

Technical Data Package - Intermediate

Project 25005: Treadmill with Soft Ambulatory Surface

Revision: B
March 4, 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 for those 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 to ensure the safety of the rat 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 regolith.

2.0 System Description & Block Diagram

Our system consists of seven subsystems: 1.1 Auger, 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 Auger: The auger subsystem is an archimedes screw in a tube that recirculates the aggregate back into the treadmill subsystem to be spread across the treadmill belt.

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.

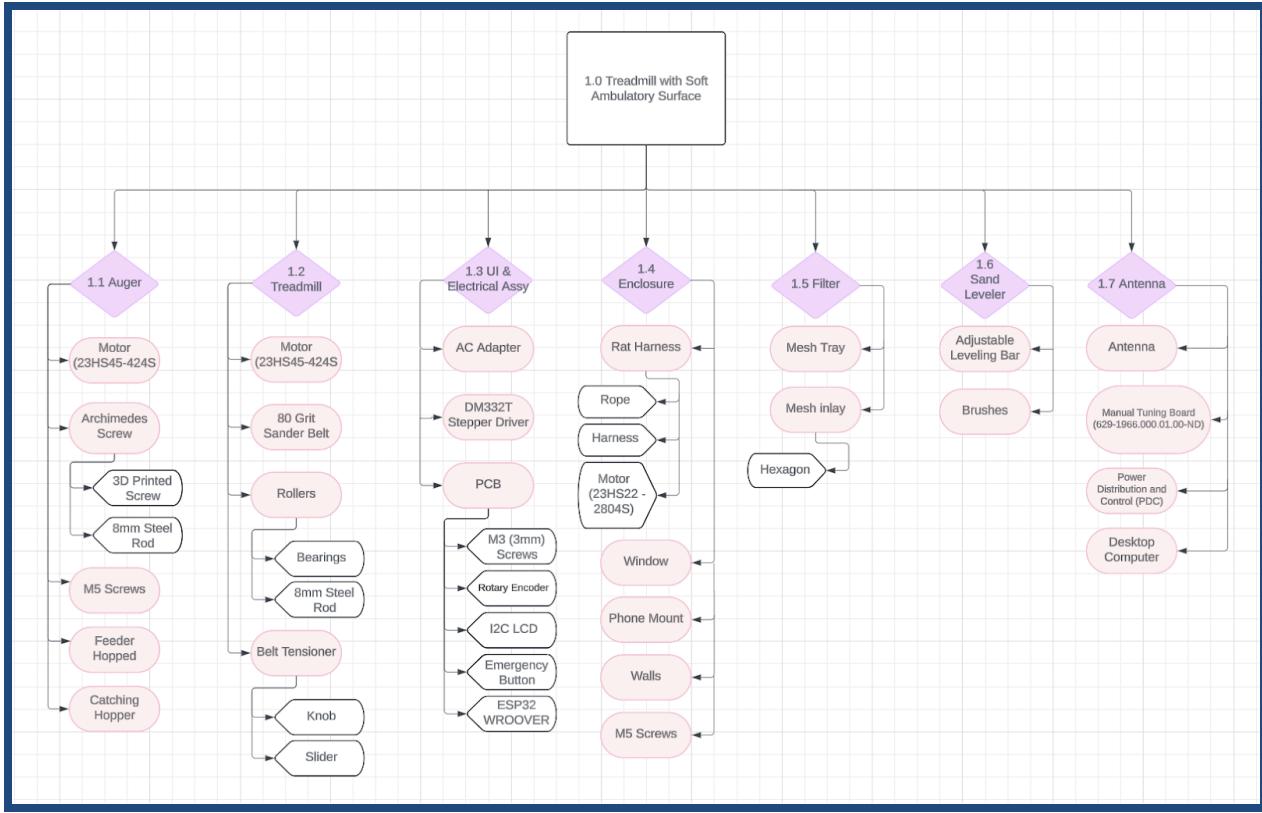
1.4 Enclosure: The enclosure in the area that can be viewed through a window to be potentially recorded. Includes the space above the treadmill and the rat harness/pulley parts.

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.

Block Diagram



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

Efficiency:

4.1.1: Due 4/01/2025 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				X
4.1.2 The sand layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters	X		X		
4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.	X	X			

Performance:

4.2.1: Finished 11/1/2024, Passed. 4.2.2: Finished 1/28/2025, Passed. 4.2.3 Due 03/27/2025

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		X		
4.2.2 The enclosure shall have an antenna that is within range of the rat to collect data	X		X	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		X	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		X	

Usability:

4.4.2: Due 4/01/2025

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	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 B

Last updated: 3/3/2025

Legend for indicating the 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		

Treadmill System:

<input type="checkbox"/> Driver Roller:	TRD-001
<input type="checkbox"/> Idler Roller:	TRD-002
<input type="checkbox"/> Leveling Bar:	TRD-003
<input type="checkbox"/> Treadmill Motor Thread Bracket	TRD-004
<input type="checkbox"/> Roller Spacer	TRD-005
<input type="checkbox"/> Idler Roller Grooved	TRD-006
<input type="checkbox"/> Driver Roller Grooved	TRD-007

Auger System:

<input type="checkbox"/> End Cap Mount 2x	AUG-001
<input type="checkbox"/> Acrylic Tube:	AUG-002
<input type="checkbox"/> Lower Hopper Auger Side	AUG-003
<input type="checkbox"/> Upper Hopper Auger Side	AUG-004
<input type="checkbox"/> End Cap M	AUG-005
<input type="checkbox"/> End Cap	AUG-006
<input type="checkbox"/> Motor Felt 2x	AUG-007
<input type="checkbox"/> Lower Hopper Enclosed Side	AUG-008
<input type="checkbox"/> Upper Hopper Enclosed Side	AUG-009
<input type="checkbox"/> Aggregate Collector	AUG-010
<input type="checkbox"/> Screw Ends 2x	AUG-011
<input type="checkbox"/> Screw 8mm Rod	AUG-012
<input type="checkbox"/> Screw Middle	AUG-013
<input type="checkbox"/> Tall Stand	AUG-014
<input type="checkbox"/> Short Stand	AUG-015
<input type="checkbox"/> Motor Endcap Acrylic Cover	AUG-016
<input type="checkbox"/> Motor Endcap Cover	AUG-017
<input type="checkbox"/> Motor Side Seal Washer	AUG-018
<input type="checkbox"/> Tube Support Upper	AUG-019
<input type="checkbox"/> Tube Support Lower	AUG-020

Electrical System:

<input type="checkbox"/> Treadmill Motor	ELC-001
<input type="checkbox"/> Auger Motor	ELC-002
<input type="checkbox"/> Harness Motor	ELC-003
<input type="checkbox"/> Freenove ESP32 Wroom	ELC-004
<input type="checkbox"/> Emergency Stop Button	ELC-005
<input type="checkbox"/> Stepper Motor Drivers	ELC-006
<input type="checkbox"/> I2C LCD	ELC-007
<input type="checkbox"/> Rotary Encoder	ELC-008
<input type="checkbox"/> AC Female adapter	ELC-009
<input type="checkbox"/> Rocker Switch	ELC-010
<input type="checkbox"/> Timer Button	ELC-011
<input type="checkbox"/> Antenna Amplifier Board	ELC-012
<input type="checkbox"/> Antenna	ELC-013

 Filter System:

<input type="checkbox"/> Filter Housing:	FIL-001
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 Enclosure System:

<input type="checkbox"/> Front Panel:	ENC-001
<input type="checkbox"/> Left Panel:	ENC-002
<input type="checkbox"/> Right Lower Panel:	ENC-003
<input type="checkbox"/> Back Panel:	ENC-004
<input type="checkbox"/> Top Panel:	ENC-005
<input type="checkbox"/> Bottom Panel:	ENC-006
<input type="checkbox"/> Front Window:	ENC-007
<input type="checkbox"/> Treadmill Base UHMW HDPE	ENC-008
<input type="checkbox"/> Screen Holder	ENC-009
<input type="checkbox"/> Treadmill Base ½in Al Angle	ENC-010
<input type="checkbox"/> Treadmill Motor Cover	ENC-011
<input type="checkbox"/> Treadmill Motor Cover Flat	ENC-012
<input type="checkbox"/> Top Center Reinforcement	ENC-013
<input type="checkbox"/> Motor Side Reinforcement	ENC-014
<input type="checkbox"/> Center Reinforcement	ENC-015

<input type="checkbox"/> Idler Side Reinforcement	ENC-016
<input type="checkbox"/> Left Side Reinforcement	ENC-017
<input type="checkbox"/> Mid Panel	ENC-018
<input type="checkbox"/> Knob	ENC-019
<input type="checkbox"/> Handle	ENC-020
<input type="checkbox"/> Door	ENC-021
<input type="checkbox"/> Hinge Part 1	ENC-022
<input type="checkbox"/> Hinge Part 2	ENC-023
<input type="checkbox"/> Door Latch Part 1	ENC-024
<input type="checkbox"/> Door Latch Part 2	ENC-025
<input type="checkbox"/> Tensioner Part 1	ENC-026
<input type="checkbox"/> Tensioner Part 2	ENC-027
<input type="checkbox"/> Tensioner Part 3	ENC-028
<input type="checkbox"/> Winch Motor Mount	ENC-029
<input type="checkbox"/> Basement Reinforcement Part 1	ENC-030
<input type="checkbox"/> Basement Reinforcement Part 2	ENC-031
<input type="checkbox"/> Foot Part 1	ENC-032
<input type="checkbox"/> Foot Part 2	ENC-033
<input type="checkbox"/> Aggregate Loader	ENC-034
<input type="checkbox"/> Cable Anchor	ENC-035
<input type="checkbox"/> Right Antenna Surface	ENC-036

Purchased Parts:

<input type="checkbox"/> Treadmill Belt:	PUR-001
<input type="checkbox"/> Rat Harness:	PUR-002
<input type="checkbox"/> 57155K512_Stainless Steel Ball Bearing	PUR-003
<input type="checkbox"/> Winch pulley (enclosure)	PUR-004
<input type="checkbox"/> 9307K876_Buna-N Rubber Grommets	PUR-005
<input type="checkbox"/> 23HS22-2804S	PUR-006
<input type="checkbox"/> 8mm Rod Part 1	PUR-007
<input type="checkbox"/> 8mm Rod Part 2	PUR-008
<input type="checkbox"/> 8mm Rod	PUR-009
<input type="checkbox"/> M5 10mm 92095A208_NO THREADS_Button Head Hex Drive Screw	PUR-010
<input type="checkbox"/> M5 8mm 92095A207_NO THREADS_Button Head Hex Drive Screw	PUR-011
<input type="checkbox"/> M5 15mm 92095A127_NO THREADS_Button Head Hex Drive Screw	PUR-012
<input type="checkbox"/> 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 Insert 94180A323_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

4.2 System Requirements Document

System Requirements

Project 25005: Treadmill with Soft Ambulatory Surface

Version: C
March 04, 2025

Team Members:

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System Requirements

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7.0 Requirements Flowdown Traceability Table

8.0 Notes:

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

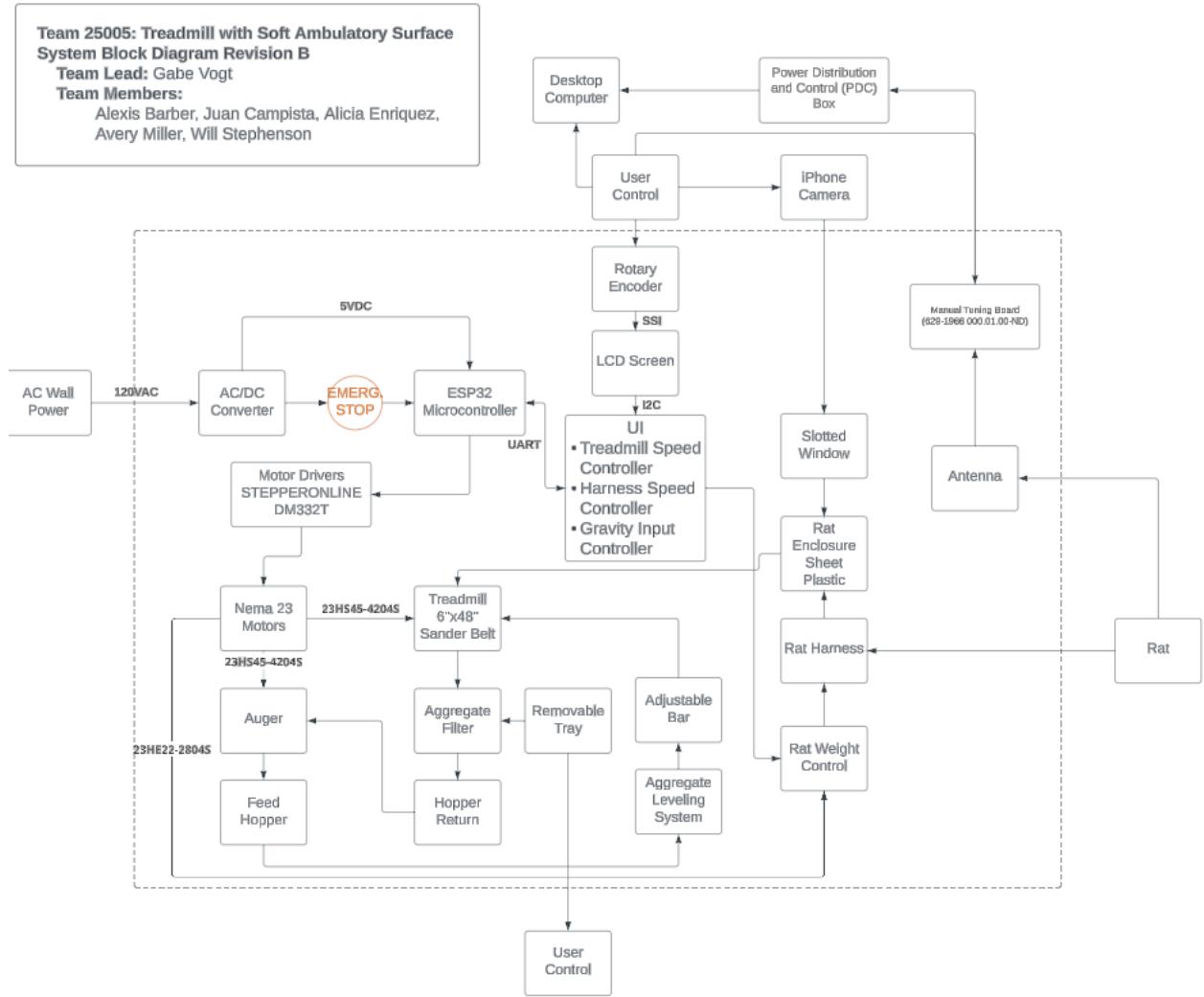
4.4.1 UI Simplicity: The user interface shall be simple to use and react upon input.

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.



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 $\pm 2\text{mm}$ 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 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 75 pounds.

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			X
6.1.2	The sand layer thickness shall be 12 millimeters with a range of plus or minus 2 millimeters	X		X	
6.1.3	The enclosure shall have a hanging harness that can hold 1kg of weight.	X	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		X	
6.2.2	The enclosure shall have an antenna that is within range of the rat to collect data	X		X	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		X	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		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	X
6.4.2 The treadmill shall weigh less than 75 pounds	X			
6.4.3 The enclosure shall be less than 26x63x26in 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		X	

7.0 Requirements Flowdown Traceability Table

System Requirements	SubSystems					
	1.1 Auger	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 auger must work for the whole time the machine is performing an experimental test.	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-All location: The auger must run fast enough for the feeder hopper to be filled for the duration of running.	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	Test/Demonstration Derived: The auger shall stop redirecting aggregate onto the treadmill when the emergency stop function is implemented.	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.		

harness up from the face of the treadmill	implemented.					
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 auger must be as small as possible while still being able to transport the regolith fast and efficiently.	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 66.04x160.02 x66.04 cm	Inspection-Allocated: The auger must fit within the back part of the fume	Inspection-Allocated: The treadmill dimensions should be 56.515 x	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.	Inspection-Allocated: The filter will be large enough to be efficient but take up no more	Inspection-Allocation: The leveling must be the width of the treadmill for

(XYZ) in to fit inside the fume hood	Hood (160.02x20.32 x66.04 cm)	15.24 x 7.62 cm for efficient sizing.		04 cm of width, height, and depth respectively and have a space for the rat to be placed onto the treadmill	than 17.78 cm of depth which is included in the 40.64 cm of the front half.	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 Auger must power on, as displayed by the UI LCD.	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:

7.1 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.

7.2 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 have nine verification procedures that will need to be completed. 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 MVP2 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.

MVP2 Inspection Report Results: Testing the system weight did not occur during MVP2 as we are reassessing aggregate options, but has been given a due date of 04/01.

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.

MVP2 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.

MVP2 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.

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.

MVP2 Inspection Report Results: This acceptance test was performed with our full assembly, resulting in a pass. Steps after MVP2 include consulting with our sponsors to determine how many additional varieties of filters they would like and to conduct this test to account for liquid rat waste.

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.

MVP2 Inspection Report Results: This acceptance test was performed with our full assembly, resulting in a pass.

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.

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

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.

MVP2 Inspection Report Results: This acceptance test was performed, resulting in a pass. Steps after MVP2 include doing this test with our final assembly, as this is one of the most crucial requirements for our system.

1.8 Gravity Simulation Test

Equipment used: Arduino IDE, ESP32, Treadmill Assembly, Stepper Motor Stepper Motor (23HS22-2804S), Stepper Driver (DM332T), Harness, Paracord Emergency Stop Switch, Rotary Encoder, LCD Screen, Force Gauge, PCB.

Summarized Procedure: Turn on treadmill, verifying PCB and all parts mounted are working correctly. Secure rat replica into harness Use LCD for the visual indication of the treadmill menu and navigate to gravity settings. Here, choose the lunar gravity setting. When it adjusts, attach a force gauge to the harness to determine it is the actual gravity seen in the lunar simulation. Repeat for Martian gravity setting. If the force gauge reflects the gravity for both environment settings, this will result in a pass.

MVP2 Inspection Report Results: This test was not included in our MVP2, will be complete by 03/27.

1.9 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.

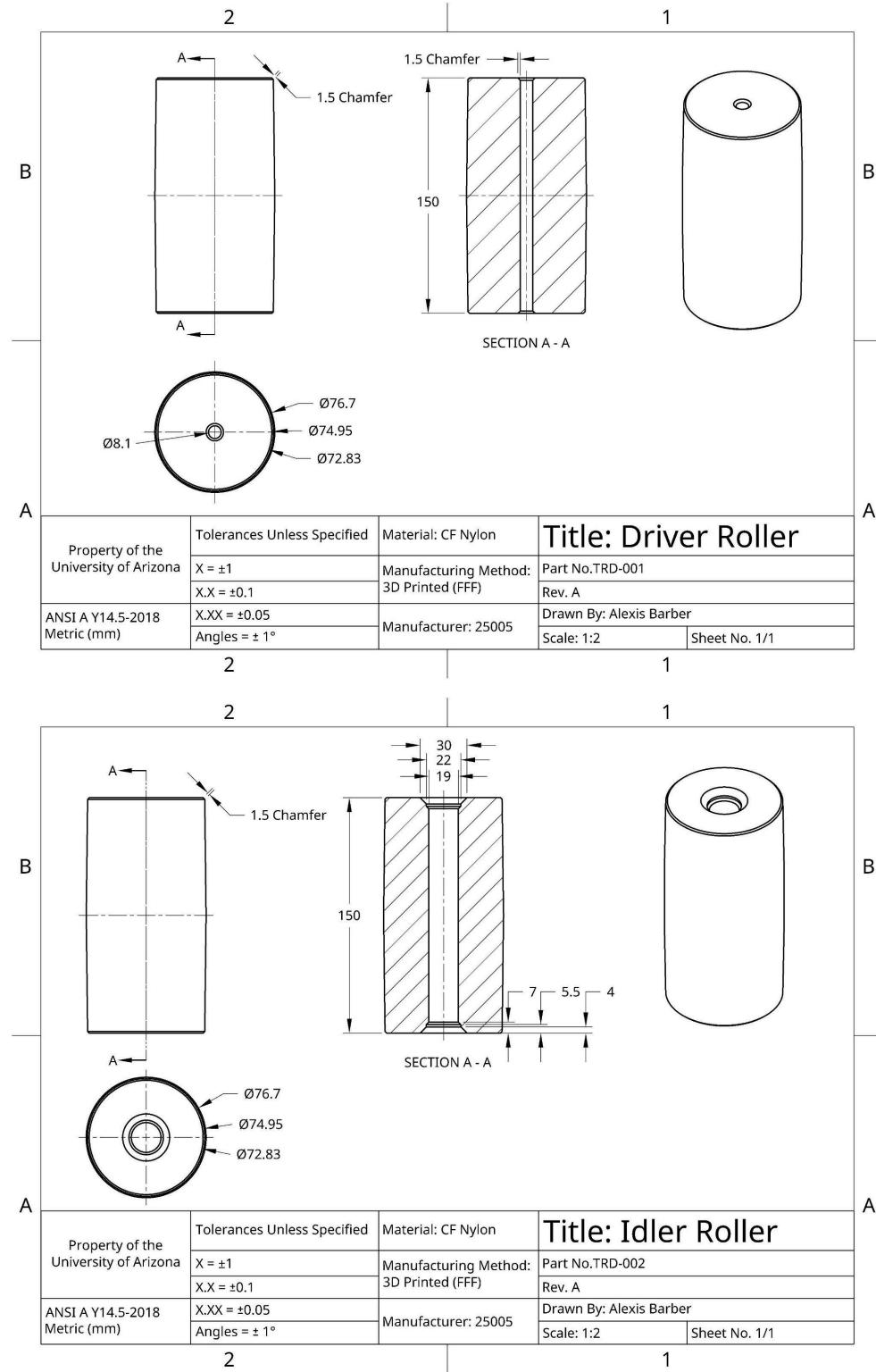
MVP2 Inspection Report Results: Testing the system weight did not occur during MVP2 as we are reassessing aggregate options, but has been given a due date of 04/01.

