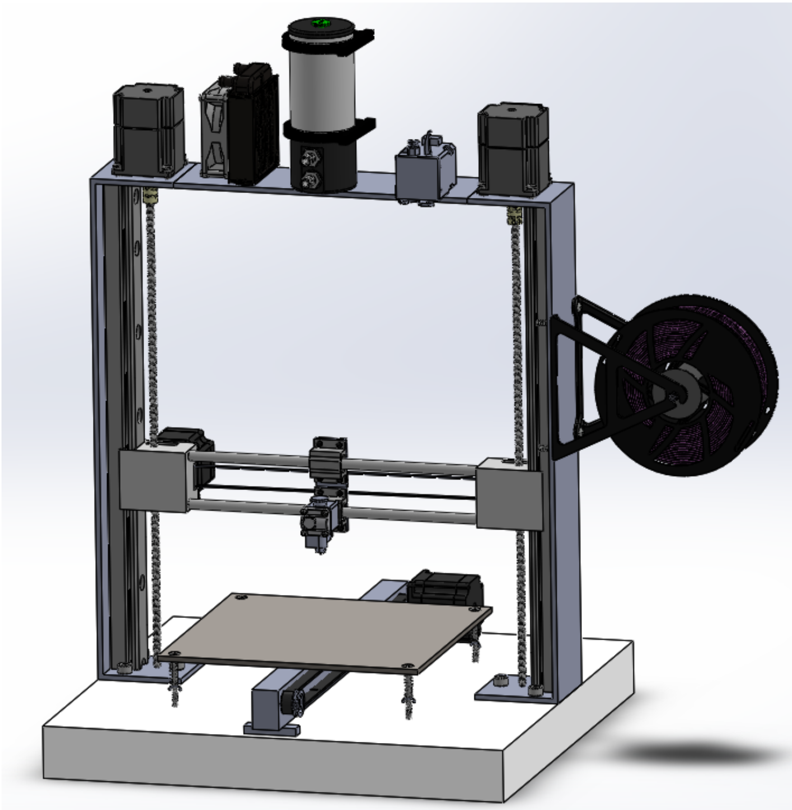
Fast 3D Printer: Final Report



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1.0 Introduction and Research

1.1 Introduction

The team have designed a conceptual design for a 3D printer that satisfies the printing speed, printing quality, and price point that is close to the market's entry level, with safety and reliability regulations taken in mind. This conceptual design will be a cost-effective solution for users to access upgraded features that will qualitatively affect their design outcomes. This is a form of computer numerical control (CNC) machine that performs heating and extruding filament, depositing controlled layers on the printing plate with the adjustments from other equipped components to form a tangible design. This document outlines the design process, including research, idea generation, analysis of candidate designs, and the final solution developed by the team.

1.2 Problem Statement

With technologies constantly evolving, various models of 3D printers have entered the market in the past two years. Entry professionals and hobbyists have been offered tons of brand-new automated features that were only available on expensive and high-grade professional machines. Though the upgrades greatly enhanced the productivity and quality of the prints, they struggled to meet the client's expectations of the pricing. The alternative for the user would be those existing entry-level printers that offer past-generation technical specifications; thus, productivity and quality can hardly catch up, as illustrated in Figure 1 and 2. Current efforts in upgrading 3D printers with newer technologies leave the product "budgetly" inaccessible for entry professionals and hobbyists. These factors hinder the cost of getting one of those high-end printers as a hobby toy, failing to reflect the perspectives on creating various high-end specs for most clients who are always willing to buy and instead represent how expensive a 3D printer is. Thus, the clients need a more affordable solution that is preferably close to the market's entry-level but can still uphold the printing speed as it is on the X1c model and maintain acceptable printing quality.

Users rely on the new automated features to elevate the efficiency and outcomes of the printed models, and pricing plays a critical role in finding the right fit for buyers' budgets. Currently, users can use new features for a lower price, but often with printers that only have one single feature practically usable. While they can choose what kind of specs they need, they should ideally be able to get their hands on the vast number of newly equipped technologies after spending the entry-level market price. Additionally, the design should be accessible and not exceed the entry-level market price.

To address these concerns, thorough research and analysis on the overall features and capabilities that are head-to-head with other printers in the same price range. The design created to address this problem must be an FDM printer that is compatible with a wide range of plastic filaments. It should only account for FDM and plastic printing materials; thus, any other material deposition methods, printed materials, or modifications related to the electrical aspects of the printer are all outside of our scope.

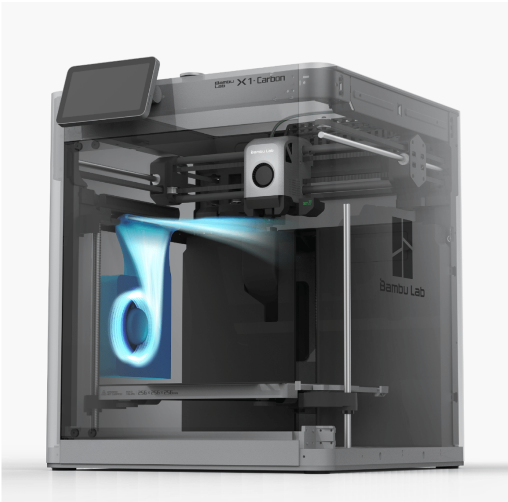

Figure 1. Bambo lab X1 Series [1]

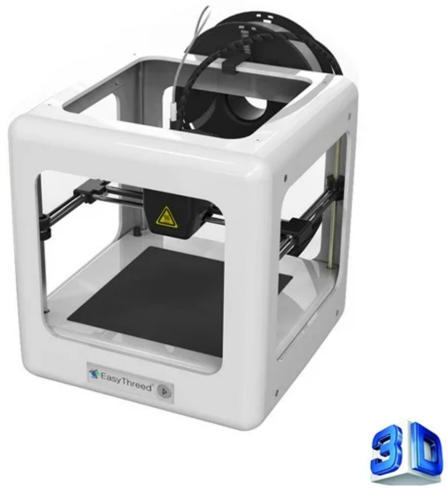

Figure 2. FMEA FM-T5 [2]

1.3 Research

We took the technical specifications of the three best, most popular fast 3D printers currently on the market, shown in Table 1. They have one common feature: they can all achieve a printing speed of up to 500mm/s.

Table 1. Market Research of Three 3D Printers

	Bamboo X1C [3]	Qidi Tech X3 Max [4]	Elegoo Neptune 4 [5]
Outer Dimension	480x480x590mm^3	553x553x601mm^3	475x445x515mm^3
Print Area	256x256x256mm^3	325x315x315mm^3	225x225x265mm^3
Max Printing Speed	500mm/s	600mm/s	500mm/s, 250mm/s recommended
Max Hot Temp	300℃	350℃	300℃
Weight	22.3kg	30.2kg	8.3kg
Cost	$1869	$1229	$420
Type	Enclosed	Enclosed	Open
Max Bed Temp	110℃	120℃	110℃

Moreover, the most popular settings and features include 10% infill, 0.2mm layer height, 0.4mm nozzle, automatic bed leveling, a removable print surface, filament runout sensors, and power-fail resume.

2.0 Engineering Specification

The engineering specification is split into the following categories: Design gap, Input, Output, and Functionality.

2.0.1 Design Gap

- Has a heavy emphasis on printing speed, at least on par with that offered by a printer like the X1C
- Maintains "acceptable" print quality (you may define what acceptable means in the context of a "hobby" user, to some extent)
- Targets a price point close to the hobbyist market's entry-level offerings, anywhere from $500 to $1500.

2.0.2 Input

Motors:

- Motion conversion: From rotational to linear
- Energy conversion: Electrical to Mechanical

Solid print filament

- Driven from its location to the extruder

Data from CAD software

- Dictate the location of the extruder, amount of print, and revolutions of the motors through wiring looms and a controller

Cooling fans:

- Motion conversion: From rotational to rotational
- Energy conversion: Electrical to Mechanical

2.0.3 Output

X-movement

- Motion would cover the entire width of the printing area, linear to linear
- Motion may be created from a motor
- Motion would be reversible
- Motion may come from a sliding system, ball screw or lead screw
- Motion must carry the weight of the extruder

Y-movement

- Motion would cover the entire length of the printing area, linear to linear
- Motion may be created from a motor
- Motion would be reversible
- Motion may come from a sliding system, ball screw or lead screw
- Motion may carry the weight of the printing bed or carry the weight of the vertical supports and x-axis component

Z- movement

- Motion would cover the entire height of the printing area, linear to linear
- Motion may be created from a motor
- Motion would be reversible
- Motion may come from a sliding system, ball screw or lead screw
- Motion may carry the weight of the X-axis components up and down

Liquidus print filament

- Energy conversion from solid state to liquid state through heat
- Motion transmission: Correct amount of filament at the right time

Cooling system

- Motion transmission from rotational to rotational if using fan
- Energy conversion from evaporated water to liquid water if using water cooling

2.0.4 Functionality

Motion Conversion

- Rotational to Linear(motor and pulley)
- Linear to Linear(belt, lead screw, and ball screw)
- Rotational to Rotational(if using cooling fans)

Motion Transmission

- Support the weight of the extruder and the printing bed
- Deliver the correct amount of filament

Energy Conversion

- Convert solid filament into liquid filament
- Convert Electrical to Mechanical energy(motor and fans)
- Convert gaseous coolant into liquid coolant if using water cooling.

2.1 Function, Objectives, and Constraints

2.1.1 Functions

The table below shows the primary function and secondary functions of the design.

Table 2. Functions of the 3D printer design

Primary Function	The design can print three-dimensional objects from solid plastic.
Secondary Functions	The design will create physical three-dimensional objects from users' digital designs.
	The design will be able to use different filament types to create three-dimensional objects.
	The design will be able to print on all x-y-z axes and stack layers of the chosen filament types on top of each other.

2.1.2 Objectives

Table 3 describes the objectives that the design should meet.

Table 3. Objectives of the 3D printer design

Objectives	Metric	Goal	Justification for Goal
Fast printing time	Printing speed	500mm/s	The printing speed of X1C 3D printer is 500mm/s
Acceptable printing quality	Resolution/layer height (microns-mm)	100 to 200 micrometers (standard mode)	Lower the number, the higher the resolution. Typically, the layer height ranges from 50-400 micrometers. We aim for the middle of that range. [6]
Reasonable price	Cost	500 CAD	Most entry-level printers are around $300, and the cheapest fast printers cost $500

2.1.3 Constraints

Table 4 shows the constraints which the design must meet.

Table 4. Constraints of the 3D printer design

Constraints	Metric	Limit	Justification for Limit
Entry level hobby's use	Cost	<= 1400 CAD	1400 Canadian Dollars (CAD) is the price of the X1C, which is the top-line, newest, and fastest printer currently on sale for non-professionals [7].
Home office size	Outer Dimension	600mm x 550mm x 650mm	The Largest personal enclosed 3D printer has an outer dimension of 645mm x 585mm x 815mm. We aim to limit our design there [8].

3.0 Candidate Designs

3.1 Idea Generation

The team started the idea-generation process through team brainstorming. Each team member devised ideas based on the main objectives and created a list of design ideas through research and intuition, shown in **Appendix A** (Table A-1). This process helps the team gain a better understanding of design space and facilitates forming the final three candidate designs.

3.2 Idea Selection

Our group has selected the best ideas for our top three candidate designs through the alternative design selection process. A combination of feasibility checks and multi-voting helped narrow the ideas down to what is shown in **Appendix A** (Table A-1). Then, the team developed a morph chart (**Appendix B,** Table B-1) to combine the ideas and get the final three candidate designs. The team concluded these designs as “Fast 3D Printer”, “ Home-use 3D” and “ Enclosed 3D Printer”.

3.3 Candidate Design Description

In this section, the characteristics and components of each candidate design will be discussed briefly. The pros and cons tables for candidate designs are shown in **Appendix C.1**.

3.3.1 Candidate Design 1: Fast 3D Printer

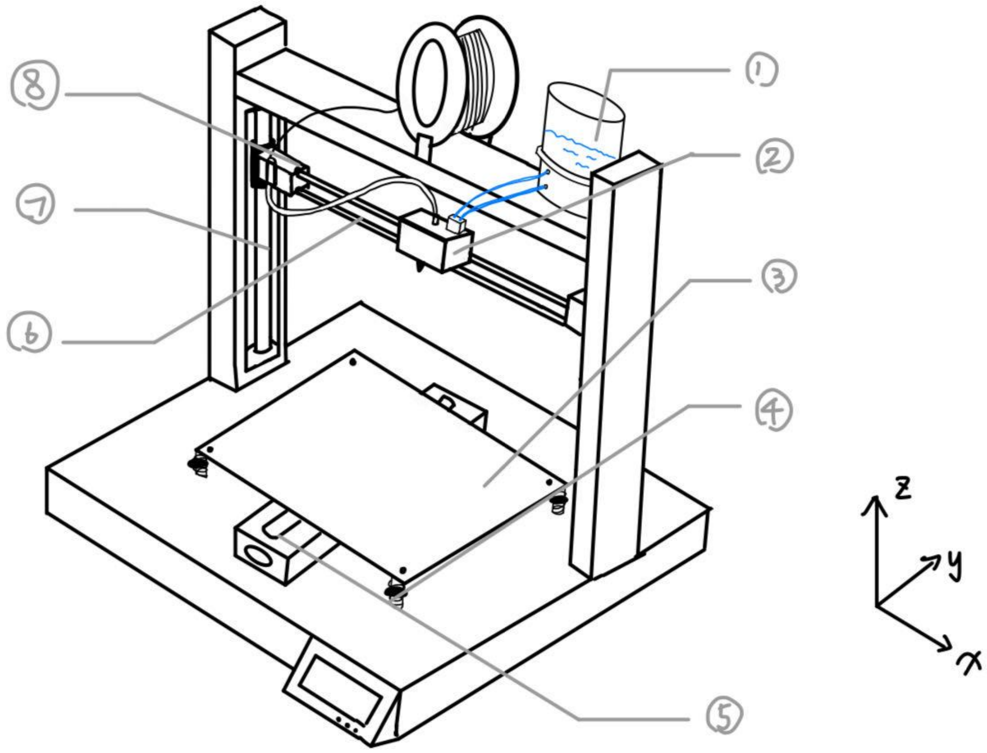

Figure 3. The Sketch of the Candidate Design 1

Table 5. The characteristic of the Candidate Design 1

Characteristics	Components
Fast	● Water-cool ● Bowden extruder ● Servo Motor
Acceptable print quality	● Auto Bed Leveling ● Carbon filament
Mid-level price	● No Side Panels, aim to be $850, which is the middle of the constraints and objective
Desktop size	● Maximum sensible size for desktop due to large footprints, which is 450x550mm

Table 6. Justifications of each component in Design 1

#	Components	Justification
1	Water Cooling of the hot-end top	● Avoid heat creep under extreme operations, which will cause melting and clogging on the cool end before it reaches the hot end [9].
2	Bowden extruder	● A lighter extruder means a higher jerk value and less time spent not printing ● Less power needed [10].
-	No side panels	● Cost-cutting measure
3	Aviation-grade aluminum built-in plate	● 6.4 mm thick for a flat surface and resistant to warping due to high heat. ● Aluminum has the best mechanical properties for these applications
4	Auto Bed Leveling	● Improve bed adhesion by taking several measurements of the bed surface and then adjusting all movement.
5	Y-axis movement underneath the bed	● Provide stability to the prints ● Less power needed
6	Dual round guide rails in Z-axis	● Two round guide rails are used to hold the extruder and nozzle. ● Reduces friction and improves load distribution
7	Dual square guide rails in the Z-axis	● Provide stability to the prints and keep the bed in place. ● Guide rail mechanism has higher load

		capability so that it can withstand the whole weight of the x-axis [11].
8	Servo Motor	● Four motors are used in design 1: one on the x-axis, one on the y-axis, and two on the z-axis. ● Quicker than stepper motors, increases the printing speed [12]. ● It is more expensive compared to stepper motors.

3.3.2 Candidate Design 2: Home-use style 3D printer

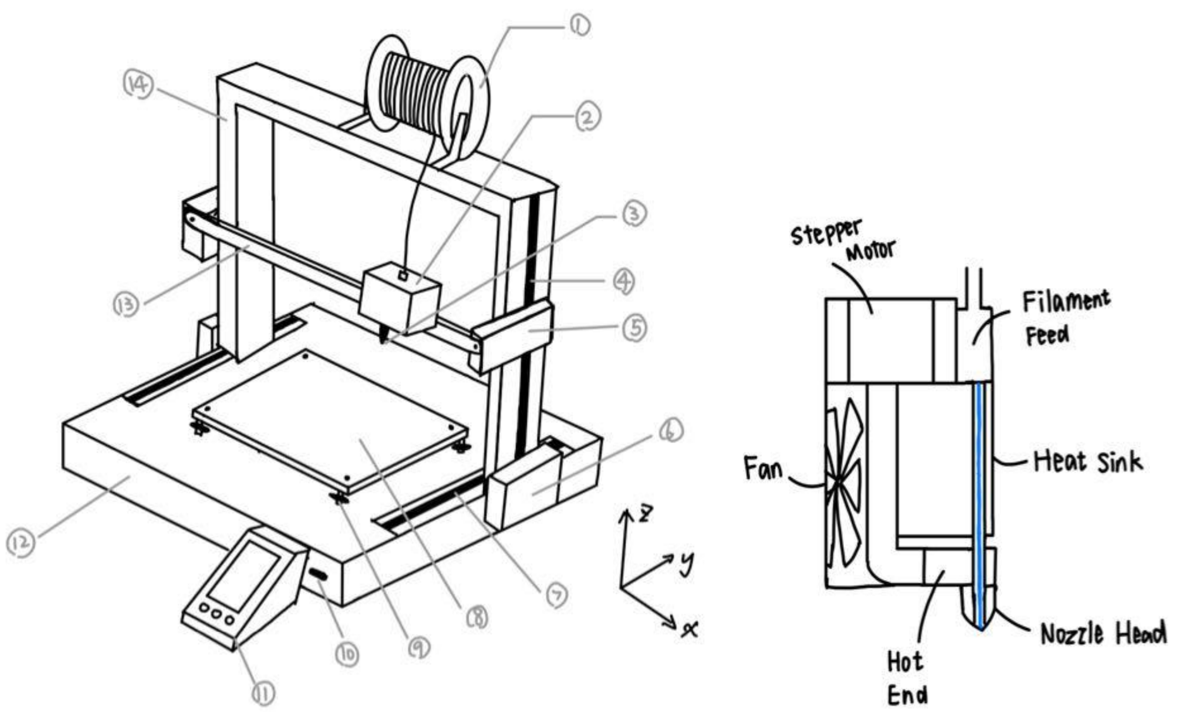

Figure 4. The Sketch of the Candidate Design 2 and its extruder

Table 7. The characteristic of the Candidate Design 2

Characteristics	**Components**
Low Price	● Stepper Motor (compared to the servo motor) ● One fan ● No enclosure ● Timing belts used for movement
Small size	Footprint: 35D * 35W cm
Low weight	Aluminum and Steel
Require minimum maintenance	Auto-bed leveling
Easy-to-use	The shape of a normal home-use 3D printer

Table 8. Justifications of each component in Design 2

#	Components	Justifications
2	Direct Extruder	● Simple and compact design ● Better control over filament ● Easier filament change ● Good retraction control (reduce stringing and oozing)
	1 Fan	● Cost-Effective ● Easier Maintenance ● Lower Power Consumption
	Volcano Hot End [13]	● Can reach higher temperature ● Higher speed: three times faster than the regular V6 hot ends ● Higher strength of the printed object
3	Brass Nozzle Head	● Great heat transfer ● Cost-Effective
4&7	Timing belt	● Timing belts are used for the movement of Y-axis and Z-axis. ● Cost-effective
5&6	Stepper motors [14]	● Cost-Effective ● 5 motors are used in the design, 2 on the y-axis, 2 on the z-axis, and 1 on the x-axis to ensure the stability of the printing.
8	Aluminum Heating bed [15] [16]	● Auto-bed leveling uses a sensor, usually attached to the printhead, to measure the height of your build plate at different points. ● Quick Heating and Cooling ● Flat and Stable (ensure the first layer adheres well) ● Good heat distribution (maintain a consistent temperature throughout the printing process)
13&14	Steel shelf for movement	● Rigid and Stabel ● Reduced vibration ● Durable ● Less flexibility

