Safety Door

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This document walks through the design and assembly for the safety door used on the Operant Cage at the Donaldson Lab, as a part of the University of Colorado Boulder. Implemented on all the operant designs, the door contains a built in safety feature to make sure that an animal will not get crushed by the force of the closing door.

I. Introduction

In order to implement a reward system in behavioral testing where the voles must learn to access a reward through an operant task, it is necessary to close them off from the reward as a baseline. Then, when they have the opportunity, they can perform the operant task and gain access to the reward. In most cases, the Donaldson Lab rewards the voles with the ability to see and interact with their partner animal, and uses and operant task of a lever press.

As a result, the lab needs a way to separate the test animal from the reward animal as a baseline, and then remove that separation once the test animal performs the operant task to get its reward. A few designs were tested before the safety door including: lowering the reward animal into the cage on a harness, and tilting a whole side of the cage up to force the reward animal into the same space as the test animal. But, simple sliding door design with a safety switch was settled on for this purpose. This design minimizes moving parts, and utilizes a relatively small servo since there is not that much weight that needs to be moved.

II. Operation & Design

The door works through a relatively simple movement paradigm. A full assembly of the door system is shown below, as it would look like in the Operant Cage environment.

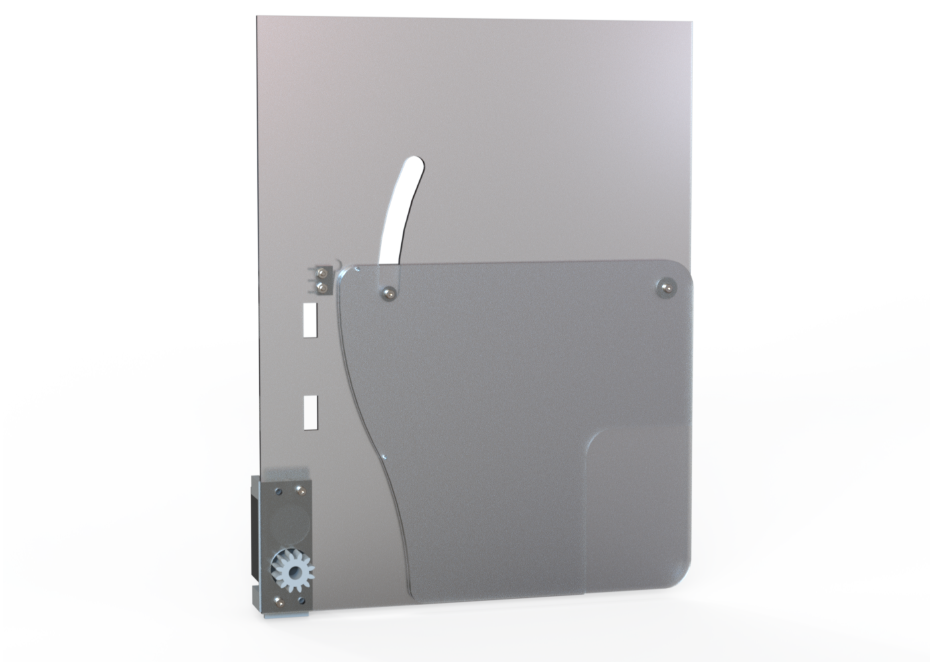


Fig. 1 Isometric view of the full door assembly

Here, there is a continuous rotation servo mounted at the back of the door, with a pinion attached on the opposite side of the door. This pinion connects to a corresponding rack, turning the rotational movement of the servo into linear movement to move the door in and out. This linear movement will block off the extremities of the Operant Cage where the reward animal is located. In this way, the door can block and reveal the reward for the test animal on any command the scientist specifies.

A. Gear Design

The lab chose to use a standard rack and pinion design in order to move the door back and forth. To calculate the necessary gear values and find the correct servo, a few calculations need to be done on the door. First, the total mass of the door is found through SolidWorks to be $M_{door} = 401.46g$ (metric units will be used for all engineering calculations here). So:

$$\begin{aligned} F_{weight} &= M_{door} * g \\ F_{weight} &= 4.0146kg * 9.8\frac{m}{s} \\ F_{weight} &= 39.343N \end{aligned} \tag{1}$$

This is the weight of the door, and therefore the force that needs to be overcome in order to move the door forward. Notice that we are negating the

Now, using the CR1425-HR servo from Hi-Tec [1], we know the max torque it can apply (at 4.8 volts) is $\tau = 2.8kg - cm = 0.028kg - m$. With this, a relation between applied torque and linear acceleration can be found, which will outline the design space.

