert to not get caught. In the future the funnel corners should be fabricated using a surface material with a high surface finish. The dimensions of the funnel corners should be kept the same, the angle works well. The actuator attachment was created using 3D printed PLA plastic. The attachment printed was not wide enough; the design has since been altered. The attachment may work better with a stronger material. The force the spring exerts on the attachment puts a large amount of strain on the 3D printed material. The actuator needs to be fastened to the frame of the design.

The gate for insert to stay parallel with the conveyor belt where the bottom of the box waits needs to be altered. The gate works so the insert levels out but the L brackets used on either side were too short. The insert slid into place correctly but instead of resting on both gates it fell through the center instead of reaching the other gate. The gates need to be longer so that they touch; they also need to be wider so the insert cannot fall to one side or the other. A possible solution is to have gates that instead of being spring loaded are two horizontal plates that slide to the opposite sides. Then at a certain point when the plates are wide enough that the insert is only being held up by an inch on either side the plates will pivot and the pneumatic cylinder will push the insert through the funnel into the box bottom. The plates will use a motor. The largest struggle this past semester was with time. If there was more time in the semester the insert funnel could have been tweaked more to get it working better and more specific recommendations for further adjustments could be made.

14.3 Pamphlet Dispenser

The pamphlet dispenser prototype does not require a lot of additional redesign as it is functioning almost perfectly. The main issue that the dispenser currently has is that the mounting brackets for the second motor and axle had to be fabricated last minute out of quarter inch plywood. These parts were designed to be precision machined out of metal that would provide a strong precise mounting location to keep the shaft in alignment. For this prototype the parts were going to be 3D printed which would have provided the precision required and had enough strength for the testing required. The lack of time at the end of the semester and limited availability of the 3D printers forced the team to have to fabricate the parts out of plywood. This plywood had a slight curve in it which prevented the motor from being attached perpendicular to the framework. The axle holder on the other side was used to pull the shaft back in alignment with the framework. The result of this is that a lot of strain was placed on the motor severely reducing its speed and torque which it could apply before it bound up. This problem resulted in some pamphlets getting stuck beneath the drive wheels because the motor did not have enough torque to pull the pamphlets from the stack. The team feels that if these parts were fabricated more precisely using stronger materials that the pamphlet dispenser would be able to more reliably dispense pamphlets. There are a few other items that need to be thought about that have to do with how the pamphlet dispenser will work with the rest of the steps. However, since these items are similar across all of the steps they will be talked about in detail in the further work section.

14.4 Box Lid Loader

The Box Lid Loader has been redesigned several times over the course of the past two semesters. Through the process of redesigning this step, many of the issues and kinks in the system have been resolved during the process of creating the several prototypes. Ultimately the team is happy with the final design and believes that this is the most adjustable and most precise version of the Box Lid Drop that the team created. The T-slotted framing allows for the system to be adjusted to make sure that it is the tightest and best fit to the box lids and the lids can drop at the most precise angle onto the box as it passes beneath the fixture.

After the Design Showcase the team has been considering all of the feedback that they received from various visitors from the University of Rhode Island and industry. One of the comments that the team received was that the Lid Drop apparatus was simple enough to make several copies of so each copy would be fine tuned and adjusted to fit each type of box. This would allow for the fixtures to be adjusted once and then fastened into place so that the lids would fit perfectly into each individual fixture. These fixtures could be interchanged in the system - still fulfilling the requirement of adjustability - while ultimately maintaining the structural integrity of each fixture.

If this part were to be considered for redesign, the frame should have markings made so that each adjustment is perfect and it takes away the need for rulers, levels, and protractors when assembling the apparatus. The team thinks that although the cost would be greater to have several Box Lid Drops assembled, that this cost is offset by the time saved in readjusting and the quality of the adjustments since they will be done once precisely then fine tuned infrequently to ensure that the quality of the adjustments and the frame structure is still in tact.

15 Operation

Unfortunately due to time constraints and issues that arose during the building process not all of the steps were able to make it to the operational stage. The box bottom loader and the pamphlet dispenser were able to operate with limited reliability while the insert funnel and lid loader still need some work done before they can reach an operational state. It is for these reasons that the team felt that creating an operation manual would not be beneficial because so many things could still change before the final machine is developed. Once the final machine has been developed an operators manual could be created that would instruct workers how to properly interact with the machine. For example, instructions for how to start up, shut down, and diagnose common issues could be put together into a operators manual.

Similar to the operators manual another set of instructions could be created to guide workers through the process of adjusting the machine for a different sized boxes/pamphlets. Unfortunately like the operators manual these adjustment guidelines could not be defined since so many items could still change before the final machine is designed. The team however did take into consideration a method to make it easier to instruct workers to adjust the complex designs. The main component of this method would rely on incremented markings or measuring tapes to be applied to the 80/20 extrusion. Along with these markings each frame member and screw could be labeled/colored in a way that makes it easy for workers to identify each piece. Once the final design has been completed an adjustment guideline could be created for each step in the automated machine. The adjustment guidelines would be comprised of a table that would list all of the measurements for the different sized packages as well as a set of steps describing how to adjust each measurement. The measurement table for the pamphlet dispenser as well as example of the adjustment steps can be seen in tables 12 and 13.

Pamphlet Dispenser Adjustment Matrix				
Ornament	Holder Width	Holder Length	Holder Height	Motor Position
White House Ornament	4.75 in	5.375 in	2.875 in	1.25 in
Standard Tall	4.125 in	4.125 in	2.875 in	1.25 in
Standard Short	4.125 in	4.125 in	2.875 in	1.25 in

Table 12: Example Pamphlet Dispenser Adjustment Matrix

Adjust Pamphlet Dispenser Length		
Step:	Instruction:	Checklist:
1.	Loosen Screws A and B with a 3 mm allen wrench	
2.	Slide the red frame members along the length of the blue frame member until the edge of the red frame member is aligned with the desired holder length measurement.	
3.	Tighten Screws A and B with a 3 mm allen wrench	

Table 13: Example Instructions for Adjusting Pamphlet Dispenser Length

An adjustment table could be provided for each step in the system and a set of instructions could be provided for each adjustment on the device. Along with these two things detailed drawings could be created from the 3D models of each step that depict how to adjust the devices. For instance the screws that need to be loosened can be called out using bubbles and arrows can be placed into the drawing to show which way components should move. Once again the team has considered all of these possibilities however since none of the designs were finalized we felt it was better to not focus heavily on this aspect of the project this semester.

16 Maintenance

Similar to the operation section since most of the designs have not been finalized the team did not focus on the maintenance aspect of the machine at this stage in development. Even thought the specifics of maintenance were not described for this machine basic maintenance practices could be followed. For instance maintenance shutdowns could be scheduled on weekly, monthly, and yearly basis. During the weekly maintenance shutdowns inspections would take place to ensure that everything is working as it should. At the monthly maintenance shutdown all sliding/rotating components would be lubricated to ensure they are moving with limited friction thereby reducing wear on surfaces and motors. This shutdown also gives an opportunity for improvements to be made to the productivity of the machine. Finally at the yearly shutdown major components like motors, gearboxes, and actuators could be replaced to ensure that there would not be a component failure in the middle of production. All of these are examples of preventative maintenance that help to prolong the life of the machine.

Another important aspect to reduce potential downtime is an inventory of spare parts for all critical components of the machine. For example critical parts like the electric motors and actuators should be kept on hands at all times, also less critical but high wear items like the rubber drive wheels should be kept on hand. Having a large inventory of all critical spare parts will help to reduce any downtime that could arise if a problem was to occur during scheduled operation. A comprehensive list of all spare parts and a detailed maintenance schedule could be provided however the team chose not to focus on them at this time since the design had not been finalized.

17 Additional Considerations

17.1 Economic Impact

The economic impact for the company ChemArt after the possible implementation of this automated packaging system could be substantial. Just by incorporating some of the ideas developed by the team would be a great saving for the company.

For example, speeding up the process skipping a step in the production chain, making the person in the last workstation directly place the ornaments in the insert and the insert onto the conveyor, it is a simple change that completely improves the overall time cycle. As it can be observed, the intelligent organization of space is vital, and it is something that the team has taken into account from the beginning of the project when choosing a linear process.

Another important impact from the economic point of view, which will generate long-term benefits, consists in eliminating the need to hire temporary workers for peak production seasons. It is true that the process developed is cobotic and that still needs workers to operate the machines and feed them with material, and that the maintenance of the equipment will suppose a cost for ChemArt, but much lower than the one they have now.

Another fact to consider is that the team has been able to develop models that work for each step of the process, and in an adjustable way, below the initial budget and with materials of very low cost that hardly need revision or maintenance, since the parts of plastic or metal will not suffer any wear when working with the boxes.

It can be observed that the current ChemArt packaging model has great potential for improvement, and that some of these ideas would be economically feasible if finally used.

17.2 Environmental Impact

This automated packaging system that the team designed a small, but negative, impact on the environment. When discussing the environmental impact of any product or system in society today it is nearly impossible to have a system that has little to no negative impact on the environment unless it is run solely on renewable energy and produces no waste. The system that the team designed runs on electricity, which is created using mainly fossil fuels in Rhode Island [11], therefore the system does contribute to energy emissions.

The system is powered by electricity - which in the state of Rhode Island is made up of only 4% renewable energy [12], therefore the system does produce waste which impacts the environment as a whole. This negative impact needs to be looked into further. Without having a conveyor belt and knowing the energy that it takes on average to run it the systems energy use is unknown. The impact of using electricity on this system could be the same as the impact of running fluorescent lights instead of energy efficient LED lighting fixtures or it could be a larger impact. The electricity use is an important factor that needs to be explored further in the future.

The system itself does not produce a physical byproduct that needs to be disposed of, as a whole ChemArt runs a relatively green facility and they make good use of packaging materials and recycle the waste created in the process of creating the Christmas Ornaments. The system takes the lids, inserts, ornaments, pamphlets, and box bottoms and combines them to create a fully packaged ornament. The boxes that the empty boxes arrive in are then used to ship the ornaments to the customers. The inserts and boxes are packaged with little waste, so there are no wrappers or extraneous parts to dispose of.

Ultimately the system does have an environmental impact. The energy used by the system in compared to the current system in place needs to be calculated at a later date to understand the environmental impact to the fullest extent.

17.3 Societal Impact

ChemArt is a local Rhode Island company, therefore ChemArt has a direct societal impact. ChemArt provides the local people with temporary jobs to package the ornaments created in the ChemArt facility. Currently, ChemArt's entire ornament assembly line and their packaging is done by hand. The workers hired are considered nonskilled workers. The team's project will replace 4 temporary non-skilled workers. The automated packaging machine replacing jobs will have an impact on the local Rhode Island community. These non-skilled workers are temporary thus they do not receive benefits from ChemArt.

The benefit of the automated packaging system is that workers will have to be hired to work the machine. The ability to operate the machine will require knowledge of how to turn on the machine, reload and adjust the machine. The employees that will be hired by ChemArt to operate the packaging system will be skilled workers. The packaging machine will be operating all year long, thus providing a full time job opportunity to the skilled worker. Full time jobs come with benefits. ChemArt will be creating more skilled workers. Society will have an increase in the number of skilled workers. Overall this packaging system will have a small impact on society but there will still be a small positive impact.

17.4 Political Impact

The political impact of this system is strongly tied to the fact that ChemArt provides Rhode Island with jobs. The creation and retention of manufacturing jobs in America was one of the most prominent political issues of the 2016 campaign season. ChemArt is an American manufacturing company and they are proud to produce quality products made in America. ChemArt proudly employs hundreds of hard working Americans in their Lincoln, Rhode Island facility, which is great for the economy. Currently the packaging process is done completely by hand by mostly temporary employees. By implementing this system ChemArt will require less people to package ornaments, therefore there will be less of a need to hire temporary employees.

Although the system is taking away the unskilled labor jobs that are now in place, this system will also create jobs for people who have to oversee that the machine is calibrated, stocked, and running properly. These jobs require training and skill, and they will create full-time skilled labor positions at ChemArt. There is obviously room for debate as to whether four unskilled part time labor positions are better than one full time skilled labor position is better for the economy. One of the main political issues of today is the creation and retention of American manufacturing jobs and this system helps to make ChemArt more efficient and promotes ChemArts growth in Rhode Island.

17.5 Ethical Considerations

The packaging system does have ethical considerations. The current packaging process is 10 temporary workers hired to hand package the ornments. The proposed packaging system will replace 4 of those temporary workers. The ethical dilemma for this project is that the system is taking local peoples jobs in Rhode Island. The employees losing their jobs are not skilled workers nor do they receive benefits due to being part time. These employees can have the opportunity to become skilled workers. New employees will need to be hired to operate the machine which is considered a skilled job. Skilled jobs increase an individuals value for possible jobs in the future. Overall the ethical decision will be made by ChemArt, but firing temporary employees to hire skilled workers happens everyday in industry.

The machine itself will not have any technology that would cause an ethical dilemma. The machine will be programmed to be operated as desired and will not be able to alter the program itself. Such machines that have large ethical considerations are robots that use artificial intelligence. The packaging machine is only for ChemArt not for any other company. If the machine were for multiple companies the ethics of several different companies would have to be considered. The packaging system only needs to comply within ChemArt's ethics.

Part of the ethical considerations is the product being produced by the packaging system. ChemArt advertises that their products will be of high quality, this includes the packaging. If the packaging is damaged due to the packaging system then ChemArt would be falsely advertising. False advertising is an ethical dilemma that could cause issues for ChemArt. Creating a high precision machine is important in preventing ethical issues. Although, the packaging system does not have any major ethical considerations there are still ethics involved in creating the packaging system.

17.6 Health, Ergonomics, Safety Considerations

The health of workers has been taken into account when developing all models, two of them use air compressors and can be noisy. They should be isolated or, if there is no better solution, offer protection to the workers.

Regarding the safety of the process, the mechanisms will have protections and barriers in the areas where the fingers or pieces of clothing can be trapped, but there are no hazardous or dangerous elements in the team's designs.

Has also been taken into account the ergonomics of the process, since workers still have to take care of feeding the machines it has been calculated the average height of a person to know where to place the equipment and machinery and the amount of bottom boxes, pamphlets, inserts and lids that could be used in each process to make the movements comfortable so the worker does not have to do a big effort. The height at which the machines are placed will also be beneficial for the employees in charge of inspections and maintenance.

The conditions of the new jobs will be much less harsh and demanding than those of the current temporary workers, since now they need to perform their work as quickly as possible and without being able to stop, and in the new positions that are created with the teams system it will be more important to evaluate the correct behaviour of the process to be able to stop the system in case of a failure, since re-stacking the machines will be much simpler than performing the whole process by hand.

17.7 Sustainability Considerations

The sustainability considerations for the automated packaging system are multifaceted. The sustainability of the system is consistent of two main parts, one of which was discussed in the Environmental Impact consideration section. The second part is the sustainability of the components that the system consists of because the system will eventually have parts that fail and parts that need replacing and what ChemArt does with the broken old parts affects the sustainability of the system. The system is designed to last, but eventually parts will fail and components will need replacing.

All of the parts in the system will be primarily made of metal, specifically T-slotted aluminum extrusions, which can be easily recycled. ChemArt already has systems in place to recycle the scrap metal from the ornament manufacturing processes that are currently in place in their Lincoln, RI facility. The fasteners in the system are mostly made of steel which can also be recycled through the same process. The metal components in the system are easily sourced and recycled which makes them sustainable.

The plastic components within the assembly are difficult to categorize seeing as many of the plastics have not been finalized. The plastics will be chosen based on surface finish, compatibility with the system, and also the ease of recycling at the end of the parts life cycles. Plastics are very commonly recycled and finding plastics that can be easily recycled should not be a difficult task to be implemented in the final design.

The actuators, motors, and electronic components in the system, if they are to eventually fail, can be recycled through the services of an electronic waste (or E-Waste) recycling service which will responsibly discard of and recycle the electronic components to limit the negative environmental impact that the components of this system have. Recycling electronic components is a very common practice in industry and individuals can even recycle their E-Waste with relative ease.

18 Further Work

After all the designs of the individual steps have been finalized some work still needs to be done to integrate all of the steps together. First of all a conveyor would need to be purchased to move the packages from one step to another. Along with this conveyor, a system would also need to be designed to stop the package at each station. This task could be accomplished using either electric or pneumatic actuators with a stopper attached.

By far the biggest task that would need to be worked out by an electrical engineer is the design of an electrical system to take all of the signals coming from the various sensors input them into a Programmable Logic Computer which would have the code to control the various mechanism in the machine. This electrical system would provide a means to control and also monitor the output of this fairly complicated machine. As well as controlling the machine the PLC would also act as a vital safety mechanism that would take in signals from the safety sensors located around the machine. These sensors would ensure that if someone gets too close to the machine in operation all moving components would be disengaged to ensure that no one gets hurt.

Along with they electrical safety measures physical measures such as machine guards and fencing would need to be designed to protect the workers around the machine. All of this further work would best be carried out by an outside automation company that has the knowhow and resources to get the job done efficiently and in a cost effective manner in accordance with common industry standards.

19 Conclusions

Team Pack-in-the-Box was tasked with the challenge of designing, creating, and testing an automatic packaging process, or a cobotic process, for Christmas ornaments that would replace the current model used by ChemArt. The current process at ChemArt is having temporary employees box each individual ornament by hand which is not the most efficient use of the companys time and resources.

During the first semester the team focused on trying to create an entirely automated system that would do every step in the packaging process. First a mechanism would separate the tightly packed, fragile inserts that the ornaments are later placed in. Then, a robotic arm would place the ornament into an insert using vacuum technology, as to not harm the surface finish on the ornament. The next step would be to have a mechanism would introduce a box bottom onto one conveyor belt and the insert onto another, set at a height above the conveyor with the box bottom on it. Once these two parts are on conveyors another instrument would place the insert into the box. Then the pamphlet would be inserted and the lid would seal the box shut. The team brainstormed ideas and chose the best to use in the Proof of Concept presentation at the end of first semester. The team built a functioning set of prototypes during the first semester using the 3D printer and various other components - these were all designed to fit the White House Ornament box which is the same dimensions each year and makes up about 40% of the total ornaments that ChemArt produces every year.

At the beginning of the second semester the team met with ChemArt and Professor Nassersharif and decided to focus mainly on four steps: introducing the bottom of the box to the conveyor, placing the insert into the box, inserting a pamphlet, then finally placing the lid on top of the box. The goal of doing this was to fine tune and perfect each of these steps and to create prototypes that fit all of the box sizes. The team then chose to have each team member focus on an individual component, while still using the other team members as resources.

The primary focus for the second semester was rebuilding the initial prototypes using more robust materials while also creating fixtures that could be easily adjusted to fit any of the boxes that ChemArt uses for their Christmas ornaments. Achieving the goal of adjustability looks different for each step. For the box bottom loader the sizes of the box bottoms change and the weights change so the pneumatic cylinder needs to be adjusted to apply the correct force for each type of box. The insert funnel had to take into account the various shapes and sizes of the many different types of ornaments that ChemArt produces and had to adjust the actuator probe to adjust to fit the different configurations. The pamphlet dispenser had to take into account the various sizes, page numbers, and surface finishes of the wide variety of pamphlets that are inserted into the boxes. For the lid loader, the fixture had to be adjustable in all directions to account for the required drop angle and the different heights of the boxes and the lids that ChemArt uses to package the ornaments.

Once all of the adjustable prototypes were designed and created the team ran a battery of tests on them to make sure that the parts would work and could be easily adjusted to fit the different sized boxes and ornaments. The four steps, by the end of second semester, were well tested and constructed and the team feels confident in the steps and the functionality of each module within the system.

The team focused on creating machines that are user friendly, easy to service and maintain, and most importantly complete each step successfully. Moving forward with this design will require work with joining the steps together cohesively. The modular designs function well on their own, but timing a conveyor belt and making sure each step is synchronized in perfect harmony will take time. The operation and maintenance of the system as a whole is still to be determined. Although the team worked out the specifics for the modular designs, once the system is on a conveyor the operation and maintenance of the system will change.

Ultimately Team Pack-in-the-Boxs Capstone Design project was a success. The team solved the problem set forth by the sponsor to the best of the teams ability given the time and resources available to them. The team used engineering skills learned at the University of Rhode Island to design, build, test, and modify machines that successfully package the

Christmas ornaments that ChemArt produces. Functioning prototypes were created and with modifications the prototypes could be used in ChemArts Lincoln, Rhode Island facilities with a conveyor system to package Christmas ornaments.

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Acknowledgements

The Pack-in-the-Box team would like to thank The University of Rhode Island's department of Mechanical, Industrial and Systems Engineering for allowing the team to use it's resources and facilities. The team would also like to thank Dr. Nassersharif and ChemArt for their time and support in assisting this team to create the Automated Packaging System.

20 Appendix

20.1 QFD

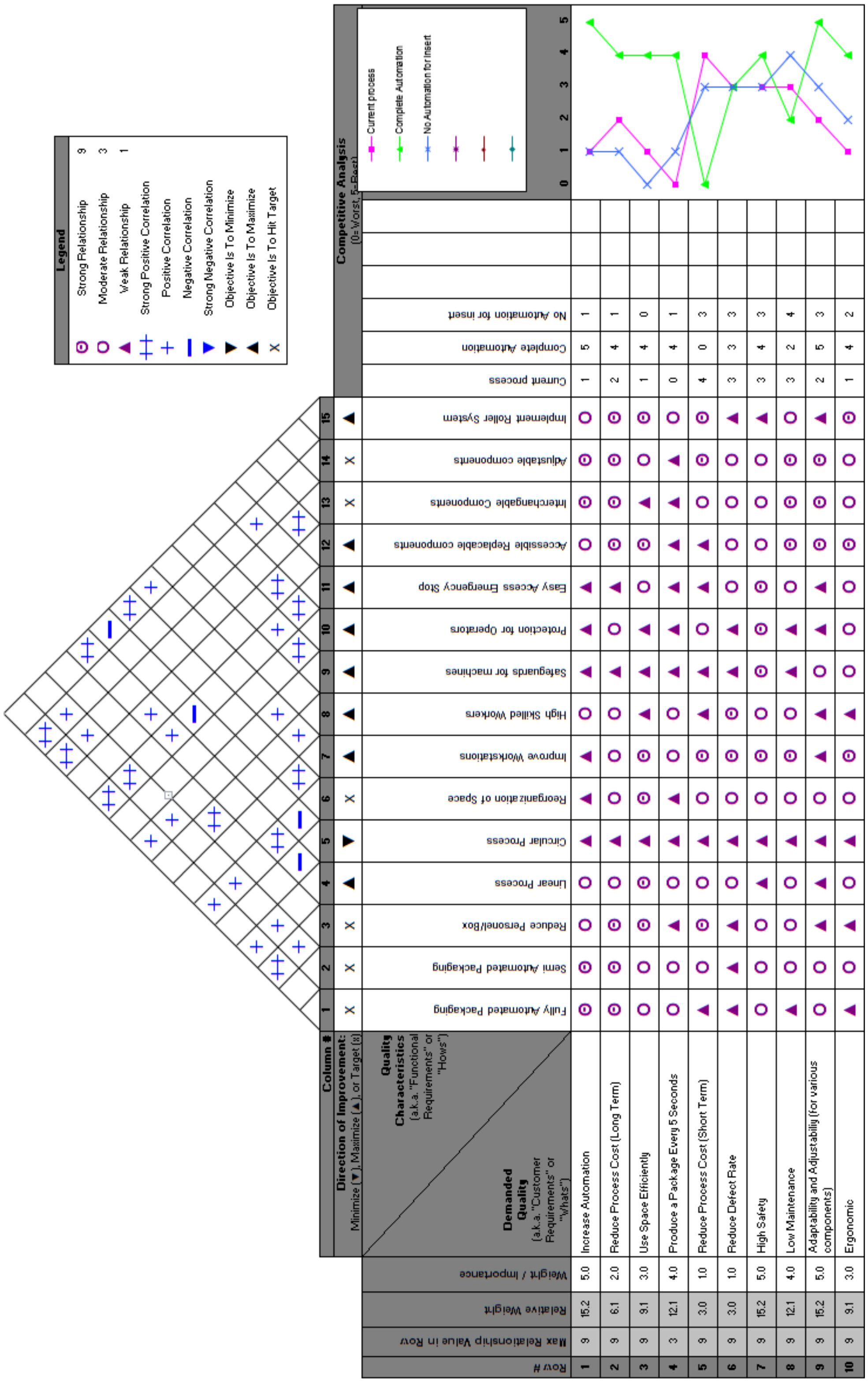


Figure 60: QFD Analysis for Design Concepts

20.2 Box Bottom Dispenser Drawings

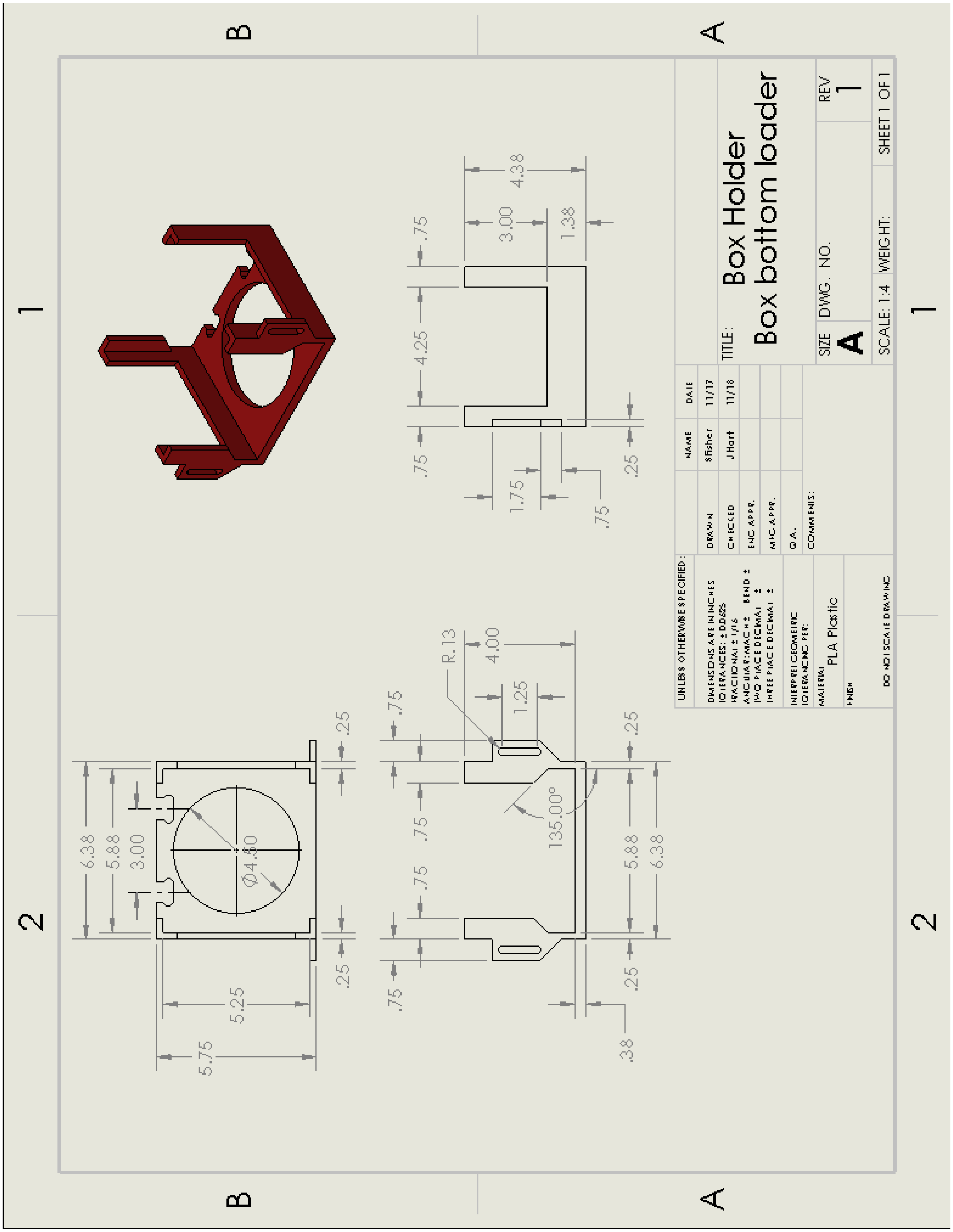


Figure 61: Box Bottom Dispenser Box Holder Drawing (not to scale)

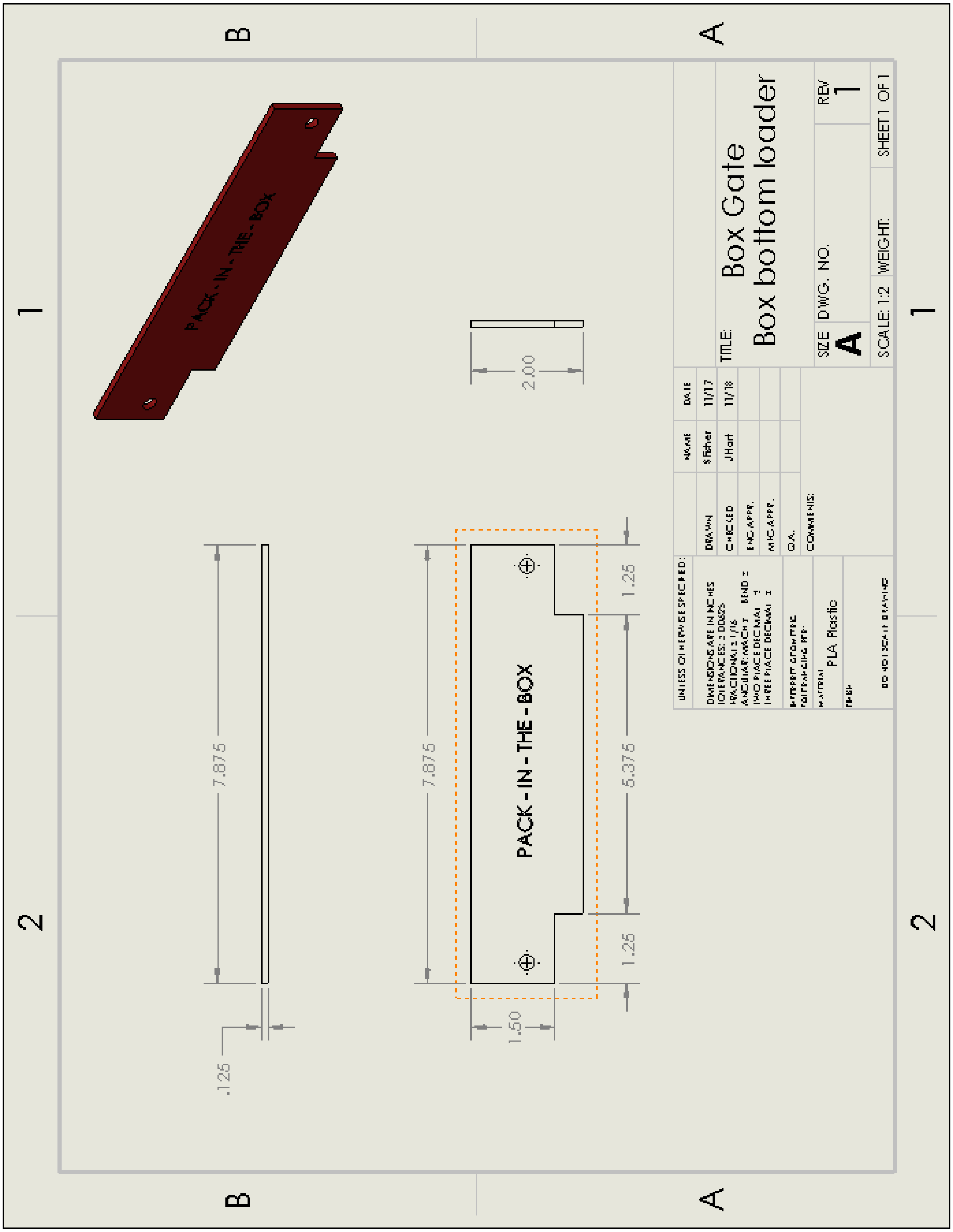


Figure 62: Box Bottom Dispenser Adjustable Gate Drawing (not to scale)

