Design of an Autonomous Canine Entertainment Device

A Major Qualifying Project
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Abstract

The goal of this project was to develop an autonomous canine entertainment device for dogs while owners are away. The team utilized the design process to develop a device that automatically launched dog treats. The device contained four mechanisms to successfully contain, individually dispense, retract, and launch the treats one at a time. A rotating arm placed within the treat container provided continuous motion of treats at the outlet. The treats were individually dispensed from the outlet with a linear motion linkage system. Lastly, a rotating cam arm retracted and launched the treat with elastic potential. Each mechanism was programmed to run simultaneously. Recommendations for future improvement were provided.

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Authorship

All partners listed in this report contributed to the project equally.

Acknowledgments

We would like to acknowledge all the people who helped and supported us throughout the year to complete our project. First, we would like to thank Professor Eben Cobb for the endless support, assistance, and guidance throughout the entire design process. Additionally, Barbara Fuhrman for providing the resources to access our budget for the project. Lastly, Shanna Bonanno from the writing center for the report structure and guidance.

Chapter 1: Introduction

The American Pet Products Association reported in 2020 that 63.4 million households in the United States of America own at least one dog (American Pet Production Association, 2020). Based on the 2019 Bureau of Labor Statistics, 82 percent of employed personnel in the United States work 7.9 hours at their workplace each workday. Far fewer Americans, 24 percent, work from home, and those in this percentage work fewer hours at an average of 3.3 hours per day (Bureau of Labor Statistics, 2020). The data collected by the Bureau of labor supports the idea that a majority of dogs are left at home without their owners for an average of 39.5 hours a week, assuming the owner works 7.9 hours a day for five days per week. Annually, dogs could be isolated at home without human interaction, entertainment, and affection for over 2,000 hours.

Completed research investigated the relation between dog-owner time deprivation and depressive behavior expressed by dogs. To analyze depression levels, the behaviors of dogs that were relinquished from their owners were compared with those of the stray dogs. The study found that the relinquished dogs exhibited even more depressive behaviors than stray dogs. (Harvey et al., 2019). Other research expanded the investigation by developing games to reduce separation anxiety in dogs while away from their owners. The study confirmed that dogs who previously exhibited anxiety due to isolation showed significantly less separation anxiety while stimulated by the interactive game (Geurtsen et al., 2015). Overall, these studies demonstrated how dogs whose minds and bodies were active and stimulated by interactive toys and devices experienced lower levels of anxiety and depression when home alone.

Several devices currently exist in the market that keep dogs entertained while their owners are away. These devices, however, do not always aim to reduce separation anxiety and depression in dogs. Most of these devices are produced by large companies focused on profit, therefore disregarding the physical and psychological needs of a dog. For example, dogs are very sensitive to loud noises but many of these devices do not account for this fact and frighten dogs (Amazon 2021a). A device that autonomously launches a treat over a large distance while accounting for the sensitivities in dogs will engage both the dog's brain and body as it would require the dog to chase down the projected treat.

The following report illustrates the design process to create a device that launches a dog treat. The report begins with an overview of dispensers and launching devices that exist currently on the pet market and patent world. The report progresses into preliminary design concepts compiled during the ideation phase to create complete design concepts. The team utilized decision matrices to determine the final sub-components of the design. We then continued into the prototyping and testing phases to develop an efficient and effective means to launch a dog treat.

Chapter 2: Background

The background section outlines the research completed to initialize and enhance the design process of the dog treat launcher.

2.1 Overview of Dogs

Prior to designing a device intended for dogs, the team investigated their social behavior along with the relationship between dogs and owners. The first section of the background outlines the importance of dogs' social well-being and their relationship with people over time.

2.1.1 Evolution of Human and Dog Relationship

Dogs, like humans, have a powerful need for affiliation and a strong desire for emotional connection. Before human domestication, dogs lived and traveled in packs, much like wolves. These packs would compete against one another in search of food and territory. The most successful packs were the largest ones, which provided the greatest number of resources to each member (Smuts, 2014).

Ancient dogs depended heavily on companionship from one another for improved well-being. However, a major shift in dog behavior occurred, forming the longest and most successful interspecies relationship ever documented: humans and canines. It appears that dogs became "man's best friend" around 26,000 years ago, serving as hunting companions and guard-dogs. These relationships utilized dogs strictly as tools, but the emotional security offered by the connection between humans and dogs could not be suppressed. This shift was found through analyzing cave paintings that depicted the powerful bond between humans and canines, as well as deposits, and the close proximity of dog footprints to those of humans. Dogs no longer needed to form packs for survival because their newfound relationship with humans satisfied their needs (Campion & Ha, 2019).

Dogs and humans for thousands of years have shared a symbiotic relationship, a bond where both species benefit from the connection. Even currently, humans depend on dogs to perform many tasks they are incapable of completing. Dogs act as police k9's, using their acute sense of smell to track criminals and find illegal drugs. Their elevated senses also allow them to detect cancer cells, explosives, low blood sugar levels, and oncoming panic attacks. Dogs are very attuned to human emotional states and even their thoughts; for example, they often provide emotional support when their owner is experiencing elevated stress. In return, humans offer dogs shelter, food, water, and emotional security (Campion & Ha). These mutually beneficial services along with the affection shared by both dogs and humans combine to form an irreplaceable relationship.

2.1.2 Emotional Stability of Dogs at Home

The strong bond formed between humans and dogs provides both parties with a sense of belonging and emotional stability. However, if the presence of the human owner is removed, the dog's sense of belonging and emotional stability is impacted. A study found that the overall welfare of a dog was severely affected by the amount of time it was left alone (Rehn, T.). Another study found that the presence of a stranger does not fill the emotional void left behind when the owner leaves (Smuts). This indicates that dogs depend heavily on their owners for their sense of well-being.

When dogs remain at home alone, they experience elevated levels of stress due to a decrease in their sense of well-being. Some dogs sit patiently by the door waiting for their owners to return while others whine, bark, or howl. Each of these behaviors indicates high levels of anxiety. Once the owner returns, the dog typically will express excitement by wagging its tail and happily greeting the owner (Parthasarathy & Crowell-Davis, 2006).

A recent study looked to analyze the welfare of dogs when left home alone and given an interactive gameplay device. The study aimed to determine whether this device would reduce the cortisol levels, a chemical produced when anxious, of dogs when left alone. In two-thirds of the subjects given the device, cortisol levels were reduced, meaning that the interactive gameplay device did reduce stress in most dogs when left home alone (Geurtsen et al.). This significant finding indicates that the owner's presence is not always required to support the well-being of their dog, rather a device can be constructed to serve this purpose. For our device, we would like to design a mechanism capable of launching singular treats to interact with isolated dogs.

2.1.3 Dog Sensitivities

Dogs, like all animals, experience emotions in reaction to their surroundings. This needs to be accounted for when designing such a device. Dogs are often frightened by loud noises. In a recent study, the cortisol levels of dogs were measured following exposure to loud sounds. The study found that their cortisol levels could increase by as much as two micrograms/dl after loud noises (Franzini de Souza et al. 2018). If a dog is exposed to a loud treat launcher, chances are they will not respond positively. Instead of correlating the launcher with entertainment, the dog might associate it with fear and experience anxiety. The team used this information to create functional requirements for the device.

2.2 Mechanical Launching Systems

A large variety of mechanical devices can be used to launch an object. We determined for our design process that we needed to understand the positive and negative features of devices that exist today. This section lays out existing designs used as launching mechanisms, specifically in existing dog toys, comparable launching devices, and existing patents.

2.2.1 Existing Dog Treat Launchers

The team discovered a wide range of dog treat launchers that existed in the marketplace. We observed similar trends within the range of devices. Therefore, we created categories to group the different design types. The first category of launchers specified consisted of expensive, high quality devices. These typically had WiFi, camera, and speaker capabilities which allowed the owner to watch their dogs 24/7, even when away from home. These devices had a high price of $100-200 and were activated by the owners on their phones. A specific example can be examined in *Table 1A* of a Furbo Dog Camera (Amazon, 2020).

The second category of dog treat dispensers/launchers on the market consisted of more affordable devices that differed from others by dispensing both a ball and treat. Generally, these devices functioned by having the dog place a ball into a hopper and then utilizing gravity to roll the ball across the floor. When inside the device, the ball would trigger a system to dispense treats. The typical price of these products ranged from $20-30. Although these were less expensive than the launchers in the first category, consumers often found that dogs were unable to use the device out of confusion and were disappointed that the ball merely rolled rather than launched. *Table 1B* depicts a specific example of this category, 4pawslife automatic dog feeder (Amazon, 2020b).

The third and final category of launching devices on the market consisted of designs that launched a ball, displayed in *Table 1C*. While these devices did propel balls into the air, they did not contain a system to dispense treats. These devices functioned similarly to those of category 2, however, instead of rolling the ball out the bottom, it was launched. These devices were typically priced at $100, making it not affordable to all consumers (Amazon, 2020c).

Table 1: Comparison Table for Existing Dog Treat Launchers

Category 1	Category 2	Category 3
• Camera, WiFI, Voice Activated • Treat launches	• Balls Roll out • Treats Roll Out	• Balls launched out • No treats
~$100-200	~$20-30	~$100
		
A. *Furbo Dog Camera (Amazon, 2020a)*	B. *4pawslife Automatic Dog Feeder (Amazon, 2020b)*	C. *IDOGMATE Rechargeable Automatic pet Ball Launcher, Ball Thrower for Dogs (Amazon, 2020c)*

2.2.2 Comparable Launching Mechanism

Beyond the existing dog treat launchers on the market today, other kinematic mechanisms have propelled objects through the air. The group investigated all typical launching mechanisms as continuation of the ideation process. We generated the list below of techniques that could be used to propel a treat into the air.

- Rotating Wheels
- Catapult
- Slingshot
- Trebuchet
- Fan powered
- Piston/Plunger powered

The rotation of two wheels in opposite directions allowed a uniformed object, typically a ball, sandwiched between the wheels and ejected less than a quarter rotation later to exit the end of the launcher with high speeds and momentum. An automatic baseball pitch or tennis ball machine is a typical system that utilizes rotating wheels as a launching mechanism.

Both catapult and slingshot mechanisms utilized a high concentration of stored potential energy converted into kinetic energy. The potential energy was stored in an elastic or spring that ejects the object over a distance once released. A catapult typically involved the movement of an entire lever arm into a position of high strain, while a slingshot technique typically involved pulling the fixture that cradles the object into a high strain position. Both techniques required the projectile object to be loaded and released from the high strain elastic to achieve movement.

Similarly, a trebuchet converted stored potential energy into kinetic energy. However, a trebuchet stored energy in large counterweight objects that gravitational forces act on. The projectile object was placed on the opposite side of the counterweight and flung as the counterweight was released.

The fan-powered and piston/plunger methods utilized unique technology to launch an object. A fan-powered mechanism relied on airflow produced by a high-power fan within an enclosed chamber to direct the wind in a contained direction. A funnel could be used in the chamber between the fan and the object to increase the velocity of the air by reducing the occupied area.

The piston/plunger method would exploit energy from a change in pressure. A piston converted heat energy into mechanical work due to the change in pressure within an enclosed cylinder. A plunger mechanism applied a large pressure over an area, the stored pressure could be released to transfer kinetic energy to an object.

We considered each of the mechanisms outlined in this section throughout several ideation sessions for a launching mechanism design. We thought about the mechanisms both individually and in conjunction with one another to develop and advance the preliminary designs.

2.2.3 Existing Patents

Before creating our preliminary designs for the launching mechanism of the dog treat flinger, we completed background research of existing launching patents and patent applications. We aimed to gather information on the technology used at the advanced levels and understand designs that exist with protected rights to ensure we do not use these designs. This section will lay out several patent designs that our team deemed might satisfy our launcher design goal.

Remote Ball Launcher: US Patent Application 2019/0388764 A1 (Witek, 2019)

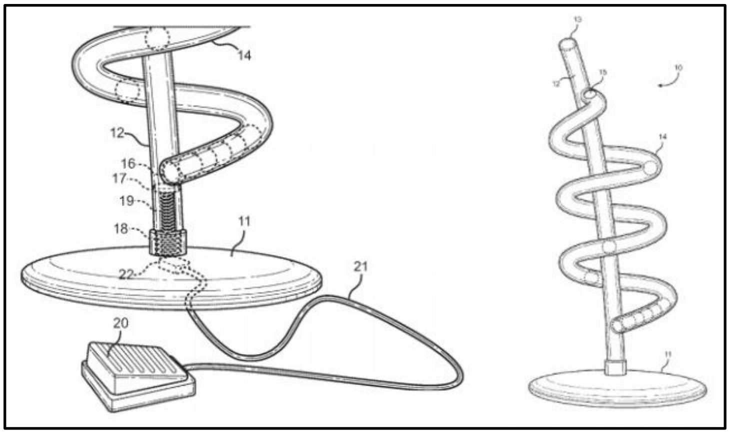


Figure 1: Remote ball launcher: US Patent Application 2019/0388764

The Remote Ball Launcher patent illustrated in *Figure 1* above, presented both launching and dispensing mechanisms that allowed a singular ball to be projected from the device after the user triggered the release with the foot pedal. This design allowed the user to release the ball from the tubing and spring mechanism when ready to strike the ball in tennis practice while alone.

Automatic Ball Launcher: US Patent No.10,625,135 (Ward, 2019)

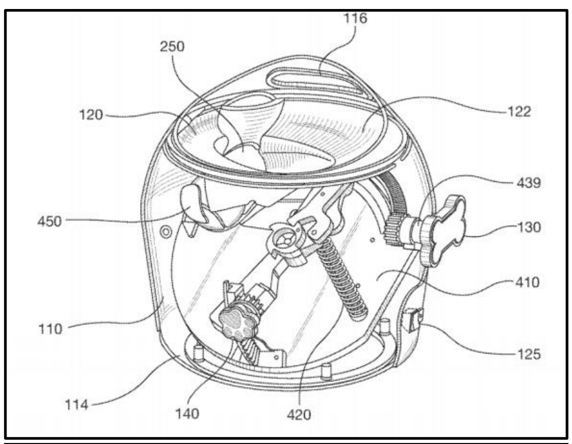


Figure 2: Automatic Ball Launcher: US Patent No.10,625,135

The Automatic Ball Launcher patent illustrated in *Figure 2* above included an enclosed funneling system that utilized gravitational forces to direct the ball towards a hammer that struck the ball out of the encasement at a selected angle. The inventor intended the device to provide a dog with exercise by retrieving the ball launched at various heights.

Automatic Ball Launcher for Pets: US Patent Application No. 2017/0326428 (Qian, 2017)

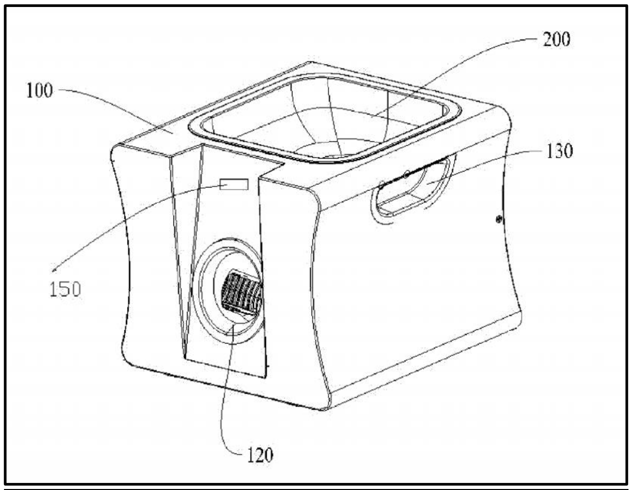


Figure 3: Automatic Ball Launcher for Pets: US Patent Application No. 2017/0326428

The Automatic Ball Launcher for Pets utilized the rotating wheel mechanism was mentioned previously in section 2.2.2. Two wheels connected to motors sit on either side of the ball aisle near the outlet of the enclosed device. The wheels' large contact area and small teeth allow the rotating mechanisms to latch onto the ball and eject it effectively.

Automatic Ball Throwing Machine: US Patent No. 4,611,571 (Tressler, 1986)

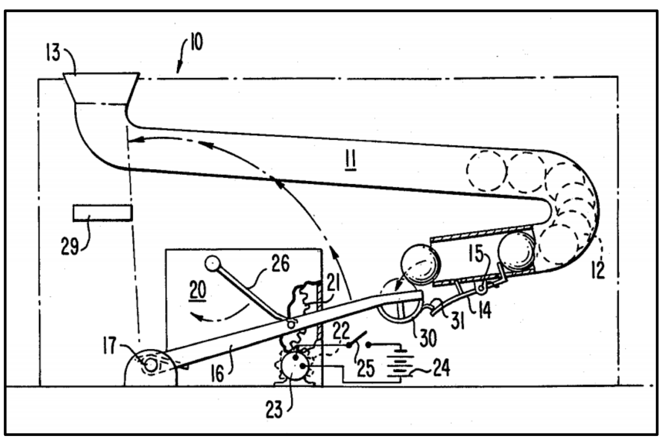


Figure 4: Automatic Ball Throwing Machine: US Patent No. 4,611,571

Depicted above in *Figure 4*, the Automatic Ball Throwing Machine included mechanisms that resembled a catapult. The position of the arm allowed balls to be released one by one into the divot of the arm. When the arm was released, the ball was projected and another ball was released into the next position in the chute.

2.3 Mechanical Single Dispensing Systems

We determined that our dog treat launcher design relied on the ability to dispense one treat at a time into the launching mechanism. Therefore, we decided to divide the design into two components: the launching mechanism and the single dispensing mechanism. The following section lays out existing single dispensing systems that our team investigated for advantages and disadvantages.

2.3.1 Existing Single Dispensing Dog Treat Systems

Most dog treat dispensers on the market were composed of a soft material with small holes and outlets on the outer surface. These holes acted as the outlets, allowing only one treat to escape at a time (Chewy, 2020). The device would be chewed on, tumbled, or pushed until a treat was released from the outlet when properly aligned. Another typical design included a puzzle that revealed and/or released the treat when completed correctly (Chewy, n.d).

Other existing treat dispensers did not regulate the number of treats ejected at once. For example, the ball launchers which also contained treats described throughout section 2.2 simply allowed several treats to roll out into a dish. Several other tumbling rotating dispensing devices had several slots along one edge that allowed multiple opportunities for treats to fall from (Amazon, 2020d).

2.3.2 Comparable Singular Dispensing Mechanism

Due to the sparse single dispensing mechanisms utilized in existing dog treat dispenser designs, we investigated other comparable singular dispensing means. The first comparable device we reviewed was the vending machine spiraling mechanism. This mechanism contained one long spiral with a motor attached to one end. One object occupied the space between each of the coils. When the user triggered the motor, the spiral rotated one full rotation, causing the object to dispense. The spiraling rotation and space between each coil of the mechanism allowed the objects to be released one at a time (Kurosawa & Anazawa, 1986).

We explored another comparable dispensing mechanism used for candy and/or cereal. The dispensing mechanism consisted of a large open-top container that reduced to a small outlet. At the end of the outlet, a crank wheel, operated manually by the user, allowed a contained amount of said object to be released. The amount released from the wheel depended on the size of the object being dispensed. This mechanism relied on gravitational forces and manual operation of the crank wheel (WebstaurantStore, 2019).

One last comparable mechanism we investigated included a rotating wheel that consisted of two slots, one on the outside that allowed the object to enter and another slot on the opposing side of the wheel that allowed the object to exit. The object would enter the rotating wheel through the front side and rotate 180 degrees until it reached the section containing the hole, located in the back side of the device. This mechanism has been used in marble sets to transport one marble from separated tracks. The rotating wheel exploits a rotating mechanism to separate the objects, like the cereal/candy dispensed explored previously.

2.3.3 Existing Dispensing Patents

Prior to creating our preliminary designs for the dispensing mechanism of the dog treat flinger, we also completed background research of existing patents on single dispensing technology. We aimed to gather information on the technology used at the advanced levels and understand designs that exist with protected rights to ensure we do not use protected designs. This section will lay out several patent designs that our team deemed might satisfy our dispensing goal.

Pet Toy Dispenser and Method: US Patent No. 9,481,504 (Dial, 2015)

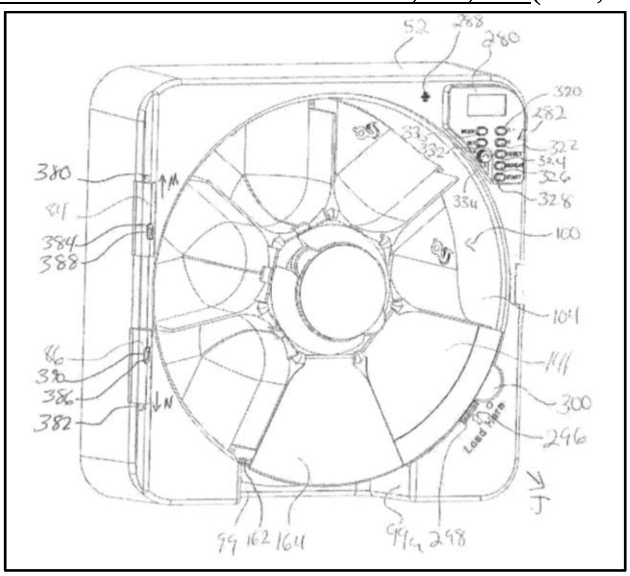


Figure 5: Pet Toy Dispenser and Method: US Patent No. 9,481,504

The Pet Toy Dispenser and Method depicted in *Figure 5*, utilized a rotating wheel that relied on the drive mechanism to move each compartment from the load location to the exit location. This patent included electrical components that detected the occupancy of each slot to ensure that each time an object was set to dispense the compartment contained the desired object.

Rotating Ornamental Candy Dispenser: US Patent Application No. 2007/0125794 (Jones, 2007)

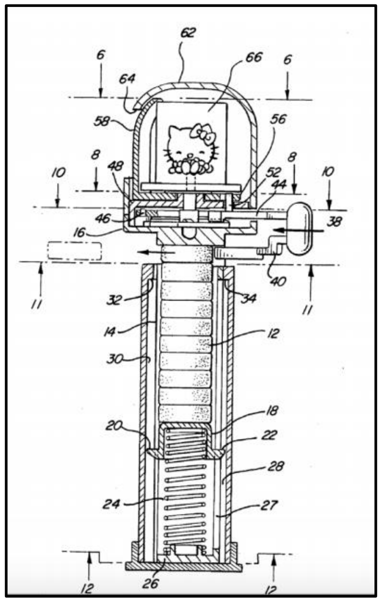


Figure 6: Rotating Ornamental Candy Dispenser:
US Patent Application No. 2007/0125794

The rotating Ornamental Candy Dispenser illustrated above consisted of stacks of candy placed on top of the other contained by the applied pressure from a spring. The user dispensed one singular candy by pressing the lever at the top of the candy stack, ejecting the candy from the device. When the user released the lever, the spring mechanism pushed the stack of candy up a level to be repeated.

Ball Launcher: US Patent No. 10,287,844 (Johnson, 2018)

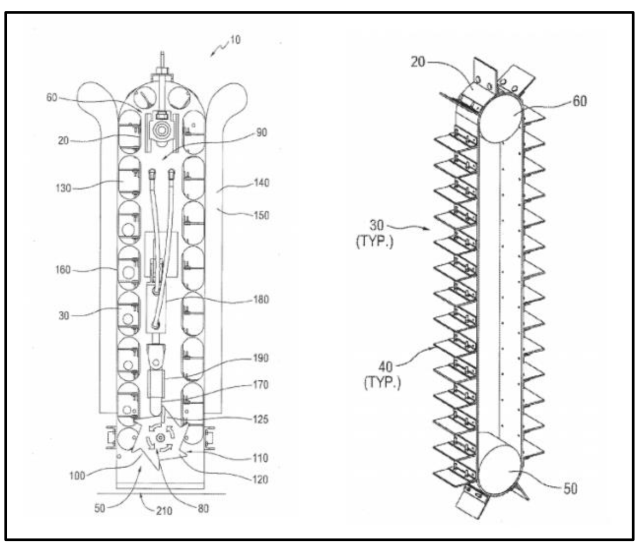


Figure 7: Ball Launcher: US Patent No. 10,287,844

The ball launcher pictured in *Figure 7*, utilized a unique method for dispensing a singular object at a time. The design consisted of an endless conveyor belt with set positions for each ball to lay. The rotation of the belt enabled one ball to fall out of the contained walls. The device controlled the pace and release of each object based on the motor speed of the belt.

2.5 Safety Requirements

The following list shows the ASTM F963 safety standards for general toy safety. The team used this information as a guide when creating the functional requirements.

ASTM F963 – Standard (ASTM, n.d.)

- 4.5.1.4 The C-weighted peak sound pressure level, LCpeak , produced by close to the ear toys shall not exceed 110 dB.
- (1) Mount close to the ear toys in a proper test rig at least 100 cm above the reflecting plane or have them operated by an adult operator with the arm outstretched.
- (3) C-weighted peak sound pressure level measurements, LCpeak, are to be made with the microphone 50 ± 1 cm from the surface of the toy where the main sound source exists such that the sound pressure level at the microphone is maximized.

2.6 Functional Requirements

We created functional requirements to properly identify and concentrate the requirements and functions of the dog treat flinger for our design. We created the requirements based on consumers' comments on existing pet toys, as well as our team's technical input based on the ASTM standards. The requirements outlined and aided our ideation of the preliminary designs and decision matrices to determine the final design.

- Must fling dog treats for a dog to retrieve
- Must launch treats 10 feet
- Holds at least 30 kibble treats
- Operated unattended by the dog (after assembly)
- Must be stable, must not tip over
- Should last at least 3,600 launches (2x/ day for 5 years)
- Design should be completed within the $750 budget
- Durability
    - Weather/dog resistant
    - Resistance to jamming
- Appearance
    - Occupy 1 cubic foot in size
- Safety
    - Must not harm children
    - Should adhere to ASTM F963 – Standard
        - Produce under 65 decibels of sound 50cm from the surface of the toy
    - Should weigh under 10lbs

Chapter 3: Preliminary Design Concepts

This chapter illustrates the initial designs considered for the dog treat launcher. The chapter consists of two sections that divide the dog treat launcher into two key components: the launching mechanism and the single dispensing mechanism. Each section contains several initial design ideas. The team created rough CAD and preliminary prototypes to identify design flaws and evaluate the functional requirements.

3.1 Launching Mechanism

This section illustrates the three initial designs of the launching mechanism, including a slingshot launcher, spinning launcher, and catapult launcher.

3.1.1 Catapult Launcher

The catapult launcher, one of the initial launching mechanism designs, converted stored potential energy in the rubber bands into kinetic energy that propelled the arm around the axel and released the dog treat when abruptly stopped. The initial design idea was expanded to contain both a computer-aided design and prototype model with K'nex, both illustrated in *Figure 8*. The models aided the team to fully assess the design in the decision matrix. Tests performed on the prototype proved the design could successfully launch a treat over a 5 ft distance consistently. As we tested a variety of rubber bands with various tensions the distance increased with increasing band tensions. However, the means to return the arm to the tension position relied on the user physically pulling the arm down.

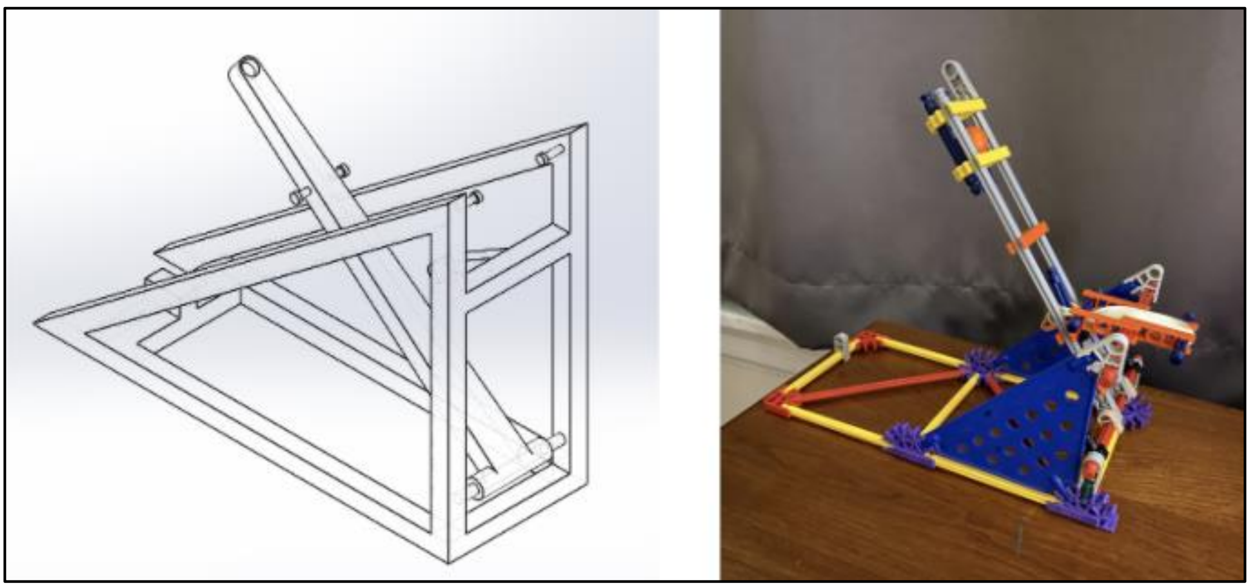


Figure 8: Catapult Design CAD and Prototype

3.1.2 Slingshot Launcher

The Slingshot launcher, the second initial launching mechanism design, converted stored potential energy in the rubber bands into kinetic energy that propelled the guided cart forward and launched the dog treat when abruptly stopped. The initial design idea utilized a motorized rotating belt with a tab extrusion located underneath the guided cart that also had a tab extrusion located on the underside of the cart. As the belt rotated the cart retracted to the launching position and released as the belt tab rotated to the lower side of the belt. The slingshot launcher would reset as the belt continued to rotate and interlock with the tab extrusion at the upper end of the ramp. Illustrated in *Figure 9* is the CAD and prototype model produced with K'nex and various other materials. The models aided the team to fully assess the design in the decision matrix.

