Haptic Interface for Brain Research

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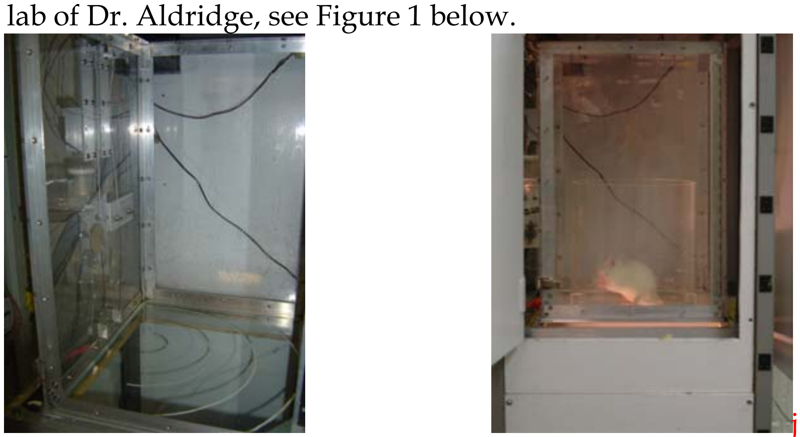
ABSTRACT
The goal of this project is to eliminate undesired sound cues during the delivery of food pellets to research rats. Unnecessary mechanical noise currently accompanies food delivery, cuing the rats to the incoming pellet before it arrives. Evidence has shown that the sound cues influence neural response of the rats, thus, affecting the research of our sponsor. Our objective is to redesign the dispenser setup to eliminate any unwanted cues (sound, smell, vibration, etc.) by masking them, while maintaining current functionality. In so doing, the neural response of rats to receiving reward can be isolated and studied more accurately.

INTRODUCTION
Dr. Wayne Aldridge has a lab in the U of M Department of Neurology. He and his fellow neuroscientists study grooming behavior in rats to better understand movement disorder in humans. Various mechanical interfaces are used in the experiments conducted on the rats. Dr. Aldridge requires programmable interfaces to encourage certain behavior in the rats. Specifically he and his lab are in need of a device to dispense sugar pellets to the rats without providing any unnecessary cues to the rats. The rats cannot be allowed to know when the pellet will be delivered by hearing the sound of the pellet release mechanism; the researchers instead want to program a response to alert the rats to the pellets. The device must perform repeatable actions, be relatively inexpensive and robust in design.

INFORMATION SEARCH
To understand the scope of our project, we spent time with Dr. Aldridge in his lab examining his current setup and the facilities he was working with. We were able to examine components of the current setup, focusing on points to improve on the design. We also conducted measurements of the cage and current dispenser used (CAD model of cage setup is shown in Appendix E).

Before brainstorming and establishing a design strategy, market research is helpful in understanding the specifications of products used for purposes similar to those of our project. To obtain accurate target values for our engineering specifications, it was necessary to specifically define all parameters of the customer requirements based on background research.

MARKET RESEARCH Given that the specifications for this project are highly specialized, there is no product on the current market that fulfills all the customer requirements. Thus, establishing industry standards proved to be difficult, forcing us to focus product research to improving the experimental set-up in place in the lab of Dr. Aldridge, see Figure 1 below.



(a) (b)

Figure 1. (a) Aldridge Lab empty rat cage set-up (b) Cage set-up during rat training

Our team, along with Professor Gillespie, met with Dr. Aldridge in his lab, in order to get an idea of the past and current work he has conducted, and to establish his future goals. In his lab, Dr. Aldridge has a pellet dispenser from Coulbourn Instruments [1] and a modified pellet dispenser from MED Associates, Inc. [2]. Neither company includes prices of their products on their websites, but we were able to obtain price quotes via email, see Table 1. With an estimated budget of $400, those commercial parts appear too expensive to incorporate into our design. Besides being expensive these products do not meet the requirements of not providing any unnecessary cues to the rats. They provide too much unwanted mechanical noise.

Products	Coulbourn Instruments	MED Associates, Inc.
Pellet Dispenser	$340	$372
Pellet Receptacle	$130	$69
Response Lever	$90	$69
Retractable Lever	$410	$324

Table 1. Price of products from Coulbourn Instruments and MED Associates, Inc.

Our team has researched a variety of motors as possible replacements to the current motor used in the dispensing of the pellets. We have gathered information on electric motor noise [3] A solenoid motor is currently used in the system. Solenoid motors are known to produce a large amount of mechanical noise. This noise is caused by the hitting of end stops in solenoid motors. Research on stepper motors has shown that they operate with little or no noise. [4] Another option for a motor to be used in our system would be a conveyor belt powered by a small motor. Professor Gillespie has recently provided us with a motor module with an oscillating arm, described in detail in the concept generation section on pages 6 and 7. The position of the arm can be controlled and the arm moves silently.

BACKGROUND RESEARCH The goal of the project is to eliminate sound cues from the sugar pellet dispenser, in effect, developing a "silent" dispenser. In order to establish a target value for noise of our apparatus, the word silent must be defined for our purpose. Research showed that the audible range for human hearing spans 16 to 20,000 Hz (20 kHz), with any sound above 20 kHz considered ultrasonic [5]. Rats can hear in the ultrasonic range, with an audible hearing range spanning 200 Hz to 80 or 90 kHz. In order to measure sounds in the ultrasonic range, a machine comparable to the Ultrasonic Vocalization (USV) Detector (sold for $772 by MED Associates, Inc. [6]) would be needed. For the scope of this project, it would be relatively expensive to measure ultrasonic sounds, so we will focus on developing an apparatus that is silent to humans. Thus, a target value for noise of the apparatus was set to the human threshold of hearing [7].

CUSTOMER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

During our meeting with our customer, Dr. Aldridge and his lab, we were able to understand the general customer requirements which we later converted to more specific engineering specifications.

CUSTOMER REQUIREMENTS The major requirement is to eliminate the unnecessary cues, such as the sound cue currently accompanying the dispensing of the food pellets, so that they will not interfere with the study of neural transmissions of the rats. Our customer requires the delivery of food pellets to be smooth, consistent, and with minimal response time, so that researchers will have the largest freedom to control the time and location at which the pellets are dispensed. Our customer also requested that we include a haptic lever as a rat response interface. However, after some early brainstorming and due to the time constraints of our project, we decided that we would be unable to complete both the initial requirement of providing a silent dispenser with no unnecessary cues and the secondary requirement of a haptic lever system. We have decided to focus our efforts on accomplishing the goal of providing a dispenser with no unnecessary cues.

We rated the importance of each requirement. The smooth delivery of food pellets while eliminating unnecessary cues will determine the success of the device to our customer. Therefore, these requirements shown in table 3 are deemed to be essential and assigned the highest importance rating. Other requirements are also rated according to their relative importance as shown in the QFD chart in Appendix A.

Customer Requirements
Eliminate unnecessary cues
Release sugar pellets smoothly
Consistent pellet dispersal location
Minimal response time
Multiple functionality
Durable and repeatable operation
Fit size constraint
Compatible to computer interface
Inexpensive
Easy to modulize

Table 2. Customer Requirements

ENGINEERING SPECIFICATIONS We generated the engineering specifications according to the requirements of our customer. In order to eliminate the cues, we want to limit the noise of the pellet release mechanism to the lower threshold of human hearing. To ensure the swift and accurate delivery of pellets, we included specifications for “release mechanism precision”, “speed of motor” and “release time of the mechanism”. To meet the requirement that the system is durable, the motor life and total number of pellets the mechanism can dispense before failure need to be specified. To integrate our design to the existing set-up and ensure compatibility, we want to limit the longest dimension of each module and set a sufficient target number of I/O ports. The engineering specifications are listed in Table 3 on page 6. The specifications of the current set-up have been measured and are listed in the benchmarks column of the QFD chart in Appendix A.

We correlated customer requirements to engineering specifications and cross-correlated the engineering specifications, determining the importance rating for each specification accordingly. The noise of the mechanism and the goal to eliminate cues are closely related, so a rating of “9” is assigned to them. The two engineering specifications “release time” and “motor speed” have strong positive relationship, thus the rating “++”. Ratings are also assigned to other relationships as showed in the QFD chart in Appendix A. The importance ratings are calculated as shown in the lower rows of the QFD chart.

TARGET VALUES We finally set our engineering targets based on the specification importance rating and the measurements of the current system. The noise of the mechanism is set to be around the lower threshold of human hearing so that no cues will be given to the rats, or, if sound masking is implemented, the masking sound must be louder than the operational noise. The precision of the pellet release is set to be 5mm so that the pellets will not be scattered in an uncontrolled manner. The response time is set to be 300ms, allowing the researches to set the time delay between the delivery of food pellet and the signal from rat to values from almost zero to several second or minutes. Other target values are listed in the QFD chart found in Appendix A.

Engineering Specification	Target
Noise of the release mechanism (mainly motor noise)	Approx. 0 dB or sound masking
Release mechanism precision	5 mm
Total # of pellets dispensed before failure	10^5
Longest dimension	14 in.
Motor life	10^{10}
# of modules	3
Release time	300 ms
Speed of motor	10 RPM
# of I/O ports per module	1

Table 3. Engineering specifications generated according to the customer requirements.

CONCEPT GENERATION

When brainstorming and developing new concepts, the engineering specifications and customer requirements were used as a guideline. In order to develop our concepts, we used a morphological chart, shown in table 4, to determine potential design solutions that would fulfill each required function of our project. We classified each potential solution based on the function that it would fulfill and the required mode of energy needed for operation. The four functions we focused on were multiple pellet preloading, single pellet separation and loading for delivery, and single pellet delivery. Because of its importance to the scope of our project, we also included considerations for quiet operation based on two distinct strategies: 1) Minimizing the actual sound of the apparatus 2) Masking the sound of the apparatus by using constant motion.

		ENERGY MODE		
		Mechanical	**Electrical**	**Misc.**
FUNCTION	**Multiple Pellet Preloading**	Cup or Hopper System		Manual Preloading
	Separation and Single Pellet Loading	Hole Alignment Concept	Interfacing for Hole Alignment	
	Single Pellet Delivery	Conveyor Belt Helix Coil System	Interfacing for Conveyor Belt	Delivery through tubing due to gravity
	Quiet Operation	Continuous Motion Sound Masking Quiet Mechanical Components	External Sound Masking	
		POTENTIAL DESIGN CHOICES FOR EACH FUNCTION		

Table 4. Morphological chart for complex concept generation.

MOTOR MODULE A motor module with an rotating armature, shown in figure 2 on page 7, was used in each of our three concepts. This module consists of a stationary stator part and an oscillating armature. When attached to a power source, the current flows through the coil within the magnets of the stator to generate an electromagnet. The stator is a permanent magnet, which interacts with the armature with a current flowing through the coil to create motion [8]. By using the Hall Effect sensor to measure position, we can accurately manipulate the position of the armature and create a moving device that is virtually silent.