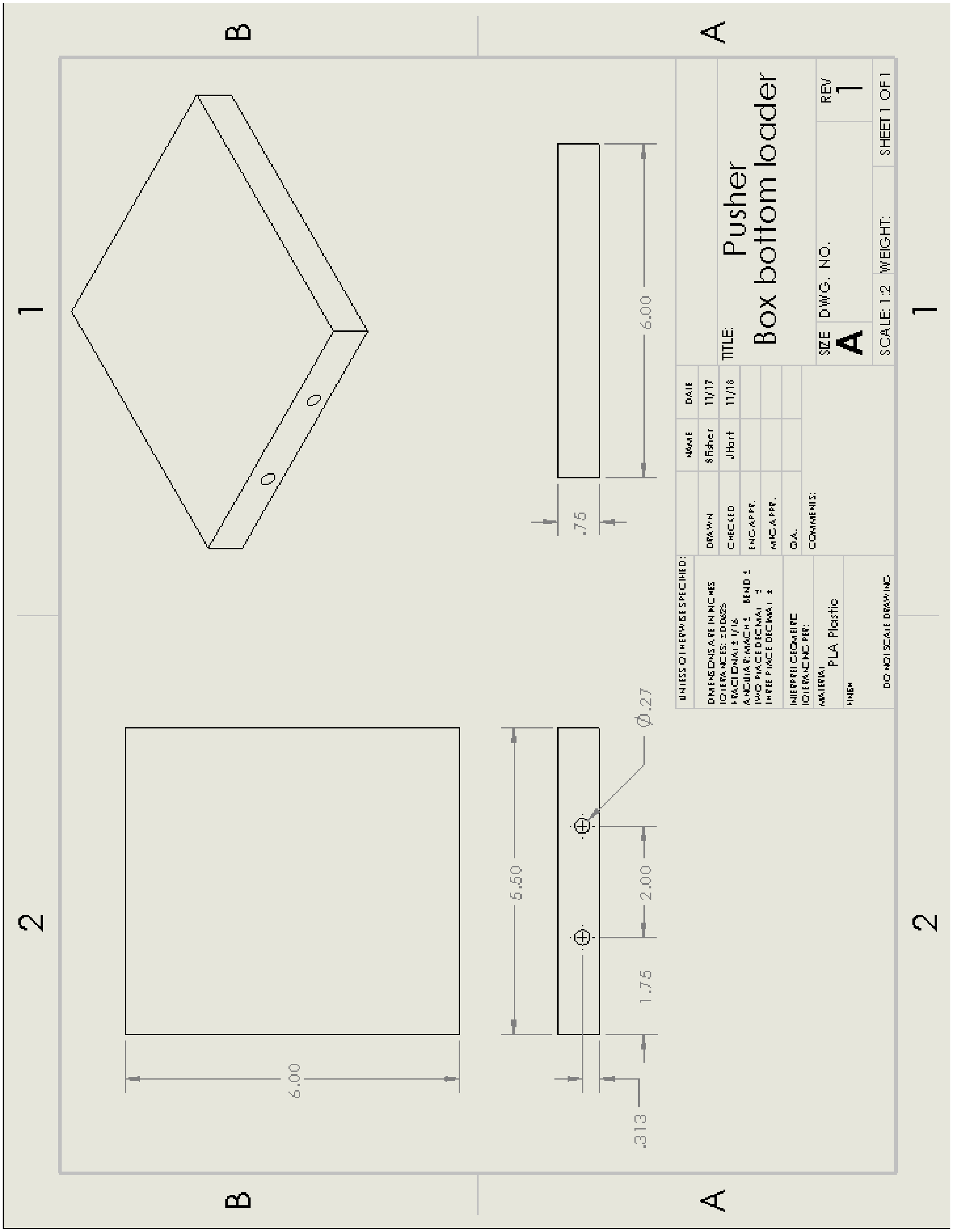


Figure 63: Box Bottom Dispenser Pusher Drawing (not to scale)

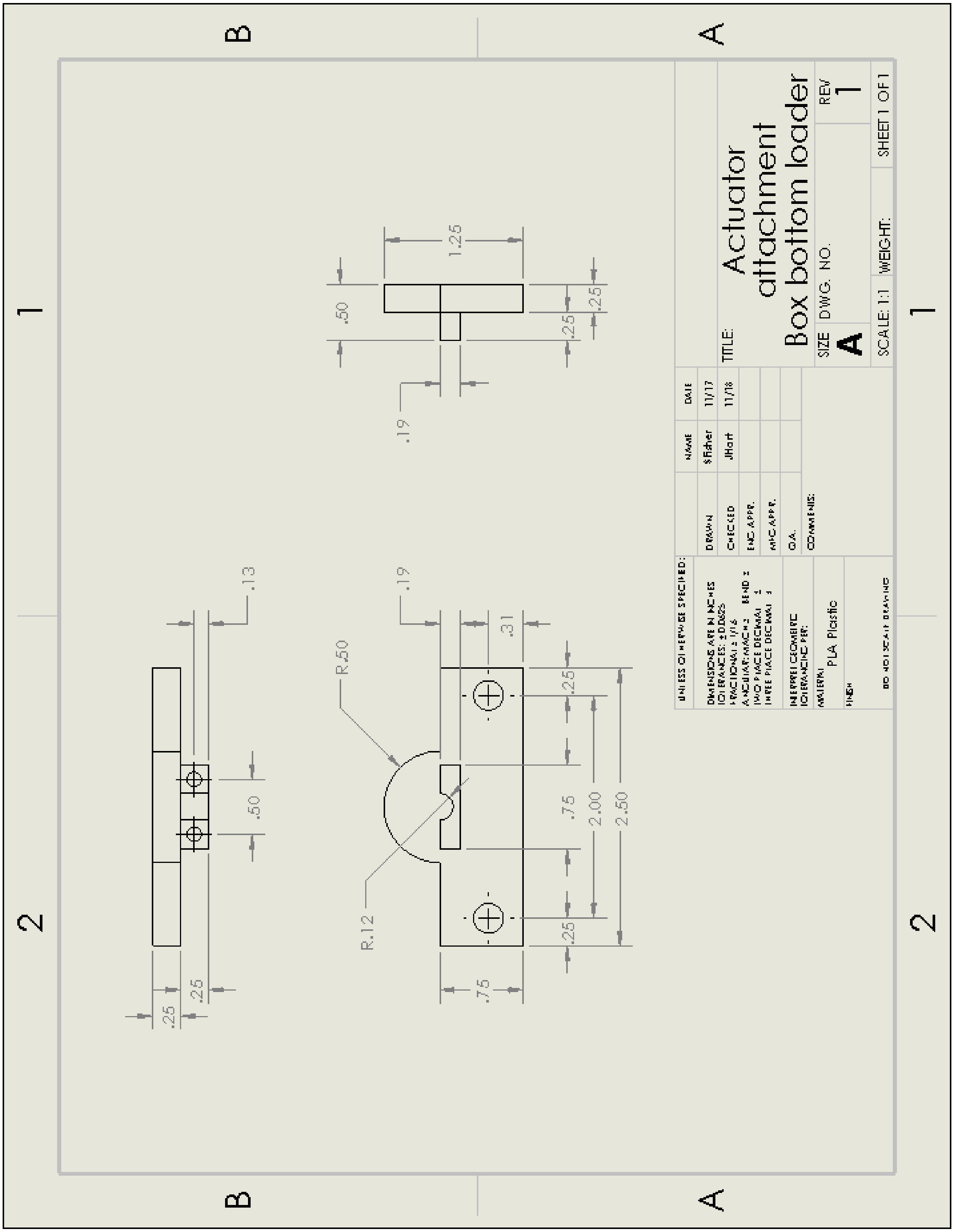


Figure 64: Box Bottom Dispenser Actuator Attachment Drawing (not to scale)

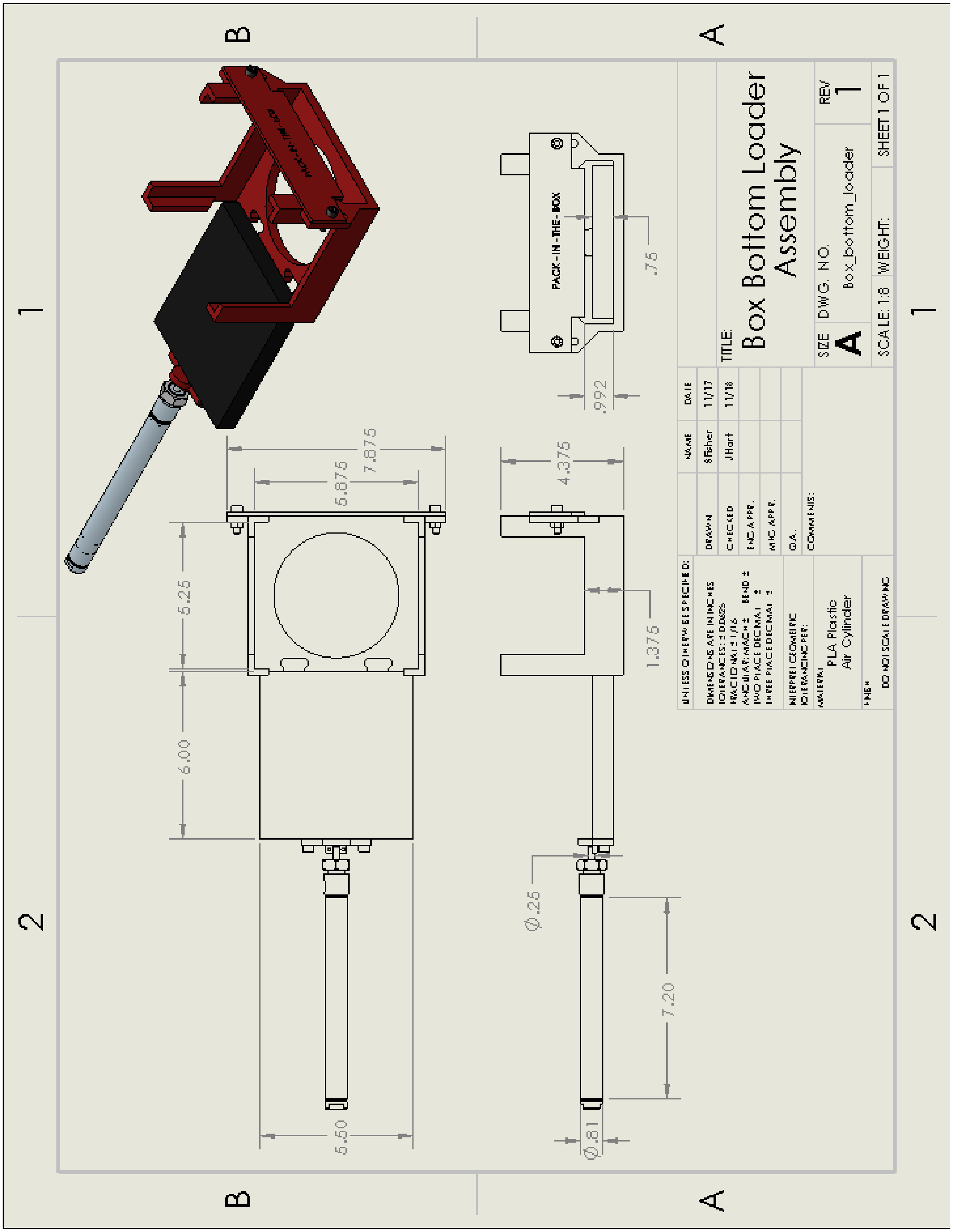
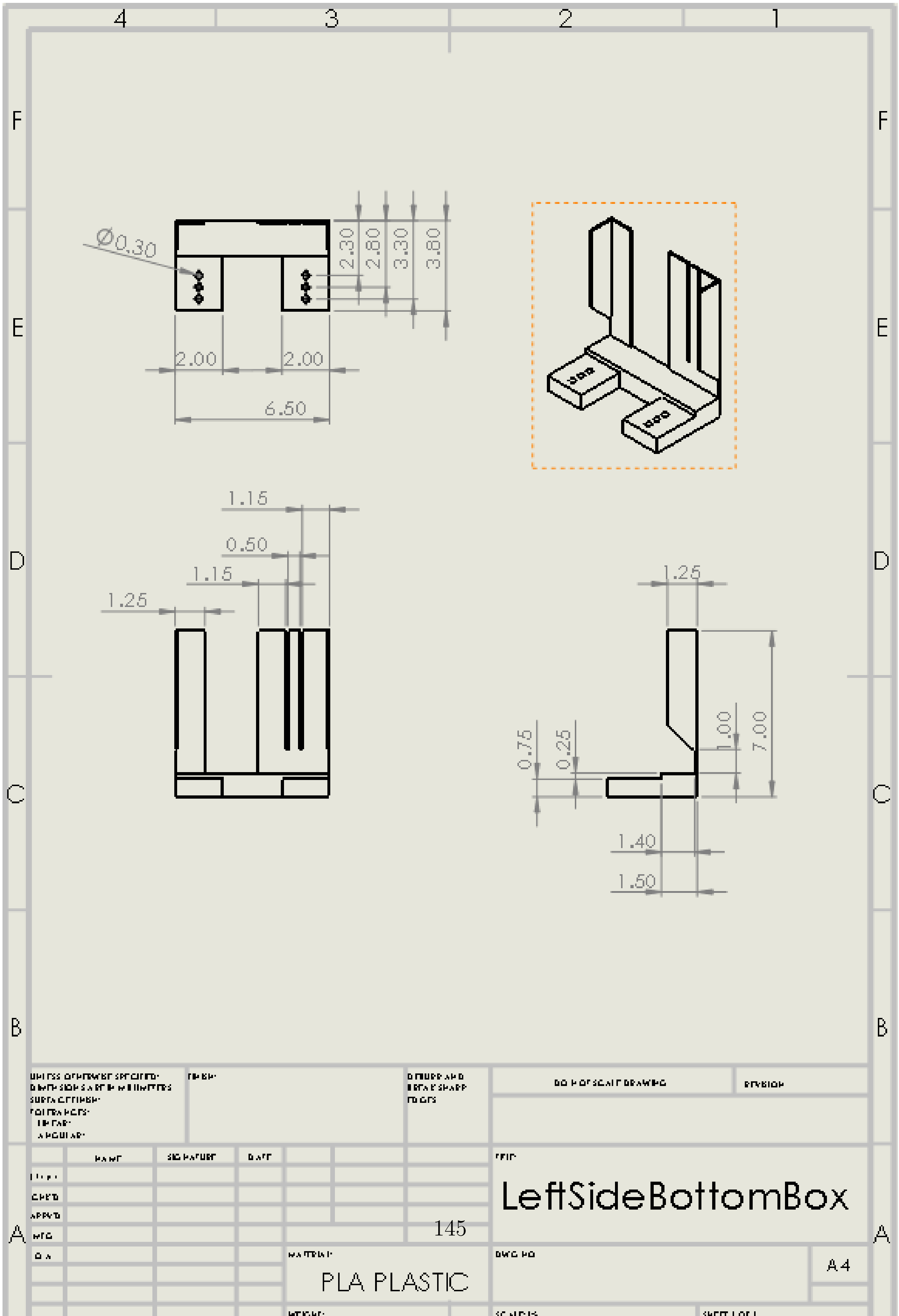
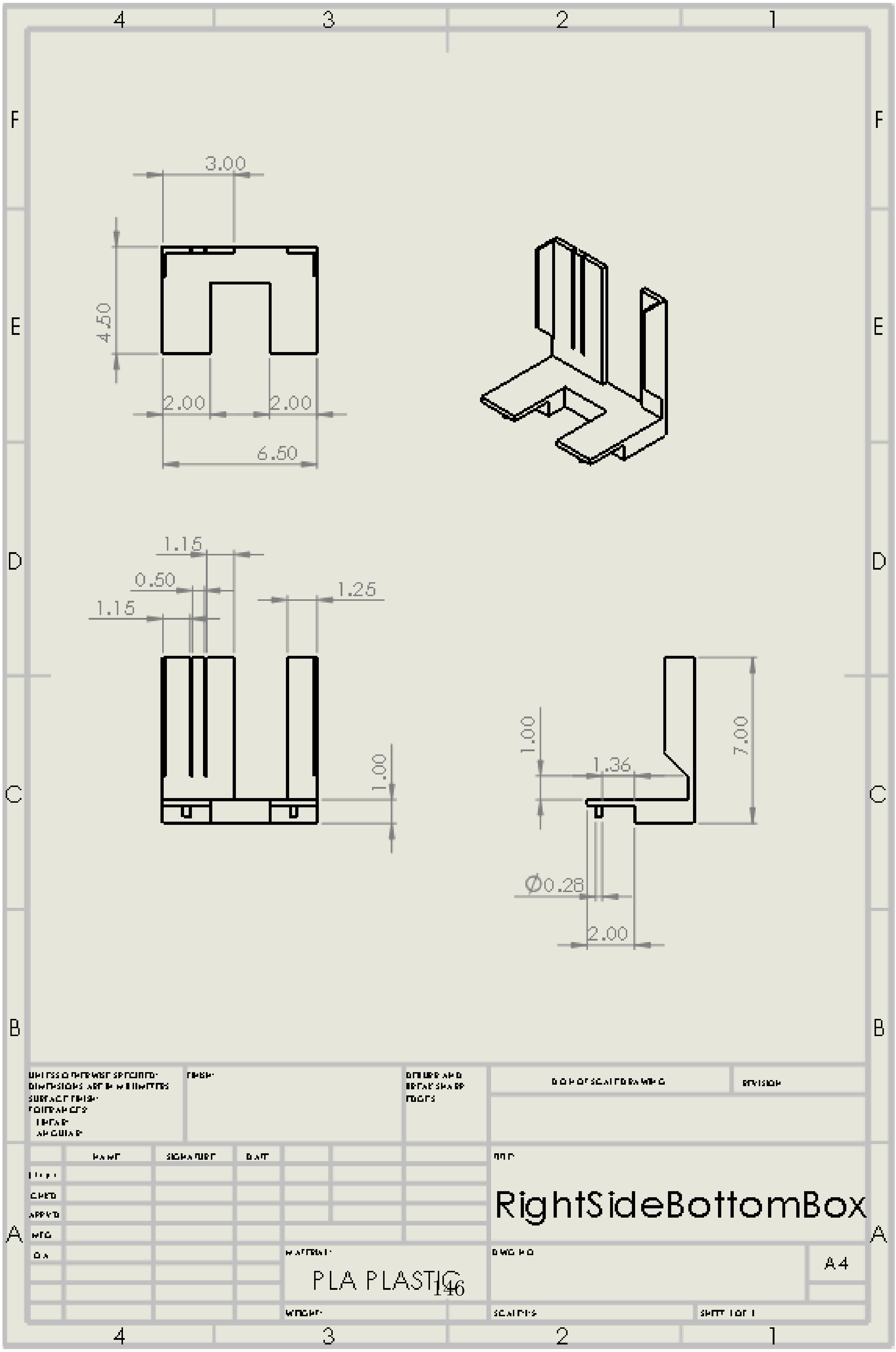


Figure 65: Box Bottom Dispenser Assembly Drawing (not to scale)

20.2.1 Final Drawings

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4.50
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6.50
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0.50
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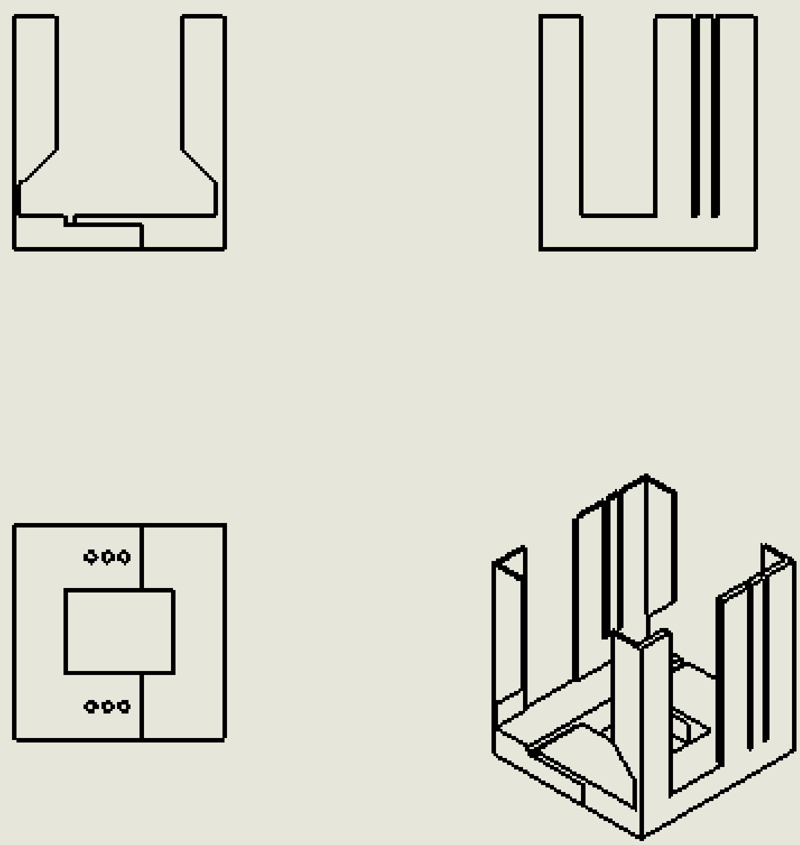
1.00
1.00
1.36
7.00
Ø0.28
2.00
RightSideBottomBox
PLA PLASTIC
A4



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
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TOLERANCES:
LINEAR:
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BREAK SHARP
EDGES

DO NOT SCALE DRAWING

REVISION

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DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE:

BottomBoxTogether

MATERIAL:
PLA PLASTIC

DWG NO.

A4

WEIGHT:

SCALE:

SHEET 1 OF 1

20.3 Funnel loader Drawings

20.3.1 Prototype Drawings

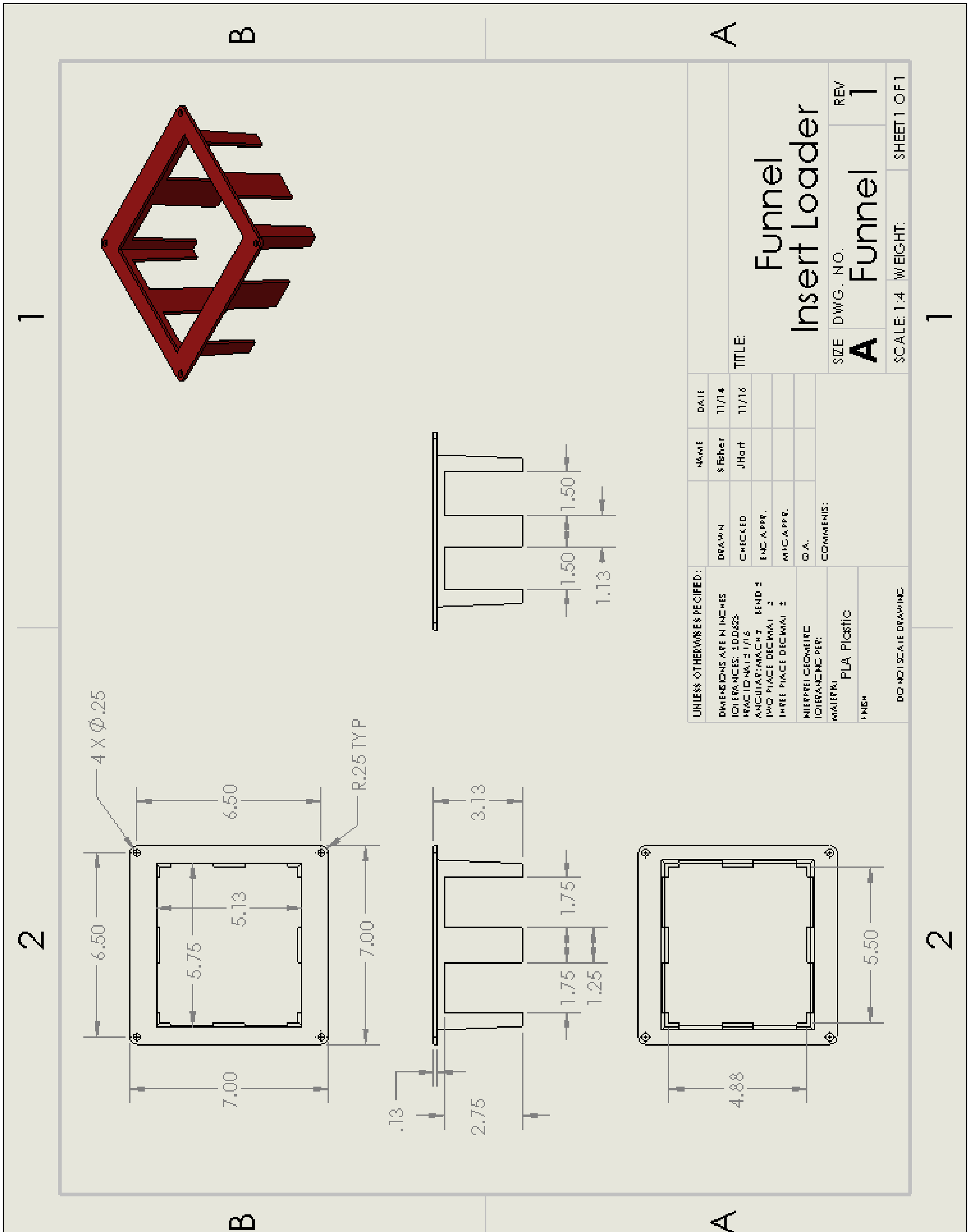

Figure 66: Insert loader funnel Drawing (not to scale)

20.3.2 Final Drawings

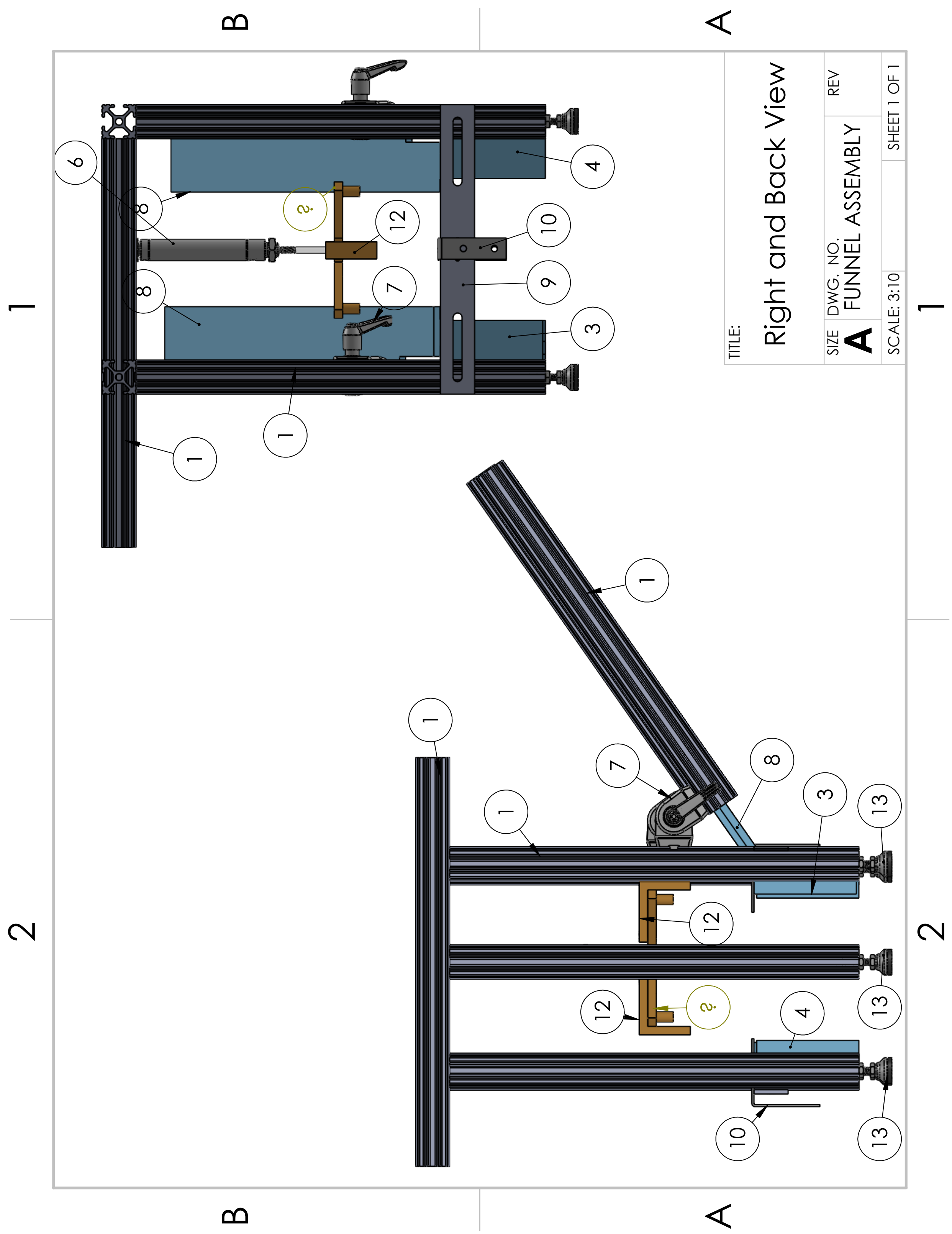

Figure 67: Funnel Assembly Drawing right and back (not to scale)

