DESIGN OF A DEVICE FOR SORTING BALL BEARINGS BY SIZE AND MATERIAL

A Final Report In MAE 4620

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Bachelor of Science in Mechanical Engineering

By

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On our honor as University students, We have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Report Assignments.

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Problem Statement

The goal of this project was to create a device that autonomously sorts ball bearings based on size and material. This project is for the 2025 American Society for Mechanical Engineers Student Design Competition and specifications for the device were followed according to the rules and restrictions of the event (ASME, 2025). For the competition, the device must sort a specific amount of ball bearings without any jams or escaped bearings. Any escaped bearings or jams will result in lost points on our overall score. Once sorted, the ball bearings should be dispensed into their designated packaging stations to be scored by the competition judges. The main objective of this device is to maximize speed and efficiency without jeopardizing accuracy. To conquer this, the device first sorts ball bearings by size with a dual track system, then identical sorting mechanisms (conductivity and magnetism) are used in parallel to decrease the time needed for sorting. Size separation is consistently accurate, however due to constraints with the conductivity sorting mechanism, there are inconsistent results that will be discussed later in this report.

Applications for such a sorting device include assembly lines, warehouses and many other different industries. Similar design principles that are used in our device could be used in industrial assembly lines, where multiple actions such as sorting and packing must be done as quickly as possible without errors. By automating the sorting process, we are relieving the workers from the task and allowing them to focus on other work at hand. In addition, manually sorting the bearings has an increased risk of incorrect placement but by using an automated device, this will ensure not only accuracy but also efficiency.

Background Research of Automated Sorting Mechanisms

To optimize the automation of an error-free sorting and packaging device, our group independently researched various aspects of how people have used automated systems to organize material. While we found a few devices that used various engineering methods to organize different types of materials, finding devices that sorted ball bearings proved to be more difficult. This prompted us to review a broader range of engineering devices designed for sorting material.

The first technology that we researched was coin sorting devices. The US4995848A patent for a coin sorter provided useful information about the tubes that the coins travel through to get to their packing station (Goh, 1991). In this design, the tubes get wider as they go farther down, to avoid jams. This design made it clear that the biggest problem with sorting is avoiding jams. Another way in which this specific patent avoided that problem was to have the coins travel the smallest distance possible before reaching their packing stations.

We also explored sorting methods like the separation of scrap metal (Metal Recycling, 2024). A common way to separate material in scrap yards is using magnets. Of the three materials that our bearing sorter needs to separate, steel is the only one that is magnetic. This is a simple and proven method to separate the steel bearings that we applied to this project. Other common methods for sorting scrap metal is through weight, reflectivity, and conductivity.

The most pertinent device that our group found was a ball bearing sorter (NDT Technology, 2024). This device uses a variety of advanced tools to sort ball bearings by their material components. At its most efficient pace the device can sort at least 10 smaller diameter ball bearings per second, and up to 6 larger ball bearings per second. Another important feature of the device was a transportation disk that loads up ball bearings to the start of the track. We found this approach to be quite interesting as it provided a blueprint for loading up multiple ball bearings to the start of our track.

Ultimately, the research we have conducted has been valuable for shaping ideas and inspiring the design of our final device. However, that does not mean every concept we explored was utilized in our final design. Our group carefully reviewed and discussed each idea until we found the best approach to move forward in our design process.

Ideation: Various Potential Design Concepts

Based on the ideas mentioned in the above section during research, we brainstormed several different ideas on sorting mechanisms and design concepts and then tested their feasibility. After preliminary testing of a variety of different concepts, a compiled list was made to rank the most viable options and is shown in Fig. 1 along with brief descriptions of each concept below.

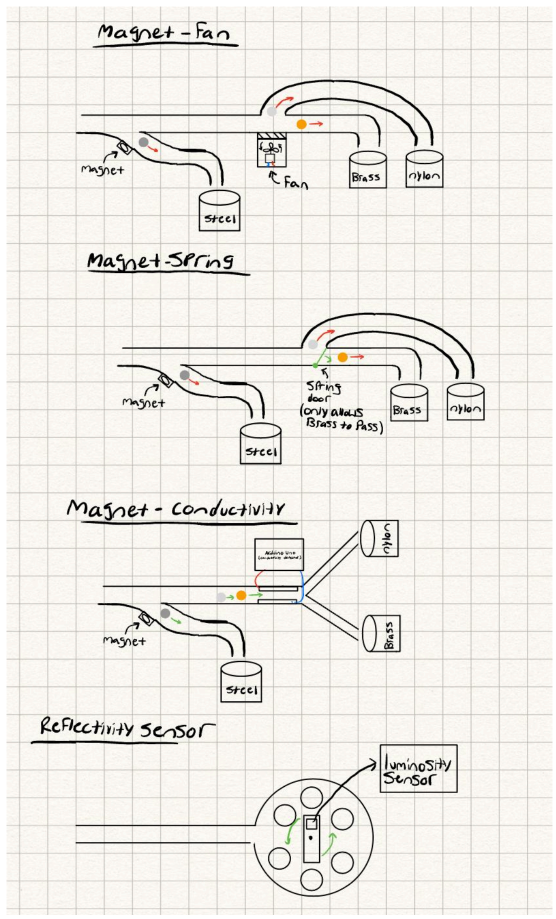

Figure 1: Initial Design Concepts

Magnet - Fan: Initially separate out steel bearings with a magnet, then use a fan to push the lightweight nylon bearings and separate them from the brass.

Magnet-Spring: Separate out steel bearings with a magnet, then use a spring loaded door with a spring stiffness to only allow brass bearings through

Magnet-Conductivity: Separate out steel bearings with a magnet, then measure the conductivity of the nylon and brass bearings and when the brass bearings complete the circuit they will be sorted accordingly.

Reflectivity Sensor: A reflectivity sensor that detects the amount of light each of the bearings reflect and sorts them accordingly.

Explanation to selected criteria and weightings

The weightings for the concepts are defined to favor a design with the highest speed and accuracy of sorting. The goal is to maximize the efficiency of the device without jeopardizing precision. Aesthetics are also a concept criterion because this design is ultimately going to take part in the ASME Student Design Competition where its appearance will represent the University, and therefore we want to ensure that the design is user friendly and visually appealing. In a wider context, this would also increase customer interest and marketability. Other factors in the criteria are ease of manufacturing, maintenance, and fragility. The manufacturability of the design is important to ensure that the device can feasibly be built with the resources available to us at the University. The upkeep of the sorting device will be kept at a minimum, however regular maintenance will be necessary to keep the machine functioning properly and the accessibility of performing this maintenance is an important design concept. The fragility and ruggedness of the device is a consideration largely because it will need to withstand travel from Charlottesville, Virginia to St. Louis, Missouri in a personal vehicle without impacting the functionality of the device.

The least weighted concepts were size and energy consumption because the overall size of the device should be compact, but the competition states the device needs to be 20” x 20” x 20” or smaller, so we already anticipate meeting this criterion (ASME, 2023). When considering the energy consumption of the device, it will function off of rechargeable batteries and not consume a large amount of energy, and therefore it was assigned the smallest weight in ranking the criteria. Despite the idea of using conductivity ranking fourth overall, we decided to move forward with this design. This decision was based on the testing data from proof of concept prototypes that we made to test different methods, including separation with a fan, which produced poor results. The prototypes for magnetic and conductive separation, however, worked extremely well. We decided to combine ideas C, A’, and C’ (as described in Table 1 in the following section) by using a wheel to control the flow of bearings, separate out the steel bearings using a magnet, then finally separating the brass and nylon using conductivity.

Preliminary Idea Selection and Screening

After developing the design concepts and selected criteria we organized the ideas into a screening matrix in order to rank them and select the best one. This was done by choosing criteria that were imperative to our design, things such as speed, size, and accuracy, and then ranking each idea based on how we thought it would perform in the criteria. To rank the concept variants, ratings of “+”, “-”, or “0” were used to count the advantages, disadvantages or neutral effects on the selection criteria. For example, concept variant A was given a “+” for the speed criteria which indicated that it would have a positive effect on speed. However, concept A was given a “0” for manufacturing ease which meant that was not a major impact for this concept. Lastly, if the concept variant was given a “-” then it meant that there was a disadvantage for that selection criteria. After ranking each concept, the sum of all the +, -, and 0’s were taken and then used to rank them to determine if the concept should be pursued or not. A key of the concept variants can be found below, followed by Table 1 with the results of the screening matrix.

Table 1. Initial Concept Screening

	Concept Variants							
Selection Criteria	**A**	**B**	**C**	**D**	**E**	**F**	G	**REF**
Speed of Sorting	+	+	0	-	+	-	+	0
Size	+	+	+	0	+	+	+	0
Manufacturing Ease	0	0	-	-	-	+	-	0
Accuracy	0	0	0	-	+	0	+	0
Energy Consumption	+	+	+	0	-	+	0	0
Aesthetics/Fun!	+	+	+	+	-	-	-	0
Maintenance	+	0	-	-	-	+	+	0
Fragility	+	+	0	0	-	+	-	0
Pluses	6	5	3	1	3	5	4	
Minuses	0	0	2	3	5	2	3	
Net	6	5	1	-2	-2	3	1	
Rank	1	2	4	6	7	3	5	
Continue?	yes	yes	yes	no	no	yes	no	

Key

A	Sieve, magnets, fan
B	Sieve, magnets, spring door
C	Sieve, conductivity
D	Sieve, magnets, centrifugal force
E	machine learning camera sensor
F	weight sensor
G	Sieve, Luminocity
REF	Person
A'	Add wheel to separate balls one at a time
B'	Add wheel to separate balls one at a time
C'	Add magnets to separate steel first, then conductivity
FG	Use the luminosity sensor in combination with a scale

After ranking the concept variants from Table 1, some ideas were modified into hybrid designs that utilized the advantages from the original concepts found in Table 1. These new modified ideas combined the benefits across different designs. To further narrow down concept selection, each selection criteria was assigned a weight between 1-25 based on how important the criteria was to the final design. For example, the accuracy was weighted the heaviest with 25 versus the energy consumption and size of the device were weighted least at 5. Once these weights were assigned to the selection criteria, the concept variants were carefully screened and given a score based on how we thought it would perform in that area. Finally, the scores were tallied and given a weighted score based on their predicted performance and then ranked and results can be found in Table 2.

Table 2. Concept Screening of Modified Ideas

Concept Scoring	Concept Variants				
Selection Criteria	Weight	**A'**	**B'**	**C'**	**FG**
Speed of Sorting	20	5	5	4	2
Size	5	4	4	3	3
Manufacturing Ease	10	5	5	3	2
Accuracy	25	5	5	4	3
Energy Consumption	5	4	5	4	3
Aesthetics/Fun!	15	4	4	4	3
Maintenance	10	5	4	4	2
Fragility	10	5	5	3	2
Sum		37	37	29	20
Weighted Sum		4.75	4.7	3.75	2.5
Rank		1	2	3	4

Starting Baseline Specifications

The device specifications are based around the rules of the Student Design Competition and were key considerations during the design phase. Although some of the specifications would result in a decreased competition score, others would result in becoming disqualified from competing overall. Thus we adhered to these specifications during the design and manufacturing of the device. Our initial specifications, which were primarily based on the competition rules, are as follows:

Size and Geometry

1. The device needs to, at minimum. fit inside a 20” x 20” x 20” box (ASME, 2025).
2. The device will need to operate within the confinements of a 4’x4’ plot with a 2”x4” lumber barrier to prevent any runaway ball bearings.
3. The device will be light enough to carry including the weight of a 20”x20”x20” box.

Reliability

4. The device should not jam under typical usage conditions. This can be tested by continually running the machine to sort ball bearings until a jam occurs, or for a reasonably long amount of time.
5. The device should keep the ball bearings from escaping the device.
6. The device will require minimal set-up and maintenance to reset between attempts. Ideally this should be done in a minute or less.
7. The device will be able to withstand minor shocks and impacts. This is so that the device will not be damaged from minor mishaps such as dropping it a short distance when taking it out of the box or travel damage.
8. The device will have a place where it can be gripped and lifted from that is connected to the main supporting structure so that it can be moved into and out of the box easily by one person.
9. The device will need to be able to operate on a variety of challenge zones surfaces that could be soft, rough or carpeted.

Performance

10. The device needs to be able to sort the ball bearings at a minimum rate of 4 per minute in order to qualify, since the device needs to sort 40 ball bearings in 10 minutes in the initial testing of the competition. Sorting the bearings at a rate of ~20 per minute is ideal.
11. The device must be able to sort ball bearings with minor variations of size, shape, and weight.

Organization and Accessibility

12. The device will organize the bearings into six clearly labeled packaging stations, which can each hold 25 units of the designated material. The top of the packaging stations should be no more than one inch from the floor.
13. The device will need to allow for materials to be easily accessible for one team member to collect.
14. The device will have a design such that the ball bearings are at least partially visible at all times.
15. The device will have a unified loading hopper that all of the ball bearings will be poured into. The hopper should be able to hold a minimum of 80 ball bearings.
16. The device will have a clearly labeled and easily accessible switch designed to both begin and end all operations for the device

Technical

17. The device will be completely autonomous and functional at the flip of a switch.
18. The device will be powered by over the counter, dry cell batteries.
19. The device will have a control that clears all of the ball bearings from the device.

Financial

20. The device will be made of materials that have a cost of < $800.

Bearing Velocity Through Separation:

Each sorting component requires the bearings to be going at a specific speed in order to function at their highest level. Two things affect the speed of the balls in a standard track: the slope of the track, and where along the track they are located (bearings gain speed as they go down).

We used energy conservation equations to derive an equation to calculate the friction coefficient from the final velocity of the ball. We assumed no slip and no air resistance. We also assumed normal force is equal to the weight of the ball since the angle of the incline is relatively small (~8.7°). Derivations of the below equations can be found in Appendix A. The kinetic friction coefficient is represented by μ, acceleration due to gravity is g, the ball's initial height is h, the ball's final velocity is V, and the length of the path traveled by the ball is x.

$$\mu = \frac{gh - 0.7\,V^{2}}{xg} \tag{1}$$

$$V = \sqrt{\frac{10}{7}gh - xg\boldsymbol{\mu}} \tag{2}$$

We then tested each of the types of ball bearings on this track. For each trial, we released the balls from the top of the track at a height of 6 ¼" and timed how long it took the ball to travel 14 ¼" in a straight line after leaving the end of the track. We did five trials of each type of bearing and averaged our results to obtain an average final velocity for each. We then used Equation 1 to calculate coefficients of friction for each type.

Table 3: Experimental Friction Coefficients for ½” Bearings

1/2" Ball Bearings	**Steel**	**Brass**	**Nylon**
Average Final Velocity (m/s)	0.6587 ± 0.0246	0.6781 ± 0.0268	0.6236 ± 0.0225
Friction Coefficient	0.1196 ± 0.0501	0.1178 ± 0.0498	0.1127 ± 0.0506

Table 4: Experimental Friction Coefficients for ¼” Bearings

1/4" Bearings	**Steel**	**Brass**	**Nylon**
Average final Velocity (m/s)	0.7417 ± 0.0315	0.7772 ± 0.0343	0.7811 ± 0.0353
Friction Coefficient	0.1117 ± 0.0489	0.1080 ± 0.0484	0.1075 ± 0.0484

We then performed five additional trials of the ½” steel bearings starting from a height of 3 ¾”and compared the average velocity resulting from this test to the velocity that Equation 2 would predict using the friction coefficient we previously calculated. We did this in order to test the accuracy of our model.

Table 5: Results from Releasing ½” Steel Bearings at 3 ¾” Height

Average Experimental Velocity (m/s)	Calculated Velocity with Friction (m/s)	Calculated Velocity without Friction (m/s)
0.5706 ± 0.0188	0.4712	1.1554

Though the results did not perfectly match what our model predicted, they were reasonably close, with a percent difference of 19.1%. Our calculations that included friction were much closer to the experimental result than the calculation that assumes no friction.

Conductivity sorting

The brass and nylon bearings are sorted using a conductivity test. There are two contacts on the track followed by an actuator further down the track that will divert the steel and brass bearings down a different path than the non-conductive nylon bearings. As the balls roll over the contacts, if they are conductive, they will complete the circuit connected to a read pin on a microcontroller that will then activate the servo motor acting as a gate to direct the balls down a separate path. A prototype of this setup is shown in Figure 1.

Figure 2: Conductivity Sorter Prototype for ½” Bearings

The speed that the bearings need to be going is dependent on the distance between the contact and the actuator, the speed of the servo motor, and the amount of time that the servo motor stays in the alternate position (time of delay).

$$v_{min} = \frac{d}{0.0033\,s + t_d} \tag{3}$$

Equation 3 defines the minimum velocity of the balls where d is the distance between the contact and the actuator,t_d is the delay time, and 0.0033s is the amount of time that the servo motor takes to move the necessary 20^o.

Magnetic Sorting

The steel bearings are sorted out using magnetism. A prototype for this sorting mechanism is shown in Figure 2. The magnet on the side of the track pulls the steel bearings onto a separate path, while the brass bearings continue straight past the magnet and into their packing station.

Figure 3: Magnetic Sorter Prototype for ½" Balls

We designed and 3D printed an adjustable framework that allows us to vary the angle of the incline and tested which of the angles worked and did not work when the balls were released from the same location on the slope. Using Equation 4 provides calculated velocities that would result from releasing the balls on an incline of a given angle. This equation was adapted from Equation 2, where θ is the angle of incline of the ramp.

$$V = \sqrt{\frac{10}{7} gx\, sin(\theta) \; - \; xg\boldsymbol{\mu}} \qquad (4)$$

We tested a series of angles for the ½" and ¼" bearings and created a range of values that works for each size bearing, as listed in Tables 6 and 7.

Table 6: Estimating Lowest Speed that Works for ½” Magnetic Sorter

Distance Traveled (m)	Lowest Angle that Worked (°)	Friction Coefficient Used	Lowest Velocity that Works (m/s)
0.0597	15.4	0.12	0.390

Table 7: Estimating Highest Speed that Works for ¼” Magnetic Sorter

Distance Traveled (m)	Highest Angle that Worked (°)	Friction Coefficient Used	Highest Velocity that Works (m/s)
0.1143	18.5	0.11	0.620

There is a decent range of speeds where it seems that the prototypes for both sizes of ball bearings work. It is likely that in our final design both sizes of bearings will be going at similar speeds when they go through their respective magnetic sorters since they will be starting from about the same height and the magnetic sorters will both likely be at similar heights. Please note that the effectiveness of this design also depends upon the track geometry and position of the magnets relative to the track, so adjustment of these factors allows for this design to work when the balls are going at speeds that did not work with the initial prototypes.

Refined Specifications For Improved Performance

After testing and prototyping many different concepts, it was decided to regenerate specifications from our own criteria while still being based upon the competition rules. These final specifications allowed us to restrict our design in effort to improve the device beyond the given guidelines.

Operational Specifications (based on ASME Design Challenge rules):

1. The device needs to, at minimum. fit inside a 20” x 20” x 20” box.

2. The device needs to sort 40 ball bearings in 10 minutes at a minimum. Ideally it should sort 40 ball bearings in 1 minute. The goal is to have the device be as quick as possible
3. The device should not jam under typical usage conditions.
4. The device will keep all of the bearings contained within the device itself. Any escaped bearings will harm the competition score. Ideally no bearings escape. A margin of 2-3 escaped balls may be acceptable.
5. The device will be autonomous, as per the design challenge rules. It will be controlled by an ELEGOO Nano.
6. The device will have a design such that the ball bearings are at least partially visible at all times.
7. The device will be powered by rechargeable, over the counter, dry cell batteries.
8. The device should be rugged enough to withstand travel damages and slight jostling. This will be done by bolting each 3D printed part to an aluminum t-slotted frame.

Unified loading hopper:

1. The device will have a unified loading hopper that all of the bearings can be poured into at the start of the challenge .
2. The internal bottom edge of the hopper should be no greater than 1” from the ground.
3. The hopper should be able to hold a minimum of 80, ½” ball bearings.
4. The hopper is designed in such a way where it is closed (no bearings can fall out) until the device is turned on when the bearings will be released in the device.

Packing stations:

1. The device will organize bearings into 6 clearly labeled packing stations.
2. Packing stations will be easily removable.

3. Stations will be able to hold 25 ball bearings.

Separation wheel:

1. The wheel will be able to hold 20 bearings.
2. The wheel will transport bearings from the bottom of the ramp, up 10” where the bearings will exit onto the track.
3. The wheel is controlled by a DC motor rotating at a speed of 80 rpm, that is geared down to 2.5 rpm with a compound gear train (See Electronics specification 2). It will take 20 seconds for the wheel to transport all of the bearings from the ramp up to the track. At this speed, the bearings will be going onto the track slowly enough as to not clog the conductivity testing, but not so slow as to unnecessarily decrease efficiency.

Electronics:

1. The device will be controlled by an ELEGOO Nano. The code will provide controls on the speed of the DC motor, stepper motor, and servo motors.
2. The DC motor should operate with 3.6V applied to it using pulse width modulation from the ELEGOO Nano. The DC motor can operate under a range of 3-6V.
3. The stepper motor should rotate at a speed so that the hopper gate opens in 4 -5 seconds, where 4.5s is the ideal time.
4. The two servo motors should both have 5V applied to them. The range at which they can operate is 4.8-6V.

Separation devices:

1. The ½” ball bearings should pass through the magnetic sorting device at a speed greater than 0.390 m/s. The ideal speed is about 0.400 m/s.

2. The ¼” ball bearings should pass through the magnetic sorting device at a speed less than 0.620 m/s. The ideal speed is about 0.600 m/s.
3. The ball bearings should pass through the conductivity sorting mechanism at a minimum speed of: $v_{min} = \frac{d}{0.0033\,s + t_d}$, where d is the distance between the contacts and the servo motor, and t_d is the delay time in the servo.

Electronics

Fig. 4 shows the electronic connections for the four motors in the device. The ELEGOO Nano controls two DRV8833 drivers that control the DC and stepper motors. The two servo motors are controlled directly by the ELEGOO Nano. The driver for the DC motor is connected to pins capable of pulse width modulation, allowing for control over the voltage supplied to the motor. Further information and calculations about motor speeds will be provided in the Testing section.

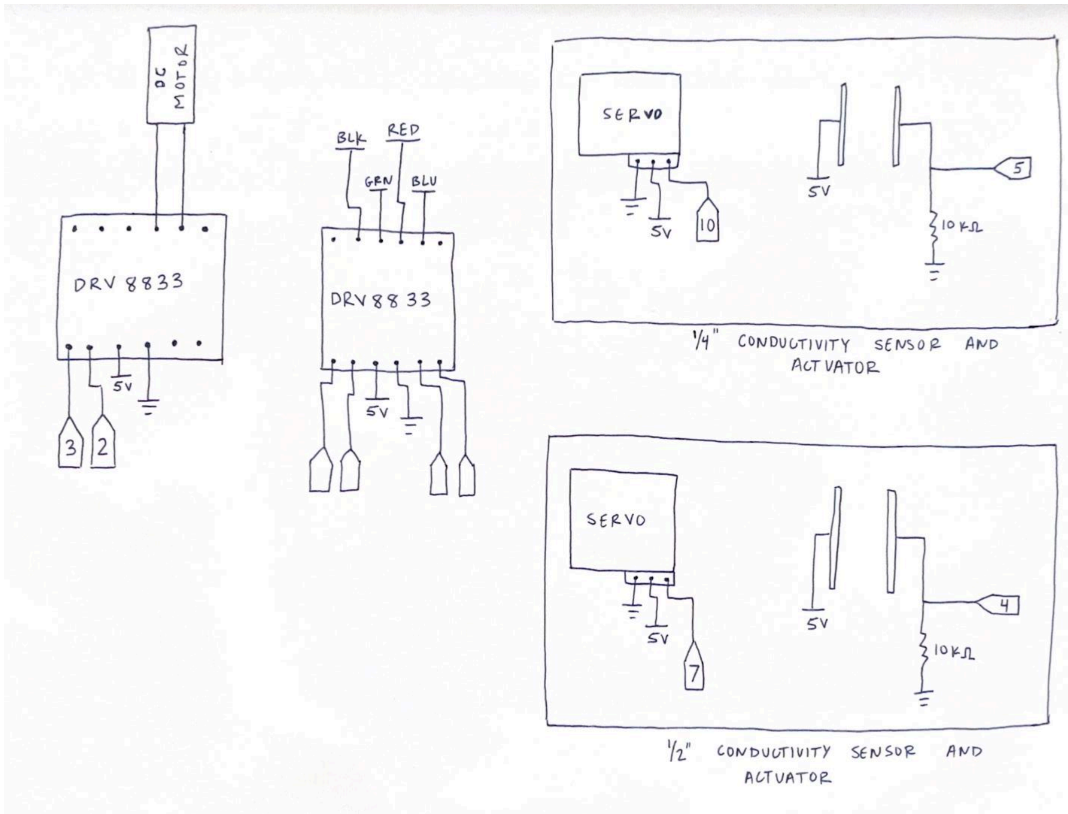

Figure 4: Master Circuit Diagram

The contacts, shown in Figure 4, act as conductivity sensors. The contacts are wired to be a completed circuit with an open switch. When a conductive ball bearings rolls over the contact, the circuit is completed therefore sending a “HIGH” output to the ELEGOO Nano read pin. This tells the controller to activate the servo motor to open the gate and redirect the conductive bearing to an alternate path.

Testing Automated Sorting Mechanisms

Modularity of the design is a key component in the testing process, and it allowed for the testing and alteration of specific components, without affecting other parts of the device. This section outlines the testing done to each component, and what changes were made as a result.

Hopper

The initial hopper design was a funnel shape, designed under the idea that the small exit hole would limit the flow of bearings and avoid major spilling or bouncing. This design, along with the final hopper design is shown below in Fig. 5.

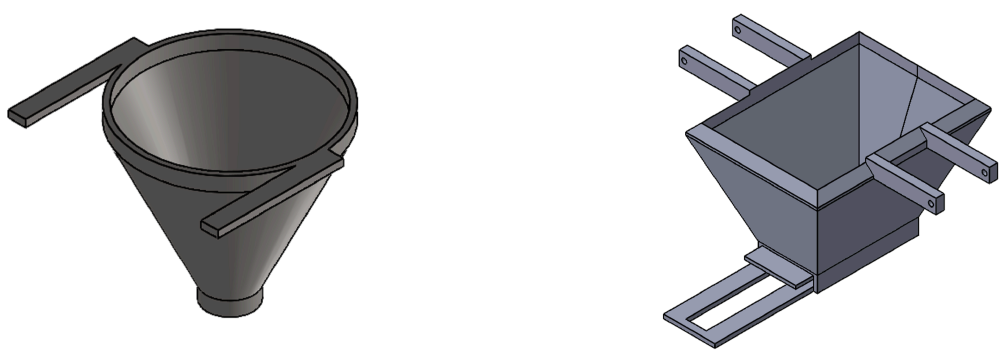

Figure 5: Initial (left) and Final (right) Hopper Designs

This initial design jammed almost immediately after bearings were poured in because the exit hole was only large enough for one ½" bearing. In theory, this would allow for one or two (if ¼") bearings to come out of the hopper at a time, giving a slow and easy flow of balls onto the ramp. In testing, however, we learned that limiting the exit hole will only increase risk of jams, and giving bearings plenty of room to move is the most reliable way to predict the flow. Another issue with this design are the cantilevered supports, which were too thin and poorly located. Using this new information, we designed a hopper supported by 4 thick cantilevered beams and a large rectangular exit hole and gate at the bottom of the hopper to allow multiple ball bearings to exit at once. The hopper also has a spring loaded gate, controlled by a stepper motor through a rack and pinion system, that opens slowly when the device is first turned on. This allows for a controlled flow of bearings leaving the hopper and dropping onto the ramp.

Ramp

The design flaws in the initial ramp are similar to that of the hopper: we did not provide enough room for the bearings to flow freely. The initial and final ramp designs are shown in Figure 6.

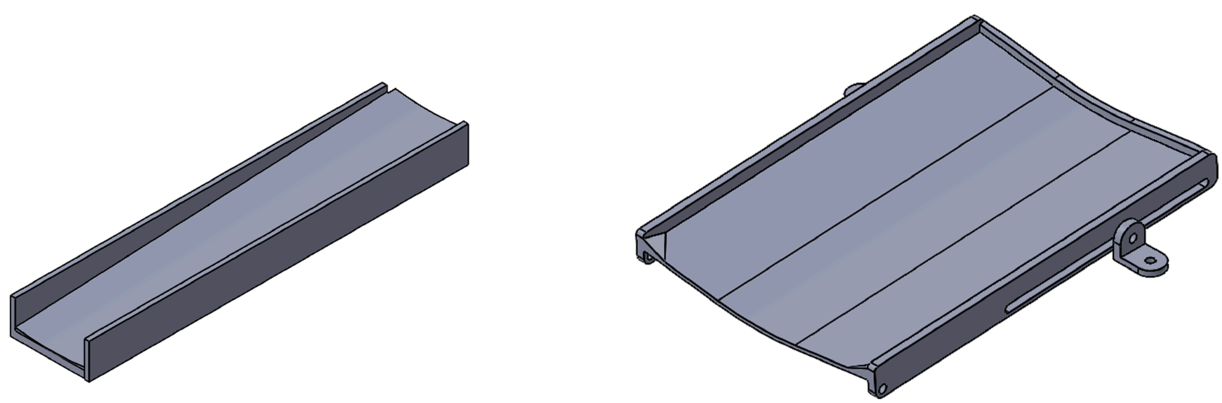

Figure 6: Initial (left) and Final (right) Ramp Designs

The first ramp design was too narrow and did not allow for a smooth flow of bearings out of the hopper. To remedy this, we made a wider ramp that follows the curvature of the wheel. The wide, curved ramp gives bearings more time in contact with the wheel which increases efficiency and probability that a bearing will enter every slot in the wheel, something that was not the case with the first ramp. The wider surface area of the ramp also eliminates the possibility of jams in the ramp. One final issue with the ramp was the surface texture. Because the ramp is 3-D printed, there were ridges along the top surface from each layer of filament. To address this we glued a thin piece of aluminum flashing to the ramp to create a completely smooth surface.

