Final Technical Data Package

Project 25005: Treadmill with Soft Ambulatory Surface

Revision: C
May 06, 2025

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1.0 Introduction & Project Description

Our team, 25005, has been tasked with designing a specialized treadmill for the University of Arizona Orthopaedic Research Laboratory, under the Department of Biomedical Engineering. The lab will use our final treadmill assembly to study rat gait on diverse terrains, including simulated extraterrestrial regolith. This supports research in biomechanics, rehabilitation, and space exploration.

The ability to study gait on various surfaces is essential for understanding mobility challenges in different environments. By stimulating extraterrestrial terrains, the treadmill will allow researchers to study how different surface characteristics influence skeletal health and mobility patterns. In space exploration, astronauts must operate in different gravity terrains, making it crucial to explore how various surfaces could affect skeletal health. In rehabilitation science, analyzing gait mechanics allows researchers to develop improved treatments who undergo musculoskeletal injuries. Our treadmill offers a controlled environment to study these factors, allowing researchers to show precise control over the experimental conditions.

The treadmill will function as a vital study tool by gathering real-time data and mimicking the conditions of extraterrestrial terrain. Accurate surface replication is ensured through an adjustable, uniform regolith layer, and material is conserved by an advanced recirculation system. Researchers will have the ability to change treadmill speed in real time, adjust harness height to simulate different weight, and analyze biomechanical responses, making our system invaluable for medical and space applications. This treadmill advances laboratory research by introducing precision engineering with innovative functionality. Challenges related to low-gravity environments, like astronaut bone density loss and muscle atrophy, can be addressed through studying gait on extraterrestrial-like terrains. Comprehensive physiological and biomechanical data will be acquired by integrated sensors and an antenna system, and safe operation and clear observation are guaranteed by the transparent window. The treadmill's effective and intuitive design makes it a vital instrument for innovative research

The treadmill will be operated by a lab technician who will be able to easily adjust parameters through our integrated user interface. Before the trial begins, the technician will be able to adjust the sand leveler to achieve a desired regolith thickness, and secure the rat in the harness. This harness acts as a safety mechanism for the rat, while simulating a reduced weight that corresponds to lunar or martian gravity. The treadmill's speed is capable of being adjusted to accommodate different types of studies. The antenna system will collect detailed data on gait mechanics, bone health, and other physiological metrics through near field communication. An emergency stop button is integrated as well in order ensure the safety of the in case of an unexpected event. To keep the lab clean and safe, the entire system will be kept inside a fume hood to help collect dust accumulated by the aggregate.

2.0 System Description & Block Diagram

Our system consists of seven subsystems: 1.1 Collection Bins, 1.2 Treadmill, 1.3 UI and Electrical Assay, 1.4 Enclosure, 1.5 Filter, 1.6 Sand Leveler, and 1.7 Antenna.

1.1 Collection Bins: The collection bin subsystem collects the aggregate at the end of the treadmill and a person dumps the aggregate into the upper hopper. A second person is needed at the bottom hopper to switch out the bins when they are full.

1.2 Treadmill: Our treadmill subsystem is driven with Nema 23 Motor (Part Number: 23HS45-424S), using an 800-grit sander belt with our aggregate placed on top of it. There are 2 rollers with herringbone patterned grooves. They allow for aggregate to be evacuated from between the belt and the rollers. On the idler roller, there is a pair of tensioners. These include blue colored knobs. These allow the belt to be tensioned and track correctly.

1.3 UI and Electrical Assembly: Our treadmill UI is wired on a breadboard using an ESP32 microcontroller (5V) for our MVP1. In this subsystem, there is an LCD screen used to change between speed settings and harness height positions, using a rotary encoder to make these decisions in the menu. There is a momentary switch used to save a specific harness position, along with an emergency stop button that will gradually stop the treadmill, lift the harness up away from the treadmill, and gradually stop the auger. Because of this, our UI subsystem maintains control over the motors in the system, supplying 24V or cutting connection depending on the use case. In our MVP2, the UI is connected on a printed circuit board.

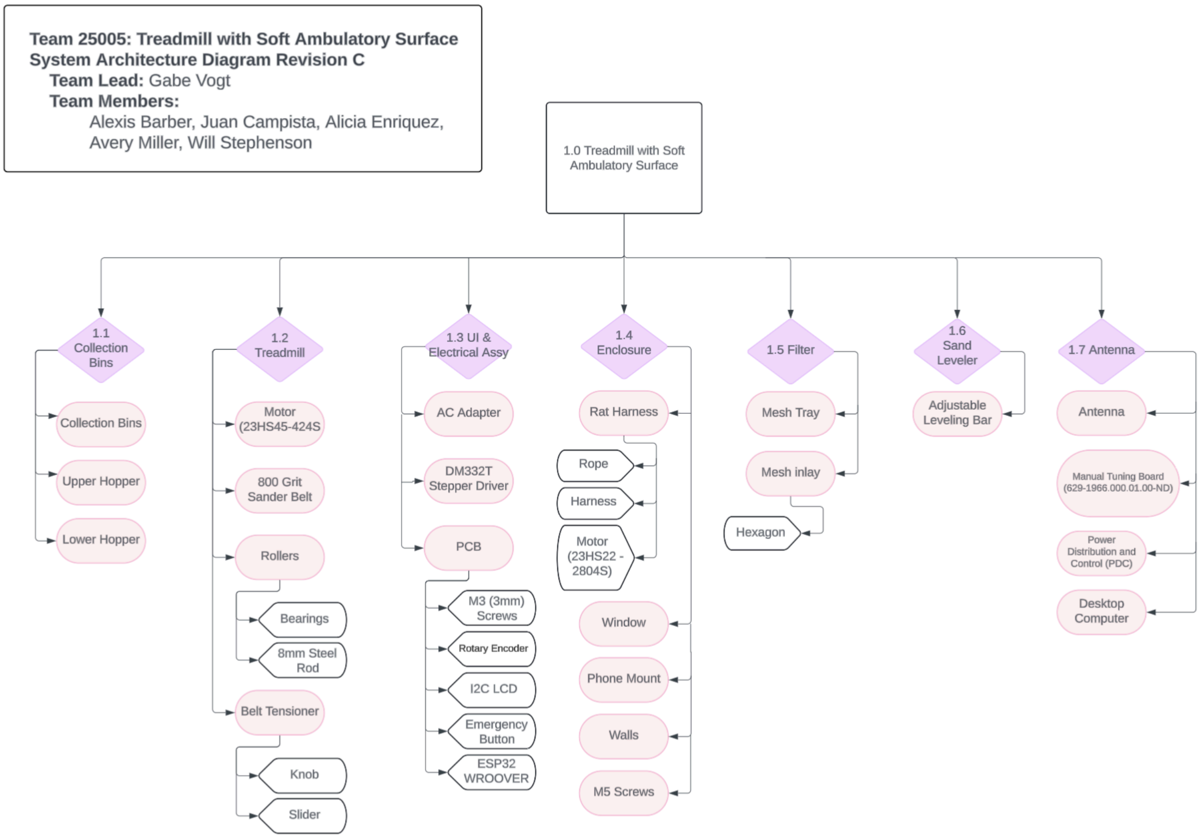
1.4 Enclosure: The enclosure in the area that can be viewed through a window to be potentially recorded. Includes the space above the treadmill and the rat harness/pulley parts.

1.5 Filter: Our filter is composed of the blue colored PETG, which is signaling to the user it is able to be handled and moved. The filter itself is a hexagon shape, which most effectively withheld the rat waste from recirculating while allowing aggregate to recirculate through the system. .

1.6 Sand Leveler: There is a sand leveler bar subsystem present at the beginning of the treadmill to properly level our aggregate across the treadmill surface to 2cm.

1.7 Antenna: Our Antenna system is composed of stranded copper wire tuned to 13.56 kHz via the manual tuning board (629-1966.000.01.00-ND). This system is further connected to a Feig Box, which gathers the data and sends it to a desktop computer with FEIG software for gathering and processing the gait data.

System Architecture Diagram



3.0 System Verification Plan & System Requirements Verification Matrix (SRVM)

Efficiency:

4.1.1: Finished 4/24/2025, Passed 4.1.2: Finished 1/23/2025, Passed. 4.1.3: Finished 1/24/2025, Passed.

4.1	**Requirements**	**Verification Method**			
		T	**A**	**D**	**I**
4.1.1 The sand recycling method shall have a 90% accuracy after 5 minutes		X			
4.1.2 The sand layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters		X			
4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.		X			

Performance:

4.2.1: Finished 11/1/2024, Passed. 4.2.2: Finished 1/28/2025, Passed.

4.2	**Requirements**	**Verification Method**			
		T	**A**	**D**	**I**
4.2.1 The treadmill shall have a speed of 0.2 meters per second within +-5%		X			
4.2.2 The enclosure shall have an antenna that is within range of the rat to collect data		X			
4.2.3 The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity				X	

Safety:

4.3.1: Finished 11/15/2024, Passed. 4.3.2: Finished 11/21/2024, Passed.

4.3 Requirements	Verification Method			
	T	A	D	I
4.3.1 The system shall have an emergency stop function that works upon pressing the emergency stop button	X			
4.3.2 The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length	X			

Usability:

4.4.2: Finished 4/24/2025, Passed

4.4 Requirements	Verification Method			
	T	A	D	I
4.4.1 The user interface shall be simple to use and react upon input			X	
4.4.2 The treadmill shall weigh less than 34.02 kilograms	X			
4.4.3 The enclosure shall be less than 66.04x160.02x66.0 cm to fit inside the fume hood			X	
4.4.4 The system shall have a window so that the user can monitor and film the rat during usage.				X
4.4.5 The system shall plug into a 120 Volt wall adapter to power the system			X	

4.0 Design Documentation

4.1 Indentured Document List

Part Numberings: Revision C

Last updated: 4/29/2025

Highlighted Parts Indicate Material/Manufacturing Method

CF Nylon (FFF) | Blue PETG (FFF) | Black PETG (FFF) | Black Felt | HDPE (Milled)
UHMW HDPE (Milled) | Acrylic (Lasercut) (except tube) | Aluminum Angle
Chrome Plated Iron Steel | Black PLA (FFF)

- ☐ **Treadmill System:**
  - ☐ Driver Roller: TRD-001
  - ☐ Idler Roller: TRD-002
  - ☐ Leveling Bar: TRD-003
  - ☐ Treadmill Motor Thread Bracket TRD-004
  - ☐ Roller Spacer TRD-005
  - ☐ Idler Roller Grooved TRD-006
  - ☐ Driver Roller Grooved TRD-007

- ☐ **Auger System:**
  - ☐ End Cap Mount 2x AUG-001
  - ☐ Acrylic Tube: AUG-002
  - ☐ Lower Hopper Auger Side AUG-003
  - ☐ Upper Hopper Auger Side AUG-004
  - ☐ End Cap M AUG-005
  - ☐ End Cap AUG-006
  - ☐ Motor Felt 2x AUG-007
  - ☐ Lower Hopper Enclosed Side AUG-008
  - ☐ Upper Hopper Enclosed Side AUG-009
  - ☐ Aggregate Collector AUG-010
  - ☐ Screw Ends 2x AUG-011
  - ☐ Screw 8mm Rod AUG-012
  - ☐ Screw Middle AUG-013
  - ☐ Tall Stand AUG-014

- ☐ Short Stand AUG-015
- ☐ Motor Endcap Acrylic Cover AUG-016
- ☐ Motor Endcap Cover AUG-017
- ☐ Motor Side Seal Washer AUG-018
- ☐ Tube Support Upper AUG-019
- ☐ Tube Support Lower AUG-020

☐ **Electrical System:**

- ☐ Treadmill Motor: ELC-001
- ☐ Auger Motor: ELC-002
- ☐ Harness Motor: ELC-003
- ☐ Freenove ESP32 Wroom: ELC-004
- ☐ Emergency Stop Button: ELC-005
- ☐ Stepper Motor Drivers: ELC-006
- ☐ I2C LCD: ELC-007
- ☐ Rotary Encoder: ELC-008
- ☐ AC Female adapter: ELC-009
- ☐ Rocker Switch: ELC-010
- ☐ Timer Button: ELC-011
- ☐ Antenna Amplifier Board: ELC-012

☐ **Antenna System:**

- ☐ Antenna Box ANT-001
- ☐ Antenna Wiring ANT-002
- ☐ Antenna Supports ANT-003

☐ **Filter System:**

- ☐ Filter Housing: FIL-001

☐ **Collection System:**

- ☐ Bin Extension COL-001
- ☐ Collection Bin COL-002
- ☐ Modified Upper Hopper COL-003
- ☐ Modified Lower Hopper COL-004

- ☐ **Enclosure System:**

☐ Front Panel:	ENC-001
☐ Left Panel:	ENC-002
☐ Right Lower Panel:	ENC-003
☐ Back Panel:	ENC-004

☐ Top Panel:	ENC-005
☐ Bottom Panel:	ENC-006
☐ Front Window:	ENC-007
☐ Treadmill Base UHMW HDPE	ENC-008
☐ Screen Holder	ENC-009
☐ Treadmill Base ½in Al Angle	ENC-010
☐ Treadmill Motor Cover	ENC-011
☐ Treadmill Motor Cover Flat	ENC-012
☐ Top Center Reinforcement	ENC-013
☐ Motor Side Reinforcement	ENC-014
☐ Center Reinforcement	ENC-015
☐ Idler Side Reinforcement	ENC-016
☐ Left Side Reinforcement	ENC-017
☐ Mid Panel	ENC-018
☐ Knob	ENC-019
☐ Handle	ENC-020
☐ Door	ENC-021
☐ Hinge Part 1	ENC-022
☐ Hinge Part 2	ENC-023
☐ Door Latch Part 1	ENC-024
☐ Door Latch Part 2	ENC-025
☐ Tensioner Part 1	ENC-026
☐ Tensioner Part 2	ENC-027
☐ Tensioner Part 3	ENC-028

- ☐ Winch Motor Mount ENC-029
- ☐ Basement Reinforcement Part 1 ENC-030
- ☐ Basement Reinforcement Part 2 ENC-031
- ☐ Foot Part 1 ENC-032
- ☐ Foot Part 2 ENC-033
- ☐ Aggregate Loader ENC-034
- ☐ Cable Anchor ENC-035
- ☐ Right Antenna Surface ENC-036

☐ **Purchased Parts:**

- ☐ Treadmill Belt: PUR-001
- ☐ Rat Harness: PUR-002
- ☐ 57155K512_Stainless Steel Ball Bearing PUR-003
- ☐ Winch pulley (enclosure) PUR-004
- ☐ 9307K876_Buna-N Rubber Grommets PUR-005
- ☐ 23HS22-2804S PUR-006
- ☐ 8mm Rod Part 1 PUR-007
- ☐ 8mm Rod Part 2 PUR-008
- ☐ 8mm Rod PUR-009
- ☐ M5 10mm 92095A208_NO THREADS_Button Head Hex Drive Screw PUR-010
- ☐ M5 8mm 92095A207_NO THREADS_Button Head Hex Drive Screw PUR-011
- ☐ M5 15mm 92095A127_NO THREADS_Button Head Hex Drive Screw PUR-012
- ☐ M3 10mm 91828A211_NO THREADS_18-8 Stainless Steel Hex Nut PUR-013

- ☐ M5 30mm Hex head 91287A127_NO THREADS_18-8 Stainless Steel Hex Head Screw PUR-014
- ☐ M5 Nut 91828A241_NO THREADS_18-8 Stainless Steel Hex Nut PUR-015
- ☐ 94180A361_NO THREADS_Tapered Heat-Set Inserts for Plastic PUR-016
- ☐ M 2.5 Insert94180A323_NO THREADS_Brass Tapered Heat-Set Inserts for Plastic PUR-017
- ☐ M3 Threaded Insert 94180A331_NO THREADS_Tapered Heat-Set Inserts for Plastic PUR-018
- ☐ M3 35mm 92095A201_NO THREADS_Button Head Hex Drive Screw PUR-019
- ☐ M5 70mm 92800A456_NO THREADS_18-8 Stainless Steel Hex Head Screw PUR-020
- ☐ M5 45mm 92125A226_NO THREADS_18-8 Stainless Steel Hex Drive Flat Head Screw PUR-021
- ☐ Connector with switch and fuse parts housing PUR-022
- ☐ Connector with switch and fuse parts switch 1 PUR-023
- ☐ Connector with switch and fuse parts switch 2 PUR-024
- ☐ Connector with switch and fuse parts switch 3 PUR-025
- ☐ Connector with switch and fuse parts switch 4 PUR-026
- ☐ M5 Locknut 93625A200_NO THREADS_18-8 Stainless Steel Nylon-Insert Locknut PUR-027
- ☐ M3 Nut 91828A211_NO THREADS_18-8 Stainless Steel Hex Nut PUR-028
- ☐ M2.5 6mm 92125A084_NO THREADS_18-8 Stainless Steel Hex Drive Flat Head Screw PUR-029
- ☐ GT2_80T_8mm_Bore_Pulley PUR-030
- ☐ GT2_80T_10mm_Bore_Pulley PUR-031
- ☐ 23HS45-4204S Wires 1-3, 4 PUR-032
- ☐ 23HE45-4204S Plate PUR-033
- ☐ 23HE45-4204S Body PUR-034

- ☐ 93625A200_NO THREADS_18-8 Stainless Steel Nylon-Insert Locknut PUR-035
- ☐ M5 20mm 94500A233_NO THREADS_316 Stainless Steel Button Head Hex Drive Screws PUR-036
- ☐ LRS-350-24 PUR-037
- ☐ DM332T PUR-038
- ☐ _autosave-25005 Schematic (1) PUR-039
- ☐ 320.221mm Belt PUR-040
- ☐ 358mm Belt PUR-041
- ☐ 25005 Rev B Outputs_Y4 PUR-042
- ☐ Blue 1mm UHMWPE Micro Cord 100Ft PUR-043
- ☐ M5 Hex Bolts Stainless Steel 0.8mm 50pcs PUR-044
- ☐ M5-0.8 x 8mm Button Head Socket Cap Screws 50pcs PUR-045
- ☐ 100pcs M3 x 8mm Thread 0.5 mm Screws PUR-046
- ☐ 70pcs 4 Pin Tactile Push Button Switch 12x12x7.3mm PUR-047
- ☐ 4Pcs Right Angle USB C to 2 Pin Bare Wire Open End Wire PUR-048
- ☐ GT2_80T_10mm_Bore_Pulley PUR-049
- ☐ GE Advanced Silicone Caulk for Kitchen & Bathroom PUR-050
- ☐ 6 Pack Small Carabiner Clips PUR-051
- ☐ CONN HEADER VERT 14POS 2.54MM PUR-052
- ☐ CONN RCPT 3POS 0.1 TIN PCB R/A PUR-053
- ☐ RG58C Coaxial Cable, SMA Male / Male, 4.0 ft PUR-054
- ☐ 8mm O.D. Hardened Rod 300mm PUR-055
- ☐ 1.75mm 1kg Strong PETG 3D Printer Filament Black PUR-056
- ☐ 3pc 304 Stainless Steel Test Sieves PUR-057
- ☐ Gorilla Crystal Clear Repair Duct Tape PUR-058
- ☐ 2.2 LBS Super Purity Talcum Powder PUR-059
- ☐ 4 lbs or 1.8 kg Ground Walnut Shell Media 18-40 Grit PUR-060
- ☐ Dr. Elsey's Premium Clumping Cat Litter PUR-061
- ☐ Sandblasting Media Glass Beads #8 Medium 70-80 Grit PUR-062
- ☐ Sandblasting Media Glass Beads #10 100-170 Grit PUR-063

☐ Gimbal Stabilizer for Smartphone	PUR-064
☐ STEPPERONLINE DM556T Digital Stepper Driver	PUR-065
☐ STEPPERONLINE Nema 23 CNC Stepper Motor	PUR-066
☐ uxcell 2pcs GT-2 Pulley Synchronous Wheel 8mm 10mm	PUR-067
☐ Jinchao-Timing Belt (2GT Length 360mm, Width 10mm)	PUR-068
☐ QWORK CNC Vacuum Brush, 70MM x 2M	PUR-069
☐ FREENOVE ESP32-WROOM Board (2 Pack)	PUR-070
☐ STEPPERONLINE Digital Stepper Motor Driver	PUR-071
☐ JST XH 2.54 mm Pitch 2-Pin/3-Pin/4-Pin	PUR-072
☐ 25005 Rev C Outputs_Y5	PUR-073
☐ GroTheory 2 Pack Under Door Draft Stopper	PUR-074
☐ Graphite Powder 0.5OZ for Pinewood Car	PUR-075
☐ QWORK CNC Vacuum Brush, 70MM x 2M Vacuum Cleaner	PUR-076
☐ HATCHBOX PETG 3D Printer Filament (Blue)	PUR-077
☐ 104 PCS 2.54mm 2.54mm Female Connectors	PUR-078
☐ 2PACK 304 Pretty Sturdy 12” X 24”(310mm X 610mm)	PUR-079
☐ 100% PTFE Dry Lubricant Ultra fine Powder	PUR-080
☐ Felt Furniture Strips 2 Pack Roll 1/2x 60 Inches Black	PUR-081
☐ Pllieay 1 Pack Felt Tape in Self Adhesive	PUR-082
☐ J-B Weld Original Steel Reinforced Epoxy Syringe	PUR-083
☐ CRC Dry PTFE Lube, 10 Wt Oz	PUR-084
☐ 100Pcs Pipe Cleaners	PUR-085
☐ 8mm O.D. Hardened Rod 1000mm x2	PUR-086
☐ UBOXES Large Moving Boxes 20" x 20" x 15"	PUR-087
☐ 12 oz/350 ml Clear Glass Storage Canister	PUR-088

4.2 System Requirements Document

System Requirements

Project 25005: Treadmill with Soft Ambulatory Surface

Version: D
May 06, 2025

Team Members:
Alexis Barber, Mechanical Engineer
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Table of Contents

1.0 Introduction and Scope:

This document contained the system requirements for a Treadmill with Soft Ambulatory Surface system, further named as the Treadmill, for the Orthopaedic Research Biomaterial Laboratory at the University of Arizona, who are the stakeholders for this project. This lab does biomedical research, particularly involving implantable sensors to monitor fractures and bone quality, specifically osteoporosis. Pairing implantable sensors with bone scaffolding, regrowth, and regeneration can be monitored until the target sight is back at full capacity.

The project will be used to aid in this research by providing a relatively small treadmill with a soft ambulatory surface for use with rats. The Orthopaedic Research Biomaterial Laboratory is sponsoring this project again because last year's Senior Capstone Team was unable to meet the expected outcomes. They are now seeking a new team to continue the design and develop a new treadmill that will meet their needs for data collection.

Surface composition significantly affects gait and energy expenditure, especially for those recovering from bone fractures and reduced bone density. The Treadmill aims to provide a small-scale environment for a rat to walk on a surface composed of regolith, simulating lunar/Martian sand. In the Treadmill, the rat will be suspended in a harness with settings to simulate weight corresponding to the Moon and Mars. A lab antenna and corresponding amplification board will be integrated with existing lab equipment to analyze the gait and bone health of the rat through NFC wireless communication.

The scope of this project is to analyze how human bone health is affected by different environments, such as a change in gravity or walking surface. This can help predict the chances of one day being able to inhabit other planets or predict changes in space worker's bone health.

The Treadmill will be low-cost due to sustainable design practices. A high-level overview of the functional requirements is as follows:
1.1 The recirculation of the regolith in the system shall be efficient,
1.2 The system shall be a user interface (UI),
1.3 The system shall fit within the lab's fume hood,
1.4 The system enclosure shall accommodate space for a rat.
1.5 The system enclosure shall incorporate a harness for the rat.
1.6 A moon and Mars weight simulation setting shall be implemented.
1.7 The belt shall have an adjustable, restricted range of speed.
A Treadmill system prototype had been previously designed and manufactured in the Engineering Design Program. Key improvements from the sponsor in the form of system requirements include addressing the previous failure to provide a thick, uniform surface layer of 1 cm and the inefficient regolith recirculation (<90%).

The Treadmill has the following constraints to consider in the team's design:

1.8 Treadmill cannot exceed the following dimensions to fit in the fume hood: 26x63x26in.

    1.8.1 Treadmill cannot operate outside of the fume hood due to ventilation concerns.

1.9 Treadmill power must run on a wall harness AC adapter (120V wall, 24V AC adapter).

1.10 Enclosure walls must be transparent to analyze the rat's gait while running the Treadmill.

1.11 Treadmill motors must not dissipate excessive power (Avoid overheating/Power Efficiency).

2.0 Referenced Documents:

2.1 25005 Proposal

This is a key document listing crucial, in-depth information on the Treadmill background, significance, technical objectives, and several factors to consider in the team's design.

2.2 25005 ConOps

This document was created to list the concept of operations for the team's design decisions. This list includes the Treadmill's stakeholders, product history/background, systems boundaries/environment/constraints/use, and the expected output of the team's final Treadmill design.

2.3 25005 Functional Requirements & Functional Block Diagram

This document lists the system's minimum functional requirements with stretch goals included. Based on these requirements, a block diagram is also included indicating how each of the components interacts on a functional level.

2.4 25005 Trades & Point Design

This document analyzes three different trade designs using weighted trade analysis to determine the team's point design. The point design is described, along with a system block diagram displayed corresponding to the point design.

2.5 25005 System Requirements Verification Matrix

This document lists the team's system requirements in logical groups in a table. Included in this table is a matrix determining the verification method necessary for each requirement(Test/Analysis/Demonstration/Inspection).

2.6 Standards & Other Specifications

ISO 7010 ISO W024 - Warning; Crushing of hands. Taking care to avoid injury to hands when in the vicinity of equipment with closing mechanical parts

US Animal Welfare Act - §2.31(d)(i) -"Procedures involving animals will avoid or minimize discomfort, distress or pain to animals."

3.0 Definitions, Acronyms, and Abbreviations:

3.1 Aggregate: Material formed from a loosely compacted mass of fragments or particles
3.2 Regolith: Heterogeneous rock deposits
3.3 Sand: A loose granular substance resulting from the erosion of siliceous and other rocks
3.4 Enclosure: The exterior of the project that houses all of the other subsystems
3.5 Feeder Hopper: The basin at the start of the treadmill that will dispense the aggregate onto the treadmill
3.6 Catcher Hopper: The basin at the end of the treadmill that will collect the aggregate to feed into the auger
3.7 Treadmill: The moving surface the rat will walk on.
3.8 Auger: The Archimedes screw will be motorized to raise the sand from the catcher hopper to the feeder hopper.
3.9 Ambulate: To walk about
3.10 User Interface (UI): the sub-system that the user will interact with to control the entire system.
3.11 Efficiency: The measure of how well a task is performed or completed considering the efforts and energy put in
3.12 Minimum Viable Product (MVP): The most basic output that follows the criteria set forth by all parties involved
3.13 Concept of Operations (ConOps): The actions and decisions made by members of a team that affect the production of the final product
3.14 Near-Field Communication (NFC): Near-field communication is a set of communication protocols that enables communication between two electronic devices.
3.15 Printed Circuit Board (PCB): A board that acts as a medium to make electrical connections between electronic components. A two-layer PCB usually consists of a top and bottom layer, the top used for connections (traces) and the bottom used for ground.
3.16 Electrostatic Discharge (ESD): An event that can occur due to ESD surge environments such as hands or furniture. ESD standards need to be followed to avoid damaging electronic components.
3.17 Pulse Width Modulation (PWM): A technique used to control the amount of power output by electrical devices. Varying by pulses in a periodic signal.
3.18 Stepper Motor Driver: Manages electrical pulses sent to the motor, determining speed, direction, and precise movements.
3.19 Universal Asynchronous Receiver Transmitter (UART): An asynchronous serial data protocol used to exchange data via two wires for a receiver (RX) and a transmitter (TX).
3.20 Inter-Integrated Circuit (I2C): synchronous, multi-master, commonly used in electronics to allow multiple low-speed devices to communicate with each other over short distances.

4.0 Requirements by System:

4.1 Efficiency

4.1.1 Recirculation: The sand recycling method shall have a 90% accuracy after 5 minutes.

4.1.2 Surface Composition: The sand layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters.

4.1.3 Harness Weight Minimum: The enclosure shall have a hanging harness that can hold 1kg of weight.

4.2 Performance

4.2.1 Treadmill Speed: The treadmill shall have a speed of 0.2 meters per second within +-5%.

4.2.2 External Antenna: The enclosure shall have an antenna that is within range of the rat to collect data.

4.2.3 Gravity Simulation: The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity.

4.3 Safety

4.3.1 Emergency Stop: The system shall have an emergency stop function that works upon pressing the emergency stop button.

4.3.2 Waste Filter: The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length.

4.1 Usability

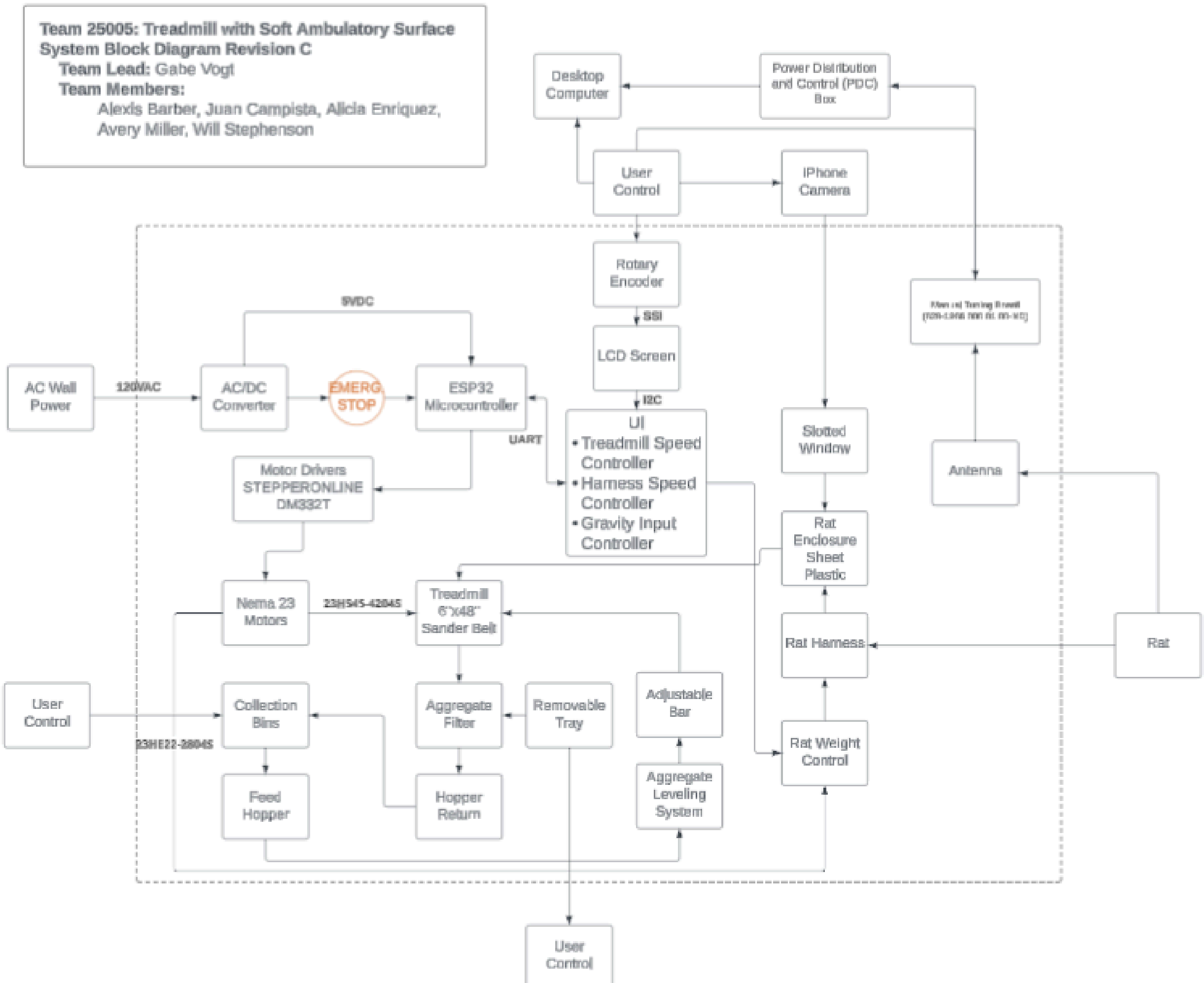
4.4.1 UI Simplicity: The user interface shall be simple to use and react upon input.

