ME 450
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FINAL DESIGN REVIEW REPORT

Team 12 - Robotic Automation to Reduce Environmental Waste

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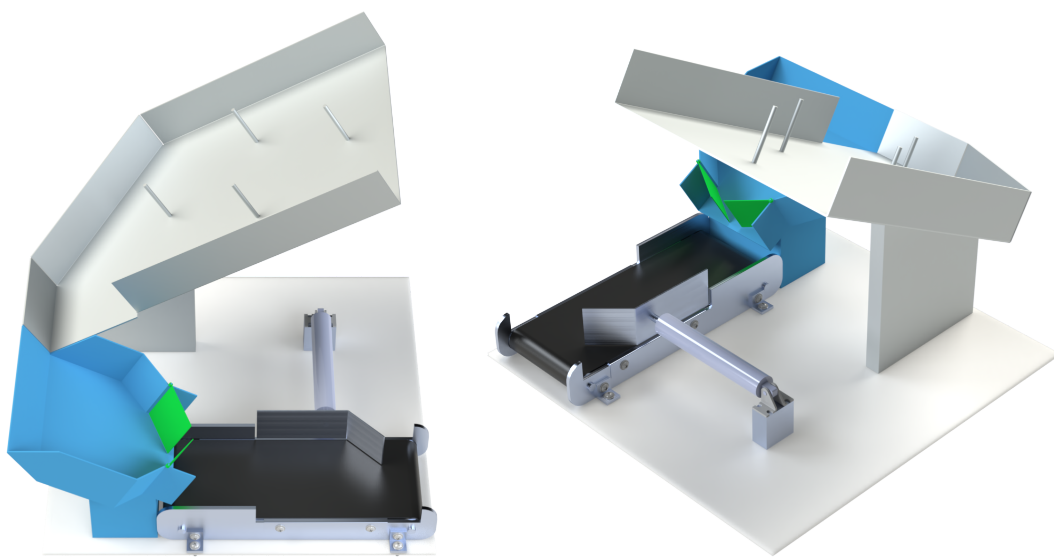

Figure a. Rendered images of the final design.

"We have fully abided by the University of Michigan College of Engineering Honor Code"
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1 ABSTRACT

With the increase of the world's population, the waste generation, especially food waste, is exponentially increasing. Composting, the recycling of organic waste, has been proven to effectively manage food waste. Instead of burning it in the landfill, the compostable waste can be processed into biofuel or biosoil. With the benefits of composting clear, such a method poses many challenges, including the contamination of the processed matter. This project focuses on the action aspect of the robotics approach to improve the physical sorting during the composting cycle. From concept generation to down selection processes, a detailed design process is used to ideate possible sorting mechanisms that could be implemented in composting. Potential candidate designs as well as the Alpha Design will be discussed. A virtual model as well as a functional prototype of the selected design are also discussed. A discussion on how an iterative design process allowed for the development of an adequate solution to a problem is also presented.

2 INTRODUCTION

2.1 Contextual Background

In today's day, the question of the condition of our environment is a concern on everyone's mind. As we work to navigate towards more sustainable methods and practices, many individuals and organizations are opting for ways they can make more mindful decisions. To keep up with today's growing population, agricultural technology has enabled the production and yielding of crops to feed the population, but the rise in farming efficiency has led to mass production of food where a significant amount is not used. In fact, according to the Feeding America organization, 119 billion pounds of food is wasted each year in the US, which equates to 130 billion meals and nearly 40% of all food in America [1]. (Further discussion on societal and environmental impact is touched upon in Section 4.2). One practice for improving sustainability in food consumption practices is composting- which is the process of decomposing organic and biodegradable contents in a soil mixture to capitalize on the biological process to source the nutrients from the degradation of the organic matter into a nutrient dense potting material. Such a process includes six main stages: generating and collecting the waste, transporting and sorting of compostable materials, processing and reusing the recycled organic matter (see Fig. 2.1, pg. 5). These steps are derived from a general compost cycle loop that is widely implemented [2].

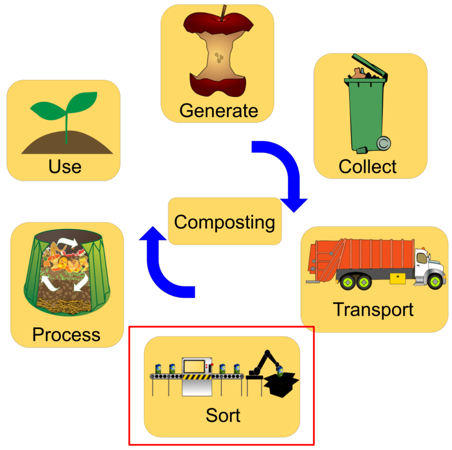


Figure 2.1 Six main stages of the composting cycle. The "Sort" stage is where most of the contaminant separation occurs; thus, most of the improvement can be made. This project is focused on improving the sorting stage of the cycle using automation.

There are several applications of compost waste. These compostable materials can be recycled into burnable biofuel which can be used for power generation. A recent study showed promising results supporting the idea of using organic compost waste as an energy source for a Rankine cycle power plant [3]. Yet, the efficiency can depend on the impurity of the organic matter that is used to process the fuel. A more widely used area for composting is farming. This waste can be processed into biosoil and fertilizers which, if properly used, can promote the lifecycle of important crops.

2.2 The Composting Process

The composting process capitalizes on the decomposition of organic material into a soil mixture to encapture the vital nutrients for plant growth such as Carbon and Nitrogen. As plants grow they extract these essential elements from their surroundings which include the soil, which is why incorporating fertilizer is important to resupply the growing substances in farming. Additionally, the use of composting itself poses many benefits from the following: reduces the waste stream, cuts methane emissions from landfills, improves the solid health and lessens erosions, conserves water, and reduces personal food waste [4]. According to the Natural Resources Defense Council, it is estimated that the average cost to landfill municipal solid waste in the U.S. was around $55 per ton in 2019 [4]. Furthermore, the US generated more than 267 million tons of municipal waste in 2017 with two-thirds of that ending up in landfills and incinerators. Through composting, these wastes can be greatly reduced by turning them into reusable resources.

When organic matter decomposes, it undergoes the aerobic decomposition in which micro-organisms break down the matter through an oxygen-dependent process. However, in landfills the waste is piled on top of each other cutting off access to oxygen, so the decomposition works through anaerobic decomposition in which the micro-organisms break down the matter without free-flowing oxygen. This creates biogas as a by-product with half of it being methane and the other half CO_2. It is also reported from the NRDC that due to the fact that solid waste infrastructure is designed around landfilling, only about 6% of food waste ends up getting composted [4]. Overall, composting serves many benefits although such a method is not so perfectly implemented yet.

As with any process, composting has conditions and requirements in order to achieve a high quality output. As stated earlier, composting utilizes the decomposition process therefore prefers conditions favoring the anaerobic process: moisture content of around 40-60% by weight, an increase in compost temperature from 40-50C within 2-3 days (the mixture contains adequate nitrogen and moisture for rapid microbial growth), neutral to acidic conditions with the pH ranging from 5.5-8 [5]. However, with any procedure, there is always the possibility of error and for the context of composting that would occur in contamination in the mixture. The main concern of potential contaminants in composting for our scope is man-made inserts which are trash that get mixed into the compost feedstock and end up in the compost mixture. These can include metal, glass, plastic, textile, and other objects that do not decompose entirely during the composting process [6]. While they don't necessarily pose dangerous consequences, they do decrease the quality of compost. A study in France showed that after 22 years of using not completely sorted compost waste, the concentration of microplastic in the soil increased statistically significantly. In general, if contaminants are present in the compost waste, they will sit there without breaking down during the composting process [7]. Of course, using contaminated soil demotes crop health. The most logical solution to compost contamination is refining the sorting process of compostable and non-compostable matter to adequately sort before sending the contents to waste management facilities.

2.3 Project Description and Scope

The amount of waste is exponentially increasing that any type of manual sorting would not be feasible on a large scale. In order to automate the process, both the software and mechanical components of the system must work together to create a safe and efficient ecosystem. Therefore, the robotics approach to solve the sorting issue in order to prevent contamination through automating the process is appropriate. First expounding on the fundamental principles of the three aspects of robotics; perception, reasoning and action [8]. Where the perception aspect is the method of capturing vital data to the process and system through the use of sensors, and the reasoning is the processing of the data captured from the perception portion and can be thought as the brain of the robot. With the last aspect being the action, which is the method or manner by which the robot will perform its intended goal.

For the perception aspect, there is information already out there of sensing methods available and those currently in use. As humans, we observe light in the visible spectrum in which our eyes are sensitive to the primary colours red, green, and blue. Whereas computer vision captures monochromatic images using three filters centered at their corresponding frequencies red (700 nm), green (546 nm), and blue (435 nm) to replicate the perception of colours as humans. Computer vision systems have the ability to provide more insightful information in addition to colour such as spatial information, but in many applications images with spatial information are not sufficient to extract important information. To enhance the applications of computer vision systems the combination of spatial and spectral information can be done through the incorporation of hyperspectral and multispectral imaging systems. The hyperspectral imaging technique uses both imaging and spectroscopic techniques in a single system and this captures a set of monochromatic images at almost continuous hundreds of thousands of wavelengths, whereas the multispectral is only within a specific range of wavelengths [9]. Referencing the research paper for the challenges of image processing of fruit and vegetables, the project studied the following aspects: influence of physical variability, whole surface detection, problem descriptions and challenges, and rapid detection systems development [9]. All in all, the main challenge for the perception aspect is making sure the system could adequately identify amongst a potential wide variety in the sorting pool given the nature that organic products have high variability in themselves.

The second robotics aspect is the reasoning principle. This is the part of the robotics system that incorporates data and other forms of machine learning such as artificial intelligence to build the intellectual network used by the apparatus to perform the reasoning behind its action and movement. There is already plenty of literature on machine learning about its use and practice both in academics and industry. One study focuses on the multi-layer hybrid deep learning method for waste classification and recycling, and found a high accuracy in classifications highlighting the efficiency and effectiveness of using the MHS system [10].

Moving to the action aspect of the robotics principles, we can reference the available literature regarding current techniques and practices already in place. This is notably the main aspect that comes to mind when thinking about robotics, in that this is the portion that contains the physical apparatus that navigates within its surroundings to complete the action. There is a lot of material already that can be used as reference for gathering information and brainstorming ideas for design decisions. Once again, the main challenge for the design process is accounting for the potential high variability in performance given the nature of high variance in organic material itself and the potential sorting pool. An interesting research paper from the journal of Mechanisms and Robotics experiments with a robotic gripper to provide a gentle gripping mechanism to handle a wide variety of unknown objects of different weights, stiffness, shape and sizes [11]. While, this is not an established design decision for the action aspect of this project, it provides useful insight to the research already done looking for mechanical solutions for grasping a wide range of shapes, sizes, and stiffness.

This project specifically focuses on the action aspect of the robotics approach. From analyzing to 3D modeling and prototyping, this project will explore different types of sorting mechanisms that can successfully remove various contaminants from a given pile of objects.

2.4 Benchmarking current technologies

There are several sorting machines currently implemented in recycled plastic areas. First being the Tomra Autosort system that uses both a spectroscopy and high-sensitivity electromagnetic sensor passing the contents through the sensor from a conveyor belt as the feeding mechanism, and runs it through a homogeneous light distribution across the entire belt for stable and constant detection to account for shape and distinguish between overlapping objects. The items are then sorted through ejecting the rejected items using pneumatic pumps pushing them out of the feeding mechanism [12]. Second, is the RoBB-AQC which is a fully automatic sorting machine that also utilizes a conveyor belt as the feeding mechanism and the contents run through the near-infrared technology, which allows the items to be detected from its material composition. Using its AI learning system, the machine then uses a mechanical arm that removes the identified target objects through a vacuum system to pick the rejected item out of the conveyor belt [13]. Neither of these machines are sorting specifically compostable contents, and their pneumatic powered actuation might not be practical for our project application; however, they provide useful insight for sorting technology already in current use that incorporates image sensing, machine learning, and some sort of action to perform the movement of sorting. It is important to note that this information is only to provide some background knowledge of these topics, and they do not indicate any design decisions; they are only used to brainstorm potential ideas and concepts.

This project is a new initiative and in its pilot phase. The team has been given the liberty to choose which aspect of the robotics principle they would like to work on for this project and has chosen the action aspect. A successful project outcome would entail a physical apparatus that can perform the action part of sorting to serve as an educational demonstration of the application of robotics towards solving mechanical and technical engineering challenges.

2.5 Problem Statement

The project aims to examine the sorting process of compost waste in order to reduce contamination. It will be conducted using automation, incorporating the perception, reasoning, and action tenets of robotics. The focus of which is on the action aspect to create a table-top functional abstraction of a compost sorting system. A structured design process will be explored with the development of the prototype to reflect on how iterative ideation can lead to an adequate solution.

3 DESIGN PROCESS

The team worked to fully define the problem statement and the motivating factors before proceeding to the solution space. This method illustrates the linearly problem-oriented design approach where “the emphasis is placed upon abstraction and through analysis of the problem structure before generating a range of possible solutions” [14]. The team will continue to use the linear approach where problem definition, concept exploration, and solution development stages are connected in series. It is important to note that this linear approach does not imply a one-way process. During the problem definition stage, the team will have generated a set of requirements and specifications. Proceeding to the concept exploration stage, the team will look back to the problem statement to effectively generate possible solutions. Similarly, the results from the concept exploration stage are crucial in the refined solution development process. Within the solution development, the prototyping and the verification stages suggest a cyclical feedback loop (see Fig. 3.1). The team will fabricate a prototype to verify the concept; make adjustments to the prototype, and re-test the solution. These steps will be repeated until a desired final product is reached. Such iterations are necessary in order to produce a high quality outcome. The design process model was developed based on the design process described in the ME450 lecture. Such a model, with the problem-oriented approach, is useful for this application because it streamlines the product development process through implementing a stage-based strategy. With the time constraints of the project, a time-efficient model will most likely work the best. Some modifications were made to the standard framework by breaking down the problem development stage into three separate phases. This ensures to distinguish between the prototyping and verification phases. It also helps visualize the iterative process between them.

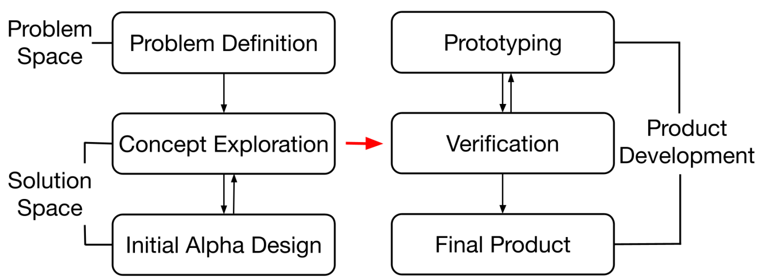


Figure 3.1 Linear problem-oriented design process that will be used during this project. Note the iterative process within the solution space exploration to generate the most adequate solution to the problem. Furthermore, this initial alpha design will be iterated and improved during the prototyping and verification phases.

Using a structured design process can help streamline the project progression. Making late design changes can be extremely costly and time consuming. Following a well-developed design process can reduce the risk of re-designing, thus saving a great amount of time and resources.

4 DESIGN CONTEXT

4.1 Stakeholder Analysis

A stakeholder analysis was conducted to identify the stakeholder groups: primary, secondary, and tertiary. This provides information regarding the demographics involved from the impacts of the problem and the role they have in relation to the project in terms of interest and influence over design decisions. Fig. 4.1, pg. 10 depicts the stakeholders in the aforementioned tiers using a stakeholder's map.

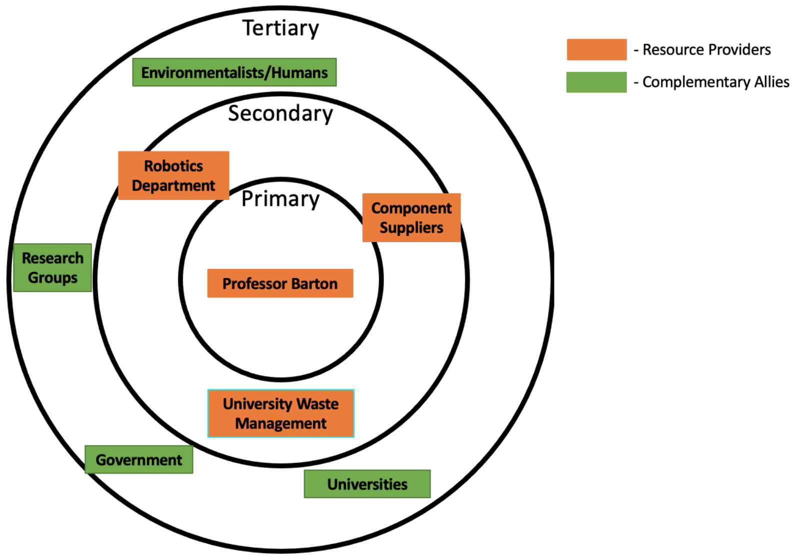


Figure 4.1 The stakeholder's map. The figure depicts the primary stakeholders in the epicenter, the secondary stakeholders in the middle and the tertiary stakeholders at the edge. The stakeholder's map is structured with the most interested groups and direct influence over the project in the center, with their role decreasing in both aspects moving outwards. The primary stakeholder is Professor Kira Barton who is also the direct sponsor of the project. The sponsor and the robotics department are the main resource providers.

The sponsor of the project, Professor Barton, Robotics department, and various component suppliers are indicated as the main resource providers. The robotics department can provide the necessary knowledge and resources for the project in order to navigate through the problem and solution spaces using the robotics approach. The university waste management can provide with the necessary knowledge in composting and current issues with such a practice. Gaining this information is crucial in defining the problem space as well as the project scope. Because of the motivating nature of the project, other research groups and universities may be interested in providing us with resources although they do not have much power as tertiary stakeholders. They would also be interested in the navigation of a structured design process that will be implemented throughout this project, which could be used as a learning tool. Environmentalists and government personnels are considered complementary allies because they value sustainability which means that the project's mission could be interesting to them. They would be more interested in the actual physical model and the sorting mechanism that will be generated throughout this project. However, they do not have much power over the outcome and direction of the project since they are tertiary stakeholders.

4.2 Environmental and Social Impact

This project's goal reaches far outside just the sponsor's interest, and motivations encompass global issues and applications. As described in the introduction section, composting can reduce the ultimate carbon footprint by recycling the organic wastes instead of burning them. Not only that, but composting allows the food wastes to become biofuel and bio-soil which can be used for other benefits. This work could be the first step in working towards global sustainability.

In addition, the project intends to provide a positive social impact to the university. As explained by the university office of sustainability, most of the major sorting is done during the front-end. This means that they rely on the students to dispose of the right materials into the proper bins [15]. Great effort is put into educating students and providing necessary help when it comes to composting on campus. Such an attitude is not uncommon. A study was done to observe the effects of compost bin design on the collection and waste segregation rate. It was concluded that the design preference, physical design, visual prompts, and past behavior significantly affected the segregation performance [16]. This suggests that compost sorting is largely reliant on the front-end sorting from the people who utilize the bins. There have been many studies to observe user behaviors to improve the front-end separation rate. In order to do so, the effort to educate and relate to the users has been largely increasing.

The sponsor values both the social and educational aspects of this project and sees these as motivating factors for the project through both an engineering and instructor's perspective. Therefore, there does not seem to be a conflict between the social, educational, or other aspects of the project that would cause the potentiality of incurring a negative impact.

This project is currently in its pilot phase. There was no responsibility to sign over intellectual property rights to the sponsor, this may be updated later as the project progresses.

5 USER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

5.1 User Requirements and Engineering Specifications

The following is a set of requirements derived from careful analysis of the problem statement and its stakeholders and utilizing the problem-orientated approach stated earlier in the design process. After discussing with the sponsor for their user requirements and intended goal of the project, these were selected as the sponsor wants the project to be an abstraction of the sorting mechanism. With this in mind, the current approach is to have a product that can display the process easily, which is reflected by the portability and table top size enumerations. The ease of assembly is also taken into consideration to account for the intended use of the project as a display demonstration. With the end goal of having the system perform the sorting through its sorting pool to account for the heterogeneity of the components which includes the range of sizes and weights. The quantifiable values for this category are determined by considering the most common food waste and contaminants: potato, banana, egg, carrot, bell pepper, plastic bottle, and plastic spoon [17].

The user requirements are listed in priority with the most important at the top and decreasing importance as one descends the list, and subdivided into needs and wants from the stakeholders (see Table 5.1). The ranking of requirements in terms of importance was conducted through evaluating their level of influence and consequence to the final project while factoring in the stakeholder's input of their wants and needs from the project as well. This is the set list of all requirements and specifications that are used for concept generation and will be used for prototyping and testing purposes. At the moment, there are not any specific codes, laws, and standards to consider since the project is in its pilot stage. The engineering specifications have been quantified for most of the given user requirements to provide a clear metric for project progression and evaluation. Which is why specifications were picked to keep in mind practicability to allow for reasonable metrics that make sense for the context of our project.

Table 5.1: User Requirements and Engineering Specifications. The criteria elements are organized as top being the most important and bottom being the least important.

	User Requirements	Engineering Specifications
Need	Sort various size and weight of typical compost feedstock	Able to handle objects with following dimensions: Sphere with diameter 4.8cm-16cm [18][19] Cylinder with 3.6cm-6.6cm diameter [11][20] and height of $\leq$ 21cm [21] Weight 27g–160g [22][11]
	Work within a table top sized space	Fit in a 60cm x 60cm x 100cm box [23]
	Accuracy	90% accuracy of dealing with the correct item [24]
	Speed	Able to handle 22 lbs/ 8 hours of work load. [25]
	Little maintenance needed	Able to go without maintenance for 110 items [25]
Want	Ease of assembly	30 mins
	Portability	Maximum weight of 10kg [26]

6 PROBLEM DOMAIN

6.1 Project Challenges

Given the project scope, one possible challenge is developing and testing meaningful metrics for engineering specifications. Team knowledge is currently limited to an academic environment and not involved in many robotics applications. Although specifications were researched and developed, revisiting and redesigning is likely needed as the concept development phase continues. Time constraints are also an important consideration. Efficiently collecting the data from relevant parties and experiments is needed to ensure the validation of the engineering specifications in a timely manner will be a concern throughout the project. Given the fact that some engineering specifications list ranges for aspects of project performance, running tests to collect this data and confirmation of whether a trial has passed the evaluation properly could also pose a challenge.

Problems that might arise in regards to assessing the engineering specifications given the state of knowledge and resources. As per laboratory procedure, safety must be taken into consideration when conducting these tests given that this project is in its pilot stage, extra precaution must be taken given possible unknown risks.

6.2 Domain Analysis and Reflection

The most important aspect of this project is exploring the design space using robotics. As of now, we have limited exposure to the current robotics practices. Therefore, it would be beneficial for our team members to gain more access to the current resources available from the Robotics department. Secondly, it is necessary for us to develop a concrete robotic product. Given the requirements, we need to gain access to current manufacturers and resources in which we can purchase parts for our robotic design. Developing our robotic application goes back to the need for our team to explore the robotic design space. Furthermore, to provide the most objective robotic performance, it is necessary for our team to gain a deep understanding of the current composting practice.

As with any task, further resources may be needed to solve the problem. At the project's current scope, problems may include difficulty in prototyping. As the focus is on the action aspect of this robotics problem, prototyping at the very least will require some manufacturing time as well as material and the expertise to fabricate them. Consultation with stakeholders has resulted in further information on the composting process, typical contaminants, and robotics principles. This helped narrow the scope and goal of the project. The overarching problem with compost sorting will be the motivating factor of the project. Furthermore, the expanded knowledge on typical compost materials as well as contaminants helped shape the specifications and testing criteria for the sorting system.

7 CONCEPT EXPLORATION AND DESIGN PHASE

7.1 Solution Space Exploration

During the Problem Definition phase, the problem space has been extensively researched to generate a clear problem statement and a focused project goal. The next stage in the design process is the Concept Exploration phase (see Fig. 3.1, pg. 9). In this phase, the solution space is carefully explored to develop possible solutions. The following subsections will discuss the process and the results of the Concept Exploration phase in detail.

7.2 Concept Generation

The project can be decomposed into the following subfunctions: segregating and providing the sorting pool, transporting the wastes, and removing mechanism for the contaminants. The first sub-function of partitioning and providing the specimens is contextually defined in each design concept as the working environment. The system must be able to lay out the waste pile in a manner that the system can proceed to the next step. The second sub function is dedicated to the importance of transporting desired objects within the workspace. The third subsection is dedicated to sorting with the contaminants themselves, whether through the sorting mechanism itself or some sort of outflow system.

Concept generation was explored using multiple forms of methodology. The initial stage of brainstorming ideas of all the possible methods was performed mainly using the concept map method. Without using any filtration, each member was able to come up with 40 unique design ideas. This was just a warm-up exercise to get as many ideas as possible thinking outside the box. Other methods like SCAMPER and Design Heuristics cards were used to build on existing ideas to create new ones. These methods allowed for divergent thinking by providing the necessary tools. For instance, SCAMPER technique promotes a new way of thinking by asking idea-spurring questions. These questions help designers to make incredible modifications to the existing ideas which can be its own unique concept [27]. New ideas generated from this method can be found in Appendix: B. Developed by design experts at University of Michigan, the Design Heuristics cards offer similar advantages but in a different approach. By using a random card out of 77 possible options, this technique forces designers to think in multi-aspect to make “outside of box” modifications to the ideas. Modifications made using this method are shown in Appendix: C. Once all the different methods for providing the desired outcome of sorting are listed, different design concepts are then drawn. Even though the concepts do have similarities within each other, they are distinct from one another from their action mechanism and the defined space or system that they operate within. One classification that could be used for the concepts is the form of power used for the actuation, whether it is mechanical or fluid. From there, each member conducted an initial screening using gut check and engineering intuition according to the user requirements to narrow down the 40 ideas to the top five project design proposals. Each member evaluated those top five ideas using pugh charts to determine the best candidate for the final design selection (see Appendix: D). Apart from individual brainstorming sessions, group sessions were also executed. One of the concept maps created from a group session is present in Fig. 7.1. The team explored an assortment of methods that could be used to perform sorting: from the traditional mechanical approach of using an arm or gripper to the unorthodox chemical approach of using insects that could digest the plastic contaminants. Initially during the problem definition stage, the team was fixated on the idea of the "Claw" machine concept. Although this idea was further developed, using different divergent thinking tools enabled for branching out from this initial ideation. Ultimately, many innovative concepts were generated using the tools. The four candidates (best idea from each member), with the help of group brainstorming sessions, were tweaked and modified to generate the final candidate designs that will be evaluated in detail.