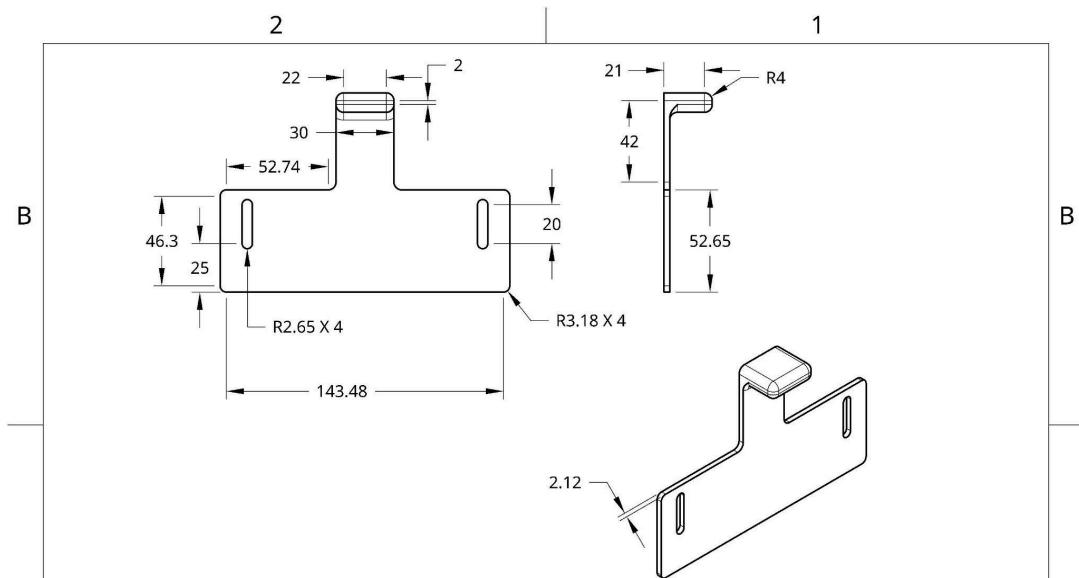
4.4 Hardware Drawing Package

Treadmill Ambulatory System Hardware Drawing Package	
Treadmill Ambulatory System (TAS) Hardware Drawing Package Team 25005	
Mar 4, 2025 REV B Prepared for UA Dept. of Biomedical Engineering	
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Section 1.0 - Mechanical Drawings <ul style="list-style-type: none">1.1 Treadmill Subsystem1.2 Auger Subsystem1.3 Filter Subsystem1.4 Enclosure Subsystem1.5 Antenna Subsystem Section 2.0 - Electrical Drawings <ul style="list-style-type: none">2.1 UI/Electrical Assembly Subsystem<ul style="list-style-type: none">2.2.1 Electrical Schematic2.2.2 PCB Layout	

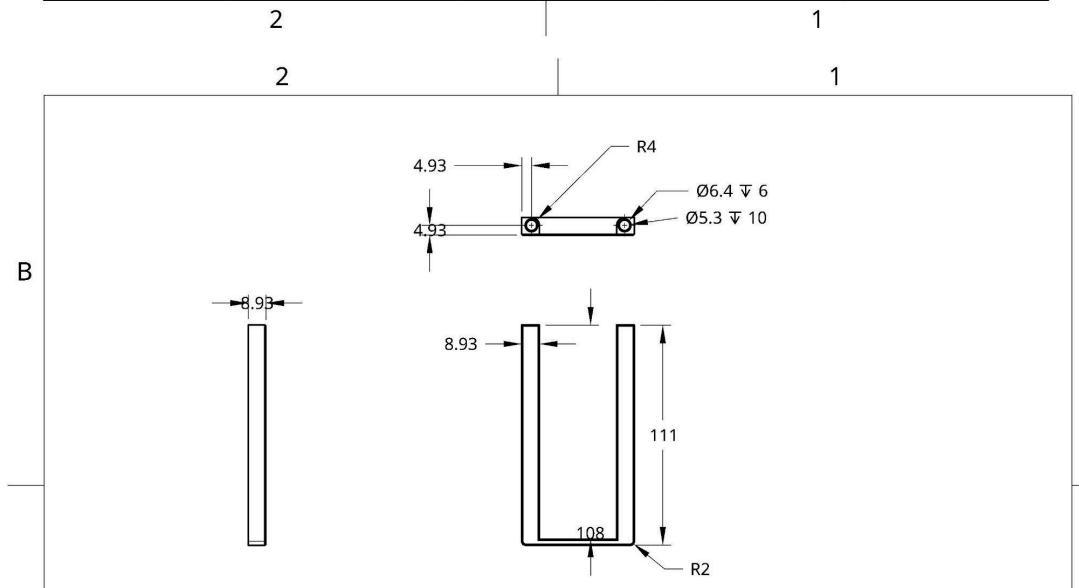
Section 1.0 – Mechanical Drawings

1.1 Treadmill Subsystem

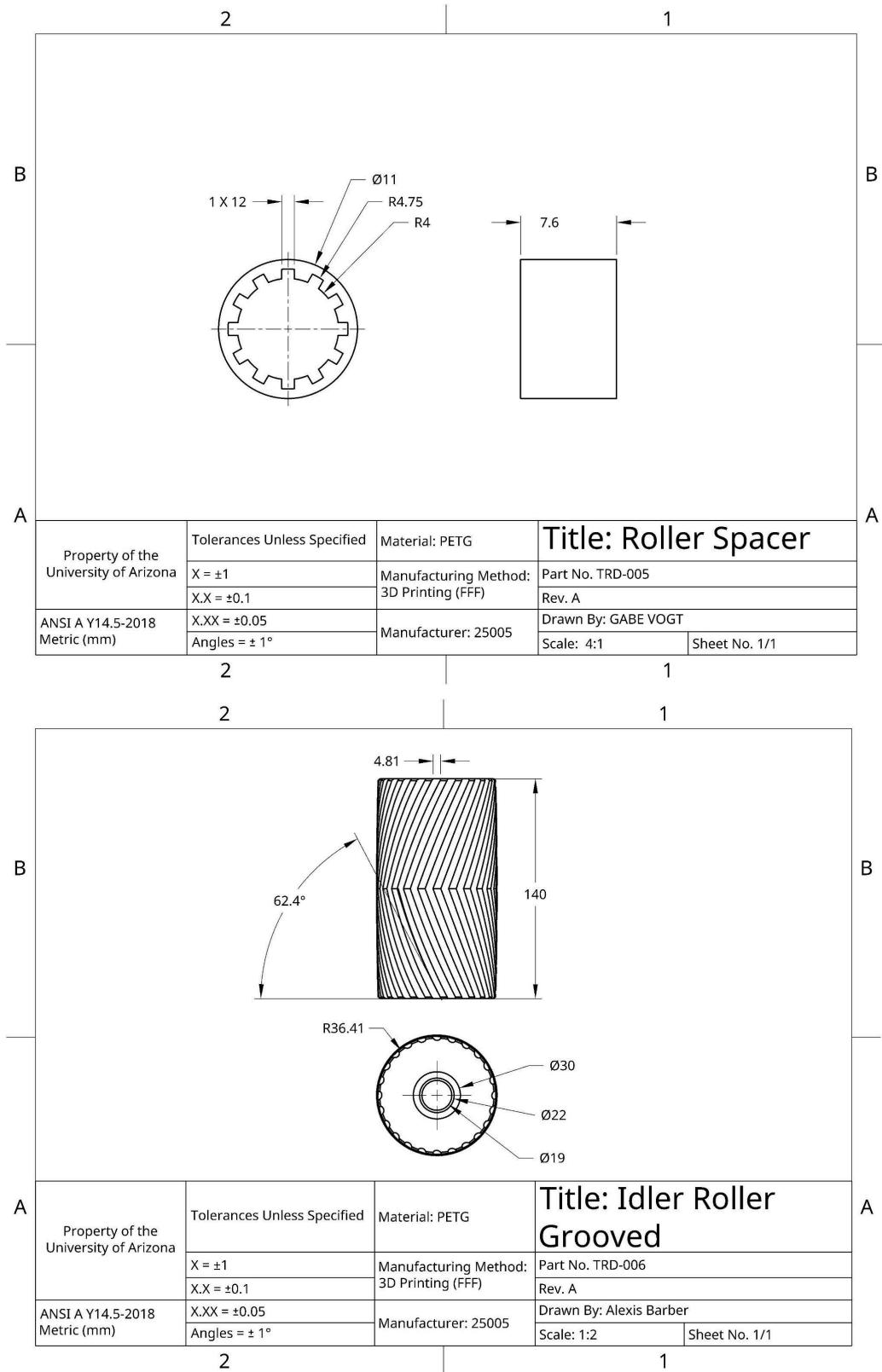


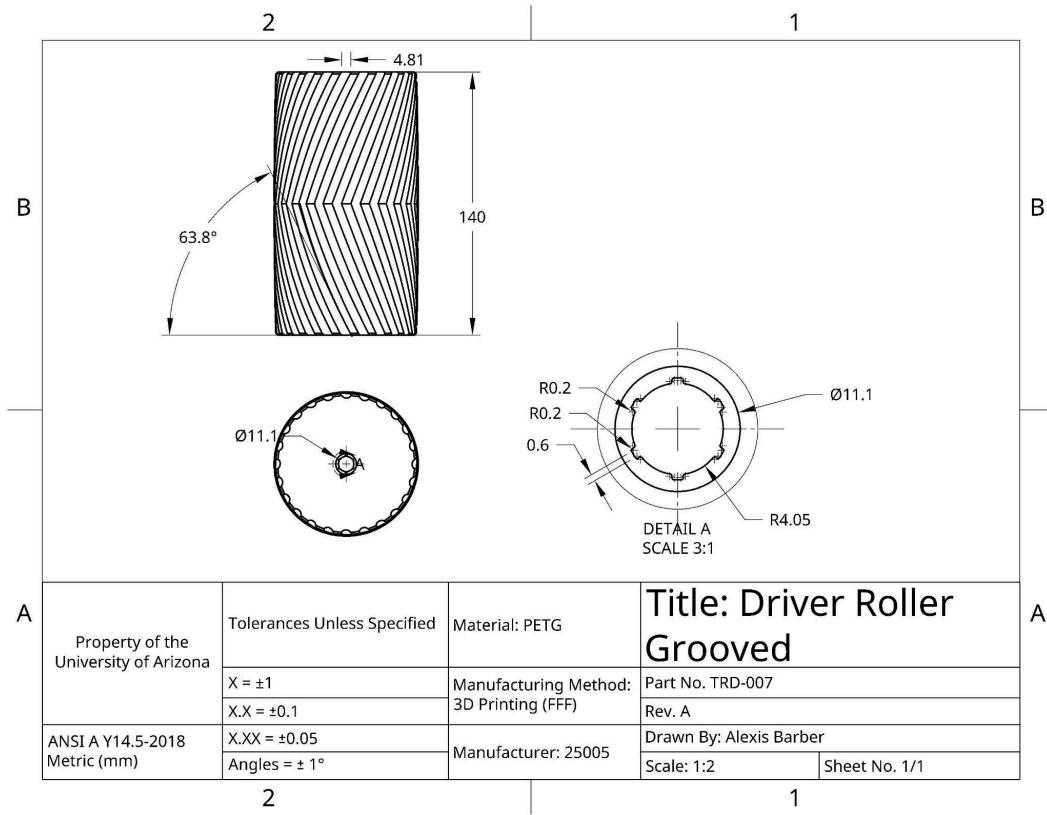


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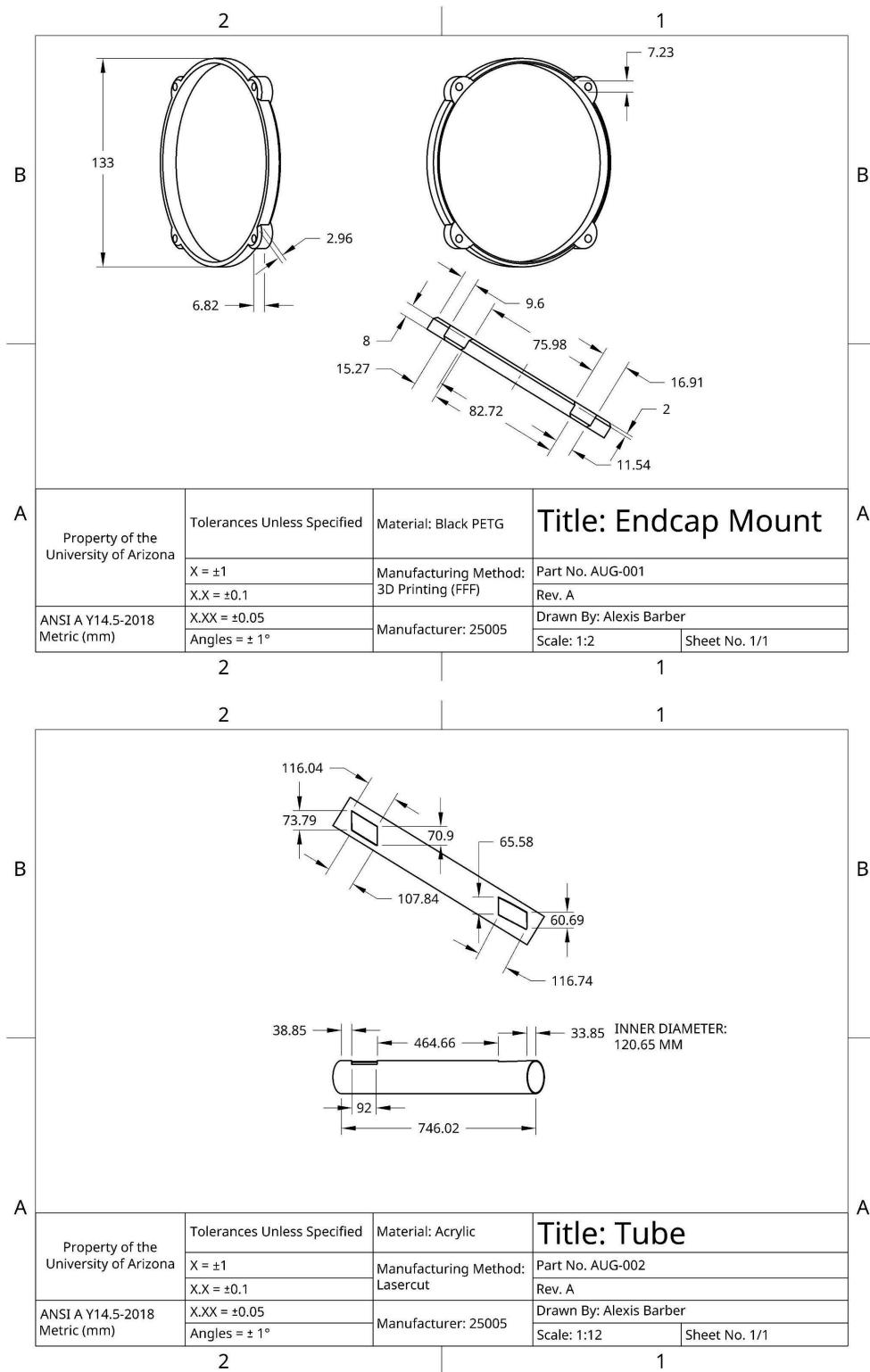


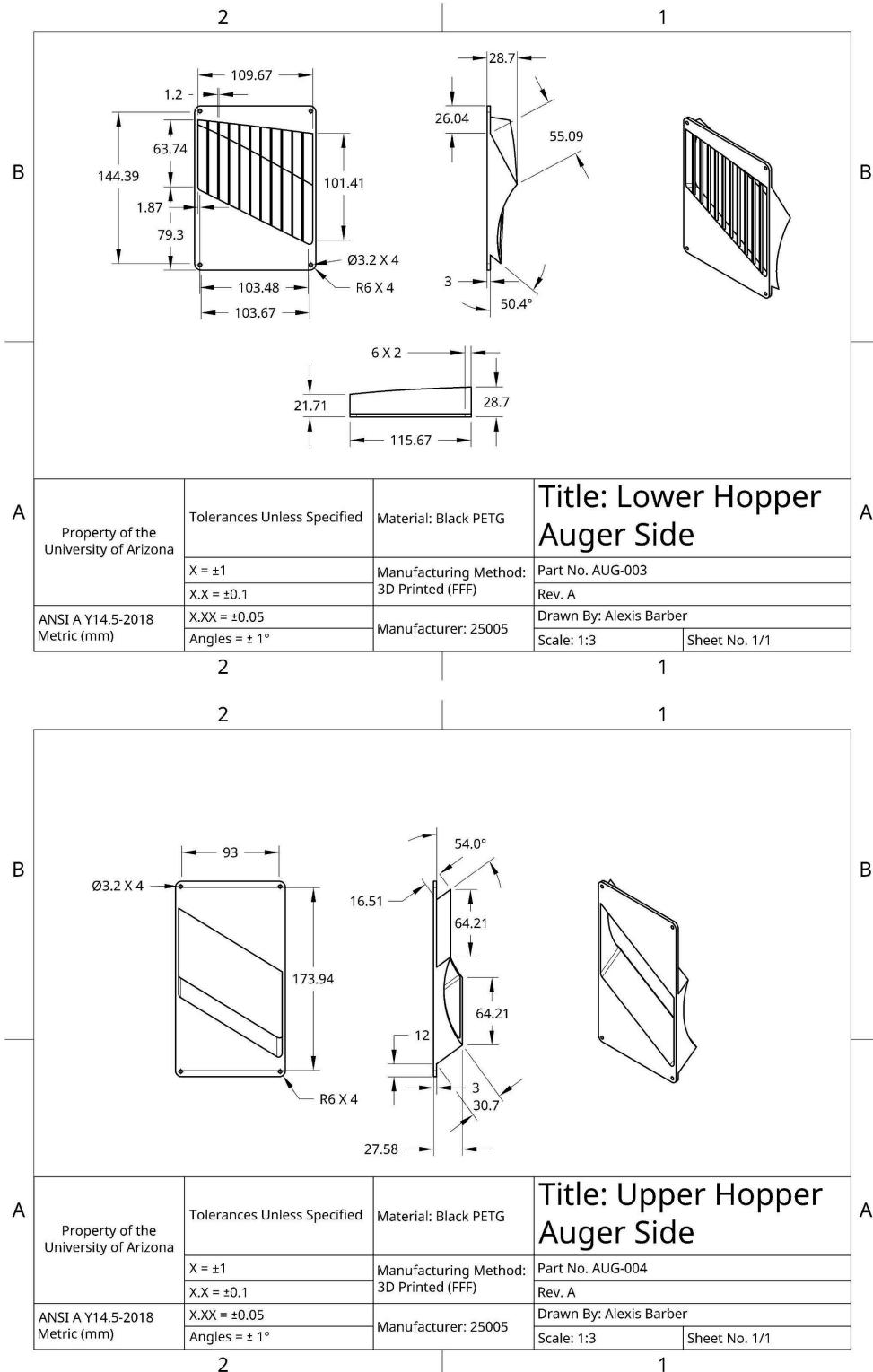
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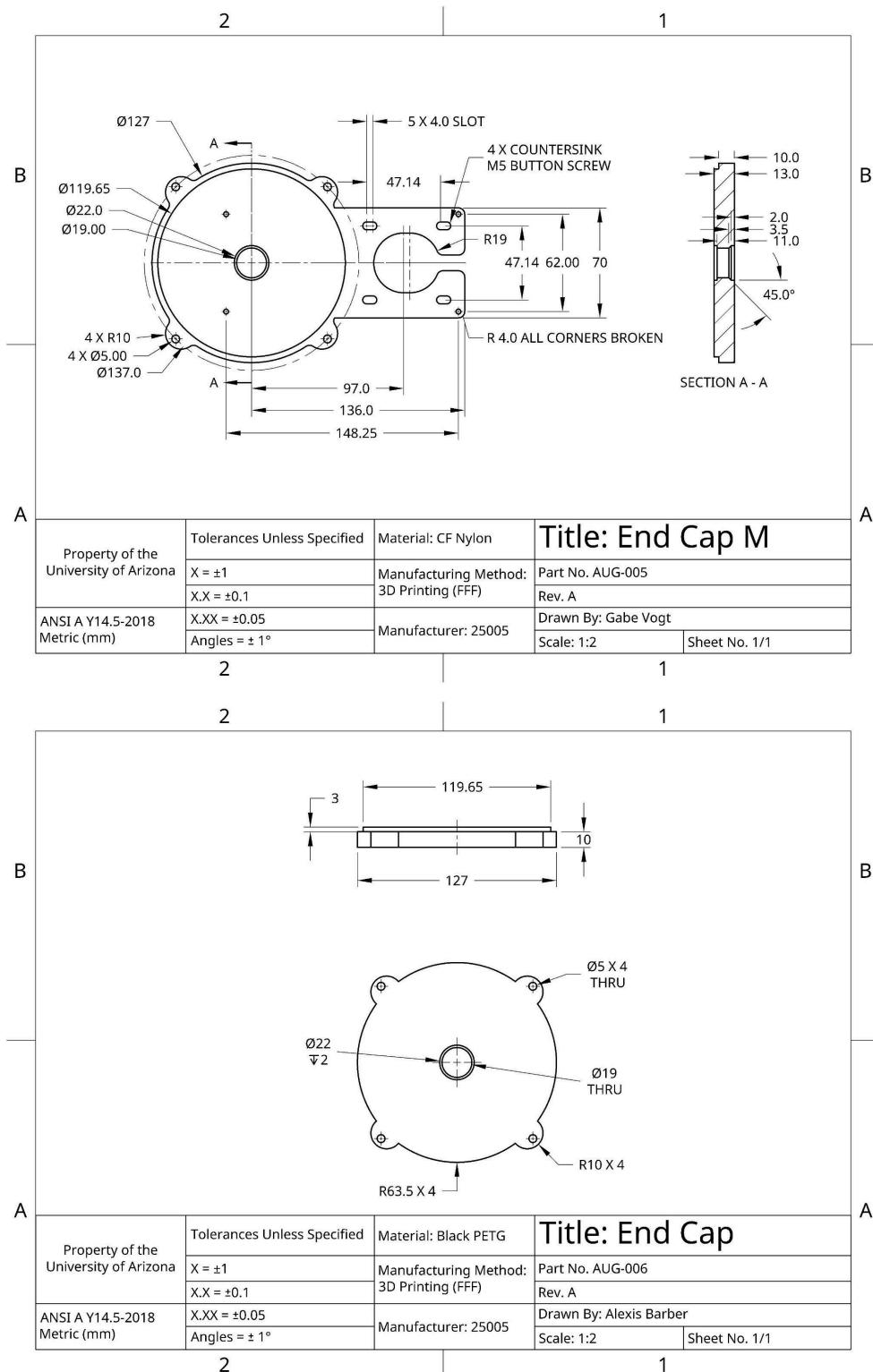