4.4.2 Enclosure Weight Maximum: The treadmill shall weigh less than 34.02 kilograms.

4.4.3 Enclosure Dimension Maximum: The enclosure shall be less than 66.04x160.02x66.0 cm to fit inside the fume hood.

4.4.4 Camera Window: The system shall have a window so that the user can monitor and film the rat during usage.

4.4.5 Power: The system shall plug into a 120 Volt wall adapter to power the system.


Team 25005: Treadmill with Soft Ambulatory Surface
System Block Diagram Revision C
Team Lead: Gabe Vogt
Team Members:
Alexis Barber, Juan Campista, Alicia Enriquez,
Avery Miller, Will Stephenson
Desktop Computer
Power Distribution and Control (PDC) Box
User Control
iPhone Camera
Rotary Encoder
SSI
LCD Screen
I2C
5VDC
AC Wall Power
120VAC
AC/DC Converter
EMERG. STOP
ESP32 Microcontroller
UART
UI
• Treadmill Speed Controller
• Harness Speed Controller
• Gravity Input Controller
Slotted Window
Antenna
Motor Drivers STEPPERONLINE DM332T
Rat Enclosure Sheet Plastic
Nema 23 Motors
23HS45-4204S
Treadmill 6"x48" Sander Belt
Rat Harness
Rat
User Control
Collection Bins
Aggregate Filter
Removable Tray
Adjustable Bar
23HE22-2804S
Feed Hopper
Hopper Return
Aggregate Leveling System
Rat Weight Control
User Control

5.0 Requirement Verification:

5.1 Efficiency

5.1.1 Recirculation Verification Method: A test shall be performed by weighing the aggregate before putting it into the feeder hopper, removing it after the 5-minute test, and weighing it again. The test will be passed if the weight of the aggregate removed after testing is within 90% of the original weight. An inspection shall occur to ensure visually that our aggregate is recirculating properly.

5.1.2 Surface Composition Verification Method: A test and demonstration shall be performed. We will run the treadmill for 5 minutes. During that 5 minutes we will have a video recording the treadmill. We will review the footage ensuring that the level of the sand does not. Exceed the +-2mm deviation allowed of the 12mm thickness. We will know that it exceeds the boundaries based on the marks indicated on the side window.

5.1.3 Harness Weight Minimum Verification Method: A finite element analysis shall be performed demonstrating that the rat harness can support the maximum stated weight of the rat before building a prototype of the system. This will be tested with a rat replica of the approximate average rat weight, along with various weights of 500g, 800g, and 1kg.

5.2 Performance

5.2.1 Treadmill Speed Verification Method: A test using a tachometer attached to the drive will be used to measure the RPM of the drive wheel. Using angular velocity equations, we will verify that the RPM of the wheel matches the RPM needed to have a linear velocity of 0.2m/s. We will test this using a secondary method as well. We will put a mark on the belt and activate the treadmill while recording a high frame-rate video measuring the amount of time that it takes for the mark to move a set distance. Using 2 verification methods will ensure that the treadmill is moving at the correct speed. A demonstration will be done with the UI speed changing setting.

5.2.2 External Antenna Verification Method: A test with a rat with the sensors embedded shall be performed by placing said rat into the enclosure on the treadmill and the test will be passed if the red LED indicator lights up inside the antenna subsystem. A demonstration will be done during the test with the red LED indicator to ensure data collection can occur. An inspection evaluating the brightness of the LED will be used to ensure strong wireless power transfer.

5.2.3 Gravity Simulation Verification Method: Using known values of Earth's gravitational force, we will demonstrate that the rat's effective weight under simulated gravity conditions matches the intended percentage of Earth's gravity, as measured by a scale. This will be done with a test, demonstration, and inspection of the UI’s performance when used to navigate to through the gravity settings.

5.3 Safety

5.3.1 Emergency Stop Verification Method: A test shall be performed such that when the system is operating and the emergency stop button is pressed, the treadmill stops, and the rat is lifted from the face of the treadmill using the gravity-simulating winch.

5.3.2 Waste Filter Verification Method: A demonstration and test will be performed. The demonstration of the filter will include measuring the size of the openings and the test will include mixing aggregate with objects at least 1 cm in length and running that mixture through the filter. The test is passed if all of the objects added are removed from the aggregate.

5.4 Usability

5.4.1 UI Simplicity Verification Method: A demonstration and inspection shall be performed, consisting of inspecting the simplicity of the UI LCD menu and assessing how user-friendly the subsystem is through a demonstration with the sponsor. The sponsor sets the expectation for simplicity in this subsystem.

5.4.2 Treadmill Weight Maximum Verification Method: A test will be performed. The entire project once it is completed will be placed on a scale and the test is passed if the enclosure and all of the components within weigh no more than 34.02 kilograms.

5.4.3 Treadmill Dimension Maximum Verification Method: A demonstration will be completed. Once the enclosure is completed it will be placed into the fume hood that it will be run in and if it fits within the fume hood then the dimensions are verified.

5.4.4 Camera Window Verification Method: A demonstration will be completed. Once a rat has been placed onto the treadmill, we will ensure that the rat is completely visible during the test and that the camera can clearly record.

5.4.5 Treadmill Power Verification Method: A demonstration shall be performed. To ensure that the treadmill is powered correctly, a demonstration can be done by powering on our assembly and running to ensure 24V is provided to the motors in the system. This demonstration will ensure the functionality of each component requiring power from this adapter.

6.0 Verification Matrix:

6.1 Efficiency

6.1	Requirements	Verification Method			
		T	A	D	I
6.1.1 The sand recycling method shall have a 90% accuracy after 5 minutes-		X			
6.1.2 The sand layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters		X			
6.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.		X			

6.2 Performance

6.2	Requirements	Verification Method			
		T	A	D	I
6.2.1 The treadmill shall have a speed of 0.2 meters per second within +-5%		X			
6.2.2 The enclosure shall have an antenna that is within range of the rat to collect data		X			
6.2.3 The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity				X	

6.3 Safety

6.3	Requirements	Verification Method			
		T	A	D	I
6.3.1 The system shall have an emergency stop function that works upon pressing the emergency stop button		X			
6.3.2 The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length		X			

6.4 Usability

6.4	**Requirements**	**Verification Method**			
		T	**A**	**D**	**I**
6.4.1 The user interface shall simple to use and react upon input				X	
6.4.2 The treadmill shall weigh less than 75 pounds		X			
6.4.3 The enclosure shall be less than 66.04x160.02x66.04 cm to fit inside the fume hood				X	
6.4.4 The system shall have a window so that the user can monitor and film the rat during usage.					X
6.4.5 The system shall plug into a 120 Volt wall adapter to power the system				X	

7.0 Requirements Flowdown Traceability Table

Key:

Aggregate Performance Acceptance Test
Harness Weight Minimum Acceptance Test
Treadmill Velocity Acceptance Test
Data Collection Acceptance Test
Emergency Stop Acceptance Test
Rat Waste Filter Acceptance Test
System Weight Acceptance Test
Aggregate Thickness Acceptance Test

System Requirements	SubSystems					
	1.1 Collection Bins	1.2 Treadmill	1.3 UI & Electrical Assembly	1.4 Enclosure	1.5 Filter	1.6 Aggregate Leveler
4.1.1 The aggregate recycling method shall have a 90% accuracy after 5 minutes	Test-Direct Flow: The bins must hold enough aggregate and be able to be lifted easily	Test-Direct Flow: The treadmill must still move at the 5-minute mark.	Test-Derived: The motors must not overheat and rotate continuously. The UI must complete the test after 5 minutes.		Test-Direct Flow: The filter must not get clogged and still be efficient after the 5 minutes.	Test-Direct Flow: The leveler must still be allocated height after the 5 minutes.
4.1.2 The aggregate layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters	Inspection-Allocation: The bins must be dumped quick enough to never left the upper hopper be almost empty	Inspection-Direct Flow: The treadmill must accommodate the height of the aggregate and contain the aggregate as it moves.			Test-Derived: The filter must be big enough to sufficiently filter the aggregate at the speed required to keep a uniform depth.	Test-Direct Flow: The aggregate must be even across the surface and at an even depth with uniform coverage.
4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.			Analysis-Derived: The motor that simulates the different gravities must be powerful enough to sufficiently work for rats within the size requirements.	Analysis-Direct Flow: The harness must be attached to the enclosure in a secure way and easily allow the rat to be placed inside.		
4.2.1 The treadmill shall have a speed of 0.2 meters		Test-Direct Flow: The treadmill will move at the speed	Test/Demonstration- Derived: The UI must use a rotary encoder/knob			Test-Direct Flow: The aggregate should be consistently

per second within +-5%		specified.	controlling the treadmill's speed. The motors must power the treadmill during use.			level up to 0.2 meters per second within +-.5%.
4.2.2 The enclosure shall have an antenna that is within range of the rat to collect data		Test/Demonstration Derived: the treadmill shall be close enough to the edge of the enclosure to collect data.	Test-Derived: The antenna will be powered by the system.	Test/Demonstration-Direct Flow: The enclosure will be large enough to accommodate an amplifier board Feig ID ISC.MAT-B to collect data efficiently.		
4.2.3 The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity			Test/Demonstration- Derived: The UI requires a rotary encoder to manually control the position of the rat harness in order to simulate lunar or Martian gravity.	Test-Derived: The mechanism will be attached to the enclosure in a safe and effective way.		
4.3.1 The system shall have an emergency stop function that works upon pressing the emergency stop button that lifts the rat within the harness up from the face		Test/Demonstration-Derived: The treadmill shall come to a stop when the emergency stop function is implemented.	Test/Demonstration- Direct Flow: The UI will implement an emergency stop function integrated with a program to gradually slow and stop the system.	Test-Direct Flow: The mechanism for rat safety must be attached to the enclosure securely and effectively.		

of the treadmill						
4.3.2 The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length		Inspection-Derived: The end of the treadmill must flow into the filter.		Demonstration Derived: The enclosure shall have access to discard the rat waste.	Test/Inspection Derived: The system shall have a filter screen for rat waste, being able to catch waste between 1-2 cm in length.	
4.4.1 The user interface shall simple to use and react upon input			Demonstration-Direct Flow: The UI must react upon input using a rotary encoder, with simplicity determined by components used in UI and instructions provided on the LCD screen/user manual.			
4.4.2 The treadmill shall weigh less than 34.02 kilograms	Inspection-Derived: The buckets must be light enough to be dumped easily and not be a significant weight	Inspection-Derived: The treadmill should be made of the least amount of material possible.		Allocation-Derived: Parts for the enclosure must be made out of the lightest enclosure - preferably 3D printed with little amounts of wood.	Allocation-derived: Filter must be made out of the lightest metal. Should also be as thin as possible to reduce weight.	
4.4.3 The enclosure shall be less than 66.04x160.02x66.04 cm (XYZ) in to fit inside the fume hood		Inspection-Allocated: The treadmill dimensions should be 56.515 x 15.24 x 7.62 cm for efficient sizing.	Inspection-Allocated:The electronics must fit within the space below the treadmill. (56.515 x 15.24 x 7.62 cm)	Inspection-Direct Flow: The Enclosure must fit within the 66.04x160.02x66.04 cm of width, height, and depth respectively and have a space for the rat to be placed onto the treadmill	Inspection-Allocated: The filter will be large enough to be efficient but take up no more than 17.78 cm of depth which is included in the 40.64 cm of the front half.	Inspection-Allocation: The leveling must be the width of the treadmill for maximum efficiency

4.4.4 The system shall have a window so that the user can monitor and film the rat during usage.		Test- Derived: The entirety of the treadmill should be able to be caught on video through the window for video analysis.				
4.4.5 The system shall plug into a 120 Volt wall adapter to power the system		Inspection-Direct Flow: The treadmill must power on, as displayed by the UI LCD.	Demonstration-Direct Flow: The UI must include an ON/OFF button to control system power, displaying the status on the LCD.			

8.0 Notes:

8.1 Inexpensive Components

The Treadmill will use inexpensive mechanical and SW/HW integrated subsystem components. An example of a sustainable design for the Treadmill includes reusing the motors bought in the previous Treadmill project.

8.2 Planned Maintenance

The previous year's treadmill had custom parts that have deteriorated. To ensure the system is usable in the long term, parts that are consumable will be easy to replace. This will include parts that are purchasable off the shelf and parts that are able to be easily 3d printed using a desktop 3d printer. We will provide documentation on replacing these parts along with documentation on maintaining parts to extend the lifetime of said parts.

4.3 Verification Procedures, Data Sheet, and Inspection Report Summary

Of our system requirements, we had nine verification procedures to complete. Each has its own data sheet and specific associated procedures to follow in testing to verify that our system meets these requirements. The following is a summarized description of our verification procedures for each data sheet, along with how our final results are reflected in the inspection report summaries.

1.1 Aggregate Performance Acceptance Test

Equipment used: Aggregate, completed system assembly.

Summarized Procedure: Load in aggregate into complete system assembly and start the treadmill to run the auger for 5 minutes. During these five minutes, our aggregate should be recycled and retain 90% of the loaded aggregate. Meeting this condition results in a pass.

Final Inspection Report Results: This was tested with our collection bin subsystem, retaining well over 90% of the fed aggregate. This resulted in a pass.

1.2 Data Collection Acceptance Test

Equipment used: FEIG LRM2500-B RFID Reader, ISC.MAT-B Antenna Tuning Board, SMA Cable (50 Ohm) with Ferrite Choke, 14-16 AWG wire, NeuroLux Power Distribution and Control (PDC) Box, FEIG Software, red LED indicator.

Summarized Procedure: Set up an antenna to wire around the treadmill enclosure horizontally, mapping out and marking the critical area quadrants of the antenna enclosure. Connect the antenna to the ISC.MAT-B antenna tuning board, ensuring the board is powered. Tune the board to 1.3 conductance using the jumpers that come with the board. Insert a red LED indicator into the treadmill enclosure, data collection via wireless power transfer occurring when the LED lights up. Using the LED indicator to verify data collection in all critical areas will result in a pass.

Final Inspection Report Results: This acceptance test was performed with our full assembly, resulting in a pass. Red LED indicator for data collection worked in all critical areas and indicated function outside some of these areas.

1.3 Harness Weight Minimum Acceptance Test

Equipment used: Arduino IDE, Arduino Uno or ESP32, Stepper Motor (23HS22-2804S), Stepper Driver (DM332T), Pulley, Paracord, Rotary Encoder, Momentary Switches, Emergency Stop Button, and an assortment of weights (500g, 800g, and 1kg).

Summarized Procedure: Assemble the breadboard circuit according to the wiring diagram in the SDD. Connect the 24V adapter to the stepper driver to give power to the single stepper motor. Attach the string to the pulley on the motor and attach the various weights, raising and lowering the harness with the rotary encoder. If the motor is operating without skipping steps and the emergency stop returns the harness to the set return point for all weights up to 1kg, this results in a pass.

Final Inspection Report Results: During our MVP2, an analysis was performed to determine the torque constraints on our harness motor. After reassuring our motor is capable of handling our minimum weight, we retested the harness height with the redesigned pulley and PCB Rev B. This resulted in a pass. Testing with PCB Rev C resulted in a pass as well.

1.4 Rat Waste Filter Acceptance Test

Equipment used: Aggregate, 10 3D printed "rate waste" (1-2cm length, ~3mm diameter, timer, 3D printed filter, electronic scale, bins to hold aggregate, and measuring cup.

Summarized Procedure: Prepare 3 cups of aggregate mixed with the 10 rat waste pellets, pour mixture over the filter to filter our waste, and count to see if all 10 rat waste pellets are in the filter.

Final Inspection Report Results: This acceptance test was performed with our full assembly, resulting in a pass.

1.5 Treadmill Velocity Acceptance Test

Equipment used: Arduino IDE, ESP32, Treadmill Assembly, Stepper Motor (23HS45-4204S), Stepper Driver (DM332T), Rotary Encoder, Reflective Tape, Tachometer, Excel

Summarized Procedure: Attach reflective tape to our pulley and assemble the breadboard circuit according to the SDD wiring diagram. Upload and run code on ESP32 after connecting the 24V adapter to the stepper driver. Use a rotary encoder and gradually increase and measure each RPM with the tachometer. Use the velocity formula and plug in RPM to determine velocity. Compare this calculation to the actual velocity documented in the code print statements. If the treadmill velocity can range from 0.2m/s to 0.8m/s, this results in pass.

Final Inspection Report Results: This acceptance test was performed with our full assembly, resulting in a pass for all PCB revisions.

1.6 Emergency Stop Acceptance Test

Equipment used: Arduino IDE, ESP32, Treadmill Assembly, Stepper Motor (23HS45-4204S), Stepper Driver (DM332T), DPDT Emergency Stop Switch, Rotary Encoder.

Summarized Procedure: Assemble the breadboard circuit according to the wiring diagram in the SDD. Connect the 24V adapter to the stepper driver to begin running the treadmill by setting the treadmill speed, setting a position height, and starting the auger with the UI. Run for one minute, press the emergency stop button, and view the results. If the treadmill and auger gradually stop, along with the harness coming back up, then this will result in a pass.

Final Inspection Report Results: During our MVP1 development, this acceptance test was performed and resulted in a pass. During our MVP2 development, we redid this test with our PCB Rev B, resulting in a pass as well. During our final testing, we redid this test with our PCB Rev C, resulting in a final pass.

1.7 Aggregate Thickness Acceptance Test

Equipment used: Upper hopper enclosed side, leveling bar, and aggregate.

Summarized Procedure: Lay the upper hopper on a flat surface, preferably cardboard. Screw the leveling bar onto the upper hopper enclosed side to a set height, depending on the desired aggregate thickness. Following this, fill the hopper with the desired aggregate and pull the upper hopper back slowly to release the aggregate. Using a ruler, measure the height of the bed of aggregate in several spots to verify aggregate thickness height. If this thickness height is 12mm with a margin of +/- 2mm, then the test is passed.

Final Inspection Report Results: This test was initially performed during our MVP2, and passed within our full assembly following.

1.8 System Weight Acceptance Test

Equipment used: Fully assembled treadmill with each subsystem included, scale.

Summarized Procedure: Completed system assembly will be measured to determine the actual weight of the system, compared to our CAD model prediction within a margin of ~2.65kg. If the system weighs 34.02kg or less/within the margin, this results in a pass.

Final Inspection Report Results: The system when weighed in its entirety was 15.04 kg, under the 34.02 kg max weight.

4.4 Hardware Drawing Package

Treadmill Ambulatory System Hardware Drawing Package
Treadmill Ambulatory System (TAS) **Hardware Drawing Package** **Team 25005** May 6, 2025 REV C Prepared for UA Dept. of Biomedical Engineering
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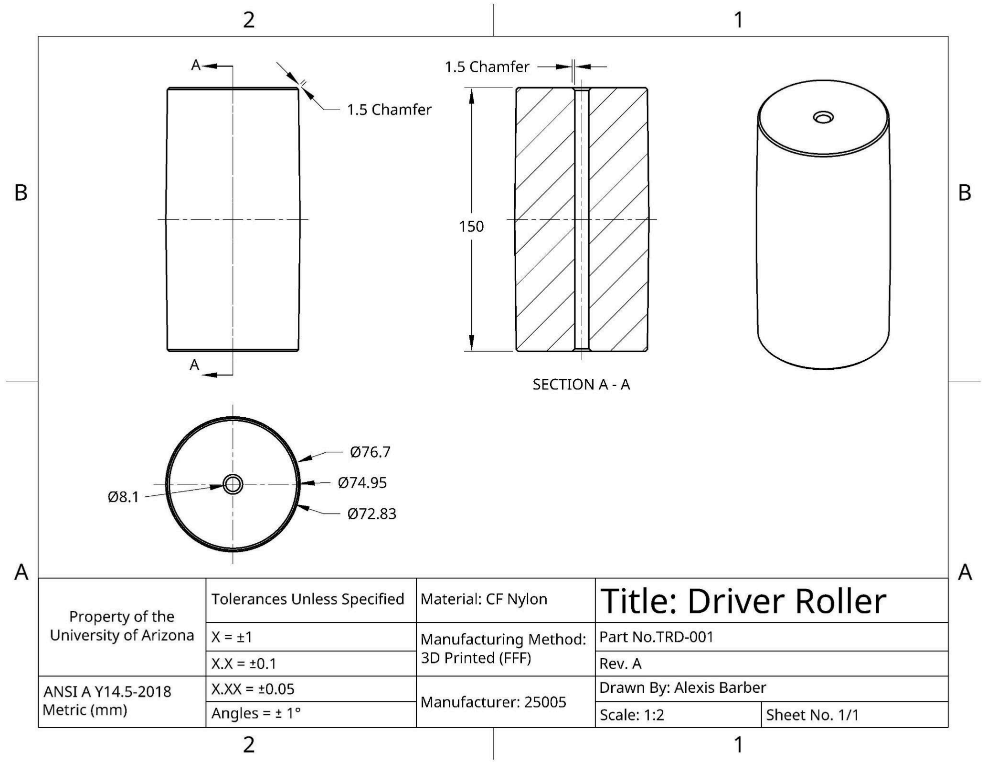
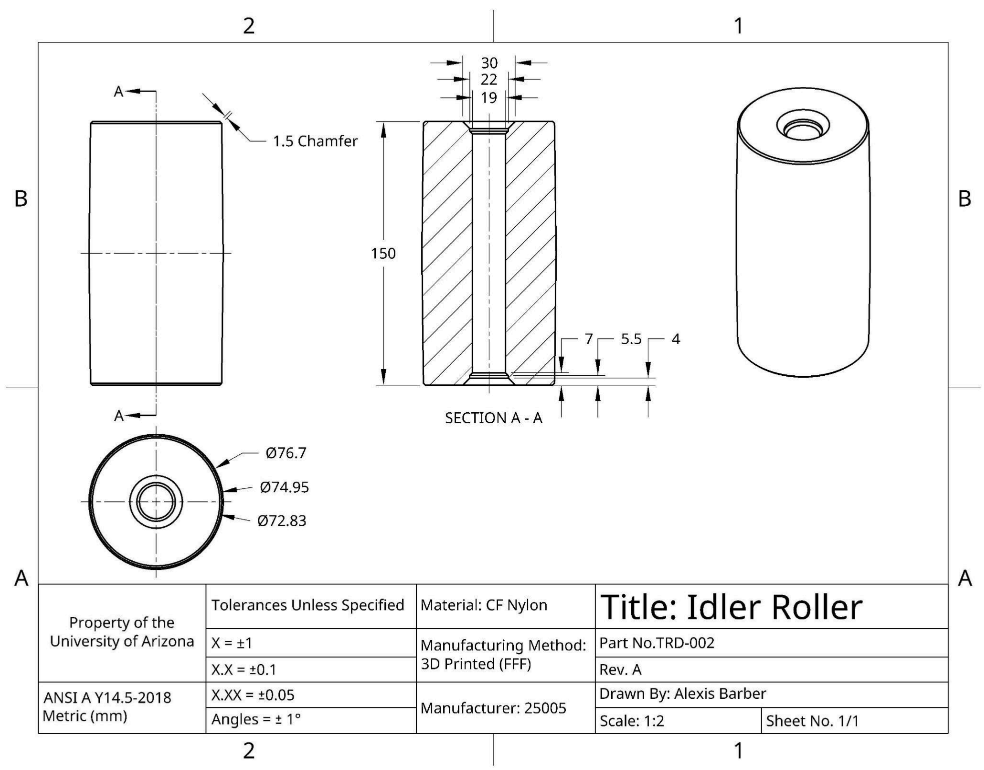
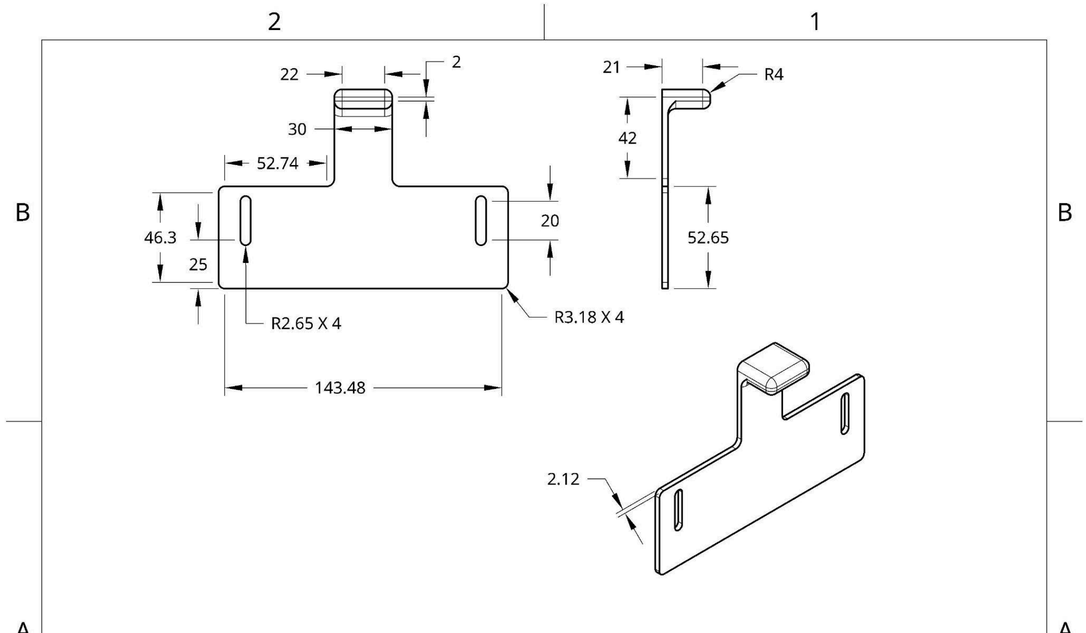
Section 1.0 – Mechanical Drawings

1.1 Treadmill Subsystem







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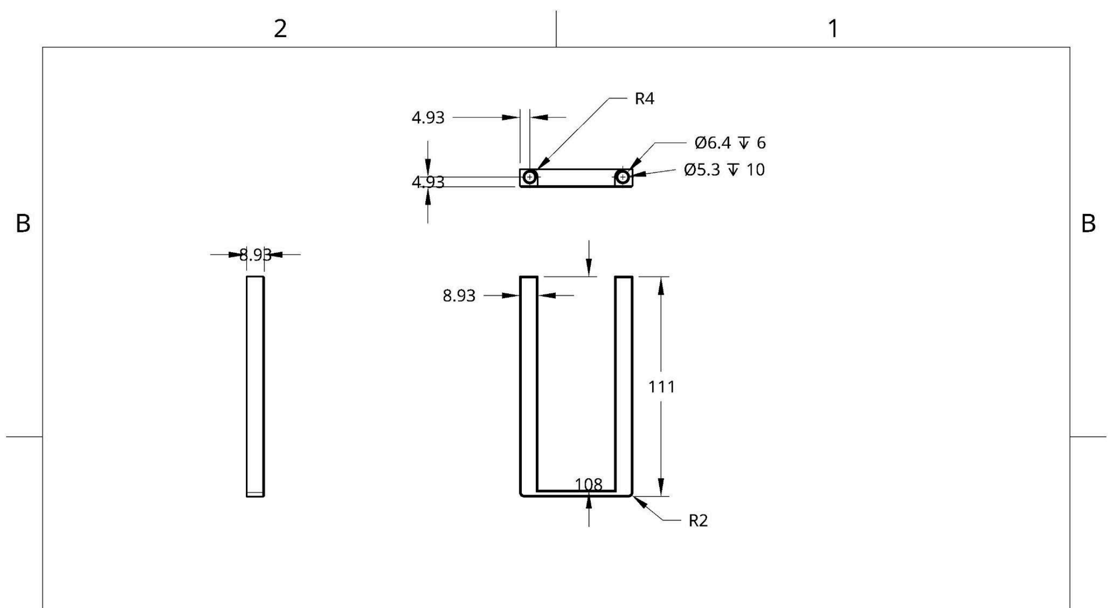

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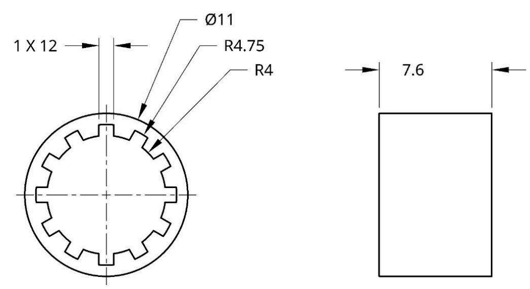

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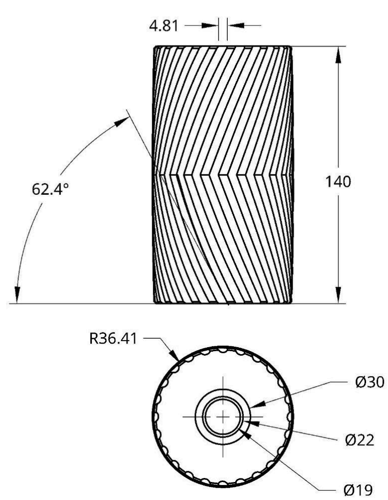

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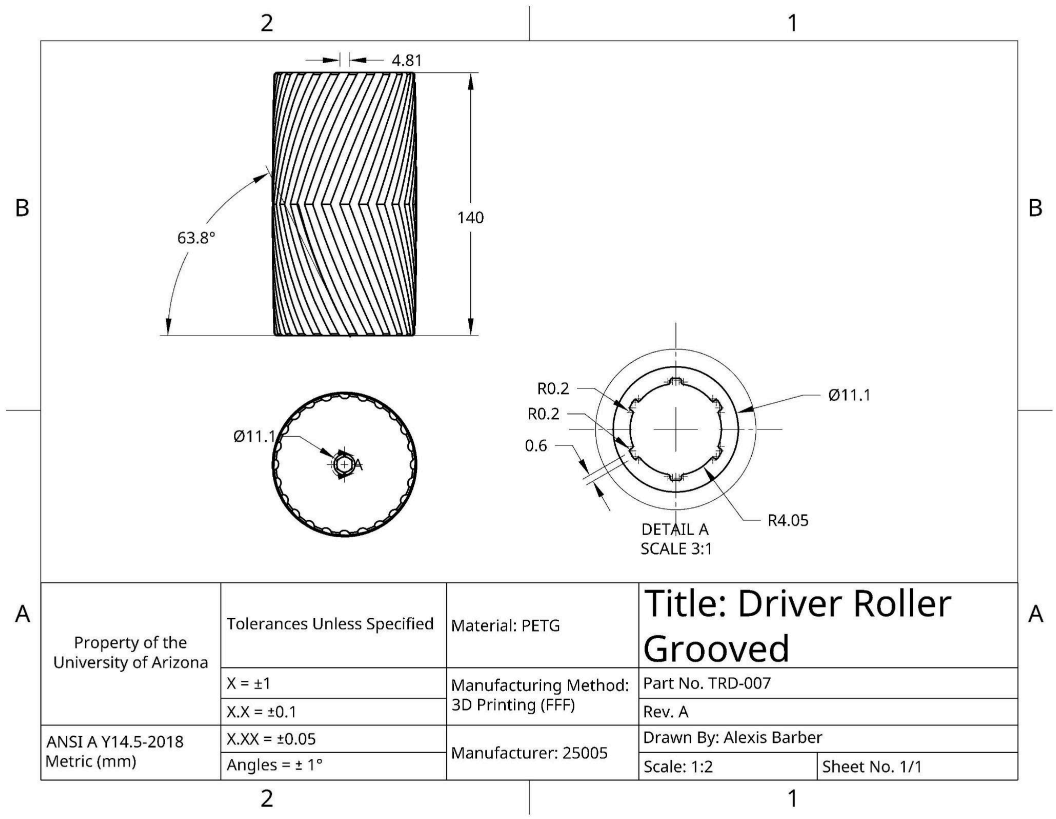
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63.8°
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B
Ø11.1
A
R0.2
R0.2
0.6
Ø11.1
R4.05
DETAIL A
SCALE 3:1
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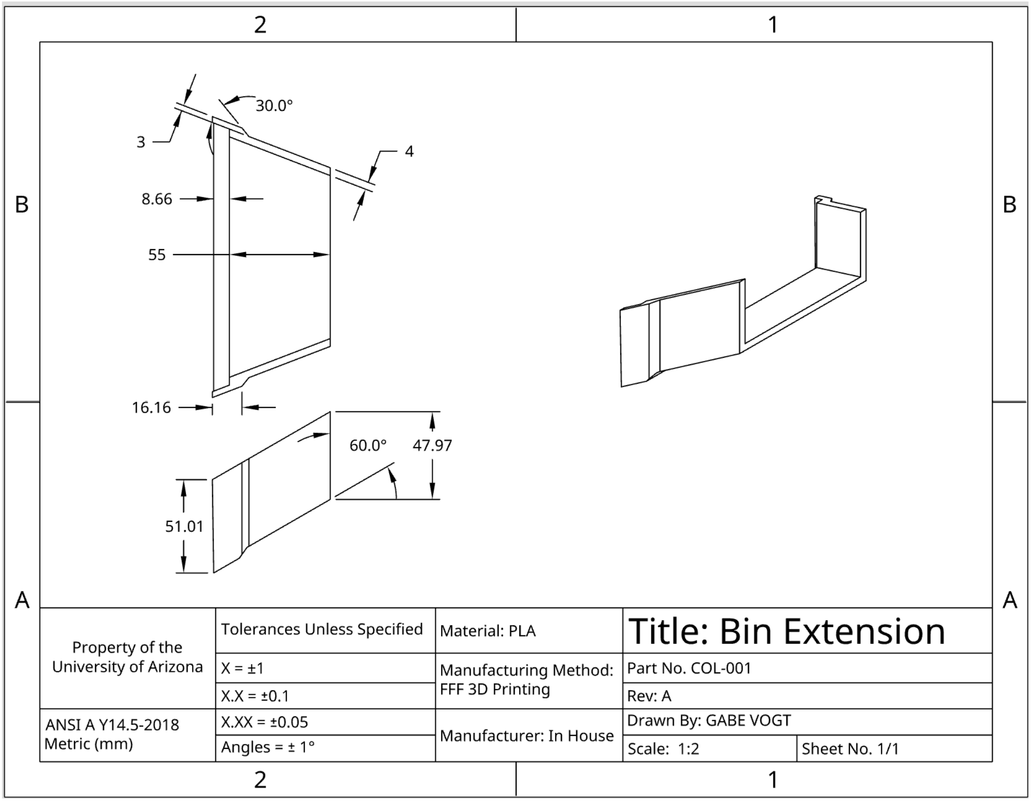
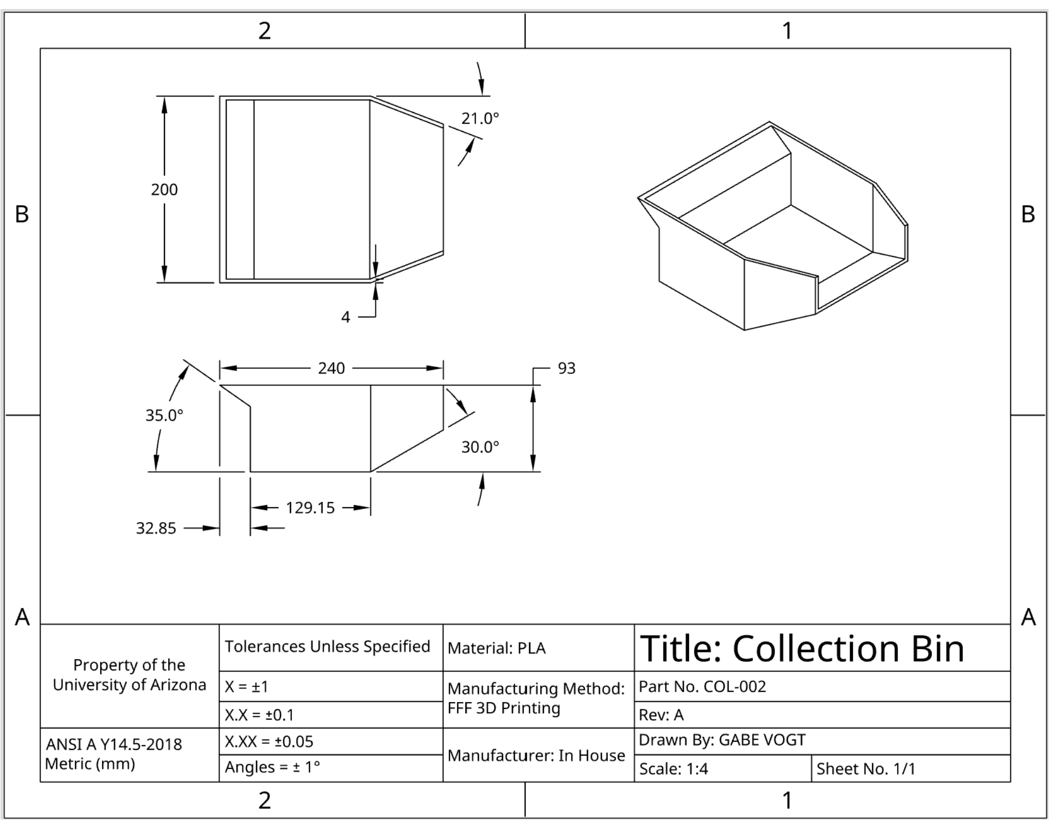
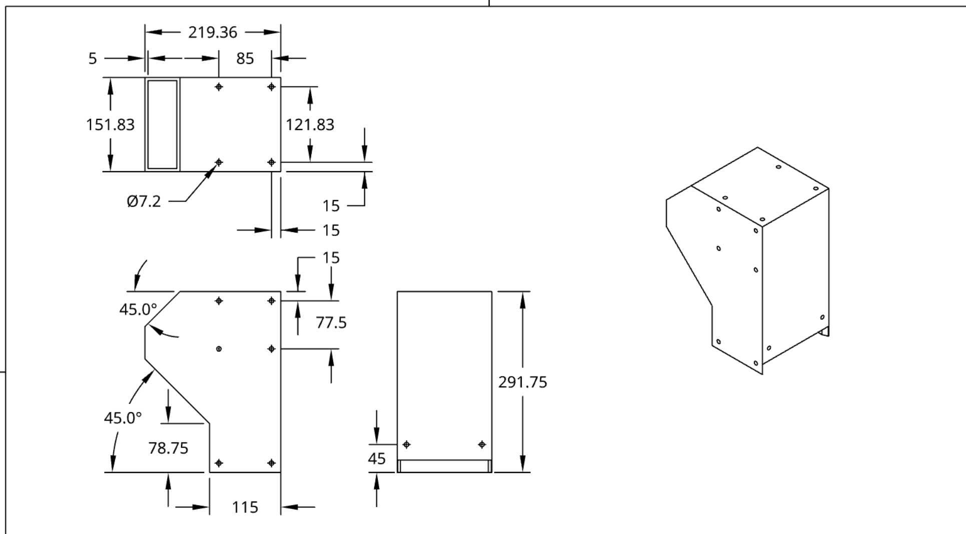
1.2 Collection Bins Subsystem