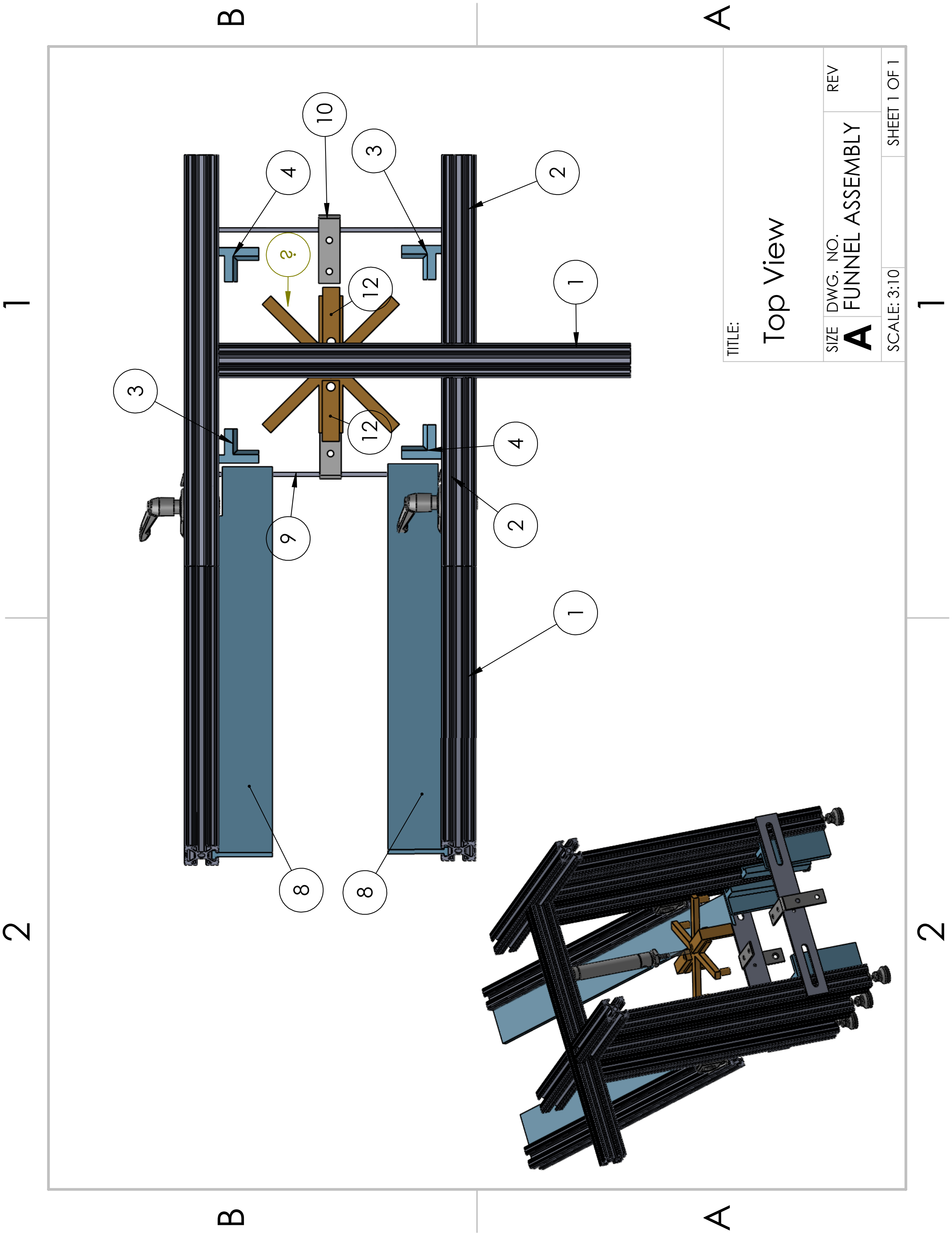

Figure 68: Funnel Assembly Drawing top (not to scale)

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	T-Slotted Framing 1 inch	Mcmaster Aluminum Extrusion	10
2	halfsize T-Slotted Framing 1 inch	Mcmaster Aluminum Extrusion	2
3	opposite funnel corner	Custom 3D printed resin	2
4	funnel corner	Custom 3D pinted resin	2
5	sidewall	Custom 3D printed resin	2
6	4952K702	Mcmaster actuator	1
7	47065T221	Mcmaster locking pivot	2
8	slide	Custom 3D pinted resin	2
9	sidebracketwall	Custom 3D printed resin	2
10	1556A43	Mcmaster L bracket	2
11	actuatorx	Custom 3D printed PLA plastic	1
12	actuatoradjuster	Custom 3D printed PLA plastic	2
13	6111K81	Mcmaster Swivel leveling mount	6

TITLE: Bill of Materials

DWG NO. BOM

A4

SCALE:1:2

SHEET 1 OF 1

Figure 69: Bill of Materials (not to scale)

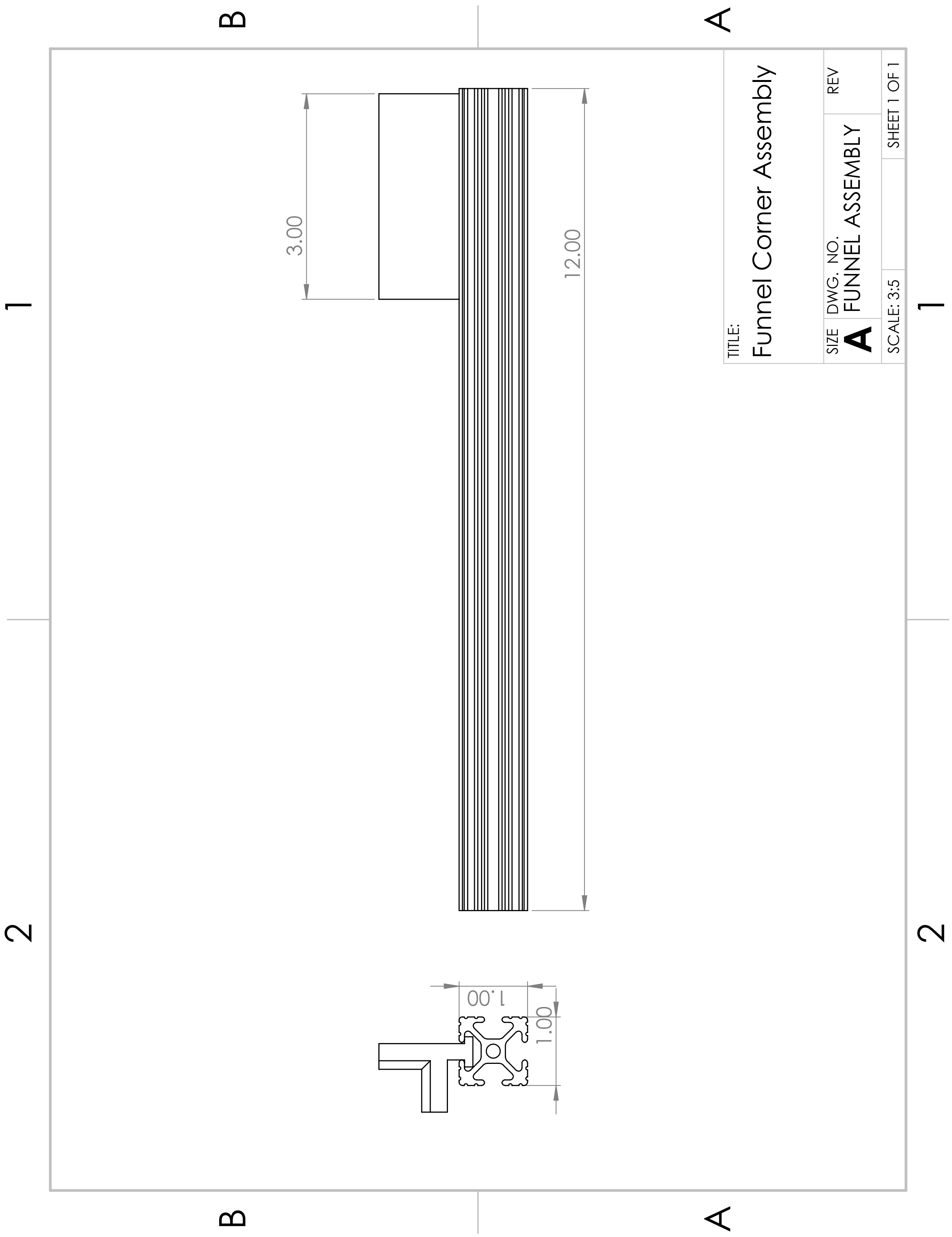

Figure 70: Funnel Corner Assembly (not to scale)

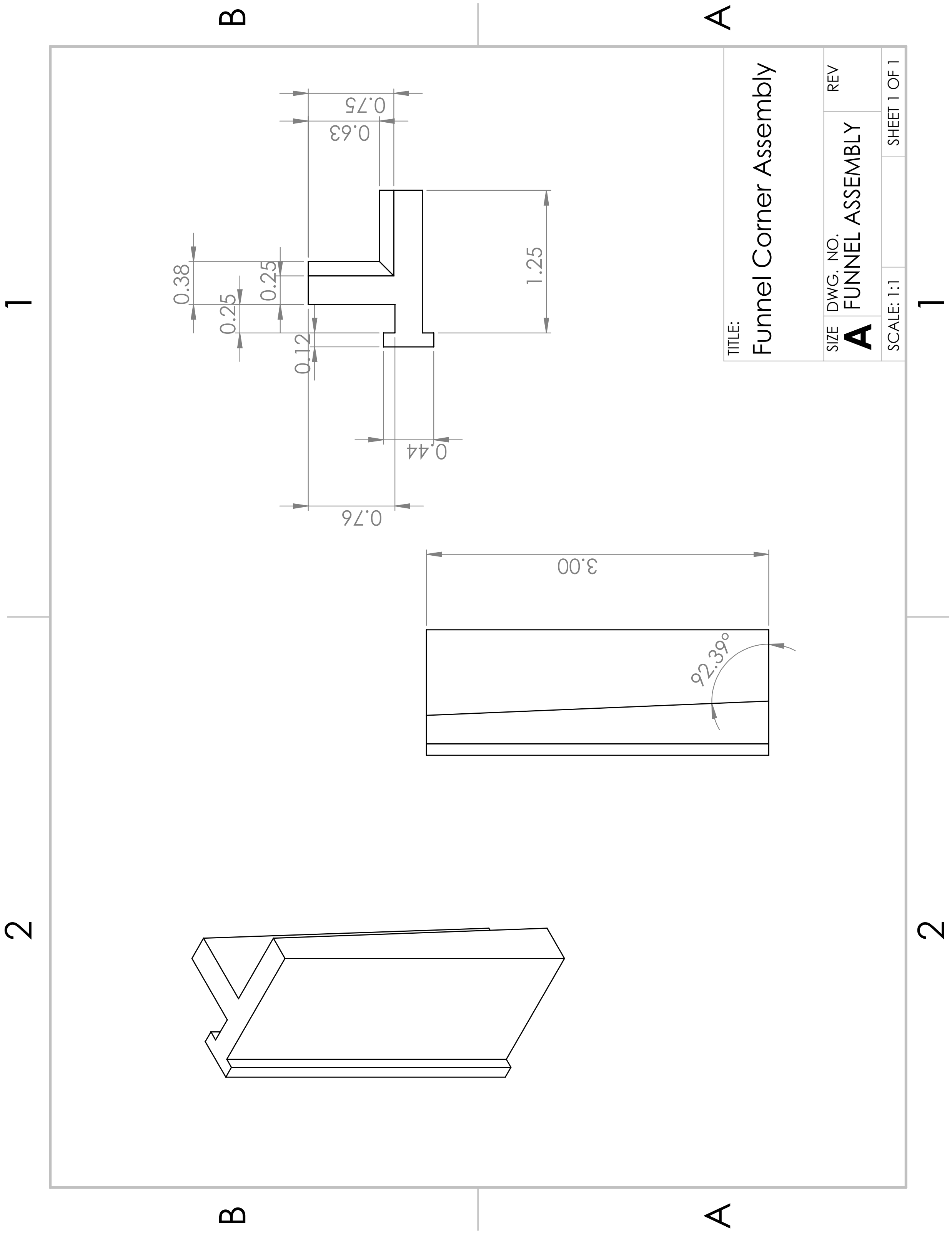

Figure 71: Funnel Corner (not to scale)

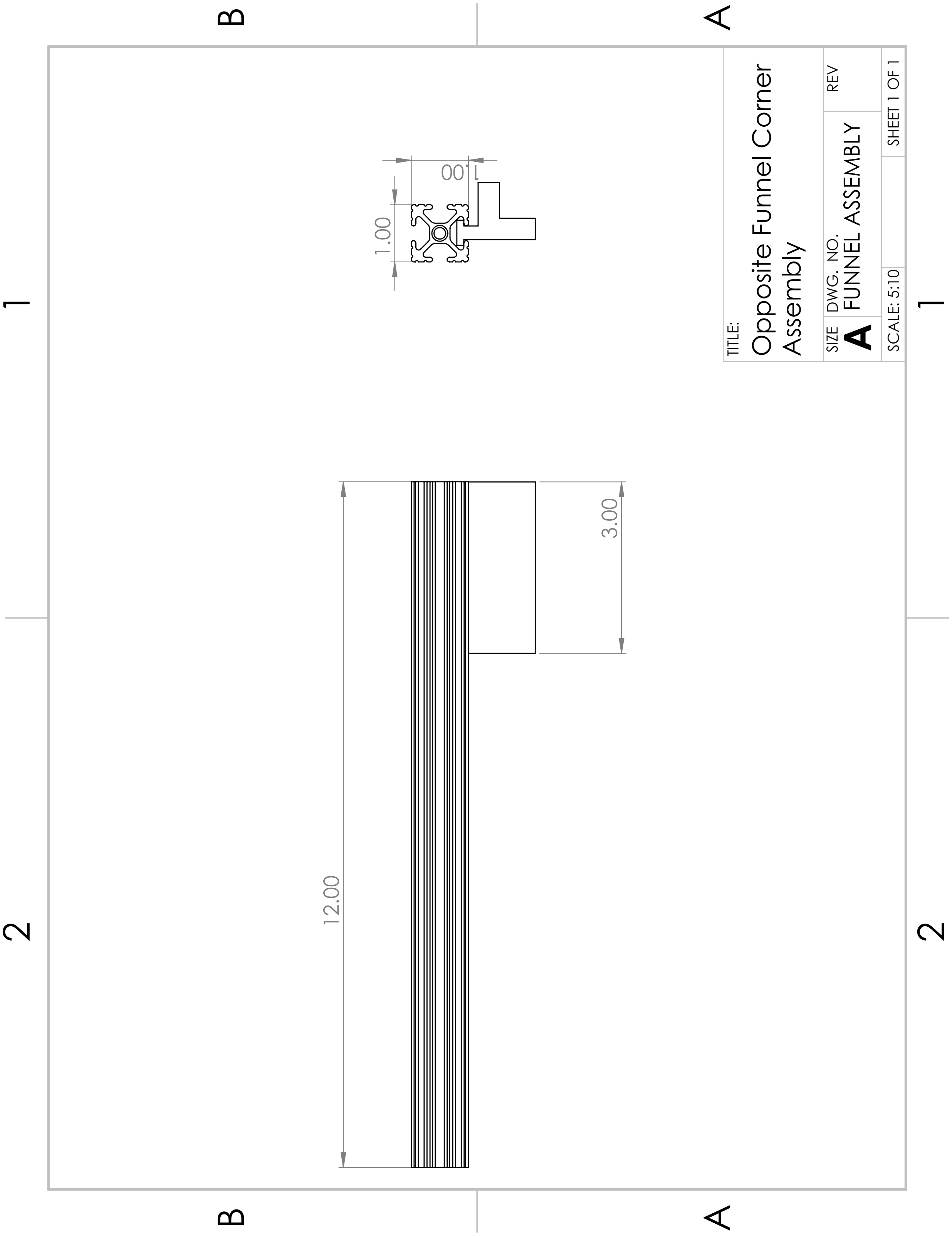

Figure 72: Opposite Funnel Corner Assembly (not to scale)

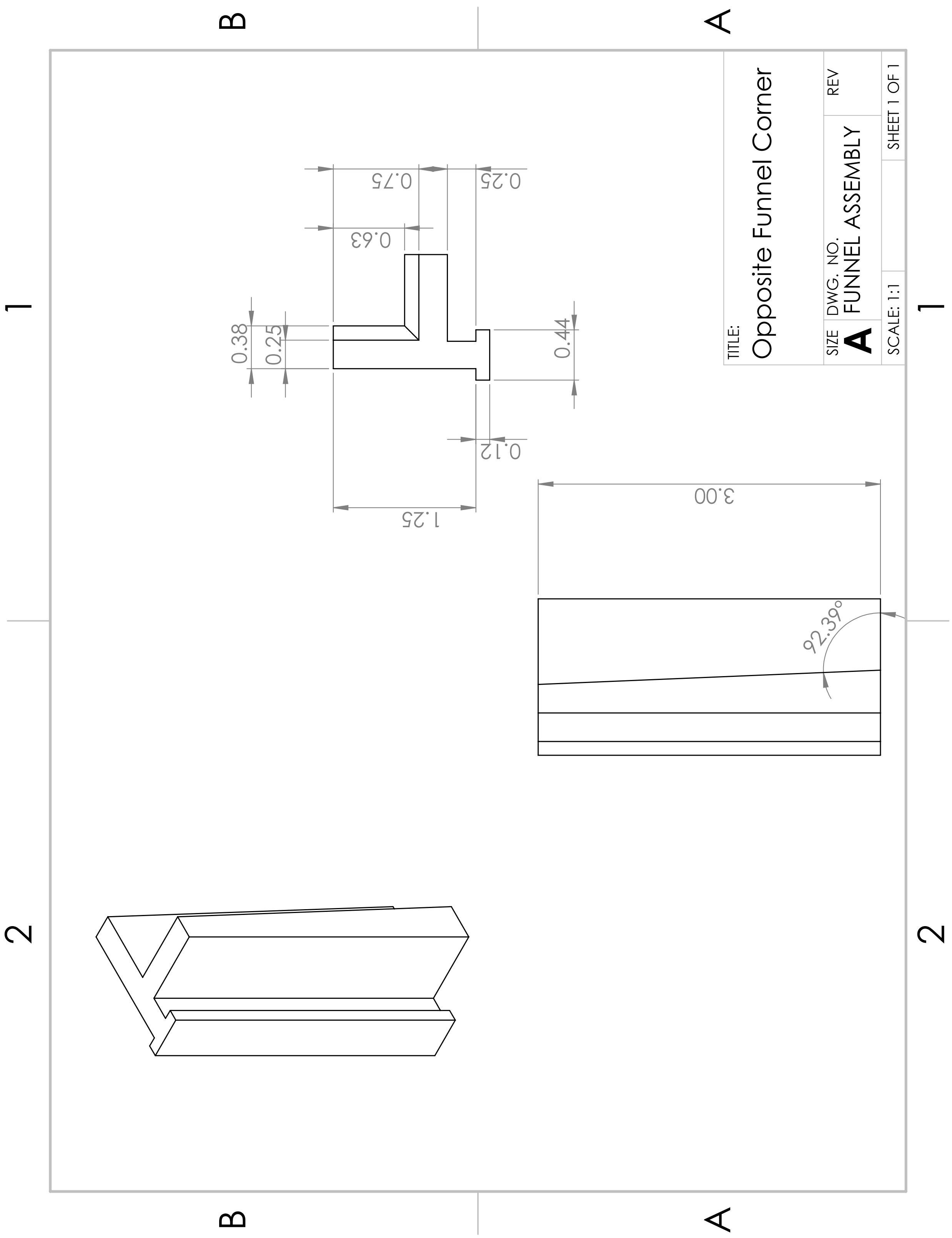

Figure 73: Opposite Funnel Corner (not to scale)

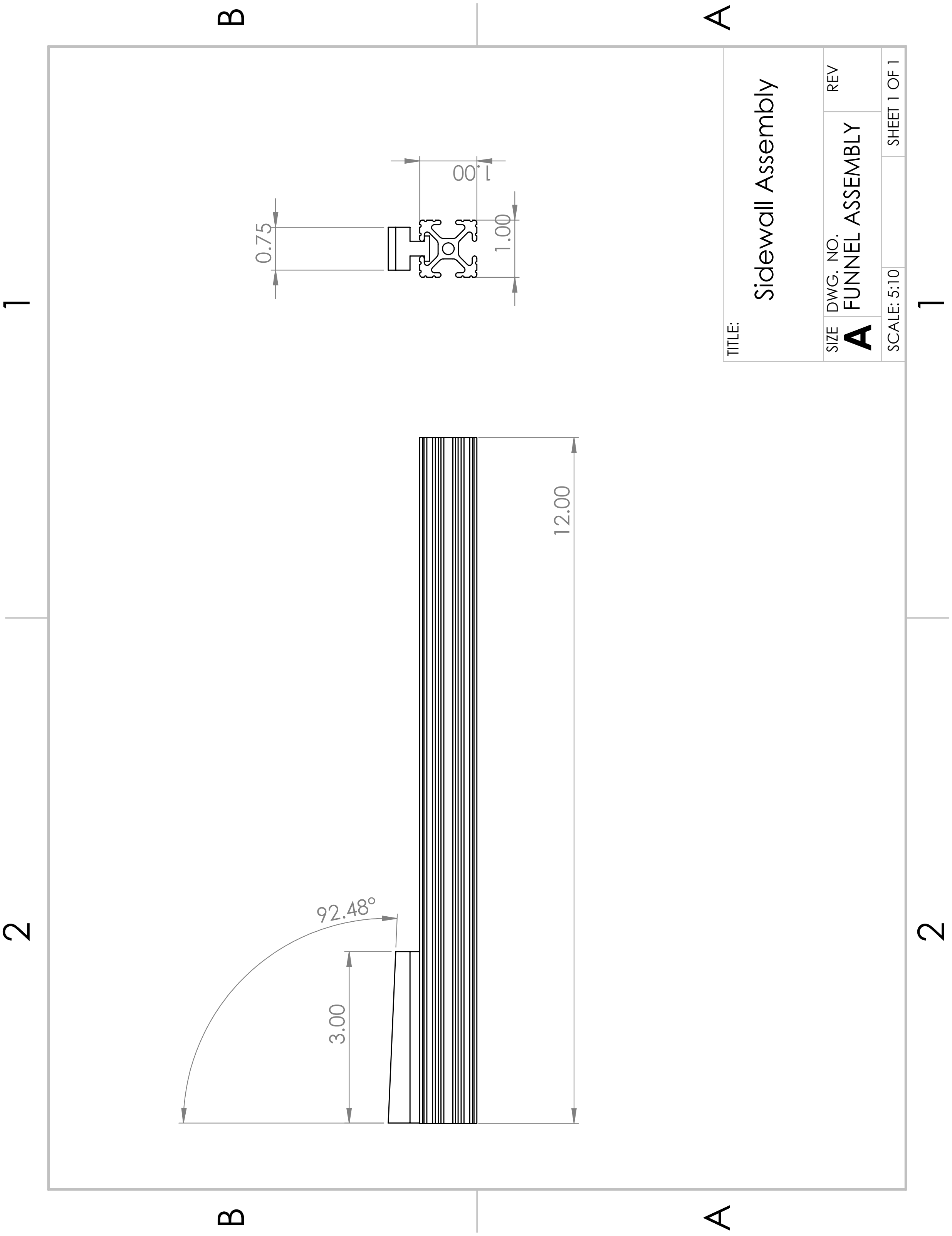

Figure 74: Sidewall Assembly (not to scale)

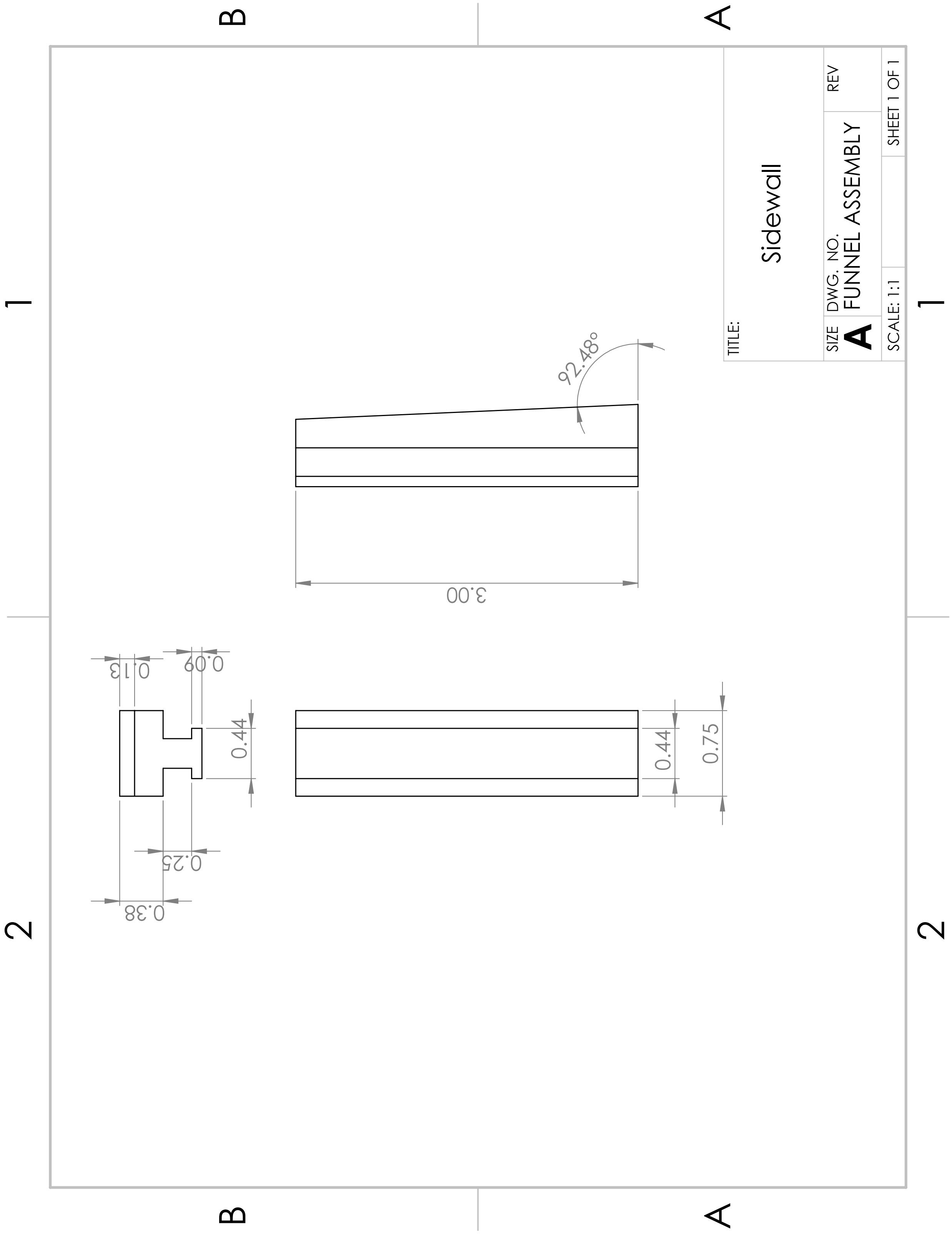

Figure 75: Sidewall(not to scale)

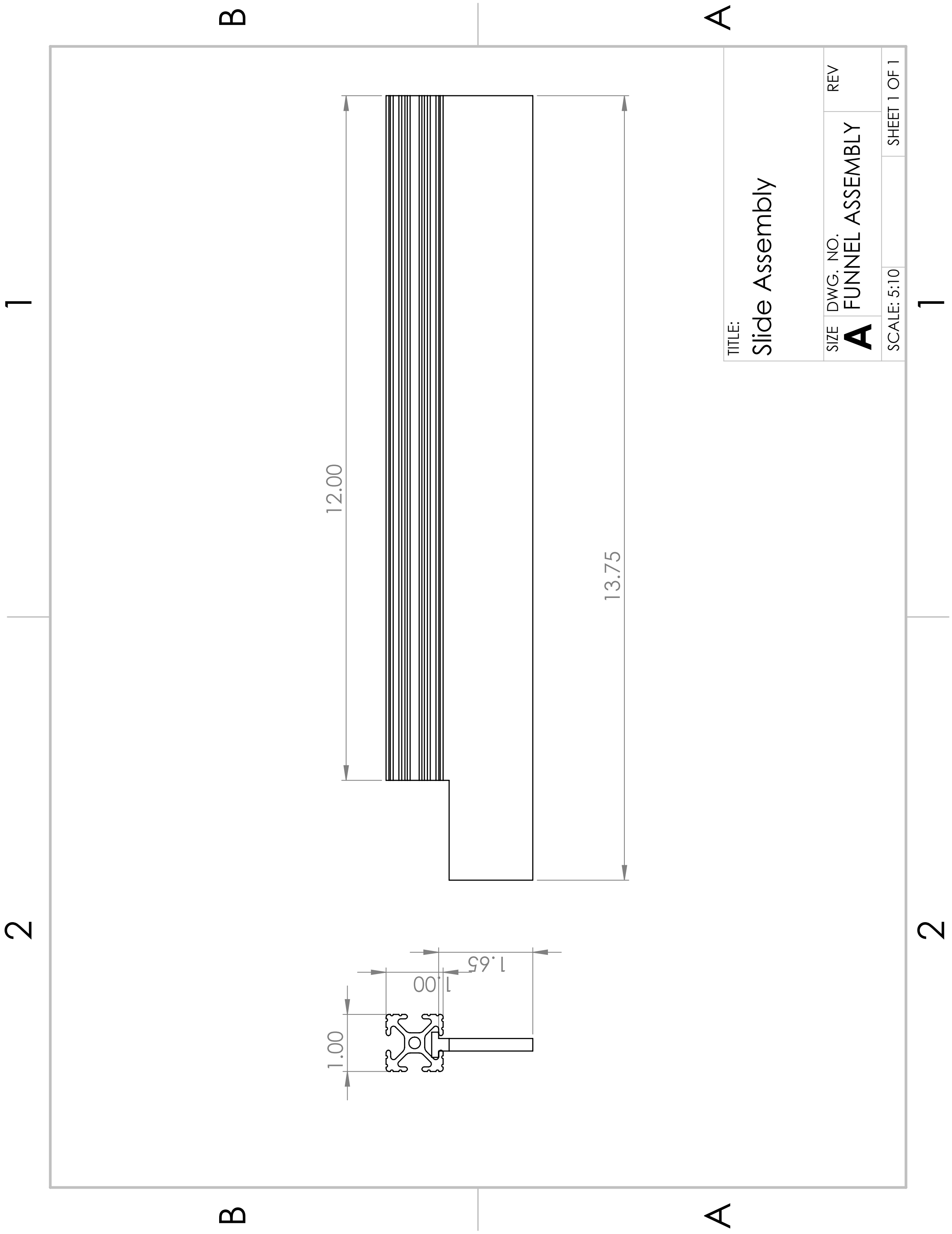

Figure 76: Slide assembly (not to scale)