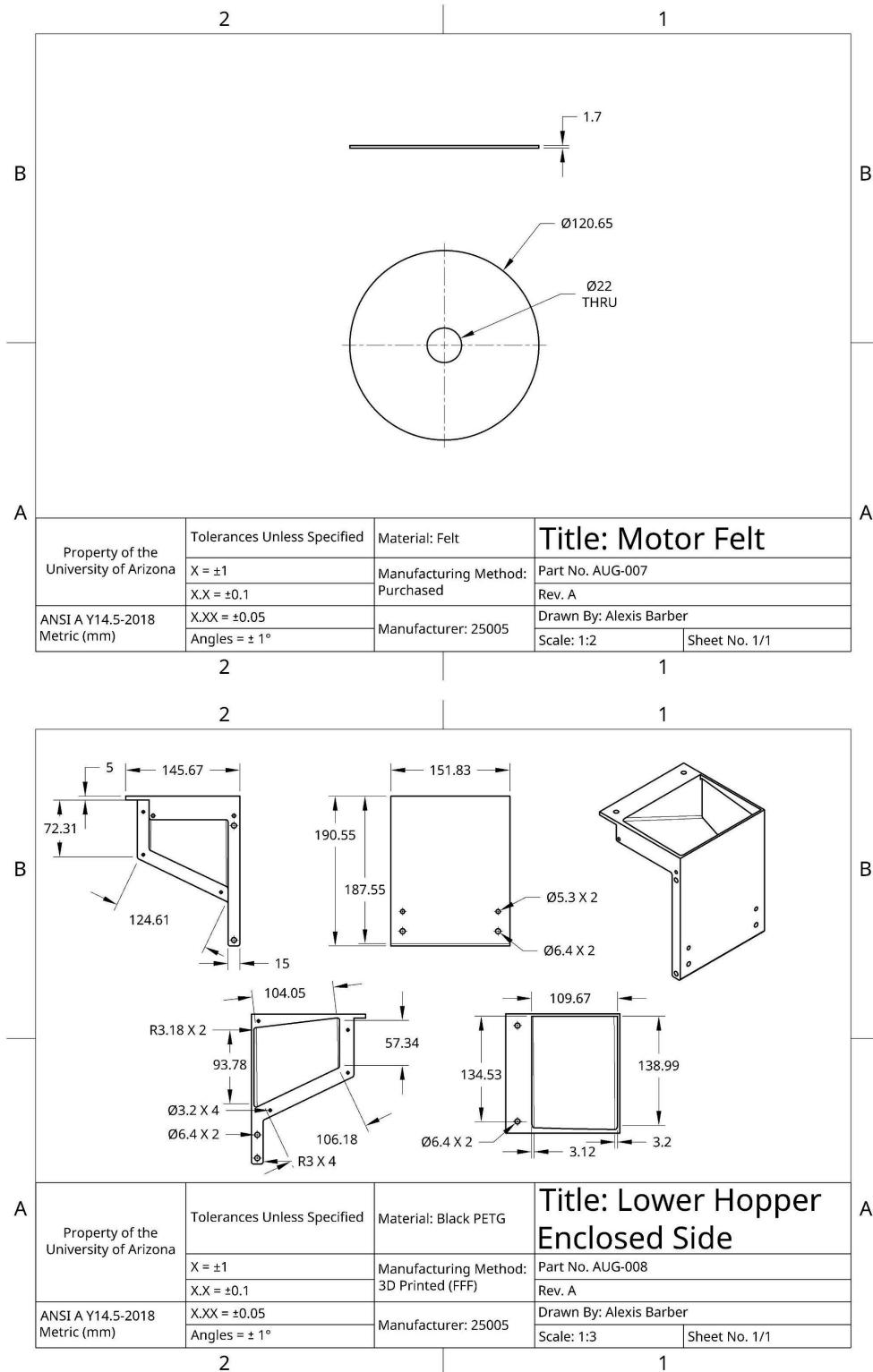


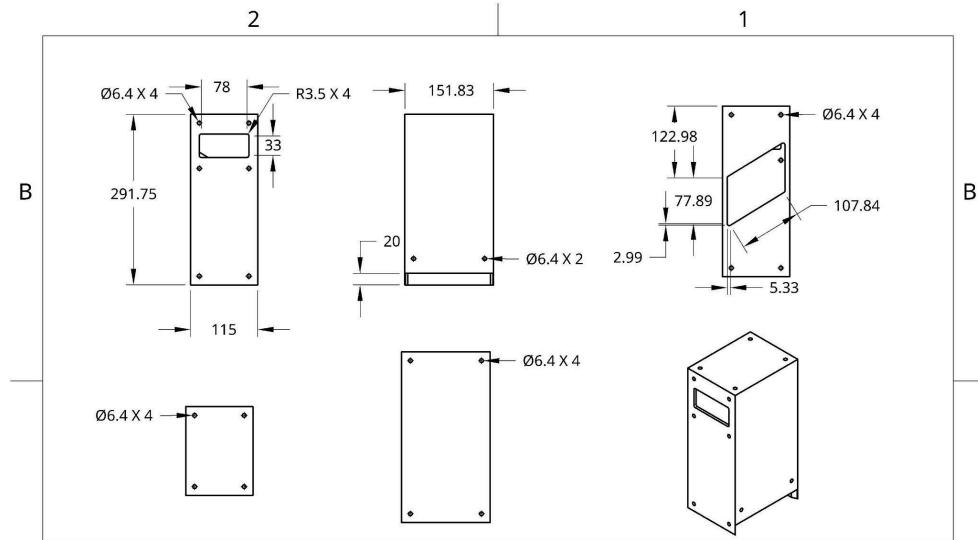
1.2 Auger Subsystem











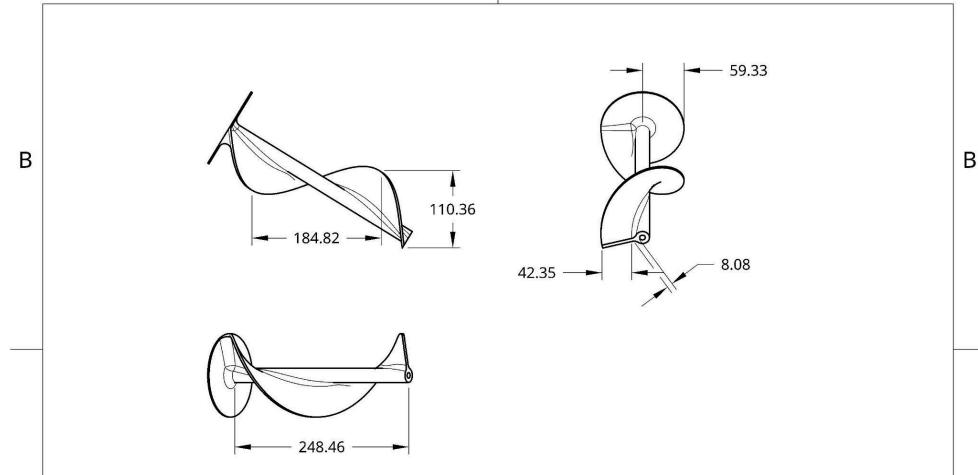
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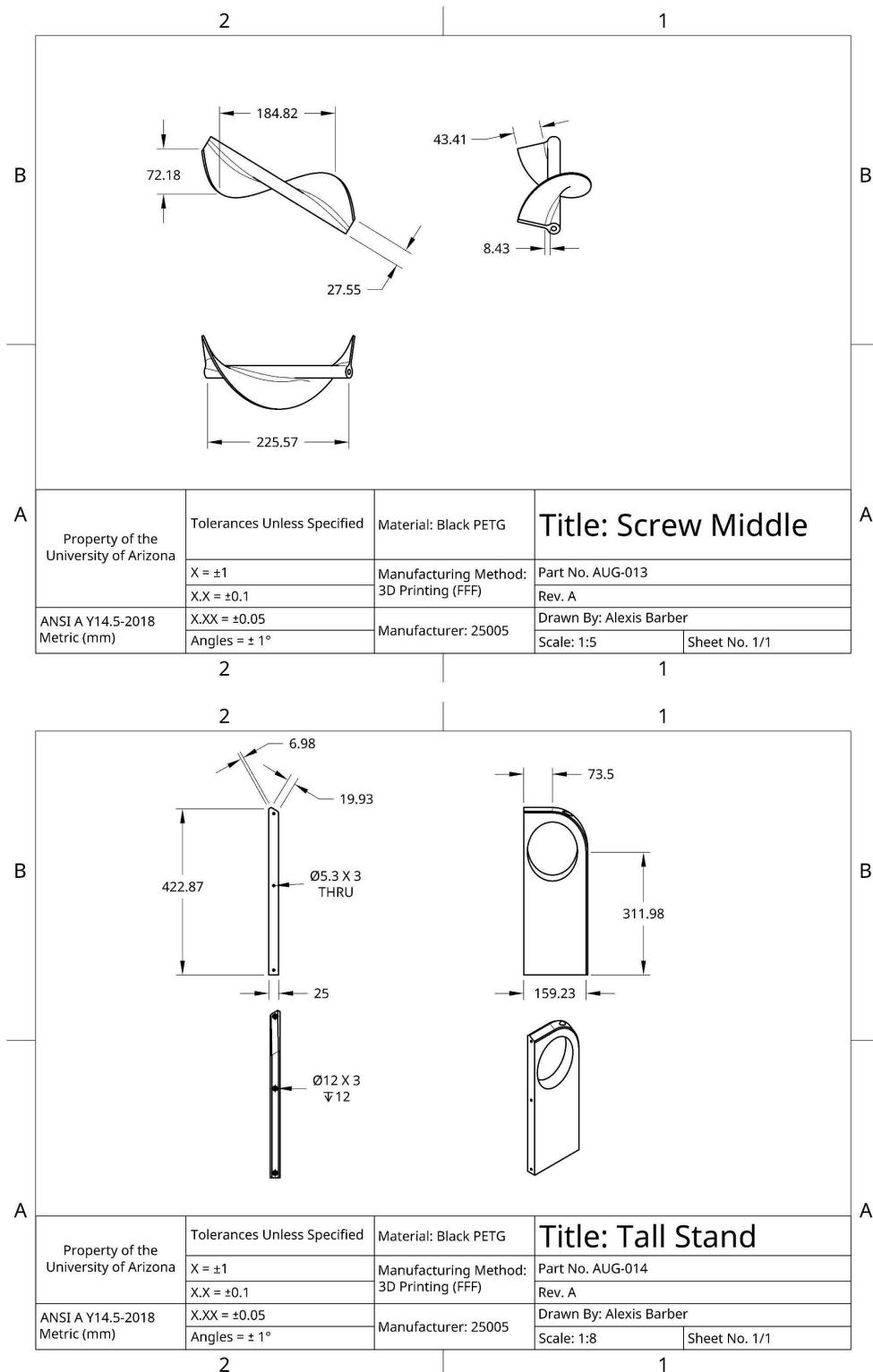
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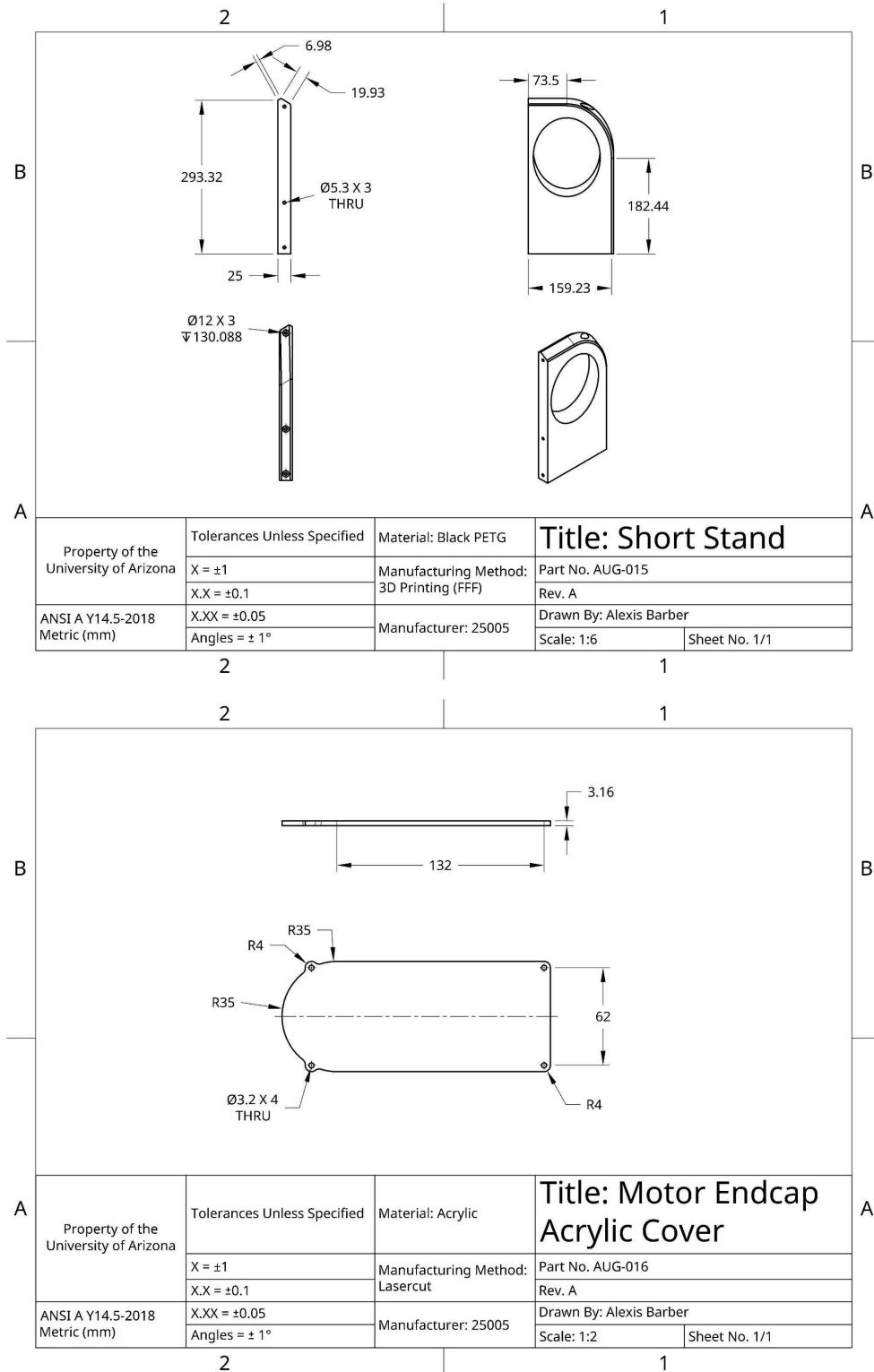


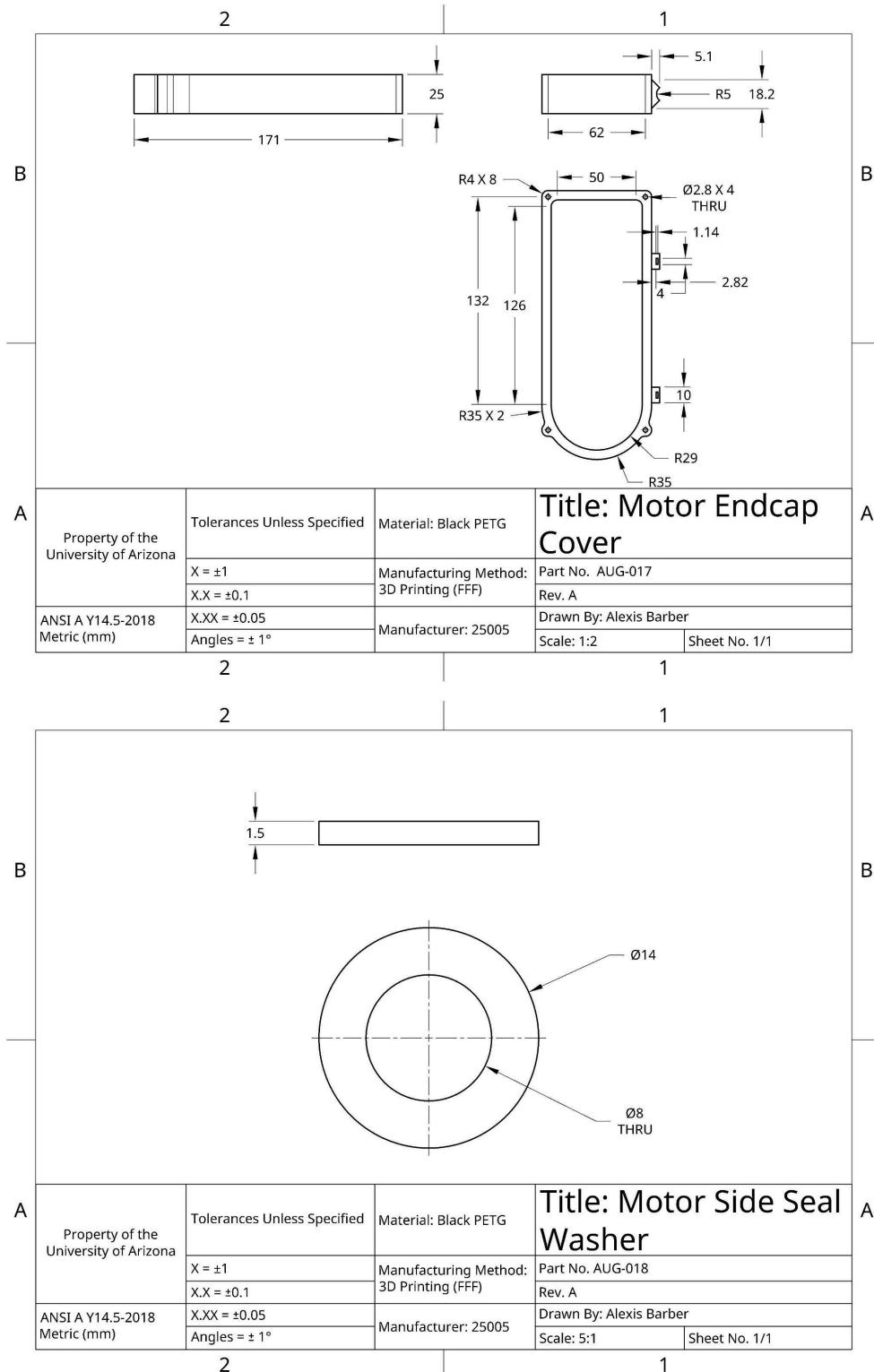
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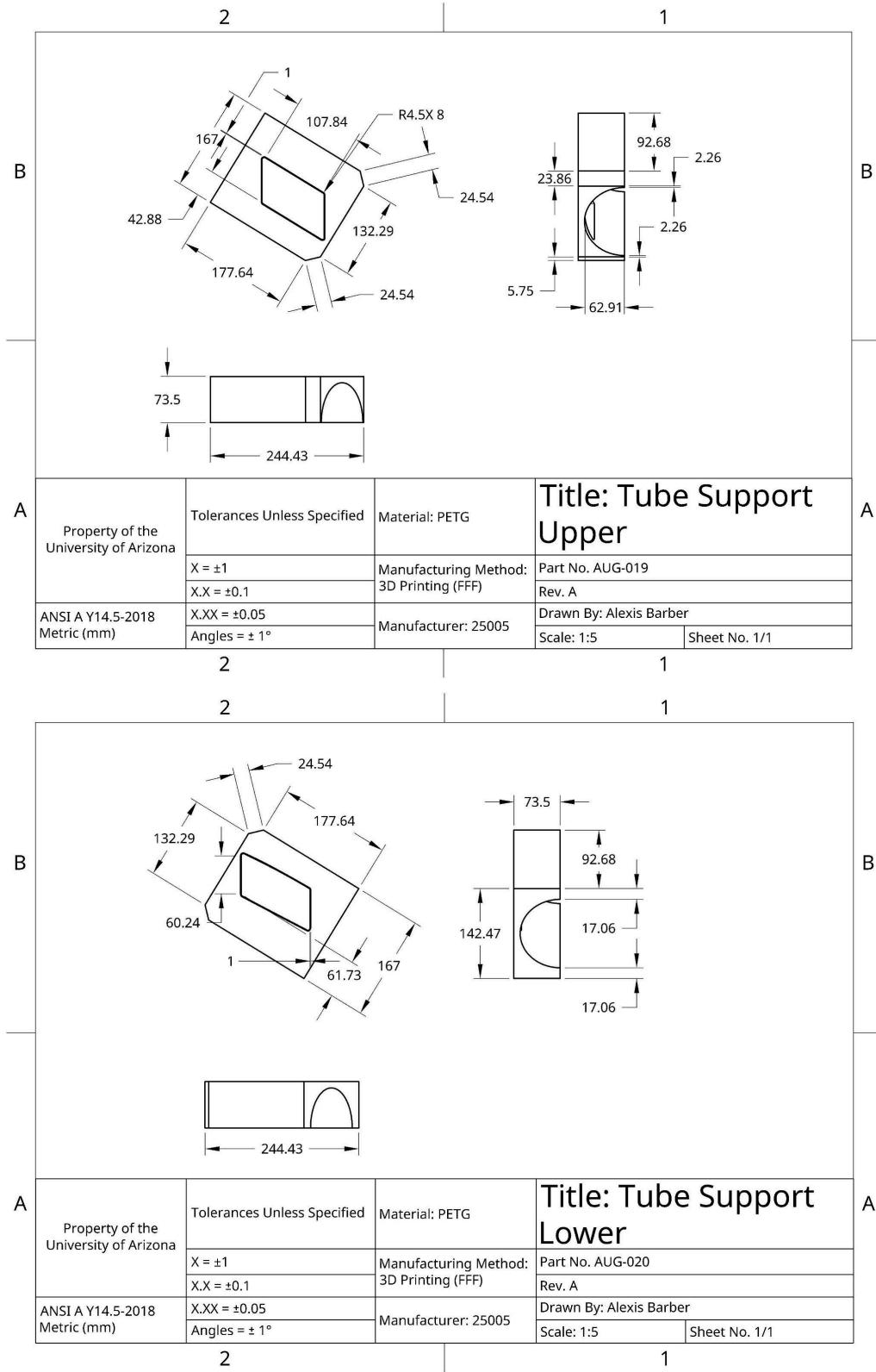
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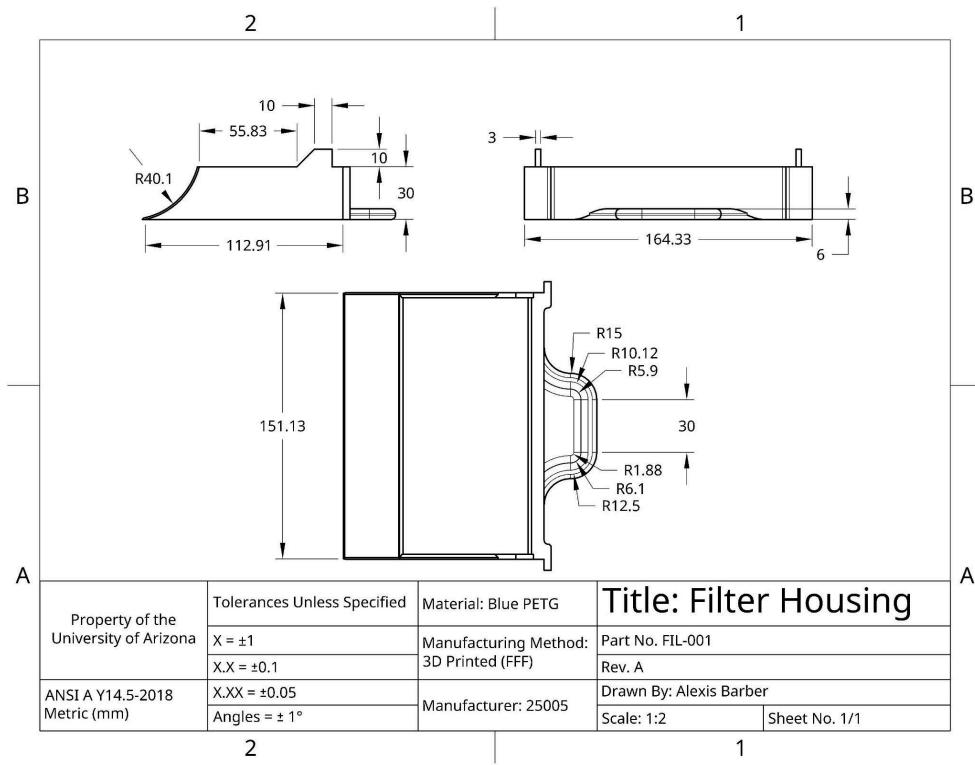