3.3.3 Candidate Design 3: Enclosed 3D Printer

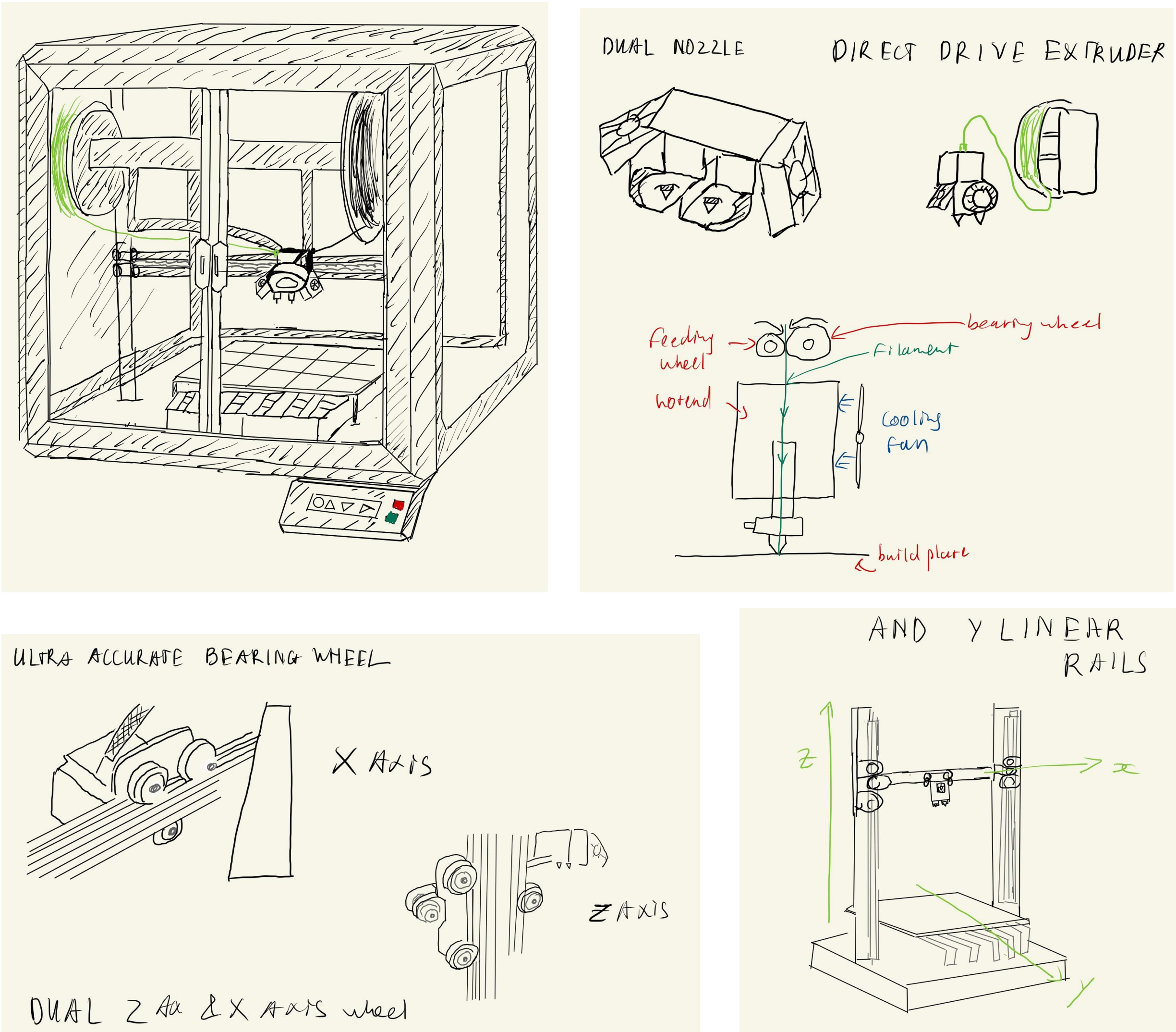

Figure 5. Sketches of the Candidate Design 3

Table 9. The characteristic of the Candidate Design 3

Characteristics	Components
Bifunctional	• Extractor fans (mounted inside the enclosure) and extruder fans (mounted directly to the extruder) • Dual Nozzle • Stepper Motor
Precision	• Auto Bed Leveling • Glass built-in plate • Direct drive Extruder • Bearing wheels
Expensive	• Full enclosure • Large size (600x600x600 mm, but within constraint)

Maintenance	• Inconvenience when performing regulatory check-ups due to the complexity of specs mounting inside the enclosure.
Robust	• Incompact sizing and weighting due to enclosure cover.

Table 10. Justifications of each component in Design 3

Features	**Justifications**
Glass built-in plate	• For a flat surface and resistance to warping due to high heat. • Low-cost option that makes part removal easier, produces a smooth bottom finish on prints [17].
Ventilation systems	• Extractor fans: help the electronics stay cool because of more mounting space. When hot air builds up inside the enclosure, it can escape through the fans mounted at the back [18]. • Extruder fans: adjust the appropriate temperature for filament and cooling rate; mounted in front of each extruder for direct airflow [19].
Use multiple materials with dual nozzles.	• It doesn't have to purge the previous filament from the nozzle each time it swaps to the new one to save time. • Nozzles are operating independently to avoid the risk of "cross-contamination" [20].
Direct drive extruder	• Better extrusion and retraction when controlling the feeds of the filament in the correct position, which results in a better surface on the printed model [21]. • Easier to change the filament.
Equipped with ultra-accurate bearing wheels	• Deliver minimal friction and superb stiffness • Impeccable dimensional stability to the prints [22].
Dual Z-axis bearing.	• Provide stability for the nozzles and the extruder.
Equipped with an X-axis linear bearing	• Provide surgical precision in terms of X-axis movement • Prevent the arm from any kind of deformation, more accurately [23].
Y-axis linear guide rails	• Higher precision for the prints, smoother motion with no rotation. • Stiffer and easier to mount than bearings [24].
Enclosed chamber	• Insulate and shield prints from overheating, melting, and printing hazards [25]. • More space to mount all the tech specs.

3.4 Weighted Pugh Method

We use the Weighted Pugh Method, a proven method used in the industry that helps select the top candidate from a small sample space. Our final design will iterate based on the result we obtained from the Pugh Method. We have mastered the method as a result of previous experiences with APS111 and APS112.

3.4.1 Weightings

We assigned the list of objectives and their weight according to their priority as below:

- **Printing speed:** Speed is the title of this problem statement. The top objective is speed, and it will get the highest weight, which is 30%.
- **Printing quality and cost:** They are the second most important objectives. The problem statement prioritizes printing speed but still highlights the importance of a hobby-level price and acceptable printing quality. Each gets 20%.
- **Size, weight and complexity** are also relevant objectives to consider for a marketable and complete design. Each gets 10%.

3.4.2 Datum

We used Elegoo Neptune 4, the new benchmark in budget-fast 3D printers, as our datum [5]. The datum acts as a reference point and will receive a 0 across the board.

- **Cost:** Relative to $450
- **Size:** Relative to Elegoo Neptune 4 (Print volume 225*225*265 mm)
- **Weight:** Relative to Elegoo Neptune 4
- **Complexity**: Include durability and user-friendliness. Relative to the single nozzle, direct drive extruder
- **Printing speed**: Relative to 200mm/s on standard mode
- **Printing quality:** Relative to 100 micrometer

3.4.3 Pugh Method

The range is from -5 to 5. With -5 being significantly worse than datum and 5 being significantly superior to datum. The grading justification of three candidates can be found in **Appendix C.2**. The result shows that Candidate Design 1 has the highest score compared with other candidates.

Table 11. The Pugh Method Decision Matrix

Objective	Cost	Size	Weight	Complexity	Printing speed	Printing quality	Total
Weight Fraction	0.2	0.1	0.1	0.1	0.3	0.2	1
Datum	0	0	0	0	0	0	0
Candidate 1	-2	2	0	-3	5	2	1.4
Candidate 2	3	5	5	2	-2	-2	0.8
Candidate 3	-2	-2	-2	-2	2	5	0.8

4.0 Final Design

After the Pugh Method selection process, we have selected Candidate Design 1 as a base for our design. We also added and combined the components and mechanisms in other candidate designs for further improvement. This section will discuss the part selection in our final design.

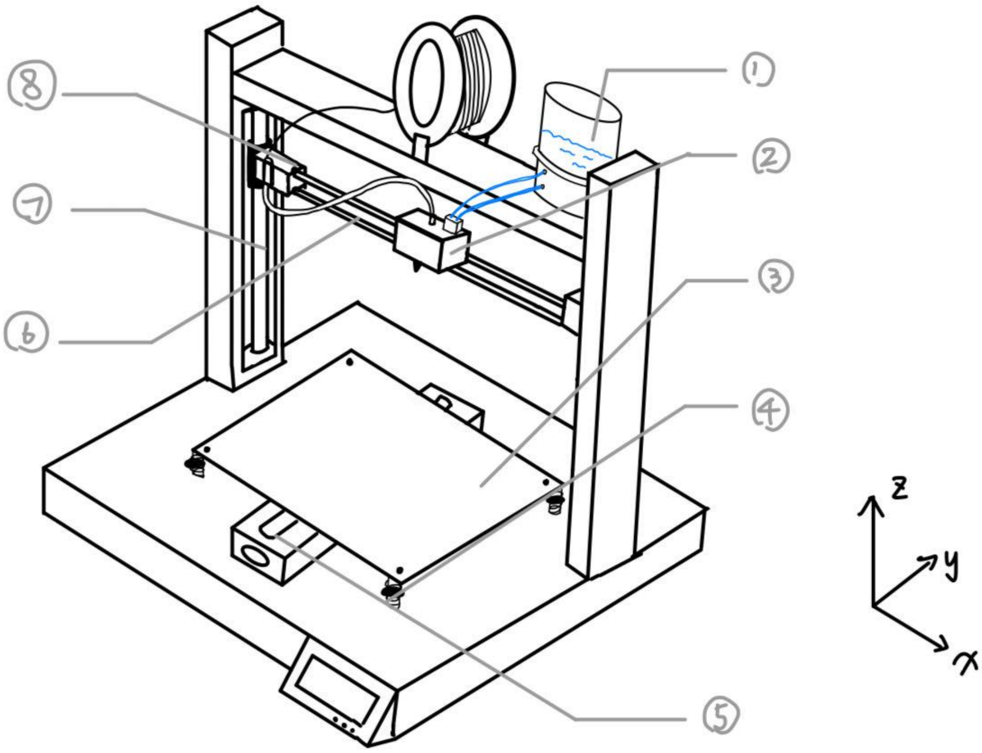

Figure 6. Sketch of Candidate Design 1

4.1 X-axis Movement Mechanism Selection

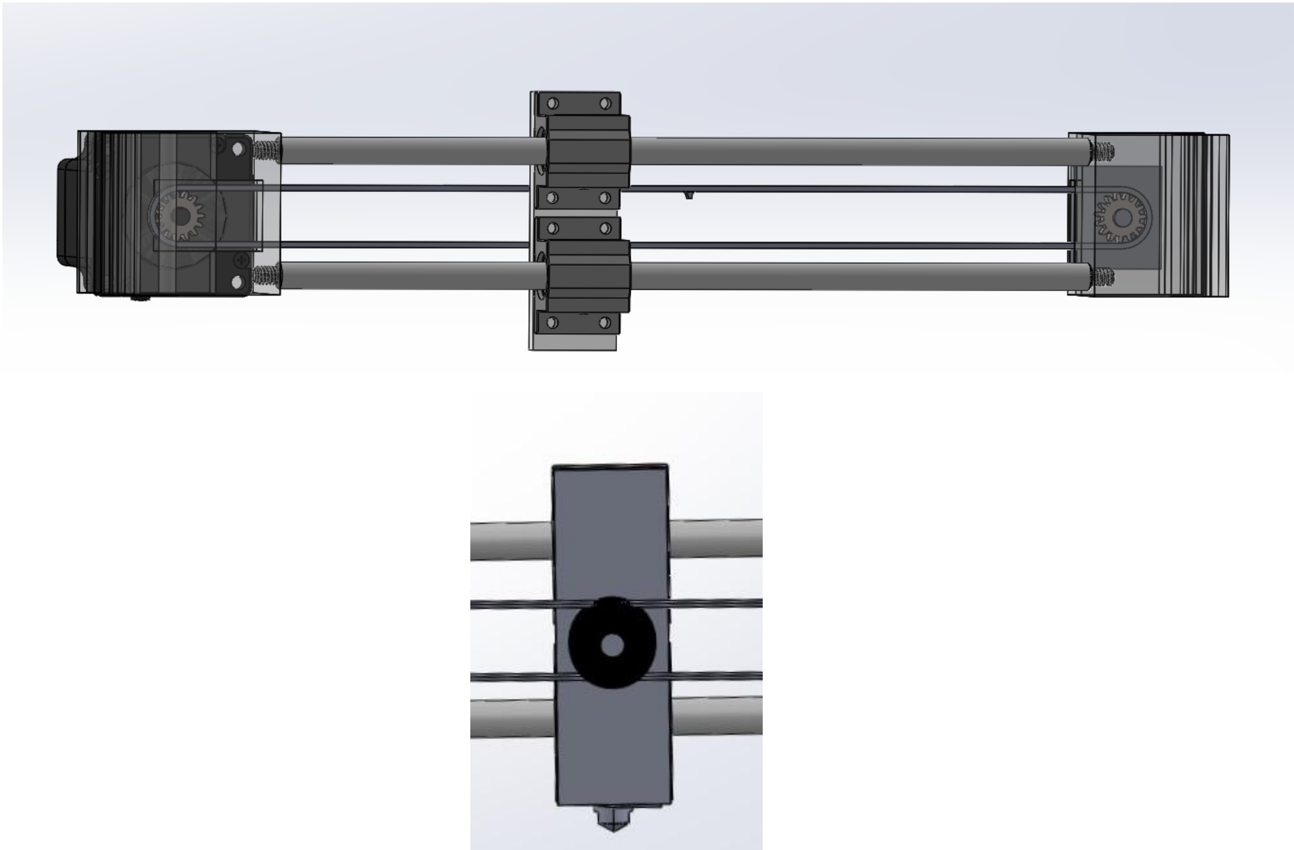

Figure 7. Guild rail system and belt moving system used in final design

The final mechanism of the X-axis combines Candidate Design 1 and Candidate Design 2. As Figure 7 shows, we use the round rail guide system for the part that holds the hot-end and nozzle, and for the part that connects the motor, we use the belt system. The choice of this mechanism is based on the load, stability, and cost requirements. By using a water-cooling system and placing it on the shelf, the load that the X-axis needs to handle is largely reduced due to the lack of fans. With that, the round guide rail system becomes better than the square guide rail system. It greatly reduces friction and improves load distribution due to its geometry [26]. This characteristic makes it suitable to hold complex and multi-part components like the hot-end of the 3D printer. Moreover, the round rail guide system with the high-load mounted linear bearings provides smoother movement, which helps the head of the 3D printer move more flexibly and achieves our objective of high print quality [26]. Finally, to maintain stability when printing, we used two rails assembled and spaced equally on the sliding blocks of the Z-axis.

A simple belt mechanism with two gears at the ends was used in the final design to facilitate the movement because it carries a relatively low weight and slides more easily. This is a low-cost and easy-replaceable mechanism with low weight that can effectively reduce the amount of weight the Z-axis needs to stand and reduce load on the motor, increasing the printing speed, which is our design goal[27].

4.2 Z-axis Movement Mechanism Selection

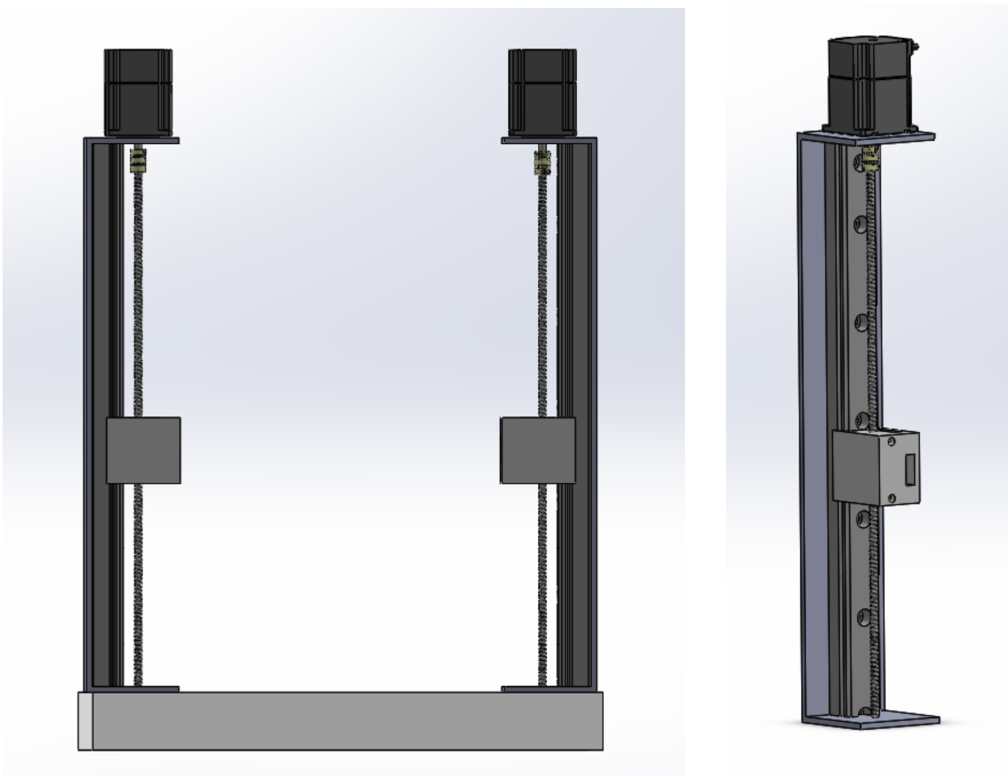

Figure 8. Guide rail system integrated with actuation used in the final design

The final mechanism of the Z-axis is chosen from Candidate Design 1, applying a square guide rail system integrated with actuation and lead screw (shown in Figure 8). This final choice is based on the high load that the Z-axis needs to hold, stability and cost requirements. Although the timing belt used in Candidate Design 2 is cost-effective and highly efficient, it has lower accuracy and positional repeatability than the guide rail system [28]. For the Z-axis, the rails need to support a large load from the whole X-axis, and itself. Therefore, the rail guide system is more suitable as it is designed to handle heavier loads and can provide more stability and accuracy in vertical orientations [11]. The timing belt mechanism may not be suitable for vertical loads due to the potential issues related to belt slippage and load drift under the weight of heavy loads [28]. Hence, the guide rail system is a better choice. Candidate Design 3 uses a guide rail system independent from actuation, it has more design flexibility but has more cost compared with the one that integrated with actuation used in Candidate Design 1. In addition, a lead screw is used rather than the ball screw because it is more cost-effective, typically only 1/10 the cost of a ball screw [29]. In addition, a rigid shaft coupling is used to transmit the rotational motion of the shaft of the motor to the lead screw, and there is no misalignment between them. We added one motor on each side to avoid sagging.

4.3 Y-axis Movement Mechanism Selection

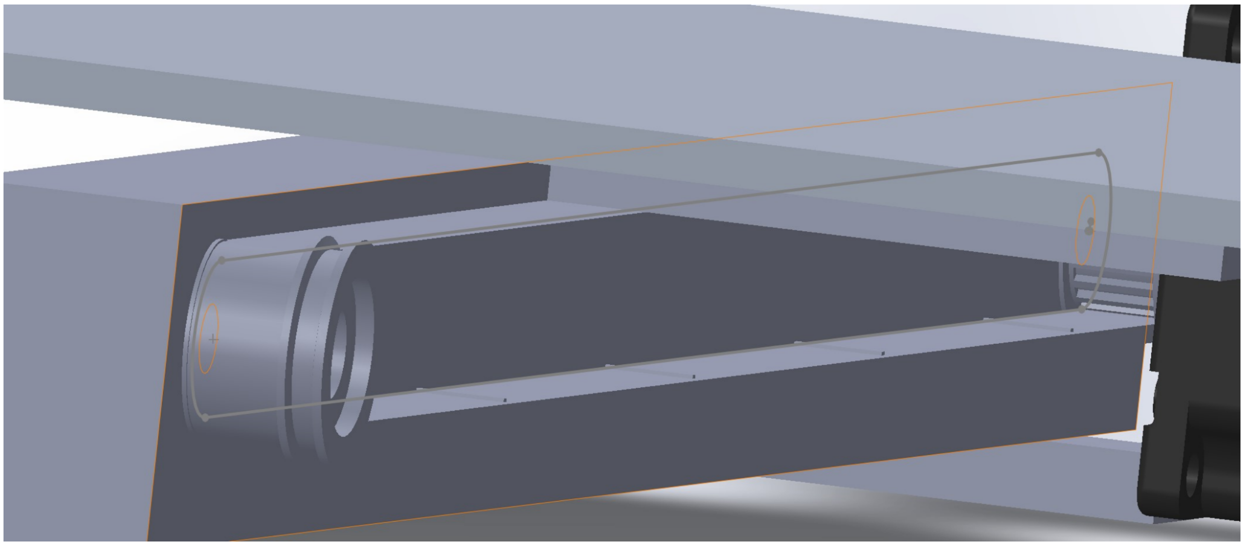

Figure 9. The Belt Mechanism of Y-axis

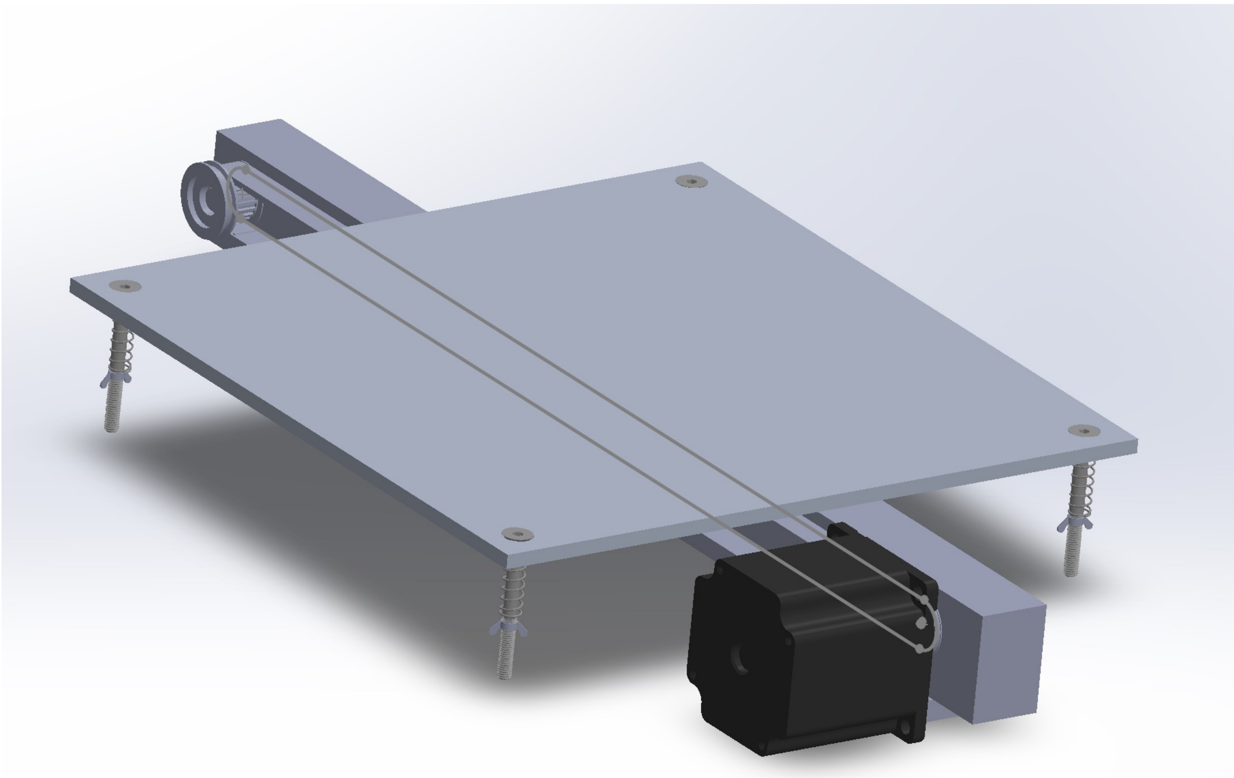

Figure 10. Assembly of the Belt with Stepper Motor, attached on is the Printing bed.