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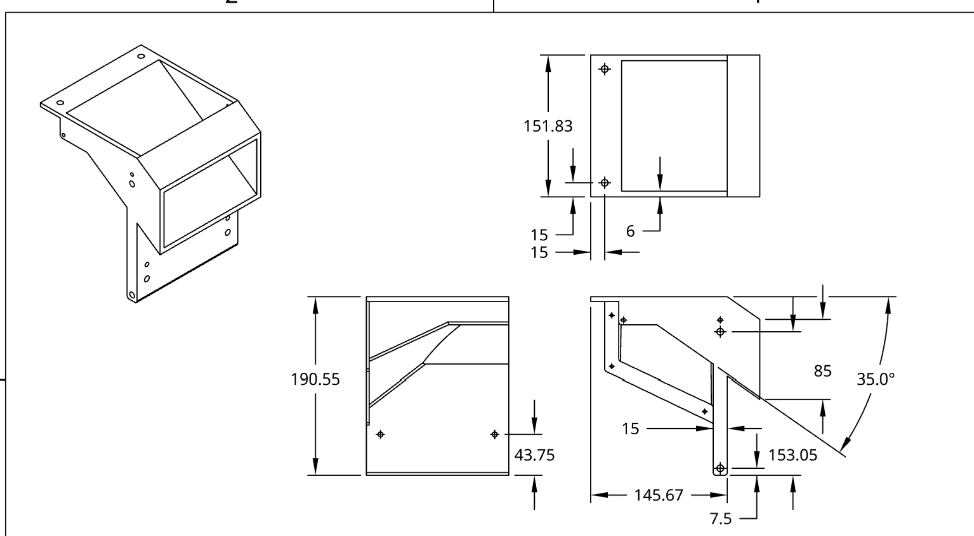

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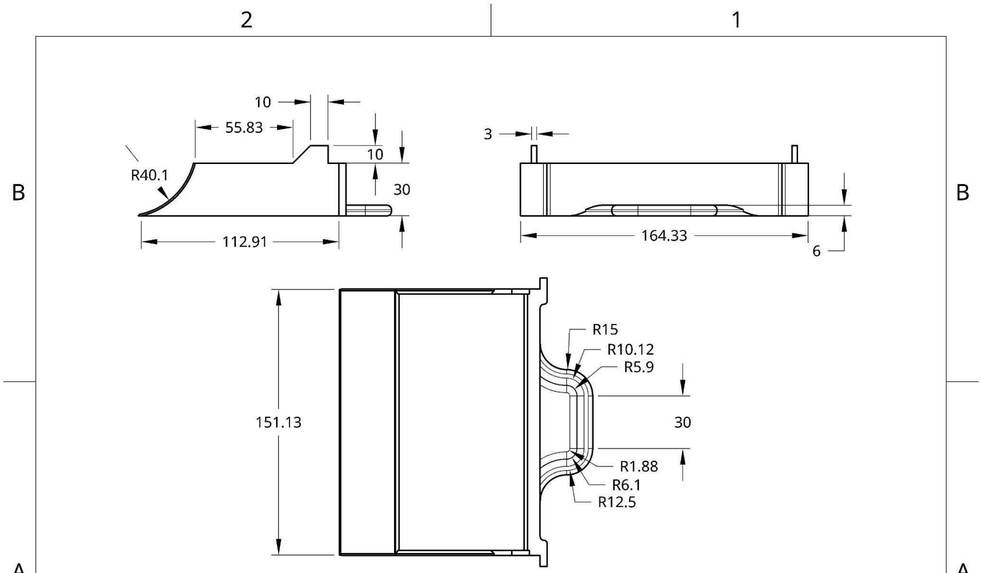
1.3 Filter Subsystem



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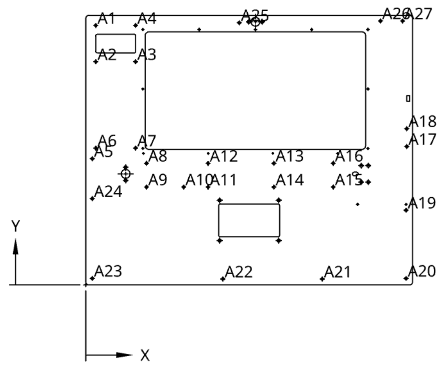
1.4 Enclosure Subsystem



TAG	X LOC	Y LOC	SIZE	QTY
A1	21.25	553.75	Ø5.3 THRU	27
A2	21.25	476.25		
A3	106.25	476.25		
A4	106.25	553.75		
A5	13.75	269.25		
A6	21.25	292.00		
A7	106.25	292.00		
A8	129.50	259.48		
A9	129.50	208.80		
A10	208.86	208.80		
A11	260.72	208.80		
A12	260.72	259.48		
A13	401.19	259.48		
A14	401.19	208.80		
A15	527.74	208.80		
A16	527.74	259.48		
A17	684.58	295.30		
A18	684.58	333.30		
A19	683.08	159.30		
A20	683.08	13.75		
A21	504.33	12.50		
A22	292.50	12.50		
A23	13.75	13.75		
A24	13.75	184.05		
A25	327.25	559.38		
A26	628.51	563.25		
A27	675.65	563.25		

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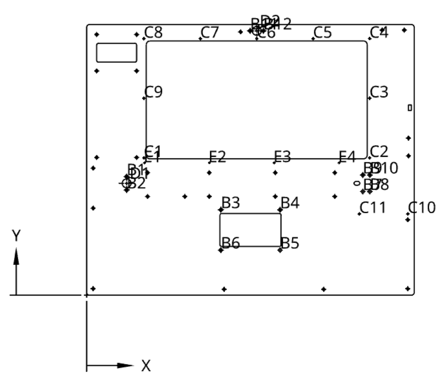
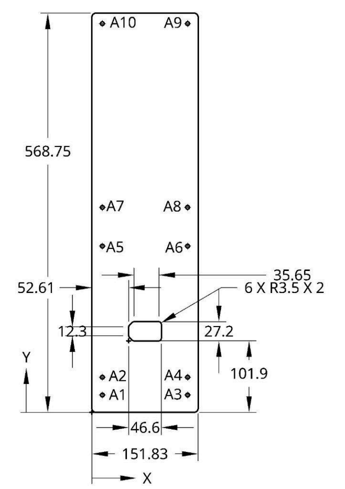


TAG	X LOC	Y LOC	SIZE	QTY
B1	85.00	251.10	Ø6.4 THRU	12
B2	85.00	222.70		
B3	285.41	180.55		
B4	411.41	180.55		
B5	411.41	94.55		
B6	285.41	94.55		
B7	587.41	219.40		
B8	602.41	219.40		
B9	587.41	254.40		
B10	602.41	254.40		
B11	347.57	561.50		
B12	375.97	561.50		
C1	121.70	291.11	Ø3.2 THRU	11
C2	601.83	291.11		
C3	601.83	418.06		
C4	601.83	545.00		
C5	481.80	545.00		
C6	361.77	545.00		
C7	241.73	545.00		
C8	121.70	545.00		
C9	121.70	418.06		
C10	683.08	171.80		
C11	579.91	171.80		
D1	85.00	236.90	Ø19 THRU	2
D2	361.77	561.50		
E1	123.00	280.56	Ø2.5 THRU	4
E2	260.97	280.56		
E3	398.94	280.56		
E4	536.91	280.56		

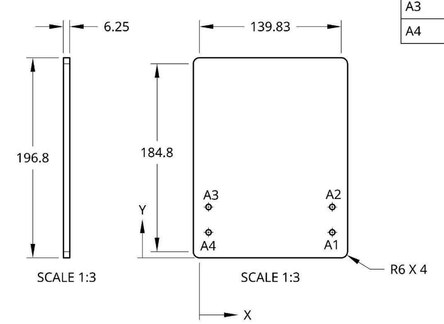
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Front Panel	
	X = ±1	Manufacturing Method: CNC Milled	Part No. ENC-001	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: In House	Drawn By: GABE VOGT	
	Angles = ± 1°		Scale: 1:8	Sheet No. 2/2



TAG	X LOC	Y LOC	SIZE	QTY
A1	15.00	24.75	Ø5.3 THRU	10
A2	15.00	50.00		
A3	136.83	24.75		
A4	136.83	50.00		
A5	15.00	236.90		
A6	136.83	236.90		
A7	15.00	292.00		
A8	136.83	292.00		
A9	136.83	553.75		
A10	15.00	553.75		

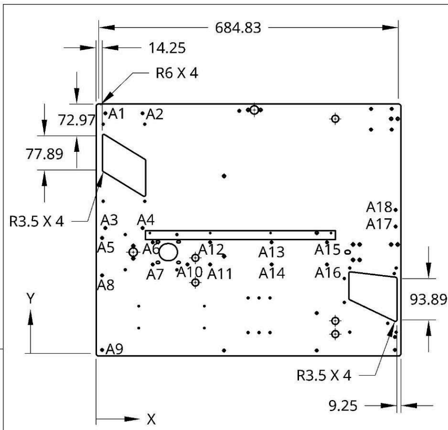
MATERIAL
THICKNESS:
6.25mm

Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Left Panel
	X = ±1	Manufacturing Method: CNC Milled	Part No. ENC-002
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:5 / Sheet No. 1:1



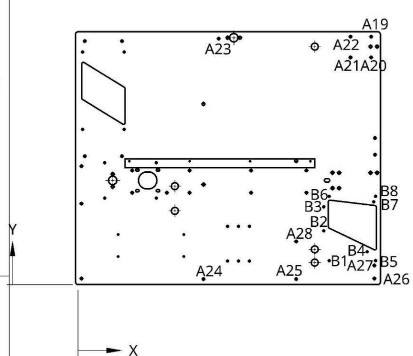
TAG	X LOC	Y LOC	SIZE	QTY
A1	130.83	25.00	Ø5.3 THRU	4
A2	130.83	50.00		
A3	9.00	50.00		
A4	9.00	25.00		

Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Right Lower Panel
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-003
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:2 / Sheet No. 1/1



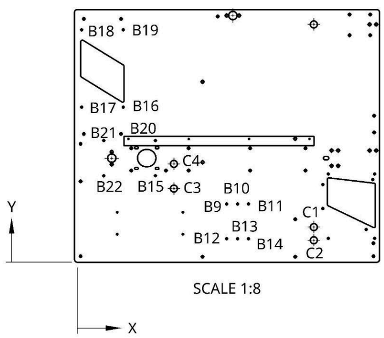
TAG	X LOC	Y LOC	SIZE	QTY
A1	21.25	547.75	Ø5.3 THRU	18
A2	106.25	547.75		
A3	21.25	286.00		
A4	106.25	286.00		
A5	13.75	263.25		
A6	129.50	253.48		
A7	129.50	202.80		
A8	13.75	178.05		
A9	13.75	7.75		
A10	208.86	202.80		
A11	260.72	202.80		
A12	260.72	253.48		
A13	401.19	253.48		
A14	401.19	202.80		
A15	527.74	253.48		
A16	527.74	202.80		
A17	684.58	289.30		
A18	684.58	327.30		

Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Back Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By
	Angles = ± 1°		Scale: 1:8 — Sheet No. 1/5



TAG	X LOC	Y LOC	SIZE	QTY
A19	669.65	563.82	Ø5.3 THRU	10
A20	669.65	516.68		
A21	622.51	516.68		
A22	622.51	563.82		
A23	321.25	559.38		
A24	286.50	12.50		
A25	498.33	12.50		
A26	677.08	13.75		
A27	677.08	43.38		
A28	498.33	97.96		
B1	573.91	54.38	Ø4.2 THRU	8
B2	561.41	122.32		
B3	561.41	176.80		
B4	660.57	74.57		
B5	679.83	54.38		
B6	573.91	200.77		
B7	675.58	188.12		
B8	679.83	200.77		

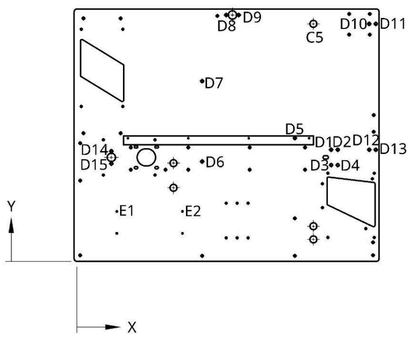
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Back Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:8 — Sheet No. 2/5



TAG	X LOC	Y LOC	SIZE	QTY
B9	341.50	132.50	Ø4.2 THRU	14
B10	366.50	132.50		
B11	391.50	132.50		
B12	341.50	53.50		
B13	366.50	53.50		
B14	391.50	53.50		
B15	178.76	196.72		
B16	105.25	353.01		
B17	10.25	353.01		
B18	10.25	528.94		
B19	105.25	528.94		
B20	178.76	277.01		
B21	60.74	277.01		
B22	60.74	196.72		
C1	540.83	80.00	Ø15.88 THRU	4
C2	540.83	50.00		
C3	221.04	167.61		
C4	221.04	223.80		

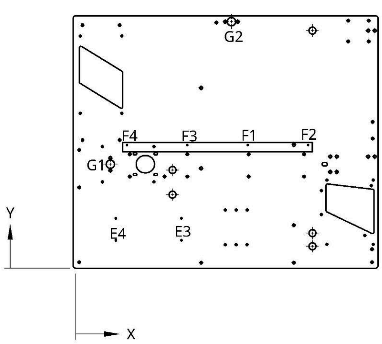
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Back Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:8 / Sheet No. 3/5

TAG	X LOC	Y LOC	SIZE	QTY
C5	540.83	541.25	Ø15.88 THRU	1
D1	581.41	254.40	Ø6.4 THRU	15
D2	596.41	254.40		
D3	581.41	219.40		
D4	596.41	219.40		
D5	498.33	281.09		
D6	286.50	227.50		
D7	286.50	410.63		
D8	341.57	561.50		
D9	369.97	561.50		
D10	668.33	541.25		
D11	683.33	541.25		
D12	668.33	254.30		
D13	683.33	254.30		
D14	79.00	251.10		
D15	79.00	222.70		
E1	91.50	113.75	Ø3.2 THRU	2
E2	241.50	113.75		

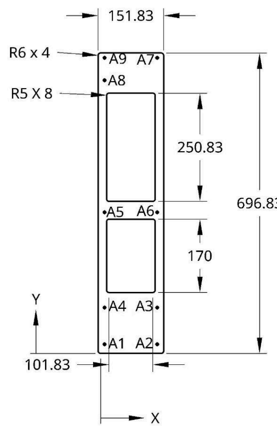


Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Back Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:8 Sheet No. 4/5

TAG	X LOC	Y LOC	SIZE	QTY
E3	241.50	63.75	Ø3.2 THRU	2
E4	91.50	63.75		
F1	392.94	280.56	Ø2.5 THRU	4
F2	530.91	280.56		
F3	254.97	280.56		
F4	117.00	280.56		
G1	79.00	236.90	Ø19 THRU	2
G2	355.77	561.50		



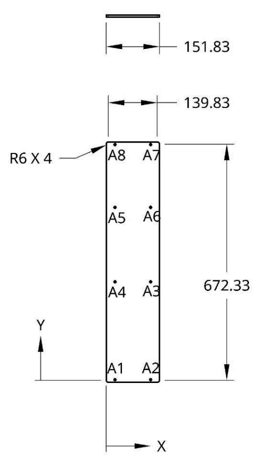
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Back Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC_004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:8 Sheet No. 5/5



TAG	X LOC	Y LOC	SIZE	QTY
A1	9.00	21.25	Ø5.3 THRU	9
A2	130.83	21.25		
A3	130.83	106.25		
A4	9.00	106.25		
A5	9.00	327.25		
A6	130.83	327.25		
A7	130.83	685.58		
A8	9.00	633.58		
A9	9.00	685.58		

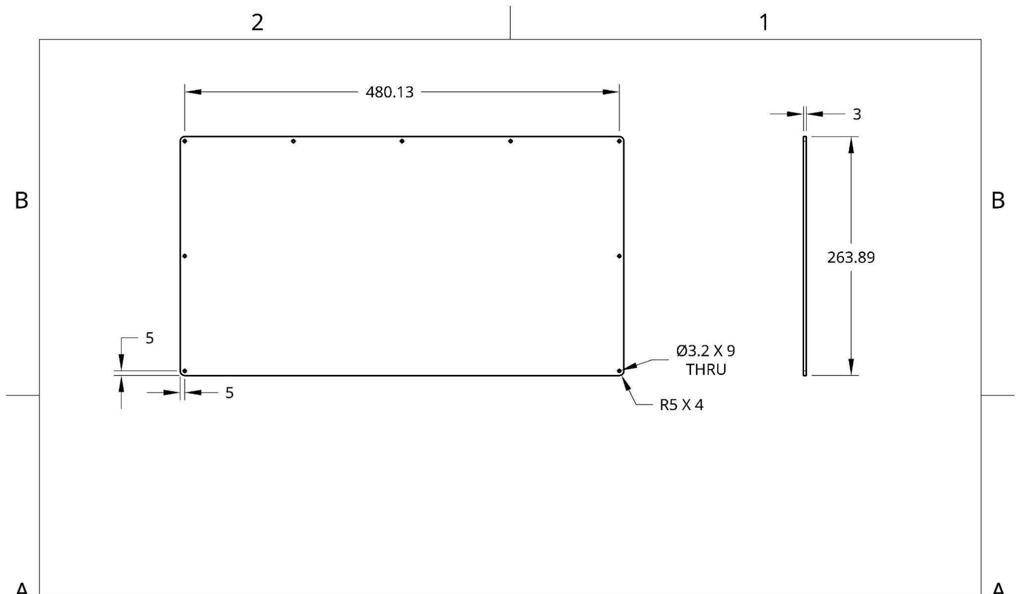
MATERIAL
THICKNESS:
6.25mm

Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Top Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-005
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:8 — Sheet No. 1/1

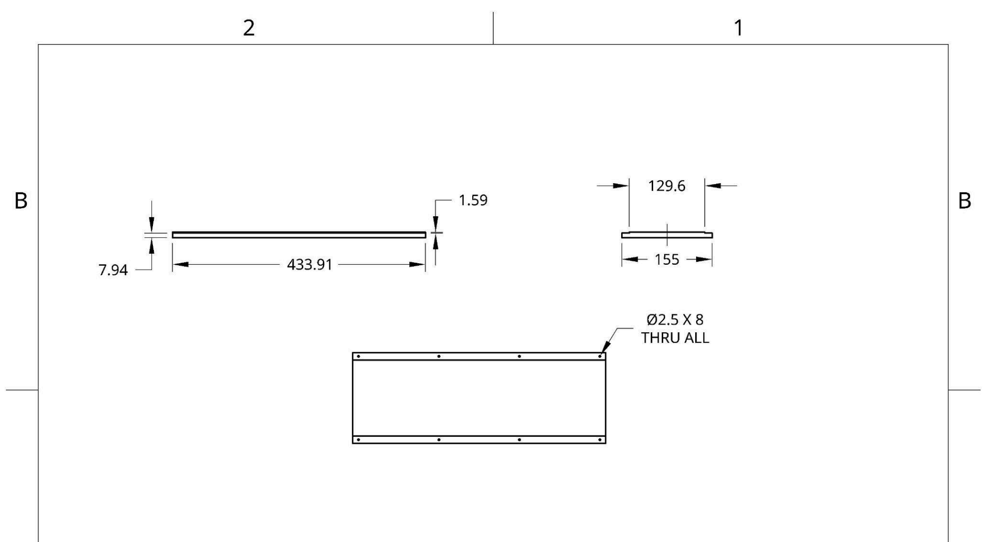


TAG	X LOC	Y LOC	SIZE	QTY
A1	25.00	1.50	Ø5.3 THRU	8
A2	126.83	1.50		
A3	126.83	280.25		
A4	25.00	280.25		
A5	25.00	492.08		
A6	126.83	492.08		
A7	126.83	670.83		
A8	25.00	670.83		

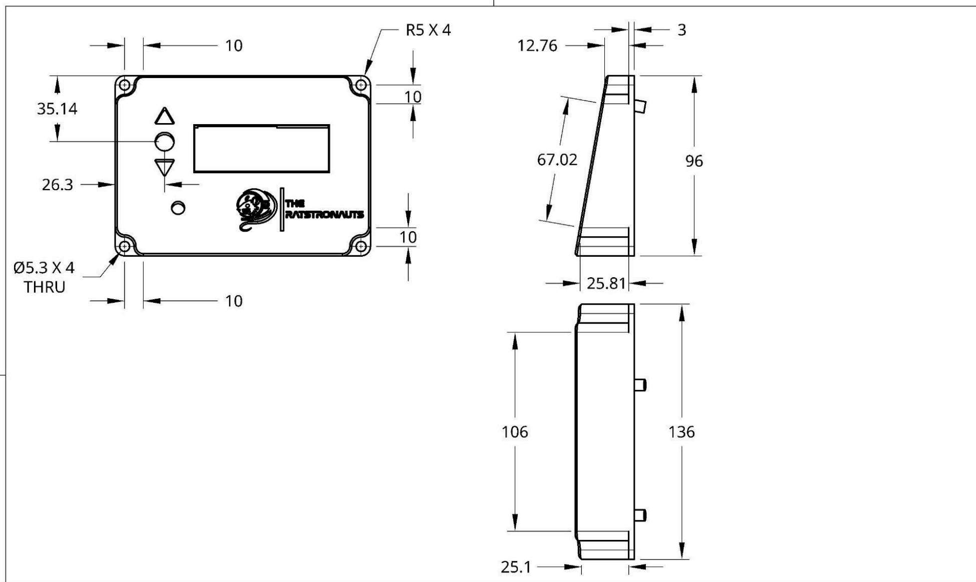
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Bottom Panel
	X = ±1	Manufacturing Method: Milled	Part No. ENC-006
	X.X = ±0.1		Rev.A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:10 — Sheet No. 1/1



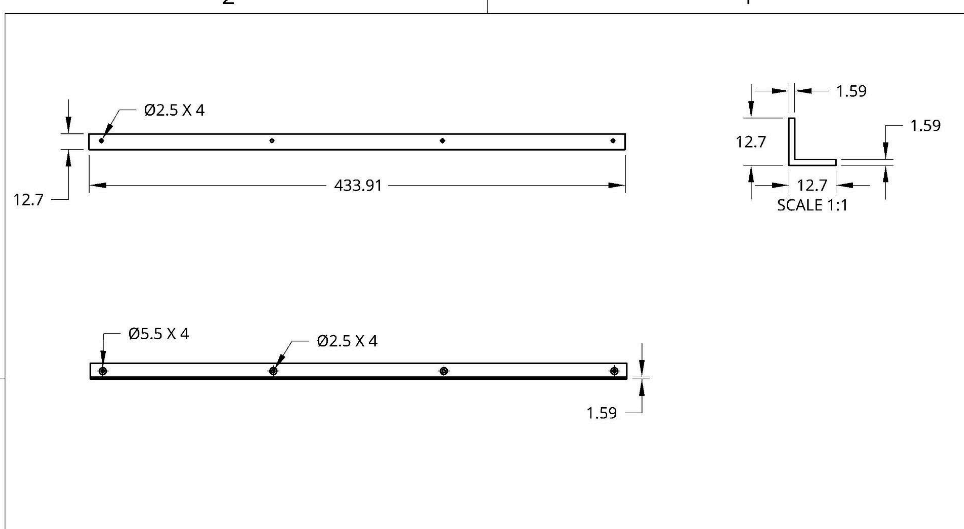
Property of the University of Arizona	Tolerances Unless Specified	Material: Acrylic	Title: Front Window
	X = ±1	Manufacturing Method: Lasercut	Part No. ENC-007
	X.X = ±0.1		Rev. B
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:4 Sheet No. 1/1



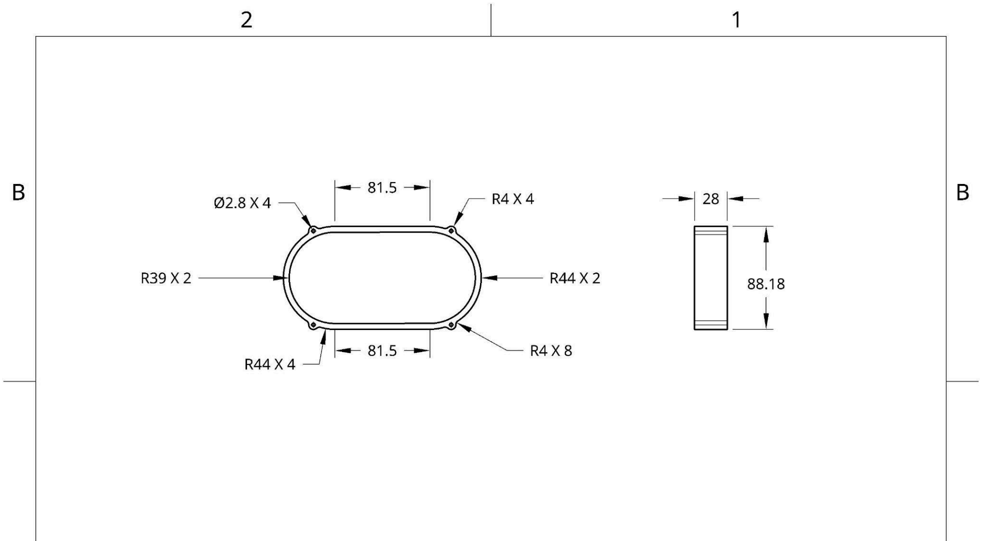
Property of the University of Arizona	Tolerances Unless Specified	Material: UHW HDPE	Title: Treadmill Base HDPE
	X = ±1	Manufacturing Method: Milled	Part No. ENC-008
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:6 Sheet No. 1/1



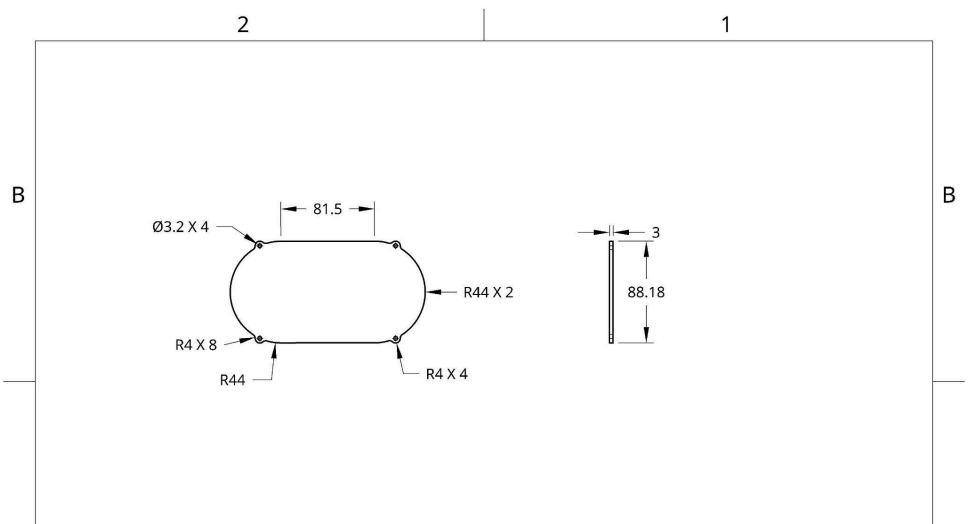
Property of the University of Arizona	Tolerances Unless Specified	Material: PETG	Title: Screen Holder	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-009	
	X.X = ±0.1		Rev. B	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



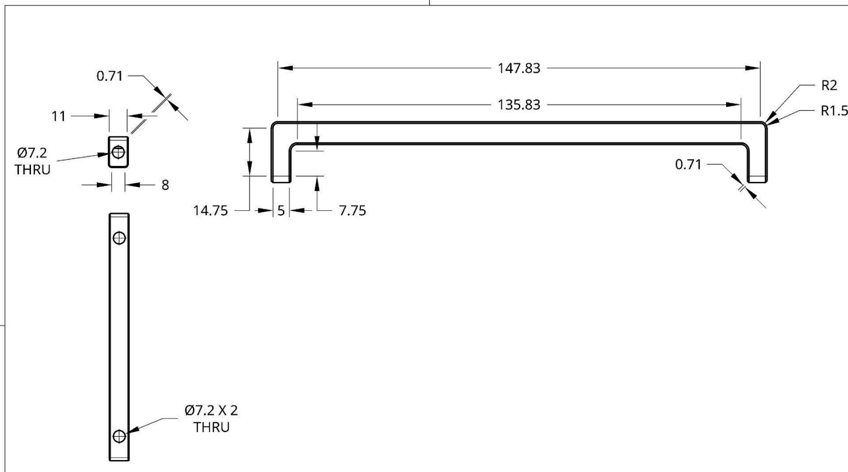
Property of the University of Arizona	Tolerances Unless Specified	Material Aluminum Angle	Title: Treadmill Base ½in Al Angle	
	X = ±1	Manufacturing Method: Purchased	Part No. ENC-010	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:3	Sheet No. 1/1