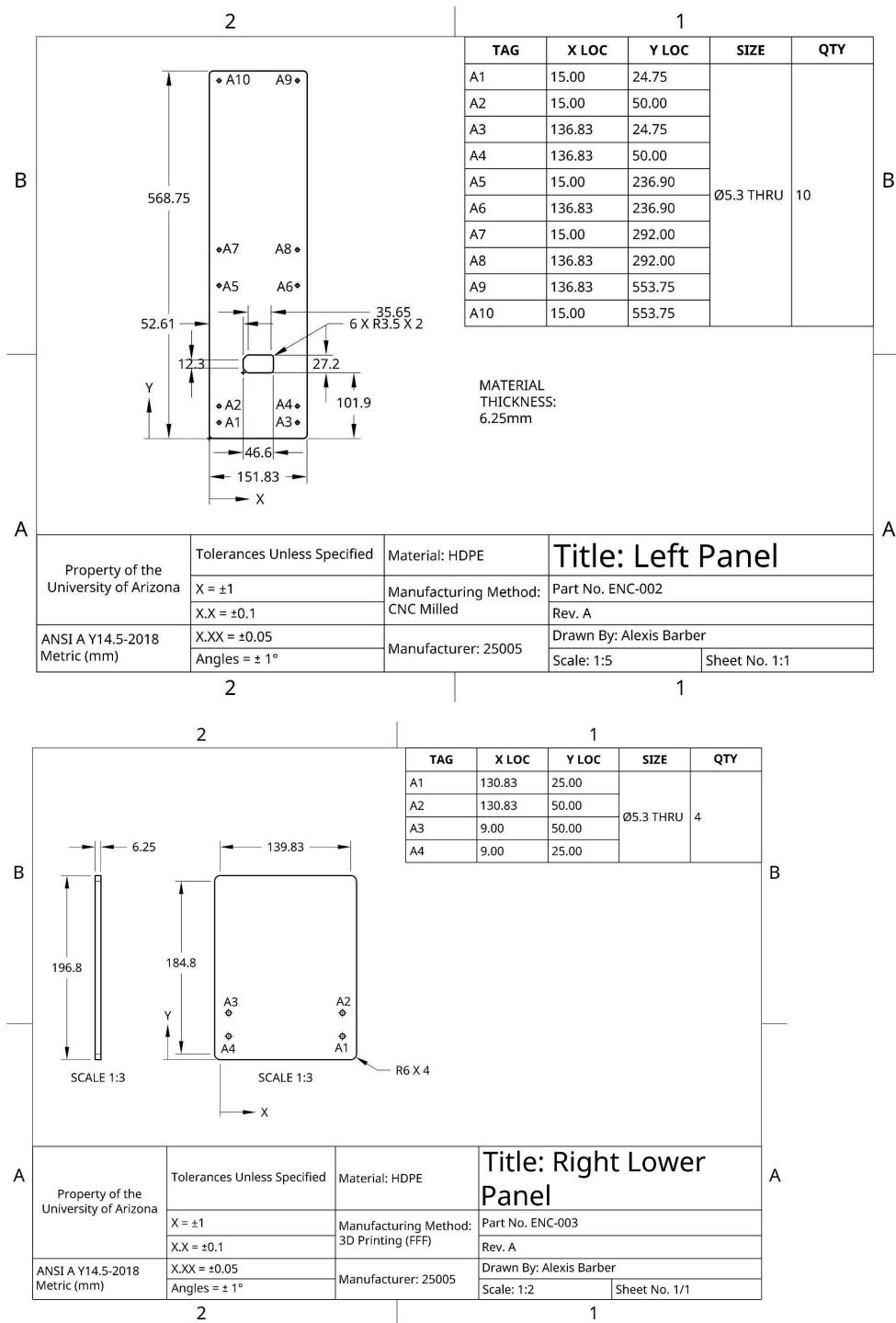


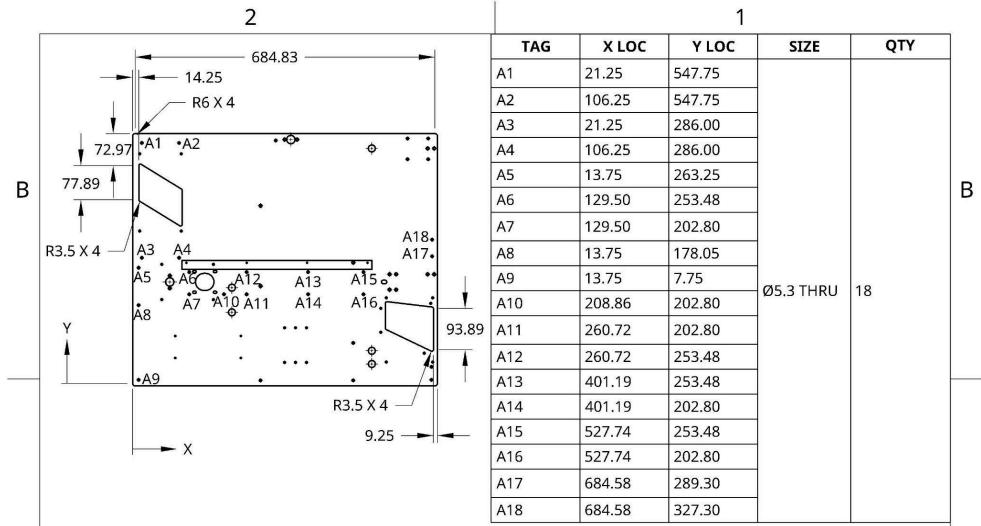


1.3 Filter Subsystem



1.4 Enclosure Subsystem

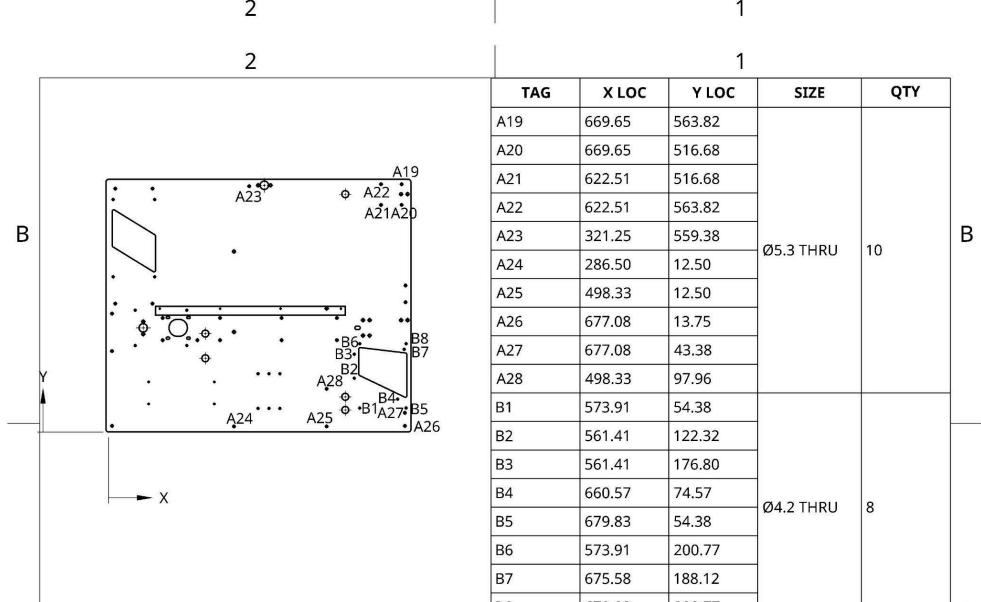




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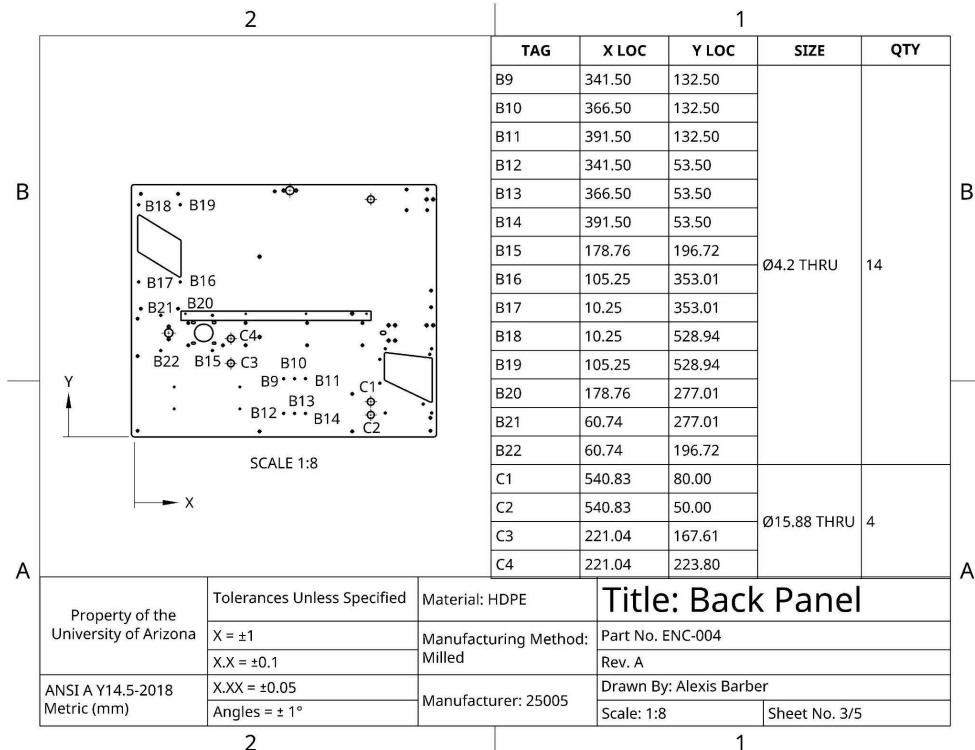
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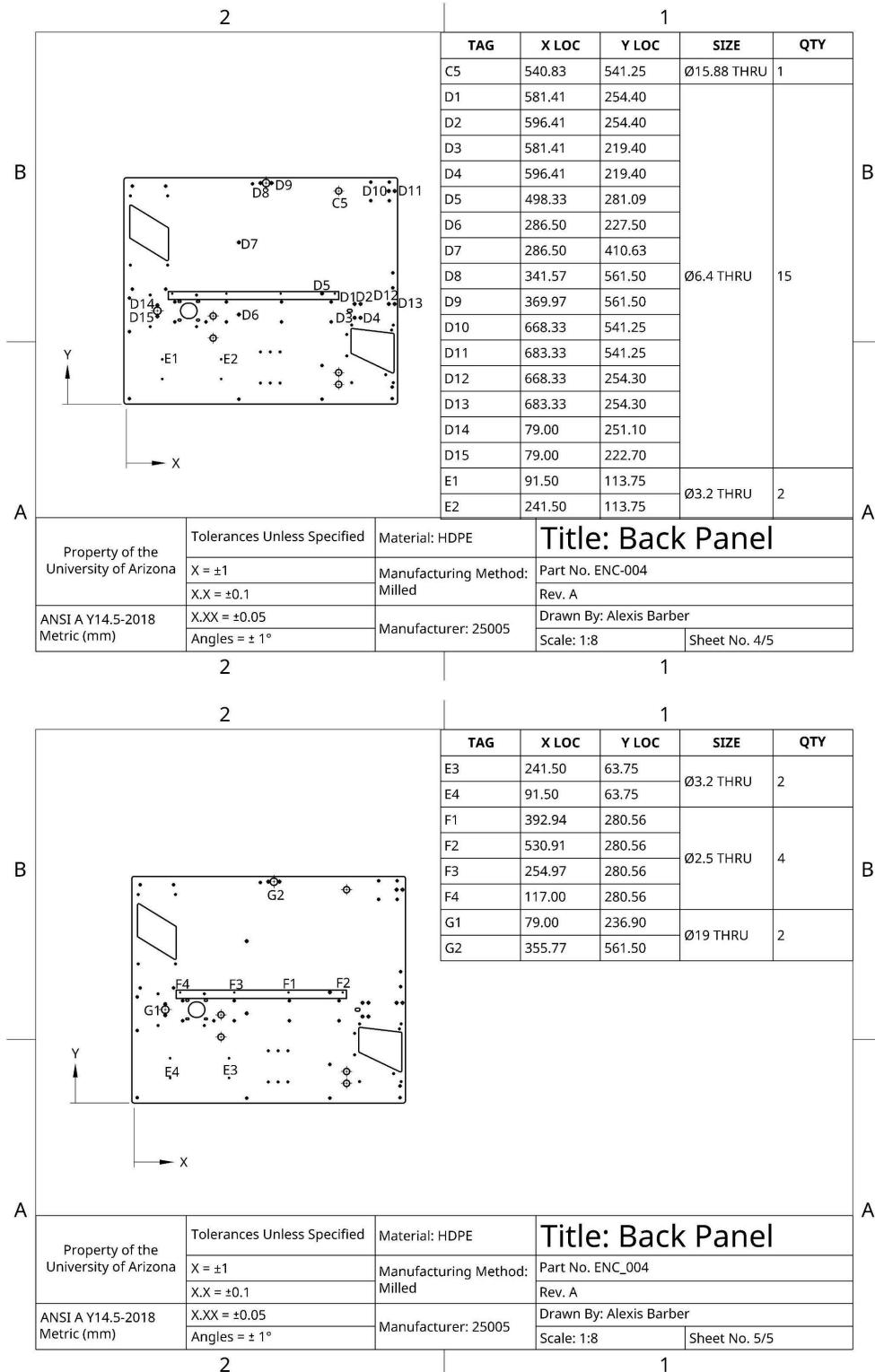


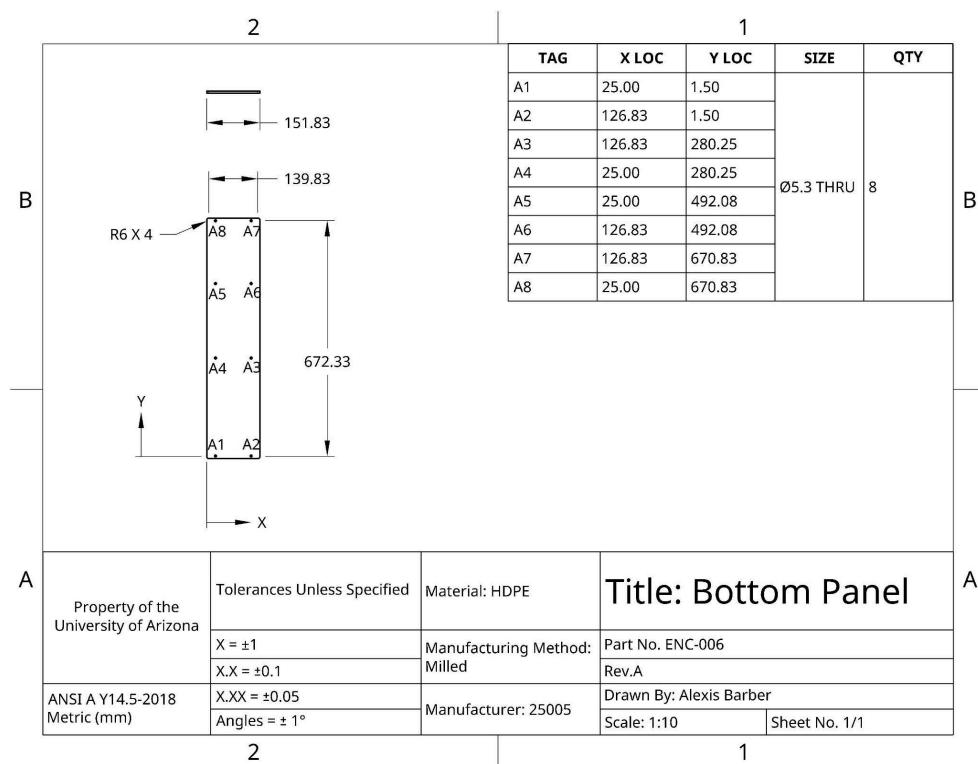
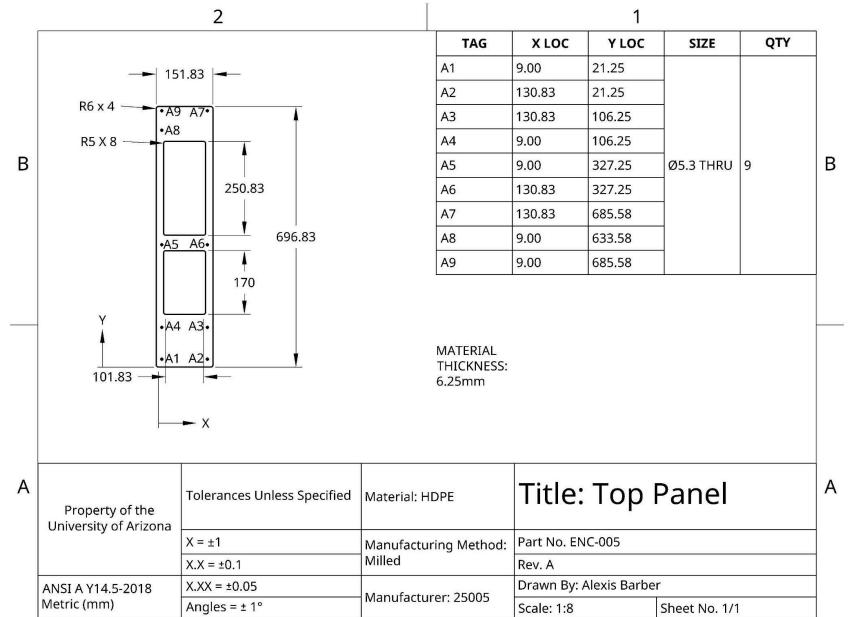
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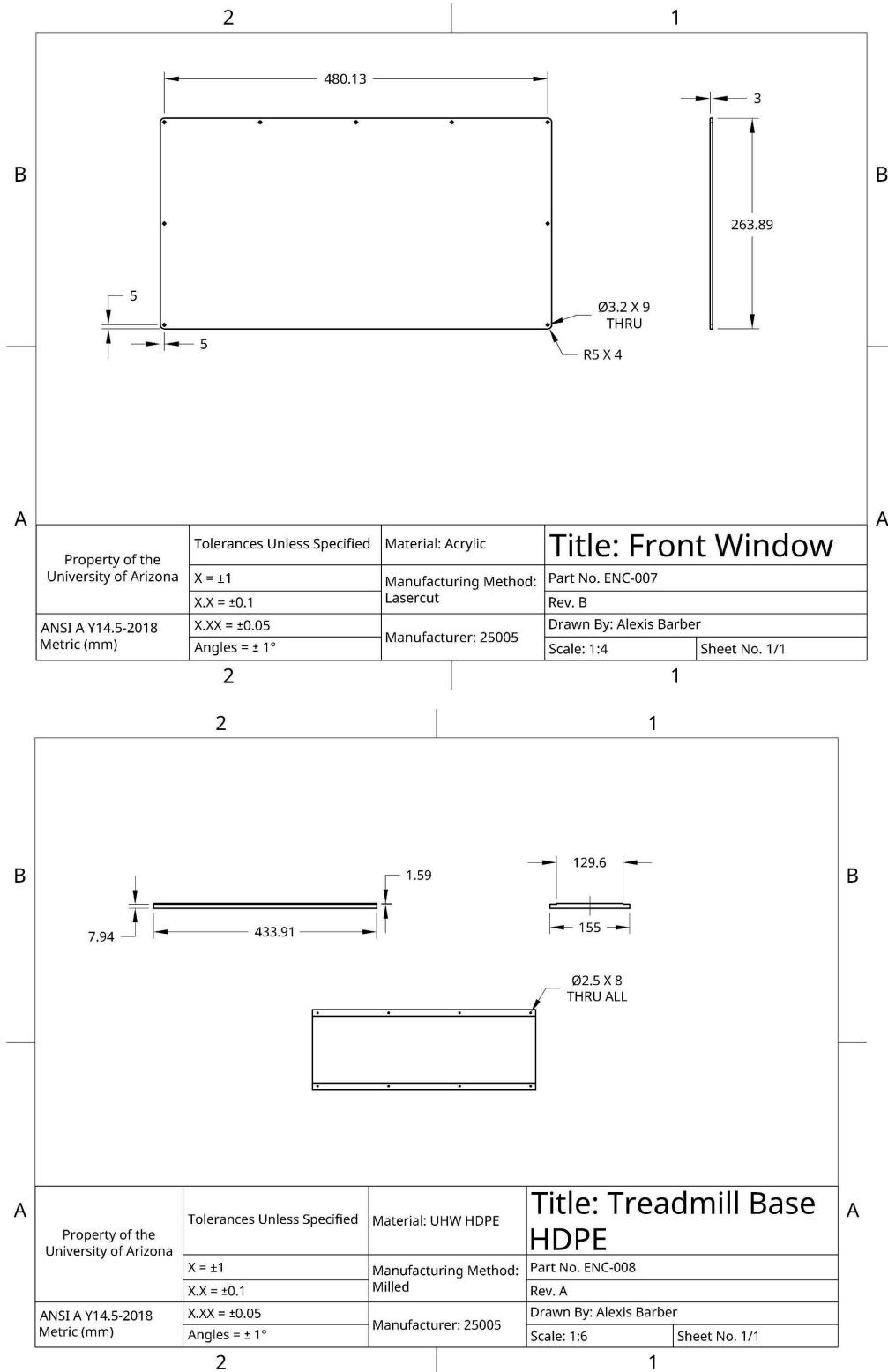
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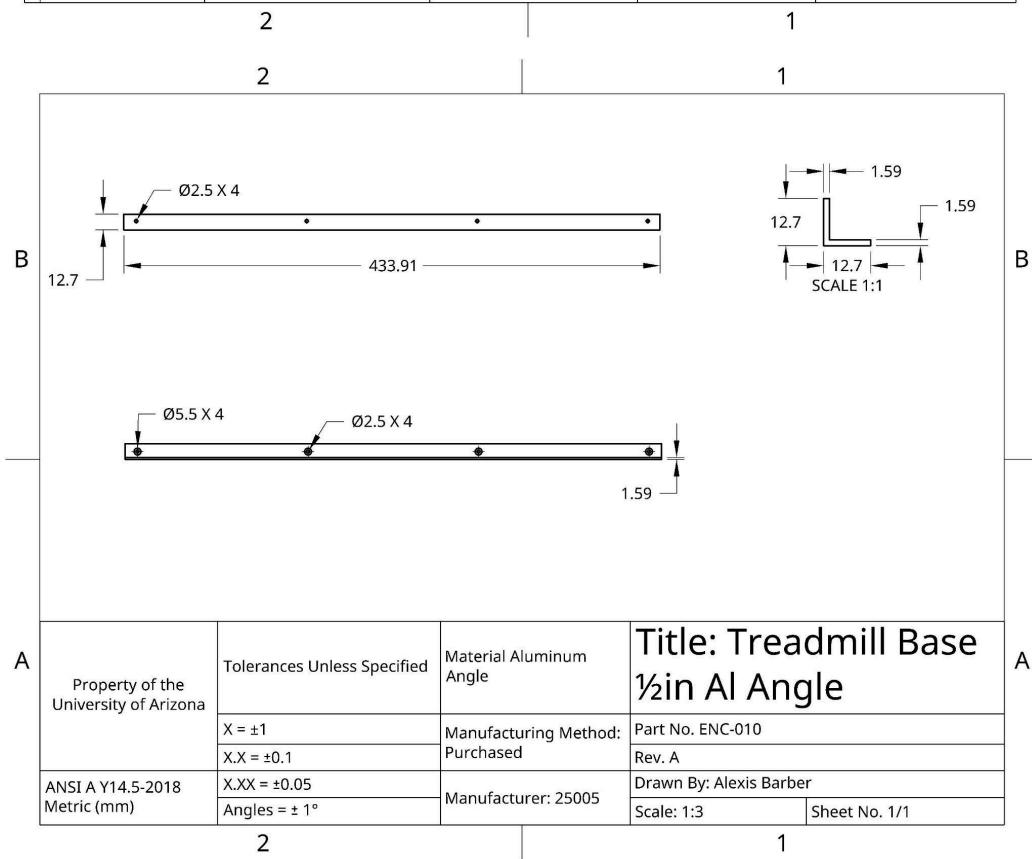
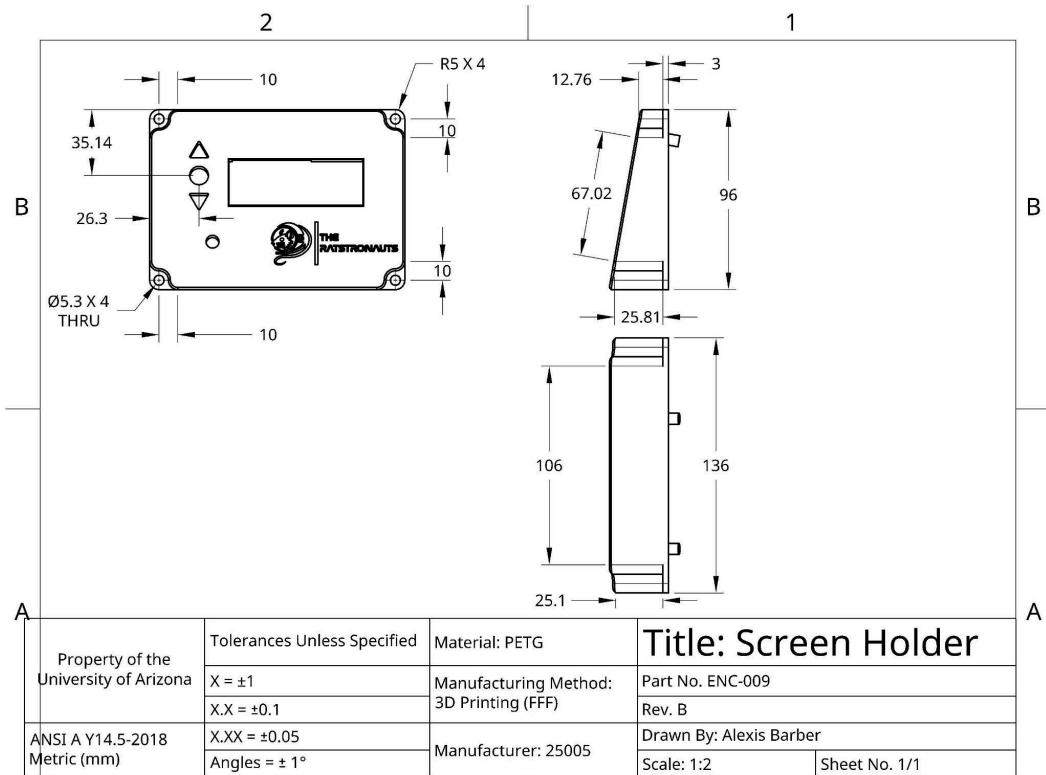
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	Angles = ± 1°		Scale: 1:8	

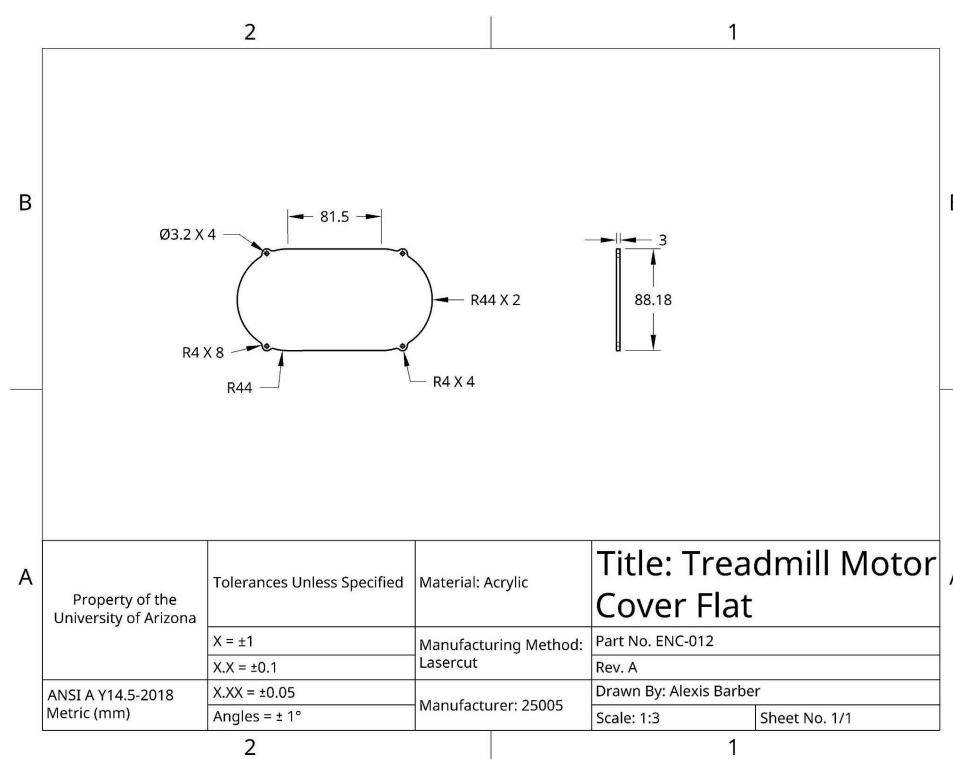
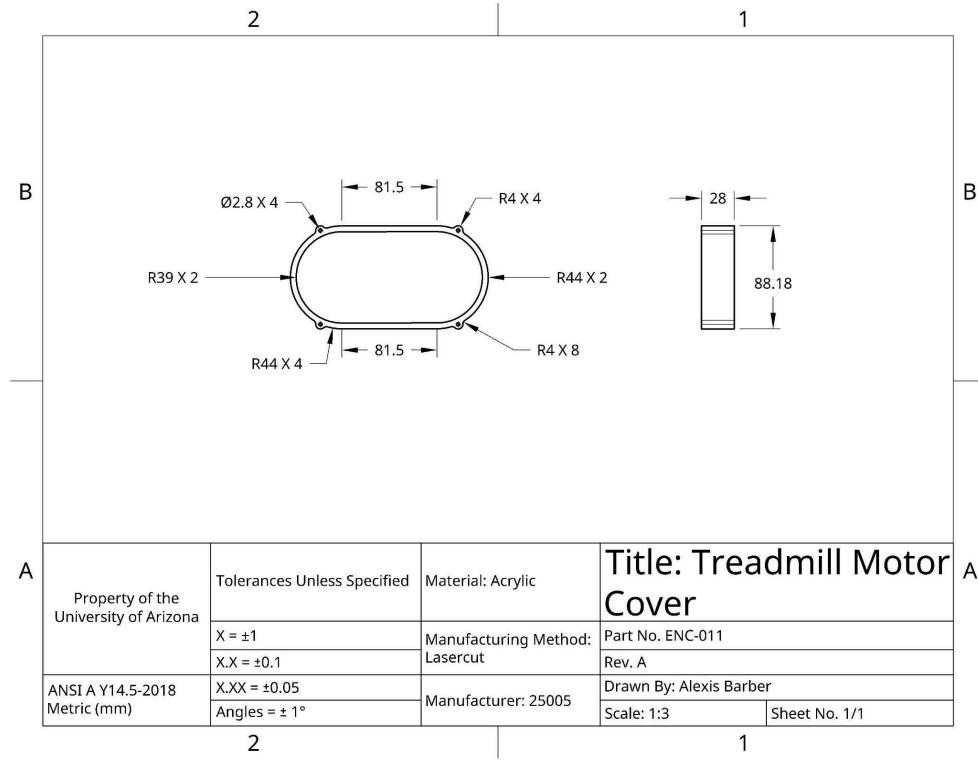