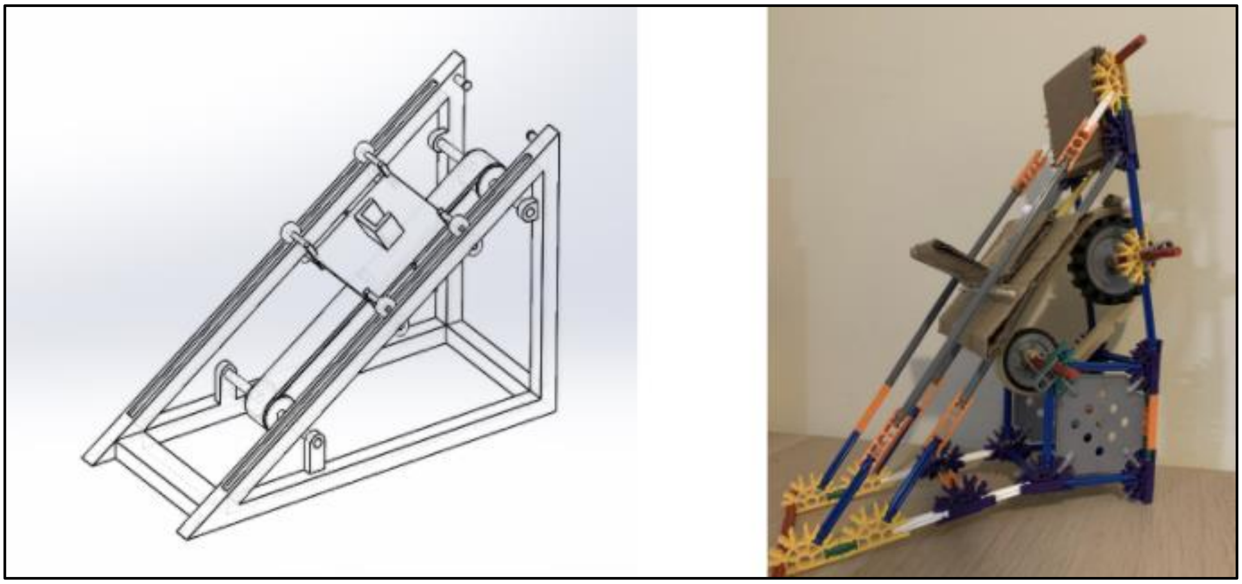


Figure 9: Slingshot Design CAD and Prototype

Tests performed on the prototype proved the design could successfully launch the treats and reset the slingshot mechanism by continuously rotating a belt-tab system underneath. The design had the potential to be motorized, eliminating the need for user interaction.

3.1.3 Spinner Launcher

The spinning launcher, the third and final potential launching mechanism design utilized angular momentum created in the rotating arm that would be transferred to the treat at the point of release. The team developed the design into a CAD model and prototype created by K'nex, illustrated in *Figure 10*. The prototype confirmed that a varying speed motor would be necessary to release of the treat at the correct angular location and ensure optimal launch distance. We noted another potential concern of how significant momentum and speed could create a physical or audible safety hazard to those around and the environment.

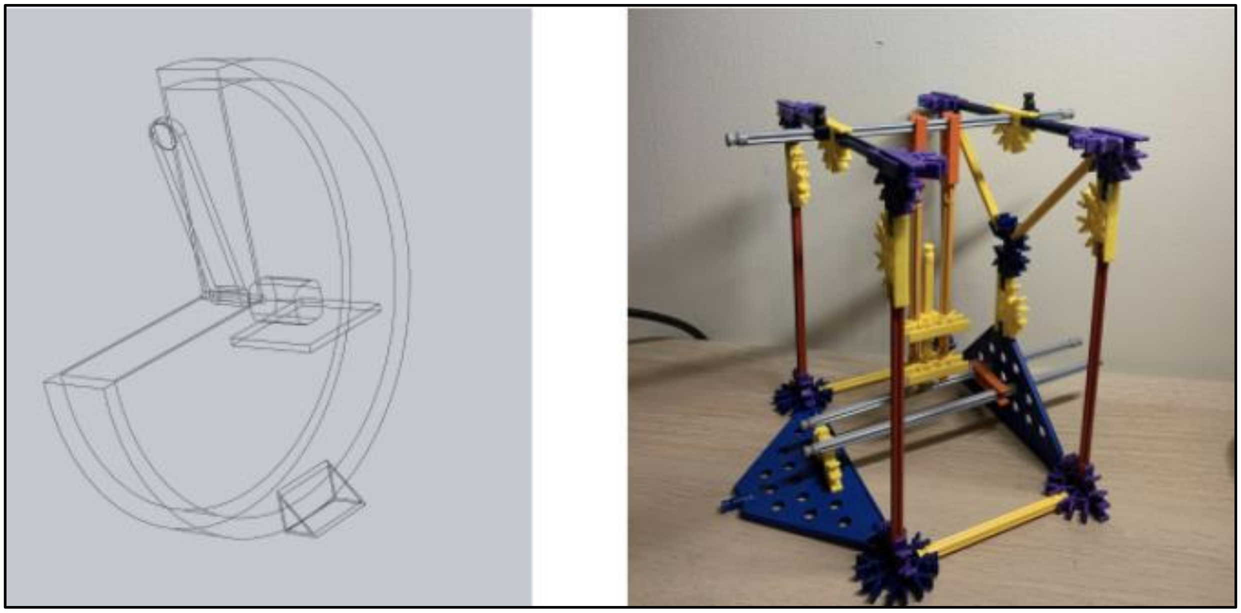


Figure 10: Spinner Design CAD and Prototype

3.2 Single Dispensing Mechanism

Section 3.2 illustrates the five initial designs of the single dispensing mechanism, including a vending machine style, slotted vertical wheel, spring fed, trap door release, and conveyor belt.

3.2.1 Vending Machine Style

The well-known vending machine mechanism was universally used to distribute one snack, beverage, or candy at a time. We initially created a CAD and prototype model of the mechanism. Prior to the testing, we had not determined the exact treats intended for the system. We hoped to find spherical treats that could be used in the device. We first investigated the success rate of the prototype with uniform-shaped marbles that mimicked the actions of spherical treats. The model was able to successfully release one marble at a time when the helix rotated. The initial design proved to be a potential option to successfully dispense individual treats.

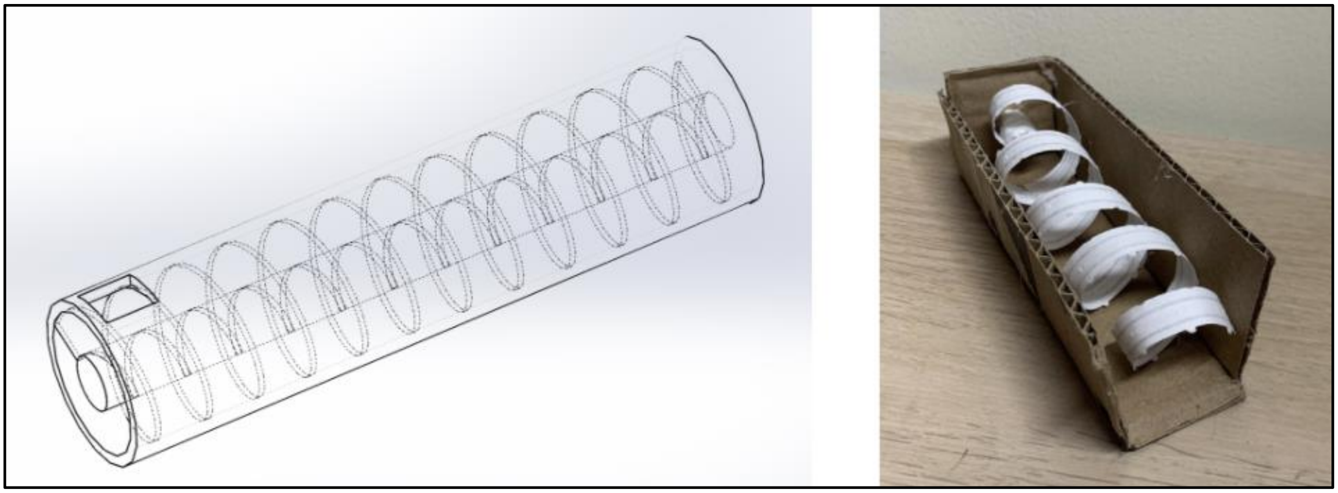


Figure 11: Vending Machine Style CAD and Prototype

3.2.2 Slotted Vertical Wheel

The slotted vertical wheel design relied on gravity to release one treat into a restricted slot of a wheel, separating treats between slots. The team planned to restrict the motion of the wheel to a step system, ensuring that the slots perfectly aligned with the opening of the hopper dispenser. The treat released from the slot after about a quarter rotation. Typical gumball machines utilized a similar wheel design to properly dispense one gumball at a time (Sutcliffe, 2003). We designed a CAD model and prototype of a vertical wheel displayed in *Figure 12.* However, gumball machines' wheels generally operated horizontally. The common use of this system in gumball machines suggested this design would be successful for our needs.

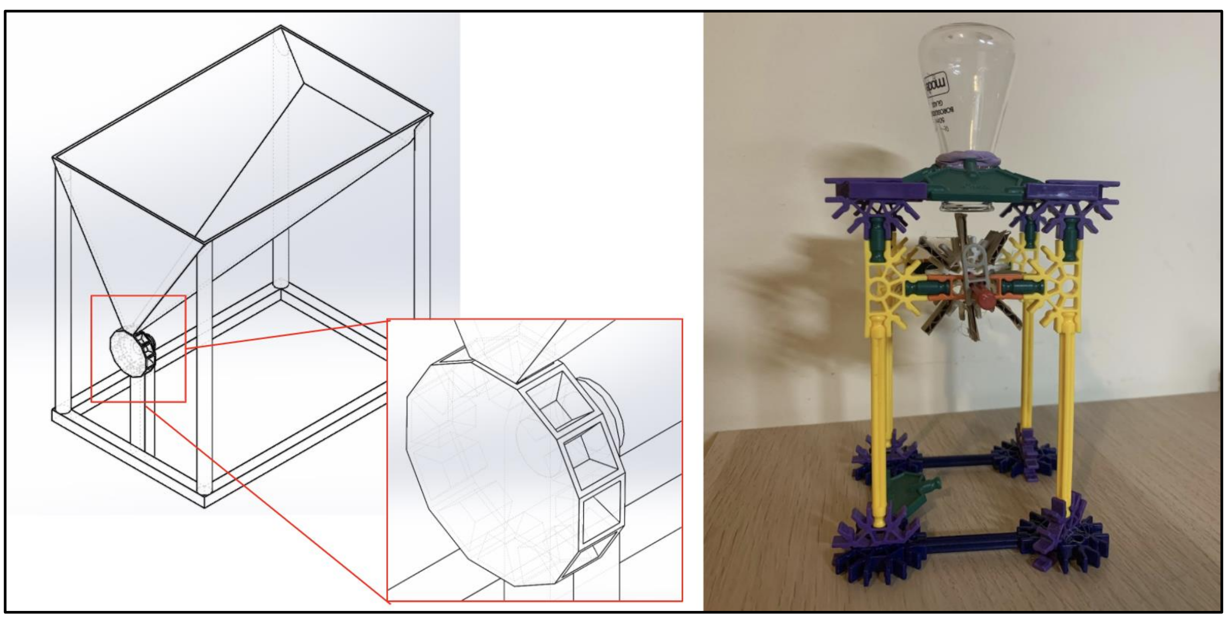


Figure 12: Slotted Vertical Wheel CAD and Prototype

3.2.3 Spring Fed

A spring-fed mechanism design utilized an applied force to overcome jamming experienced when relying solely on gravity. The spring attached to a plate applied a constant force on one end of the container full of treats. The container narrowed down to a width of one treat and had open edges at the bottom, allowing a device to extract one treat at a time. However, through basic prototype modeling, we identified several flaws that were overlooked in the initial design and would be difficult to overcome. The major obstacle we identified was the plate that applied the force to the treats. The plate needed to be flexible or contractible to ensure all treats would be pushed along as the container narrowed. This factor presented a time-consuming and challenging impact that would reduce accuracy in the design.

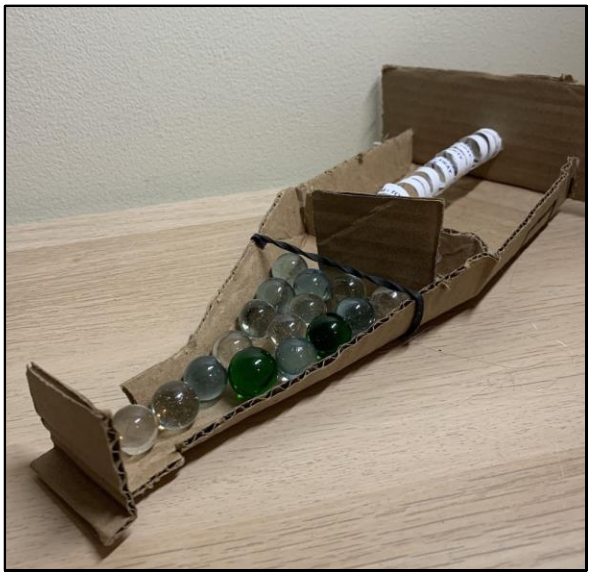


Figure 13: Spring Fed Dispensing Prototype

3.2.4 Trap Door Release

The trap door release design mimicked the two-door idea used for a pass-through in a temperature and pressure-controlled environment. The design required that each treat be aligned one by one in a contained tube with a closed tab/door at the outlet. At the time of release, a second door would rise in between the last and second to last treats, separating them. The last treat could then be dispensed into the launcher while the other treats remained in the tube. The second door would then fall once more, allowing the treat stack to move down one position. This process would then repeat. Preliminary design did not fully develop the mechanics of aligning all treats perfectly one by one and did not function as expected.

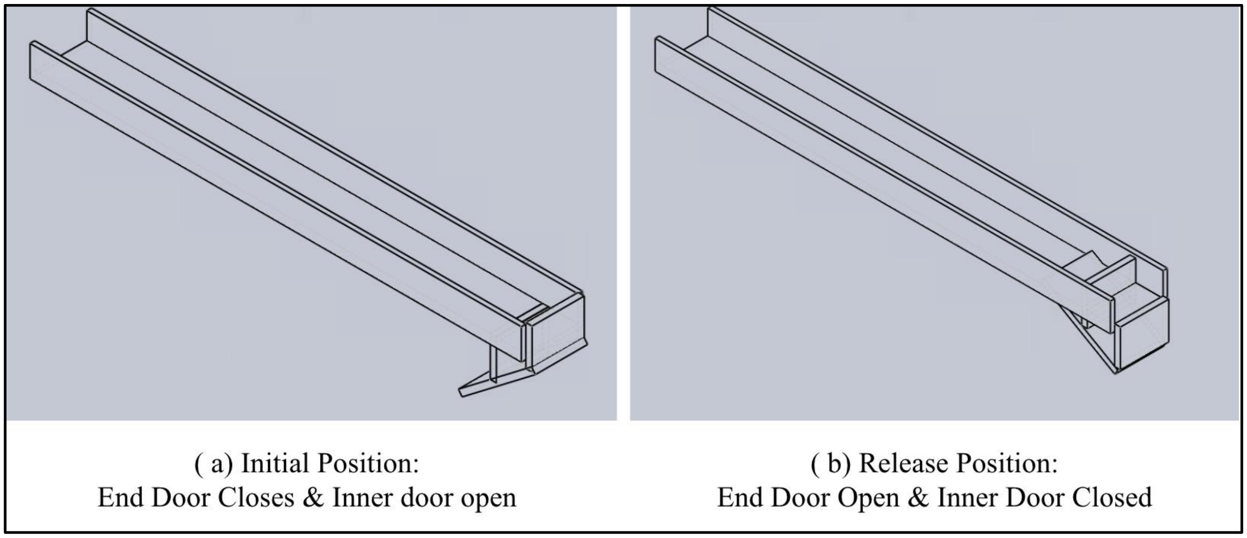


Figure 14: Trap Door Release Positions in CAD

3.2.5 Conveyor Belt with Tabs

The conveyor belt design contained features for continuous movement and separation of treats. The conveyor belt provided a continuous motion to prevent jamming and congestion while the tabs provided separation capabilities to prevent multiple treats launching at once. The preliminary design did not address how the treats would be placed in each tab without the user tediously placing each treat in the provided slots. We aimed to have a design that allowed the user to quickly refill the device, therefore this design was not ideal. However, the design still offered key mechanisms to overcome common obstacles and flaws of single dispensing devices.

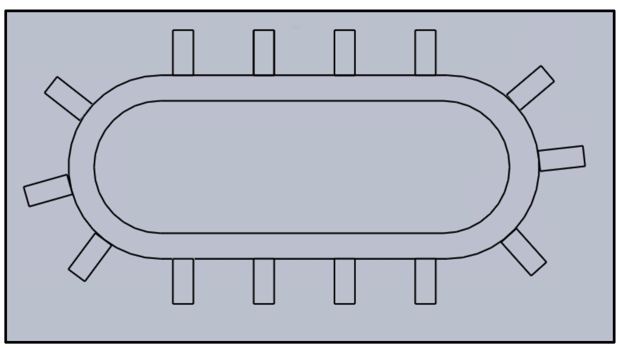


Figure 15: Conveyor Belt with Tabs CAD

Chapter 4: Preliminary Design Decision

This chapter demonstrates the selection process for both the launching and single dispensing mechanisms. We aimed to narrow our ideas to specific designs to develop and advance towards the final design. With the aid of several decision matrices, we determined a single launching mechanism and two single dispensing mechanisms to continue to develop, design, and test for the final dog treat launcher.

4.1 Compatibility of Launcher and Dispensing Mechanism

We determined that the adaptability of each launching and dispensing mechanism with one another was vital to the success of the overall design. We aimed to identify the various preliminary designs that could work with one another effectively. To assess the compatibility of the various launching and dispensing mechanisms we created a table of compatibility. The top row listed each launching design the leftmost column listed each dispensing design discussed in Chapter 3. The corresponding inner cells of the chart rated the compatibility of the two mechanisms on a scale one to ten. The yellow cells illustrated the average rating of the dispensers and launchers compatibility scores. The average rating of compatibility was utilized in the decision matrices of both the dispensers and launchers in the sections that follows.

Table 2: Compatibility Matrix for Preliminary Launcher and Dispensing Designs

		Launcher Designs			**Overall Avg Compatibility for Dispensers**
		Design 1: Catapult	Design 2: Slingshot	Design 3: Spinner	
Dispenser Designs	Design 1: Vending Machine Style	5	6	6	5.667
	Design 2: Slotted Vertical Wheel	6	6	6	6
	Design 3: Spring Fed	3	4	6	4.333
	Design 4: Trap Door Release	7	8	6	7
	Design 5: Conveyor Belt with Tabs	4	5	5	4.667
Overall Avg Compatibility for Launchers		5	5.8	5.8	

Table 2 identified the trap door release as the dispensing mechanism with the highest capability. The design consumed a small amount of space and therefore could be placed easily

with various launching designs. The launching mechanism with the highest dispenser compatibility was tied between the slingshot and spinner. The computed average of each launching and dispensing design from *Table 2* determined the value for the compatibility score of the launching and single dispensing decision matrices, shown below in *Table 3 and Table 4* respectively.

4.2 Launching Mechanism Decision Matrix

The decisions matrix allowed us to identify the design that satisfies the requirements necessary for a successful dog treat launcher based on computed values that factor in weighted importance. For each decision matrix used throughout the design process, we followed the same steps. First, we identified the important factors that were vital to the success of the design, located on the left side of the table. Next, the team gave each factor a weight of importance based on consumer needs. The more important the factor was to the consumers, the more weight it received. The given weight value appeared directly below the factor. Overall, the sum of all the weighted factors equaled one. We placed the various designs below these factors. Each consumed an entire row used to rate the success of the design. Using a scale of one to ten, each design received a score for meeting the factor, ten being the best. Ultimately, each design received a weighted factor score calculated by the product of the weight factor and the one to ten score given. The design's final score was the sum of all weighted factor scores, displayed in the right-hand column.

Factors that we deemed important for the launching mechanism included safety, durability, reliability, cost, manufacturability, noise, and compatibility. Safety had the highest weighted factor, to ensure the product would avoid injuries and potential lawsuits. We determined reliability as another highly important factor because this would determine if customers would invest in the product. Other factors such as cost, manufacturability, accuracy, and noise impacted the success of the product compared to others on the market but were not the defining factors and therefore received a lower weight.

Table 3: Decision Matrix for Preliminary Launching Designs

Factors	**Cost**	**Safety**	**Reliability**	**Manufacturability**	**Accuracy**	**Noise**	**Durability**	**Compatibility**	**Score**	**RANK**
Weight	0.12	0.24	0.14	0.1	0.05	0.1	0.2	0.05	1	
Design 1: Catapult	6	7	7	6	7	7	5	5		2
	0.72	1.68	0.98	0.6	0.35	0.7	1	0.25	6.28	
Design 2: Slingshot	4	8	6	7.5	7	7	5	5.8		1
	0.48	1.92	0.84	0.75	0.35	0.7	1	0.29	6.33	
Design 3: Spinner	5	6	5	7	3	4	7	5.8		3
	0.6	1.44	0.7	0.7	0.15	0.4	1.4	0.29	5.68	

Appendix A of the report describes decisions used to determine values for each design and factor in *Table 3*. Overall, based on the predetermined factors of importance, the slingshot mechanism presented the highest chance of success for the launching mechanism design with a score of 6.33. However, the catapult score only differed by 0.05. Based on the scores, the slingshot design was developed for further testing and prototyping, with the catapult design as a potential backup.

4.3 Dispensing Mechanism Decision Matrix

Like the launching mechanism, we deemed the safety, cost, reliability, manufacturability, and compatibility as important factors. Additionally, we added capacity as an important factor to represent the quantity of treats that could be held in each device. We aimed to create a device that users did not have to frequently refill; therefore, this factor had a high weight. The safety factor still held the highest weight to ensure the product avoided injury.

Table 4: Decision Matrix for Preliminary Single Dispensing Designs

Factors	**Cost**	**Safety**	**Reliability**	**Manufacturability**	**Capacity**	**Noise**	**Compatibility**	**Score**	**RANK**
Weight	0.13	0.24	0.13	0.15	0.2	0.1	0.05	1	
Design 1: Vending Machine Style	5	9	8	4	5	5	5.667	6.23335	**4**
	0.65	2.16	1.04	0.6	1	0.5	0.28335		
Design 2: Slotted Vertical Wheel	5	8	7	6	7	5	6	6.58	**2**
	0.65	1.92	0.91	0.9	1.4	0.5	0.3		
Design 3: Spring Fed	8	7	4	8	5	8	4.333	6.45665	**3**
	1.04	1.68	0.52	1.2	1	0.8	0.21665		
Design 4: Trap Door Release	4	8	9	7	5	6	7	6.61	**1**
	0.52	1.92	1.17	1.05	1	0.6	0.35		
Design 5: Conveyor Belt with Tabs	3	6	6	3.3	5	4	4.667	4.73835	**5**
	0.39	1.44	0.78	0.495	1	0.4	0.23335		

As previously mentioned, the determined values in *Table 4* are described in detail in Appendix A. Overall, the trap door release design met our determining factors with the highest score of 6.61. However, the slotted vertical wheel scored 0.03 below and four designs had scores within 0.38 of one another. Due to similarities in scores, four of the designs presented potential success for the dispensing component of the overall design: vending machine style, slotted vertical wheel, spring-fed, and trap door release. Nevertheless, the team determined to further develop the trap door release and slotted wheel dispensers with the other designs serving as potential backups.

Chapter 5: Development of Subcategory Designs

Chapter 5 will describe the progression from the preliminary designs we determined to develop in chapter 4 to a combined final design. We aimed to create an entire dog treat flinger device that included both the launching and dispensing mechanisms in union. Throughout the development, we identified flaws in the preliminary designs, through rapid prototyping, and advanced the designs to overcome the obstacles presented.

5.1 Initial Combined Modular Design

Prior to developing the mechanisms that created the launching device, we created a basic modular layout of the entire system, pictured in *Figure 16.* We aimed to create a modular design that allowed the user to easily disassemble the device or replace one part if necessary.
A one-foot cube contained the original design to make certain we meet the dimensional functional requirements. The visual of the modular design assisted our team to develop realistic measurements, understand the functionality, and create the necessary connections of each component of the system.

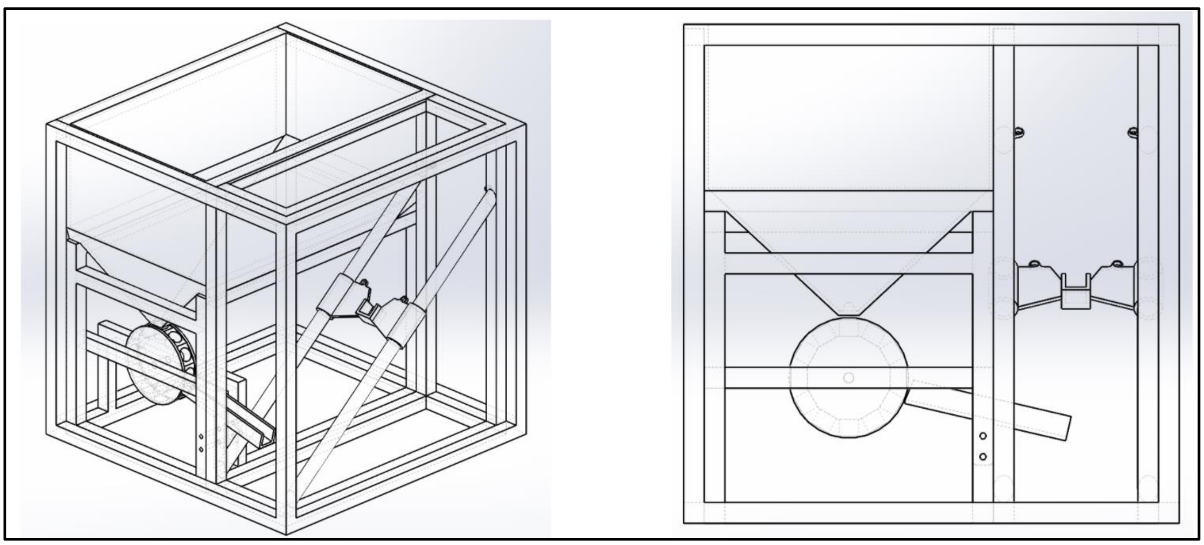


Figure 16: Initial Modular Design

We determined that the overall design contained four subcategories: (1) Launcher (2) Retracting Mechanism (3) Dispenser (4) Buffer zone (area between the dispenser and launcher). The following sections will outline the detailed development of each subcategory. We aimed to identify flaws and optimize each subcategory design before a full assembly to increase chances of success.

5.2 Development of Slingshot Launcher

First, we determined specific parts and variations of the original slingshot launching mechanism that could be used to produce the slingshot rail system. We developed three variations, pictured in *Figure 17*, that utilized a variety of parts. The first design (a) created was a cart on guided tracks, like a roller coaster. The second design (b) contained a cart attached to a ball bearing that would be guided by rods. The last design (c) incorporated a hollow tube that enclosed an inner ball bearing slider to launch the treat.

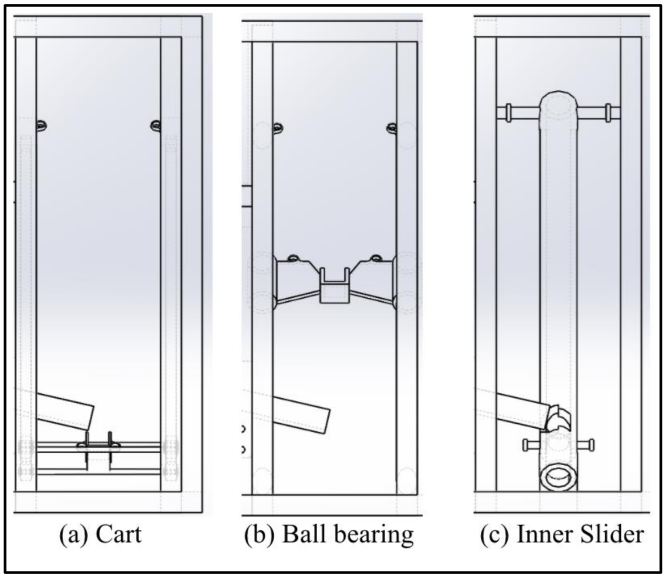


Figure 17: Variations in Slingshot Launcher

A decision matrix assisted the team in determining the design to develop for prototyping and testing. We determined that the most important factors to consider for the success of the launcher were friction and alignment. Both factors would impact the speed/distance of the treat and the reliability of the product. We also deemed ease of assembly, and cost as important as they would impact the manufacturability and price of the entire device. We investigated specific parts available to purchase to fully understand the price and assembly process. The researched parts also aided the team in determining the alignment and friction factor. Refer to Appendix B for a breakdown of parts and prices.

Table 5: Decision Matrix for Variations in Slingshot Launcher

Factors	Cost	Frictionless	Alignment	Size	Ease of Assembly	Durability	Score	RANK
Weight	0.15	0.25	0.25	0.1	0.15	0.1	1	
Rail	7	7	3	5	3	2		3
	1.05	1.75	0.75	0.5	0.45	0.2	4.7	
Ball Bearing Slider	4	7	9	7	5	7		1
	0.6	1.75	2.25	0.7	0.75	0.7	6.75	
Plunger	6	7	4	8	5	7		2
	0.9	1.75	1	0.8	0.75	0.7	5.9	

The decision matrix indicated that the ball bearing slider design had the highest chance of satisfying the important factors specified. Therefore, we continued to develop the CAD model and design. We advanced our original design by indicating that shaft collars would secure the cart to the ball bearings, pictured in *Figure 18 (a)*. Additionally, we developed an alternative design, *Figure 18 (b)*, in the chance that the ball bearing launcher did not perform as expected during prototyping and testing.

