Retractable Lever

Donaldson Lab, University of Colorado Boulder

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Abstract

This document details the retractable levers that are used for behavioral studies in the Donaldson Lab at the University of Colorado Boulder, specifically for the research of prairie voles. These levers are currently used in operant tests in which they reinforce lever pressing by enabling the voles to dispense food pellets and open doors. Here, we will discuss the lever assembly, which was designed to perform reliably and consistently, be easily and intuitively constructed, and present a safe and smooth interaction with the animals.

Introduction

The press of a lever is often used in operant conditioning to reward an animal by dispensing food. In the Donaldson Lab, we also implement levers into social operant paradigms in which they open automatic doors and reward a test subject with access to either a partner or novel animal. Due to the extensive use of these levers in the lab, we developed a custom design, as shown in Figure 1, that can be easily and inexpensively constructed and modified to the needs of the user.

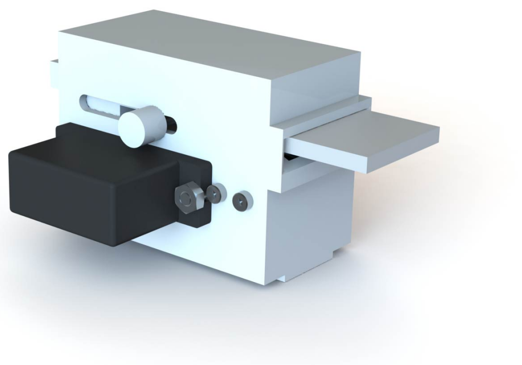


Fig. 1: Retractable lever design (2021)

When connected to an external computer or microcontroller, in our case a Raspberry Pi computer[1], our levers can send high and low digital signals. These provide the frequency and precise time measurements of an animal's individual lever presses, which help quantify their learning and preferential behavior. If a user does not want to permit access to a lever, it can be automatically retracted from the system and then again extended when needed. They can also be intuitively taken apart and reassembled for easy replacement of parts. The design discussed in this document was intended for use with voles, but can also be used with other small animals with little to no modification

This design has gone through several iterations to fix issues including inconsistent performance that interferes with data collection, loud motors that startle the animals, exposed surfaces that voles can chew through, and difficult assembly procedures. The next section will detail the components that comprise the updated lever assembly and how they interface with one another.

Design and Components

For quick and inexpensive construction, the lever assembly is made up of off-the-shelf parts and components that can be fabricated in-house using laser cutters, 3D printers, and a 3-axis mill in the University of Colorado Boulder machine shop. The components are shown in Figure 2 below to illustrate how they interface between one another.

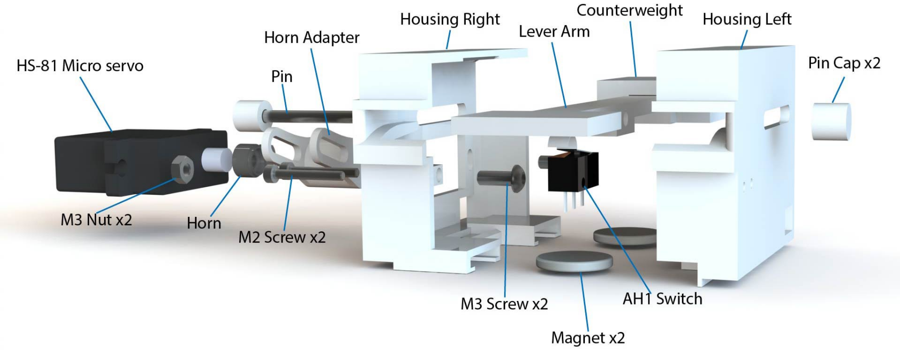


Fig. 2: Exploded view of lever components

When pressed, the lever arm actuates an electronic switch that sends a signal to an external microcontroller. To retract and extend the lever arm, a micro servo motor rotates a horn adapter and pushes the pin that the arm is attached to. These components are all mounted into a protective housing that encloses them using two snap-fit joints. A more detailed explanation of the assembly process is provided later but a description of each component is given in the next section.

Lever Arm

The arm is the only component in the lever assembly that the voles interact with, so it is critical that it can be easily and effectively sanitized and withstand frequent chewing. To accomplish this, we use stock 1"x$\frac{5}{16}$" 6061 aluminum bar[2] and mill it down to the specifications given in Appendix A. The paddle shape of the arm offers a 25.4x20mm surface for the animals to interact with and also provides a surface that can slide along guides in the lever housing to prevent false presses, as discussed in the Lever Housing section. Since average vole strength is not widely known, the lever arm was initially designed through trial and error, obtaining feedback on a collection of sizes until finding a design that was neither too easy nor too hard for voles to press. This arm design has been used in several lever iterations and, due to time constraints and the higher efficiency of 3D printing parts relative to machined parts, has yet to be updated. Updates were instead made to the surrounding components, including housing design and electronic switch model and placement. These changes required careful consideration in order to maintain the same expected static loads on the arm, as illustrated in Figure 3 below.

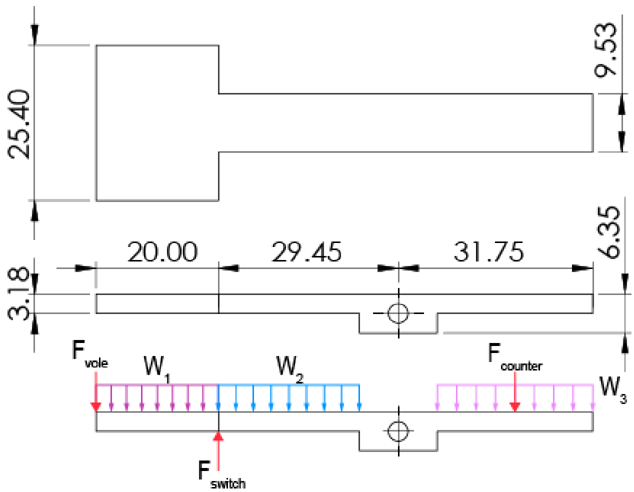


Fig. 3: Simplified dimensions of lever arm [mm] and a static load diagram

The forces marked W are the masses of the individual sections of 6061 aluminum; F_{vole} is the force applied by the vole; F_{switch} is the operating force of the AH1 switch; and $F_{counter}$ is the unknown mass of a counterweight that may be needed to balance the arm. The masses were all derived from the given dimensions and a 6061 aluminum density of $0.00271\frac{\text{g}}{\text{mm}^2}$. The operating force of the AH1 switch, 26gf, was obtained from the part's datasheet[3], discussed further in the Switch section, and the force applied by the vole was calculated with a previous lever iteration as shown in Appendix B. That design required a minimum 12.7gf to overcome the 25g operating force of a D2RV-L13 switch[4], showing that the voles are comfortable with applying a force of roughly 12.7gf. Using conservation of momentum about the pin hole and assuming the angle of the arm has a negligible effect on the static load, we find that a counterweight mass, $F_{counter}$, of 1.5gf would achieve a required F_{vole} of 12.7gf. The AH1 switch datasheet, however, also provides a "release force" of 2.039gf, which is important so that the lever arm returns to its horizontal, unpressed position. Substituting this into the F_{switch} variable and removing the F_{vole} term gives a $F_{counter}$ value of 5.6gf. This makes the required press force, F_{vole}, increase to 14.3gf when adding a 5.6gf counterweight, which has had no effect on animal behavior in our experiments.

Counterweight

As discussed in the previous Lever Arm section, we use a 5.6g counterweight on the back end of the lever arm in order for the arm to return to its unpressed position after animal interaction. When attached, this counterweight has a center of mass inline with the middle of the lever arm's rear end, as indicated by the $F_{counter}$ load in Figure 3. In addition to balancing the lever arm, we also use the counterweight to center the arm within the housing, leaving 0.25mm between the housing walls and the sides of the weight. With a known material density, this is easily fabricated on a 3D printer. We use a Zortrax M200 Plus FDM printer[5] with the 1.75mm Z-ULTRAT material, which is primarily comprised of ABS and has a density of $1.179 \frac{\mathrm{g}}{\mathrm{cm}^2}$[6]. The design is shown in Figure 4 below and the specifications for the Z-ULTRAT-based design are given in Appendix A.