The final mechanism of the Y-axis is chosen from the combination of Candidate Designs 1 and 2. During the 3D printing process, the front and back lateral movement is usually assigned to the Y-axis. To illustrate, the “belt” refers to the movements of Y-Head through the cartesian coordinate system. The timeline belt or “toothed” rubber belt will hold the mobility to transfer rotation motion for the printing plate (the building platform). The whole printing bed (Figure 10.) will be mounted directly on the carriage of the belt (Figure 9.). Similarly to the X-axis, the belt system is chosen again due to the relatively low load that it needs to sustain and low cost. Stepper motor is the chosen candidate for Y-axis spec (referring to 4.5 Motor Selection section). In a linear movement, the motor is attached to one end, which will be responsible for driving the pulley for a minimum standard speed of 50-150mm/sec [30]. One revolution of the motor would produce an equivalent pulling of the belt around the teeth and introduce linear motion for the printing bed. One design constraint is that the motor pulley must have the same number of teeth as the timing belt to ensure the coping process is seamlessly put into motion. There will be no contact between the motor and other specs' positioning to minimize mechanical failure, and thus, it is only dependent on the life of the bearings. Stepper motors are cost effective compared to Servo Motors because stepper does not have the unnecessary specs that are used in positional and torque feedback systems [31]. They are mainly used in an Open Loop System that is simpler to set up, run, and control.

4.4 Frame and Bed Selection

4.4.1 Frame Material Selection

Most common materials for 3D printer bases are aluminum and stainless steel. Therefore, we did some research on these two materials, shown in Table 12.

Table 12. Properties of Aluminum and Stainless Steel

	Stainless Steel	Aluminum
Density [32]	7.8kg/m^3	2.8kg/m^3
Cost [32]	$1.2/kg	$1.7/kg
Tensile Strength [32]	>650 MPa	90-570 MPa

Regardless of how superior stainless steel is in terms of strength, aluminum is three times lighter. Since we might have all of our extra gadgets compared to our competitors, such as a bowden tube, the guide screw, a radiator and cooling system, it is critical for us to have a lighter frame to keep weight from increasing uncontrollably.

4.4.2 Frame Size and Production

We have finalized our final dimension of the frame to accommodate our axis movement and our target print area of 250x250x250 mm. The base dimension is 450x550mm, which is well within our constraint of 585x645mm. We have a few options for the production of our 3D printer base/frame, shown in Table 13.

Table 13. Characteristics of different manufacturing procedures for 3D printer frame [33]

	Joint and Member	CNC	Injection Molding
Cost	Low	Very Low	Moderately High
Aesthetic	Poor. Exposed frame and look unfinished	Poor. Prone to scratches and splits	Good. Clean and professional look
Suitable Material	Metals	Plywood, Acrylic, and Plastic	Metals
Safety	Low. Exposed structure, especially belt and heat can pose potential danger	Low. Plastics and polymers are prone to warping under load and heat	High. Usually used for enclosed 3D printer and large size commercial use
Ease of Assembly	Easy. Clearly defined and standardized threads and fasteners.	Poor. Puzzle-like structure and inconsistent tolerance.	Good. Next to zero assembly needed

Due to its intricate requirement, choosing a frame for our 3D printer is not a win-win situation. Our 3D printer is about 25% larger than our competitor (450mm to 350mm) so using plastic and polymer CNC is inappropriate for our purpose due to its small size. Injection molding is also too expensive and our 3D printer is too small for it [34]. That left us with one option, which is to use a joint and member for our frame.

We have also chosen to stick with our original decision to have a flat, square Aluminum base, for ease of mounting other components (Figure 11). Even though an extrusion rod saves weight, we believe a hollow base can negate the effect of its footprint, compared to the rod. We have elected to join the base and Z-support with socket head screws, which reduce manufacturing and shipping cost. It also allows customers to easily assemble it with a set of Allen keys.

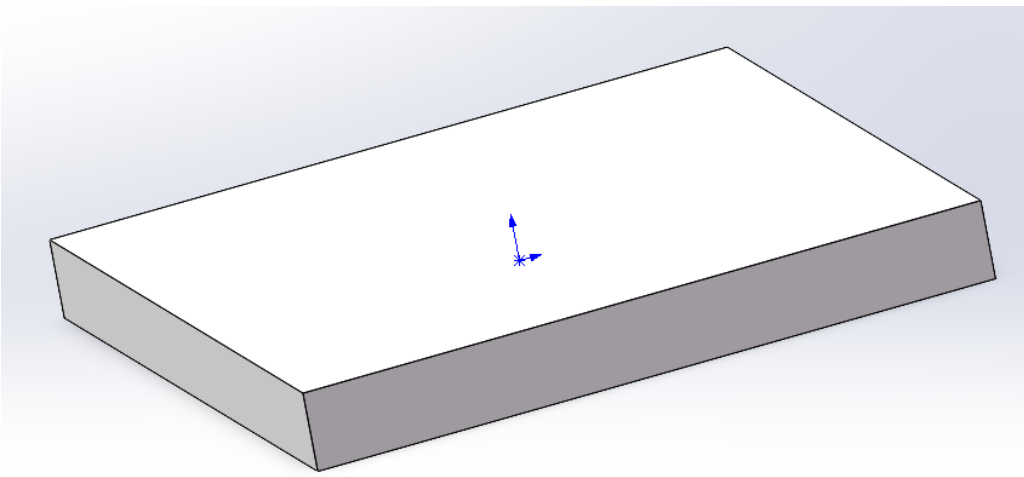

Figure 11: Hollow Aluminium Base

4.4.3 Bed Selection and Mounting

We have decided to not stick with our original decision to field an aviation-grade aluminum print bed. Even with its great resistance to warping under high heat, aluminum offers no adhesion to the print material and it is very difficult to make aluminum completely flat as a bed. We have a few options to consider, which are smooth glass, textured glass, smooth spring steel, and textured spring steel.

Table 14. Characteristics of Glass print bed and Spring Steel print bed [35]

	Glass	Spring Steel
Material cost	$20-40	$25-50
Adhesion with filaments	Only works great with PLA	No difference in performance between types of filaments
Part removal	Only easy when the bed cools	Part pops off immediately due to its magnetic properties
Bed attachment	Need fasteners	Quick removal

We believe that the ease of bed attachment and print removal fully justifies the spring steel's $5 bump in cost. The difference between smooth and textured finishes are at the bottom of our print. We would like to have it as an option because this pertains to the customer's preference and offers zero performance gain. In our opinion, we would like a smooth finish, thus we have chosen smooth spring steel as the material for our print bed. With the spring steel magnetic properties, it made bolts and mount redundant for this application, ensuring a completely flat print bed.

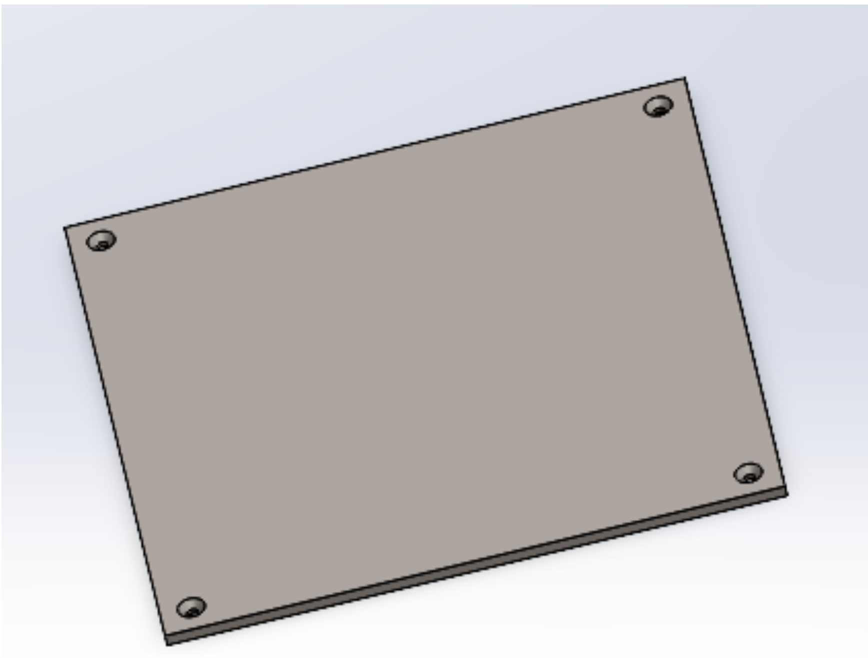

Figure 12: Spring Steel Print Bed

4.5 Motor Selection

Stepper motors are by far the best and most used driving motors during the printing process [36]. They are cost-effective and simplified to be precise with their rotation, and dynamically between torque and speed. Even if they are slightly less capable of maintaining the positional accuracy compared to the closed-loop servo motors, we still chose it due to its cost and its low weight, contributed by the lack of sensors. The motor pulley will be stationary during the printing and belt movement, thus reducing the weights of moving parts. With each revolution divided into steps and pulses offers precise positioning even when commanded with a long operation process of repetitive movement back and forth. The printer uses belts for the X and Y-axis to transfer linear movement and typically uses only one motor on each axis. As a result, the simplicity of the system reveals no problem corresponding to start, stop, or reverse motion. Two motors are used in the Z-axis to transmit the rotary motion of the motor shaft to the lead screw, and avoid sagging.

4.5.1 Standard Specification (For all motors featured in our design)

- **Faceplate diameter:** ~1.7 inches (~43.18mm). [1.7″ x 1.7″ faceplate to 2.3″ x 2.3″ faceplate; a larger faceplate implies a larger torque, as torque is a result of the transmission components (like the rotor and gear sets) that fit inside the shell of the motor.
- **Torque range:** 40-45Ncm to 100-125 Ncm, and the formula of calculating the torque is $Torque = Force \times Distance$. So the more torque something has, the more weight it can push around in a circle.

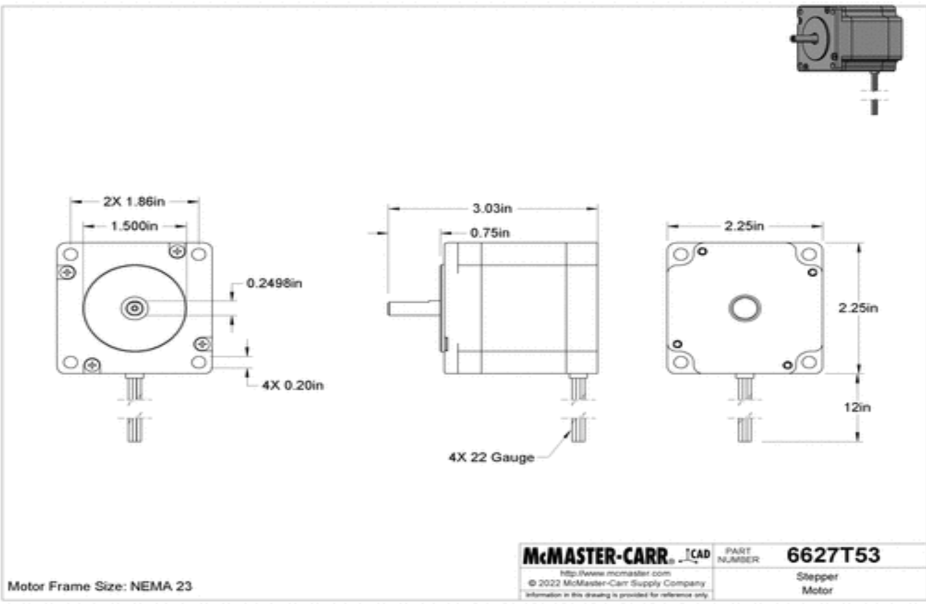

Figure 13. Drawing with Specification for the NEMA 23 Stepper motor [37]

4.5.2 Type of Stepper Motor

The market currently offers a wide range of stepper motors. The National Electrical Manufacturers Association (NEMA) has set a standard for stepper motors worldwide, allowing people to choose and integrate motors on their printer conveniently. There are two types of stepper motors: bipolar and unipolar [38]. Bipolar stepper motors offer motor torque but are harder to wire, while unipolar stepper motors are less powerful but easier to integrate. For our final ensign, we chose the NEMA 23 which the motor will have a 2.3 inch by 2.3 inch faceplate and can be used as a unipolar or bipolar motor [39]. When used as a unipolar, all six leads are used. Web used as a bipolar, the center-tap yellow and white wires can be left disconnected. The NEMA 23, had twice the torque of the 17 model because it is a casual use when working with heavier materials like metals. It is important to choose a stepper motor that is powerful enough to drive the linear axis on the 3D printer, but neither overpowered underperformed, because it will only waste the electricity source to operate for the same as the "matched power" rotor would require, and often not a cost-effective solution for the long term. As a result, our final design will be equipped with the NEMA 23 model.

4.6 Extruder and Hotend Selection

4.6.1 Drive Selection

We have two options for extruder type, either a Bowden drive or a Direct Drive. Table 15 below shows the pros and cons of these two options.

Table 15. Pros and Cons of Bowden drive and Direct Drive [40]

	Pros	Cons
Bowden Drive	1. Less weight on the carriage. Faster, quieter and better print quality due to better heat dissipation 2. Smaller carriage means higher print volume	1. Higher motor load due to extra friction from the long distance of the bowden tube 2. Might not have Bowden compatible material
Direct Drive	1. Common and cheaper 2. Reliable, lower load on the motor and better retraction due to the close distance between the motor	1. Vibration and loss of accuracy on X and Y movement due to large weight on the carriage 2. Difficult to maintain due to tight space

It is obvious that there is no clear cut winner for this decision. But after considering the trade-offs and design direction, we have decided to still stick with our current decision, which is to go with Bowden drive. We prioritize speed and accuracy while accepting trickier hardware, calibration and reliability. That makes it obvious that the Bowden drive suits our purpose more. The demonstration of Bowden drive is shown in Figure 14. The biggest weakness of the Bowden drive is its limited range of filaments option, but since the problem statement never asked for any specific filament, it's an acceptable weakness to us [41].

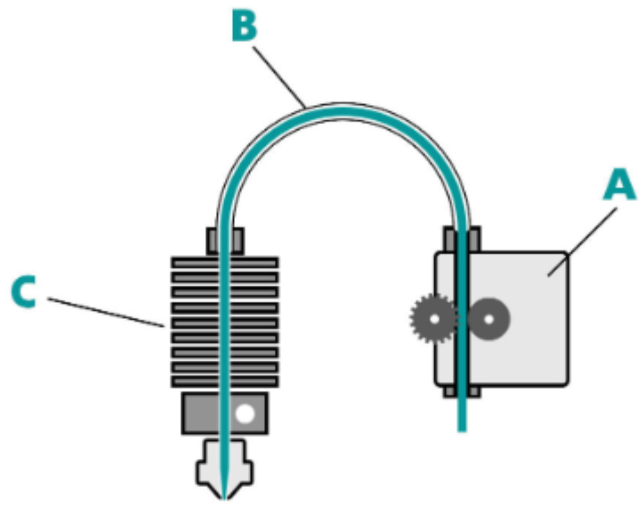

Figure 14: Bowden drive demonstration:
A: Extruder
B: Bowden Tube, with filament inside
C: Hotend [42]

4.6.2 Extruder Selection

We have found a few options online for our extruder, which are all from world class manufacturers of 3D printers parts, shown in Table 16.

Table 16. Characteristics of three extruders

	Dyze Design GT [43]	Micro Swiss Bowden Dual [44]	Creality E-Fit [45]
Bowden or Direct	Both	Only one or another	Both
Gear Ratio	5.65:1	3:1	3:1
Weight	275g	300g	288g
Cost(CAD)	$205 (all inclusive)	$150 (80 base +70 motor)	$170 (100 base + 70 motor)

We have elected to go with the Dyze Design Extruder GT. Dyze Design is a well known supplier of 3D printer parts. Albeit a bit more expensive than its competitor, we believe it will be worth the price due to its superior performance and capability. It is the lightest of the three. It has the highest gear ratio, which gives us more torque, and also suited our application because the bowden drive system requires significantly more power to overcome the friction along the bowden tube. It also has a latch that makes it easy to connect the Bowden tube. The actual and CAD models of Dyze Design Extruder GT are shown in Figure 15 and 16.

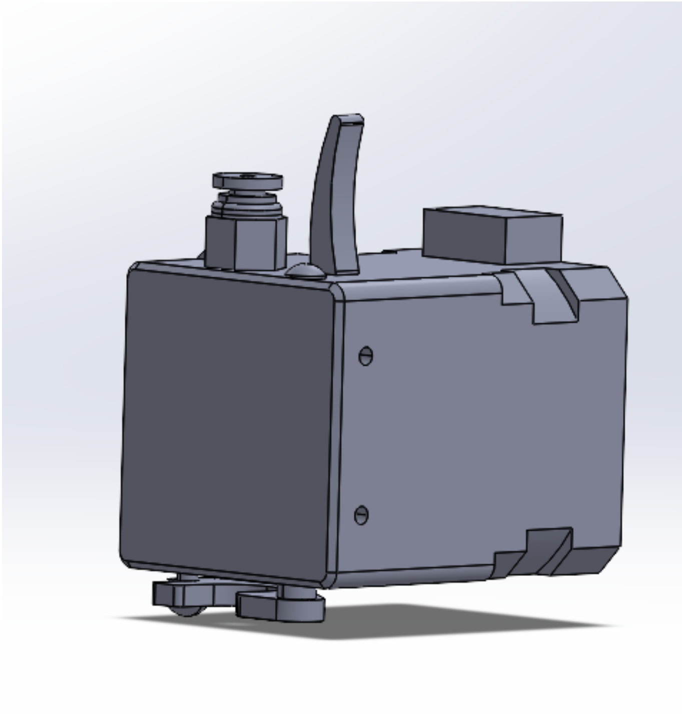

Figure 15: CAD Model Dyze Design Extruder GT

Figure 16: Dyze Design Extruder GT

We have also elected to not go with the highest spec of this company, which is the Extruder PRO [46]. We believe that its extra features over the GT, which consists mainly of aesthetics and easier maintenance and swapping, do not justify its $75 bump in cost. Even if the price bump is lower, we would have hesitated with using the PRO, as our priority has never been on aesthetics and ease of swapping the components.

4.6.3 Hot End Selection

We have found a few options online for our hot end, which are all from world class manufacturers of 3D printers parts, shown in Table 17.

Table 17. Characteristics of three hot ends

	Dyze Design X Hotend [47]	Micro Swiss Flowtech [48]	Creality Spider Speedy [49]
Max Temp	500	500	300
Heating speed	70 sec to 210℃	N/A	40 sec to 200℃
Cost(CAD)	$116	$126	$110
Weight	52g	45g	40g
Max Flow	36.3mm^3/s	N/A	32mm^3/s

We have elected to go with the Dyze Design Hotend X (shown in Figure 17 and 18). Albeit a bit more expensive than its competitor, we believe it will be worth the price due to its superior performance and capability. It has the joint highest maximum hotend temperature of the three. It also has the highest possible flow rate of the three options, and it aligns with our design goals of printing speed. We believe 12g heavier is negligible. It also improves reliability, ease of repair and calibration, since we already selected a Dyze Extruder.