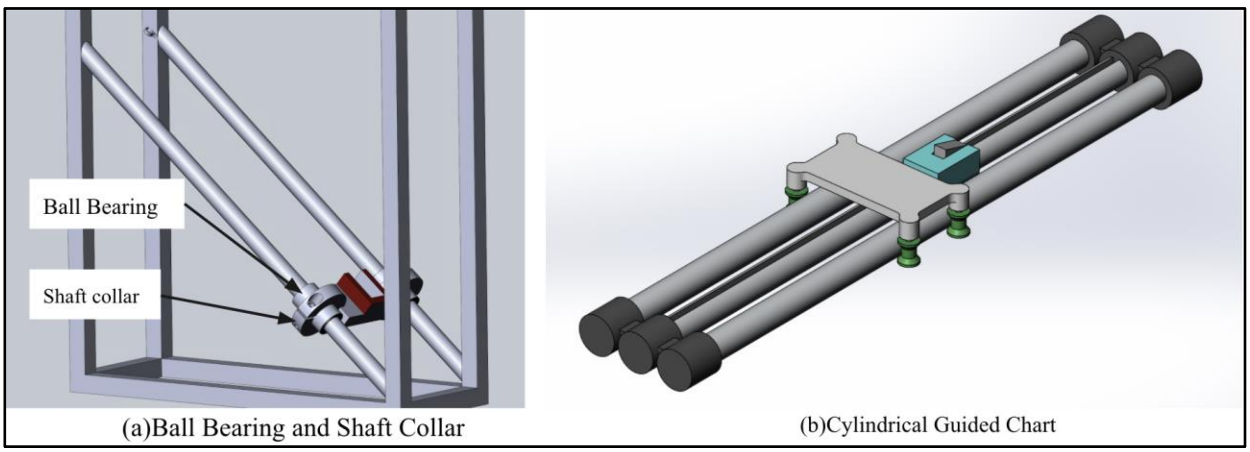


Figure 18: CAD Models for Rod Guided Slingshot

The assembly of the rods and 3D printed shaft collar to secure the ball bearings allowed our group to test the computer model and understand the friction, motion, and performance of the design. After we assembled the launcher, illustrated in *Figure 19*, we determined that the ball bearings experienced higher levels of friction when sliding across that rails than anticipated. Furthermore, the addition of the ball bearings to the cart added a significant amount of mass which impacted the force that the rubber bands could apply to the cart, shortening the launch distance of the treat.

Figure 19: Ball Bearing and Shaft Collard Build

We continued to alter the design to reduce the mass of the cart to increase the treats' projectile motion. While testing, we discovered that a 3D printed tube with a 0.5-inch inner diameter offered linear motion with limited friction against the carbon steel rods and a low mass. Therefore, we developed a cart design that included two cylindrical tubes on either side to allow direct attachment to the steel guide rods, *Figure 20*.

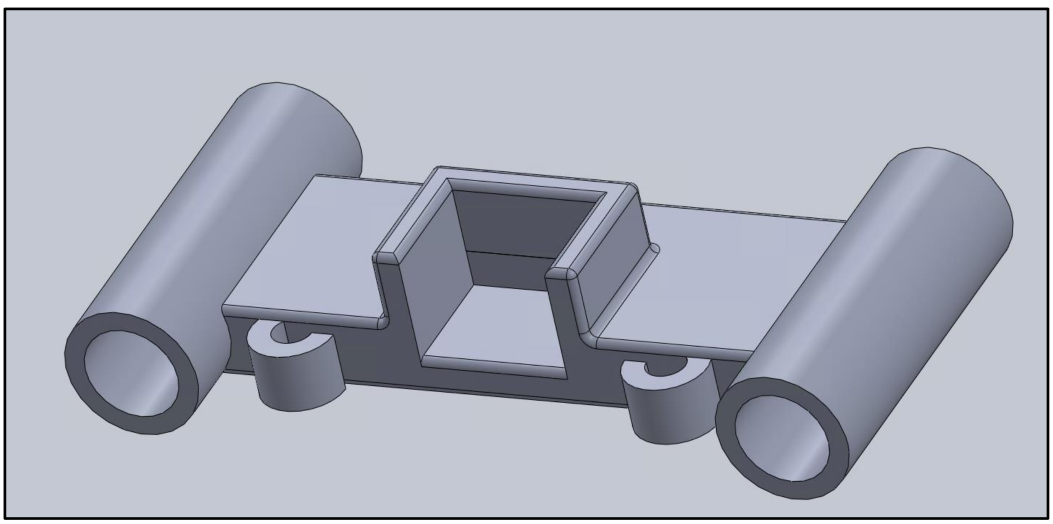


Figure 20: Cart with Direct Attachment Method

Completed testing on the 3D printed part proved that using the 0.5-inch inner diameter cylindrical shafts was an effective sliding method for our launcher. The friction encountered between the rods and the launcher was minimal, and the weight of the PLA 3D printed material was tremendously smaller than the weight of the ball bearings.

The launcher was further developed by smoothing the edges and adjusting the band attachment location. We also included a tab on the bottom to attach to a retracting mechanism.

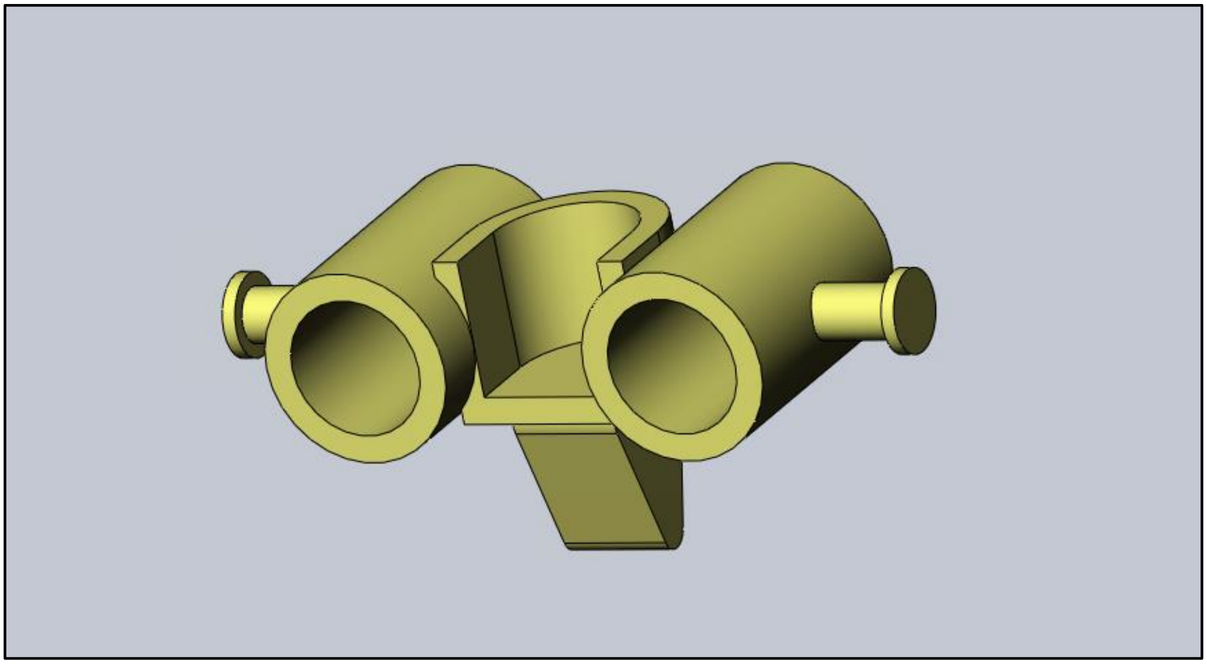


Figure 21: Developed Slingshot Cart

Development of the attachment methods and structure of the overall slingshot design continued with the development of the retracting mechanism subcategory.

5.3 Development of Retracting Mechanism

As the designs for the slingshot launcher advanced, we generated various retracting mechanisms in SolidWorks. We initially wished to create a pulley retraction design that utilized a tab to pull the cart into the loaded position. Due to this, we focused on creating end caps to secure the parallel launcher rails and incorporate this pulley system. Pictured in *Figure 22* are two versions, one with the pulley system slightly suspended below and the other with the pulleys aligned with the parallel rods.

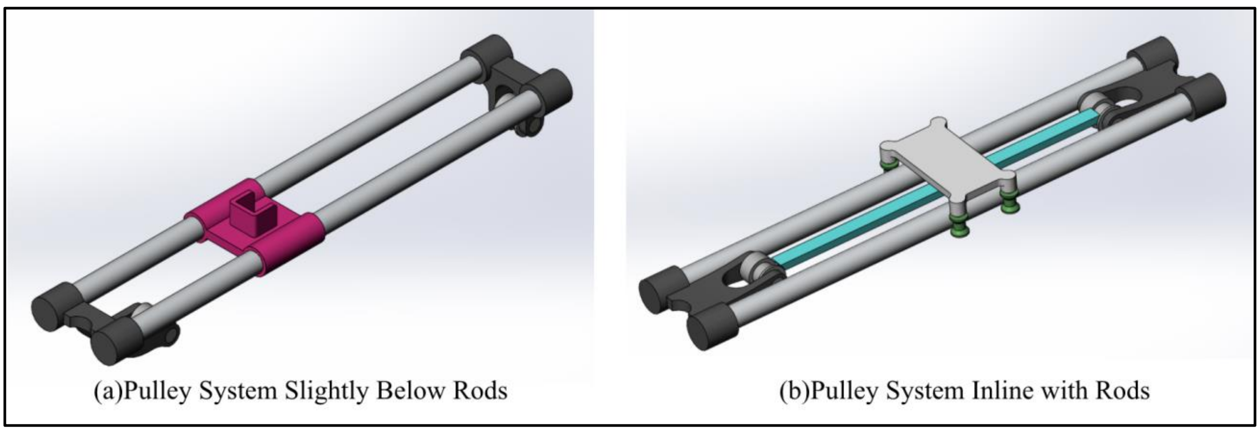


Figure 22: CAD Models for Timing Belt Pulley Retracting Systems

Throughout the design process, the team struggled with designing a sound way to attach a tab to the pulley belt. We needed a design that could resist the force of the rubber bands to retract the cart but also be flexible enough to rotate around the pulleys at each end. When we created designs of greater strength, the flexibility worsened and vice versa. Another idea we had was to directly connect the pulley to the cart, however, this meant that the motor would resist the bands during launch, shortening the launch distance.

To maintain both strength and flexibility, we tested a 3D printed chain as a method of retraction. This design copied the pulley system. However, sprockets replaced the pulleys, and a chain replaced the belt. With this design, we could attach a tab to the links of the chain, ensuring a secure method of retraction. We chose to test PLA chain instead of steel because it was lighter, cheaper, more easily accessible, and produced less noise.

Figure 23: Chain Retracting Mechanism

After testing this method of retraction, we realized that the chain's links were stiff, causing the chain to fall off the sprockets, and that the PLA was not strong enough to resist the force rubber bands the number of repetitions we needed.

Our next idea was to attach a lever arm directly to a stepper motor to retract the banded launcher. We inquired this would require a high torque motor to retract the rubber bands the necessary distance. Through testing, the team determined that the launcher must be retracted by two inches to launch the treats 10 feet. *Figure 24* shows the testing setup used and *Table 6* shows the raw data.

Figure 24: Launcher Retraction Testing Setup

Table 6: Launcher Retraction Testing Raw Data

Length of Retraction [in]	Distance Traveled [ft]
1/2	0
1	3
1.5	6.8
2	9.8
2.5	15
3	20

With this information, the team could shorten the length of the rails and develop the lever arm design to the specified 2-inch retraction length. Using CAD, we 3D printed a frame that incorporated the slider launcher and the lever arm retraction mechanism.

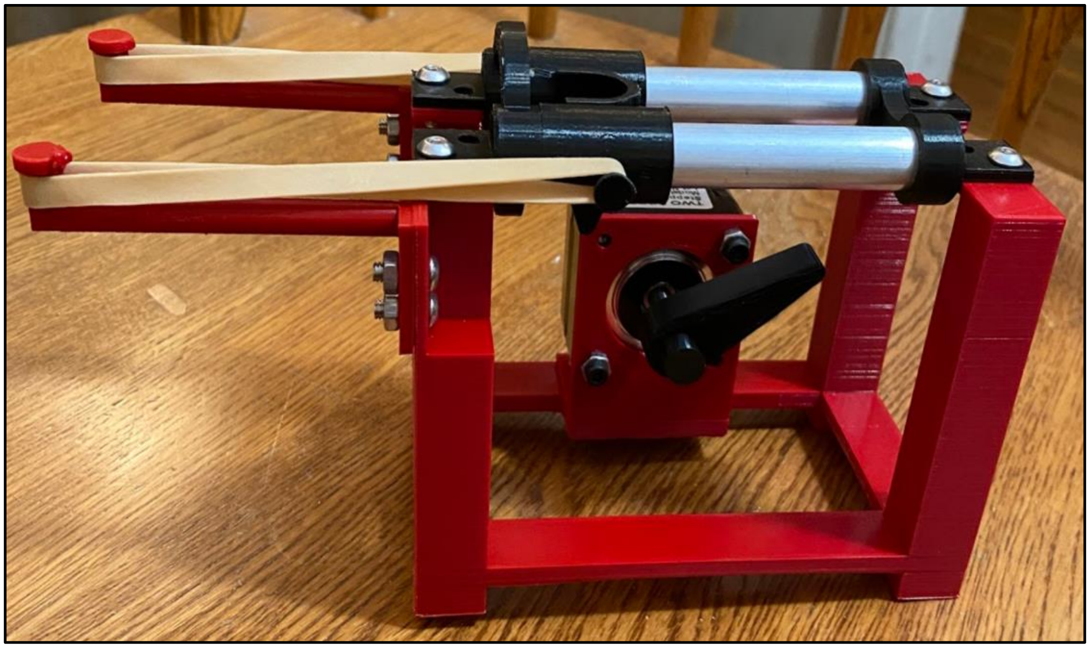


Figure 25: Modular retracting mechanism

With this 2-inch retraction length, our team conducted another test to determine the optimal release angle to achieve the desired 10 feet launch distance. We 3D printed modular bases at angles of 15, 20, and 45 degrees and performed 3 launches at each angle. We took the average of the 3 attempts and displayed these values in *Table 7* below. From this data, the team determined an angled base of 20^o was the optimal design.

Table 7: Launcher Angle Raw Testing Data

Angle of Retraction [degree]	Distance Traveled [ft]
15	8
20	12
45	15

We tested this retraction mechanism on a year-old Australian Shepherd and to our surprise, he lost the treat when it was launched. Our team concluded that a 12-foot distance was too far for a dog to chase a small treat. We tested various rubber bands similar in size to the ones in *Figure 25* to see how they compared. We obtained the spring constant of each band by creating an at-home experiment. The experiment consisted of hanging an empty zip-block bag with a rubber band and adding water, measuring the distance it traveled and the weight of the water added. "Original band" refers to the bands pictured in *Table 8*, and the following colors are different colored rubber bands.

Table 8: Spring Constant Calculations

Band	Water amount	Force (N)	Distance (in)	Distance (m)	Spring Constant	Avg. Spring constant
Original Band	1	2.31516	0.75	0.01905	121.5307087	**86.06514337**
	2	4.63032	2.25	0.05715	81.02047244	
	3	6.94548	3.75	0.09525	72.9184252	
	4	9.26064	5.3	0.13462	68.79096717	
Yellow	1	2.31516	1.25	0.03175	72.9184252	**53.00089239**
	2	4.63032	4	0.1016	45.57401575	
	3	6.94548	6.75	0.17145	40.51023622	
	4	9.26064	-	-	-	
Blue	1	2.31516	1.75	0.04445	52.08458943	**42.61466408**
	2	4.63032	5.5	0.1397	33.14473873	
	3	6.94548	-	-	-	
	4	9.26064	-	-	-	
Purple	1	2.31516	1.25	0.03175	72.9184252	**53.53138358**
	2	4.63032	3.75	0.09525	48.61228346	
	3	6.94548	7	0.1778	39.06344207	
	4	9.26064	-	-	-	
Green	1	2.31516	0.75	0.01905	121.5307087	**85.74311314**
	2	4.63032	2	0.0508	91.1480315	
	3	6.94548	3.8	0.09652	71.95897223	
	4	9.26064	6.25	0.15875	58.33474016	
Red	1	2.31516	0.75	0.01905	121.5307087	**96.86944473**
	2	4.63032	1.5	0.0381	121.5307087	
	3	6.94548	3.5	0.0889	78.12688414	
	4	9.26064	5.5	0.1397	66.28947745	

With this information, our team decided to choose the purple band for our launcher. The band provided the enough tension to launch the treat the appropriate distance while reducing the amount of force required by the motor. At this point, the developed retracting mechanism design advanced to the final design development discussed in Chapter 6 to be combined with the other subcategories for testing.

5.4 Development of Single Dispensing Mechanisms

We established the single dispensing mechanism as an imperative function to the overall design. We needed to dispense individual treats into the launcher to satisfy the functional requirements. The slotted vertical wheel was our initial dispensing mechanism determined from the decision matrix. We performed several tests on a 3D printed prototype, displayed in *Figure 26*, which identified flaws. The wheel itself operated as planned, but two treats sometimes fit into the slot depending on their orientation. We tried decreasing the slot sizes to eliminate this issue, however, this failed. During testing, we also observed significant jamming at the hopper outlet. We tested several styles and shapes of hoppers including funnels and slides at steep and shallow slopes, each design created similar jamming as observed in *Figure 26*. This valuable observation established the need for a hopper with continuous motion to prevent the jamming of the treats.

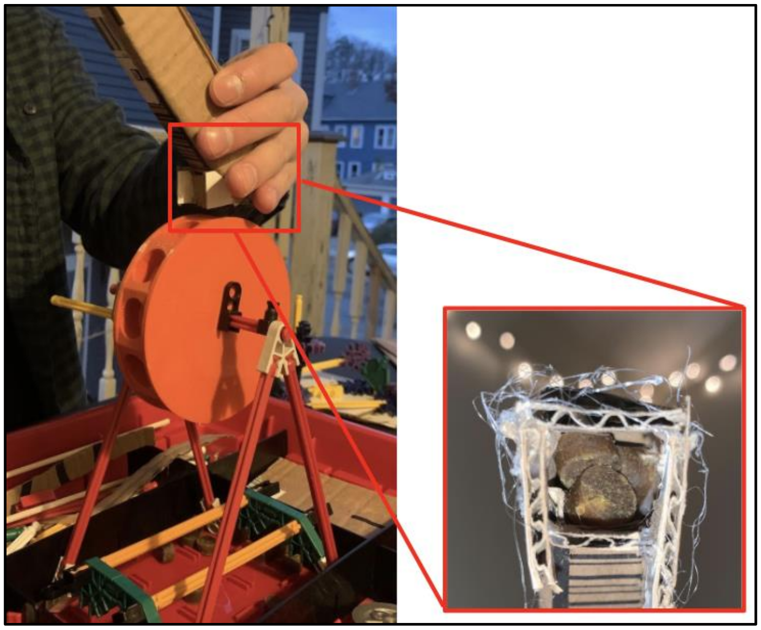


Figure 26: Prototype and Testing Slotted Vertical Wheel

We produced several designs to prevent jamming in the outlet of the hopper and dispense one treat at a time. We designed multiple rotational motion models in CAD and tested their 3D prints. The three designs tested, (a) vertical spiral (b)spiral troft (c) rotating drum, are illustrated in *Figure 27*.

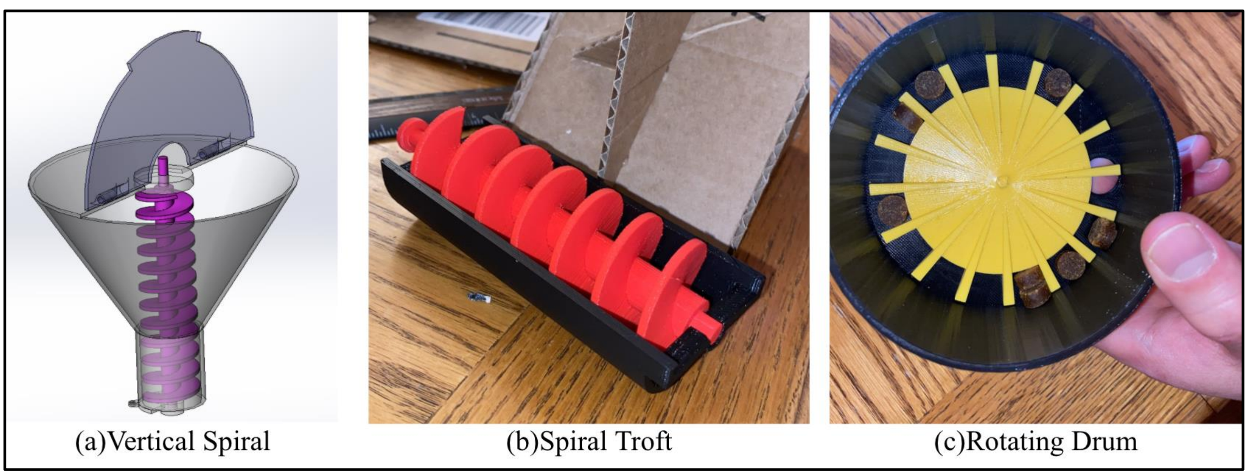


Figure 27: Circular Motion Dispensing Designs

The vertical spiral did not work as intended because the spiral rotation acted in the same direction as gravity. The treats laid stationary on the spiral when rotated rather than rolling down the spiral to the exit at the bottom.

The spiral trough successfully prevented jamming of the treats because the rotation occurred perpendicular to the direction of gravity. However, we observed the treats were often dispensed in groups. We observed that treats would dispense individually if one treat were placed in each spiral slot. But we did not want the user to have to manually place each treat in a specific spot.

The last design, the rotating drum, successfully reduced jamming and ensured single dispensing of the treats through the bottom outlet. We recognized that treats were often temporarily jammed between the base of the drum and the underside of the rotating piece. Due to this observation, we determined to reduce the contact area between the rotating piece and the treats. As a result, we tested a singular rotating bar around the circular drum held at an angle. This motion mimicked the use of an automatic mixing device. We detected minimal jamming with this method and treats dispensed one by one through the outlet at the base of the drum.

Due to the observed success in the rotating drum, we continued to develop this design. We designed a new drum dispenser with one rotating lever arm. The constant rotation of the lever arm along with the 25-degree angle of the drum forced treats through a hole at the base of the drum and into a tube. We tested various tube inner diameters to determine the dimension that would best allow the treats to stack in a single file, vertical line.

Figure 28: Rotating Drum Dispenser

After testing the design for optimal diameters and positions, we designed a mount to attach a Nema 17 stepper motor to the drum dispenser and rotating arm. Additionally, we developed parts to attach the drum dispenser to the retraction test frame, enabling simultaneous testing with the launcher system.

5.5 Development of Buffer Zone

As discussed in section 5.1 of the initial modular design, we established that the buffer zone was the component that connected the single dispensing and launching mechanisms. The buffer zone components relied on the outlet method of the single dispensing mechanism. Due to this, we could not develop initial ideas for the buffer zone until the single dispensing mechanism was finalized.

The first idea for the connection method included a slide the width of a singular treat. Through testing, however, we found that slide would often jam at lower inclines. Treats would flow smoothly at greater inclines, but our intentions were to include the trap door release system at the end to dispense singular treats into the launcher. The trap door release system functioned better at lower inclines. These results were not optimal.

The team also considered a conveyor belt design with hopes that continuous motion would limit treats jamming. This system was complicated compared to other ideas and occupied a large amount of space in the device. Additionally, there was no guarantee that one treat would be dispensed at a time. For these reasons, we decided to consider other designs.

With the development of the single dispensing system, the team also designed an outlet tube and another idea for the buffer zone. The tube proved to successfully align the treats into a vertical stack. Next, we needed a way to separate these treats individually and dispense them into the launcher. We developed a linear motor sliding system to push the lowest treat in the buffer tube stack into the launcher cart.

This system seemed ideal, however, we thought of one flaw. As the cylindrical treats fall into the linear motor, they may fall on their flat side, or they may orient themselves on their curved edge. Treats that resided on their curved edge would be about twice as tall as treats on their flat side. This meant when pushed, treats on their curved edge would jam between the wall of the buffer tube and the slider of the linear motor. To counter this, we thought to make the buffer tube move instead of being rigid. Initially, we designed a spring system that attached between the tube and the drum dispenser. This system allowed the buffer tube to displace upwards in reaction to a treat being pushed against its wall. The springs served to return the tube to its initial position after the treat was dispensed. This system is depicted in *Figure 29.*

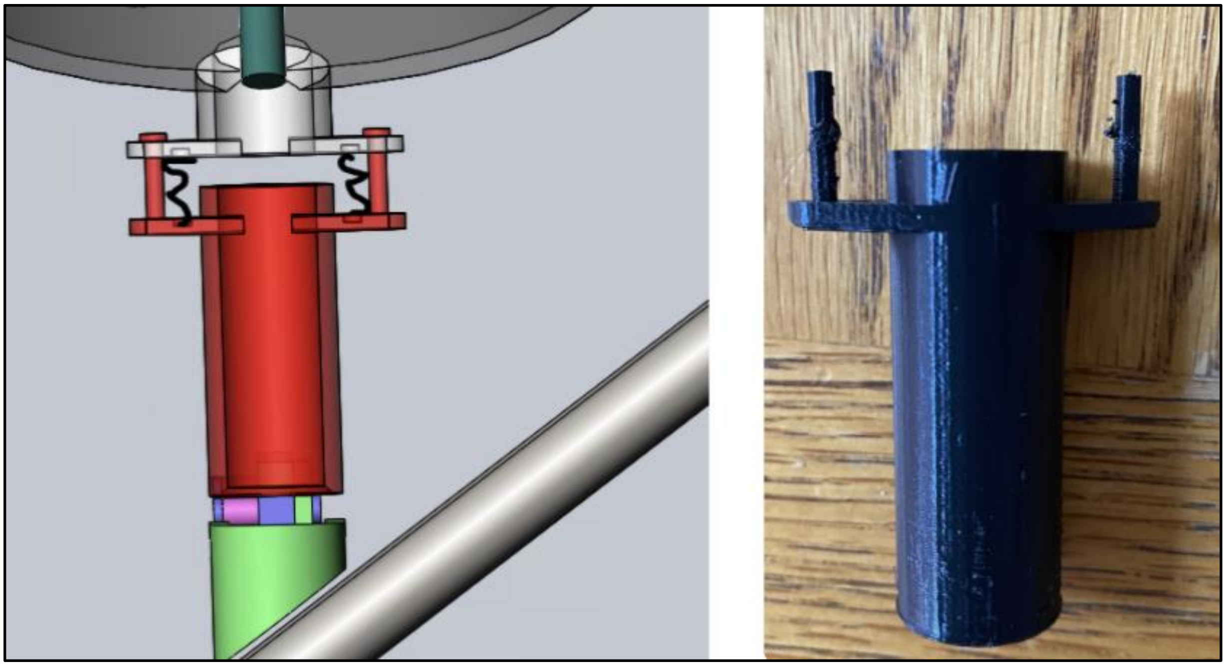
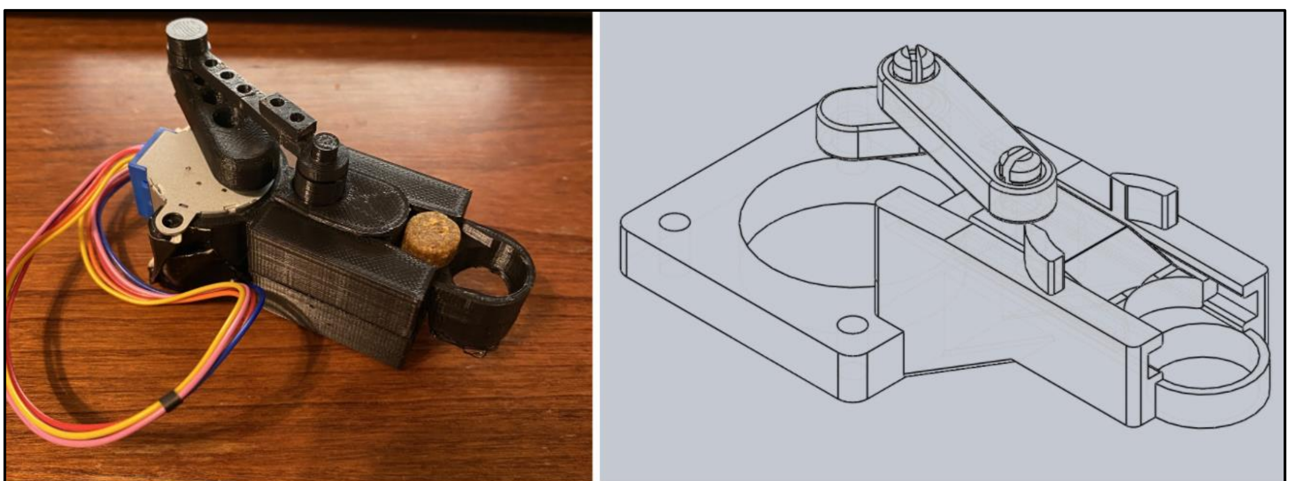


Figure 29: Original Spring Buffer Tube Design

Along with the spring buffer tube, we prototyped and 3D printed an initial design for the linear motor to determine if the design functioned as planned. After assembling the design, we tested its functionality by determining if it would separate one treat from the buffer tube and dispense it into the launcher. We found that our initial design intersected with itself and the buffer tube above. The redesign of the linear motor included attachment methods for a Nema 17 motor and compatibility with the buffer zone and the frame.



(a) Original Linear Motor Prototype (b) Adapted Linear Motor CAD Design

Figure 30: Initial Linear Motor Designs

Initial tests performed on the integrated spring buffer tube and linear motor determined the spring design did not function as intended. The tube did not provide the flexibility needed to dispense the treats in both the vertical and horizontal orientation.

We redesigned the attachment method of the buffer tube to the drum dispenser and replaced the spring design with hinge system. The hinge allowed the tube to sway when treats were jammed against the slider of the linear motor, allowing the system to dispense treats in either orientation. We utilized an elastic band around the tube to ensure it would snap back to its original position.

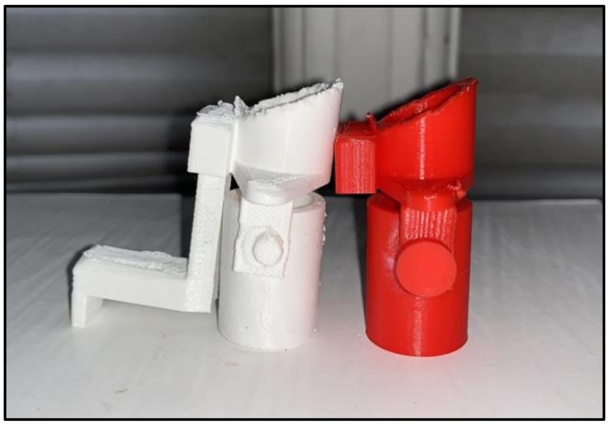


Figure 31: Hinge Buffer Tube Design

We continued the development of the buffer zone with an initial assembly of the entire system in Chapter 7.

Chapter 6: Electrical Components and Code

To power the device, we utilized two Nema 17 17HS4023 stepper motors, one 27:1 Nema 17 17HS19-1684S-PG27 geared stepper motor, three A4988 stepper driver modules, one CNC shield, one Arduino Uno, one DC power cable 5.5x2.1 mm pigtail (female), and one 12V 8A AC to DC adapter. A block diagram of the electrical components used is shown below.