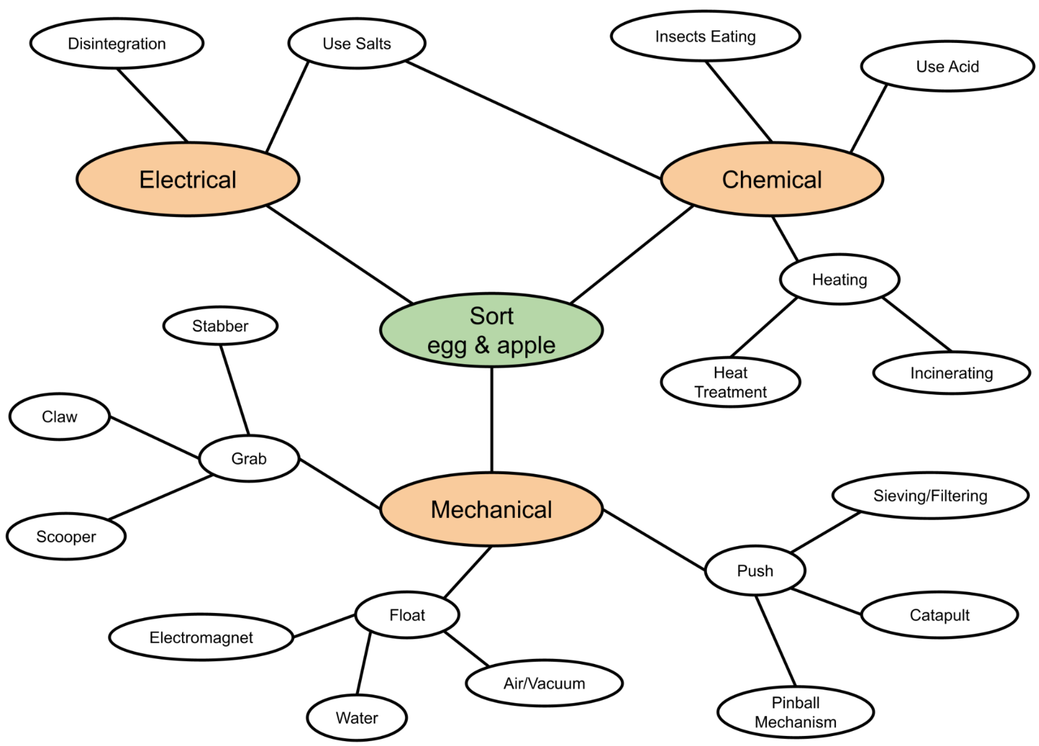


Figure 7.1 Initial group brainstorming concept map. The green bubble represents the main functional requirement that the system needs to fulfill. The orange bubbles represent the sub categories that the main function could be executed with. At this stage, no filtering is used; therefore, some of the "out of the box" ideas were generated. Concepts like using insects to remove contaminants or heat to incinerate the wastes might not be plausible for this application which will be filtered out in the selection process.

8 CONCEPT SELECTION PROCESS

8.1 Initial Selection Process and Potential Designs

During the concept generation stage, each member developed 40 unique design ideas. As an initial design selection process, gut check and engineering intuition were used to eliminate some of the implausible and difficult-to-execute ideas. As a result, each member's 40 ideas were reduced to five potential concepts which can be further evaluated. As a group, these 20 total ideas were further refined and combined to generate four final candidate designs that will be assessed through a systematic down selection process.

The first design is the "Robotic Umbrella-like Arm." The key to this design is the gripper itself which is constructed of linkages to imitate the structure and mechanism of an umbrella. The second idea is the "One-by-One Pneumatic Pushing Mechanism." The waste is fed into the feeding system that will align the waste so they can enter the conveyor belt one by one. The contaminants are pushed out of the line with a pneumatic cylinder. The third design is the "Vacuum Actuator Gantry System." A vacuum actuator is attached to a gantry system which can move to a desired location. The design takes inspiration from the movement of the 3D printer, using a 3 dimensional axis frame to move the compost around. The vacuum actuator will grab the object and remove it from the waste pile. The last design is called the "Individual Tilting Plates Mechanism." The work space is constructed of many small individual plates that are attached to individual motors. The plates can be adjusted to specific angles to shift items to different locations. When the system detects the contaminants, those plates under the object can shift to a 90 degree angle imitating a trap door. The waste is then separated from the workspace. The schematic sketched for these four ideas are present in Fig. 8.1, pg. 17.

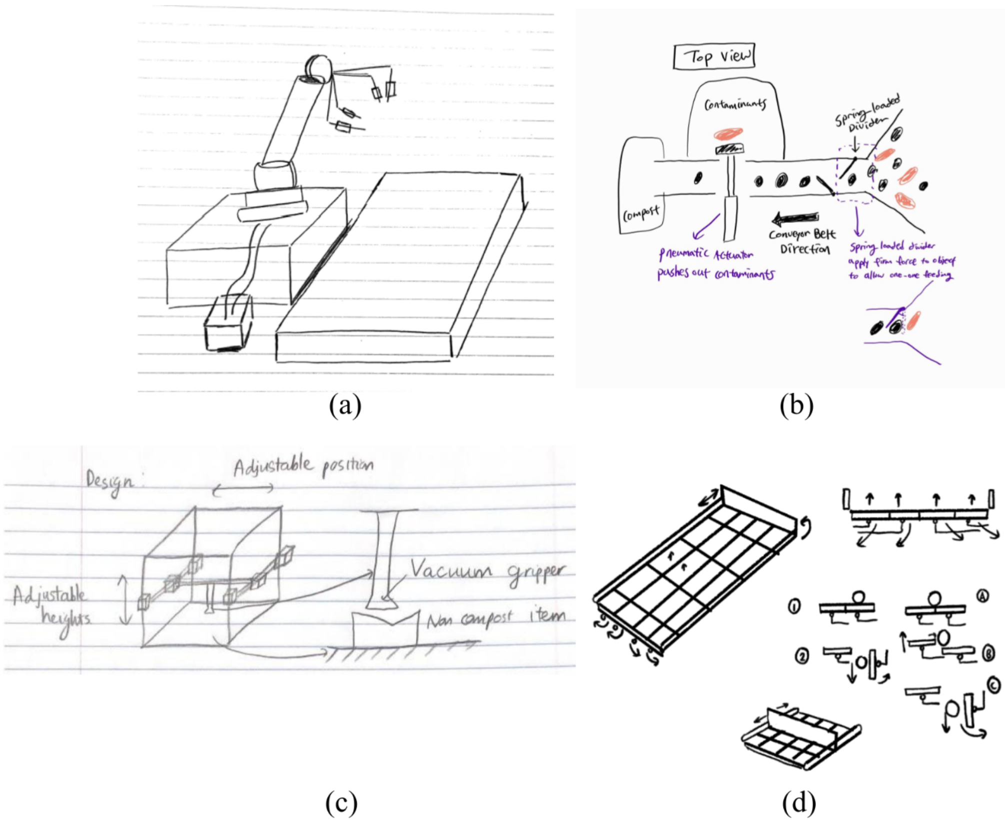


Figure 8.1 The concepts depicted above are the top choices by each team member described above. (a) is an isometric view of the "Robotic Umbrella-like Arm", (b) is an overhead view of the "One-by-One Pneumatic Pushing Mechanism", (c) is an isometric view and cut out of the "Vacuum Actuator Gantry System", and (d) is an isometric and front view of the "Individual Tilting Plates Mechanism"

All the selected design concepts are consistent with the engineering specifications and customer requirements as these were the driving factors for the idea concept generation for the project designs, and their proposal was based on their ability to satisfy these specifications and requirements. Further elaboration of each project design proposal ability to satisfy these requirements and explored in the next subsection.

8.2 Down Selection using Pugh Charts

The four final design ideas were fully evaluated using a systematic down selection process. Two pugh charts were used for the process. The first pugh chart focused on the project quality in regards to its ability to meet the user requirements and engineering specifications mentioned in Table 5.1 in Section 5. Below is the first pugh chart, Table 8.1, pg. 18.

Table 8.1: The following pugh chart for the product quality in regards to satisfying the user requirements and specifications. The categories of each engineering specification are listed along the rows with their weighted value, and the project design proposals along the columns. A scoring system of [-3,+3] was used with a negative value denoting the inability or hindrance to meet the category, and a positive value for the ability to satisfy the said category.

Category	1	2	3	4
Able to Sort (5)	2(10)	1(5)	2(10)	3(15)
Speed (4)	0	3(12)	2(8)	1(4)
Table-Top Size (3)	1(3)	2(6)	2(6)	2(6)
Accuracy (4)	3(12)	-1(-4)	3(12)	0
Ease of Assembly (2)	2(4)	2(4)	2(4)	1(2)
Portability (2)	0	0	0	0
Maintenance (4)	-2(-8)	2(8)	0(0)	-1(-4)
Total:	21	31	**40**	21

Here each design is evaluated against how well it fulfills the requirements. The requirements are weighted from 1-5, five being the most important. Criteria such as “able to sort,” “speed,” and “accuracy” are rated high. Whereas, “ease of assembly” is rated low because such a criterion is more of a “want” than a “need.” After each design is evaluated, the “Vacuum Actuator Gantry System” fulfills the requirements the best.

However, in a design process, it is important to consider other aspects of the design that would affect the overall requirement as well as incorporating the stakeholder requirements. Therefore, each is further evaluated using a second pugh chart which takes into account other relevant factors unique to the project. Below is the second pugh chart in Table 8.2.

Table 8.2: The following pugh chart takes into account other necessary elements unique to the project. A scoring system of [-4,+4] was used with a negative value denoting the inability or hindrance to meet the category, and a positive value for the ability to satisfy the said category.

Category	1	2	3	4
Quality (5)	2.1(10.5)	3.1(15.5)	4.0(20)	2.1(10.5)
Novelty (2)	0	1(2)	1(2)	2(4)
Ease of Prototype/Manufacturing (4)	-1(-4)	2(8)	0	-1(-4)
Low Cost (1)	0	1(1)	0	0
Aesthetic (2)	1(2)	1(2)	2(4)	3(6)
Total:	8.5	**28.5**	26	16.2

The second pugh chart factors in the Quality category which corresponds to the result from the first pugh chart. This category was weighted high because meeting the user requirements and engineering specifications is the most important, along with the ease of prototyping and manufacturing as this would be an ideal design quality given the time constraint and the desired goal of having a finished functional prototype within the deadline. Other design qualities are also listed such as: cost, novelty, and aesthetic as these are qualities that are desired but not high priority relative to the other categories. Overall, the second project design proposal, the “One-by-One Pneumatic Pushing Mechanism,” yielded the highest score from the down selection process via the pugh charts.

9 THE ALPHA DESIGN - SOLUTION DEVELOPMENT

9.1 The “Alpha” Design Justification

After each of the four potential proposals described in the previous section were evaluated, the “One-by-One Pneumatic Pushing Mechanism” was determined to be the most appropriate solution for this project’s application. Notice that the Vacuum Actuator Gantry System scored the highest in the user requirements evaluation, not the selected design (see Table 8.1, pg. 18). The “Vacuum Actuator Gantry System” is able to pick up the targeted object one by one accurately given the system hovering over the stationary workspace; therefore, such a candidate scored high in the “Accuracy” criteria. On the other hand, the Alpha Design did not do well in the same criteria because of its sorting mechanism. Because the contaminants are pushed out of the moving conveyor system (dynamic workspace), timing of the sorting system and the conveyor system must be in perfect sync to avoid unwanted pushing actions. The Alpha Design scored high in the “Maintenance” and “Speed” categories because of its simple and fast ejection mechanism; this design ranked the second in the requirements pugh chart. However, there are other elements that need to be considered for the project given the constraints. Other important elements such as “Ease of Manufacturing” and “Cost” are evaluated for the four candidates. Additionally, its compartmentalization of the sensing from the action site allows for a simple and practical design. Ultimately, the “One-by-One Pneumatic Pushing Mechanism” scored highest from the overall down selection process. During the solution development process, the sponsor’s input was constantly taken into consideration. Although the gathered feedback was considered during the concept exploration stage, such information did not heavily influence the outcome of the down selection process. The meetings with the sponsor were constructive in nature; most of the comments and questions were open ended to encourage divergent thinking. They provided the guidance for the process without favoring certain designs. The objective selection process could have resulted in a different outcome. Although each member used different divergent thinking techniques to minimize bias and fixation on certain ideas, members could have allowed their biases to determine certain aspects of the selection process unconsciously. After all, all the members are from the Mechanical Engineering department; thus, the decisions each member made could have resulted from a narrowed vision. Involving people from different fields of study could be useful in the future for a more objective selection process.

9.2 The "Alpha Design"

The "One-by-One Pneumatic Pushing Mechanism" was selected as the Alpha Design after a careful selection process. The design consists of three subsystems: the feeding system, the conveyor system, and the sorting system as seen in Fig. 9.1. The feeding system is responsible for aligning the waste objects in a single row to be entered into the conveyor system. The feeding system is attached to one end of the conveyor system which is simply there to transport the wastes. The sorting system is positioned on the side of the conveyor system to push out the contaminants when appropriate.

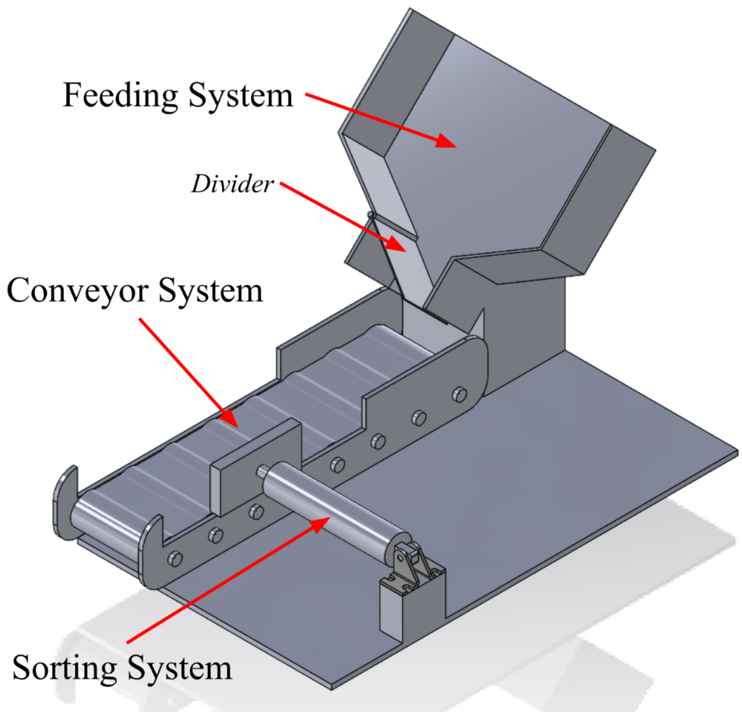
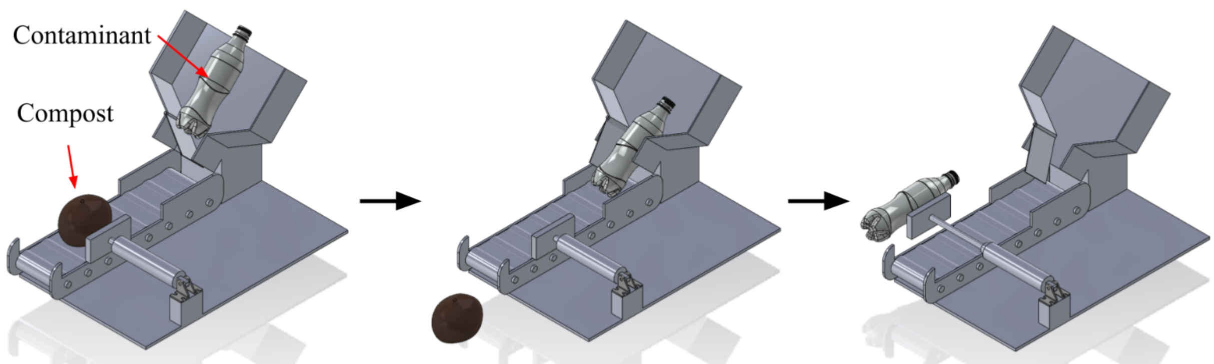


Figure 9.1 Isometric view of the "One-by-One Pneumatic Pushing Mechanism." The mechanism is consisted of three subsystems: feeding system which enables the wastes to align in a single file line (due to spring loaded divider), conveyor system which transports the wastes, and sorting system which pushes the contaminants out of the workspace through a pneumatic air cylinder.

The mixed waste pile is dumped into the feeding system which is then fed to the conveyor system one by one executed by the spring loaded divider. The waste objects in a single-aligned row are transported through the conveyor belt. While being transported, each object will be identified as either a compost or a contaminant by the perception and reasoning aspects of the system (not the focus of this project). If identified as a compost, the object will remain in the conveyor belt: if identified as a contaminant, the sorting system will push the object out of the conveyor system using a pneumatic air cylinder. The three main steps of the sorting process are present in Fig. 9.2, pg. 21.



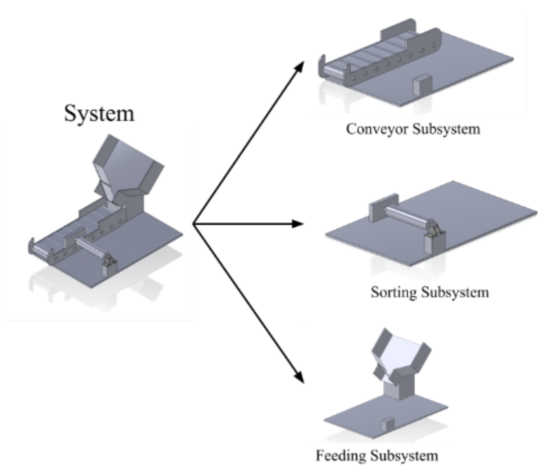
(a) (b) (c)

Figure 9.2 (a) Mixed wastes (both composts and contaminants) are entered through the feeding system to the conveyor system. Compost wastes remain in the conveyor system and pass by the sorting system. (b) The compost wastes are collected in the correct area while the next object enters the conveyor system. The spring loaded divider enables the wastes to enter the conveyor system one by one. (c) The identified contaminant is pushed out of the conveyor system by the sorting system actuated by a pneumatic air cylinder.

10 BUILD DESIGN AND ITS SUBSYSTEMS

10.1 Subsystems of the "Alpha" Design

The initial "Alpha" design can be decomposed into three subsystems according to different functional responsibilities. The three subsystems are depicted in Fig. 10.1.



Responsible Requirements	Design Iteration	Notes
Speed	N/A	Electronic components will be implemented (just to test the system)
Sort, Accuracy, Speed	Physical Shape of Pushing Plate	Mockups (cardboard and tape) will be implemented
Align Object	Mechanism	Additional Concept Generation will be executed

Figure 10.1 Three decomposed subsystems of the "Alpha" design. The systems are separated according to their responsible functions. The conveyor subsystem is responsible for transporting the object with certain speed. The sorting subsystem is mainly responsible for sorting, accuracy, and speed requirements. The feeding subsystem is important in making sure the feedstock objects align in a single line. Notice that this requirement of "align object" is a new function generated during the development of the "Alpha" design. This will be further discussed in the following subsections.

Decomposing into subsystems allows for a more efficient and structured prototyping and verification process. Because the goal of the conveyor subsystem is to simply transport objects, no design iteration is necessary. On the other hand, the sorting and feeding subsystems are responsible for more important objectives such as sorting and accuracy; therefore, design iterations are necessary in order to successfully fulfill the engineering specifications. The decomposition also allowed for a more detailed planning of the project. The fully developed project workflow is shown in Fig. 10.2.

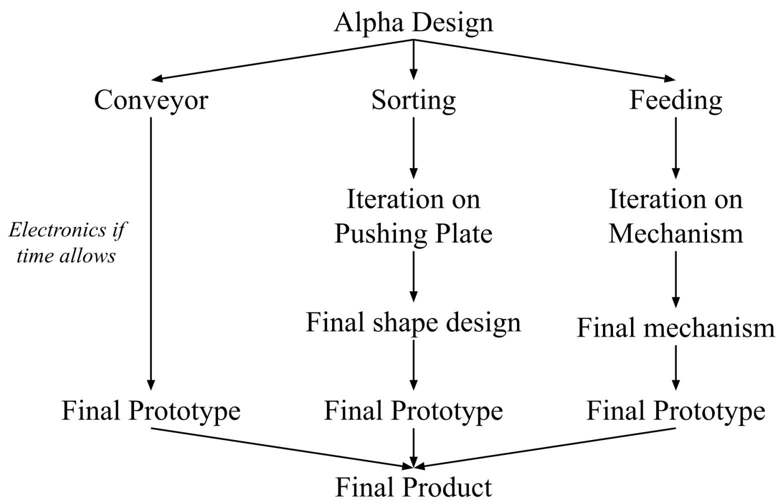


Figure 10.2 The general workflow of the project. The "Alpha" design is decomposed into three different subsystems which can also be considered three different paths and goals of the project. Since the conveyor subsystem doesn't require design iteration, it will move onto the final prototyping. However, the sorting and the feeding subsystems will go through design iterations before moving onto the final prototyping stage.

Each subsystem will be produced using stock aluminum, 3D printing, and other off the shelf components. A full list of Bill of Materials is presented in Appendix: E. More detailed discussion of the manufacturing plan will be provided in a later section.

10.2 The Conveyor Subsystem

Before moving on to the final prototyping stage, initial engineering analysis must be fulfilled in order to determine the specifications of the required components for the conveyor subsystem. The motion of the conveyor belt must be able to transport the object within the "Speed" requirement. The schematic diagram of the conveyor system is shown in Fig. 10.3, pg. 23.

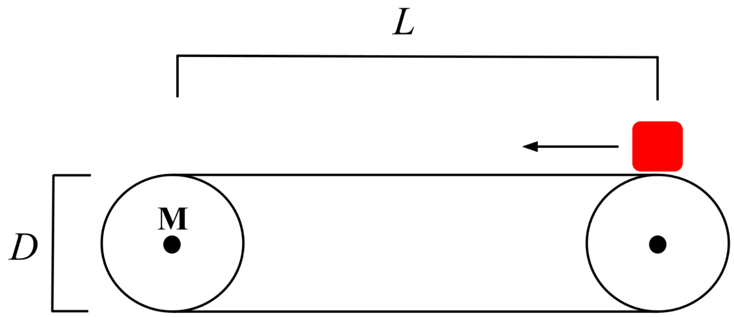


Figure 10.3 Side view schematic diagram of the conveyor system. The red square represents the waste object entering the conveyor system from the feeding system. Point M represents the center of mass of the conveyor belt roller where an actuator will be attached to allowing rotational movement of the roller. The variables *L* and *D* represent the distance that the waste needs to travel and the diameter of the roller, respectively.

From the "Speed" user requirement, the system must be able to sort 22 pounds of waste per eight hours of operation. This can translate into approximately one item per minute. The actuator operating the conveyor system must be able transport one item from start to finish in under one minute. Then, the speed required for the motor with given dimensions of the subsystem is calculated using Eq. (10.1):

$$\omega = L \times \frac{1\ revolution}{\pi D} \times \frac{1}{1\ minute} \tag{10.1}$$

where, ω is the required angular speed in RPM, *L* is the total distance needed to travel in meters, and *D* is the diameter of the conveyor roller in meters. These variables are indicated in the schematic diagram (see Fig. 9.3, pg. 21). The required RPM of the motor resulted in 3.61 RPM. Since the speed is in direct relation with the torque of the motor, such a quantity also needs to be evaluated. The total moment is taken around the center of the motor shaft indicated as point M. Assuming that the maximum torque needed by the motor to move the object occurs when it is furthest away from the motor shaft, the required torque can be calculated using the following Eq. (10.2):

$$T = L \times m \times g \tag{10.2}$$

where, *T* is the required torque is N·m, *L* is the maximum distance from the shaft center to the object in meters, *m* is the mass of the item being transported in grams, and *g* is the gravitational acceleration of 9.81 m/s^2. The required motor torque is calculated to be 0.678 N·m. During the manufacturing planning, these motor specifications will be considered to acquire the appropriate component for the prototype. The use of force and moment analysis is appropriate in this situation because such a system doesn't require a strict accuracy. The purpose of this analysis was to acquire the general idea of what specifications of the component are necessary to realize the selected design (according to the engineering specifications). The analyzed scenario contains the upper bound for all the parameters; it is assumed that the heaviest mass is being transported the maximum amount of distance.

10.3 The Sorting Subsystem

Since the sorting mechanism includes an action of “punching out” the object using a pneumatic actuator, it is important to analyze the pushing force exerted by the actuator to the object to ensure efficiency and safety. The anticipated trajectory of the waste is shown in Fig. 10.4.

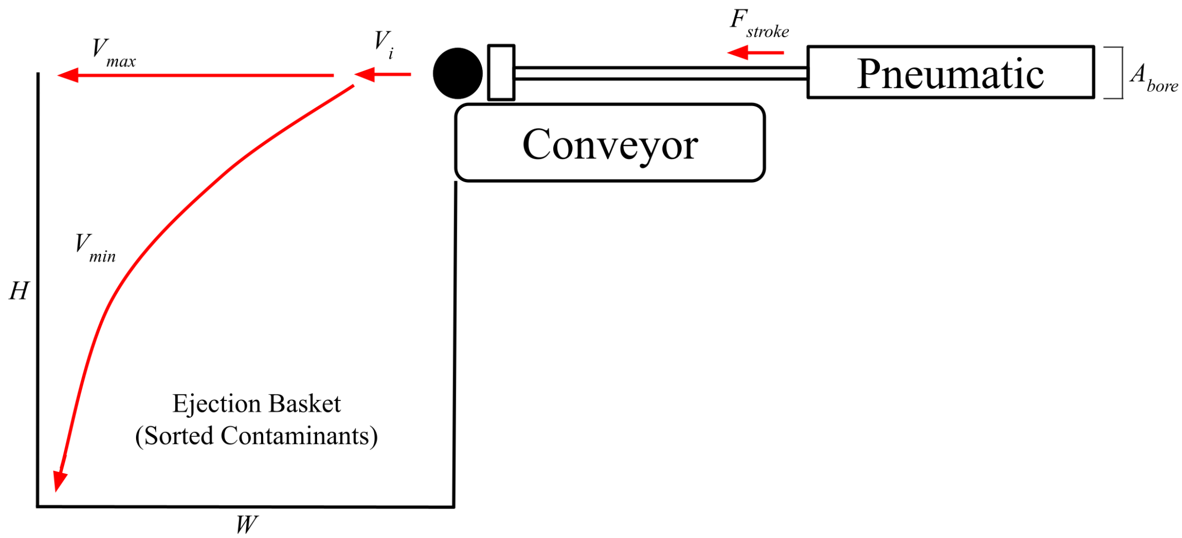


Figure 10.4 Front view schematic diagram of the sorting subsystem. The black circle represents the waste object that is being ejected. F_{stroke} is the pushing force applied by the pneumatic actuator with a piston area of A_{bore} to the object. The object ejected with an initial velocity of V_i which is then collected in a basket of height H and width W. V_{max} and V_{min} represent the allowable maximum and minimum initial velocities, respectively.