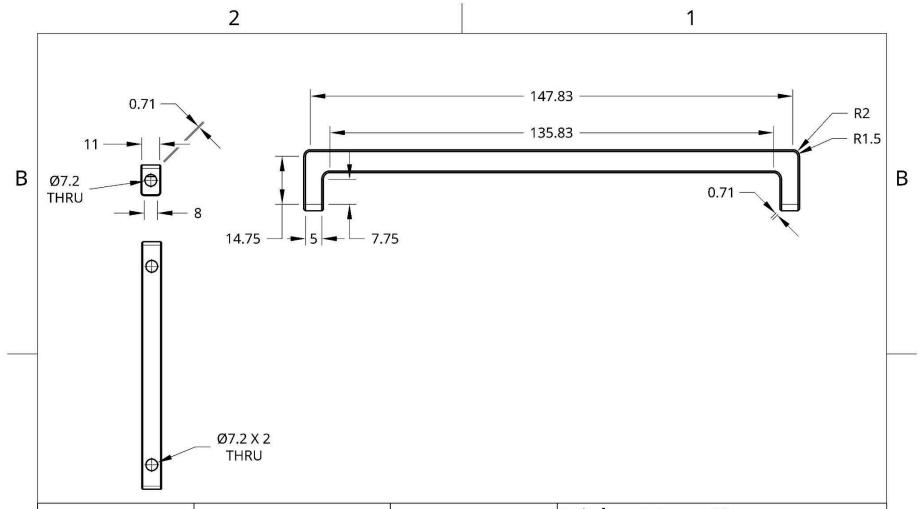




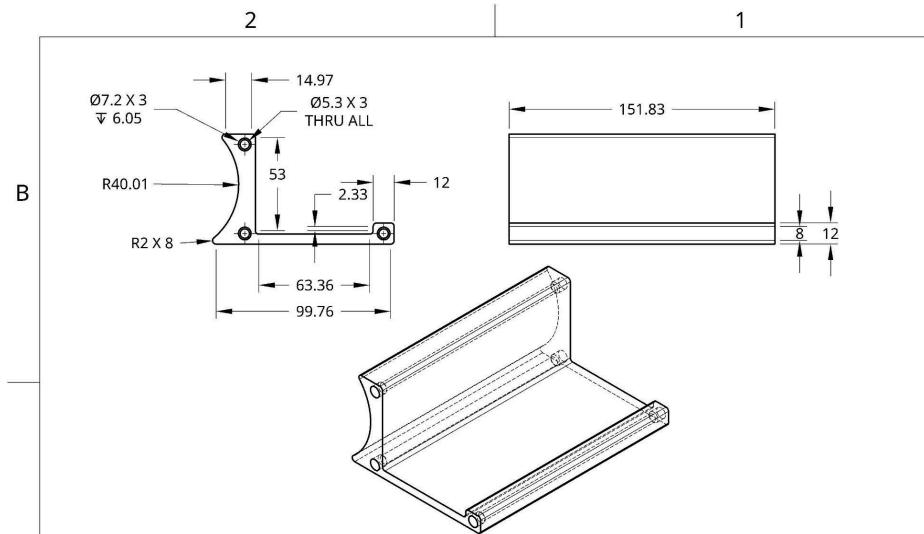




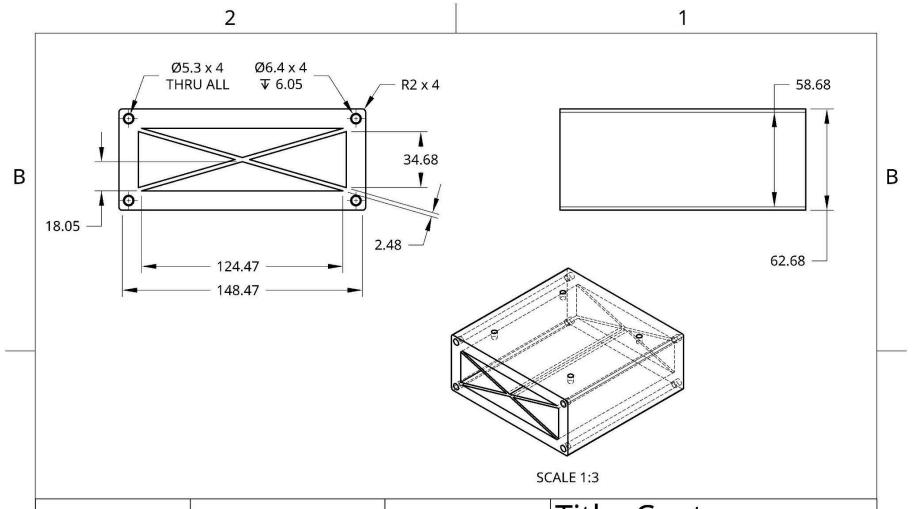




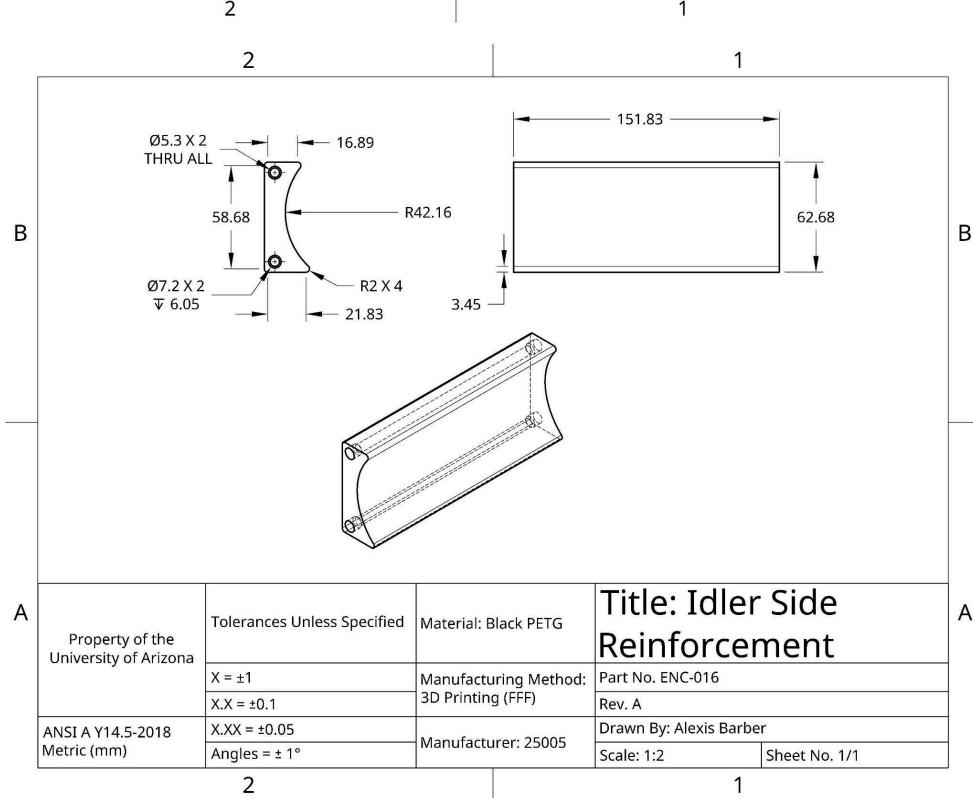
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Property of the University of Arizona	Tolerances Unless Specified	Material: Black PETG	
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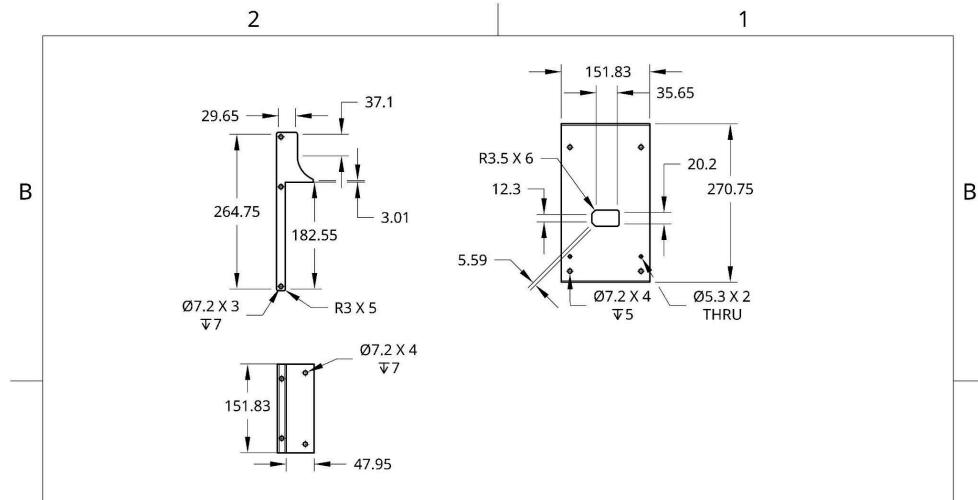


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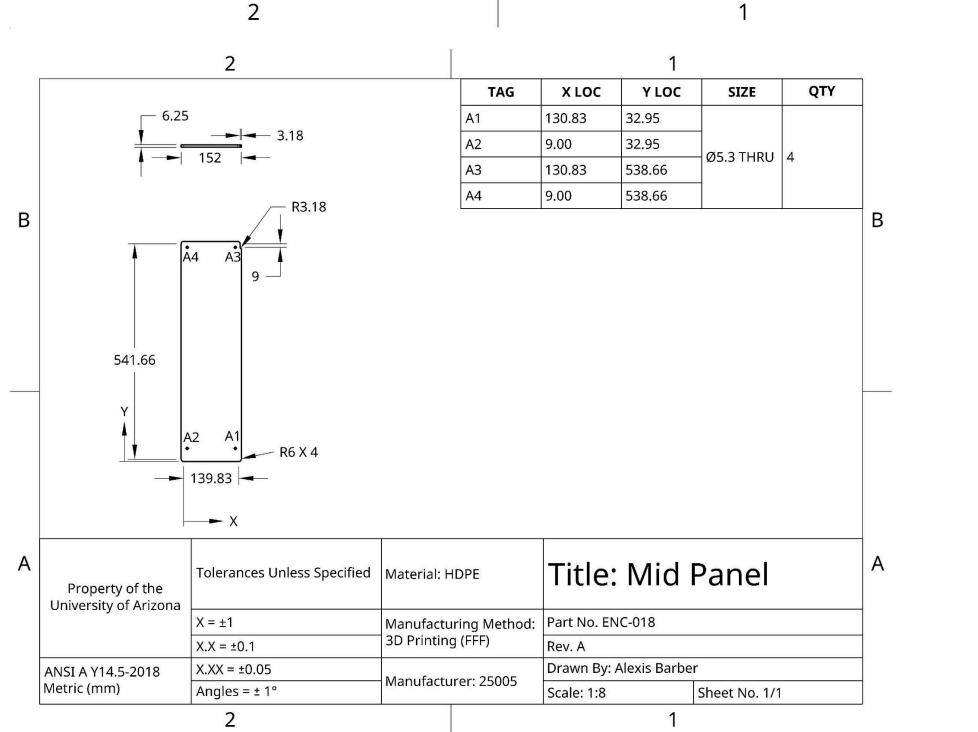


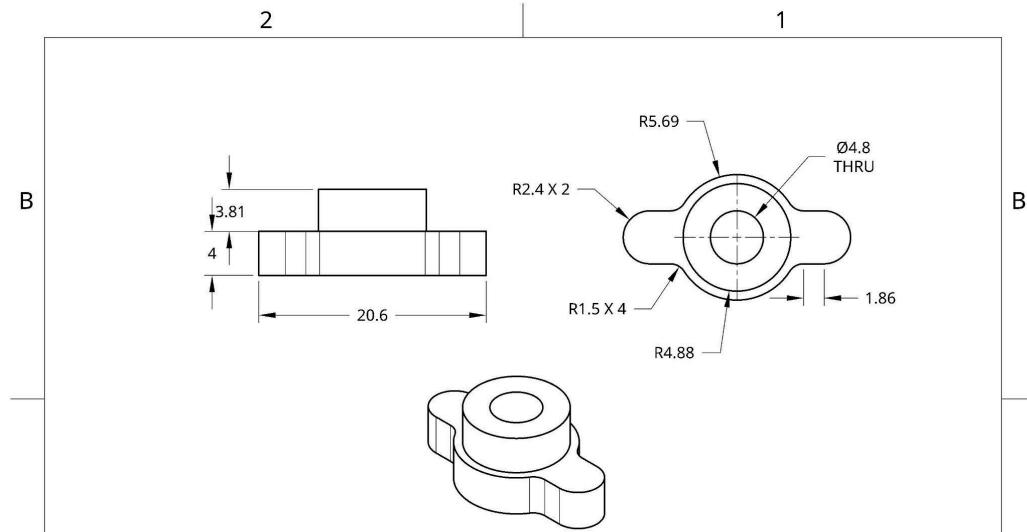
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	Angles = ± 1°				



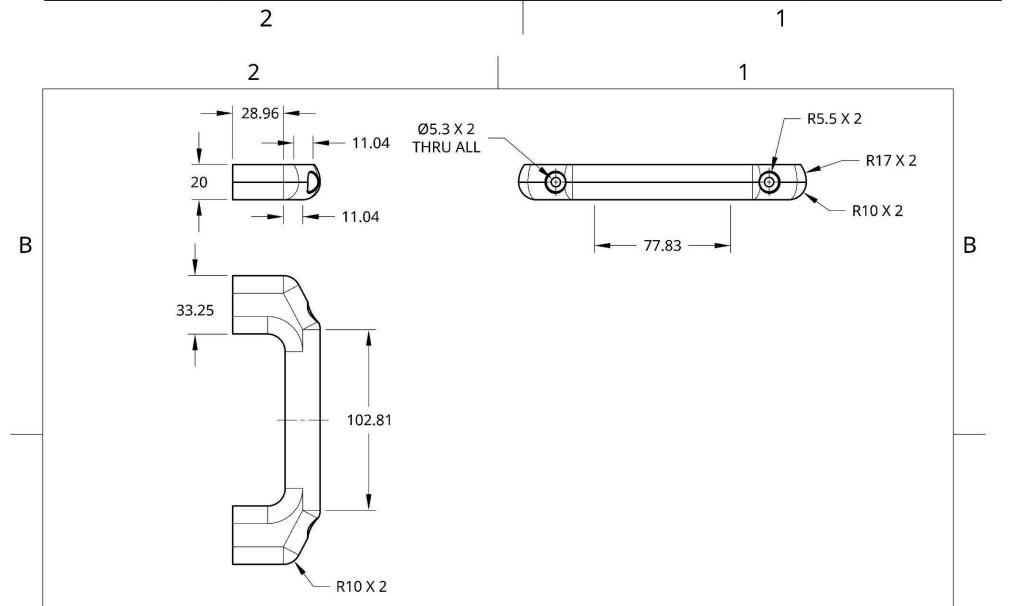


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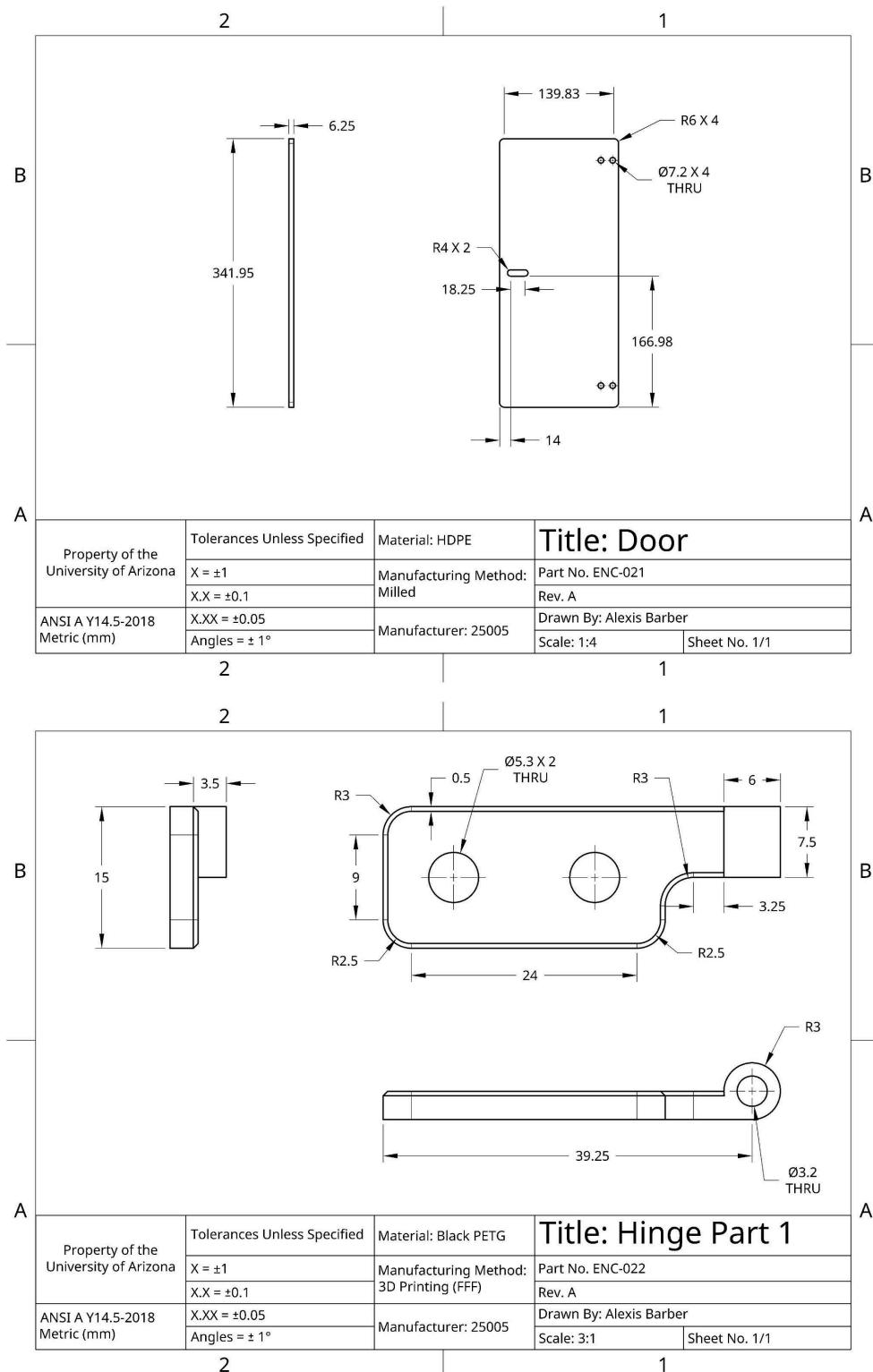