(a) **(b)**

Figure 2. Motor module (a) photo of top view and (b) schematic drawing.

VENDING MACHINE HELIX COIL PRELOADER SYSTEM The "Vending Machine" inspired helix coil preloader system employs a rotating coil helix to distribute food pellets to a specific location on the armature plate of the motor module. This helix coil can either be preloaded with a small amount of pellets or be connected to a container that holds a large amount of pellets. This pre-loader system shown below in Appendix C 3 enables precise preloading of pellets.

Helix Coil

The diameter of the helix coil is less than the dimension of the food pellet and the pitch length of the coil is slightly larger than the pellet dimension. When he helix coil rotates, pellets placed in the pitch of each coil will be moved forward and eventually fall into a designated point on the armature plate. A similar mechanism can be found in most vending machines to deliver products. The helix coil faces a length limit since the bending stiffness will be reduced as the length of the helix is increased. Thus there is only potential to fit a small number of pellets into the pitches of the helix coil.

Container

Due to the length constraints of the helix coil, the number of the pellets it can deliver will be limited. Thus it is necessary to use a larger container to store extra pellets in order to enable the researcher conveniently conduct a large series of tests without having to manually reload the pellets onto the helix coil. However, how to silently move pellet from the container to the helix coil remains a concern.

DUAL MOTOR MODULE CONCEPT

Preloading Module

The dual motor module concept, as its name suggests, implements one motor module, as described above, for preloading and a second motor module for pellet delivery. The preloading armature is designed with an L-shaped geometry in its radial cross-section as shown in Appendix C. The curvature edge, with a pellet shaped notch, is functional to both block the pellets and pick up one pellet at a time. The pellets are placed on a slope next to that edge and slide down due to their own gravity. The armature edge can be positioned so the notch does not line up and instead blocks the pellets. To pick up one pellet, the armature can be controlled to align the notch with the pellet lineup (process is shown in Appendix C). Since the notch geometry is designed to hold only one pellet, when aligned, the first pellet in line should slide into position and the pellets above should each move one position forward in the line. This pellet in the notch will move out of the pellets slope with the swing and finally be dispensed. Another fixed slope is positioned beneath the swing, covering the trace of the movement of notch. A hole, which is larger than the pellet, is placed in one position that notch will pass by. The slope will hold the pellet in the notch until the notch is above the hole and then the pellet will drop into the hole. A tube, which connects the hole, will lead the pellet to the dispenser swing or right to the rats.

Dispensing Module

Inclusion of a second dispensing module is optional, given that a pellet could be delivered directly to the rats by the preloading module through a tube. However, the dispensing module will probably provide better control on the dispensing time, and there may be a sound cue associated with the friction of the pellet passing through a tube. The dispensing module would be designed with two separate chambers. The empty chamber is usually open to the rats. The other one, called dispensing chamber, is connecting to the tube and able to hold the pellet. To dispense the pellet, the armature would be controlled to move the dispensing chamber to a position that is open to the rats (process is shown in Appendix C). After the pellet is delivered to the rat, the armature can be controlled back to its original position until the next dispense. Precision and timing of this setup is a concern, as the preloading time depends on the tube length and cannot be exactly controlled.

TWO DISK—MOTOR MODULE—CONVEYOR BELT CONCEPT

Rotating Disk

Side and top view sketches of the two disk—motor module—conveyor belt concept are shown in Figure 3 on pages 9 and 10 and in Figure D.1 in Appendix D. In this concept, a disk, with pellet-sized holes cut at evenly spaced and symmetric intervals along the outer rim, rotates at constant angular velocity about its center point. The thickness of the disk is slightly greater than the height of a pellet, so a single pellet can fit down into the hole.

Fixed Disk

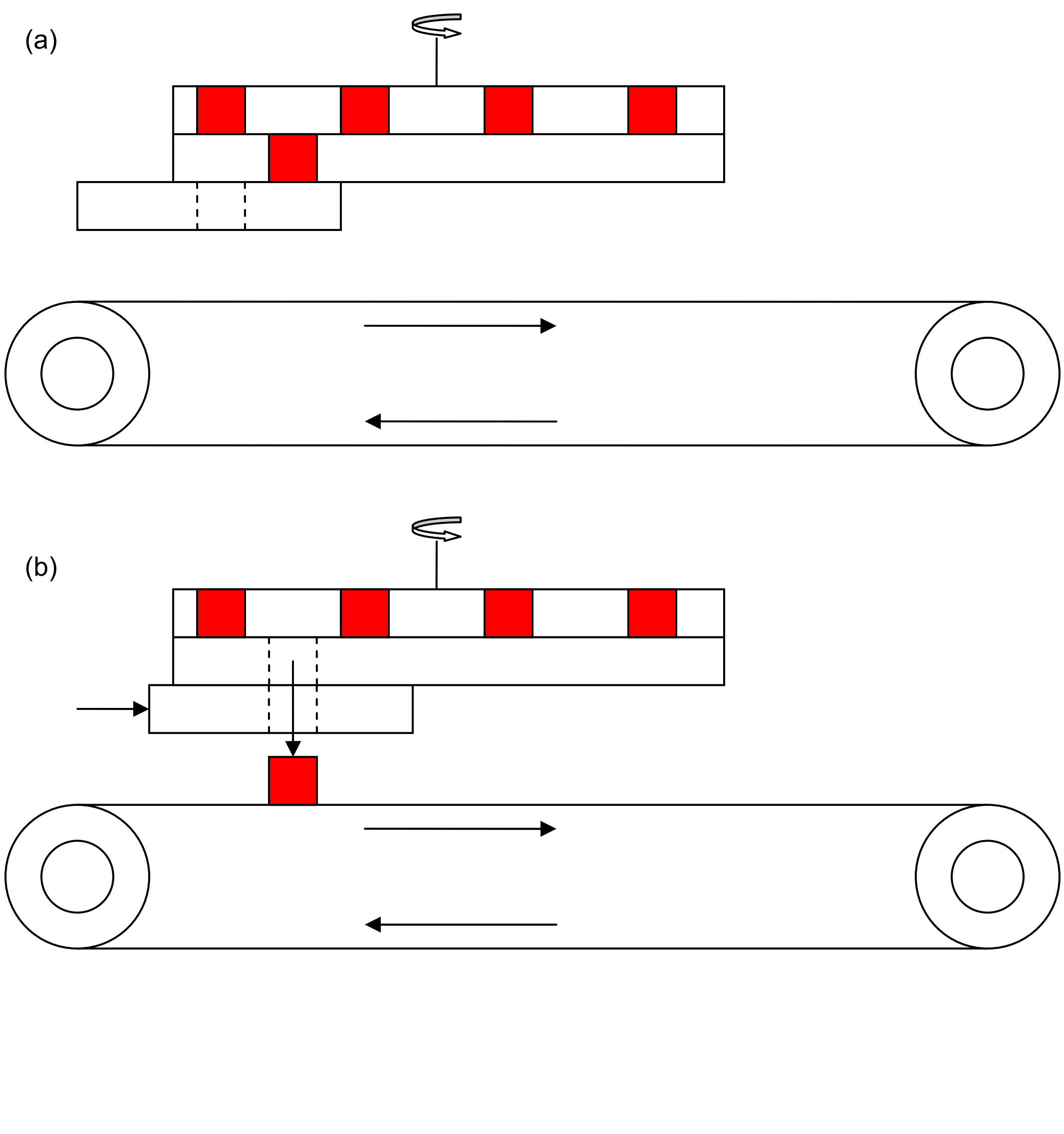
A fixed disk, of similar size to that of the rotating disk, is positioned directly below the rotating disk. The fixed disk has one pellet sized hole, located at a point along the outer rim which corresponds to the path traversed by the holes of the top disk. Thus, if the rotating disk were loaded with pellets in each hole and set in motion, the pellets would each fall through the hole of the fixed disk one at a time. The hole can be blocked by the armature of the motor module, described below, that is positioned directly below the fixed disk. Thickness of the fixed disk should accurately match the height of a pellet, so only one pellet can fit in the hole; there should be no empty space between the pellet and the top disk, and no part of the pellet should stick out of the top of the hole, so as not to interfere with the motion of the rotating disk.

Motor Module/Analog Potentiometer Controller

A motor module, see Motor Module Figure, controlled by an analog potentiometer will be positioned under the fixed plate. The armature of the motor module has a single pellet-sized hole cut into it. The potentiometer will control the position of the armature between two resting positions. In the first position, the hole in the armature is unaligned with the hole in the fixed disk, thus, preventing a pellet from falling through. In the second position, the hole in the armature is aligned with the hole in the fixed disk, thus allowing a pellet to fall through.

Conveyor Belt
A continuously running conveyor belt will be placed directly underneath the aligned pellet holes, so when the motor module is in aligned position a single pellet will drop onto the belt. The belt will be used to transport pellets from the two-disk/motor module loading device to a position in which the rats can receive them. In theory, the continuous noise of the motor used to propel the conveyor belt will be sufficiently loud to mask any sound cue that would signal the rat to an incoming pellet.

One design concern: The disk should rotate relatively slowly or the pellets should be spaced relatively far apart, so as to reduce the chance that a second pellet will drop before the motor module moves out of the aligned position. We may need to consider some other method to control this; i.e., before the motor module moves to the aligned position, the disk would be controlled to stop rotating at a point where no pellets are aligned with the hole in the fixed disk. If this is deemed necessary, we should consider a fairly loud conveyor belt motor to mask the sound associated with start/stop of the rotating disk.



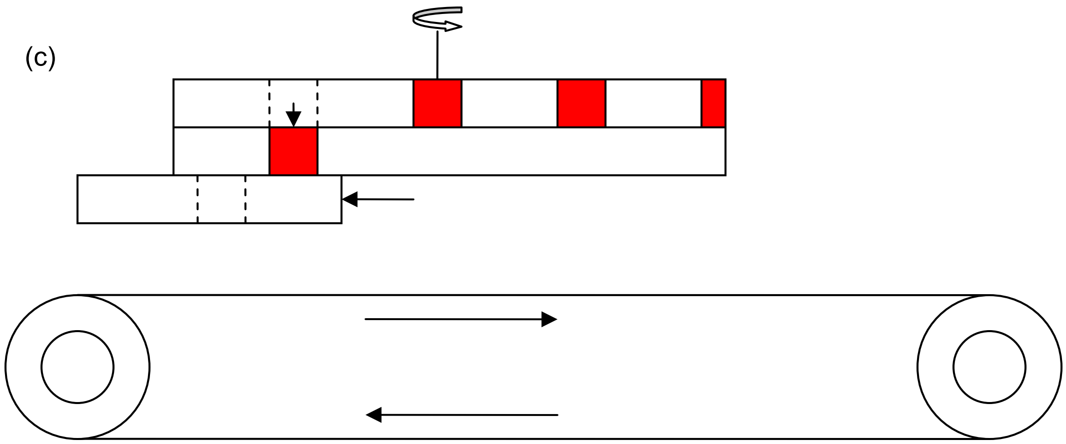


Figure 3. Side view of two disk-motor module-conveyor belt setup with (a) pellet loaded and armature in unaligned position (b) pellet unloading with armature aligned and (c) pellet reloading with armature back in aligned position. Red block represents pellet.