In order to calculate the initial velocity of the object V_i the timespan of the projectile needs to be determined with the simplified kinematic equation shown in Eq. (10.3).

$$\Delta H = \frac{1}{2}gt^2 \tag{10.3}$$

where, H is the vertical distance that the ejected object will fall, g is the gravitational acceleration of 9.81 m/s^2, and t is the time it takes to fall distance of ΔH. The ejected object must be cleared out of the sorting area to minimize malfunctioning; therefore, it is aimed at the edge of the sorting basket. For calculation purposes, the targeted area is set slightly below the edge of ΔH = 1 cm. Then, the calculated projectile timespan is t = 0.443 s. Using this value, the initial velocity can be determined by Eq. (10.4):

$$V_i = \frac{W}{t} \tag{10.4}$$

where, V_i is the initial velocity and W is the horizontal distance traveled which is also defined as the width of the collection basket W = 30 cm. The resulting initial velocity is V_{max} = 0.677 m/s. Using the same method, the minimum initial velocity (object aimed at the bottom corner of the basket) resulted to be V_{min} = 0.124 m/s. This initial velocity must be created by the force exerted by the pneumatic air cylinder. The simplified stroke mechanism of the air cylinder is shown in Fig. 10.5.

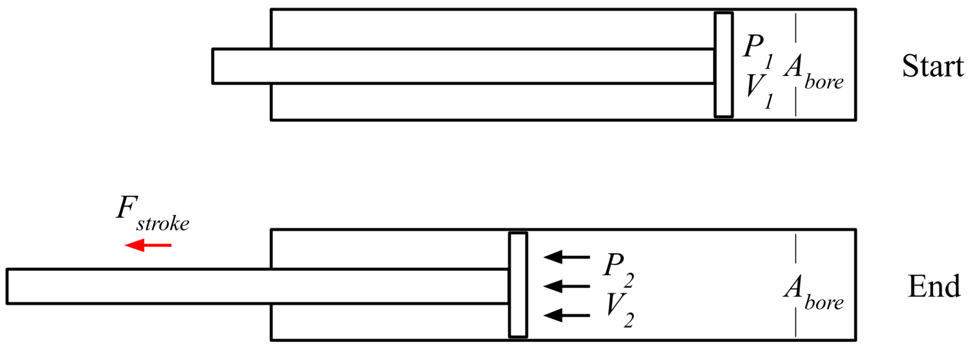


Figure 10.5 Cross section schematic view of the pneumatic air cylinder. The "Start" stage represents the retracted position while the "End" stage represents the extending position. P_1 and V_1 indicate the internal pressure and air velocity, respectively, at the 'Start" stage. P_2 and V_2 indicate the internal pressure and air velocity, respectively, at the "End" stage. With a given piston diameter of A_{bore} the stroke applies F_{stroke} amount of pushing force.

The kinematic equations can be used to determine the acceleration required to exert the desired pushing force. Assuming that the stroke velocity during the extension is identical to the initial ejection velocity of the waste object, the velocity and acceleration of the rod is related by following equations Eq. (10.5) and Eq. (10.6):

$$V_{21} = V_1 + a\Delta t^2 \quad (10.5)$$

$$V_{22} = \sqrt{V_1^2 + 2 \times a \times \Delta x} \quad (10.6)$$

where, V_1 is the rod velocity in retracted position which is zero, V_2 is the air velocity during extension, a is the acceleration, Δt is the change time, and Δx is the change in distance. Notice that Δx is also defined as the stroke length of the piston ($\Delta x = s = 0.127$ m). Furthermore, with the desired speed of 1 full cycle (both extension and retraction) per second, Δt is set to 0.5 seconds. With these parameters, Eq. xx and Eq. xx can be plotted with acceleration and velocity as variables which is shown in Fig. 10.6, pg. 26.

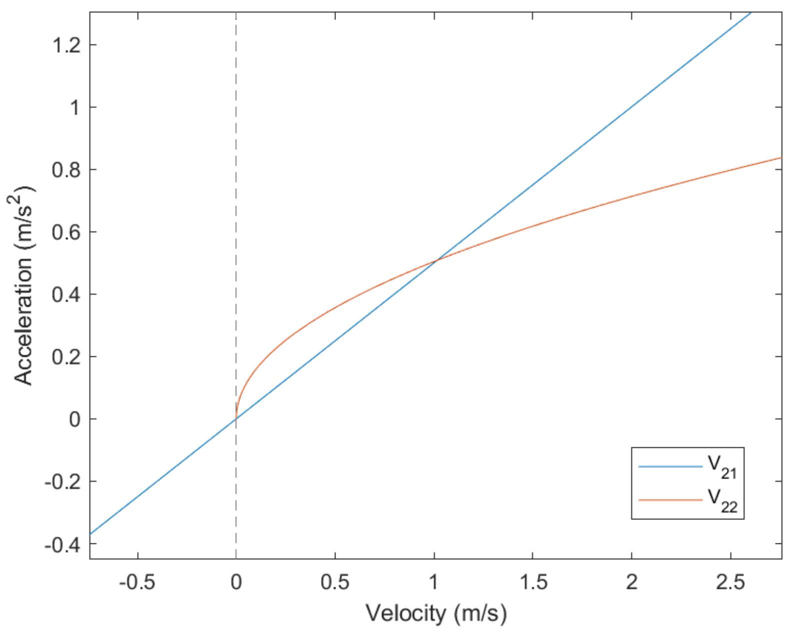


Figure 10.6 The motion of the ejected object is characterized by two different kinematic equations. Finding the intersection allows for optimizing (meeting the required parameters) the trajectory. The resulting acceleration tion is a = 1.02 m/s^2 and velocity is V_i = 0.508 m/s.

Finding the intersection between the two functions, also the optimized scenery in terms of acceleration and velocity, the desired acceleration is a = 1.02 m/s^2 and velocity is V_i = 0.508 m/s. The desired velocity is within the range set in the previous calculations. This acceleration and the mass of the sorting object are used to calculate the pushing force needed by the rod. The exerted force is resulted to F_{stroke} = 0.1632 N. Since force exerted and the pressure applied to the pneumatic cylinder are directly proportional with its piston's cross sectional area, appropriate pressure needed to achieve the desired exertion force can be determined. Furthermore, a virtual CAD model was used to experiment with the physical dimensions (especially the stroke length) of the system. The use of both analytical and virtual model methods are appropriate for this application because the main purpose of this analysis is to acquire general idea of the component specifications needed; high accuracy is not of concern. Furthermore, the pressure applied to the cylinder can be adjusted manually by the operator. Experimental analysis will be executed in the future to fine tune the amount of pressure applied to the actuator to successfully meet the engineering specifications. During the manufacturing planning, these pneumatic specifications will be considered to acquire the appropriate component for the prototype.

As the engineering specifications were developing and finalized, the dimensions of the testing pieces (representations of the feedstock) became clear. Just focusing on sorting round objects, it is determined that the flat surface of the pushing plate may no longer be viable. Therefore, a new round of concept generation and evaluation was executed. Fig. 10.7, pg. 27 shows several of the pushing plate shape ideas generated during a brainstorming session.

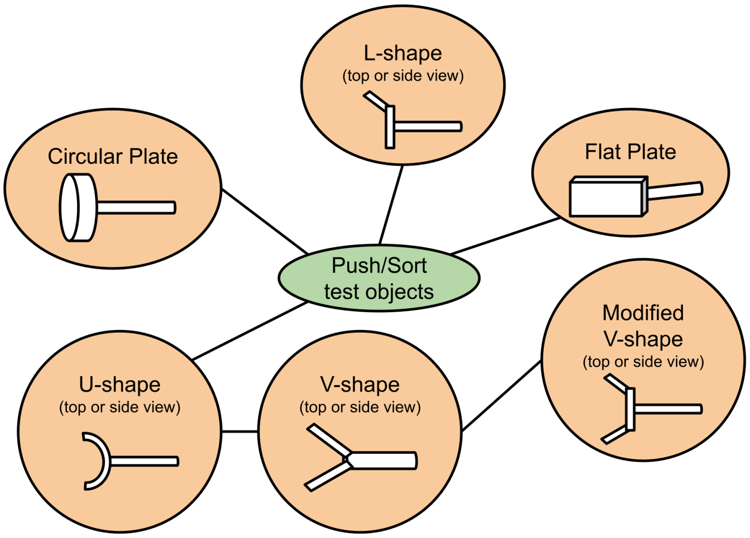


Figure 10.7 A concept map created during the revisited concept generation stage for the pushing plate shape. The main focus during this stage was: "push of round objects defined by the engineering specification." Some of the ideas included U-shaped and L-shaped plates.

As an initial selection process, gut check and engineering intuition were used. After eliminating ideas that will not work, three candidates survived: the flat plate, the L-shape, and modified V-shape ideas. These designs were evaluated and tested using mockups to determine the final design that will move onto the final prototyping stage. The two final designs are the flat plate and the L-shape.

10.4 The Feeding Subsystem

After the initial "Alpha" design was fully developed, a new functional requirement was generated. which is "align objects one-by-one." Such a requirement was not considered during the early stages of the design process. This was a result of a specific "Alpha" design development. The new engineering specification is listed in Table 10.1, pg. 28 along with the previously introduced criteria.

Table 10.1. A complete list of User Requirements and Engineering Specifications. The criteria elements are organized as top being the most important and bottom being the least important. The newly added requirement is bolded for emphasis.

	User Requirements	Engineering Specifications
Need	Sort various size and weight of typical compost feedstock	Able to handle objects with following dimensions: Sphere with diameter 4.8cm-16cm [18][19] Cylinder with 3.6cm-6.6cm diameter [11][20] and height of $\leq$ 21cm [21] Weight 27g–160g [22][11]
	Align feedstock objects in a single line (one-by-one)	**Able to align the test feedstock in a single line with a spacing of 2-4 cm between the objects**
	Work within a table top sized space	Fit in a 60cm x 60cm x 100cm box [23]
	Accuracy	90% accuracy of dealing with the correct item [24]
	Speed	Able to handle 22 lbs/ 8 hours of work load. [25]
	Little maintenance needed	Able to go without maintenance for 110 items [25]
Want	Ease of assembly	30 mins
	Portability	Maximum weight of 10kg [26]

Now, the newly formed requirement must be achieved largely by the feeding subsystem. Because the current design of the feeding subsystem does not account for the new requirement, a different design must be implemented to fulfill the requirement. Therefore, a new round of concept generation and evaluation was executed. Fig. 10.8, pg. 29 shows several of the feeding mechanism ideas generated during a brainstorming session.

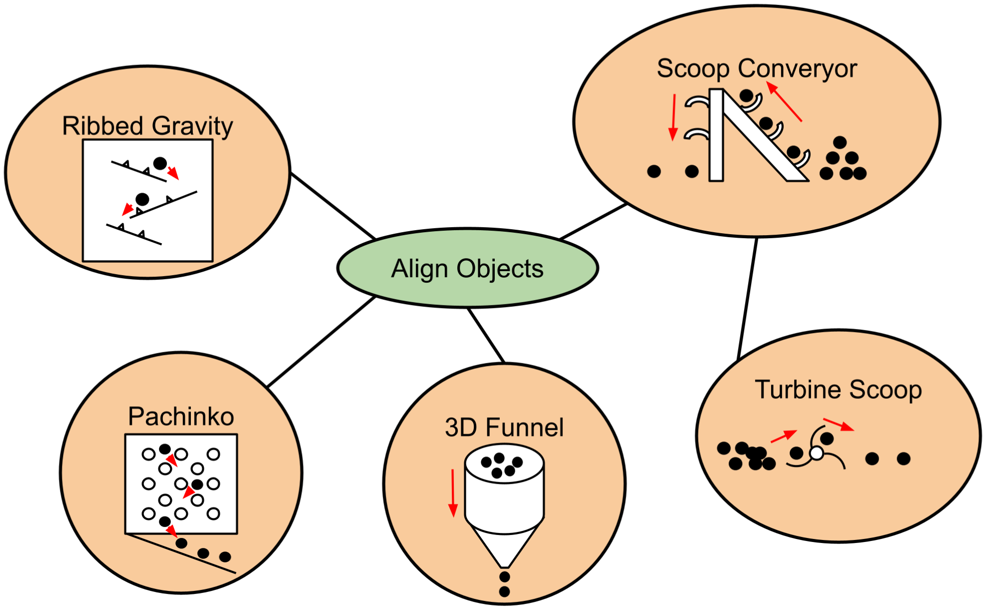


Figure 10.8 A concept map created during the revisited concept generation stage for the feeding mechanism. The main focus during this stage was: "align the objects in a single line." Some of the ideas included the Pachinko mechanism and the Turbine Scoop mechanism.

These ideas were evaluated using virtual models (CAD) and engineering intuition to determine the final design that will move onto the final prototyping stage. The Pachinko mechanism was selected as the final design for the feeding subsystem.

11 FINAL DESIGN & PROTOTYPING

11.1 Final Design

As expected, the final design of the prototype is fairly different from the initial "Alpha" design. The final design of the conveyor subsystem will remain the same as the build design because no further design iterations and changes will be pursued. The sorting and feeding subsystems went through the iterative solution development phase which resulted in different final designs. The final sorting subsystem design candidates are the flat plate and the L-shape, while the final feeding subsystem design candidate is the pachinko mechanism. These design changes are presented in Fig 11.1, pg. 30.

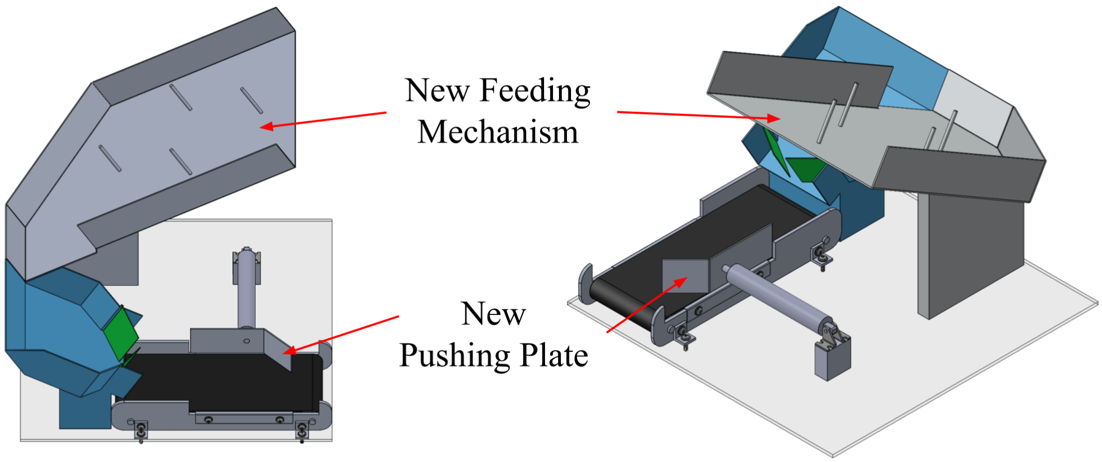


Figure 11.1 Updated CAD model of the final prototype. The major changes include the new feeding mechanism (pachinko machine inspired design) and the new pushing plate (L-shape plate). The sorting process is the same as described in Figure 9.2, pg. 21.

The rendered images of the final design are shown in Appendix: F. The final prototype will be operated using a simple circuitry. The conveyor subsystem will be operated using a DC motor with a potentiometer speed controller while the sorting subsystem will be operated using an air cylinder with a solenoid controller. The air cylinder will be manually activated using a limit switch to push out the contaminants whenever applicable. The circuit diagram for the system is shown in Fig 11.2.

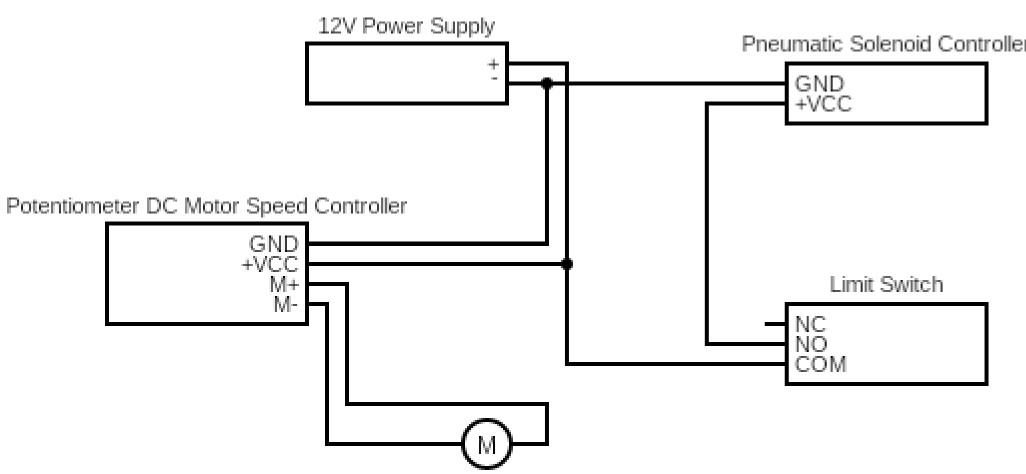


Figure 11.2 Circuit diagram for the final prototype. The "M" represents the DC motor that will operate the conveyor subsystem. The speed of the conveyor will be controlled by the potentiometer DC motor speed controller (with a dial knob). The solenoid controller will be activated whenever the limit switch is pressed manually, pushing out the contaminants. Both the solenoid and motor controller are powered by a single standard +12V DC power supply.

11.2 Manufacturing & Prototyping

The final design will be prototyped in four separate stages. Each subsystem will be manufactured separately and will be combined at the last stage of the prototyping process. Once all three subsystems have been built separately, they will be tested individually according to their corresponding requirements (refer to Section 12.1) before assembling the subsystems to complete the whole system. The assembled system will also be evaluated using all the engineering specifications. The verification methods and results are detailed in the next section of this report.

Most of the machining will be required for the conveyor subsystem. Since buying a small conveyor belt is not economically viable, making a simple abstraction is more reasonable. Most of the parts for this subsystem will be machined using a lathe and/or a mill machine (in addition to waterjet) while the traction belt will be purchased. The DC motor that will run the conveyor subsystem will also be purchased. Because of its unusual shape and dimensions, the feeding subsystem will most likely be 3D-printed using a polymer material. The added “Pachinko” mechanism will be manufactured using sheet metal (cutting and bending) with long screws to create the pole features. The sorting system mainly consists of a pneumatic actuator (air cylinder) which will be purchased as a whole. The subsystems will be assembled together on a flat plane made out of a square 60cm x 60cm acrylic board. Engineering drawings for the major components (which require manufacturing) are organized in Appendix: G. Other electronic components including the motor controller and the pneumatic solenoid controller will be purchased. All the components and materials needed to manufacture each subsystem are detailed out in the Bill of Materials (Appendix: E). The CAD model for the actual prototype is shown in Fig. 11.3, pg. 32.

The testing pieces (representations of the feedstock) will be virtually modeled using SolidWorks which will then be 3D-printed. The dimensions of the objects will be determined by the engineering specification and its verification plan (first requirement in Table 12.1, pg. 34).

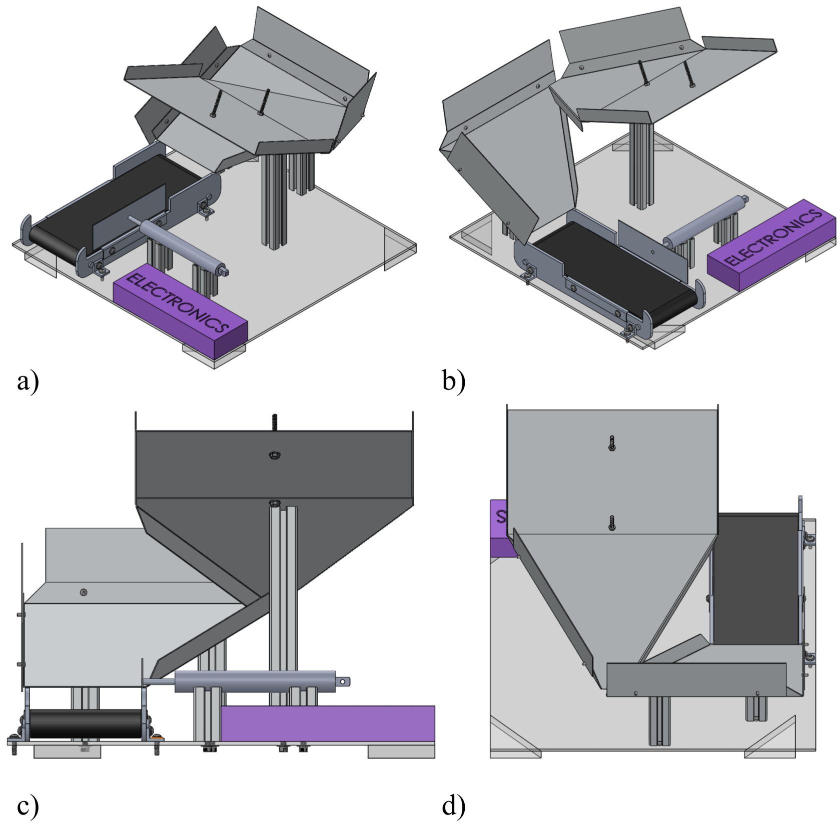


Figure 11.3 3D CAD model of the final physical prototype. a) Front isometric view of the model. b) Back isometric view of the model. c) Front view of the model. The electronic components will be organized on one edge which is indicated with a purple box. d) Top view of the model.

11.3 Physical Prototype

The physical prototype was constructed as planned with some adjustments. The feeding subsystem was originally planned to be fabricated with both 3D-printing and sheet metal forming methods. However, with given constraints, the subsystem was manufactured entirely out of sheet metal forming (and extruded aluminum for support). The final prototype is shown in Fig. 11.4, pg. 33.

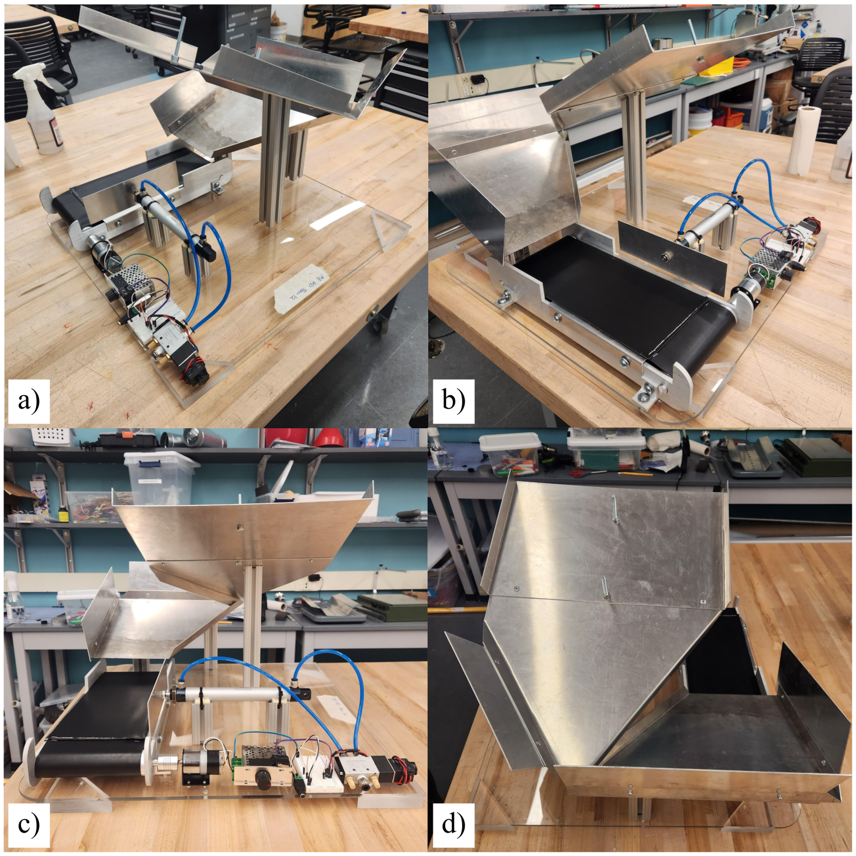


Figure 11.4 Images of the final physical prototype. a) Front isometric view of the model. All three subsystems are assembled on a square 60cm x60xm acrylic board. b) Back isometric view of the model. c) Front view of the model. The electronic components are organized on one edge of the board for easy access and control. d) Top view of the model. The "Pachinko" mechanism is imitated using long screws.

Notice that the spring loaded dividers are not presented in the final model. This was because of the time constraints of the project. The priority was set on manufacturing the "Pachinko" feeding mechanism. The discussion on such a design restraint will be given further in the Discussion and Reflection sections. The testing pieces were 3D-printed in two-piece. This allowed for adding weights to the center of the object. The sample of testing objects are presented in Fig. 11.5.

Figure 11.5 3D-printed testing specimens. The cylindrical objects represent the contaminants while the spherical ones represent the compost wastes. The size and weight of the specimen are chosen according to the engineering verification thereof specified.

12 VERIFICATION & VALIDATION PROCEDURE

12.1 Verification Plan & Results

Referencing the user requirements and engineering specifications in Table 10.1, pg. 28, the following tests were established to conduct experiments to allow for engineering evaluation and metric to test and verify whether the finalized prototype meets the specifications set thereof. The verification methods are organized in Table 12.1 below.

Table 12.1: The following table represents the tests developed for each requirement and specification. These tests function as a way to verify the engineering specifications defined earlier in the design process.