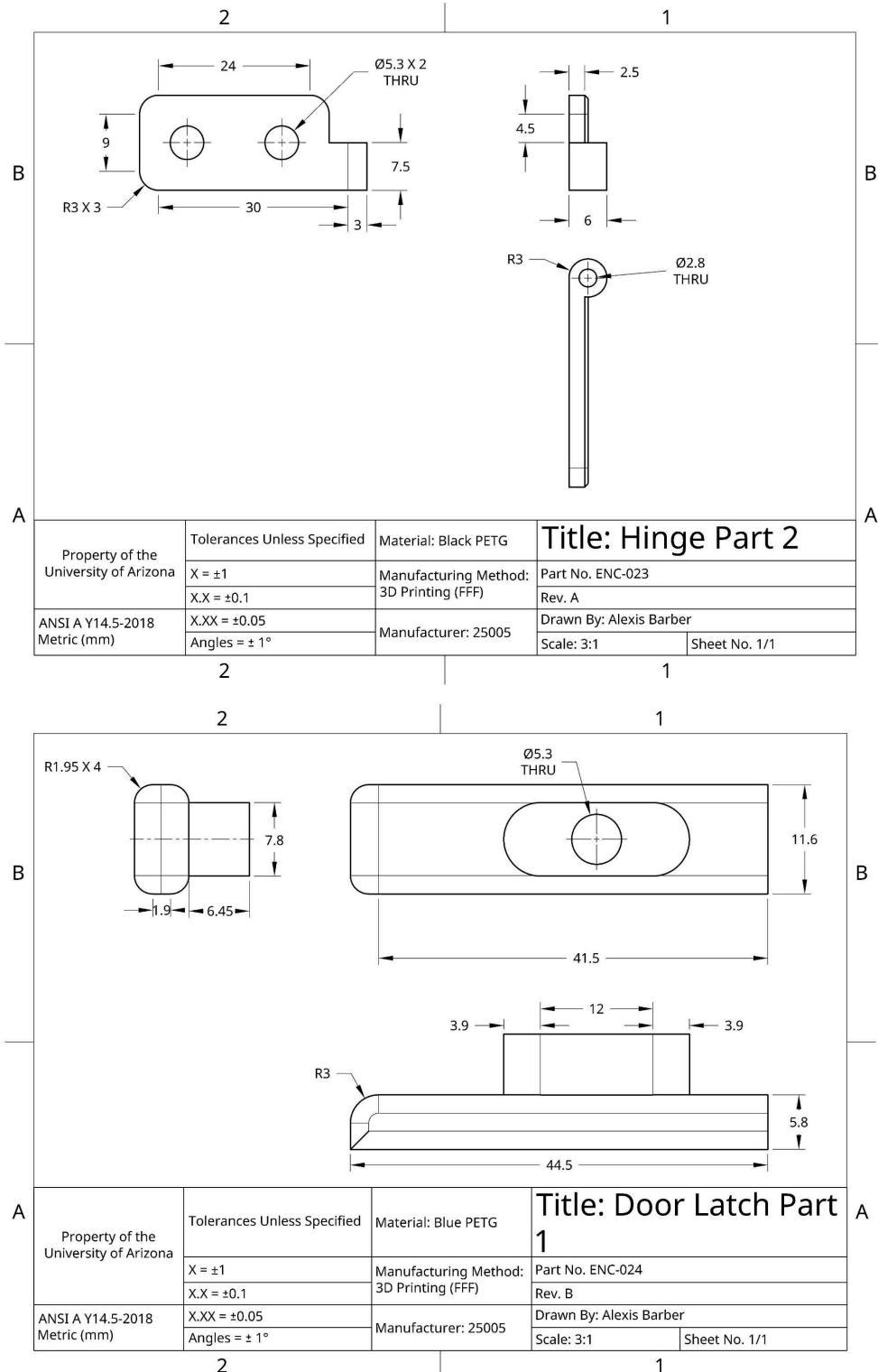


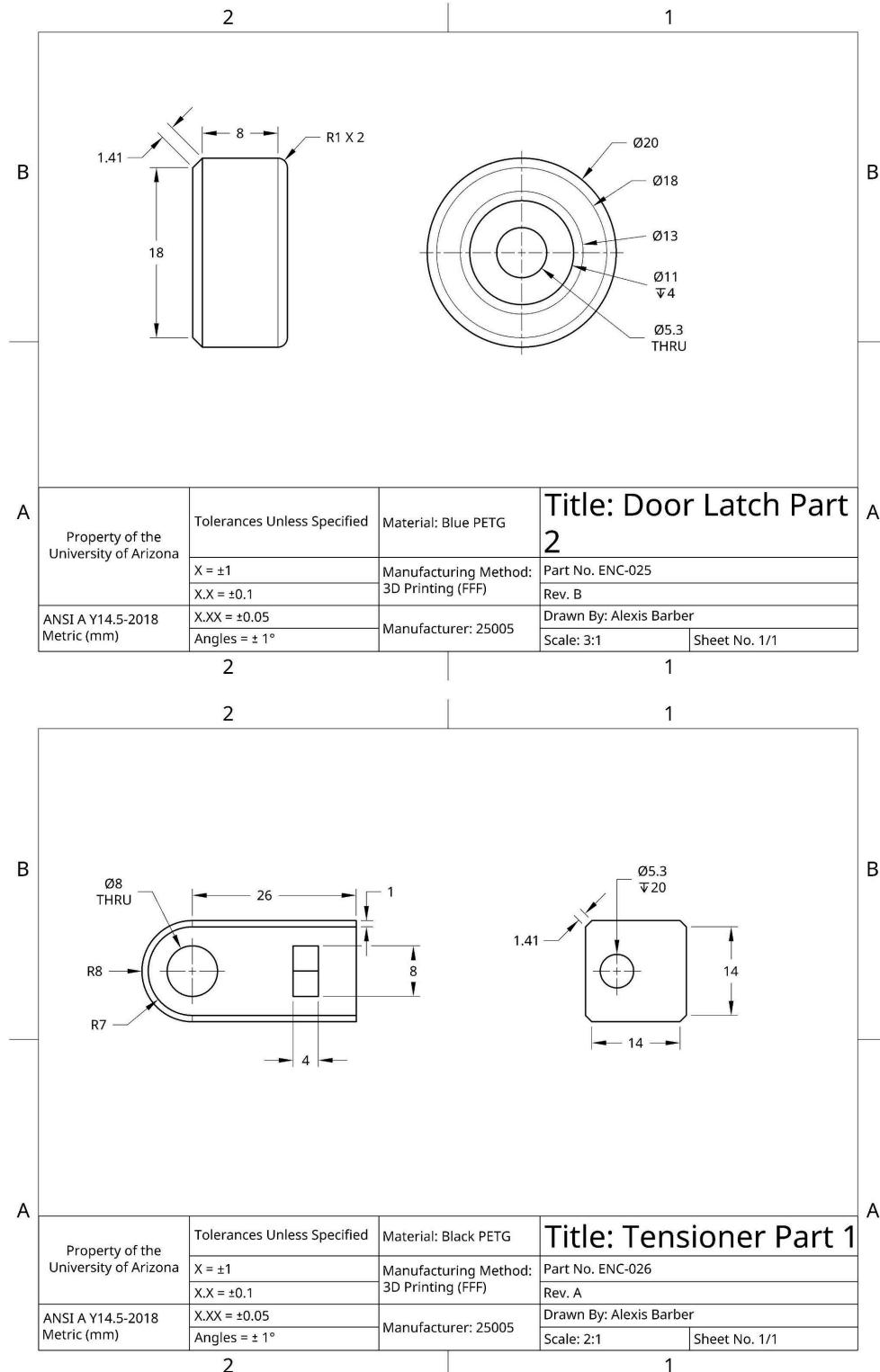
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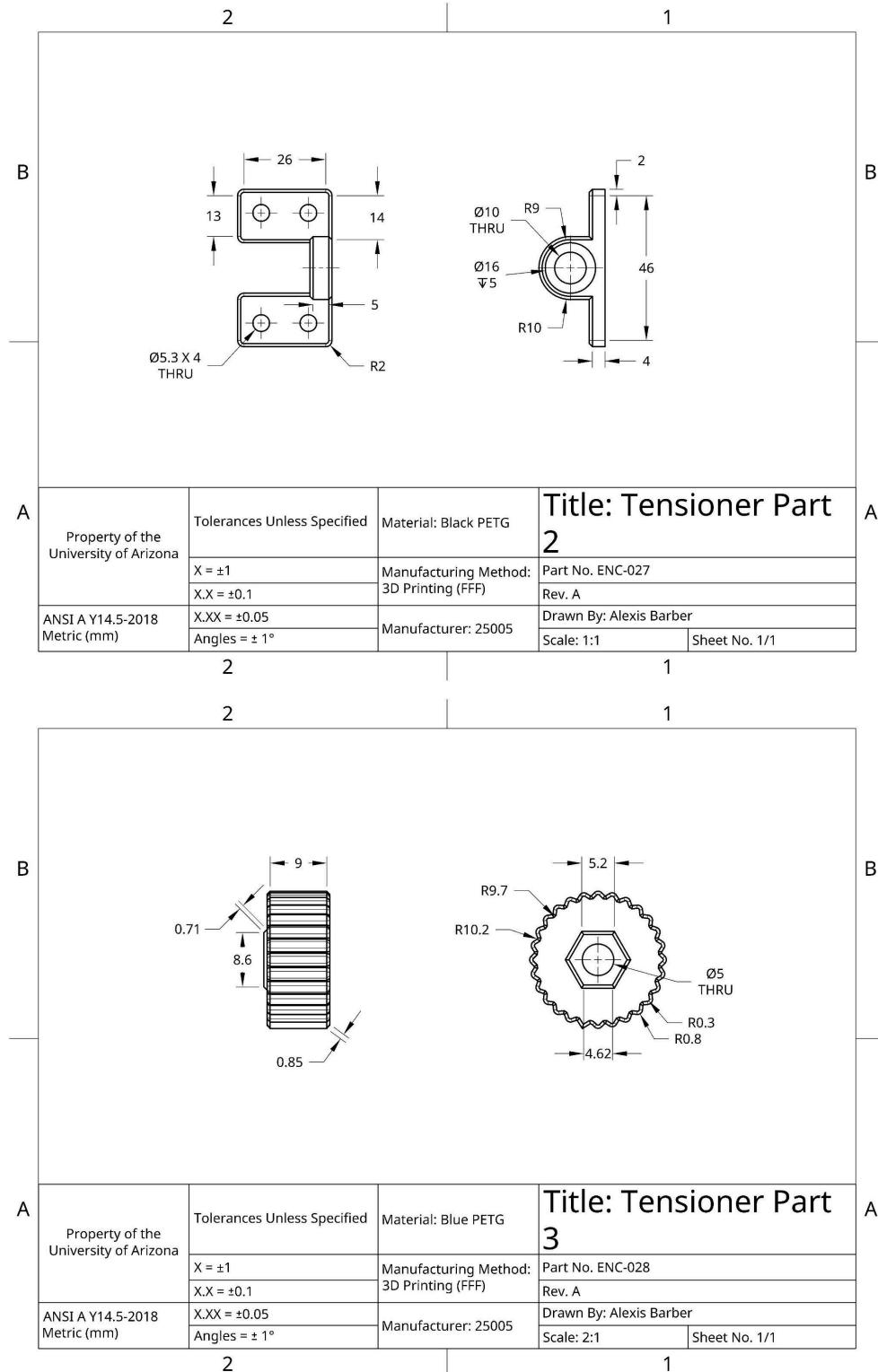


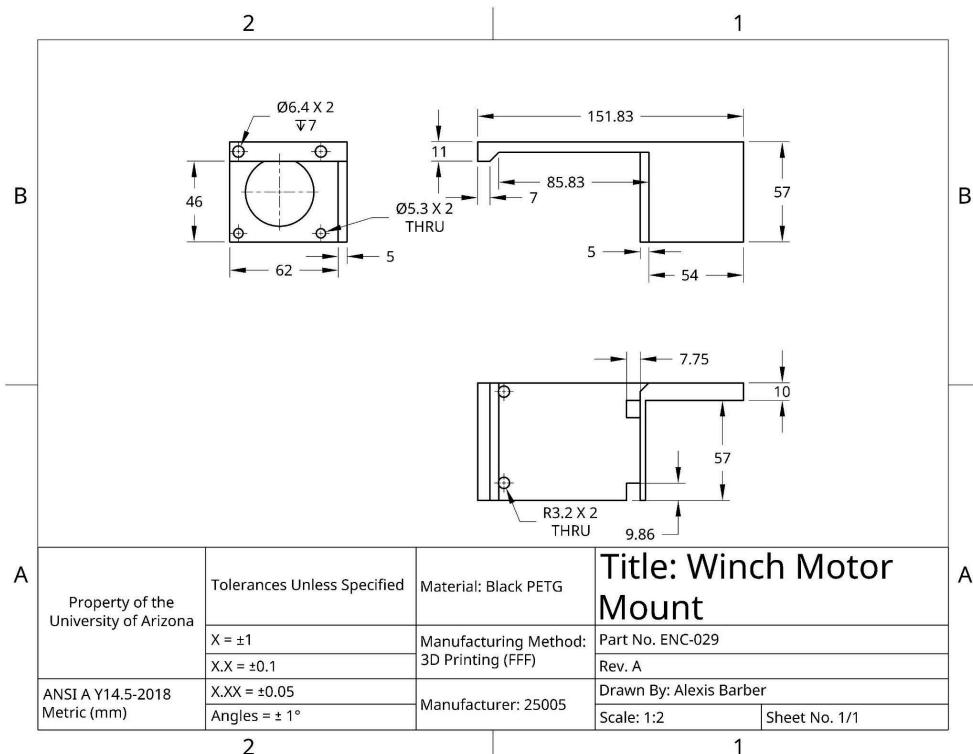
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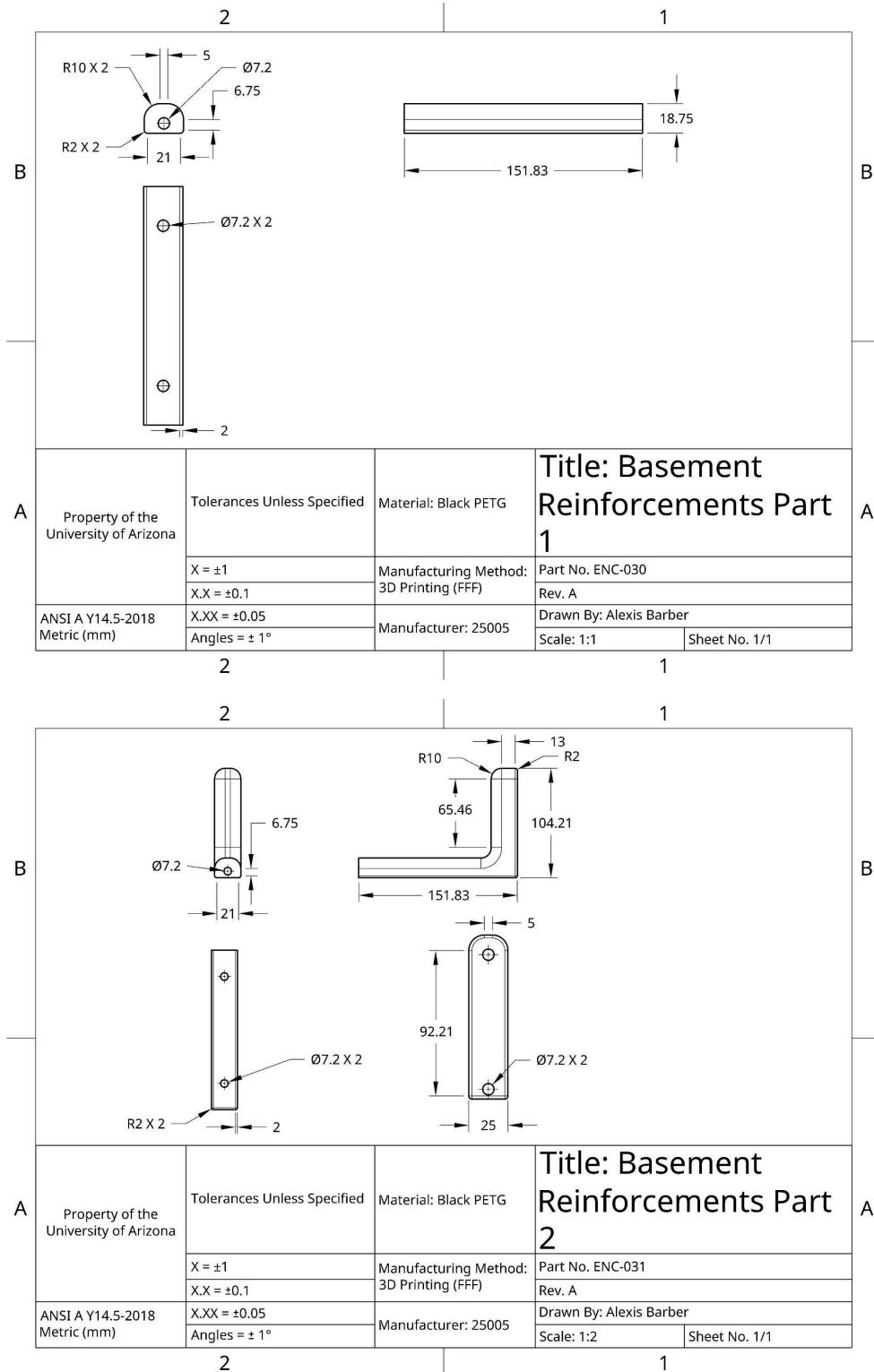


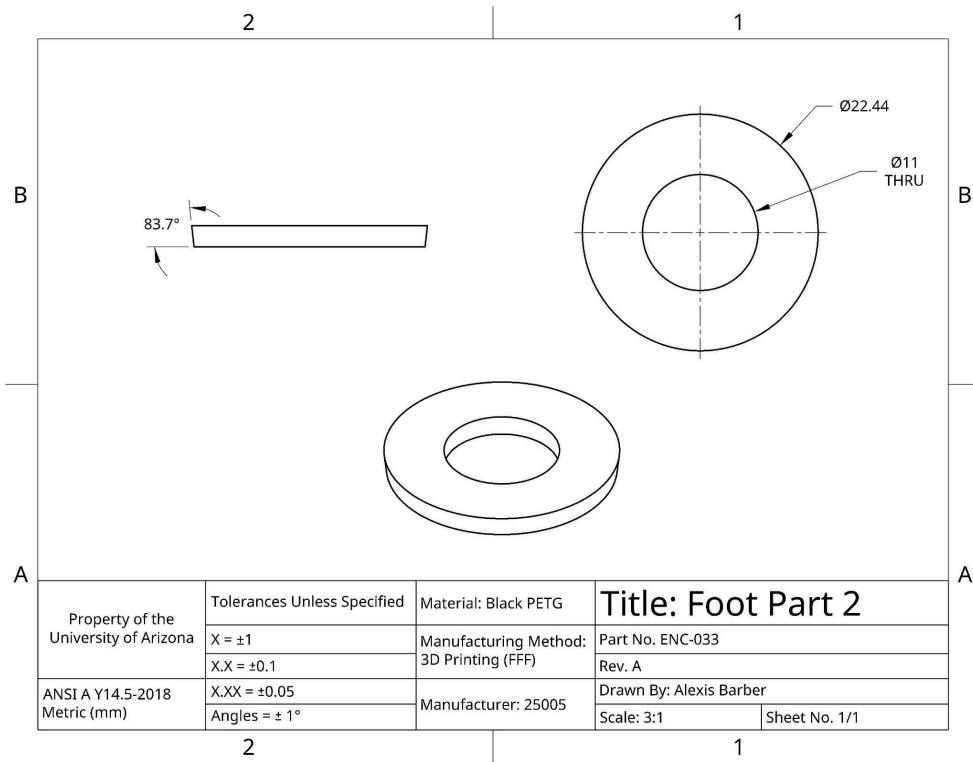
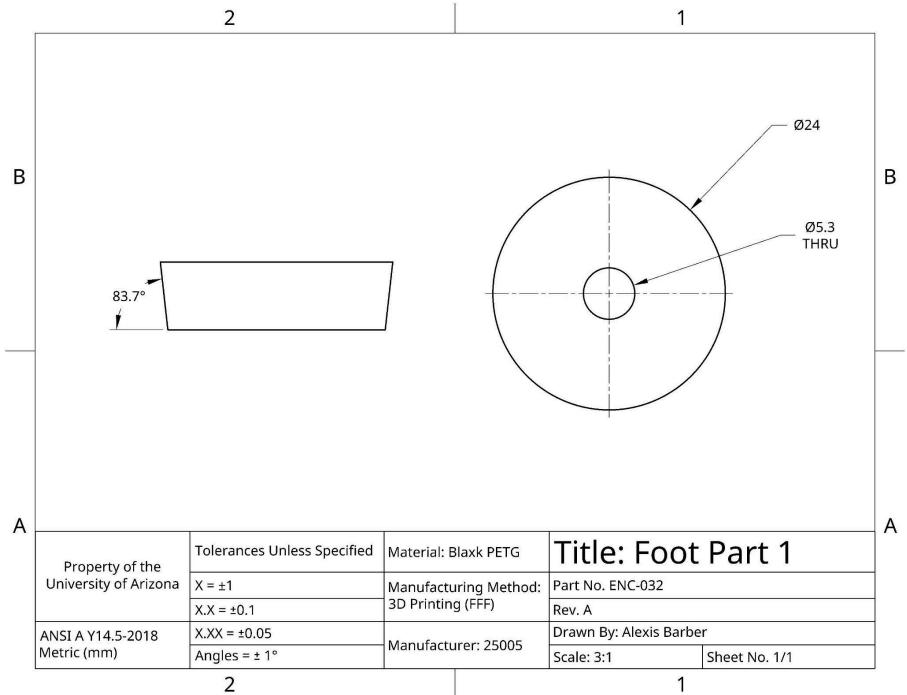