CONCEPT EVALUATION AND SELECTION

When evaluating the concepts and narrowing down to a final two, the following guidelines [9] were used:

- Targeting true customer needs and wants, by eliminating unimportant customer requirements
- Ranking the potential for each concept to fulfill each of the targeted requirements
- Determining the concept that best fulfills the customer requirements and is most feasible for production

Using the results of the QFD and new information, the true customer requirements were ranked in order of importance. Since we are no longer considering the haptic lever design, multiple functionality and ease of modulation were eliminated as customer requirements. The three concepts were ranked for the potential of each to fulfill each of the customer requirements.

Customer Requirements	Helix Coil	Dual Motor Module	Conveyor Belt Disk
Eliminate unnecessary cues	3	2	1
Release sugar pellets smoothly	3	1	1
Consistent pellet dispersal location	1	1	1
Minimal response time	3	2	1
Durable and repeatable operation	3	1	1
Fit size constraint	2	2	1
Compatible to computer interface	1	1	1
Inexpensive	2	1	3
TOTAL	18	11	10

Table 5. Concept ranking for each customer requirements.

Table 5, on page 10, shows the concept rankings from 1 to 3 with 1 being the best—for each of the customer requirements. The customer requirements are listed in order of importance with "eliminate unnecessary cues" the most important and "inexpensive" listed last as the least important.

The conveyor belt-disk concept had the lowest total score and clearly rated as the best concept, receiving the top ranking in all customer requirements except the least important requirement of cost. Theoretically, the conveyor belt disk concept will perform all the required functions, is feasible to manufacture, and should be easy to integrate into the current lab setup. Although the concept ranked 3rd as potentially the most expensive concept, we have projected that all three concepts will be well under budget, so this is not an issue.

Each of the other two concepts carried specific design concerns. The helix coil would be difficult to manufacture for silent operation and would not be robust enough for repeated use. Jamming of the preloading device is a concern for the dual motor module concept. Integration of both these concepts to the current setup would be difficult. The motor module would take up a lot of space inside the cage, and, if it were to be implemented outside the cage, modifications would need to be made to the current setup.

SELECTED CONCEPT

Based on our customer requirements we chose the dual motor module concept, which is shown below in Figure 4. The design consists of the following moving parts: a stepper motor, motor module and armature, rotating disk, and conveyor belt. The disk with cup-like pellet container rotates above a fixed plate in the frame and is powered by the stepper motor attached by an axel. A hole in the center plate of the frame corresponds to the path of the holes in the rotating disk. The motor module mounts directly to the center plate in the frame.

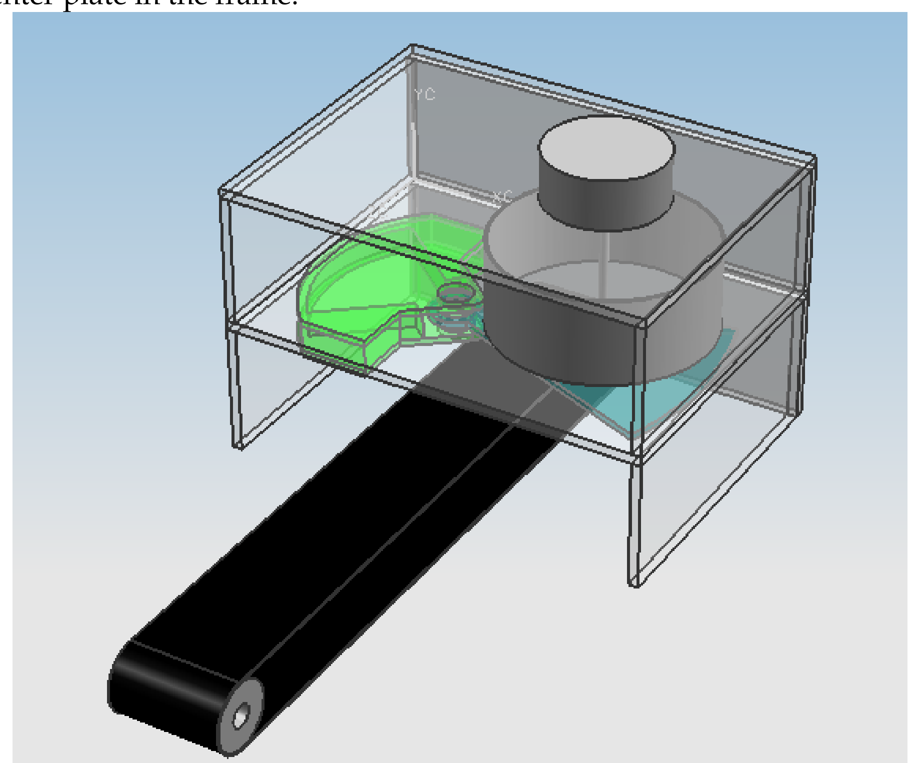


Figure 4. 3D Cad model of Assembly of two disk-motor module

ENGINEERING ANALYSIS

During the design process, important decisions were made on key variables of the design based on qualitative and quantitative engineering analysis. Final design decisions of dimensions and tolerances, material choices, manufacturing strategy, and parts selection are summarized in Table 5 and were justified by the methods explained in the text.

Design Variable	Engineering Decision
Plexiglas thickness	4,5 mm
Frame width	150 mm
Size of pellet holes	4.5 mm
Number of pellet holes	20
Axel diameter	4 mm
Tolerances	0.5 mm
Material Choice	Plexiglas, Soft Latex Rubber Tubing
Manufacturing strategy	Machine Plexiglas mainly using laser cutter
Motor Selection	DC Stepper Motor for disk and conveyor belt
Inclusion of Cup-Like Loading Container?	No, does not work as expected
Inclusion of Motor Module?	No longer necessary
Inclusion of Conveyor Belt?	No, latex tubing will be implemented instead
Inner radius of tube	0.5" ≈ 12.70 mm

Table 5. Selections for key design variables.

Quantitative Analysis

Given the complex interactions of oddly shaped pellets and moving parts of our concept, mathematical modeling or computer simulation of the process would be very complicated and probably would not be sufficient to answer our design questions. Instead, we relied upon the results of tests conducted on a rapid concept prototype to assess the feasibility of the design.

We rapid prototyped a two disk test apparatus from Plexiglas to model the interaction between the pellets for different combinations of hole diameters. In each disk we cut four holes with diameters ranging from 4.5 mm (approximately the diameter of a single pellet) to 6.0 mm by 0.5 mm intervals. With the disks stacked on top of a desk, the top disk could either be manually rotated while the bottom disk was fixed to simulate the concept in the unaligned motor module position. With the disks stacked so that one hole was hanging outside the edge of the desk, a similar rotation could be carried out to simulate the concept in the aligned motor module position.

We observed the interaction of the pellet when loaded in all possible configurations and we modeled the cup-like pellet container part of the concept using a cut out soda bottle. The results of our tests were not satisfactory since our engineering specification for smooth and repeatable operation could not be achieved by the prototype. The pellets passed smoothly through the two plates when the holes on the two plats are aligned, however, the cup part did not work as expected, as loading of the holes was very inconsistent (sometimes pellets cannot pass certain holes due to; sometimes multiple pellets often dropped through when in the holes are aligned,). We decided to discard the cuplike container from our design and instead manually preload the pellets.

Unfortunately that was not the only flaw we found in our design, as jamming, pellet popping out of the disk, and/or pellet damage occurred frequently when the pellets loaded in the top disk passed above pellets loaded in the bottom disk. Analysis of the problem led us to conclude that the disk thickness--especially the thickness of the fixed lower disk—was too large in the case when a pellet lying flat at the bottom of a hole, contributing to jamming. As shown in Figure 5, as the pellet in the top disk passes over the pellet in the lower disk, gravity forces the pellet to descend into the lower hole, impeding rotation of the top disk.

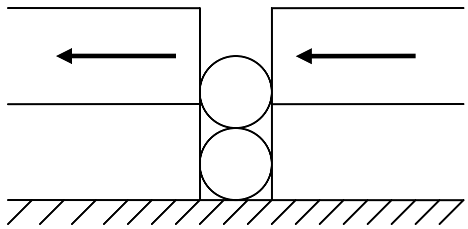


Figure 5. Cross-sectional diagram of jamming during concept prototype testing.

Our first inclination was to modify the thickness of the plate to better correspond to the height of the pellet in the hole. However, due to asymmetry of the pellets and inconsistencies in the orientation of the pellets in the hole, it would be impossible to design the thickness of the disk to consistently correspond to this height.

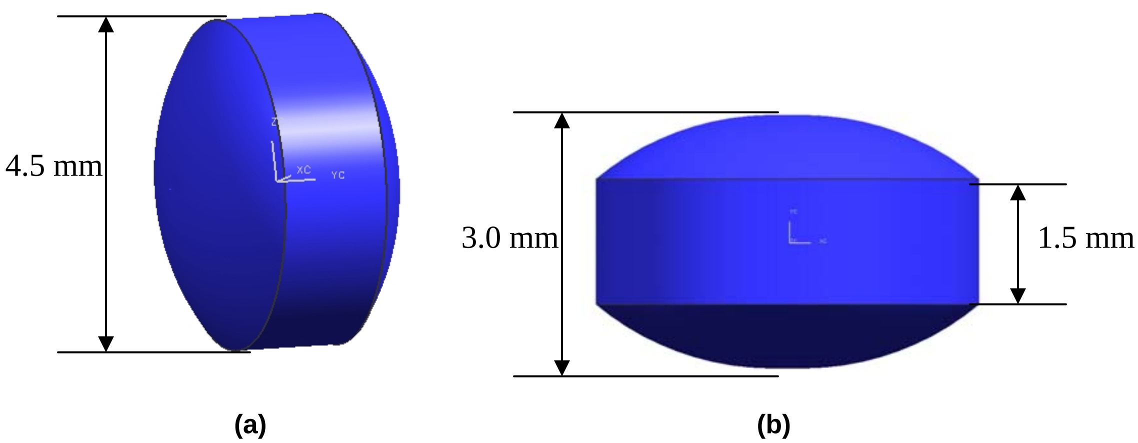


Figure 6. CAD model of pellet in (a) inverted and (b) flat views.