User Requirements	Test	Testing Platform	Method	Results
Sort various size and weight of typical compost feedstock	Create 12 object prototypes (feed stock representations) falling into 2 categories: composts-like objects and contaminant-like objects (Represented by varying Weight: 27-160g, Size: Sphere and Cylinder)	Sorting Subsystem	Analytical, Virtual Model	PASS
Align feedstock objects in a single line	Use the 12 created objects: feed all 12 at the same time and record the experimental results. At least 10 trials will be executed	Feeding Subsystem	Experimental	FAIL
Work within a table top sized space	Create a hollow 60x60x100cm cardboard or measure	Whole System	Virtual Model	PASS
Accuracy	3 sequences of 10 tests: collect data on number of correct sortings	Sorting Subsystem	Virtual Model, Experimental	PASS
Speed	Able to handle 2 items per five minutes (need 100g/ 5 mins, 2 items - 200g/min)	Conveyor, Sorting Subsystem	Analytical, Experimental	PASS
Little maintenance needed	Test 20 items sorting in 50 mins. Repeat the interval 3 times	Whole System	Experimental, Empirical Observation	FAIL

In the context of our project, the main scientific fields where the principles could be applied are the following: solid mechanics, dynamics, fluid dynamics, and the manufacturing courses. These topics are relevant to the design problem in that they incorporate the different aspects and areas of engineering applied within the project. These engineering principles can be used to execute engineering analysis to pursue analytical verification of a design. Initial engineering analyses were fulfilled in SECTION 10 which helped determine what parameters are required within the system (or subsystems) to successfully meet the engineering specification. Furthermore, the use of computer imaging software, such as SolidWorks, were utilized to build a virtual CAD model to establish product dimensions and characteristics to help predict product performance such as the volume, density, etc. This will be especially useful in optimizing the project apparatus's dimensions and properties given the restrictions and limitations set on the volume, weight, and cost which would be dependent on the material sourced.

Other testing methods include both experimental and empirical approaches. For some of the engineering specifications, the quickest and easiest way to determine if the selected concept solution is likely to meet the criteria would be through experimentation. This is because it is the most efficient way to gather data on the performance of the project, given that our interest is in its ability to complete the desired goal of sorting while remaining within the pre-defined space and sorting specimens. Again, considering the many complex components within our project it would be more efficient and effective to conduct empirical observation to determine the outcome of the project's overall performance. Since most of the engineering specifications focus on the performance of the system and its ability to sort the specimens, this data would be relatively straightforward to collect such as the dimensions, speed, accuracy, and maintenance. The maintenance requirement will be tested through an examination of the frequency of upkeep needed from the system.

One thing to note is that each engineering specification is tied to a specific subsystem(s). Such a categorization allows for a more efficient and structured testing procedure. When developing each subsystem, the engineering specifications it is responsible for will be tested throughout the building process. Once all three subsystems have been tested and integrated into one system to realize the final prototype, all of the engineering specifications will once again be verified.

After selecting our alpha design, we communicated with Professor Barton to create the appropriate users requirements and then translate them into engineering specifications to verify that our prototype will do what it is supposed to. The requirements in Table 11.1 are organized in the order of priority. The first and most important requirement is the ability of the prototype to sort. We conduct data research based on the trip to the University Waste Management and by identifying the most common types of waste in the University of Michigan compost bin. We come up with a list of the actual things that we think our prototype should be able to sort, namely contaminants and compsots. Some examples of contaminants are food containers made of plastic, water bottles, cardboard paper and boxes. Some examples of composts are food containers and utensils made of composing materials, food and produce like bananas, apples, potatoes, eggs. Using the collected data, we create 12 object prototypes in Solidworks that have different shape, size, and weight that resemble the typical compost feedstock as stated in Table 12.1. The type of testing used for this sorting subsystem is a virtual and analytical model. The result of the testing was a success as the prototype was able to successfully push the objects out of the conveyor belt.

Upon going through the iterative process for our alpha design, talking with Professor Sita Syal, and dividing our prototype into 3 subsystems, we made new requirements to fit with the feeding mechanism of the prototype. The requirement is to ensure all objects are fed one by one into the conveyor subsystem. We performed the testing for the feeding subsystem experimentally by feeding all 12 objects at the same time. The requirement wasn't met because the objects fell to each other and blocked the pathway in the feeding system in all of 10 executed trials. The failure is largely due to the fact that we omitted the spring loaded divider - an important feature of the chosen feeding mechanism to ensure the objects slow down in its pathway down to the conveyor belt system.

Our third requirement indicates the prototype to work within a table top sized space. We created a CAD virtual model and also built the prototype physically on a 60cm x 60cm physical acrylic plate. This testing for the whole system was met.

Our fourth and fifth requirement indicates the efficiency of the sorting subsystem and the conveyor subsystem namely accuracy and speed requirements. For accuracy, we performed a virtual model testing and followed up with the physical testing of 3 sequences of 10 feedstock objects. The recorded testing was 10/10 for the first two trials, and 9/10 for the last trial. For speed, the prototype must be able to handle 2 items per five minutes indicated by the object weight/ minutes. This was done analytically using engineering principles and followed up with experimental testing. The speed requirement was met. In conclusion, the prototype passed both the accuracy and the speed test.

Our last requirement was to make sure the prototype doesn't require a lot of maintenance. This test was done experimentally combining empirical observation. We run the whole system to sort 20 consecutive items and record the performances three times. After performing the test, we observed that the air cylinder was moved away from its original position and required manual adjustment. The movement of the pneumatic cylinder indicates that the maintenance requirement wasn't met. We suspect this requirement failed because we made changes to the fastening method for the air cylinder during the prototyping stage due to material availability.

12.2 Validation Plan

While the verification process is important in evaluating the design in accordance with each engineering specification, the validation process is important for evaluating the design in terms of the user requirements and the defined problem statement. In the earlier stages of the design process, a problem statement and the overarching goals of the project have been fully defined. In order to validate the proposed solution to ensure that it meets the sponsor's expectations as well as the problem statement's overarching goal, stakeholder inclusion is crucial in the process. Regular communication with the sponsor to acquire feedback on the direction and the progress on the project will lead to a successful development of the final solution. It is common that the user requirements change over the course of the project timeframe. Active stakeholder involvement along with an iterative design process will help meet those changing demands.

The deliverables for this project consists of two parts: a physical abstraction and a documentation of a structured design process. The main focus will be the reflection on the iterative design process that allowed for the development of an adequate solution. The physical model will represent the results of the process, demonstrating the working prototype of the final solution. These deliverables will be handed to the sponsor at the end of the project deadline, hoping to be used as useful tools for future projects.

The deliverables of the project require us to have a validation plan to build a physical abstraction and a documentation of a structured design process. The physical prototype was built. We also documented our iteration process to come up with our final prototype design.

13 DISCUSSION

13.1 Problem Definition

Looking back on the project as a whole, there were a myriad of issues that could have been mitigated. Starting with the problem definition section, there were a few items that merited further attention. For one, the waste itself needed more research; the typical properties of the waste in compost would be monumental for the task as a whole, whether for the sensing, reasoning, or action portion. The typical distributions of the waste composter fields receive would be immensely helpful for the task. While we know the rough numbers and the overall statistics of waste as a whole, having a focused study on the field in Ann Arbor would be relevant. Having access to an "organic" (a field that only accepts food and yard waste, no compostable plastics) to compare their contamination rates would be another point of interest.

Whether using the connections of the university waste management system or other means, getting into contact with more industry professionals would be one step into getting more information on these rates. If that is not possible, using articles afforded by the university would be the next best way to at least get the information on typical properties of waste.

13.2 Design Critique

The design had some strengths and weaknesses. The most notable strength is the simplicity of the sorting and conveyor subsystems, which will likely require little work on it when integrating the reasoning and perception systems. The largest sorespot of the design is, however, the feeding subsystem. This will require iteration between the sensing, action, and reasoning parts of the system to optimize the feeding, not to mention the flaws within the system itself.

As it is, the larger feedstock tends to get clogged in the system and smaller feed is not made one by one at all. Any further iterations would likely focus entirely on the feeding subsystem, as it failed its one requirement. The clogging was caused by not scaling down the testing specimen even though the prototype's working area was scaled down.

A preliminary modification would either be expanding the working area or lowering the sizes of the test specimen. However, the main modification that needs to be made is, of course, the addition of the perception and reasoning systems. As has been previously discussed, the modifications to the feeding subsystem need to be quite extensive and will need to work closely with the perception and reasoning systems. Properly integrating them will take considerable effort and modifications.

13.3 Risks

Throughout the project, the team had some very clear missteps. Due to having to narrow the scope and change the problem statement multiple times, the group waffled on starting prototyping. Making mock ups and ordering parts this late caused a general delay, stalling production for nearly a week when the time scale was severely limited. The team also did not have the one by one feeding requirement until the prototyping phase started. The limited timescale was a major stressor of the project and ultimately limited what could be accomplished.

To mitigate the time issues, the team broke the design down into subsystems that could clearly be worked on and iterated on their own. This helped with the conveyor and sorting subsystems, where we had some iterations before making the final product. The feeding subsystem hit a snag, where problems emerged when it was integrated with the whole system; however, there was at least one to have problems with.

To any future users of the physical prototype, be cautious of the speed of the pneumatic system. Items tend to be launched due to its speed, make sure to remain clear of the ejection area and other moving parts.

14 REFLECTION

14.1 Impact Discussion

Upon completion of the final project, the team has deliberated meaningful reflection on their initial perspective and how it has evolved over the semester. The first facet of the social impact of the project pertains to public health, safety, and wealthfare. This factor was prevalent in the beginning stages of the course given the nature of the assigned project and its relevance to enhancing the composting process. Due to the fact that composting itself is a sustainable practice towards mitigating the amount of waste that ends up in landfills and extending the use of biodegradable waste for a further purpose, the project has a positive impact in its goal of improving this method. The goal of automating the sorting process would improve public safety by reducing the amount of human involvement in the actual sorting, especially given the potential variety of the sorting stock.

In addition, its impact could be extended to a global scope as automation in composting sorting could be exercised from every marketplace as compostable waste is produced globally. This also introduces the consideration of its social consequences associated with its manufacturing, operation, and disposal. With an overall assumed positive impact given that the design allows for improvement in composting enabling the opportunity for a wider integration within the state and even nation. This could result in an improved consensus amongst potential users as it becomes more accessible to the public. The economical impacts are also taken into consideration to build a coherent reflection. From the design of automating the sorting process, it would require an initial cost associated with its implementation and integration from the machinery. However, with time, the project should yield a net positive economic benefit from improving the efficiency and reducing the amount of resources needed in terms of its operation. This includes its performance from its operational use with a slight increase in the beginning of the project implementation, but plateauing to a consistent rate. In regards to its disposal, there is not any outstanding cost compared to the disposal of other automated machinery, but there could be a notable contribution from the handling of chemical elements such as battery components. For characterization of potential societal impacts of the design, both stakeholder maps and product life-cycle were constructed to gather a comprehensive analysis.

14.2 Influence of Social Identities

The biases of the team were also considered to address the potential personal influences. With first noting the role of the team as engineering students, and how this played into a favourable position championing the design. This also explains the emphasis of the physical and economical impact more so than the social effects. Since as engineering students, the focus is on the engineering or mechanical side of the project and inherently the economic side as well since this is usually the driving factor for engineering practice in industry. This explains why the project introduces the potential method of a physical automated system rather than working on the front end of the problem towards building a better public knowledge of sorting compostable waste in the first place.

14.3 Inclusion and Equity

Addressing the power dynamics between the team and the stakeholders is also important to establish a solid understanding of the role that inclusion and equity played into the design project. With the first relationship between the team and stakeholder being a mentor and mentee dynamic, in that there was a lot of liberty in project design and exploration since even though the project's motivation factor was automation of sorting compost, the project goal was to serve as an abstraction of the design process and how the team navigated through this process throughout the semester. Also, there exists the relationship between the team and the end user, which could include potential treatment facilities or institutions that would benefit from automating their sorting process of compost. This dynamic is characterized as a client and vendor relationship, in that our team is working to build a solution that others would benefit from and use. In the case of the project, our focus as the engineering students shaped our emphasis more so on the design process that we took and how we iterated through the prototyping process, and looped through the design process. However, this journey for the design process is not the priority or major concern of the end users, as their focus is the final product that is shown to them and whether it satisfies their requirements. The team took approaches to include a diverse viewpoint of the stakeholders and the team members through understanding the goal and priority of each involved party and working towards a compromise that would satisfy each group. This involved communicating with the stakeholder in what they were looking for in terms of the manifestation of a physical prototype that still served as a learning demonstration of the overall project design process as a potential learning module for the Robotics capstone course. While there were not any real end-users to discuss their input on the project's performance, the team made considerations of making a solid system that could prove as a solid solution or approach as a small scale prototype.

14.4 Ethical Reflection

The team also would like to note an ethical dilemma that arose in the design of the project. One issue that posed a concern, was that this project proposed a solution for a problem that is typically only prevalent in affluent areas. While composting is a good practice, this is usually only available in wealthy areas that make composting an option to begin with. This is an issue with sustainability in general, since most of the sustainable options are not affordable to begin with and not accessible to most people. Therefore, the dilemma with this project is that it would again only be accessible to affluent communities, and then implicitly marginalizing certain demographics. A potential attempt to manage this would be making the technology cheap so that it would provide an economic incentive to be applied at a larger scale to ensure its accessibility.

Overall, this deliberation of ethics is important for engineering students and engineers because as practicing professionals there will be moments in which personal ethics might not align with the professional ethics expected by the institution or employer, and thus require important decisions in whether we choose to participate and perpetuate the work and consequences from our contributions.

15 RECOMMENDATIONS

The following recommendations after completion of the project would contain starting the physical prototyping stage of the apparatus much earlier, to allow for time to conduct meaningful design exploration and realization. This would include down-sizing the test specimens as well since the system showed discrepancies between the small and larger test specimens given the space constriction from the listed dimensions. This could also entail changing the timeline of the DR reports and curriculum in general, since a majority of the time was spent in background research to establish a solid problem definition given the nature of the project having a scarce amount of solid working parameters. This project was more so focused on the physical manifestation of a design and exploring the design process, therefore it would have been beneficial to allow for more time in the physical prototyping and verification stages. In terms of the design process, decomposing the system into subsystems and identifying the "functions" of each subsystem can help develop the solution in smaller stages. Reviewing the concept generation stage of the design process with these "functions" in mind can produce innovative yet relevant design ideas. The next step for this project would be to build an improved version of the feeding subsystem and to incorporate sensing and reasoning principles into the system.

16 CONCLUSIONS

With an indefinite increase in food waste, the world needs a sustainable waste management system. Composting, the recycling of organic matter, is known to be an effective way to control food waste. Through composting, these wastes can be transformed into another form of resources including fertilizers and biofuels. However, the quality of these resources are highly dependent on the impurity of the organic matters used to produce them. In order to reduce the contamination of the resources, an accurate and efficient sorting system is necessary, as manual sorting is unreasonable at a large scale due to its laborious and dangerous nature. A robotics automation approach can improve the overall productivity of sorting [28]. This project focuses on the action part from the robotics principles in an effort to create an abstraction of a physical sorting mechanism. During the first three weeks of the project initiation, a clear motivation has been defined and a problem statement has been developed. The problem space was extensively explored to generate possible concepts. Each design was evaluated using a systematic down selection process to determine an Alpha Design for further exploration. Virtual modeling and engineering analysis of the selected concept were also performed. Prototyping as well as verification and validation procedures and results are also presented. Two of the engineering specifications were not met with the current design/prototype. More iteration on the feeding mechanism is necessary to improve the design in order to successfully pass the currently failed criteria. Apart from the abstraction, a structured design process was examined throughout the project. A linear design process might streamline the overall product development process, but it may not be the best solution. A thorough analysis of the problem as well as an ample amount of design iteration (both virtually and physically) are essential when it comes to generating the most adequate solution. The initial "Alpha" design is noticeably different from the final design. This will also look much different from the improved design in the future. The cyclic nature of the iterative design process will help push through this project in the future, whatever that might be. The future projects may have varying focuses, but they will all have the same motivating factor: helping the earth by reducing landfill waste.

17 ACKNOWLEDGEMENTS

We would like to express our deepest gratitude to Professor Alex Shorter and Professor Kira Barton for their sincere feedback and guidance throughout the project milestones. We would also like to extend our thanks to Professor Syal, Graduate Students Instructors Caleb and Robert, ME machine shop staff and Kemal Duran for full support during our physical prototyping.

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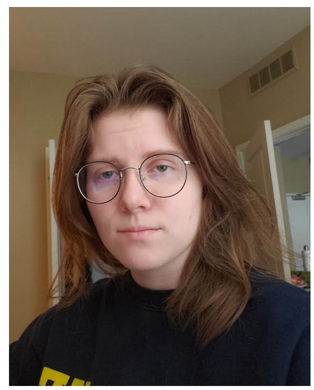
APPENDIX A - Team Member Biography

Arif Amini

Hello, my name is Arif Amini. I am from Kalamazoo, Michigan. I will be completing my program after this semester, and looking forward to graduating. My current plan is to join the industry and work either in the biomedical device or automotive industry. In my free time I like to spend time with friends and family, and find any reason to be outdoors when the weather is nice.

Sophia Carlson

Hi, I'm Sophia. I'm from Belding, Michigan and will be graduating in December 2023. I decided to go into engineering because I like to fiddle with things and optimize them, while also making enough money to support myself. My plans for this next year are to finish my degree, get a job, and have enough time to enjoy some hobbies like drawing or music. If I had to eat one food for the rest of my life I would choose spaghetti.

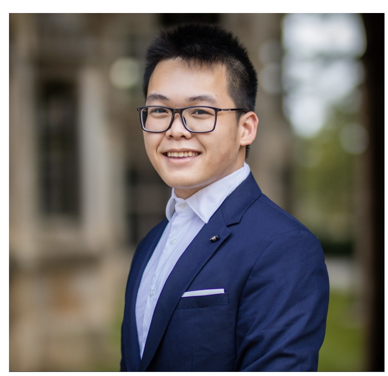


Su Sung Kim

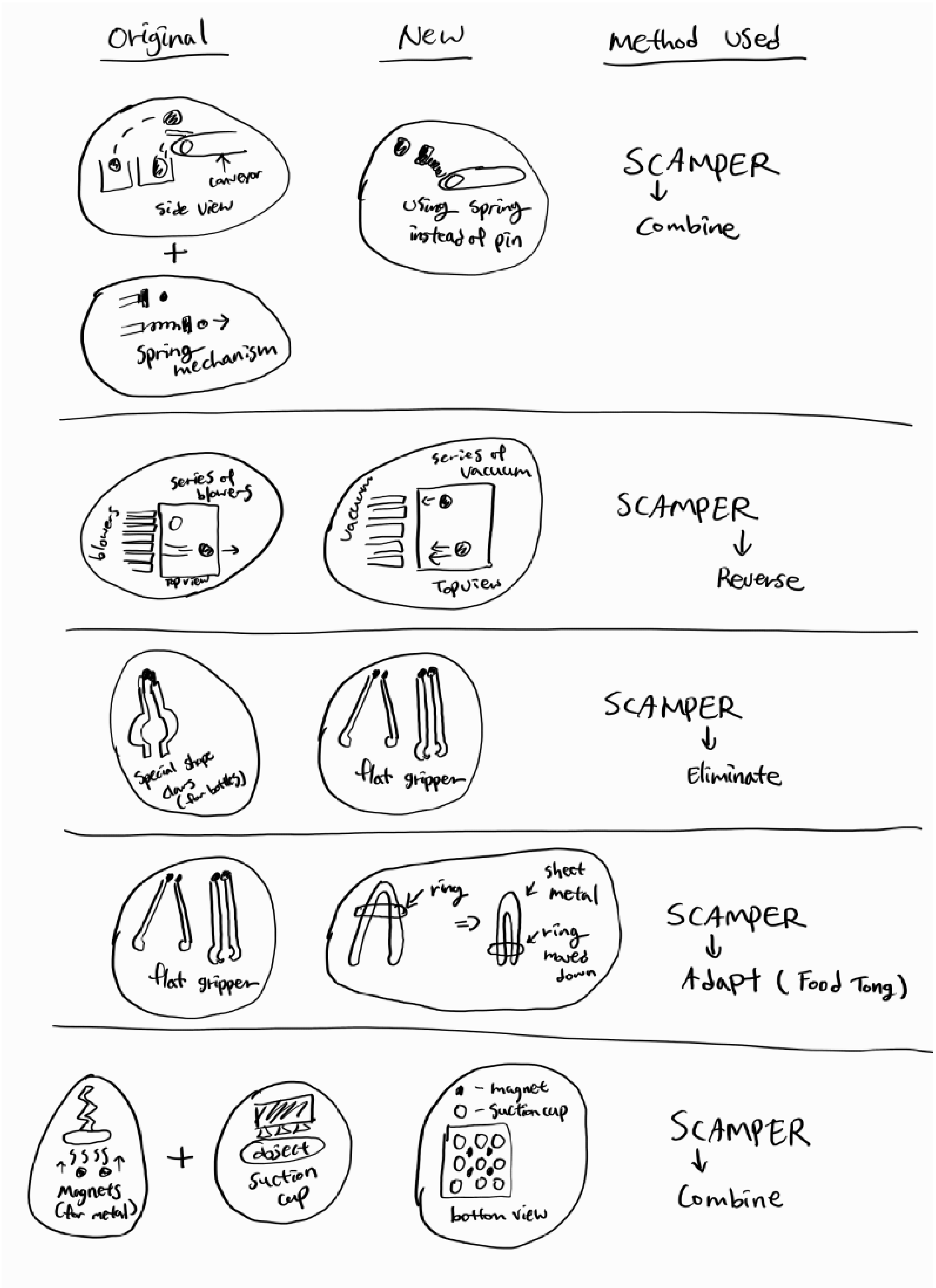
Hi, I'm Su Sung. I'm a senior in Mechanical Engineering who loves to design physical products that hold positive societal impacts. I want to continue exploring my passion in the industry by working in the medical devices or renewable energy fields. As an international student, I sometimes miss my home back in Korea. And I love hot chocolate!

Nam Le

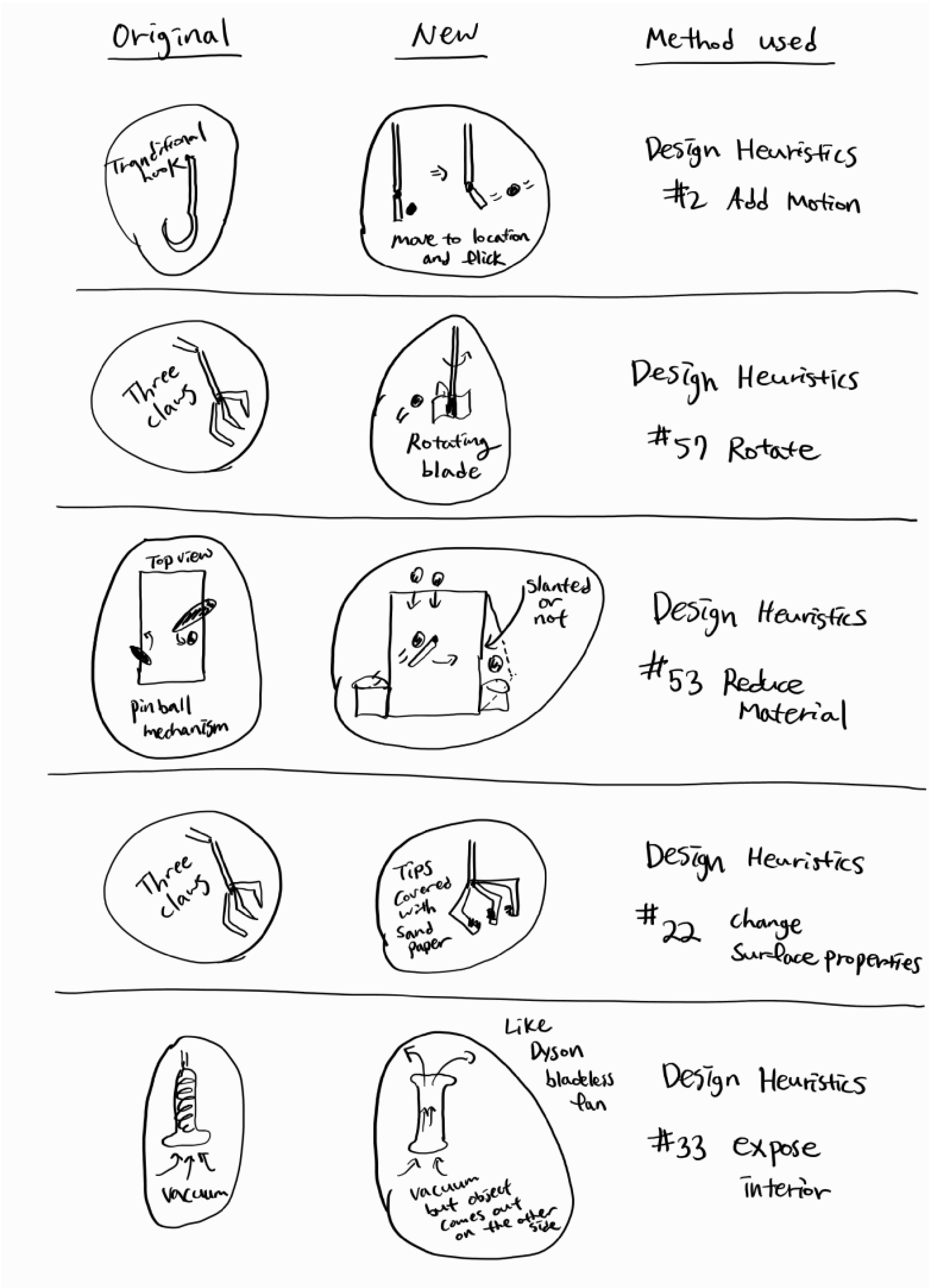
Hello everyone, I am Nam, a senior majoring in Mechanical Engineering and minoring in International Studies from Vietnam. I like Mechanical Engineering because it gives me the tools and skills to design and make things. I plan to use the skills and experiences I have to create a product that can bring tremendous value to their customers. If I were to not become an engineer, I would love to go pro in poker.