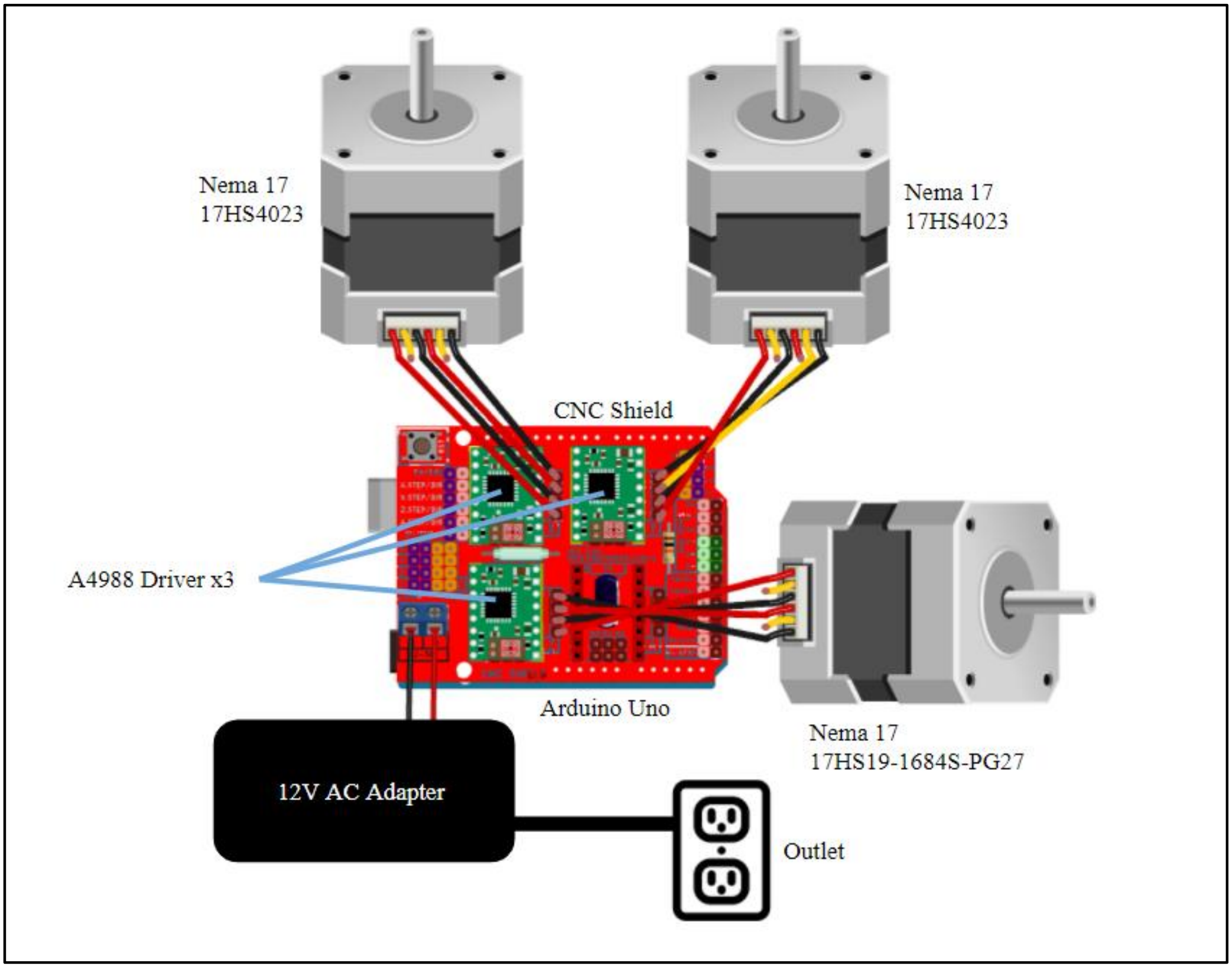


Figure 32: Electrical Components Block Diagram

The CNC shield connected directly on top of the Arduino, allowing the Arduino to control three motors at once. Everything was powered by the 12V 8A AC-DC adapter.

6.1 Launching and Retraction Electrical Components

The launching and retraction mechanism used the 4-axis high torque 27:1 Nema 17 geared stepper motor driven by an A4988 stepper driver. The motor had four leads with the corresponding windings, black: A, green: A\, red: B, and blue: B\. The motor was connected to the Z-axis of the CNC shield and its red, blue, green, and black leads were connected to the driver's B2, A2, A1, and B1 pins respectively. A datasheet of the motor's leads and windings can be found in Appendix D1.

6.2 Single Dispensing Electrical Components

The single dispensing mechanism used the 4-axis used the Nema 17 17HS4023 driven by an A4988 stepper driver. The motor had four leads with the same colors and winding correspondence as mentioned above. The motor was connected to the X-axis of the CNC shield and its red, blue, green, and black leads were connected to the driver's B2, A2, A1, and B1 pins respectively, like above. A datasheet of the motor's leads and windings can be found in Appendix D2.

6.3 Buffer Zone Electrical Components

The buffer zone mechanism used the same motor and driver as the motor used for the single dispensing mechanism. The motor's leads and windings were the same as above as well as the driver pins the leads were connected to, however, the motor was connected to the Y-axis of the CNC shield. A datasheet of the motor's leads and windings can be found in Appendix D2.

6.4 Code

The team wrote a code in the Arduino IDE to run the X, Y, and Z axes of the CNC shield, allowing all three motors in the system to run simultaneously. Additionally, this code allowed the motors to run at different speeds by adjusting their rotation rates. The motor that powered the retraction mechanism had a 27:1 gear reduction, therefore, we multiplied its rate by 27 of the linear motor rate to make them synchronous. We set the rate of the drum motor to 10 times that of the linear motor. The drum motor did not need to be synchronous with the retraction motor and linear motor. Images of the code used can be found in Appendix E.

Chapter 7: Final Design Development

Chapter 7 illustrates the development of the final design to ensure that each subcategory operates properly with one another. We aimed to optimize the overall system to ensure proper integration of the four subcategories, attachment methods, and overall system stability.

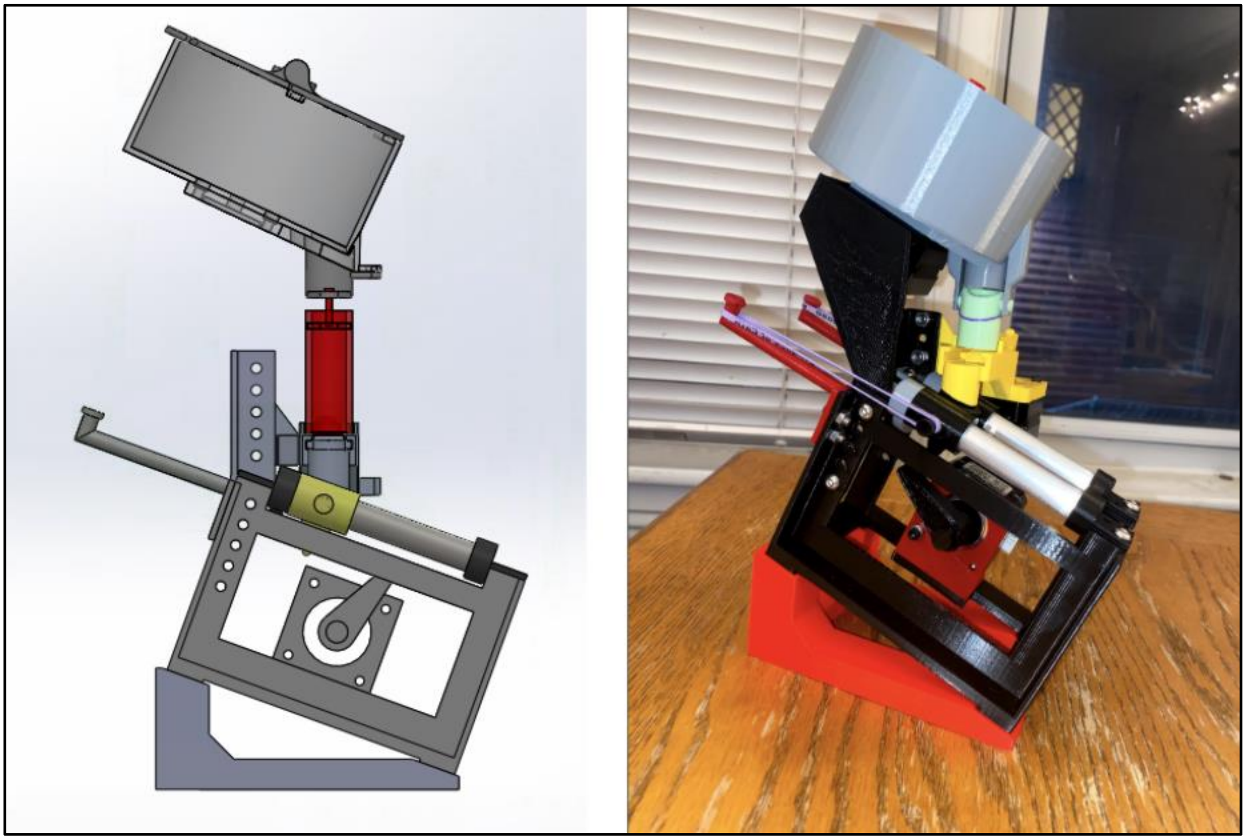


Figure 33: CAD and Prototype of Overall System for Testing

The initial full design prototype allowed the team to test the electronic components and determine the optimal device's wiring and layout for each component. The temporary frames allowed the team to slightly adjust each component during initial testing to ensure only one treat was dispensed each time. The buffer tube and linear motor were focused on during this phase to ensure the length of the tube and stroke length were optimized. Several slightly adjusted components were tested until every component worked individually and as one unit.

Chapter 8: Final Design

Chapter 8 will discuss the final design of the dog treat launcher. The final design will be broken down into each component to discuss each mechanism in detail. *Figure 34* depicts the overall final design. Once the team optimized the components using the temporary frames, we developed of the final frame to ensure stability and durability.

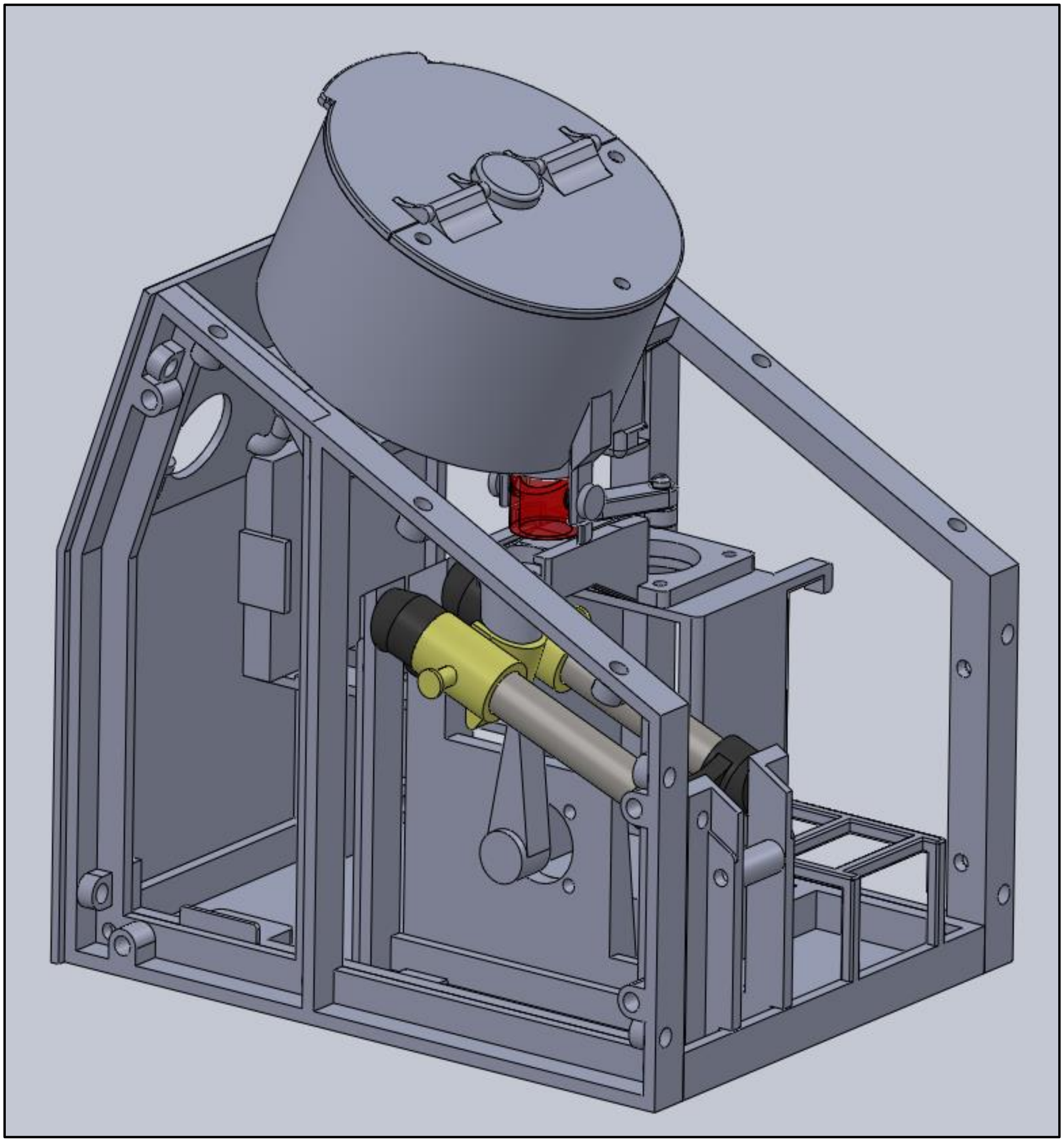


Figure 34: Final Design CAD

The final frame design contained all mechanisms, electrical components, and walls encasing the device for safety. These walls are not shown in *Figure 34* above for viewing purposes. The team utilized additive manufacturing by 3D printing each frame from PLA. Each frame and component fastened to one another using M4x8mm screws and M4x4x5mm thread inserts. We hammered the thread inserts into designated holes on one part and fastened the screws through corresponding holes of adjacent parts, joining two pieces together. We determined this method of fastening to reduce the vibrations and rattling. Additionally, we fastened the Nema 17 motors using M3x10mm screws. Overall, this system met the specified functional requirements and remained within one cubic foot.

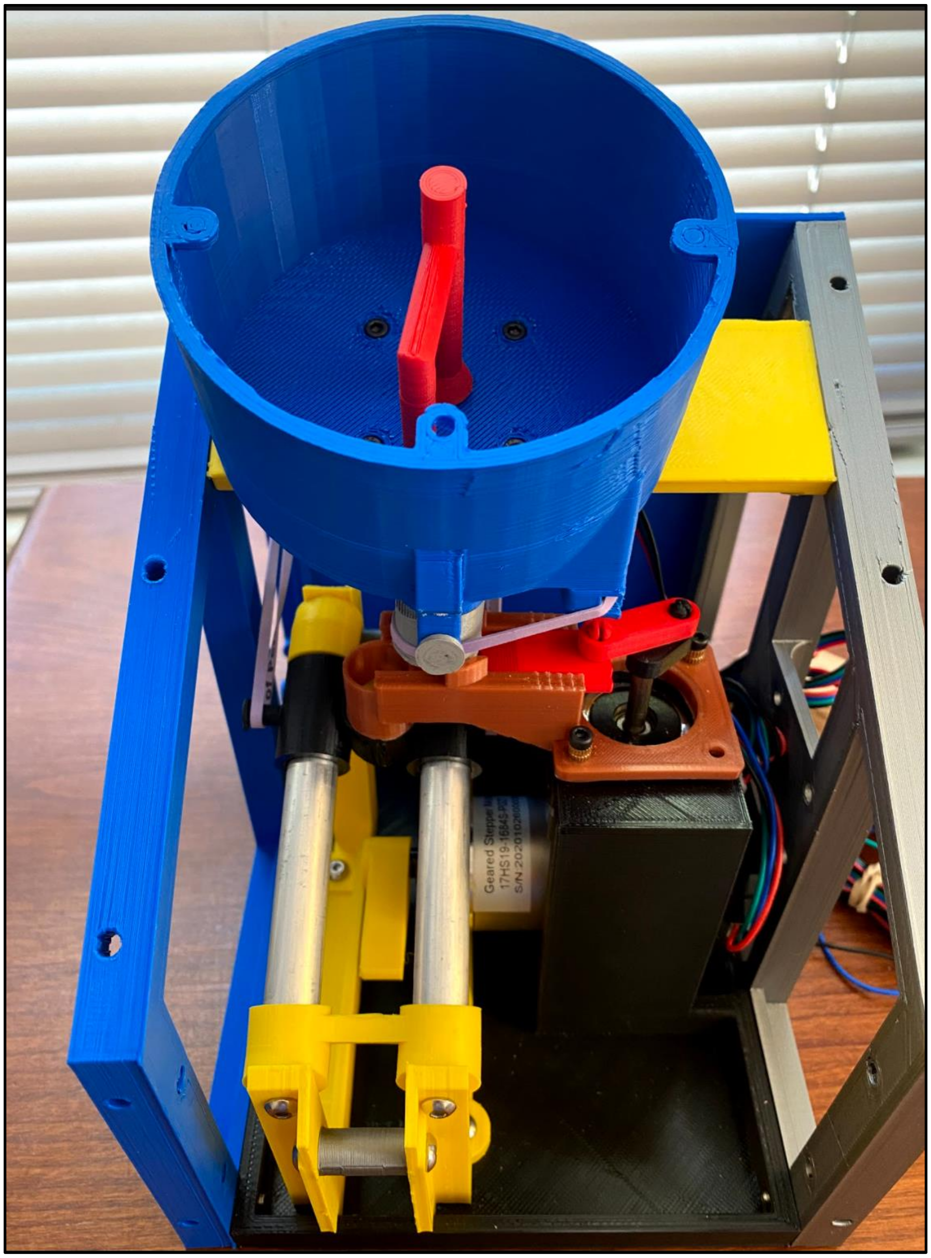
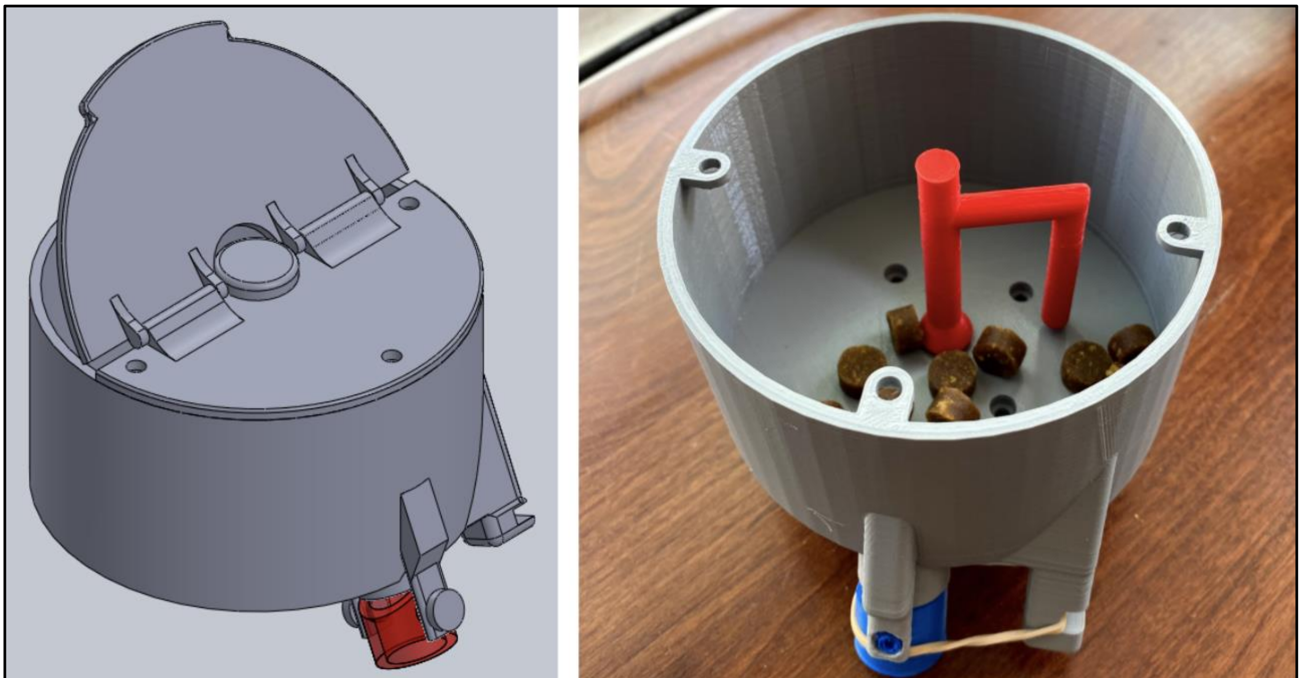


Figure 35: Final Device

Figure 35 depicts the entire system assembled incorporating each 3D printed component, all electrical components, and wiring. We tested this system and made adjustments accordingly until all components performed properly with one another. Again, the wall encasements are not shown; these can be found in *Figure 39* below.

8.1 Single Dispensing and Buffer Zone Components

In the final design, the buffer tube and dispenser were integrated together. Through testing, we discovered that these two systems operated better in conjunction. In this design, the team secured the buffer tube to the dispenser drum using a 3D printed hinge system, allowing the tube to sway. We attached a rubber band around the buffer tube and a tab extending from the dispenser which pulled the tube to its original position if pushed. Additionally, the team created an angled notch in the top of the buffer tube, ensuring that the tube could only rotate in the desired direction.

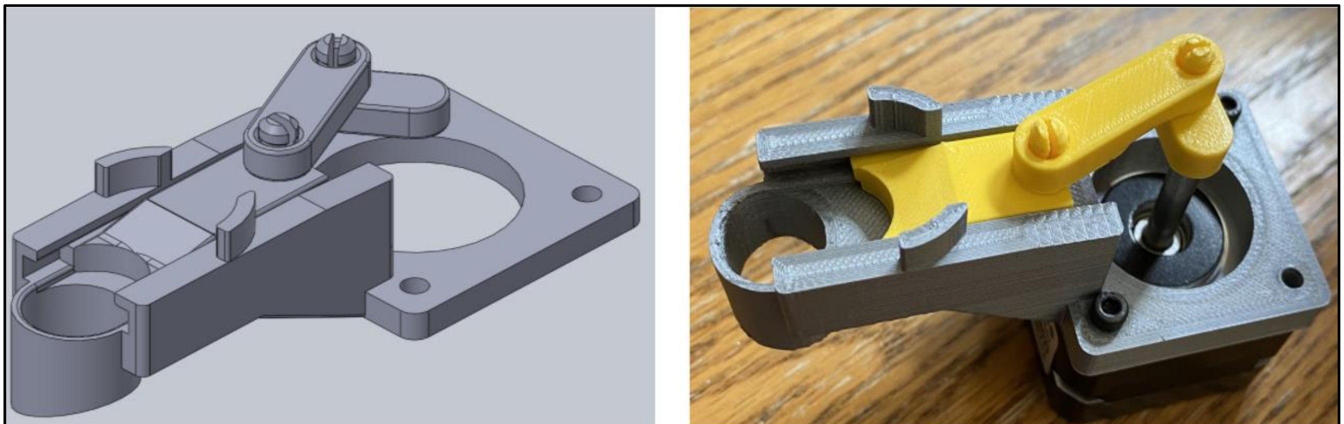


(a) Final Dispenser and Buffer Tube Design CAD

(b) Final Dispenser and Buffer Tube Device

Figure 36: Final Dispenser and Buffer Tube Design

After treats aligned vertically in the buffer tube, they fell into the chamber of the linear motor, a four-link system that translated rotational motion of the motor to translational motion of a slider. This system functioned by sliding individual treats into the launcher cart. As the slider retracted, the lowest treat in the buffer tube would fall into the chamber. The slider would then push forward, separating this treat from the stack. The stack of treats above were held in place by the walls of the buffer tube. The single treat would fall through a hole in the linear motor at the slider's maximum stroke length and into the launcher cart. This process would then repeat. The team optimized the stroke length of the linear motor to ensure treats had enough space to fall into the chamber and were pushed far enough to fall into the launcher. By dispensing treats individually into the launcher, the team accomplished the requirement of launching one treat at a time.

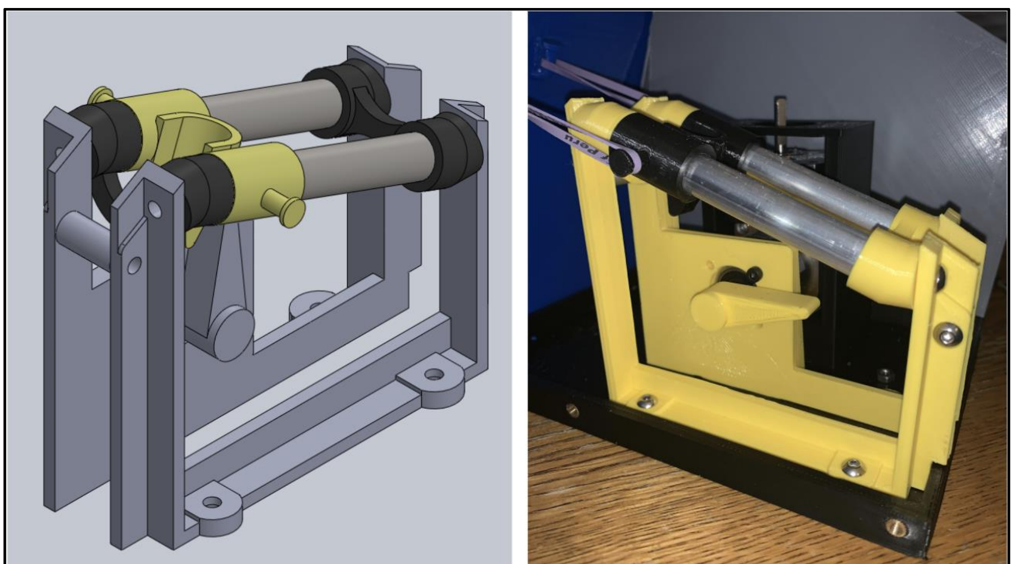


(a) Final Linear Motor CAD (b) Final Linear Motor Device

Figure 37: Final Linear Motor Design

8.2 Launching and Retraction Components

Like the buffer zone and single dispensing region, the team combined the launching and retraction mechanisms through testing. The launching mechanism utilized stored potential energy in the rubber bands, mimicking a slingshot, and the retraction mechanism modeled a cam lever arm.

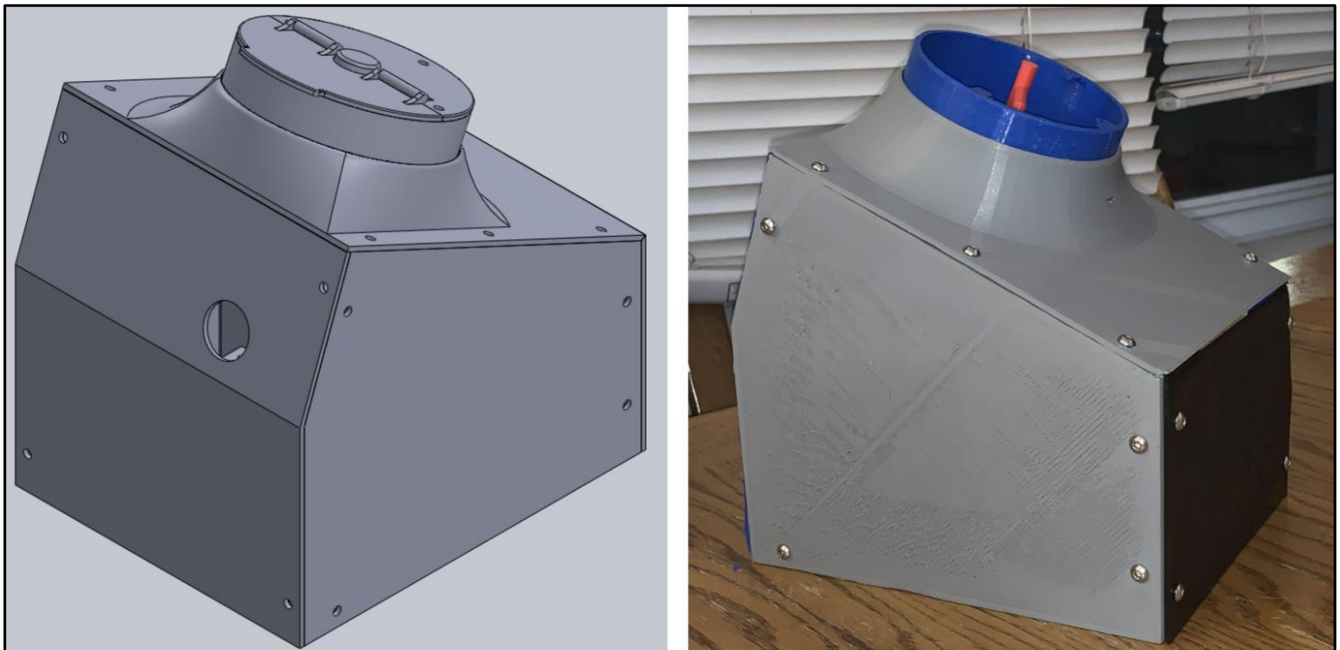


(a) Final Launcher & Retraction CAD (b) Final Launcher & Retraction Device

Figure 38: Final Launcher and Retraction Design

The final launching design utilized two rubber bands each with an average spring constant of 53.3 N/m. One end of the rubber bands attached to the launching cart while the other looped around inner hooks located on the backside of the front wall encasement. We placed the bands on either side of the launcher cart to equally disperse the applied force. The launching cart remained at rest directly below the linear motor outlet, which allowed the treat to fall directly into the cart. To launch the treats, the cam lever arm rotated and latched onto a tab located underneath the cart. The team designed the lever arm to lose contact with the tab at a retraction length of 2 inches to launch the treats the desired distance of 10 feet. After release, the lever arm would complete its rotation and repeat the process.

8.3 Wall Encasements



(a) Final Fully Encased CAD (b) Final Fully Encased Device

Figure 39: Final Fully Encased Device

The final device included a fully encased interface compiled of 5 3D printed walls fastened and secured with the same M4x8mm screws and M4x4x5mm thread inserts as mentioned above. The encasement of the device ensured safety for all dogs, children, and other users by limiting the risk of fingers and other limbs getting caught inside the device's moving components.