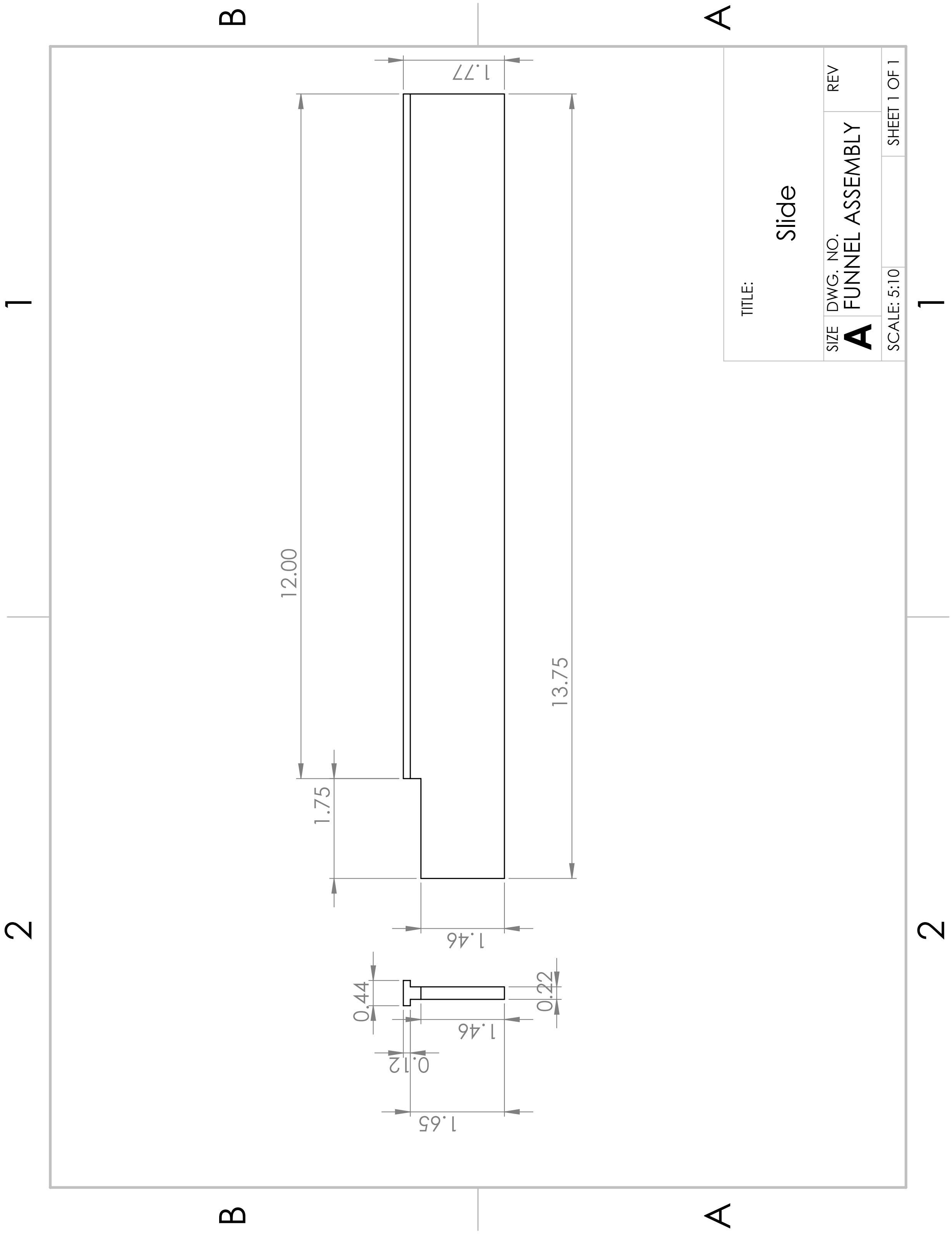

Figure 77: Slide (not to scale)

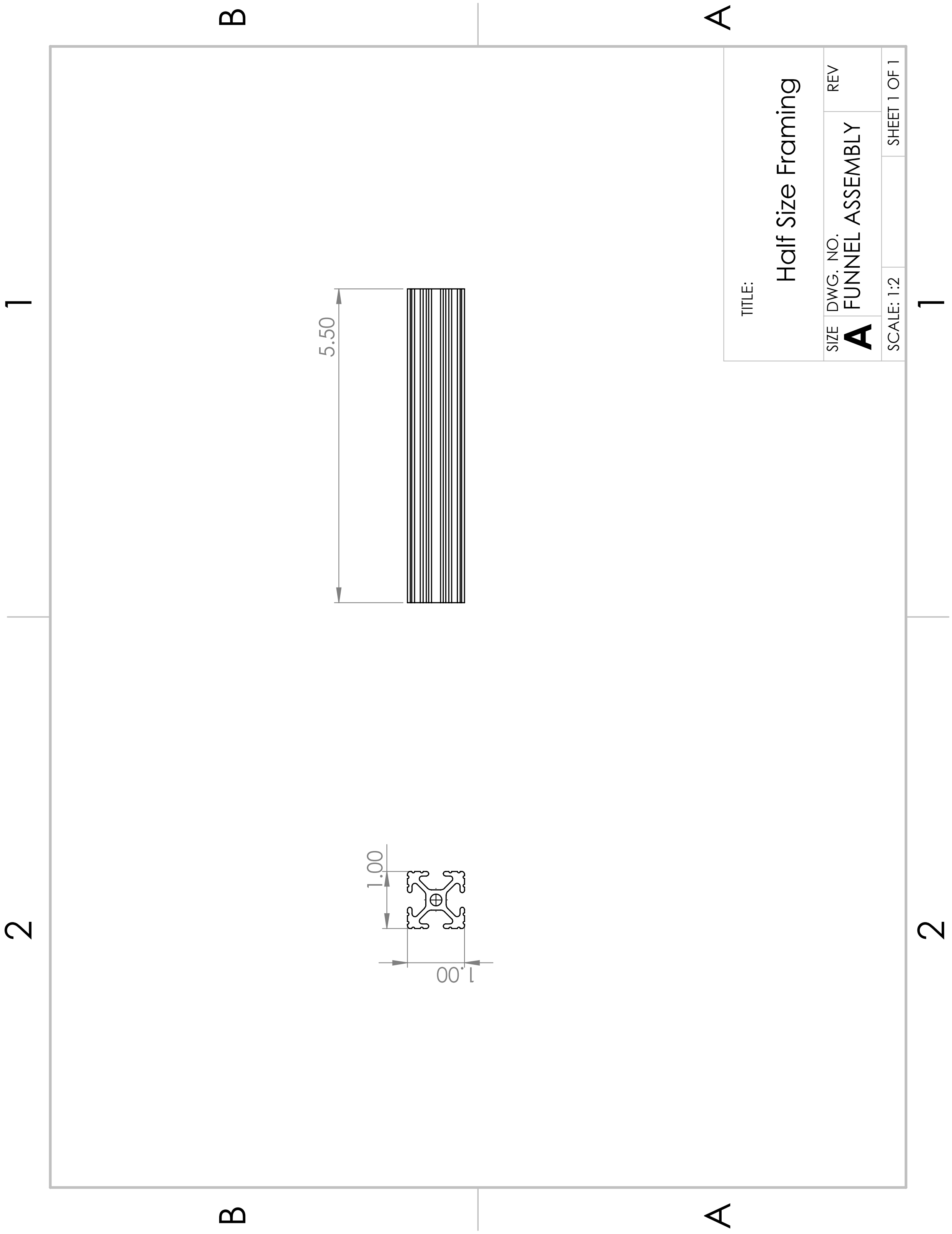

Figure 78: Half Size Framing (not to scale)

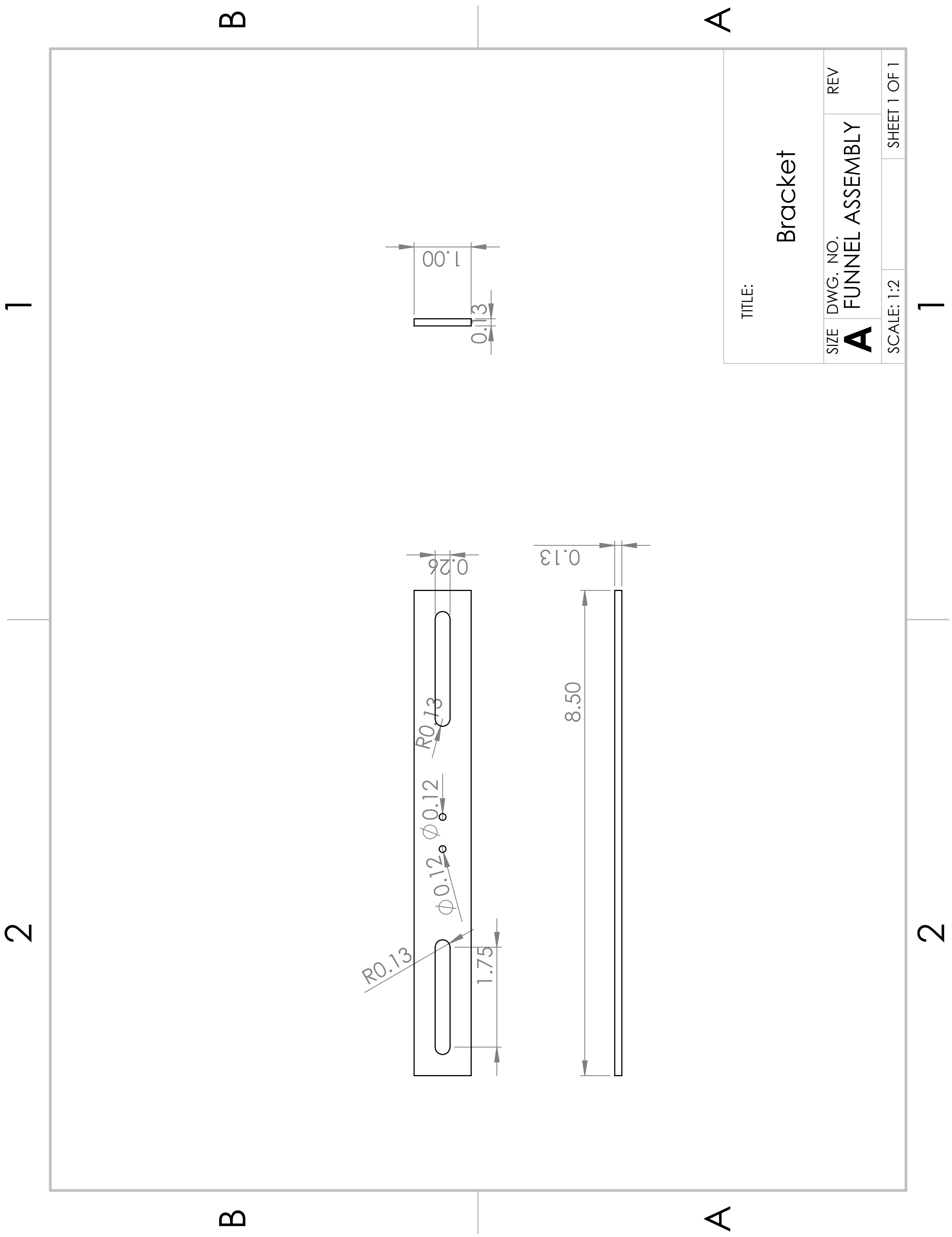

Figure 79: Side Bracket (not to scale)

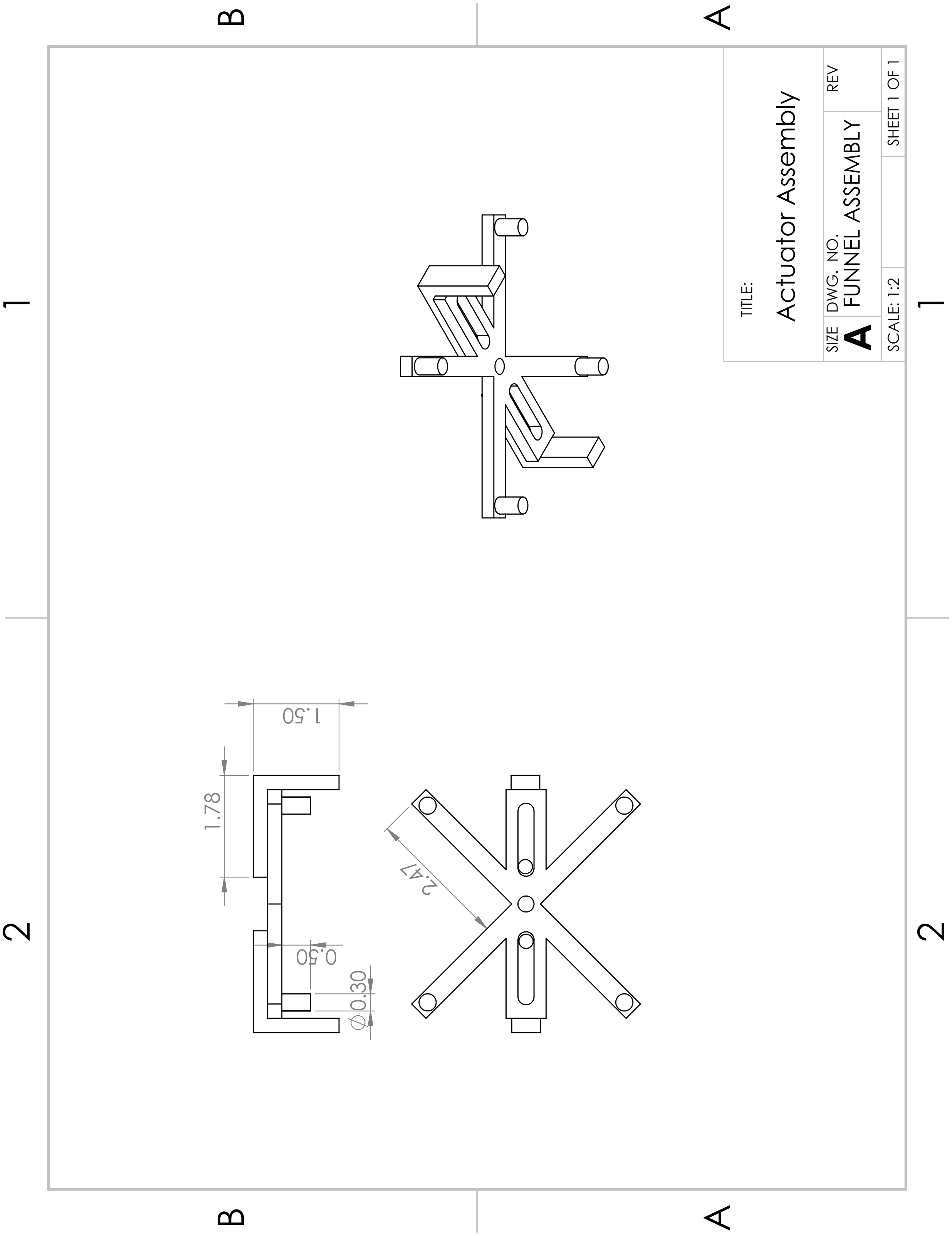

Figure 80: Actuator Assembly (not to scale)

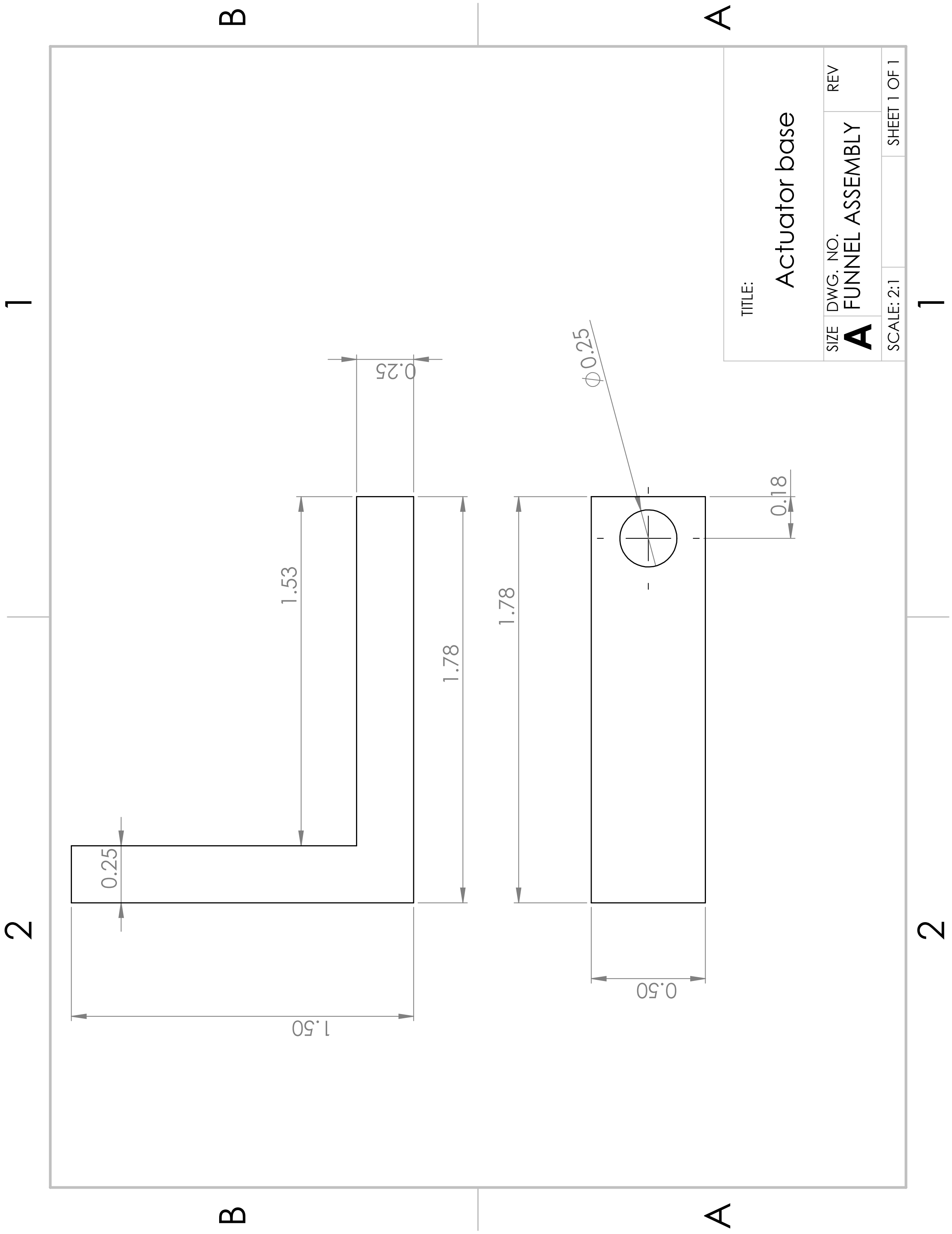

Figure 81: Actuator Adjuster (not to scale)

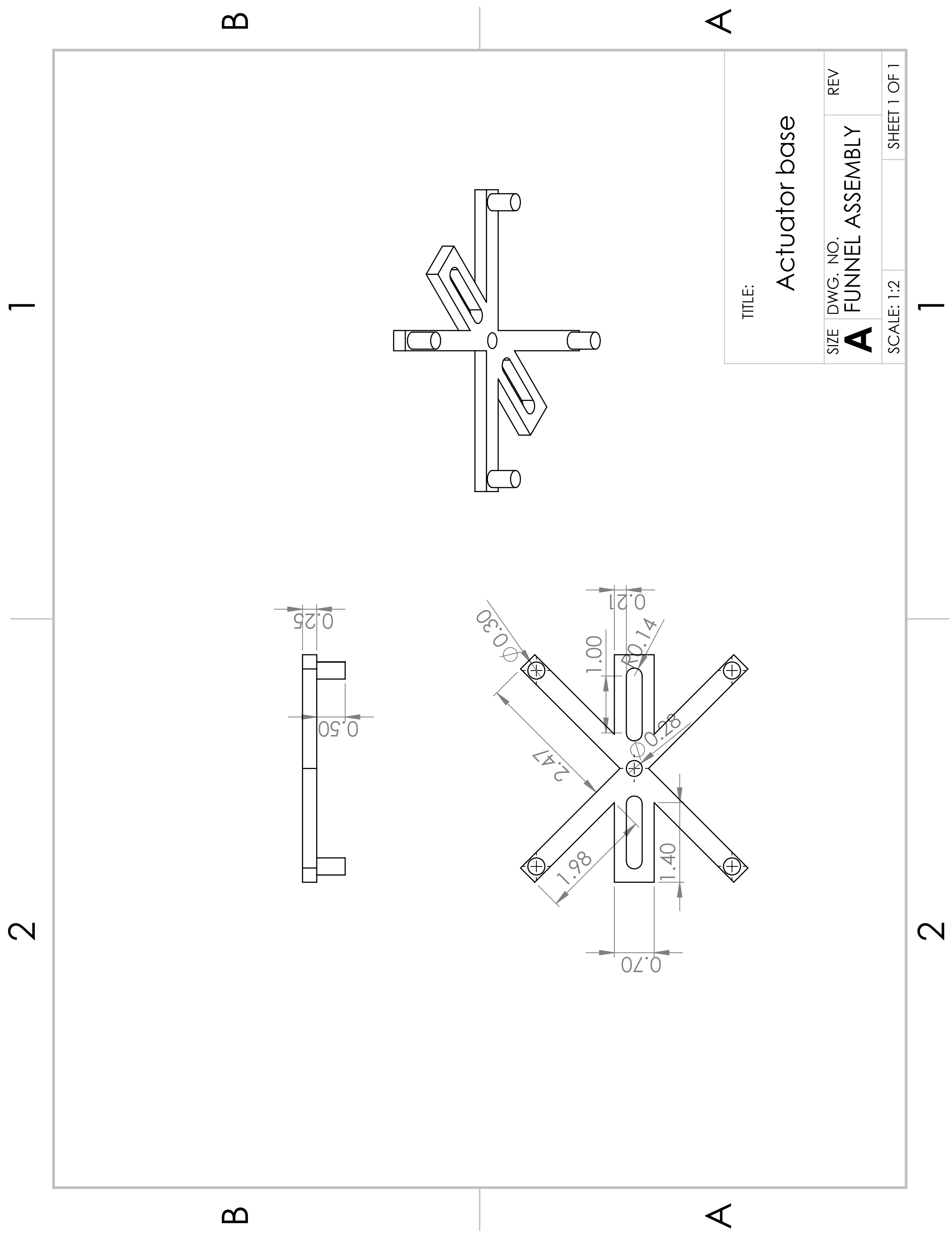

Figure 82: Actuator Base (not to scale)

20.4 Pamphlet Dispenser Drawings

20.4.1 Prototype Drawings

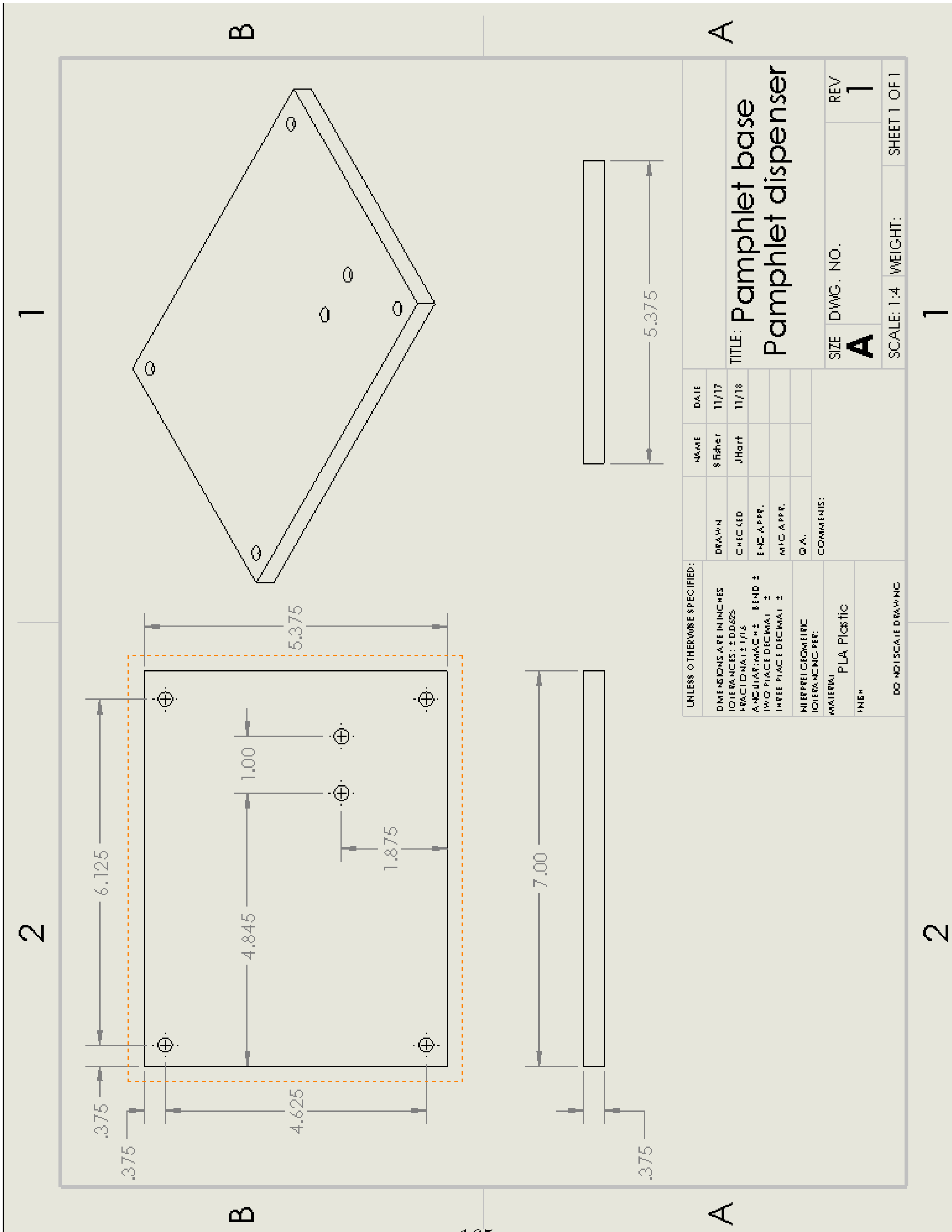

Figure 83: Prototype Pamphlet Dispenser Base Drawing (not to scale)

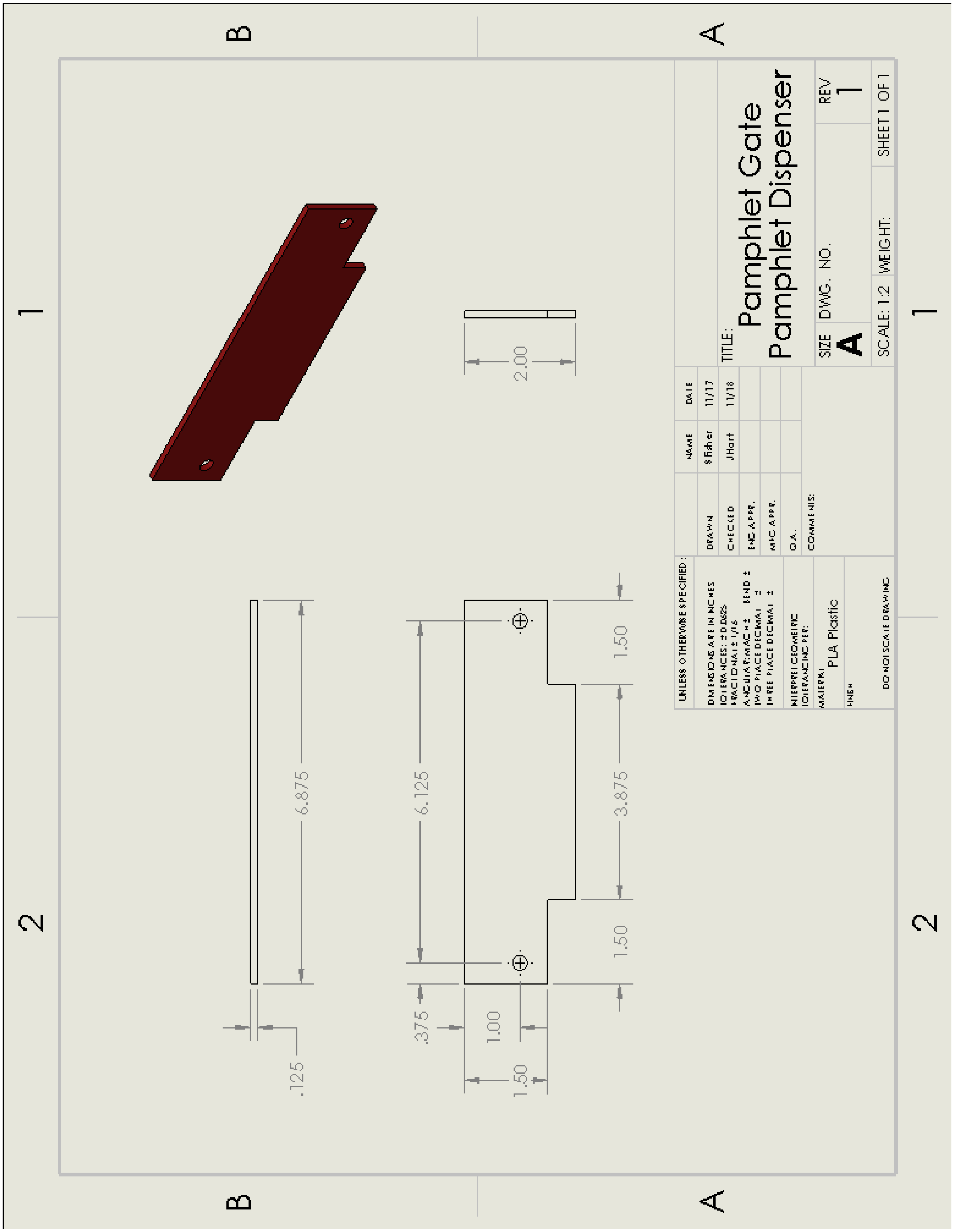

Figure 84: Prototype Pamphlet Dispenser Adjustable gate Drawing (not to scale)

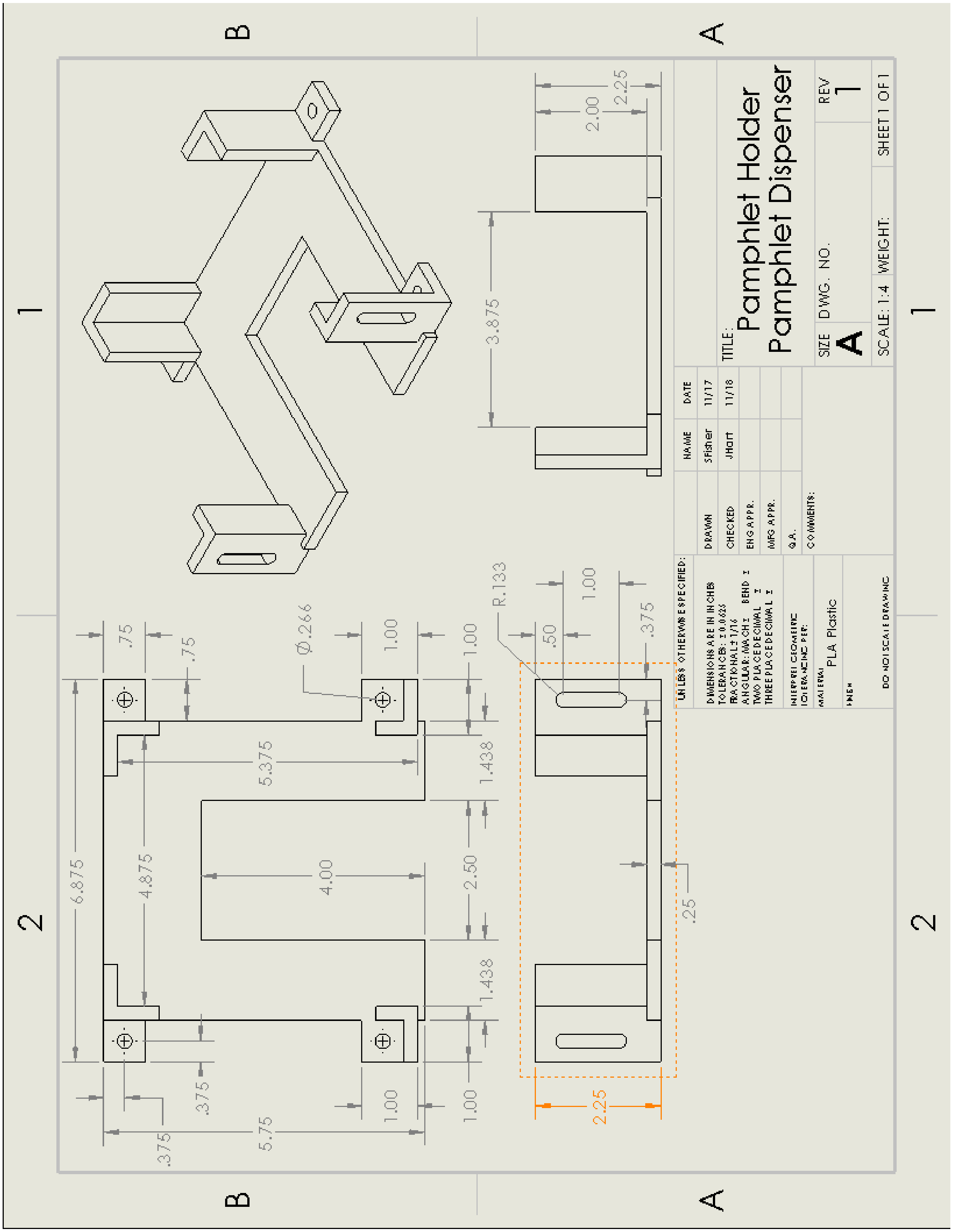

Figure 85: Prototype Pamphlet Dispenser Pamphlet Holder Drawing (not to scale)