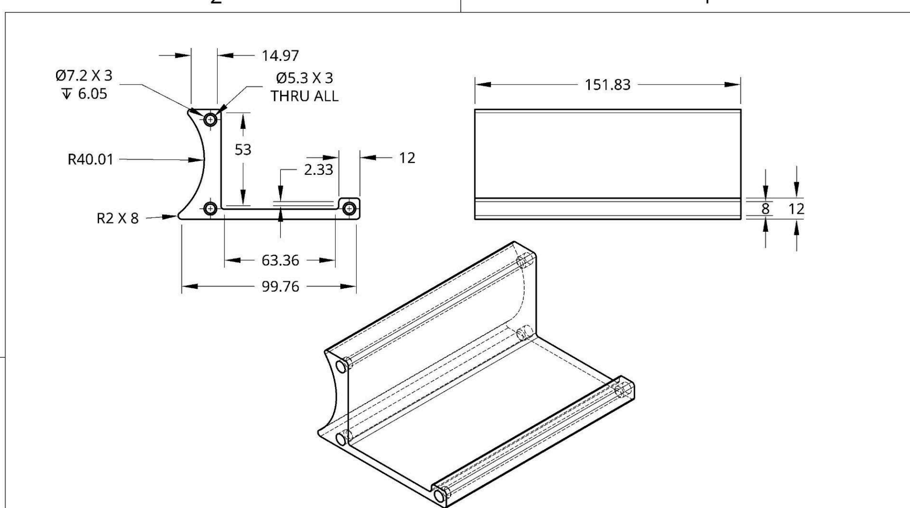
Property of the University of Arizona	Tolerances Unless Specified	Material: Acrylic	Title: Treadmill Motor Cover	
	X = ±1	Manufacturing Method: Lasercut	Part No. ENC-011	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:3	Sheet No. 1/1



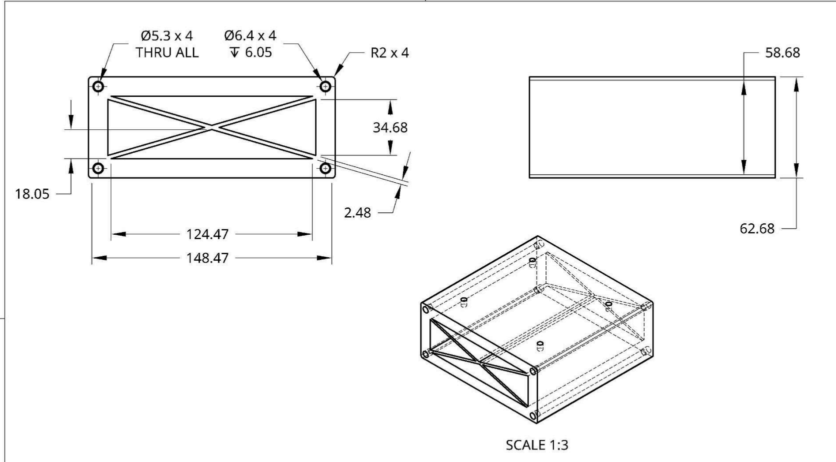
Property of the University of Arizona	Tolerances Unless Specified	Material: Acrylic	Title: Treadmill Motor Cover Flat	
	X = ±1	Manufacturing Method: Lasercut	Part No. ENC-012	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:3	Sheet No. 1/1



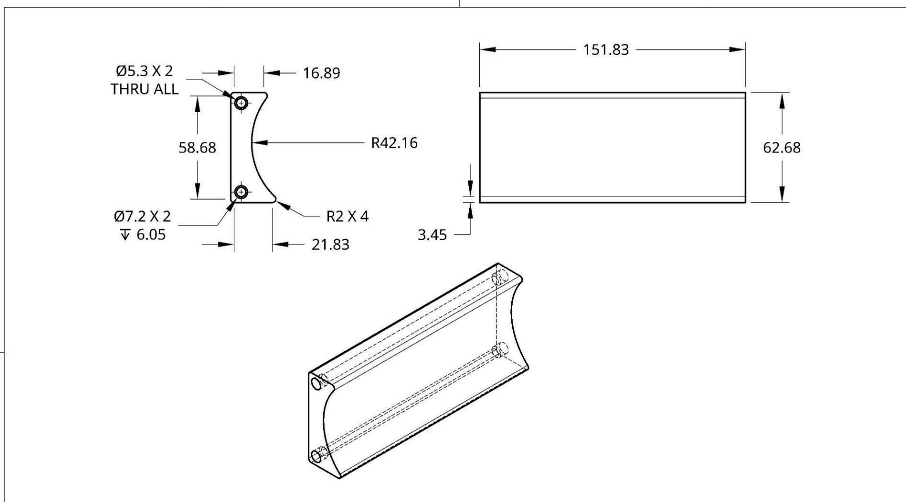
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Top Center Reinforcement	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-013	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:1	Sheet No. 1/1



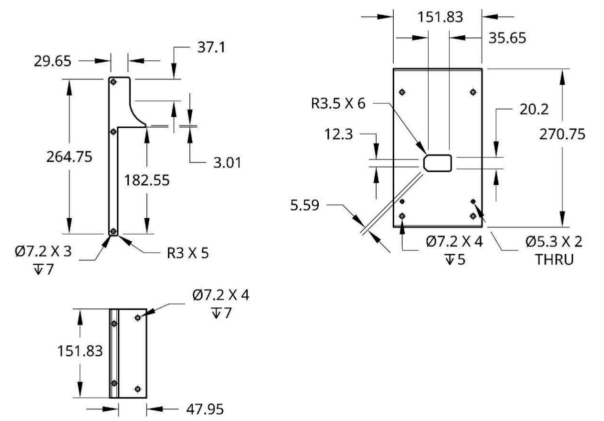
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Motor Reinforcement	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-014	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Center Reinforcement	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-015	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1

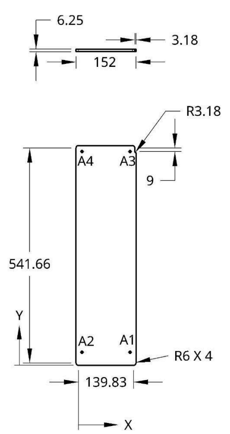


Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Idler Side Reinforcement	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-016	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1

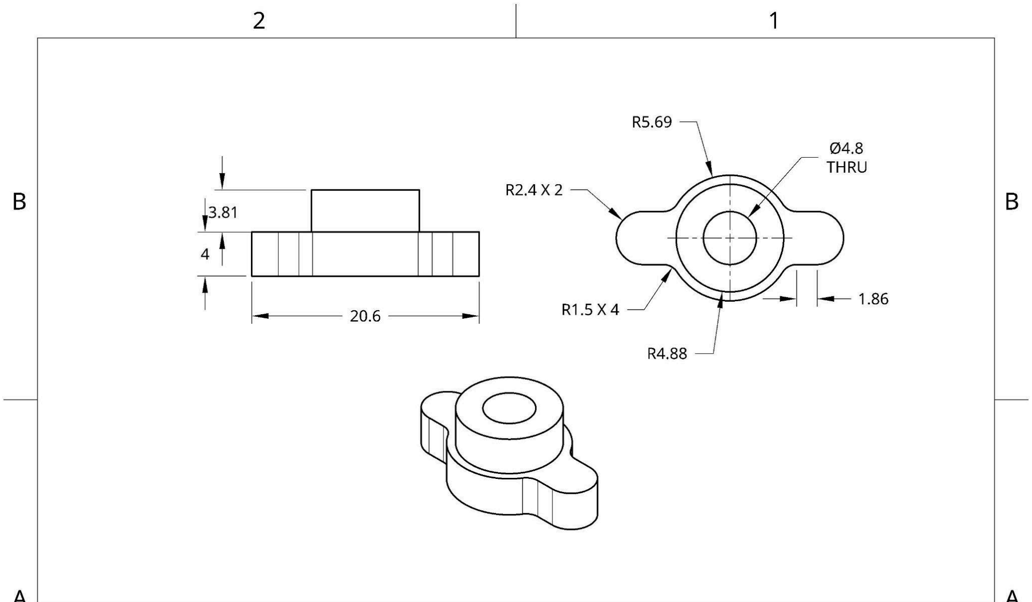


Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Left Side Reinforcement	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-017	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:6	Sheet No. 1/1

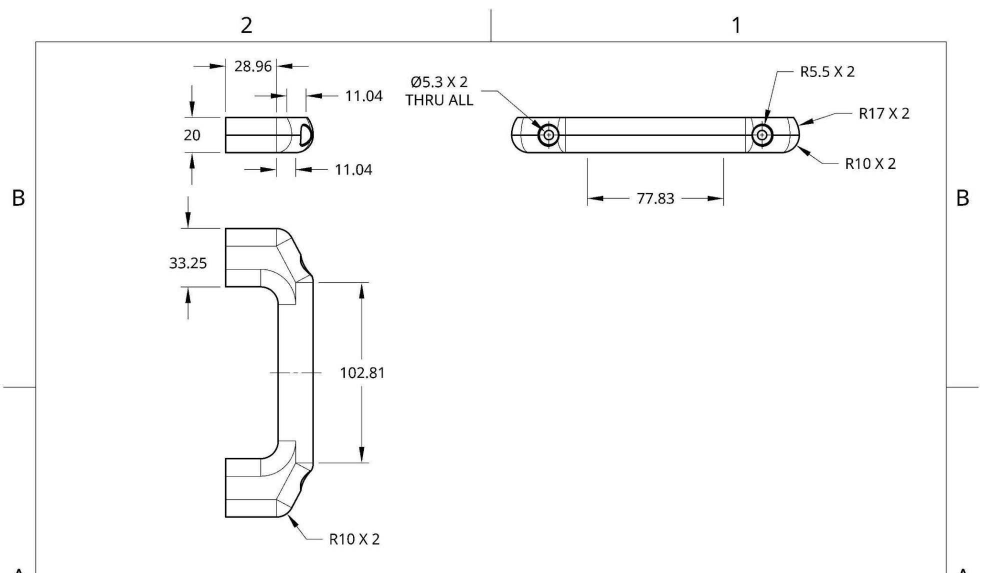
TAG	X LOC	Y LOC	SIZE	QTY
A1	130.83	32.95	Ø5.3 THRU	4
A2	9.00	32.95		
A3	130.83	538.66		
A4	9.00	538.66		



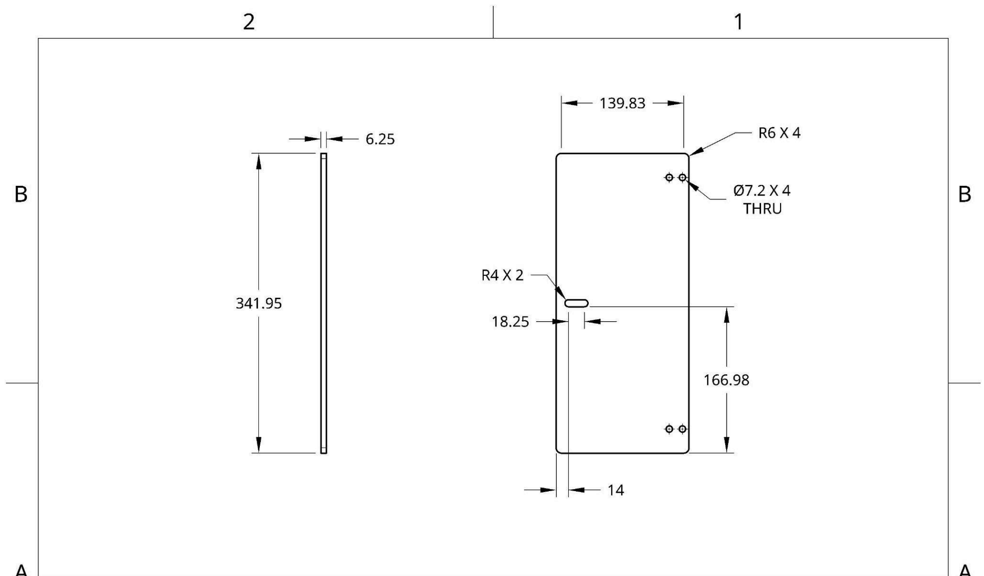
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Mid Panel	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-018	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:8	Sheet No. 1/1



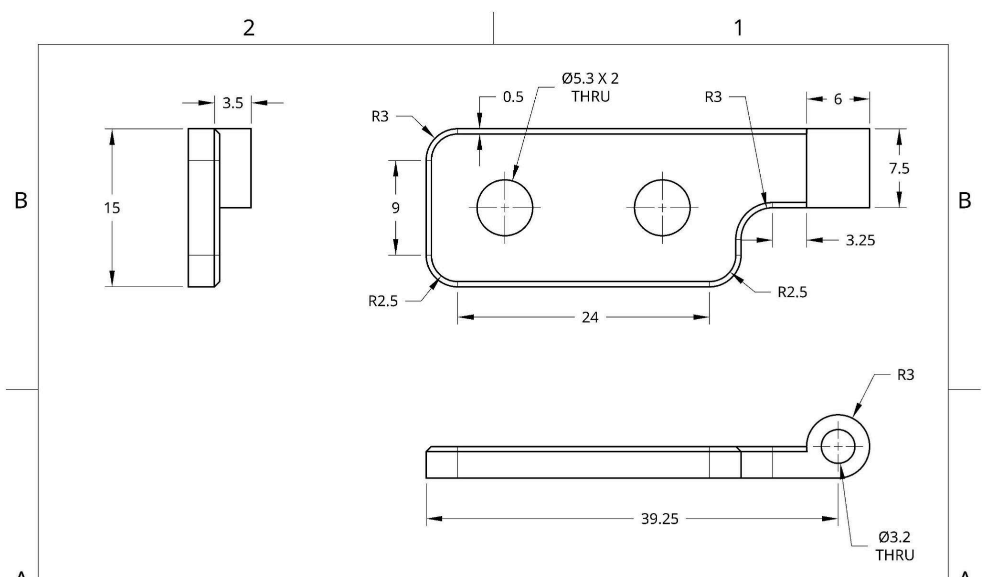
Property of the University of Arizona	Tolerances Unless Specified	Material: Blue PETG	Title: Knob	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-019	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 3:1	Sheet No. 1/1



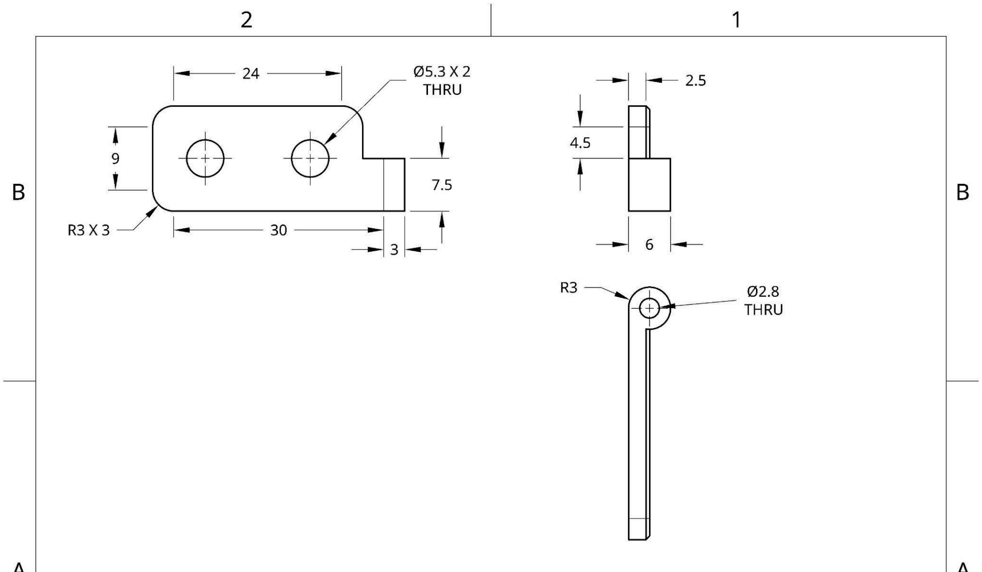
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Handle	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-020	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



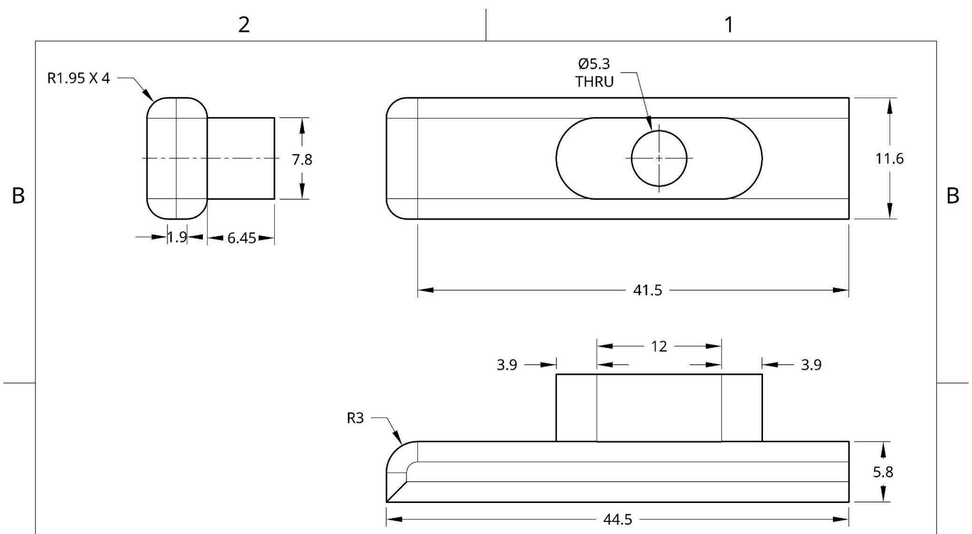
Property of the University of Arizona	Tolerances Unless Specified	Material: HDPE	Title: Door
	X = ±1	Manufacturing Method: Milled	Part No. ENC-021
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:4 / Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Hinge Part 1
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-022
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 3:1 / Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Hinge Part 2
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-023
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 3:1 · Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Blue PETG	Title: Door Latch Part 1
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-024
	X.X = ±0.1		Rev. B
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
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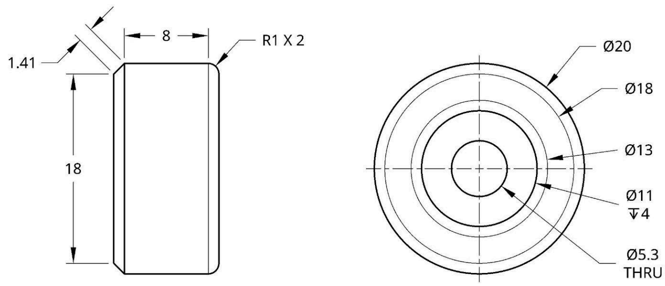

Property of the University of Arizona	Tolerances Unless Specified	Material: Blue PETG	Title: Door Latch Part 2
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ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
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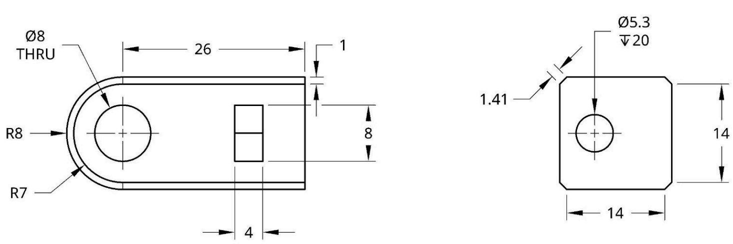

Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Tensioner Part 1
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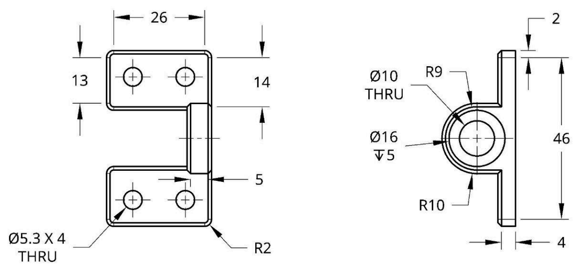

Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Tensioner Part 2	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-027	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
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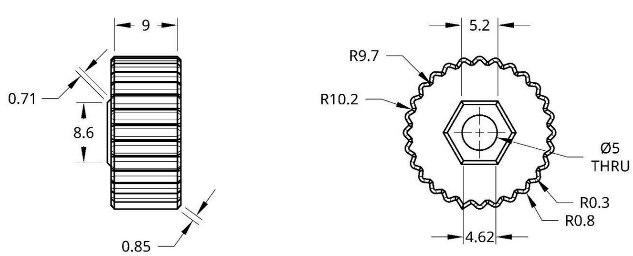

Property of the University of Arizona	Tolerances Unless Specified	Material: Blue PETG	Title: Tensioner Part 3	
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	X.X = ±0.1		Rev. A	
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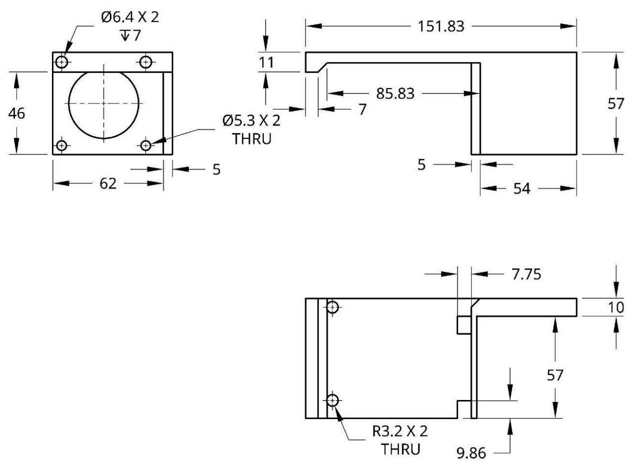

Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Winch Motor Mount
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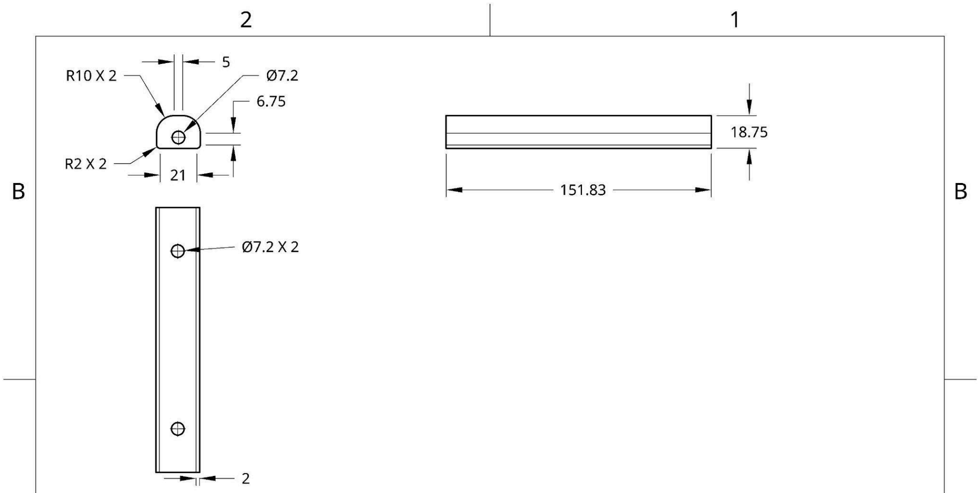
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:2 · Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Basement Reinforcements Part 1
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-030
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:1 / Sheet No. 1/1

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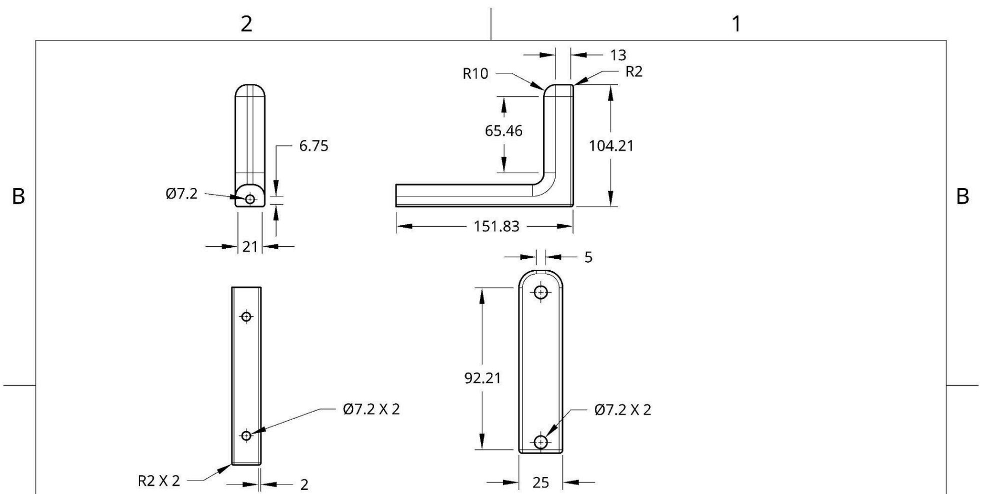
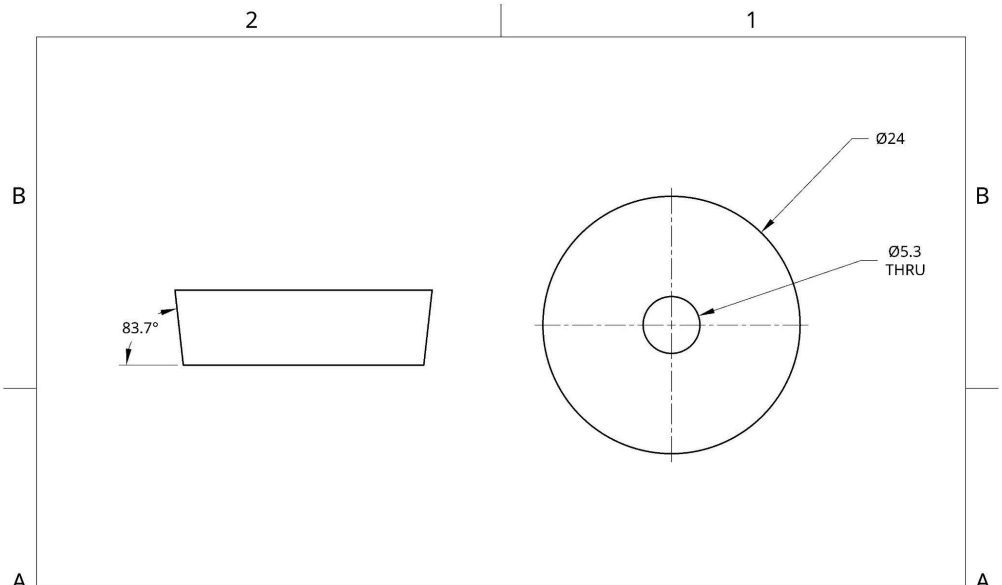
2 1



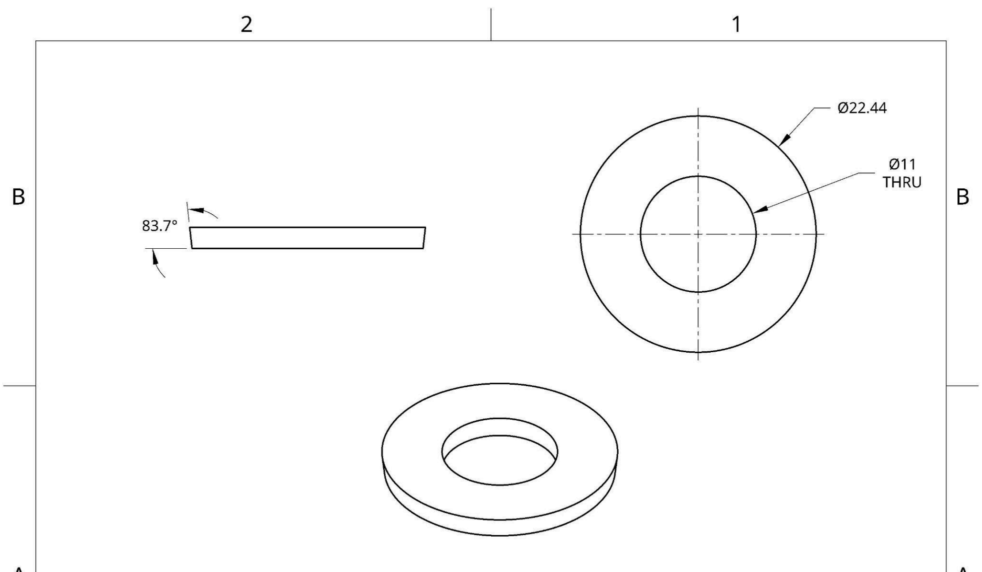
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Basement Reinforcements Part 2
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-031
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:2 / Sheet No. 1/1

A A
2 1



Property of the University of Arizona	Tolerances Unless Specified	Material: Blaxk PETG	Title: Foot Part 1
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-032
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 3:1 / Sheet No. 1/1

2 1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Foot Part 2
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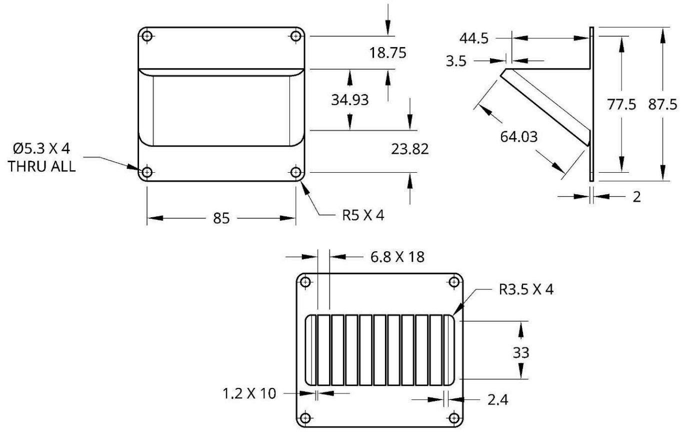
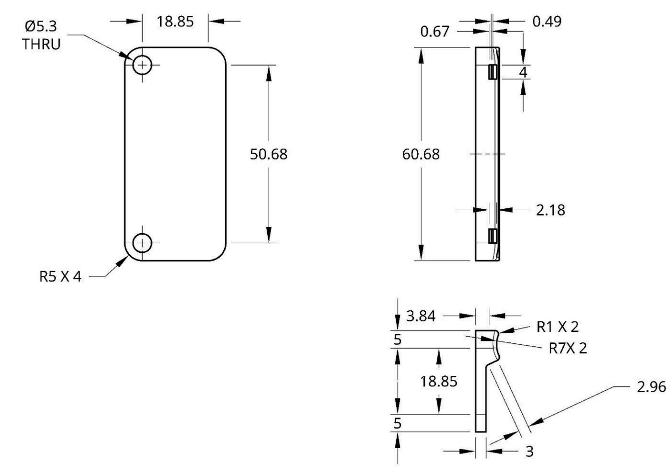
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 3:1 / Sheet No. 1/1