The first known equation is to determine the tangential force that needs to be applied.

$$F_T = m_{door} * g * \mu + m_{door} * a_l \tag{2}$$

Here, F_T is the tangential force, $g = 9.81\frac{m}{s}$ is the acceleration of gravity. $\mu = 0.8$[**?**] of acrylic on acrylic, and a_l is the linear acceleration. In addition, the torque on the pinion, τ_p, can be defined as:

$$\tau_p = F_T * r_p \tag{3}$$

Here, r_p is the radius of the pinion. Now, these equations can be combined and reduced into Eq. 4.

$$\begin{aligned} \tau_p &= F_T * r_p \\ &= (m_{door} * g * \mu + m_{door} * a_l) * r_p \\ &= (m_{door} r_p) * (g\mu + a_l) \end{aligned} \tag{4}$$

With this relation, all the values are added to the equation and it is reduced to Eq. 5.

$$a_{l_{max}}[\frac{m}{s^2}] = \frac{\tau_p}{0.06117} - 7.848 \tag{5}$$

This equation shows how aggressive the acceleration of the servo is with the mass properties of the door. Here, it is clear that the servo will provide more than enough to rapidly bring the door up to speed.

As a note with this, the number of teeth on the pinion was simply decided based on a fairly standard value that strikes a balance between connection to the rack, and strength of each individual tooth.

B. Safety

Since the servo can provide so much torque to push against a stopping force on the door, some sort of safety mechanism is necessary to keep the voles from getting stuck in between the closed door and the wall. If allowed, the servo has more than enough torque to seriously injure an animal. This provides an interesting problem though where the system needs to account for anything getting stuck along the door axis, but also completely close off the chamber when nothing is stuck.

As a result, it was decided to have part of the door break or move away, to provide space for an animal to free itself before the door continues to close. With that decided, the door simply uses the force of gravity to bring the sliding mechanism back to its resting state. In this fashion, only the force of gravity on the mass of the sliding mechanism needs to be counteracted. Figure **??** shows the design of the safety mechanism used, and how it moves back and forth.

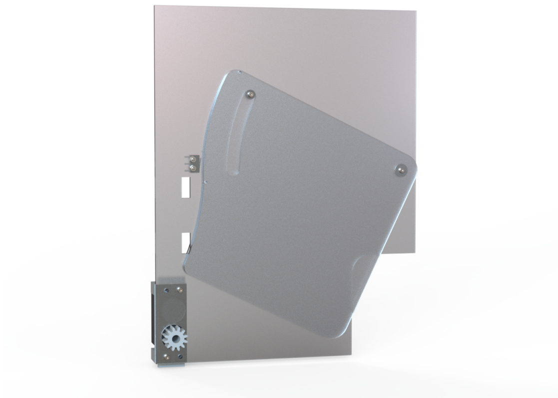


Fig. 2 Safety Triggered

Fig. 3 Fully closed door

The forces at work here are relatively simple since there are no external forces acting on the system. The only calculations that need to be done are finding the rotational force (moment) that the mass of the safety doors create as a result of gravity. Basically, a moment is defined from Equation 6, where F_p is the perpendicular force to the distance d from the rotation point.

$$M = F_p d \tag{6}$$

Then, defining F_p requires a little bit of trigonometry, and can reduce down to Equation 7.

$$\begin{aligned} cos(\theta) &= \frac{F_p}{F_g} \\ F_p &= F_g cos(\theta) \end{aligned} \tag{7}$$

Thus, the final moments is reduced as a function of the angle the moment arm as seen in Equation 8.

$$M = F_g cos(\theta) d \tag{8}$$

Now inserting the values found through SolidWorks about the mass properties of, $d = 0.09818m$, $\theta_0 = 66.168\,\text{deg}$, and $F_g = m_{safety} * g = 1.689N$, the starting forces that need to be counteracted are outlined in Equation 9.

$$\begin{aligned} M_0 &= 1.689N * cos(66.168\,\text{deg}) * 0.09818m \\ &= 0.067Nm \\ F_p &= 0.682N \end{aligned} \tag{9}$$

Both of these values represent the force the animal needs to withstand to trigger the safety mechanism, and these are both relatively small and well under any dangerous force.