Chapter 9: Broader Impacts

Throughout the design process of the dog treat flinger, the Code of Ethics for Engineers was considered. The safety, health, and welfare of the public is the first fundamental canon of Engineering. Throughout all phases of the process, the team aimed to create a safe device for pets, and children in a household. One of the listed functional requirements specified that the safety of the design had to be analyzed in each preliminary design. The team specifically investigated the safety of the launching velocity, trajectory, and casing of the device. The case was designed to ensure no fingers or paws could be placed in any part of the device, limiting injuries that could occur. Lastly, the strength of the elastic band considered the launching velocity for safety. A heavy pair of elastic bands could potentially injure someone in front of the outlet.

The design of the treat launching device could create a behavioral impact on the dog’s personality as well as on the economy of dog treat launchers. As the production of the device increases, access to the device also increases. As the autonomous dog treat launching device becomes more common in households, this could alter the interactions between the owner and their dog. Whether or not this change will be for the better can only be evaluated through behavioral analysis of the dogs given the device. Based on the conducted research, the team predicts that the device would have a positive impact on the emotions of the dog while left alone.

Lastly, the material selection for the device in mass production should consider the safety and recyclability of the material. The materials used mustn't produce any toxic fumes or particles since it stores and launches treats to be consumed by the dog. It is also important for production to consider a proper disposal plan of the components when the consumer wants to get rid of them. The model prototyped by the team in this submission had components made of polylactic acid (PLA) which is a biodegradable material. However, the product has several fasteners and motors composed of metal. These items are not biodegradable, and therefore take up unneeded space in landfills. An alternative sustainable disposal method of metals is scrap metal recycling, which reuses disposed metals for other applications. Scrap metal recycling has numerous beneficial impacts on the environment since the energy to form metal from iron ores is dependent on coal (King, 2019). This disposal method should be considered by the marketing team to be emphasized to customers. Additionally, the device is intended for indoor use which could result in limited air ventilation. Overall, considerations of the ethics behind the safety and societal impacts guided the design process at all times. Future studies could investigate the impact of the device on the dogs' anxiety levels while utilizing the device at home compared to other devices.

Chapter 10: Conclusion and Future Recommendations

The following recommendations could be investigated and explored in future design ideations:

Sound and vibration dampening material within the encasement

Reduction in the noise produced by the device will ensure dogs are not frightened by the noise of the motors. During testing, the vibrations of the fittings and fasteners created a significant amount of noise in combination with the operation of the motor. The team determined an insulation layer within the encasement could reduce the amount of noise that escapes from the device. Another method to decrease the amount of noise could be to also reduce the number of fasteners that create the rattling noise.

Method to secure base to increase stability and reduce movement

Stability and stationary use of the device are important for the safety of the dog, owners, and the surrounding floor. The addition of an attachment method on the base of the device could increase the stability of the system and reduce movement on the floors, eliminating the possibility of scratching or denting of the floor surfaces. Suction cups placed on the bottom could be a potential solution for indoor use and holes with stakes for potential outdoor application.

Customization attachments to increase adaptability to consumers' space

The device has the potential to expand and adapt according to the consumer needs, creating a device optimal to anyone's space requirements. Further design and optimization could be completed to create a design with additional pieces, attachments, and alterations to expand the usage of the device. An example of how the design can be changed is by modifying the angle of the rods or the thickness of the rubber bands. Making adjustments to these factors would influence the flight trajectory of the treat. The device could include these adjustments in additional packages, increasing the profit and idioms that need to be purchased. Additional packages could include a wall attachment method that could be used by consumers with limited floor space.

Reduce the sharp edges on the encasement

The importance of safety in the product was of high importance. The team determined that creating rounded edges on the encasement would increase the safety of the device. The round corners would limit the risk of children and dogs getting cut or injured by the corners. Due to time restrictions and accessibility, this identified risk could not be addressed in the design but would significantly improve safety.

Metal frame to increase lifetime and durability

Consideration of a metal wire frame could increase the lifetime and durability of the product. Due to uncertainty and limited accessibility to machining spaces during COVID-19, rapid prototyping the frame with 3D printing was the reliable method to produce the design. Future improvements might consider the use of lightweight extruded rods.

Increase ease of cleaning the device

Due to the use of food consumed by dogs, it is important that the device can be easily maintained for sanitation needs. This action could be completed in numerous methods. The first could consist of a removable tray placed on the base of the interior of the device to increase the ease in removing treats that are miss launched or jam. Another method could be to create a brush that can be used in tough to reach places within the device or jams created by the crumbling of the treats. The last is to ensure all surfaces can be easily cleaned with an all-purpose cleaner used in most households.

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Appendix A: Detailed Preliminary Decision Matrix Ratings

LAUNCHERS

Design 1: Catapult

- Costs (6)
  - Powerful Motor, or another mechanism to wind the arm of catapult back each time
- Safety (7)
  - Enclosing the device reduces safety concerns
- Reliability (7)
  - When tested using treats able to be launched every time
- Manufacturability (6)
  - A limited number of parts, rotating arm, base, and tension band
- Accuracy (7)
  - When tested the launch span of the treats distance were consistent
- Noise (7)
  - Moderate noise produced by the use of a motor to wind the device and sound of a band
- Durability (5)
  - Tensions in the band might decrease over time
- Compatibility (5)
  - Rating based on average compatibility with the five dispensers

Design 2: Slingshot

- Costs (4)
  - Motor, belt, and tabs typically expensive
- Safety (8)
  - Fully encasing the device is possible, only the end needs to be open to release treats
- Reliability (6)
  - Mechanism to wind and release slingshot will hit every time
- Manufacturability (7.5)
  - Many parts already available in mass production
- Accuracy (7)

    - Highly accurate mechanism to wind and release slingshot
- Noise (7)
    - Impact zone lined with sound-absorbing material, use of motor
- Durability (5)
    - Impact zone at stopper might get run down, the motor could wear out
- Compatibility (5.8)
    - Rating based on average compatibility with the five dispensers

<u>Design 3: Spinner</u>

- Costs (5)
    - A high capacity motor that can vary in speed, expensive
- Reliability (5)
    - Variance in location or release and motor speed creates barriers
- Manufacturability (7)
    - Limited and non-complicated parts: axial moving arm, stand, encasement
- Accuracy (3)
    - Change speed of motor, hard
- Noise (4)
    - A large amount of noise produced by the use of a time-varying and powerful motor
- Durability (7)
    - Low impact, creates high durability
- Compatibility (5.8)
    - Rating based on average compatibility with the five dispensers

DISPENSERS

Design 1: Vending Machine Style

- Costs (5)
  - Motor, encasement, custom flange shaped insert in helix shape insert because treats are not perfect spheres
- Safety (9)
  - Enclosed dispense, limits harm to users
- Reliability (8)
  - Testing with marbles on prototype properly dispensed one at a time
- Manufacturability (4)
  - The custom helix insert for non-spherical treats could be expensive
- Capacity (5)
  - Limited to the number of the slot between helix
- Noise (5)
  - Moderate noise produced by the use of a motor
- Compatibility(5.667)
  - Rating based on average compatibility with the three launchers

Design 2: Vertical Rotating Wheel with slot

- Costs (5)
  - Motor/servo to rotate wheel one position at a time, unique shaped slotted wheel
- Safety (8)
  - Enclosed in a container at low moving speed, limited risk
- Reliability (7)
  - One treat can fit into the slot at a time, but slightly reliant on gravity
- Manufacturability (6)
  - A limited number of parts, low complexity in parts
- Capacity (7)
  - Large slanted feeding container on top allows for high capacity
- Noise (5)
  - Moderate noise produced by the use of a motor/servo
- Compatibility(6)
  - Rating based on average compatibility with the three launchers

Design 3: Spring Fed

- Costs (8)
  - No motor required, typical spring inexpensive
- Safety (7)
  - Encasing the spring mechanism limits the risk of injury to the user
- Reliability (4)
  - Surface applying force the treats might not fit through the entire narrowing path
- Manufacturability (8)
  - Limited parts simple path, spring, and extended surface on one end.
- Capacity (5)
  - Narrowing path limits the capacity, only one single layer of treats can be held at once
- Noise (8)
  - Minimal noise produced by spring
- Compatibility(4.33)
  - Rating based on average compatibility with the three launchers

Design 4: Trap Door Release

- Costs (4)
  - Use of Arduinos to trigger the motion of each door
- Safety (8)
  - Limited momentum and motion in the design
- Reliability (9)
  - A two-door system ensures that only one treat is dispensed at once
- Manufacturability (7)
  - A path with two slots on the bottom, with two small doors that can pass through each
- Capacity (5)
  - The path can only hold one row
- Noise (6)

    - Moderate noise produced by the use of an Arduino
- Compatibility(7)
    - Rating based on average compatibility with the three launchers, highly compatible

<u>Design 5: Conveyor Belt with Tabs</u>

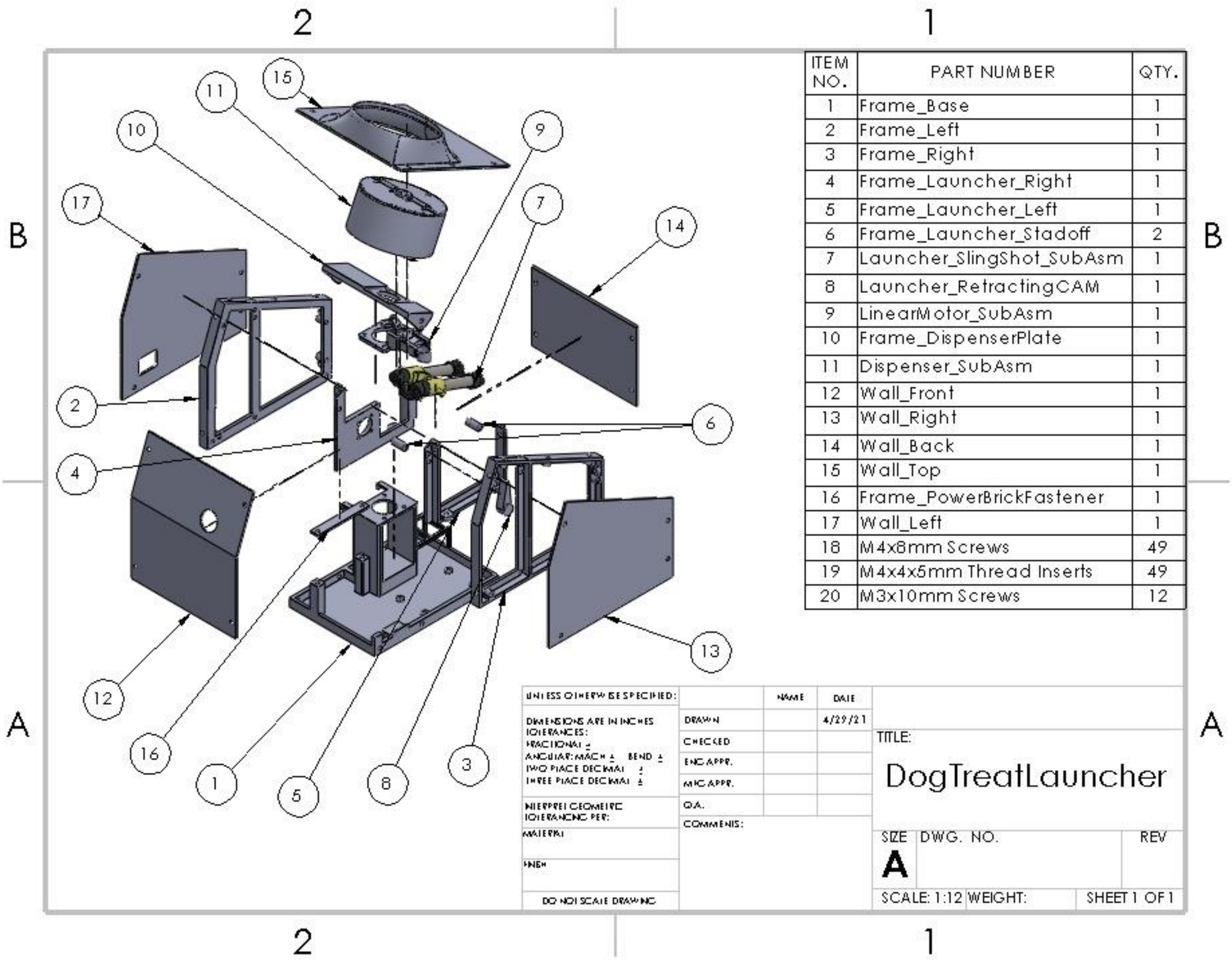
- Costs (3)
    - Belt, motor, and tabs expensive
- Safety (6)
    - The rotating device, hard to fully encase, creates a potential danger to the user
- Reliability (6)
    - Relies on the user placing each treat into a slow, tedious and heavily reliant on the user knowing what to do, potential error
- Manufacturability (3.3)
    - Various moving and flexible parts
- Capacity (5)
    - Limited by number of slots on the belt
- Noise (4)
    - The noise produced by the use of a motor
- Compatibility(4.667)
    - Rating based on average compatibility with the three launchers, low compatibility due to space

Appendix B: Prices for Slingshot Variation

Rail and Cart	Guided Tracks	$12.29	~$20.28
	Wheels on tracks	$2.99	
	Cart	<$5	
Ball Bearings	Bearing	$21.99	~$49.00
	2 Rods	$21.99	
	Cart	<$5	
Inner Slide	PVC Pipe	$5.84/ft	~$34.00
	Inner Slide Bearing	$21.99	

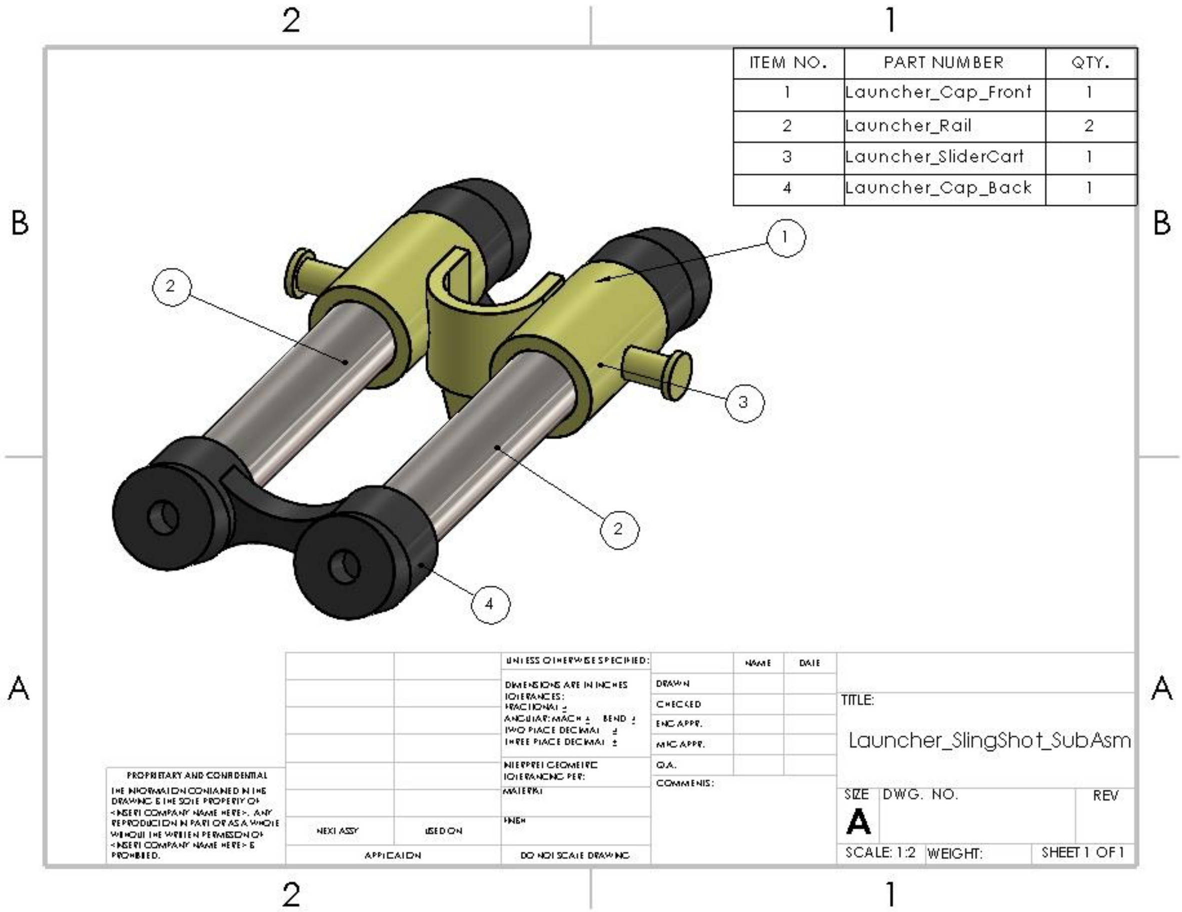
Appendix C: Technical Drawings

C1: Full Assembly

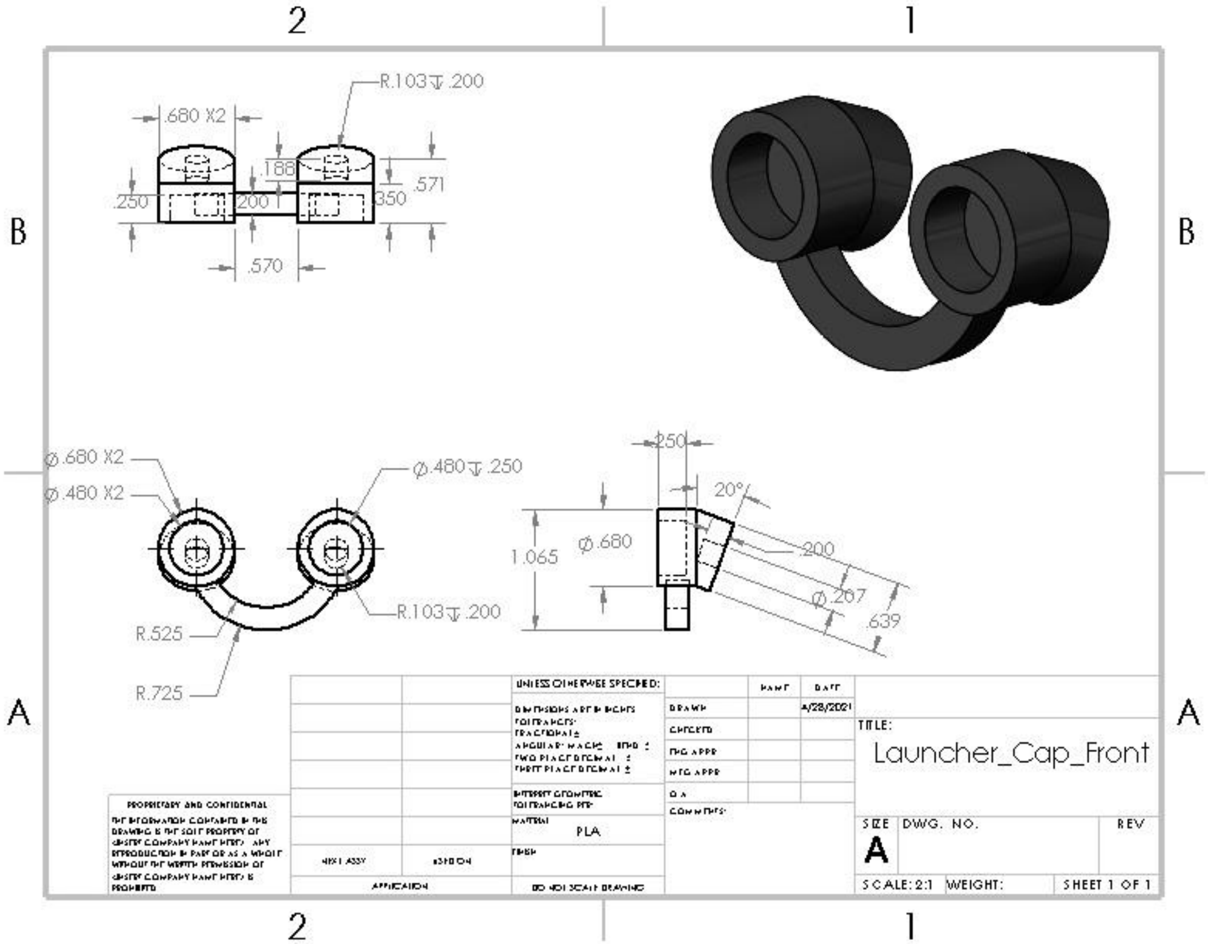


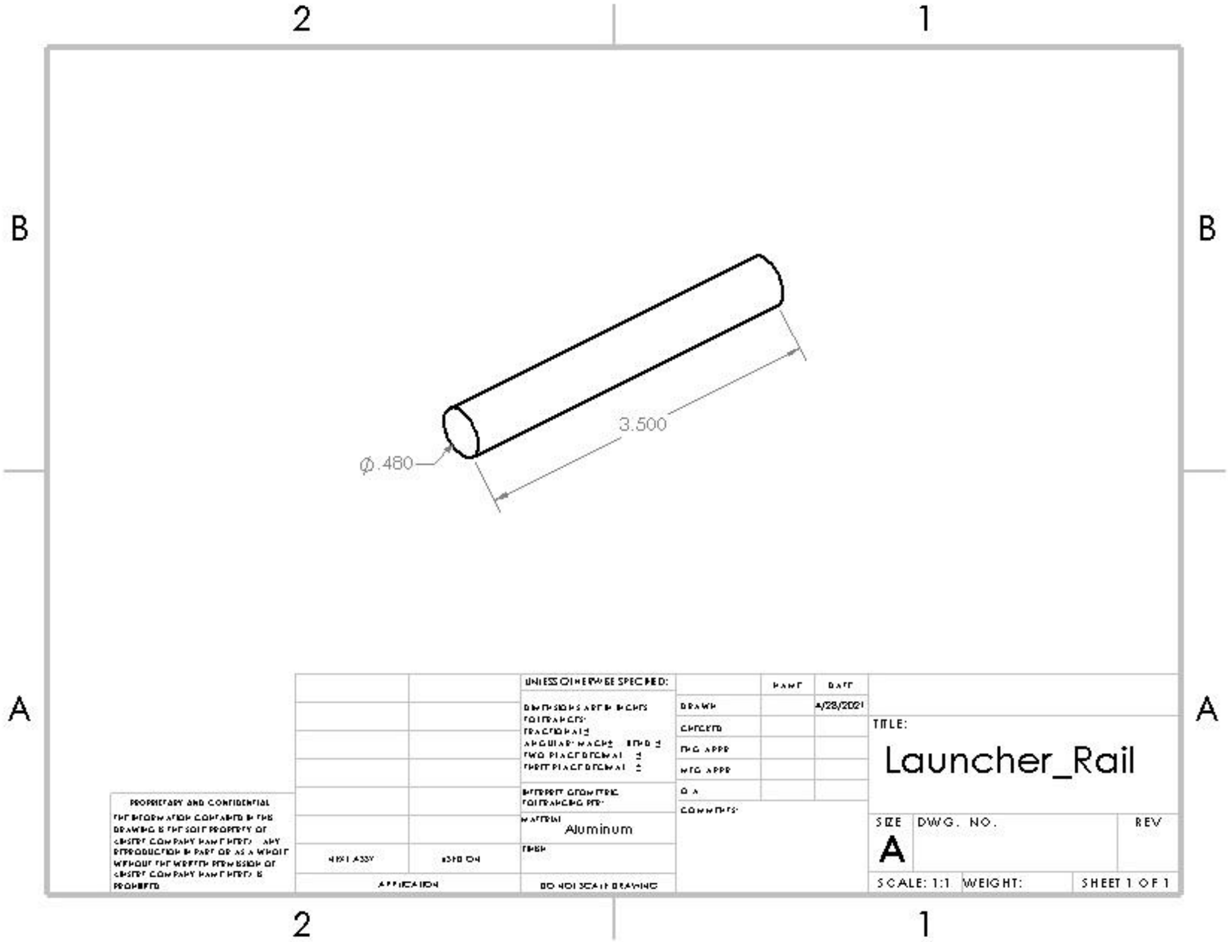
ITEM NO.	PART NUMBER	QTY.
1	Frame_Base	1
2	Frame_Left	1
3	Frame_Right	1
4	Frame_Launcher_Right	1
5	Frame_Launcher_Left	1
6	Frame_Launcher_Stadoff	2
7	Launcher_SlingShot_SubAsm	1
8	Launcher_RetractingCAM	1
9	LinearMotor_SubAsm	1
10	Frame_DispenserPlate	1
11	Dispenser_SubAsm	1
12	Wall_Front	1
13	Wall_Right	1
14	Wall_Back	1
15	Wall_Top	1
16	Frame_PowerBrickFastener	1
17	Wall_Left	1
18	M4x8mm Screws	49
19	M4x4x5mm Thread Inserts	49
20	M3x10mm Screws	12

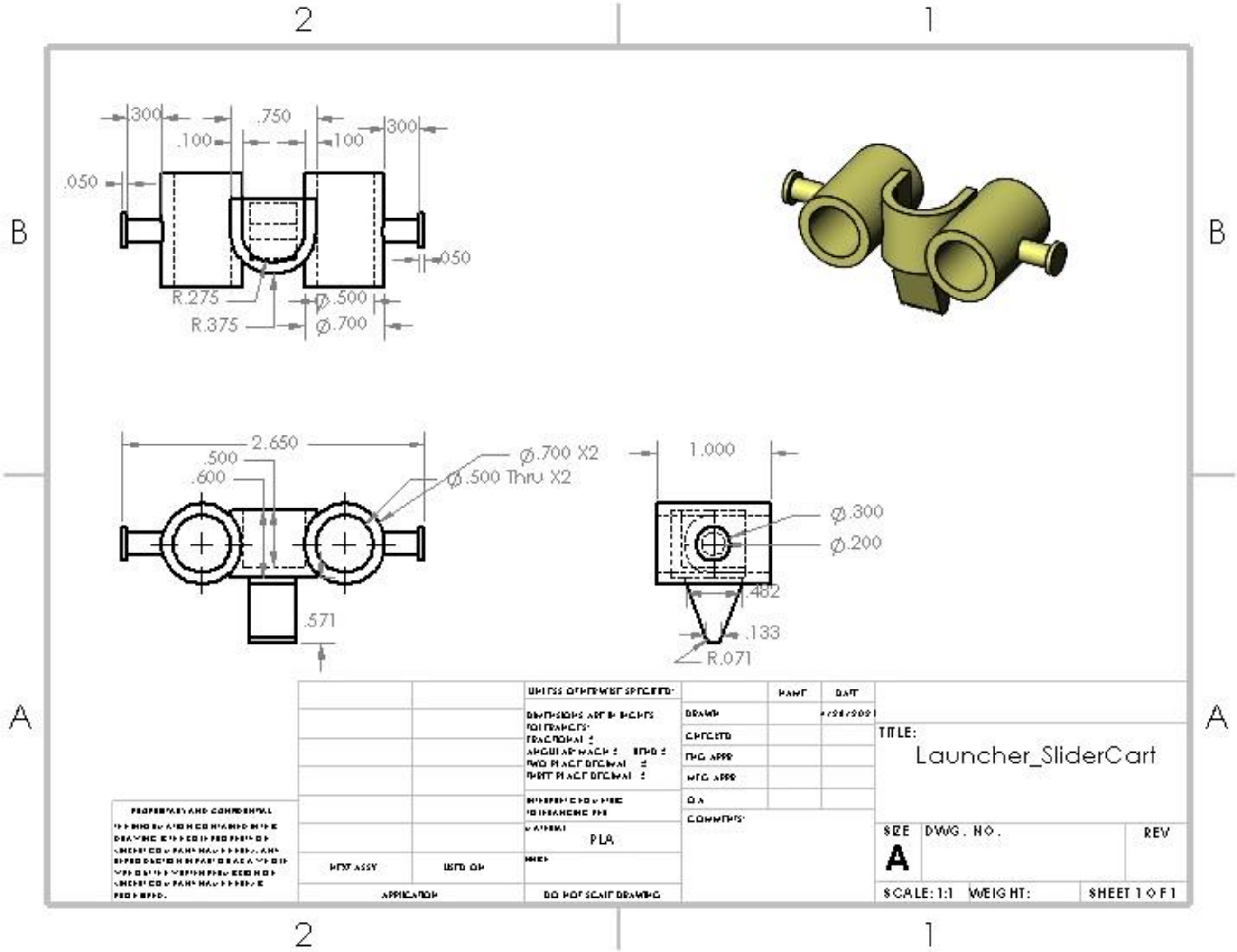
C2: Launcher

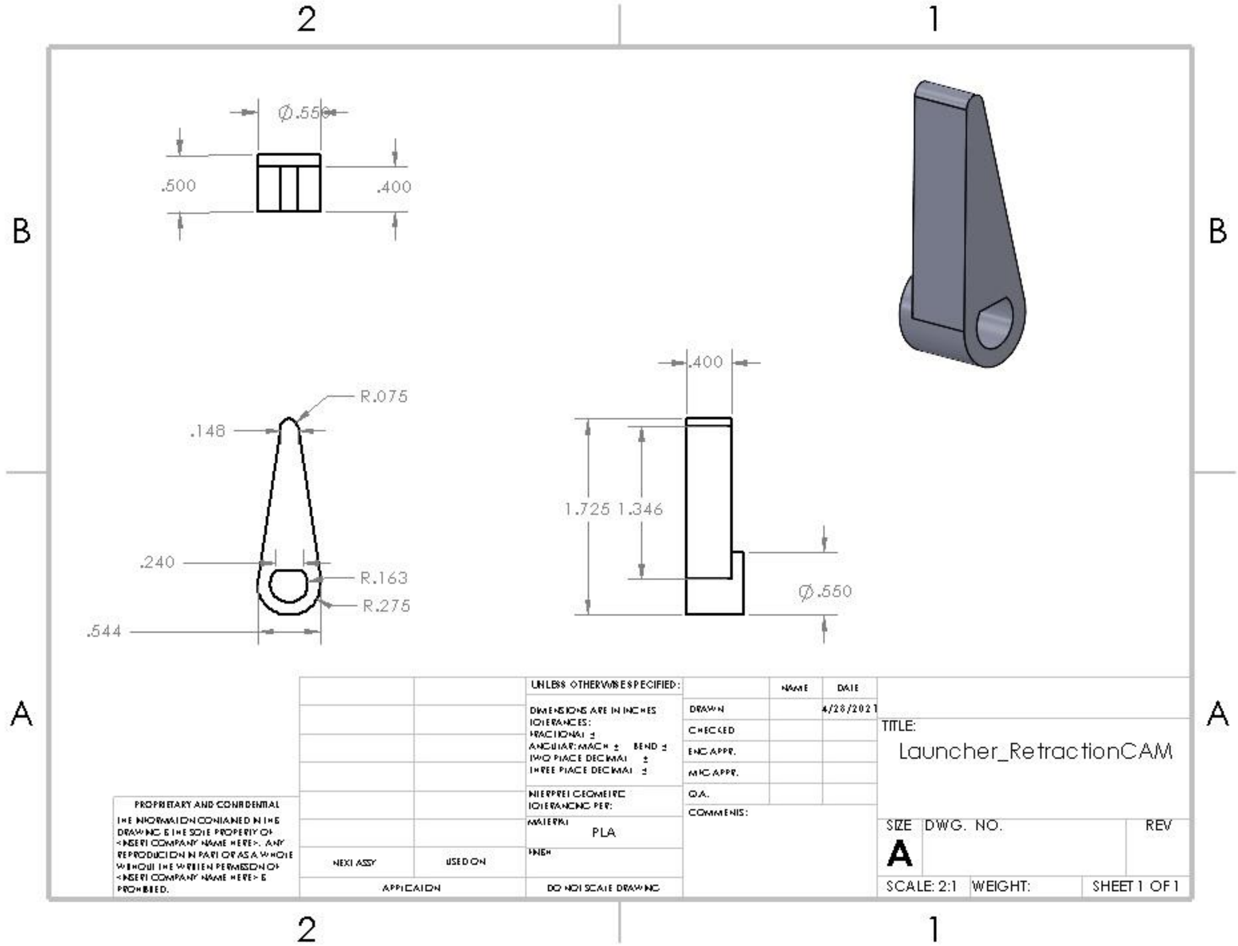


ITEM NO. | PART NUMBER | QTY.
1 | Launcher_Cap_Front | 1
2 | Launcher_Rail | 2
3 | Launcher_SliderCart | 1
4 | Launcher_Cap_Back | 1
1
2
3
4
2
1
B
A
TITLE:
Launcher_SlingShot_SubAsm
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