2 1



Property of the University of Arizona	Tolerances Unless Specified	Material: Blue PETG	Title: Aggregate Loader	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-034	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Cable Anchor	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-035	
	X.X = ±0.1		Rev. A	
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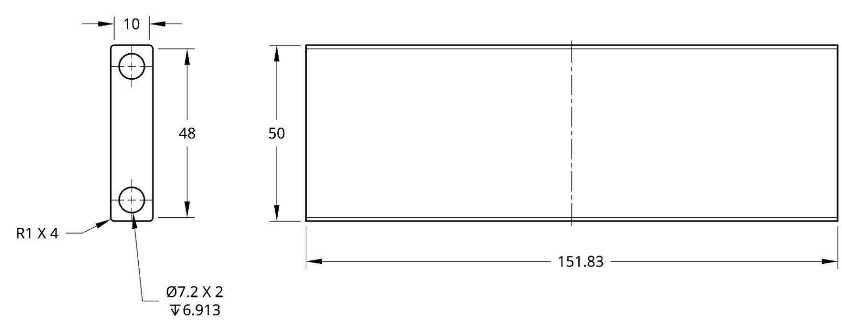
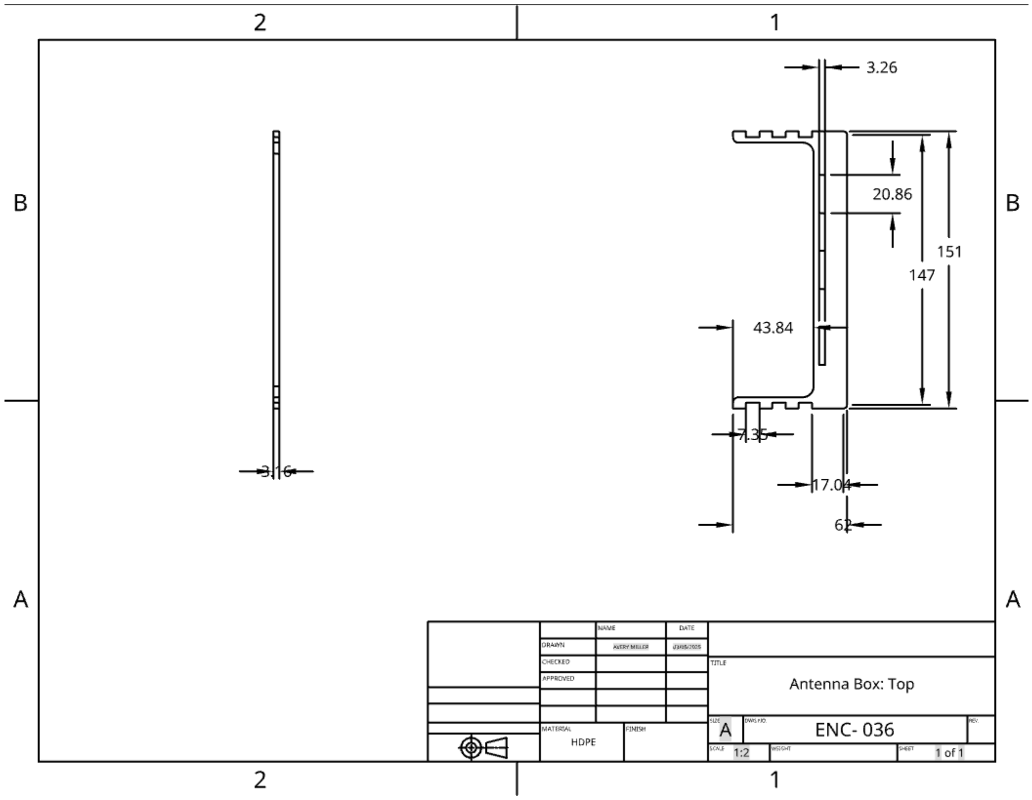
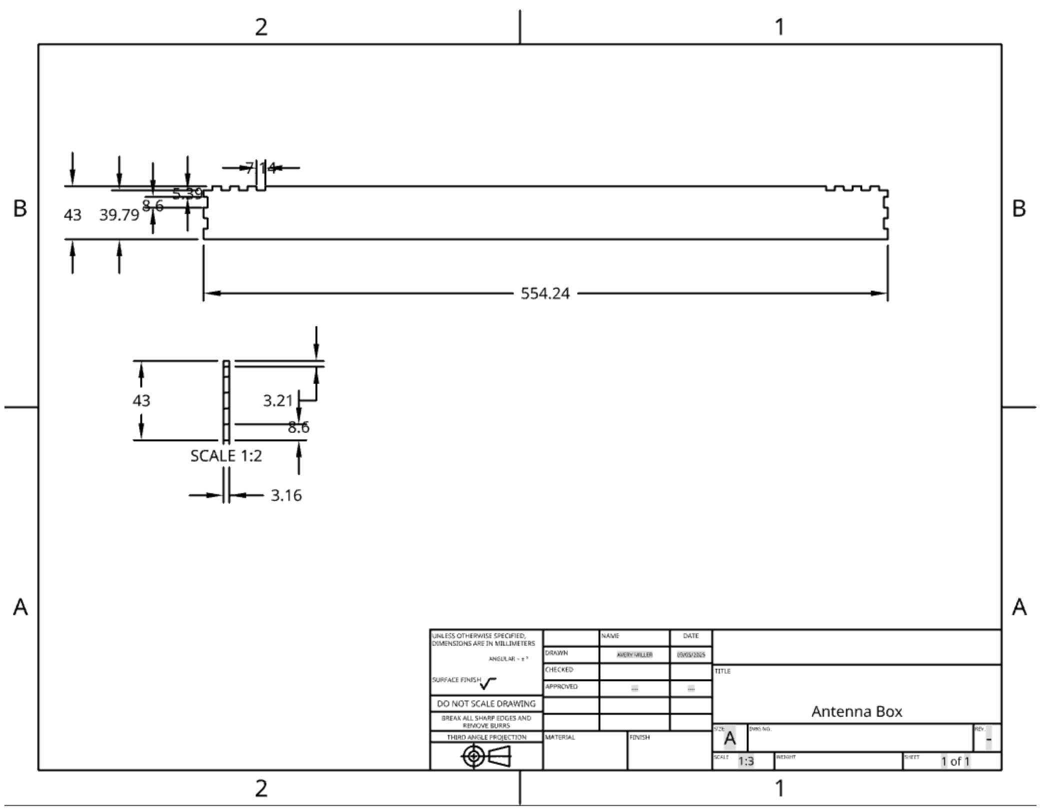


Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Right Antenna Surface	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. ENC-036	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:1	Sheet No. 1/1

1.5 Antenna Subsystem

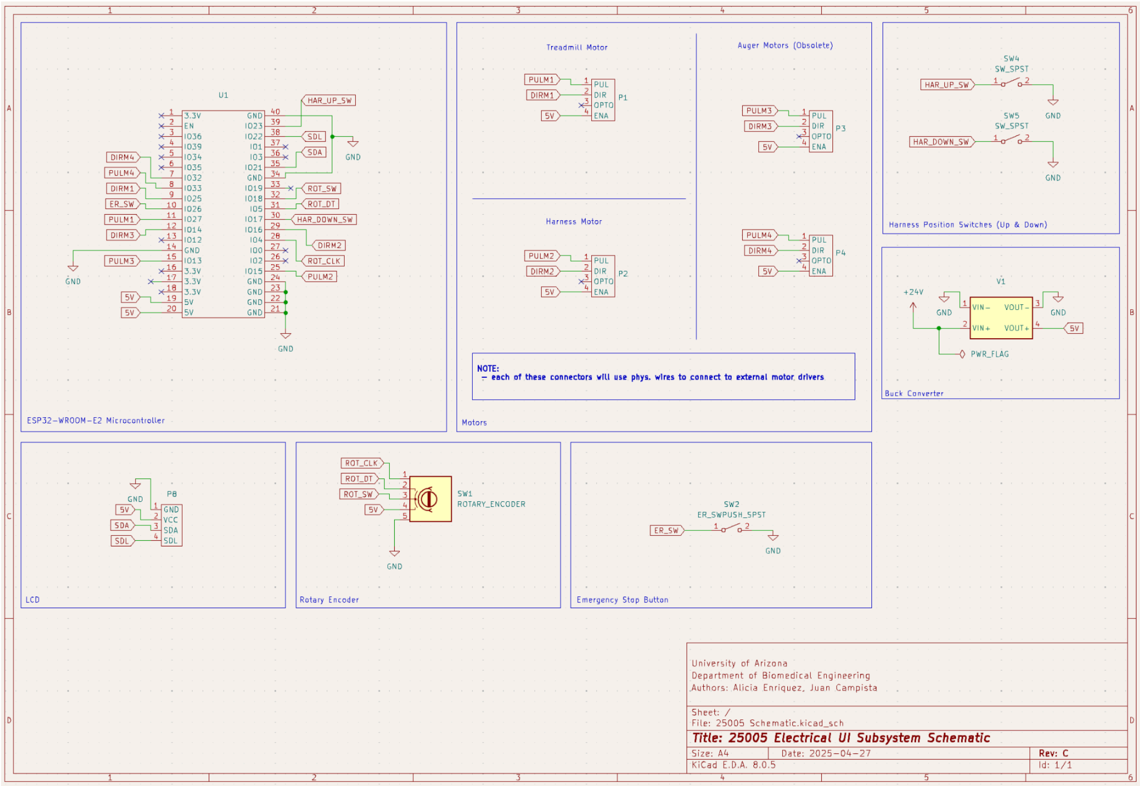




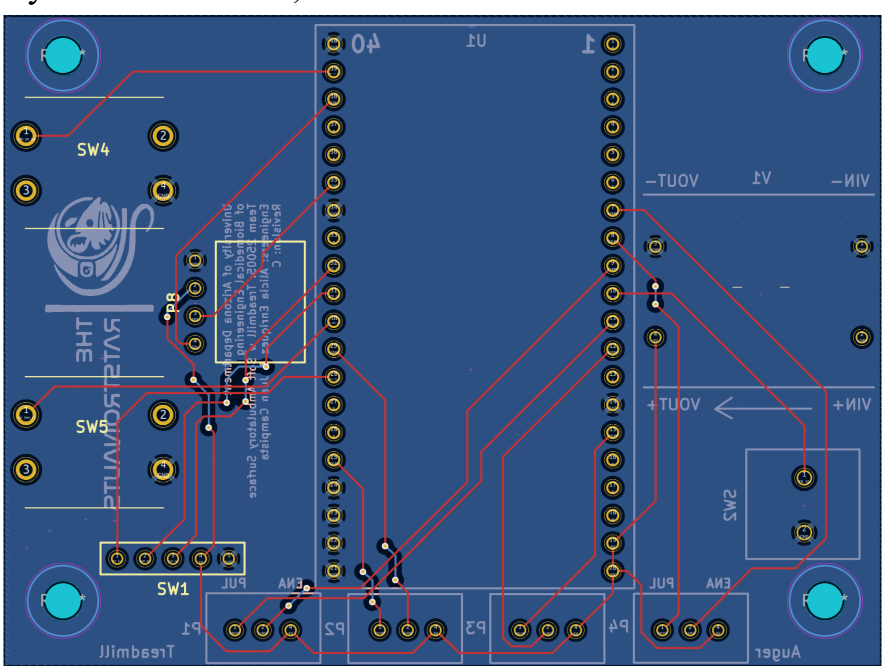
Section 2.0 – Electrical Drawings

2.1 UI/Electrical Assembly Subsystem

2.1.1 Electrical Schematic - Revision C, PUR-073



2.2.2 PCB Layout - Revision B, PUR-073



4.5 Software Documentation

Treadmill Ambulatory System Software Design Document
Treadmill Ambulatory System (TAS) **Software Design Document (SDD)** **Team 25005** May 6, 2025 REV (C) Prepared for UA Dept. of Biomedical Engineering

Table of Contents

Section 1.0 - Scope

1.1 Identification

Our primary objective is to develop a Treadmill with a Soft Ambulatory Surface that fully satisfies all system requirements. This year's focus is on creating a significantly improved design that addresses the limitations of last year's iteration while introducing enhanced functionality and efficiency. This project is inspired by the vision of our sponsor, Dr. Margolis, an orthopedic surgeon with a keen interest in the study of bone and gait health. The treadmill system is intended to facilitate his research into the effects of mechanical stress on rat bones as they move across various aggregate surfaces. A standout feature of the system will be its ability to simulate different gravitational environments, such as those of Earth, Mars, and the Moon. This functionality will enable researchers to investigate how diverse gravitational forces and surface conditions impact gait and bone stress.

1.2 System Overview

The system is specifically designed for testing purposes on small animals, making safety a primary focus. To enhance safety, the new design includes an emergency stop button. When pressed, this feature will gradually decelerate the treadmill while simultaneously raising the harnessed rat to a pre-set position, ensuring its protection during an emergency. The system also offers precise user control over critical parameters, including the speed of the treadmill motor, as well as the vertical displacement (z-axis) of the harness motor. For ease of operation, the user interface (UI) will feature an I2C LCD, providing clear visual feedback on the system's status. The LCD will support a navigable menu, enabling users to easily monitor and adjust settings as needed.

1.3 Document Overview

This document outlines the firmware design for the Treadmill with a Soft Ambulatory Surface, detailing its functionality, features, and integration to ensure optimal performance and safety.

Section 2.0 - Referenced Documents

Team 25005 System Requirements Document

- Revision B, October 17th, 2024

Team 25005 Proposal

- Revision A, September 24th, 2024

FREENOVE ESP32 WROOM

Section 3.0 Software Specific Requirement Traceability

Requirement (4.0)	setup()	loop()	method()
4.1 Efficiency Requirements			
4.1.3 Harness Weight Minimum: The enclosure shall have a hanging harness that can hold 1kg of weight	The Nema 23 motor is initialized and powered to maintain a static hold strong enough to support a 1kg load.		handleHarnessMode() Enables the motor to smoothly lift and lower the payload, ensuring precise control and preventing skipped steps.
4.2 Performance Requirements			
4.2.1 Treadmill Speed: The treadmill shall have a speed of 0.2 meters per second within +-5%	Initializes the Nema 23 motor and configures its maximum and minimum speeds to stay within the defined speed range.		handleSpeedMode() Enables smooth acceleration and deceleration of speed, seamlessly adjusting within the range of 0.2 to 0.8 m/s. (0 - 2444 pulses)
4.3 Safety Requirements			
4.3.1 Emergency Stop: The system shall have an emergency stop function that works upon pressing the emergency stop button that lifts the rat within the harness up from the face of the treadmill		The function can be invoked in all system states, including Menu, Harness, and Speed.	eStopProcedure() Gradually lifts the rat harness while smoothly decelerating the treadmill motor to ensure a controlled and safe stop.
4.4 Usability Requirements			
4.4.1 UI Simplicity: The user interface shall be simple and friendly to use, reacting immediately to input			Provides an intuitive interface utilizing a rotary encoder and momentary switches for seamless navigation and control

Section 4.0 - Software Design

4.1.1 Design Decisions Regarding I/O

Microcontroller Unit:

- Freenove ESP32 Wroom

Inputs:

- Rotary Encoder
- Double Pole Double Throw Switch (Emergency Stop)
- Momentary Switch (Set Position)
- Momentary Switch (Clockwise)
- Momentary Switch (Counterclockwise)

Outputs:

- I2C Liquid Crystal Display (LCD)
- Nema 23 4.2A 3Nm
- Nema 23 2.8A 1.26Nm

4.1.2 Design Decisions on CSCI Behavior

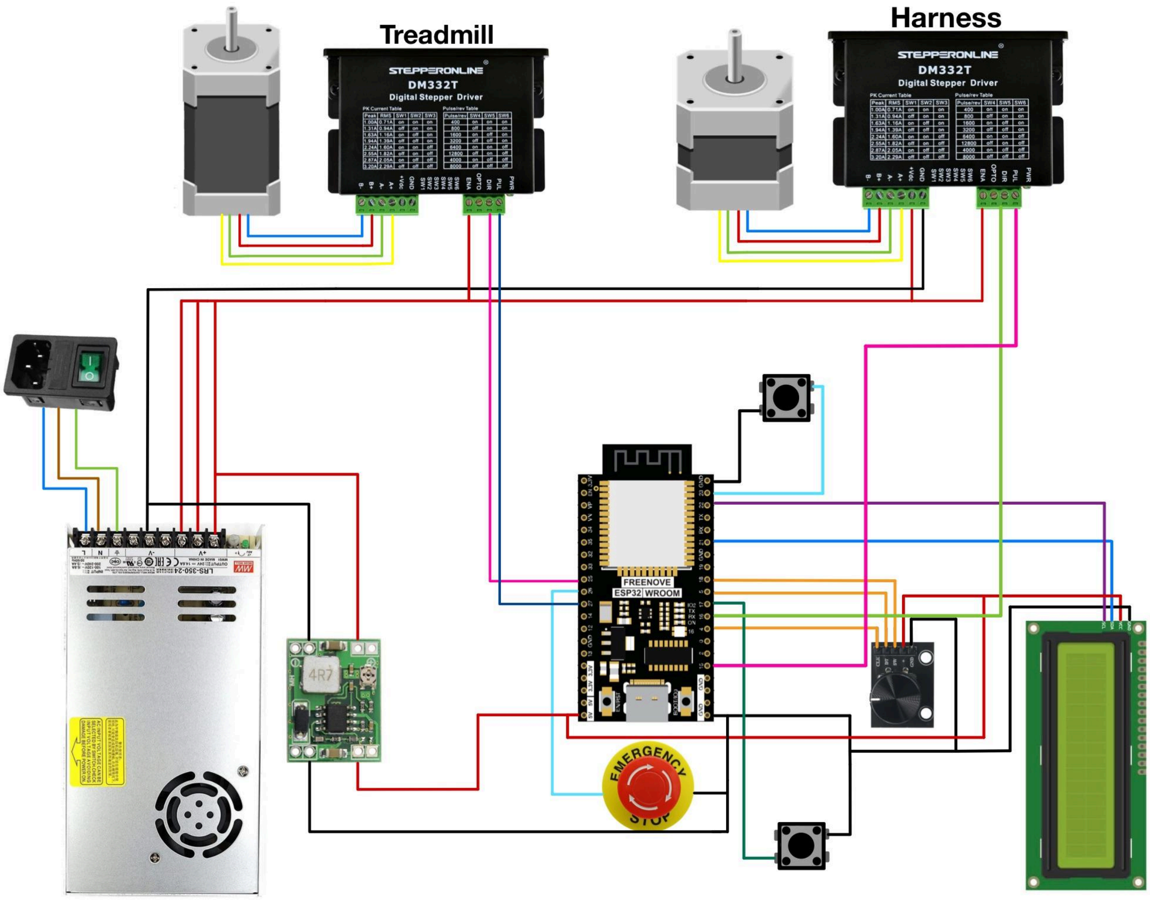
The Treadmill Ambulatory System is activated via a rocker switch. Upon powering on, all components are initialized, and the LCD displays a menu with two options: Speed and Harness. Users can navigate the menu using a rotary encoder and select a mode by pressing the encoder button. In Harness mode, the user can elevate the harness to a desired position and save it by pressing a momentary switch. Once saved, the harness can lower the rat onto the treadmill for operation. In Speed mode, the user can adjust both the treadmill speed with smooth acceleration, while the LCD displays the treadmill's speed in real time. For safety, the system includes an emergency stop (E-Stop) feature controlled by a DPDT switch. If the E-Stop is triggered, the harness will automatically ascend to the saved position, or lift off the treadmill if no position was set, while the treadmill gradually decelerates to a complete stop. After activating the E-Stop, all system functionality is disabled, requiring a reset to resume operation.

Section 4.2 - CSCI Architectural Design

4.2.1 Identification

The system is designed to control and monitor a multi-functional device comprising a treadmill and harness motor. It provides real-time interaction through a rotary encoder, buttons, and an LCD display while managing motor operations using stepper drivers. The ESP32 acts as the central controller, interfacing with all components.

Wiring Diagram:



Stepper Driver Settings:

Treadmill:

Harness:

Pin Assignment

Component	Pin Name	Microcontroller Pin	Signal Type
I2CLCD	CLK	GPIO4	Digital Input (Pulse)
	DT	GPIO5	Digital Input (Direction)
	Button	GPIO18	Digital Input
	GND	GND	Common Ground
	VCC	5V	Power
Treadmill Motor	Pulse	GPIO27	Digital Output (Pulse)
	Direction	GPIO25	Digital Output
	Enable	5V	Power
Harness Motor	Pulse	GPIO15	Digital Output (Pulse)
	Direction	GPIO16	Digital Output
	Enable	5V	Power
Momentary Swiitch (Up)	Signal	GPIO17	Digital Input
	GND	GND	Common Ground
Momentary Swiitch (Down)	Signal	GPIO23	Digital Input
	GND	GND	Common Ground
E Stop Switch	Signal	GPIO26	Digital Input
	GND	GND	Common Ground

Libraries:

- **<LiquidCrystal_PCF8574.h>**
  - A library used for handling LCD displays via I2C interface. Including PCF8574 I/O expander chip, reducing the number of GPIO pins needed**.**
- **<AccelStepper.h>**
  - A library used for controlling stepper motors providing the capabilities for smooth acceleration, deceleration, precise speed control & supports multiple drivers.

- **<esp_sleep.h>**

  - A library in the ESP-IDF framework provides functions for managing low-power sleep modes on ESP32 microcontrollers. It allows the ESP32 to enter different sleep states to reduce power consumption while maintaining the ability to wake up under certain conditions.

Methods:

- **Void setup()**
  - **Status:** Developed
    - Initializes the LCD, rotary encoder pins, and motor settings (treadmill and harness motor). Sets pin modes for buttons and configures acceleration and max speed for motors.

- **Void loop()**
  - **Status:** Developed
    - Manages program flow based on the current mode (MENU, SPEED_MODE, HARNESS_MODE). Processes rotary encoder input for navigation of menu selection. Depending on the choice of selected mode within the Menu, a method will be called.

- **Void handleEncoderForMenu()**
  - **Status:** Developed
    - Reads the rotary encoder input to navigate the menu. Updates the menuIndex (Speed or Harness) based on the direction of rotation and refreshes the LCD menu display.

- **Void handleMenuSelection()**
  - **Status:** Developed
    - Executes the selected menu action, switching modes (SPEED_MODE or HARNESS_MODE) and updating the LCD.

- **Void displayMenu()**
  - **Status:** Developed
    - Displays the menu on the LCD with the current selection highlighted.

- **Void handleSpeedMode()**
  - **Status:** Developed
    - Adjusts treadmill speed using the rotary encoder. Ensures speed constraints, updates motor settings, and calculates/display speeds. This is the only state where the user is able to press the emergency stop button to slow the treadmill motor, as well as raise the harness.

- **Void handleHarnessMode()**
  - **Status:** Developed
    - Controls the harness motor with the input of two momentary switches (clockwise or counterclockwise) used for ascending & descending rat harness..

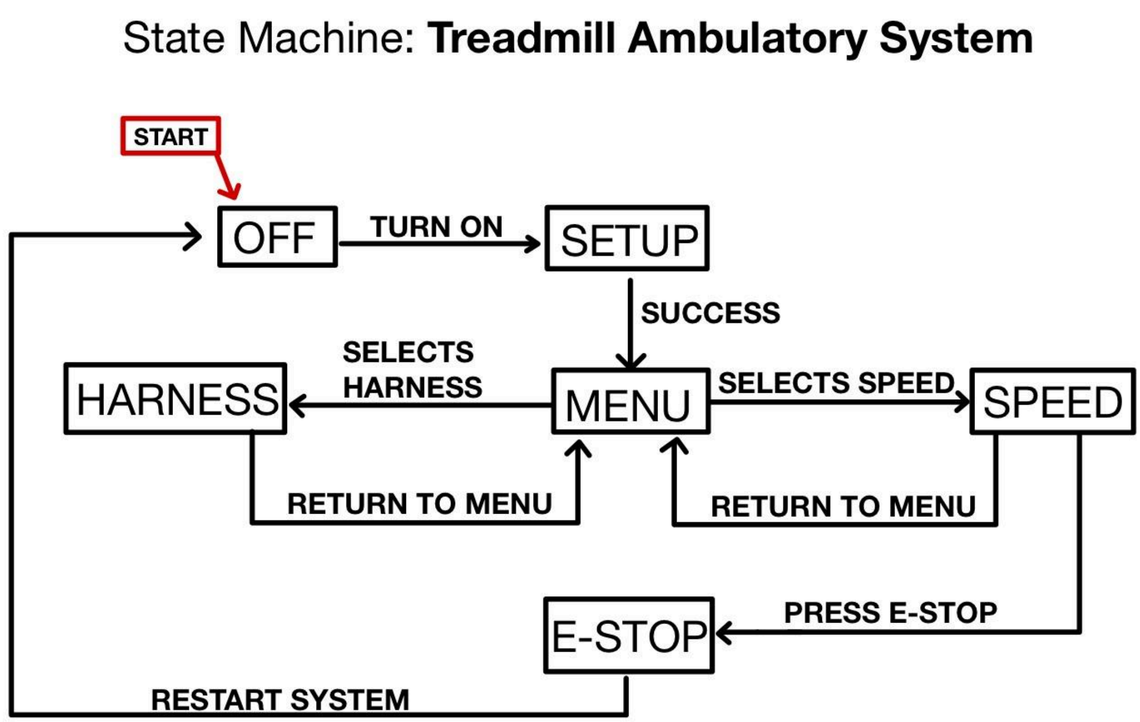
- **Bool buttonPressed(int pin)**
  - **Status:** Developed
    - Detects button presses with debounce logic, returning true when a valid press is registered.

- **Void eStopProcedure()**
  - **Status:** Developed
    - This method decelerates all motors to a complete stop and raises the harness displacement. After all instructions are completed the ESP32 will then be set in sleep mode, where further inputs will be invalid. A message

will be prompted on the LCD screen indicating the user must reset the system and start it back up if user wants to continue using the system.

- **Void returnToMenu()**
  - **Status:** Developed
    - Transitions back to Menu mode, resets relevant flags, keeps the treadmill running, and updates the LCD menu display.

4.2.2 Concept of Execution



Menu:

- Displays Menu Selection (Speed & Harness)
- Controls selection using encoder

Harness:

- Controls the displacement of the harness at the z axis.
- Ability of setting return position for E-stop
- Capable of returning to Menu Selection

Speed:

- Controls the speed of the treadmill motor
- Displays speed of treadmill (m/s)
- E - Stop can be pressed in this state
- Capable of returning to Menu Selection

E - Stop:

- Slowly decelerates Treadmill motor
- Gradually raises the harness back to its set position, or slightly above the treadmill if necessary
- Enters deep sleep mode (no user input is available), hence user must restart system

4.2.3 Software & Interface Design

Interfacing Entities

Freenove ESP32 WROOM

Interfaces with:

- Buck Converter
- DM332T Digital Steppers (2)
- Nema 23 4.2A 3Nm
- Nema 23 2.8A 1.26Nm
- I2C LCD
- Rotary Encoder
- Momentary Switch
- DPDT Switch (Emergency Stop)

TAS Main

Status: Partially Developed

Interfaces with:

- Freenove ESP32 Wroom
- DM332T Digital Steppers (2)
- Nema 23 4.2A 3Nm
- Nema 23 2.8A 1.26Nm
- I2C LCD
- Rotary Encoder
- Momentary Switch (3)
- DPDT Switch
- Instructions detailing how the ESP32 will interact with various sensors, inputs, outputs, and connected devices.

DM332T Digital Steppers

Interfaces with:

- Freenove ESP32 WROOM
- Nema 23 4.2A 3Nm
- Nema 23 2.8A 1.26Nm
- The stepper drivers receive step and direction signals from the ESP32 and control the power to the motor coils.

Nema 23 4.2A 3Nm

Interfaces with:

- Freenove ESP32 WROOM
- Momentary Switch
- DM332T Digital Steppers
- Integrates with the encoder to ensure smooth and precise motor speed control.

Nema 23 2.8A 1.26Nm

- Freenove ESP32 WROOM
- Momentary Switch
- Rotary Encoder
- DM332T Digital Steppers
- The rotary encoder regulates the displacement of the harness along the Z-axis.

I2C LCD

Interfaces with:

- Freenove ESP32 WROOM
- Rotary Encoder
- DPDT Switch (Emergency Stop)
- Interfaces with the microcontroller to display the current state of the system.

Rotary Encoder

Interfaces with:

- Freenove ESP32 WROOM
- I2C LCD
- DM332T Digital Steppers
- Nema 23 4.2A 3Nm
- Nema 23 2.8A 1.26Nm
- Integrates with menu selection, motor speed control, and displacement adjustments.

Momentary Switch

Interfaces with:

- Freenove ESP32 WROOM
- I2C LCD
- Nema 23 2.8A 1.26Nm
- Interfaces with the motor to save its position as a reference return point.

DPDT Switch (Emergency Stop)

Interfaces with:

- Freenove ESP32 WROOM
- I2C LCD
- Nema 23 2.8A 1.26Nm
- Nema 23 4.2A 3Nm
- DM332T Digital Steppers
- Momentary Switch
- Smoothly decelerates the motors, increases motor displacement, and transitions to low power mode.

4.2.4 Code

- Refer to Appendix 6.1 to see full code

Section 5.0 - User's Manual

Status: Complete

Full user's operating manual below:

Owner's/Operator's Manual for Rat Treadmill

Instructions for Use, Maintenance, and Safety

THE RATSTRONAUTS

Revision C

Date of Issue: 05/06/2025

Table of Contents

1. Introduction

Welcome to the Owner's/Operator's Manual for the Rat Treadmill, a specialized research device designed to facilitate controlled exercise and locomotion studies in laboratory rodents. This treadmill's advanced harness system, adjustable belt speed, and integrated data collection features enable researchers to study a range of physiological and behavioral parameters under standardized, reproducible conditions. Whether you are investigating muscle function, bone density changes, or aerobic capacity, the Rat Treadmill is engineered to help you gather accurate and consistent data while maintaining high standards of animal welfare.

This manual provides comprehensive guidance on setting up, operating, and maintaining the Rat Treadmill to ensure optimal performance and reliability. You will find safety instructions, technical specifications, and best practices for routine and preventative maintenance. Adherence to these guidelines not only helps protect the animals and operators but also contributes to the integrity and repeatability of your research findings.

By familiarizing yourself with the contents of this manual, you will gain an understanding of:

1. **Safe Operation**: Essential safety measures to protect both lab personnel and animals, including correct harness usage and emergency stop procedures.
2. **Installation and Setup**: Step-by-step instructions on how to calibrate and prepare the treadmill for use.
3. **Daily Use and Study Protocols**: Best practices for monitoring the animal's condition and adjusting exercise parameters
4. **Maintenance and Troubleshooting**: Guidelines for regular cleaning, inspection, and repairs to maintain accuracy, prolong the lifespan of the equipment, and reduce downtime.

Please read this manual thoroughly before using the Rat Treadmill and keep it readily available for reference. Together, we can uphold the highest standards of care, safety, and scientific rigor in every research endeavor.

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2. Safety Guidelines

- General Safety Reminder
  - Although the Rat Treadmill is designed for ease of operation, safety must remain a priority. Only handle the treadmill by the areas that are color-coded in **blue**, as these sections are specifically intended for user interaction. Avoid touching or bypassing any other parts—particularly those marked with warning labels or guarded compartments—while the device is running. If you need to load or handle the aggregate, use a suitable respirator to protect against airborne particles and use the treadmill in a suitable environment. Always power down and wait for all motion to stop before clearing any obstructions or performing any maintenance tasks.
- Warnings and Precautions
  - Proper Harness Use: Always ensure the harness is correctly fitted to the animal before operation. A loose or poorly adjusted harness can lead to injury or compromised research data. If in doubt, consult the harness fitting guidelines in this manual.
  - Preventing Aerosolization of Regolith: Handle regolith gently and within a fume hood to minimize dust generation. A fume hood is required for usage of the system with aggregate. Avoid shaking, pouring, or dumping regolith in a way that creates airborne particles.
- Emergency Stop and Safety Features
  - Unlike many traditional machines, the Rat Treadmill's **emergency stop (E-stop)** feature initiates a **gradual deceleration** rather than an immediate halt. This prevents sudden jolts or stress on the rat, helping maintain its well-being during unexpected stops. Once the E-stop is engaged, the harness system **automatically lifts** the rat slightly above the belt and then sets the rat back down, ensuring the animal is safely out of contact with any moving parts.
  - To further protect users and animals, all **approved interaction points are color-coded in blue**. Areas prone to pinch or crush injuries are equipped with **warning decals and protective grates/covers**, discouraging contact with moving mechanisms. Always avoid reaching into any section not marked in **blue**, and do not bypass guards or safety covers.

- **Warning Decals (ISO 7010)**

- **P015 – No reaching in**

  - Aggregate used in the treadmill may collect or clump in the hoppers, especially during heavy or prolonged use. While it might be tempting to manually guide or clear these

accumulations, doing so places hands and fingers at risk of being trapped or pinched by the moving mechanical components.
    - **Do not** insert hands, fingers, or tools into the hopper area while the treadmill is running. Always **power down** the treadmill before attempting any maintenance or cleaning.
    - If you observe a clog or excessive buildup of aggregate, refer to the "Maintenance and Cleaning" section of this manual for instructions on safely clearing the blockage.

- **P016 – Do not spray with water**

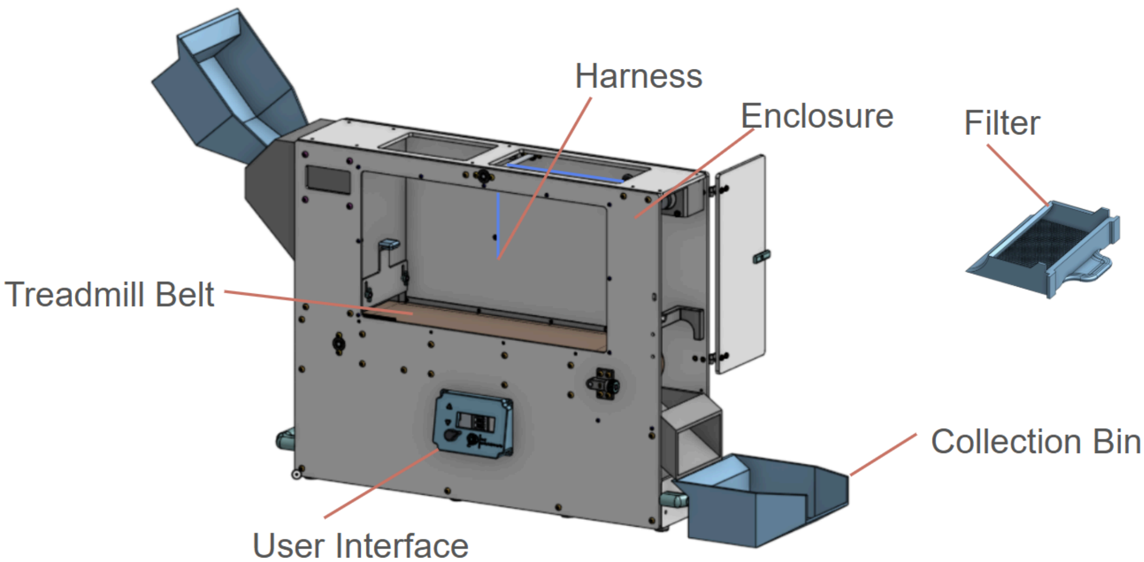
    - Spraying or misting water can cause the aggregate to clump, disrupting the treadmill's functionality and potentially damaging seals, leading to mechanical failure.
    - **Do not** spray or apply water in or around the treadmill. Keeping the system dry is essential to maintain proper operation and prolong equipment life.
    - If dust generation is a concern, operate the treadmill **inside a fume hood**. This ensures both operator safety and the prevention of moisture-related damage to the system.