Hoping to find a suitable plate thickness, we effectively reduced the thickness by partially filling the hole with small pieces of paper, and repeated the test. But that turn out to be futile, the reason is as follows. The pellets are not perfectly spherical—the height of the pellet (3mm) is significantly less than the diameter (4.5mm)—and, based on observation of concept prototype tests, as the pellets fell into holes in the lower disk, they came to rest randomly in either the flat (diameter in the horizontal plane) or in the inverted (diameter in the vertical plane) orientation. Therefore, if we decided to reduce the thickness of the lower disk to correspond to the height of the pellet, if in the inverted orientation the pellet would protrude the top of the hole in the lower disk and impede rotation of the top disk, or even disintegrate in the process.

Our next consideration was to design to machine the hole in the bottom disk with a chamfer, as shown in figure 7, in order to reduce the frequency of jamming. However, we were not able to test this because it is very difficult to machine a chamfer into Plexiglas, especially in very small holes. Therefore, although adding a chamfer to the hole in the lower disk could potentially reduce the frequency of jamming, we do not have enough evidence to support its implementation.

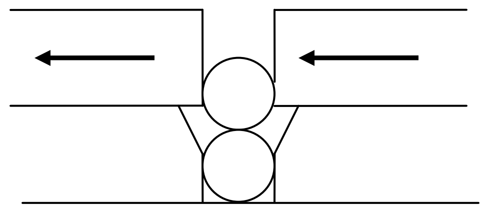


Figure 7. Cross-sectional diagram of jamming during concept prototype testing.

Based on the concept testing and analysis of our dilemma, we decided that the best way to improve our design would be to simplify it to eliminate the process by which the problem occurred—continuous disk rotation. We expect, based on the prototype testing, that we can consistently control the smooth release of multiple pellets by manually preloading the top disk and controlling rotation in step increments (each step moving another hole in the top disk into alignment with the bottom disk). In this design the swinging-arm motor module is no longer needed, further simplifying our design and reducing the dimensions of the apparatus.

Based on the engineering specifications, we seek to maximize the number of pellets that can be loaded into the disk to maximize repeatability of the device. The lowest angular displacement of the DC stepper motor is 7.5°, so the maximum number of pellet holes that can be included is 24 holes positioned evenly at 7.5° increments.

Prior to prototype testing and the subsequent alteration of our concept design, we established a target disk rotational velocity of 2.5 RPM and a target number of holes of 10 holes. However, since the design no longer requires continuous rotation of the disk, these target values are no longer necessary for our purposes. A detailed outline of the process by which these target values were established is included as Appendix F.

To cut the Plexiglas parts, we will use a laser cutter which does not cut at a perfectly perpendicular angle. From our simulations using the test prototype, we have determined that the cut angle will /will not have a significant effect on smooth operation of the dispenser for our application.

Qualitative Analysis

Design for Manufacture and Assembly (DfMA), Failure Mode and Effect Analysis (FMEA), and Design for Environment (DfE) were all considered when selecting values of design variables.

Design for Manufacture

Much of our design process was focused on developing a design that would not only serve its purpose but also be able to be manufactured with relative ease. The pieces that will make up our frame are simple rectangular shapes and will be very easy to machine with the laser cutter. Interlocking notches along the edges of the frame sides were added to the design to increase strength and robustness. Plexiglas was selected for the frame due to ease of manufacture, cost, and strength. Tolerances equal .5

mm based on laser resolution of about .25 mm based on beam thickness and application of a SF of 2. The rotating disk will be made from Plexiglas as well.

Design for Assembly

The reason we chose a frame was that it allowed for the other pieces to be attached with ease, while also providing a strong and robust foundation for the apparatus. The frame will be assembled and secured using a Plexiglas glue solvent, limiting the amount of hardware required. The disk motor mounts securely to the top of the frame. Our original plan of using a conveyor belt became difficult because there was no good way to attach the conveyor belt securely to the frame. We were unable to find pillow blocks that fit our size (most sold are industrial size) to fit the conveyor to the frame. The center of the frame will be machined so that the rotating disk will mount easily to it. The frame design was chosen so stepper motor could be mounted above disk axel and motor module could be mounted to center plate. A fixed hole in center plate was chosen over two disk design. This design is more robust with fewer parts.

Failure Mode Effect Analysis

There are very few potential failures associated with our design. We are not worried especially about failure because our device is a low strain application. However there are a couple of possible failures, but they can be easily fixed. Debris may accumulate in the tubing and cause this pellets to become stuck in the tubing. This could cause testing to be interrupted. However if the tubing is cleaned periodically this should not be a problem. The second failure that could occur would be the stepper motor failing due to overuse. However the motor will be easy to disassemble and replace when necessary. Also a set schedule of replacing the motor could be used so that testing would never be interrupted by a dead motor.

Design for Environment

In an effort to utilize space and material our design is made out of parts that if they fail are easily accessible and can be changed. Materials that we plan to use are mostly recyclable materials. Our motor will use very little energy and therefore be environmentally friendly. We plan to optimize material use by using Plexiglas for a variety of our parts. Manufacturing will be done with the laser cutter which is highly efficient, fast, and repeatable. The production of our prototype will be optimized by minimizing machining time, spending under our budget, and only building one prototype. There will be very little material wasted. Our parts will be easy to modulate allowing for swapping.

FINAL DESIGN

A detailed CAD drawing of the assembled design is shown in Figure 8 on page 16. Engineering drawings of the individual parts, including dimensions, are included in Appendix G. The disk, mounted to the motor by an axel and coupler, rotates above the center plate of the frame over a bearing. The center plate of the frame has a hole cut through it that aligns with the path of the holes in the disk. A tube, attached to a threaded metal fixture which was secured to the center plate using epoxy, runs from the hole to an opening in the rat cage. The motor is mounted to the top of the frame by two nylon screws and metal bolts.

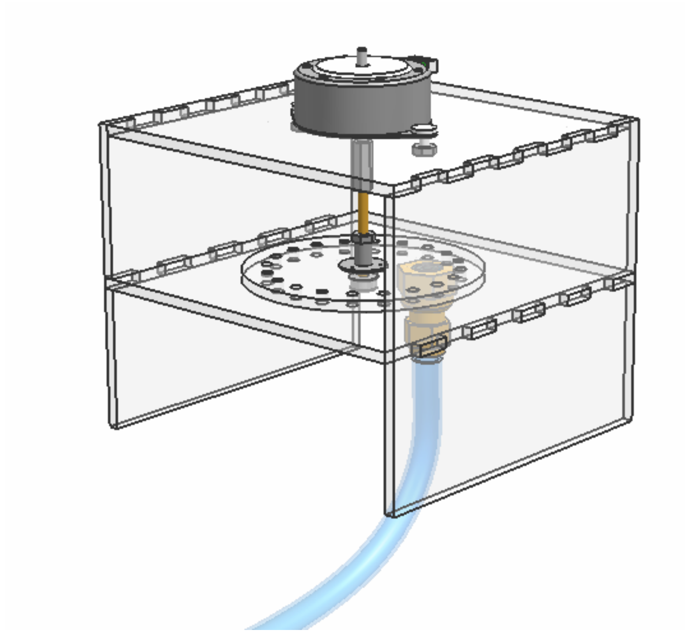


Figure 8. Isometric CAD model of assembled apparatus.

The Bill of Materials (BOM) is shown in Table 6. We were able to remain well under the $400 budget and project to stay well within the cost constraints of this project. Electrical components, including an ooPic microcontroller and H-bridges, were provided by the University.

Quantity	Purchased From	Part Description	Part Number	Total Price
1	McMaster-Carr	24"X48" Plexiglass Sheet	8589 K64	$43.26
2	Futurlec	Stepper Motor	M55SP-1	$25.90
1	Carpenter Bros. Hardware	3' Soft Latex Tubing	N/A	$4.73
1	Lowes Hardware	Tubing Fixture	N/A	$2.89
1	Carpenter Bros. Hardware	Coupler, Axle	N/A	$3.50
2	University of Michigan	H- Bridges	N/A	$0.00
1	VXB.com	Bearing	694-2RS	$17.06
1	University of Michigan	ooPIC - R Microprocessor	N/A	$0.00
2	Meijer	9 Volt battery	N/A	$5.99
			Total =	$99.83

Table 6. Bill of Materials.

MANUFACTURING

Mechanical

We have constructed a physical model of our final design. To manufacture a prototype of our final design we required a variety of parts, some of which we purchased and others we needed to make ourselves. The parts that we purchased were a stepper motor for the rotating disk, tubing, and assembly hardware, including couplers, bearings, the axle, and the tube fixture.

The frame and disk were made from Plexiglas which we also purchased. We used the Plexiglas to make the rotating disk to determine the correct hole sizes for the pellets. We created a CAD model of the disk, and then used a laser cutter to machine out the disk. We used the laser cutter to cut out the pieces for the frame as well. We used a compound to connect the frame pieces.

The first step in the assembly was building the frame. The next step was attaching the rotating disk.

The stepper motor was then connected to the disk via the coupler and mounted on the top of the frame. Next the tubing was attached to disk using a tubing mount. The whole assembly will be mounted outside of the cage with the tubing leading to the cage.

Our design is not really intended for mass production, because it is being created for a specific use for a very specific customer. However it would not be very difficult to produce another model. Our prototype will remain under budget and will satisfy not only the cost requirements, but also the engineering and environmental requirements.

Electrical

Assistance from Professor Gillespie and students from his ME 552 class was required to wire and program our stepper motor. In order to control the DC stepper motor to rotate at fixed step intervals on command, we implemented a bipolar stepper driver circuit, consisting of two H-bridges and an ooPIC microcontroller. Each H-bridge consists of four transistors which are used to energize two independent windings inside the motor. Using the ooPIC as a controller, we were able to sequentially control and change the direction of the current through each internal winding, thus manipulating the magnetic field within the motor. Within the motor, a permanent magnet rotor rotates as a result of changes in the induced magnetic field. By directing the magnetic field in a four step looped sequence, using buttons programmed on the ooPIC, we were able to rotate the motor through the entire revolution in half steps.

TESTING

Prototype testing was conducted to determine whether the apparatus adequately fulfills each design requirement. Due to a lack of robustness of the electronic wiring components in our design, the final prototype did not successfully operate for the length of the design expo; however, we were able to conduct several tests prior to the subsequent failure of our circuit. While operational, we observed the disk to rotate at the expected half step interval, and each hole of the disk accurately aligned with the hole in the center plate. We then tested the interaction of the disk and center plate when filled with pellets. We were able to consistently release all twenty four preloaded pellets in sequence. Operation of the device was barely audible in a quiet room, and the stepper motor proved significantly quieter than the solenoid used by Dr. Aldridge. Due to inconsistent delivery of pellets through the original latex tubing, we increased the inner diameter of the tubing to ½" for the final prototype resulting in smooth and consistent delivery of the pellets.

We attempted to troubleshoot our technical difficulties during the expo, but we were not able to sufficiently repair our wiring problems. For our presentation, we were able to drive the motor in the clockwise direction (counterclockwise is the designed direction), while skipping the third step in the sequence and thus causing the holes in the disk to become unaligned with the hole in the center plate. As we found no permanent damage to any of the electrical components, we expect that, after rewiring the bipolar stepper driver circuit, the prototype will operate as tested and will fulfill all engineering specifications.