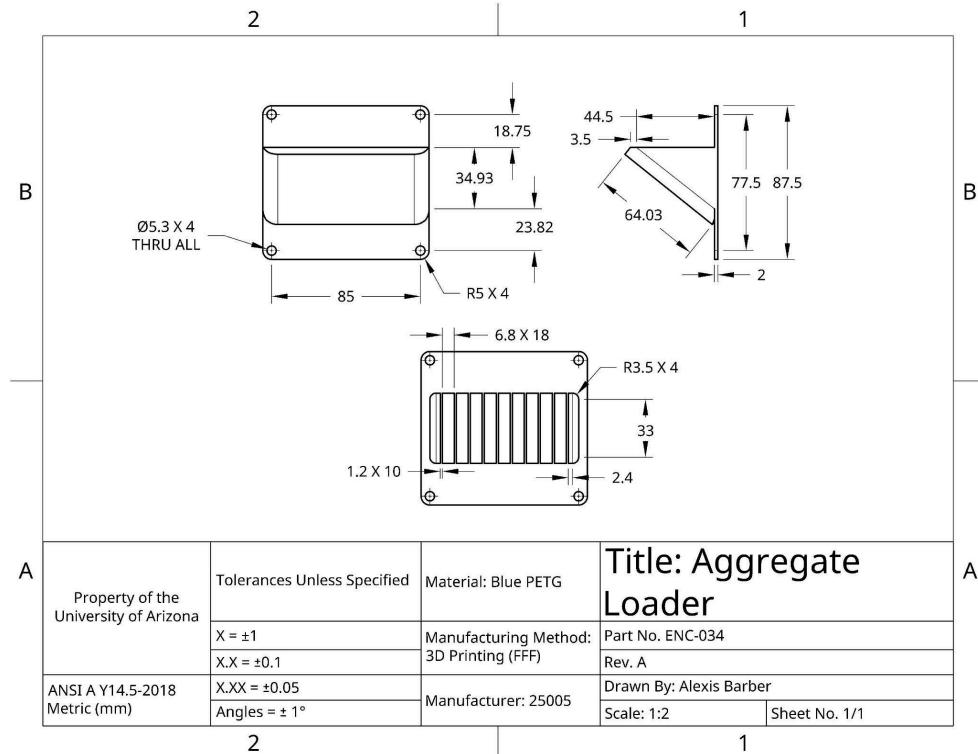


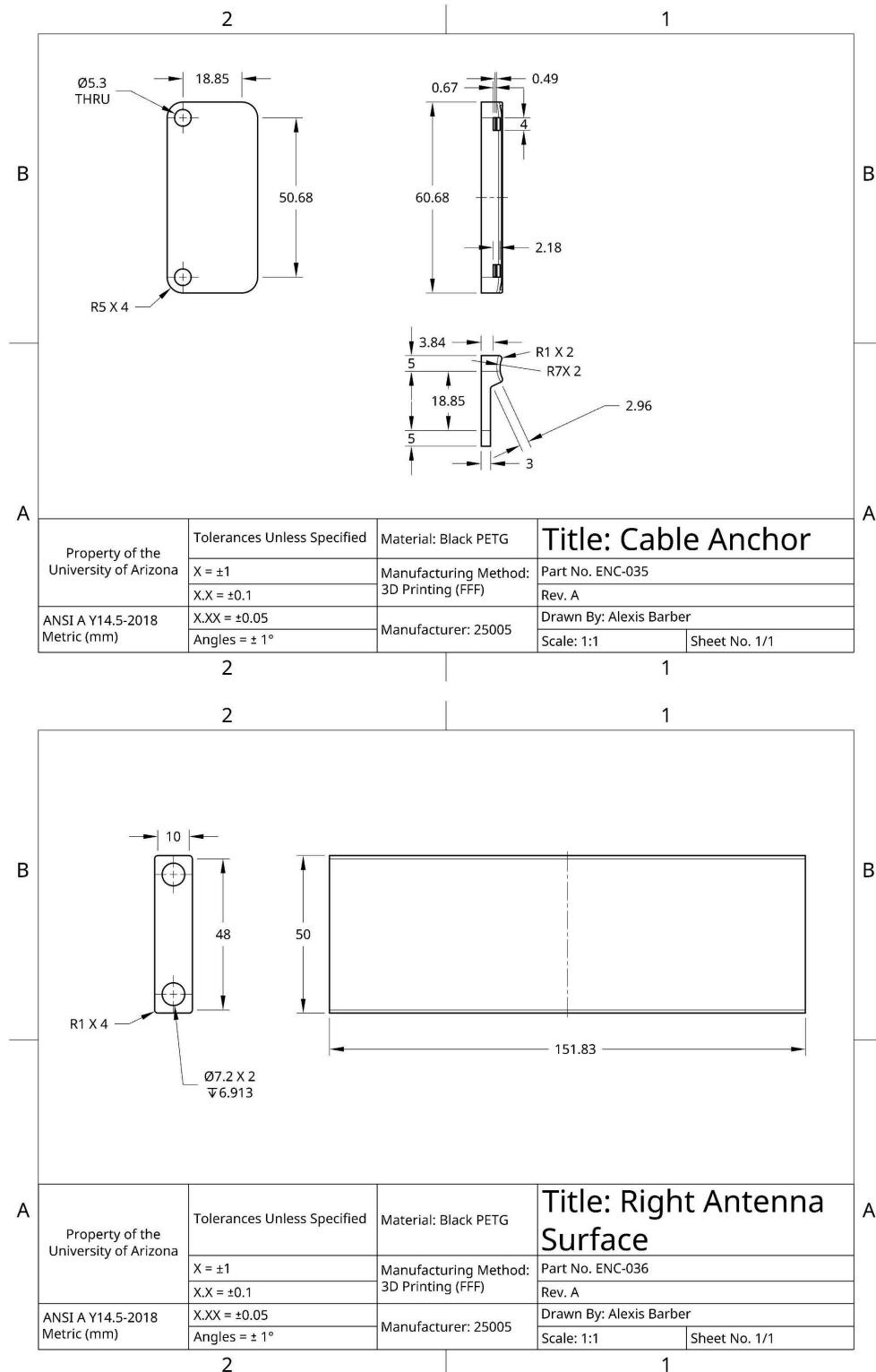




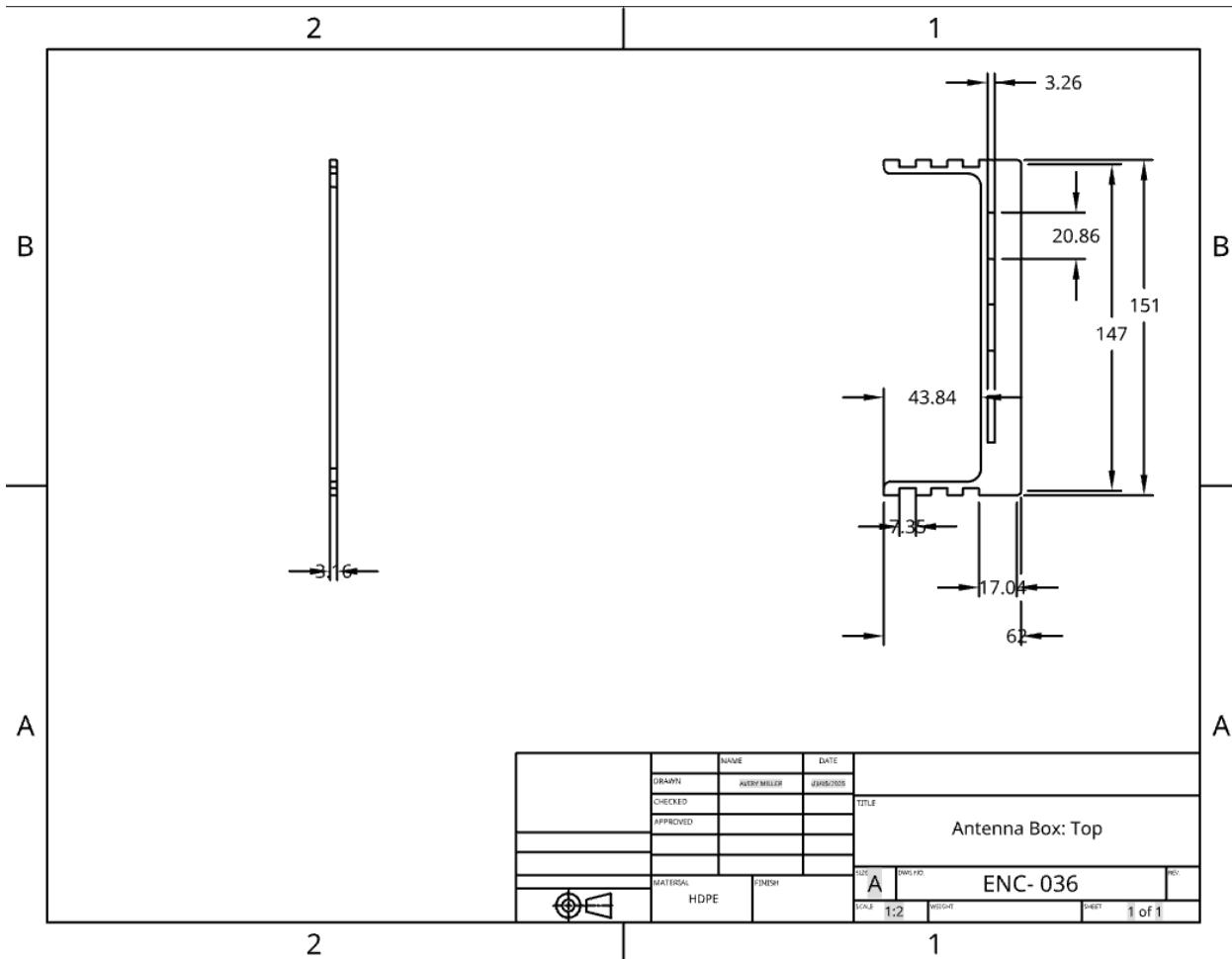


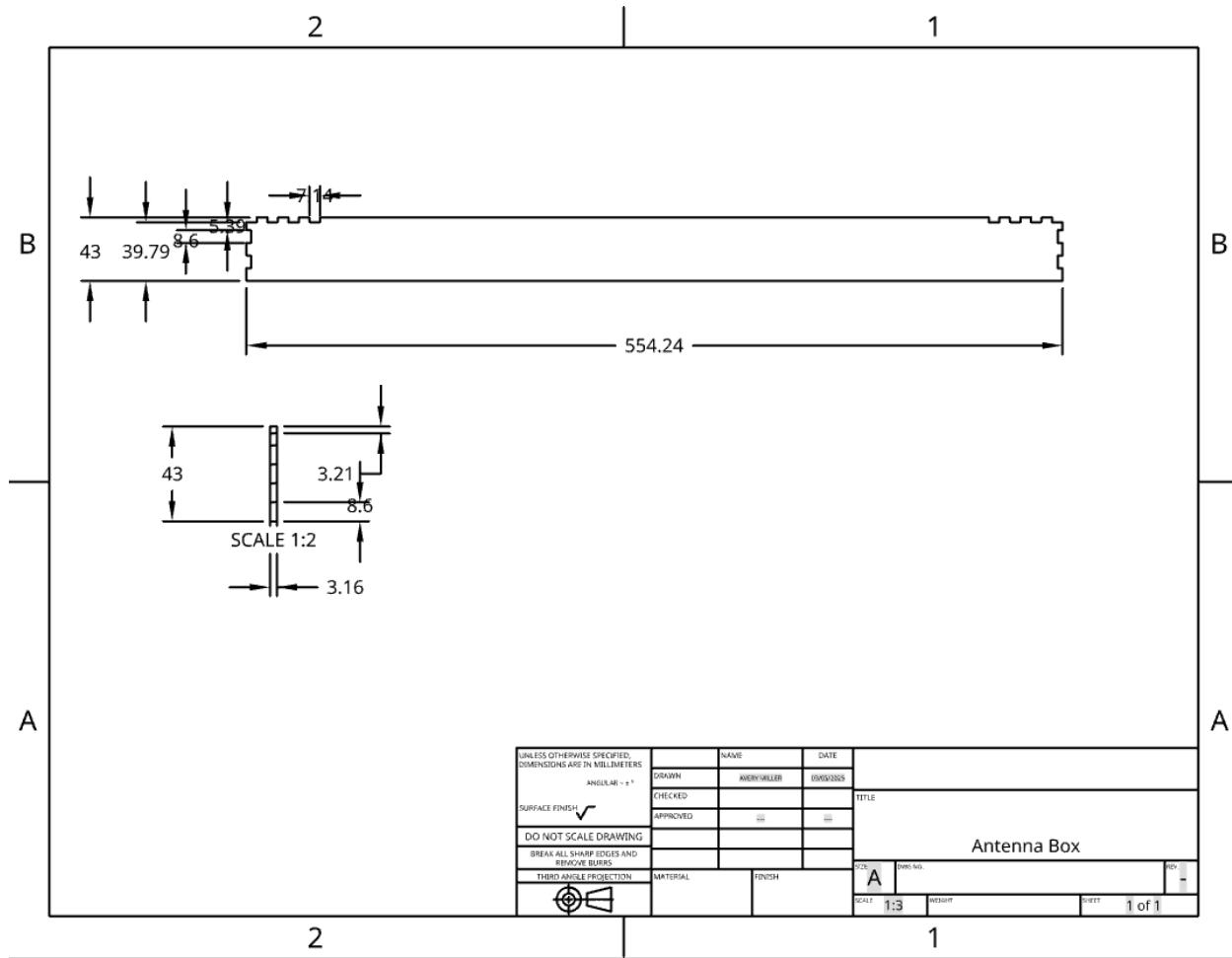






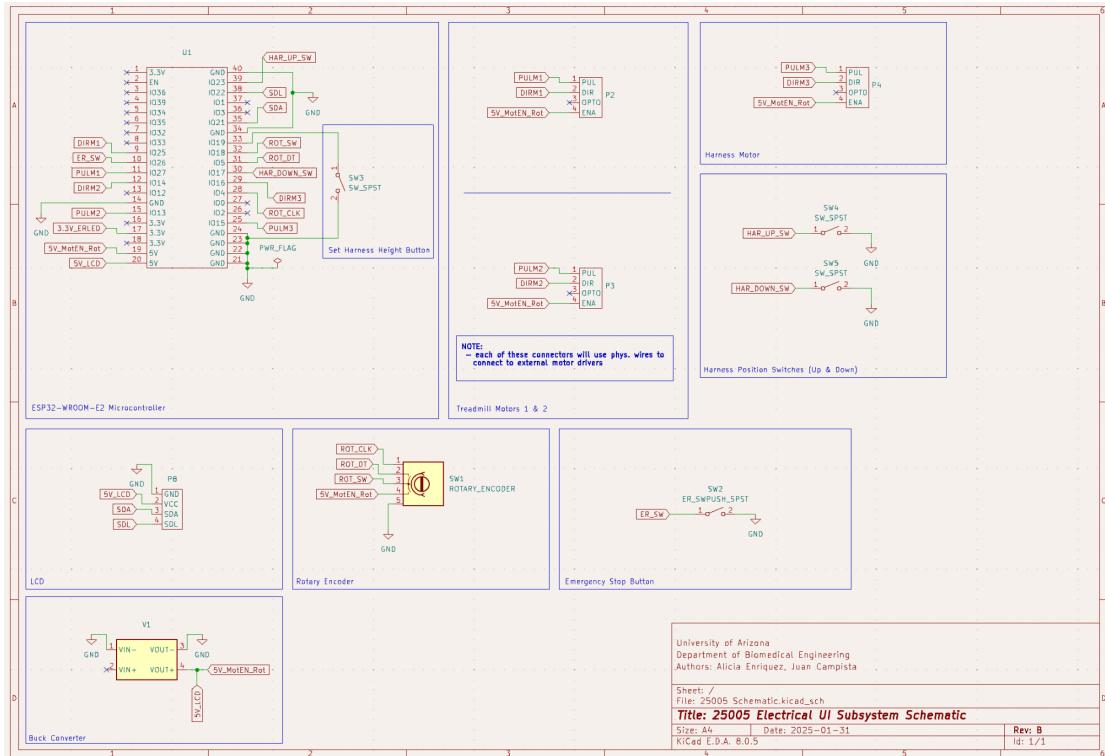
1.5 Antenna Subsystem



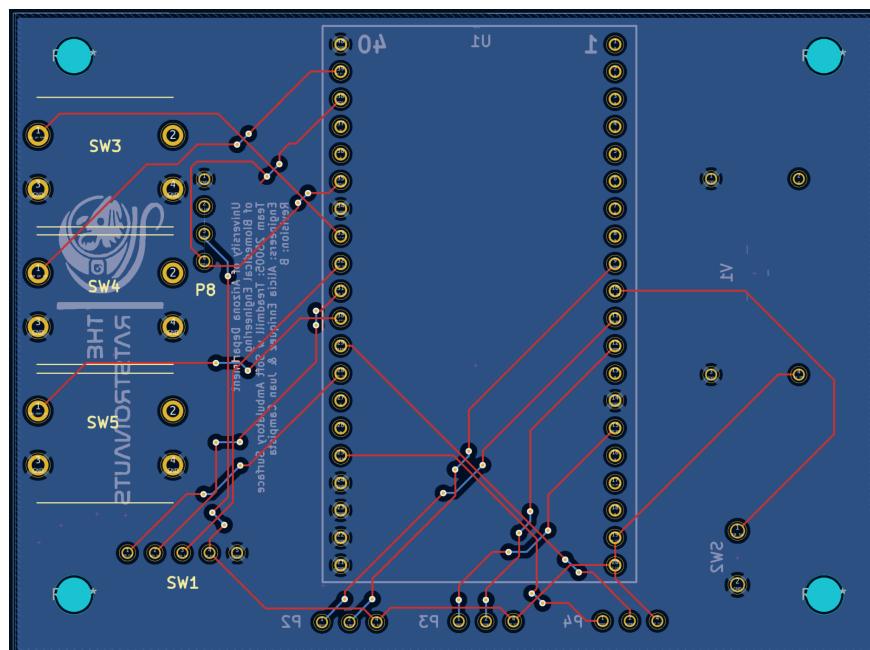


Section 2.0 – Electrical Drawings

- 2.1 UI/Electrical Assembly Subsystem
- 2.1.1 Electrical Schematic - Revision B, PUR-042



2.2.2 PCB Layout - Revision B, PUR-042



4.5 Software Documentation

Treadmill Ambulatory System Software Design Document	
Treadmill Ambulatory System (TAS) Software Design Document (SDD) Team 25005	
Feb 20, 2025 REV B Prepared for UA Dept. of Biomedical Engineering	
Table of Contents	
Section 1.0 - Scope 1.1 Identification 1.2 System Overview 1.3 Document Overview	
Section 2.0 - Referenced Documents	
Section 3.0 - Software Specific Requirement Traceability	
Section 4.0 - Software Design 4.1 Software Wide Design Decisions 4.1.1 Design Decisions Regarding I/O 4.1.2 Design Decisions on CSCI Behavior 4.2 CSCI Architectural Design 4.2.1 Identification 4.2.2 Concept of Execution 4.2.3 Software & Interface Design 4.2.4 Code	
Section 5.0 - User's Manual	
Section 6.0 - Notes	

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 and auger motors, 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 <u>Harness Weight Minimum</u> : 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 <u>Treadmill Speed</u> : 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 <u>Emergency Stop</u> : 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 both the auger and treadmill motors to ensure a controlled and safe stop.
4.4 Usability Requirements			
4.4.1 <u>UI Simplicity</u> : 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
- Single Pole Single 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 (2)
- Nema 23 2.8A 1.26Nm

4.1.2 Design Decisions on CSCI Behavior

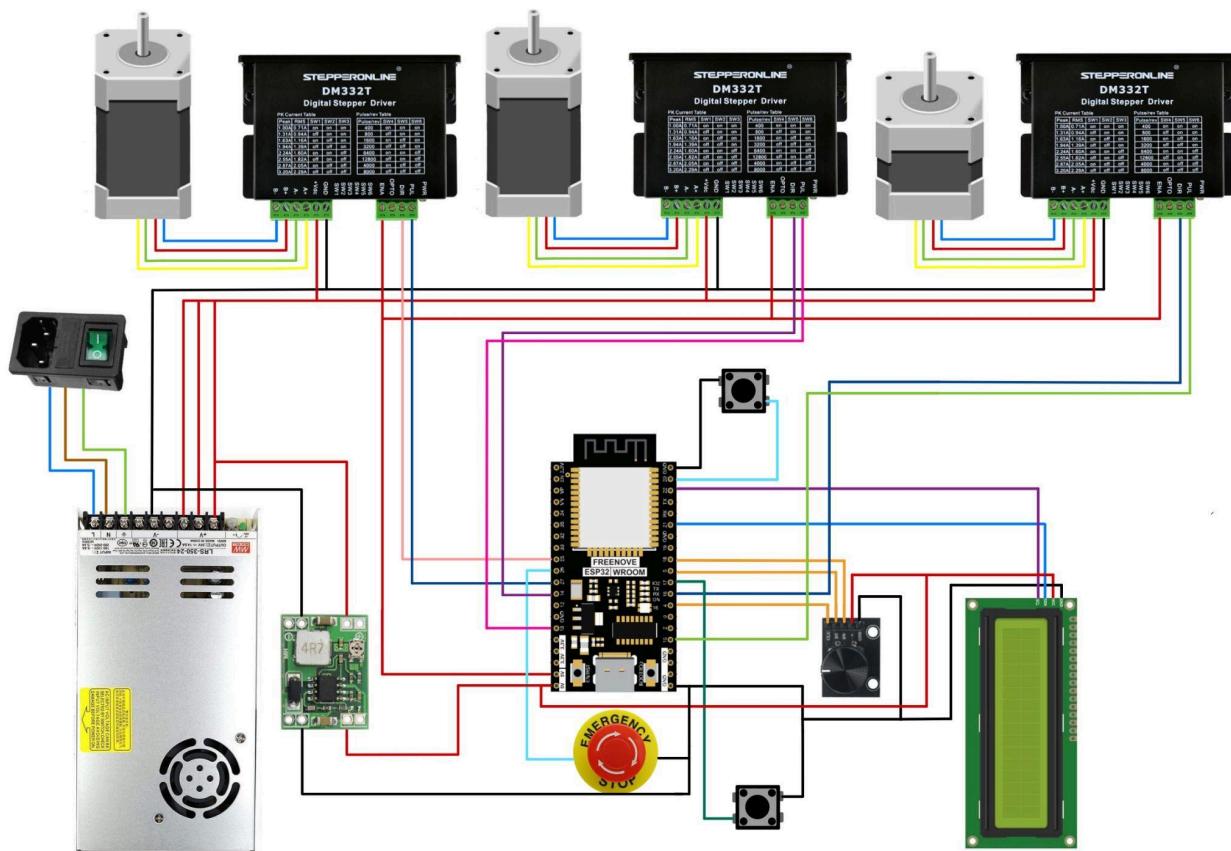
The Treadmill Ambulatory System is activated via a rocker switch. Upon powering on, all components are initialized, and the LCD displays a menu with two options: Speed and Harness. Users can navigate the menu using a rotary encoder and select a mode by pressing the encoder button. In Harness mode, the 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 and auger speeds 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, auger, 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:



Pin Assignment

Component	Pin Name	Microcontroller Pin	Signal Type
I2C LCD	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
Auger Motor	Pulse	GPIO13	Digital Output (Pulse)
	Direction	GPIO14	Digital Output
	Enable	5V	Power
Harness Motor	Pulse	GPIO15	Digital Output (Pulse)
	Direction	GPIO16	Digital Output
	Enable	5V	Power
Momentary Switch	Signal	GPIO19	Digital Input
	GND	GND	Common Ground
DPDT Switch	Signal	GPIO2	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, auger, 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 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

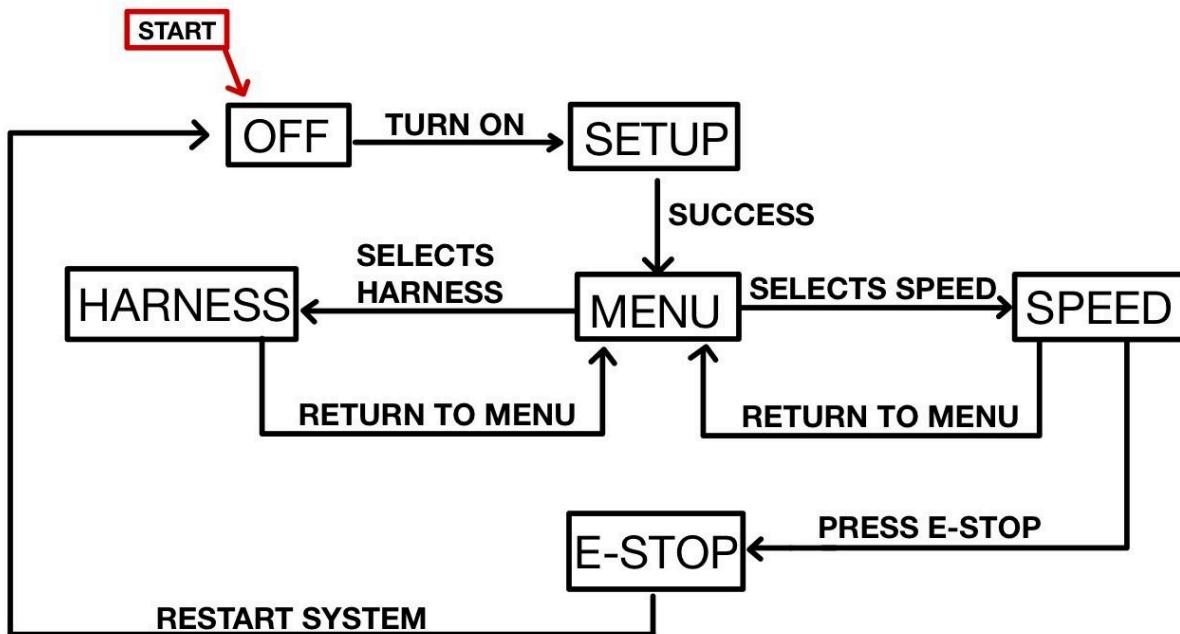
- Executes the selected menu action, switching modes (SPEED_MODE or HARNESS_MODE) and updating the LCD.
-
- **Void displayMenu()**
 - **Status:** Developed
 - Displays the menu on the LCD with the current selection highlighted.
-
- **Void handleSpeedMode()**
 - **Status:** Developed
 - Adjusts treadmill and auger speeds 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 auger and treadmill motors, as well as raise the harness.
-
-
- **Void updateLCD()**
 - **Status:** Developed (Not Implemented)
 - Calculates the speed (m/s) of the treadmill and displays on the LCD.
-
-
- **Void handleHarnessMode()**
 - **Status:** Developed
 - Controls the harness motor with the input of two momentary switches (clockwise or counterclockwise). User is able to set a saved position on the harness, this is for the eStopProcedure() logic.
-
-
- **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

State Machine: Treadmill Ambulatory System



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 & Auger simultaneously
- Serial Monitor displays speed of treadmill (m/s)
- E - Stop can be pressed in this state
- Capable of returning to Menu Selection

E - Stop:

- Slowly decelerates Auger & treadmill
- 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 (3)
- Nema 23 4.2A 3Nm (2)
- Nema 23 2.8A 1.26Nm
- I2C LCD
- Rotary Encoder
- Momentary Switch
- SPST Switch (Emergency Stop)

TAS Main

Status: Partially Developed

Interfaces with:

- Freenove ESP32 Wroom
- DM332T Digital Steppers (3)
- Nema 23 4.2A 3Nm (2)
- Nema 23 2.8A 1.26Nm
- I2C LCD
- Rotary Encoder
- Momentary Switch (3)
- SPST 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 (2)
- 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
- SPST 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 (2)
- 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 (2)
- 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: Partially Developed

Waiting for completion of the system to finalize operations and instructions.

Owner's/Operator's Manual for Rat Treadmill

Instructions for Use, Maintenance, and Safety



THE
RATSTRONAUTS

Revision B

Date of Issue: 03/04/2025

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4. Installation and Setup	8
5. Operating Instructions	10
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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.

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**



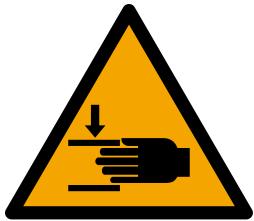
- Aggregate used in the treadmill may collect or clump in the hoppers, especially during heavy or prolonged use. While it might be tempting to manually guide or clear these accumulations, doing so places hands and fingers at risk of being trapped or pinched by the moving mechanical components.
- **Do 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 auger 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 auger assembly.

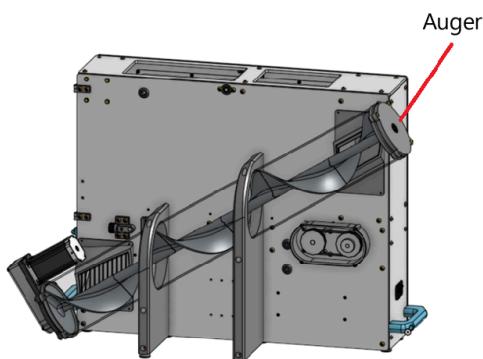
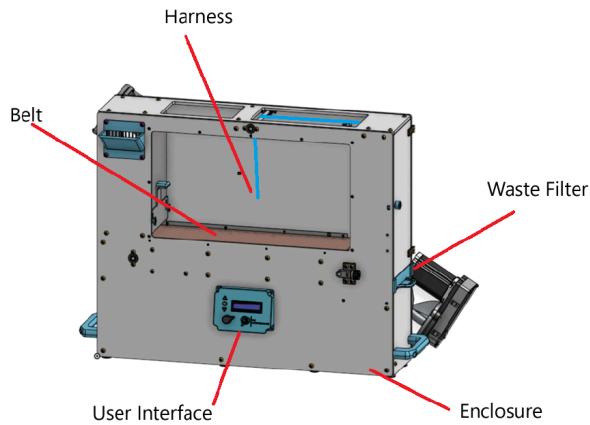
- **W024 – Crushing of hands/Danger of crush injuries**



- 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 abigulatory 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.
- Auger - Recirculates the aggregate to be redispersed over the treadmill.

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 **1100 × 400 × 660 mm [43.3" × 15.7" × 26.0"]** 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 confirm the auger and circulation system are working correctly. Introduce a small amount of aggregate to observe its flow and check for clogging or uneven distribution. Make any necessary adjustments before conducting formal experiments.

5. Operating Instructions

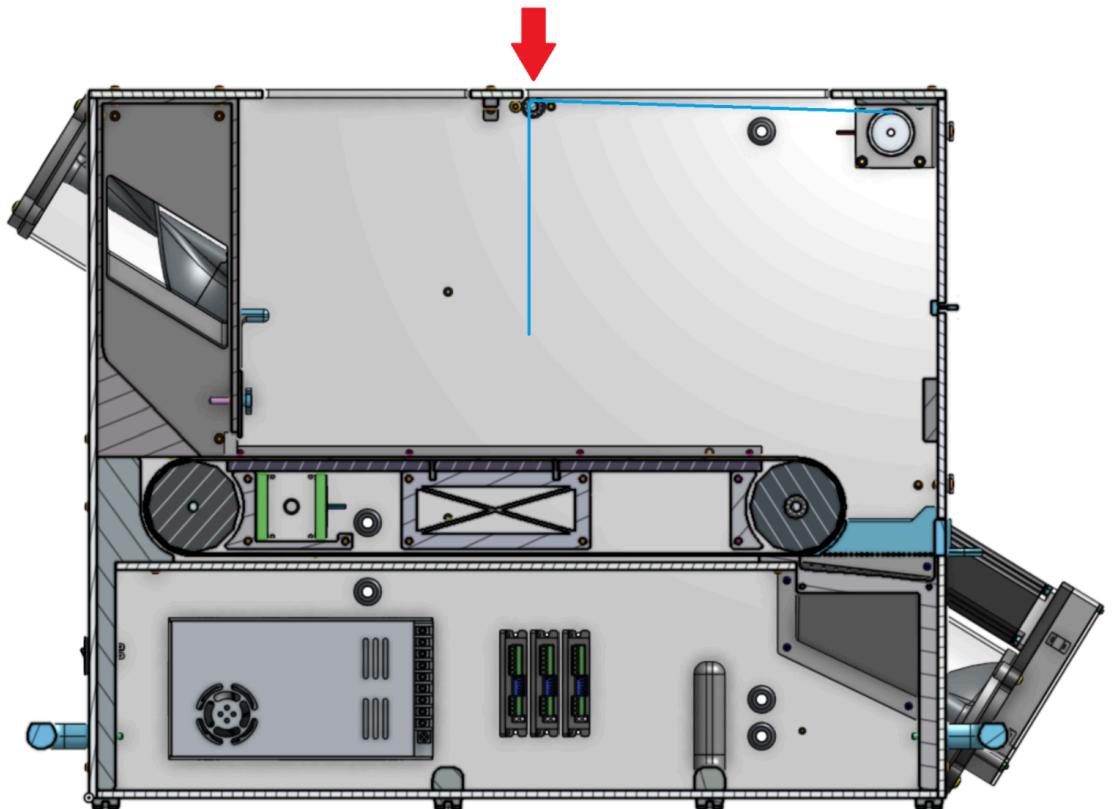
- **Starting the System**

- 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.
- Loading Aggregate
 1. Load the upper hopper using the **blue** fill port on the top left of the front panel and the supplied filling cup.
 2. Power on the treadmill as per Powering On instructions.
 3. Run the treadmill's speed mode.
- Removing Aggregate
 1. Remove the Filter
 2. Insert the aggregate collector
 3. Run the treadmill's speed mode until a majority of the aggregate is removed from the system.
- 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
 - c. Tighten the thumbscrews.
 2. Turn on the treadmill using the powering on procedures

3. Run the treadmill for a few minutes 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 XXX
- Clip the harness into the **BLUE** chord using the carabiners. Ensure the chord is threaded properly. See Fig. XXXX for reference.