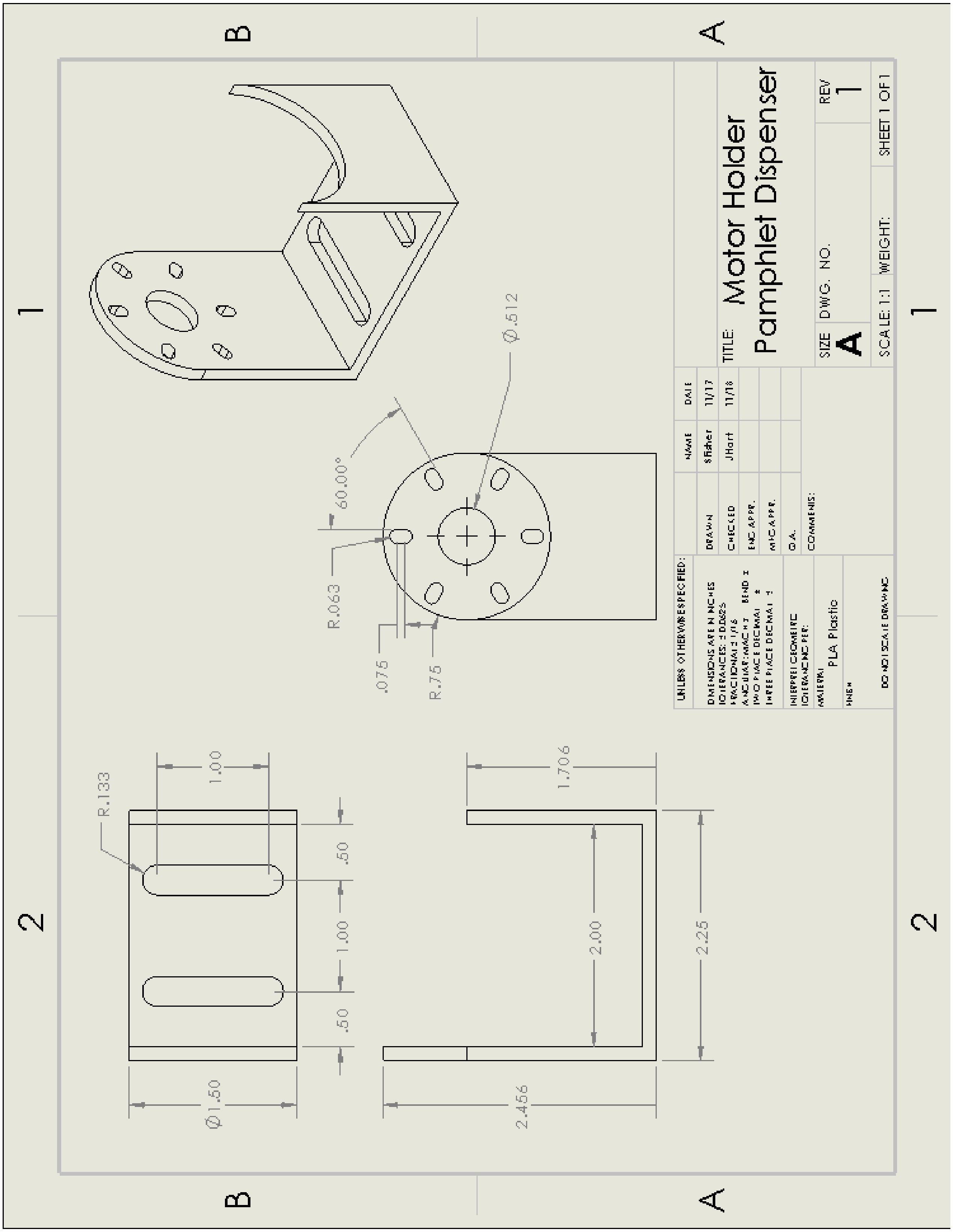

Figure 86: Prototype Pamphlet Dispenser Motor Holder Drawing (not to scale)

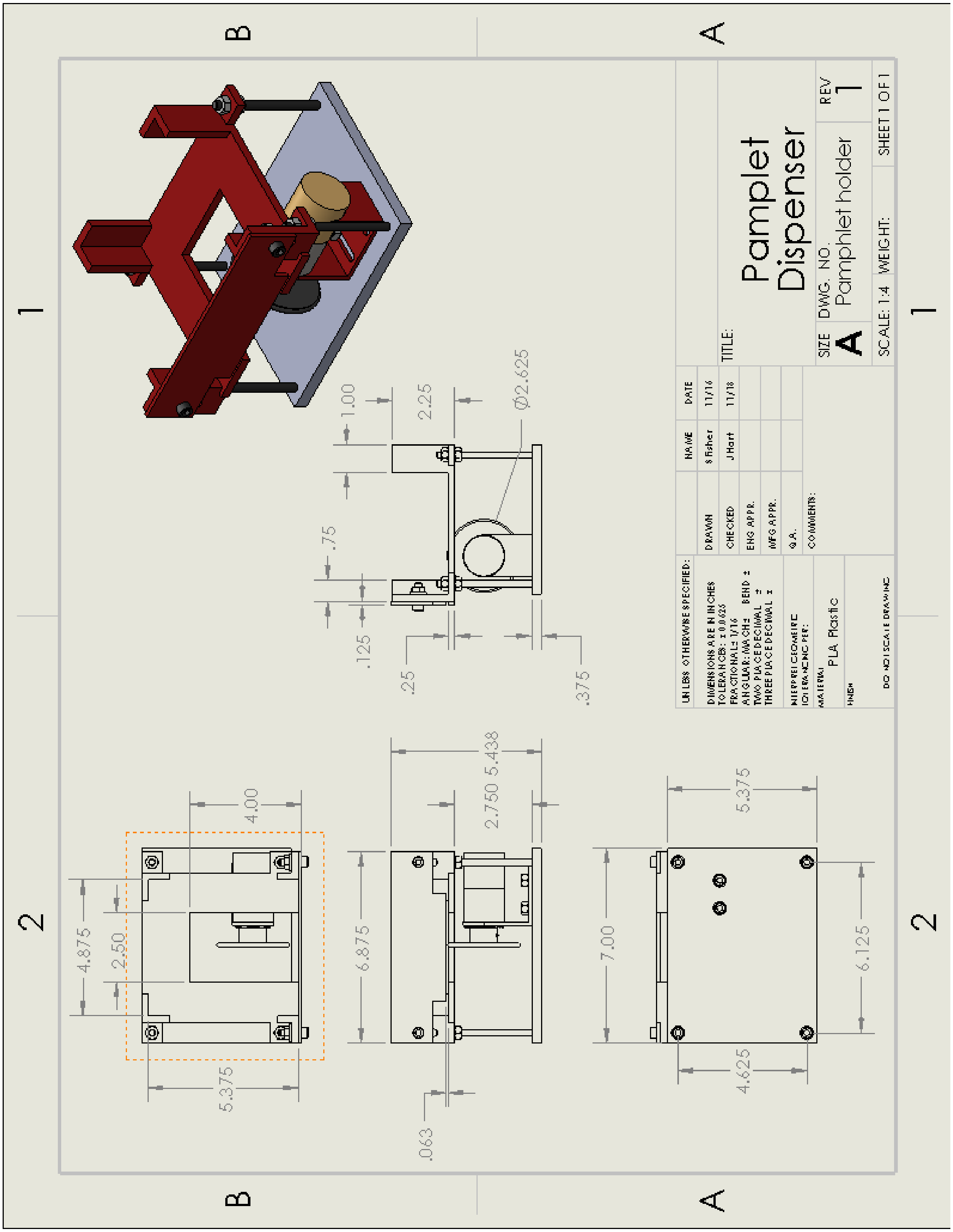

Figure 87: Prototype Pamphlet Dispenser Assembly Drawing (not to scale)

20.4.2 Final Drawings

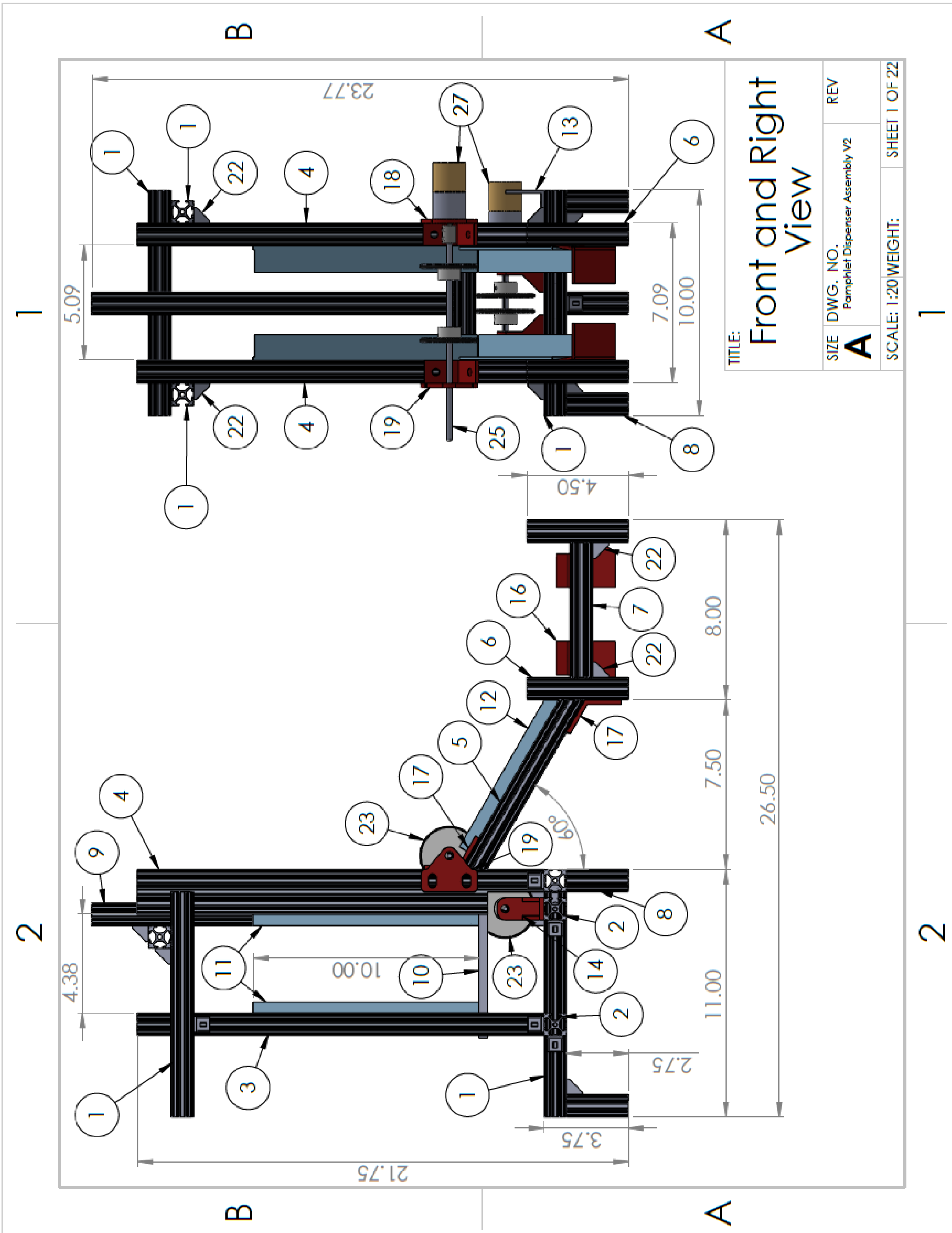

Figure 88: Pamphlet Dispenser Assembly Drawing (not to scale)

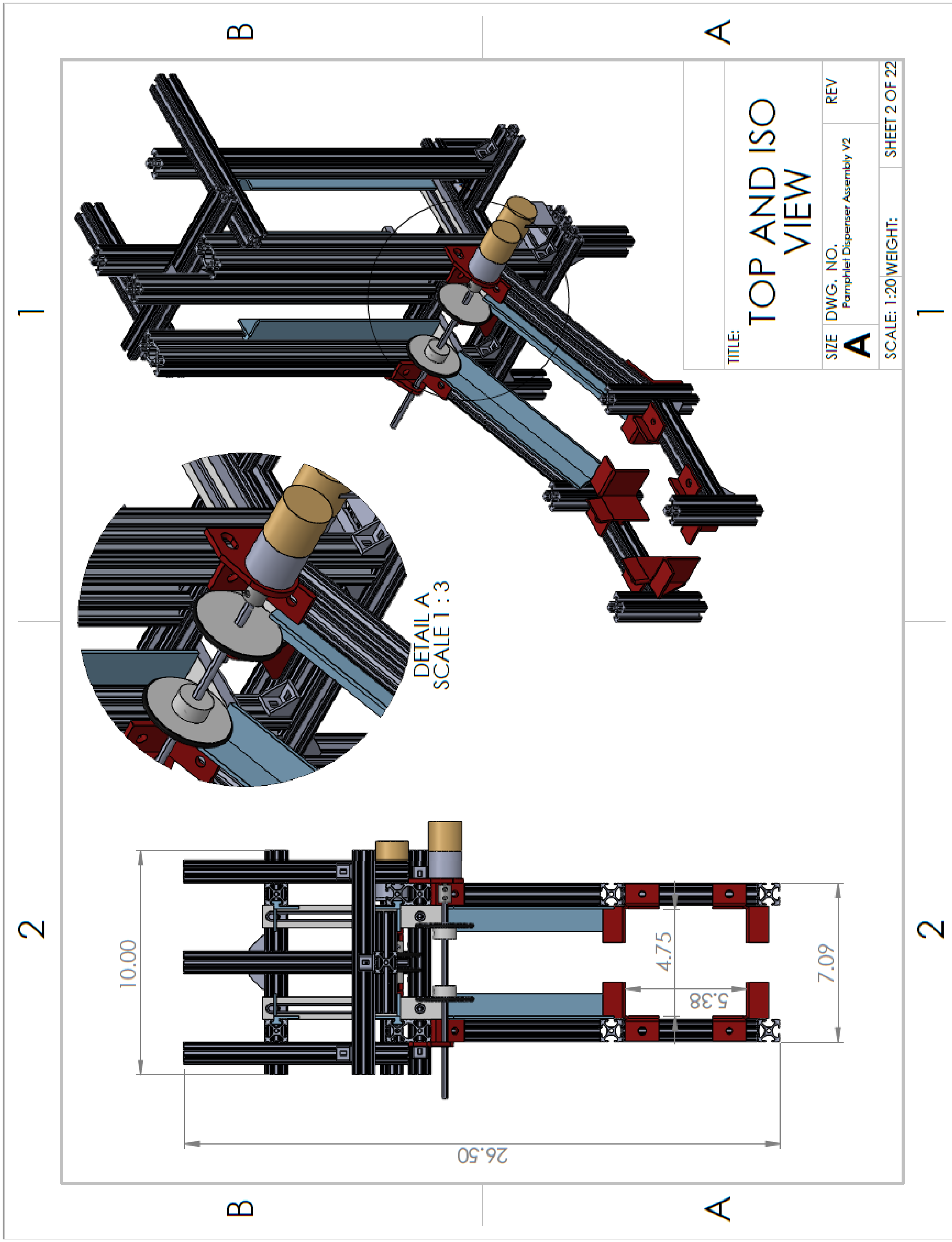

Figure 89: Pamphlet Dispenser Assembly Drawing (not to scale)

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Cross Frame Long	Mcmaster Aluminum Extrusion	5
2	Cross Frame Short	Mcmaster Aluminum Extrusion	5
3	Pamphlet Corner Support	Mcmaster Aluminum Extrusion	2
4	Pamphlet Corner Support Double	Mcmaster Aluminum Extrusion	2
5	Ramp Support	Mcmaster Aluminum Extrusion	2
6	Leg	Mcmaster Aluminum Extrusion	4
7	Funnle Support	Mcmaster Aluminum Extrusion	2
8	Leg Small	Mcmaster Aluminum Extrusion	3
9	Plunger	Mcmaster Aluminum Extrusion	1
10	Pamphlet Base rail	Machined Delrin support	2
11	Corner Angle Top	Custom 3D printed resin	4
12	Ramp Angle	Custom 3D printed resin	2
13	Motor Holder_v2	Custom 3D printed PLA Plastic	1
14	Axle Holder	Custom 3D Printed PLA Plastic	2
15	Funnle Corner 1	Custom 3D printed PLA Plastic	2
16	Funnle Corner 2	Custom 3D printed PLA Plastic	2
17	Ramp Bracket	Custom 3D printed PLA Plastic	4
18	Motor Holder 2	Custom 3D printed PLA Plastic	1
19	Axel Holder 2	Custom 3D printed PLA Plastic	1
20	47065T236	Mcmaster extrusion L bracket	4
21	5537T316	Mcmaster extrusion L connector	2
22	47065T216	Mcmaster Extrusion Corner brace	23
23	2471K260	Mcmaster _SLIM-TREAD DRIVE ROLLER mod	4
24	8632T132	Mcmaster 6 inch shaft	1
25	8632T139	Mcmaster 12 inch shaft	1
26	5395T112	Mcmaster Shaft coupling	2
27	12volt_200RPM_motor	Amazon Uxcell 12 volt 200 RPM	2

TITLE: Bill of Materials			
SIZE A	DWG. NO. Pamphlet Dispenser Assembly V2		REV
SCALE: 1:20	WEIGHT:		SHEET 3 OF 22

Figure 90: Pamphlet Dispenser Bill of Materials (not to scale)

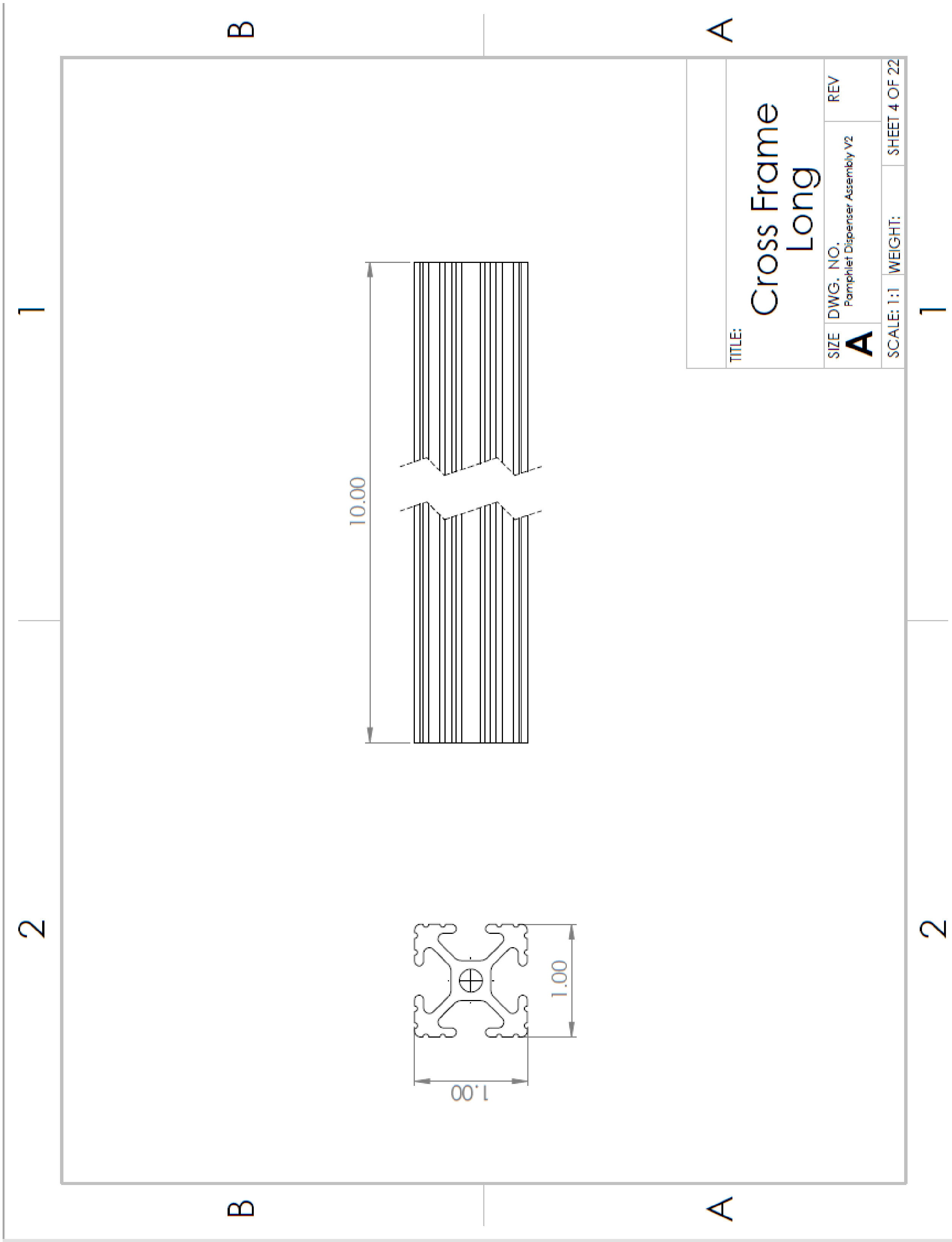

Figure 91: Pamphlet Dispenser Cross Frame Long Drawing (not to scale)

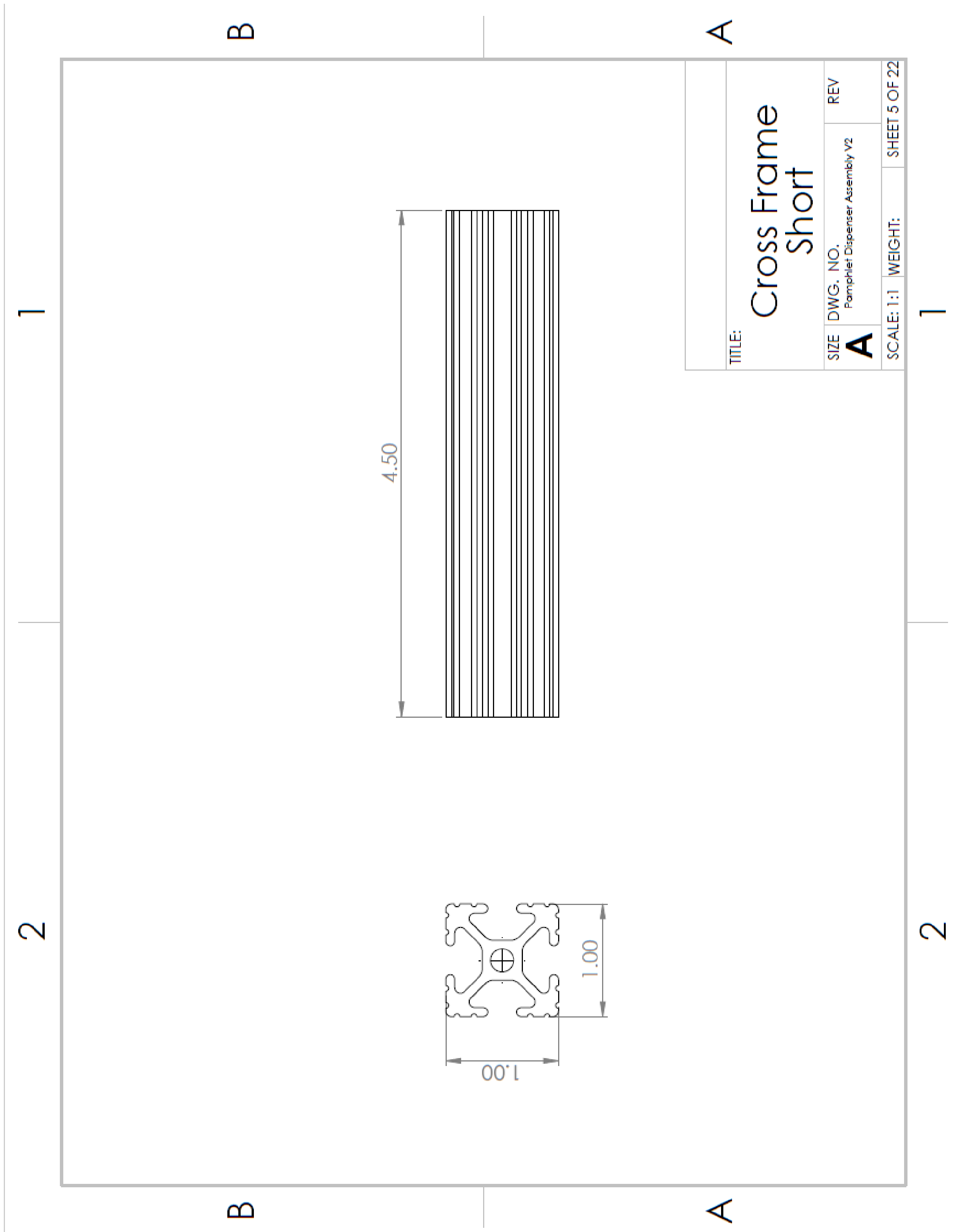

Figure 92: Pamphlet Dispenser Cross Frame Short Drawing (not to scale)

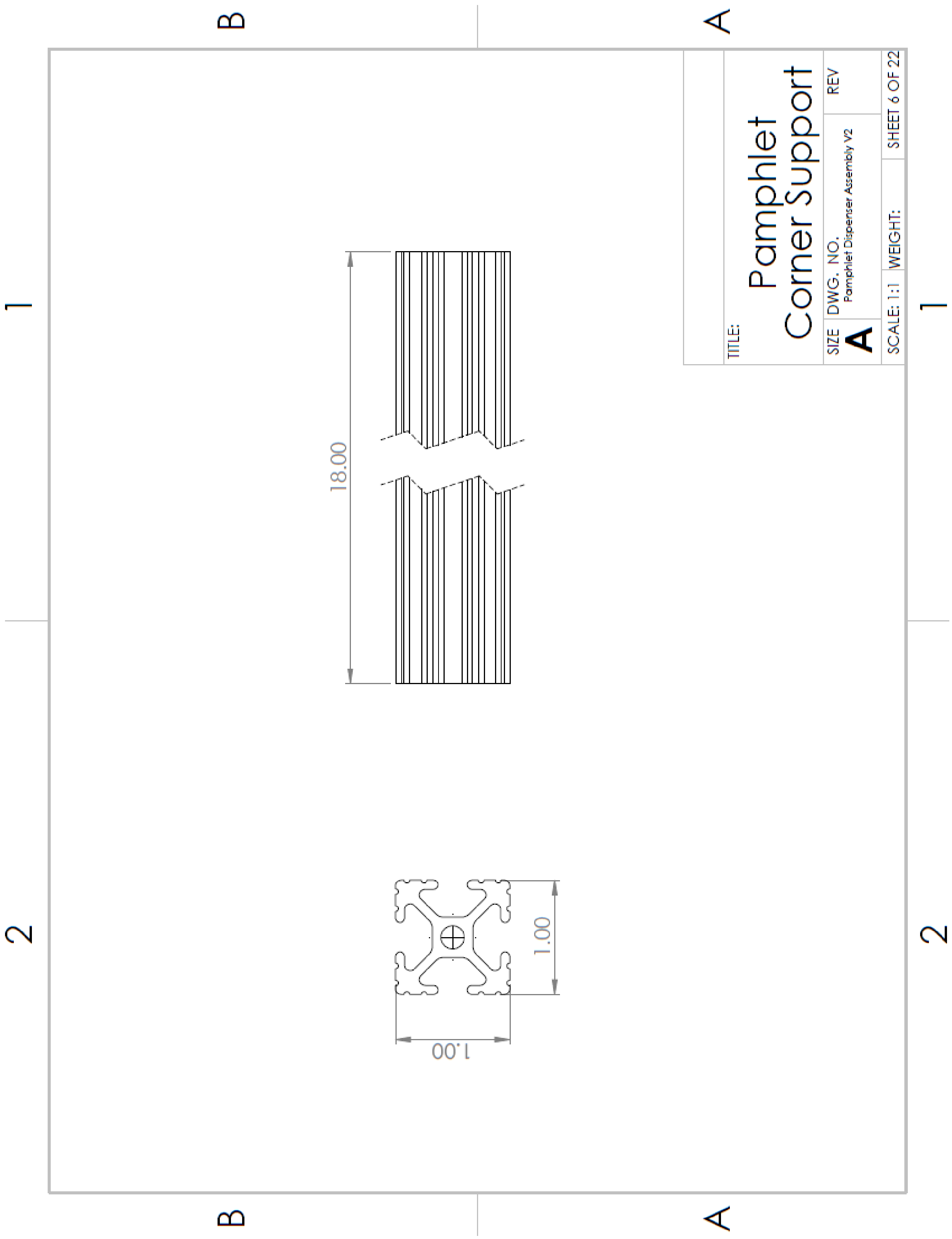

Figure 93: Pamphlet Dispenser Pamphlet Corner Support Drawing (not to scale)