FUTURE IMPROVEMENTS

Before presenting our device to our sponsor, we plan to rewire the stepper driver circuit so that it is again operational. In our current circuit setup, nodes of the H-bridge and ooPic are connected using ribbon connectors, wires, and a breadboard. More robust circuitry was not implemented due to time constraints and our limited expertise in electronics. Due to the difficulty maintaining operation under the current circuit setup, our sponsor suggested that he may outsource the wiring to a professional in order to improve the robustness of the device.

We hope to test the pellet dispenser prototype in the rat cage setup of Dr. Aldridge's lab. By observing our device during operation, it will be possible to directly check that the prototype fulfills the original engineering specifications. Based on previous tests, we expect that laboratory operation will verify that the prototype mounts easily to the lab setup and fits the size constraints, operation is repeatable and consistently successful, and all cues have been eliminated during pellet delivery. Dr. Aldridge has recently purchased an ultrasonic detector, which we plan to use to monitor noise in the ultrasonic range.

We were not able to find latex tubing with ½" inner diameter at the hardware store, so we instead used a slightly less quiet piece of plastic tubing. If laboratory testing indicates that the noise of the tubing is a problem, we plan to order latex tubing to reduce the sound.

Based on the requirements of our sponsor, twenty four preloaded pellets should be a sufficient number of pellets for any experiment. However, since we are using half stepping of our DC stepper motor, it would be possible, by modifying the disk, to increase the number of preloaded pellets from 24 to 48.

CONCLUSIONS

Through our information search into the field of rat research and testing suppliers and meeting with our sponsor we have succeeded in determining the goals of our project. We have gained insight into the field of rat research. We have been able to determine the customer's requirements and establish the engineering specifications. For the scope of our project; given no other products to compare to the QFD may not be totally reliable. However the steps used to make the QFD, specifically generating target values helped us better understand our goals. From these specifications we will now brainstorm and begin designing a model to meet the requirements of a silent pellet dispenser. We plan on making our design a less expensive than a combination of commercial products available.

The dual disk—motor module—conveyor belt concept is our best option, based on our concept evaluation and comparison. In theory, this concept will perform all the required functions of the current setup while eliminating any sound cues by masking the sound with the conveyor belt motor. It should easily fit the size constraint as the preloading device can be set up outside the cage and the conveyor belt can be built to deliver the pellets to a point that the rats can receive them. We will now proceed to a final design and prototype manufacturing.

Upon further research, rapid prototyping, and engineering analysis we have decided to modify our original selected concept a great deal. We have eliminated the conveyor belt concept and replaced it with tubing. We have added a frame to our design and reduced the number of disks to one. We have selected the appropriate materials and parts to build our model. When considering these parts and materials we looked at how they would affect the ability to manufacture and assemble our model, as well as effects on the environment. Also we looked at the possible failure modes. Our final design has very limited possible failure modes. Our final design appears to satisfy all of the requirements that we set out to meet. We now have the majority of parts and materials to begin constructing our final model.

Now that we have finished our model and presented it at the design expo, we will continue to make some modifications to it to make it ready for final use in Dr. Aldridge's lab. Dr. Aldridge appears to be eager to implement our design in his lab.

BIOS

Ben Frey
I am 21 years old. I am originally from Cincinnati, OH but have lived in Bloomfield Hills, MI for the last eight years. I originally chose mechanical engineering, because I wanted to work in the automotive industry, but now in addition to my interest in the automotive field, I have developed an interest in thermodynamics. I have had internships involving both fields. After graduation I plan to join the Air Force as an officer. I plan to serve in the civil engineering field of the Air Force. I currently play rugby for the University of Michigan and have been playing for four years. I am the social chair for the team and helping to plan a spring break trip to Argentina this year. I also work as a delivery driver for Tios, a Mexican restaurant in Ann Arbor.

Daniel Kresge
I am twenty two years old and grew up in Newton, NJ. I came to the University of Michigan as an LS&A student, as I had not yet decided whether to pursue a major in the College of Engineering or the Business School. After a year of college, I decided that I am more interested in a career related to engineering, so I transferred to the ME program. I am currently a senior and I am in my final semester at the University of Michigan. After I graduate this April, I plan to return to New Jersey to pursue my career. I have an interest in biomechanics and psychology, so I would like to work in an engineering field related to biology.

Xiaoming Tang
I am an international student from Shanghai China. Before my transfer to the University of Michigan in the winter semester of 2006, also major in mechanical engineering, I studied in the Shanghai Jiaotong University. I chose mechanical engineering because I don't like electronic engineering and computer science while engineering school is considered to be the only destination for all the smart boys in my family. I am now applying for several graduate schools in the United Sates and willing to do some research in the fluid field especially about micro fluid. After my graduation, it might be 5 or 6 years later, I plan to work in the R&D department for some companies and maybe teach fluid and do research in some college in China. After my retirement, it might be 30 or 40 years later, I plan to write a book of the good times I am now living.

Min Zhu
I was born on Jan 1, 1985 and grew up in Shanghai, China. I transferred to University of Michigan from Shanghai Jiao Tong University in the winter semester of 2006. I have a quite general interest in mechanical engineering and especially enjoy dynamics and design. My research and intern experiences are mostly related to fluid mechanics and my research interest for graduate study is energy technology. However, for the ME 450 project, I do not want to limit my choice to the areas that I have previous experience and determine venture into the topic of haptic devices to broaden my view and explore my interest in this field.

ACKNOWLEDGMENTS
We would like to acknowledge Professor Gillespie, Dr. Wayne Aldridge and his staff for their assistance on this project. We are also grateful for the help from the instruction team of professors and our GSI. We would like to thank the members of ME 552 for their assistance in electrical interfacing.

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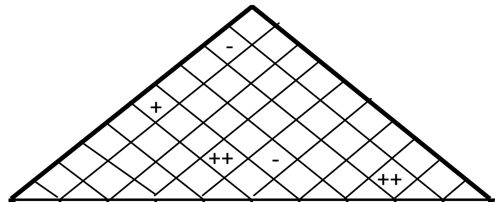
APPENDIX A

QFD

Relationships

- ++ Strong Positive
- \+ Medium Positive
- \- Medium Negative
- \- - Strong Negative



Benchmarks

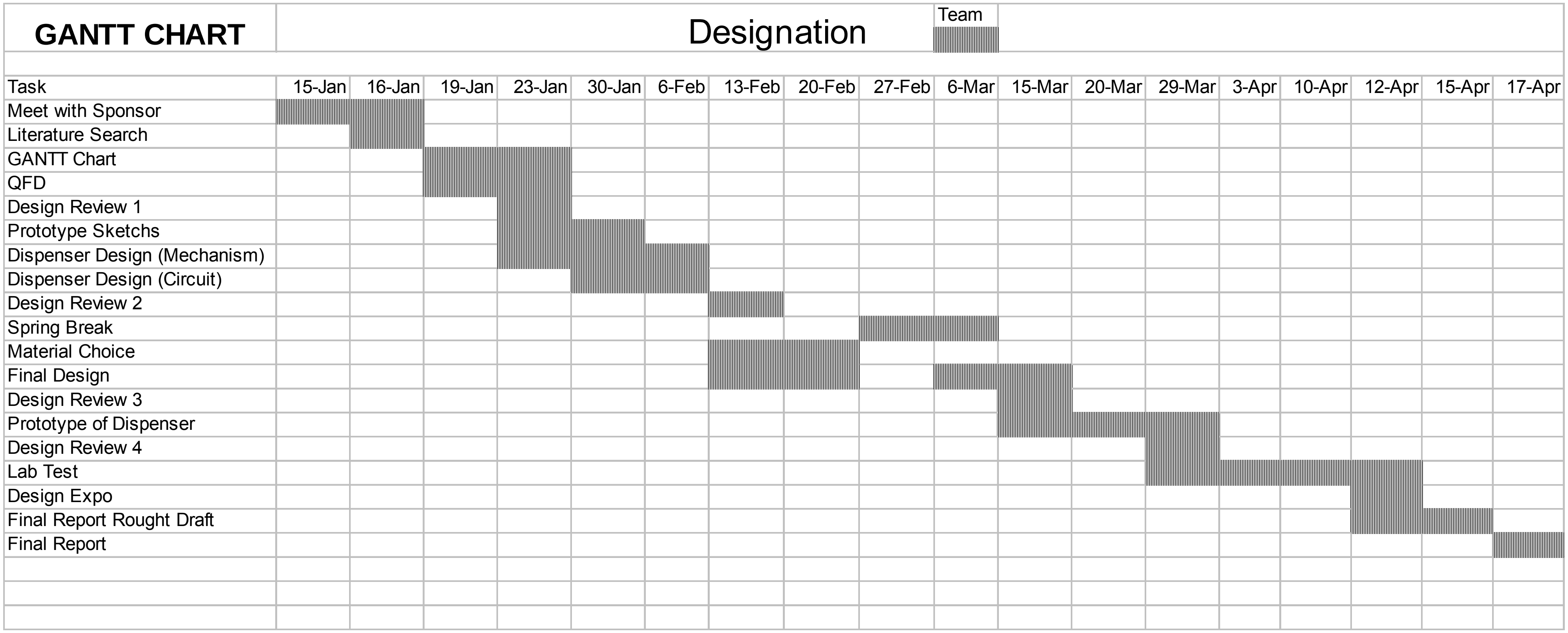
	Weight*	Noise of the release mechanism (mainly motor noise)	# of sensitivity settings of trigger mechanism	Release mechanism precision	Total # of pellets dispensed before failure	Longest dimension	Motor life	# of modules	Release time	Speed of motor	# of I/O ports per module		*Current Setup*		
Eliminate unneccessary cues	10	9					1		3	1			1		
Releases sugar pellets smoothly	10			9					3				5		
Consistant pellet dispersal location	9			9					3	1			5		
Minimal response time	8			1					9	9			3		
Multiple fuctionality	8		9					9			3		2		
Durable and repeatable operation	8				9	3	9						5		
Fits size constraint	6					9		3					5		
Compatible to computer interface	6										9		5		
Inexpensive	4	3					3	3		3	3		2		
Easy to modulize	3					3		3					2		
Measurement Unit		Db	#	mm	#	in.	cyc.	#	ms	rpm	#				
Target Value		0	3	5	10^5	14	10^10	3	300	10	1				
Importance Rating		5	3	1	10	9	8	5	2	5	4				
Total		###	###	###	###	###	###	###	###	###	###				
Normalized		####	####	####	####	####	####	####	####	####	####				
Current Setup		40	-	5	-	14		1	-	-	1				