It is also important here to note the drawbacks and issues with this design. In the full assembly in Figure 1, the switch placed high up on the door to avoid fit issues where the switch will not run into anything on the ground. This creates an issue though where, the higher up the sidewall something is pushing, the less room an animal has to escape. So, it is possible that with tall headmounted gear, or if an animal jumps up at the wrong time, it could get stuck in the closing door and not trigger the safety switch.

Next, in the calculations of force here, friction between all the panels was not accounted for. This is because the force of friction of the acrylic panels on each other can be highly variable and changes depending on how tight everything is screwed together, any moisture that is between the panels, or where any sort of liquid acting as an adhesive gets stuck in between like cleaning solutions.

III. Assembly

Here, the process of assembly will be outlined as well as some tips to keep in mind along the way.

Basically, the door assembly is split into 3 parts: the main panel that the torque force is acting on, and the 2 sliding panels on each side of the main panel that make up the safety mechanism.

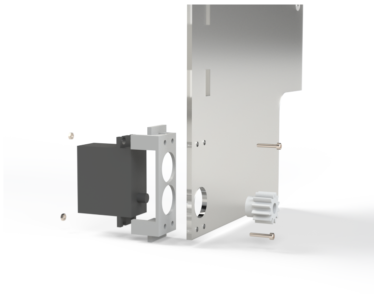


Fig. 4 Center panel of assembly

Fig. 5 Outside safety panels

Fig. 6 Safety panel secondary view

A. Main Panel

Figure 4 shows an exploded view of how the servo is connected to and mounted on the door. To do this, two 12mm M3 screws tighten the servo itself to the mount, and through the connection holes on the door. On the opposite end of these screws two M3 nuts should be placed in order to secure the bolt. It is important here that the screws are both placed above the servo so that they do not interfere with the triggering of the door state switch. Also, make sure that the flange on the servo mount is positioned so that it is farther towards the back of the door. This ensures that the door state switch is triggered at the correct time.

Once these are put on, the pinion can be attached to the opposite side of the door as the servo is on. Following a similar process as in the Retractable Lever Documentation [2], the gear adapter should be sanded down to fit inside the pinion, and then glued in to secure it. This gear adapter attaches straight to the gear on the servo, and the pinion can be secured. To make sure the pinion stays on the servo, a screw (that comes with the servo) can be threaded through the front of the pinion and into the servo. This ensures that, in response to excess torque from the servo, the pinion does not dismount from the gear system.