R.103 ↧ .200
.680 X2
.188
.250
.200
.350
.571
.570
Ø.680 X2
Ø.480 X2
Ø.480 ↧ .250
R.103 ↧ .200
R.525
R.725
.250
20°
1.065
Ø.680
.200
Ø.207
.639
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
4/28/2021
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Launcher_Cap_Front
SIZE
DWG. NO.
REV
A
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

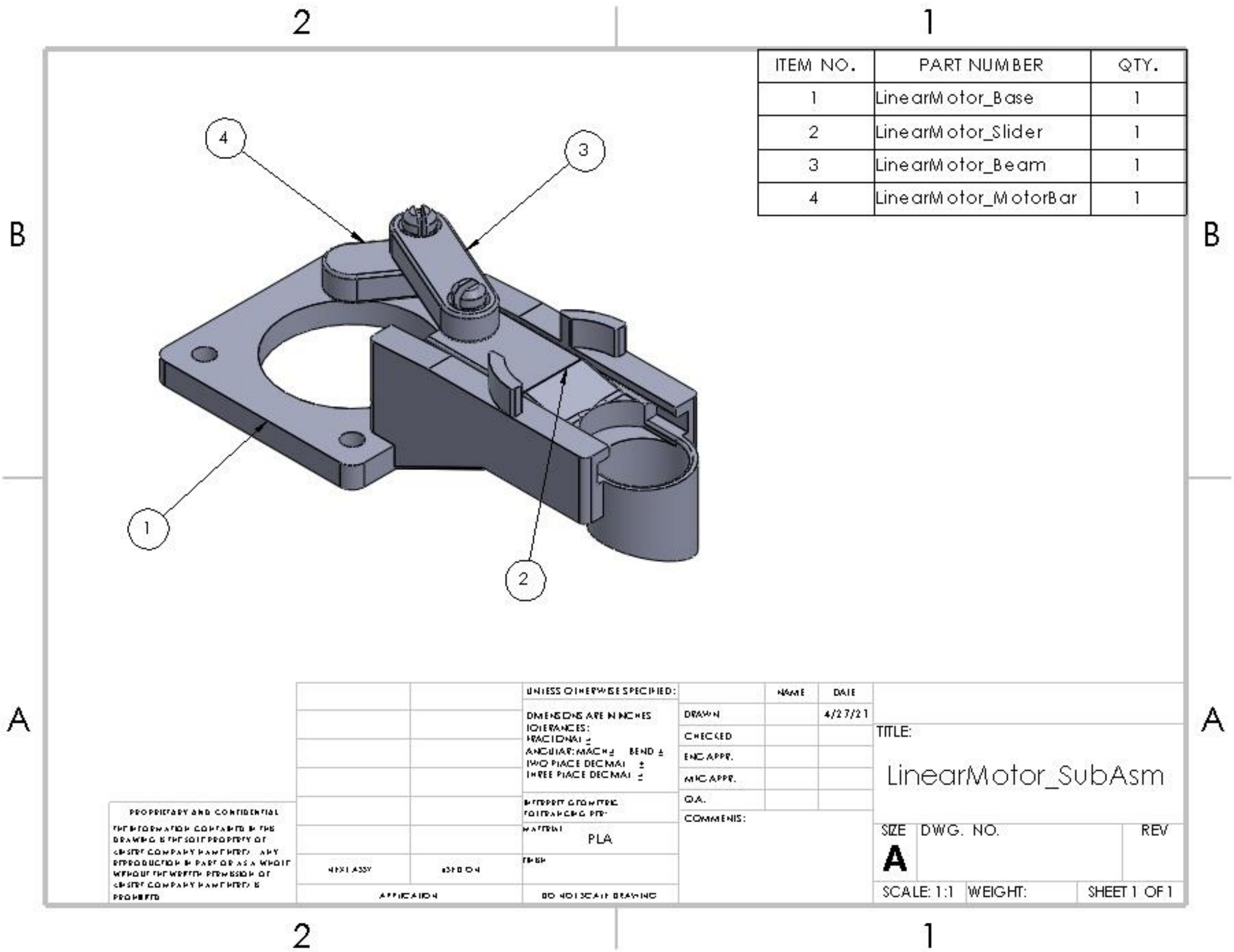

Ø.480
3.500
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DRAWN
4/28/2021
TITLE:
Launcher_Rail
Aluminum
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
APPLICATION
DO NOT SCALE DRAWING

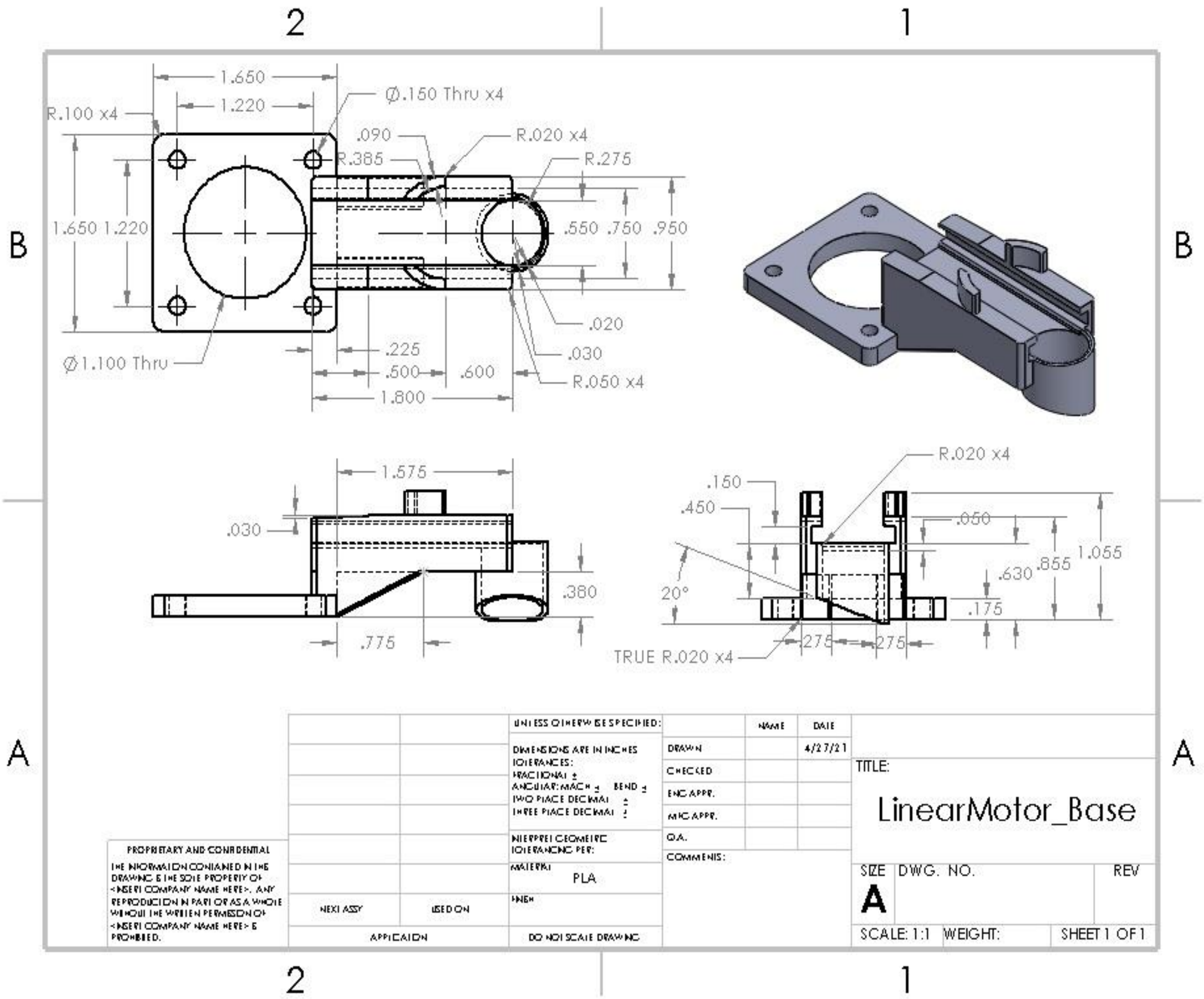

.300
.100
.750
.100
.300
.050
.050
R.275
R.375
Ø.500
Ø.700
2.650
.500
.600
Ø.700 X2
Ø.500 Thru X2
.571
1.000
Ø.300
Ø.200
.462
.133
R.071
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
PLA
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Launcher_SliderCart
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



Ø.550
.500
.400
R.075
.148
.240
R.163
R.275
.544
.400
1.725
1.346
Ø.550
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
4/28/2021
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
TITLE:
Launcher_RetractionCAM
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

C3: Linear Motor




1.650
1.220
Ø.150 Thru x4
R.100 x4
.090
R.020 x4
R.385
R.275
1.650 1.220
.550 .750 .950
.020
.225
.030
Ø1.100 Thru
.500
.600
R.050 x4
1.800
1.575
R.020 x4
.150
.450
.030
.050
1.055
.630 .855
.380
20°
.175
.775
TRUE R.020 x4
.275
.275
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
4/27/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
LinearMotor_Base
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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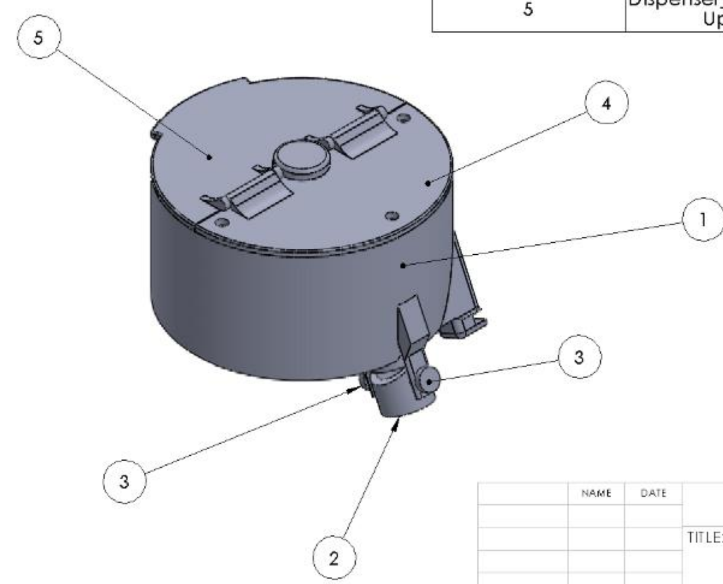
USED ON
APPLICATION

C4: Dispenser

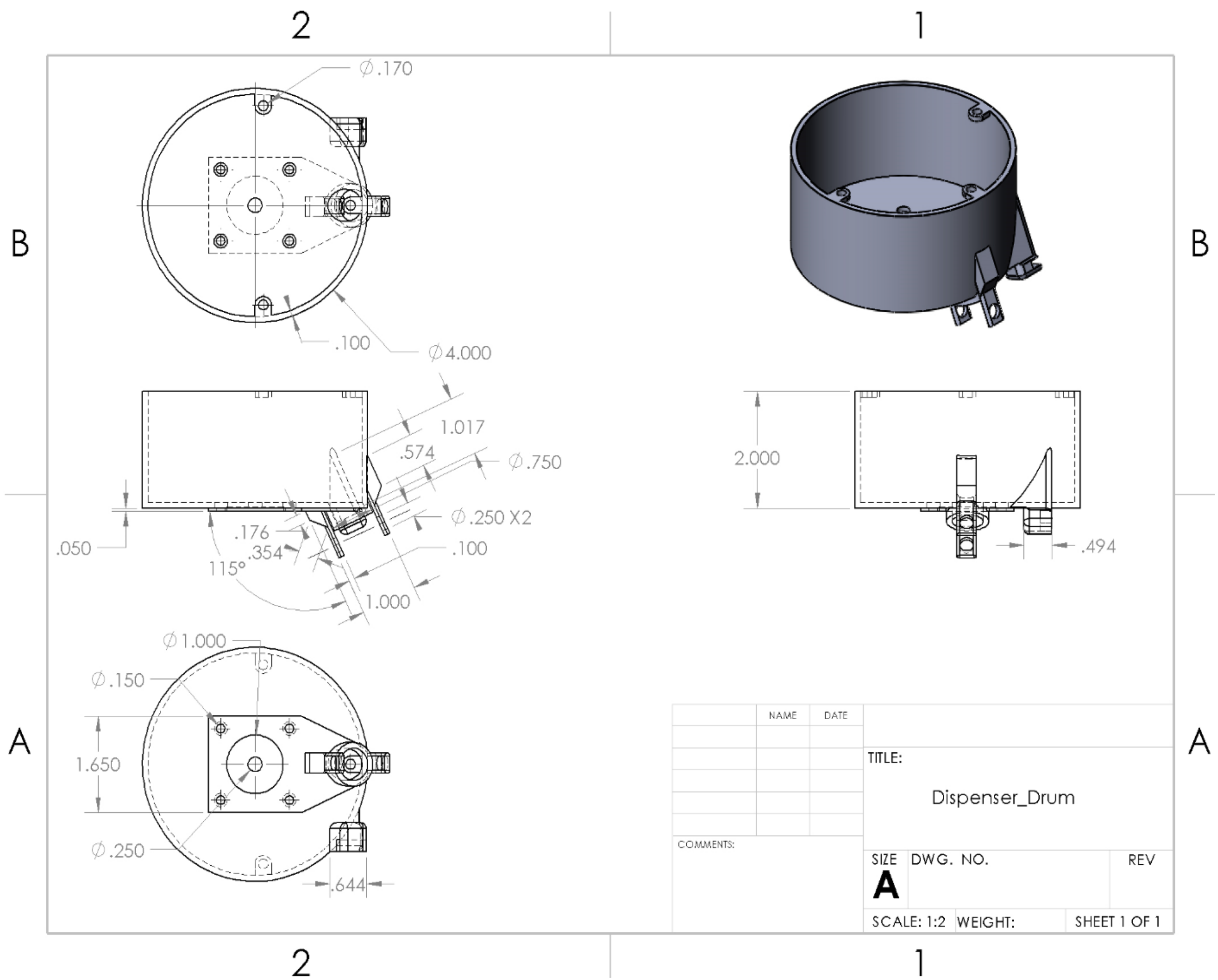
ITEM NO.	PART NUMBER	QTY
1	Dispenser_Drum	1
2	Dispenser_BufferTube	1
3	Dispenser_BufferCap	2
4	Dispenser_DrumCap_Lower	1
5	Dispenser_DrumCap_Upper	1

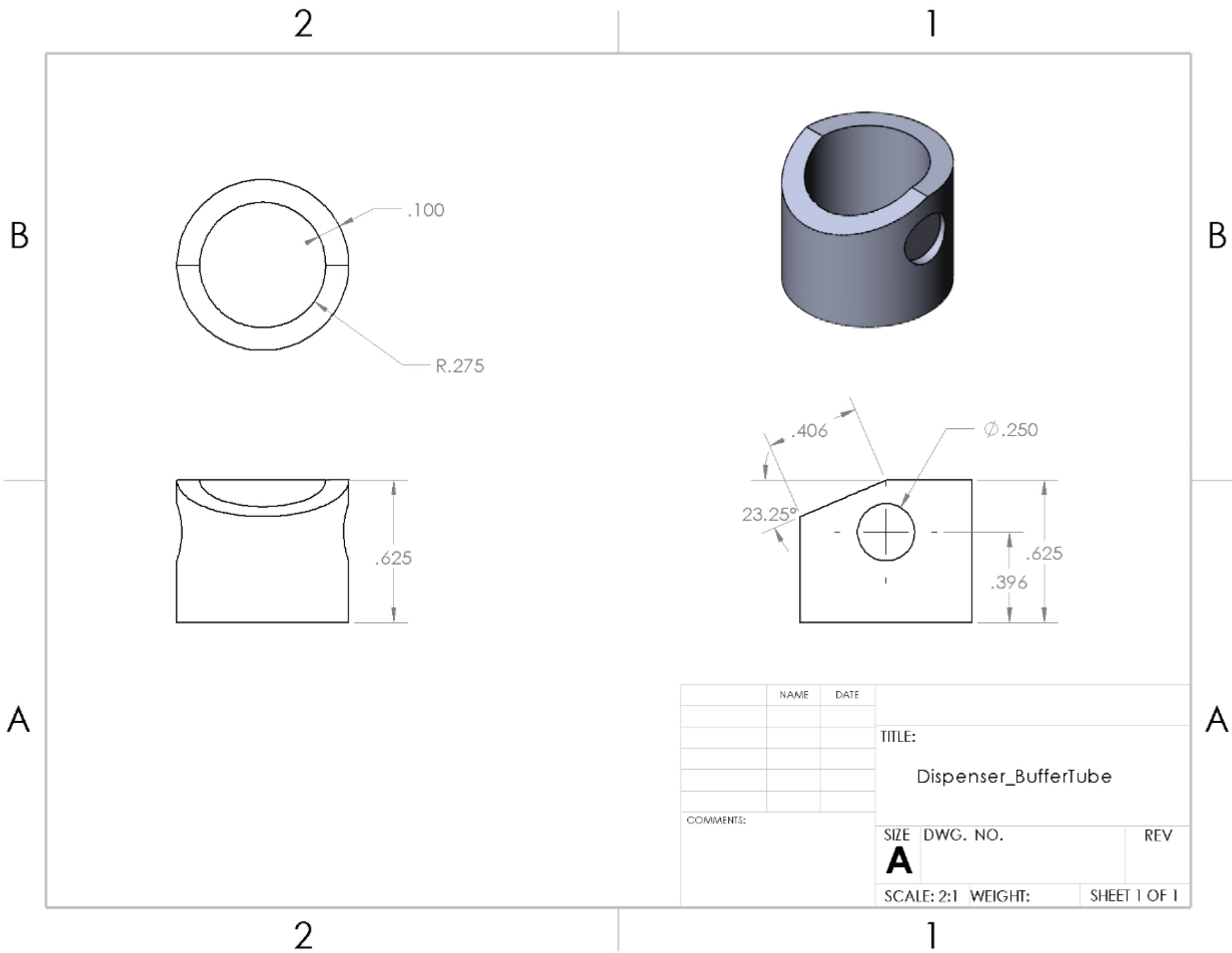


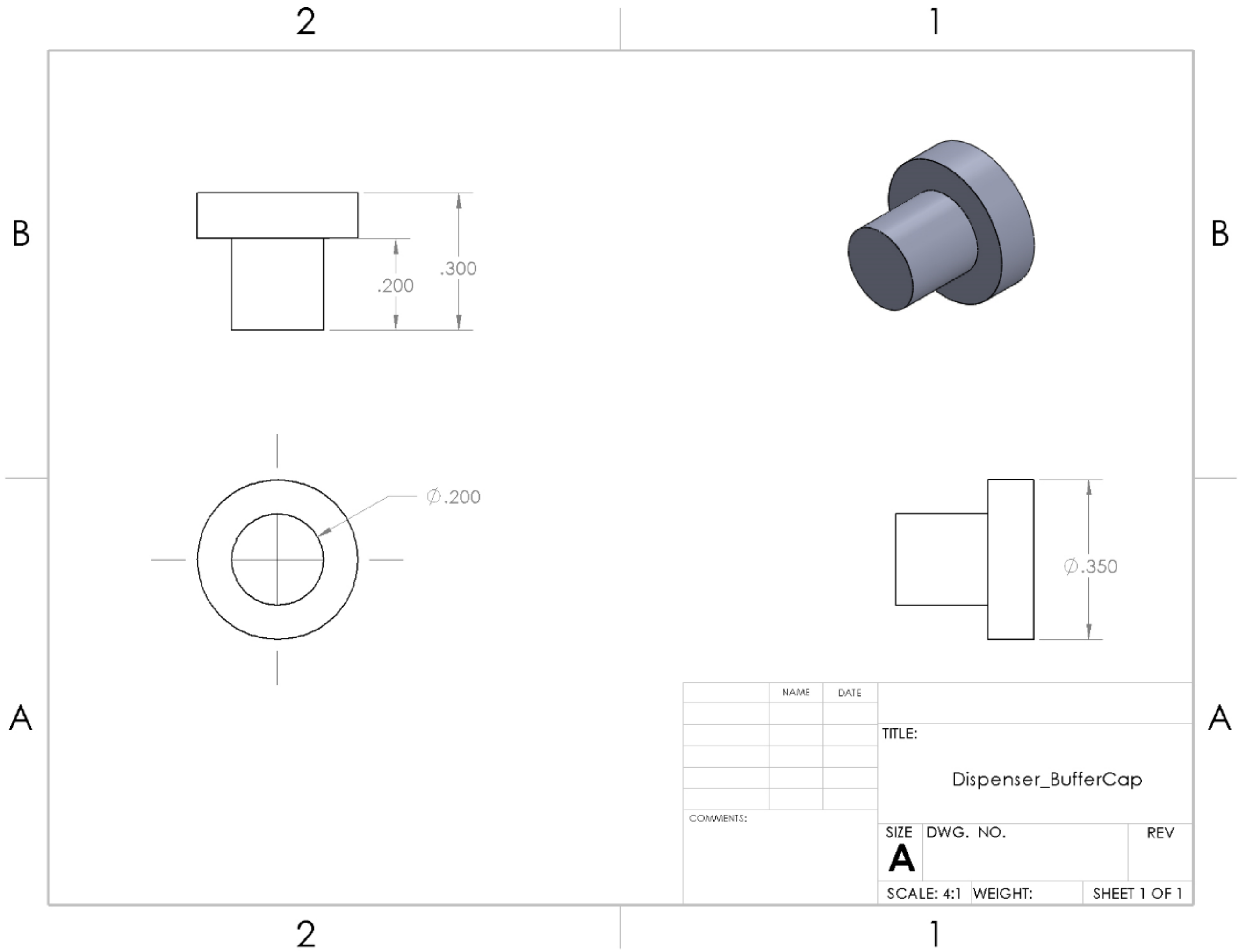
TITLE: Dispenser_SubAsm

SIZE A DWG. NO. REV

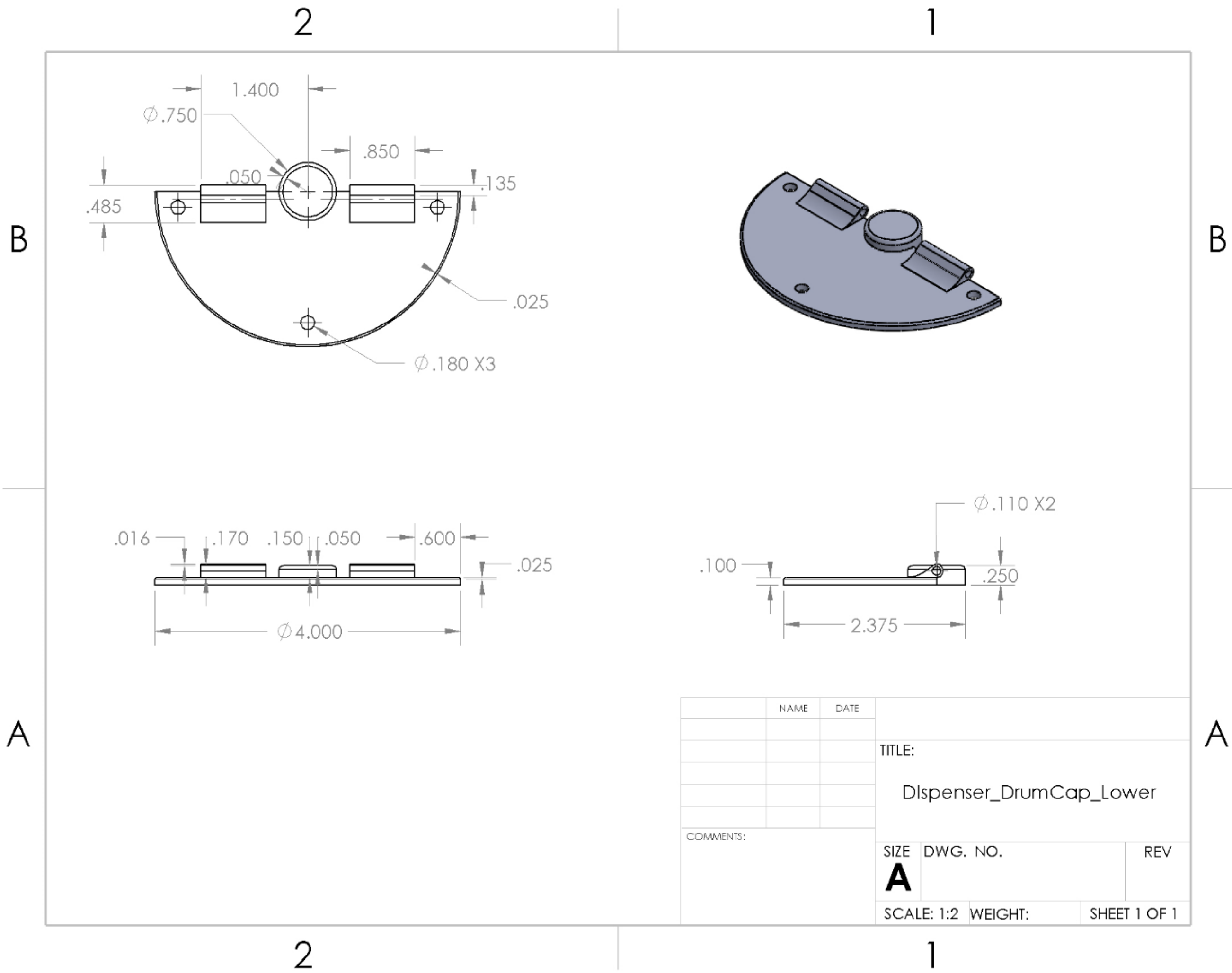
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

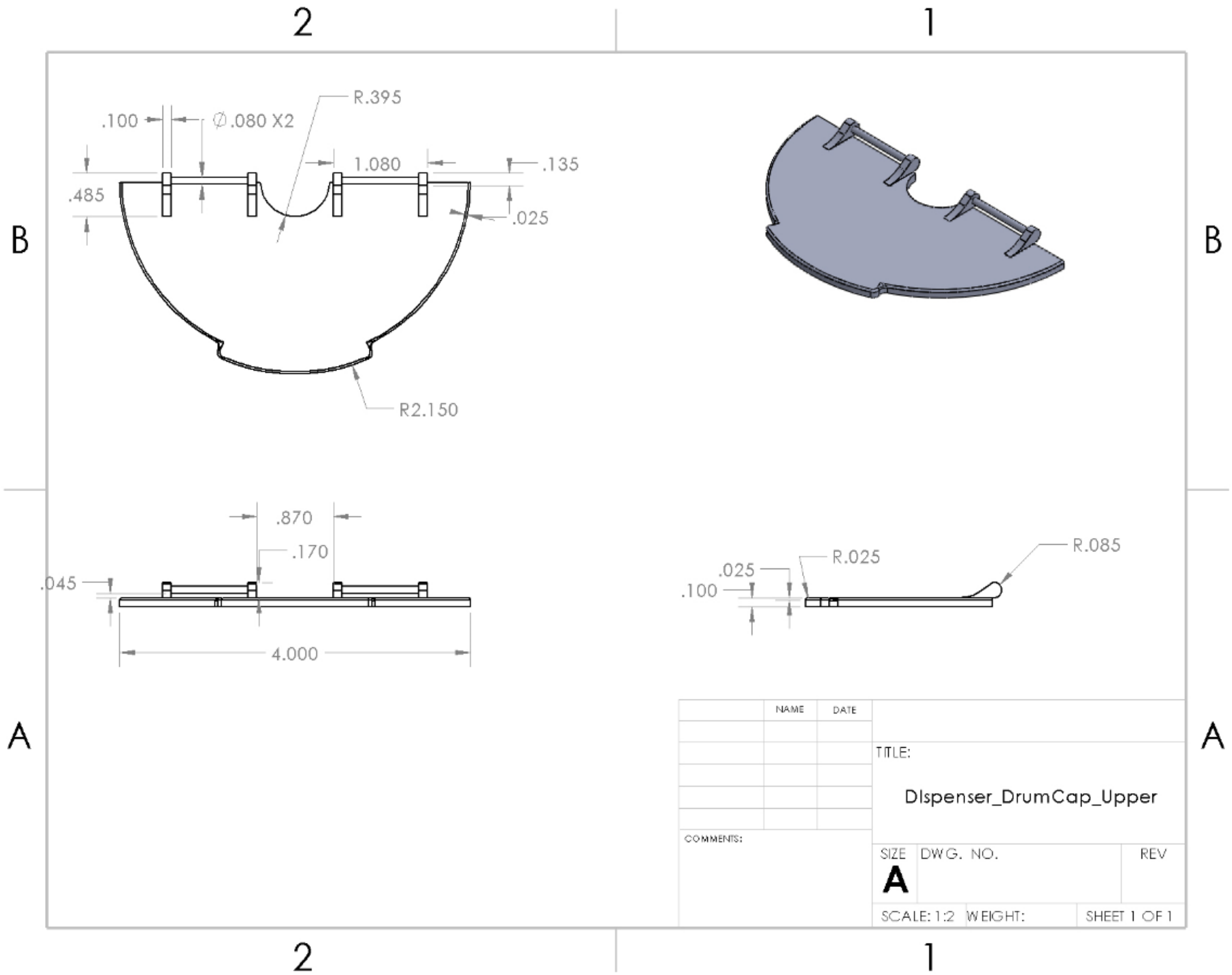

2
1
B
A
Ø.170
.100
Ø4.000
1.017
.574
Ø.750
Ø.250 X2
.100
.050
.176
.354
115°
1.000
2.000
.494
Ø1.000
Ø.150
1.650
Ø.250
.644
NAME
DATE
TITLE:
Dispenser_Drum
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