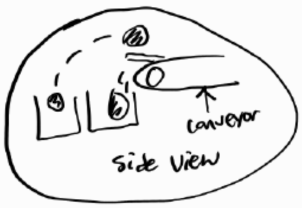
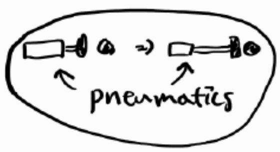
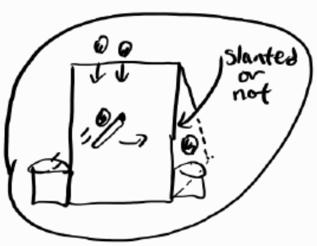
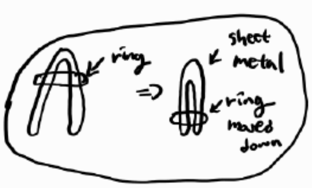
APPENDIX B - SCAMPER Technique Implementation

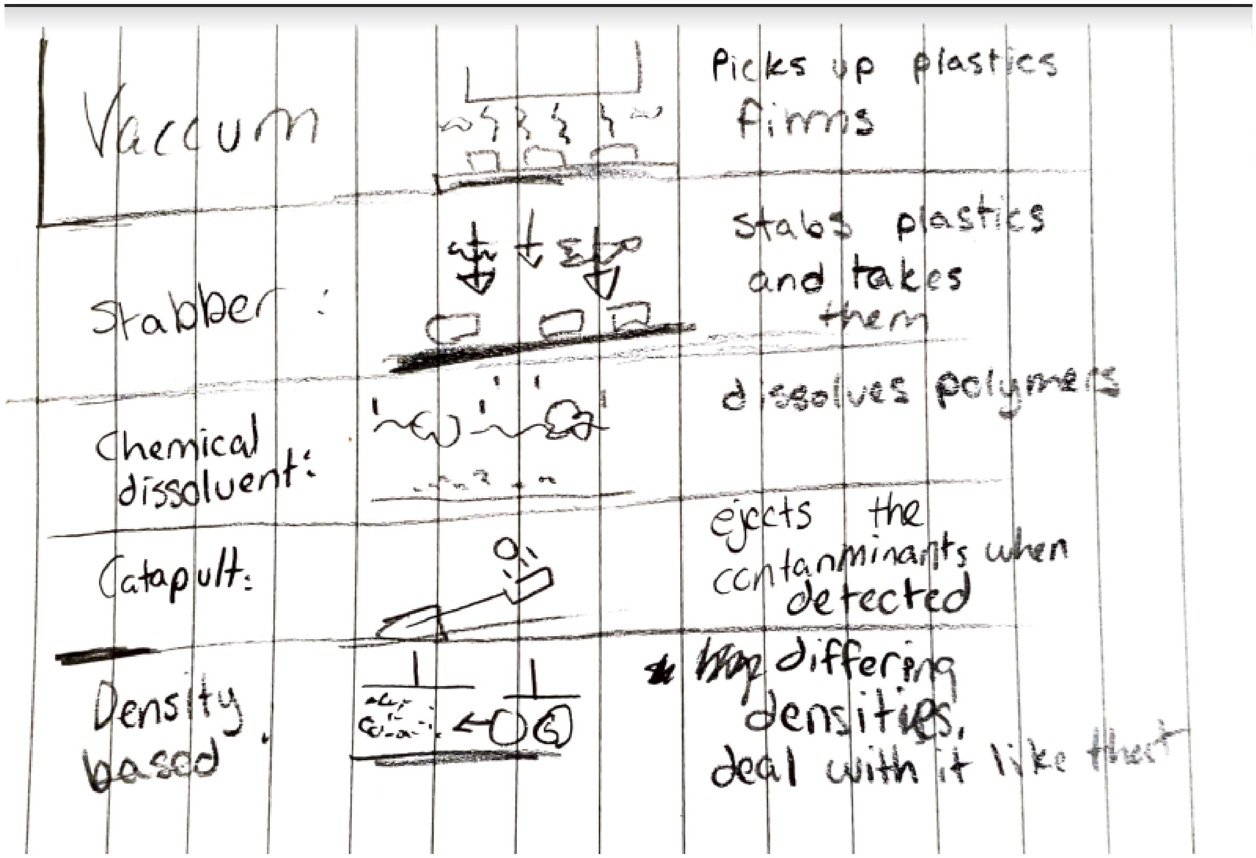


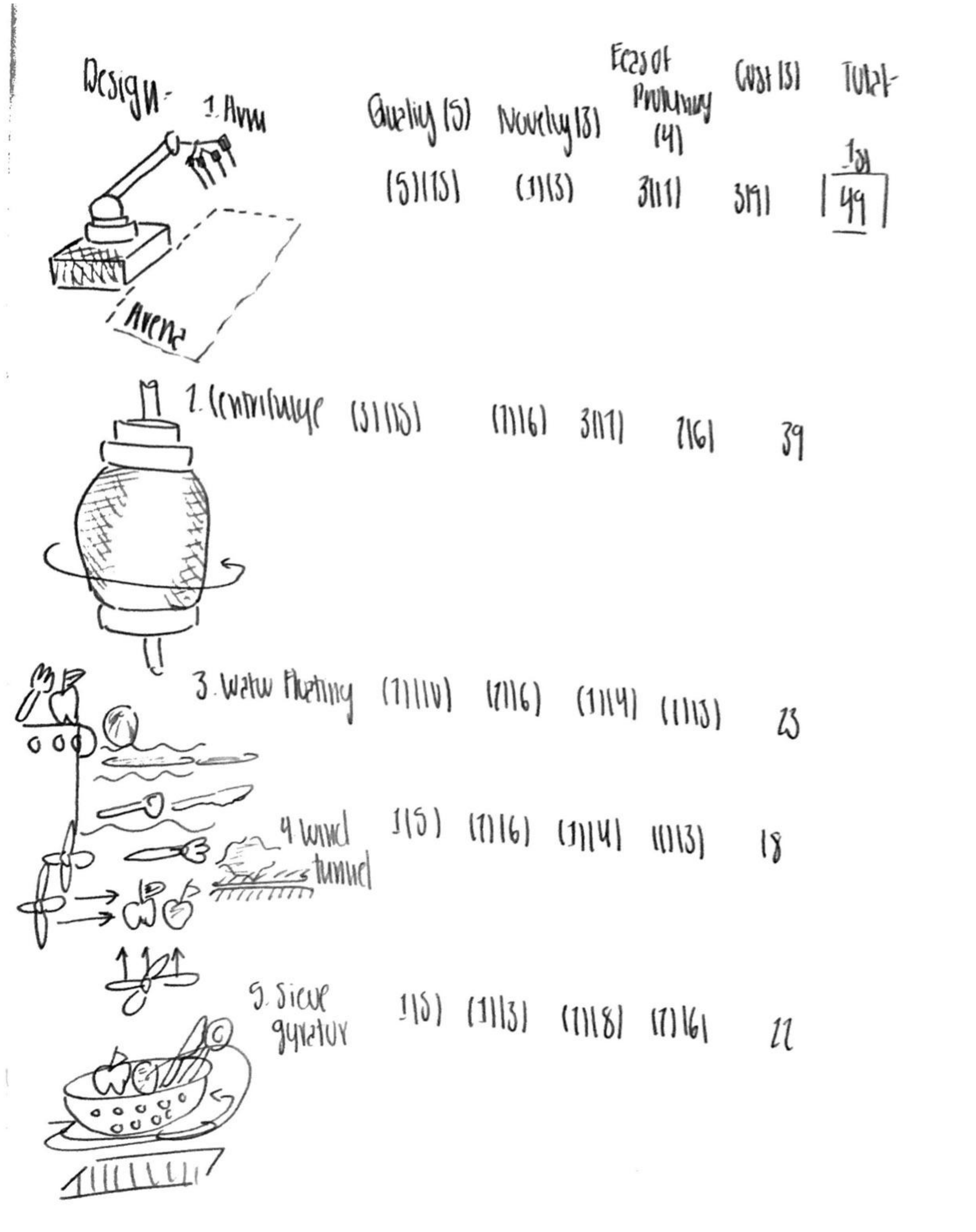
APPENDIX C - Design Heuristics Implementation

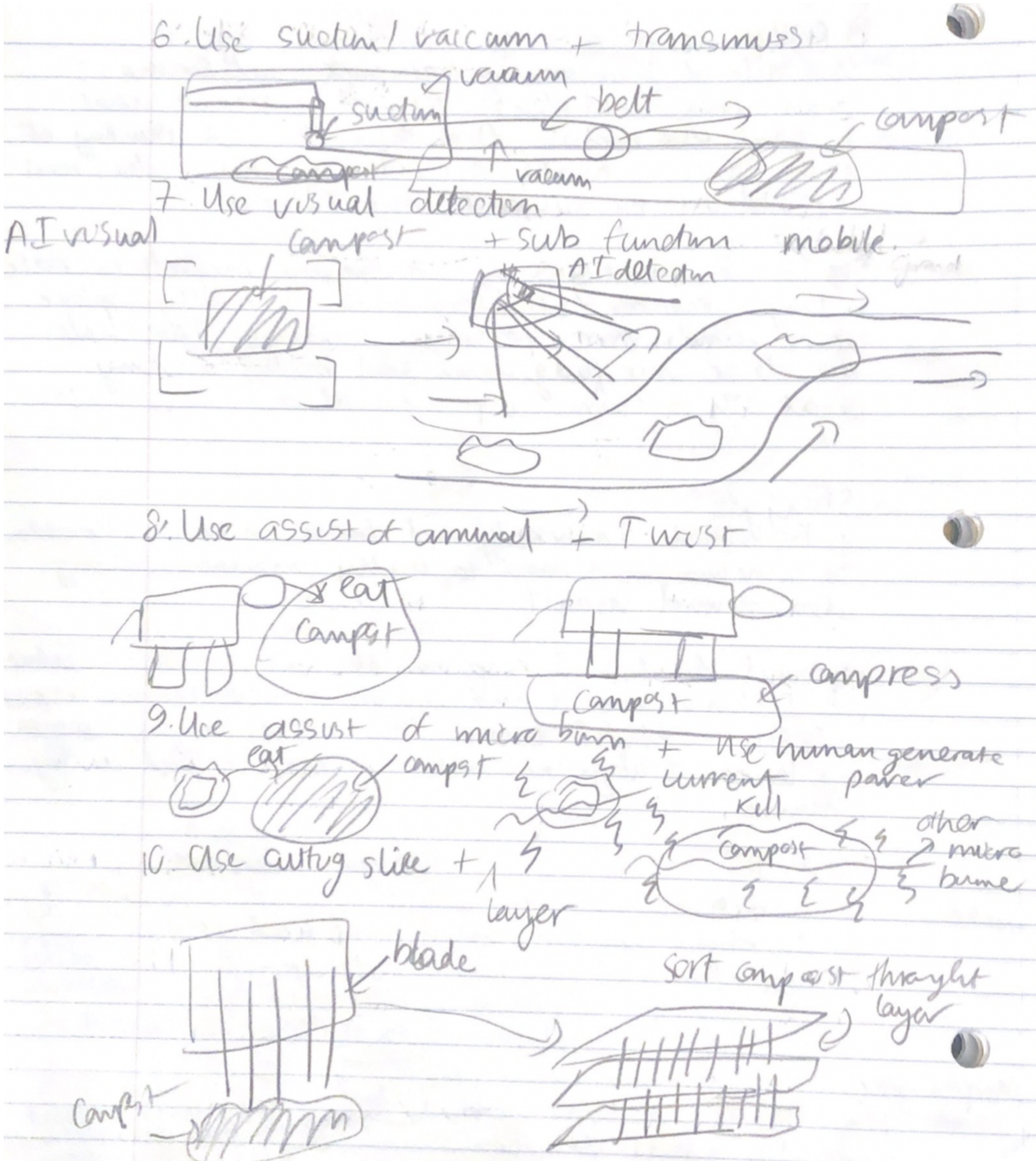


APPENDIX D - Top Five Ideas from Individual Member

Design	Quality (5)	Novelty (3)	Ease of Prototyping (4)	Less Manufacturing cost (3)	Total
	3 (15)	4 (12)	2 (8)	4 (12)	47
	2 (10)	3 (9)	2 (8)	2 (6)	33 X
	3 (15)	3 (9)	4 (16)	2 (6)	46 X
	3 (15)	3 (9)	4 (16)	4 (12)	52
	4 (20)	4 (12)	3 (12)	4 (12)	56


Vaccum
Picks up plastics films
Stabber:
stabs plastics and takes them
Chemical dissoluent:
dissolves polymers
Catapult:
ejects the contaminants when detected
Density based
differing densities, deal with it like that


Design:
1. Arm
Quality (5)
Novelty (3)
Ease of Prototyping (4)
Cost (3)
Total
1st
49
Arena
2. Centrifuge
39
3. Water Floating
23
4. Wind tunnel
18
5. Sieve gyrator
22

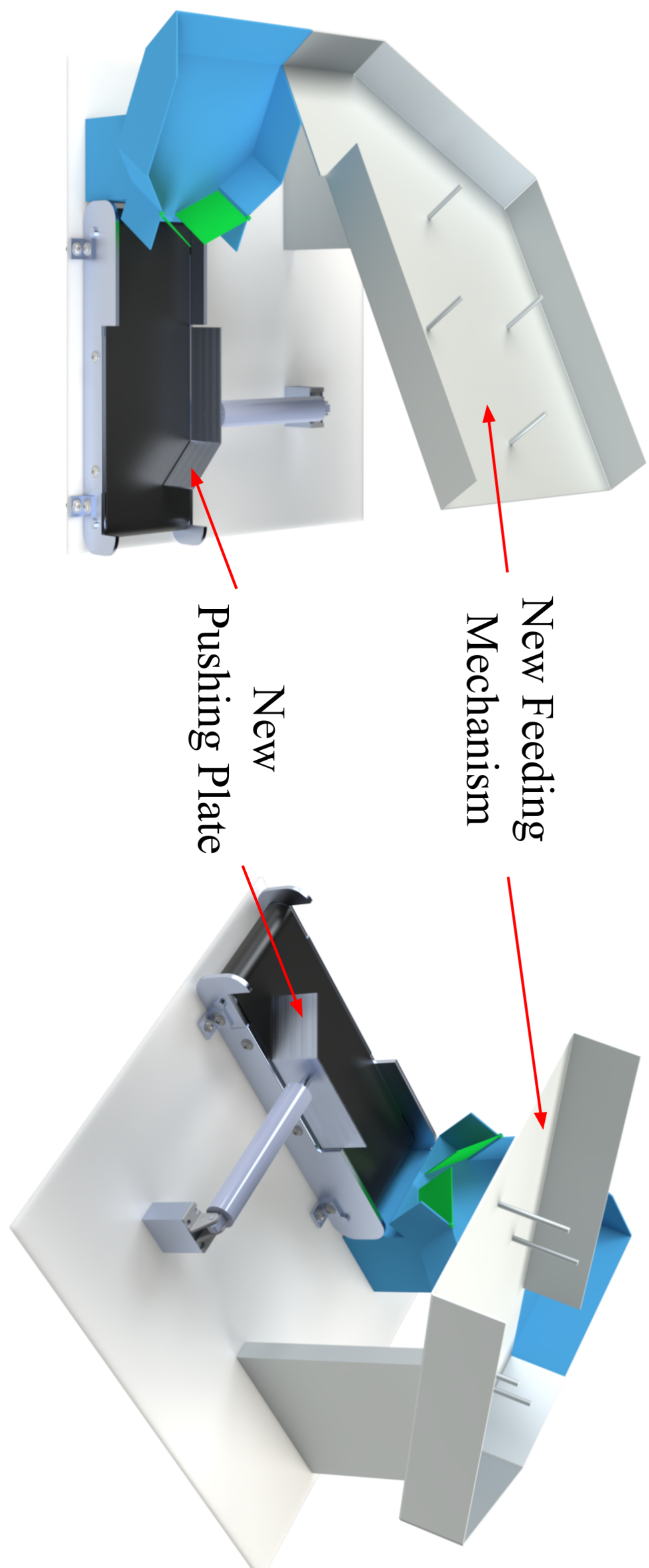

6. Use suction / vaccum + transmiss
vacuum
suction
belt
compost
vacuum
7. Use visual detection
AI visual
compost
+ sub function mobile.
AI detection
8. Use assist of animal + Twist
eat
Compost
compress
Compost
9. Use assist of micro b... + Use human generate current power
eat
compost
kill
Compost
other micro ...
10. Use cutting slice + layer
blade
Compost
Sort compost through layer

APPENDIX E - Bill of Materials

Part #	Part Name	Part Specification	Part Quantity	Product Name	Product Specification
1	**Conveyor Subsystem**				
1.1	Roller Driver	1.5" Diameter (6.3" Length)	1	Multipurpose 6061 Aluminum	1.5" Diameter (6 ft. Length)
1.2	Roller Follower	1.5" Diameter (6.3" Length)	1	Same as above	-
1.3	Side Plate	W = 3" , L = 17" (0.25" thick)	2	Multipurpose 6061 Aluminum	W = 4" , L = 36" (0.25" thick)
1.4	Middle Plate	11.5" x 8.76"	1	Scrap 6061 Aluminum Sheet Metal (0.06")	-
1.5	Conveyor Bracket	1" x 1" x 1" (0.266" hole diameter)	4	Scrap 6061 Aluminum 90 angle stock	-
1.6	Conveyor Belt	W = 6.3" , L = 32" (1.2mm thick)	1	PU Fabric Material 1 Yard 54" x 36" Faux Synthetic Leather Sheets 1.2mm Thick Perfect fo	1 Yard 54" x 36" (1.2mm thick)
1.7	DC Motor	Shaft Diameter = 6mm	1	Greartisan DC 12V 200RPM	Shaft Diameter = 6mm, 12V 200RPM
1.8	Motor Mount	37mm Body DC Gear Motor	1	Black 37mm DC Gear Motors Mounting Bracket, Iron Anti-Rust Gearbox L-Shape Fixed Se	For 37mm DC Motor
1.9	Motor Coupling	6mm to 12mm motor shaft	1	uxcell 6mm to 12mm Shaft Coupling 30mm Length 25mm Diameter Stepper Motor Coupler	For 6mm shaft to 12mm shaft
2	**Sorting Subsystem**				
2.1	Pneumatic Air Cylinder	22mm Bore , 150mm Stroke	1	TAILONZ PNEUMATIC 20mm Bore 150mm Stroke Air Cylinder Double Action with Y Conn	20mm Bore , 150mm Stroke
2.2	Air Cylinder Support	3.0625" Height	2	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-
2.3	Pushing Plate (Flate Plate)	2.6" x 8.625" rectangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
2.4	Pushing Plate (L-Shape)	2.6" x 8.625" , bent at 2.5"	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
2.5	Air Hose	ID = 4mm , OD = 6mm	1	TAILONZ PNEUMATIC Blue 6mm OD 4mm ID Polyurethane PU Air Hose Pipe Tube Kit	ID = 4mm , OD = 6mm
3	**Feeding Subsystem**				
3.1	Feeder	11" x 14.5", trapezoid	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
3.2	Pachinko Mechanism Top	9.75" x 15.5" rectangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
3.3	Pachinko Mechanism Bottom	14" x 14" x 15.5" triangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
3.4	Feeder Support Long	6.5" Height	1	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-
3.5	Feeder Support Short	5.3" Height	1	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-
3.6	Pachinko Support	11.875" Height	1	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-
3.7	Feeder Side Wall	4.25" x 10.59" rectangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
3.8	Feeder Back Wall	4.25" x 13.23" rectangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
3.9	Pachinko Wall	4.25" x 11.68" rectangle	1	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-
4	**Electronics/Miscellaneous**				
4.1	DC Motor Controller	Rating = 7-70V , 30A	1	RioRand DC Motor Speed Controller Switch	Rating = 7-70V , 30A
4.2	Pneumatic Controller	12V 2 Position 5 Way Connection	1	TAILONZ PNEUMATIC 1/4"NPT Solenoid Valve 12V/24V/110V	12V/24V/110V, 2 Position 5 Way Connection
4.3	Female 12V DC Power Jack	5.5mm x 2.1mm	1	Scrap from MEx50 Room	-
4.4	Dupont Cable	Length = 20cm	10	Chanzon 120pcs 20cm Jumper Wire Dupont Cable Line Connector	Length = 20cm
4.5	Breadboard	400 Point	1	MCIGICM Breadboards, 2Pcs 830 Point and 2Pcs 400 Point Solderless Bread Board	830 , 400 Point
4.6	Assembly Plate	60cm x 60cm, 0.21" thick	1	Scrap Acrylic Board	-
4.7	Assembly Plate Leg	3.75" right triangle, 0.725" thick	4	Scrap Acrylic Stock	-
5	**Fasteners**				
5.1	1/4" - 20, 1" length	rounded head phillips screw	12	used for bulding the conveyor subsystem	
5.2	1/4" flat washer	-	12	used for bulding the conveyor subsystem	
5.3	1/4" - 20 lock nut	-	4	used for fastening the conveyor subsystem to the assembly plate	
5.4	5/16" - 18, 1" length	socket head screw	5	used for fastening the extruded aluminum supports to the assembly plate	
5.5	5/16" flat washer	-	5	used for fastening the extruded aluminum supports to the assembly plate	
5.6	1/4" - 20, 2.5" length	hex head screw	2	used for pachinko poles	
5.7	1/4" split lock washer	-	2	used for pachinko poles	
5.8	1/4" hex nut	-	2	used for pachinko poles	
5.9	3/16" diameter aluminum rivet	1/8" grip	6	used for attaching the walls to the feeding subsystem	

Part #	Part Name	Product Name	Product Specification	Provider	Model #	Product Qty. Unit	Product Quantity	Price/unit ($)	Total price ($)
1	**Conveyor Subsystem**								
1.1	Roller Driver	Multipurpose 6061 Aluminum	1.5" Diameter (6 ft. Length)	McMaster-Carr	8974K18	Each	1	93.96	93.96
1.2	Roller Follower	Same as above	-	-	-	-	-	-	-
1.3	Side Plate	Multipurpose 6061 Aluminum	W = 4" , L = 36" (0.25" thick)	McMaster-Carr	8975K514	Each	1	39.32	39.32
1.4	Middle Plate	Scrap 6061 Aluminum Sheet Metal (0.06")	-	-	-	-	-	-	-
1.5	Conveyor Bracket	Scrap 6061 Aluminum 90 angle stock	-	-	-	-	-	-	-
1.6	Conveyor Belt	PU Fabric Material 1 Yard 54" x 36" Faux Synthetic Leather Sheets 1.2mm Thick Perfect fo	1 Yard 54" x 36" (1.2mm thick)	Amazon	B08SM37RXM	Each	1	18.99	18.99
1.7	DC Motor	Greartisan DC 12V 200RPM	Shaft Diameter = 6mm, 12V 200RPM	Amazon	B071GTTSV3	Each	1	14.99	14.99
1.8	Motor Mount	Black 37mm DC Gear Motors Mounting Bracket, Iron Anti-Rust Gearbox L-Shape Fixed Se	For 37mm DC Motor	Amazon	B07BHDZH7Y	Each	1	8.99	8.99
1.9	Motor Coupling	uxcell 6mm to 12mm Shaft Coupling 30mm Length 25mm Diameter Stepper Motor Coupler	For 6mm shaft to 12mm shaft	Amazon	B06X9V1ZD4	Each	1	9.99	9.99
2	**Sorting Subsystem**								
2.1	Pneumatic Air Cylinder	TAILONZ PNEUMATIC 20mm Bore 150mm Stroke Air Cylinder Double Action with Y Conn	20mm Bore , 150mm Stroke	Amazon	B08CZ3WP1Q	Each	1	16.99	16.99
2.2	Air Cylinder Support	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-	-	-	-	-	-	-
2.3	Pushing Plate (Flate Plate)	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
2.4	Pushing Plate (L-Shape)	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
2.5	Air Hose	TAILONZ PNEUMATIC Blue 6mm OD 4mm ID Polyurethane PU Air Hose Pipe Tube Kit	ID = 4mm , OD = 6mm	Amazon	B07RJ1BYKV	Kit	1	15.99	15.99
3	**Feeding Subsystem**								
3.1	Feeder	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
3.2	Pachinko Mechanism Top	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
3.3	Pachinko Mechanism Bottom	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
3.4	Feeder Support Long	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-	-	-	-	-	-	-
3.5	Feeder Support Short	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-	-	-	-	-	-	-
3.6	Pachinko Support	Scrap 6061 Extruded Aluminum (40mm x 40mm)	-	-	-	-	-	-	-
3.7	Feeder Side Wall	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
3.8	Feeder Back Wall	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
3.9	Pachinko Wall	Scrap 6061 Aluminum Sheet Metal (0.06" thick)	-	-	-	-	-	-	-
4	**Electronics/Miscellaneous**								
4.1	DC Motor Controller	RioRand DC Motor Speed Controller Switch	Rating = 7-70V , 30A	Amazon	B071NQ5G71	Each	1	14.99	14.99
4.2	Pneumatic Controller	TAILONZ PNEUMATIC 1/4"NPT Solenoid Valve 12V/24V/110V	12V/24V/110V, 2 Position 5 Way Connection	Amazon	B081PTW87K	Each	1	16.99	16.99
4.3	Female 12V DC Power Jack	Scrap from MEx50 Room	-	-	-	-	-	-	-
4.4	Dupont Cable	Chanzon 120pcs 20cm Jumper Wire Dupont Cable Line Connector	Length = 20cm	Amazon	B09FPGT7JT	Pack	1	9.99	9.99
4.5	Breadboard	MCIGICM Breadboards, 2Pcs 830 Point and 2Pcs 400 Point Solderless Bread Board	830 , 400 Point	Amazon	B08115P2T4	Kit	1	7.77	7.77
4.6	Assembly Plate	Scrap Acrylic Board	-	-	-	-	-	-	-
4.7	Assembly Plate Leg	Scrap Acrylic Stock	-	-	-	-	-	-	-
5	**Fasteners**								
5.1	1/4" - 20, 1" length	used for bulding the conveyor subsystem							
5.2	1/4" flat washer	used for bulding the conveyor subsystem							
5.3	1/4" - 20 lock nut	used for fastening the conveyor subsystem to the assembly plate							
5.4	5/16" - 18, 1" length	used for fastening the extruded aluminum supports to the assembly plate							
5.5	5/16" flat washer	used for fastening the extruded aluminum supports to the assembly plate							
5.6	1/4" - 20, 2.5" length	used for pachinko poles							
5.7	1/4" split lock washer	used for pachinko poles							
5.8	1/4" hex nut	used for pachinko poles							
5.9	3/16" diameter aluminum rivet	used for attaching the walls to the feeding subsystem							
								Total Price ($) =	268.96