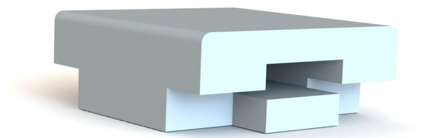


Fig. 4: 3D printed counterweight to balance lever forces

The counterweight fits onto the back of the lever arm and sits flush with its bottom face so that it does not catch on the housing when retracting and extending. The corner cutouts prevent interference with the servo horn adapter when retracting and extending. This design was intended for Z-ULTRAT filament with 100% infill, but it can be modified for any filament by simply changing the top wall thickness until the desired mass is met. In our testing, however, we have found that the mass does not need to be exact for proper lever performance and can vary between 2.039g and 5.6g as long as it is consistent within the testing procedure.

Pin

The pin slides through the horn adapter and the pinhole on the lever arm, allowing translational motion of the arm while also providing a pivot point when the lever is pressed. Due to the small 3mm diameter, we found 3D printed pins resulted in fracture or binding during extension and retraction, so we instead use a 40mm-long 52100 alloy steel dowel pin from Mcmaster Carr[7]. The length is dependent on the 29.9mm width of the lever housing, discussed further in the Lever Housing section, as well as the size of the pin's end caps. The end caps prevent the pin from sliding out of the pinhole and cover 4mm of both ends of the pin, leaving 32mm of the pin exposed. The cap has an internal draft angle to fit tightly onto the pin and can be printed out of any material, though we use PLA or ABS-based filaments. The dimensions for both the pin and the cap are provided in Appendix A and an assembly including the arm, pin, counterweight, and caps is also shown in Figure 5.

Servo and Horn Adapter

The final component involved with the lever retraction and extension is the servo assembly, consisting of a Hitec HS-81 Standard Micro Servo motor[8], a modified servo horn, and a custom horn adapter. This interfaces with the lever arm via the pin, which slides within the slots of the adapter on both sides of the arm, as shown in the assembly in Figure 5. The servo is the source of rotation, which it transmits through the adapter to provide a guide for linear motion of the pin and, correspondingly, lever arm. Similarly to the AH1 switch, as discussed in the Switch section, the servo is connected to a Raspberry Pi computer, however, since Raspberry Pi's do not handle pulse width modulated (PWM) signals well, we also connect an Adafruit Servo Hat [**?**] and an external 5-6V power supply for proper control of the servo. The electronic components we use are discussed in more detail in a separate Operant Cage document and a code sample for controlling a lever is provided in the Code Sample section.

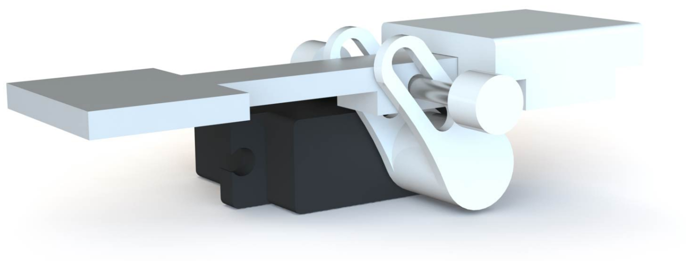


Fig. 5: Servo assembly with lever arm, pin, counterweight, and pin caps

HS-81 Micro Servo

When compared to most micro servos, the HS-81 has a relatively high torque of 3.0 $\frac{\text{kg}}{\text{cm}}$, which prevents the animals from moving the lever arm in any undesired direction. It is also smaller and less expensive than higher torque servos, meaning the lever assembly can be smaller and less expensive. That said, other micro servos, such as the HS-85[9], can be easily substituted with some minor changes to the lever housing, discussed further in the Lever Housing section.

Servo Horn

Servo horns (or arms) are included with servos when purchased and are the components that mesh with the teeth on the output spline of the servo. They typically vary between servo models and have very small features, so we choose to modify these included horns instead of trying to model and 3D print custom ones for every individual servo that we use. This modification only involves cutting away the outer features of a stock horn, as illustrated in Figure 6, until it is completely circular and fits into the socket of the horn adapter.

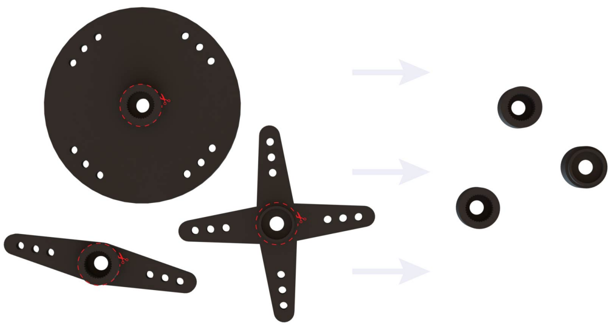


Fig. 6: Stock servo horns (left) with cutting guides that result in a circular servo horns (right)

Servo Horn Adapter

The horn adapter, shown in Figure 7, is a 3D printed component designed to fit on the modified HS-81 servo horn. The material used for this is not critical, so we use PLA or ABS-based filament. The design provides the lever arm with about 22.5mm of travel, which makes the widest portion of the arm accessible to the animals when extended and provides an extra 2.5mm to wiggle and relieve the servo of any residual stall torque. The adapter has two slotted guides that distribute a balanced load on both sides of the pin in order to reduce the applied torque and maintain straight extension of the lever arm. When assembled, there is 0.375mm of space between the slotted guide features and the lever arm to reduce friction and a minimum of 0.4mm between the end of the adapter and the lever housing's interior at all times. If further extension of the lever arm is needed, both the length of the adapter's slotted guide features and the height of the lever housing need to be adjusted to avoid interference. The dimensions for these features are provided in Appendix A

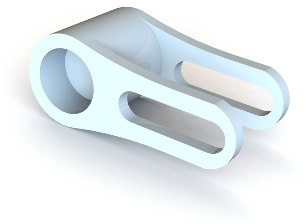


Fig. 7: 3D printed servo horn adapter for HS-81 micro servo

Switch

The component that actually identifies when an animal presses the lever is an electronic switch, or more specifically, the Panasonic AH1684619-A switch[10]. When selecting switches, the most important considerations included the voltage and current ratings, external dimensions, mounting type, termination style, and required operating forces. The voltage and current ratings have to handle a connection to a Raspberry Pi, which can provide a maximum of 5V from a power rail and 16mA from its GPIO pins[11]. The overall size, mounting type, and termination style are not critical features but do drive the design of the housing, so through-hole chassis mounting and solderable terminals are the most ideal. A small external volume is also helpful in keeping the lever assembly as small as possible. As discussed in the Lever Arm section, the operating force is crucial, since it dictates whether or not a vole will press the lever, and we found that an operating force of roughly 25gf is suitable when paired with the lever arm design. This was determined with earlier iterations of the lever that used an Omron D2RV-L13 switch[4], however, when larger quantities of the levers were needed, the AH1 switch was found to be a smaller, less expensive option that satisfied all of the same requirements.

Fig. 8: Panasonic AH1684619-A switch[10]

The AH1 switch, showed in Figure 8, has a chassis volume around 10% of that of the D2RV-L13 and costs about 10% as much as well. It has an operating force of 26gf, holes in the chassis for mounting with M2 bolts, and three solderable terminals. This switch provides options for connecting it as Normally Open (NO) or Normally Closed (NC), so we connect it as an NO switch, like the D2RV-L13. To do this, we solder a ground wire to the *COM* pin and a signal wire to the *NO* pin, as provided in the Figure below.

It has maximum current and voltage ratings of 100mA and 30V, which is plenty for connecting to a Raspberry Pi. Like the D2RV-L13, the AH1 switch also has a simulated roller lever, which helps reduce the friction between the switch and the lever arm when extending and retracting.