Wheel

The wheel serves two main purposes: first, to transport bearings from the base of the ramp up to the track, and second, to space out the bearings so that they can be sorted one by one. This was in part due to the fact that ASME guidelines specified that the bottom of the hopper must be less than 1 inch off the ground. Our group briefly considered an elevator design for transporting ball bearings at the start of the design process, which would likely be able to lift the bearings faster, but it would not space them out, making sorting impossible. Instead, the bearings enter slots in a rotating 10" diameter wheel tilted at an angle (6 degrees) with the back side blocked to allow ball bearings to rest in the slots of the wheel. At the top of the wheel, there is a gap in the back plate to the wheel, where the balls will fall out the back side and onto the ramp. These holes in the wheel are 0.52" in diameter and can easily hold both quarter inch and half inch bearings. Originally the wheel had 40 holes, but after testing, we limited it to 20 holes to slow down the flow of bearings onto the track, and to limit the weight on the wheel which decreases motor efficiency.

The wheel is controlled by a DC motor and the speed of the wheel is determined both by the voltage supplied to the motor, which we are able to alter through pulse width modulation from the ELEGOO Nano, as well as the gear train that connects the motor to the wheel. The gear train is shown in Figure 7.

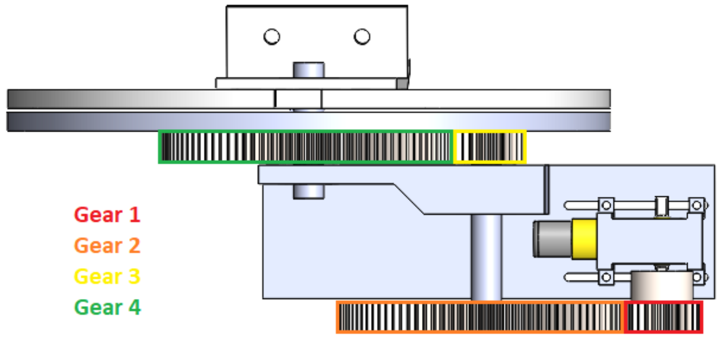

Figure 7: Compound Gear Train Controlling Wheel

In Fig. 7, Gear 1 has 20 teeth, Gear 2 has 95, Gear 3 has 15, and Gear 4 has 103 teeth. The calculations for the speed of the wheel and the voltage needed to the DC motor are shown in the below Fig. 8. The DC motor runs off of a pulse-width-modulated signal powered by our 5 V battery supply, operating at a speed ranging from roughly 90 to 200 rpm. We were able to adjust the duty cycle of the PWM signal and vary our speed, and through experimentation found that 2.5 rpm was the ideal speed to let bearings into the wheel, avoid jams, and maintain an efficient flow rate.

Desired speed of wheel = $v_{wheel} = 2.5$ rpm

$$v_{wheel} = \frac{n_1}{n_2} \cdot \frac{n_3}{n_4} \cdot \frac{1}{48} \cdot v_{motor}$$

$$= \frac{20}{95} \cdot \frac{15}{103} \cdot v_m$$

$$24.75\, v_{wheel} = v_{motor}$$

Motor specs:
3V → 90 RPM
6V → 200 RPM

$$\frac{200-90}{6-3} = m = \frac{110}{3} \qquad v = \frac{110}{3}(V-3) + 90$$

$$24.75\, v_{wheel} = \frac{110}{3}(V-3) + 90$$

$$V = (24.75\, v_{wheel} - 90)\left(\frac{3}{110}\right) + 3$$

$$V = (24.75 \cdot 2.5\,\text{rpm} - 90\,\text{rpm})\left(\frac{3}{110}\right) + 3$$

$$\boxed{V = 2.77 \text{ volts}}$$

↳ ideal voltage to the wheel.

PWM scale of 0-255
↳ 0V - 5V.

$$y = \frac{255}{5}x$$

$$y = \frac{255}{5}(2.5) = 127.5 \sim 128 \Rightarrow \boxed{\text{plug in speed} = 128 \text{ in ELEGOO Code}}$$

Figure 8: Calculations For The Speed of The Wheel

Size Separation

An issue that arose when testing the size separation was the ¼” bearings bouncing out of the track after they fell through the sizing hole in the ½” track. This was resolved by increasing the height of the walls on the catcher piece on the ¼” track and laying a piece of thin cardboard to dampen the impact of the bearings when they fall from one track to the other.

Conductivity Separation

The contacts that the bearings roll over to detect if they are conductive or not were the biggest challenge of the entire design.

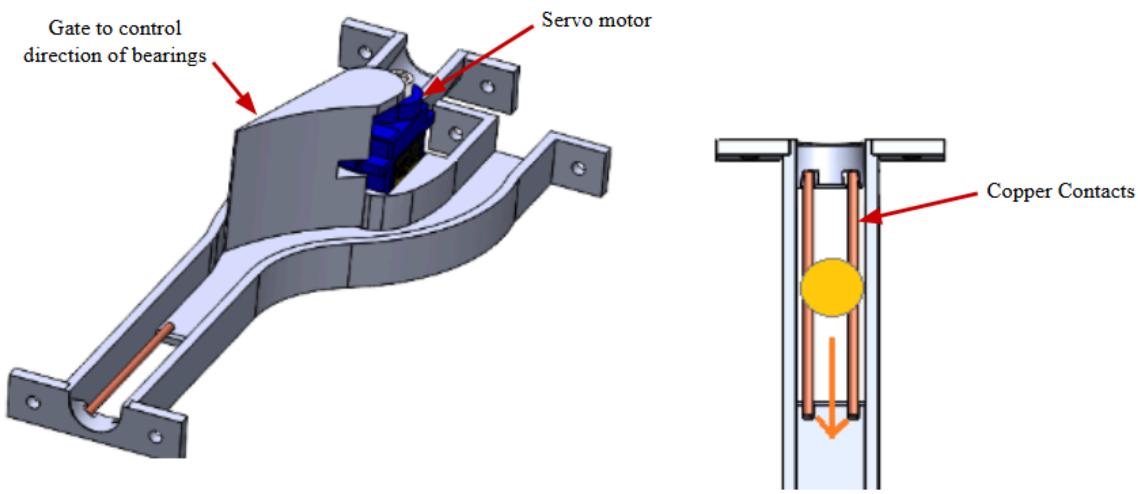

Figure 9: Conductivity Separation with Copper Contacts

In our proof of concept prototype, we used “super conductive copper rods” with wires soldered onto them that connected to a circuit on the breadboard (see Fig. 4). They worked well in the prototype, but we were unable to successfully manufacture a way for them to work in the final design. Next, we used stripped 12 gauge copper wires as the contacts which worked well at first, but the wires tarnished, which made it to where the lightweight ¼” bearings did not have enough force pressing them against the contacts to complete the circuit. However, these contacts worked well with the ½” bearings and are shown below in Fig 9. Another problem with both of these contacts was that, because they were round rods, they created a small lip that the bearings would have to go over. The ¼” bearings would get stuck on this lip if they were going too slow and bounce over the contacts if they were going faster. To combat this, we made contacts out of flat aluminum flashing that the bearings can roll over with little interference. To even further reduce the bump in the track that the contacts create, the contacts are clipped in from the outside of the track meaning they are flush with the track, as opposed to being glued to the inside surface of the track.

Packaging Stations

In testing the packaging stations, the two problems were the placement and bearings bouncing out of the stations. The stations were placed almost sporadically below the track to catch the bearings. This did not allow for easy access and greatly reduced the efficiency of the device. As shown in Figure 10, the packaging stations are now aligned at the edge of the device for full access.

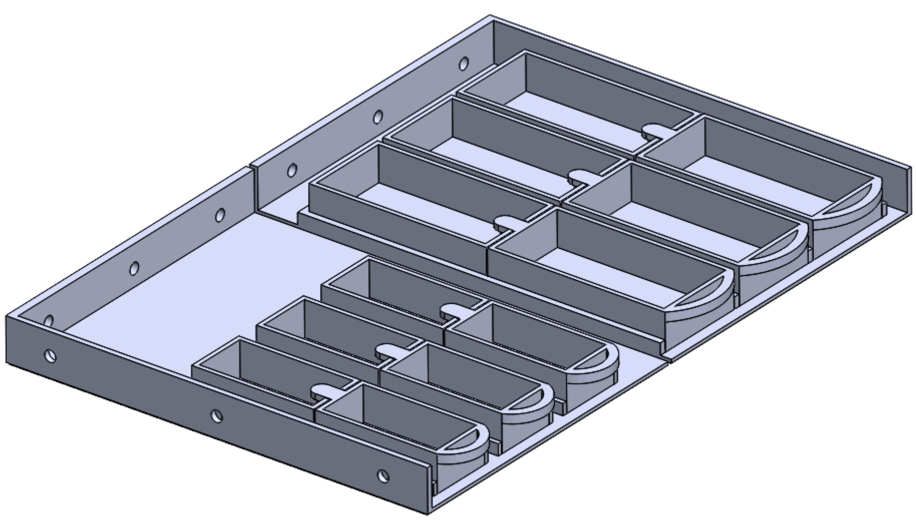

Figure 10: Packaging Stations

Also, there are secondary packing stations to catch excess bearings if the first packing station is taken out. This is part of the ASME design challenge rules, where you must remove the packaging station when a certain number of bearings have been collected, while at the same time continuing to collect bearings that might still be in the device. To stop the bearings from bouncing out of the packaging stations, we added a fabric dampener that absorbs the impact of the fall and limits bouncing.

ASME Competition

Prior to the trip to St. Louis, the device had a few minor complications regarding the conductivity test. Specifically, the contacts for the ¼” track were inconsistent. Because of this, we decided to implement a different type of contact that used metal flashing and clipped onto the sides of the track. Initially, this worked well but after testing it was noticed the contacts were not being held securely. The night before traveling we adjusted the contact, and the ¼” bearings were being sorted accurately. This trend followed suit as we arrived in St. Louis and made some minor adjustments prior to the competition. Just before the competition, the device worked well and accurately. After arriving at the competition the ASME judges measured the sizing box to ensure that it met the competition rules. However, when transporting the device up to the judges to get measured, we jostled the device and one of the ¼” aluminum contacts came loose. In the few minutes before competition we replaced the contact in time to compete and, even though we had a few sorting errors, made it through qualifiers and were ranked 5th seed in the bracket of 16 teams. During the time between rounds, we continuously tuned and adjusted the device. The next round was tournament style, where we were pitted against Virginia Tech, and successfully moved onto the next round.. During this round though, several problems arose that we had never encountered before and we had to make adjustments and improvements on the spot. During the elimination rounds, each team had to bring 10 bearings of one size/material to the judges in exchange for a letter and the letters spelled out A.S.M.E. During this phase, the device had many jams and a build up of bearings that would not leave the ramp. In the end, we ranked 5th overall.

Conclusion and Lessons Learned

The goal of this design project was to create a device that can autonomously sort ball bearings by size and material. The biggest success in the design process was the modularity of our design. When testing, there were many parts of the device that needed to be adjusted, re-printed, and some that very plainly did not work. The modularity of the design allowed for the alterations of small parts of the device, and avoided a massive amount of waste to material, time, and energy. The three biggest design strategies that we neglected in our design process were manufacturability, durability, and efficiency. The problem with the contacts was not theoretical, but in the difficulty of manufacturing. Creating two perfectly parallel and straight copper rods or aluminum flashing that a ¼” bearing will roll across while maintaining contact with both contacts, proved to be almost impossible. In our design, both the contacts and the track are small and difficult to reach. This proved to create a very frustrating manufacturing process and an unreliable sensor for conductivity. Durability was another issue. Even when we were able to successfully align the contacts, they were not strong enough to withstand any amount of force or jerking. We learned that it is not enough to simply consider the feasibility of a design, but we also needed to create a detailed plan on how to manufacture certain parts of the design. A better utilization of 3D printing could have greatly decreased the fragility of the contacts, by embedding the contacts directly into the print. This way there would be no possibility of slipping contacts, and would also ensure that the contacts were perfectly in line with the track. Finally, to better the design as a whole, creating sorting mechanisms that can sort the bearings all at once would be far more efficient. A key design consideration of this design was spacing the bearings out enough to be able to sort them one by one. This greatly slows down the sorting process, and a more efficient design would sort as many bearings at once all at the same time.

References

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NDT Technology. (2024). High Speed Ball Sorting Machine: Revolutionize Production Control

with ibg Ball Sorter. Ibg. https://ibgndt.com/instruments-systems/bearing-ball-testing/high-speed-ball-structure-sorter

Appendix A: **Derivation of Friction Coefficient Equation**

$$(Potential\ Energy)_{initial} + (Kinetic\ Energy)_{initial} - (Friction\ loss) = (Potential\ Energy)_{final} + (Kinetic\ Energy)_{final}$$

$$mgh_{initial} - F_{friction}d_{traveled} = \frac{1}{2}mv_{final}^{2} + \frac{1}{2}I\omega_{final}^{2}$$

$$mgh_{initial} - F_{normal}\mu d_{traveled} = \frac{1}{2}mv_{final}^{2} + \frac{1}{2}(\frac{2}{5}mr^{2})(\frac{v_{final}}{r})^{2}$$

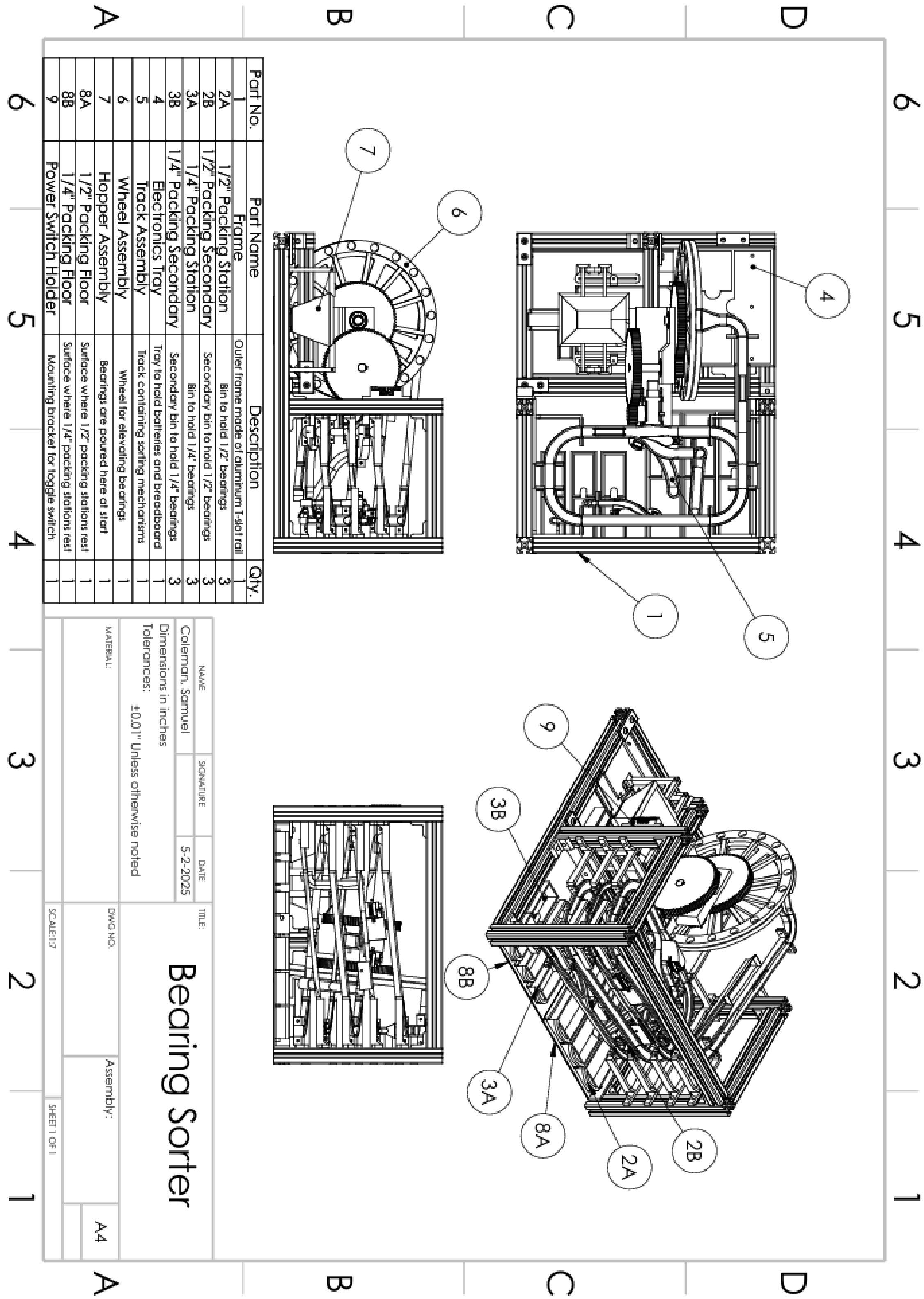
$$mgh_{initial} - mg\mu d_{travelled} = \frac{1}{2}mv_{final}^{2} + \frac{1}{5}mv_{final}^{2}$$

$$g(h_{initial} - \mu d_{travelled}) = 0.7v_{final}^{2}$$

$$-g\mu d_{travelled} = 0.7v_{final}^{2} - gh_{initial}$$

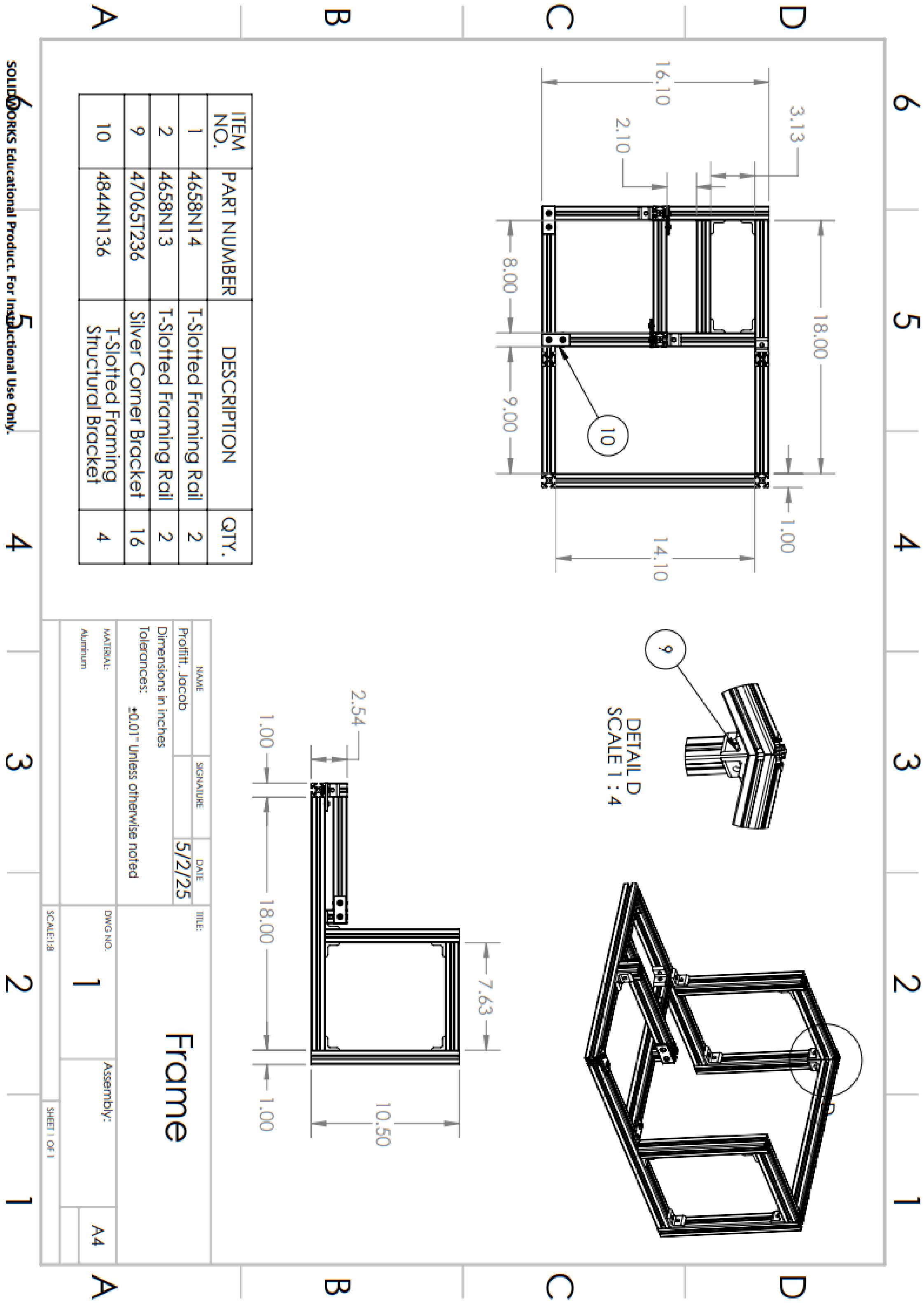
$$\mu = \frac{gh_{initial} - 0.7v_{final}^{2}}{gd_{travelled}}$$

Appendix B: Full Assembly Drawing

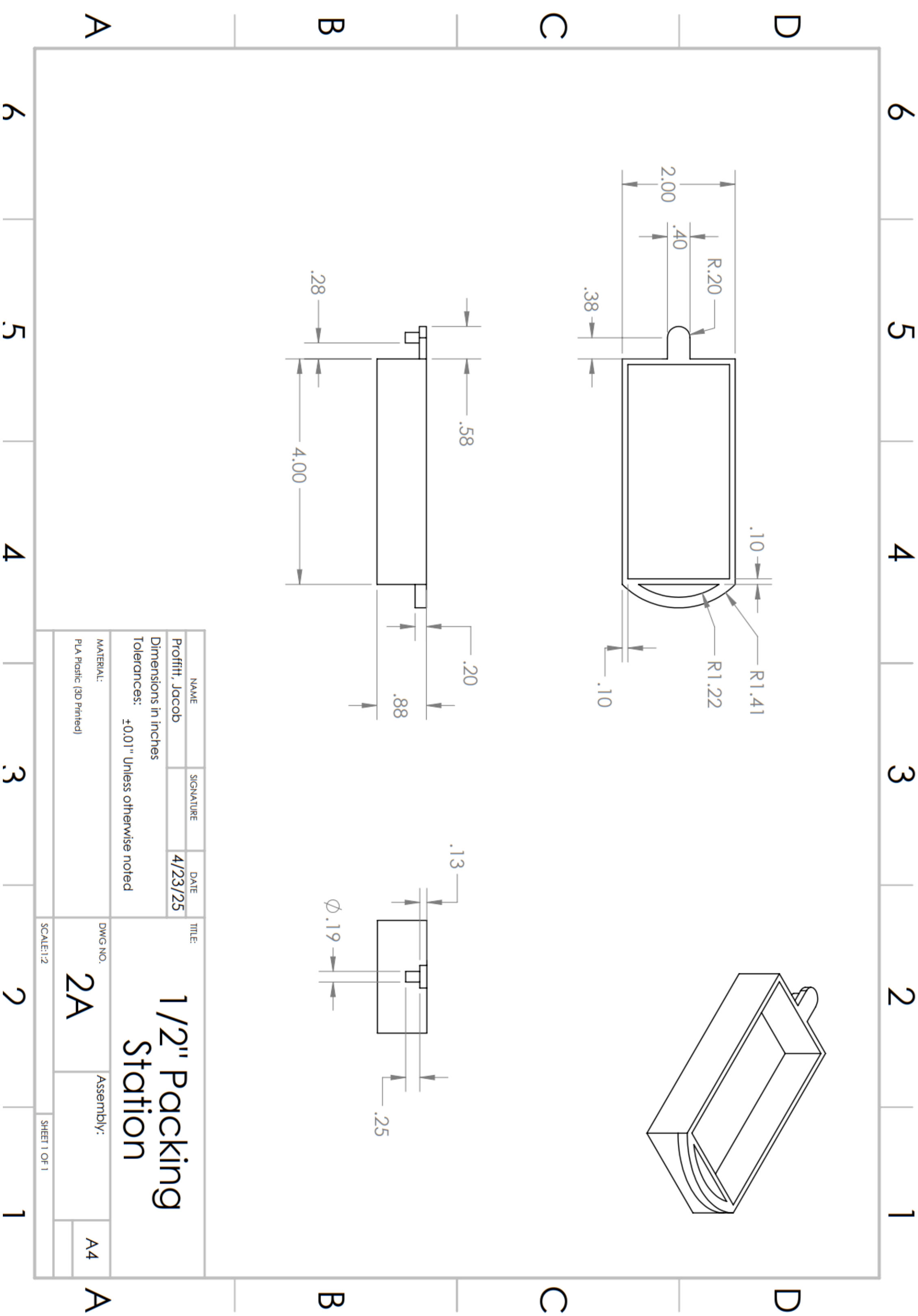


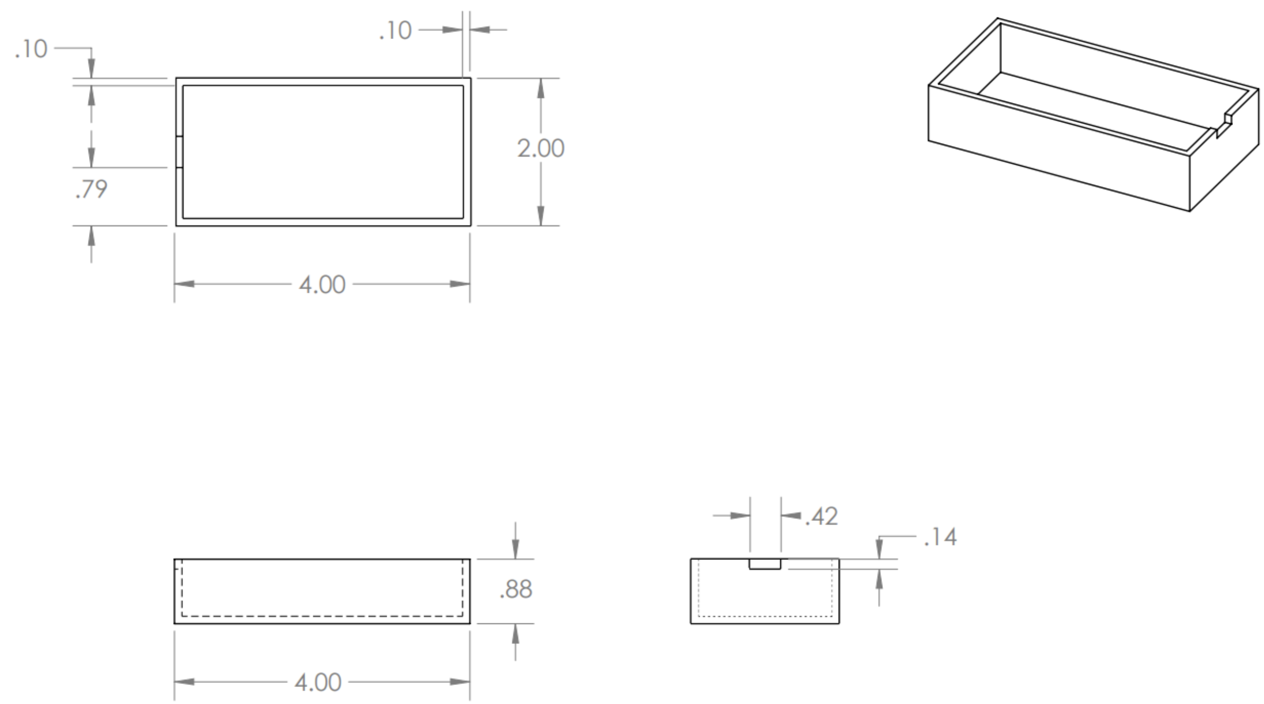
Part No.	Part Name	Description	Qty.
1	Frame	Outer frame made of aluminum T-slot rail	1
2A	1/2" Packing Station	Bin to hold 1/2" bearings	3
2B	1/2" Packing Secondary	Secondary bin to hold 1/2" bearings	3
3A	1/4" Packing Station	Bin to hold 1/4" bearings	3
3B	1/4" Packing Secondary	Secondary bin to hold 1/4" bearings	3
4	Electronics Tray	Tray to hold batteries and breadboard	1
5	Track Assembly	Track containing sorting mechanisms	1
6	Wheel Assembly	Wheel for elevating bearings	1
7	Hopper Assembly	Bearings are poured here at start	1
8A	1/2" Packing Floor	Surface where 1/2" packing stations rest	1
8B	1/4" Packing Floor	Surface where 1/4" packing stations rest	1
9	Power Switch Holder	Mounting bracket for toggle switch	1