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

***Weights are figured on a scale of 1 to 10**
(ten being most important)

APPENDIX B

GANTT CHART



APPENDIX C

DUAL MOTOR MODULE CONCEPT

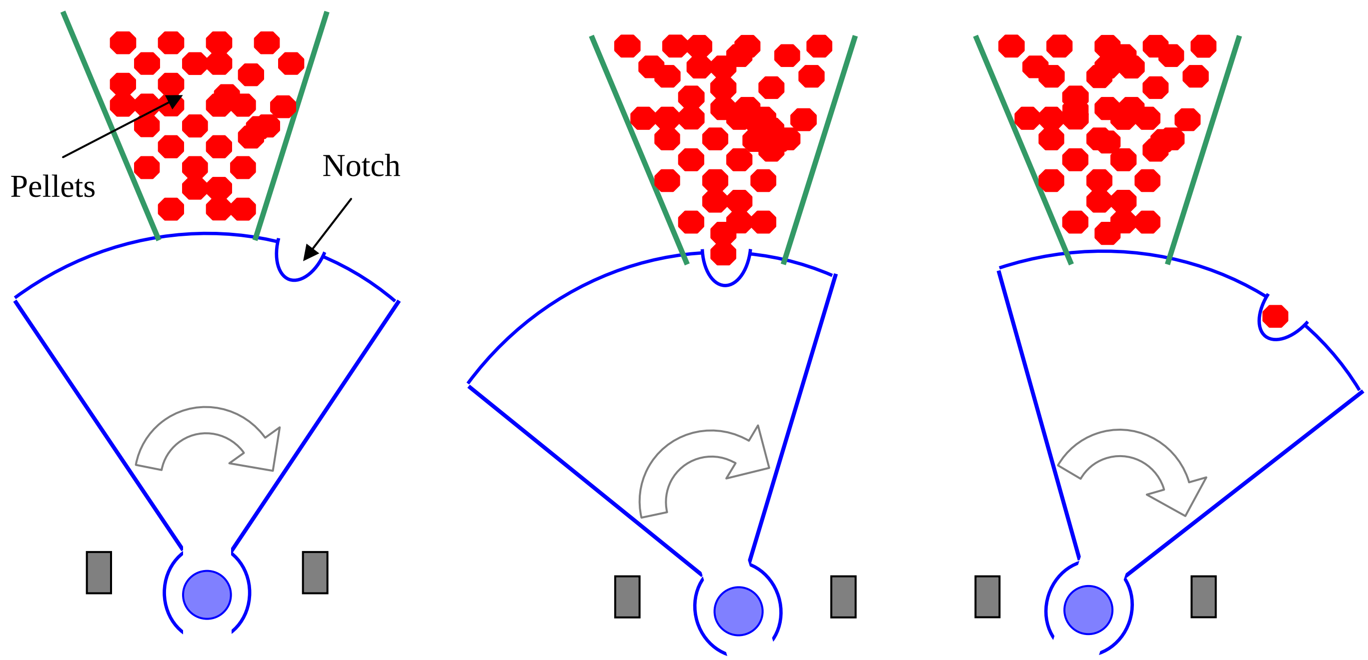


Figure C.2 Preloader process shown

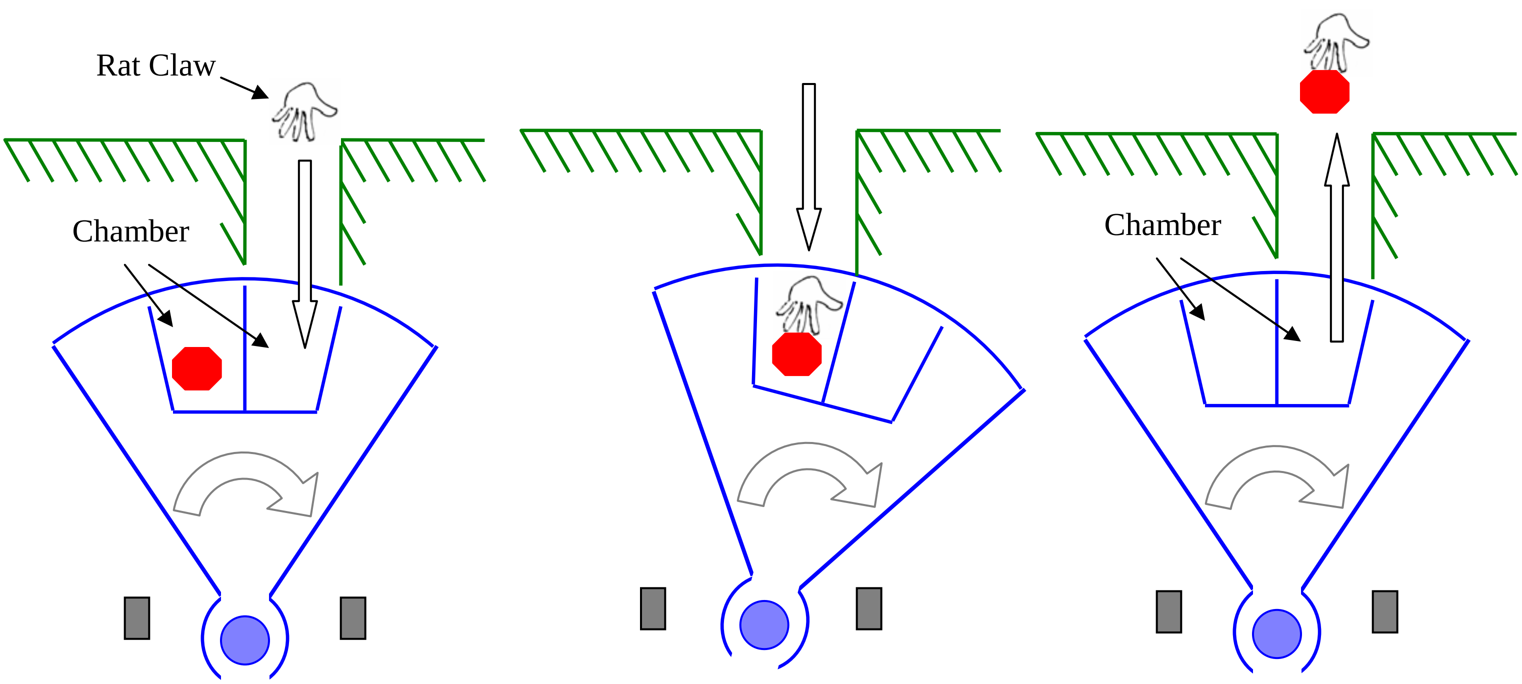
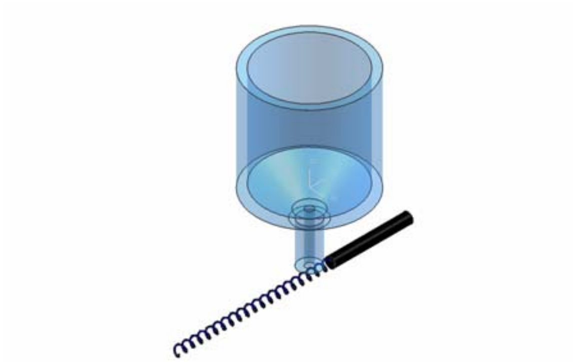
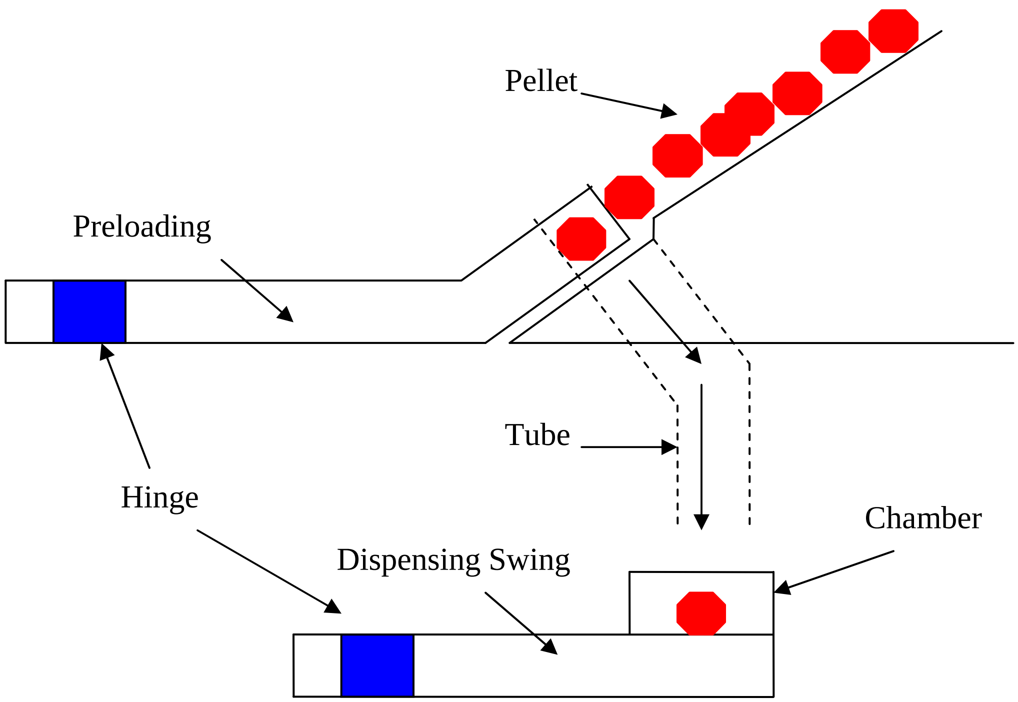


Figure C.3 Delivery process shown

APPENDIX C (Cont.)
OTHER CONCEPTS



Helix coil preloader concept



Dual motor module concept diagram

APPENDIX D

TWO DISK-MOTOR MODULE-CONVEYOR BELT CONCEPT SKETCHES

(a)

(b)