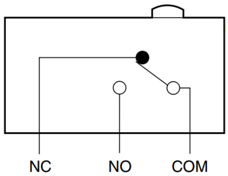


Fig. 9: AH1 Contact Form[10]

Lever Housing

The lever housing encases all of the lever components and provides mounting and guiding features to maintain proper function of the lever. Since it has gone through many iterations, we continue to fabricate the housing using a 3D printer which allows for easy adjustment and modification. To reduce microbial exposure and allow for proper sanitation, we use an ABS-based Z-ULTRAT filament because ABS is less porous than PLA and can be cleaned at a higher temperature. For a more efficient printing process and more intuitive assembly and dissassembly, the housing is composed of two halves that fit together using snap fit joints. Figure 10 shows these joints and other important features within the housing.

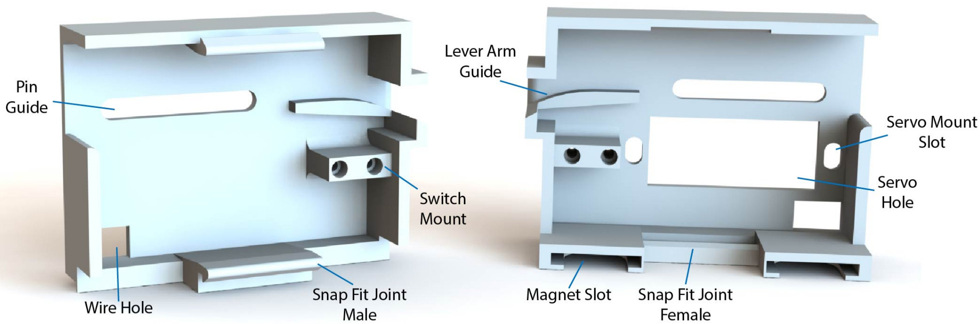


Fig. 10: Left and right halves of lever housing with labeled features

In our operant chambers, the levers sit behind $\frac{1}{8}$" walls and have an $\frac{1}{8}$" lip that aligns flush with the inside of the chamber. This removes any interface between the lever arm and chamber walls, meaning the performance of the lever is solely dependent on itself. The pin guides are slots that hold the pin and lever in place vertically, where the pin caps are attached on the outside to keep the pin from sliding through horizontally. Similarly, the lever arm guide is a sloped extrusion that prevents the lever arm from being pressed until it is fully extended. It is sloped towards the lever arm outlet so that the arm can be retracted smoothly back into the housing. The servo hole and mount slots are for attaching the HS-81 micro servo with M3 bolts and can also fit an HS-85 micro servo, as discussed in the Servo and Horn Adapter section. The switch mounts are extrusions that pinch the sides of the AH1 switch when assembled to prevent horizontal motion and have holes for M2 bolts for vertical securement. Since the AH1 switch needs to connect to an external controller, the wire hole is necessary to route its wires externally. Lastly, the magnet slots are rounded pockets in which the magnets are placed, where the bottom of the slots have thin walls to reduce the distance between the lever and floor magnets. Instead of slots, the left half of the housing has flat surfaces that prevent the magnet from sliding. The dimensions for both halves of the levers and the features contained in each are provided in Appendix A.

Magnets

Previous operant chamber iterations fastened the levers to the floor using nuts and bolts, so we made assembly easier by incorporating magnets. Each lever contains two 15x2mm neodymium magnets[12] within its housing that attract to another set of two magnets attached to the underside of the floor. The floor mount for the magnets may be modified to any desired shape or size, but the mount we use is shown in Figure 11 below.

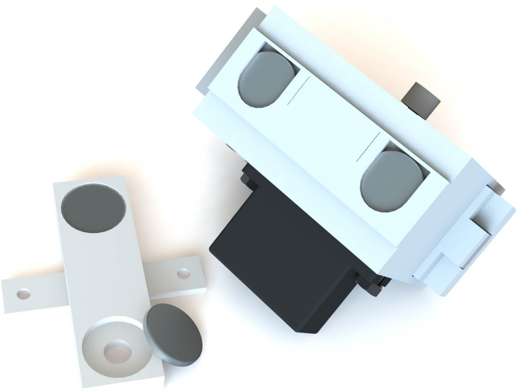


Fig. 11: Floor magnets with mount and lever magnets in lever assembly

This mount can be 3D printed out of any material and is designed with a press fit tolerance so that no adhesive or other fastening tool is needed to secure the magnets. The through-holes under the magnets allow for easy removal and the wings with holes on either side of the mount are for fastening to a floor using M3 bolts. Since the magnet mount attaches to the underside of the floor and the lever assembly attaches to the top, the distance between the floor magnets and lever magnets is dependent on the thickness of both these wings and the floor. The mount design given in Appendix A gets the magnets as close as possible when using a 0.22" floor thickness, where the bottom of the lever housing sits flush with the top of the magnet mount. The 15x2mm magnets we use provide sufficient strength to secure the lever assembly to the floor and do not cause any interference with the servo motors. Prior to finalizing this design, we ensured that these magnets do not alter the performance of the servos in any way, but we did not test with any other sizes.

Assembly

This section describes the recommended procedure for assembling a lever in the most efficient way. Each component, along with its method of procurement, is listed in the bill of materials (BOM) below, followed by the assembly steps. An assembly drawing is also provided in Appendix A.

Table 1: Bill of Materials

Item No.	Part No.	Description	Quantity
1	lvrV2_housingL	3D printed Z-ULTRAT (ABS)	1
2	lvrV2_housingR	3D printed Z-ULTRAT (ABS)	1
3	lvrV2_arm	Machined 6061 Al	1
4	lvrV2_counterweight	3D printed PLA/ABS/etc.	1
5	lvrV2_pin	OTS[7]	1
6	lvrV2_pinCap	3D printed PLA/ABS/etc.	2
7	lvrV2_hornAdapter	3D printed PLA/ABS/etc.	1
8	servo_HS81micro	OTS[8]	1
9	servoHorn_HS81micro	Included w/ servo and modified	1
10	AH1_switch	OTS[10]	1
11	lvrV2_magnet	OTS[12]	2
12	socketButtonCapScrew_M3x8	OTS	2
13	hexNut_M3	OTS	2
14	socketButtonCapScrew_M2x16	OTS	2

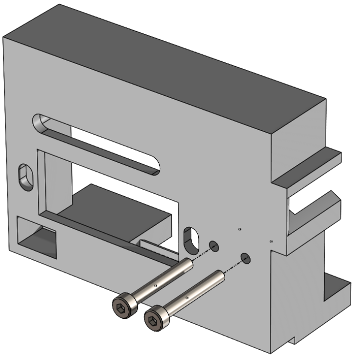
Notes:
- An epoxy is needed to adhere the servo horn and lvrV2_hornAdapter.
- OTS represents off-the-shelf parts.

Assembly Procedure

Files for each component can be pulled from GitHub at https://github.com/donaldsonlab/Operant-Cage, including SolidWorks parts and assemblies, engineering drawings, and .STL files used to fabricate all of the custom components. The .STL files are saved in the optimal orientation for 3D printing on an FDM printer, but printer settings will differ slightly between printers and materials. Some of the off-the-shelf files are stored in the Global directory here: https://github.com/donaldsonlab/Operant-Cage/tree/main/GLOBAL.

1. Insert M2 Bolts into Lever Housing

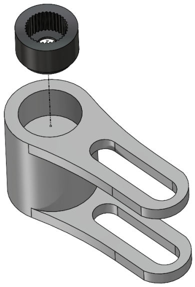
The bolts used for this are M2 x 16mm and they screw into the 2mm holes on the housing. They can be screwed into either the left or right housing, depending on how the user wants to route the AH1 switch wires.