- **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:

Aggregate Collection

- **Observation:** Over time, aggregate can collect in hoppers, along the belt edges, or around the auger.
- **Procedure:**
 1. **Power Down:** Turn off the treadmill and wait for all moving parts to stop.
 2. **Remove Excess Aggregate:** Use a small, soft brush or vacuum to collect any loose aggregate around the hoppers and belt.
 3. **Dispose or Recycle:** Dispose of or recycle aggregate as per your lab's guidelines.

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.

Belt and Pulley Checks

- **Inspection:**
 1. Ensure the treadmill belt is tracking correctly (running true) and has proper tension.
 2. 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 buckles, 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 auger, hoppers, and ducting, potentially causing clogs or uneven flow.
- **Procedure:**
 1. **Power Down and Unplug:** Ensure the treadmill is off and disconnected before cleaning.
 2. **Open Accessible Panels:** Follow the steps in the "Maintenance" section to safely remove or open panels.
 3. **Vacuum or Brush:** Use a vacuum with a HEPA filter or a soft brush to remove fine dust buildup.
 4. **Recheck Seals:** Verify that seals and gaskets are intact to prevent further leakage or dust escape.

Belt Replacement

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

1. **Power Down and Unplug**
 - For safety, **disconnect the treadmill from its power source** before performing any maintenance on the drive system.
2. **Release Tension on the Treadmill Belt**
3. **Remove the Front Tensioner**
 - Remove the blue knob.
4. **Remove Front Screws**
 - Unscrew the front panel to gain full access to the belt path.
5. **Remove 12 remaining screws attaching the upper hopper.**
 - Locate and remove these 12 screws securing the front panel/frame.
6. **Remove Front Panel**
 - Gently lift the front panel away from the unit.
7. **Remove the Upper Hopper**
 - Remove the Antenna if not already removed.

- Bend the top panel to allow the upper hopper to come out.

8. Replace Belt

- Slide the old belt off the rollers. Carefully position the new belt on the drive and idler rollers.

9. Reassemble

- Reverse the above steps to reattach the front panel and to re-secure screws.
- Retighten and adjust the belt tension.

10. Final Check

- Power on the treadmill briefly to ensure the belt runs smoothly and aligns properly.

7. 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 or idler assembly** 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, 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:** (Provide exact measurements if available)
- **Weight:** (Provide approximate weight in kilograms/pounds)

Power Requirements

- **Voltage:** (e.g., 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

- **Particle Sizing:** Use regolith or aggregate with a **sieve size of XXXX or smaller.** Larger particles may clog the internal auger or circulation system.
 - **Recommended Volume:** (Provide maximum volume or mass if known)
 - Overfilling the hoppers can lead to jams or uneven distribution.
-

8. Appendices

- **Calibration Logs**
 - Tables for Recording Adjustments and Maintenance
- **Detailed Diagrams**
 - Exploded Views of Components
- **Parts List**
 - Replacement Parts
- **References**
 - Any Scientific or Manufacturer Documents Used in Development
 - ISO 7010 an International Organization for Standardization technical standard for graphical hazard symbols on hazard and safety signs.

This section will be finished for the final TDP

9. Revision History

- Rev A - Created Owners Manual
 - Rev B - Updated Procedures, added Figures.
-

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	$F = m \cdot g_{moon}$	Excel

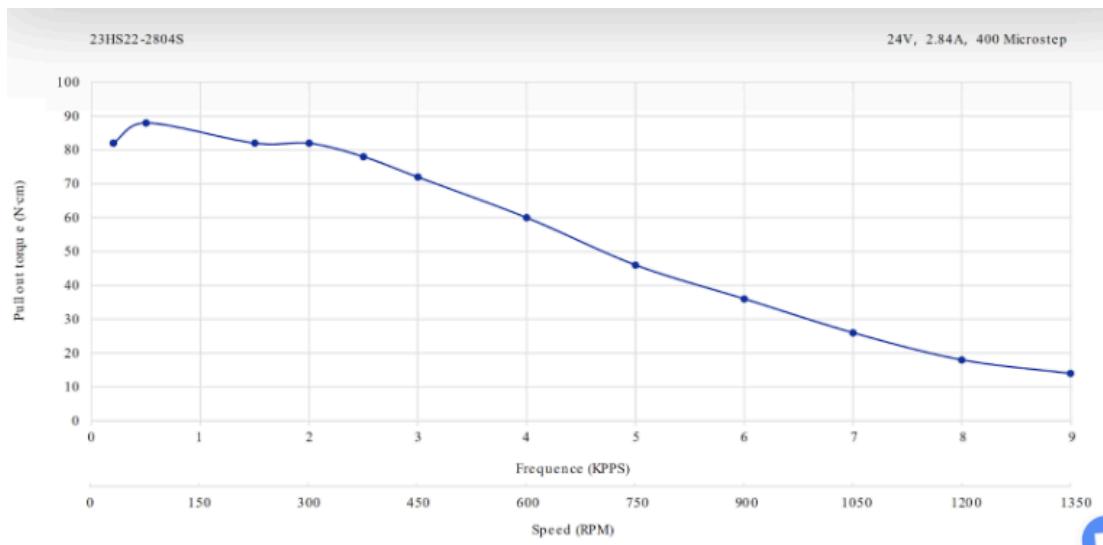
Harness Analysis:

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.

5.0 Verification Documentation

Treadmill Ambulatory System Verification Test Procedure	
<p style="text-align: center;">Treadmill Ambulatory System (TAS) Verification Test Procedure Team 25005</p>	
<p style="text-align: center;">March 4, 2025 REV B Prepared for UA Dept. of Biomedical Engineering</p>	
<p style="text-align: center;">Description of Changes</p> <p><u>Rev A:</u> 01/28/2025 - Initial Release <u>Rev B:</u> 03/04/2025- Second Release with Updates</p>	
<p style="text-align: center;">Table of Contents</p> <p>Section 5.1 Acceptance Test Descriptions Section 5.2 Acceptance Test Data Sheets</p>	

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 auger 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	<u>Recirculation:</u> 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, 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	<u>External Antenna:</u> 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	<u>Harness Weight:</u> 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 the stepper motor with 3D printed higher pulley walls.
5. Attach the string to the pulley on the motor.
6. Start with 500g weight, attached 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

5.1.4.1 Rat Waste Filter Acceptance Test

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 “rat 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

5.1.5.1 Treadmill Velocity Acceptance Test

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 in 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.	<u>Emergency Stop:</u> 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

5.1.7.1 Aggregate Thickness Acceptance Test

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 or 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 Gravity Simulation Acceptance Test

5.1.8.2 Introduction: This procedure outlines the acceptance criteria for the gravity simulation functions 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 UI subsystem to successfully position the rat harness according to either a lunar or Martian gravity input.

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

5.1.8.4 Required Test Equipment: Arduino IDE, ESP32, Treadmill Assembly, Stepper Motor Stepper Motor (23HS22-2804S), Stepper Driver (DM332T), Harness, Paracord Emergency Stop Switch, Rotary Encoder, LCD Screen, Force Gauge, PCB Rev B/C.

5.1.8.5 Table of Tests:

Test #	Test	Requirement
4.2.3	Lunar and Martian gravity settings.	<u>Gravity</u> : The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity

5.1.8.6 Step-By-Step Procedure:

1. Ensure PCB has the correct components mounted onto it.
2. Turn on the treadmill with the power switch on the side of the assembly.
3. Secure the rat replica, a realistic version filled to an appropriate rat weight, into the harness.
4. Navigate the LCD menu to the gravity settings.
5. Press the rotary encoder knob and choose the lunar gravity setting.
6. Wait for the harness to adjust based on the setting.
7. Following the adjustment, attach a force gauge to the harness to determine the force on the rat.
8. Ensure that the force gauge reflects lunar gravity, then repeat steps 5-8 with Martian gravity setting.

9. If the force gauge reflects the correct gravity for the lunar and Martian gravity settings, the test will have passed.

5.1.8.7 Support Requirements:

- 4.1.3 The enclosure shall have a hanging harness that can hold 1kg of weight.
- 4.4.1 The user interface shall simple to use and react upon input
- 4.4.5 The system shall plug into a 120 Volt wall adapter to power the system.

5.1.9.1 System Weight Acceptance Test

5.1.9.2 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.

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

5.1.9.4 Required Test Equipment: Fully assembled treadmill, scale.

5.1.9.5 Table of Tests:

Test #	Test	Requirement
4.4.2	Weight	<u>System Weight:</u> The treadmill shall weigh less than 34.02 kilograms

5.1.9.6 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.

5.1.9.7 Support Requirements:

- N/A

5.2 Acceptance Test Data Sheets

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: Auger	Part Number: AUG-011		
	AUG-012		
	AUG-013		
	Part Number: FIL-001		
Name: Filter		Part Number: PUR-001	
Name: Treadmill Belt		Part Number: TRD-003	
Name: Leveling Bar			
Results (Pass / Fail):		Date of Test:	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Computations, (Include Analyses Results, if any):			

Signatures:

Tester _____ Customer: Dr. David Margolis

Antenna Acceptance Test

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

Table below is direct representation of grid inside the field

Pass	Pass	Pass	Pass
Pass	Pass	Pass	Pass

Signatures:

Tester: Avery Miller Customer: Dr. David Margolis

Harness Weight Minimum Acceptance Test

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

Harness Test	
Weight (g)	Passed
100	<input checked="" type="checkbox"/>
200	<input checked="" type="checkbox"/>
300	<input checked="" type="checkbox"/>
400	<input checked="" type="checkbox"/>
500	<input checked="" type="checkbox"/>
600	<input checked="" type="checkbox"/>
700	<input checked="" type="checkbox"/>
800	<input checked="" type="checkbox"/>
900	<input checked="" type="checkbox"/>
1000	<input checked="" type="checkbox"/>

Signatures:

Tester: Juan Campista

Customer Dr. David Margolis

Rat Waste Filter Acceptance Test

Acceptance Test Data Sheet (4)																																																																													
<p>Referenced ATP Paragraph Number:</p> <p>4.3.2 The system shall have a filter screen for rat waste, being able to catch pellets between 1-2 cm in length</p>																																																																													
<p>Analysis Referenced (for verification by T/A): none</p>																																																																													
<p>Name of Test: Rat Waste Filter Test</p>																																																																													
<p>Unit Under Test (UUT):</p>																																																																													
<p>Name: Filter</p>			<p>Part Number: FIL-001</p>																																																																										
<p>Results (Pass / Fail):</p>			<p>Date of Test: 11/21/2024</p>																																																																										
<p>Recording of Test Measurement:</p> <ul style="list-style-type: none"> - Filter Accuracy 	<p>Requirement (SRD, with Tolerances):</p> <ul style="list-style-type: none"> - 100% filtration 	<p>Test Equipment Error:</p> <p>n/a</p>	<p>Adjusted Test Limit: n/a</p>																																																																										
<p>Computations, (Include Analyses Results, if any):</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th colspan="6" style="background-color: #002060; color: white; text-align: center;">Rat Filter Acceptance Test</th> </tr> <tr> <th>Cups of Aggregate</th> <th>Weight of Aggregate (g)</th> <th>Number of "rat waste" before filter</th> <th>Number of "rat waste" after filter</th> <th>Accuracy of Filter</th> <th></th> </tr> </thead> <tbody> <tr><td>3</td><td>695</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>694.2</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>693.5</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>694.8</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>695.3</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>694.2</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>693.8</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>694.5</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>693.9</td><td>10</td><td>10</td><td>100%</td><td></td></tr> <tr><td>3</td><td>696.7</td><td>10</td><td>10</td><td>100%</td><td></td></tr> </tbody> </table>						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%	
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																																																																									
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3	693.9	10	10	100%																																																																									
3	696.7	10	10	100%																																																																									

Signatures:

Tester: Avery Miller, Will Stephenson Customer: Dr. David Margolis

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)					Treadmill Acceptance Test Results (Timer)				
RPM	$V = \frac{RPM \times \pi \times Diameter (Roller)}{Conversion Factor \times 60}$	Serial Monitor	% Accuracy	% Error	Seconds / 5 Laps	$V = \frac{Distance Traveled (m)}{Time (s)}$	Serial Monitor	% Accuracy	% Error
12	0.047877872	0.05	95.75574408	4.244256	127.06	0.047977334	0.05	95.954667	4.04533
24	0.095755744	0.1	95.75574408	4.244256	63.66	0.095758718	0.1	95.758718	4.24128
38.8	0.15480512	0.16	96.75319975	3.2468	39.23	0.155391282	0.16	97.119551	2.88044
49.9	0.199092151	0.2	99.54607562	0.453924	30.38	0.200658328	0.2	100.32916	0.32916
62.5	0.249363917	0.25	99.74556675	0.254433	24.32	0.250657895	0.25	100.26316	0.26315
74.3	0.296443824	0.3	98.81460813	1.185392	20.44	0.298238748	0.3	99.412916	0.58708
86.4	0.344720679	0.35	98.49162248	1.508378	17.69	0.34460147	0.35	98.457563	1.54243
100.3	0.400179214	0.41	97.60468629	2.395314	15.04	0.405319149	0.41	98.858329	1.14167
112.6	0.449254033	0.45	99.83422948	0.165771	13.61	0.447905952	0.45	99.534656	0.46534
123.4	0.492344117	0.5	98.4688235	1.531177	12.3	0.495609756	0.5	99.121951	0.87804
132.5	0.528651504	0.55	96.11845523	3.881545	11.31	0.538992042	0.55	97.998553	2.00144
147.2	0.587301897	0.6	97.88364951	2.11635	10.31	0.591270611	0.6	98.545102	1.45489
158.7	0.633184858	0.65	97.41305504	2.586945	9.49	0.642360379	0.65	98.824674	1.17532
170.5	0.680264765	0.69	98.58909641	1.410904	9.05	0.67359116	0.69	97.621907	2.37809
184.9	0.737718212	0.75	98.36242823	1.637572	8.29	0.735343788	0.75	98.045838	1.95416
195.4	0.77961135	0.8	97.45141872	2.548581	7.91	0.770670038	0.8	96.333755	3.66624
Average % Accuracy Average % Error					Average % Accuracy Average % Error				

Emergency Stop Acceptance Test

Acceptance Test Data Sheet (6)			
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			
Analysis Referenced (for verification by T/A): none			
Name of Test: Emergency Stop Test			
Units Under Test (UUT):			
Name: Auger	Part Number: AUG-011		
	AUG-012		
	AUG-013		
	Name: Filter		
	Part Number: FIL-001		
	Name: Treadmill Belt		
Name: Rat Harness		Part Number: PUR-001	
Name: Emergency Stop Button		Part Number: PUR-002	
Name: Harness Motor		Part Number: ELC-005	
Name: Harness Motor		Part Number: ELC-003	
Results (Pass / Fail)		Date of Test: 11-15-24	
Recording of Test Measurement: n/a	Requirement (SRD, with Tolerances):	Test Equipment Error: n/a	Adjusted Test Limit: n/a

Computations, (Include Analyses Results, if any): n/a

Signatures:

Tester Alicia Enriquez and Juan Campista Customer: Dr. David Margolis

Aggregate Thickness Acceptance Test

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

Simulated Gravity Acceptance Test

Acceptance Test Data Sheet (8)			
Referenced ATP Paragraph Number: 4.2.3 The rat harness mechanism shall take gravity input from the user interface and adjust accordingly to simulate lunar or Martian gravity			
Analysis Referenced (for verification by T/A): Lunar Gravity: 1.625 m/s^2 Martian Gravity: 3.73 m/s^2			
Name of Test: Simulated Gravity Acceptance Test			
Units Under Test (UUT): Name: Harness Motor Part Number: ELC-003 Name: Stepper Motor Drivers Part Number: ELC-006 Name: Harness Part Number: PUR-002			
Results (Pass / Fail):		Date of Test: 3/27/25	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Computations, (Include Analyses Results, if any):			
Signatures: Tester: _____ Customer: Dr. David Margolis			

System Weight Acceptance Test

Acceptance Test Data Sheet (9)			
Referenced ATP Paragraph Number: 4.4.2 The treadmill shall weigh less than 34.02 kilograms			
Analysis Referenced (for verification by T/A): none			
Name of Test: System Weight Acceptance Test			
Units Under Test (UUT):			
Name: Treadmill System Name: Auger System Name: Electrical System Name: Filter System Name: Enclosure System Name: Purchased Parts		Part Number: TRD Part Number: AUG Part Number: ELC Part Number: FIL Part Number: ENC Part Number: PUR	
Results (Pass / Fail):		Date of Test: 4/1/25	
Recording of Test Measurement:	Requirement (SRD, with Tolerances):	Test Equipment Error:	Adjusted Test Limit:
Computations, (Include Analyses Results, if any): n/a			
Signatures: Tester _____ Customer: Dr. David Margolis			

6.0 Appendix

6.1 Code

```
#include <LiquidCrystal_PCF8574.h>
#include <AccelStepper.h>
#include <esp_sleep.h> // might change back

// Pin Definitions
#define encoderCLK 4
#define encoderDT 5
#define rotaryButton 18
// #define enablePin 12 // Enable pin FOR TREADMILL (optional)
#define treadDirectionPin 25
#define treadPulsePin 27
#define augerDirectionPin 14
#define augerPulsePin 13
#define harnessPulsePin 15
#define harnessDirectionPin 16
#define emergencyButton 26
#define clockwiseButton 17 //23
#define counterclockwiseButton 19 // 17

// LCD Settings
const int lcdColumns = 16, lcdRows = 2;
LiquidCrystal_PCF8574 lcd(0x27);

// Treadmill Settings
AccelStepper treadmill(1, treadPulsePin, treadDirectionPin);
int treadmillSpeed = 0; // Initial Treadmill Speed
const int maxSpeed = 1337; // Max Treadmill Speed
const int treadmillIncrement = 17; // Speed Adjustment Step

// Auger Settings
AccelStepper auger(1, augerPulsePin, augerDirectionPin);
int augerSpeed = 0; // Initial Auger Speed
const int augerMaxSpeed = 2044; // Max Auger Speed
const int augerIncrement = 26; // Speed Adjustment Step
```

```
// Harness Motor Settings
AccelStepper harness(1, harnessPulsePin, harnessDirectionPin); // Harness motor
bool positionSaved = false;
int setPosition = 0; // Saved position for harness adjustments
bool eButtonPressed = false;
unsigned long lastMoveTime = 0; // To track the last movement time
int count = 0; // Initialize the count for rotary encoder steps

// Menu Variables
enum Mode { MENU, SPEED_MODE, HARNESS_MODE } currentMode = MENU;
const String menuItems[] = {"SPEED", "HARNESS"};
int menuIndex = 0;
const int numMenuItems = 2;

// Rotary Encoder State
int lastCLKState = LOW;
unsigned long lastDebounceTime = 0;
const unsigned long debounceDelay = 50;

// Button Release Guard
bool buttonReleaseGuard = false;
unsigned long buttonReleaseTime = 0;
const unsigned long buttonReleaseDelay = 200; // Ignore button presses for 200ms

int eButtonState = 0;

void setup() {
    Serial.begin(115200);

    // Initialize LCD
    lcd.begin(lcdColumns, lcdRows);
    lcd.setBacklight(255);
    displayMenu();

    // Initialize Rotary Encoder Pins
    pinMode(encoderCLK, INPUT);
```

```

pinMode(encoderDT, INPUT);
pinMode(rotaryButton, INPUT_PULLUP);
pinMode(emergencyButton, INPUT_PULLUP);
pinMode(clockwiseButton, INPUT_PULLUP);
pinMode(counterclockwiseButton, INPUT_PULLUP);

// Treadmill Setup
treadmill.setMaxSpeed(maxSpeed);
treadmill.setAcceleration(2000);

// Auger Setup
auger.setMaxSpeed(augerMaxSpeed);
auger.setAcceleration(2000);

// Harness Motor Setup
harness.setMaxSpeed(800);           // Adjust max speed for smooth
operation
harness.setAcceleration(300);       // Set acceleration for smoother
transitions
harness.setSpeed(0);               // Initially, set the motor speed
to 0

lastCLKState = digitalRead(encoderCLK);
}

void loop() {
    static Mode previousMode = MENU; // Keep track of the previous mode

    if (currentMode == MENU) {
        if (buttonReleaseGuard && millis() - buttonReleaseTime >
buttonReleaseDelay) {
            buttonReleaseGuard = false;
        }

        if (!buttonReleaseGuard) {
            if (previousMode != MENU) {
                lcd.clear();
                displayMenu();
                previousMode = MENU;
            }
        }
    }
}

```

```
}

handleEncoderForMenu();
if (buttonPressed(rotaryButton)) handleMenuSelection();
}

if (treadmillSpeed > 0) {
    treadmill.runSpeed();
    auger.runSpeed();
}
} else if (currentMode == SPEED_MODE) {
    handleSpeedMode();
    if (treadmillSpeed && augerSpeed == 0) {
        if (buttonPressed(rotaryButton)) returnToMenu();
    }
} else if (currentMode == HARNESS_MODE) {
    handleHarnessMode();
    if (buttonPressed(rotaryButton)) returnToMenu();
}
}

void handleEncoderForMenu() {
    int currentCLKState = digitalRead(encoderCLK);
    if ((millis() - lastDebounceTime) > debounceDelay &&
currentCLKState != lastCLKState) {
        if (digitalRead(encoderDT) != currentCLKState) {
            menuIndex++;
        } else {
            menuIndex--;
        }
        menuIndex = constrain(menuIndex, 0, numMenuItems - 1);
        displayMenu();
        lastCLKState = currentCLKState;
        lastDebounceTime = millis();
    }
}

void handleMenuSelection() {
    lcd.clear();
    lcd.print(menuItems[menuIndex] + " SELECTED");
}
```

```
Serial.println(menuItems[menuIndex] + " SELECTED");
delay(1000);

if (menuIndex == 0) {
    currentMode = SPEED_MODE;
    lcd.clear();
    lcd.print("Speed Mode");
    treadmill.setSpeed(treadmillSpeed);
} else if (menuIndex == 1) {
    currentMode = HARNESS_MODE;
    lcd.clear();
    lcd.print("Harness Mode");
}
}

void displayMenu() {
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("MENU");
    lcd.setCursor(0, 1);
    lcd.print(menuIndex == 0 ? "-> SPEED" : "-> HARNESS");
}

bool buttonPressed(int pin) {
    if (digitalRead(pin) == LOW && (millis() - lastDebounceTime) >
debounceDelay) {
        lastDebounceTime = millis();
        return true;
    }
    return false;
}

void handleSpeedMode() {
    int currentCLKState = digitalRead(encoderCLK);
    if (currentCLKState != lastCLKState) {
        if (digitalRead(encoderDT) != currentCLKState) {
            treadmillSpeed += treadmillIncrement;
            augerSpeed += augerIncrement;
        } else {
```

```
treadmillSpeed -= treadmillIncrement;
augerSpeed -= augerIncrement;
}
treadmillSpeed = constrain(treadmillSpeed, 0, maxSpeed);
augerSpeed = constrain(augerSpeed, 0, augerMaxSpeed);
treadmill.setSpeed(-treadmillSpeed);
auger.setSpeed(augerSpeed);
lastCLKState = currentCLKState;
}

treadmill.runSpeed();
auger.runSpeed();
}

void eStopProcedure() {
eButtonPressed = true;
harness.setMaxSpeed(800);
harness.setAcceleration(300);

if (positionSaved) {
harness.moveTo(setPosition);
harness.runToPosition();
} else {
harness.moveTo(harness.currentPosition() - 200);
}

treadmill.setAcceleration(300);
auger.setAcceleration(300);

int currentTreadmillSpeed = treadmillSpeed;
int currentAugerSpeed = augerSpeed;

treadmill.setSpeed(-currentTreadmillSpeed);
auger.setSpeed(currentAugerSpeed);

unsigned long lastUpdate = millis();
int decelStep = 10;
int updateInterval = 30;

while ((currentTreadmillSpeed > 0 || currentAugerSpeed > 0) ||
```

```
harness.distanceToGo() != 0) {  
    if (millis() - lastUpdate >= updateInterval) {  
        lastUpdate = millis();  
        if (currentTreadmillSpeed > 0) {  
            currentTreadmillSpeed = max(0, currentTreadmillSpeed -  
decelStep);  
            treadmill.setSpeed(-currentTreadmillSpeed);  
        }  
        if (currentAugerSpeed > 0) {  
            currentAugerSpeed = max(0, currentAugerSpeed - decelStep);  
            auger.setSpeed(currentAugerSpeed);  
        }  
    }  
    treadmill.runSpeed();  
    auger.runSpeed();  
    harness.run();  
}  
  
treadmill.setSpeed(0);  
auger.setSpeed(0);  
lcd.clear();  
lcd.print("SYSTEM SHUTDOWN");  
lcd.setCursor(0, 1);  
lcd.print("RESTART REQUIRED");  
delay(5000);  
esp_sleep_enable_ext0_wakeup(GPIO_NUM_0, 0);  
esp_deep_sleep_start();  
}  
  
void returnToMenu() {  
    currentMode = MENU;  
    buttonReleaseGuard = true;  
    buttonReleaseTime = millis();  
    positionSaved = false;  
    eButtonPressed = false;  
    lcd.clear();  
    displayMenu();  
    Serial.println("Returned to MENU");  
}
```