2
1
B
A
.100
R.275
.625
.406
⌀.250
23.25°
.625
.396
NAME
DATE
TITLE:
Dispenser_BufferTube
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1

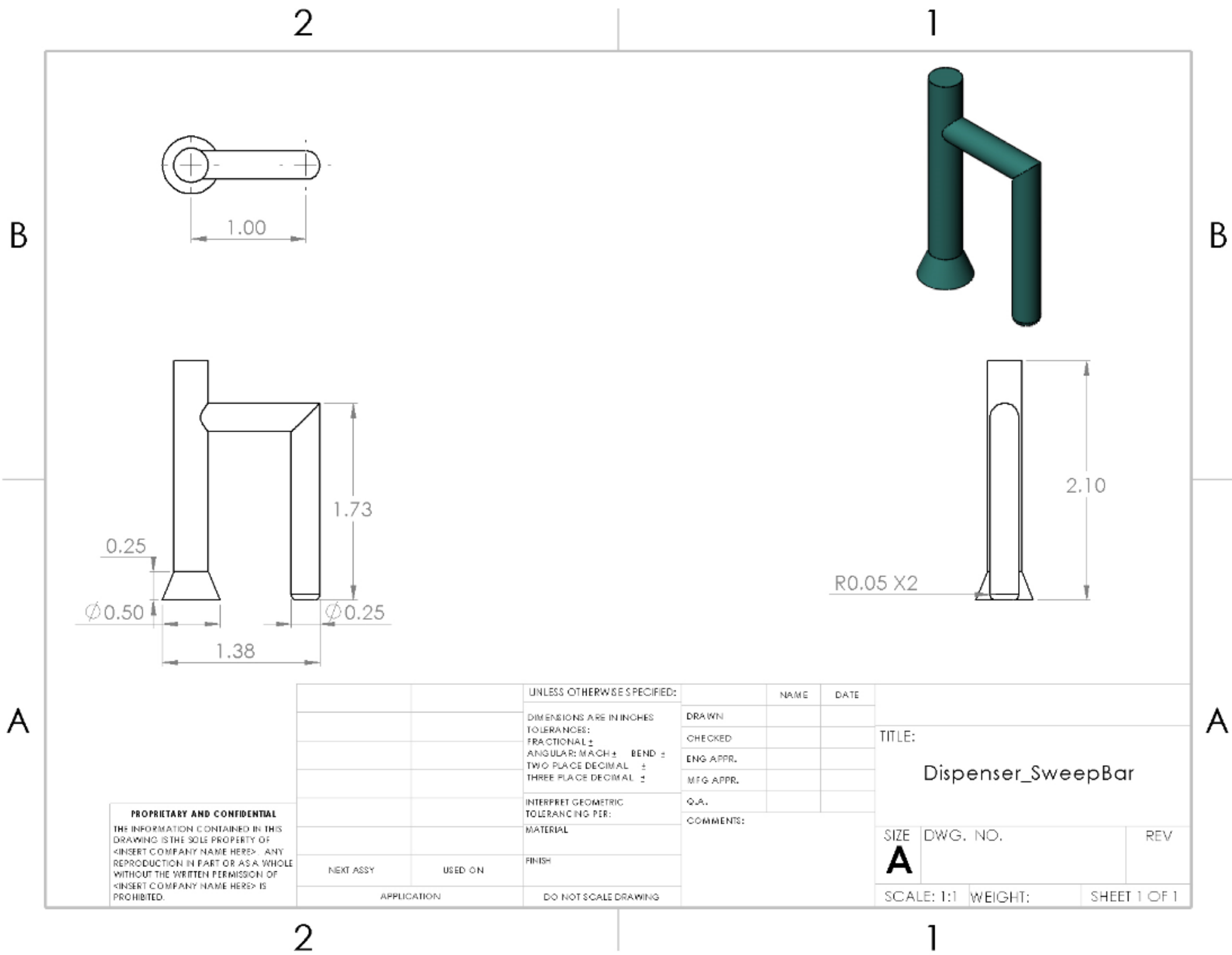


2
1
B
B
A
A
2
1
.300
.200
∅.200
∅.350
NAME
DATE
TITLE:
Dispenser_BufferCap
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1


1.400
∅.750
.850
.050
.135
.485
.025
∅.180 X3
∅.110 X2
.016
.170
.150
.050
.600
.025
∅4.000
.100
.250
2.375
NAME
DATE
TITLE:
DIspenser_DrumCap_Lower
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1



.100
∅.080 X2
R.395
1.080
.135
.485
.025
R2.150
.870
.170
.045
4.000
.025
.100
R.025
R.085
NAME
DATE
TITLE:
DIspenser_DrumCap_Upper
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


2
1
B
A
1.00
1.73
0.25
Ø0.50
Ø0.25
1.38
2.10
R0.05 X2
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Dispenser_SweepBar
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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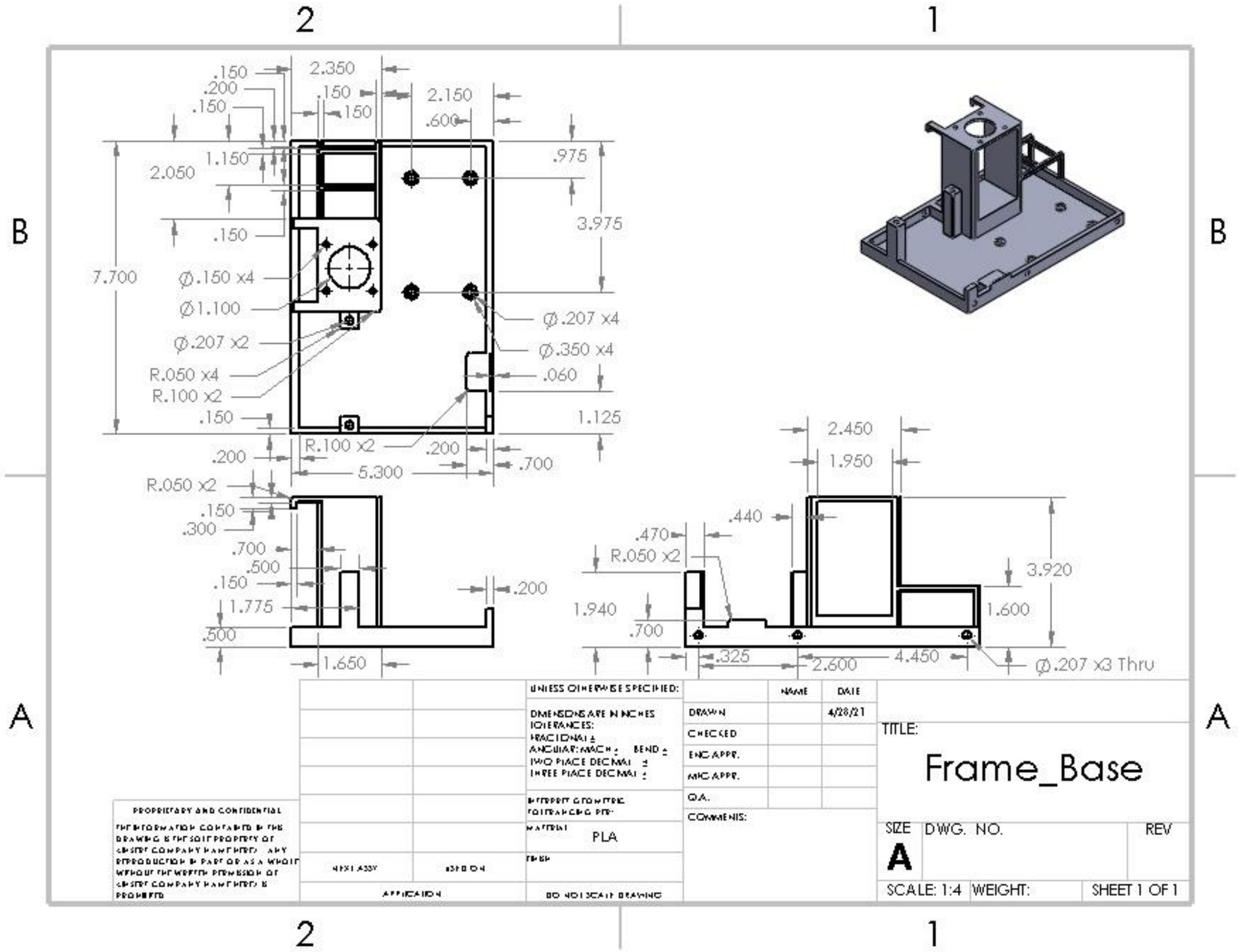
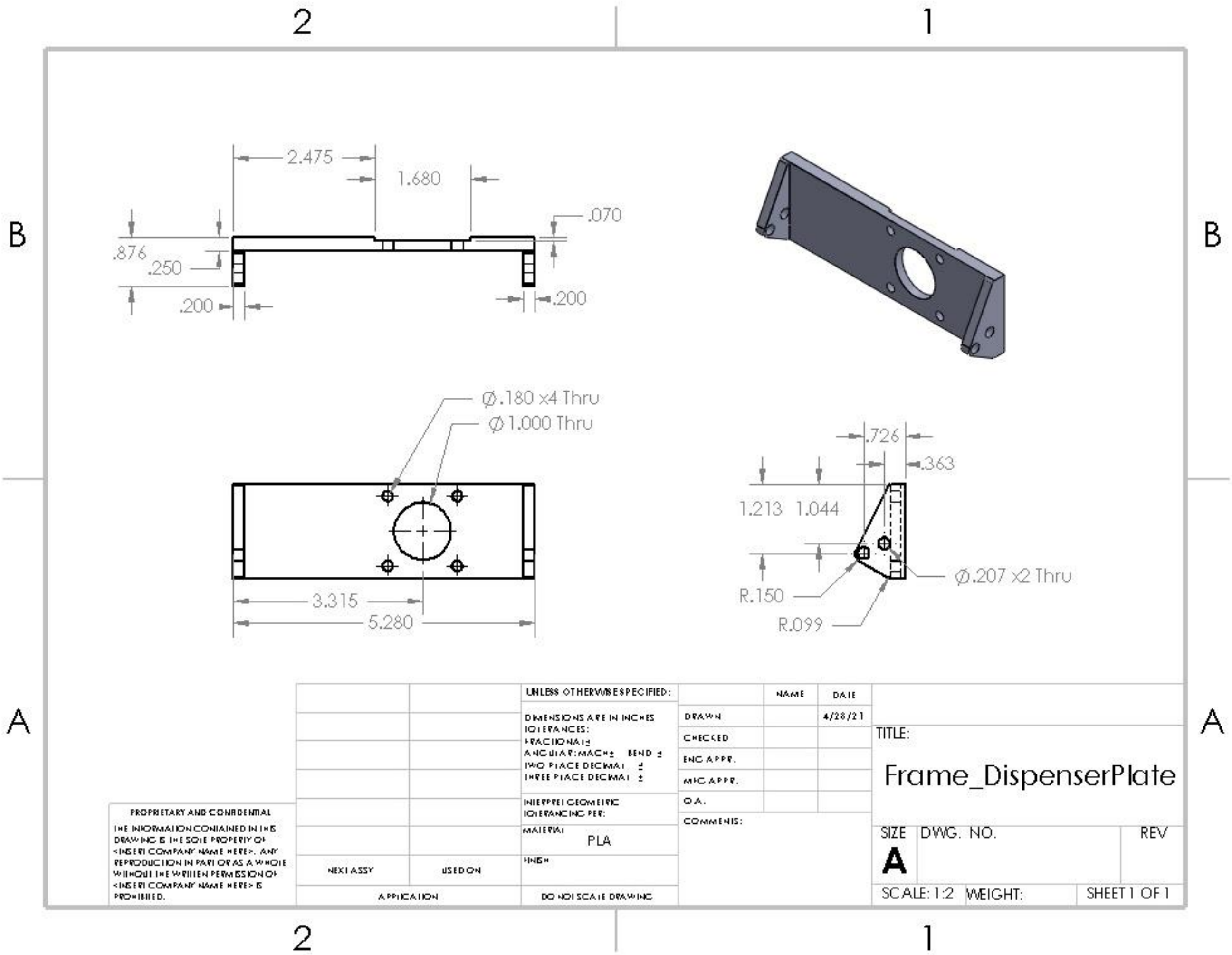
C5: Frame




2.475
1.680
.070
.876
.250
.200
.200
Ø.180 x4 Thru
Ø1.000 Thru
3.315
5.280
.726
.363
1.213
1.044
R.150
R.099
Ø.207 x2 Thru
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
4/28/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Frame_DispenserPlate
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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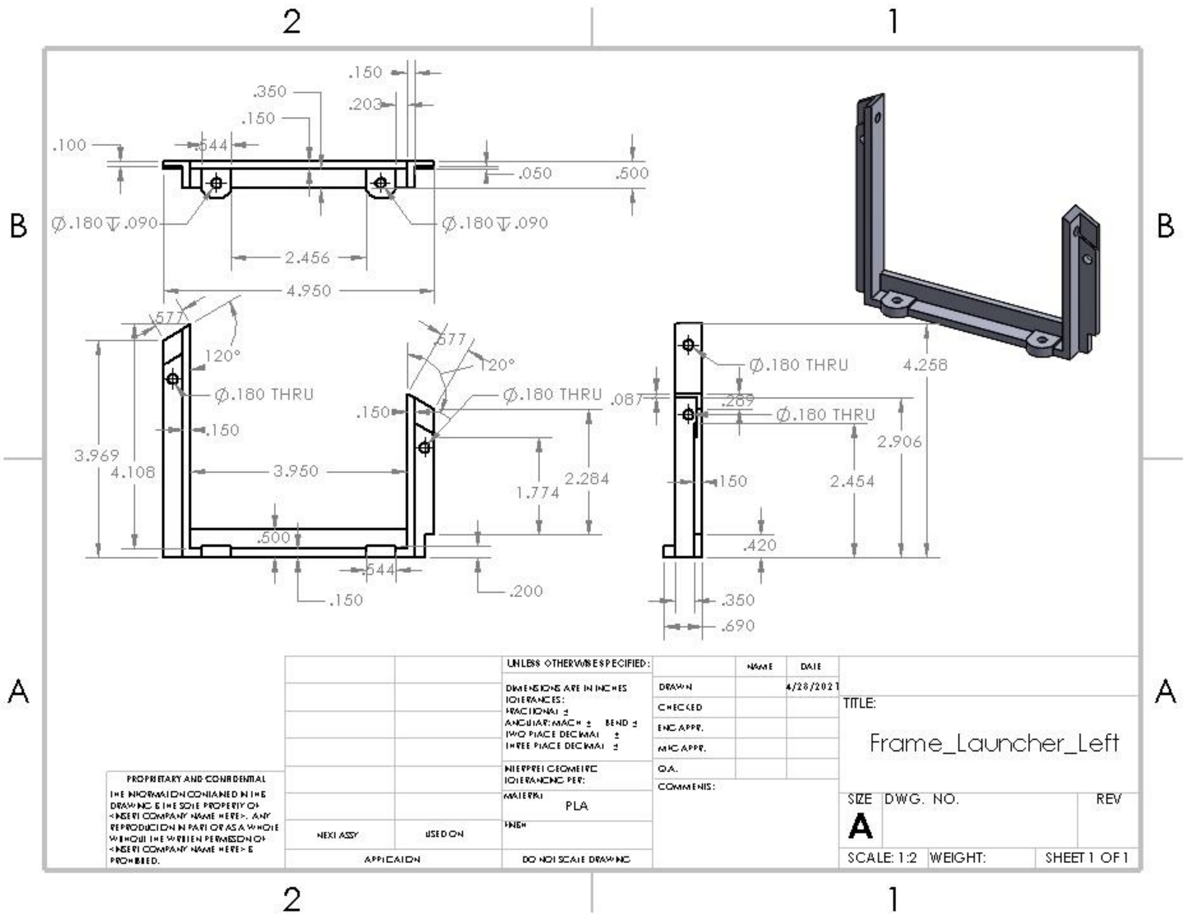
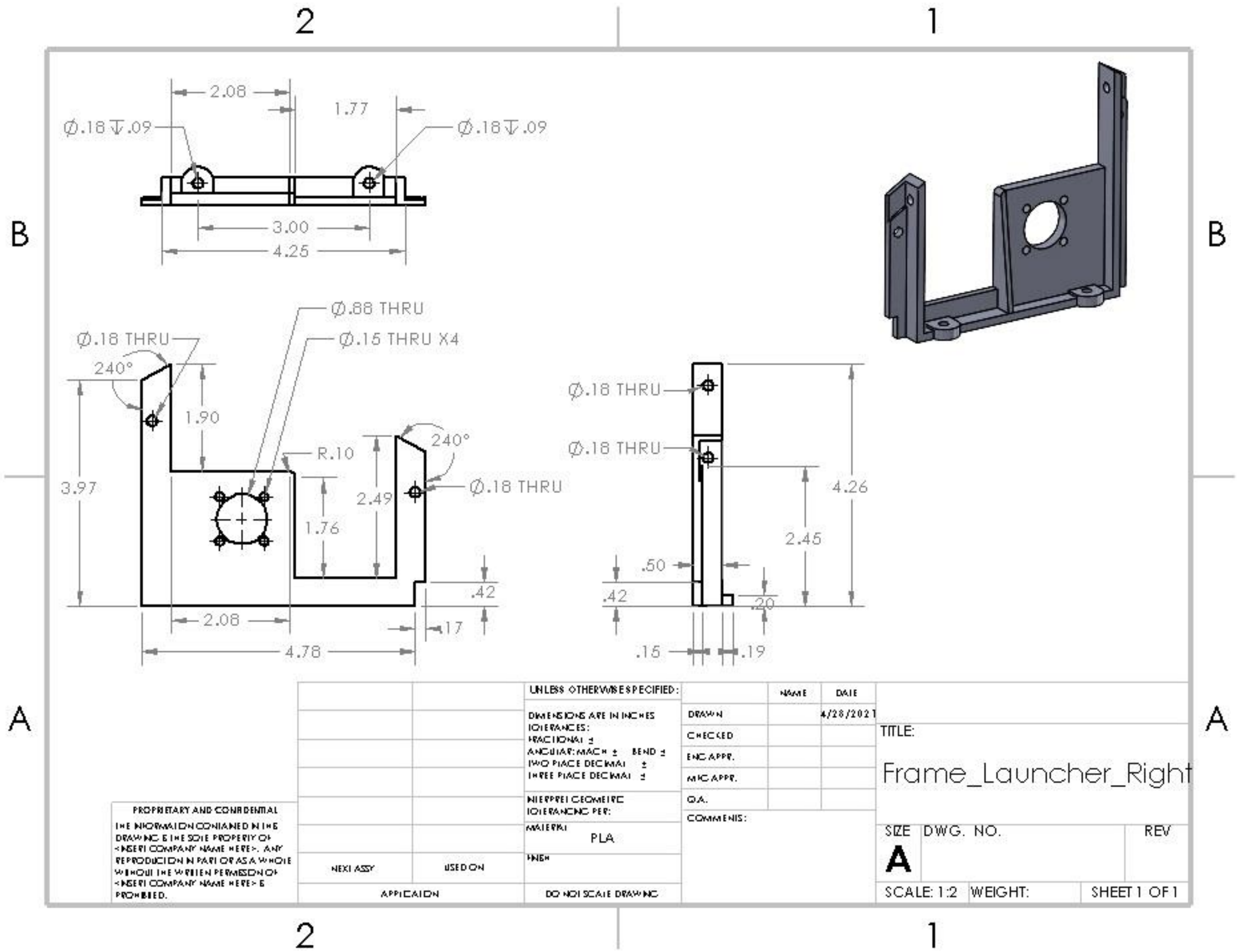


Frame_Launcher_Left
PLA
SCALE: 1:2
SHEET 1 OF 1
SIZE A
DWG. NO.
REV
WEIGHT:
TITLE:
DRAWN
4/28/2021
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
Ø.180 ⊽ .090
Ø.180 THRU
2.456
4.950
3.950
3.969
4.108
4.258
2.906
2.454
2.284
1.774
120°
.577
.544
.500
.350
.690
.420
.200
.150
.100
.050
.203
.087
.289


2.08
1.77
Ø.18 ↧.09
Ø.18 ↧.09
3.00
4.25
Ø.88 THRU
Ø.15 THRU X4
Ø.18 THRU
240°
1.90
3.97
R.10
240°
2.49
Ø.18 THRU
1.76
.42
2.08
.17
4.78
Ø.18 THRU
Ø.18 THRU
4.26
2.45
.50
.42
.20
.15
.19
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
4/28/2021
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Frame_Launcher_Right
SIZE
DWG. NO.
REV
A
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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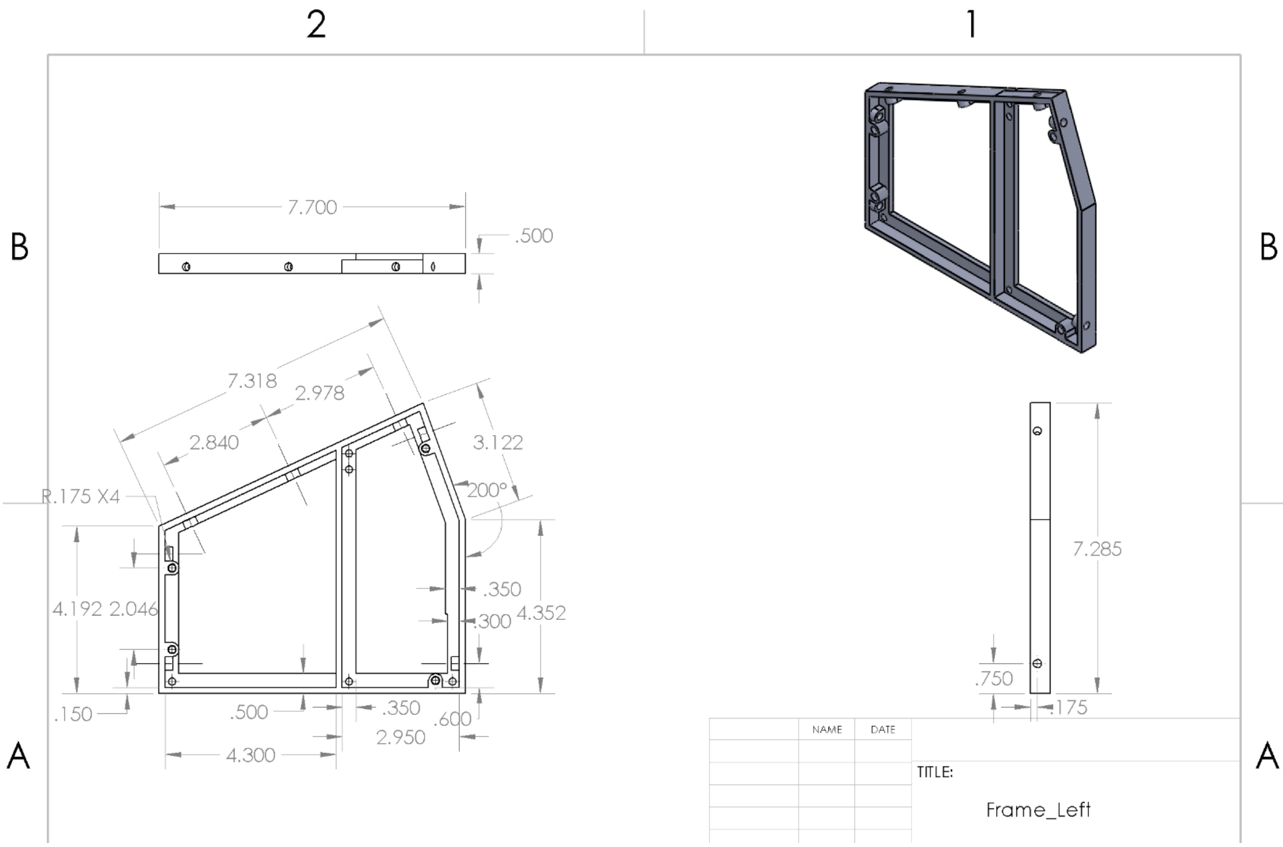
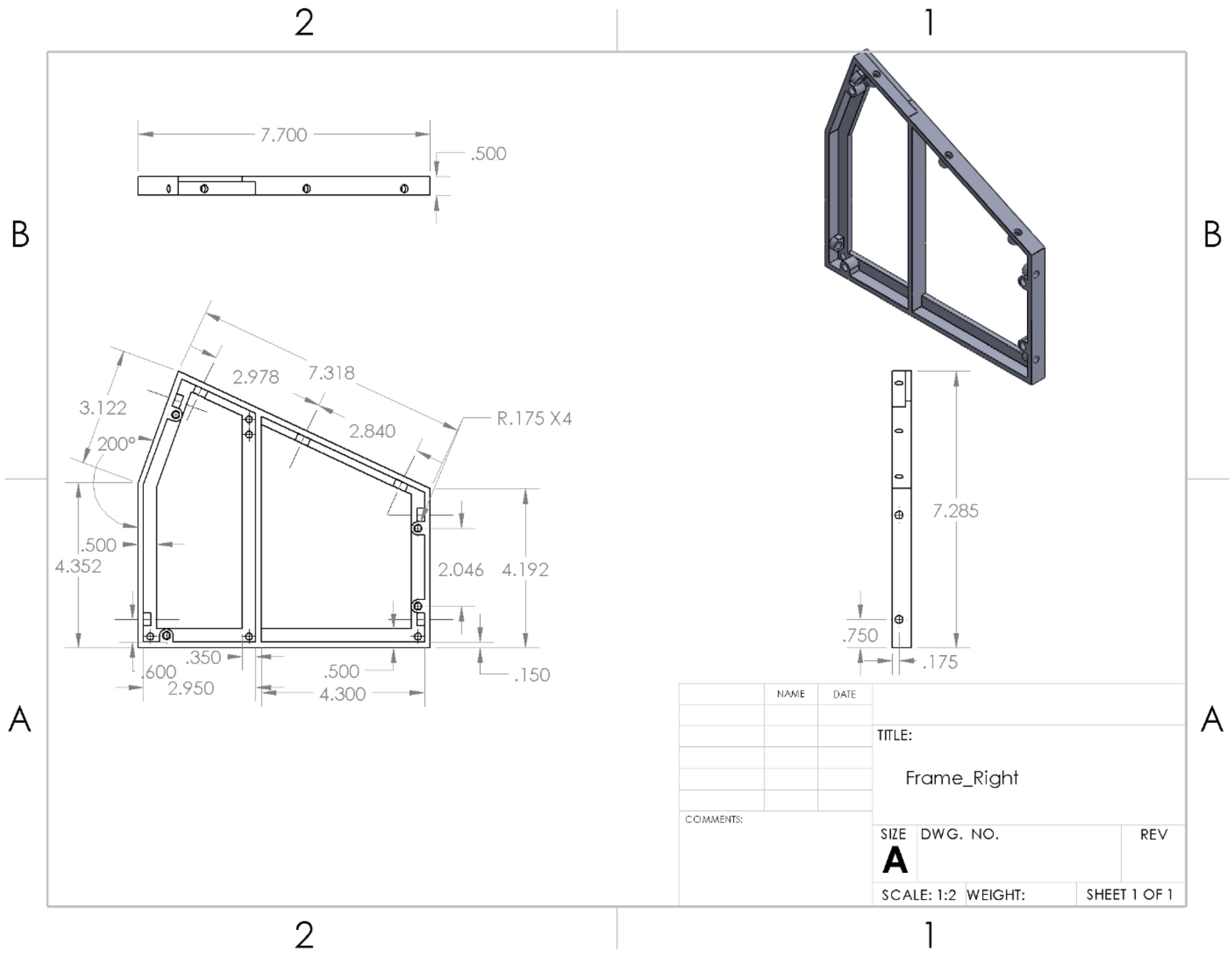
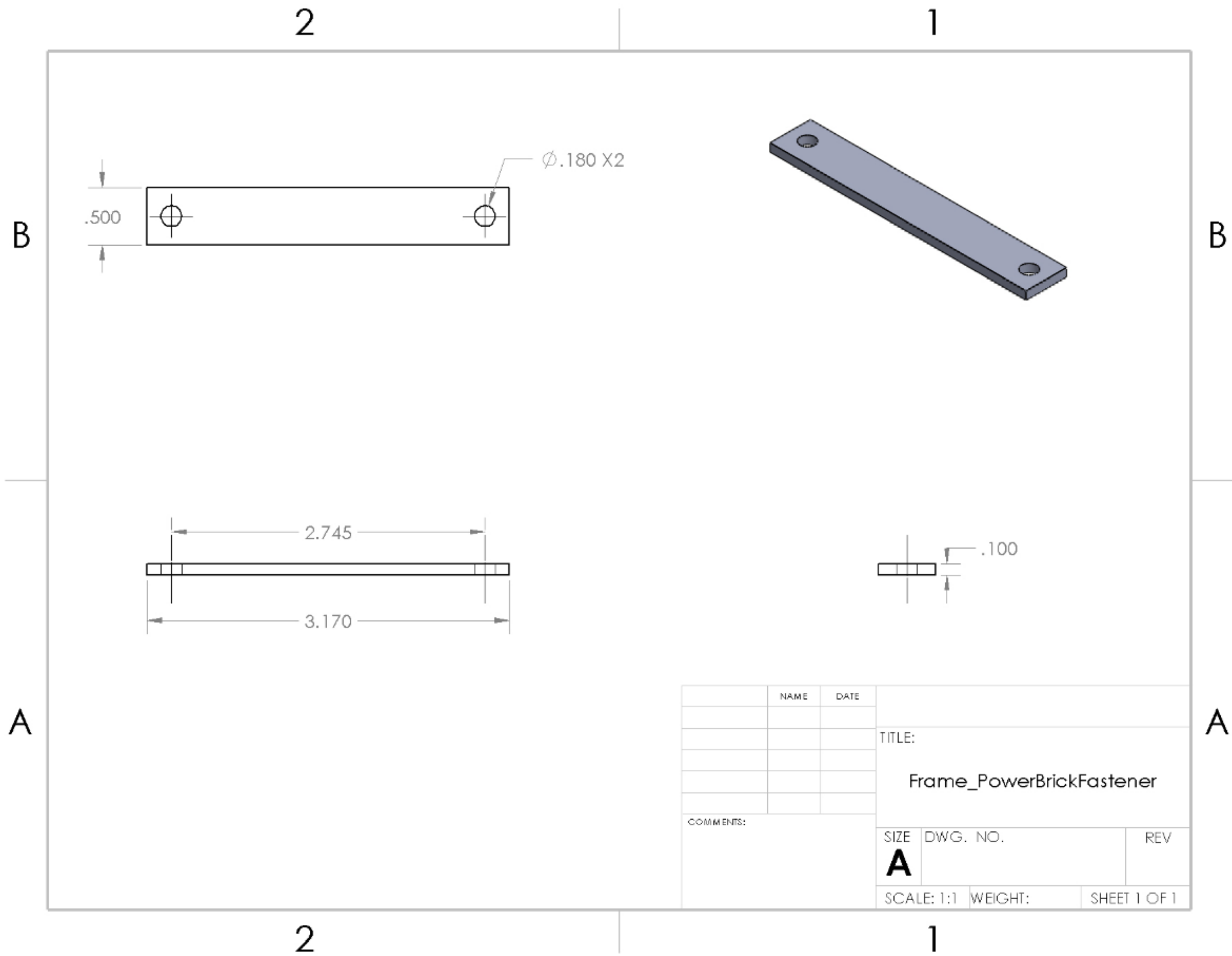