Appendix C: Sub-Assemblies and Parts in Full Assembly

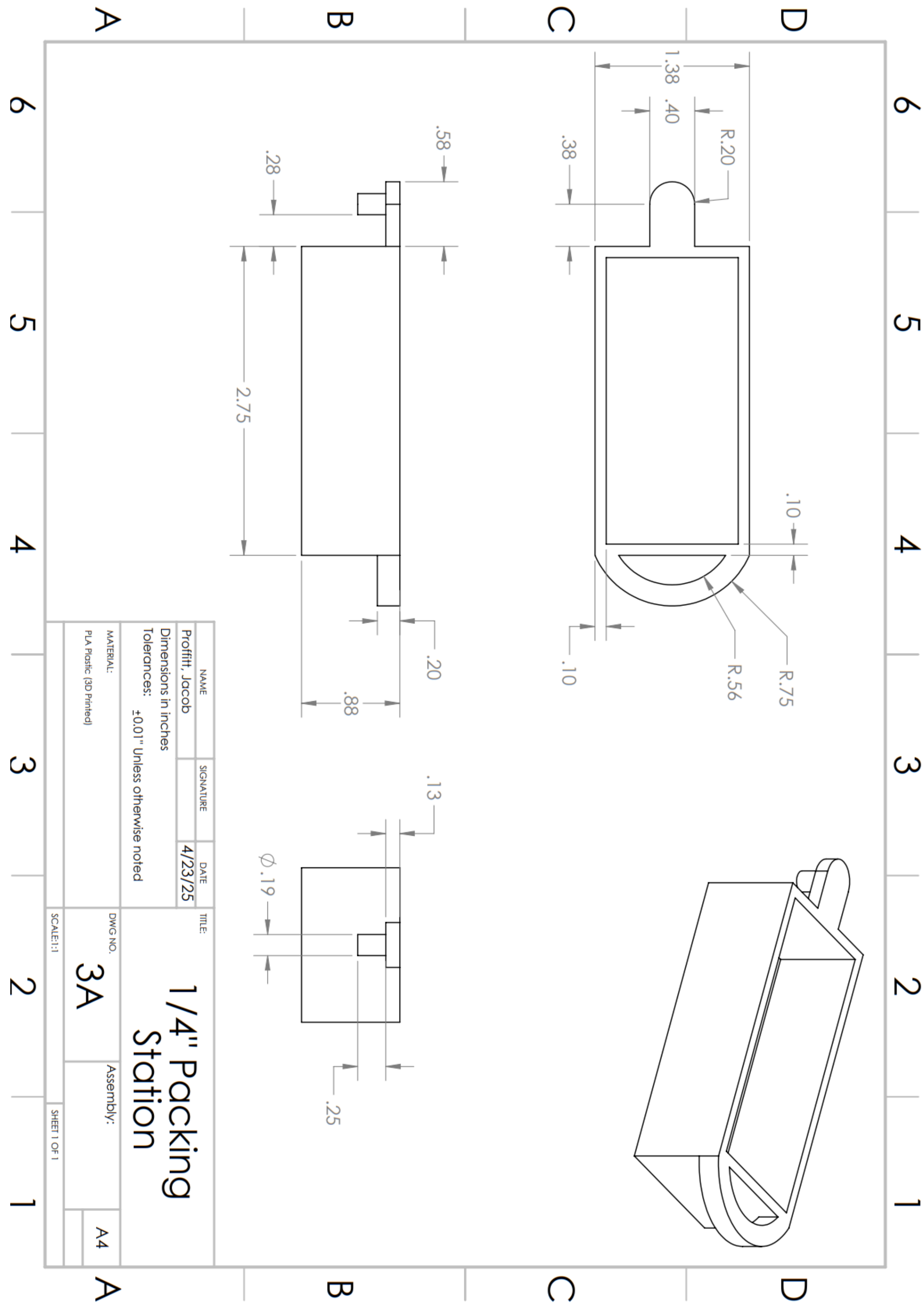


ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	4658N14	T-Slotted Framing Rail	2
2	4658N13	T-Slotted Framing Rail	2
9	47065T236	Silver Corner Bracket	16
10	4844N136	T-Slotted Framing Structural Bracket	4

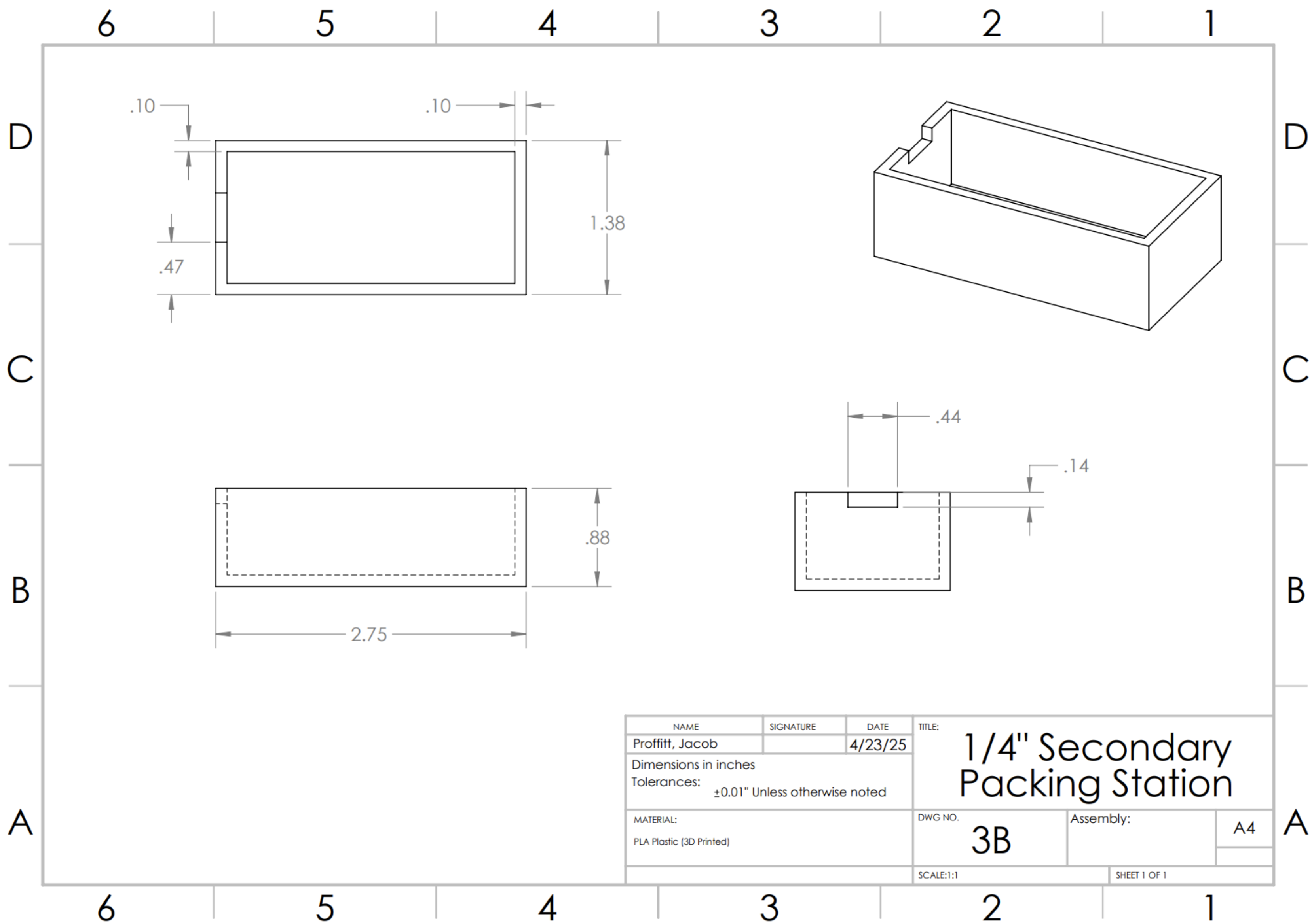

NAME
Proffitt, Jacob
SIGNATURE
DATE
4/23/25
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/2" Packing Station
DWG NO.
2A
Assembly:
A4
SCALE:1:2
SHEET 1 OF 1
2.00
.40
R.20
.38
.10
R1.41
R1.22
.10
.28
.58
4.00
.20
.88
.13
⌀.19
.25

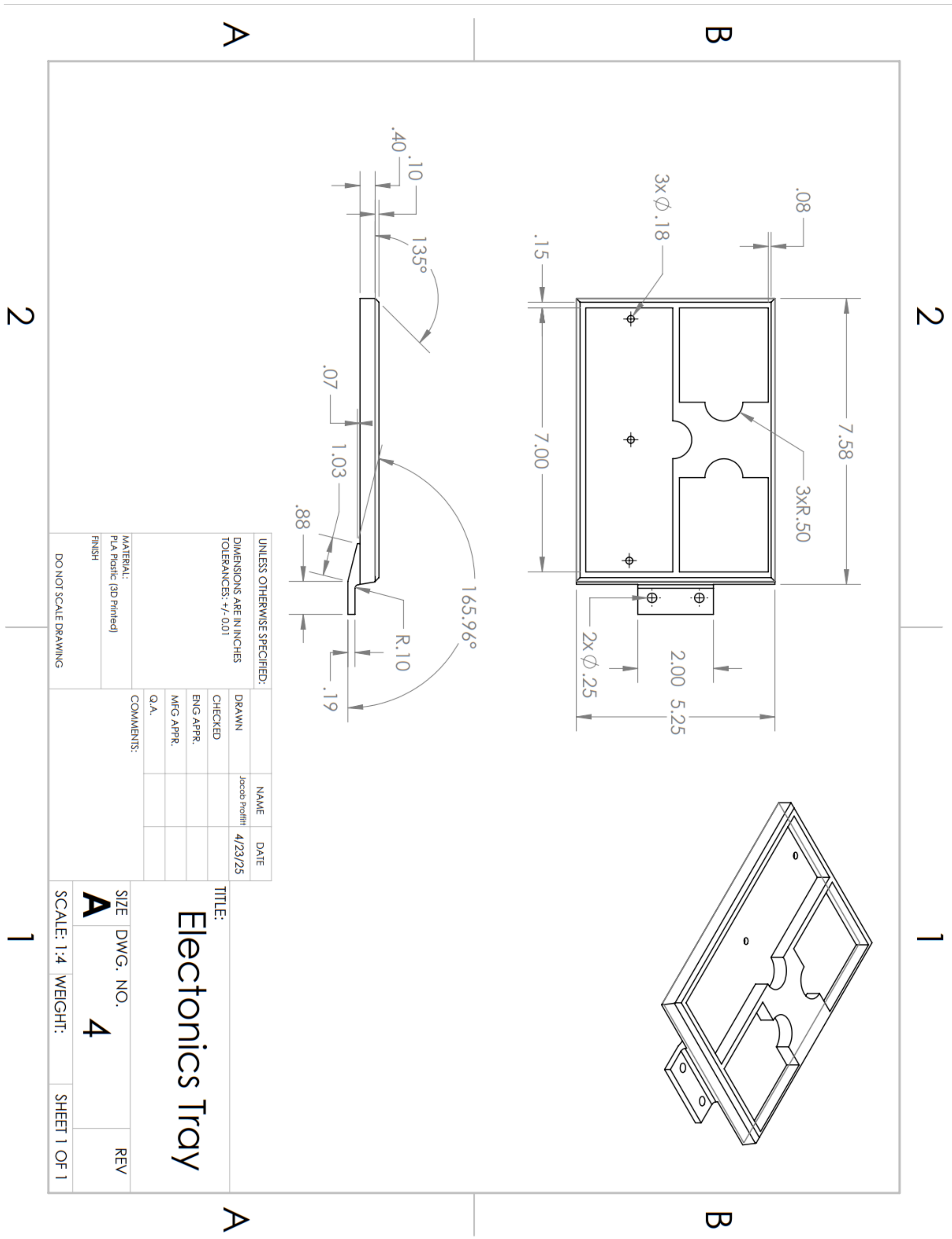


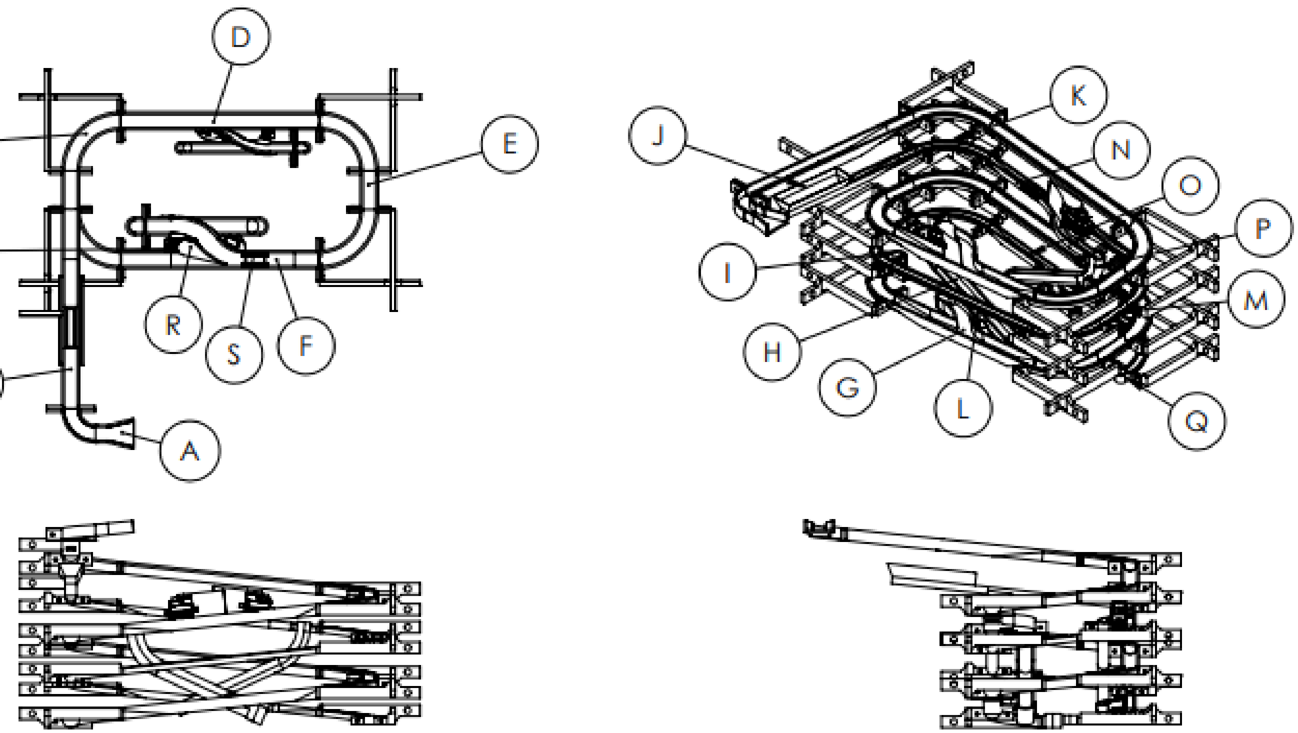
NAME	SIGNATURE	DATE	TITLE: 1/2" Secondary Packing Station
Proffitt, Jacob		4/23/25	
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 2B
			Assembly:
			A4
			SCALE:1:1
			SHEET 1 OF 1



1/4" Packing Station
NAME
Proffitt, Jacob
SIGNATURE
DATE
4/23/25
TITLE:
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
3A
Assembly:
A4
SCALE:1:1
SHEET 1 OF 1
1.38
.40
R.20
.38
.10
R.56
R.75
.58
.28
2.75
.20
.88
.13
Ø.19
.25


.10
.10
.47
1.38
.88
2.75
.44
.14
NAME
SIGNATURE
DATE
Proffitt, Jacob
4/23/25
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/4" Secondary Packing Station
DWG NO.
3B
Assembly:
A4
SCALE:1:1
SHEET 1 OF 1


Electonics Tray
TITLE:
SIZE A
DWG. NO. 4
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: +/- 0.01
MATERIAL:
PLA Plastic (3D Printed)
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
Jacob Proffitt
4/23/25
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
.08
3x∅.18
.15
7.58
7.00
3xR.50
2x∅.25
2.00
5.25
.40
.10
135°
.07
1.03
.88
165.96°
R.10
.19
A
B
1
2



Part No.	Part Name	Qty.
A	1/2" Track Start	1
B	Size Separator	1
C	1/2" Turn	8
D	1/2" Long Straight	2
E	1/2" Short Straight	3
F	1/2" Conductivity Separator	1
G	1/2" Magnetic Separator	1
H	1/2" Drop Tube	1
I	1/2" Stop	1
J	1/4" Track Start	1

Part No.	Part Name	Qty.
K	1/4" Turn	6
L	1/4" Long Straight	1
M	1/4" Short Straight	2
N	1/4" Conductivity Separator	1
O	1/4" Magnetic Separator	1
P	1/4" Drop Tube	1
Q	1/4" Stop	1
R	Conductivity Separation Door	2
S	1/8" x 1" Copper Rod	4
T	SG90 Servo Motor	2

NAME	SIGNATURE	DATE
Coleman, Samuel		12-12-24

Dimensions in inches

Tolerances: ±0.01" Unless otherwise noted

MATERIAL:

TITLE:

Track Assembly

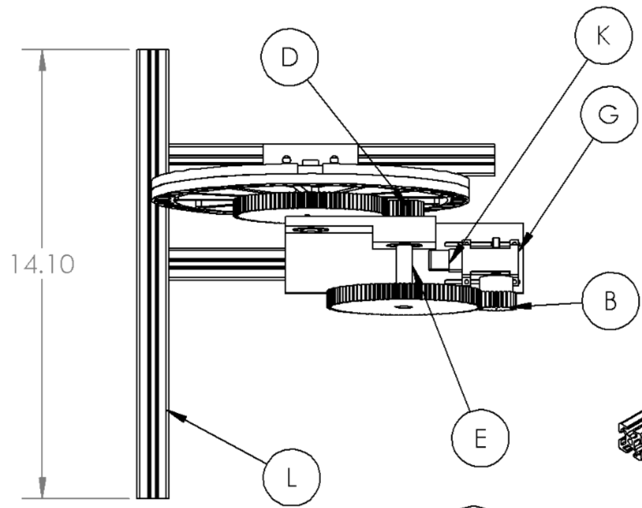
DWG NO. 5

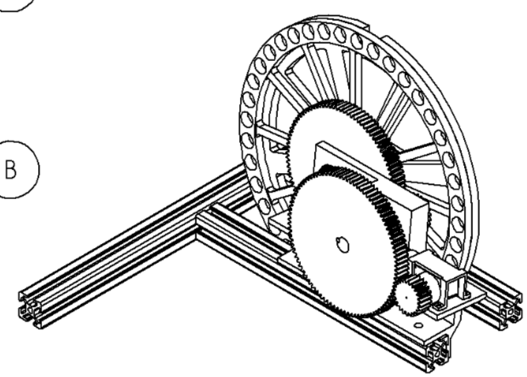
Assembly: Ball Bearing Sorter

A4

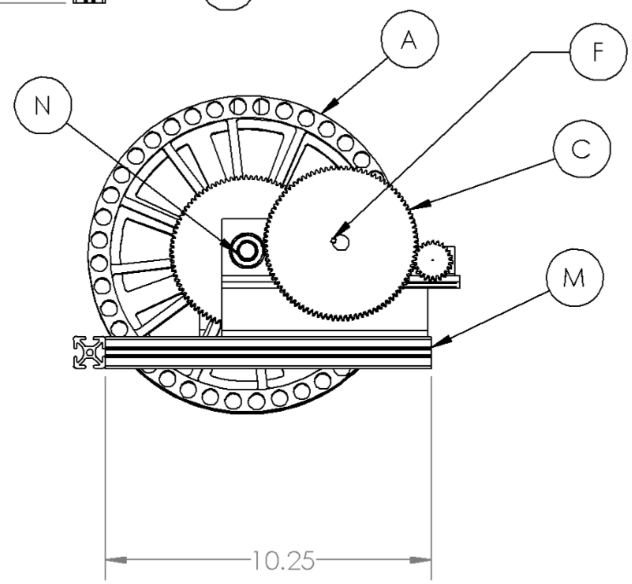
SCALE:1:6

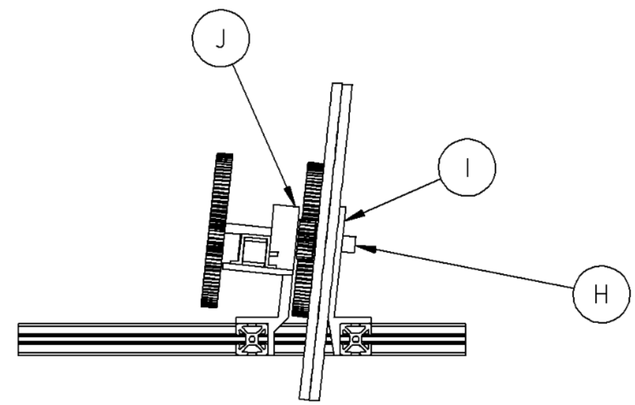
SHEET 1 OF 1



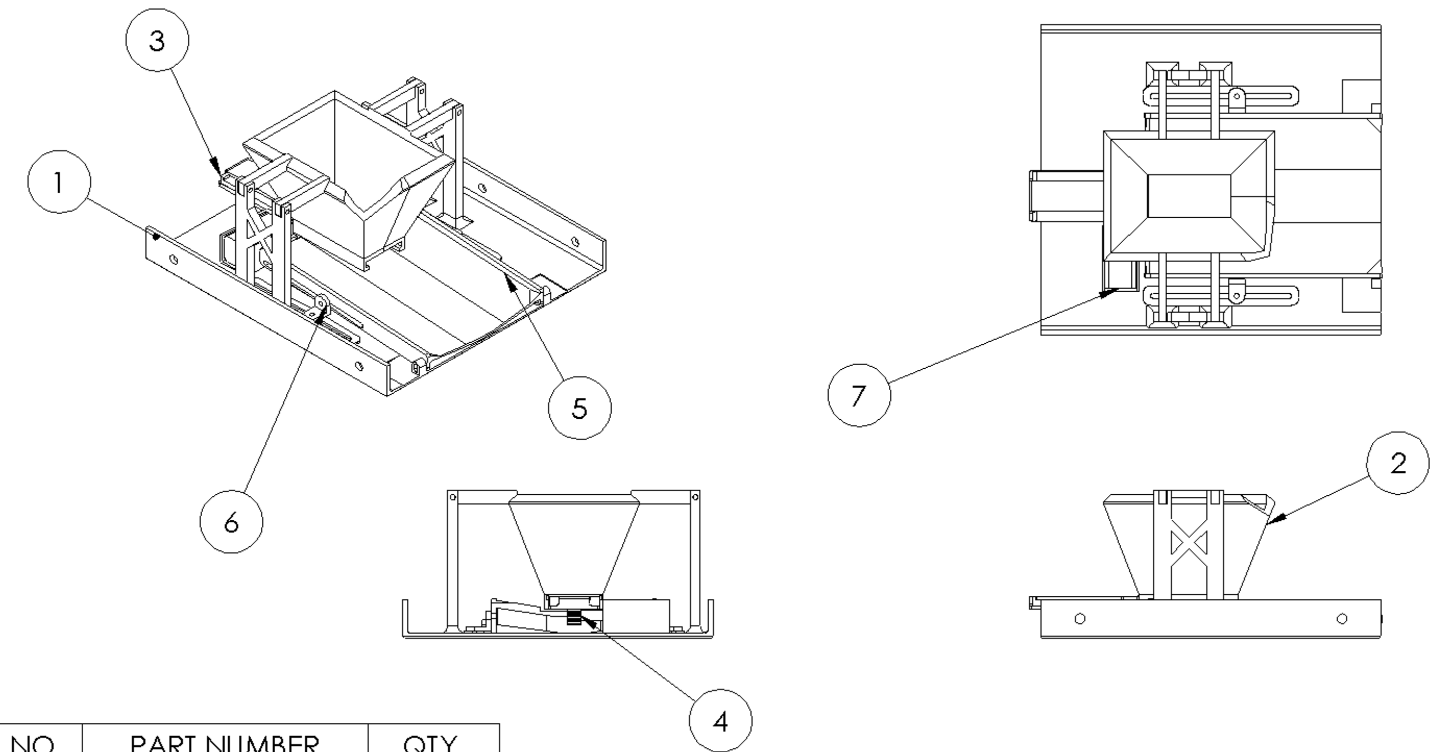


Part Number	Part Title	Quantity
A	Wheel	1
B	DC Motor Spur Gear 20DP 23T 20PA 0.5FW	1
C	Spur Gear 20DP 95T 20PA 0.5FW	2
D	Spur Gear 20DP 23T 20PA 0.5FW	1
E	Compound Gear Shaft	1
F	1.25" Shaft key	1
G	DC Motor Holder	1
H	Wheel Shaft	1
I	Wheel Back Bracket	1
J	Wheel Front Bracket	1
K	DC Motor	1
L	14.1" T-Slotted Framing Rail	1
M	10.25" T-Slotted Framing Rail 2	1
N	Shaft Bearing	2





NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	Wheel Assembly
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL:			DWG NO. 6 / Assembly: / A4
			SCALE:1:8 / SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	Hopper Floor	1
2	Hopper	1
3	Hopper Gate	1
4	Stepper Gear	1
5	Ramp	1
6	Ramp Bracket	2
7	Stepper Motor	1

NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		5/2/2025	Hopper Assembly

Dimensions in inches
Tolerances: ±0.01" Unless otherwise noted

MATERIAL:

DWG NO. 7

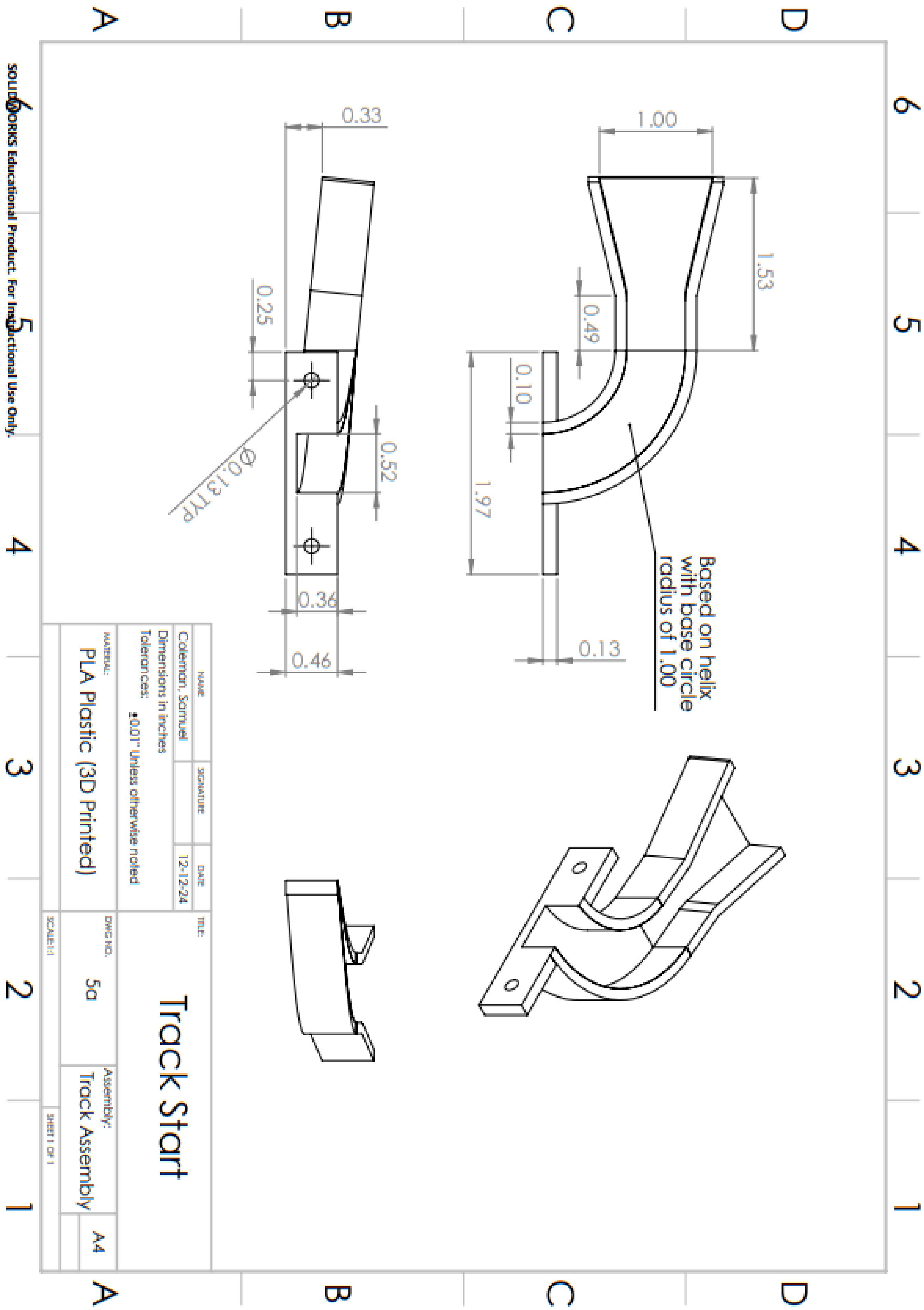
Assembly:

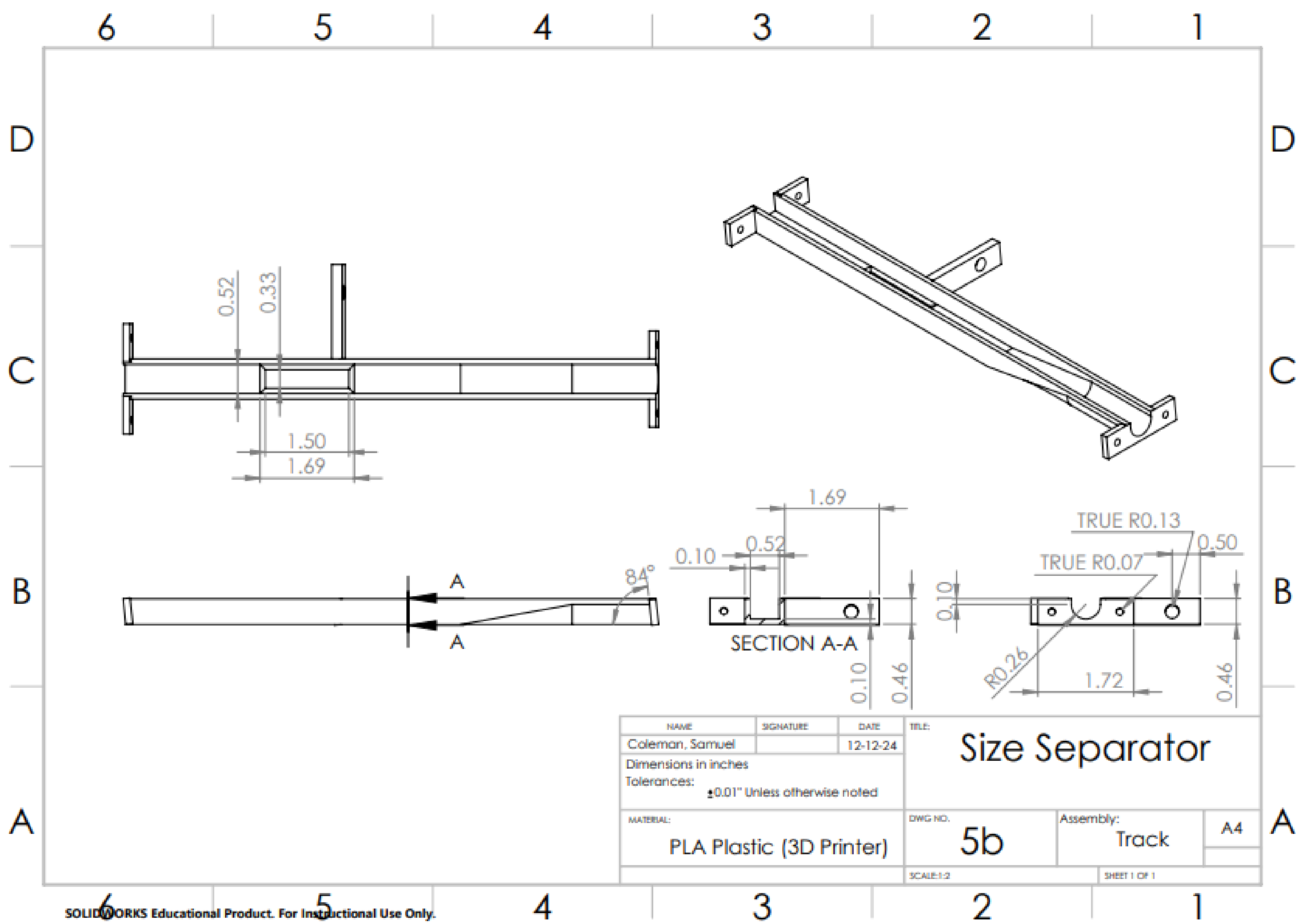
A4

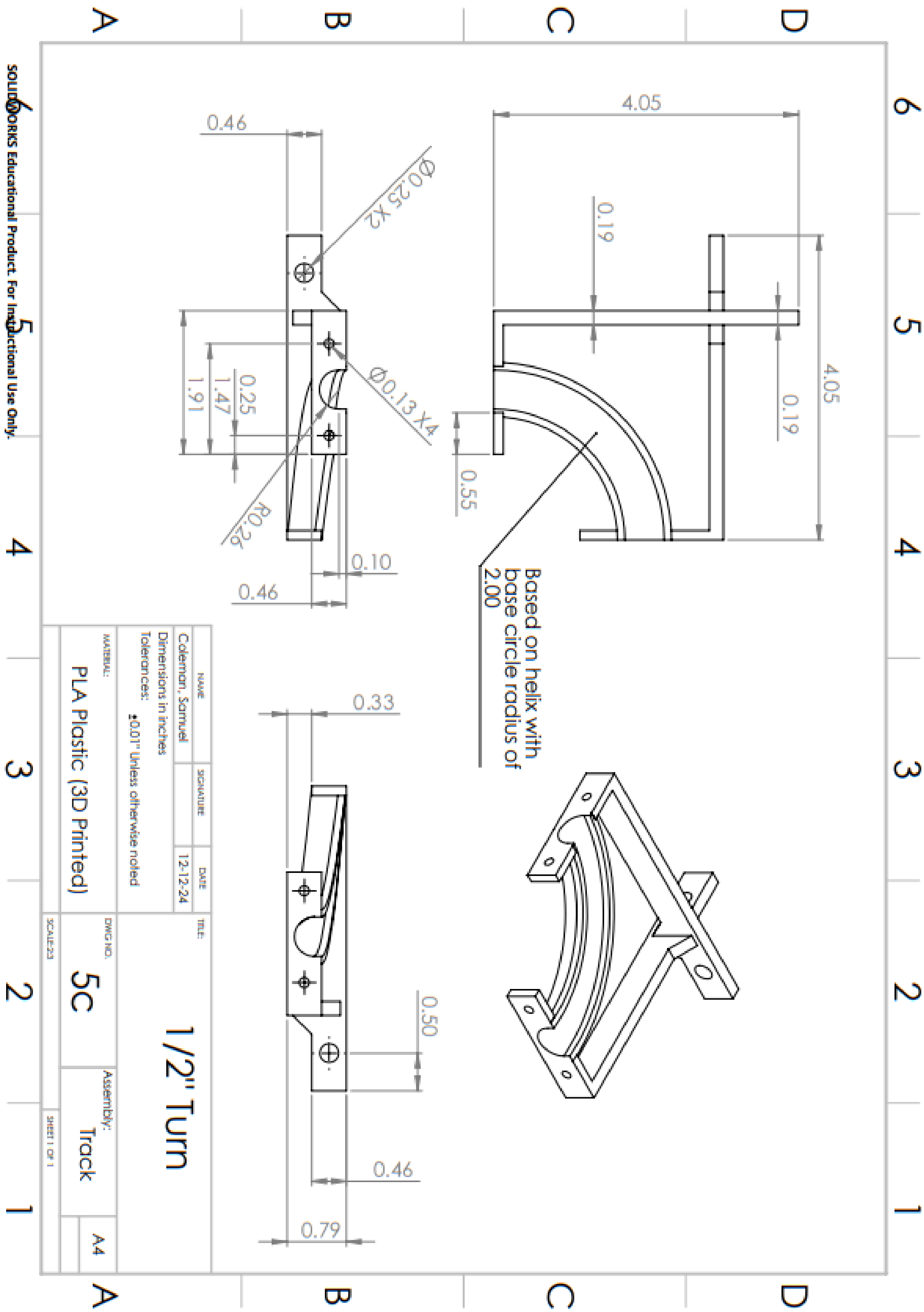
SCALE:1:5

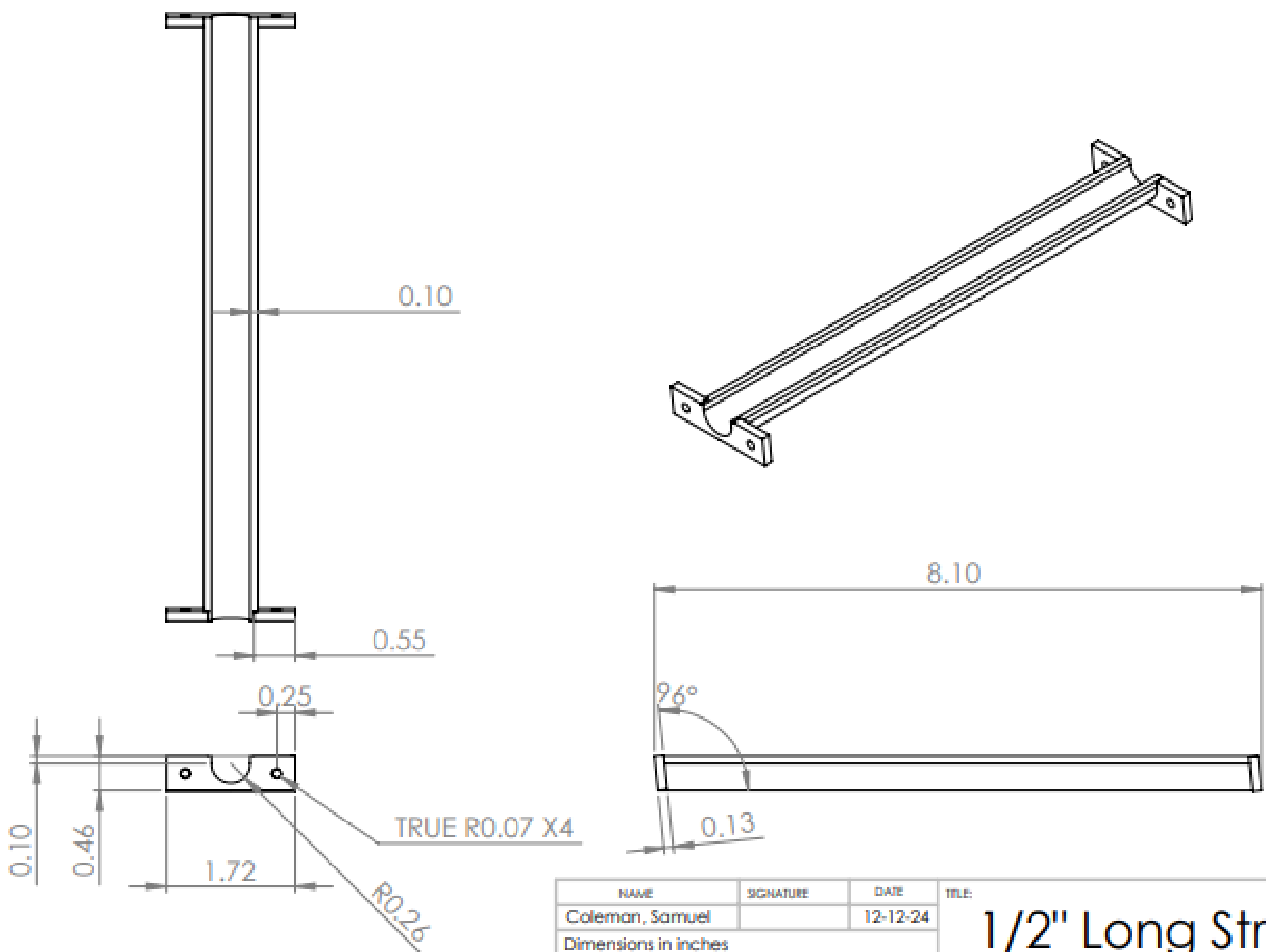
SHEET 1 OF 1

Appendix D: Track Assembly Part Drawings

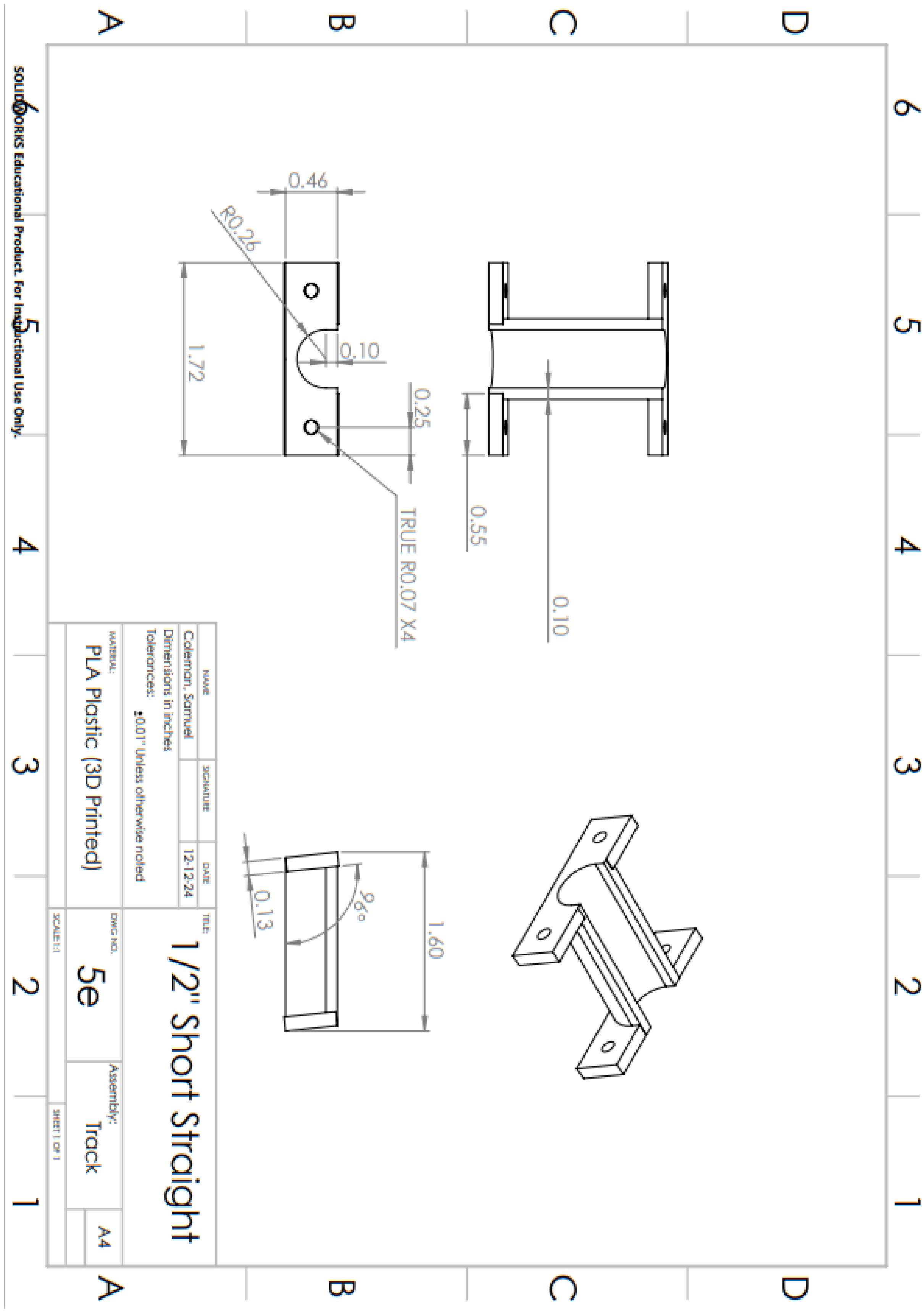


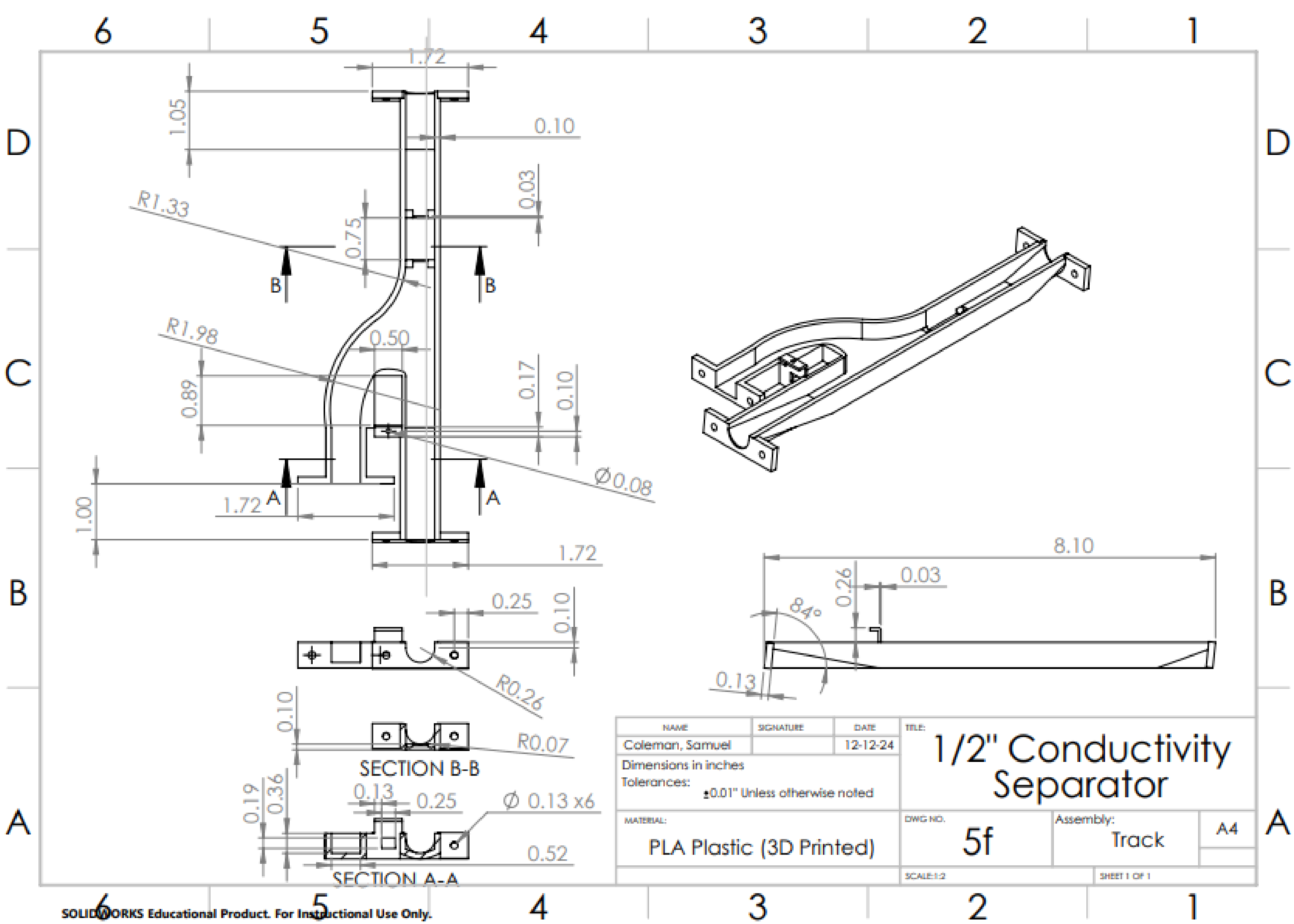

0.52
0.33
1.50
1.69
A
A
84°
0.10
0.52
1.69
SECTION A-A
0.10
0.46
TRUE R0.13
TRUE R0.07
0.50
0.10
R0.26
1.72
0.46
NAME
SIGNATURE
DATE
Coleman, Samuel
12-12-24
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printer)
TITLE:
Size Separator
DWG NO.
5b
Assembly:
Track
A4
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

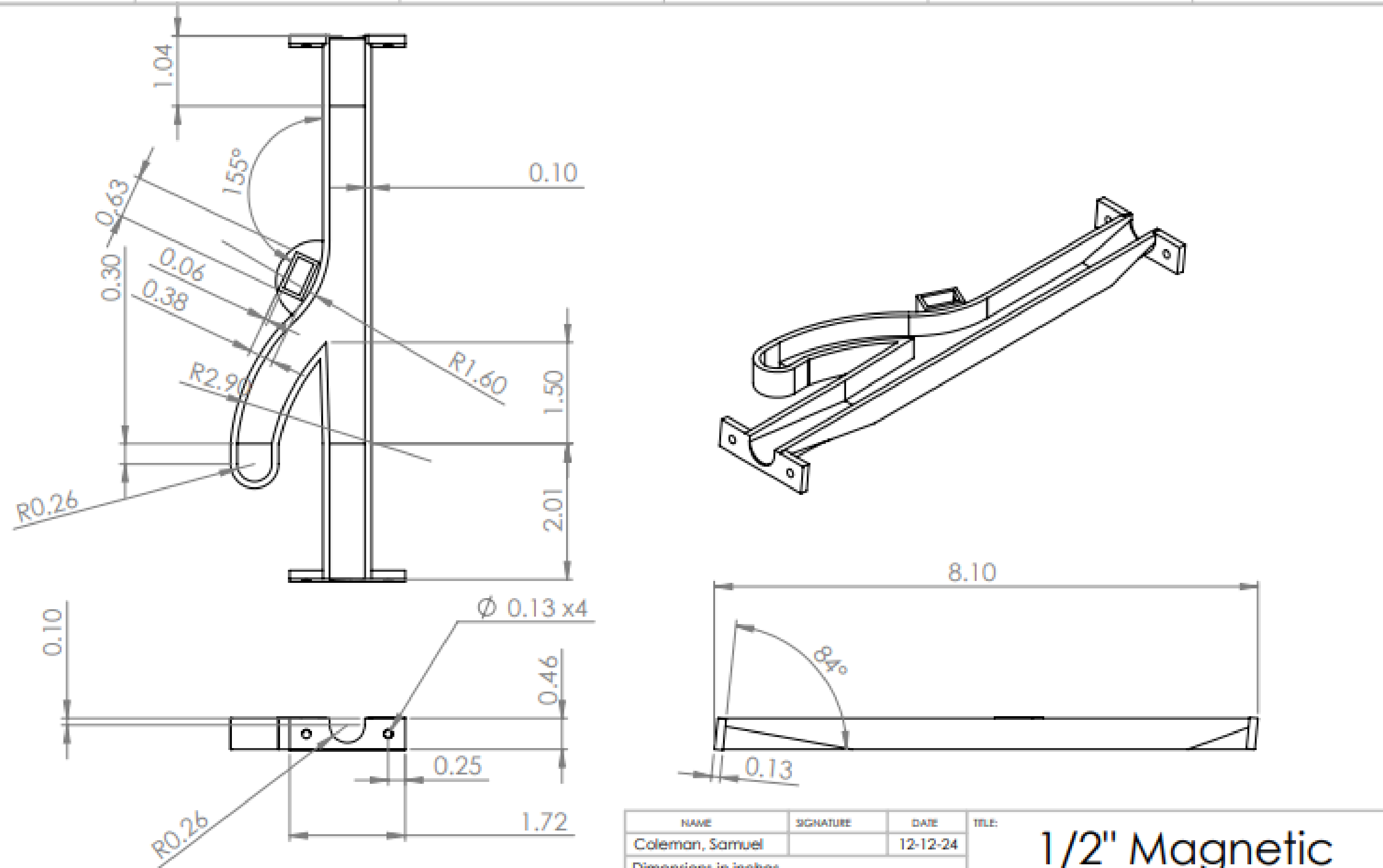

4.05
0.19
4.05
0.19
0.55
Based on helix with base circle radius of 2.00
0.46
Ø0.25 X2
Ø0.13 X4
0.25
1.47
1.91
R0.26
0.10
0.46
0.33
0.50
0.46
0.79
NAME
Coleman, Samuel
SIGNATURE
DATE
12-12-24
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/2" Turn
DWG NO.
5C
Assembly:
Track
SCALE:2:3
SHEET 1 OF 1
A4
SOLIDWORKS Educational Product. For Instructional Use Only.



NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/2" Long Straight
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA PLastic (3D Printed)	DWG NO. 5d	Assembly: Track	A4
	SCALE:1:2	SHEET 1 OF 1	

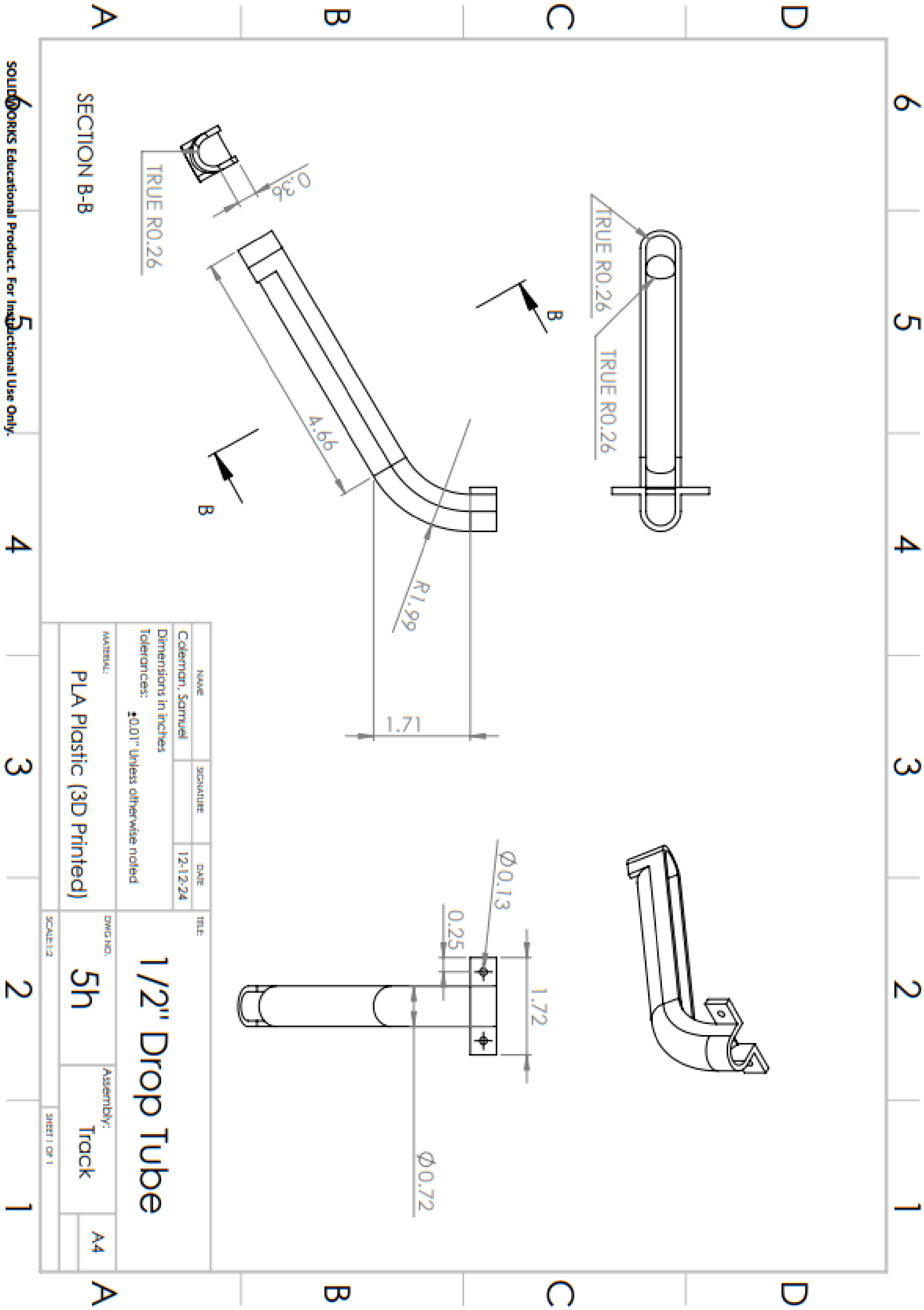

0.46
R0.26
0.10
1.72
0.25
TRUE R0.07 X4
0.55
0.10
1.60
0.13
96°
NAME
Coleman, Samuel
SIGNATURE
DATE
12-12-24
Dimensions in inches
Tolerances: ±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/2" Short Straight
DWG NO.
5e
Assembly:
Track
A4
SCALE:1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