- **W024 – Crushing of hands/Danger of crush injuries**

    - The continuous motion of the treadmill belt and other internal mechanisms can **pinch, crush, or entangle** hands and fingers if they come into contact with these areas while the system is operational.
    - **Do not** touch or reach into the belt area or any moving components while the treadmill is running. Always ensure the treadmill is powered off and fully stopped before performing any cleaning, adjustments, or maintenance tasks.
    - If foreign objects fall onto the belt or inside the treadmill, **Shut Down** the unit and wait until all moving parts come to a complete stop before carefully removing them. Keep all guards, covers, and safety features in place to help prevent accidental contact. If there is an emergency, refer to "Emergency Stops" in "Operating Instructions"

3. System Components

- **Treadmill Overview**



- **Key Components**
    - Harness - suspends the rat to create a synthetic reduced gravity.
    - Belt - Surface that aggregate is placed on to create an ambulatory surface
    - Waste Filter - Collects rat waste to prevent recirculation
    - User Interface - allows user to interact with and control the system
    - Enclosure - ties the subsystems together and encloses the space for the Rat.
    - Collection Bin - Collects aggregate for recirculation.

---

4. Installation and Setup

- **Inspection**
    - **Check for Damage or Missing Parts**
      Inspect for visible damage or missing components. Ensure all parts match those listed in the “Parts List” section of this manual.
    - **Inspect the GT2 Belts (Behind Clear Covers)**
      Locate and visually check the GT2 drive belts behind the clear covers. Confirm they are

free from cracks, tears, or misalignment. If a belt appears damaged or excessively loose refer to the "Maintenance" section for replacement and tensioning instructions.

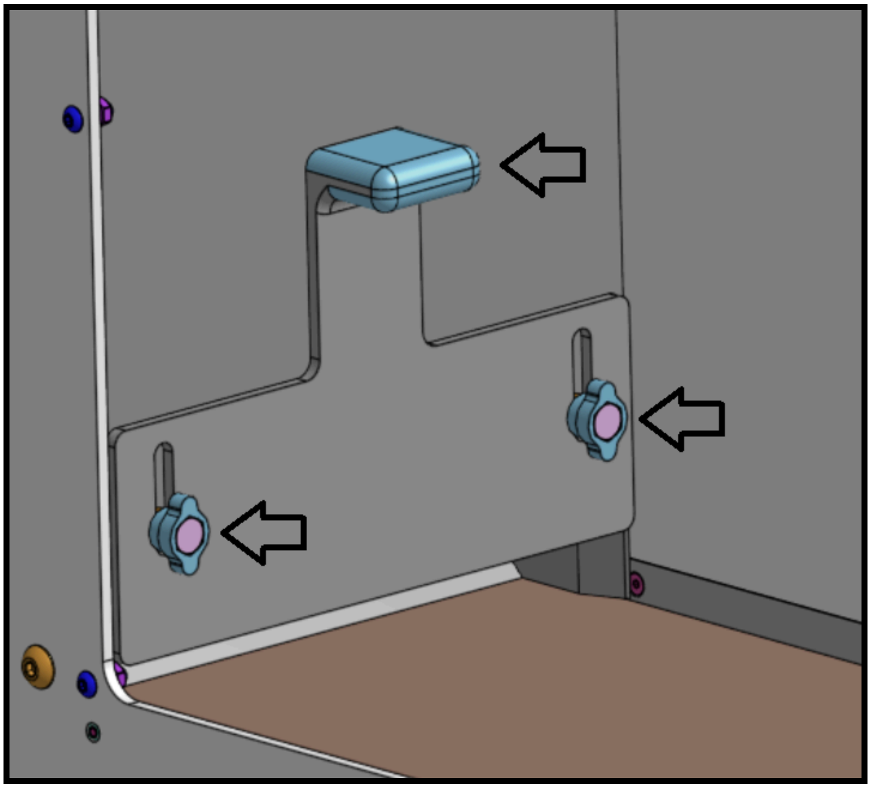
- **Check the Treadmill Belt Alignment**
  Before powering on, confirm the treadmill belt runs true (i.e., it does not drift to one side). If the belt is off-center, refer to the "Troubleshooting" or "Maintenance" sections for alignment and tension adjustment procedures.
- **Check for Potential Jams**
  Carefully examine the belt, hoppers, and any visible moving parts for obstructions. If you notice foreign objects or misaligned components, remove or correct them before using the treadmill.
-

- **Placement Requirements**
  - **Fume Hood or Tabletop Use**
    - **For Experiments with Aggregate**: Place the treadmill inside a **fume hood** to help extract any aerosolized dust and maintain a safe working environment.
    - **For Experiments without Aggregate**: You may safely position the treadmill on a **sturdy table** capable of supporting its weight and operation.
  - Clearance and Ventilation
    - Allow for **900 × 400 × 600 mm (L × W × H) [35.4" × 15.7" × 23.6]** of clear space around the device to ensure smooth operation, with a preferred clearance of **1400 × 650 × 660 mm (55.12 in × 25.59 in × 25.98 in)** if possible.
    - If you are using a fume hood, position the top of the treadmill to align with the hood's exhaust for optimal dust extraction and airflow.
  - **Initial Calibration**
    - **Belt Tensioning**
      Before first use, confirm that the treadmill belt is properly tensioned. This helps prevent slippage, ensures consistent speed, and prolongs belt life. Refer to the "Maintenance" or "Troubleshooting" sections for specific tensioning instructions.
  - **Testing Aggregate Circulation**
    If you will run tests involving aggregate, perform a brief dry run to observe aggregate flow and check for clogging or uneven distribution. Make any necessary adjustments before conducting formal experiments.

5. Operating Instructions

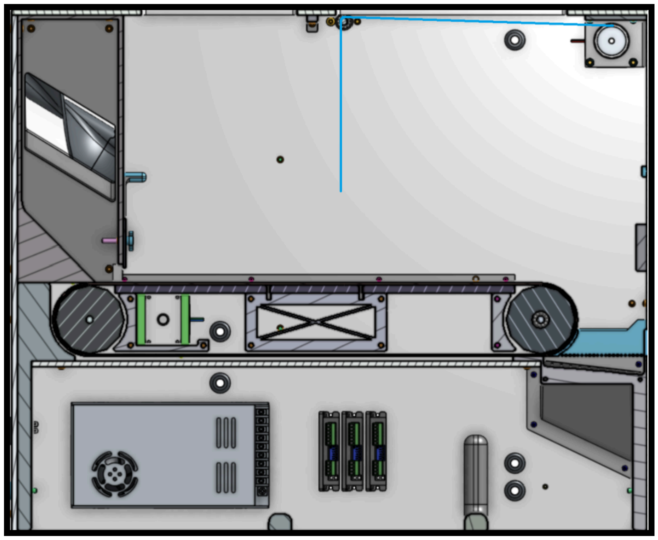
- **Starting the System**
  - Powering On
    1. Ensure the system is clear of any debris, no animal is loaded into the system, and that the system is in an appropriate location of operation.
    2. Ensure the system is plugged into 120V AC wall power.
    3. Flip the green power switch on the left hand side of the enclosure
    4. Disengage the emergency stop
    5. You will be greeted on the screen and the system is ready for use.
  - Selecting Settings (Speed, Weight Simulation)
    1. Rotate the rotary encoder to select the sub menu that you desire. Once over the submenu desired, click the rotary encoder by pressing it in.
       a. Weight Simulation - Use the arrow buttons to raise and lower the rat until in a desired position. Click the rotary encoder to navigate back to the main menu.
       b. Speed - Use the rotary encoder to select a desired speed. Clockwise increases the speed while counter clockwise lowers the speed. **To go back to the main menu, the speed must be at 0m/s.** Click the rotary encoder to navigate back to the main menu.

          Note: The Speed on the screen takes 1 second to update.
  - Loading Aggregate
    1. Load the upper hopper using the fill port on the top of the left panel and the bins.
    2. Power on the treadmill as per “Powering On” instructions.
    3. Run the treadmill’s speed mode.
  - Removing Aggregate
    1. Remove the Filter
    2. Run the treadmill’s speed mode until a majority of the aggregate is removed from the system while collecting the aggregate in the bins
  - Setting Aggregate Height (assuming the system is filled with aggregate)
    1. Roughly estimate the height of the leveling bar
       a. Loosen the **blue** thumbscrews.
       b. Lift the leveling bar to the height desired using the **blue** handle.
       c. Tighten the thumbscrews.



2. Turn on the treadmill using the powering on procedures
3. Run the treadmill for a few seconds to let the aggregate disperse through the system and add aggregate as needed per the aggregate loading instructions
4. Measure the thickness of the aggregate layer and make adjustments to the leveling bar accordingly.

- **Loading the Rat**
    - Proper Harness Attachment
        - Refer to **https://www.lomir.com/slings/sling-suit-rodent-sling/** for harness attachment to the rat and propper usage.
    - Clip the harness into the **BLUE** chord using the carabiner. Ensure the chord is threaded properly



- **Stopping the System**
  - Routine Stops
    1. Slow the treadmill to a stop using the rotary encoder
    2. Disconnect the Rat from the harness chord and remove the Rat
    3. Power off the machine
  - Emergency Stops
    1. Press the large **RED E-Stop** button on the front of the machine in case of emergency.

    2. Gently remove the rat to ensure no harm is caused.
    3. Power off machine then restart using the “Powering On” procedure

6. Maintenance and Cleaning

Maintenance:

Lubricating the Bearings

- **Frequency**: Check bearings monthly or as dictated by the treadmill's usage level.
- **Procedure**:
    1. **Access Bearings**: Remove covers or guards if necessary (follow instructions in "Maintenance" or "Troubleshooting" sections).
    2. **Apply Light Oil**: Use a small amount of light machine oil on the bearings.
    3. **Wipe Excess**: After a brief rotation to distribute lubricant, wipe away any surplus oil to prevent drip or contamination.

Treadmill Belt and Pulley Checks

- **Inspection**:
    1. Ensure the treadmill belt is tracking correctly (running true) and has proper tension. Tightening a knob will make the belt veer away from that knob.
    2. Use the **blue** knobs to tension the belt. It is desired to have it track as closely to the center. It should be able to move by hand, driving the motors backwards easily.
    3. Inspect pulleys for visible wear or misalignment.
- **Adjustment**:
    1. If the belt shows signs of drifting or slipping, refer to the "Belt Alignment and Tensioning" instructions in the "Troubleshooting" section.
    2. Replace belts or pulleys if damage or significant wear is evident.

Harness System Inspection

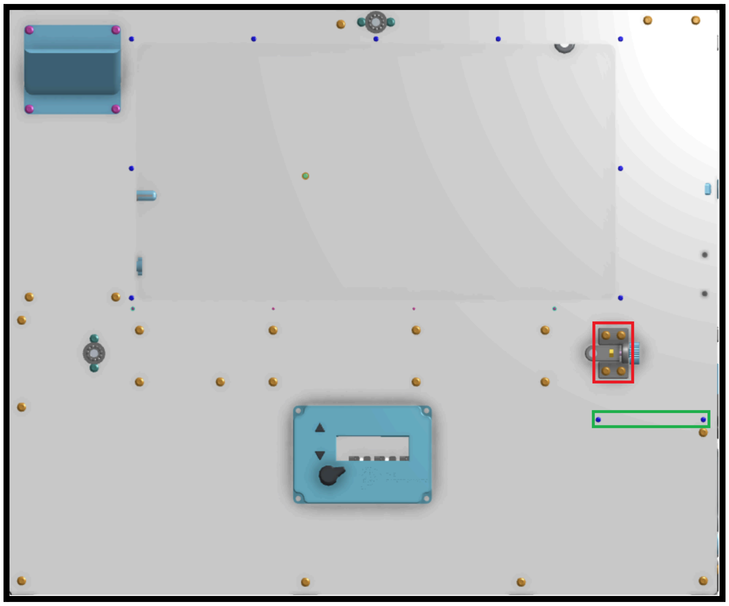
- **Purpose**: A properly functioning harness system is essential for animal safety and data integrity.
- **Procedure**:
    1. **Visual Inspection**: Look for fraying straps, worn clips, or loose stitching.
    2. **Attachment Points**: Confirm that all clips and fasteners are secure and functioning.
    3. **Testing**: Manually pull the harness lightly to ensure it holds steady without slipping or detaching.

Aggregate Circulation System Cleaning

- **Fine Dust Buildup**: Dust can accumulate in the hoppers, rollers, and the electronics compartment, potentially causing clogs, uneven flow, jamming, or electrical failure.
- **Procedure**:
    1. **Power Down and Unplug**: Ensure the treadmill is off and disconnected before cleaning.
    2. **Open Accessible Panels**:

        Rollers/Beneath Belt

- Untension the Treadmill belt
- Remove the 23 M5x10mm Button head Screws (Yellow), the 4 M5x15mm Button Head Screws (Magenta), and the 2 M3x10mm Button Head Screws (Blue Inside green Box). Do not remove the 4 M5x10 Screws holding the tensioner on.



- Remove the entire front panel, being cautious with the electronics. Disconnect the power to the ESP32 and the motor driver cables.
- Clean out the build up using a vacuum, brush, etc.
- Replace the panel ensuring to plug in the cables and that all of the rods (both rollers and the harness) are all lined up.
- Replace and tighten all of the screws.

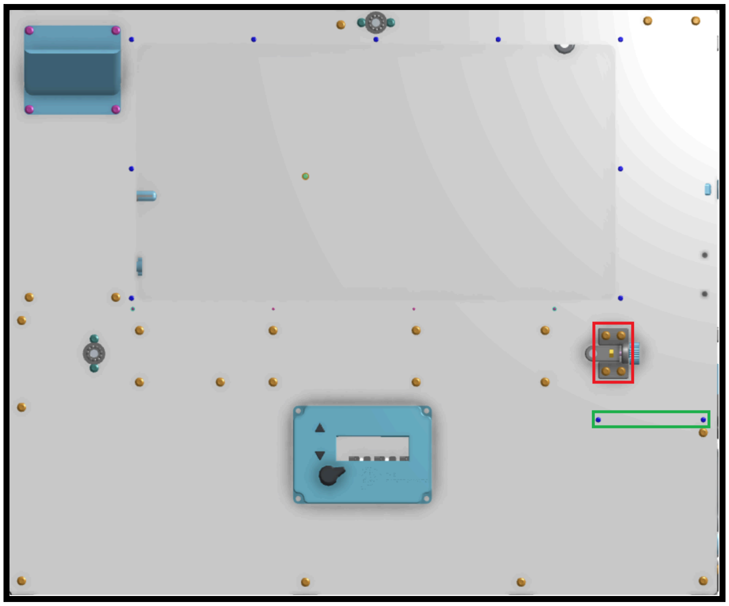
Electronics

- Remove the 8 M5x15mm Button Head Screws
- Remove the bottom panel
- Clean out the build up using a vacuum, brush, etc.

Belt Replacement

If the treadmill belt becomes worn, frayed, or damaged, replace it promptly to maintain safe and accurate operation.

1. Untension the Treadmill belt
2. Remove the 23 M5x10mm Button head Screws (Yellow), the 4 M5x15mm Button Head Screws (Magenta), and the 2 M3x10mm Button Head Screws (Blue Inside green Box). Do not remove the 4 M5x10 Screws holding the tensioner on.



3. Remove the entire front panel, being cautious with the electronics. Disconnect the power to the ESP32 and the motor driver cables.
4. Remove the remaining screws for the upper hopper
5. Remove the Belt and replace the belt
6. Reverse the steps to assemble the system

Replacement and Tensioning Instructions for the GT2 Belts

1. **Power Down and Unplug**
    - For safety, **disconnect the treadmill from its power source** before performing any maintenance on the drive system.
2. **Access the Belt Area**
    - Remove the **clear cover** that protects the GT2 belt.
    - Consult the exploded diagrams or parts list to identify the belt tensioning bolts or motor adjustment slots.
3. **Loosen the Tensioner or Motor Mount**
    - Locate the 4 screws that allow the motor to slide and **loosen them carefully**. This will reduce tension on the belt, making it easier to adjust.
4. **Adjust the Belt Tension/Replace Belt**
    - **Pull the motor** gently in the appropriate direction to increase or decrease the belt tension.
    - Replace Belt if needed.
    - Take care not to **over-tighten** the belt; excessive tension can lead to accelerated wear on bearings or belt teeth.
    - Conversely, **under-tension** may cause slipping or skipping, especially during operation at higher loads.
5. **Verify Alignment**

    - Ensure the GT2 belt is **aligned properly** with the pulley teeth. The belt should track straight across the pulleys without drifting toward the edges. Realign the motor or idler pulley if necessary.
6. **Tighten the Screws**
    - Once you have the desired tension, **securely retighten** the screws.
    - Double-check that the belt remains aligned and maintains the appropriate tension as you tighten.
7. **Test Run**
    - Reinstall the clear cover(s).
    - **Restore power** and perform a brief test run at a low speed to confirm smooth, reliable operation.
    - Listen for unusual noise or clicking, which can indicate **excessive tension** or belt misalignment.
8. **Re-check After Initial Use**
    - After several test runs or one full session, **re-check belt tension** and alignment. Minor readjustments might be necessary as the belt wears in or settles into position.

Cleaning Instructions

Disinfecting the Belt and Harness

- **Frequency**: After each experimental run or whenever contamination is suspected.
- **Procedure**:
    1. **Mild Disinfectant**: Use a lab-approved disinfectant that does not compromise materials (e.g., soap-water solution for the belt material).
    2. **Soak and Wipe**: Apply disinfectant with a cloth, not by spraying. Thoroughly wipe belt and harness surfaces.
    3. **Allow to Dry**: Ensure everything is fully dry before reassembling or using again.

Wiping Down Plastic Sides and Components

- Important: **Do not use alcohol-based wipes on the clear acrylic window**, as this can cause clouding and/or cracking over time.
- **Approved Surfaces**: White HDPE surfaces and black/blue PETG parts tolerate cleaners and alcohol-based wipes well.
- **Procedure**:
    1. **Use a Non-Abrasive Cloth**: Microfiber or soft lint-free cloths are recommended.
    2. **Use Appropriate Cleaning Agent**: Water with mild soap or an approved cleaner for acrylic/PETG/HDPE.
    3. **Gentle Pressure**: Avoid scrubbing aggressively to prevent scratches or surface damage.

Empty Waste Collection Tray

- Open Door
- Remove tray and dispose of waste

Troubleshooting

Common Issues and Resolutions

- **Belt Motor Skipping**
  - **Possible Cause**: Motor belt tension is too loose, or the GT2 drive belt is worn.
  - **Solution**: Check motor belt tension, replace GT2 belt if damaged.
- **Belt Tension Too High**
  - **Possible Symptoms**: Excessive strain on the motor, unusual noise (motor skipping), or belt damage.
  - **Solution**: Refer to tensioning instructions to loosen the belt slightly.
- **Jam in Treadmill Belt Area**
  - **Possible Cause**: Aggregate or foreign objects stuck under belt or in rollers.
  - **Solution**: Power down, remove obstruction, inspect belt for damage.
- **GT2 Drive Belt Issues**
  - **Possible Cause**: Misaligned pulleys, worn or torn belt.
  - **Solution**: Realign pulleys and/or replace belt following the steps in "GT2 Belt Replacement."
- **System Immediately Raising Harness When Powered On**
  - **Cause**: The emergency stop (E-stop) or fail-safe trigger may be **disengaged** upon startup.
  - **Solution**: Fully **engage the E-stop** (release or reset), then power on as per the "Powering On" procedure.

7. Technical Specifications

Dimensions and Weight

- **Overall Dimensions XYZ**: 844.94mm × 219.16mm × 586.75mm (33.26in × 8.63in × 23.10in)
- **Weight**: 15.4 Kg (33.95lb)

Power Requirements

- **Voltage**: (110–120 V AC)
- **Frequency**: 60 Hz
- **Power Consumption**: (350 W)

Supported Weight Ranges for Simulated Gravity

- This treadmill is designed to accommodate rats weighing up to **800 grams**.
- Refer to **https://www.lomir.com/slings/sling-suit-rodent-sling/** for detailed guidance on selecting and installing the correct harness size for your specific animal weight range.

User Interface Features

1. **Rotary Encoder**
   - Turn the encoder to navigate through menus on the main screen.
2. **Up/Down Buttons**
   - Press these to adjust the rat's position or harness height in small increments.
3. **Set Position Button**
   - Once the desired harness height or position is reached, press this button to lock it in place.
4. **Screen**
   - Displays current speed, harness position, error messages, and other operational data.
5. **E-Stop Button**
   - Initiates a gradual deceleration of the treadmill rather than an immediate stop, preventing sudden jolts to the animal. Also triggers the harness to raise the rat off the belt.

Aggregate Type and Volume Guidelines

- **Aggregate Type**: Use regolith or aggregate that is safe with animals and that is electrically non-conductive. The maximum particle size should not exceed the sieve size being used.
- **Recommended Volume**: ~5kg or 5L (Assuming Clumping Litter Usage).

8. Revision History

- Rev A - Created Owners Manual
- Rev B - Updated Procedures, added Figures.
- Rev C - Updated to reflect design changes.

4.6 Models

Treadmill Table of Models

Functional Group	**Model**	**Equations**	**Tools**
Power & Motors	Power	$P = VI$	Excel, PSPICE
	Ohm's Law	$V = IR$	Excel, PSPICE
Treadmill	Angular Velocity	$\omega = RPM \times \frac{2\pi}{60}, \omega = v \cdot r$	Excel
	Linear Velocity	$v = \frac{x - x_0}{t}$	Excel
	Tangential Velocity	$v = r \cdot \omega$	Excel
Auger	Work (Force Distance)	$W = F \cdot d \cdot \cos(\theta)$	Excel
	Work (Electrical Power)	$W = V \cdot I \cdot t$	Excel
	Work (Torque)	$W = \tau \cdot \theta$	Excel
Gravity Suspension system	Force Due to Gravity	$F = m \cdot gmoon$	Excel

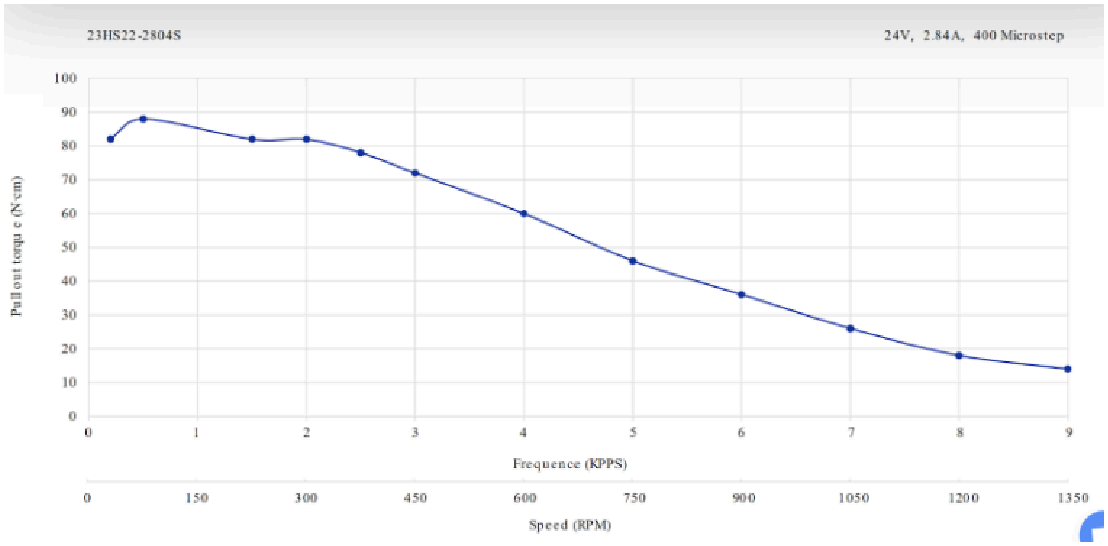
Harness Analysis:

Plan for analysis:

- Use the correct diameter pulley (previous analysis did not match the current design).
- Find a torque curve for the motor and find working torque rating at the expected speed.
- Compare actual vs. expected working torque.
  - If enough, determine why the motor does not supply enough torque
    - Check the motor quality by using other (same model)motors.
      - Replace the motor if the motor is bad.
    - Check if the motor is exceeding the working torque spec by having too high of an acceleration (this is the expected outcome after some more research).
      - Adjust the code to smooth out acceleration and reduce jerk.

Calculations:

Provided torque curve:



Same Voltage, Amperage, and Microstepping Used			
Steps/Second sent	Microstepping	RPM Calculated	Torque (N*cm) @ RPM from Table
200	400	30	~80
Radius (cm)	Force (N)	Inefficiency	Torque Required
1.55	9.81	1.2	18.2466

Conclusions:
The motor is more than enough using correct numbers. Our code needed reevaluation. We changed from using a rotary encoder to using a pair of buttons to control the motor. We also upgraded our pulley to prevent the string from shock loading, causing significant increases in required torque. This analysis has been **VERIFIED** in our passing harness weight acceptance test.

9.0 Next Steps

Our auger worked to some degree, but didn't have full coverage over the treadmill at all times. After much trial and error with the Auger the following are some next steps that could improve the Auger to the point where it would work properly:

<u>Decrease the pitch of the archimedes screw:</u>

- A lower pitch (i.e., the angle between screw threads) results in a more gradual movement of the material. This can help prevent clumping or jamming of aggregate materials, which can occur when the material is pushed too quickly through the system.
- With a lower pitch, the material moves more smoothly, allowing it to be transported without creating bottlenecks or causing the auger to stall.
- With a higher pitch, material can slip past the screw threads, leading to inefficiencies in material recirculation. A smaller pitch means that the material is more effectively trapped between the threads, reducing the likelihood of slippage and improving the system's overall efficiency.

<u>Increase amount of turns in the Archimedes Screw:</u>

- With more turns, the screw has more opportunities to evenly distribute the material along the length of the auger. This can result in better mixing and homogenization of materials, which is important when working with different aggregate types or when seeking uniform distribution across the treadmill surface.
- This also means that when the material is recirculated, it will be more evenly distributed, reducing the chances of uneven wear on the system or areas where the material could pile up.

<u>Reduced Material Loss and Spillage:</u>

- Add pipe cleaners to the exterior edge of the archimedes screw to reduce fine aggregate loss but minimize the friction between the screw and the pipe. This was tested after the Final Acceptance Review Presentation, and worked well, pictured below.

Figure 9.1: Auger with pipe cleaner aggregate fall out testing.

Overall, outsourcing an auger would allow for a clean and effective final design implemented into the final recirculating system. If the auger system is not the route of preference moving forward with future iterations of the project, here are other options that would be successful.

Bucket Pulley System:

- A bucket pulley system can provide more predictable and consistent material flow compared to a screw mechanism. Each bucket moves a defined amount of material, ensuring that the system operates with less variation in flow rate. This is especially important when dealing with aggregates like sand, which can cause inconsistent movement in a screw system due to clogging or slippage.

- Buckets are less likely to get jammed than an auger, especially when working with irregularly shaped or larger materials. With the screw, materials can slip past the threads or get stuck between the screw and the tube, which can stop the system from working. A bucket system, on the other hand, is more resistant to blockages since the material is physically contained in the bucket and only moves when it's lifted and dropped.

Spinning Disk System:

- A spinning disk can help evenly distribute the aggregate across the treadmill surface by keeping it flat and uniformly spread out. The centrifugal force generated by the spinning motion ensures that the material stays in a consistent layer, reducing the chances of uneven accumulation, clumping, or pileups.

- By keeping the aggregate uniformly spread, the disk prevents the treadmill from developing areas with varying thickness or uneven surfaces, ensuring a consistent walking experience for the rat and improving the simulation of different terrains (like extraterrestrial regolith).

5.0 Verification Documentation

Treadmill Ambulatory System Verification Test Procedure
Treadmill Ambulatory System (TAS) **Verification Test Procedure** **Team 25005** May 6th, 2025 REV C Prepared for UA Dept. of Biomedical Engineering
Description of Changes Rev A: 01/28/2025 - Initial Release Rev B: 03/04/2025 - Second Release with Updates Rev C: 05/06/2025 - Third Release with All Completed Tests
Table of Contents **Section 5.1 Acceptance Test Descriptions** **Section 5.2 Acceptance Test Data Sheets**

5.1 Acceptance Test Descriptions

5.1.1.1 Aggregate Performance Acceptance Test

5.1.1.2 Introduction: This procedure outlines the acceptance criteria for the collection bin subsystem, which can be performed in the lab or the EDC. This procedure will test the ability of this subsystem to recycle the aggregate within the system to a 90% accuracy over five minutes of run time, directly correlating to our requirement.

5.1.1.3 Referenced Documents: System Requirements Document (SRD), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.1.4 Required Test Equipment: Aggregate, completed system assembly.

5.1.1.5 Table of Tests:

Test #	Test	Requirement
4.1.1	Aggregate Mass	Recirculation: The aggregate recycling method shall have a 90% accuracy after 5 minutes

5.1.1.6 Step-By-Step Procedure:

1. Load aggregate into complete system assembly via the feeder hopper, weighing the aggregate in the process.
2. Use the UI to power the treadmill.
3. Run the treadmill with the aggregate across it for five minutes.
4. Weigh the remaining aggregate following run time.
5. Calculate the percentage of aggregate left over the initial loaded aggregate.
6. Mark Pass/Fail in the datasheet. To pass, 90% of the loaded aggregate needs to be retained.

5.1.1.7 Support Requirements:

- 4.1.2 The aggregate layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters
- 4.2.1 The treadmill shall have a speed of 0.2 meters per second within +-5%

5.1.2.1 Data Collection Acceptance Test

5.1.2.2 Introduction: These procedures outline the acceptance criteria for the antenna subsystem, which can be performed in the lab or at the EDC. This procedure will test the ability for the subsystem to interface with the FEIG software and provide data for our Biomedical Engineers to interpret.

5.1.2.3 Referenced Documents: System Requirements Document (SRD), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.2.4 Required Test Equipment: FEIG LRM2500-B RFID Reader, ISC.MAT-B Antenna Tuning Board, SMA Cable (50 Ohm) with Ferrite Choke, 14-16 AWG wire, NeuroLux Power Distribution and Control (PDC) Box, and FEIG Software.

5.1.2.5 Table of Tests:

Test #	**Test**	**Requirement**
4.2.2	Antenna	External Antenna: The enclosure shall have an antenna that is within range of the rat to collect data

5.1.2.6 Step-By-Step Procedure:

1. Assemble 14-16 AWG wire parallel with the enclosure to create an antenna.
2. Connect wires to ISC.MAT-B Antenna Tuning Board on the enclosure.
3. Measure distance from antenna and rat harness.
4. Connect FEIG LRM2500-B RFID Reader to NeuroLux Power Distribution and Control (PDC) Box.
5. Tune the ISC.MAT-B board to 1.3 Conductance using the jumpers that come with the tuning board.
6. Connect NeuroLux Power Distribution and Control (PDC) Box to a Windows PC with the FEIG Software.
7. Open FEIG and choose the detect device in menu selection.
8. Select the COM port the PDC box is connected to and wait for it to load.
9. Ensure data is being collected. Record and interpret these values in the datasheet. Mark Pass/Fail on datasheet. A pass requires the readings to appear in the software without errors.

5.1.2.7 Support Requirements: N/A

5.1.3.1 Harness Weight Minimum Acceptance Test

5.1.3.2 Introduction: This procedure outlines the acceptance criteria for the harness weight minimum requirement in our enclosure subsystem, which can be performed in the lab or the EDC. This procedure will test the ability of this subsystem to hold a rat that weights up to 1kg, the maximum approximate weight seen in testing in the Orthopaedic Research Lab.

5.1.3.3 Referenced Documents: System Requirements Document (SRD), Minimal Viable Product (MVP1), Indentured Document List (IDL)

5.1.3.4 Required Test Equipment: Arduino IDE, Arduino Uno or ESP32, Stepper Motor (23HS22-2804S), Stepper Driver (DM332T), Pulley, String, Rotary Encoder, Momentary Switch, DPDT Emergency, and an assortment of weights (500g, 800g, and 1kg).

5.1.3.5 Table of Tests:

Test #	**Test**	**Requirement**
4.1.3	Weight	Harness Weight: The enclosure shall have a hanging harness that can hold 1kg of weight

5.1.3.6 Step-By-Step Procedure:

1. Assemble the breadboard circuit according to the wiring diagram in the SDD or use PCB Rev B.
2. Connect the 24V wall adapter to the stepper driver (DM332T).
3. Set up the stepper motor (23HS22-2804S) on a flat surface and secure it with a clamp.
4. Attach the pulley to the stepper motor with 3D printed higher pulley walls.
5. Attach the string to the pulley on the motor.
6. Start with 500g weight, attach it to the string.
7. Raise and lower the harness position with the rotary encoder.
8. Use the emergency stop to return the harness position to it’s preset position.
9. Document any skipping motor steps that occur.
10. Repeat steps 6-10 with the 800g and 1kg weight. Document Pass/Fail in datasheet, a pass requires no skipping motor steps.