2. Assemble Servo Assembly

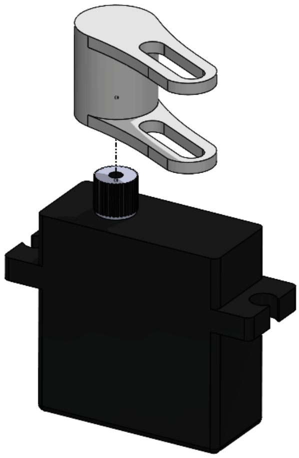
2.1 Insert Modified Horn into Horn Adapter

Figure 6 in the Servo and Horn Adapter section provides guides for cutting a servo horn to fit into a horn adapter. As discussed in that section, an adhesive is also required to secure the horn in the adapter



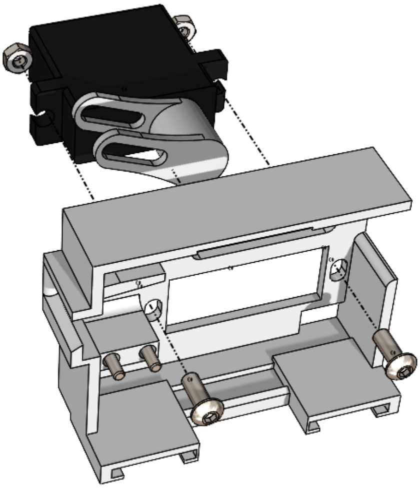
2.2 Attach Horn Adapter to Servo

This step may be performed during the previous adhesive step in order keep the horn/adapter interface flat. Just be careful not to get adhesive on the servo motor.



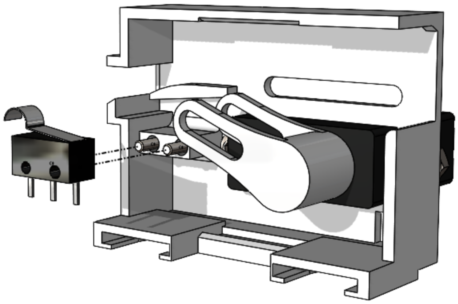
3. Attach Servo Assembly to Right Lever Housing using M3 Nuts and Bolts

The bolts used to mount the servo assembly are M3 x 8mm with corresponding nuts. The servo only permits 180° rotation, so ensure that the servo horn can rotate to fully extend and retract the lever.



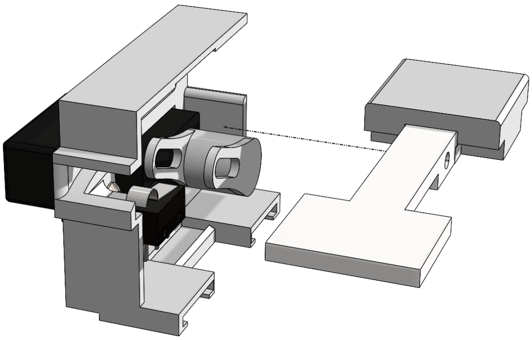
4. Mount AH1 switch onto M2 Bolts

Nuts are not used when mounting the AH1 switch, since it will be secured by the other half of the housing. During this step, it may also be helpful to route the wires through the rectangular hole of the lever housing, as discussed in the Lever Housing section.



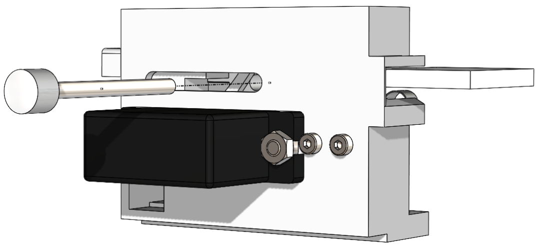
5. Slide Lever Arm with Counterweight Between Horn Adapter Guides

This step may require rotating the horn adapter until the lever arm can be slid between its guides. The counterweight is symmetrical and can be attached to the lever arm in either direction.



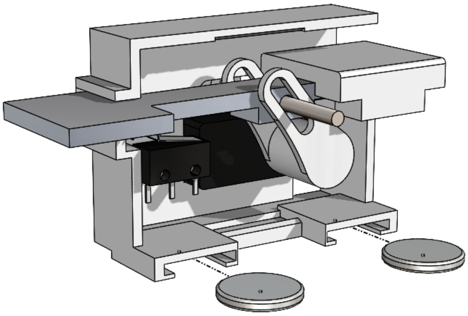
6. Insert Pin

Prior to sliding the pin through the housing, put one of the pin caps on the end of the pin. Ensure that the pin slides through the housing, lever arm, and both sides of the horn adapter.



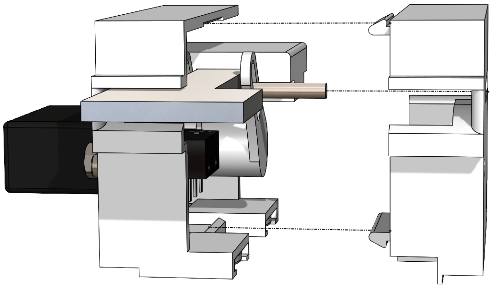
7. Insert Magnets into slots

To ensure the correct orientation of the magnets, it is helpful to assemble the magnet mount, as described in the Magnets section, prior to inserting them into the lever housing. The magnets sit loosely in the slots until the second half of the lever housing is attached.



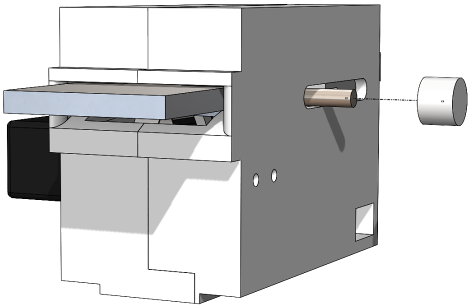
8. Snap Left and Right Lever Housing Together

The male snap fit joints on the left lever housing can be inserted into the female joints one at a time for easier assembly. If the AH1 switch is mounted on the left lever housing, be careful to avoid collision between it and the lever arm. The lever arm should sit on top of the switch arm. Also ensure that the pin slides through the slot on the left housing and that the two halves completely close when snapped together. This may require extra attention to the removal of support material from the printed parts.



9. Attach Pin Cap

This step concludes the lever arm assembly. Test that the pin will actuate extension and retraction by pushing it back and forth. There should be some resistance from the servo motor. Test that the lever arm can be pressed when extended. There should be very little resistance. These elements can be further tested when connected to an external controller.