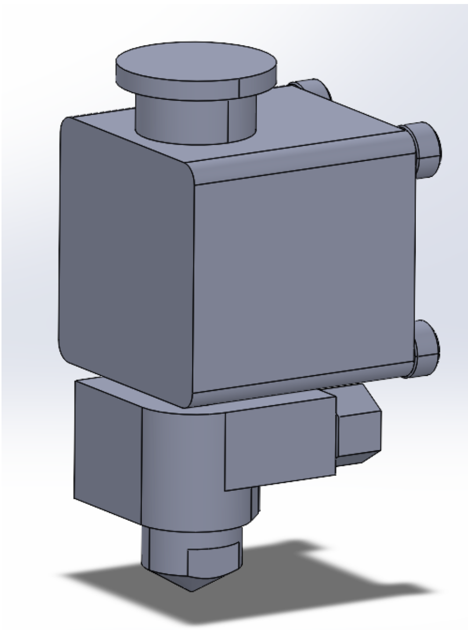

Figure 17: CAD Model of Dyze Design Hotend X

Figure 18: Dyze Design Hotend X

Again, we have also elected to not go with the highest spec of this company, which is the Hotend PRO [50]. We believe that its extra features over the X, which consists of the exact same set of upgrades as with the case of the Extruder GT and Extruder Pro, which are mainly of aesthetics and easier maintenance and swapping, do not justify its $62 bump in cost. Even if the price bump is lower, we would have hesitated with using the PRO, as our priority has never been on aesthetics and ease of swapping the components.

4.7 Water Cooling System

We have found a few options online for our water cooling kit, which are all from world class manufacturers of 3D printers parts.

Table 18. Characteristics of three water cooling kits

	SysCooling Kit [51]	Dyze Design Cooling Block [52]	Triangle Lab Cooling Block [53]
Working Temp	110℃	120℃	120℃
Cost	$134 (include a radiator too)	$48	$50
Hotside Max Temp	500℃	500℃	450℃
Motor Heat Resistance	130℃	N/A	N/A

We have elected to stick with the decision to add the liquid cooling system due to its many benefits over the air cooling system, with the only downsides of cost and weight. Fans can only blow hot air and replace it with cooler air around it. But it becomes useless at a certain temperature, and will constantly blow hot air to the cool end, which will cause the filament to melt and clog the hot end, ruining the print [54].

Water cooling system, however, ensures that the fan(radiator) is far away from the hot zone and the internal structure of the hot end would constantly be cooled by coolant running through. Manufacturers have stated that liquid cooling systems can comfortably double the operating temperature of an air cooled system. And hotter always means faster print time, which is our design goal.

We have selected the cooling block from Dyze Design, despite their similar cost and price to their competitors (shown in Figure 19 and 20). We believe that it is not worth comparing the performance of cooling systems because they are very similar. Dyze Design is the only company that provides a calibrated and purposely designed liquid cooling system with their entire line-up of extruders and hot-ends. And because we have already elected to go with Dyze Design hot end and Dyze Design extruder, it makes sense to choose the same brand again. Our goal is to have a consistent set of parts, to ensure smooth and reliable printings.

Furthermore, we have also elected to only liquid cool the hot end, rather than the extruder. Since we are using the Bowden drive set-up, the extruder is far away from the hot zone, therefore excessive cooling only adds weight and cost, but not performance gain.

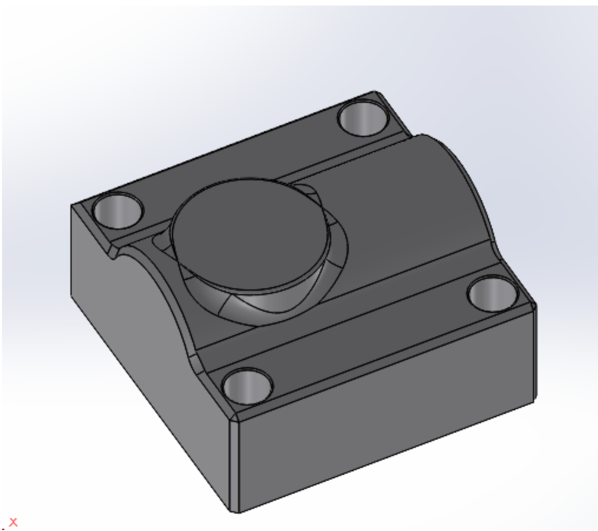

Figure 19: CAD Model of DyzeDesign Cooling Block

Figure 20: DyzeDesign Cooling Block on the Hotend [52]

Finally, we have chosen to purchase the reservoir and the radiator from SysCooling (shown in Figure 21) [51]. Even though their cooling block is not as easy to calibrate as the Dyze Design one, their radiator and cooling block come as a set, and at a significantly cheaper price than any other brand that makes radiators as small as ours (80mm).

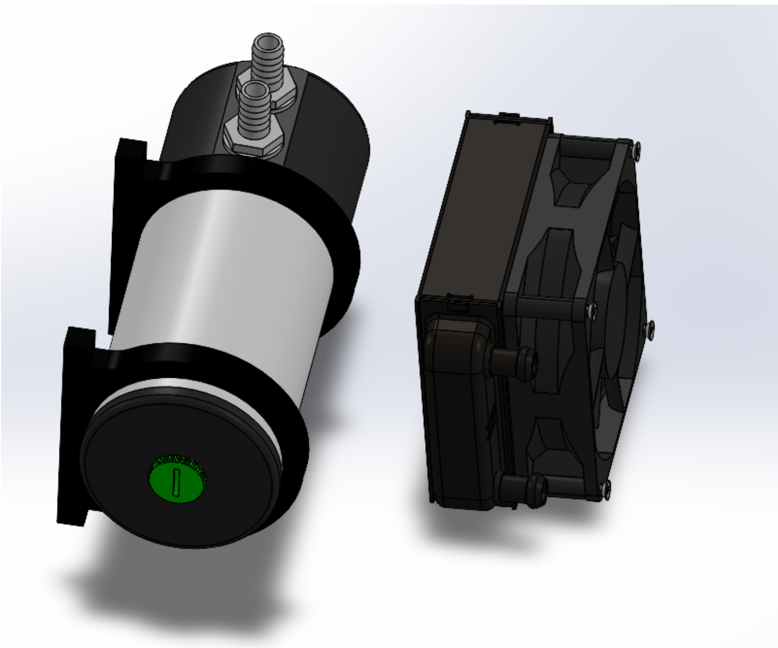

Figure 21: CAD Model of SysCooling Reservoir and Radiator [55]

We would recommend the buyers to use car coolant instead of PC coolant due to its difference in operating temperature. Water temperature in cars is around 90-115℃, which is similar to our targeted operating temperature of 120℃ maximum. PC coolant is much more expensive and operates at a much lower temperature than desired [56].

Finally, we decided to use standard fittings and hoses as no performance gain can be found there (shown in Figure 22).

Figure 22: Standard Fitting for Small Application [57]

4.8 Fasteners and Filament Spool Selection

4.8.1 Fasteners Selection

We have decided to buy bolts and screws from McMaster-Carr, which is the biggest hardware supplier in North America.

We have decided to put screws at six locations:

1. Z-axis motor and the top shelf. Since the total thickness from surface to surface is 14mm, and the diameter is 3.54mm, we used M3.5 x 10mm screws, with a socket head.
2. X-axis motor and the mount. Since the total thickness from surface to surface is 14mm, and the diameter is 3.54mm, we used M3.5 x 10mm screws, with a socket head.
3. The hot-end mount and the X-axis rail. Since the total thickness from surface to surface is 5/16 in, and the diameter is 5/32 in, we used 5-40 x 1/4in screws, with a socket head.
4. The Y-axis support and the base. Since the total thickness from surface to surface is 65mm, and the diameter is 6mm, we used M6 x 16mm screws, with a socket head.
5. The Z-axis support and the base. Since the total thickness from surface to surface is 65mm, and the diameter is 8mm, we used M8 x 16mm screws, with a socket head. We put 3 screws on each side due to the large load it needs to handle. Which is also why we increased the thread diameter compared to the Y-axis support.
6. The filament spool and the Z-axis support. Since the total thickness from surface to surface is 10mm, and the diameter is 3.5mm, we used M3.5 x 8mm screws, with a socket head.
7. The cooling block and the hot-end. Since the total thickness from surface to surface is 21mm, and the diameter is 3.5mm, we used M3.5 x 16mm screws, with a Phillips head.

In conclusion, our customer only needs an Allen key set and a Phllips screwdriver to assemble the 3D printer. Our design is easy and convenient to assemble, while saving shipping cost too.

4.8.2 Filament Spool Selection

Our 3D printer with the bowden tube, spring steel print bed, well calibrated and consistent hardware from the same company makes it more compatible with different print materials than our competitors. Furthermore, the Filament Spool offers no performance gain or loss on printing speed and insignificant price or weight difference. With that, we have decided to go with a standard filament spool on the market.

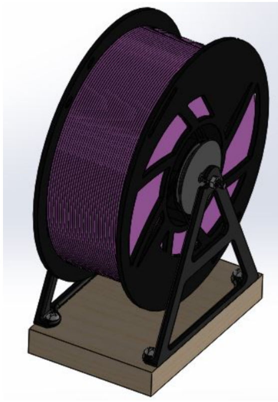

Figure 23: CAD Model of Standard Filament Spool [58]

4.9 Test of Moving Speed

There are lots of factors that will affect the printing speed of the 3D printer. Such as the width of the nozzle, heat dissipation of the extruder, and resolution of the layer height. However, this can be controlled by the user and is out of our design scope. Therefore, we will only discuss the moving speed of each axis's mechanisms.

4.9.1 X-axis Moving Speed

The X-axis moving speed is based on the rotation speed of the motor because it will affect the gear's rotation speed and then the belt's moving speed. The moving speed of the belt will directly affect the moving speed of the extruder. In the X-axis, we used a 6627T53 Stepper motor with a maximum speed of 3300 rpm [59], and the radius of the gear is 9mm. The calculation of the moving speed is shown below:

$$3300\,rpm = \frac{3300\times2\pi}{60}\,rad/s = 345.58\,rad/s$$

$$v = r\omega = 9 \times 345.58 = 3110.22\,mm/s$$

As the result, the maximum moving speed of the X-axis would be $3110.22\,mm/s,$ which is much higher than our objective of 500 mm/s. However, taking into account heat dissipation, print quality, etc, the actual print speed will be much less than the maximum speed of the belt movement.

4.9.2 Z-axis Moving Speed

The Z-axis moving speed is controlled by one stepper motor as the lead screw will rotate with the motor shaft together and drive the carriage to move vertically. As the shaft coupling is rigid, the lead screw will rotate at the same speed with the motor shaft. As mentioned in 4.7.1, the maximum rotary speed of motor is $345.58\,rad/s$. Rotational speed (rpm) is equal to the linear speed (mm/minute) divided by the lead of the screw (mm/rev.)

[60]. The radius of the lead screw is ¼ inch and threads per inch is 20, so we can calculate the lead of screw as follows:

$$\text{Lead of screw (L)} = \text{Screw Diameter} \times \text{Threads per Inch} =$$
$$1/4 \times 20 = 5\, inch/rev = 127mm/rev$$

Then the linear speed in Z-axis could be calculated as:

$$v = L\omega = 127 \times 345.58 = 43815\, mm/s$$

However, this maximum speed is under the free load. If we take into account the load on the carriage and the entire X-axis, the actual moving speed will be much lower.

4.9.3 Y-axis Moving Speed

The speed of the Y-axis is maintained and controlled by the Stepper motor, the NEMA 23. Different sets of coils then orderly energize to change the polarity of the stepper motor, thus causing the motor to turn one step, approx 1.8 degrees per step (**Appendix D**). The shaft will then rotate, which causes the bearings attached with it to rotate, and as a result transferring circular motion to the belt. The timing belt offers back and forth motion by which it is powered and followed by the stepper motor's command. As a result, the stepper motor affects the movement of the printing bed mounted on top of the belt, thus impacting the shape and the outcome of the 3D design.

With the desired speed of 3300 rpm, and the diameter of the bearing is 10mm. The calculation of the moving speed is shown below:

$$\omega = \frac{3300 \times 2\pi}{60}\, rad/s = 345.58\, rad/s$$
$$v = r\omega = 10\, x\, 345.58 = 3455.8\, mm/s$$

Therefore, the moving speed of the motor would be 3455.8 mm/s. This desired speed is higher than the maximum speed for X-axis movement because it does directly affect the shape of the design, along with the fact that it has to correspond to the maximum speed in the X-axis motor. The purpose of this motor is to provide a constant movement for the belt and can speed up if desired to accommodate the desired printing shape.

4.10 Summary of Components

This section is to summarize all the components used in the final design with justifications and their cost (shown in Table 19). Some components and prices are referenced from the McMaster-Carr and AliExpress website. The price listed is the retail price, which is more expensive than the raw materials. Assume a margin of 100% over the raw cost, we would divide the final cost by 2 to get the true value. The cost analysis of self-built components is shown in **Appendix E**. Our final design is shown in Figure 24.

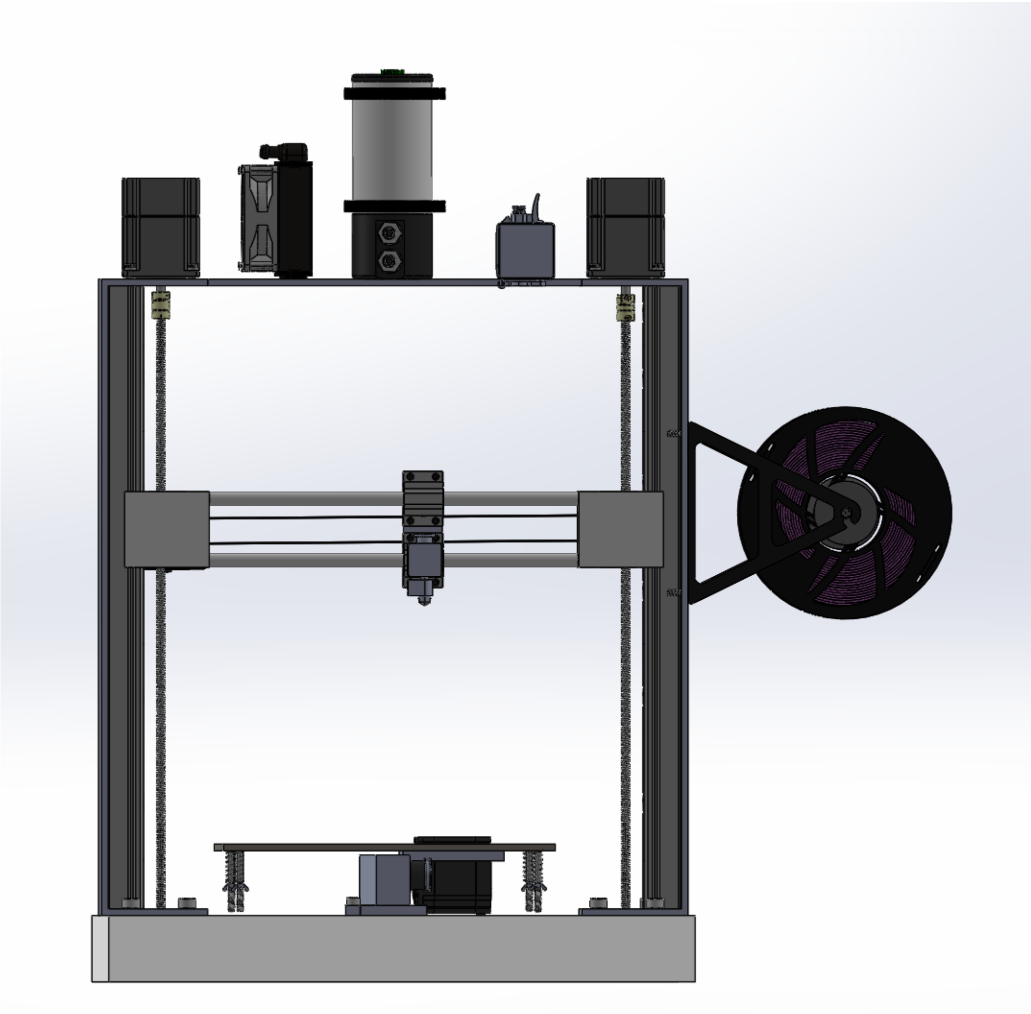

Figure 24. Overall Assembly of 3D Printer

Table 19. Summary of components in final design.

Type	Part	Justification	Cost
Motion Support	Square Guide Rail (5708K56) with Stainless Steel Carriage	• This mechanism is used for the Z-axis. • This mechanism was chosen rather than a timing belt due to its higher stability and load capability. • The carriage is made of aluminum steel to avoid corrosion, thus enhancing its durability.	• The guide rail will be $90 per each, so a total of $180. • The mass of one carriage is 277.6 g with a material and manufacturing cost of $0.250 each.

Motion transmission /conversion	Lead screw (98957A112) with Rigid Shaft Coupling	● This mechanism is used for the Z-axis. ● The shaft coupling is used to transmit the rotational motion of the shaft of the motor to the lead screw. The lead screw converts rotary motion to linear movement of the carriage. ● The shaft coupling could be rigid because there is no misalignment between the motor shaft and the lead screw. ● This mechanism is chosen rather than a ball screw because it is more cost-effective.	● The lead screw is \$10.31 per each, so a total of \$20.62. ● The rigid shaft coupling is \$1.50 per each on AliExpress, so a total of \$3.00.
Motion transmission	Alloy Steel Threaded Linear Motion Shaft (8350T29_52100)	● This mechanism is used for the X-axis. ● Two shafts were chosen because they provide a more stable motion for the extruder. ● The shaft is made of alloy steel because of its high strength, high hardness, low corrosion probability, and cost-effectiveness.	\$34.36 per each, a total of 68.72
Motion transmission	High-Load Mounted Linear Bearing (6255K31)	● This mechanism is used for the X-axis. ● Two bearings were chosen because they can stand considerable load from the extruder to ensure the stability of the whole mechanism. ● Linear ball bearings provide a smooth linear motion with minimal friction, high precision, considerable speed, and minimal maintenance.	\$42.21 per each, a total of \$84.42.
Motion Conversion	Belt (740mm, 4PK890)with two gears 1M Gear Drive (24 teeth and 9mm radius)	● This mechanism is used for the X-axis. ● Belt mechanism is used due to its smooth and quiet operation, low maintenance, low weight and cost-effectiveness. ● The two gears are connected to the motors and one gear on the belt. They transform the motion from rotary to linear.	The belt is \$21.26. The gear is \$8.51 per each, a total of \$25.52

Motion Conversion	Stepper Motor (6627T53)	● A total of four motors are used for the three axes. ● Max speed of 3300 rpm and max torque of 2.8 in -oz ● The stepper motor provides a rotary smooth motion with small, equal step increments of 1.8°. ● The stepper motor is used due to its precision and control, low cost, low-speed torque and reliability.	\$38 each x 4 motors = \$156
Motion support	Wing nuts (90876A370) Lead screws (91253A018) Compression (9434K56)	● Four-piece wing nuts to stabilize four-piece lead screws and four-spring compressions to the printing bed.	The wing nut is \$5.73 each The lead screw is \$15.16 each The spring is \$7.63 each
Motion transmission / Conversion	Timing belt with two bearings (B085NMDTDM) (32897710779)	● The belt will directly support the y-axis movement of the printer, equipped with match up teeth with the bearings. ● The 10mm bearings will be mounted directly to the belt support base.	The belt is \$16.99 and 2 gears are \$27.9 each.
Motion support	Base/Shell	● A flat, square Aluminum base is responsible for supporting weights from all other printer's components when they are mounted on. ● The side support (shell) on the Z-axis protects the guide rail systems and the mounting of the rigid shaft coupling on top to offer rotational motion. ● The support base on the Y-axis for the belt is mounted directly to the base to support the weight from the belt system and the printing plate. ● The top support is used for mounting most of the "high end" components like the water cooling system and the Dyze Design Extruder GT.	Total cost for the base is \$0.9138 Cost for side support is \$77.46 each Total cost for belt support is \$77.46 Total cost for top support is \$0.3414 (see Appendix E)
Motion transmission / Conversion	ABL (B08MD45NH)	● The auto bed leveling is equipped with a sensor attached to the extruder (print head) to measure the	Auto leveling kit and sensor is \$48.44

		height of the printing bed for adjustment before printing.	
Motion support	Spring steel printing plate	● The steel platform makes the print easy to pop out due to the flexibility of the spring steel build plate.	The plate is $40 each
Energy conversion	Hotend	● Dyze Design Hotend X	$126->$100 (Set discount)
Motion transmission	Extruder	● Dyze Design Extruder GT.	$200
Motion transmission	Cooling Block	● Dyze Design Cooling Block	$48
Motion support	Bowden Tube 3D Lab Tech ID 3mm, OD 4mm	● PTFE Bowden tube	$7
Motion support	Fitting	● Dyze Fitting	$7
Motion transmission	Radiator	● SysCooling Radiator	$60
Motion support	Reservoir	● SysCooling Reservoir	$60
Motion support	Screws (90128A234) M3.5 x 10mm	● For the Z-axis motor and the top shelf. ● 8 for 8 holes	8/100 x 9.07 = $0.73
Motion support	Scews (90128A234) M3.5 x 10mm	● For the X-axis motor and the top shelf. ● 4 for 4 holes	4/100 x 9.07 = $0.36
Motion support	Screws (90380A366) M3.5 x 16mm	● For the cooling block and the hot-end ● 4 for 4 holes	4/50 x 5.73 = $0.46
Motion support	Screws (92196A125) 5-40 x ¼ in	● For the hot-end mount and the X-axis rail. ● 4 for 8 holes. Due to the extremely light load, it’s not necessary to put	4/50 x 4 = $0.32

		screws on all holes, especially when our main goal is to save weight on the hot-end assembly	
Motion support	Screws (91292A348) M3.5 x 8mm	• For the filament spool and the Z-axis support • 2 for 2 holes	⅖ x 15.02 = $6.01
Motion support	Screws (91292A135) M6 x 16mm	• For the Y-axis support and the base • 1 for each side	2/50 x 9.64 = $0.39
Motion support	Screws (91292A145) M8 x 16mm	• For the Z-axis support and the base. • 3 for each side	6/25 x 9.64 = $2.31
TOTAL			**$1308.14**

5.0 Conclusion

In summary, the conceptual design of an FDM 3D printer equipped with sufficient and practical upgraded technologies to help the user achieve the desired productivity, quality, and budgeting aspects. We have provided a design of the 3D Printer which addresses our original problem statement. Based on the project requirements revolving around the design functions, objectives, and constraints - which arrived from the client's needs, the categorized list of chosen materials, technologies, and specifications were formed to help navigate the solution for the final design. After thorough consideration and analysis with three check-ins, they were then combined into candidate designs using the listed characteristics and components taken from the Idea Generation and Selection process, along with multimodal decision making techniques. Following the primary and secondary functions, our design of a 3D printer was able to construct three-dimensional objects from solid plastic, use different filament types to create three-dimensional objects, print on all x-y-z axes and stack layers of the chosen filament types on top of each other, thus qualified to produce physical three-dimensional objects from users' digital designs. Our design uses the guide rail system for high load handling on complex components, improves stability, reduces friction and provides smoother movement. The movement of the extruder and the printing bed is fairly accurate with the use of a simple belt mechanism controlled by a stepper motor which offers an ideal speed for printing purposes. All of our components are chosen and designed with the weight and cost-effectiveness kept in mind. The overall price is $1308.14. In conclusion, there will not be any opportunities for components to collide, collapse, interfere with each other when they are puzzled up and released. The next step of this process is to produce a tangible product, which is now cost-effective, quality and specs controlled based on the framework that this document has represented.