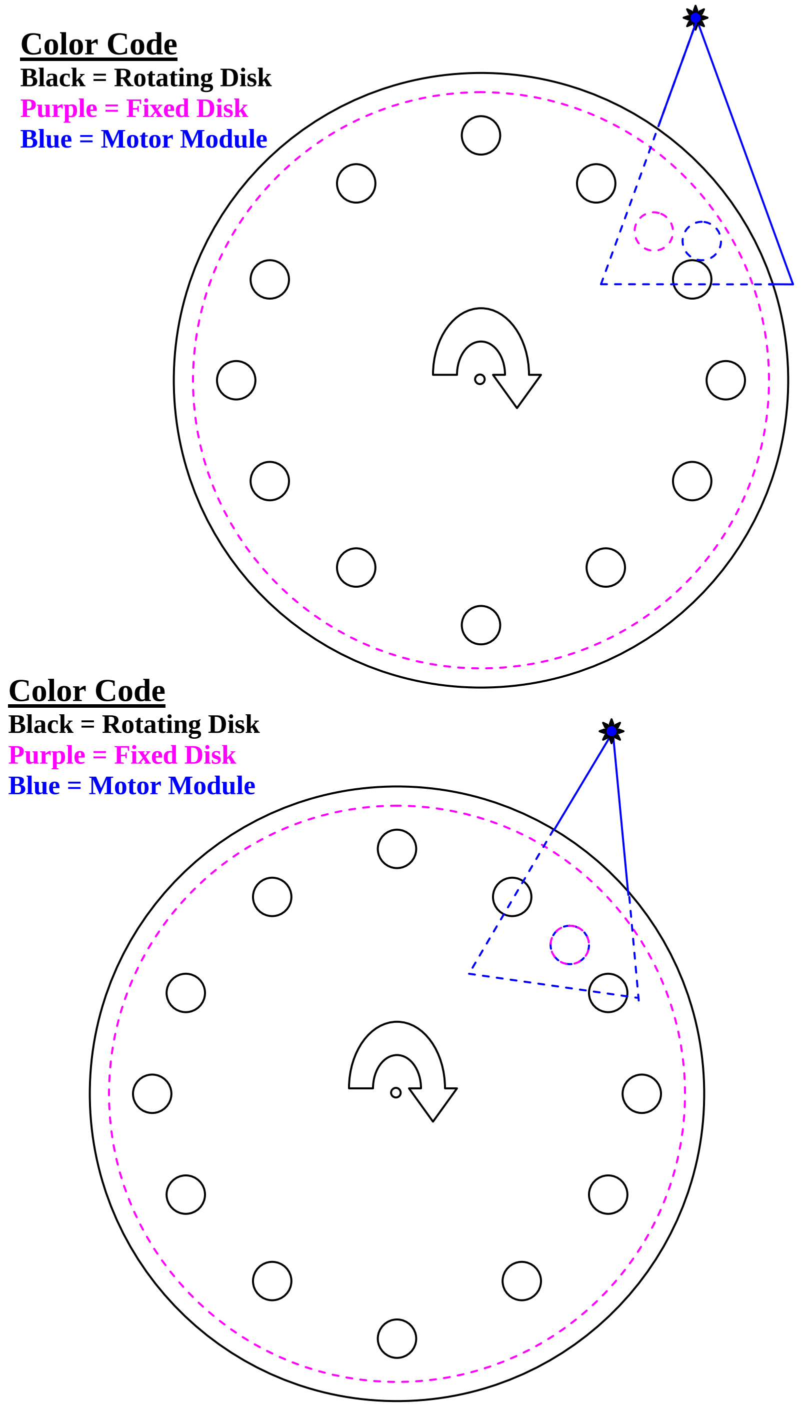
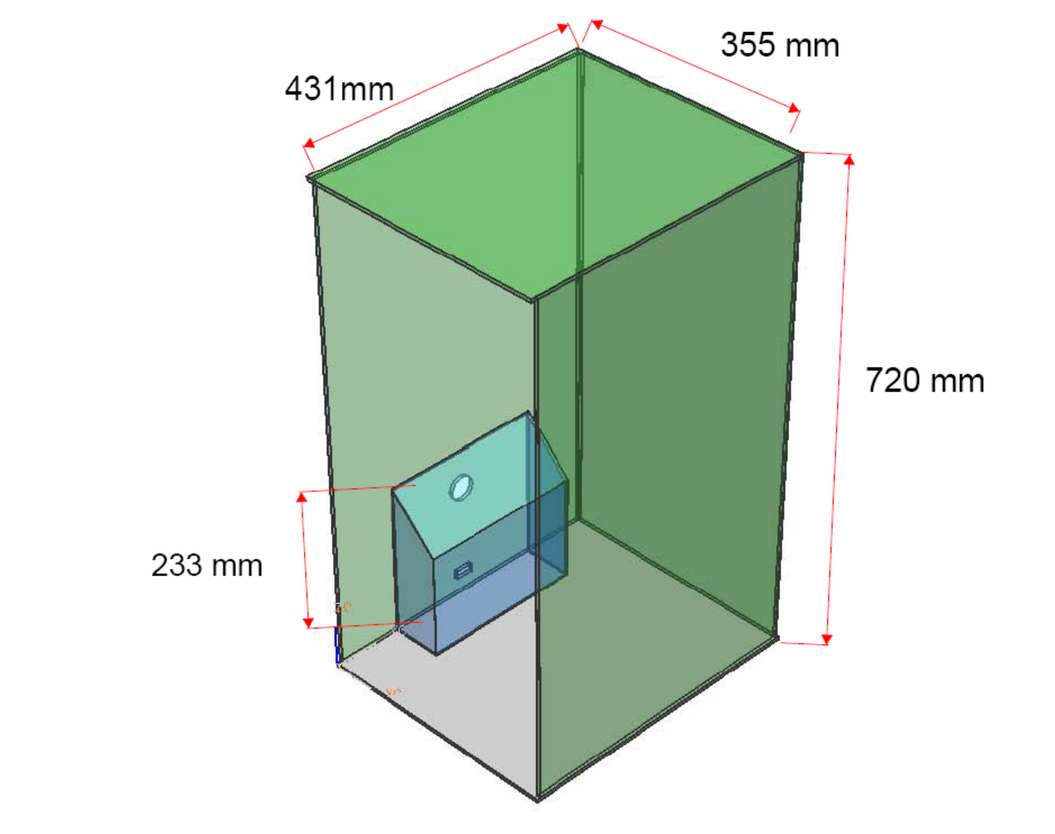


Figure D.1. Top view of disks with armature in (a) unaligned and (b) aligned positions

APPENDICE E

Cage Dimensions



APPENDICE F

Target disk RPM and number of pellets

The number of pellets released per minute if the machine were free to operate can be estimated using Equation A.F.1, given the following two parameters: constant RPM of the rotating disk and number of pellets per revolution (or number of pellet holes). The time per pellet release can then be found by taking the multiplicative inverse of the calculated value for pellets per minute and converting it to seconds.

$$\frac{pellets}{\min} = \frac{revolutions}{\min} \times \frac{pellets}{revolution} \qquad \textit{Equation A.F.1}$$

For our concept, we seek to minimize the occurrence of multiple pellet release during a single operation cycle—armature moving into and out of aligned position—so we designed for a minimum rate of time per pellet release. A rate of at least 2 seconds per pellet was targeted as sufficient for continuous and repeatable operation of the device. Based on the engineering specifications, optimal design should achieve the target rate while maximizing number of pellets. Table A.F.1 shows calculations for pellets per minute and seconds per pellet for several values of RPM and number of pellets. Optimal concept design: 2.5 RPM and 10 pellet holes.

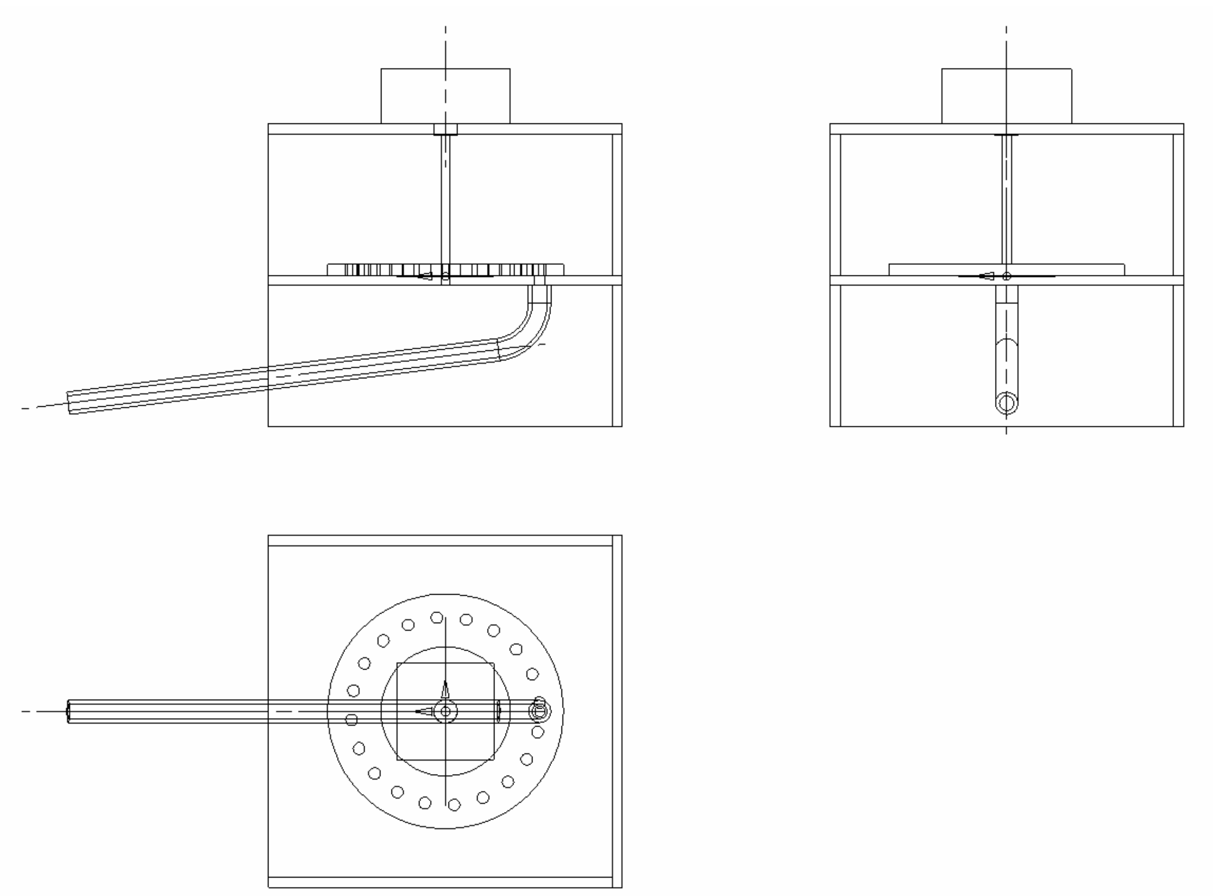
RPM	Number of pellets	Pellets per Minute	Seconds per Pellet
10	20	200	0.3
10	10	100	0.6
10	5	50	1.2
5	20	100	0.6
5	10	50	1.2
5	5	25	2.4
2.5	10	25	2.4

Table A.F.1. Calculated rates of pellet release per unit time based on RPM and number of pellet holes.