APPENDIX F - Rendered Images of the Final Design



APPENDIX G - Engineering Drawings

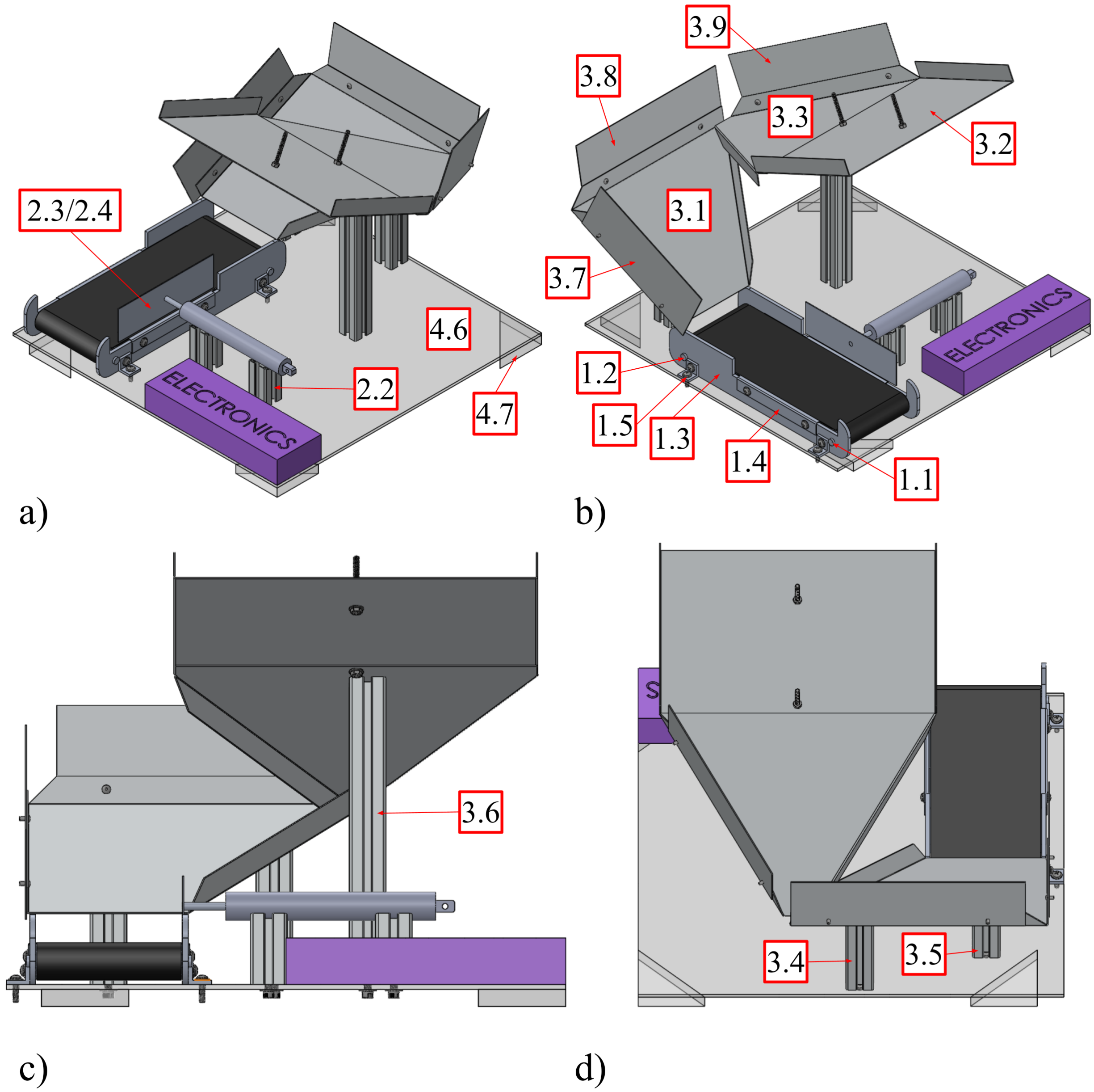
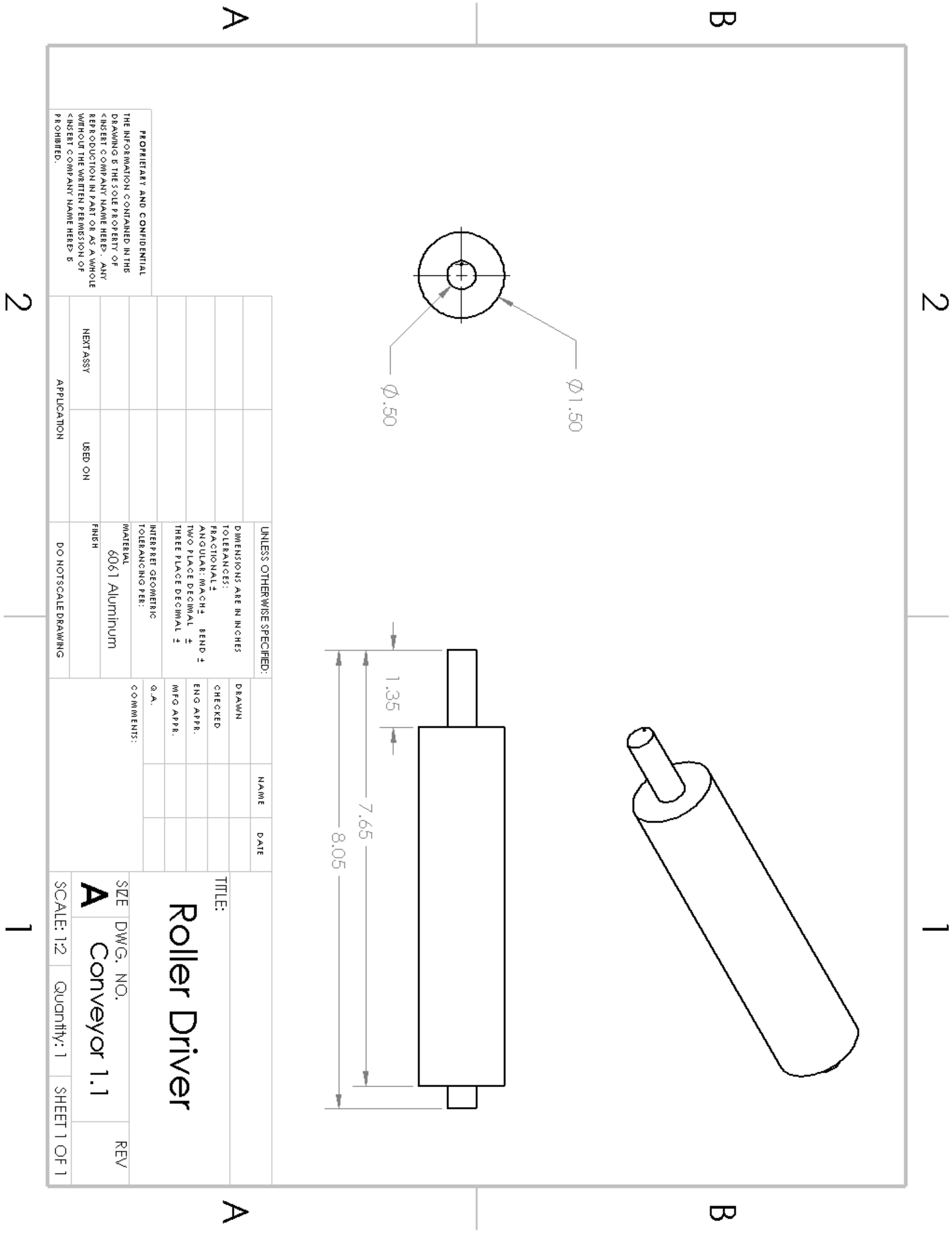
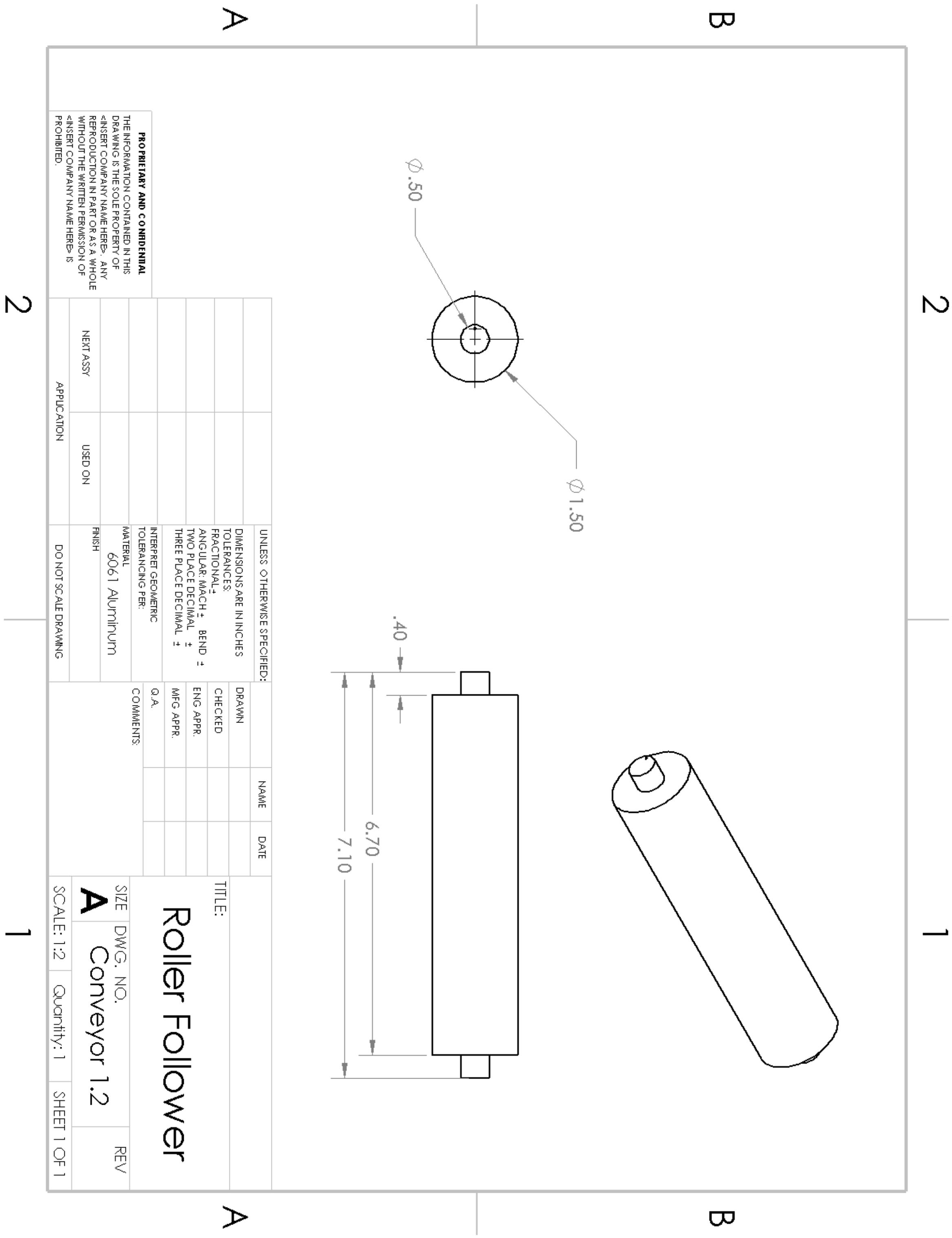


Figure G.1 3D CAD model of the final physical prototype. a) Front isometric view of the model. b) Back isometric view of the model. c) Front view of the model. d) Top view of the model. The part numbers correspond to the part numbers in Bill of Materials and Engineering Drawings.


Roller Driver
Conveyor 1.1
6061 Aluminum
Ø1.50
Ø.50
1.35
7.65
8.05
SIZE A
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL



A
B
2
1
∅.50
∅1.50
.40
6.70
7.10
PROPRIETARY AND CONFIDENTIAL
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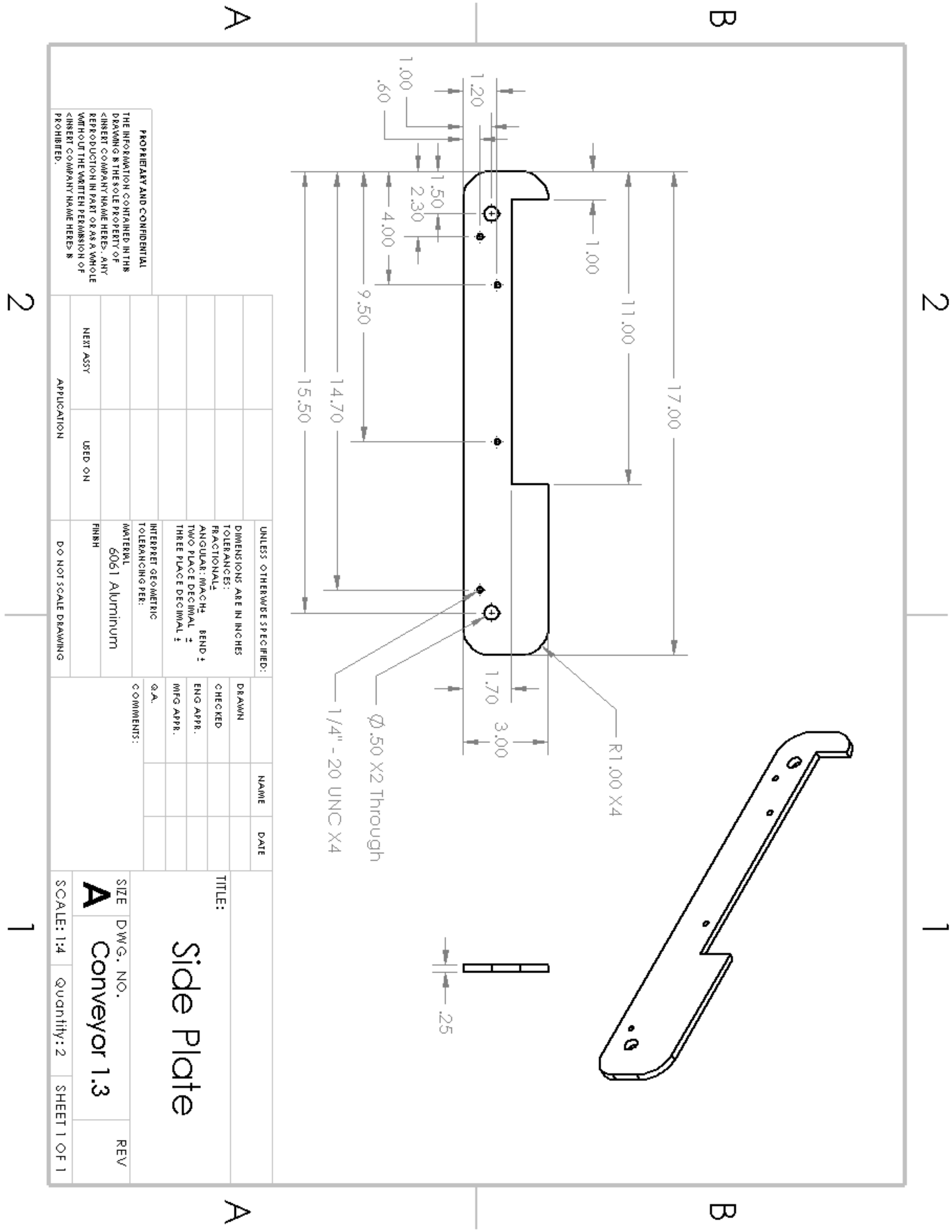
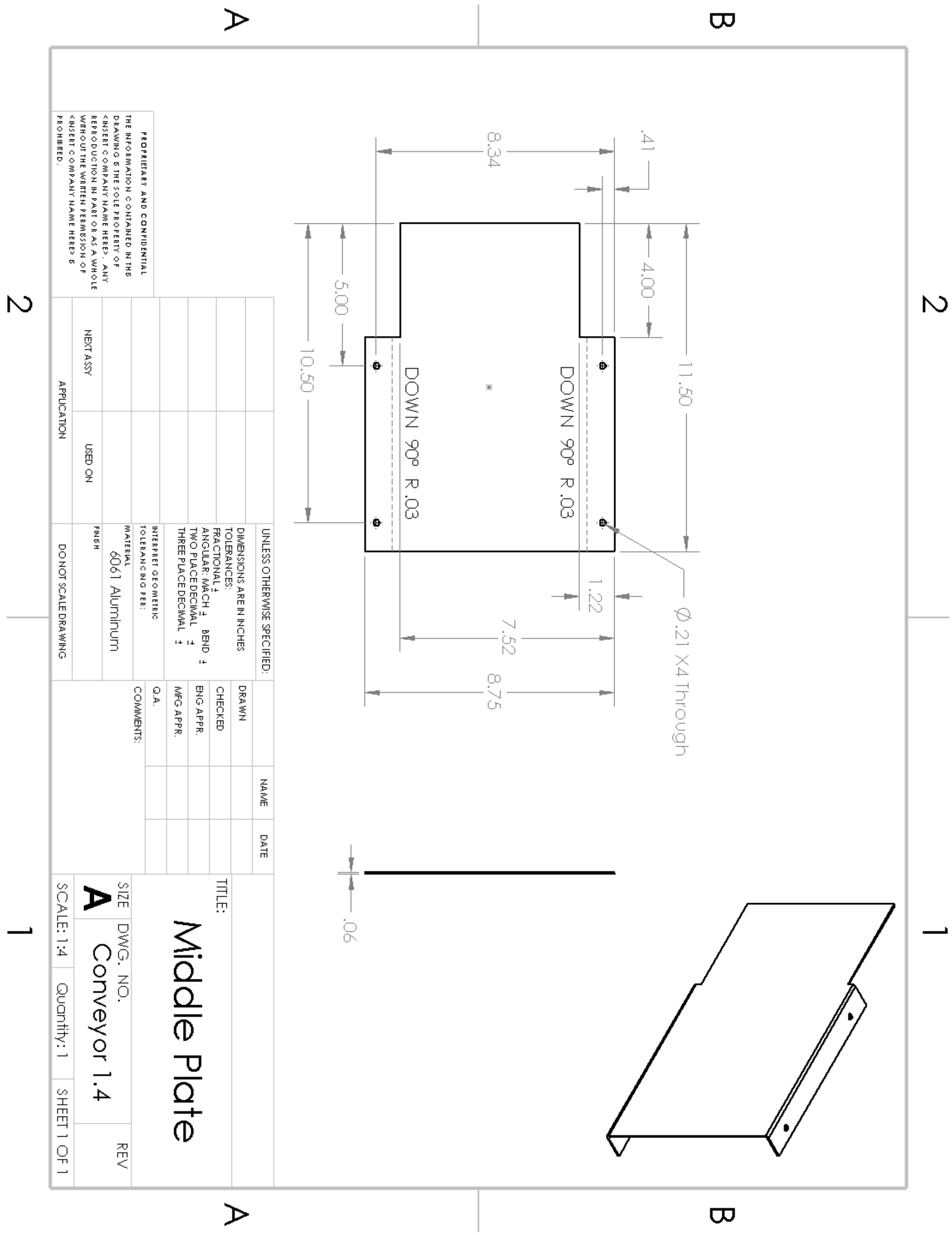
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Roller Follower
SIZE
A
DWG. NO.
Conveyor 1.2
REV
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1



Side Plate
Conveyor 1.3
6061 Aluminum
SCALE: 1:4
Quantity: 2
SHEET 1 OF 1
SIZE A
DWG. NO.
REV
TITLE:
Ø.50 X2 Through
1/4" - 20 UNC X4
R1.00 X4
17.00
15.50
14.70
11.00
9.50
4.00
2.30
1.50
1.20
1.00
.60
1.70
3.00
.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL


8.34
.41
4.00
11.50
5.00
10.50
DOWN 90° R .03
DOWN 90° R .03
1.22
7.52
8.75
Ø.21 X4 Through
.06
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Middle Plate
SIZE
A
DWG. NO.
Conveyor 1.4
REV
SCALE: 1:4
Quantity: 1
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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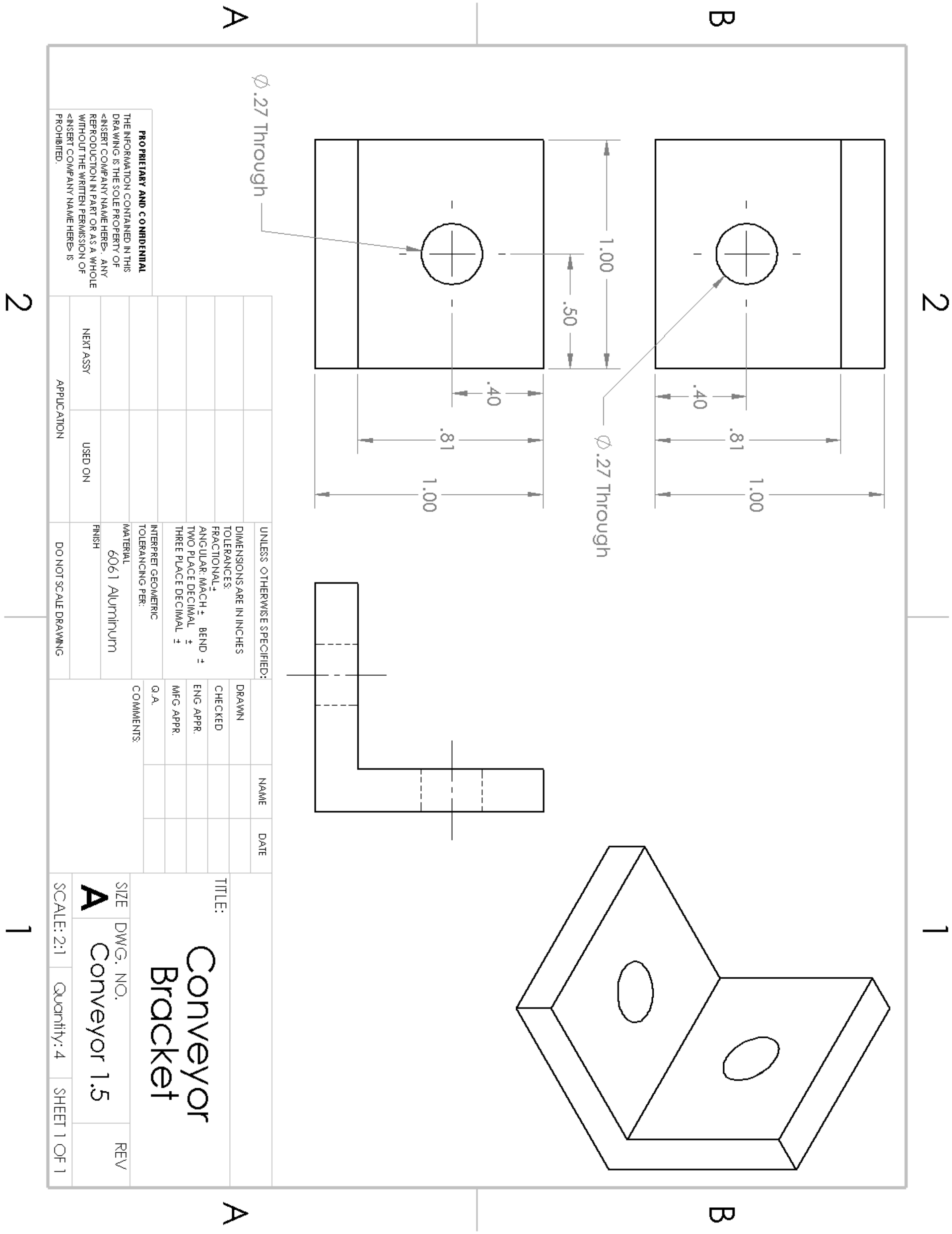
A
B
2
1


A
B
2
1
Ø.27 Through
1.00
.50
.40
.81
1.00
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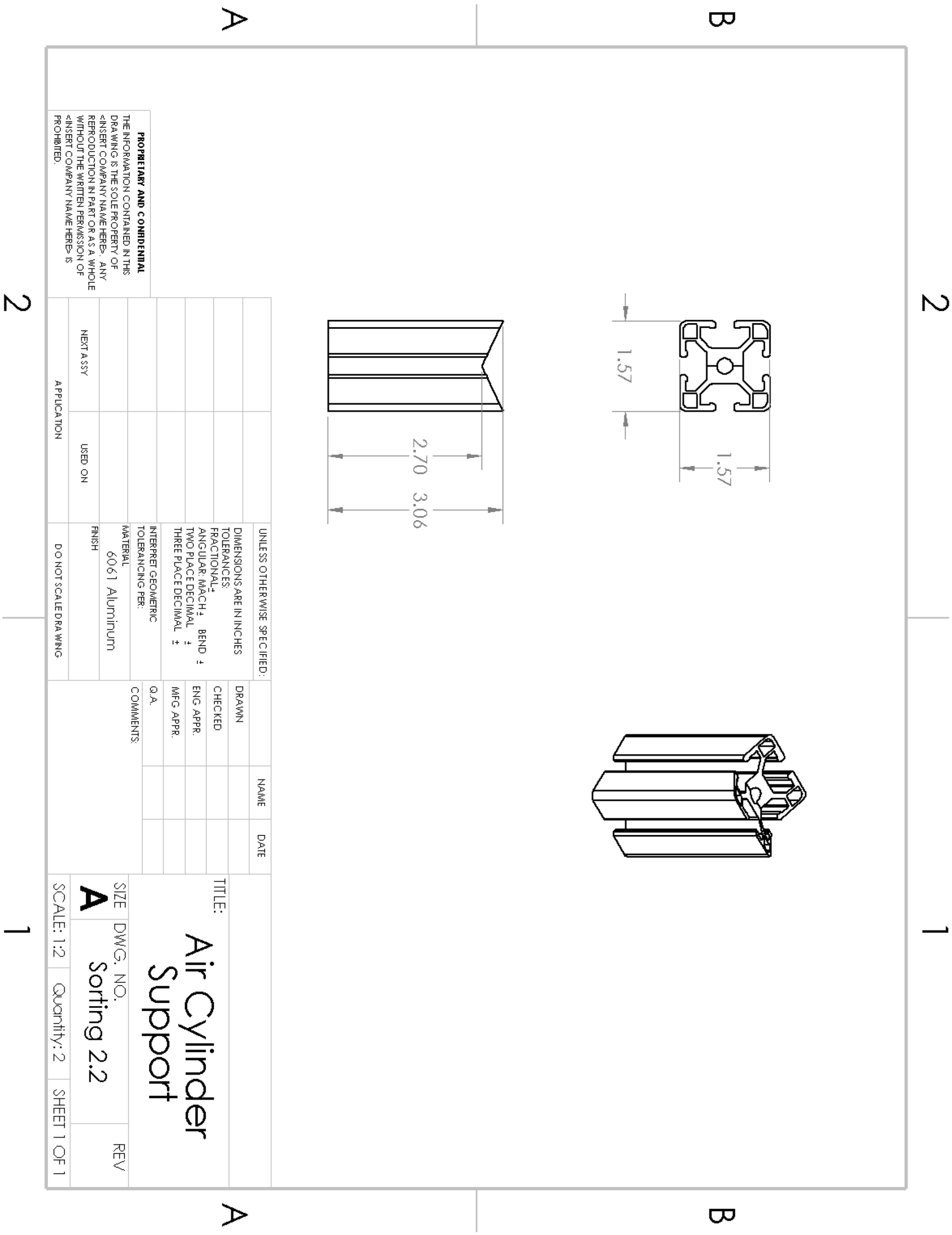
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Conveyor Bracket
SIZE
A
DWG. NO.
Conveyor 1.5
REV
SCALE: 2:1
Quantity: 4
SHEET 1 OF 1