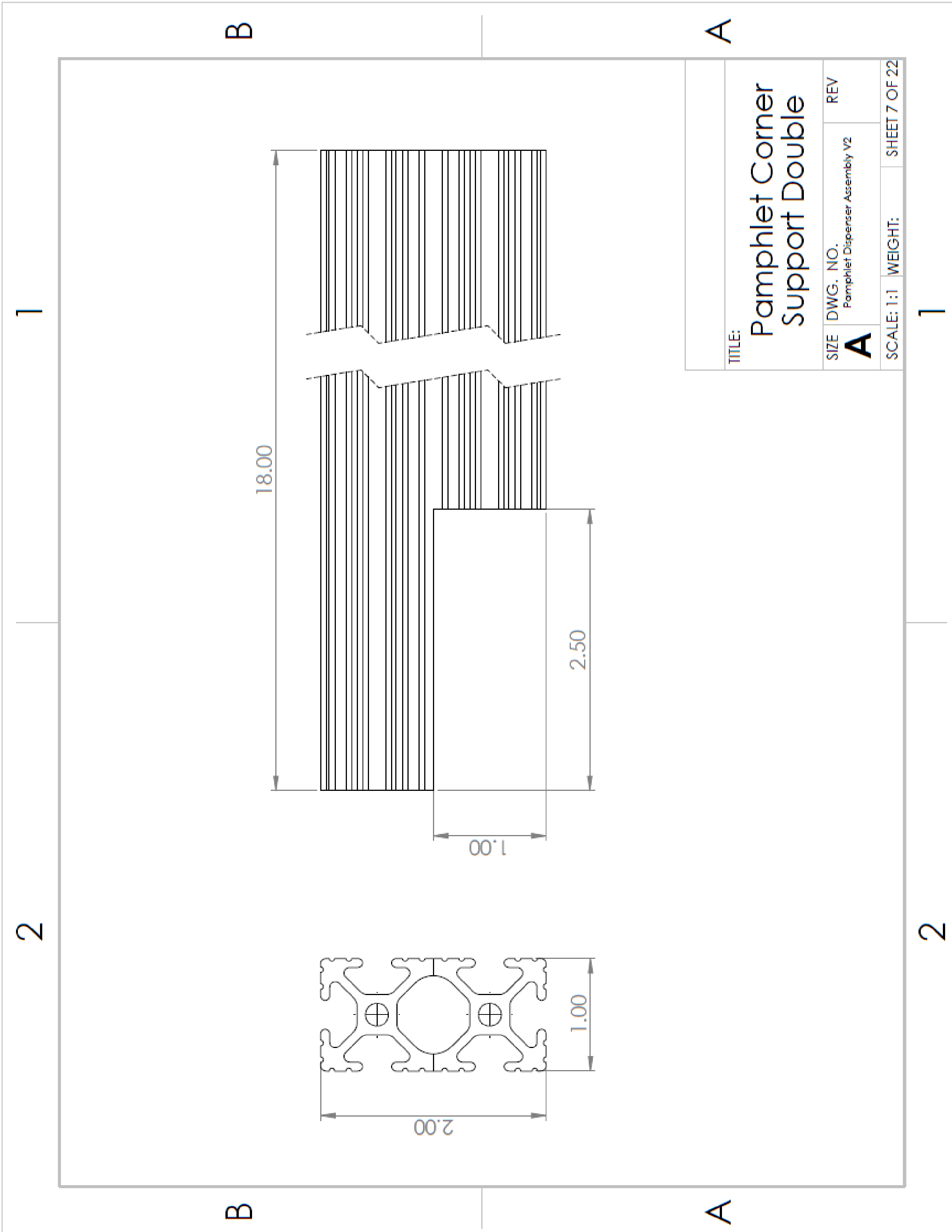

Figure 94: Pamphlet Dispenser Pamphlet Corner Support Double Drawing (not to scale)

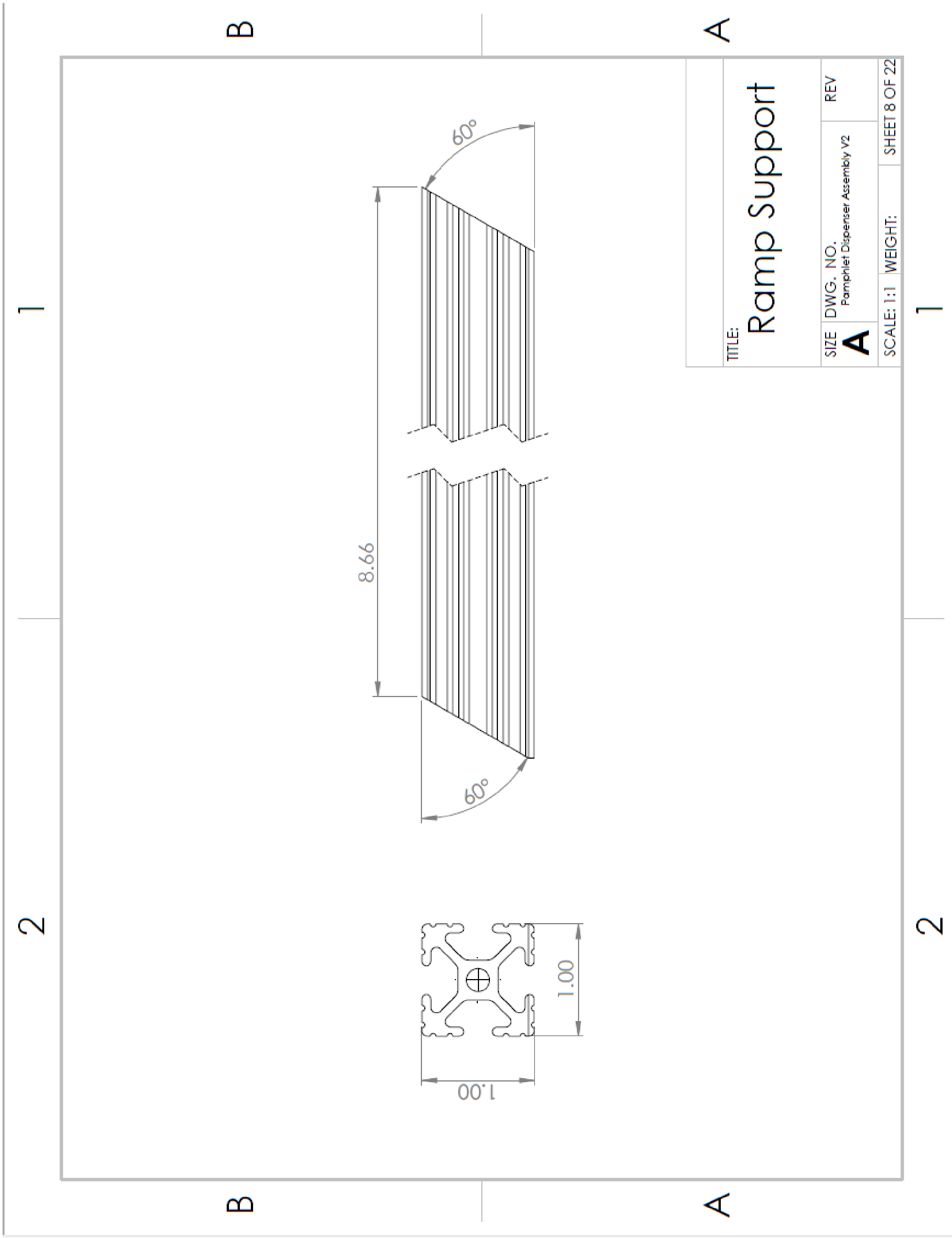

Figure 95: Pamphlet Dispenser Ramp Support Drawing (not to scale)

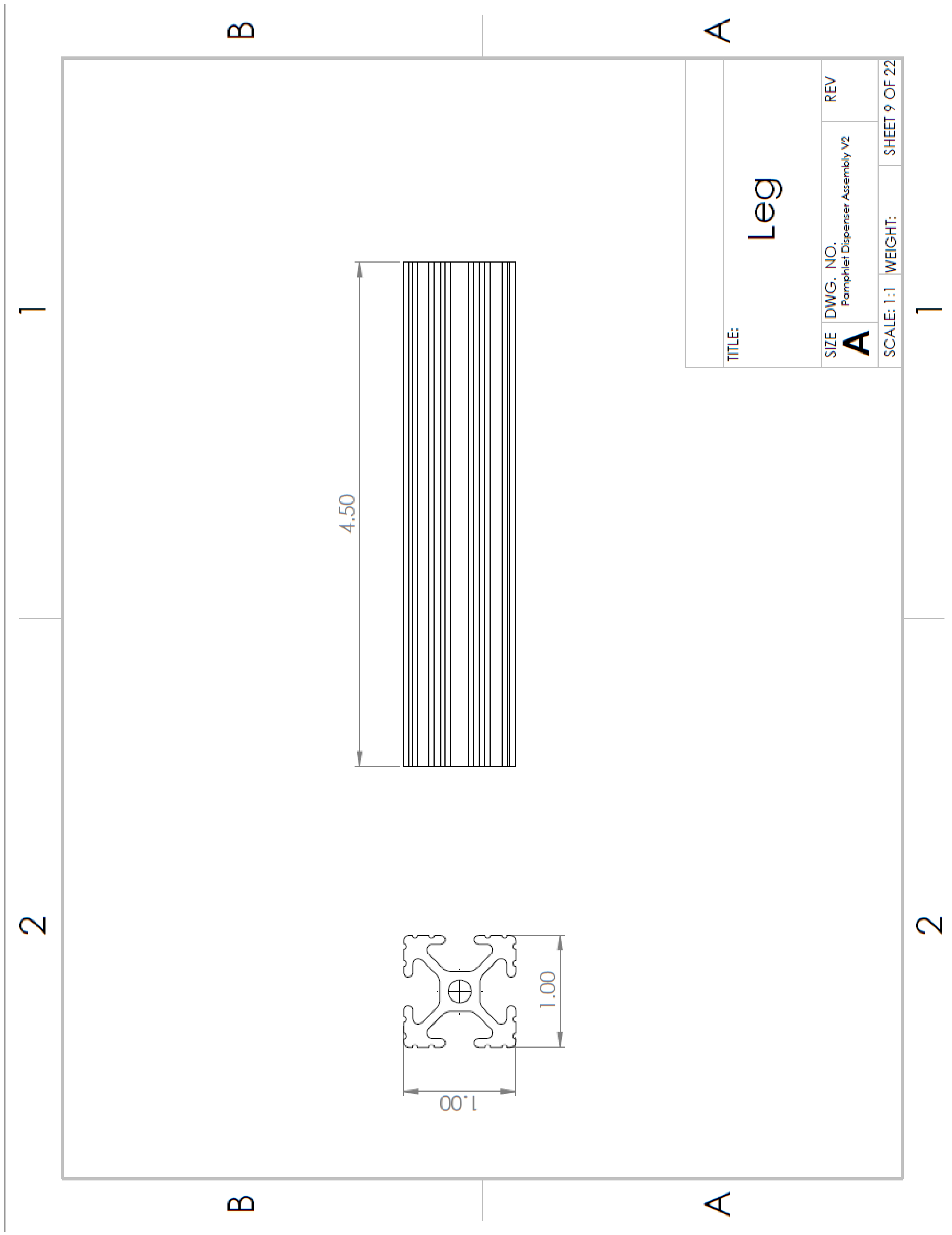

Figure 96: Pamphlet Dispenser Leg Drawing (not to scale)

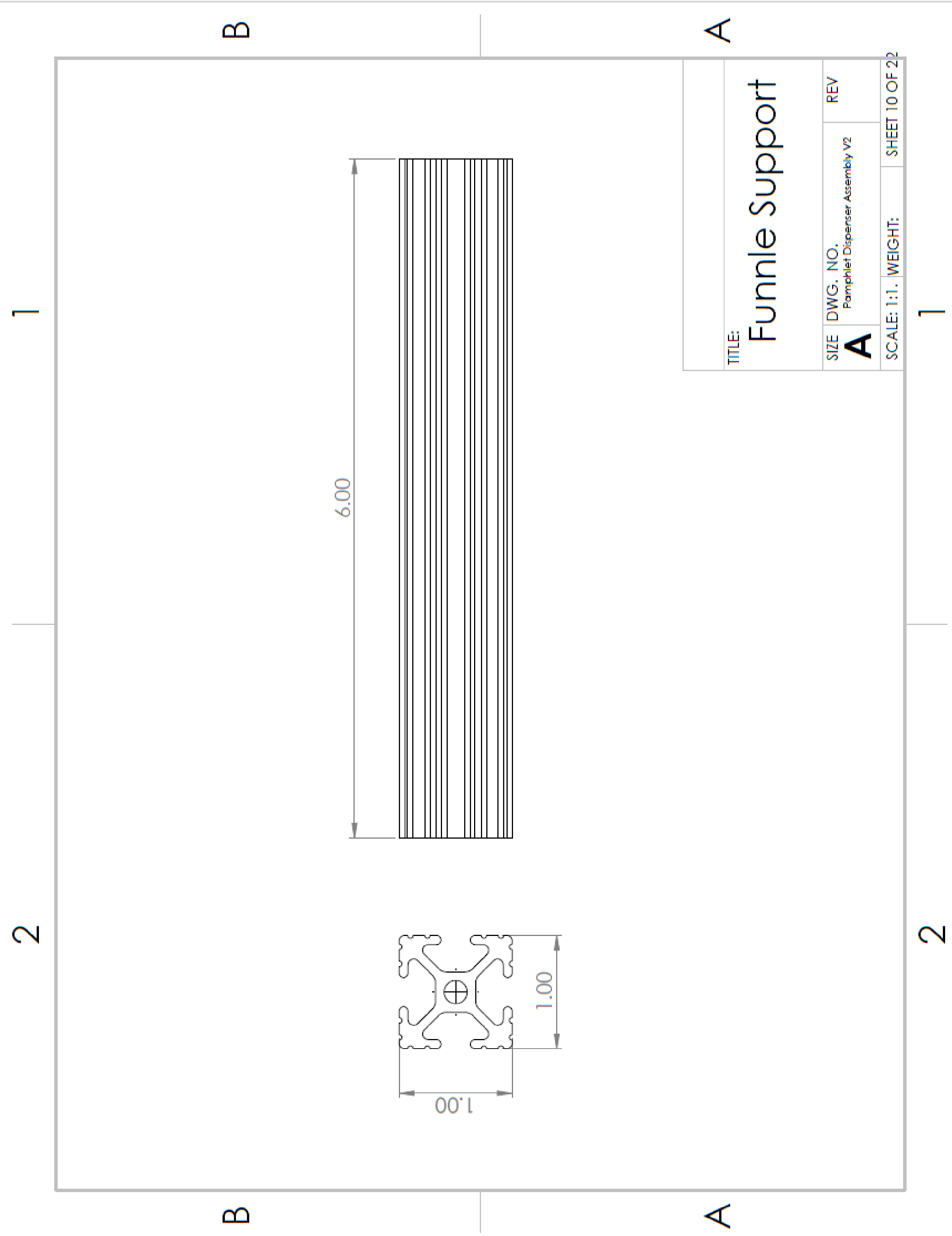

Figure 97: Pamphlet Dispenser Funnel Support Drawing (not to scale)

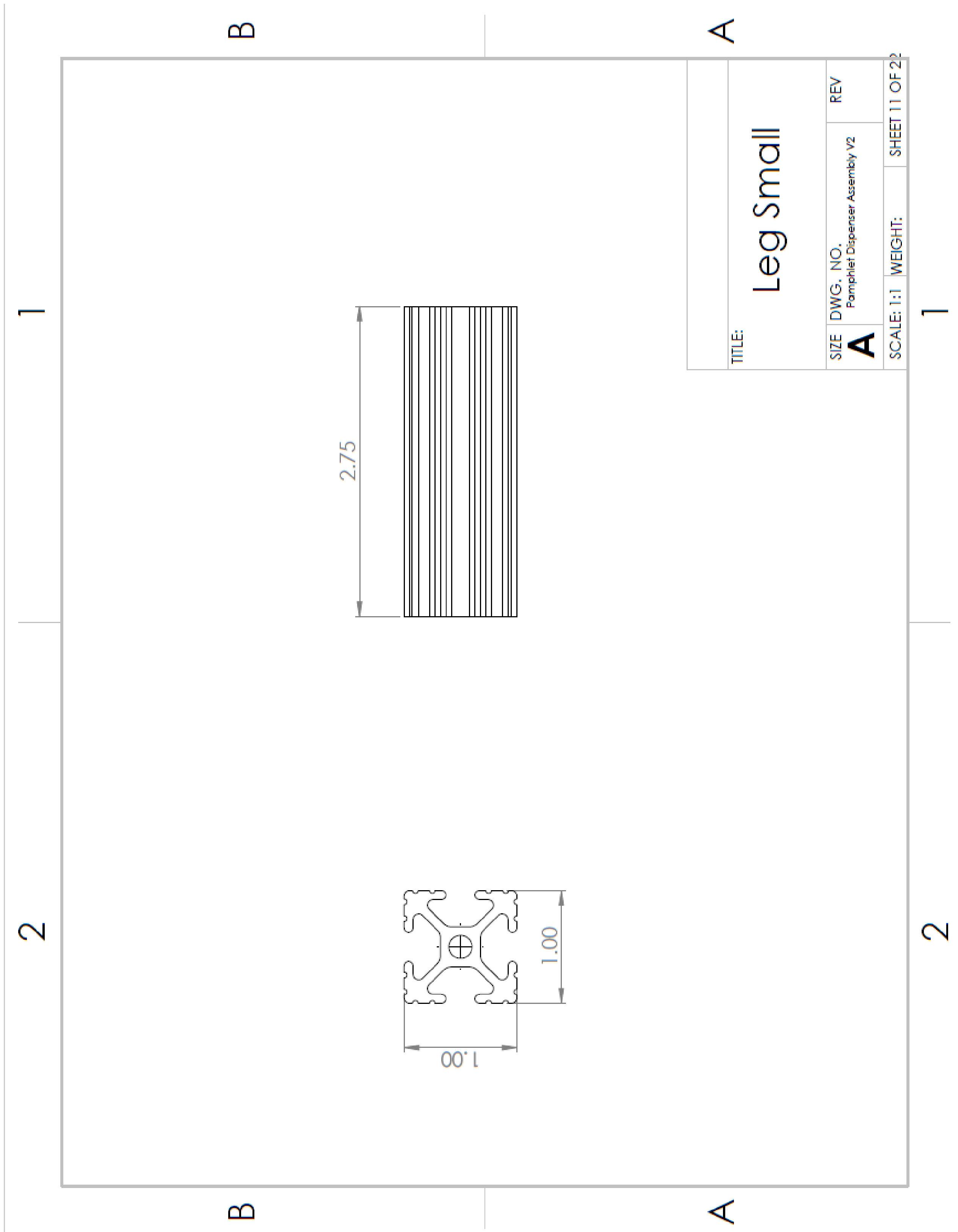

Figure 98: Pamphlet Dispenser Leg Small Drawing (not to scale)

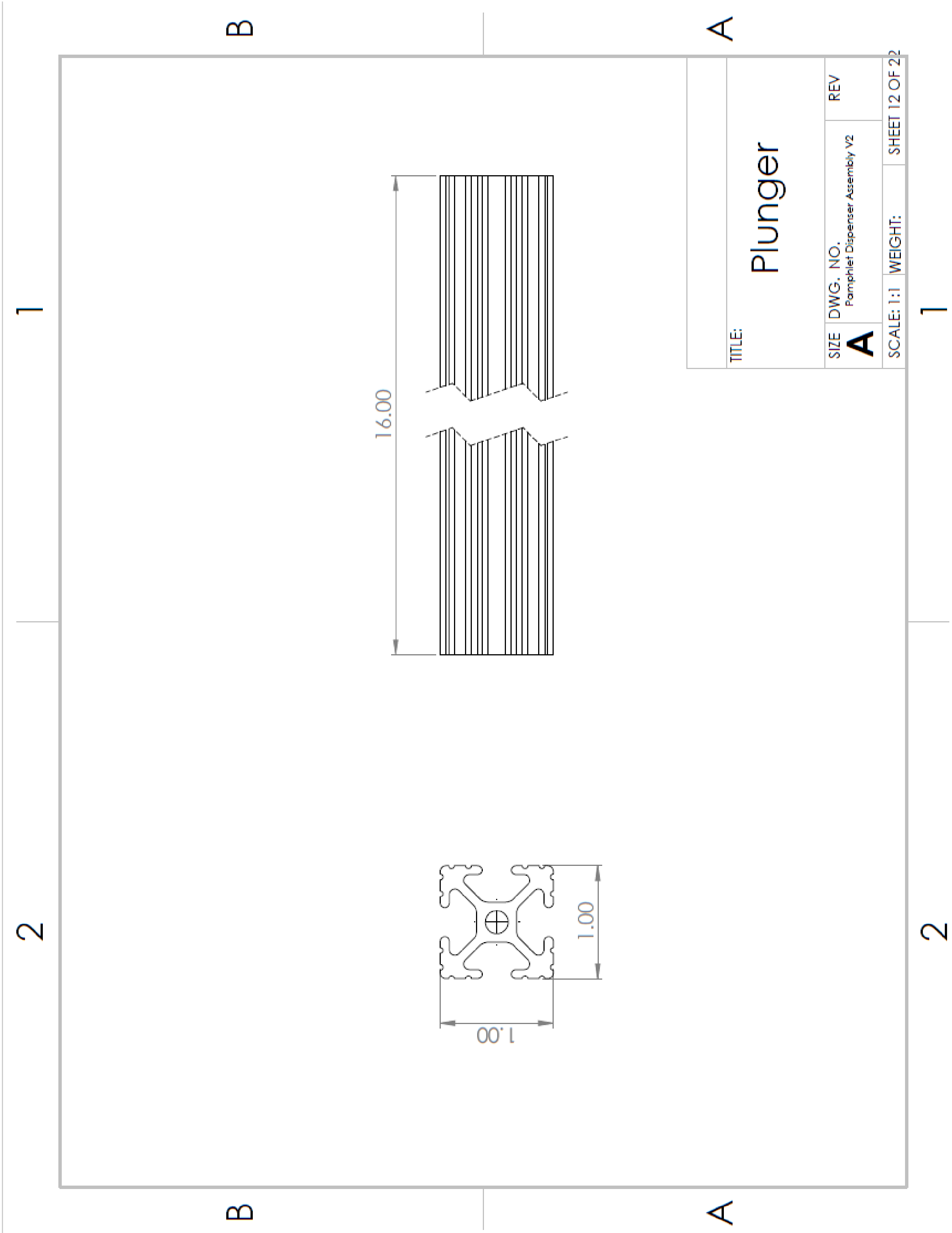

Figure 99: Pamphlet Dispenser Plunger Drawing (not to scale)

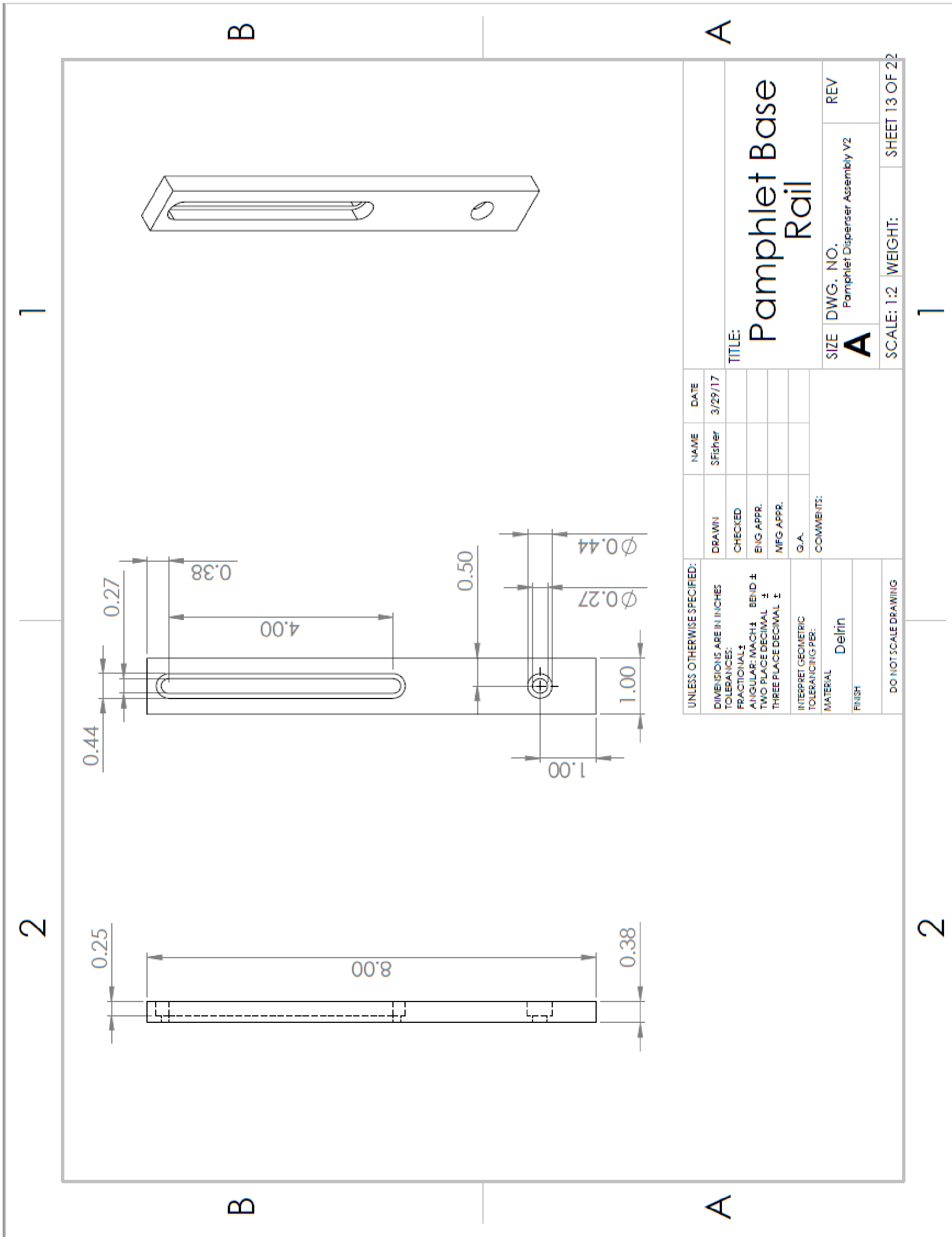

Figure 100: Pamphlet Dispenser Pamphlet Base Rail Drawing (not to scale)

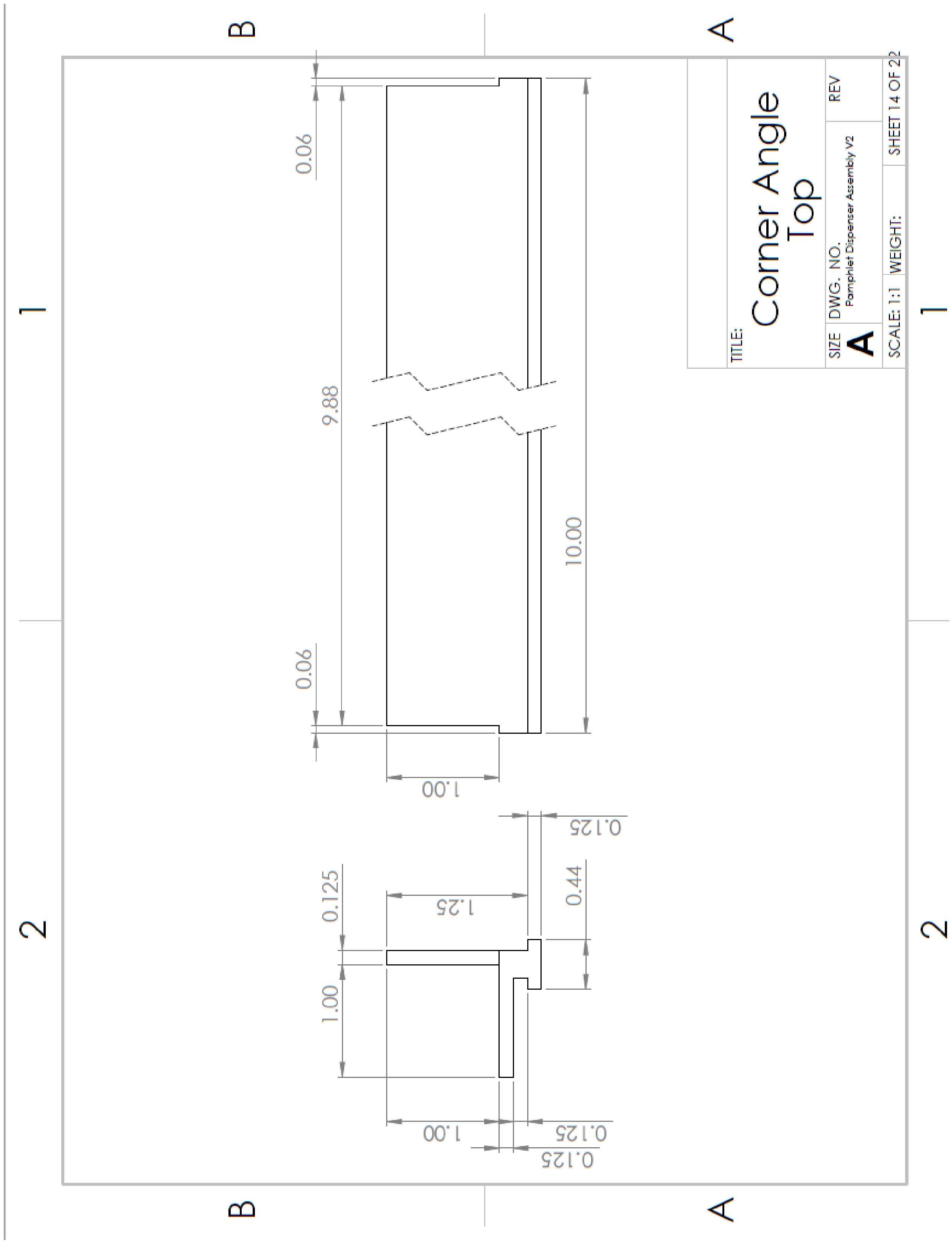

Figure 101: Pamphlet Dispenser Corner Angle Top Drawing (not to scale)