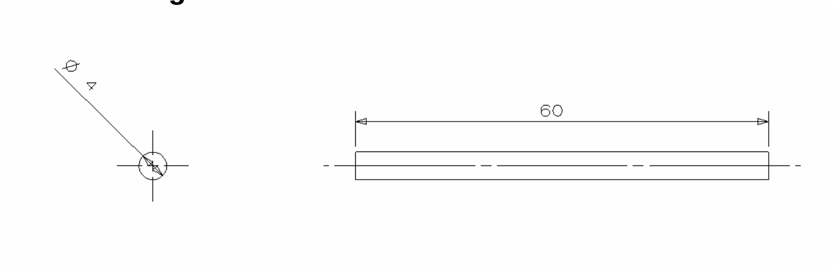
APPENDIX G

CAD Models and Engineering Drawings

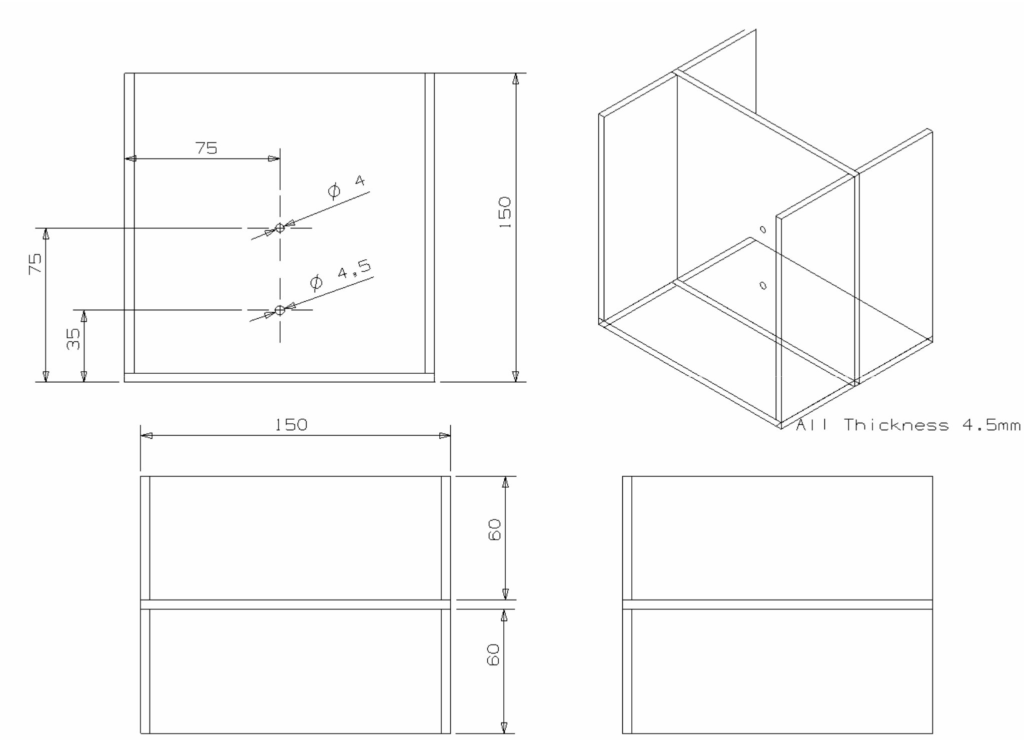
Assembly Drawing



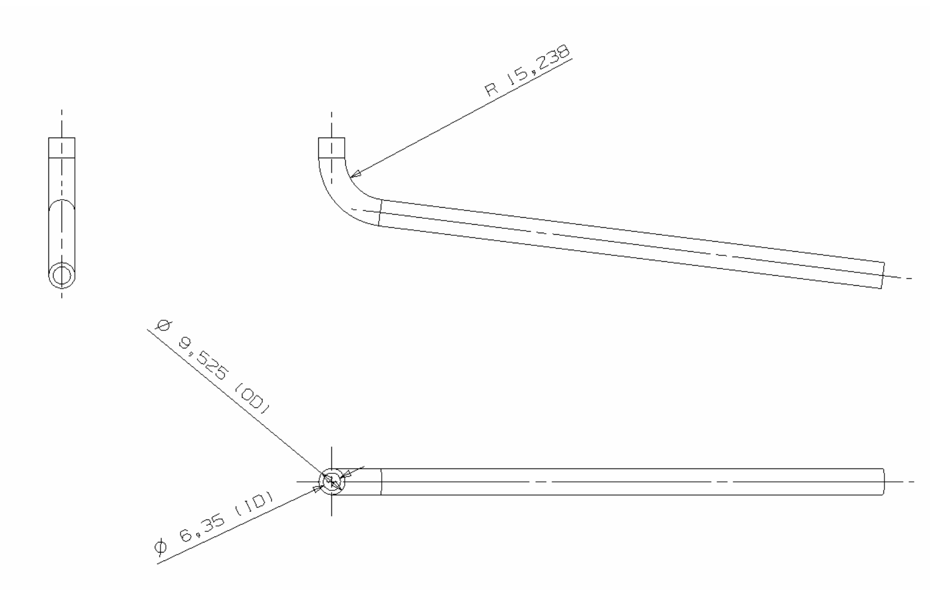
Axel Drawing



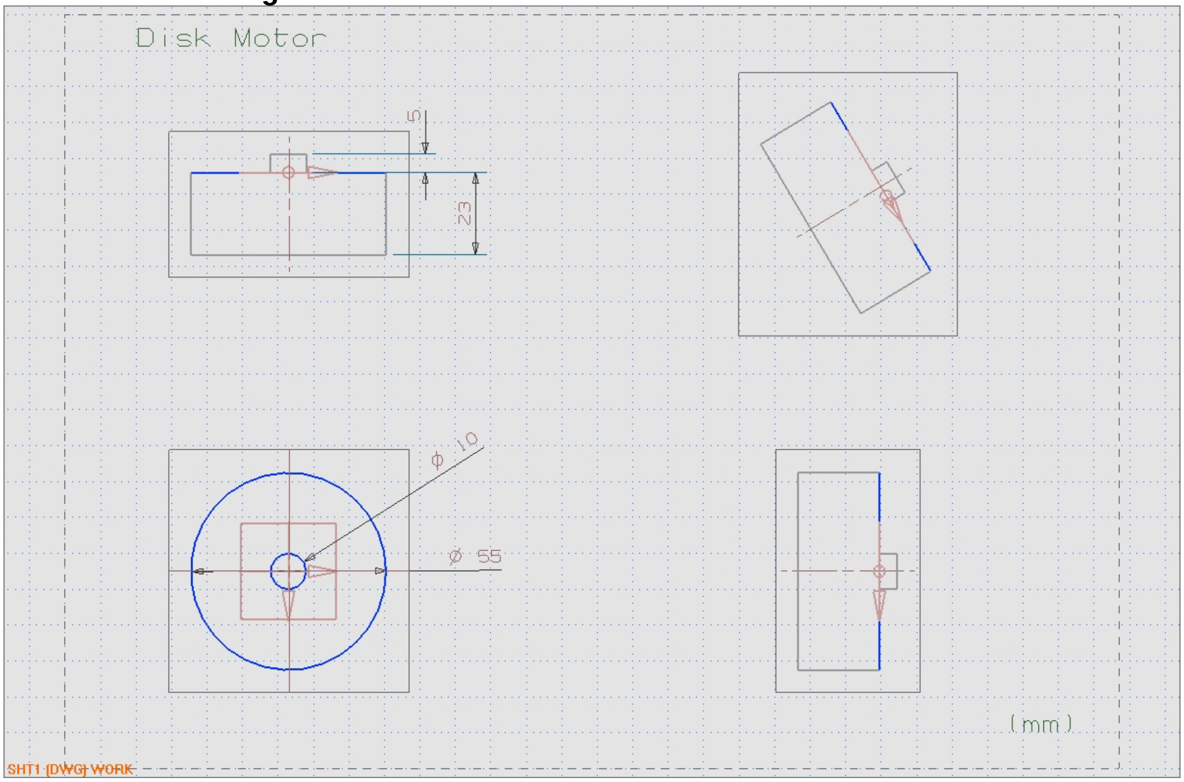
Frame Drawing



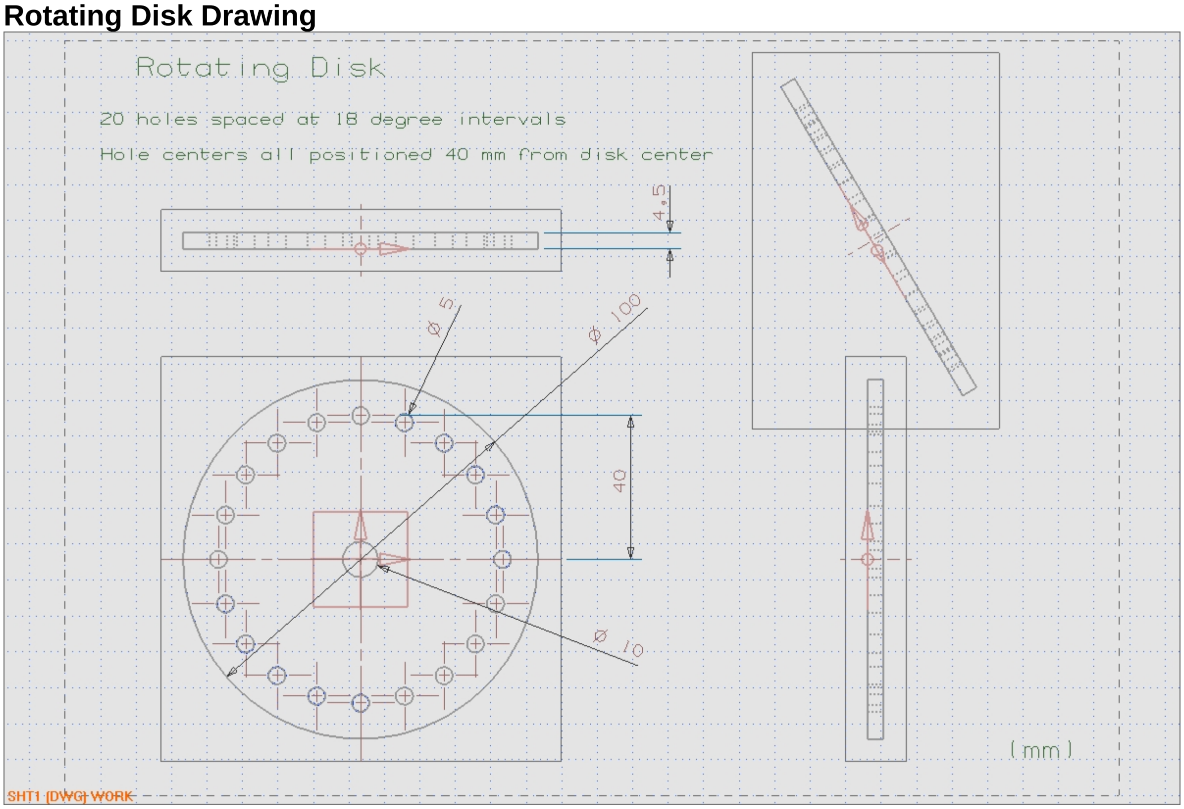
Tube Drawing



Disk Motor Drawing



Rotating Disk Drawing



Rotating Disk Drawing