A
B
1
2
1.57
1.57
2.70
3.06
PROPRIETARY AND CONFIDENTIAL
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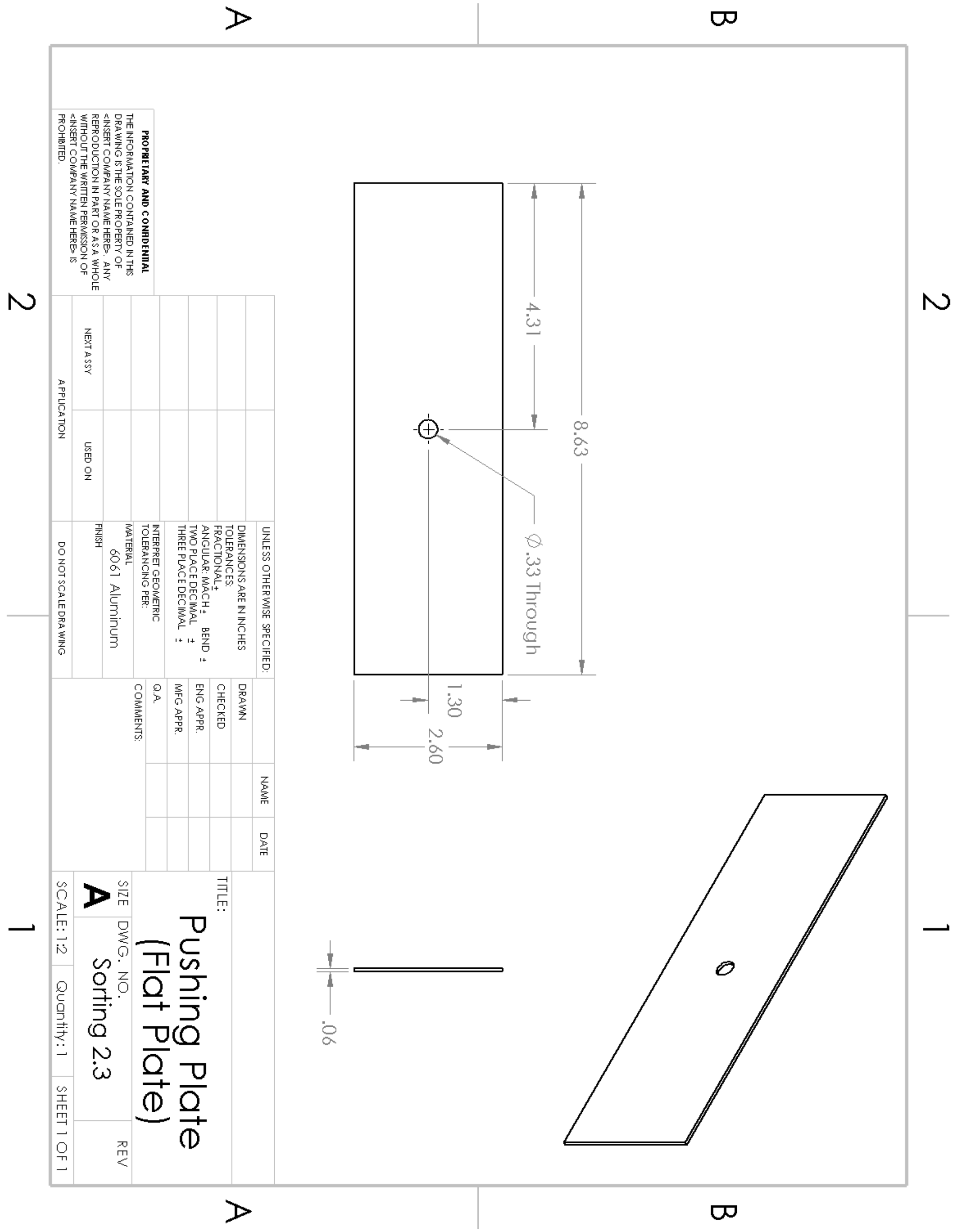
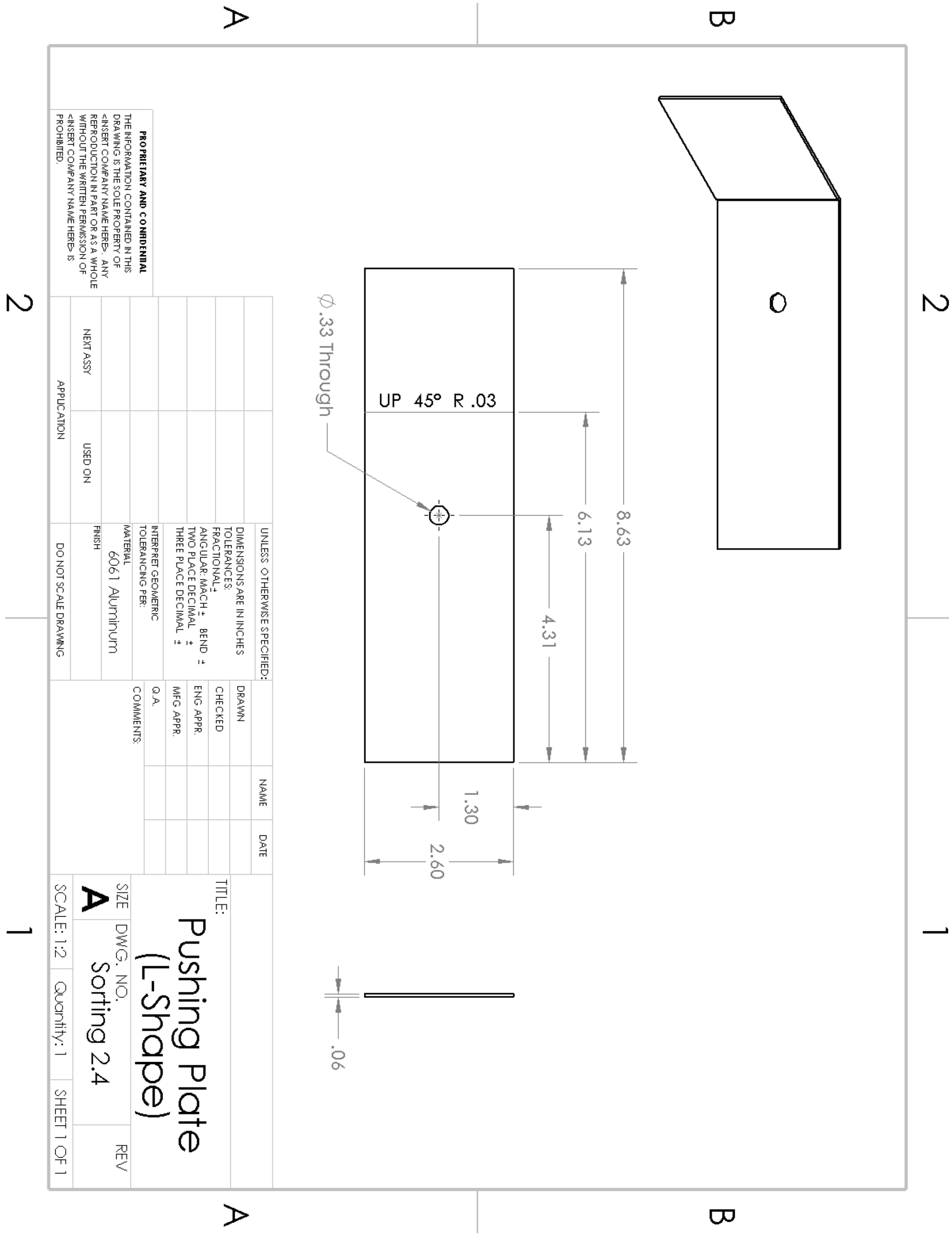
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Air Cylinder Support
SIZE
A
DWG. NO.
Sorting 2.2
REV
SCALE: 1:2
Quantity: 2
SHEET 1 OF 1


4.31
8.63
Ø.33 Through
1.30
2.60
.06
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
APPLICATION
NEXT ASSY
USED ON
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Pushing Plate
(Flat Plate)
SIZE
A
DWG. NO.
Sorting 2.3
REV
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1


Ø.33 Through
UP 45° R .03
8.63
6.13
4.31
1.30
2.60
.06
PROPRIETARY AND CONFIDENTIAL
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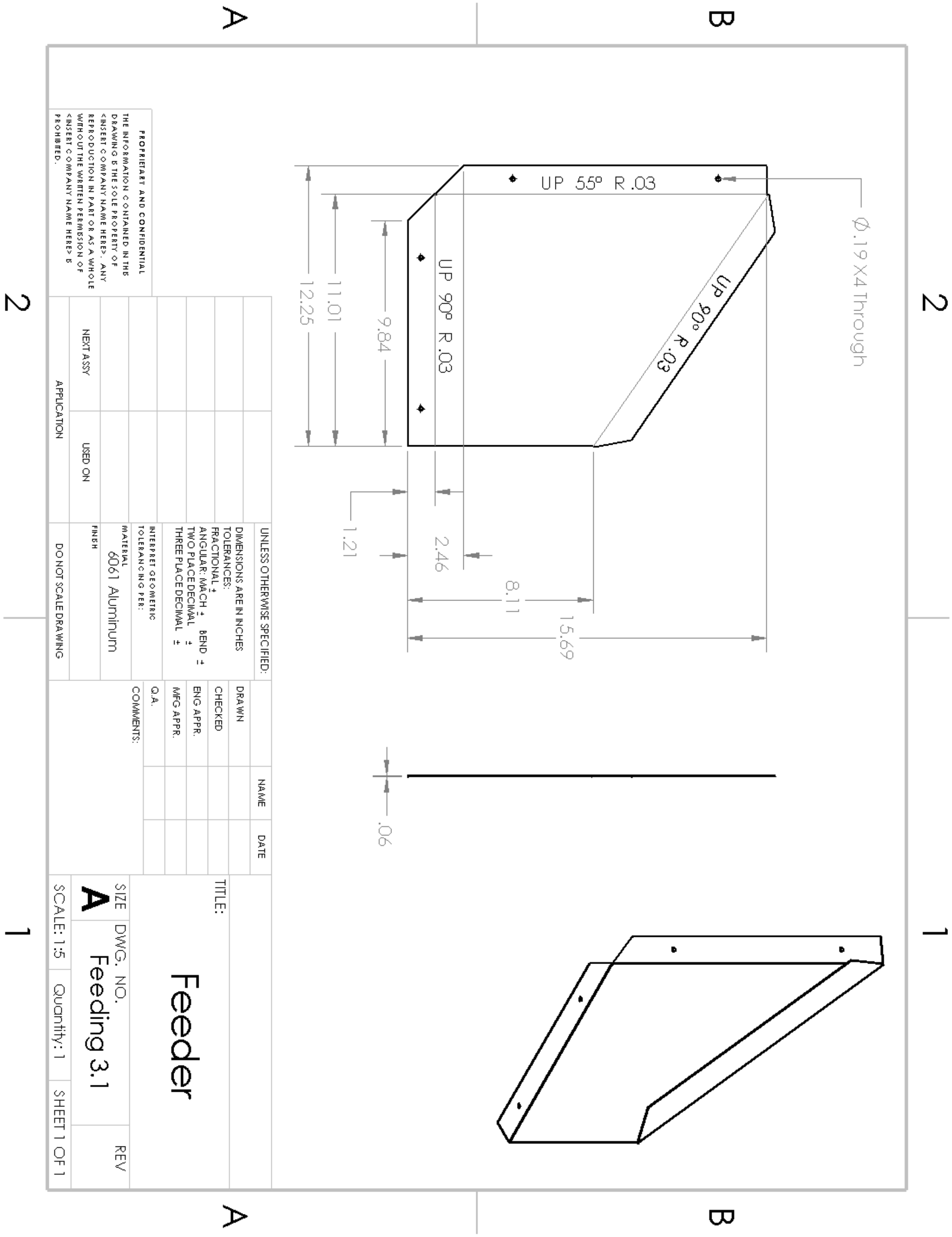
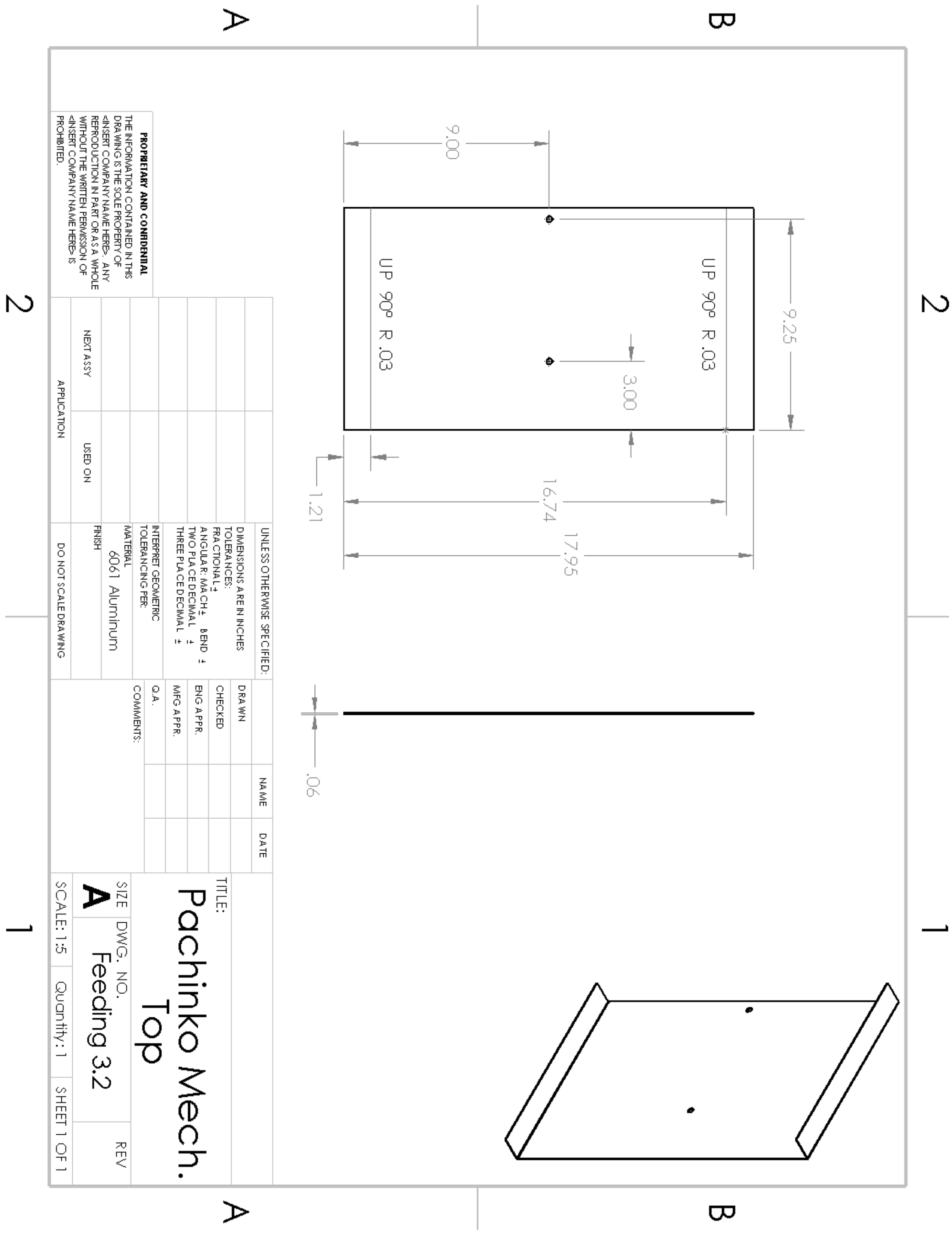
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Pushing Plate (L-Shape)
SIZE
A
DWG. NO.
Sorting 2.4
REV
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1
A
B
1
2


UP 55° R.03
UP 90° R.03
UP 90° R.03
Ø.19 X4 Through
12.25
11.01
9.84
1.21
2.46
8.11
15.69
.06
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061 Aluminum
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Feeder
SIZE
A
DWG. NO.
Feeding 3.1
REV
SCALE: 1:5
Quantity: 1
SHEET 1 OF 1



A
B
2
1
9.00
9.25
3.00
UP 90° R .03
UP 90° R .03
1.21
16.74
17.95
.06
PROPRIETARY AND CONFIDENTIAL
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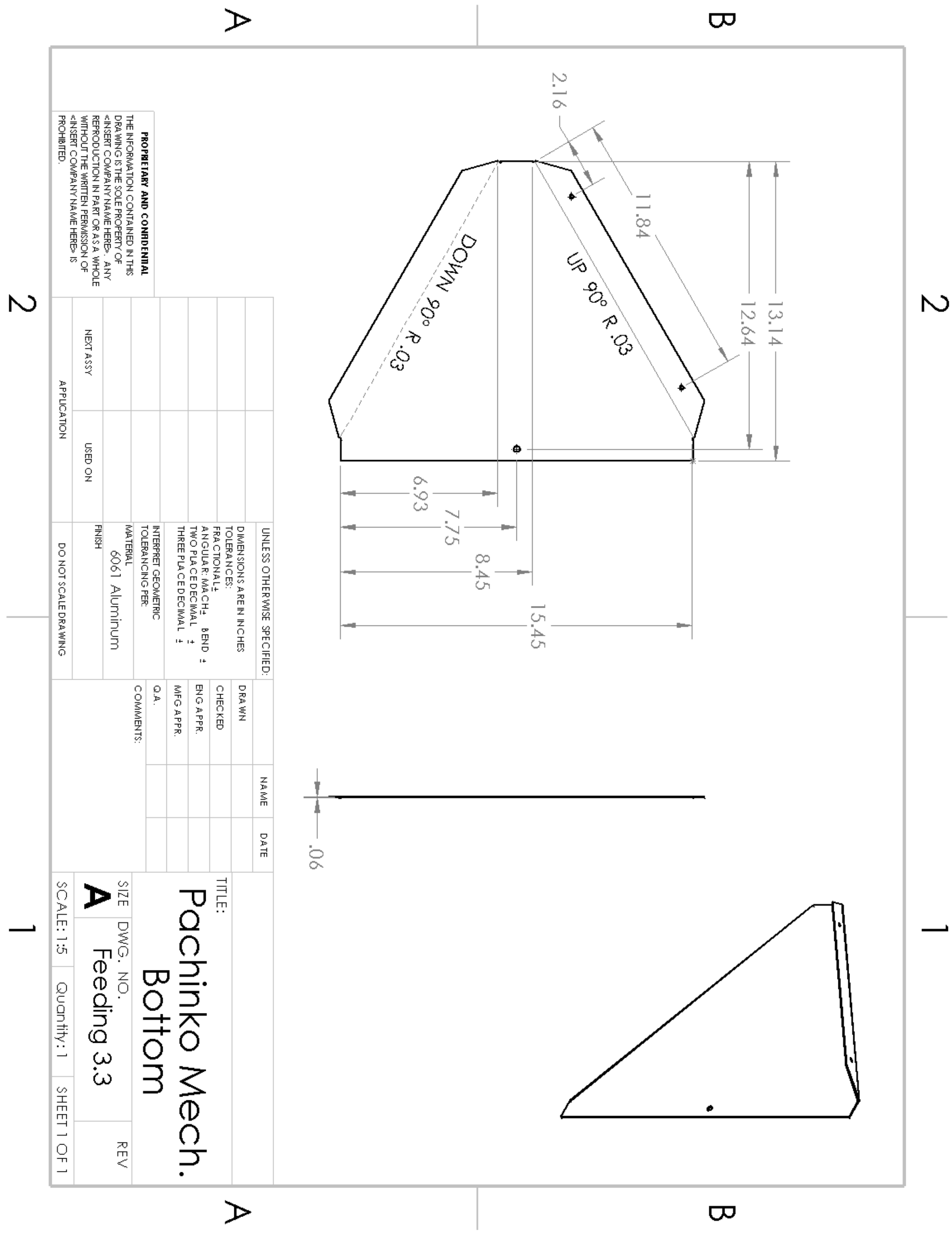
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Pachinko Mech. Top
SIZE
A
DWG. NO.
Feeding 3.2
REV
SCALE: 1:5
Quantity: 1
SHEET 1 OF 1



2.16
11.84
12.64
13.14
DOWN 90° R .03
UP 90° R .03
6.93
7.75
8.45
15.45
.06
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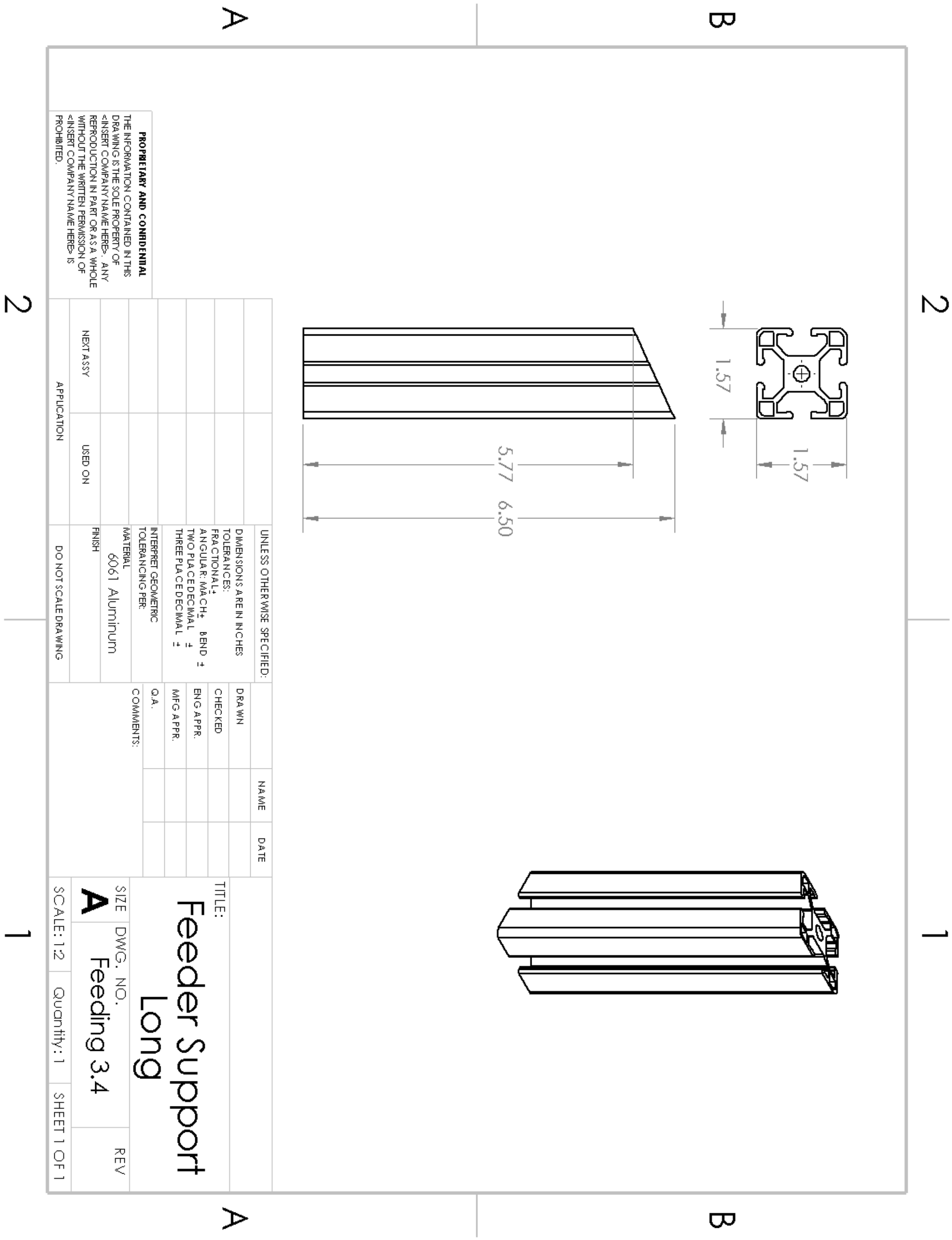
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Pachinko Mech. Bottom
SIZE
A
DWG. NO.
Feeding 3.3
REV
SCALE: 1:5
Quantity: 1
SHEET 1 OF 1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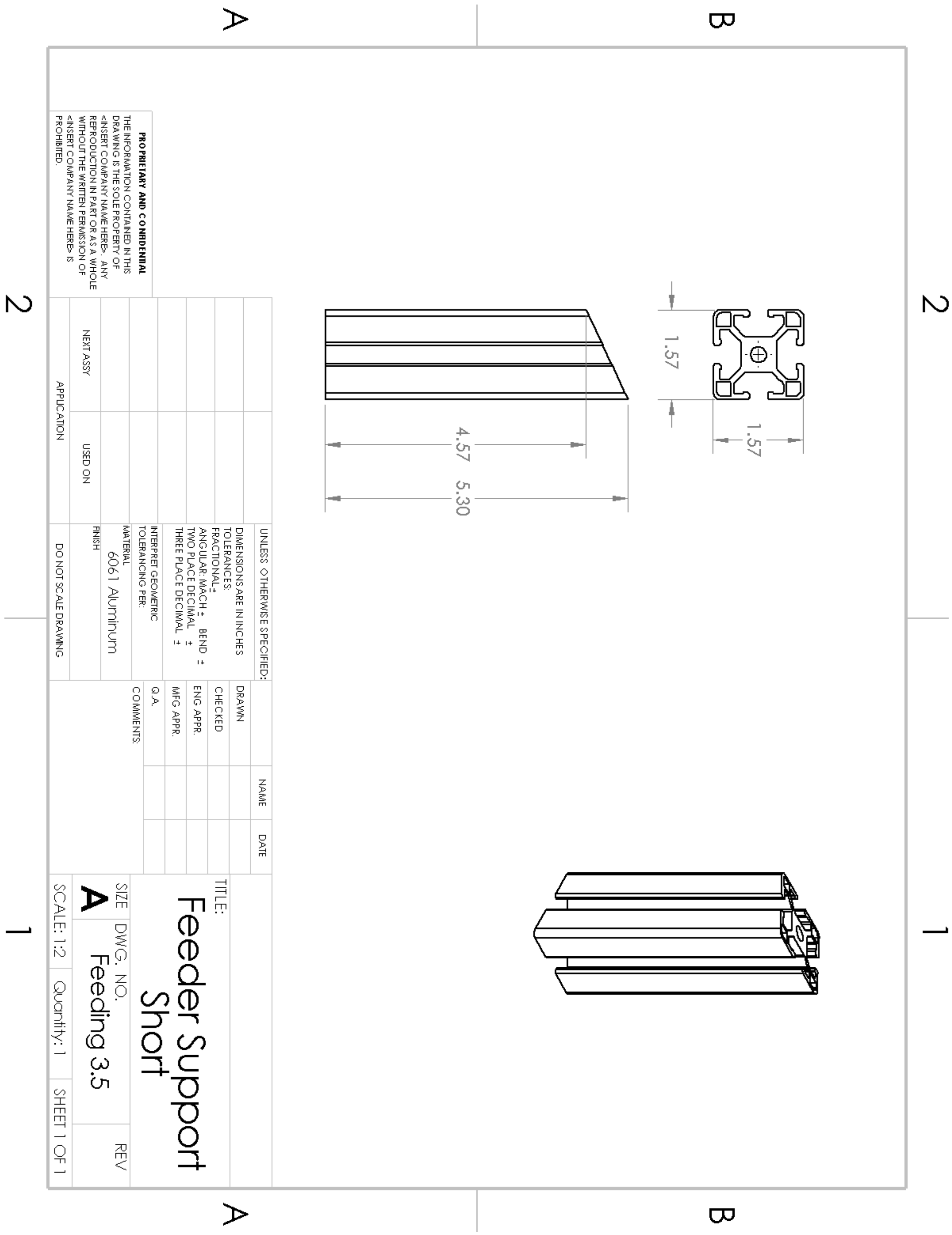
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Feeder Support Long
SIZE
A
DWG. NO.
Feeding 3.4
REV
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1
1.57
1.57
5.77
6.50
A
B
1
2