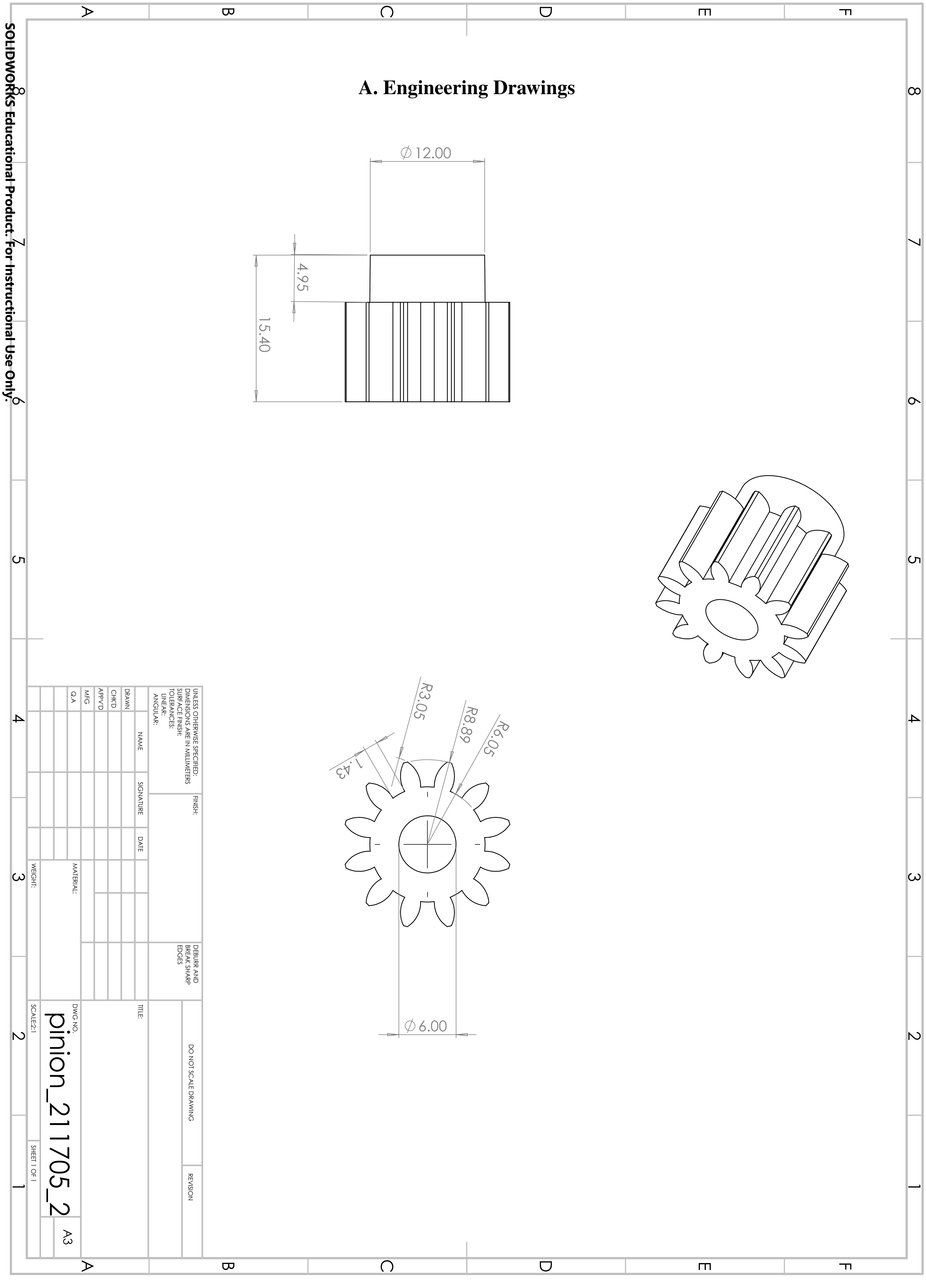
B. Safety Panels

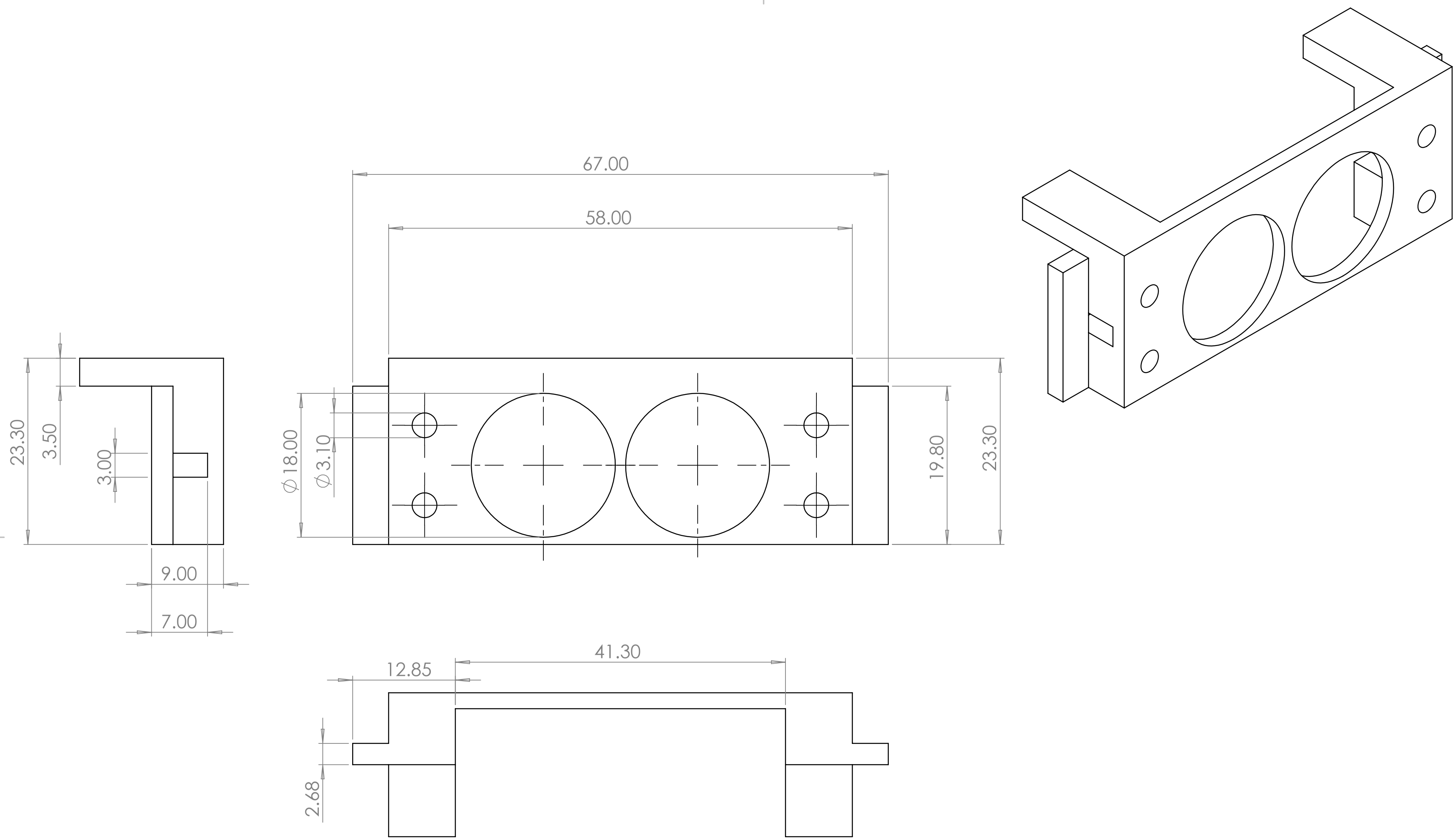
To finish the door assembly, the safety panels are screwed into opposite sides of the main door panel. An exploded view of this is shown in Figure 5. There are two holes here for a nut and bolt assembly used with M3 screws and nuts. On the front, the three holes line up directly and an M3 screw should be threaded through and secured with a lock nut on the back side. Then on the back, an M3 screw should be threaded through one panel, into a 3D printed space, and through the second safety panel. The spacer is then set into the movement track, and the screw secured with a lock nut again.

With both of these screws, it is very important not to over tighten the nuts so that there is not an excess amount of friction occurs between the panels. If there is, this would stop the safety mechanism from working properly and could result in animal injury. So, make sure the lock nuts sit against the panel, but do not tighten it further than simply resting against the face.

Lastly, the safety switch can be mounted on the back with two M2 screws and nuts, and placed so that the curve of the switch is pointed upwards. To test the friction of the door, once everything is assembled simply slide the panels up with you hands, and let the force of gravity take over. If the door does not fall all the way down, there is too much friction between the panels and the nuts should be loosened until the safety panels fall freely under the force of its own weight.