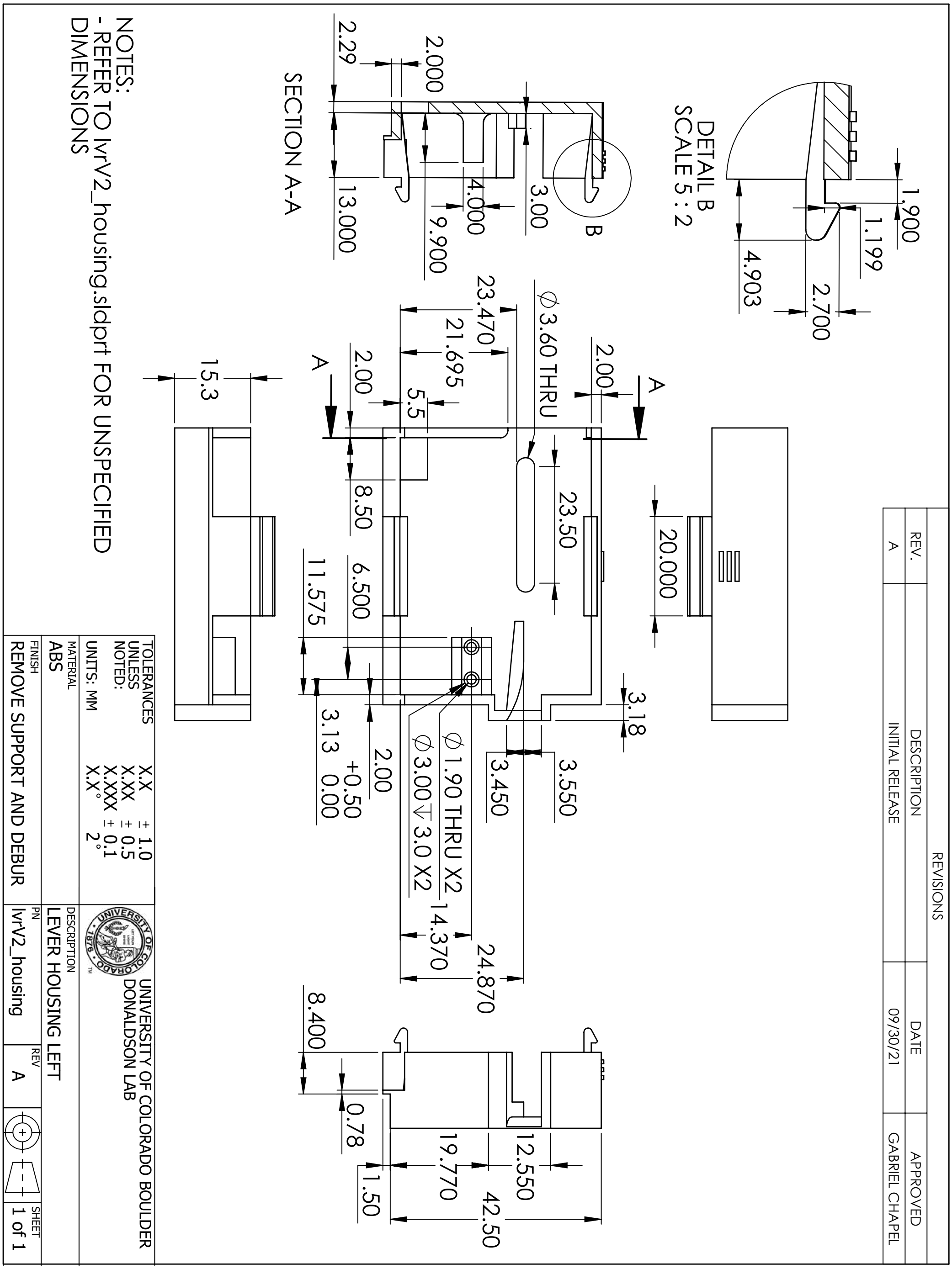
Code Sample

Two of the components within this assembly, the AH1 switch and servo motor, must be controlled by an external computer or microcontroller to operate the dispenser. A sample of Python code is given below for operating the dispenser using a Raspberry Pi. This code will first rotate a servo motor to the specified angle, extending the lever arm. Once the lever arm is pressed, the code will output the time and the servo will rotate in the opposite direction to a specified angle, retracting the lever arm. Then there will be a 5 second delay and the code will restart.

```
#External Module Imports
import RPI.GPIO as GPIO
import time
from adafruit_servokit import ServoKit
kit = ServoKit(channels=16)

#Pin Setup
switch = 1                                        #Plug switch signal wire into GPIO pin 1
GPIO.setup(switch, GPIO.IN, pull_up_down=GPIO.PUD_UP) #switch pin set as input w/ pull-up
leverServo = kit.servo[0]                         #Plug servo into pins 0 on hat

#User Variables
extendAngle = 130                    #Servo angle for extending lever
retractAngle = 50                    #Servo angle for retracting lever

#Start Test
leverServo.angle = extendAngle              #extend lever
while True:
    if not GPIO.input(switch):              #if the lever is pressed
        print("The lever was pressed at ", time.time())
        leverServo.angle = retractAngle     #retract lever
        sleep(5)                            #wait 5 seconds
        leverServo.angle = extendAngle      #extend lever
```

As mentioned previously and discussed further in the Electronic Hardware documentation, we use an Adafruit Servo Hat to control the servos, which requires and external power supply of 5-6V and the installation of the Circuit-Python ServoKit library. A tutorial for powering the hat and installing this library for use with Python is given on the Adafruit website [13].

Appendix A



NOTES:
- REFER TO lvrV2_housing.sldprt FOR UNSPECIFIED DIMENSIONS
SECTION A-A
DETAIL B
SCALE 5 : 2
B
A
A
2.29
2.000
13.000
9.900
4.000
3.00
1.900
1.199
4.903
2.700
23.470
21.695
Ø3.60 THRU
2.00
5.5
2.00
15.3
8.50
23.50
20.000
6.500
11.575
3.18
3.13
+0.50
0.00
2.00
Ø1.90 THRU X2
Ø3.00 ↧ 3.0 X2
3.450
3.550
14.370
24.870
8.400
0.78
19.770
12.550
1.50
42.50
REVISIONS
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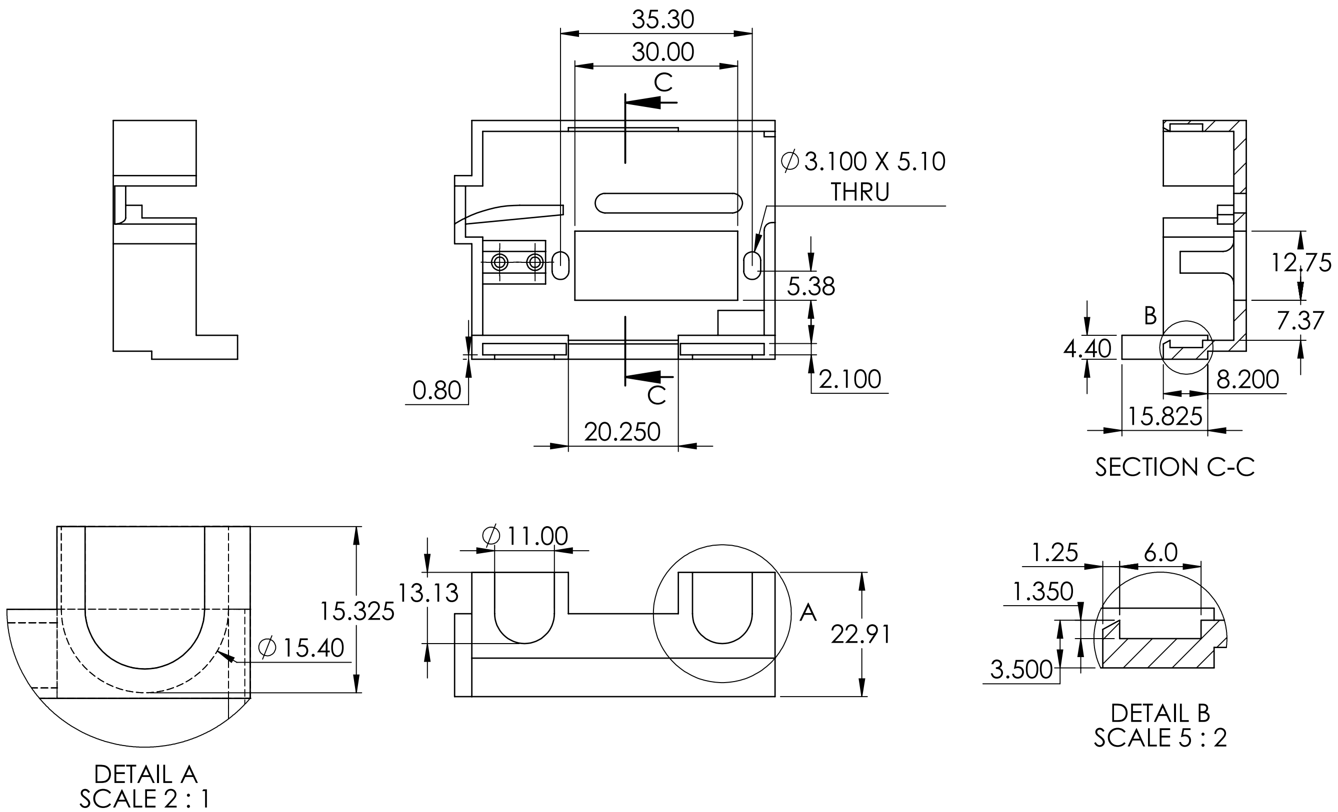
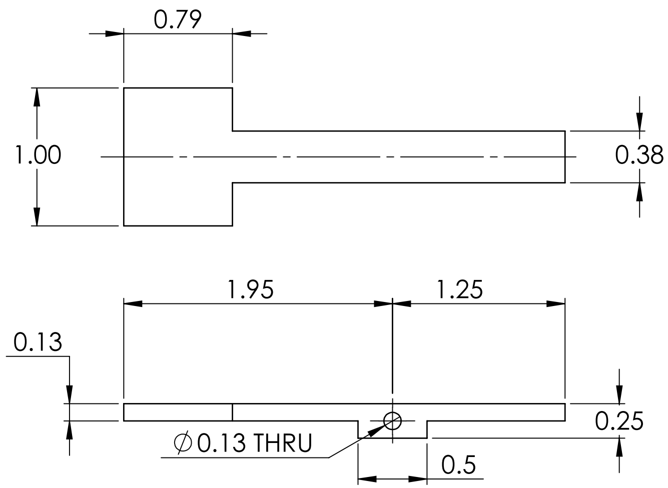
09/30/21
GABRIEL CHAPEL
TOLERANCES UNLESS NOTED:
X.X ± 1.0
X.XX ± 0.5
X.XXX ± 0.1
X.X° ± 2°
UNITS: MM
MATERIAL
ABS
FINISH
REMOVE SUPPORT AND DEBUR
UNIVERSITY OF COLORADO BOULDER
DONALDSON LAB
DESCRIPTION
LEVER HOUSING LEFT
PN
lvrV2_housing
REV
A
SHEET
1 of 1



NOTES:
- REFER TO lvrV2_Housing.sldprt OR lvrV2_HousingL.dwg FOR UNSPECIFIED DIMENSIONS.