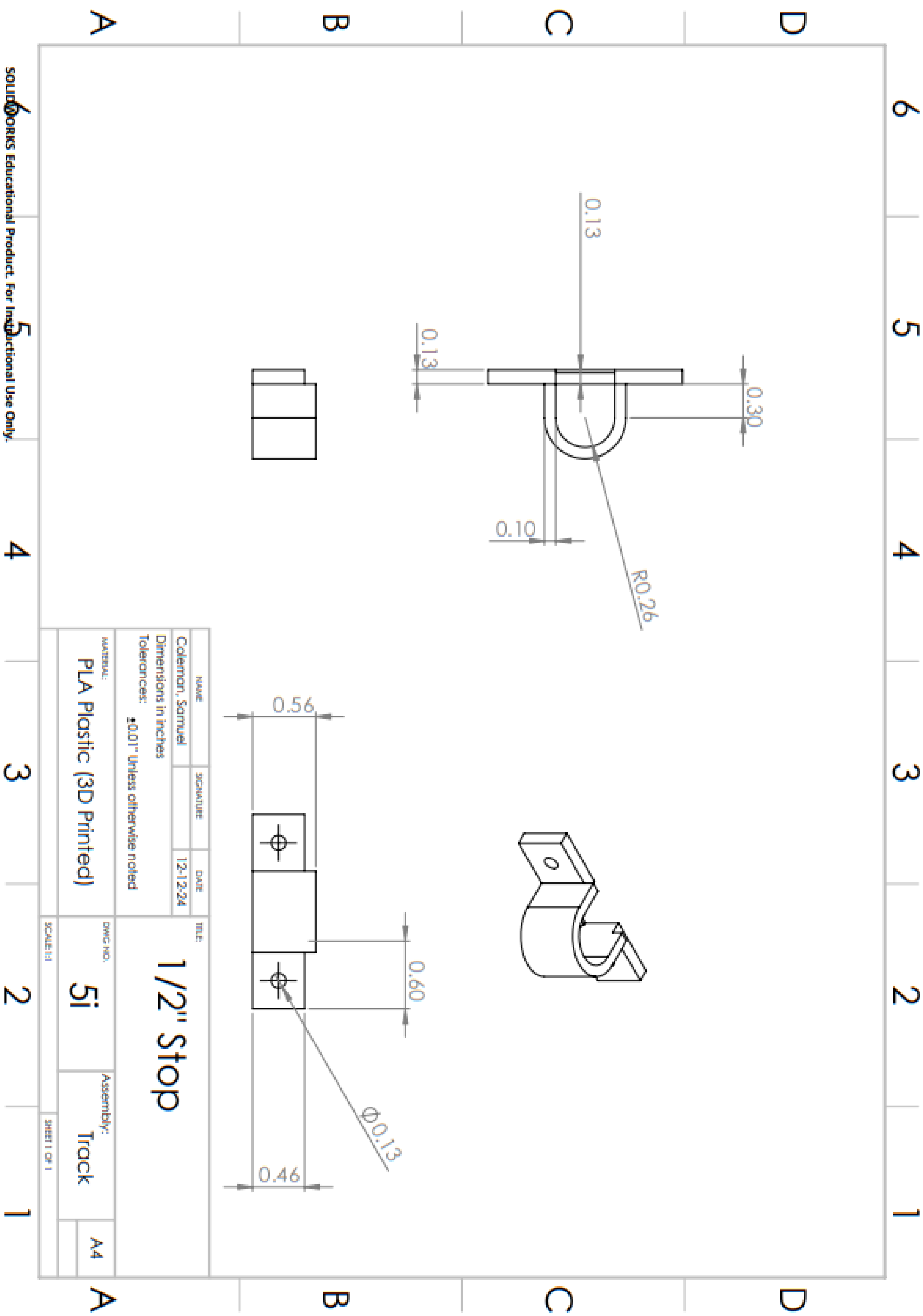

1.72
1.05
0.10
0.03
R1.33
0.75
B
B
R1.98
0.50
0.89
0.17
0.10
Ø0.08
1.00
1.72
A
A
1.72
0.25
0.10
R0.26
0.10
R0.07
SECTION B-B
0.19
0.36
0.13
0.25
Ø 0.13 x6
0.52
SECTION A-A
8.10
0.26
0.03
84°
0.13
NAME
SIGNATURE
DATE
Coleman, Samuel
12-12-24
Dimensions in inches
Tolerances: ±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/2" Conductivity Separator
DWG NO.
5f
Assembly:
Track
A4
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



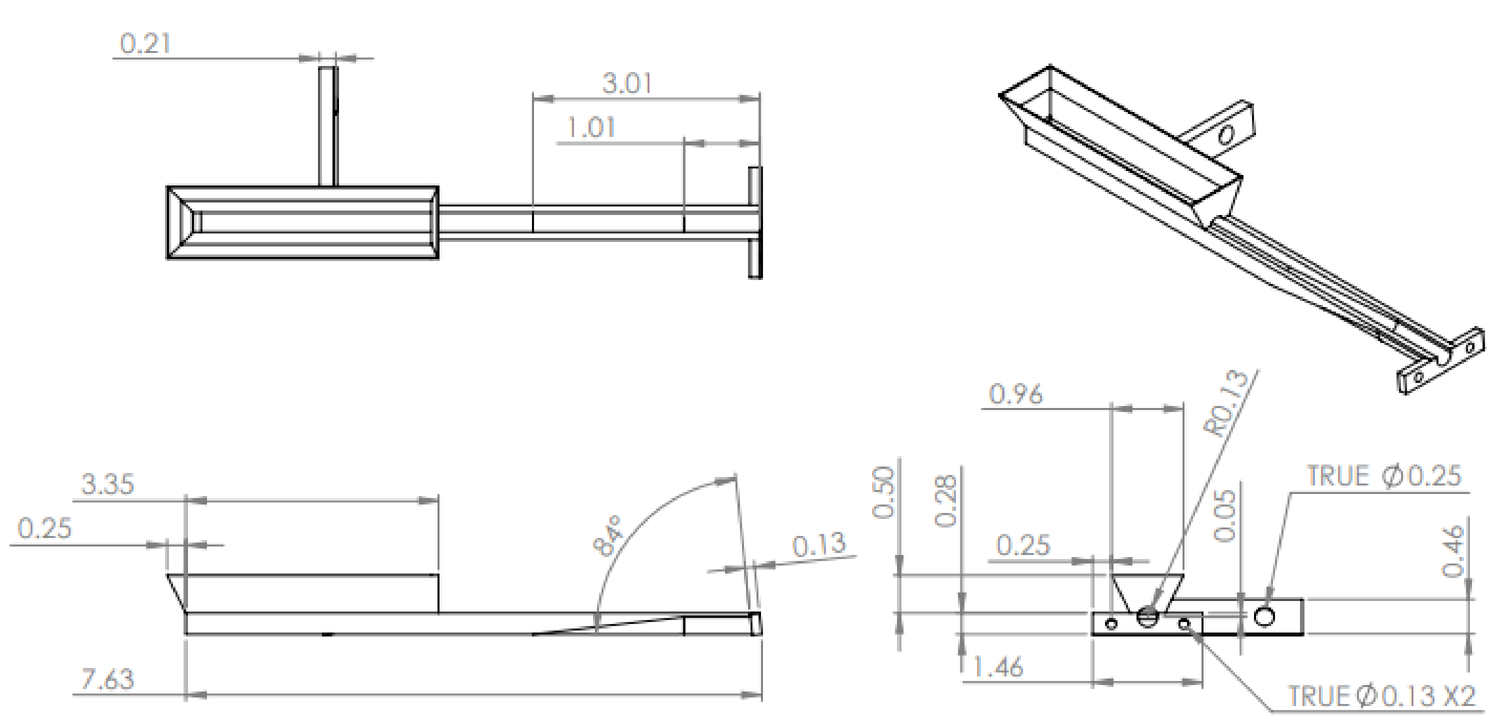
NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/2" Magnetic Separator
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)	DWG NO. 5g	Assembly: 5g	A4
	SCALE:1:2	SHEET 1 OF 1	

SOLIDWORKS Educational Product. For Instructional Use Only.

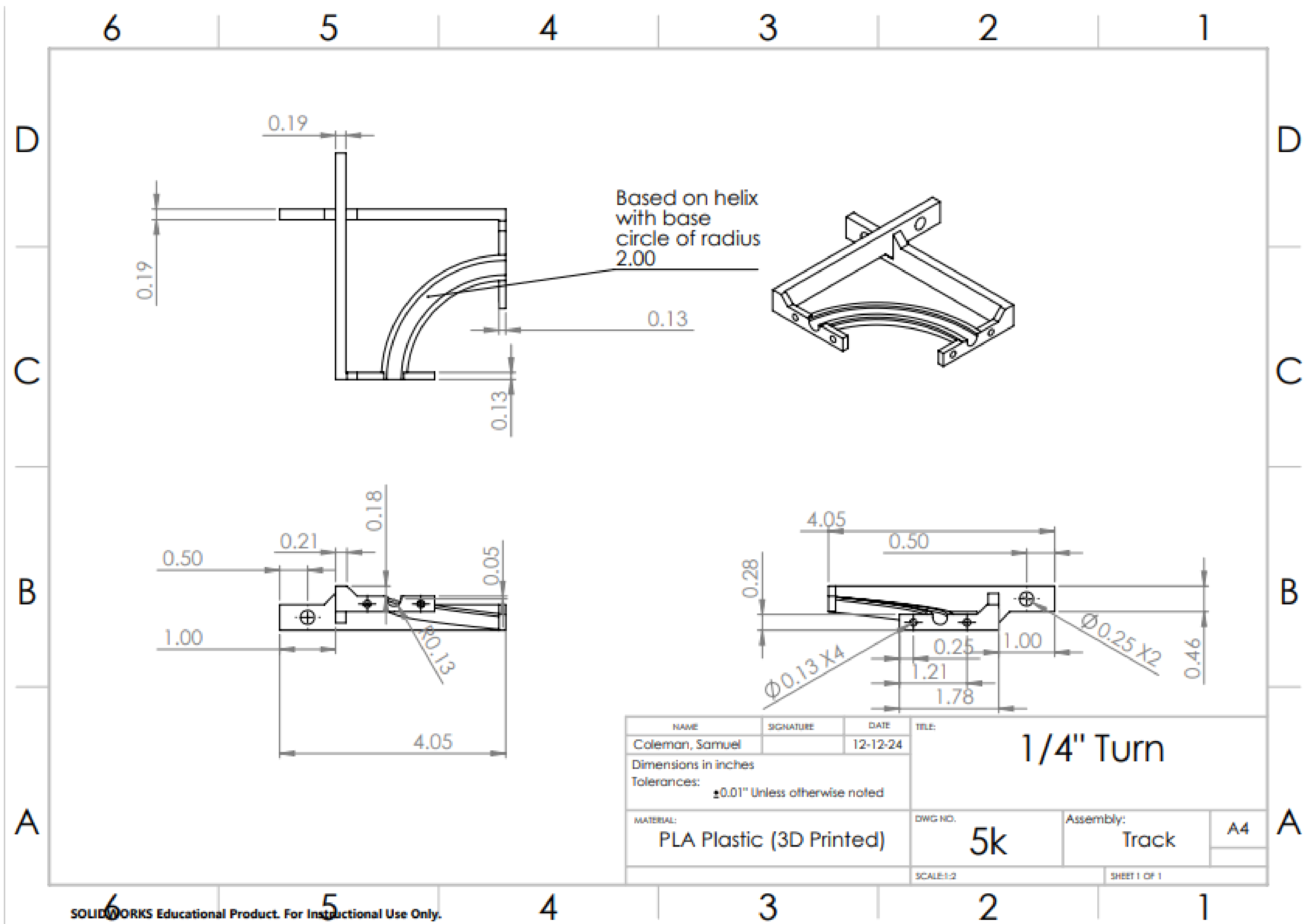

SECTION B-B
TRUE R0.26
0.36
4.66
B
B
TRUE R0.26
TRUE R0.26
R1.99
1.71
Ø0.13
0.25
1.72
Ø0.72
NAME
Coleman, Samuel
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
SIGNATURE
DATE
12-12-24
TITLE:
1/2" Drop Tube
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
5h
Assembly:
Track
A4
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

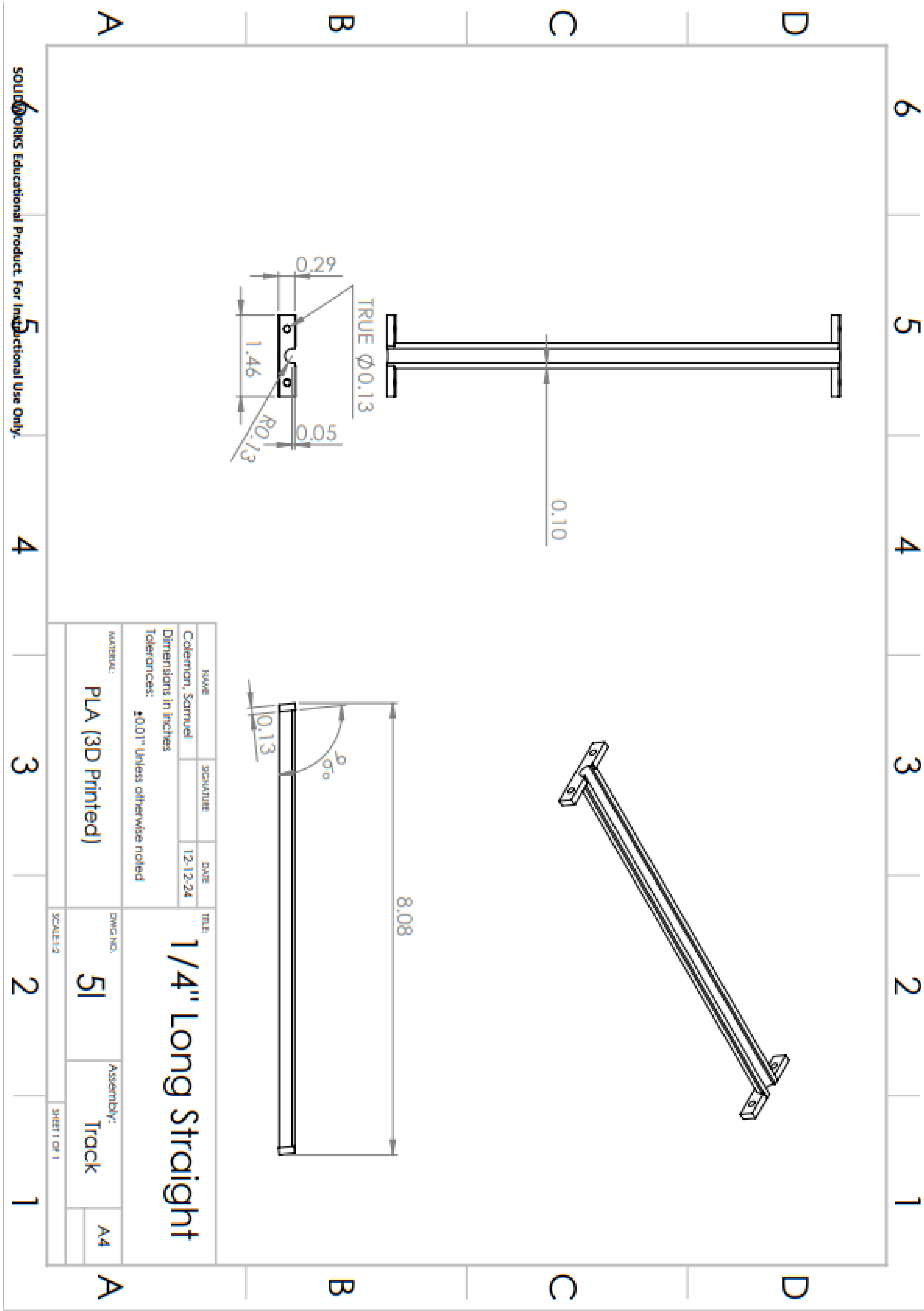


SOLIDWORKS Educational Product. For Instructional Use Only.
0.13
0.13
0.30
0.10
R0.26
0.56
0.60
Ø0.13
0.46
NAME
Coleman, Samuel
SIGNATURE
DATE
12-12-24
TITLE:
1/2" Stop
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
5i
Assembly:
Track
A4
SCALE:1:1
SHEET 1 OF 1

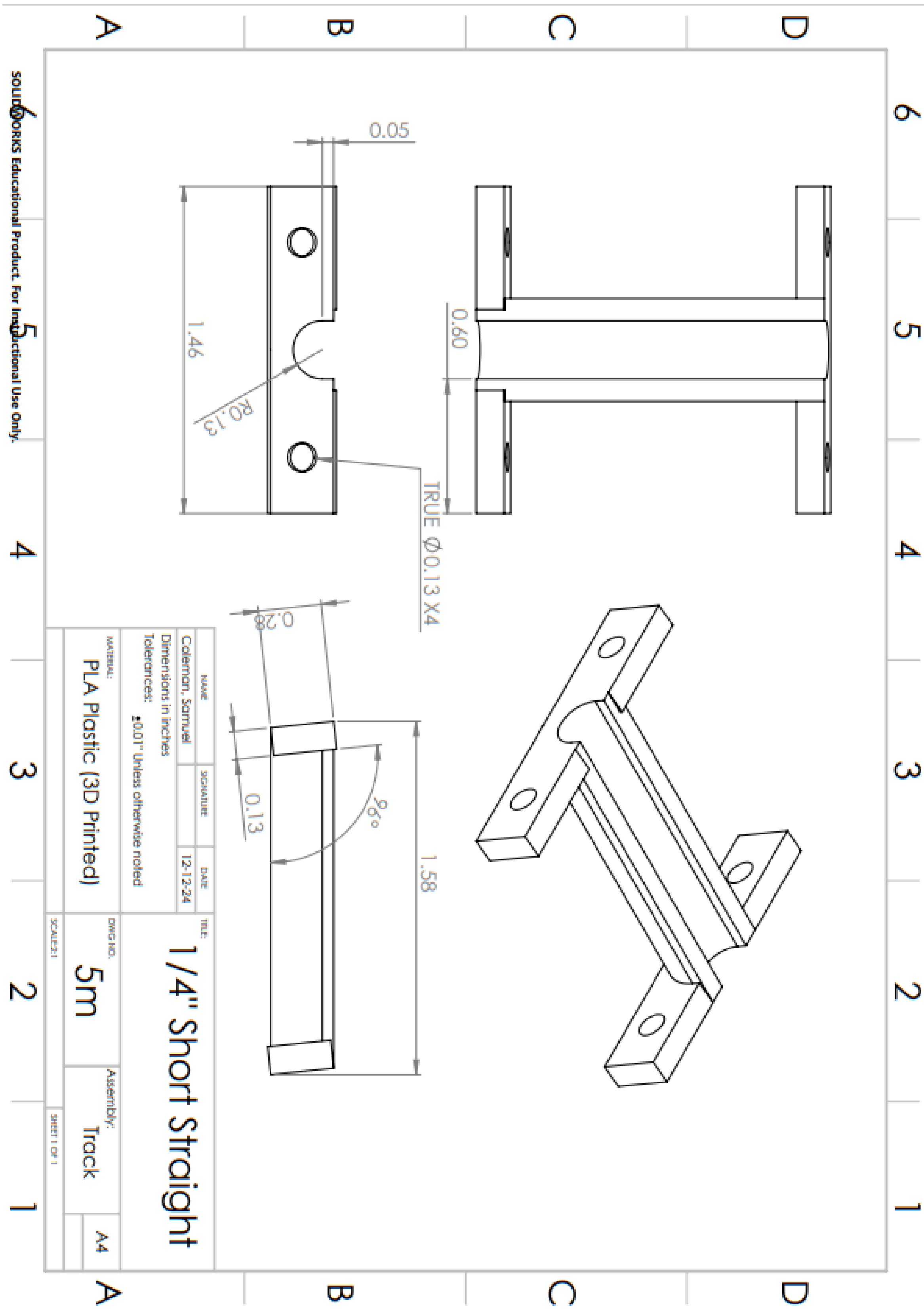


NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/4" Track Start
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)		DWG NO. 5j	Assembly: Track A4
		SCALE:1:2	SHEET 1 OF 1

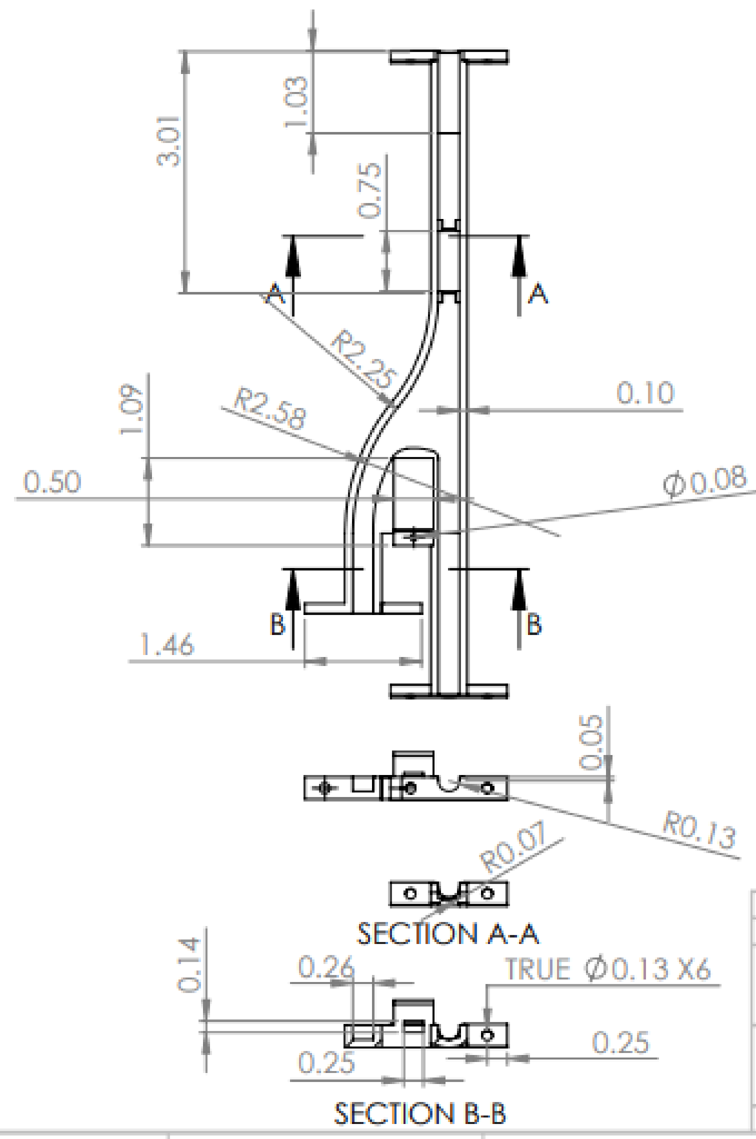

0.19
0.19
Based on helix
with base
circle of radius
2.00
0.13
0.13
0.50
0.21
0.18
0.05
1.00
R0.13
4.05
4.05
0.50
0.28
Ø0.25 X2
0.25
1.00
Ø0.13 X4
1.21
1.78
0.46
NAME
SIGNATURE
DATE
Coleman, Samuel
12-12-24
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
TITLE:
1/4" Turn
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
5k
Assembly:
Track
A4
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

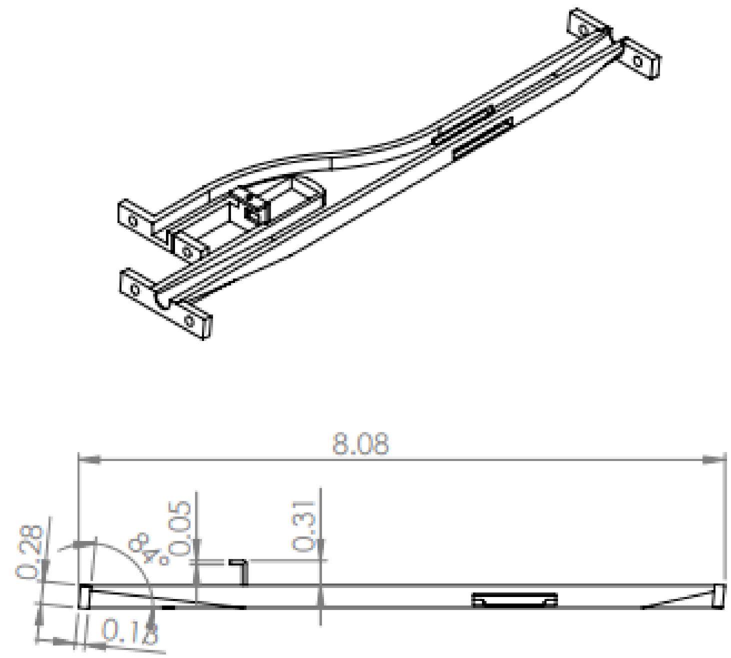


SOLIDWORKS Educational Product. For Instructional Use Only.
0.29
TRUE Ø0.13
1.46
R0.13
0.05
0.10
8.08
0.13
6°
NAME
SIGNATURE
DATE
Coleman, Samuel
12-12-24
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA (3D Printed)
TITLE:
1/4" Long Straight
DWG NO.
51
Assembly:
Track
A4
SCALE:1:2
SHEET 1 OF 1

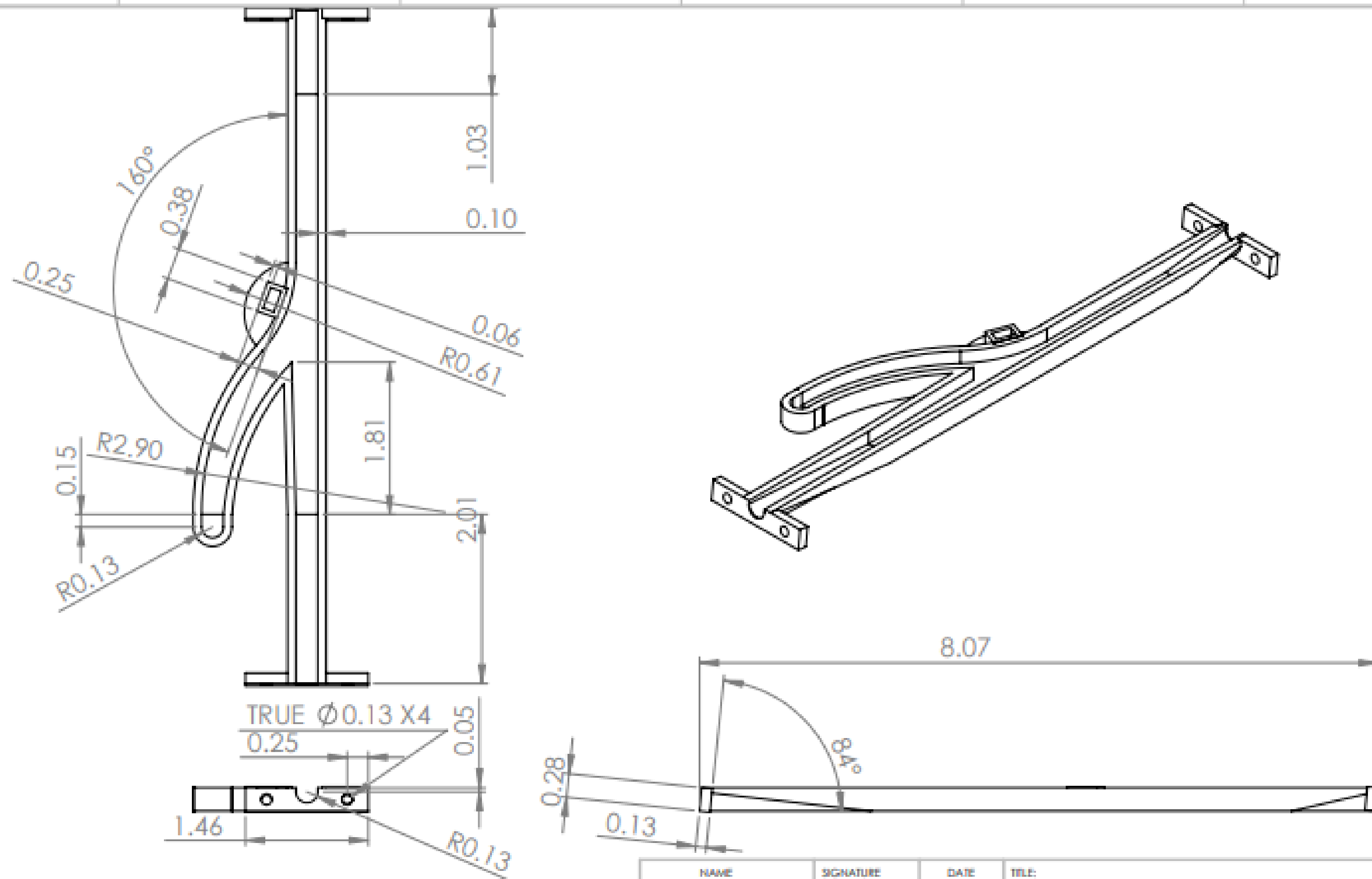


0.05
1.46
R0.13
0.60
TRUE Ø0.13 X4
0.28
0.13
9°
1.58
NAME
Coleman, Samuel
SIGNATURE
DATE
12-12-24
Dimensions in inches
Tolerances: ±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
1/4" Short Straight
DWG NO.
5m
Assembly:
Track
A4
SCALE:2:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