5.1 Teamwork and Professionalism Statement

As a team, we have been continuously evaluating our decisions and results throughout the term to best improve our productivity, professionalism, team morale, and future results.

After finalizing the team roster as of the end of September, we immediately started with a general meeting to divide roles between members. Nam Nguyen used to be the team leader in both engineering design projects in our first year, so he was elected as a team leader. Bryan Vu is organized and tech-savvy, so he is the meeting coordinator, often handling deadlines, and housekeeping items. Betty Wen is great at formatting, writings so she was going to handle the document side of things. Stefanie Lyu is very talented in design, both on a computer and on paper, so she was going to handle most of our final sketches and initial conceptual design.

After deliberating, we figured out the timeline for each of our check-ins by correlating the schedule with our own schedule of finals, reading week, and elective classes. We figured that we had a lot of time in hand before Check-in 1, but not a lot of time from Check-in 3 until the Final Report. We decided to sign up for the first slot of Check-in 1 and 3. While selecting the second slot of Check-in 2, due to the reading week being in between and a condensed midterms schedule. We wanted to get a head start to give ourselves some breathing room towards the end of the project.

After that, we decided to reuse the Team Charter that we have crafted and perfected four times in our first year, due to the relatively similar nature of these teams. We all agreed to consult the Team Charter procedures if things go wrong. We are happy that we have rarely had to open the book nor had any big conflict or issue.

Immediately after, we decided on the meeting schedule that works best for everyone. Since we are all in the same cohort, it was a quick and undisputed decision to have two meetings per week, one online and one in-person. We decided to follow this style because we found it to be effective based on past experiences in APS111 and APS112. The online meeting always happens before the in-person meeting. We usually meet online at the beginning of the week, Monday to discuss the direction of this week, with items such as individual tasks, deadlines, general ideas, Q&A, and future plans. Usually, the team leader would do his research beforehand and present his plan for the week, while his teammates pose concerns and questions to make it the best possible plan for everyone and for our results. That way we would have the team leader as a conversation starter that takes charge, while still valuing teammates ideas and concerns, which results in good team morale. We also used the online meeting for idea generation, selection, voting, and proofreading.

We then meet in-person later on in the week, as more of a collaborative session, that we would describe as a “sprint”. Usually in these sprints, that can last up to 3 hours, we would each have our laptops open and work on the project flat-out with a significantly improved cohesion and concentration compared to other meeting formats. We also find it much easier to answer practical, CAD, sketches, and report questions face-to-face.

We agreed to let each person pick their shares first and divide all workload equally to all members in the team, based on their strengths and weaknesses. We value consistency and harmony so we tried to keep the person who worked on a particular section in the design phase to keep working on it for the rest of the project. That way we would have the most knowledgeable person that voluntarily chose it at the beginning of the term to continuingly deliver great results.

We also used all of our allocated time with the TA as we value his inputs and comments that would solve many questions that we, otherwise, would never find an acceptable answer. And indeed, we went into each Check-in with a complete set of work, and even over-delivered in Check-in 2 with a conceptual CAD model of the 3D printer. We also prepared a list of questions for the TA in each check-in, and used both office hours towards the end of the term that helped us create a good final report.

6.0 References

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7.0 Appendices

Appendix A. Idea Generations with respect to the main objects

This section outlines the ideas we generated for designing the candidate designs based on the main objective we defined in section 2.1.1. After a feasibility check and multi-voting, the ideas that were not used in three candidate designs have been crossed out.

Table A-1. Idea generated with respect to main objectives

Faster Speed	Better Printing Quality	Lower Price
~~Larger nozzle size (>= 0.4 mm)~~	The print is aviation-grade aluminum for a flat surface and resistant to warping due to high heat.	No side panels to reduce material and shipping costs
~~Increase the temperature of the nozzle to melt materials quickly.~~	~~Carbon fiber filament for lightweight and extra durable prints.~~	~~Fast mode and standard mode for better marketing purposes.~~
Water Cooling of the nozzle is more efficient than fan cooling.	~~Print the model using vapor smoothable material such as ABS or polysmooth.~~	Noisier and cheaper bearings:
Use multiple nozzles to print at the same time	~~Mist print with proper chemical (enclosed 3D type required) such as IPA to polish the print.~~	~~Fumes allowed. Less cooling required~~
Bowden Drive Extruder. Raw, inaccurate, and old technology, but very fast at delivering filament.	~~Use of MSLA technology to illuminate the whole build plate at once, rather than specific areas; the more we add to the plate, the shorter the production times.~~	~~Manual plate leveling. Less electronics and technology are required~~
Use a Servo Motor (quicker compared to stepper motors, but more expensive)	Use multiple materials with double nozzles. It doesn't have to purge the previous filament from the nozzle each time it swaps to the new one.	Direct-drive extruder. Newer, cheaper, and more common technology than the Bowden drive, but we sacrifice speed.
~~Use DC motors (very cheap, but slow and low quality)~~.	Use Auto Bed leveling technology to improve the quality of printing and bed adhesion	Robust metal wheels for support
~~Increase the 3D printer flow~~	Use of adhesion assistants	Rubber belt

~~rate (by default, it's 1 or 100%, we can increase to 101%-104%)~~		
~~Use two or more print heads to handle with different materials and colors~~	Use of a touchscreen interface for better adjustment of the nozzle, and bed temperature. Compatible with pretty much every OS: MacOS, Windows, etc.	Use parts and motors that are less efficient
Smaller print bed	~~Equipped with a shielded power supply to prevent overheating and internal electrical damage.~~	~~Loud and cheap motors~~
~~Lower infill density~~	It is equipped with an ultra-accurate bearing wheel to deliver minimal friction,	~~Let users assemble it like Ikea. Less manufacturing and cost~~
Use belt drives on the x-axis and y-axis (must be tight enough)	Use Dual Z-axis rails to provide stability to the prints and keep the bed in place.	~~Simplified design~~
~~Reduces the vibration of the nozzle~~	Durable metal frame that is remarkably stable and light to give the printing ability of portability and compactness.	Use Stepper motors (mostly used, but slower)
~~Use the printing materials which can be pushed through the extruder at relatively fast speeds (PLA, PETG)~~	Guide bearing wheels for better precision in terms of Z-axis movement while preventing the arm from any kind of deformation, more accurately.	The print bed is glass. A very low-cost option and makes part removal easier.
A properly leveled heating bed and a surface with good adhesion	~~Featured the enclosed chamber to insulate and shield ABS prints from overheating and melting~~.	
~~Using a well-tuned PID controller ensures that the printer's hot end and bed quickly reach their target temperatures.~~		
Dual big fans for extra		

cooling.		
~~Higher Jerk value of the motors~~		

Appendix B. Idea Selection

Table B-1 below shows the chosen ideas, and the numerical notation at the end of each idea stands for the candidate design number. All the candidate designs are derived from the chosen ideas. The number after each idea indicates which candidate design it is used for (① stands for Candidate Design 1, ② stands for Candidate Design 2, ③ stands for Candidate Design 3)

Table B-1. An Updated Table after Feasibility Check and Multi-voting

Speed	Printing Quality	Price
Water Cooling of the nozzle. More efficient than fan cooling. ①	Featured the enclosed chamber to insulate and shield ABS prints from overheating and melting. ③	No side panels for lower material and shipping cost ① ②
Use multiple nozzles to print at the same time. ③	The built-in plate is aviation-grade aluminum for a flat surface and is resistant to warping due to high heat. ① ③	Noisier and cheaper bearings ②
Bowden Drive Extruder. Raw, inaccurate, and old technology, but very fast at delivering filament ①	Use multiple materials with double nozzles. It doesn't have to purge the previous filament from the nozzle each time it swaps to the new one. ③	Direct-drive extruder. Newer, more accurate extrusion is cheaper and more common than the Bowden drive extruder.[2] ③
Use Servo Motor (quicker compared to stepper motors, but more expensive) ①	Use Auto Bed Leveling technology to improve bed adhesion ① ② ③	Robust metal wheels for support. ① ② ③
Smaller print bed ②	Use of a touchscreen interface for better adjustment of the nozzle, and bed temperature. Compatible with pretty much every OS: MacOS, Windows, etc. ③	Rubber belt and pulley for moving mechanism. Low cost for low load application. ① ② ③
Auto bed leveling and a surface with good adhesion ① ② ③	Expensive bearing wheel to deliver minimal friction. ③	Use parts and motors that are less efficient. ①
Dual big fans for better cooling. ③	Use Dual Z-axis rails to provide stability to the prints and keep the bed in place.	The print bed is glass. A very low-cost option and makes part removal easier.

	①	②
	Equipped with guide-bearing wheels that provide better precision in terms of Z-axis movement while preventing the arm from deformation. ③	Use Stepper motors (cheaper, more popular, but slower) ② ③

Appendix C. Candidate Design

C.1 Pros and Cons of the design

The following table shows the pros and cons of each candidate's designs based on the main components.

C.1.1 The Fast Speed 3D Printer

Table C-1. Pros and Cons of First Design

Components	Pros	Cons
Water Cooling of the hot-end top.	● Avoid heat creep under extreme operations, which will cause melting and clogging on the cool-end before it reaches the hot end ● More exotic material can be used and faster speed ● Faster due to less clogging and repairs	● Cost ● Weight ● Complexity
Bowden extruder	● Lighter extruder means higher jerk value and less time spent not printing ● Less power needed	● Old technology ● No spare parts ● Cost ● Need exotic material
No side panels	● Cost-cutting measure	● Lack of aesthetic ● Room for contaminant ● Room for moisture and extreme temps to sensors
Y-axis movement underneath the bed	● Provide stability to the prints ● Less power needed	● Difficult calibration ● More motors needed
Use Servo Motor	● Quicker compared to stepper motors ● Less time spent not printing	● Expensive ● More power needed
Use of Dual Z-axis rails	● Stabilize the nozzle for better print quality.	● Heavy
Carbon fiber filament	● Lightweight and extra-durable prints ● Could be tuned to serve our unique extruder and axis movement	● Expensive ● Rare

C.1.2 The Home-use 3D Printer

Table C-2. Pros and Cons of the Second Candidate Design

Number	Components	Pros	Cons
2	**Direct Extruder**	• Simple and compact design • Better control over filament • Easier filament change • Good retraction control (reduce stringing and oozing)	• Increase weight on print head • reduce print head mobility • smaller build volume • increase the vibration
	1 Fan	• Cost-Effective • Easier Maintenance • Lower Power Consumption	• Reduced printer speed • Inadequate Cooling • In consistent Printing Result • Some components like hot end and motors may become too hot which leads to shorter service time • Limited material compatibility
	Volcano Hot End	• Can reach higher temperature • Higher speed: three times faster than the regular V6 hot ends • Higher strength of the printed object	• Lower revolution
3	**Brass Nozzle Head**	• Great heat transfer • Cost-Effective	• Highly vulnerable to wear • Not suitable for abrasive filaments because they can ruin the nozzle's internal surfaces
5&6	**Stepper motors**	• Cost-Effective • Open Loop Control (simplifies the control system and reduces the cost)	• Limit speed and torque • Inefficient at high speed • Resonance and Vibration • Heat Generation at high speed

		• Simplifies the control (simplifies the design)	
8	**Aluminum Heating bed**	• Quick Heating and Cooling • Flat and Stable (ensure the first layer adheres well) • Good heat distribution (maintain a consistent temperature throughout the printing process) • Durability	• Heavy • Cost is high • Consume more power • Heat lose
13&14	**Steel shelf for movement**	• Rigid and Stabel • Reduced vibration • Durable • Less Flex	Cost is high compared to Al and acrylic • Weight • complex Assembly

C.1.3 The Enclosed 3D Printer

Table C-3. The Pros and Cons of the Third 3D Printer

#	Components	Pros	Cons
1	Dual Nozzle	• Allows users to print more complex pieces by combining materials to obtain different mechanical properties in one single print to save time. • Dissolvable supports: extremely useful because it eliminates the need to remove supports and also ensures that no support marks are left on the final print. • Strengthened infill: One nozzle prints most of a print, while the other prints only specific areas using a carbon fiber-based filament. • Two different colors can be used, saving a maker hours in painting and drying. • Two extruders are controlled independently, with no risk of cross-contamination.	• Increased maintenance (twice as much that can go wrong during a print). replacing parts as they age • Increased printer cost is the natural consequence of increased device complexity. • More time is needed to optimize settings for all of the different kinds of filament out there.

2	Filament Versatility	- High-resolution, good surface quality - Excellent toughness and dimensional stability - Available in a wide range of colors to choose from. no need for assembly after printing because assembly can be time-consuming, and models will often be prone to breakages at the points where two parts connect.	- If your design is complex, you may require material changes many times within a single print, so multi-material printing can be dramatically slower than printing in a single material. - Switching materials is not simple. To swap between them, you'd need to change the nozzle and bed temperatures, the print speed, the retraction settings, etc. You also need to make sure you purge all of one material before printing in another to avoid causing blockages.
3	Glass Built-in Plate	- Flatness ensures your bed's leveling remains consistent. Smooth finish. - Durability: much stronger than normal glass and will not flake when removing 3D prints from it. It is also shatter-resistant. Tempered glass is also heat resistant; it does have a relatively long lifecycle with 3D printing. - Easy removal: Glass print beds are famous for easily releasing prints, which makes the whole printing experience that much more enjoyable. - Easy cleanup: due to smooth, flat, and stiff surface. - Uniform heating	- Need glues or tapes to enhance bed adhesion (both) - longer to heat up (both) - commonly gathers grease, dust, and unwanted plastic fragments that result in an uneven and unreliably adhesive print surface. (both) - Easy to break (normal glass) - Expensive (tempered)
4	Direct Extruder	More precise control of the loading amount than the	Vibrations: With the extruder mounted to the printhead,

		Bowden Extruder, and greater retraction. ● A wider range of filaments: more compatible with a wider range of filaments. ● results in a better surface on the printed model because it is easier to change the filament.	weight is added. This extra weight adds speed constraints, causing more wobble and possibly a loss of accuracy in X and Y movements. ● Maintenance: In some direct extrusion setups, the extruder is mounted to the printhead can make accessing certain parts for maintenance more difficult.
5	Y Linear Rails	● Linear rails are stiffer. Linear rails flex significantly less than linear rods, due to factors such as shape and metal stiffness. ● No rotation of the carriage. Using a linear rail can create a simpler, lighter, and more nimble assembly, which will also reduce 3D print ringing. ● Higher precision, smoother motion. ● Linear rails are much easier to mount than rods.	● Linear rails are expensive. ● Linear rails must be handled with care. If the carriage accidentally falls off the rail, some ball bearings may roll out, leading to inconsistent motion.
6	Z & X Axis Bearing Wheels	● Deliver minimal friction, stiffness, and dimensional stability to the prints. ● Provide stability for the nozzles and the extruder. This allows a smooth moving movement as the balls roll between the surface areas. ● Provides surgical precision in terms of X-axis movement while preventing the arm from any kind of deformation, more accurately.	● vibrates more than linear rails.

7	Enclosed Chamber	● Dust-free printing and protects the progressing print ● More space to mount all the tech specs. ● Less noisy ● Great looks ● Safety for applications involving children and pets	● Removing, doing minor cleanup, and adding hardware in mid-print is harder
8	ABL	● Improve the quality of printing and bed adhesion by taking several measurements of the bed surface and then adjusting all movement	● the distance at which it reads it will change depending on build surface type (their readings are affected by temperature and humidity changes)

C.2 Pugh Method Justification

C.2.1 Design 1 Grading Justification

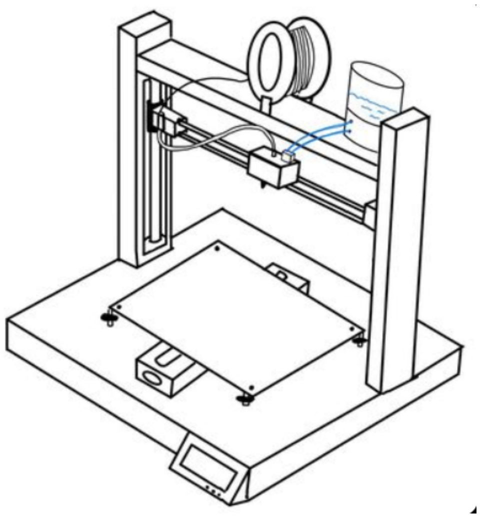


Figure C-1. Sketch of Candidate Design 1

Cost: -2. Added complexity with the water cooling and the Bowden drive will drive up the price significantly. We cut it down with a simpler filament extruder, y-rail setup and x-rail setup.

Size: 2. The design is much more compact than the datum. The Elegoo Neptune 4 uses heavy and coarse materials and cheap manufacturing techniques to cut costs. We can clearly see the over-dimension of parts(drive, x-rails, extruder housing).

Weight: 0: Similar to the Neptune 4 due to better manufacturing technique, smaller parts, and lower tolerance but added weight in the water cooling system.

Complexity: -3. The water cooling system and the bowden drive extruder are impractical due to how rare it is. Replacement parts will be expensive, and there is little help nor information on this design.

Printing speed: 5. We aim to have 500mm/s on standard mode, which is three times the standard mode speed of the Neptune 4. The water-cooling eliminates clogging of the extruder, which is the main time-consuming problem in 3D printing.

Printing quality: 2. The water-cooling eliminates clogging of the extruder, which improves print quality. Other than that, no significant attention was given to the printing quality over the Elegoo Neptune

C.2.2 Design 2 Grading Justification

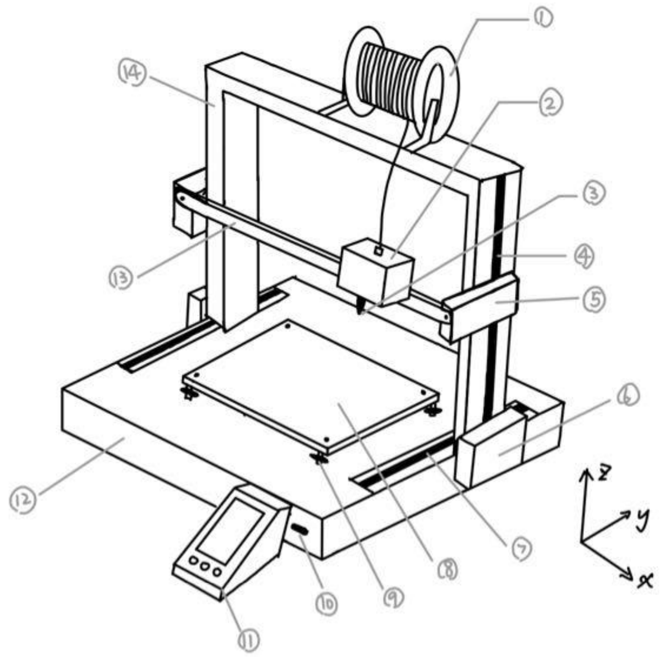


Figure C-2 Sketch of Candidate Design 2

Cost: 3. About $300 refers to a similar size 3D printer. Use of Brass Nozzle Head, Stepper motors and rubber belt for z-axis and y-axis movement, which are cost-effective. Also, the size is small so it saves the materials.

Size: 5. The size of this 3D printer is 20D * 20W * 23H cm. Compared to Elegoo Neptune 4 which is 225 * 225 * 265mm, Design 2 is smaller in all the dimensions. At the same time, the size of the product it can print is limited.

Weight: 5. This design is supposed to be the lightest design among all three candidates. It has fewer components than the Elegoo Neptune 4. The smaller number of both fans and stepper motors allows the design to have a lighter weight compared to the datum. Moreover, the smaller size results in a lower overall material weight. At the same time, the simpler interaction system also greatly reduces the weight of the 3D printer.