TOLERANCES UNLESS NOTED: UNITS: MM	X.X ± 1 X.XX ± 0.5 X.XXX ± 0.1 X.X° 2°	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB			
MATERIAL ABS		DESCRIPTION LEVER HOUSING RIGHT			
FINISH REMOVE SUPPORT AND DEBUR		PN lvrV2_HousingR	REV A		SHEET 1 of 1

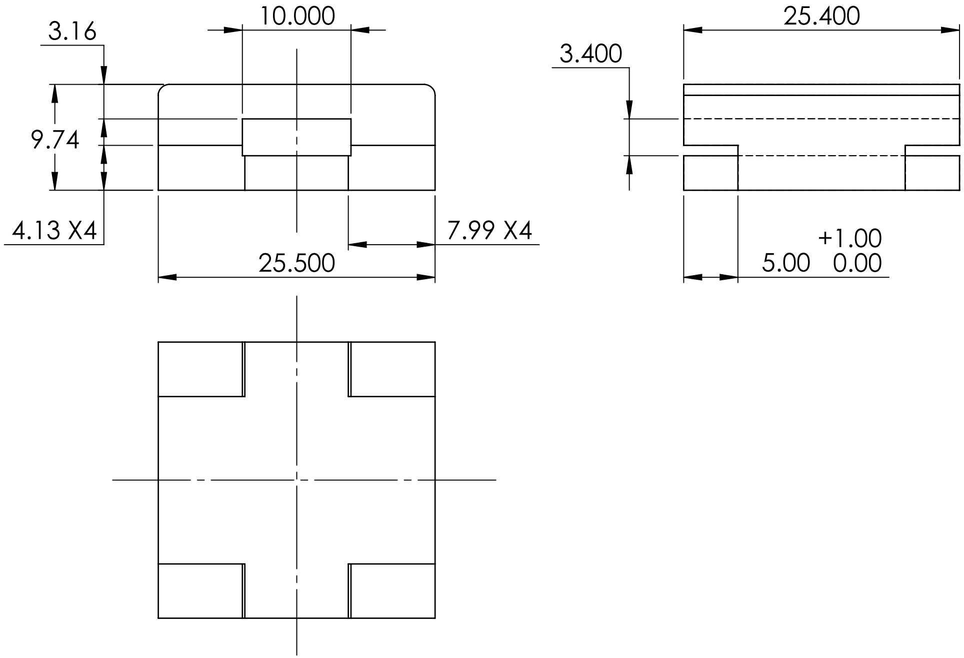
REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	09/23/21	GABRIEL CHAPEL



NOTES:
- THE THRU HOLE IS AN 1/8" HOLE FOR THE 3MM lvrV2_pin

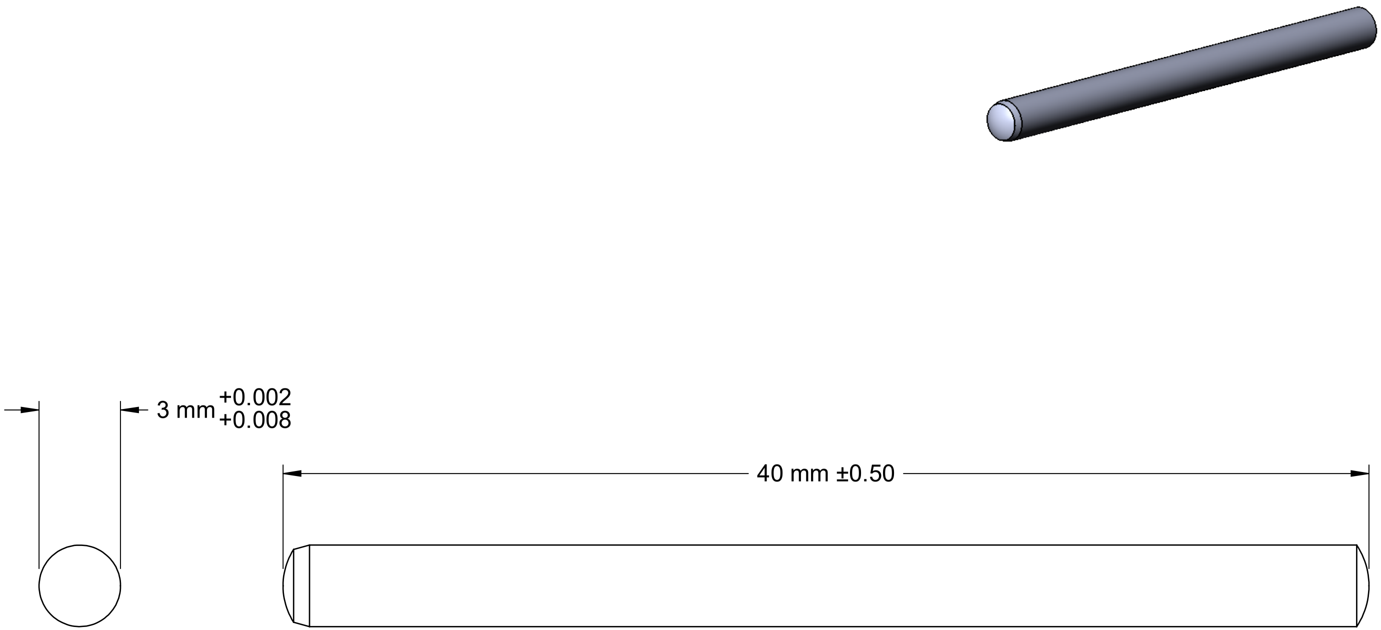
TOLERANCES UNLESS NOTED: X.X ± 0.1, X.XX ± 0.01, X.XXX ± 0.005, X.X° 2°; UNITS: IN	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB			
MATERIAL 5/16" ALUMINUM 6061 FLAT BAR	DESCRIPTION LEVER ARM			
FINISH DEBUR EDGES	PN lvrV2_pinCap	REV A		SHEET 1 of 1

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	10/12/2021	GABRIEL CHAPEL



NOTE:
- REFERENCE lvrV2_counterweight.sldprt FOR ANY UNSPECIFIED DIMENSIONS

TOLERANCES UNLESS NOTED: X.X ± 1; X.XX ± 0.5; X.XXX ± 0.1; X.X° 2° UNITS: MM	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB		
MATERIAL ABS/PLA	DESCRIPTION LEVER ARM COUNTERWEIGHT		
FINISH DEBUR AND SMOOTH SIDES	PN lvr2_counterweight	REV A	SHEET 1 of 1



McMASTER-CARR® CAD	PART NUMBER	91595A142	
http://www.mcmaster.com © 2021 McMaster-Carr Supply Company	Dowel Pin		
Information in this drawing is provided for reference only.			