A. Engineering Drawings





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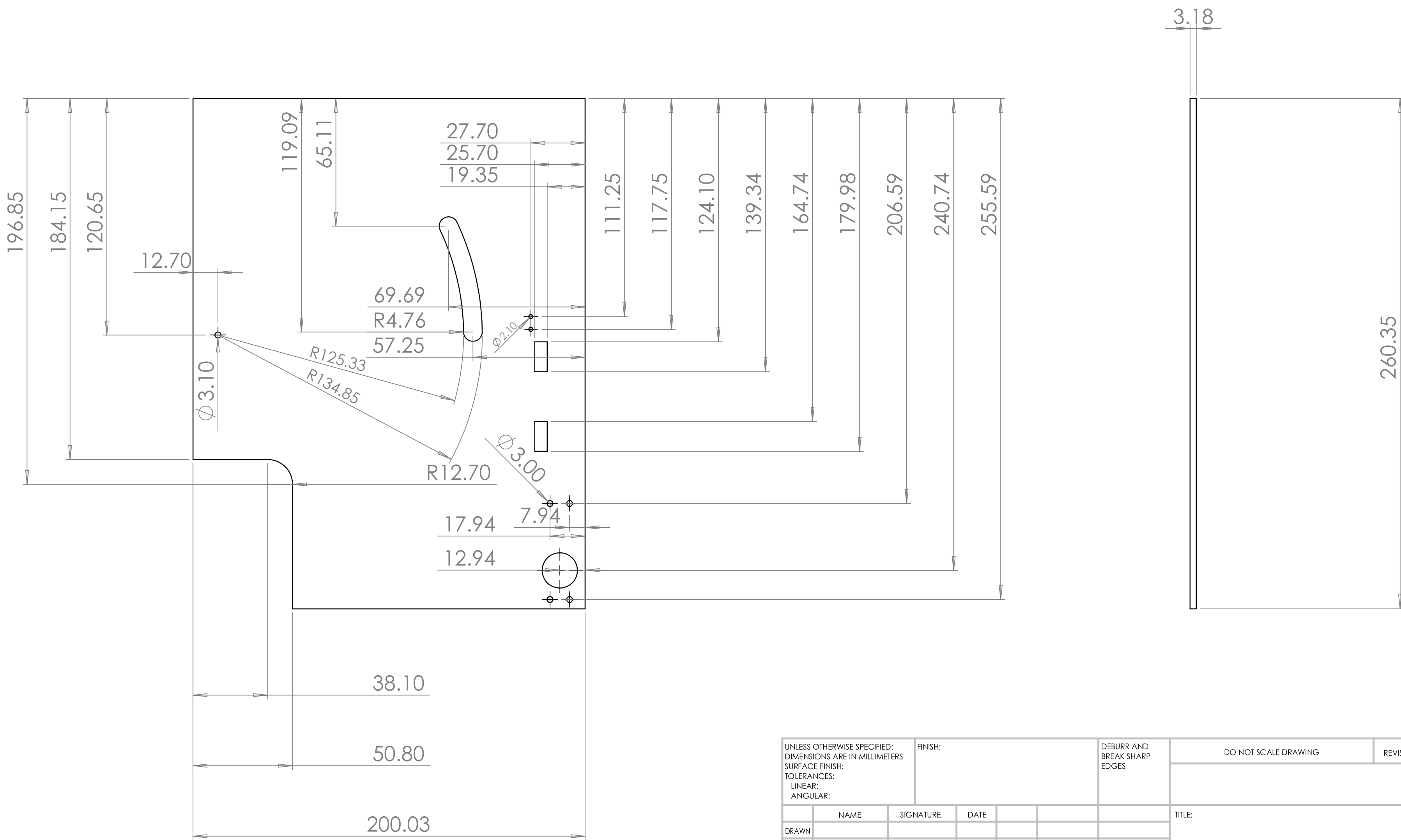