Complexity: 2 This design is the simplest design among all three candidates and is simpler than the Elegoo Neptune 4. Compared to the datum, it only has one simple extruder, while the datum has a dual-gear one. Second, the design only uses one fan, and the datum uses four. Moreover, the datum has a wear-resistant POM, a 4.3-inch screen, and LED lights for better visibility. These are all the components that the home-used printer doesn't have. This makes design 2 have the lowest complexity and is very easy to assemble and use.

Printing speed: -2. A general home-use 3D printer can have a printing speed of about 100 mm/s, which is half lower than 200mm/s in standard mode.

Printing Quality: -2. In this design, we do not use the water cooling system and use only one fan. It limits the heat dissipation of the extruder and negatively influences the printing quality. Moreover, using just four stepper motors limits the stability and speed of moving. These factors lead to a printing quality lower than 100mm.

C.2.3 Design 3 Grading Justification

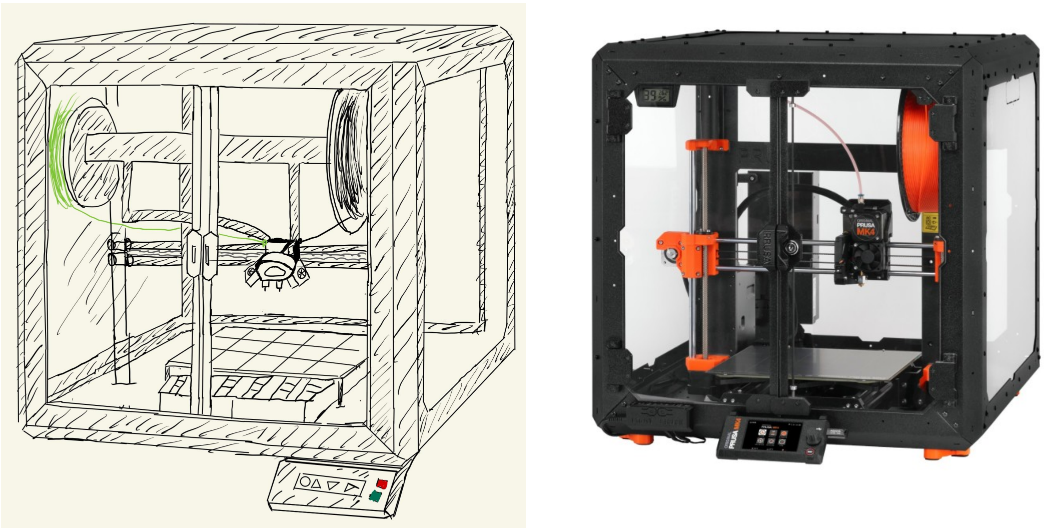


Figure C-3 [61].

Cost: -2

The average price range of a 3D enclosure printer is $400. Referring to the $450 price of the Elegoo Neptune 4, the elevated cost can be explained by the fact that the dual nozzles will increase maintenance due [62] to complexity (users may need to troubleshoot two nozzles instead of one). Additionally, replacing parts as they age can drive up the investment budget in the long term. Furthermore, tempered glass [63] is more durable but tends to be more expensive. Y-Linear Rails offer smoother and more precise movement along the Y-axis, but also a higher-end feature.

Size: -2

The average device dimension for this candidate design is 530 mm (w) × 545 mm (h) × 715 mm (d) with an average printing volume of 250x250x300mm mm^3. On the other hand, the device dimension of the datum is 475(w) x 445(h) x 515 mm (d) with the printing volume 225 x 225 x 265mm^3. The difference in size can be explained by the fact that an enclosed printer will tend to be more visually appealing. Additionally, the cover will provide a quieter working environment, protect the printer from dust, and enhance safety, especially for households with children and pets [64]. Furthermore, it helps trap or limit fumes emitted during printing and protects prints from temperature changes.

Weight: -2

With the enclosure typically made of plastic and glass, the average weight is 10,6 kg (23.4 lbs). Referring to the weight of Datum: 5.3kg (11.46lbs), the difference in the size can be explained through the additional weight of features like 2 different ventilation systems [65], extract fans, and extruder fans since the design offers more space to mount tech specs. The fire suppression system is necessary to ensure the safety of an enclosure design operating at constantly changing temperatures. Due to the robustness, the candidate design offers a large building volume of 153.36mm(l) x 77.76mm(w) x 175mm(h). Furthermore, the outside appearance of a touchscreen, mechanical lock, metal frame, and panels with side panels are made from PETG plastic, screws, mounting elements, installation specs, etc.

Complexity: -2
Referring to the complexity of Datum with a single nozzle, the drawback of those added features besides cost more is the number two it adds complexity meaning more points of failure, and also makes it harder to fix. There might be some features that are optional but from my research, those are two options that major 3D enclosures must have such as the speed feedback sensor [66], which monitors the fan's speed ensuring that the fan can operate at its optimal speed at all times. The enclosure design will typically be equipped with a filament run-out sensor [67] to eliminate the problem of empty spools during printing and notify the user to change the filament when it’s empty.

Printing speed: 2
Compared to Datum with a speed of 200mm/s, with a dual nozzle, a typical enclosure can achieve a top speed of 500 mm/s, and accelerating from zero to 500 mm/s takes just 0.025 seconds. The dual nozzle setup results in a printing speed that is twice as fast leading to a 50% reduction in printing time.

Printing quality: 5
Referring to Datum with the quality of 100 micrometers for each print, an enclosure 3D printer can reduce the temperature changes around the part being printed thus being able to achieve an average printing quality of 50 micrometers. With the design that the motor is directly connected to the extruder, it has better control over the extrusion and retraction of flexible filaments for smooth and no-blur prints. The Z-axis is driven by a linear guide rail that ensures stable and precise movement during printing, effectively making the model surface smoother (Z-axis accuracy: 0.02mm).

Appendix D. Hybrid Motor Motion

The NEMA 23 is a hybrid stepper motor [68], a combination of variable reluctance and permanent magnet stepper motor. The speed can be explained by the Axially Magnetized Rotor motion (FigureX.). There are 4 coils connected into pairs, which form north and south poles when the coils are energized. Those then form a magnetic field to interact with the rotor, which the rotor's south pole tooth is repelled by the other end's south pole while it is attracted by the north pole, meanwhile, the north pole will repel the opposite north pole, and be attracted by the south pole. Those principles of magnetic field will cause the rotor to rotate.

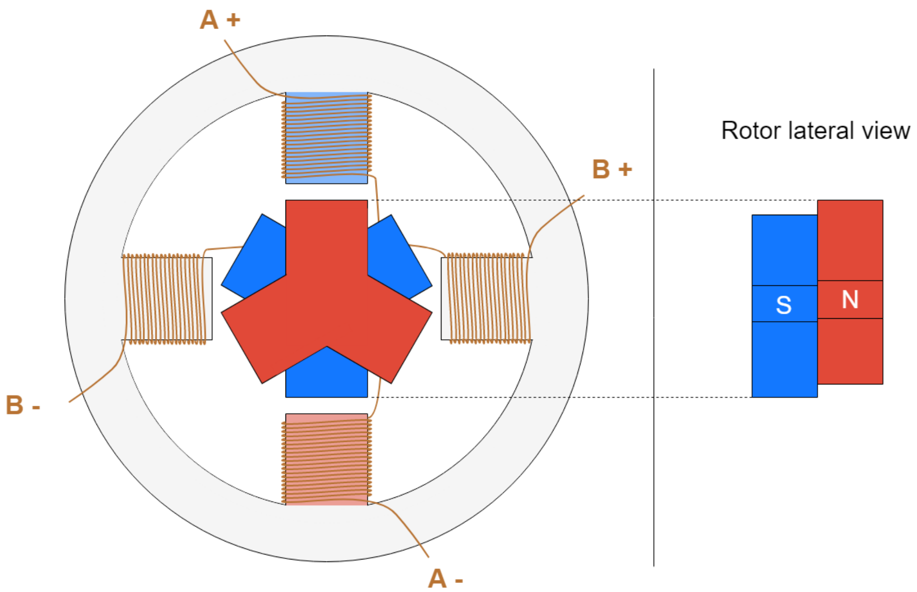


Figure D1. Stepper motor's motion explanation simplified-sketch [68]

Appendix E. Cost Analysis

Base and shell calculations:

Equations [69] :

- Vol = b.w.h
- Hollow vol = outer vol - inner vol
- Inner vol = b-thickness . w-thickness . h-thickness
- Mass = vol . density
- Price = price/kg . mass
- Machining cost= (hourly cost x cycle time for single piece) / efficiency
- Total cost = material price + manufacturing cost

Information:

- Base: 450x550x60mm
- Shell:
  - Plate support: 350x110x75mm
  - Side support: 500x100x50mm
  - Top support: 450x75x25mm
  - Z-axis carriage: 60x25x40mm
- Thickness: 1mm
- Density: 2750 kg/m^3 [70]
- Average Cycle Time: 10sec
- Manufacturing time:
  - Base ~ 10 sec
  - Side support ~ 1hr
  - Plate support ~1hr
  - Top support ~ 10 sec
- Efficiency: 90%
- Hourly manufacturing cost: $77.30
- Cost of aluminum per kg: $0.8/kg [71]

Purchase condition:

- Base: hollow
- Side support: whole
- Belt support: whole
- Top support: hollow

Calculations:

- Base: (outer vol - inner vol) x 10^{-9} x density

  = (450x550x60mm) - (449x549x59mm) x 10^{-9} x 2750 = 0.846 kg

  Material cost: $0.8/kg x 0.846kg = $0.6768

  Machining cost = (77.30 x 10) / (0.9 x 3600) = $ 0.239

  Total cost = $0.6768 + $ 0.239 = $ 0.9138

- Side support: (outer vol - inner vol) x 10^{-9} x density

  = (500x100x50mm) - (499x99x49mm) x 10^{-9} x 2750 = 0.205 kg

Material cost: \$0.8/kg x 0.205 kg = \$0.164

Machining cost = \$77.30

Total cost = \$0.164 + \$77.30 = \$ 77.46

- Plate support: (outer vol - inner vol) x 10^{-9} x density
  = (350x110x75mm) - (349x109x74mm) x 10^{-9} x 2750 = 0.201 kg

  Material cost: \$0.8/kg x 0.201kg = \$0.161

  Machining cost = \$77.30

  Total cost = \$0.161 + \$77.30 = \$ 77.46

- Top support: (outer vol - inner vol) x 10^{-9} x density
  = (450x75x25mm) - (449x74x24mm) x 10^{-9} x 2750 = 0.128 kg

  Material cost: \$0.8/kg x 0.128kg = \$0.1024

  Machining cost = (77.30 x 10) / (0.9 x 3600) = \$ 0.239

  Total cost = \$0.1024 + \$ 0.239 = \$0.3414
- Stainless steel carriage: (outer vol - inner vol) x 10^{-9} x density
  = (60x25x40mm) - (59x24x39mm) x 10^{-9} x 2750 = 0.0132 kg

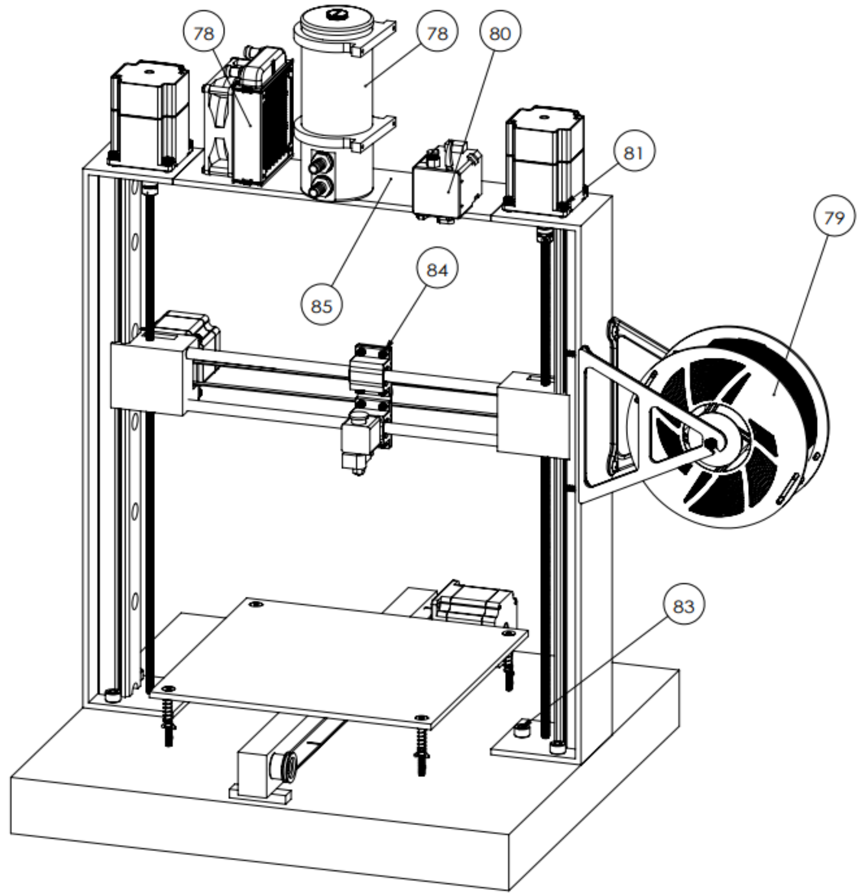
  Material cost: \$0.8/kg x 0.0132kg = \$0.0106

  Machining cost = (77.30 x 10) / (0.9 x 3600) = \$ 0.239

  Total cost = \$0.0106+ \$ 0.239 = \$0.250

Appendix F. CAD Drawings and Models

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
78	3D printer Water Cooling Kit	E3D Water Cooling Kit	1
79	Filament Spool		1
80	DyzeXtruder-GT-Solid-160719		1
81	90128A234	Zinc-Plated Alloy Steel Socket Head Screw	12
82	91292A135	18-8 Stainless Steel Socket Head Screw	1
83	91292A145	18-8 Stainless Steel Socket Head Screw	6
84	92196A125	18-8 Stainless Steel Socket Head Screw	8
85	Top Plate		1



AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008753920	TITLE: 3D PRINTER ASSEMBLY		
DATE: 2023/12/4			
MATERIAL:	PART NO.		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:10		SHEET 1 OF 1

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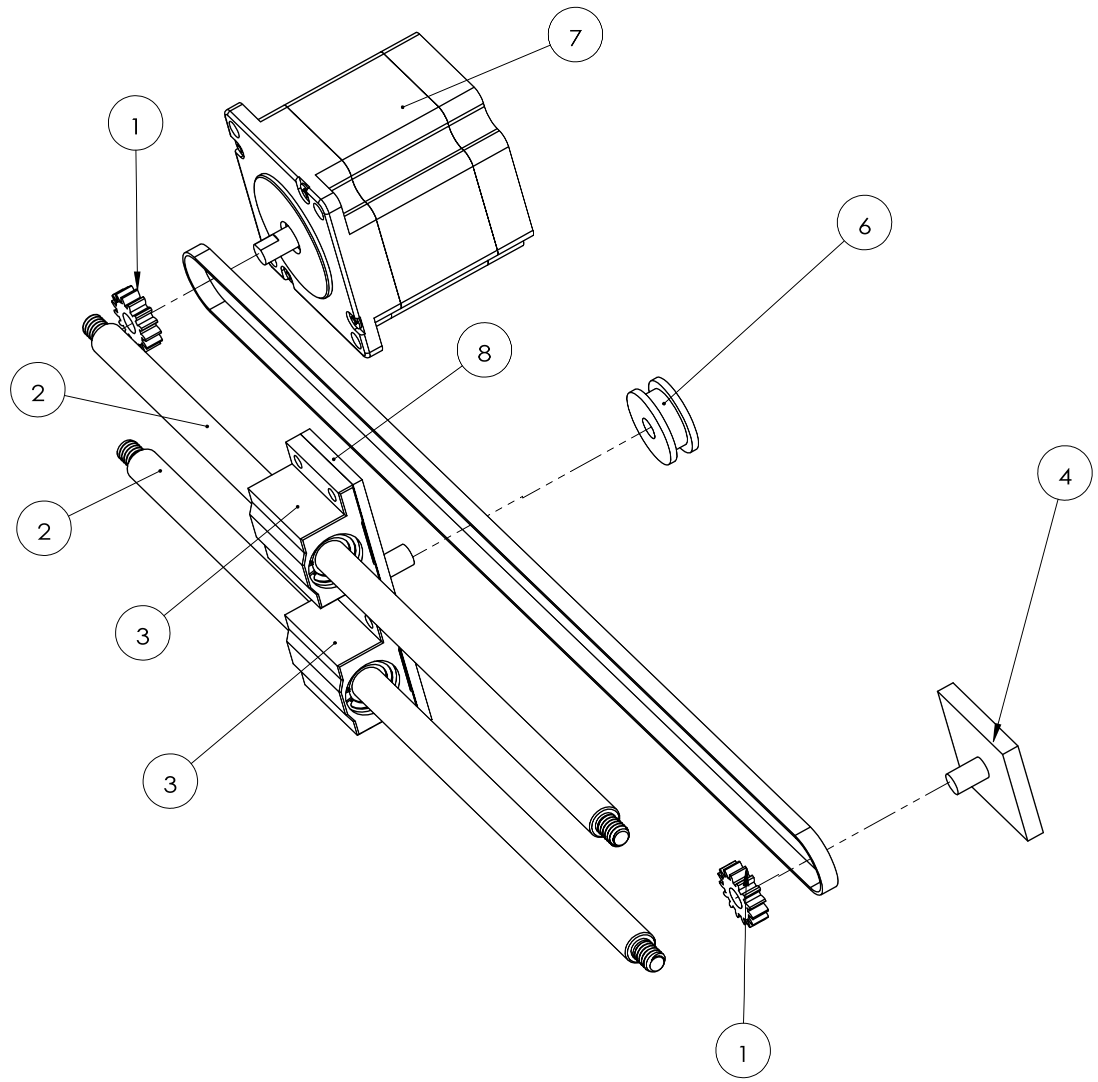
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	8350T29	52100 Alloy Steel Threaded Linear Motion Shaft	2
3	6255K31	High-Load Mounted Linear Ball Bearing	2
7	6627T53	Stepper Motor	1
1	gear		2
8	Part3^new x axis		1
4	gear support		1
6	gear 2		1



AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008753920	TITLE: Assembly OF X-AXIS		
DATE: 2023/12/4			
MATERIAL:	PART NO.		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:5		SHEET 1 OF 1

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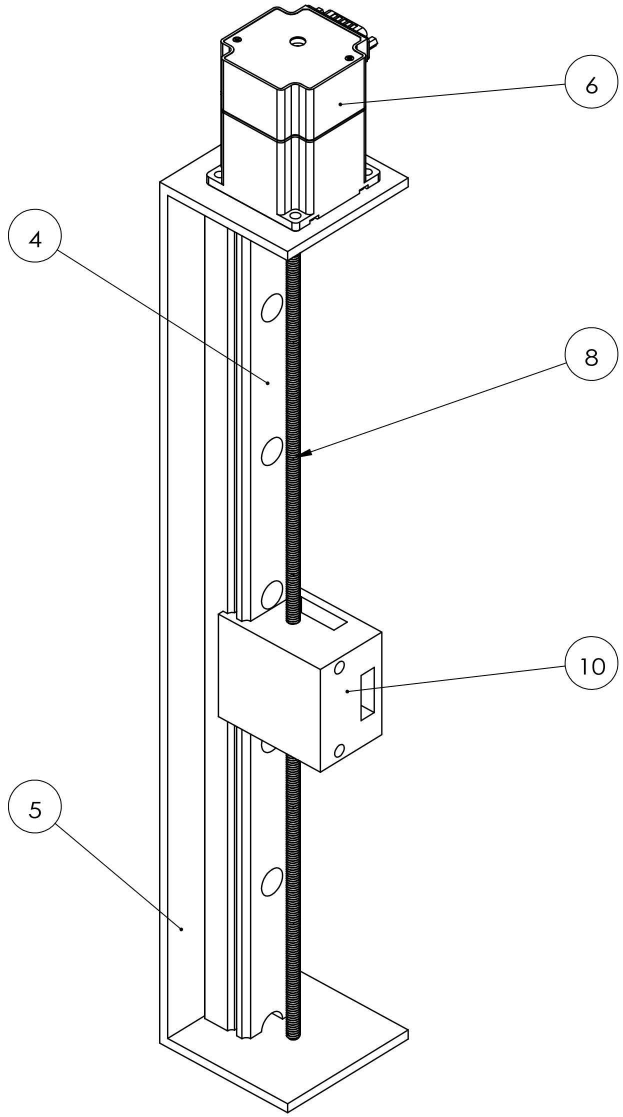
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
4	5708K56	34 mm Wide x 500 mm Long Guide Rail for Corrosion-Resistant Ball Bearing Carriage	2
5	column		2
6	6627T101	Stepper Motor	2
8	98957A112	Grade B7 Medium-Strength Steel Threaded Rod	2
10	5708K56	34 mm Wide x 500 mm Long Guide Rail for Corrosion-Resistant Ball Bearing Carriage	2



AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008753920	TITLE: Z-AXIS ASSEMBLY		
DATE: 2023/12/4			
MATERIAL: MATERIAL	PART NO.		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:5	SHEET 1 OF 1	