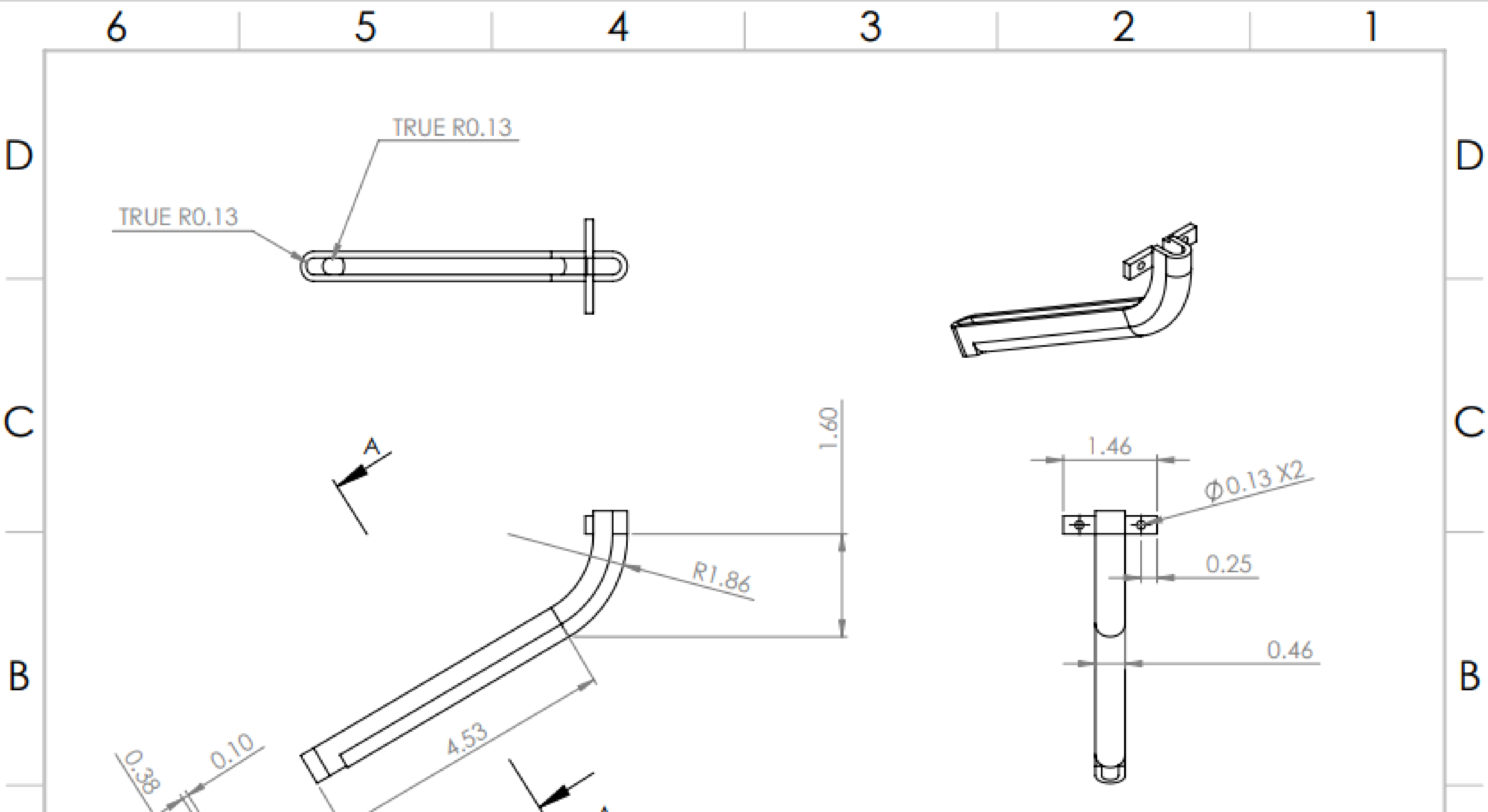




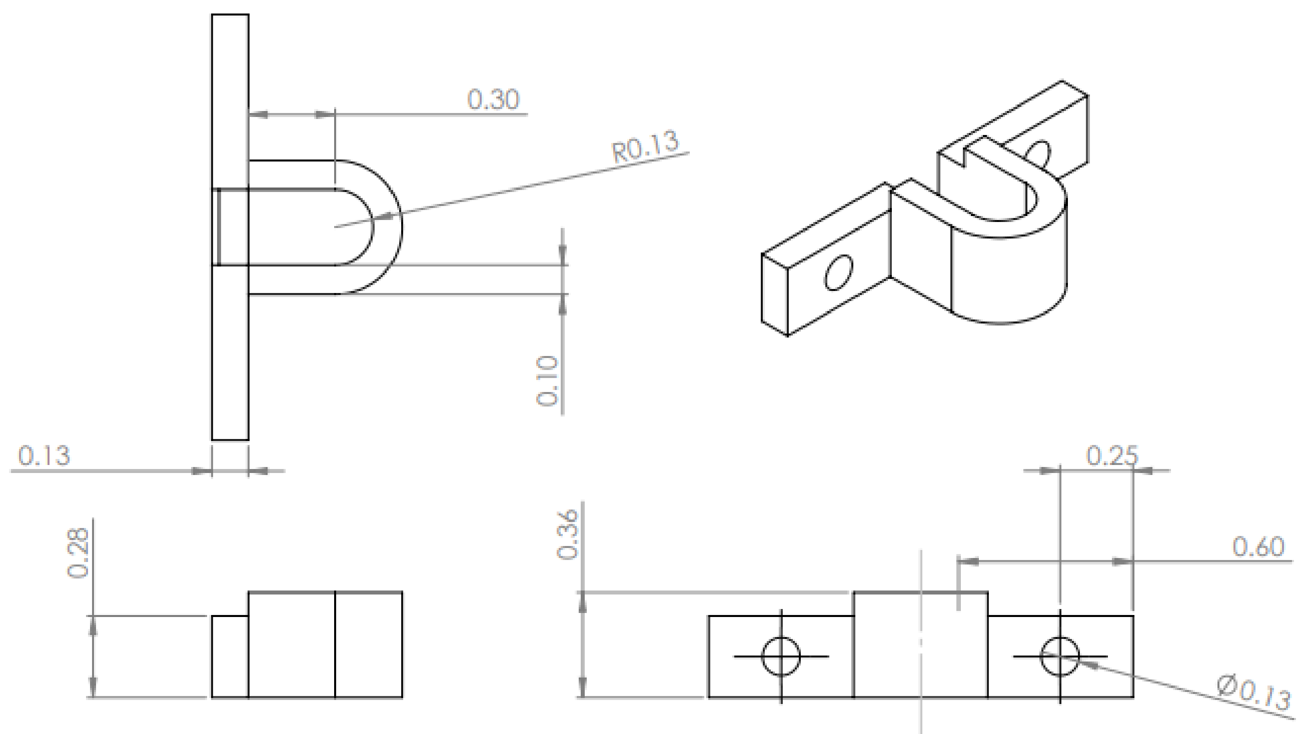
NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/4" Conductivity Separator
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 5n | Assembly: Track | A4
			SCALE:1:2 | SHEET 1 OF 1



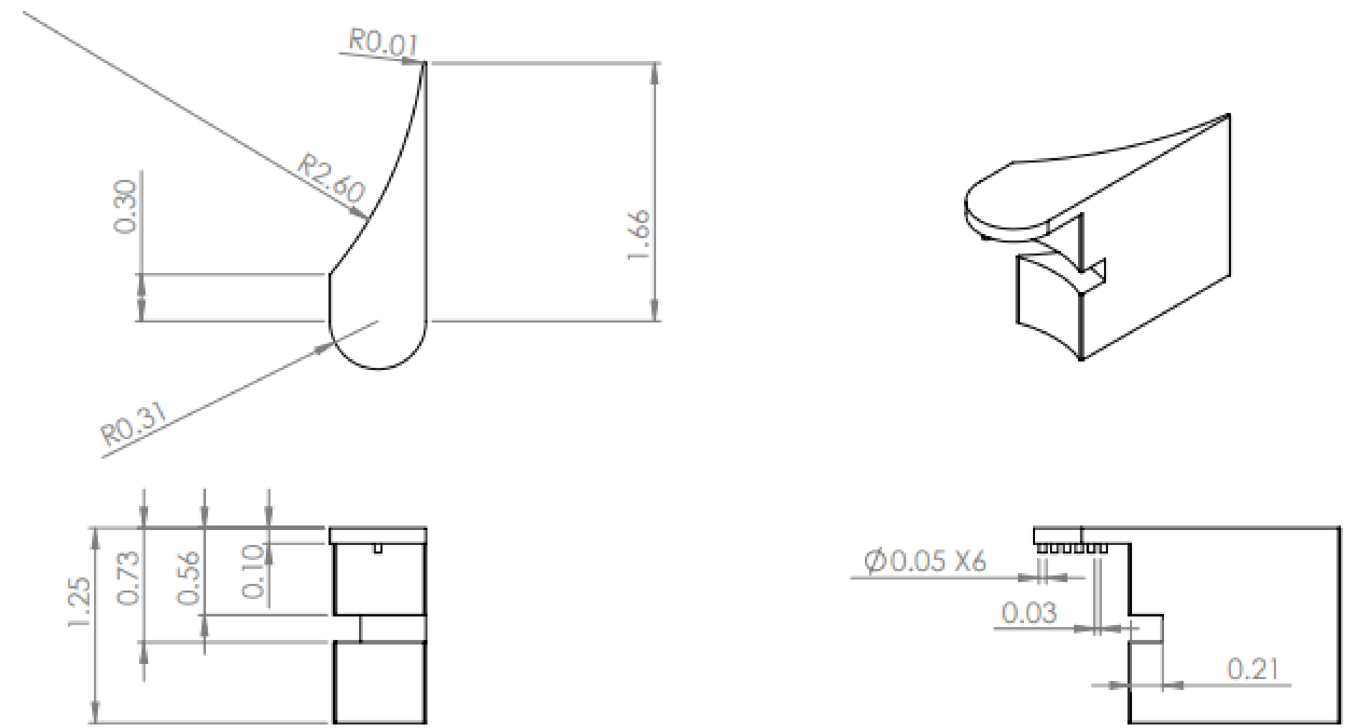
NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/4" Magnetic Separator
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 5o
			Assembly: Track
			A4
			SCALE:1:1.7
			SHEET 1 OF 1



NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/4" Drop Tube
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)	DWG NO. 5p	Assembly: Track	A4
	SCALE:1:2	SHEET 1 OF 1	

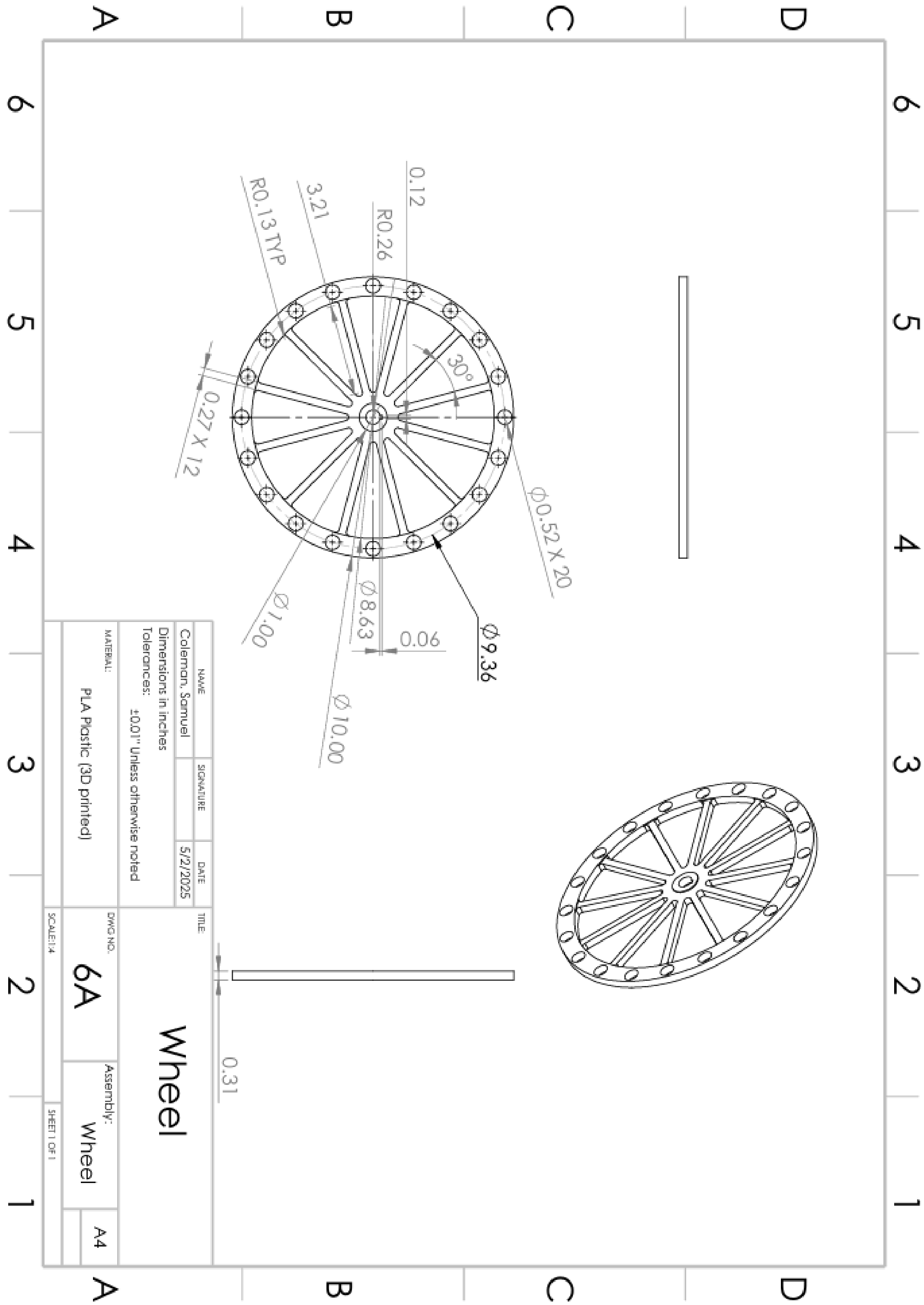


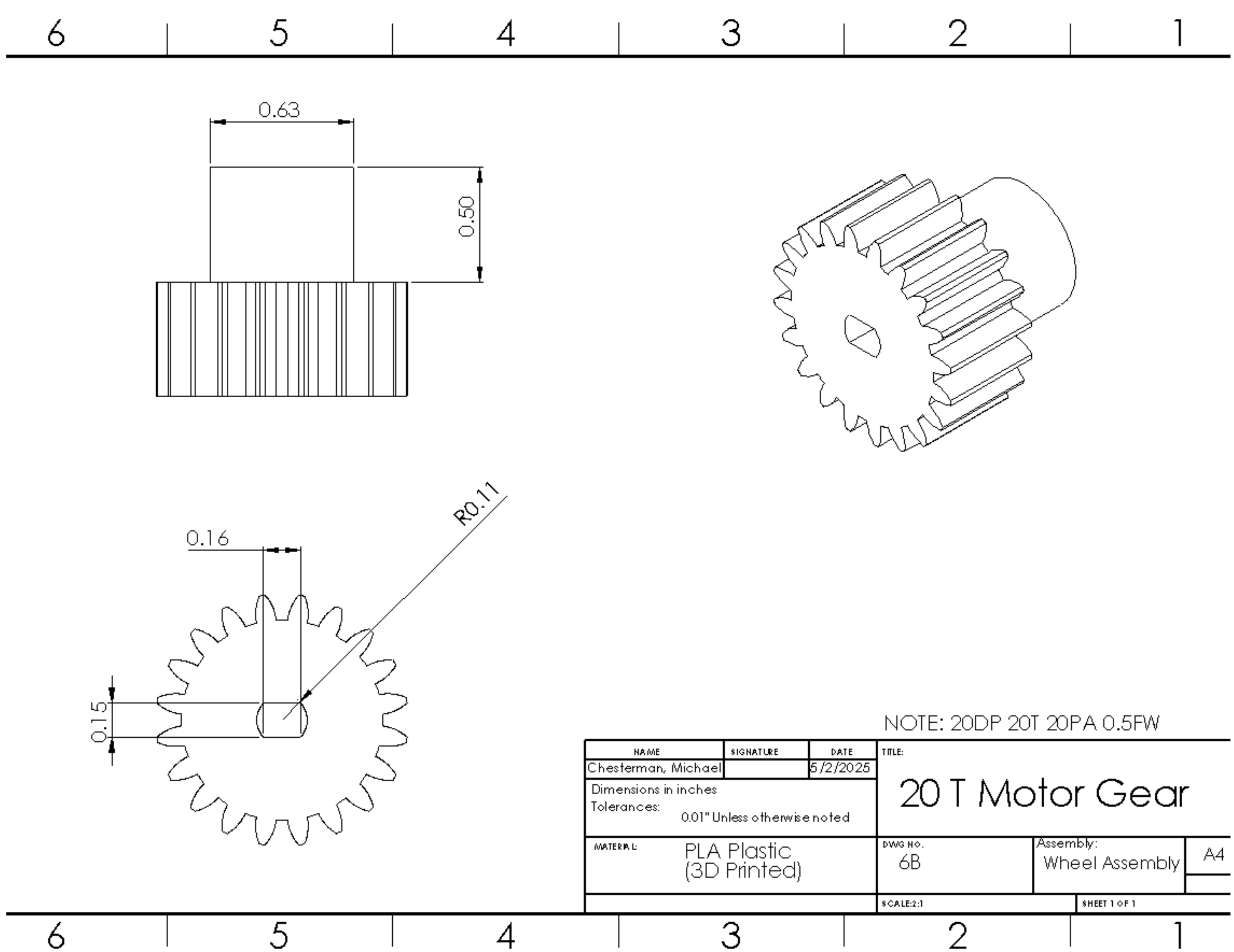
NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	1/4" Stop
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)	DWG NO. 5q	Assembly: Track	A4
	SCALE:2:1	SHEET 1 OF 1	



NAME	SIGNATURE	DATE	TITLE:
Coleman, Samuel		12-12-24	Conductivity Separation Door
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 5r · Assembly: Track · A4
			SCALE:1:1 · SHEET 1 OF 1

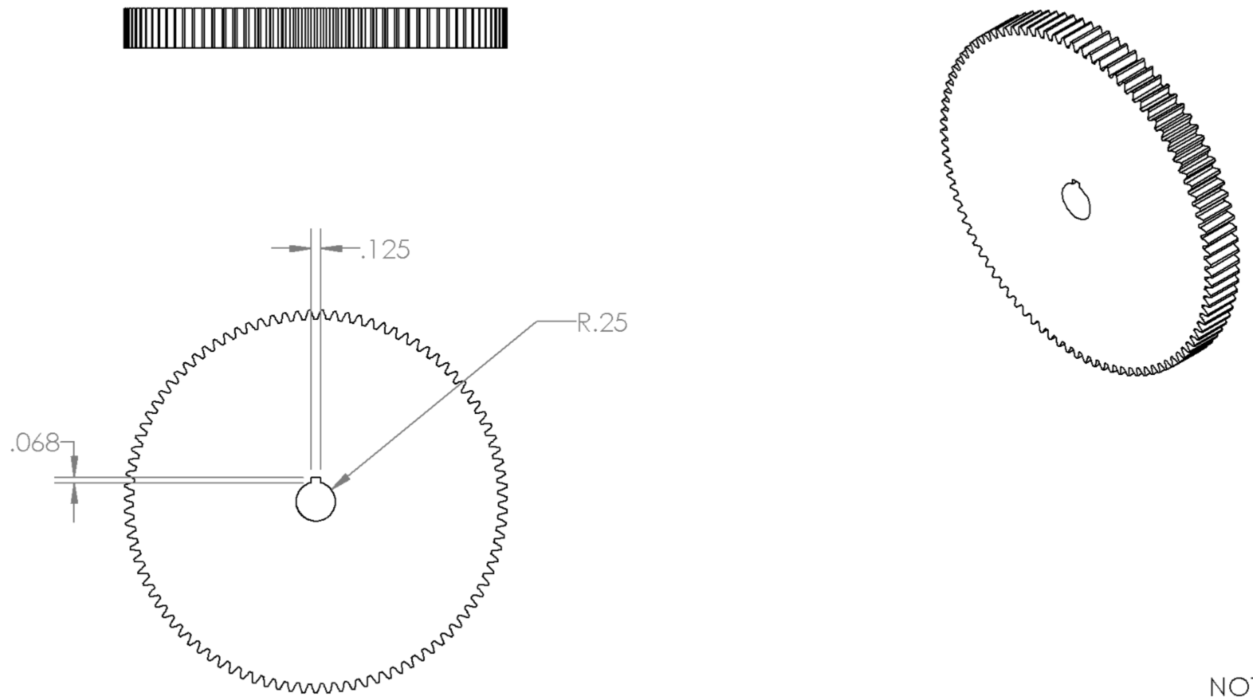
Appendix E: Wheel Assembly Part Drawings





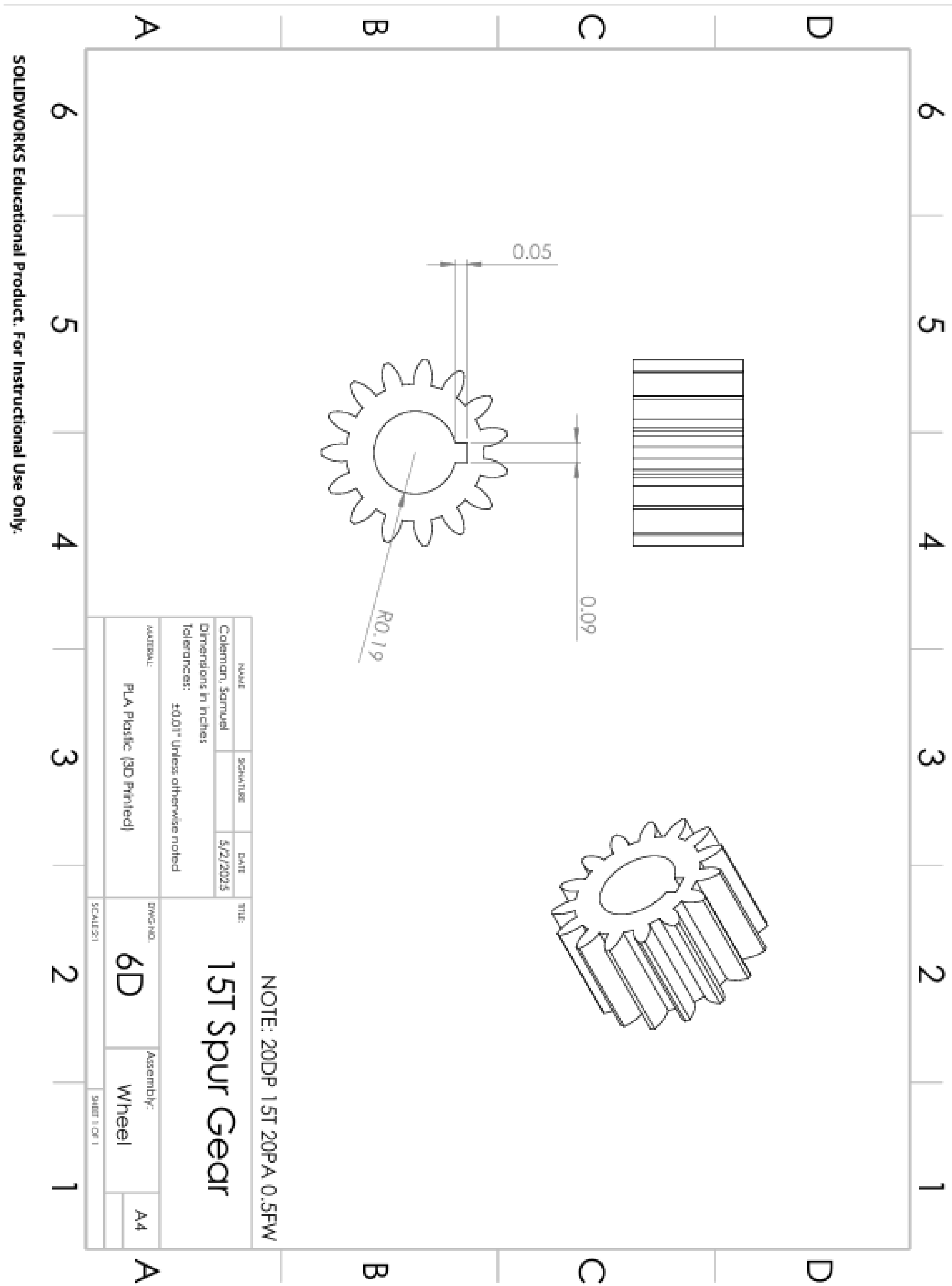
NOTE: 20DP 20T 20PA 0.5FW

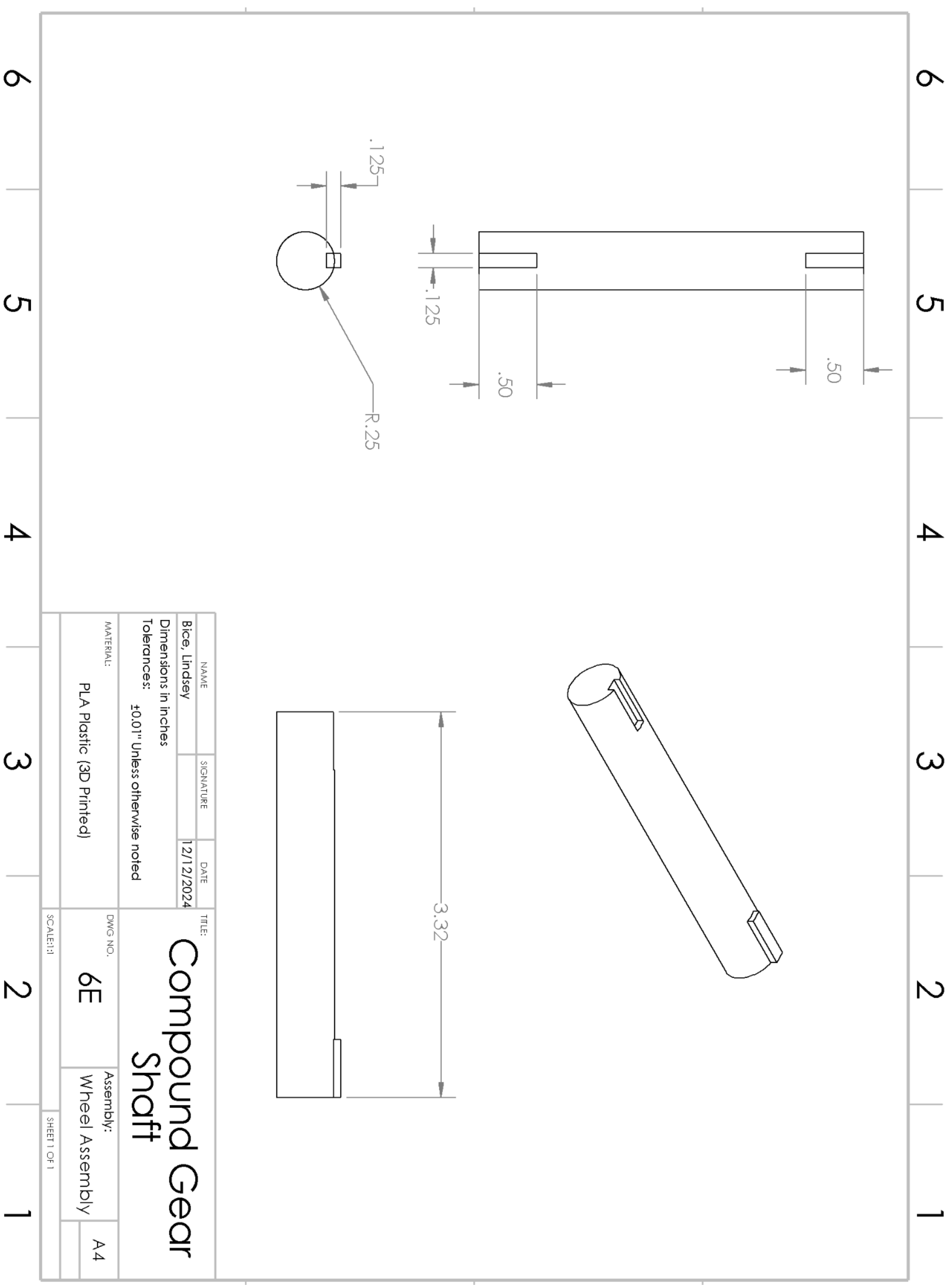
NAME	SIGNATURE	DATE	TITLE:
Chesterman, Michael		5/2/2025	20 T Motor Gear
Dimensions in inches Tolerances: 0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6B ; Assembly: Wheel Assembly ; A4
			SCALE:2:1 ; SHEET 1 OF 1