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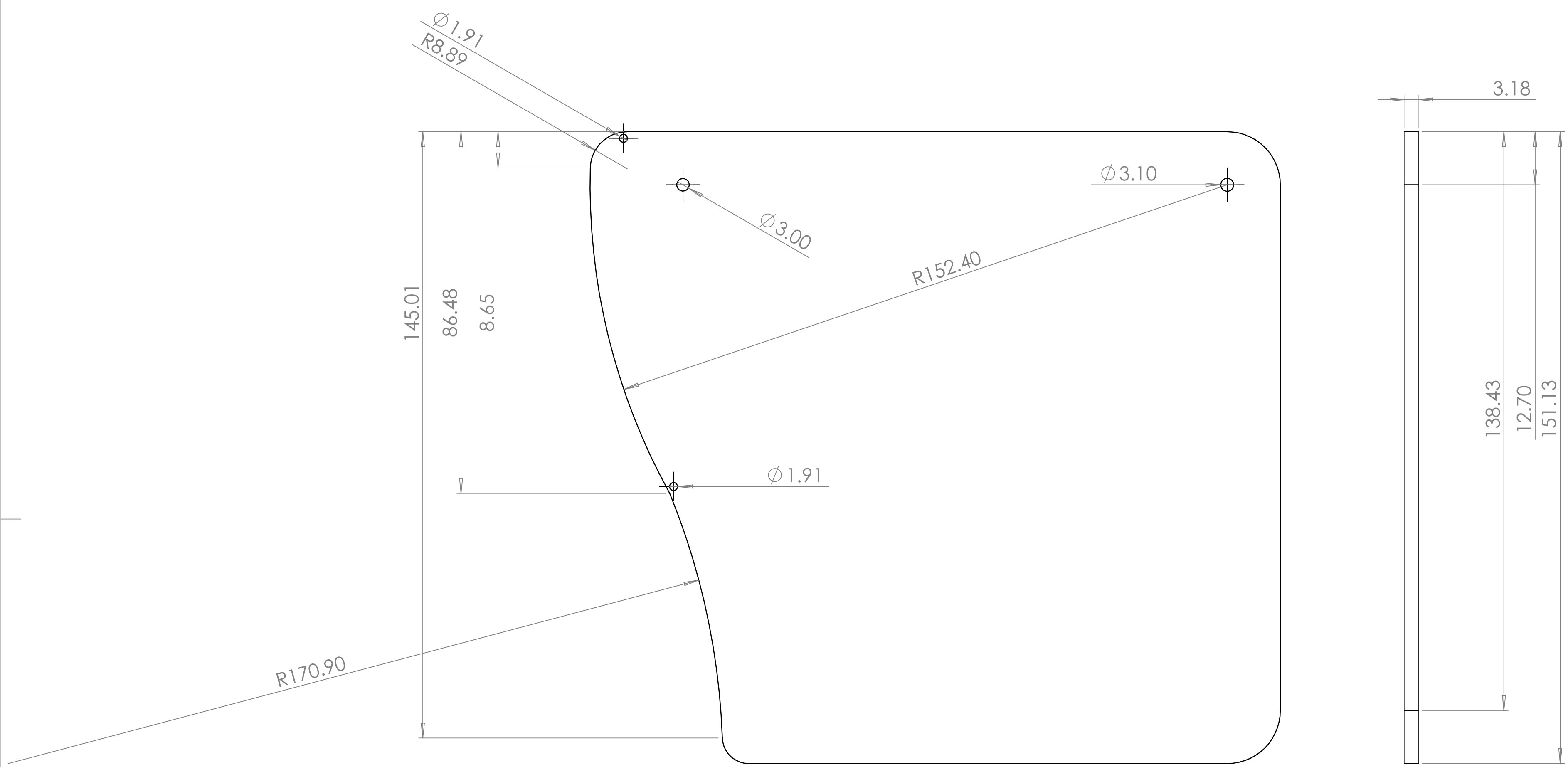

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Q.A				MATERIAL:	DWG NO. 2TiltCageV2_doorPanel	A3
				WEIGHT:	SCALE:1:2	SHEET 1 OF 1

B. Bill of Materials

Name	Quantity	Price (if applicable)	Manufacturer	Part No.
Main Panel	1	N/A	In House	N/A
Safety Panel	2	N/A	In House	N/A
M3 x 16mm Screw	2	$7.09 per 100	McMaster Carr	91292A115
M3 x 12mm Screw	2	$6.00 per 100	McMaster Carr	91292A114
M3 Nut	4	$4.73 per 100	McMaster Carr	91828A211
M2 Screw	2	$10.34 per 25	McMaster Carr	91292A031
M2 Nut	2	$6.14 per 100	McMaster Carr	91828A111
Servo Mount	1	N/A	In House	N/A
Hi-Tec HSR-1425CR Servo	1	$21.99	Servo City	31425CR
Pinion	1	N/A	In House	N/A
Pinion Mount	1	N/A	In House	N/A
Door Spacer	1	N/A	In House	N/A

Acknowledgments

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References

[1] ServoCity, "HSR-1425CR Servo," https://www.servocity.com/hsr-1425cr-servo/, 2023.

[2] Gabriel Chapel, R. C., "Retractable Lever Documentation," https://github.com/donaldsonlab/Operant-Cage/blob/main/V2/Documentation/Retractable_Lever_Documentation.pdf, 2021.