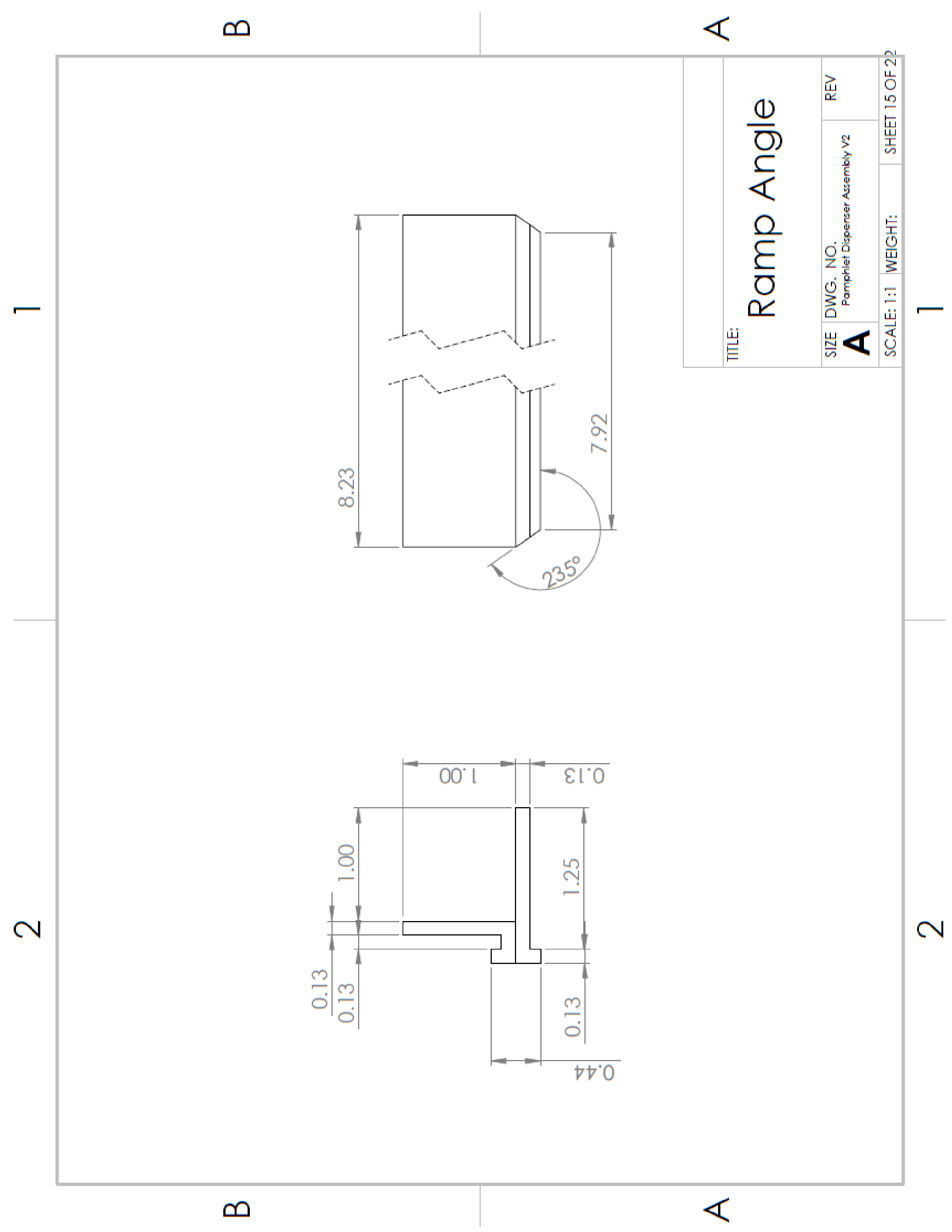

Figure 102: Pamphlet Dispenser Ramp Angle Drawing (not to scale)

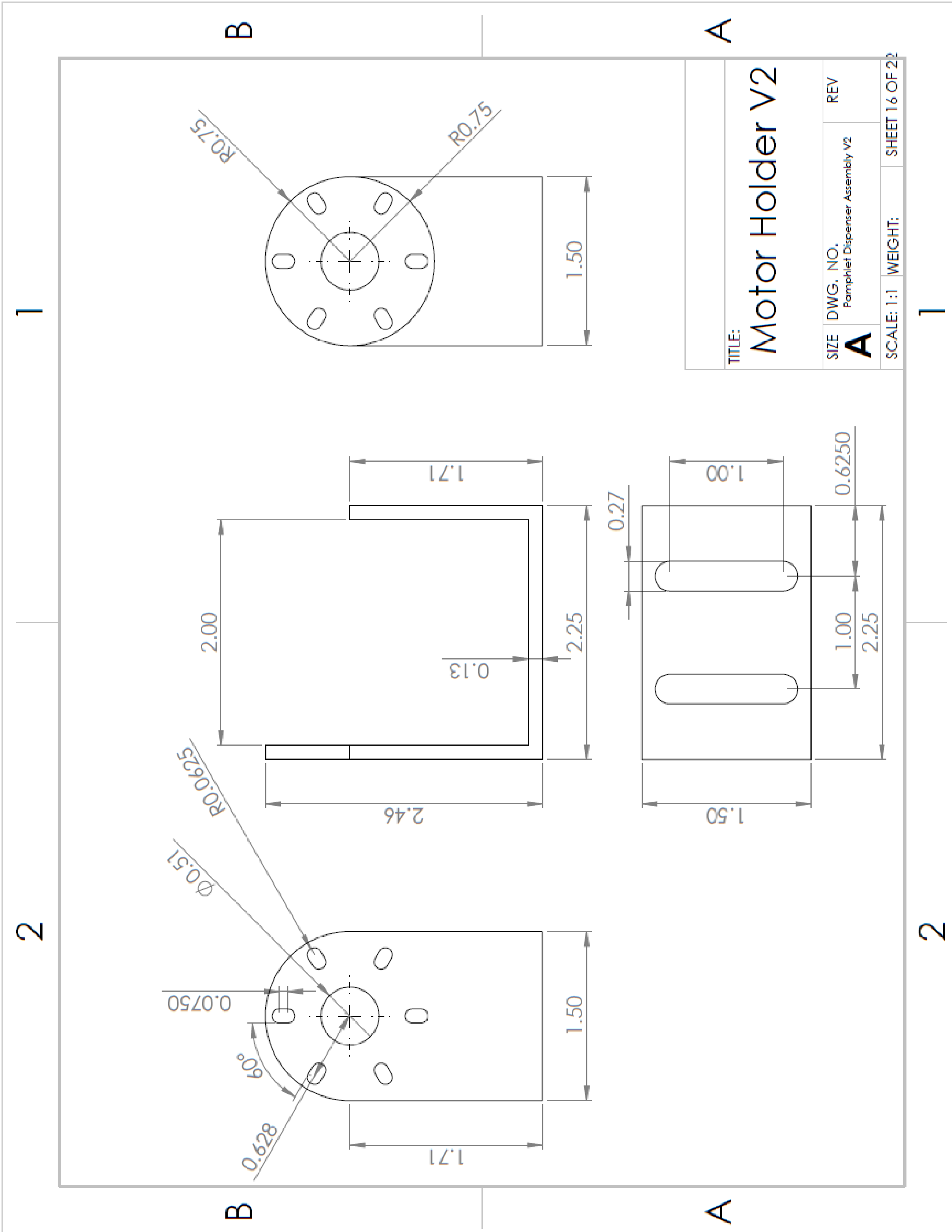

Figure 103: Pamphlet Dispenser Motor Holder V2 Drawing (not to scale)

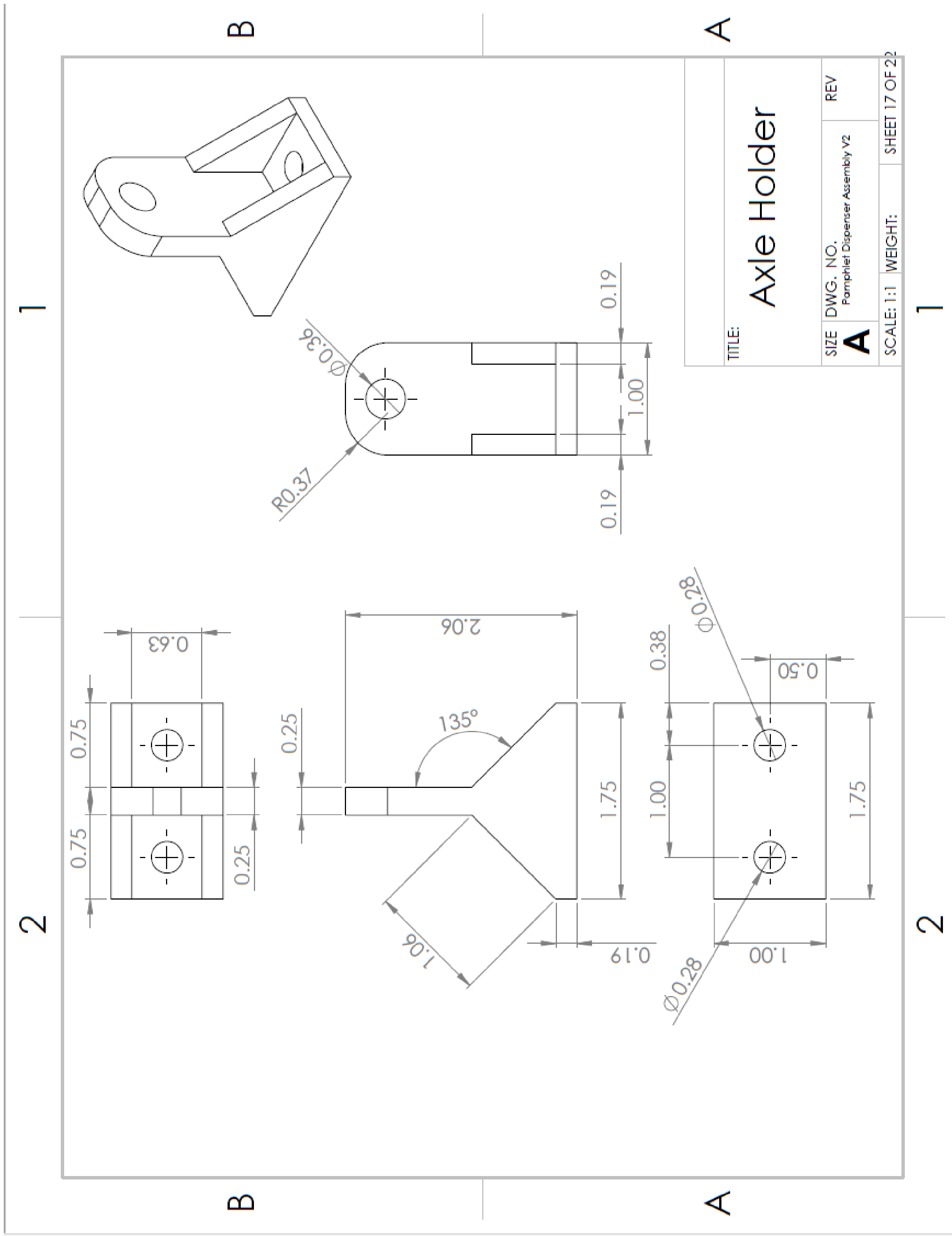

Figure 104: Pamphlet Dispenser Axle Holder Drawing (not to scale)

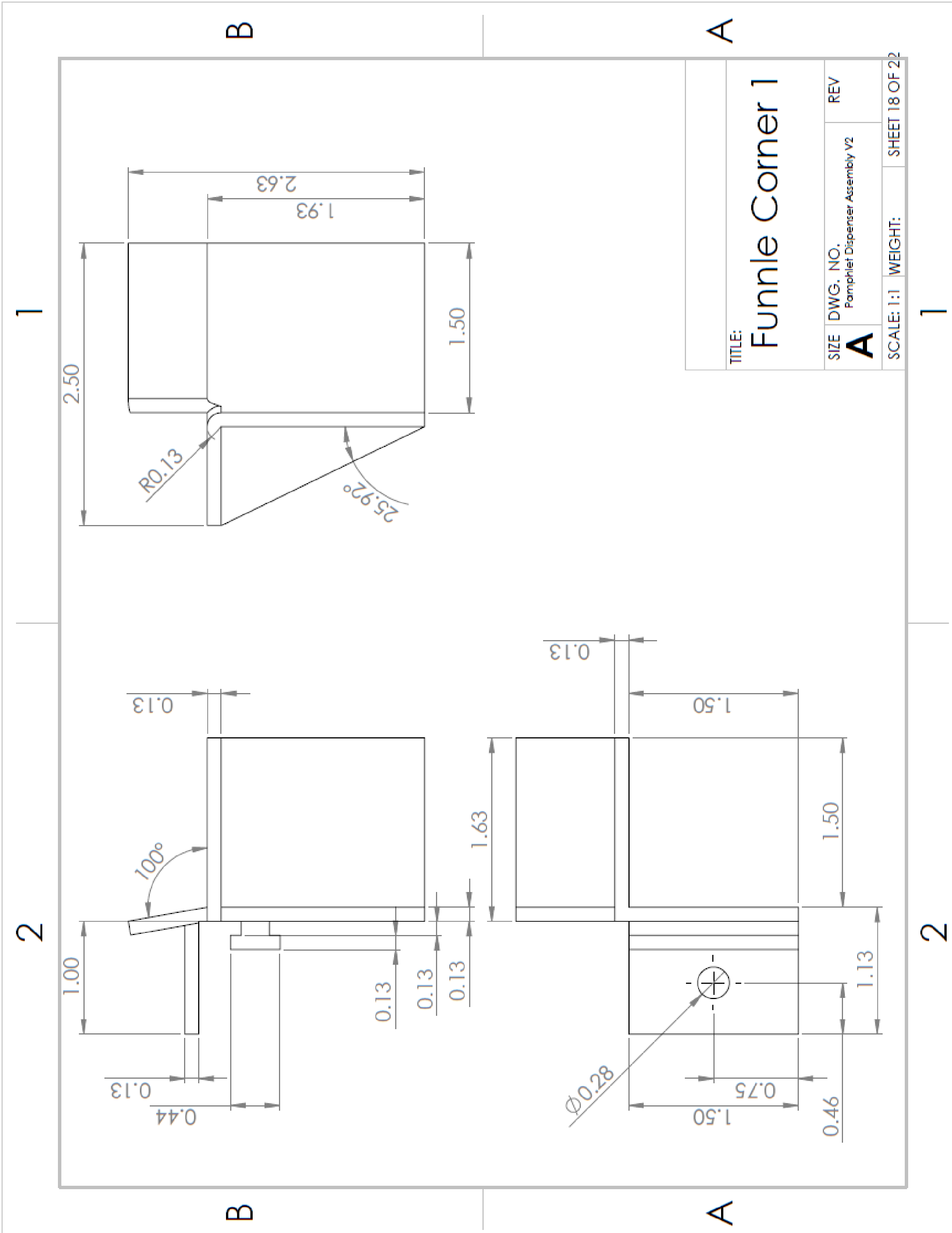

Figure 105: Pamphlet Dispenser Funnel Corner 1 Drawing (not to scale)

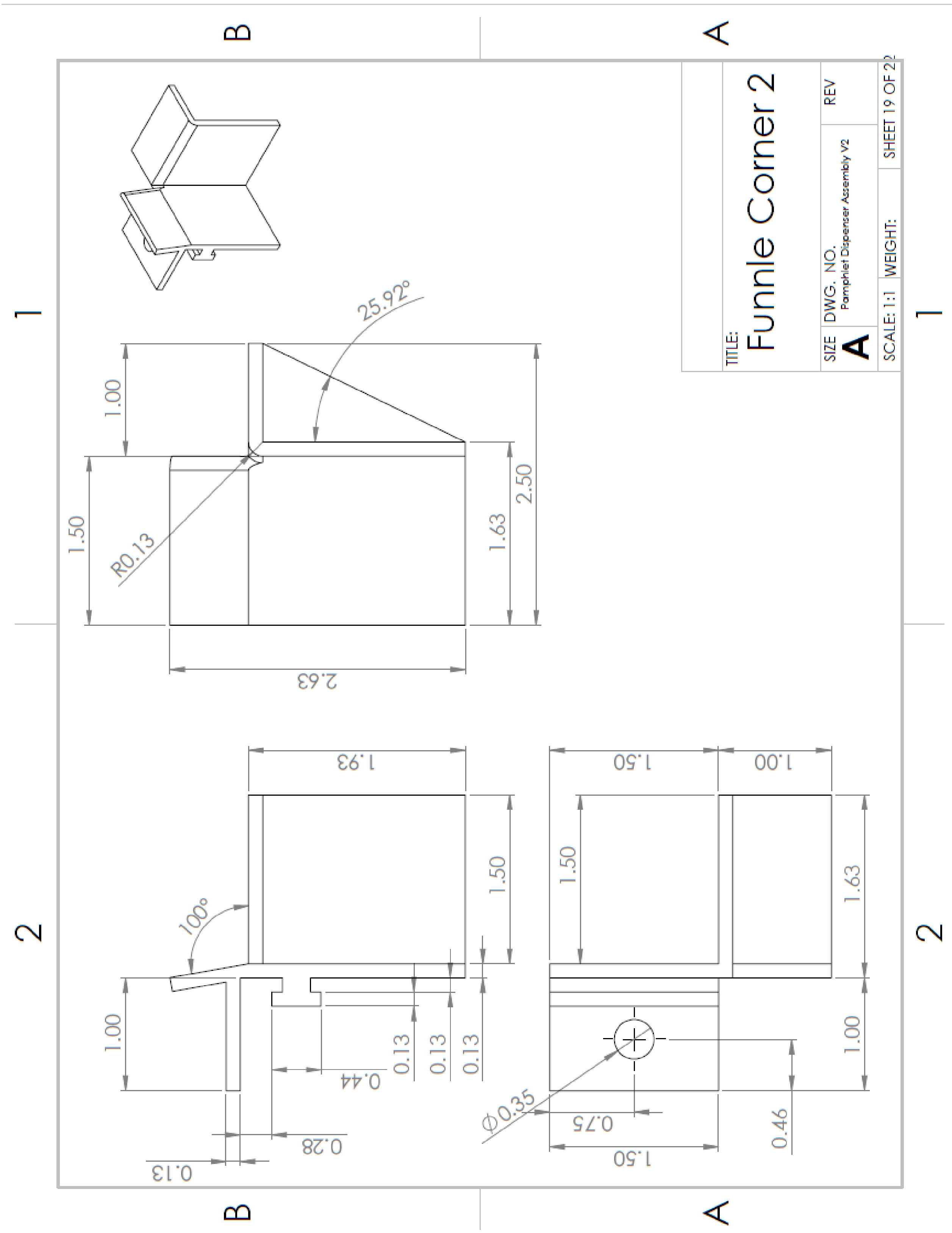

Figure 106: Pamphlet Dispenser Funnel Corner 2 Drawing (not to scale)

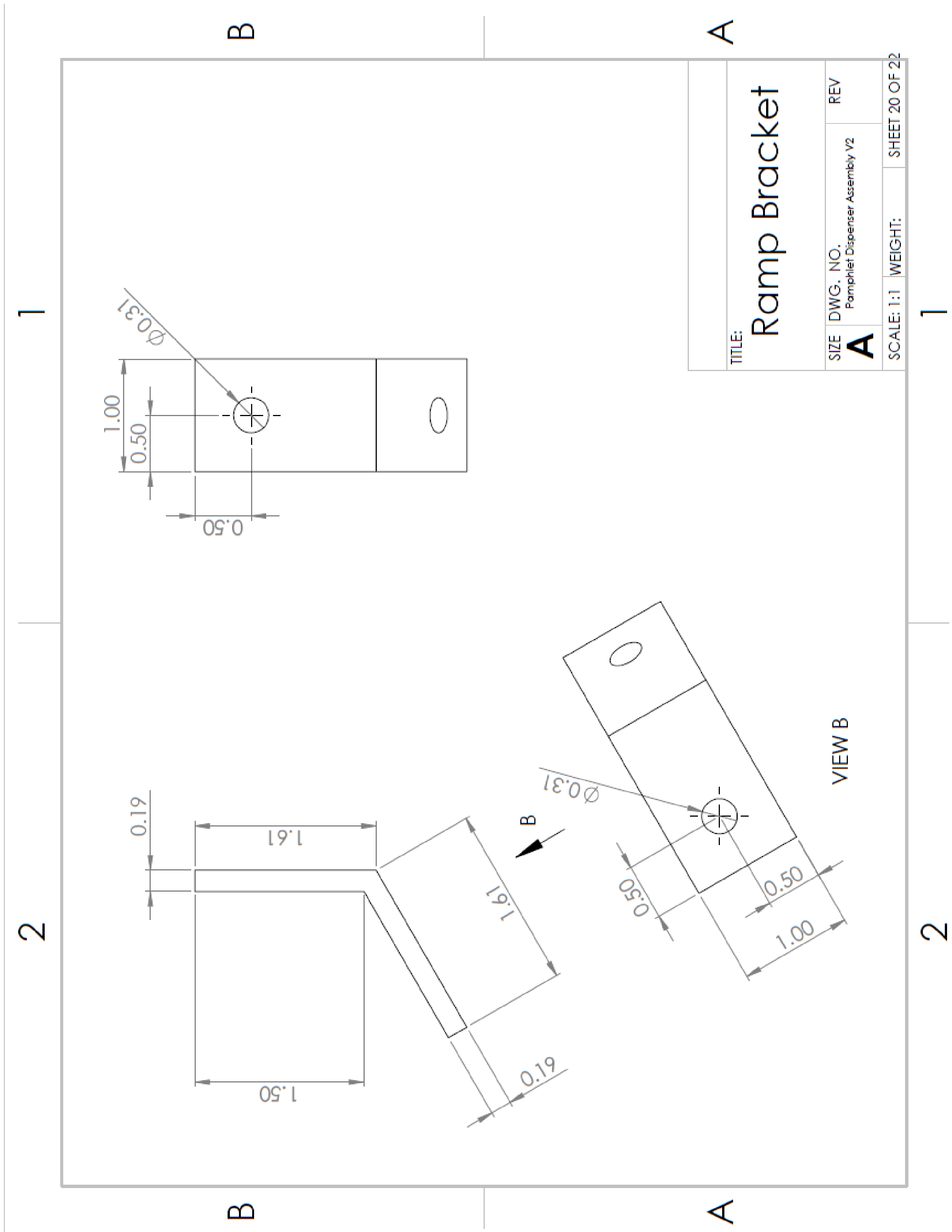

Figure 107: Pamphlet Dispenser Ramp Bracket Drawing (not to scale)

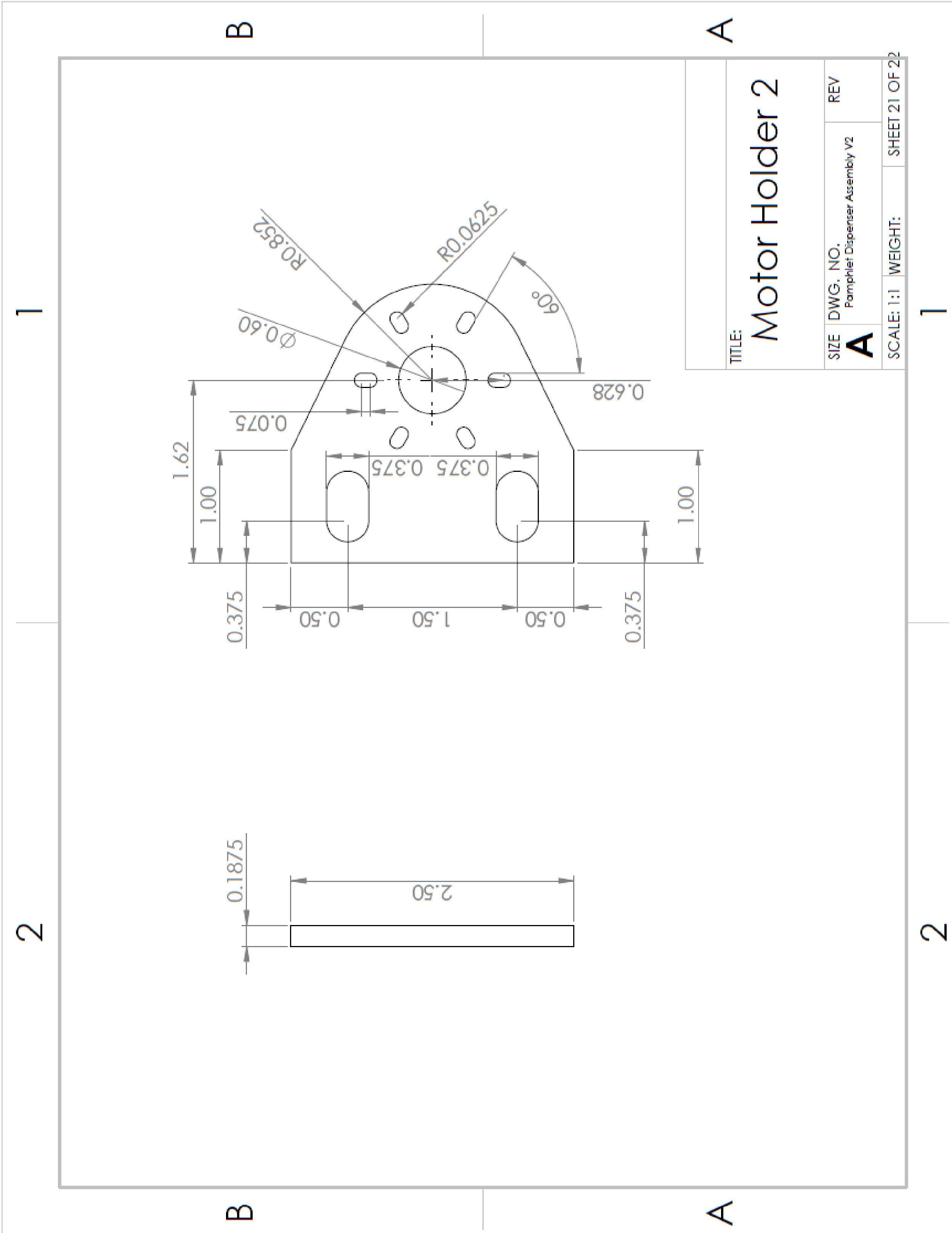

Figure 108: Pamphlet Dispenser Motor Holder 2 Drawing (not to scale)

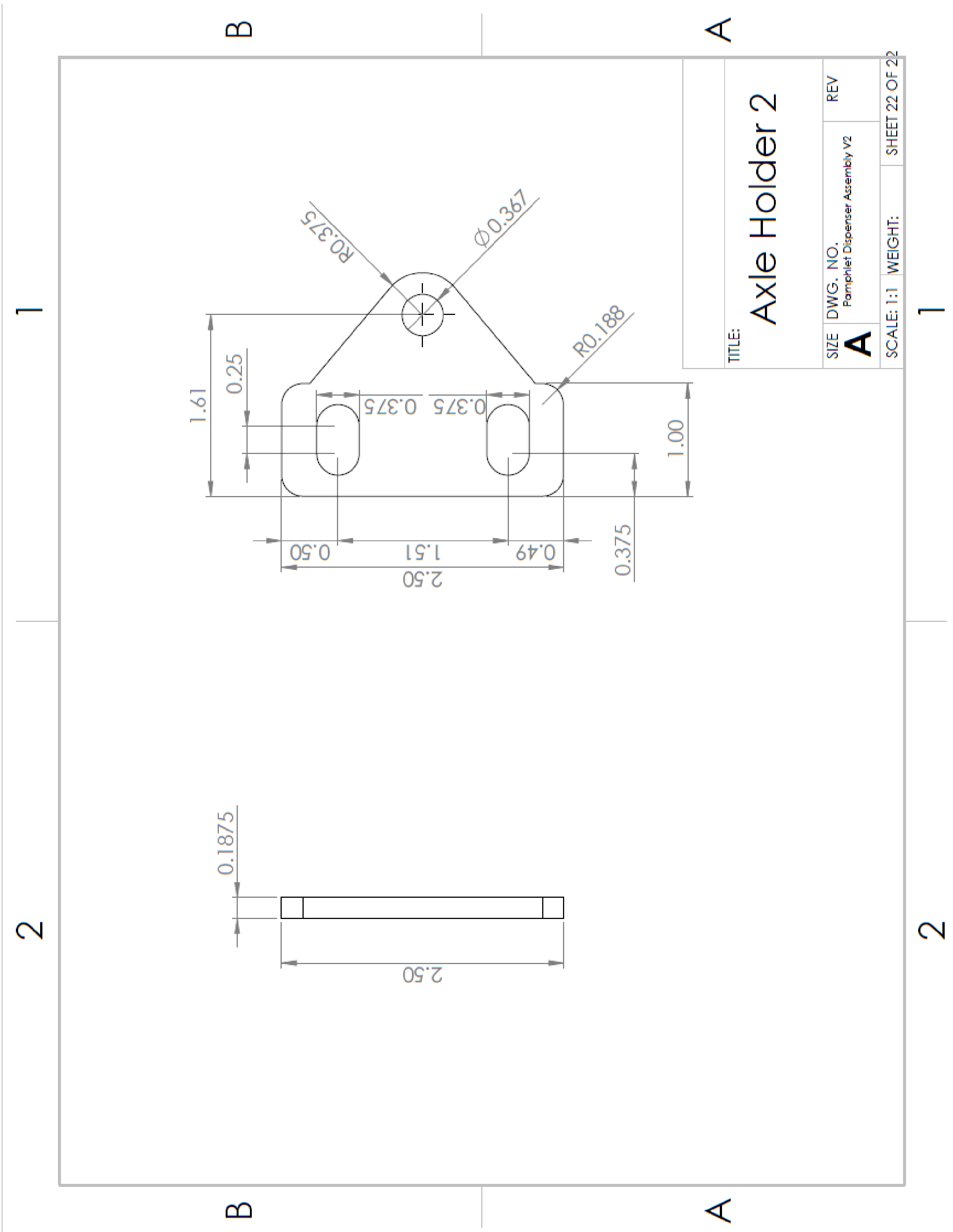

Figure 109: Pamphlet Dispenser Axle Holder 2 Drawing (not to scale)

20.5 Lid Drop

20.5.1 Prototype Drawings

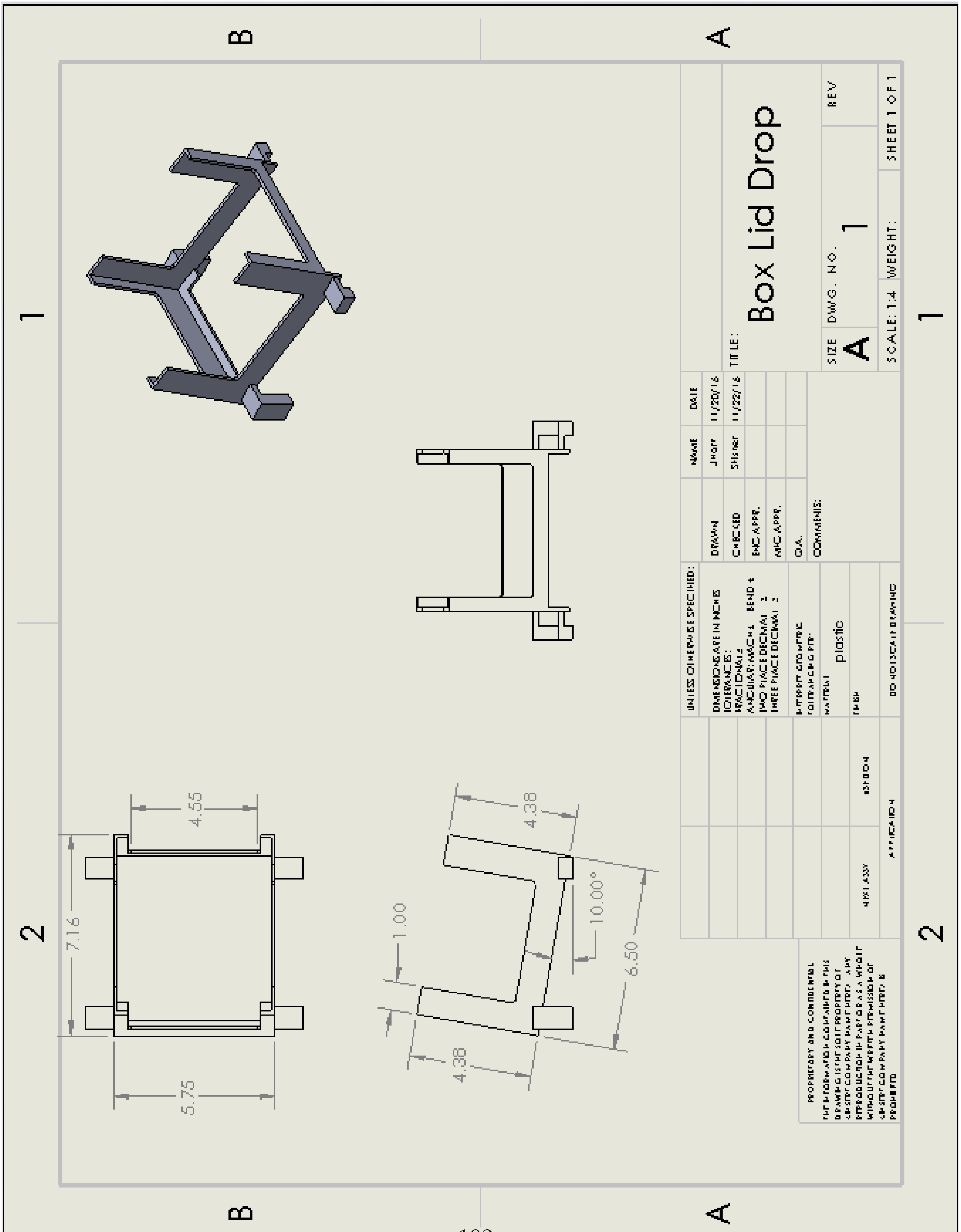

Figure 110: Box Lid Gravity Drop Drawing (not to scale)