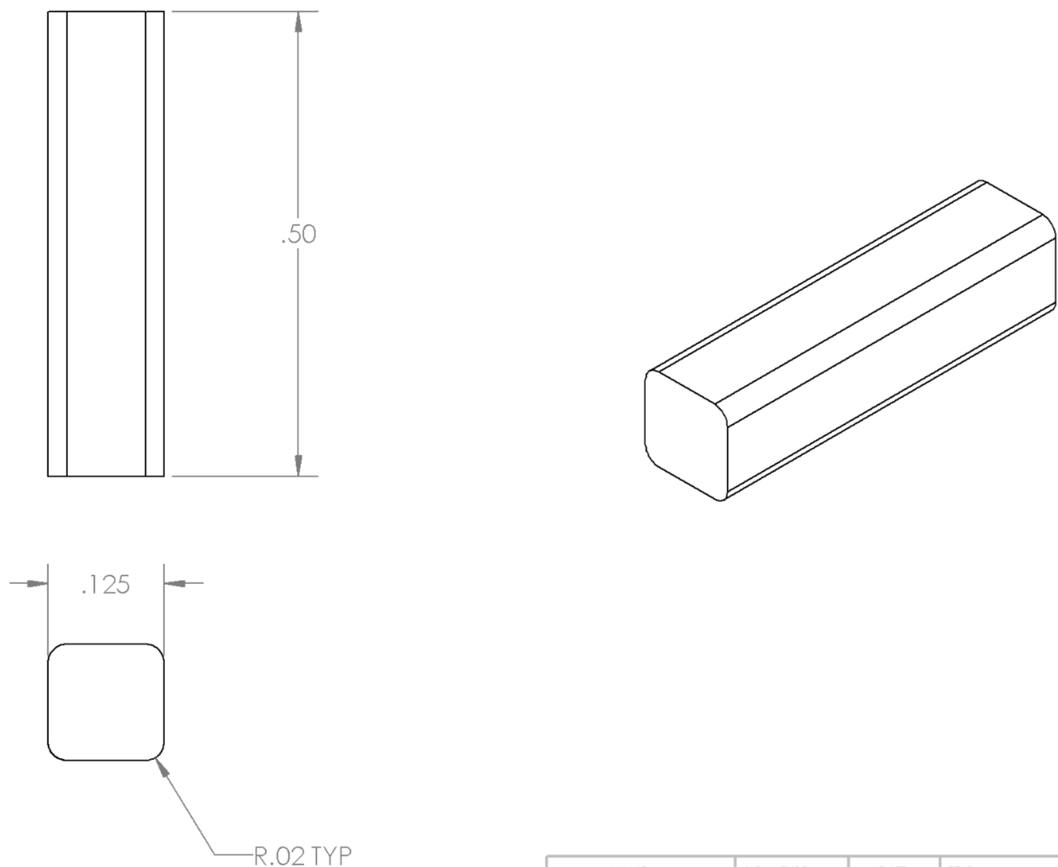


NOTE: 20DP 95T 20PA 0.5FW

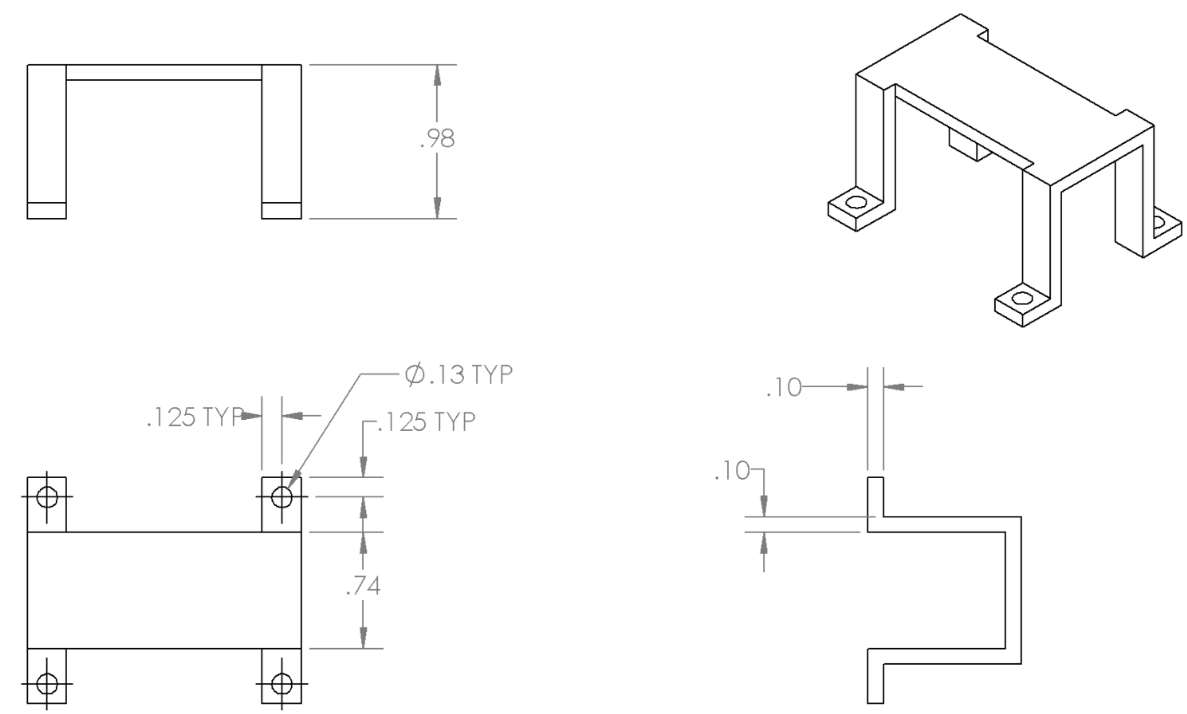
NAME	SIGNATURE	DATE	TITLE:	
Bice, Lindsey		12/12/2024	95 T Spur Gear	
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted				
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6C	Assembly: Wheel Assembly — A4
			SCALE:1:2	SHEET 1 OF 1


0.05
0.09
R0.19
NOTE: 20DP 15T 20PA 0.5FW
NAME
SIGNATURE
DATE
TITLE:
Coleman, Samuel
5/2/2025
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
15T Spur Gear
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
6D
Assembly:
Wheel
A4
SCALE 2:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.

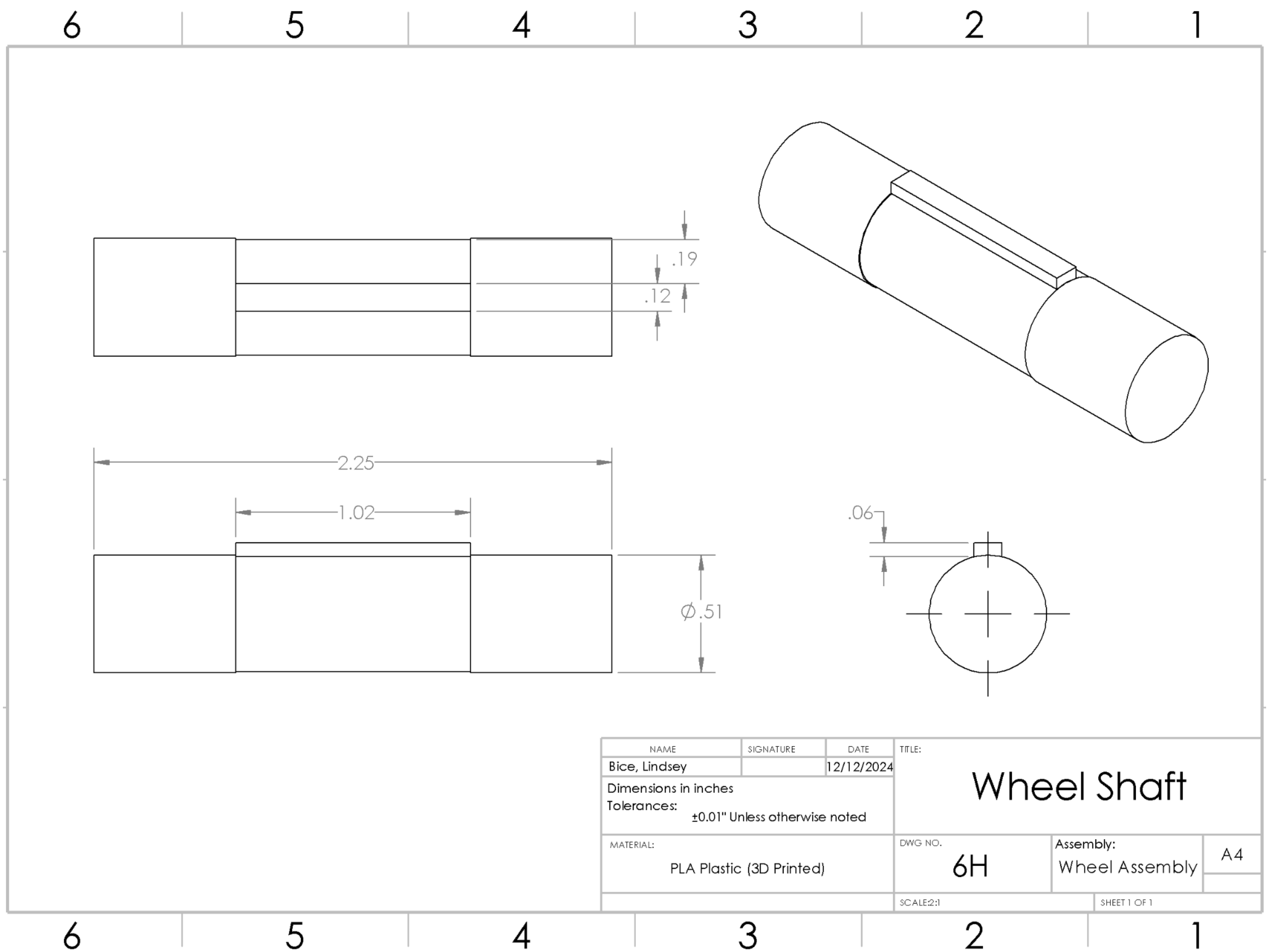

.125
.125
.50
.50
R.25
3.32
NAME
Bice, Lindsey
SIGNATURE
DATE
12/12/2024
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
Compound Gear Shaft
DWG NO.
6E
Assembly:
Wheel Assembly
A4
SCALE:1:1
SHEET 1 OF 1



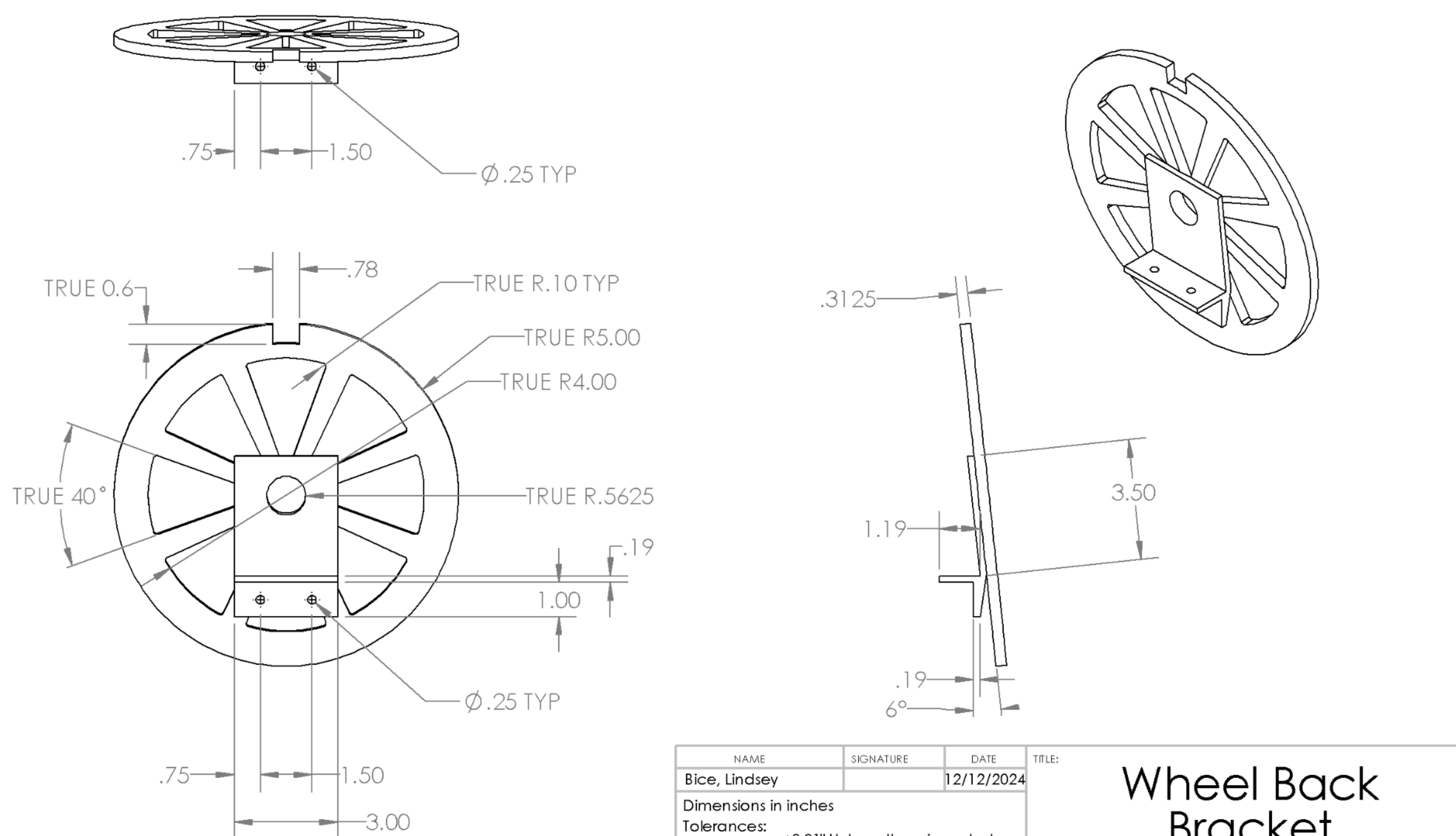
NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	Shaft Key
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6F — Assembly: Wheel Assembly — A4
			SCALE:6:1 — SHEET 1 OF 1



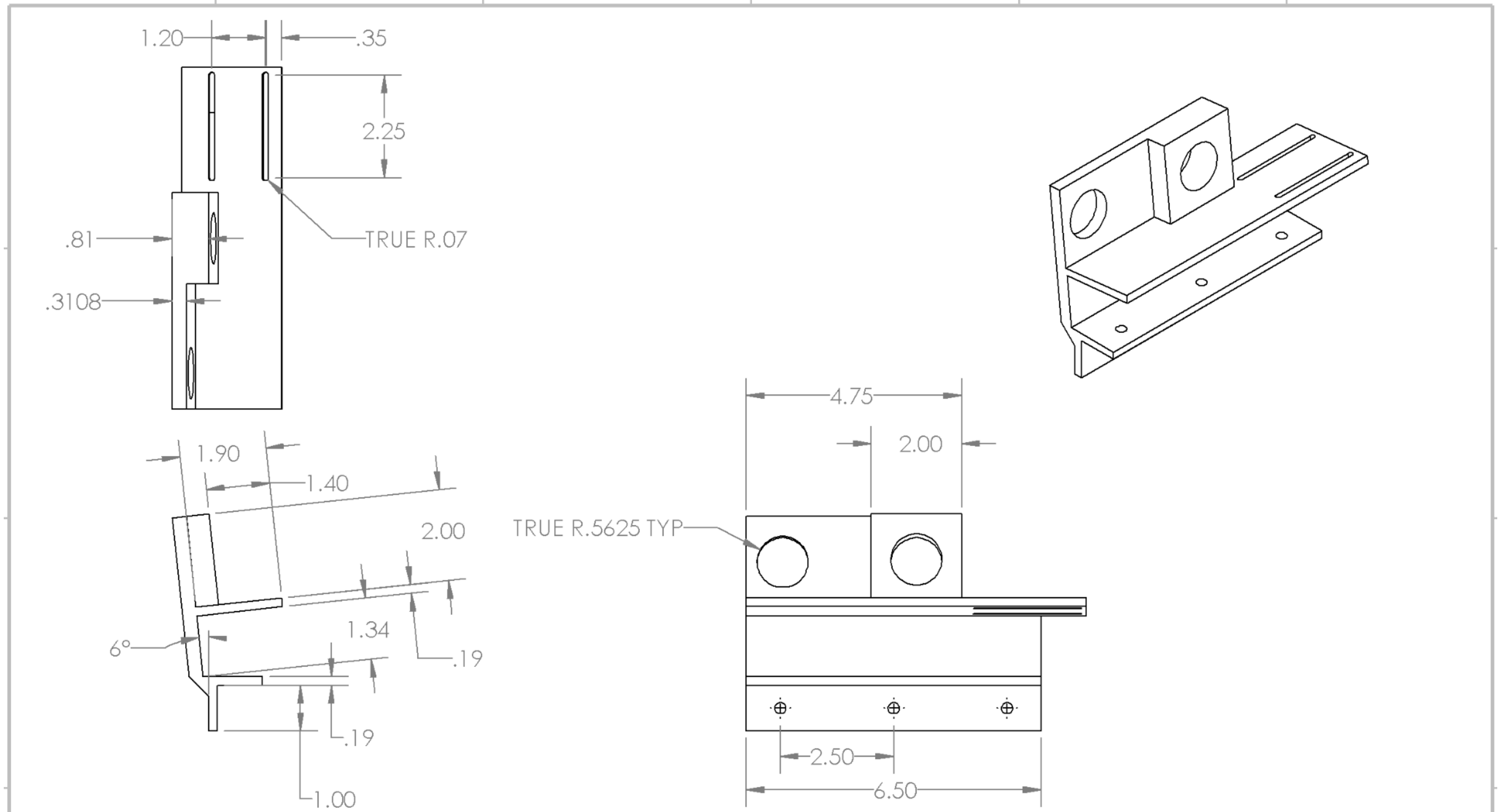
NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	DC Motor Holder
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6G
			Assembly: Wheel Assembly
			A4
			SCALE:1:1
			SHEET 1 OF 1



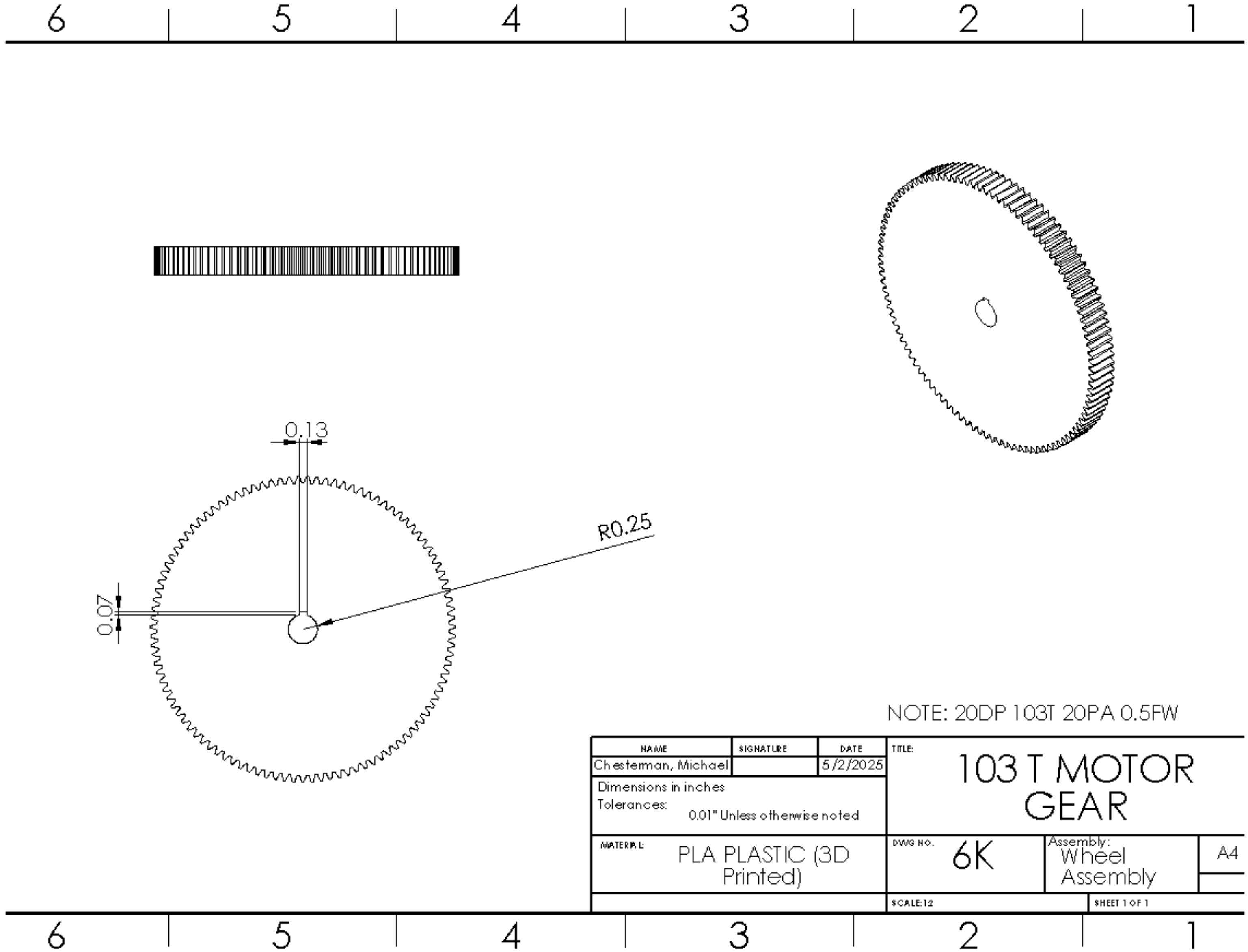
NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	Wheel Shaft
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6H; Assembly: Wheel Assembly; A4
			SCALE:2:1; SHEET 1 OF 1



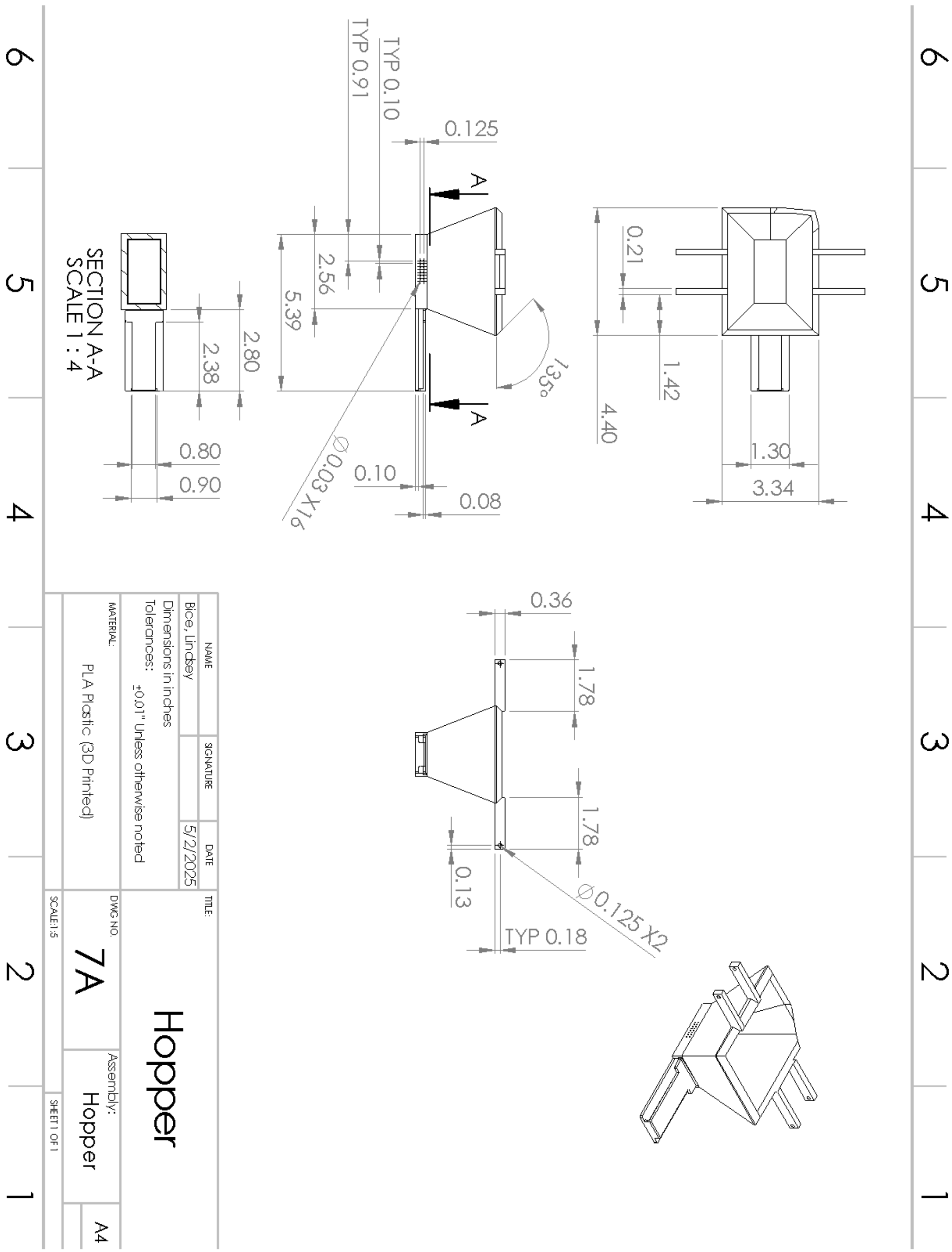
NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	Wheel Back Bracket
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6I; Assembly: Wheel Assembly; A4
			SCALE:1:4; SHEET 1 OF 1

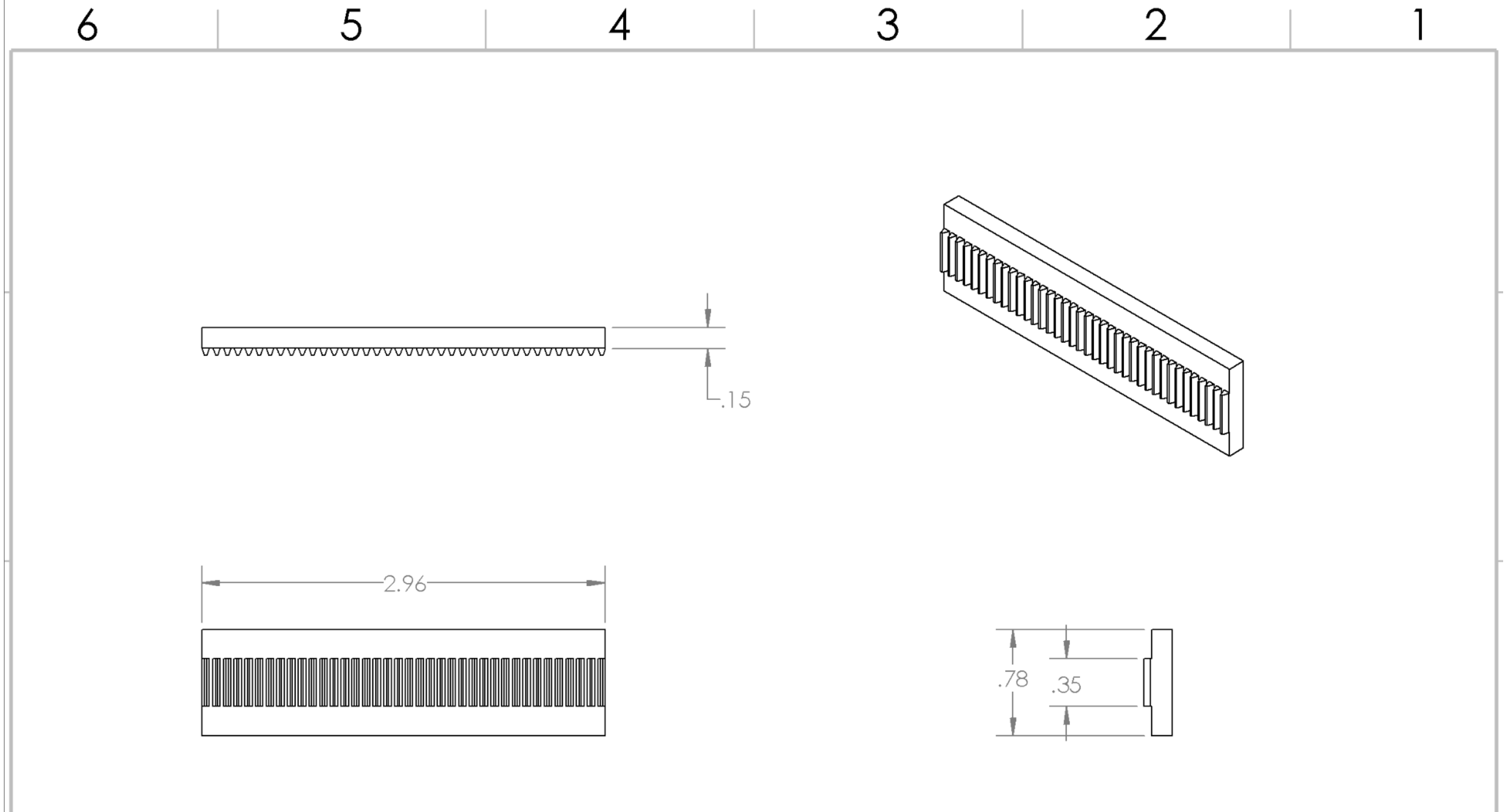


NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		12/12/2024	Wheel Front Bracket
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 6J
			Assembly: Wheel Assembly
			A4
			SCALE:1:3
			SHEET 1 OF 1


0.13
0.07
R0.25
NOTE: 20DP 103T 20PA 0.5FW
NAME
SIGNATURE
DATE
Chesterman, Michael
5/2/2025
Dimensions in inches
Tolerances:
0.01" Unless otherwise noted
MATERIAL:
PLA PLASTIC (3D Printed)
TITLE:
103 T MOTOR GEAR
DWG NO.
6K
Assembly:
Wheel Assembly
A4
SCALE:1:2
SHEET 1 OF 1