1.57
1.57
4.57
5.30
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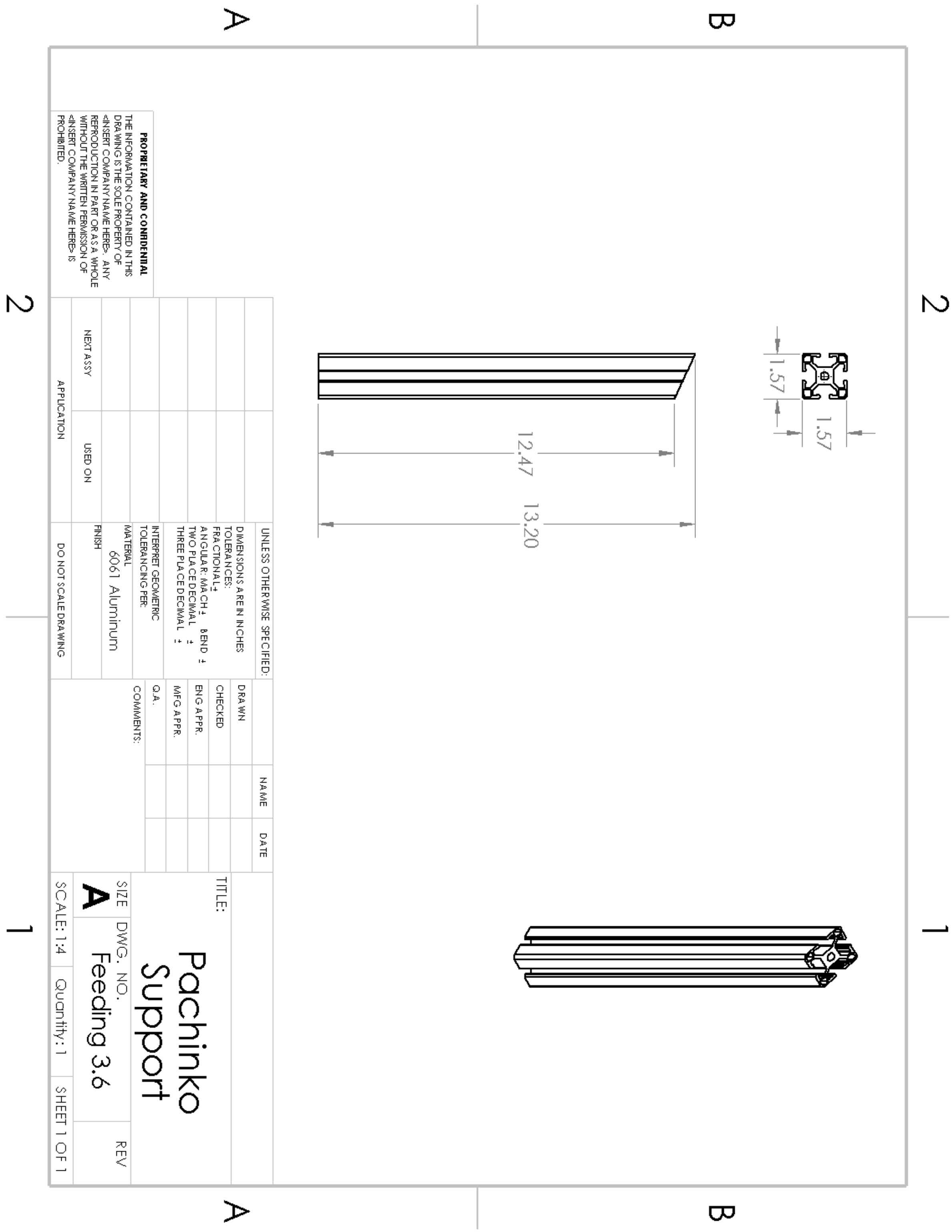
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Feeder Support Short
SIZE
A
DWG. NO.
Feeding 3.5
REV
SCALE: 1:2
Quantity: 1
SHEET 1 OF 1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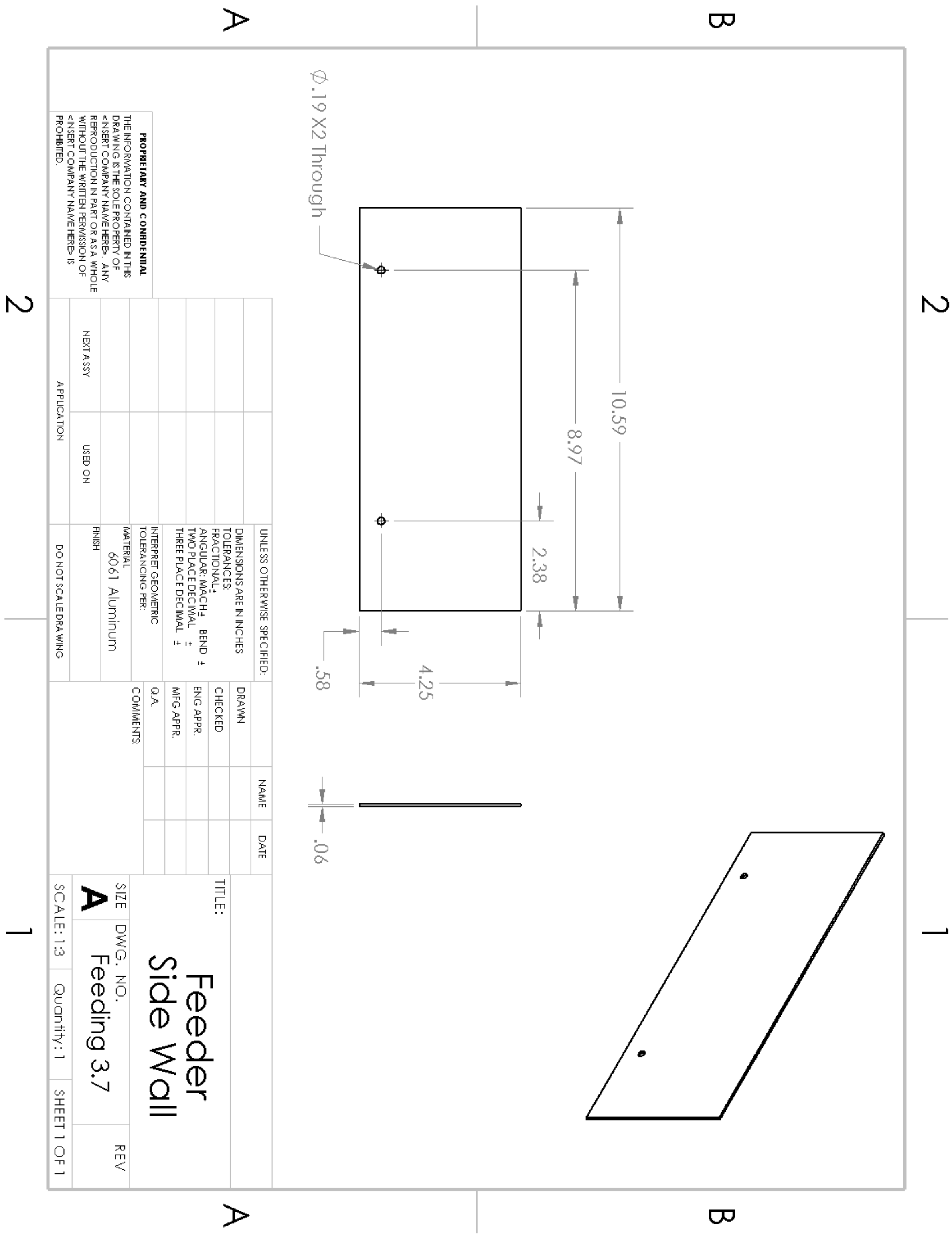
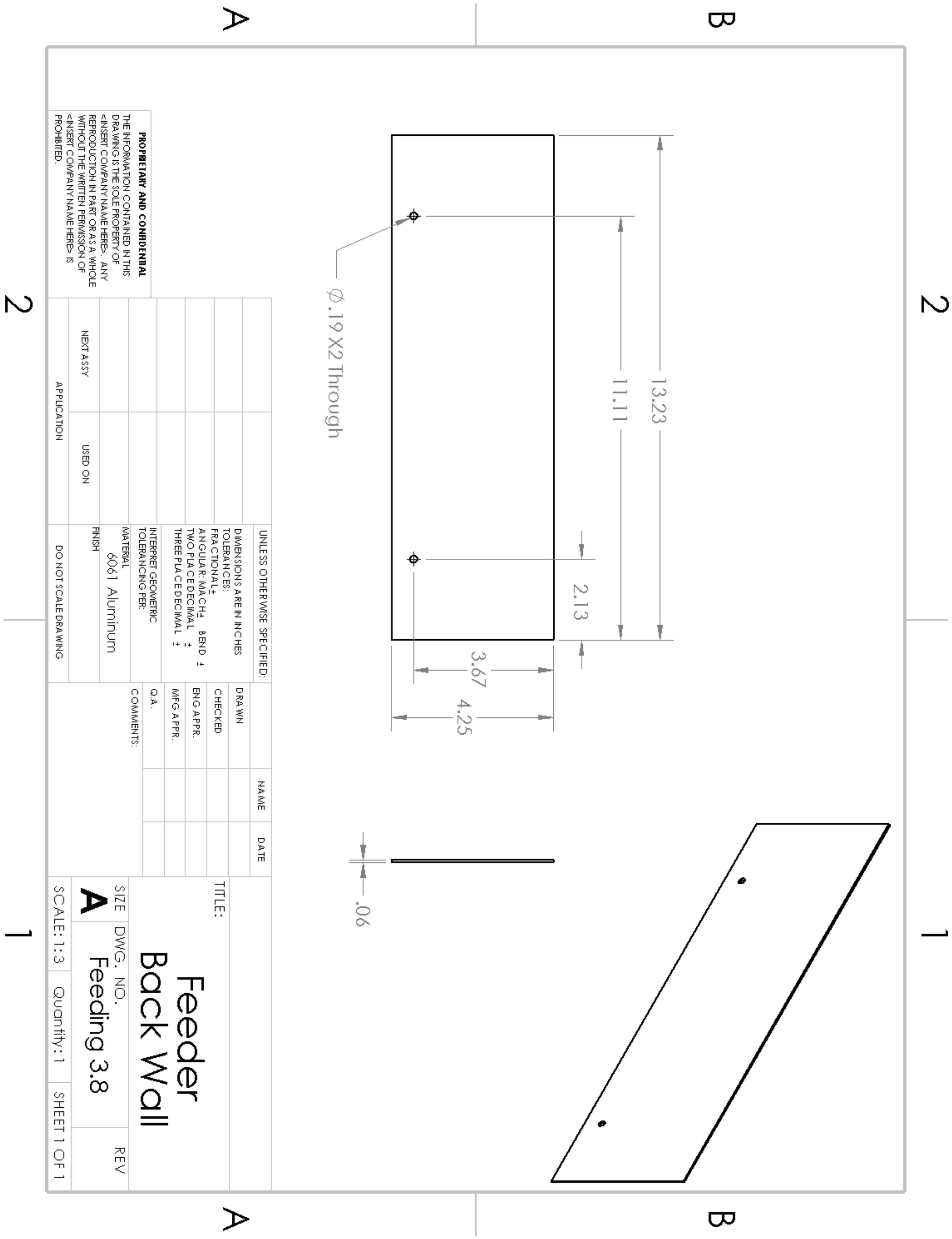
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Pachinko Support
SIZE
A
DWG. NO.
Feeding 3.6
REV
SCALE: 1:4
Quantity: 1
SHEET 1 OF 1
1.57
1.57
12.47
13.20
A
B
1
2


Ø.19 X2 Through
10.59
8.97
2.38
4.25
.58
.06
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
6061 Aluminum
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Feeder
Side Wall
SIZE
A
DWG. NO.
Feeding 3.7
REV
SCALE: 1:3
Quantity: 1
SHEET 1 OF 1


∅.19 X2 Through
13.23
11.11
2.13
3.67
4.25
.06
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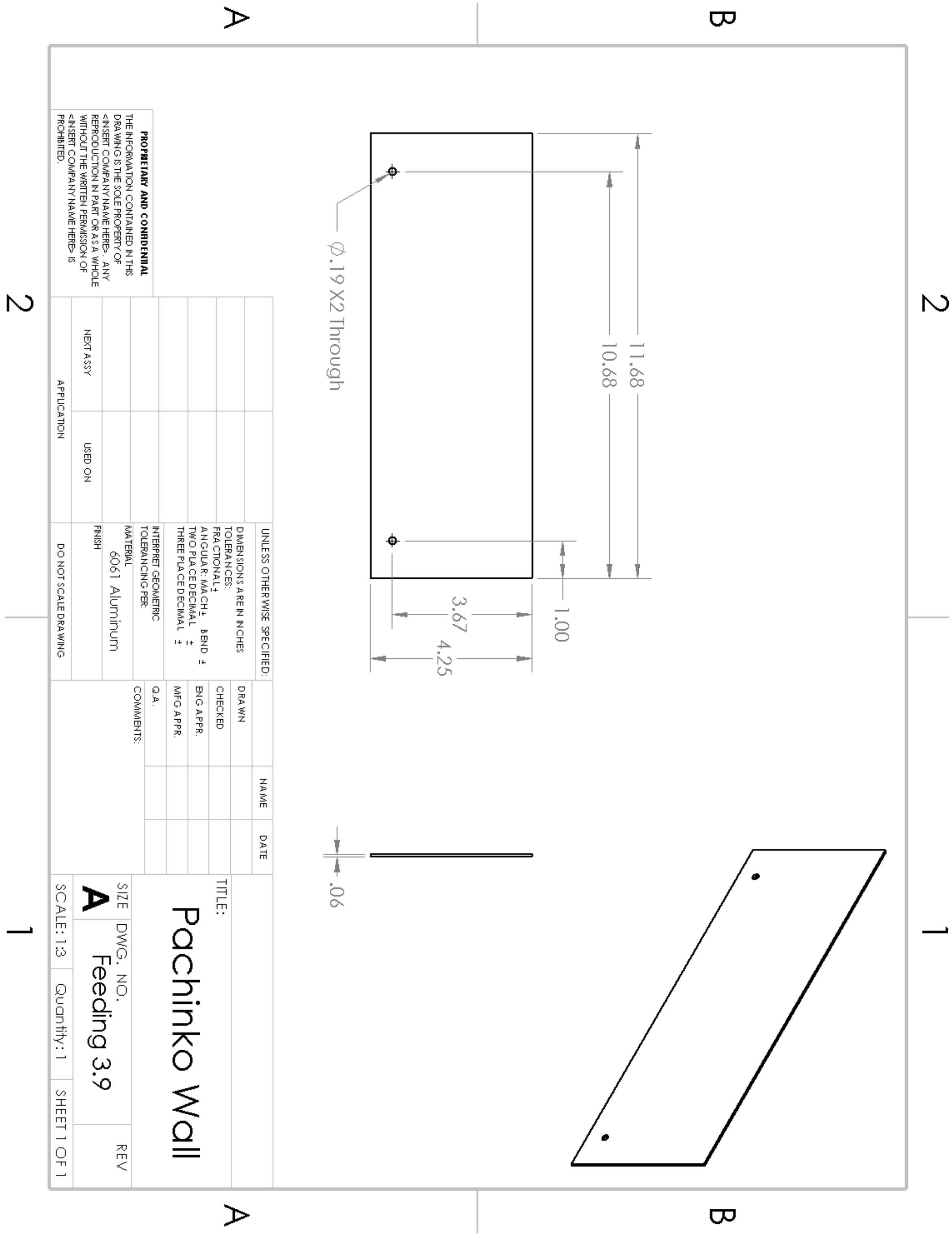
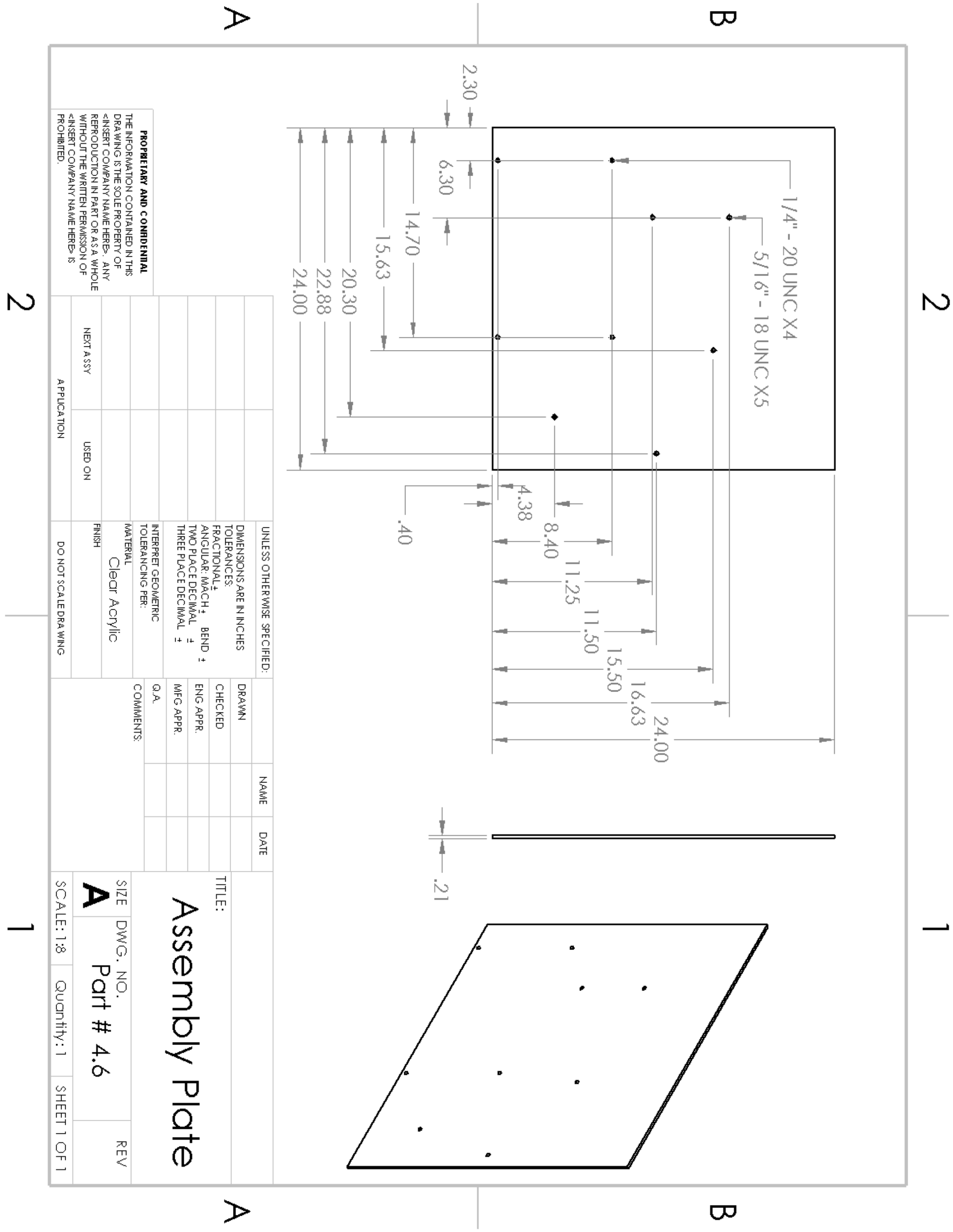
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Feeder Back Wall
SIZE
A
DWG. NO.
Feeding 3.8
REV
SCALE: 1:3
Quantity: 1
SHEET 1 OF 1
A
B
1
2



Ø.19 X2 Through
11.68
10.68
1.00
3.67
4.25
.06
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
MATERIAL
6061 Aluminum
DO NOT SCALE DRAWING
TITLE:
Pachinko Wall
SIZE
A
DWG. NO.
Feeding 3.9
REV
SCALE: 1:3
Quantity: 1
SHEET 1 OF 1


1/4" - 20 UNC X4
5/16" - 18 UNC X5
2.30
6.30
14.70
15.63
20.30
22.88
24.00
.40
4.38
8.40
11.25
11.50
15.50
16.63
24.00
.21
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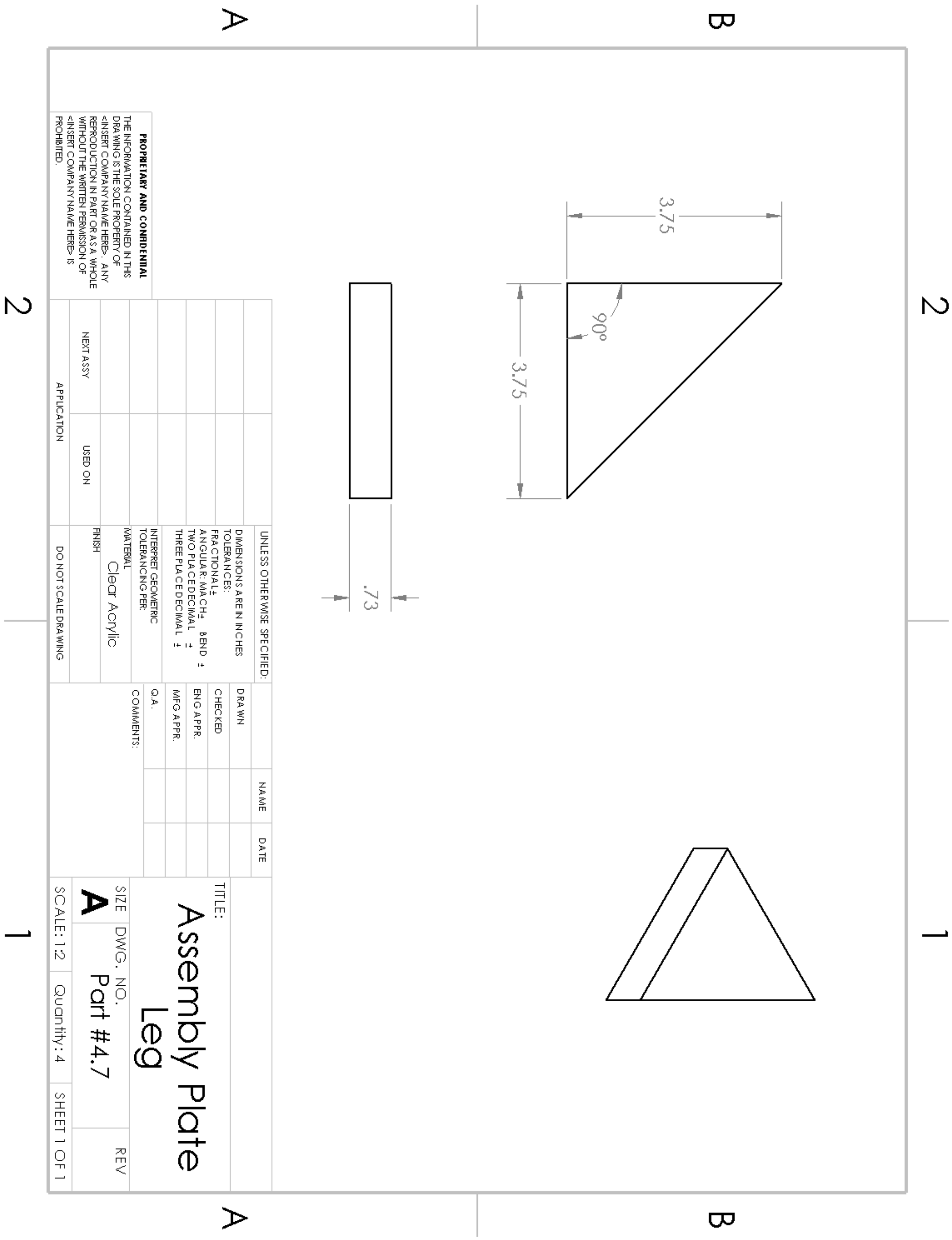
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Clear Acrylic
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Assembly Plate
SIZE
A
DWG. NO.
Part # 4.6
REV
SCALE: 1:8
Quantity: 1
SHEET 1 OF 1


3.75
3.75
90°
.73
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FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Clear Acrylic
FINISH
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Assembly Plate Leg
SIZE
A
DWG. NO.
Part #4.7
REV
SCALE: 1:2
Quantity: 4
SHEET 1 OF 1
A
B
1
2