20.5.2 Final Drawings

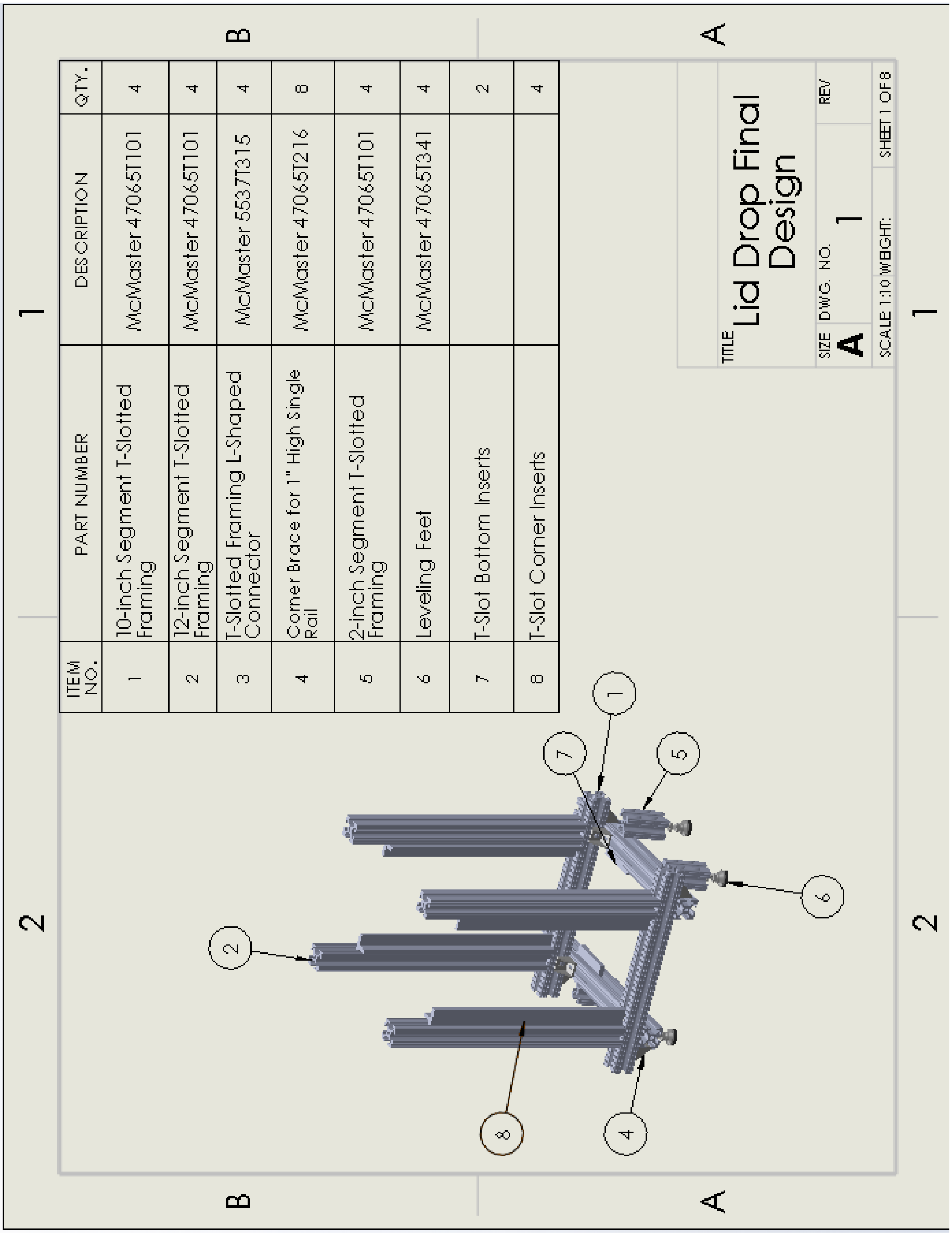

Figure 111: Box Lid Drop Final Design (not to scale)

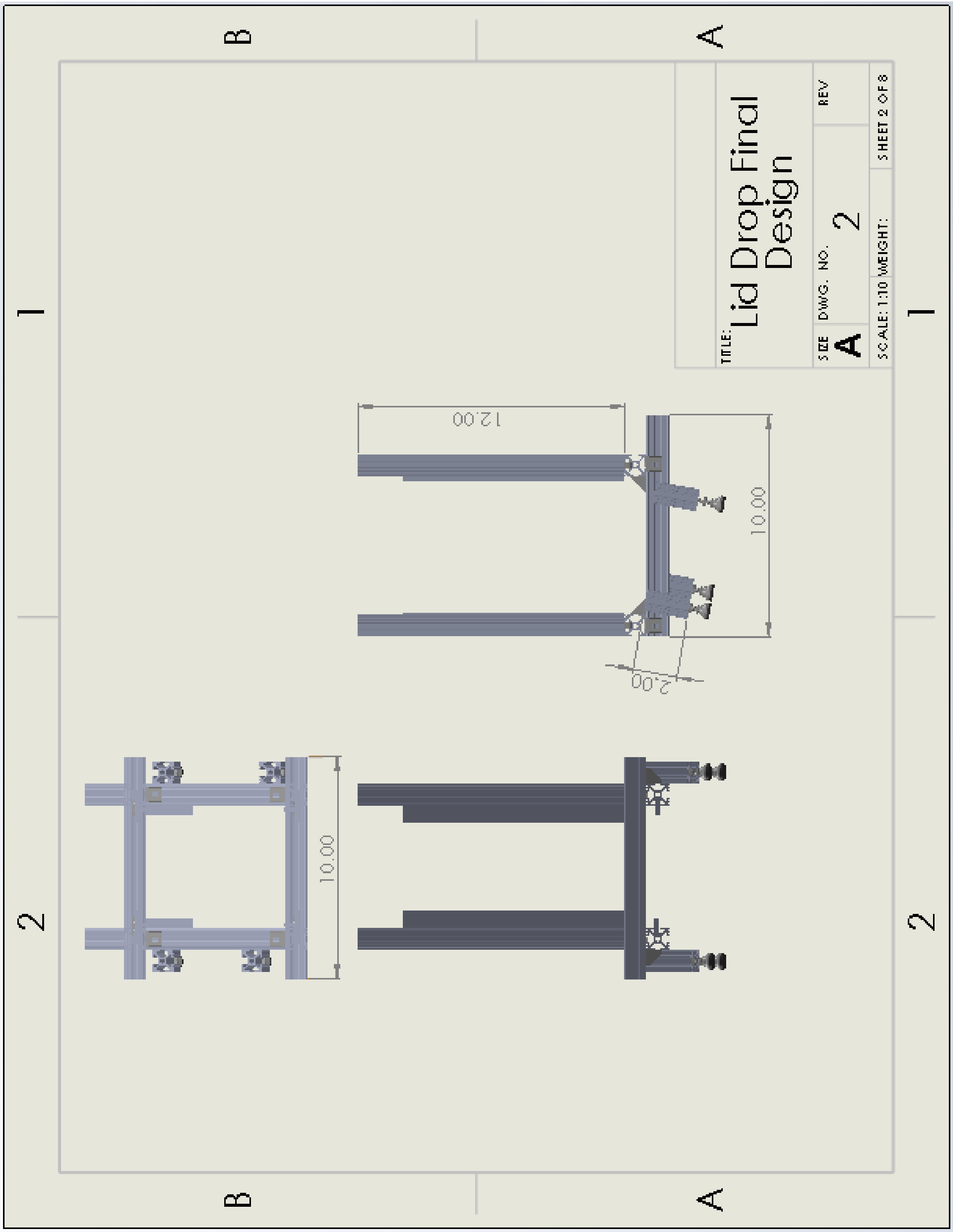

Figure 112: Box Lid Drop Final Design (not to scale)

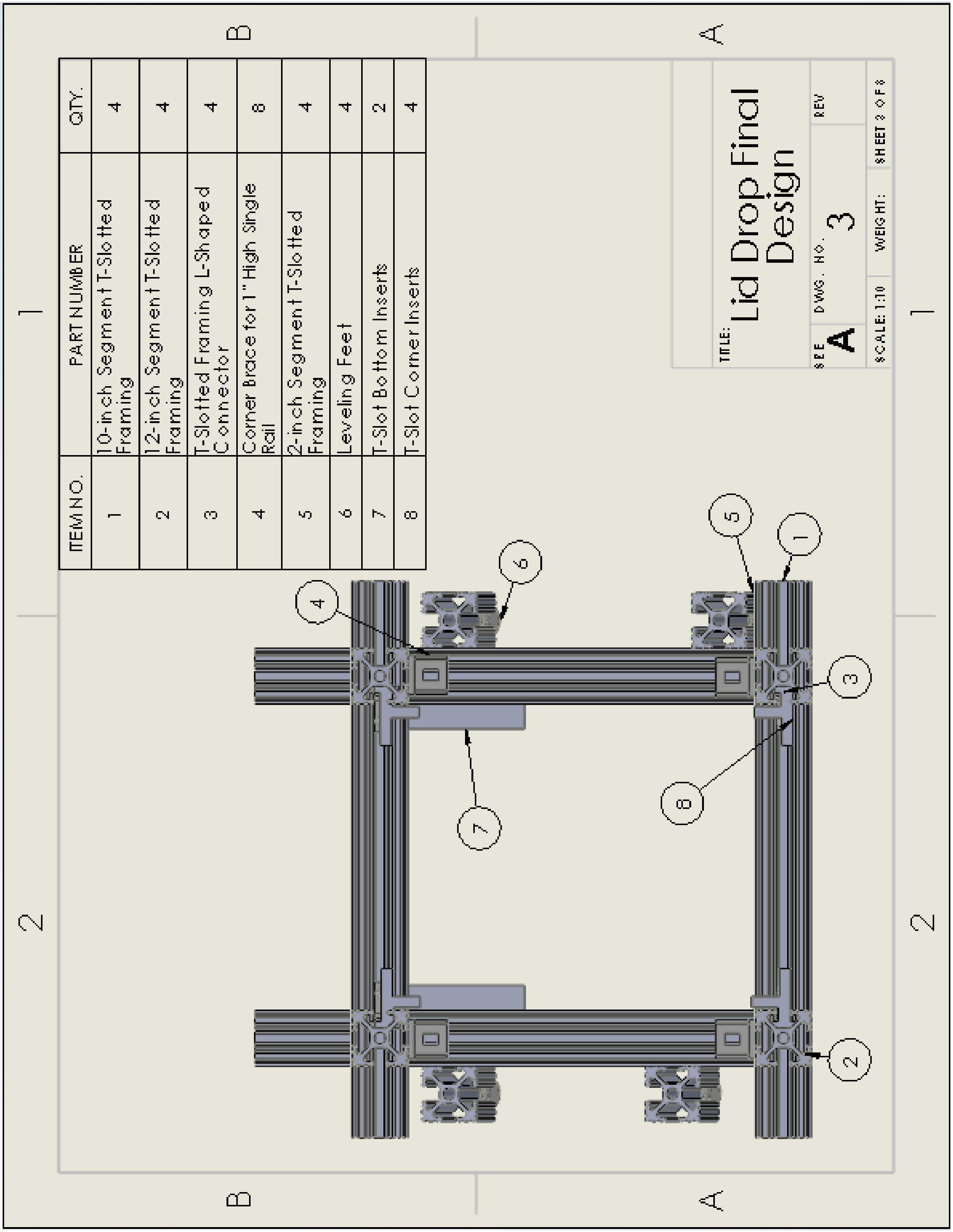

Figure 113: Top View of Box Lid Drop Final Design (not to scale)

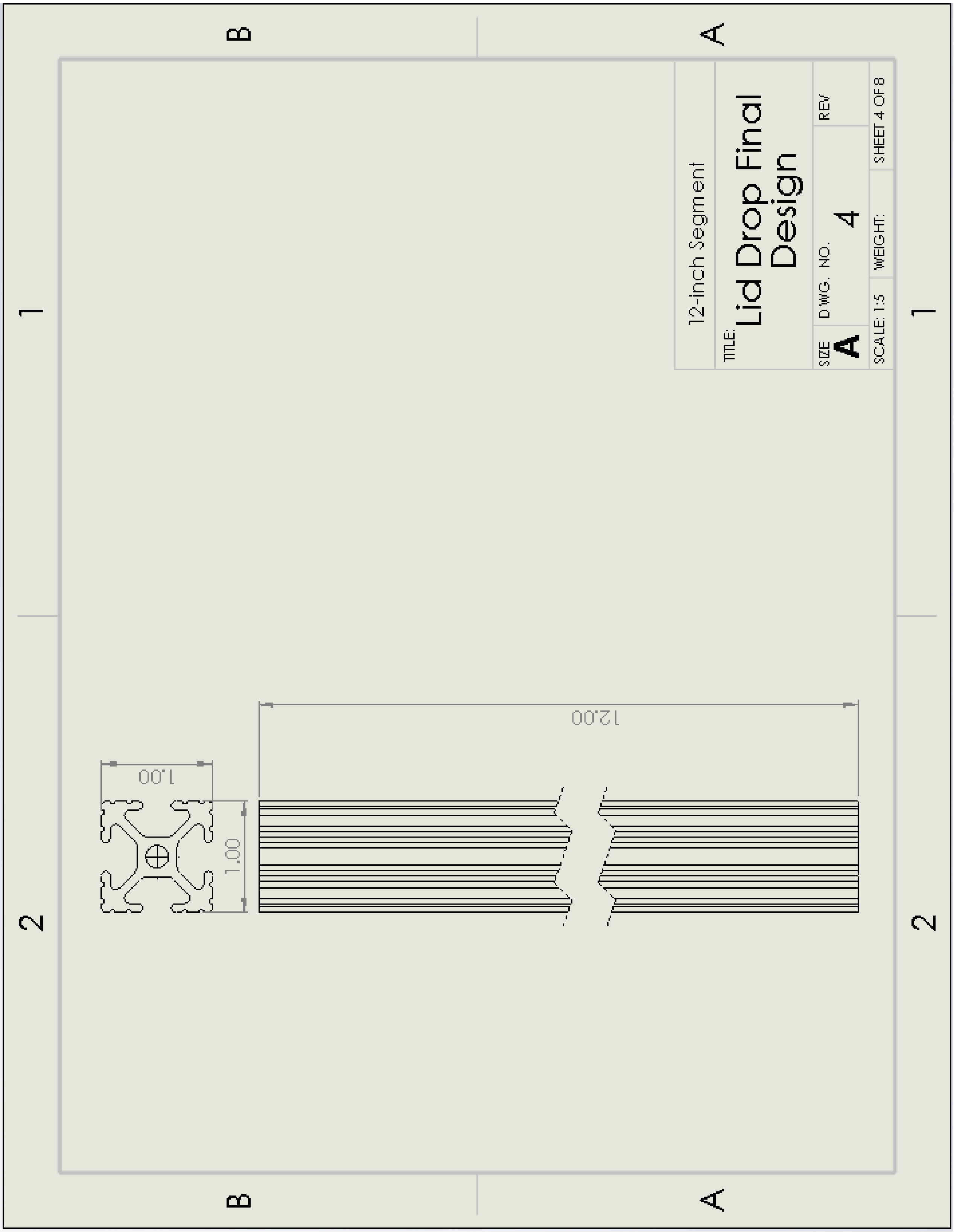

Figure 114: 12-Inch 80-20 Segment (not to scale)

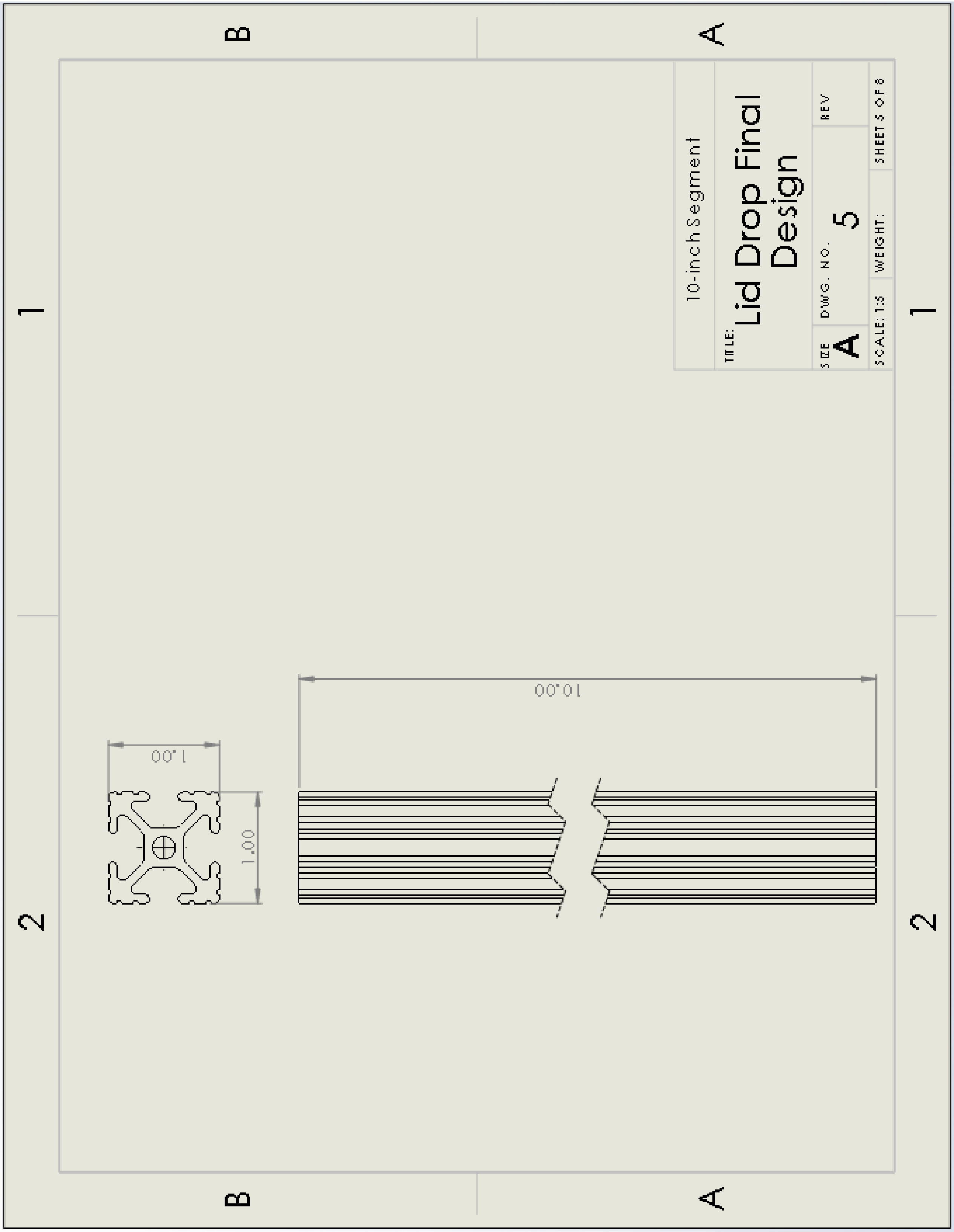

Figure 115: 10-Inch 80-20 Segment (not to scale)

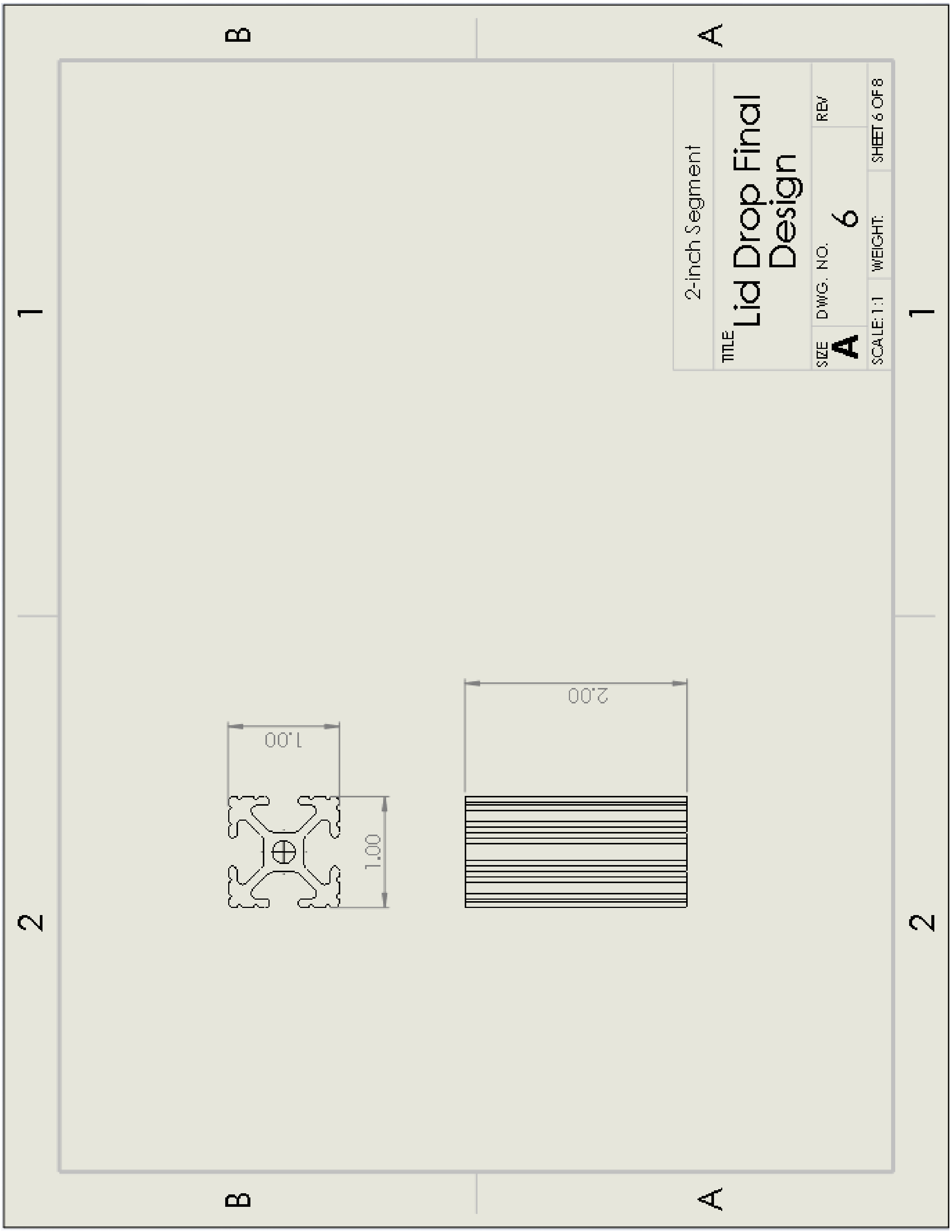

Figure 116: 2-Inch 80-20 Segment (not to scale)

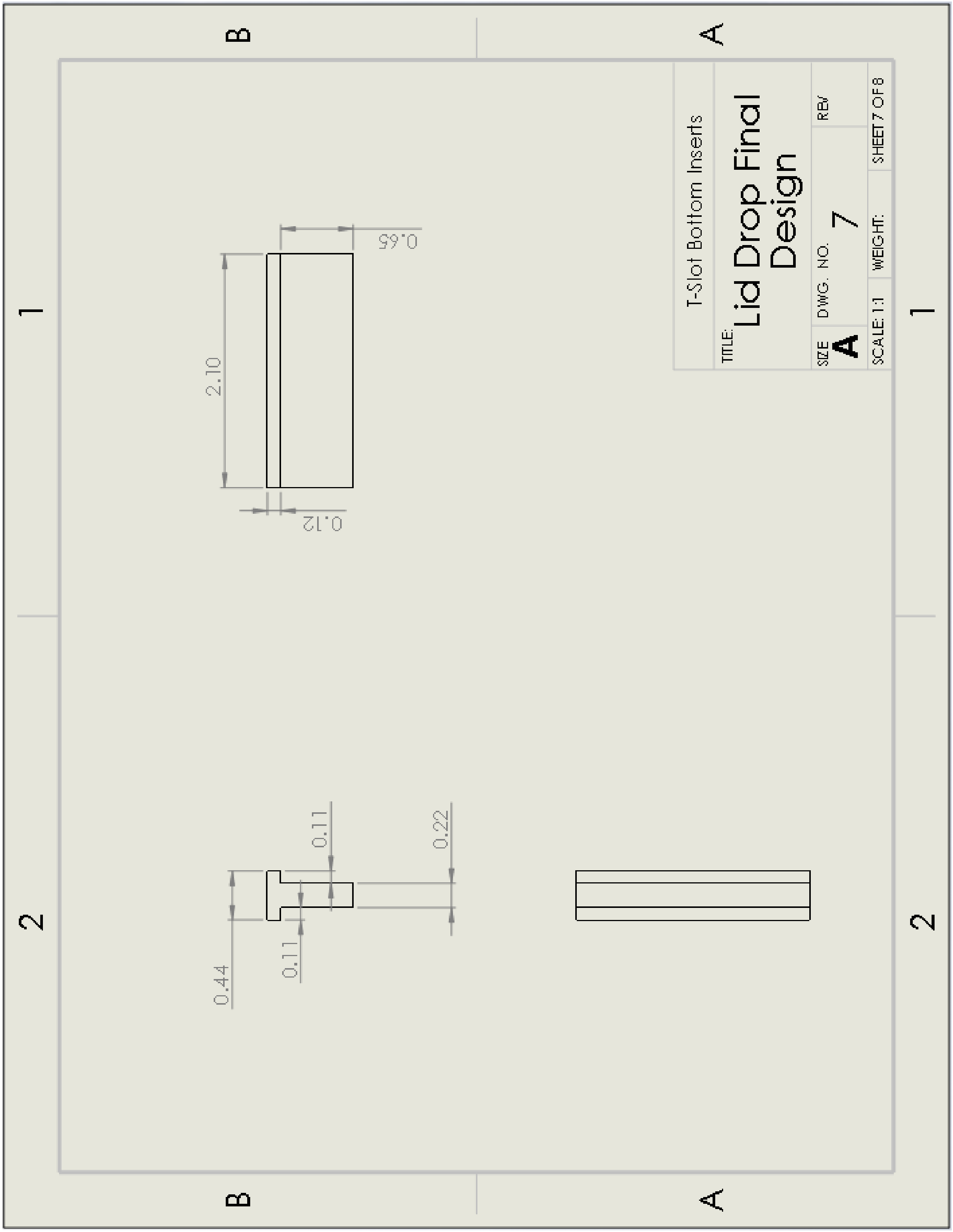

Figure 117: T-Slot Bottom Inserts for Box Lid Drop (not to scale)

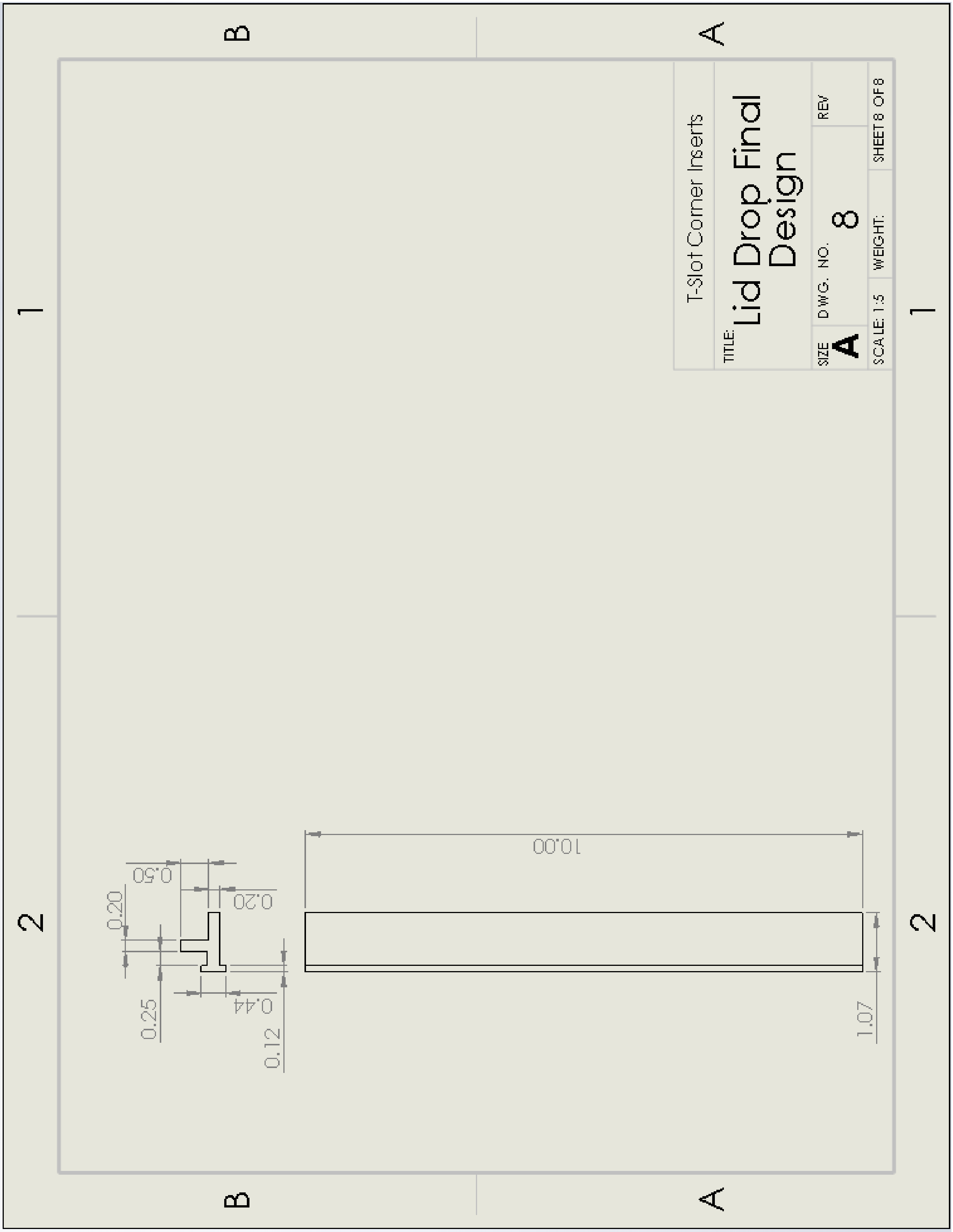

Figure 118: T-Slot Corner Inserts for Box Lid Drop (not to scale)