2
1
B
B
A
A
7.700
.500
7.318
2.978
2.840
3.122
R.175 X4
200°
4.192
2.046
.350
.300
4.352
.150
.500
.350
.600
2.950
4.300
7.285
.750
.175
NAME
DATE
TITLE:
Frame_Left

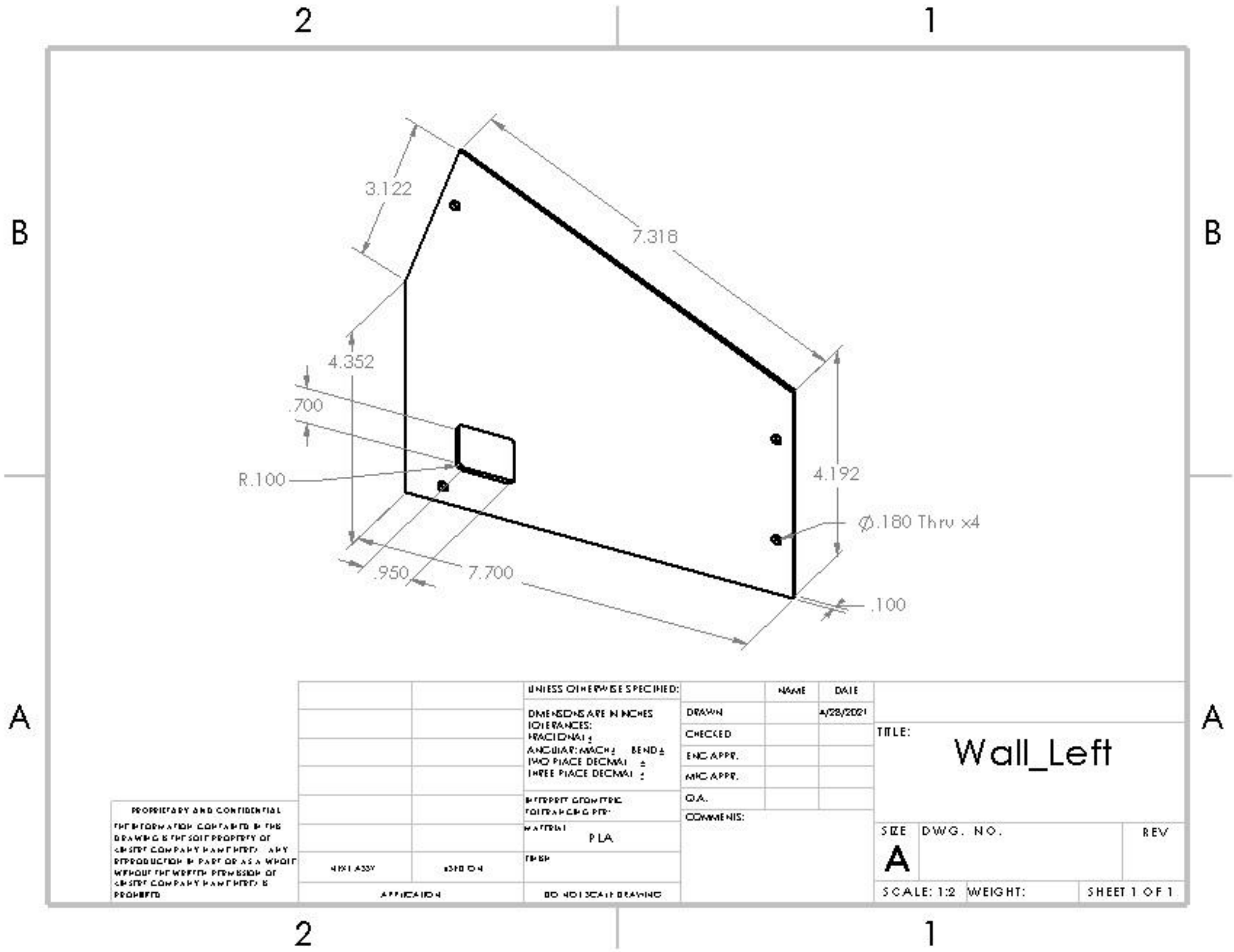


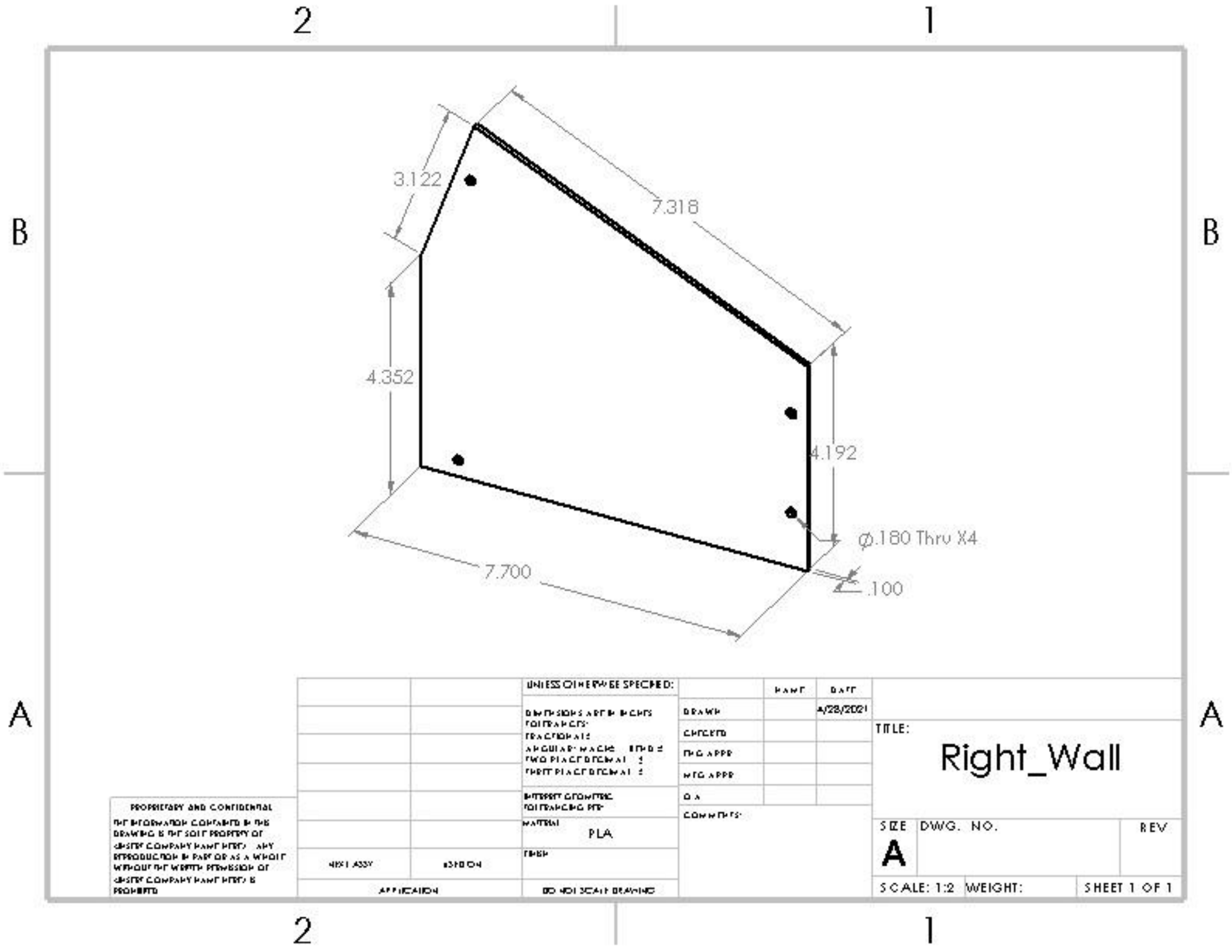
2
1
B
A
7.700
.500
3.122
2.978
7.318
2.840
R.175 X4
200°
.500
4.352
2.046
4.192
.600
.350
2.950
.500
4.300
.150
7.285
.750
.175
NAME
DATE
TITLE:
Frame_Right
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

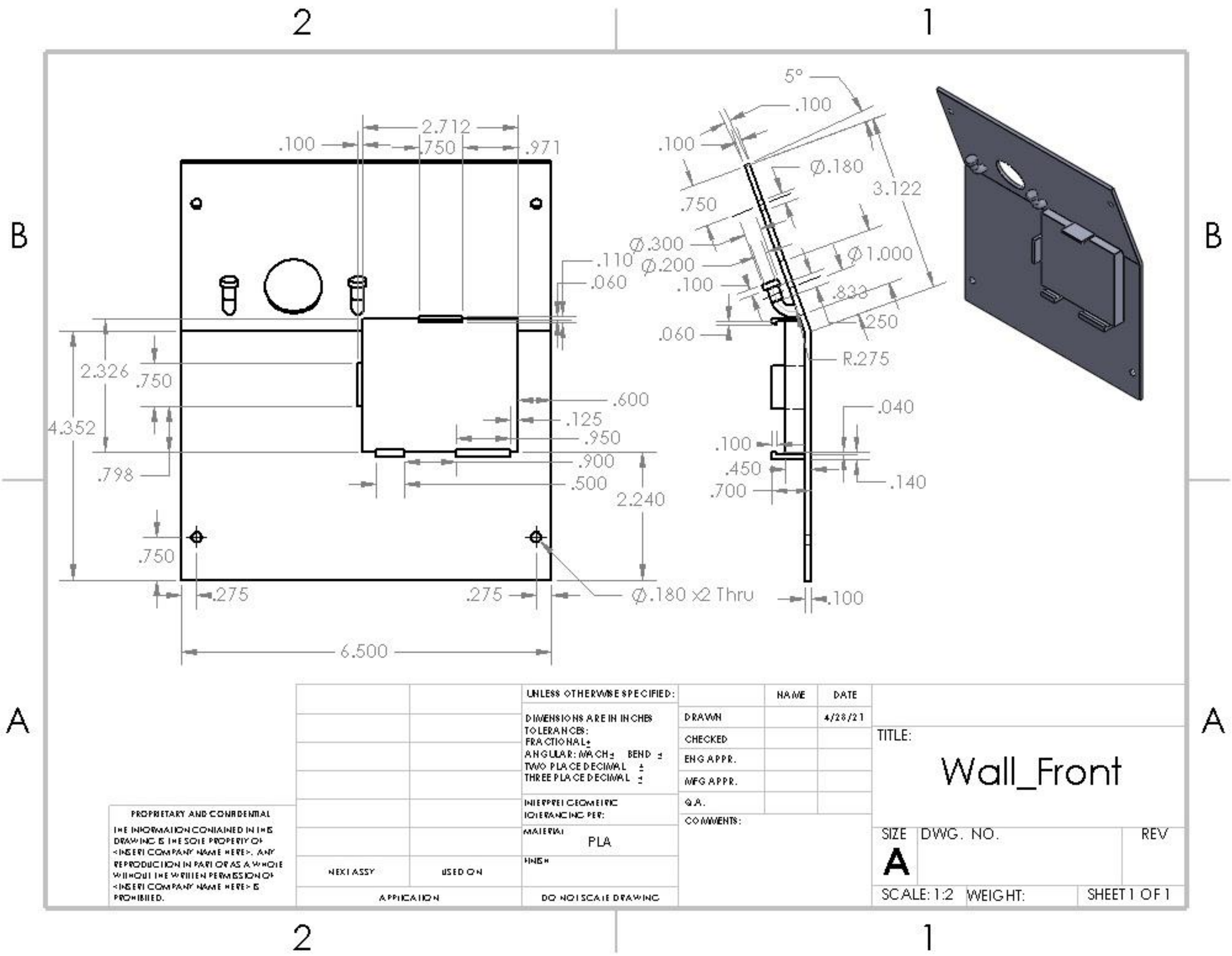


2
1
B
A
∅.180 X2
.500
2.745
3.170
.100
NAME
DATE
TITLE:
Frame_PowerBrickFastener
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

C6: Encasement Walls




3.122
7.318
4.352
4.192
Ø.180 Thru X4
7.700
.100
UNLESS OTHERWISE SPECIFIED:
DRAWN
4/28/2021
CHECKED
TITLE:
Right_Wall
MATERIAL
PLA
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


2.712
.100
.750
.971
5°
.100
.100
Ø.180
3.122
.750
Ø.300
Ø.200
Ø1.000
.110
.060
.100
.833
.250
.060
R.275
2.326
.750
.600
.125
4.352
.950
.900
.798
.500
2.240
.040
.100
.450
.700
.140
.750
.275
.275
Ø.180 x2 Thru
.100
6.500
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
4/28/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Wall_Front
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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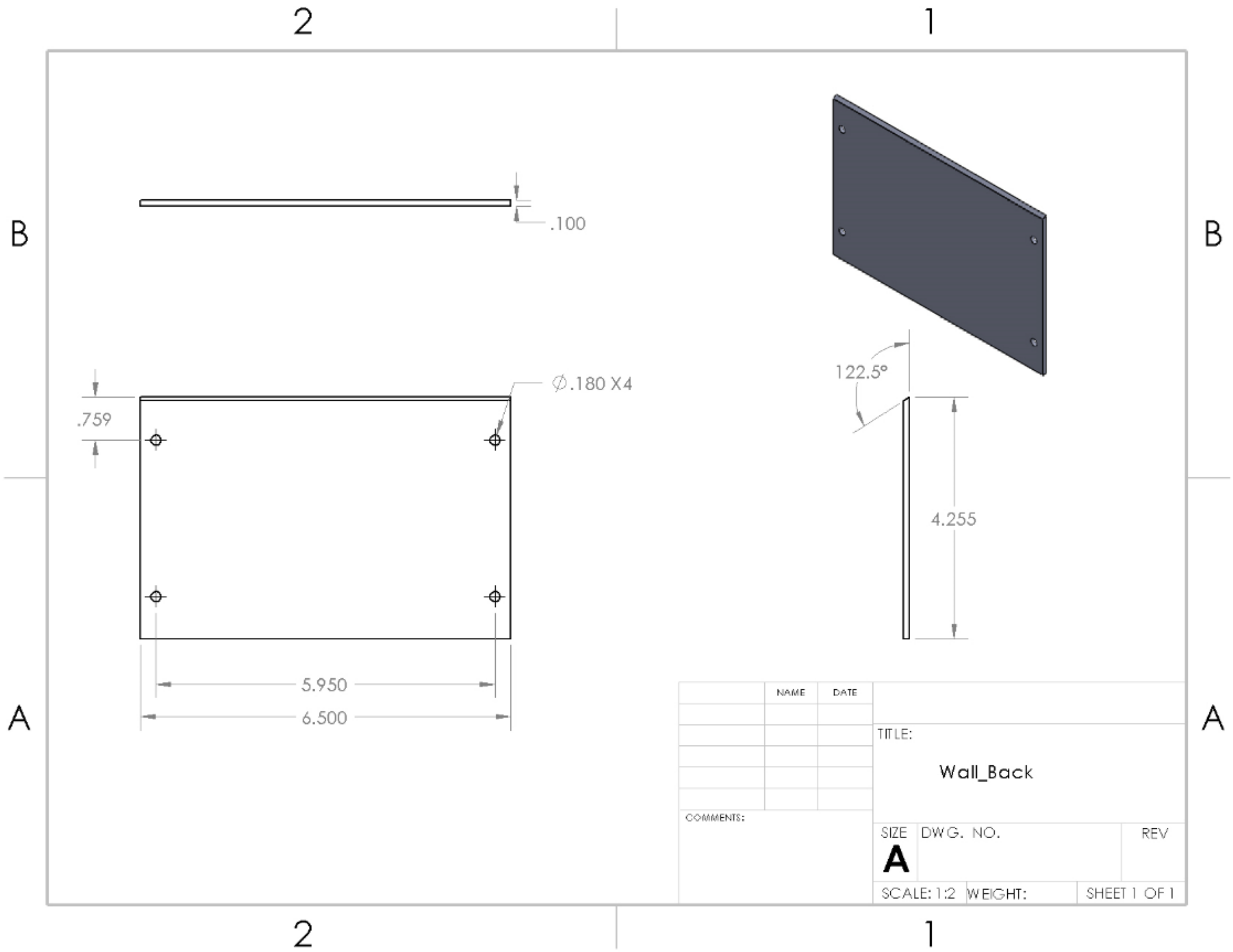
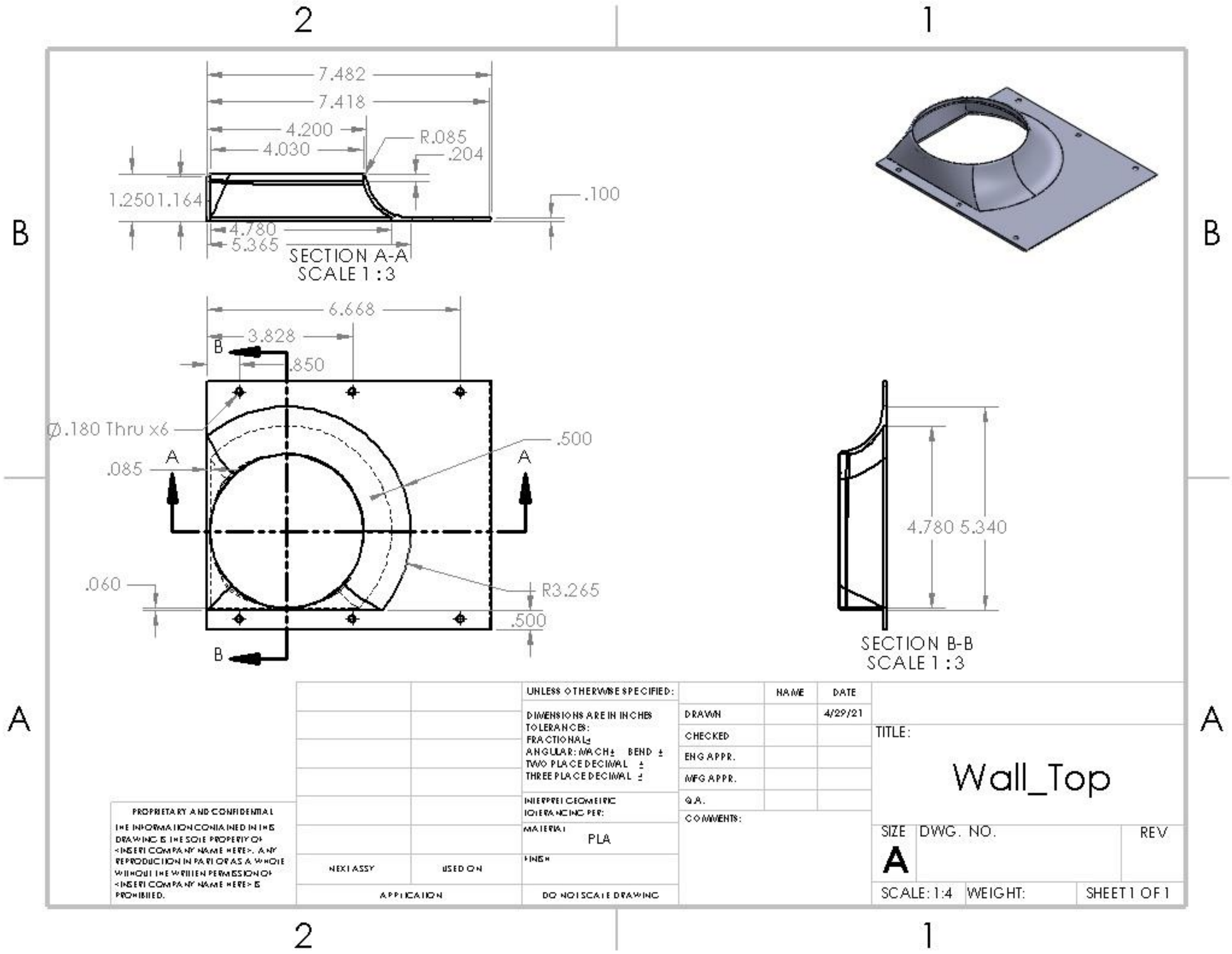
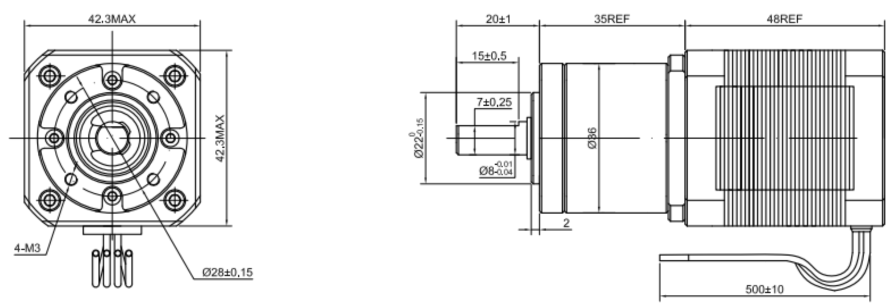


2
1
B
A
.100
.759
∅.180 X4
5.950
6.500
122.5°
4.255
NAME
DATE
TITLE:
Wall_Back
COMMENTS:
SIZE
A
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


7.482
7.418
4.200
4.030
R.085
.204
1.250
1.164
.100
4.780
5.365
SECTION A-A
SCALE 1 : 3
6.668
3.828
.850
Ø.180 Thru x6
.500
.085
.060
R3.265
.500
4.780
5.340
SECTION B-B
SCALE 1 : 3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLA
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
4/29/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Wall_Top
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

Appendix D: Electrical Component Datasheets

D1: 27:1 Nema 17 17HS19-1684S-PG27 Geared Stepper Motor Datasheet

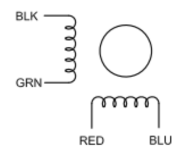


SPECIFICATION \ CONNECTION	BIPOLAR
AMPS/PHASE	1.68
RESISTANCE/PHASE(Ohms)@25°C	1.80±10%
INDUCTANCE/PHASE(mH)@1KHz	3.20±20%
HOLDING TORQUE w/o GEARBOX(Nm)[lb-In]	0.52[4.60]
GEAR RATIO	26 103/121
EFFICIENCY	81.00%
STEP ANGLE w/o GEARBOX(°)	1.80
BACKLASH@NO-LOAD	<=1°
MAX.PERMISSIBLE TORQUE(Nm)	3.00
MOMENT PERMISSIBLE TORQUE(Nm)	5.00
SHAFT MAXIMUM AXIAL LOAD(N)	50.00
SHAFT MAXIMUM RADIAL LOAD(N)	100.00
WEIGHT(Kg)[lb]	0.60[1.32]
TEMPERATURE RISE:MAX.80°C（MOTOR STANDSTILL;FOR 2PHASE ENERGIZED）	
AMBIENT TEMPERATURE -10°C~50°C[14°F~122°F]	
INSULATION CLASS B 130°C[266°F]	

TYPE OF CONNECTION (EXTERN)		MOTOR	
PIN NO	BIPOLAR	LEADS	WINDING
1	A —	BLK	A
2	A\ —	GRN	A\
3	B —	RED	B
4	B\ —	BLU	B\

FULL STEP 2 PHASE-Ex.,
WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\	CW ↓	CCW ↑
1	+	+	-	-		
2	-	+	+	-		
3	-	-	+	+		
4	+	-	-	+		



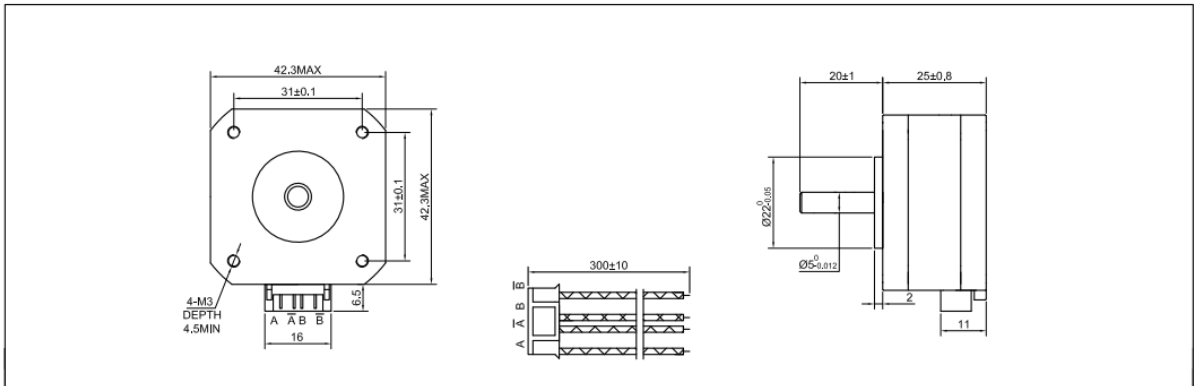
STEPPERONLINE®

	APVD		8.18.2018
	CHKD		
1:1	DRN		
SCALE	SIGNATURE		DATE

STEPPER MOTOR

17HS19-1684S-PG27

D2: Nema 17 17HS4023 Stepper Motor Driver



SPECIFICATION / CONNECTION	BIPOLAR
AMPS/PHASE	0.70
RESISTANCE/PHASE(Ohms)@25°C	4.20±10%
INDUCTANCE/PHASE(mH)@1KHz	5.50±20%
HOLDING TORQUE(Nm)[lb-In]	0.13[1.15]
STEP ANGLE(°)	1.80
STEP ACCURACY(NON-ACCUM)	±5.00%
ROTOR INERTIA(g-cm²)	20.00
WEIGHT(Kg)[lb]	0.18[0.40]

TEMPERATURE RISE:MAX.80°C（MOTOR STANDSTILL;FOR 2PHASE ENERGIZED）
AMBIENT TEMPERATURE -10°C~50°C[14°F~122°F]
INSULATION RESISTANCE 100 Mohm（UNDER NORMAL TEMPERATURE AND HUMIDITY）
INSULATION CLASS B 130°C[266°F]
DIELECTRIC STRENGTH 500VAC FOR 1MIN.(BETWEEN THE MOTOR COILS AND THE MOTOR CASE)
AMBIENT HUMIDITY MAX.85%(NO CONDENSATION)

TYPE OF CONNECTION (EXTERN)		MOTOR	
PIN NO	BIPOLAR	LEADS	WINDING
1	A —	BLK	A
2	A\ —	GRN	A\
3	B —	RED	B
4	B\ —	BLU	B\

FULL STEP 2 PHASE-Ex.,
WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\
1	+	+	-	-
2	-	+	+	-
3	-	-	+	+
4	+	-	-	+

CCW ↑ CW ↓

BLK GRN RED BLU

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	APVD		8.18.2018	STEPPER MOTOR
	CHKD			
1:1	DRN			17HS10-0704S
SCALE	SIGNATURE		DATE	

Appendix E: Arduino Code

MQP_final_code

```
#define EN          8

//Direction pin
#define X_DIR      5
#define Y_DIR      6
#define Z_DIR      7

//Step pin
#define X_STP      2
#define Y_STP      3
#define Z_STP      4

int x_high = 1;
int y_high = 1;
int z_high = 1;

int x_rate = 27;
int y_rate = 10;
int z_rate = 1;

int x_counter = 1;
int y_counter = 1;
int z_counter = 1;

int delay_time = 500;

void setup() {
  Serial.begin(9600);
  pinMode(EN, OUTPUT);
  pinMode(Y_DIR, OUTPUT); pinMode(Y_STP, OUTPUT);
  pinMode(X_DIR, OUTPUT); pinMode(X_STP, OUTPUT);
  pinMode(Z_DIR, OUTPUT); pinMode(Z_STP, OUTPUT);
```

```
  digitalWrite(EN, LOW);
  digitalWrite(X_DIR, 1);
  digitalWrite(Y_DIR, 1);
  digitalWrite(Z_DIR, 1);
}

void loop(){
  if (x_counter % x_rate == 0 && x_high == 1){
    digitalWrite(X_STP, HIGH);
    x_high = 0;
  }
  else if (x_counter % x_rate == 0){
    digitalWrite(X_STP, LOW);
    x_counter = 0;
    x_high = 1;
  }

  if (y_counter % y_rate == 0 && y_high == 1){
    digitalWrite(Y_STP, HIGH);
    y_high = 0;
  }
  else if (y_counter % y_rate == 0){
    digitalWrite(Y_STP, LOW);
    y_counter = 0;
    y_high = 1;
  }

   if (z_counter % z_rate == 0 && z_high == 1){
     digitalWrite(Z_STP, HIGH);
     z_high = 0;
   }
   else if (z_counter % z_rate == 0){
     digitalWrite(Z_STP, LOW);
     z_counter = 0;
     z_high = 1;
   }

   delayMicroseconds(delay_time);

   x_counter += 1;
   y_counter += 1;
   z_counter += 1;
 }
```