5.1.3.7 Support Requirements:

- 4.4.1 The user interface shall be simple and friendly to use, reacting immediately to input.
- 4.4.5 The system shall plug into a 120 Volt wall adapter to power the system

<u>5.1.4.1 Rat Waste Filter Acceptance Test</u>

5.1.4.2 Introduction: This procedure outlines the acceptance criteria for the filter subsystem, which can be performed in the lab or the EDC. This procedure will test the ability of this subsystem to filter potential rat waste pellets of an average size (1-2cm length, ~3mm diameter) out of the aggregate that will be recycled in the system.

5.1.4.3 Referenced Documents: System Requirements Document (SRD), Minimal Viable Product (MVP1), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.4.4 Required Test Equipment: Aggregate, 10 3D printed "rate waste" (1-2cm length, ~3mm diameter), timer, 3D printed filter, electronic scale, bins to hold aggregate, and measuring cup.

5.1.4.5 Table of Tests:

Test #	**Test**	**Requirement**
4.3.2	Filtering	<u>Waste Filter</u>: The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length

5.1.4.6 Step-By-Step Procedure:

1. Prepare 3 cups of aggregate.
2. Mix in ten of the rat waste pellets into the aggregate.
3. Pour the mixture over the 3D printed rat waste filter.
4. Count the number of rat waste pellets left in the filter. Mark Pass/Fail on the datasheet, all pellets need to be in the filter for a pass.

5.1.4.7 Support Requirements:

- 4.1.1 The aggregate recycling method shall have a 90% accuracy after 5 minutes

<u>5.1.5.1 Treadmill Velocity Acceptance Test</u>

5.1.5.2 Introduction: This procedure outlines the acceptance criteria for the treadmill subsystem, which can be performed in the lab or the EDC. This procedure will test the ability of this subsystem to reach the potential range of velocity we will need, which is 0.2m/s - 0.8m/s.

5.1.5.3 Referenced Documents: System Requirements Document (SRD), Minimal Viable Product (MVP1), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.5.4 Required Test Equipment: Arduino IDE, Arduino UNO or ESP32, Treadmill Assembly, Stepper Motor (23HS45-4204S), Stepper Driver (DM332T), Rotary Encoder, Reflective Tape, Tachometer, Excel

5.1.5.5 Table of Tests:

Test #	**Test**	**Requirement**
4.2.1	Velocity	<u>Treadmill Speed</u>: The treadmill shall have a speed of 0.2 meters per second within +-5%

5.1.5.6 Step-By-Step Procedure:

1. Set up treadmill subsystem.
2. Assemble the breadboard circuit according to the SDD wiring diagram.
3. Upload and run code to ESP32 in UI subsystem.
4. Attach reflective tape to our treadmill pulleys.
5. Connect 24V adapter to stepper driver.
6. Use rotary encoder to gradually increase the speed.
7. Measure the RPM with the tachometer.
8. Use the velocity formula to calculate the velocity.
9. Compare these calculations with the velocity readings displayed in the code print statements in the Arduino IDE.
10. Mark Pass/Fail on datasheet. If the treadmill velocity can range from 0.2m/s to 0.8m/s, this results in pass.

5.1.5.7 Support Requirements:

- 4.4.1 The user interface shall be simple and friendly to use, reacting immediately to input.
- 4.4.5 The system shall plug into a 120 Volt wall adapter to power the system.

5.1.6.1 Emergency Stop Acceptance Test

5.1.6.2 Introduction: This procedure outlines the acceptance criteria for the emergency stop function in the electrical assembly/UI subsystem, which can be performed in the lab or at the EDC. This procedure will test the ability of our emergency stop to gradually stop the treadmill and auger, along with the rat harness position in the enclosure returning to its set position or a preset position if no position is set.

5.1.6.3 Referenced Documents: System Requirements Document (SRD), Minimal Viable Product (MVP1), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.6.4 Required Test Equipment: Arduino IDE, Arduino UNO or ESP32, Treadmill Assembly, Stepper Motor (23HS45-4204S), Stepper Driver (DM332T), DPDT Emergency Stop Switch, Rotary Encoder.

5.1.6.5 Table of Tests:

Test #	Test	Requirement
4.3.1	Stopping all functions.	Emergency Stop: The system shall have an emergency stop function that works upon pressing the emergency stop button that lifts the rat within the harness up from the face of the treadmill

5.1.6.6 Step-By-Step Procedure:

1. Assemble the breadboard circuit according to the wiring diagram in the SDD.
2. Connect the 24V wall adapter to the stepper driver (DM332T).
3. Now that the treadmill is powered, set the speed to ~0.2m/s.
4. Set an unspecified rat harness height.
5. Run for one minute, then press the emergency stop button.
6. Ensure treadmill and auger come to a gradual, eventually complete stop.
7. Ensure rat harness height returns to set position. Mark Pass/Fail on the datasheet.

5.1.6.7 Support Requirements:

- 4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.
- 4.2.1 The treadmill shall have a speed of 0.2 meters per second within +-5%.
- 4.4.1 The user interface shall be simple and friendly to use, reacting immediately to input.
- 4.4.5 The system shall plug into a 120 Volt wall adapter to power the system

<u>5.1.7.1 Aggregate Thickness Acceptance Test</u>

5.1.7.2 Introduction: This procedure outlines the acceptance criteria for the aggregate leveling subsystem, which can be performed at the EDC.

5.1.7.3 Referenced Documents: System Requirements Document (SRD), Minimal Viable Product (MVP1), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.7.4 Required Test Equipment: Aggregate, Upper Hopper Enclosed Side, Leveling Bar.

5.1.7.5 Table of Tests:

Test #	**Test**	**Requirement**
4.1.2	Aggregate	<u>Thickness:</u> The thickness of the aggregate layer produced by the upper hopper must be 12mm with a range of plus of minus 2mm

5.1.7.6 Step-By-Step Procedure:

1. Screw the leveling bar onto the upper hopper enclosed side to the height needed to produce the desired aggregate thickness
2. Place the upper hopper on a piece of cardboard for easy cleaning and load with aggregate.
3. Pull the upper hopper backwards slowly to release a level amount of aggregate.
4. Using a ruler, measure the height of the bed of aggregate in several places. If the thickness is 12mm with a range of plus or minus 2mm, then the test is passed.

5.1.7.7 Support Requirements:

4.1.2 The aggregate layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters

5.1.8.1 System Weight Acceptance Test

5.1.8.2 Introduction: This procedure outlines the acceptance criteria for the overall weight of the completely assembled system, which can be performed in the lab or at the EDC.

5.1.8.3 Referenced Documents: System Requirements Document (SRD), Indentured Document List (IDL), Verification Procedures Document (VP)

5.1.8.4 Required Test Equipment: Fully assembled treadmill, scale.

5.1.8.5 Table of Tests:

Test #	Test	Requirement
4.4.2	Weight	System Weight: The treadmill shall weigh less than 34.02 kilograms

5.1.8.6 Step-By-Step Procedure:

1. Place the scale on a flat surface.
2. Place the system on the scale and verify weight reading.
3. If the weight is 34.02kg or less/within the margin, this will result in a pass.

5.1.8.7 Support Requirements:

- N/A

5.2 Acceptance Test Data Sheets

Key:

Aggregate Performance Acceptance Test	Harness Weight Minimum Acceptance Test
Treadmill Velocity Acceptance Test	Data Collection Acceptance Test
Emergency Stop Acceptance Test	Rat Waste Filter Acceptance Test
System Weight Acceptance Test	Aggregate Thickness Acceptance Test

Overall Aggregate Performance Acceptance Test

Acceptance Test Data Sheet (1)	
Referenced ATP Paragraph Number: 4.1.1 The aggregate recycling method shall have a 90% accuracy after 5 minutes	
Analysis Referenced (for verification by T/A): none	
Name of Test: Overall Aggregate Performance Acceptance Test	
Units Under Test (UUT):	
Name: Collection Bins	Part Number: COL-001 COL-002 COL-003 COL-004
Name: Filter	Part Number: FIL-001
Name: Treadmill Belt	Part Number: PUR-001
Name: Leveling Bar	Part Number: TRD-003
Results (Pass / Fail)	Date of Test: 4/24/2025

<table>
<tr><td>Recording of Test Measurement:</td><td>Requirement (SRD, with Tolerances):</td><td>Test Equipment Error:</td><td>Adjusted Test Limit:</td></tr>
<tr><td colspan="4">Computations, (Include Analyses Results, if any):

Tested Accuracy = 99.4%</td></tr>
<tr><td colspan="4">Signatures:

Tester Alexis Barber (Alexis Barber) Gabriel Vogt (Gabe Vogt)

Customer: Gerardo Figueroa (Gerardo Figueroa)</td></tr>
</table>

Antenna Acceptance Test

Acceptance Test Data Sheet (2)			
Referenced ATP Paragraph Number: 4.2.2 The enclosure shall have an antenna that is within range of the rat to collect data			
Analysis Referenced (for verification by T/A): n/a			
Name of Test: Antenna Acceptance Test			
Unit Under Test (UUT): Pass/Fail			
Name: Antenna Amplifier Board Name: Antenna		Part Number: ELC-012 Part Number: ELC-013	
Results (Pass / Fail):		Date of Test: 1/28/25	
Recording of Test Measurement: Pass/Fail	Requirement (SRD, with Tolerances): Pass	Test Equipment Error: n/a	Adjusted Test Limit: 0%
Computations, (Include Analyses Results, if any): 			

Table below is direct representation of grid inside the field

Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass

Signatures:

Tester: Avery Miller (Avery Miller)

Customer: Gerardo Figueroa (Gerardo Figueroa)

Harness Weight Minimum Acceptance Test

<table>
<tr><th colspan="4">Acceptance Test Data Sheet (3)</th></tr>
<tr><td colspan="4">Referenced ATP Paragraph Number:
4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.</td></tr>
<tr><td colspan="4">Analysis Referenced (for verification by T/A): none</td></tr>
<tr><td colspan="4">Name of Test: Harness Weight Minimum Acceptance Test</td></tr>
<tr><td colspan="4">Unit Under Test (UUT):</td></tr>
<tr><td colspan="2">Name: Harness Motor
Name: Stepper Motor Drivers
Name: Harness</td><td colspan="2">Part Number: ELC-003
Part Number: ELC-006
Part Number: PUR-002</td></tr>
<tr><td colspan="2">Results: (Pass / Fail)</td><td colspan="2">Date of Test: 1-24-25</td></tr>
<tr><td>Recording of Test Measurement:
N/A</td><td>Requirement (SRD, with Tolerances):
- 1kg movement capability</td><td>Test Equipment Error:
N/A</td><td>Adjusted Test Limit:
N/A</td></tr>
<tr><td colspan="4">Computations, (Include Analyses Results, if any):</td></tr>
</table>

Harness Test	
Weight (g)	**Passed**
100	☑
200	☑
300	☑
400	☑
500	☑
600	☑
700	☑
800	☑
900	☑
1000	☑

Signatures:

Tester: (Juan Campista)

Customer: Gerardo Figueroa (Gerardo Figueroa)

Rat Waste Filter Acceptance Test

Acceptance Test Data Sheet (4)			
Referenced ATP Paragraph Number: 4.3.2 The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length			
Analysis Referenced (for verification by T/A): none			
Name of Test: Rat Waste Filter Test			
Unit Under Test (UUT):			
Name: Filter		Part Number: FIL-001	
Results (Pass / Fail):		Date of Test: 11/21/2024	
Recording of Test Measurement: - Filter Accuracy	Requirement (SRD, with Tolerances): - 100% filtration	Test Equipment Error: n/a	Adjusted Test Limit: n/a
Computations, (Include Analyses Results, if any):			

Rat Filter Acceptance Test				
Cups of Aggregate	Weight of Aggregate (g)	Number of "rat waste" before filter	Number of "rat waste" after filter	Accuracy of Filter
3	695	10	10	100%
3	694.2	10	10	100%
3	693.5	10	10	100%
3	694.8	10	10	100%
3	695.3	10	10	100%
3	694.2	10	10	100%
3	693.8	10	10	100%
3	694.5	10	10	100%
3	693.9	10	10	100%
3	696.7	10	10	100%

Signatures:

Tester: Avery Miller (Avery Miller) Will Stephenson (Will Stephenson)

Customer: Gerardo Figueroa (Gerardo Figueroa)

Treadmill Velocity Acceptance Test

Acceptance Test Data Sheet (5)			
Referenced ATP Paragraph Number: 4.2.1 The treadmill shall have a speed of 0.2 meters per second within +-5%			
Analysis Referenced (for verification by T/A): none			
Name of Test: Treadmill Velocity Acceptance Test			
Units Under Test (UUT):			
Name: Treadmill Belt Name: Treadmill Motor		Part Number: PUR-001 Part Number: ELC-001	
Results (Pass / Fail):		Date of Test: 11/1/2024	
Recording of Test Measurement: Treadmill Velocity: Auger Velocity:	Requirement (SRD, with Tolerances): ~0.2 m/s ± 5%	Test Equipment Error: N/A	Adjusted Test Limit: N/A
Computations, (Include Analyses Results, if any):			

Treadmill Acceptance Test Results (Tachometer)				
RPM	$V = \frac{RPM \times \pi \times Diameter\ (Roller)}{Conversion\ Factor \times 60}$	Serial Monitor	% Accuracy	%Error
12	**0.047877872**	**0.05**	95.75574408	4.244256
24	**0.095755744**	**0.1**	95.75574408	4.244256
38.8	**0.15480512**	**0.16**	96.75319975	3.2468
49.9	**0.199092151**	**0.2**	99.54607562	0.453924
62.5	**0.249363917**	**0.25**	99.74556675	0.254433
74.3	**0.296443824**	**0.3**	98.81460813	1.185392
86.4	**0.344720679**	**0.35**	98.49162248	1.508378
100.3	**0.400179214**	**0.41**	97.60468629	2.395314
112.6	**0.449254033**	**0.45**	99.83422948	0.165771
123.4	**0.492344117**	**0.5**	98.4688235	1.531177
132.5	**0.528651504**	**0.55**	96.11845523	3.881545
147.2	**0.587301897**	**0.6**	97.88364951	2.11635
158.7	**0.633184858**	**0.65**	97.41305504	2.586945
170.5	**0.680264765**	**0.69**	98.58909641	1.410904
184.9	**0.737718212**	**0.75**	98.36242823	1.637572
195.4	**0.77961135**	**0.8**	97.45141872	2.548581
Average % Accuracy | Average % Error			97.94246564	2.088225

Treadmill Acceptance Test Results (Timer)				
Seconds / 5 Laps	$V = \frac{Distance\ Traveled\ (m)}{Time\ (s)}$	Serial Monitor	% Accuracy	% Error
127.06	**0.047977334**	**0.05**	95.954667	4.04533
63.66	**0.095758718**	**0.1**	95.758718	4.24128
39.23	**0.155391282**	**0.16**	97.119551	2.88044
30.38	**0.200658328**	**0.2**	100.32916	0.32916
24.32	**0.250657895**	**0.25**	100.26316	0.26315
20.44	**0.298238748**	**0.3**	99.412916	0.58708
17.69	**0.34460147**	**0.35**	98.457563	1.54243
15.04	**0.405319149**	**0.41**	98.858329	1.14167
13.61	**0.447905952**	**0.45**	99.534656	0.46534
12.3	**0.495609756**	**0.5**	99.121951	0.87804
11.31	**0.538992042**	**0.55**	97.998553	2.00144
10.31	**0.591270611**	**0.6**	98.545102	1.45489
9.49	**0.642360379**	**0.65**	98.824674	1.17532
9.05	**0.67359116**	**0.69**	97.621907	2.37809
8.29	**0.735343788**	**0.75**	98.045838	1.95416
7.91	**0.770670038**	**0.8**	96.333755	3.66624
Average % Accuracy | Average % Error			98.261281	1.81275

Signatures:

Tester: (Juan Campista)

Customer: Gerardo Figueroa (Gerardo Figueroa)

Emergency Stop Acceptance Test

<table>
<tr><th colspan="4">Acceptance Test Data Sheet (6)</th></tr>
<tr><td colspan="4">Referenced ATP Paragraph Number:

4.3.1 The system shall have an emergency stop function that works upon pressing the emergency stop button that lifts the rat within the harness up from the face of the treadmill</td></tr>
<tr><td colspan="4">Analysis Referenced (for verification by T/A): none</td></tr>
<tr><td colspan="4">Name of Test: Emergency Stop Test</td></tr>
<tr><td colspan="4">Units Under Test (UUT):</td></tr>
<tr><td colspan="2">Name: Auger

Name: Filter
Name: Treadmill Belt
Name: Rat Harness
Name: Emergency Stop Button
Name: Harness Motor</td><td colspan="2">Part Number: AUG-011
AUG-012
AUG-013
Part Number: FIL-001
Part Number: PUR-001
Part Number: PUR-002
Part Number: ELC-005
Part Number: ELC-003</td></tr>
<tr><td colspan="2">Results (Pass / Fail)</td><td colspan="2">Date of Test: 11-15-24</td></tr>
<tr><td>Recording of Test Measurement:

n/a</td><td>Requirement (SRD, with Tolerances):</td><td>Test Equipment Error:

n/a</td><td>Adjusted Test Limit:

n/a</td></tr>
</table>

Computations, (Include Analyses Results, if any): n/a
Signatures: Tester: Alicia Enriquez (Alicia Enriquez) (Juan Campista) Customer: Gerardo Figueroa (Gerardo Figueroa)

Aggregate Thickness Acceptance Test

Acceptance Test Data Sheet (7)			
Referenced ATP Paragraph Number: 4.1.2 The aggregate layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters			
Analysis Referenced (for verification by T/A): none			
Name of Test: Aggregate Thickness Test			
Units Under Test (UUT):			
Name: Upper Hopper Enclosed Side Name: Leveling Bar		Part Number: AUG-010 Part Number: TRD-003	
Results (Pass / Fail)		Date of Test: 1/23/2025	
Recording of Test Measurement:	Requirement (SRD, with Tolerances): 12mm ±2mm	Test Equipment Error: 0%	Adjusted Test Limit:
Computations, (Include Analyses Results, if any): N/A			
Signatures: Tester: Alexis Barber (Alexis Barber) (Will Stephenson) Customer: Gerardo Figueroa (Gerardo Figueroa)			

System Weight Acceptance Test

<table>
<tr><th colspan="4">Acceptance Test Data Sheet (8)</th></tr>
<tr><td colspan="4">Referenced ATP Paragraph Number:
4.4.2 The treadmill shall weigh less than 34.02 kilograms</td></tr>
<tr><td colspan="4">Analysis Referenced (for verification by T/A): none</td></tr>
<tr><td colspan="4">Name of Test: System Weight Acceptance Test</td></tr>
<tr><td colspan="4">Units Under Test (UUT):</td></tr>
<tr><td colspan="2">Name: Treadmill System
Name: Collection Bin System
Name: Electrical System
Name: Filter System
Name: Enclosure System
Name: Purchased Parts</td><td colspan="2">Part Number: TRD
Part Number: COL
Part Number: ELC
Part Number: FIL
Part Number: ENC
Part Number: PUR</td></tr>
<tr><td colspan="2">Results (Pass / Fail)</td><td colspan="2">Date of Test: 4/24/25</td></tr>
<tr><td>Recording of Test Measurement:
N/A</td><td>Requirement (SRD, with Tolerances):
34.02 kg ± 0</td><td>Test Equipment Error:
0%</td><td>Adjusted Test Limit:
N/A</td></tr>
<tr><td colspan="4">Computations, (Include Analyses Results, if any):
Final Weight = 15.04 kg</td></tr>
</table>

Signatures:

Tester Alexis Barber (Alexis Barber) Gabriel Vogt (Gabe Vogt)

Customer: Gerardo Figueroa (Gerardo Figueroa)

6.0 Appendix

6.1 Code

```
// Authors: Juan Campista & Alicia Enriquez
// Date:    4/23/2024
// Summary: This code implements a rotary encoder-controlled user interface for a treadmill system
//          with two modes: speed control for a treadmill motor and directional control for a harness
//          motor. It displays a menu on an I2C LCD, handles rotary input for navigation and selection,
//          and adjusts motor behavior based on user interaction. Emergency stop and directional
//          control buttons are also integrated for safety and manual overrides.
//------------------------------------------------------------------------------------------------------//
#include <LiquidCrystal_PCF8574.h>         // Include the library for controlling an I2C LCD
#include <AccelStepper.h>                  // Include the library for controlling stepper motors
#include <esp_sleep.h>                     // Include the library for ESP32 sleep functions

// Pin Definitions
#define encoderCLK 4                       // Rotary encoder CLK pin
#define encoderDT 5                        // Rotary encoder DT pin
#define rotaryButton 18                    // Rotary encoder push button pin

#define treadDirectionPin 25               // Direction control pin for treadmill motor
#define treadPulsePin 27                   // Step (pulse) control pin for treadmill motor

#define harnessPulsePin 15                 // Step (pulse) control pin for harness motor
#define harnessDirectionPin 16             // Direction control pin for harness motor

#define Button 29                          // General-purpose button (not yet used)
#define emergencyButton 26                 // Emergency stop button pin
#define clockwiseButton 17                 // Button to move harness clockwise
#define counterclockwiseButton 23          // Button to move harness counterclockwise

// LCD Settings
const int lcdColumns = 16, lcdRows = 2;    // LCD dimensions (16 columns, 2 rows)
LiquidCrystal_PCF8574 lcd(0x27);           // Create LCD object with I2C address 0x27

// Treadmill Settings
AccelStepper treadmill(1, treadPulsePin, treadDirectionPin); // Create treadmill stepper object
int treadmillSpeed = 0;                    // Current speed of treadmill
const int maxSpeed = 1337;                 // Maximum speed for treadmill
const int treadmillIncrement = 17;         // Increment/decrement value for treadmill speed
```

```
// Harness Motor Settings
AccelStepper harness(1, harnessPulsePin, harnessDirectionPin); // Create harness stepper object
bool positionSaved = false;             // Flag for saved harness position
int setPosition = 0;                    // Target position for harness (not used in this version)
bool eButtonPressed = false;            // Flag for emergency button state
unsigned long lastMoveTime = 0;         // Last time harness moved (not used in this version)
int count = 0;                          // Counter for rotary changes (not used in this version)

// Menu Variables
enum Mode { MENU, SPEED_MODE, HARNESS_MODE } currentMode = MENU; // Mode state
const String menuItems[] = {"SPEED", "HARNESS"}; // Menu options
int menuIndex = 0;                      // Current index in menu
const int numMenuItems = 2;             // Total number of menu items

// Rotary Encoder State
int lastCLKState = LOW;                 // Last known state of encoder CLK
unsigned long lastDebounceTime = 0;     // Last debounce time
const unsigned long debounceDelay = 50; // Debounce delay in milliseconds

// Button Release Guard
bool buttonReleaseGuard = false;        // Prevents button re-triggering
unsigned long buttonReleaseTime = 0;    // Time when button was released
const unsigned long buttonReleaseDelay = 200; // Delay before button can trigger again

int buttonState = 0;                    // Current button state (not used in this version)
int eButtonState = 0;                   // Current emergency button state

void setup() {
  Serial.begin(115200);                 // Initialize serial communication

  lcd.begin(lcdColumns, lcdRows);       // Initialize the LCD
  lcd.setBacklight(255);                // Set LCD backlight to max
  displayMenu();                        // Show the main menu on LCD

  pinMode(encoderCLK, INPUT);           // Set encoder CLK pin as input
  pinMode(encoderDT, INPUT);            // Set encoder DT pin as input
  pinMode(rotaryButton, INPUT_PULLUP);  // Set rotary button pin as input with pull-up
  pinMode(Button, INPUT_PULLUP);        // Set general button pin as input with pull-up
  pinMode(emergencyButton, INPUT_PULLUP); // Set emergency button as input with pull-up
  pinMode(clockwiseButton, INPUT_PULLUP); // Set clockwise button as input with pull-up
  pinMode(counterclockwiseButton, INPUT_PULLUP); // Set counterclockwise button as input with
pull-up
```

```
  treadmill.setMaxSpeed(maxSpeed);        // Set maximum treadmill speed
  treadmill.setAcceleration(2000);        // Set treadmill acceleration

  harness.setMaxSpeed(800);               // Set maximum harness speed
  harness.setAcceleration(300);           // Set harness acceleration
  harness.setSpeed(0);                    // Initialize harness speed to 0

  lastCLKState = digitalRead(encoderCLK);  // Save initial encoder CLK state
}

void loop() {
  static Mode previousMode = MENU;        // Store the previous mode for LCD updates

  if (currentMode == MENU) {              // If in menu mode
    if (buttonReleaseGuard && millis() - buttonReleaseTime > buttonReleaseDelay) {
      buttonReleaseGuard = false;         // Reset button guard after delay
    }

    if (!buttonReleaseGuard) {
      if (previousMode != MENU) {         // If mode changed to menu
        lcd.clear();                      // Clear the LCD
        displayMenu();                    // Display the menu
        previousMode = MENU;              // Update previous mode
      }
      handleEncoderForMenu();             // Handle rotary input for menu
      if (buttonPressed(rotaryButton)) handleMenuSelection(); // If button pressed, select menu item
    }

    if (treadmillSpeed > 0) {             // If treadmill is running
      treadmill.runSpeed();               // Continue running treadmill
    }
  } else if (currentMode == SPEED_MODE) {  // If in speed adjustment mode
    handleSpeedMode();                    // Adjust speed based on encoder
    if (treadmillSpeed == 0) {
      if (buttonPressed(rotaryButton)) returnToMenu(); // Return to menu if stopped
    }
  } else if (currentMode == HARNESS_MODE) {// If in harness control mode
    handleHarnessMode();                  // Run harness motor
    if (buttonPressed(rotaryButton)) returnToMenu(); // Return to menu on button press
  }
}

void handleEncoderForMenu() {
```

```
  int currentCLKState = digitalRead(encoderCLK); // Read encoder CLK
  if ((millis() - lastDebounceTime) > debounceDelay && currentCLKState != lastCLKState) {
    if (digitalRead(encoderDT) != currentCLKState) {
      menuIndex++;                         // Rotate clockwise: increment index
    } else {
      menuIndex--;                         // Rotate counterclockwise: decrement index
    }
    menuIndex = constrain(menuIndex, 0, numMenuItems - 1); // Keep index in bounds
    displayMenu();                         // Update menu display
    lastCLKState = currentCLKState;        // Update last CLK state
    lastDebounceTime = millis();           // Update debounce time
  }
}

void handleMenuSelection() {
  lcd.clear();                             // Clear LCD for new mode
  lcd.print(menuItems[menuIndex] + " SELECTED"); // Show selected item
  Serial.println(menuItems[menuIndex] + " SELECTED"); // Print to serial
  delay(1000);                             // Pause for 1 second

  if (menuIndex == 0) {                    // If SPEED selected
    currentMode = SPEED_MODE;              // Change mode to speed
    lcd.clear(); lcd.print("Speed Mode");  // Display mode
    treadmill.setSpeed(treadmillSpeed);    // Set treadmill speed
  } else if (menuIndex == 1) {             // If HARNESS selected
    currentMode = HARNESS_MODE;            // Change mode to harness
    lcd.clear(); lcd.print("Harness Mode");// Display mode
  }
}

void displayMenu() {
  lcd.clear();                             // Clear LCD
  lcd.setCursor(0, 0);                     // Set cursor to top left
  lcd.print("MENU");                       // Print "MENU" header
  lcd.setCursor(0, 1);                     // Move to second line
  lcd.print(menuIndex == 0 ? "-> SPEED" : "-> HARNESS"); // Show selected menu item
}

bool buttonPressed(int pin) {
  if (digitalRead(pin) == LOW && (millis() - lastDebounceTime) > debounceDelay) {
    lastDebounceTime = millis();           // Update debounce timer
    return true;                           // Return true if button is pressed
  }
```

```
  return false;                              // Otherwise return false
}

void handleSpeedMode() {
  static unsigned long lastEncoderMoveTime = 0;       // Time of last encoder input
  static bool speedDisplayed = false;                 // Tracks if speed was already shown
  const unsigned long displayDelay = 1000;            // Wait time before showing speed
  const float speedStep = 0.05;
  float linearSpeed;
  int currentCLKState = digitalRead(encoderCLK); // Read encoder CLK

  if (currentCLKState != lastCLKState) {
    if (digitalRead(encoderDT) != currentCLKState) {
      treadmillSpeed += treadmillIncrement; // Increase speed
      // displaySpeed += speedStep;
    } else {
      treadmillSpeed -= treadmillIncrement; // Decrease speed
      // displaySpeed -= speedStep;
    }

    treadmillSpeed = constrain(treadmillSpeed, 0, maxSpeed); // Gauge speed value
    treadmill.setSpeed(-treadmillSpeed);    // Set treadmill speed (negative for direction)
    // displaySpeed = constrain(displaySpeed, 0, 0.80);

    // Calculate RPM and linear speed
     float rpm = (abs(treadmillSpeed) * 60.0) / 400.0; // Assuming 400 steps per revolution
     linearSpeed = (rpm * 0.0762 * PI) / 60.0;   // Convert RPM to m/s
    Serial.println(linearSpeed);

    lastCLKState = currentCLKState;         // Update CLK state
    lastEncoderMoveTime = millis();                   // Reset last movement time
    speedDisplayed = false;                          // Reset display flag
  }

  treadmill.runSpeed();                     // Run treadmill

    eButtonState = digitalRead(emergencyButton);

  if (eButtonState == HIGH) {
    eButtonPressed = false;
  }
    if (eButtonState == HIGH ) {
    eStopProcedure();
```

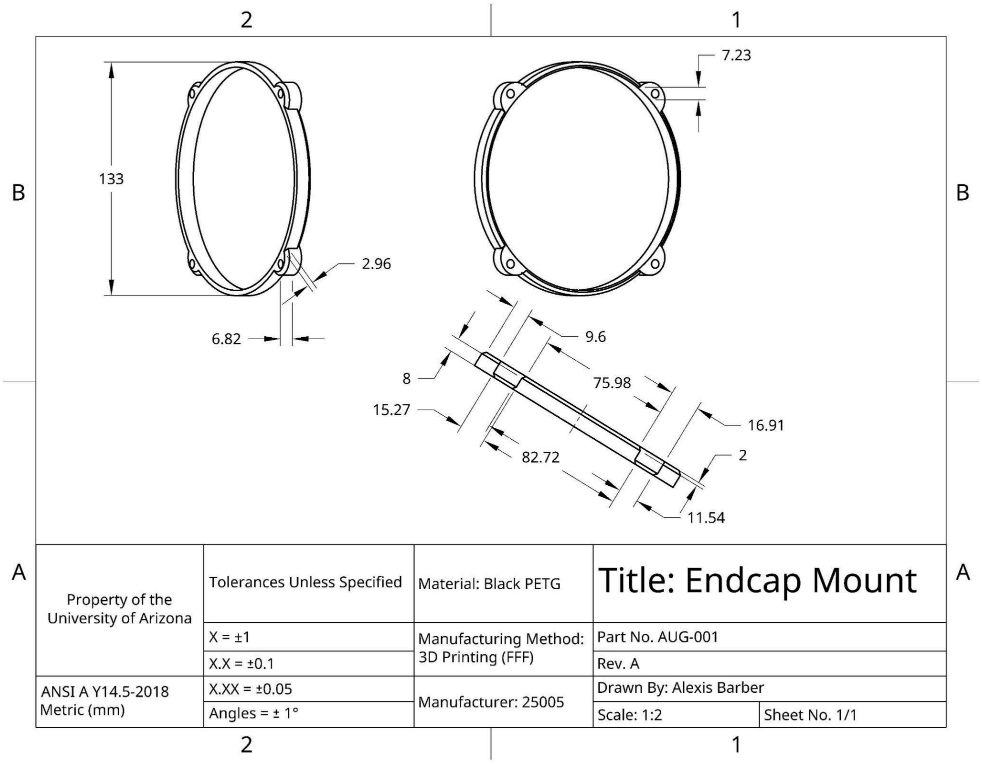
```
    }

  if ((millis() - lastEncoderMoveTime > displayDelay) && !speedDisplayed) {
    lcd.setCursor(0, 1);                        // Second row of LCD
    lcd.print("Speed: ");
    lcd.print(linearSpeed, 2);          // Display speed in user units
    lcd.print(" m/s     ");                     // Fill/clear line
    speedDisplayed = true;                      // Prevent re-print
  }
  if (treadmillSpeed == 0) {
    if (buttonPressed(rotaryButton)) returnToMenu(); // Return to menu if button pressed
  }
}

void eStopProcedure() {
    eButtonPressed = true; // Set emergency stop flag

    // Start harness movement *without blocking execution*
    harness.setMaxSpeed(800);              // Set maximum speed for harness motor
    harness.setAcceleration(300);          // Set acceleration for harness motor

    harness.moveTo(harness.currentPosition() - 200); // Move harness 200 steps backward

    // Keep treadmill & auger running during stepper movement
    treadmill.setAcceleration(300);        // Set treadmill acceleration

    int currentTreadmillSpeed = treadmillSpeed; // Store current treadmill speed locally

    treadmill.setSpeed(-currentTreadmillSpeed); // Start treadmill in reverse at current speed

    // Timing-based gradual deceleration while stepper is moving
    unsigned long lastUpdate = millis();    // Record the current time
    int decelStep = 10;                    // Amount to decrease speed per step
    int updateInterval = 30;               // Time interval between deceleration steps (ms)
    int augDec = 20;                       // Unused variable for auger deceleration

    // While treadmill is still running or harness hasn't finished moving
    while ((currentTreadmillSpeed > 0 ) || harness.distanceToGo() != 0) {
        if (millis() - lastUpdate >= updateInterval) { // Time to update?
            lastUpdate = millis();                 // Reset last update time

            if (currentTreadmillSpeed > 0) {         // If treadmill is still running
                currentTreadmillSpeed = max(0, currentTreadmillSpeed - decelStep); // Gradually slow down
```