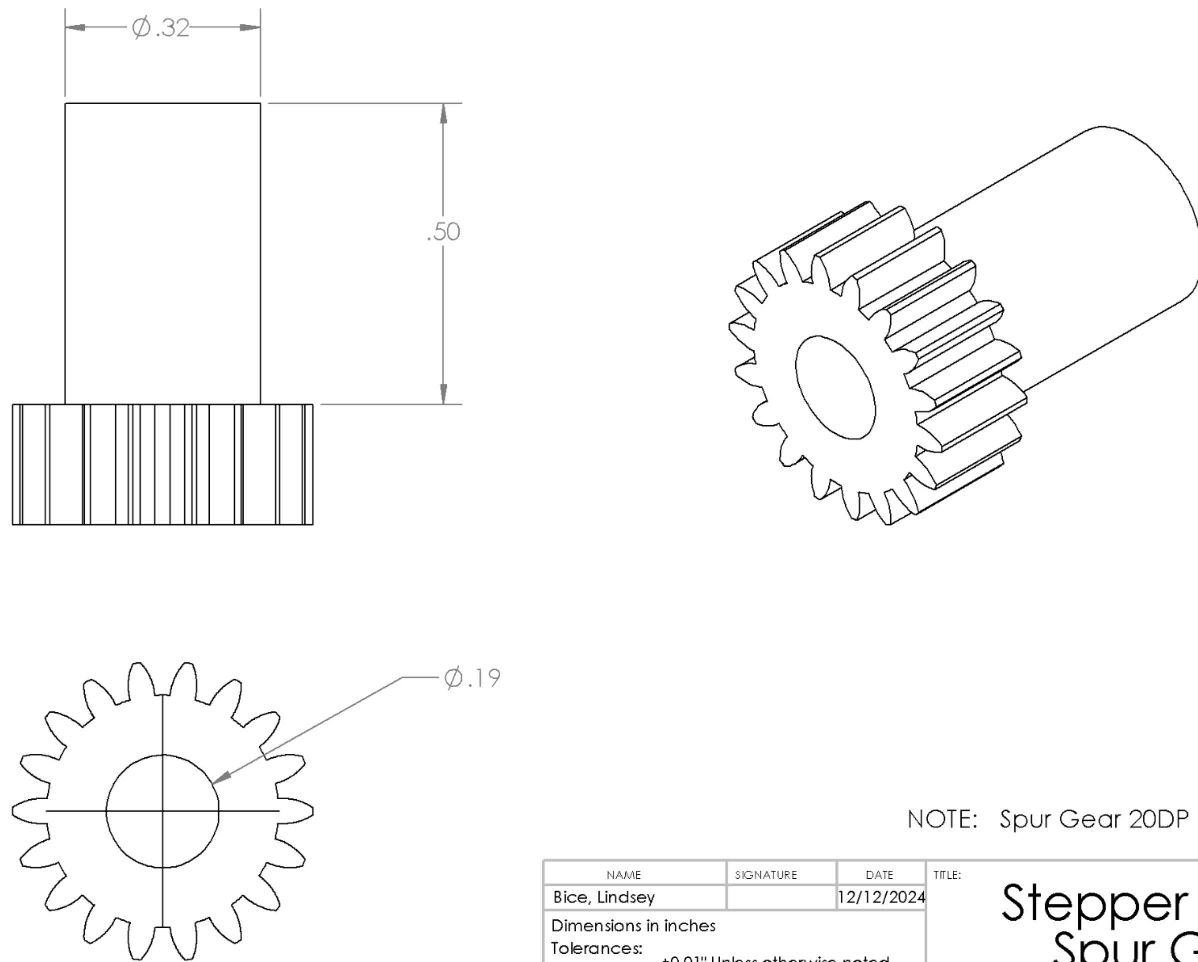
Appendix F: Hopper Assembly Part Drawings





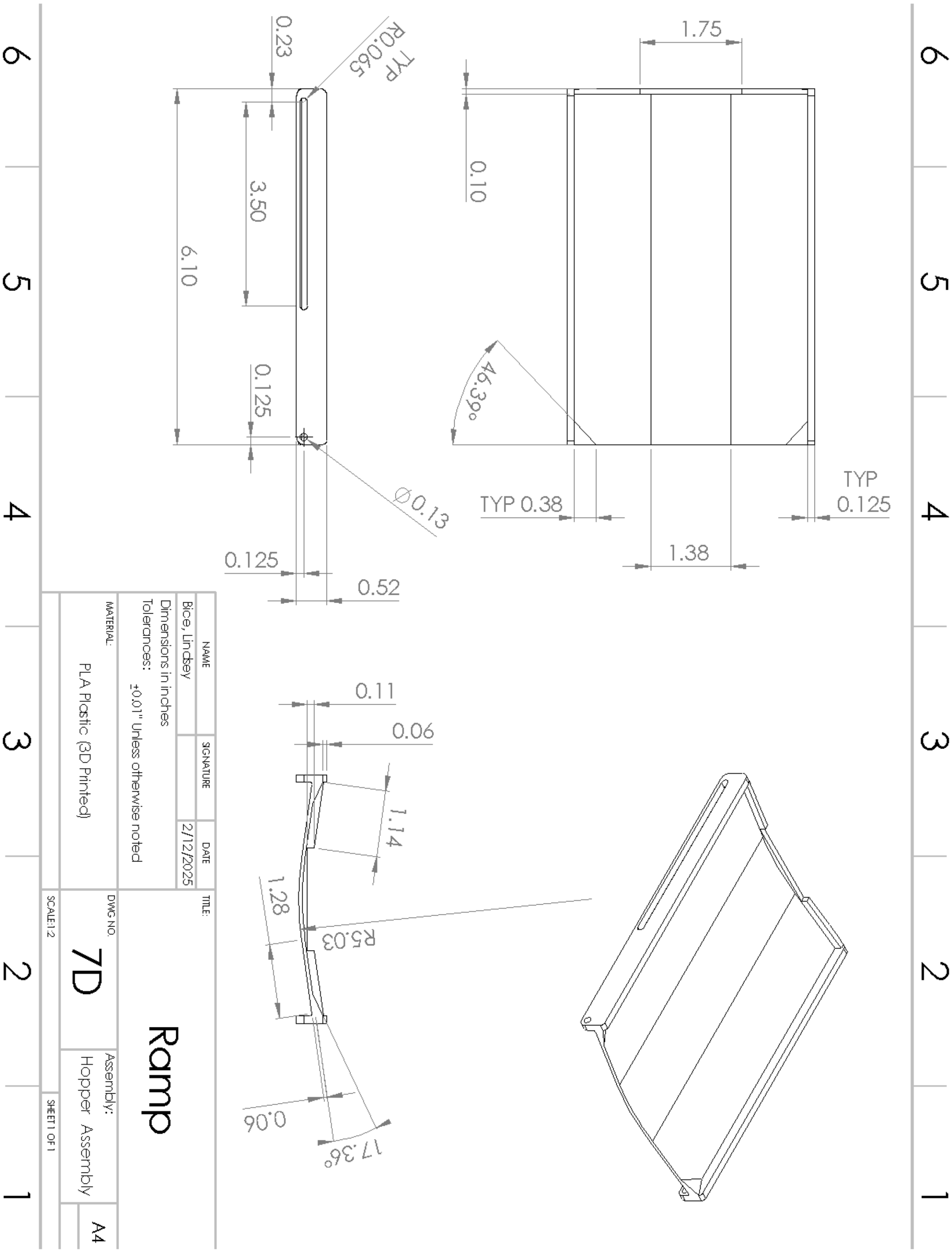
NOTE: Rack 20DP 38T 20PA 0.35FW

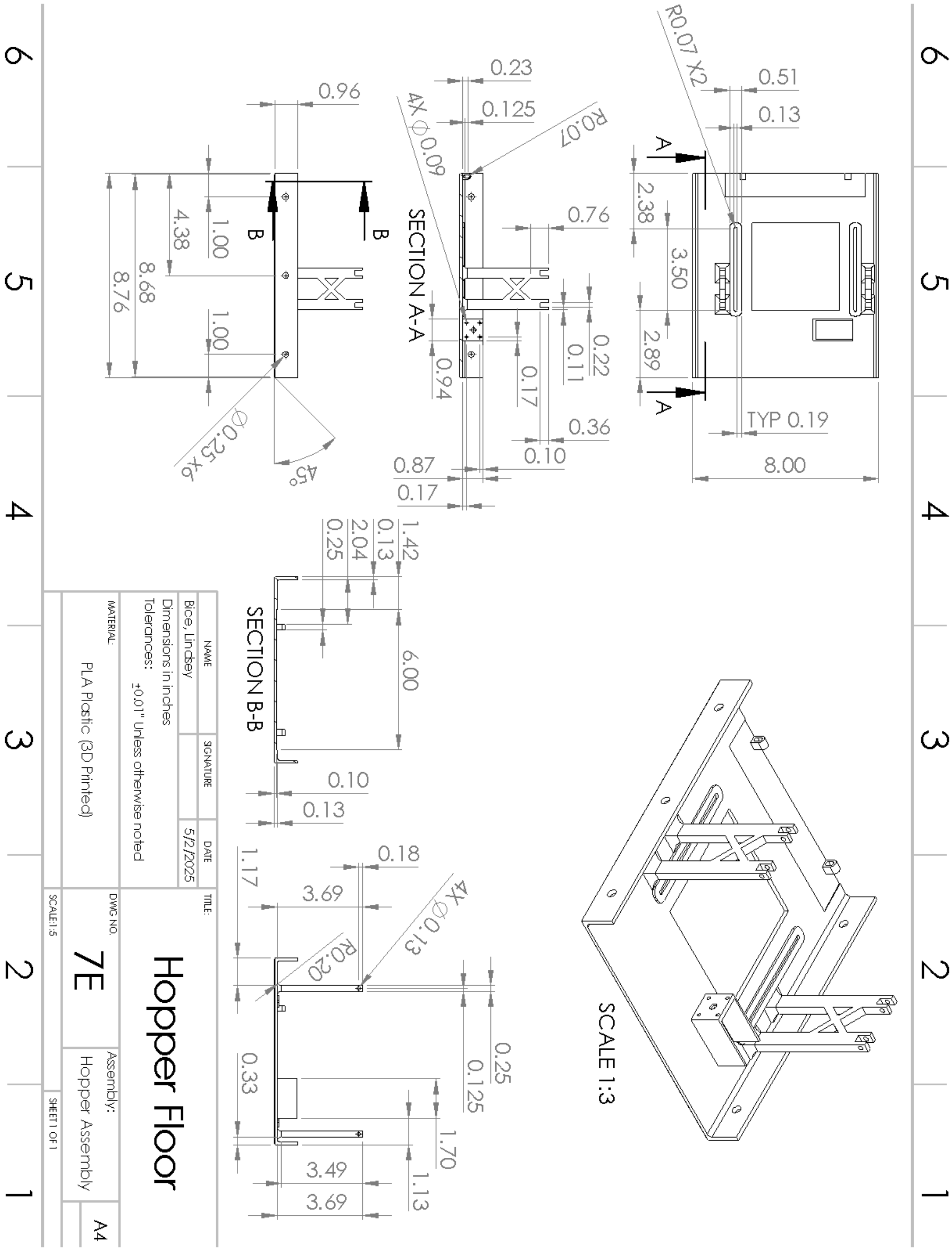
NAME	SIGNATURE	DATE	TITLE:		
Bice, Lindsey		12/12/2024	Hopper Gate		
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted					
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 7B	Assembly: Hopper Assembly	A4
			SCALE:1:1	SHEET 1 OF 1	

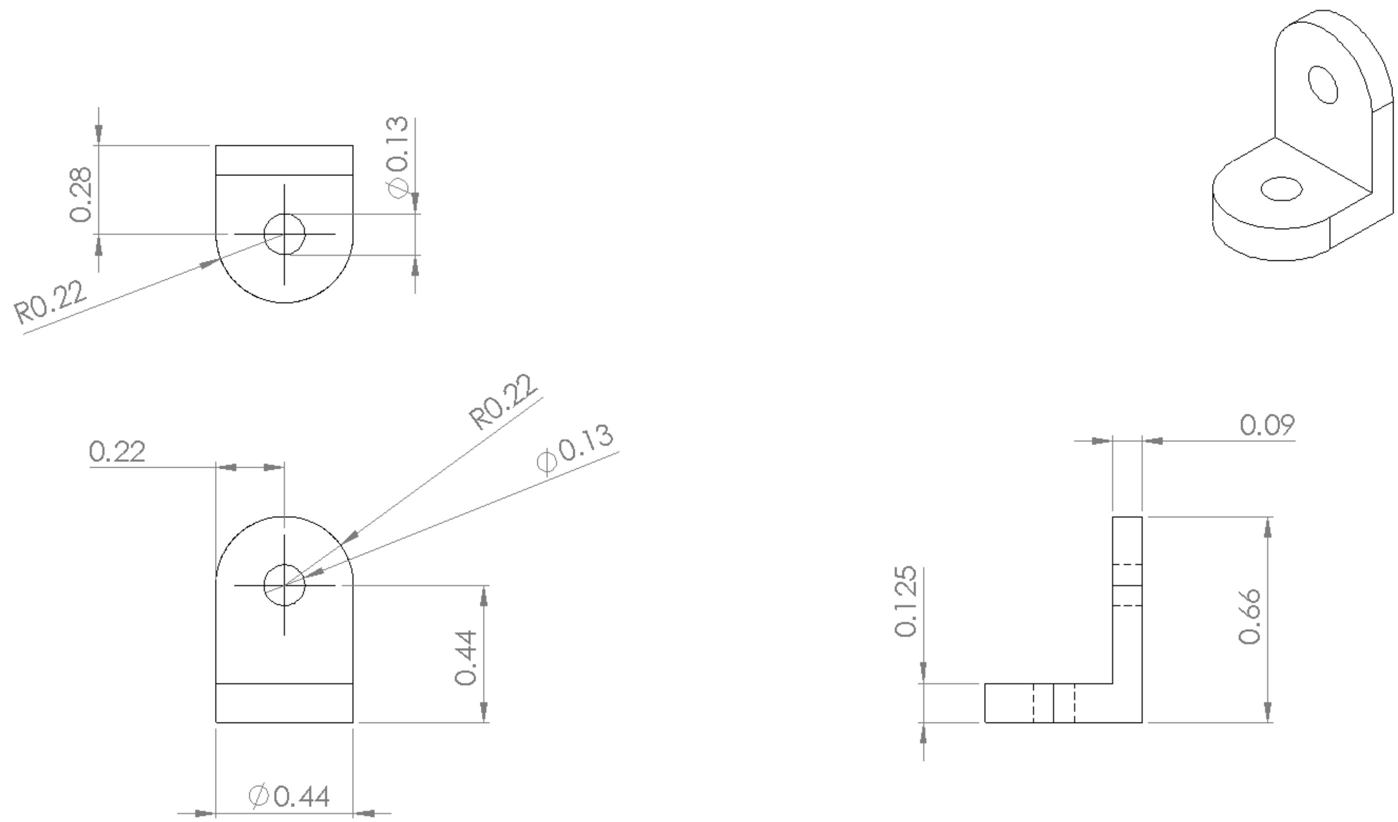


NOTE: Spur Gear 20DP 18T 20PA 0.2FW

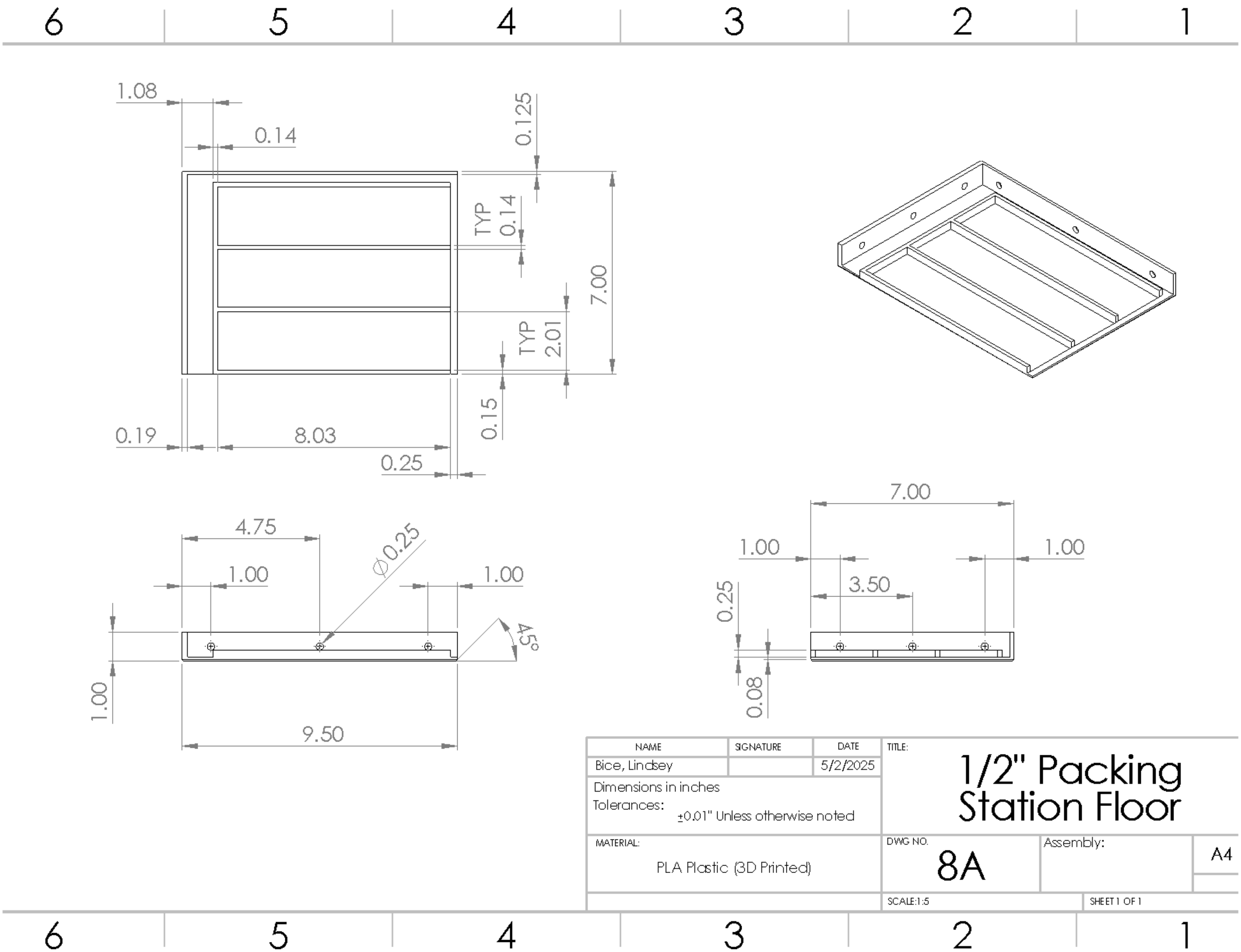
NAME	SIGNATURE	DATE	TITLE:		
Bice, Lindsey		12/12/2024	Stepper Motor Spur Gear		
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted					
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 7C	Assembly: Hopper Assembly	A4
			SCALE:4:1	SHEET 1 OF 1	


Ramp
NAME
SIGNATURE
DATE
TITLE:
Bice, Lindsey
2/12/2025
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
DWG NO.
7D
Assembly:
Hopper Assembly
A4
SCALE:1:2
SHEET 1 OF 1
1.75
0.10
46.39°
TYP 0.38
TYP
0.125
1.38
0.23
R0.065
TYP
3.50
6.10
0.125
Ø0.13
0.125
0.52
0.11
0.06
1.14
1.28
R5.03
0.06
17.36°

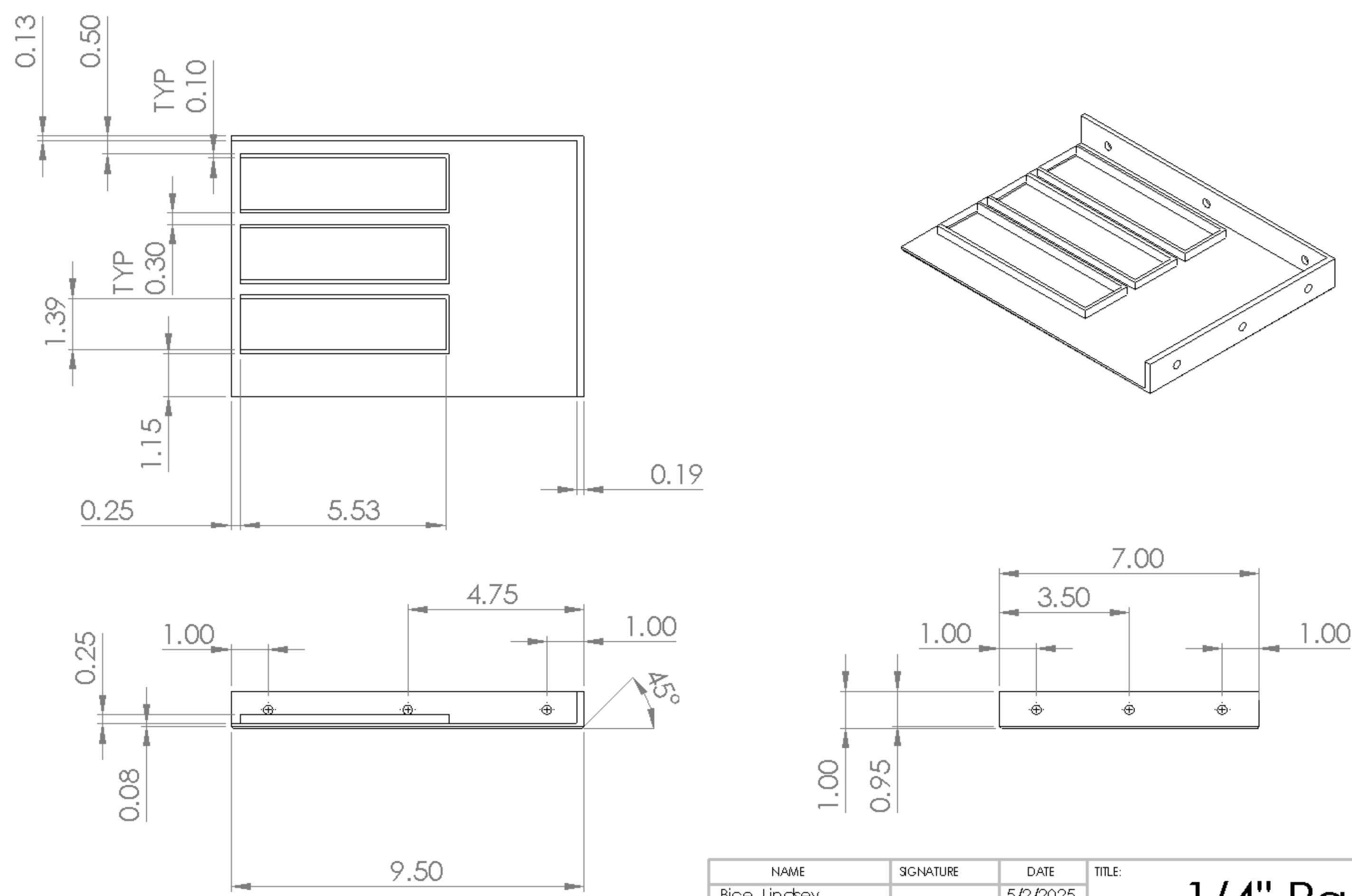

SECTION A-A
SECTION B-B
SCALE 1:3
R0.07 X2
0.51
0.13
TYP 0.19
8.00
2.38
3.50
2.89
0.23
0.125
R0.07
4X Ø0.09
0.76
0.22
0.11
0.17
0.94
0.36
0.10
0.87
0.17
0.96
4.38
1.00
8.68
8.76
Ø0.25 X6
45°
1.42
0.13
2.04
0.25
6.00
0.10
0.13
1.17
3.69
0.18
4X Ø0.13
R0.20
0.25
0.125
1.70
1.13
0.33
3.49
3.69
NAME
SIGNATURE
DATE
Bice, Lindsey
5/2/2025
Dimensions in inches
Tolerances:
±0.01" Unless otherwise noted
MATERIAL:
PLA Plastic (3D Printed)
TITLE:
Hopper Floor
DWG NO.
7E
Assembly:
Hopper Assembly
A4
SCALE:1:5
SHEET 1 OF 1



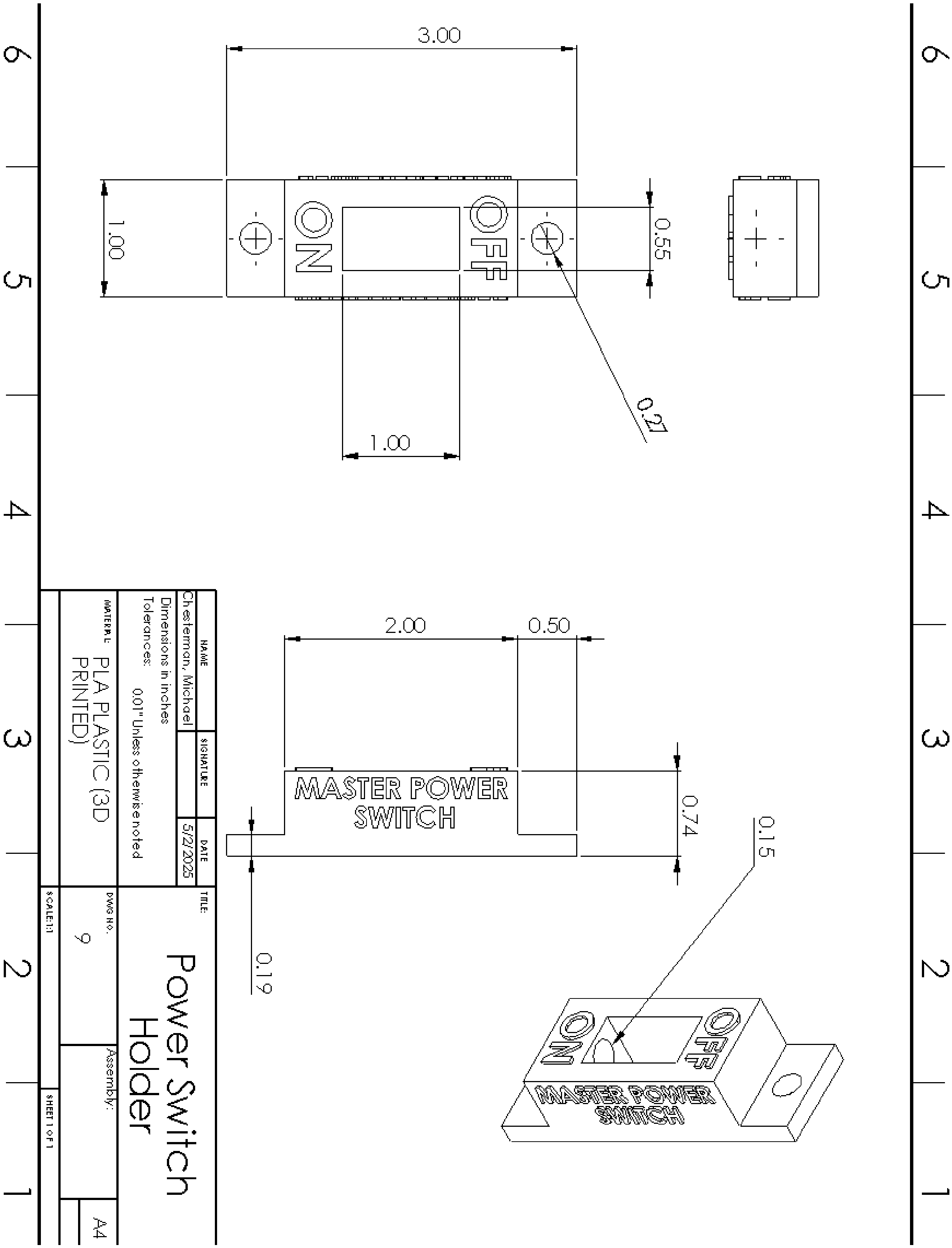
NAME	SIGNATURE	DATE	TITLE:		
Bice, Lindsey		5/2/2025	Ramp Bracket		
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted					
MATERIAL: PLA Plastic (3D printed)			DWG NO. 7F	Assembly: Hopper Assembly	A4
			SCALE:2:1	SHEET 1 OF 1	



NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		5/2/2025	1/2" Packing Station Floor
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL: PLA Plastic (3D Printed)			DWG NO. 8A
			Assembly:
			A4
			SCALE:1:5
			SHEET 1 OF 1



NAME	SIGNATURE	DATE	TITLE:
Bice, Lindsey		5/2/2025	1/4" Packing Station Floor
Dimensions in inches Tolerances: ±0.01" Unless otherwise noted			
MATERIAL:			DWG NO. 8B
			Assembly:
			A4
			SCALE:1:5
			SHEET 1 OF 1


Power Switch Holder
NAME
Chesterman, Michael
SIGNATURE
DATE
5/2/2025
TITLE:
Dimensions in inches
Tolerances: 0.01" Unless otherwise noted
MATERIAL
PLA PLASTIC (3D PRINTED)
DWG NO.
9
Assembly:
A4
SCALE:1:1
SHEET 1 OF 1
MASTER POWER SWITCH
ON
OFF
3.00
1.00
0.55
0.27
1.00
2.00
0.50
0.74
0.15
0.19