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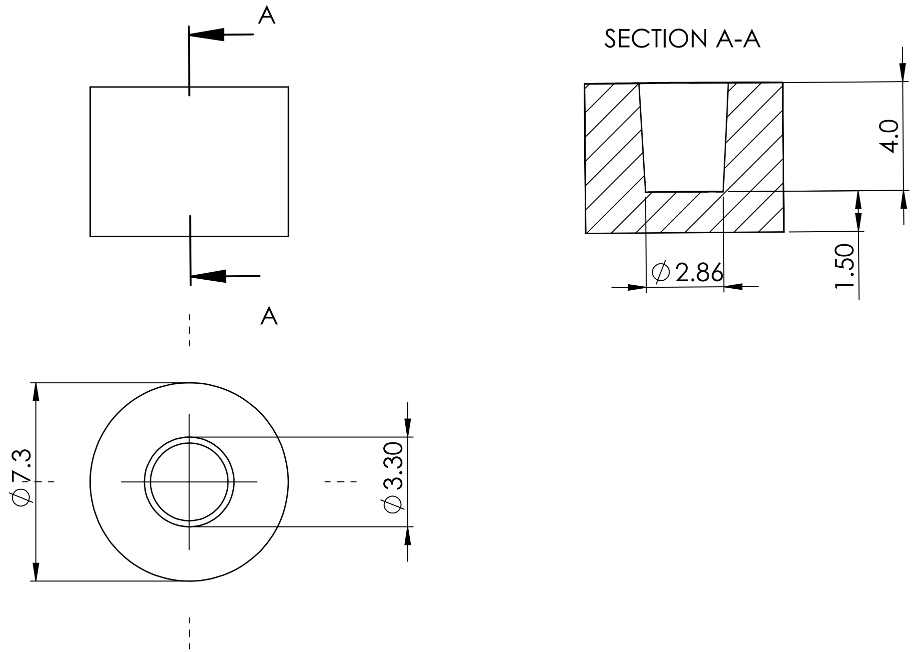
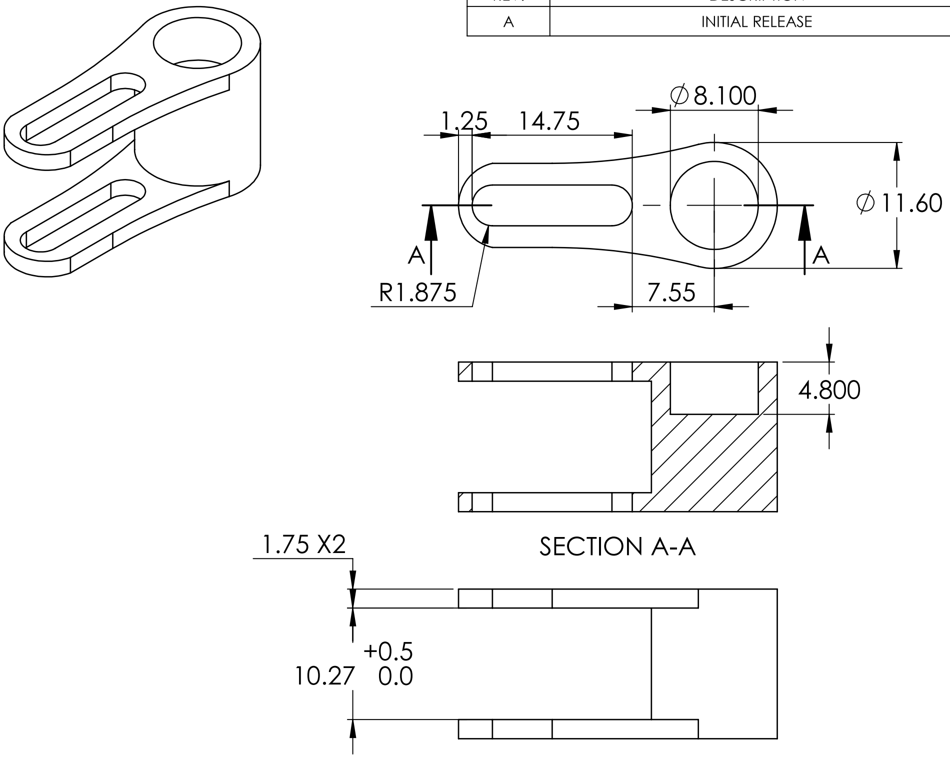


NOTES:
- THIS WAS 3D PRINTED WITH A ZORTRAX M200 PLUS AND Z-ULTRAT FILAMENT.
- THIS FITS ONTO lvrV2_pin

TOLERANCES UNLESS NOTED: UNITS: MM	X.X ± 1 X.XX ± 0.1 X.XXX ± 0.01 X.X° 2°	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB	
MATERIAL PLA or ABS		DESCRIPTION LEVER ARM PIN CAP	
FINISH N/A		PN lvrV2_pinCap	REV A
			SHEET 1 of 1

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	09/23/21	GABRIEL CHAPEL



NOTES:
- FOR UNSPECIFIED DIMENSIONS, REFER TO CAD MODEL lvrV2_hornAdapter.sldprt
- THIS PART WAS 3D PRINTED ON BOTH A ZORTRAX M200 PLUS WITH Z-ULTRAT FILAMENT AND A CREALITY ENDER 5 PRO WITH PLA FILAMENT.

TOLERANCES UNLESS NOTED: UNITS: MM	X.X ± 1 X.XX ± 0.5 X.XXX ± 0.1 X.X° 2°	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB
MATERIAL ABS OR PLA		DESCRIPTION LEVER SERVO HORN ADAPTER
FINISH REMOVE SUPPORT AND DEBUR		PN lvrV2_hornAdapter · REV A · SHEET 1 of 1

ITEM NO.	PART NUMBER	QTY.
1	lvrV2_housingL	1
2	lvrV2_housingR	1
3	lvrV2_arm	1
4	lvrV2_counterweight	1
5	lvrV2_pin	1
6	lvrV2_pinCap	2
7	lvrV2_hornAdapter	1
8	servo_HS81micro	1
9	servoHorn_HS81micro	1
10	AH1_switch	1
11	lvrV2_magnet	2
12	socketButtonCapScrew_M3x8	2
13	hexNut_M3	2
14	socketButtonCapScrew_M2x16	2

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
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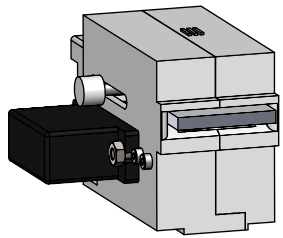
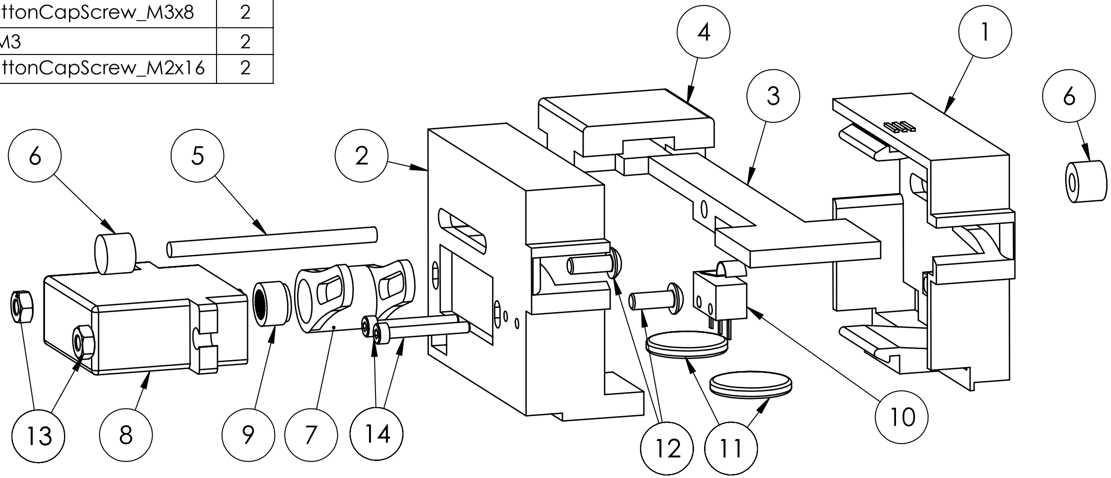
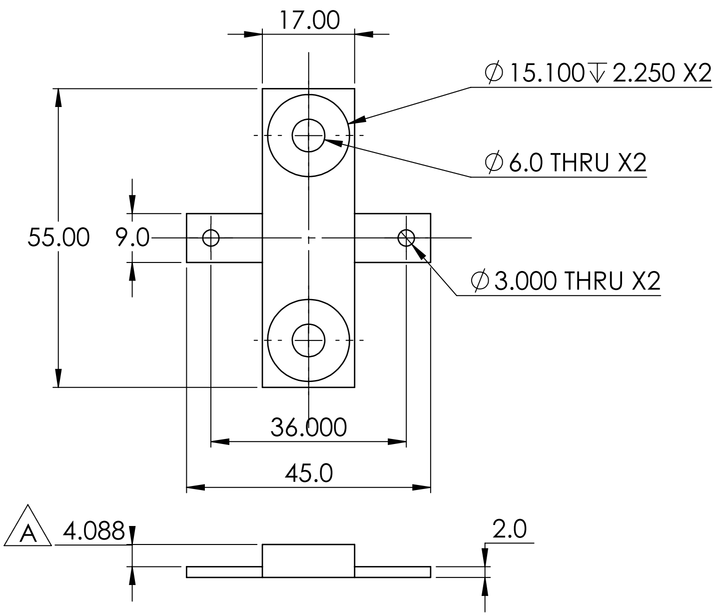