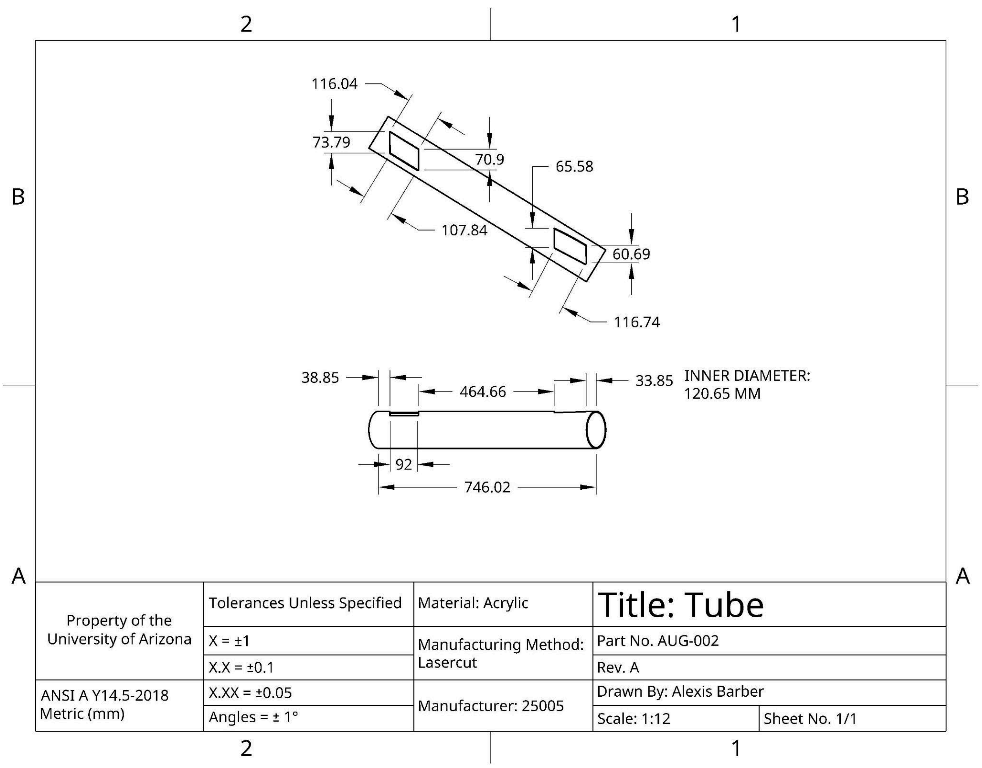
```
            treadmill.setSpeed(-currentTreadmillSpeed); // Apply new speed
          }
        }

        // Keep all motors running while decelerating & moving stepper
        treadmill.runSpeed();        // Keep treadmill stepping
        harness.run();               // Keep harness stepping (non-blocking)
    }

    // Ensure all motors fully stop
    treadmill.setSpeed(0);           // Stop treadmill
    treadmill.runSpeed();            // Apply 0 speed to stop stepper motion

    harness.moveTo(harness.currentPosition() + 200); // Return harness to original position
    while (harness.distanceToGo() != 0) {            // Wait until return move is complete
        harness.run();                               // Continue moving harness
    }

    Serial.println("EMERGENCY STOP COMPLETE - ENTERING LOW POWER MODE"); // Notify
over serial

    lcd.clear();                     // Clear LCD screen
    lcd.setCursor(0, 0);             // Set LCD cursor to first row
    lcd.print("SYSTEM SHUTDOWN");    // Display shutdown message
    lcd.setCursor(0, 1);             // Set LCD cursor to second row
    lcd.print("RESTART REQUIRED");   // Display restart notice

    delay(5000);                     // Pause 5 seconds before sleep
    esp_sleep_enable_ext0_wakeup(GPIO_NUM_0, 0); // Enable external wakeup on GPIO 0
    esp_deep_sleep_start();          // Enter deep sleep mode
}

void handleHarnessMode() {
  eButtonState = digitalRead(emergencyButton); // Read emergency button
  if (eButtonState == HIGH) eButtonPressed = false; // Reset emergency flag if not pressed

  if (digitalRead(clockwiseButton) == LOW) {
    harness.setSpeed(200);           // Set harness speed CW
    harness.runSpeed();              // Run harness motor
  } else if (digitalRead(counterclockwiseButton) == LOW) {
    harness.setSpeed(-200);          // Set harness speed CCW
    harness.runSpeed();              // Run harness motor
  } else {
```

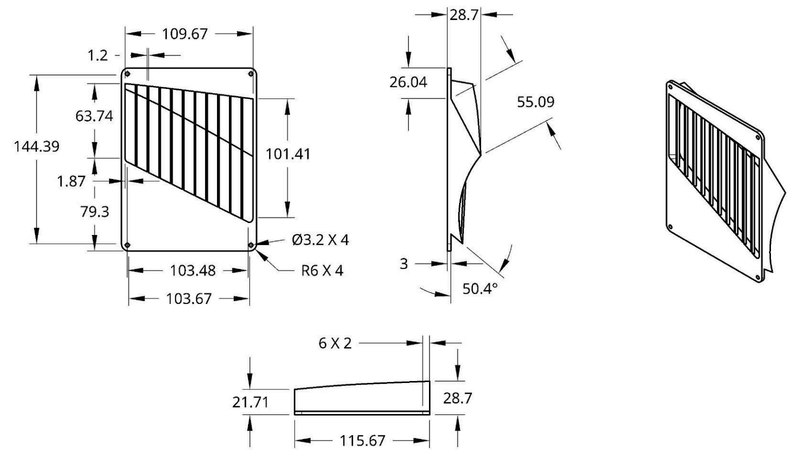
```
    harness.setSpeed(0);                  // Stop harness motor
  }

  harness.runSpeed();                     // Ensure harness motor runs at current speed
}

void returnToMenu() {
  currentMode = MENU;                     // Switch mode to menu
  buttonReleaseGuard = true;              // Enable guard to prevent immediate reentry
  buttonReleaseTime = millis();           // Save time of return
  positionSaved = false;                  // Reset saved position flag
  eButtonPressed = false;                 // Reset emergency button flag
  lcd.clear();                            // Clear LCD
  displayMenu();                          // Show menu
  Serial.println("Returned to MENU");     // Print to serial
}
```

Next are the Auger Drawings. They are part of the original design but are not used in the final system They are included for reference.

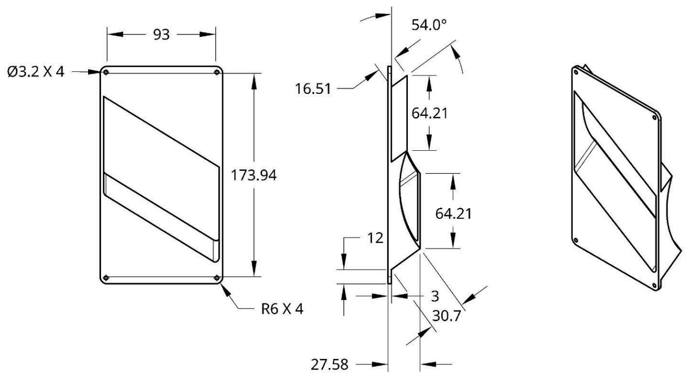
6.2 Auger Part Drawings (Deprecated Due to Change in Design)



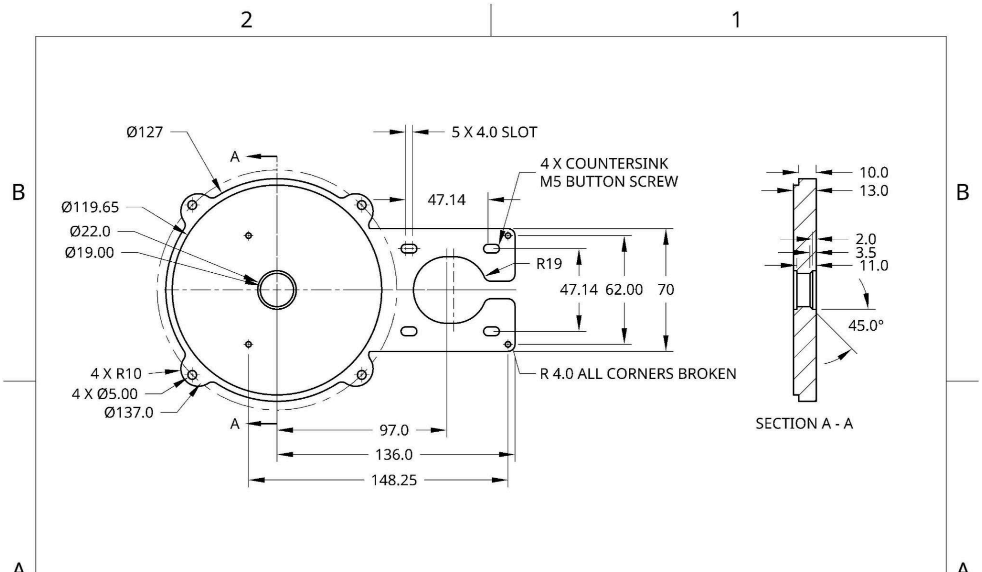




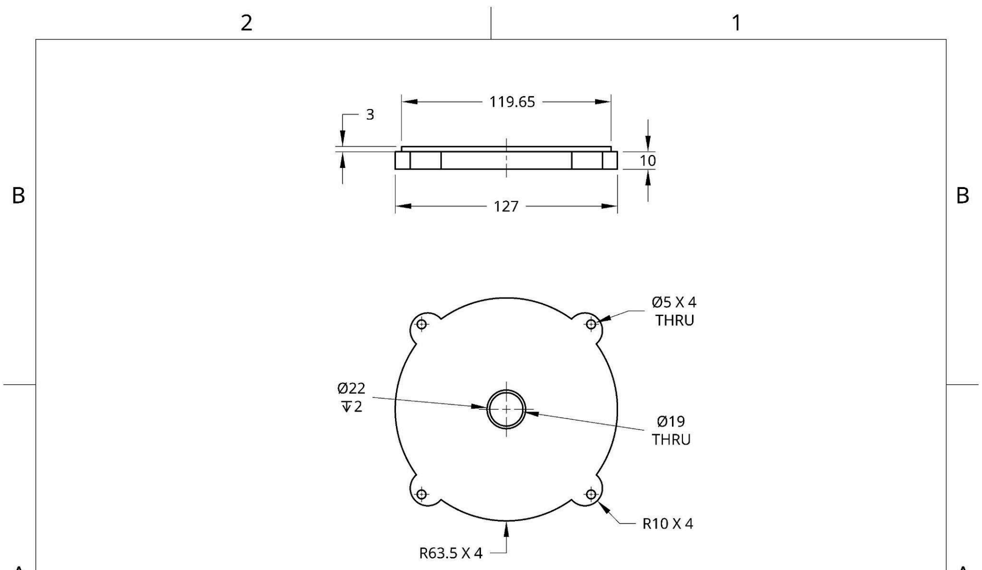
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Lower Hopper Auger Side
	X = ±1	Manufacturing Method: 3D Printed (FFF)	Part No. AUG-003
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:3 — Sheet No. 1/1



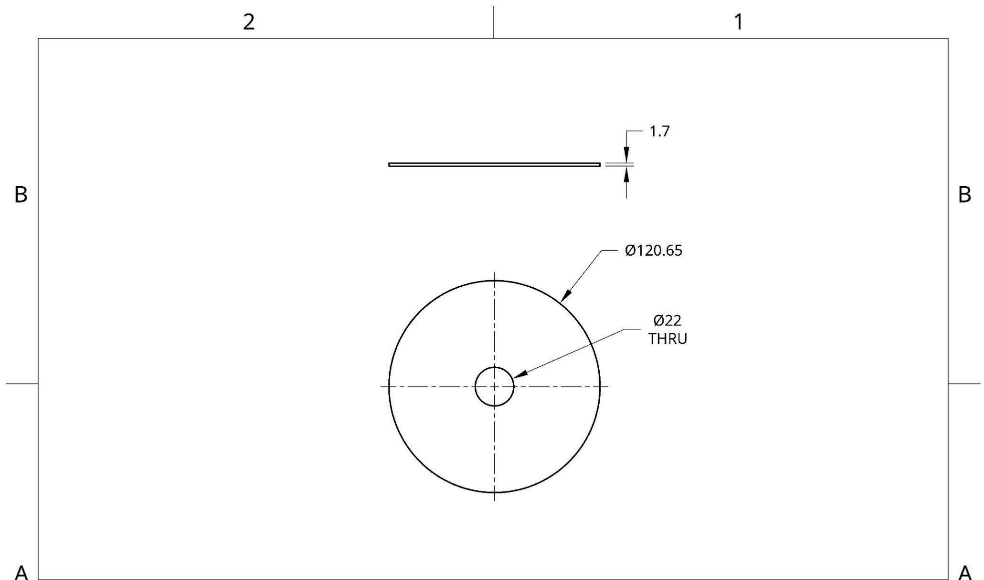
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Upper Hopper Auger Side
	X = ±1	Manufacturing Method: 3D Printed (FFF)	Part No. AUG-004
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:3 — Sheet No. 1/1



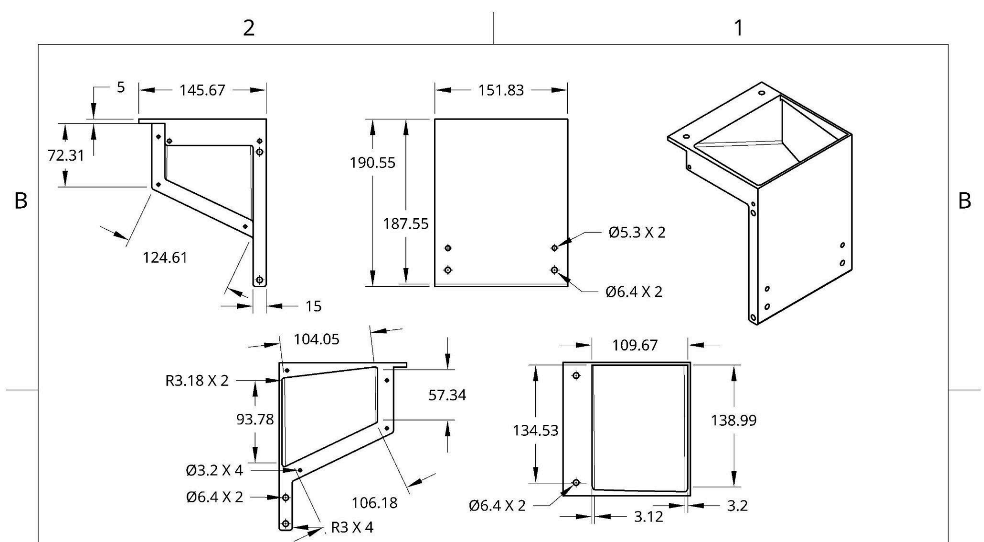
Property of the University of Arizona	Tolerances Unless Specified	Material: CF Nylon	Title: End Cap M	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-005	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Gabe Vogt	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



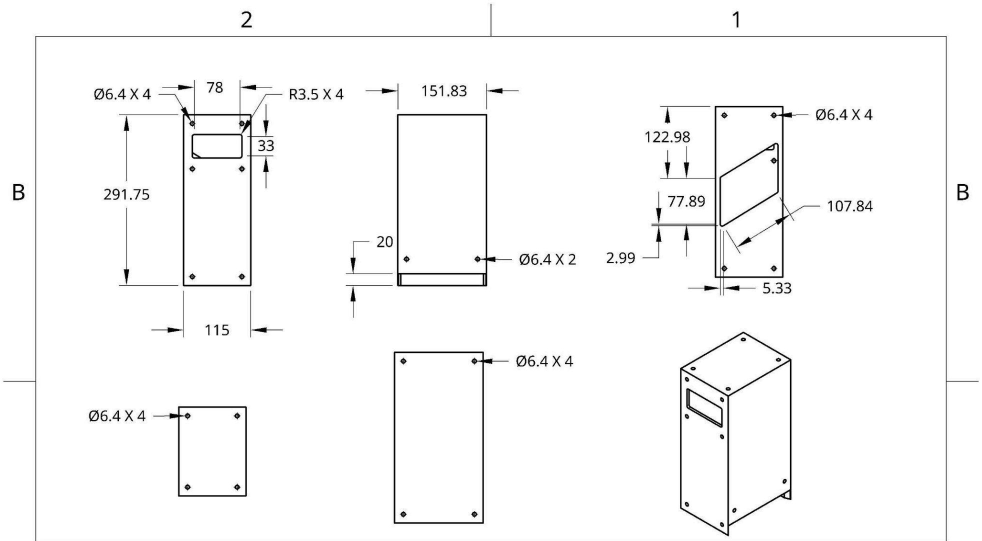
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: End Cap	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-006	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



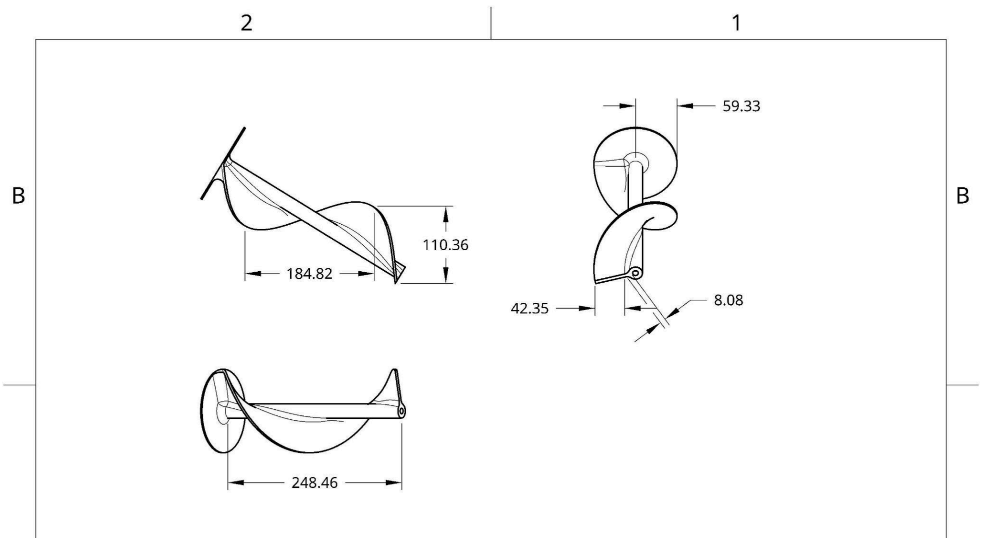
Property of the University of Arizona	Tolerances Unless Specified	Material: Felt	Title: Motor Felt
	X = ±1	Manufacturing Method: Purchased	Part No. AUG-007
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:2 — Sheet No. 1/1



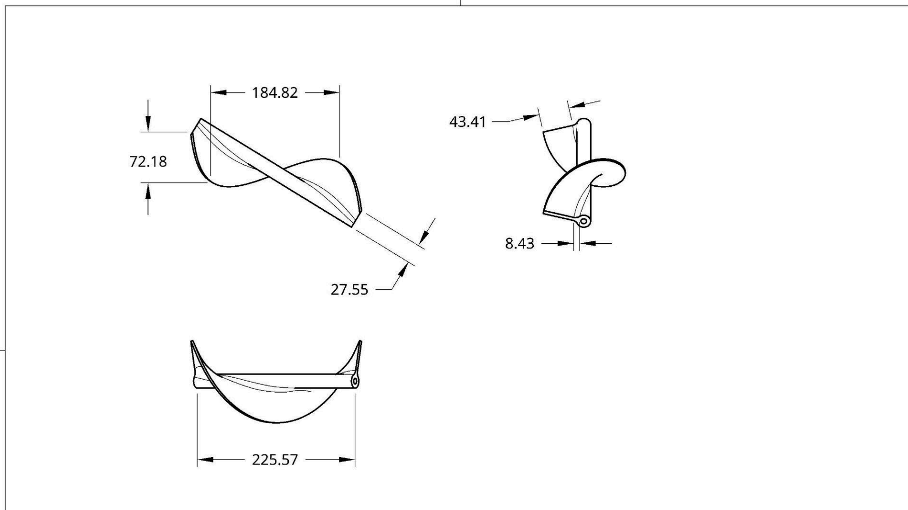
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Lower Hopper Enclosed Side
	X = ±1	Manufacturing Method: 3D Printed (FFF)	Part No. AUG-008
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:3 — Sheet No. 1/1



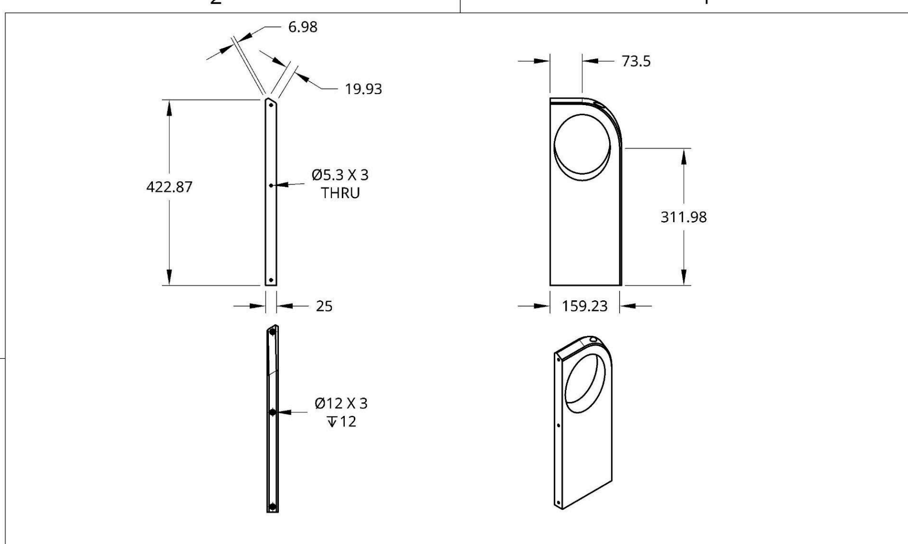
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Upper Hopper Enclosed Side	
	X = ±1	Manufacturing Method: 3D Printed (FFF)	Part No. AUG-009	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:6	Sheet No. 1/1



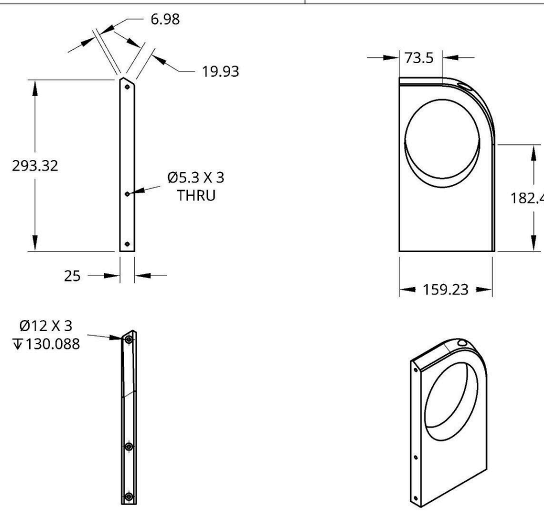
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Screw Ends	
	X = ±1	Manufacturing Method: 3D Prtinting (FFF)	Part No. AUG-011	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:5	Sheet No. 1/1



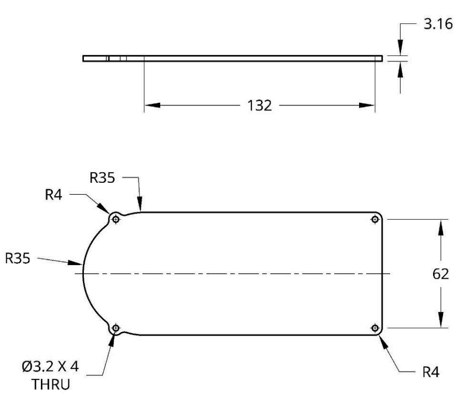
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Screw Middle	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-013	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:5	Sheet No. 1/1



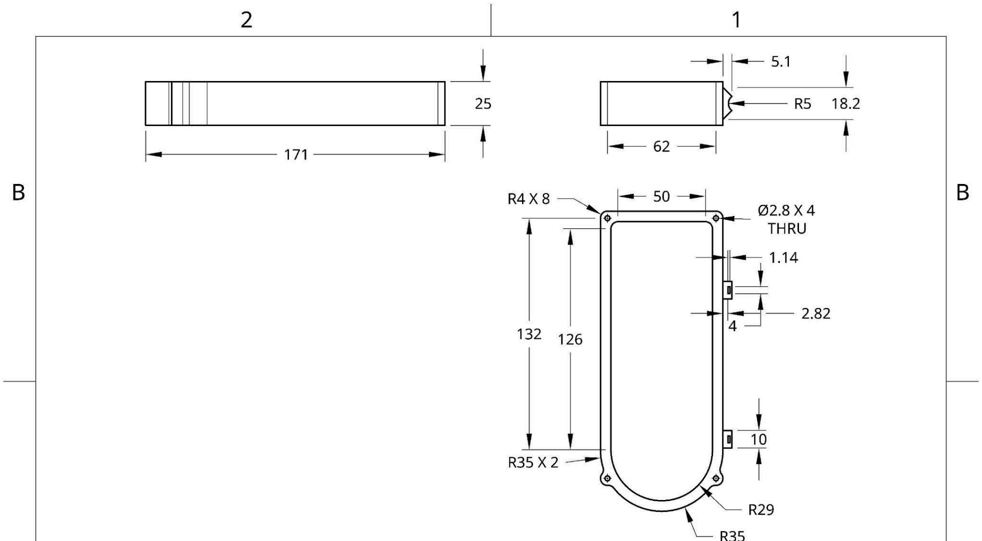
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Tall Stand	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-014	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:8	Sheet No. 1/1



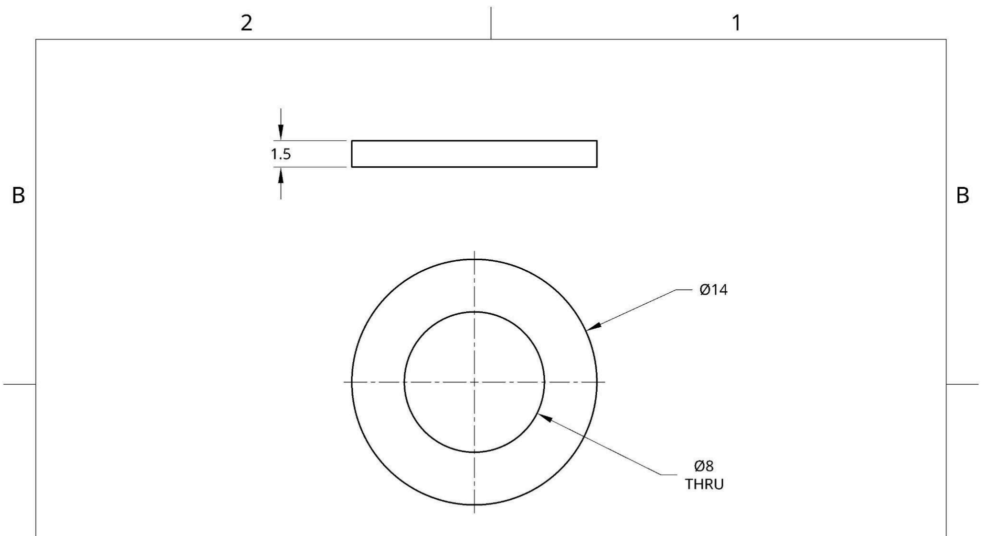
Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Short Stand	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-015	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:6	Sheet No. 1/1



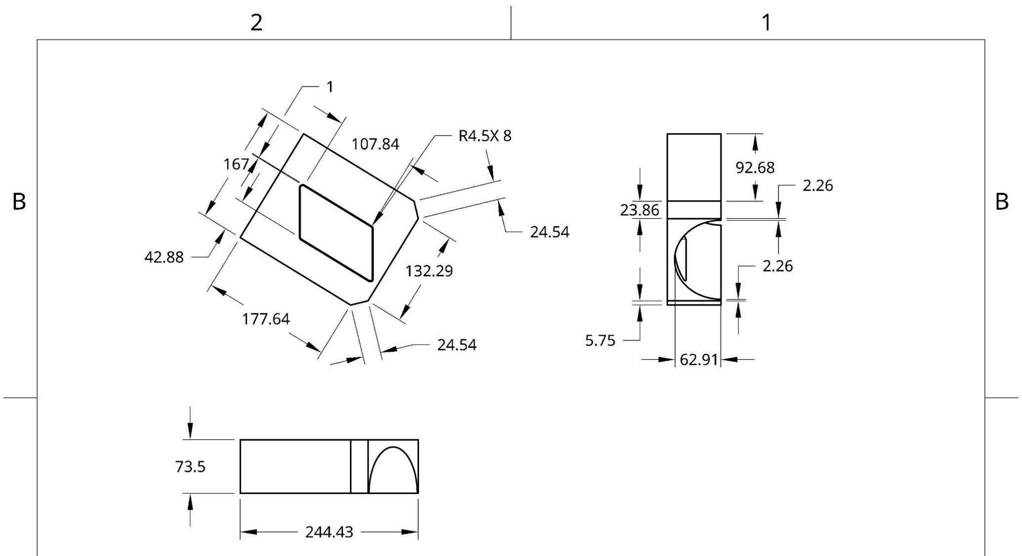
Property of the University of Arizona	Tolerances Unless Specified	Material: Acrylic	Title: Motor Endcap Acrylic Cover	
	X = ±1	Manufacturing Method: Lasercut	Part No. AUG-016	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Motor Endcap Cover	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-017	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 1:2	Sheet No. 1/1

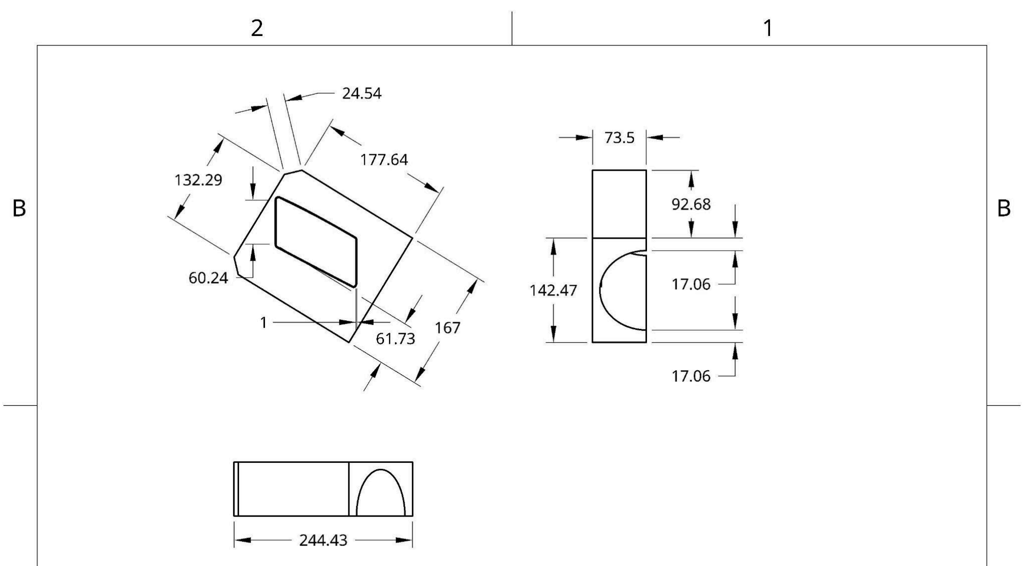


Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	Title: Motor Side Seal Washer	
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-018	
	X.X = ±0.1		Rev. A	
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber	
	Angles = ± 1°		Scale: 5:1	Sheet No. 1/1



Property of the University of Arizona	Tolerances Unless Specified	Material: PETG	Title: Tube Support Upper
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-019
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:5 / Sheet No. 1/1

2 1



Property of the University of Arizona	Tolerances Unless Specified	Material: PETG	Title: Tube Support Lower
	X = ±1	Manufacturing Method: 3D Printing (FFF)	Part No. AUG-020
	X.X = ±0.1		Rev. A
ANSI A Y14.5-2018 Metric (mm)	X.XX = ±0.05	Manufacturer: 25005	Drawn By: Alexis Barber
	Angles = ± 1°		Scale: 1:5 / Sheet No. 1/1

2 1