TOLERANCES UNLESS NOTED: UNITS: MM	X.X ± 0.1 X.XX ± 0.01 X.XXX ± 0.001 X.X° 2°	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB	
MATERIAL VARIOUS		DESCRIPTION LEVER ASSEMBLY	
FINISH VARIOUS		PN VARIOUS	REV A · SHEET 1 of 1

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
A	INITIAL RELEASE	10/13/2021	GABRIEL CHAPEL



NOTE:
- THIS DESIGN IS FOR A FLOOR THICKNESS OF 0.22"

A THIS DIMENSION INTERFACES WITH THE BASE OF lvrV2_housingL AND lvrV2_housingR AND SHOULD BE CHANGED IF A DIFFERENT FLOOR THICKNESS IS USED

TOLERANCES UNLESS NOTED: UNITS: MM	X.X ± 1 X.XX ± 0.5 X.XXX ± 0.1 X.X° 2°	UNIVERSITY OF COLORADO BOULDER DONALDSON LAB
MATERIAL ABS/PLA		DESCRIPTION LEVER MAGNET MOUNT
FINISH DEBUR		PN lvrV2_magnetMount · REV A · SHEET 1 of 1

Appendix B

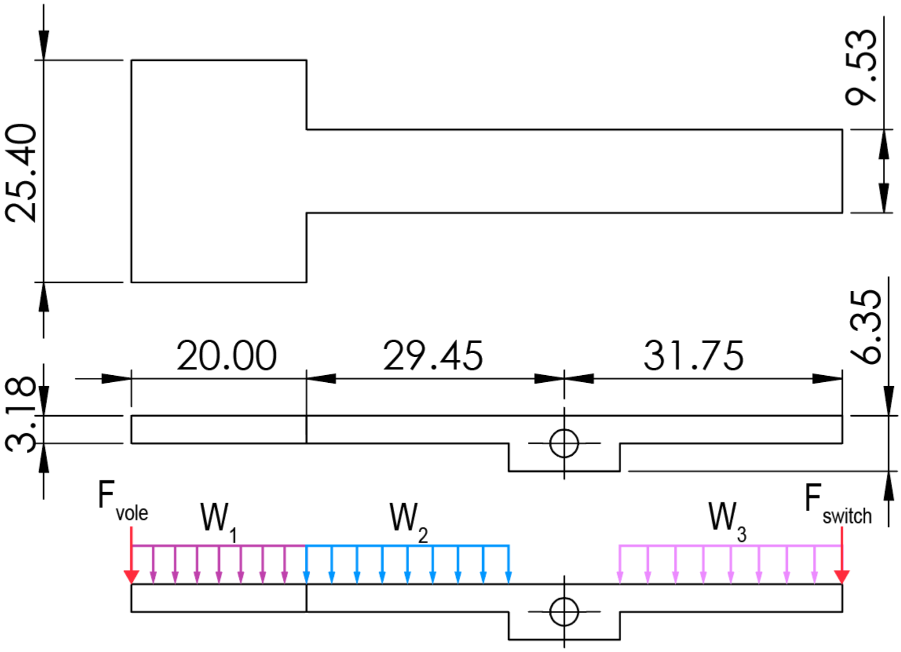
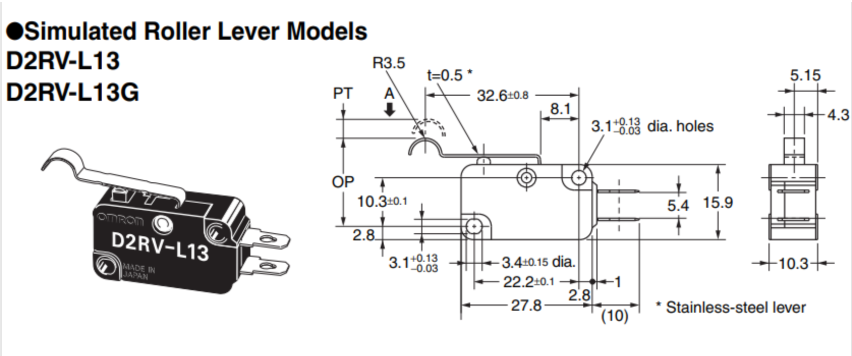


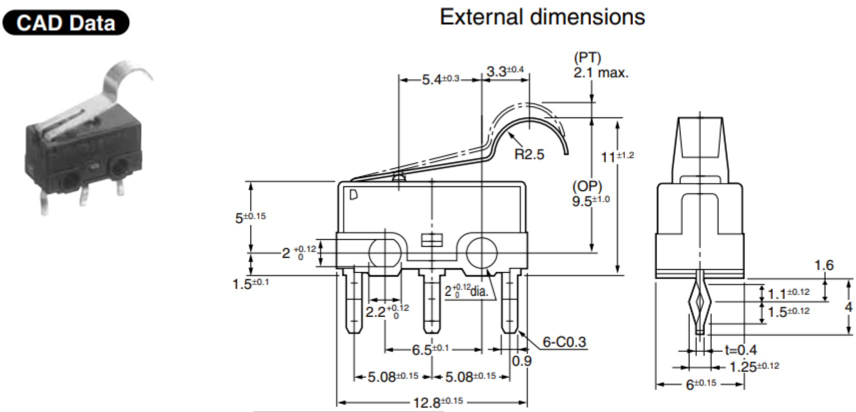
Fig. 1: Simplified dimensions of lever arm [mm] and a static load diagram for previous lever iteration using a D2RV-L13 switch



Model / Operating characteristics			D2RV-L13	D2RV-L13G
Operating Force	OF	Max.	0.25 N {25 gf}	0.49 N {50 gf}
Pretravel	PT	Max.	4.0 mm	
Overtravel	OT	Min.	1.0 mm	
Movement Differential	MD	Max.	1.6 mm	
Operating Position	OP		18.1±1.2 mm	

Note 1. Unless otherwise specified, a tolerance of ±0.4 mm applies to all dimensions.
Note 2. The operating characteristics are for operation in the A direction (⬇).

Fig. 2: D2RV-L13 switch dimensions [4]



Pretravel PT, Max.		2.1 mm
Movement Differential MD, Max.		0.5 mm
Overtravel OT, Min.		0.5 mm
Operating Position OP	Distance from mounting hole	9.5±1.0 mm
	Distance from stand-off	11.0±1.2 mm

PC board pattern

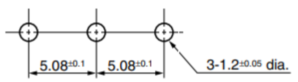


Fig. 3: AH1 switch dimensions [10]

References

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[4] D2RV-L13 Omron Electronics. https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/D2RV-L13/1811964

[5] Zortrax M200 Plus FDM Printer. https://zortrax.com/3d-printers/m200-plus/

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[9] HS-85 Premium Metal Gear Micro Servo. https://hitecrcd.com/products/servos/analog/micromini/hs-85mg/product

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