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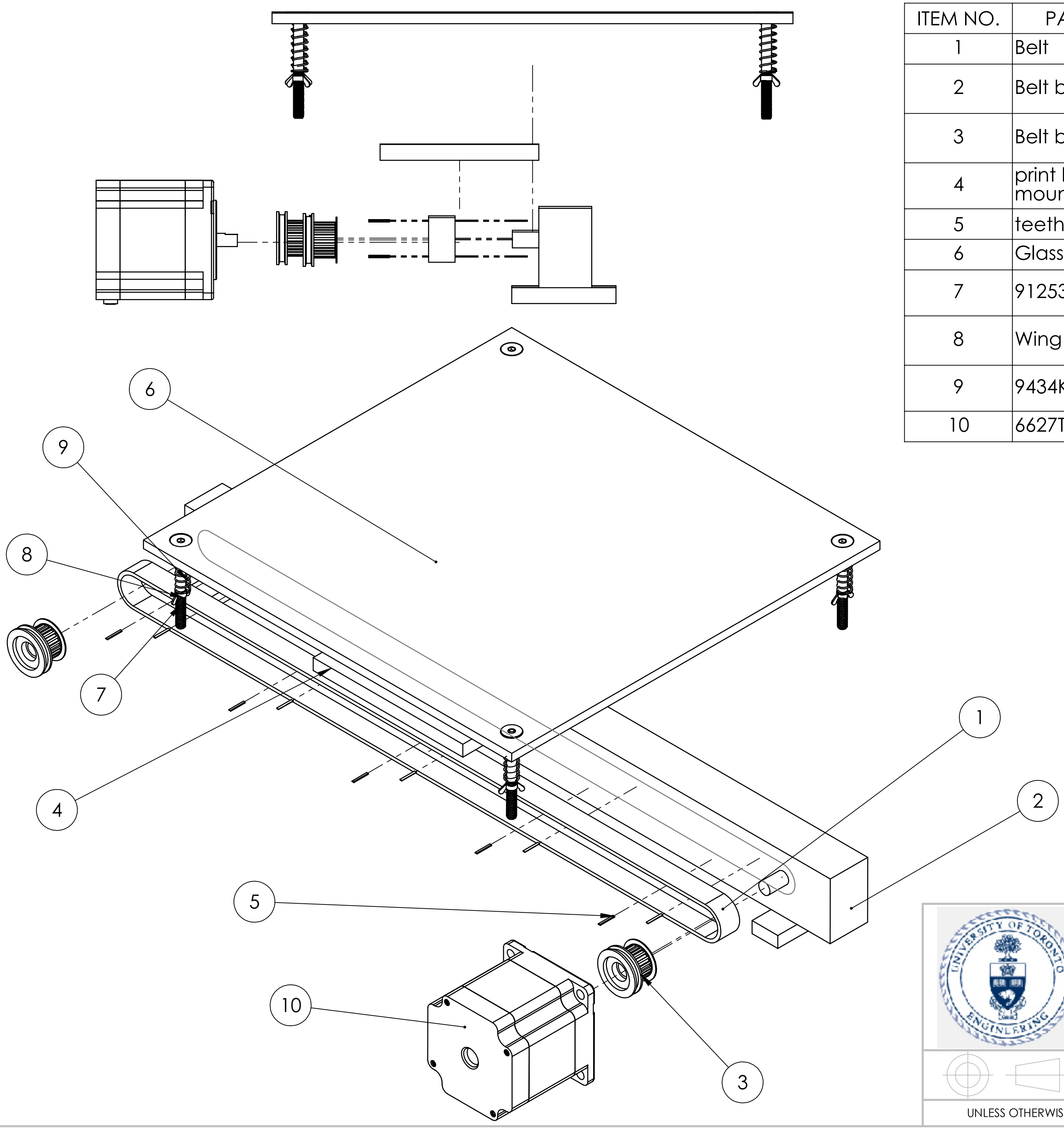

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Belt	Attach to the bearings	1
2	Belt base	Support the belt and printing bed	1
3	Belt bearing	Support the circular motion of belt with teeth	2
4	print bed + belt mounting plate 1	Mounting of the printing bed and the belt	1
5	teeth	Aid circular motion	10
6	Glass bed	Printing bed	1
7	91253A018	Black-Oxide Alloy Steel Hex Drive Flat Head Screw	4
8	Wing nuts	Stabilize head screws and compression springs to the bed	4
9	9434K56	Music-Wire Steel Compression Springs	4
10	6627T53	Stepper Motor	1

AUTHOR: BRYAN VU	CLASS: MIE 243	LAB SECTION: N/A	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008920116	TITLE: Y-AXIS SYSTEM		
DATE: 2023-12-05			
MATERIAL: N/A	PART NO.		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:2	SHEET 1 OF 1	

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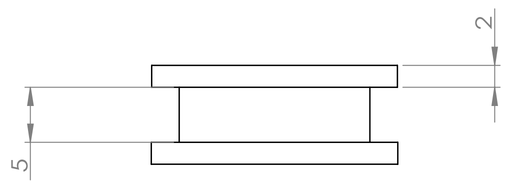

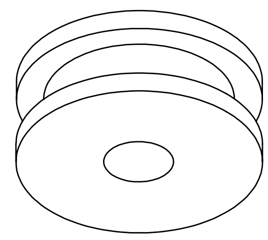

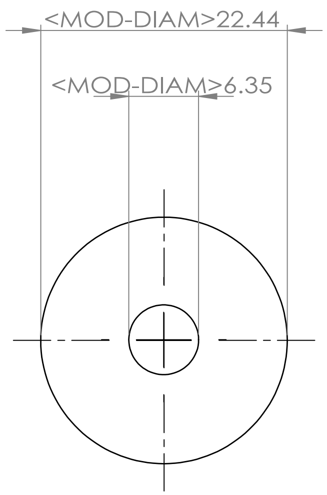

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	DATE: 2023/12/4			
	MATERIAL: Aluminum	PART NO. X – 6		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE		SCALE:5:1		SHEET 1 OF 1

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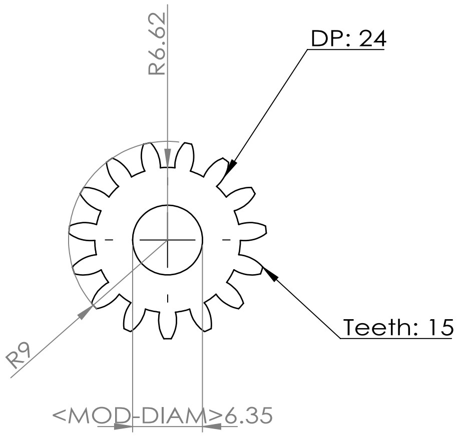

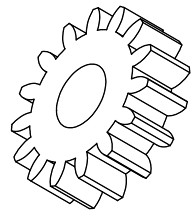

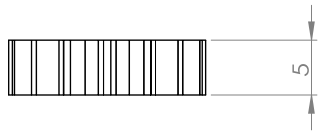

AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008753920	TITLE: Gear 1 OF X-AXIS		
DATE: 2023/12/4			
MATERIAL: Aluminum	PART NO. X- 1		REV. 1
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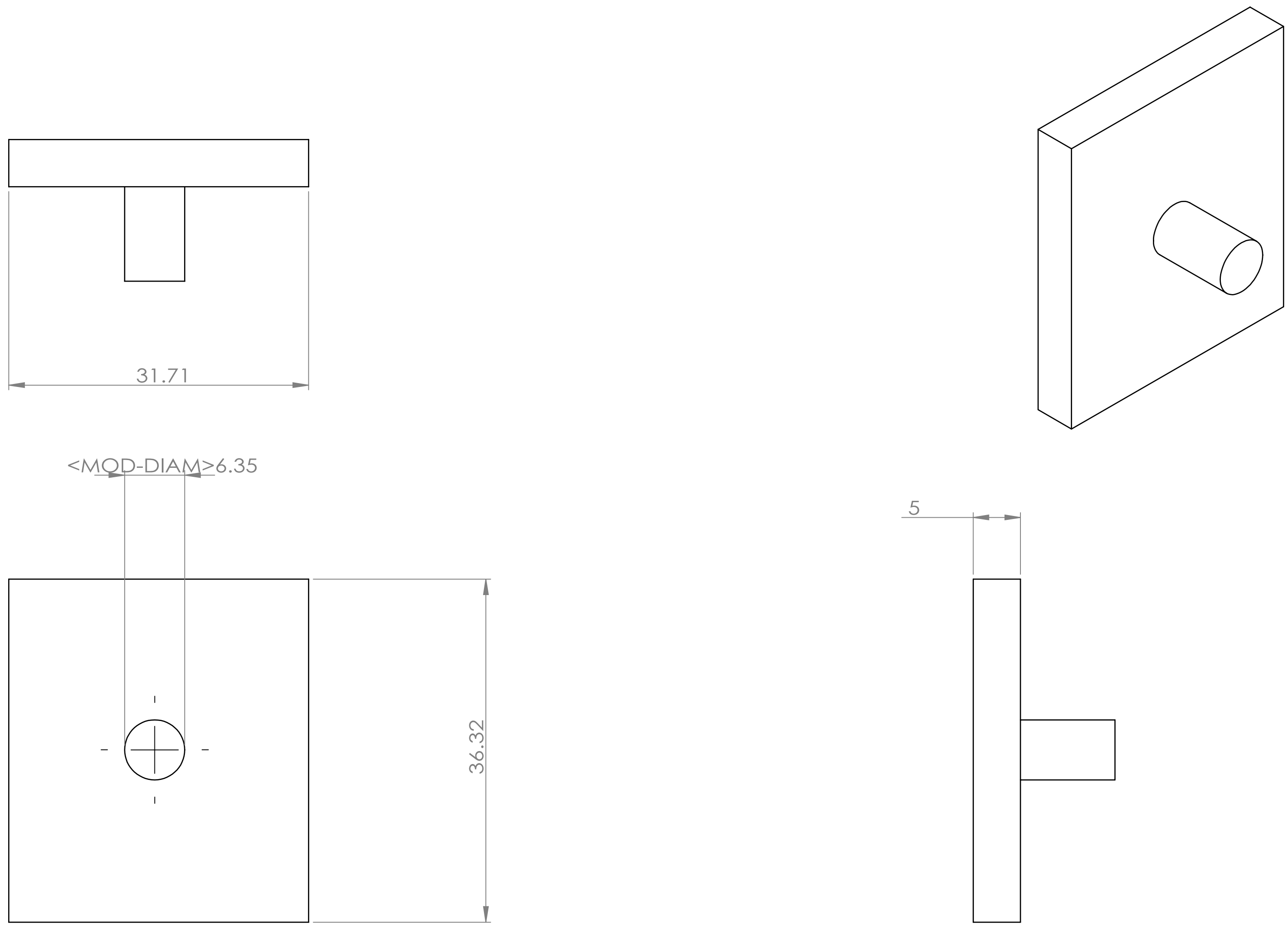

	AUTHOR: Shu Wen	CLASS: MIE 243 / LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
	STUDENT NO. 1008753920 / DATE: 2023/12/4	TITLE: GEAR SUPPORT OF X-AXIS	
	MATERIAL: Aluminum	PART NO. X-4	REV. 1
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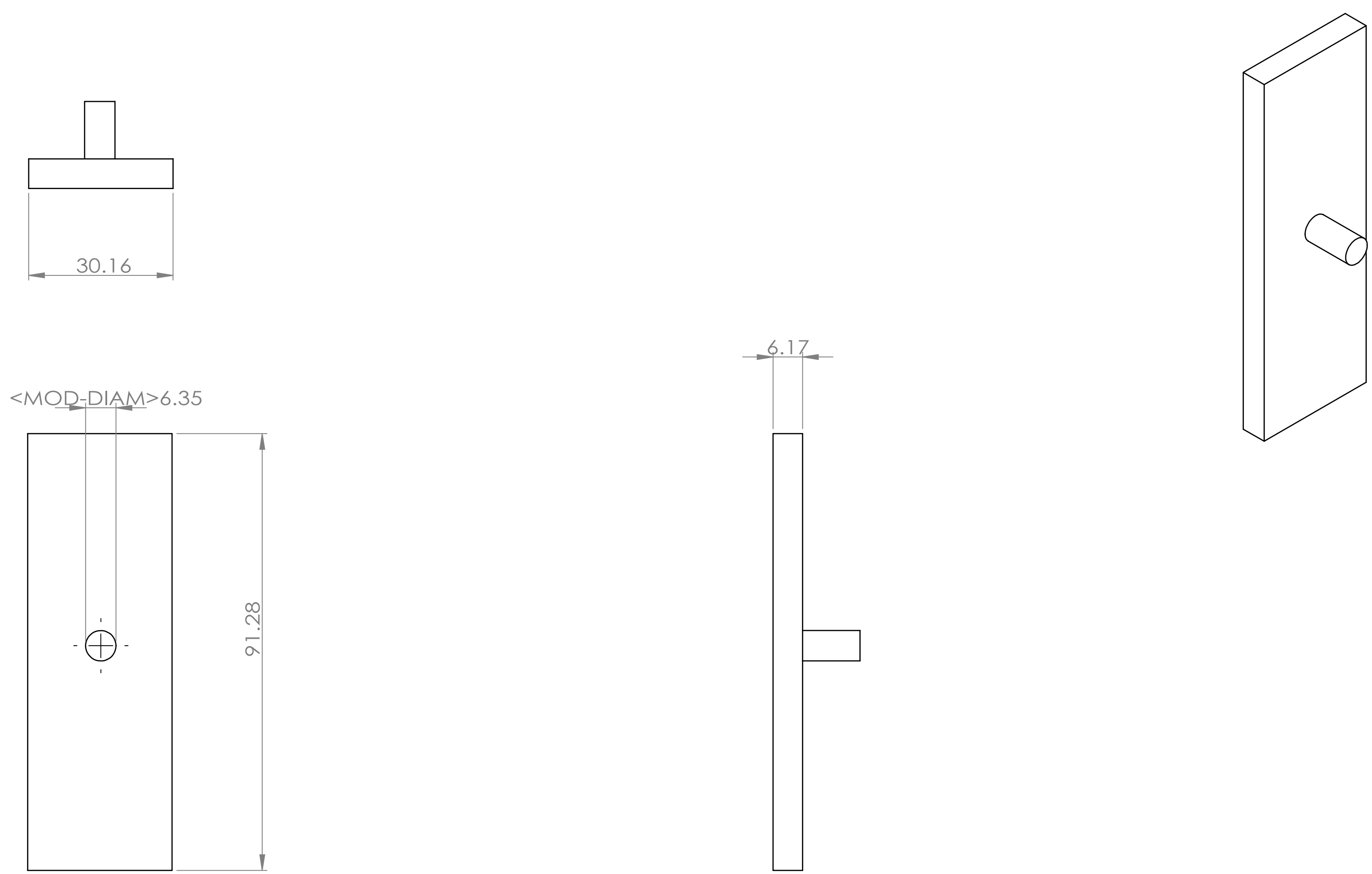

	AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER
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	DATE: 2023/12/4			
	MATERIAL: Aluminum	PART NO. x-8		REV. 1
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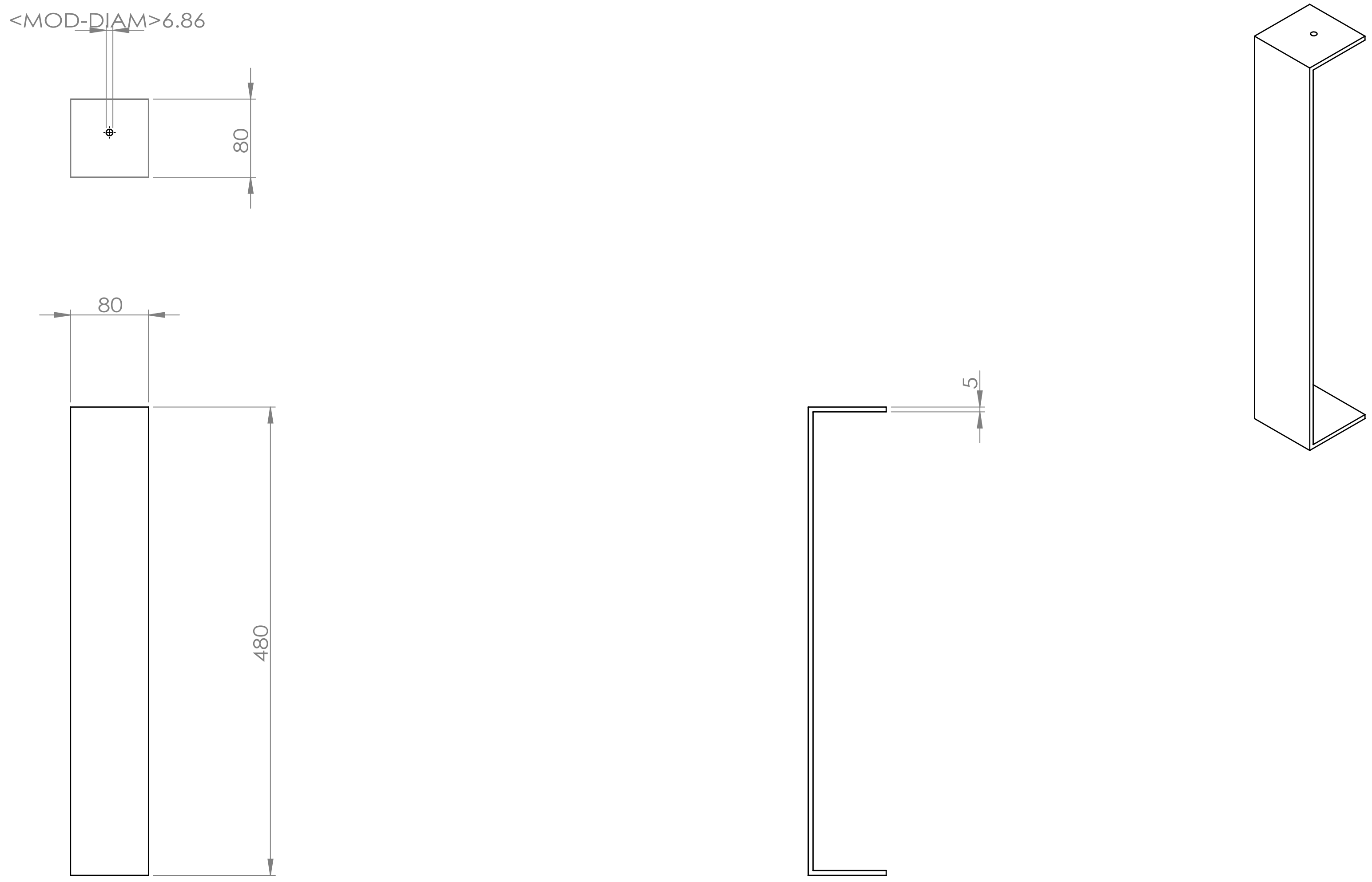

AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER	
STUDENT NO. 1008753920	TITLE: SUPPORTING SHELF OF Y-AXIS			
DATE: 2023/12/4				
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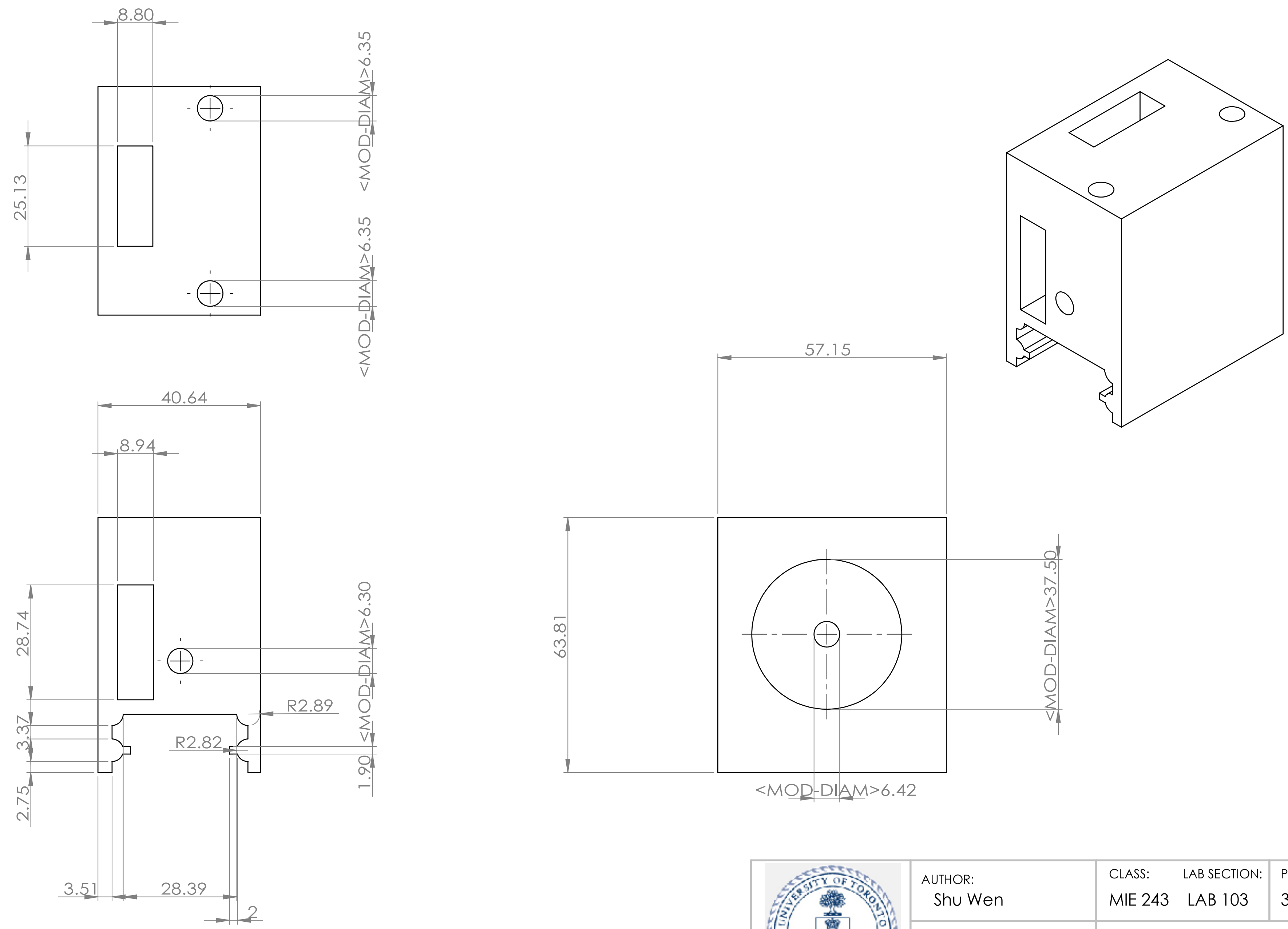

AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER	
STUDENT NO. 1008753920	TITLE: BLOCK OF Z-AXIS			
DATE: 2023/12/4				
MATERIAL: Aluminum	PART NO. Z- 10		REV. 1	
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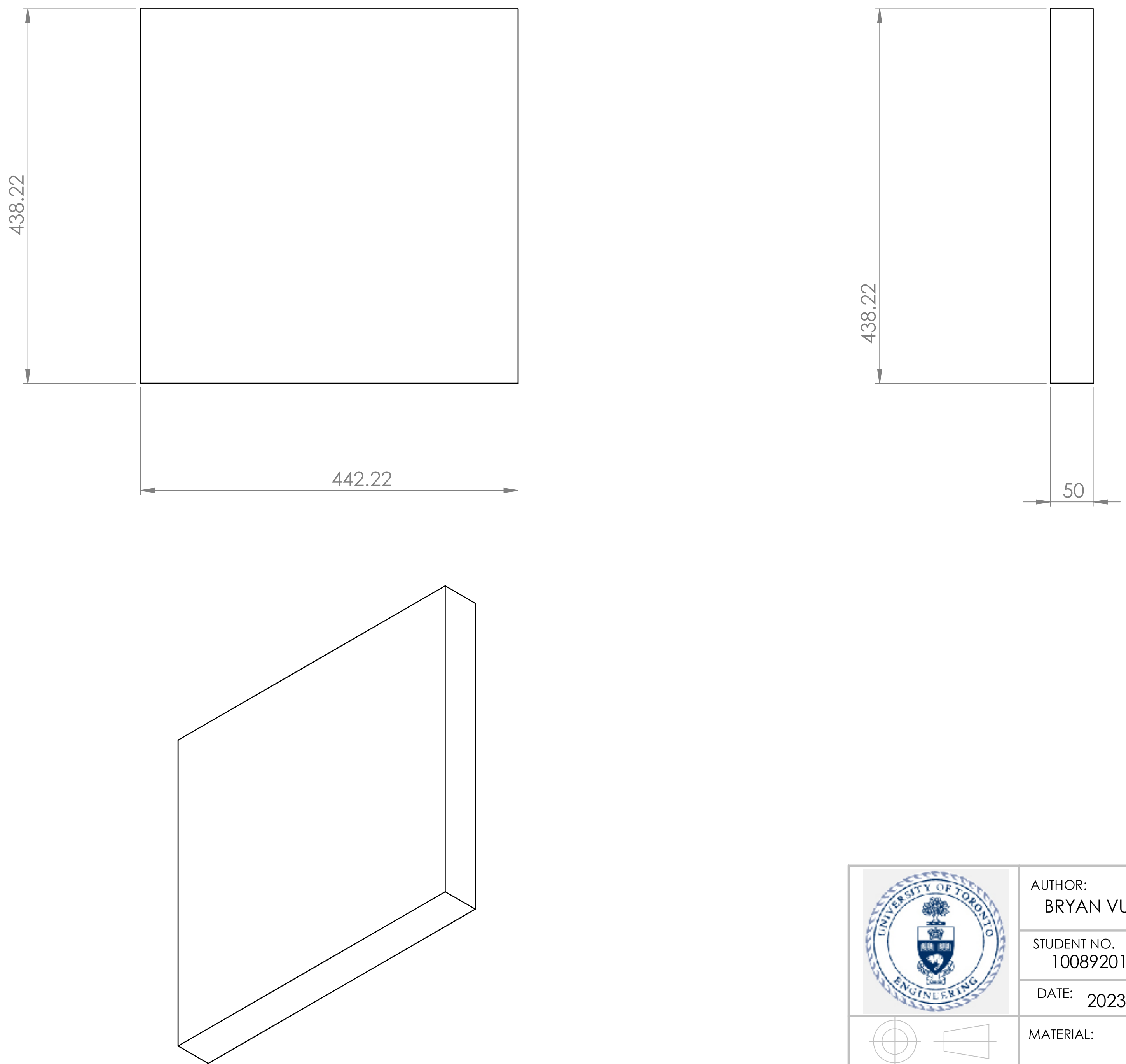

AUTHOR: BRYAN VU	CLASS: MIE 243	LAB SECTION: N/A	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008920116	TITLE: 3D PRINTER BASE		
DATE: 2023-12-06			
MATERIAL: N/A	PART NO.		REV. 1
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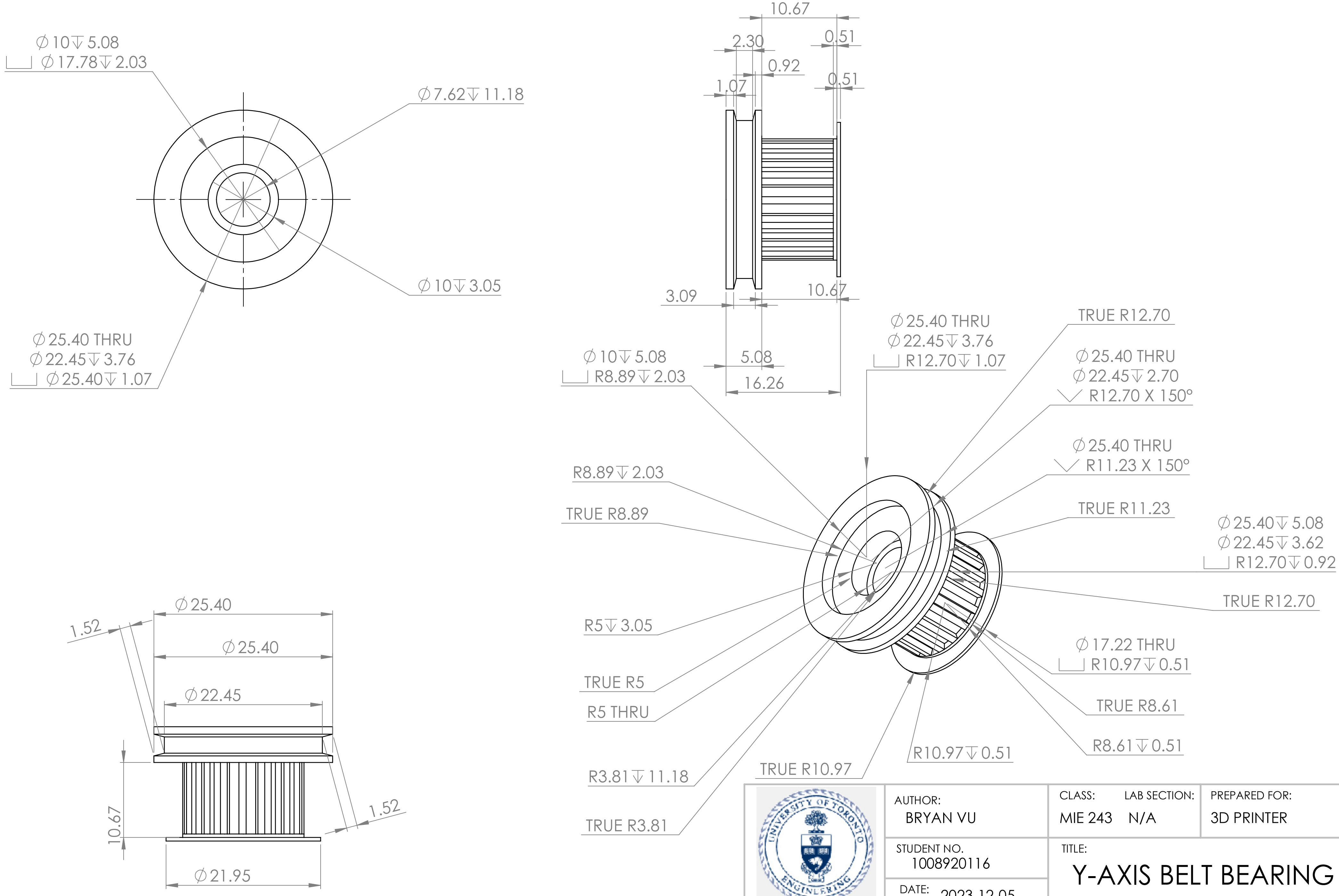

AUTHOR: BRYAN VU	CLASS: MIE 243	LAB SECTION: N/A	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008920116	TITLE: Y-AXIS BELT BEARING		
DATE: 2023-12-05			
MATERIAL: N/A	PART NO. Y-3		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:2:1		SHEET 1 OF 1

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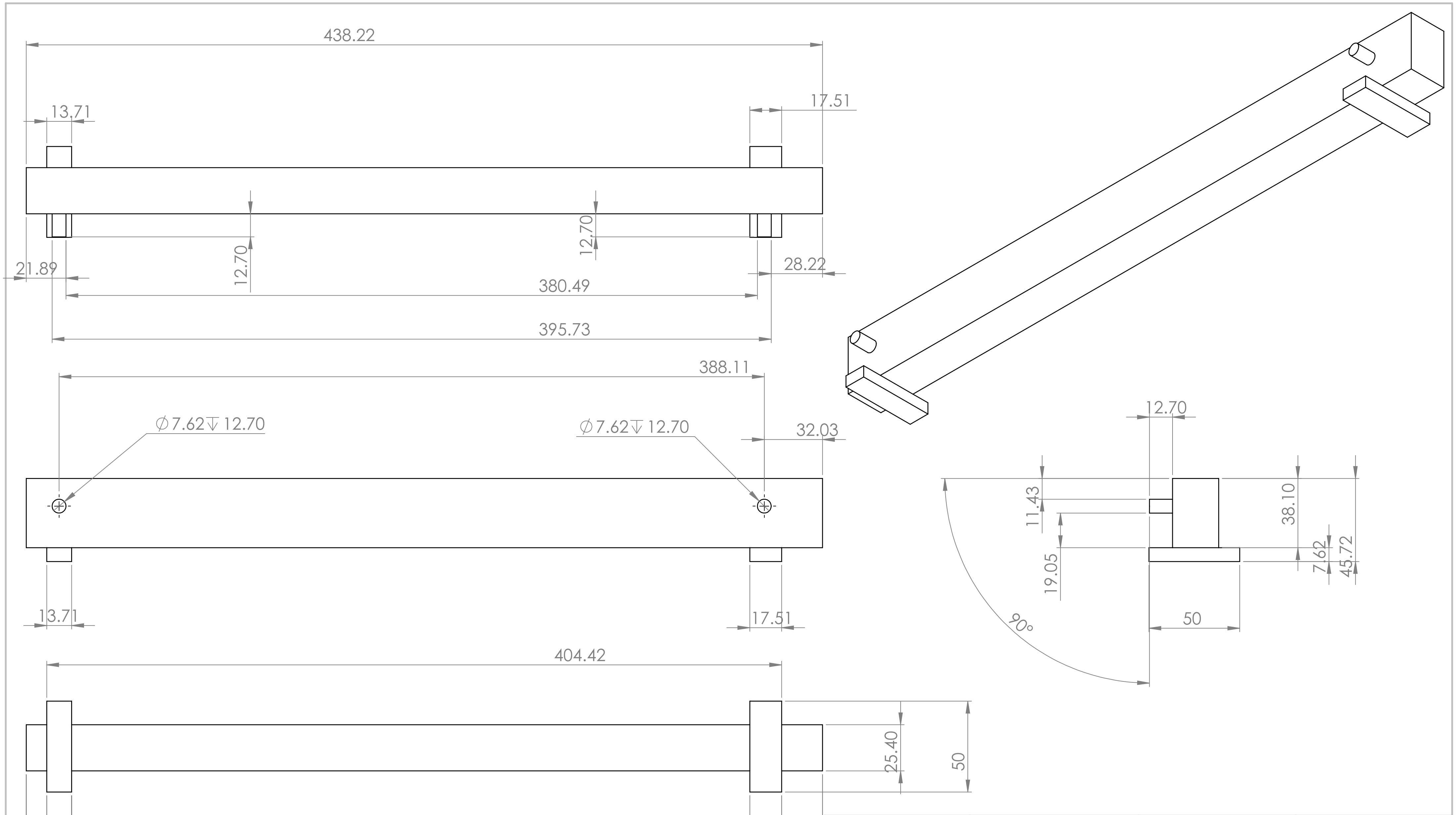

AUTHOR: BRYAN VU	CLASS: MIE 243	LAB SECTION: N/A	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008920116	TITLE: Y-AXIS BELT BASE		
DATE: 2023-12-05			
MATERIAL: N/A	PART NO. Y-2		REV. 1
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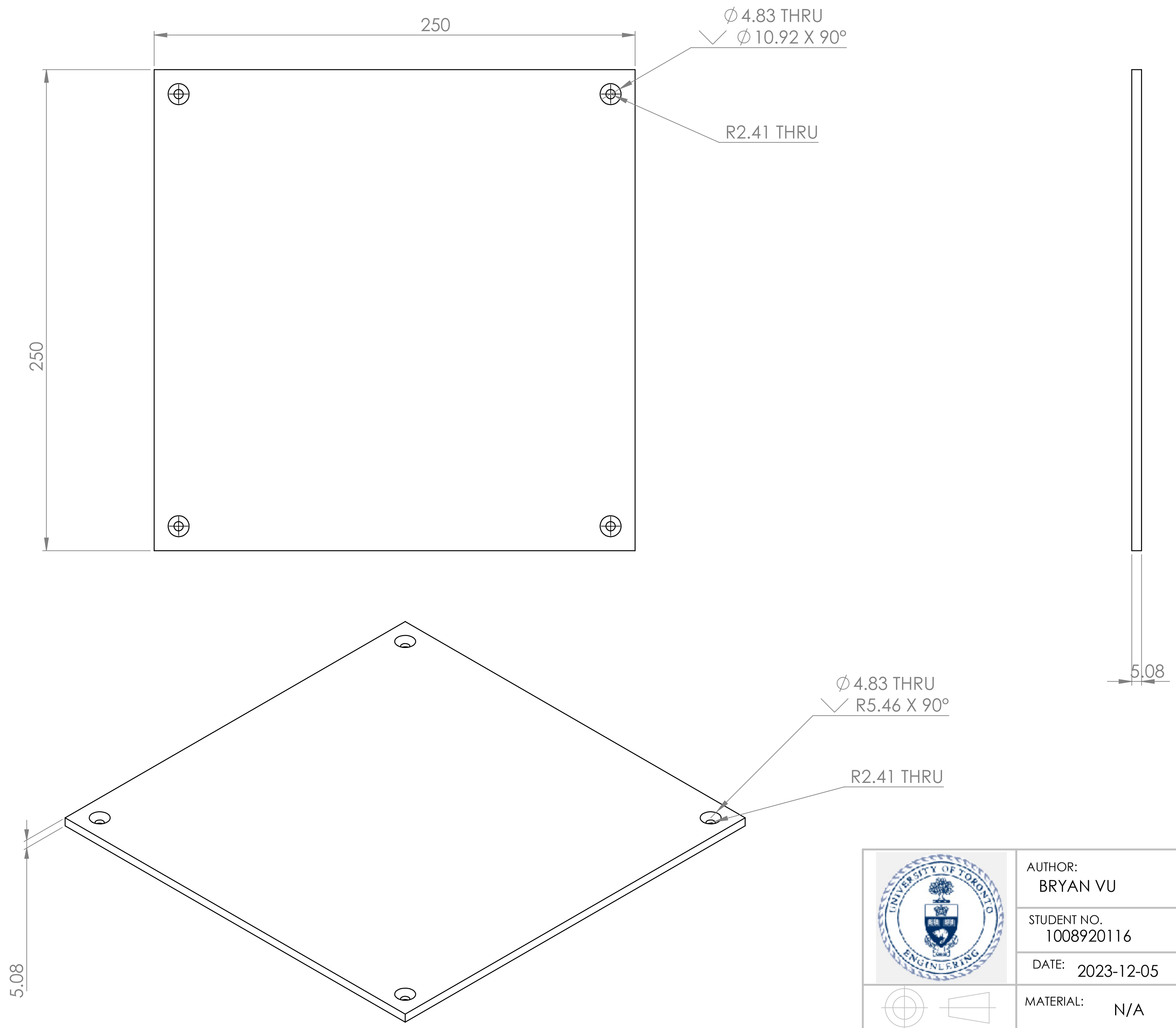

AUTHOR: BRYAN VU	CLASS: MIE 243	LAB SECTION: N/A	PREPARED FOR: 3D PRINTER
STUDENT NO. 1008920116	TITLE: PRINTING BED		
DATE: 2023-12-05			
MATERIAL: N/A	PART NO. Y-6		REV. 1
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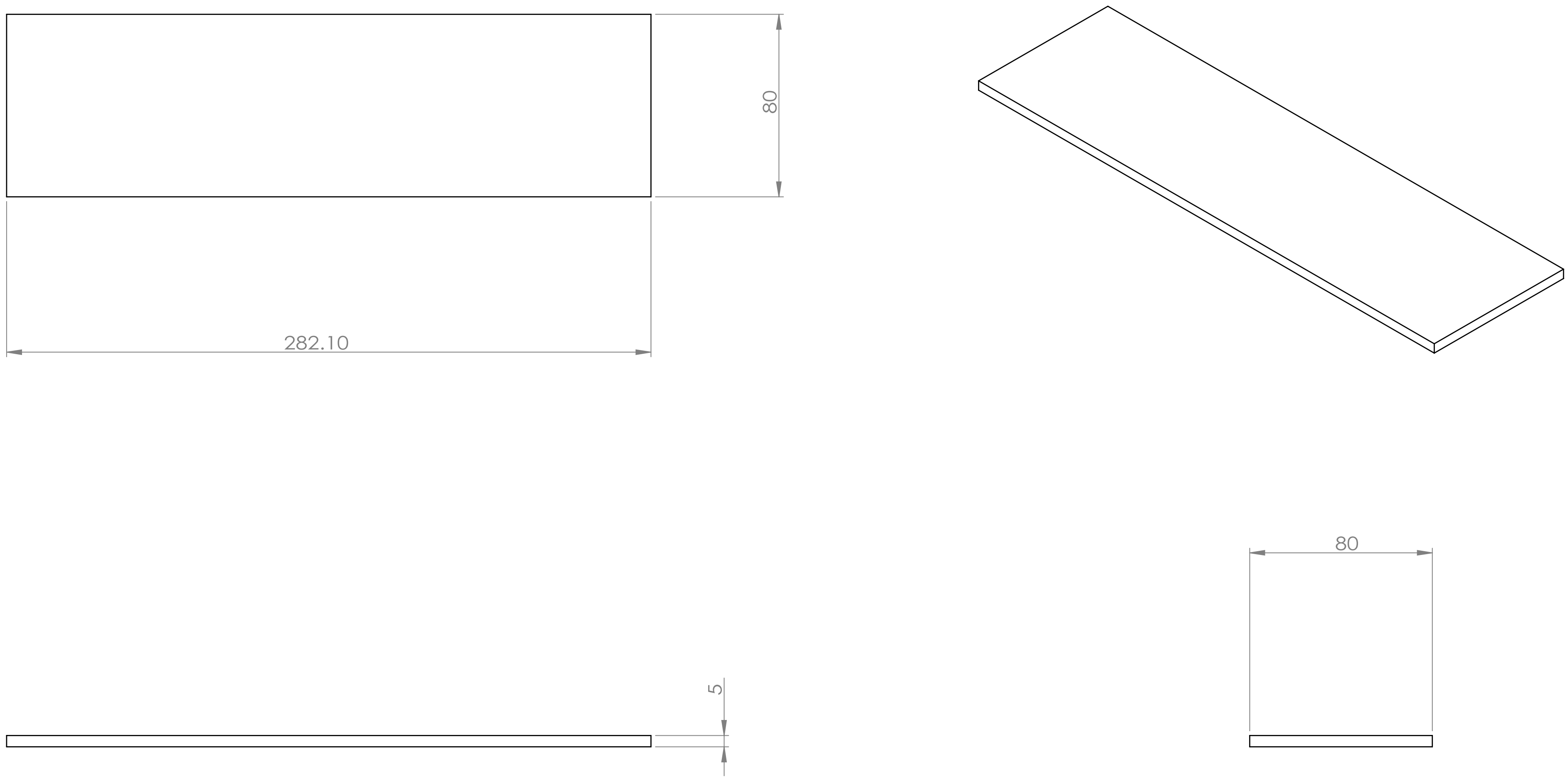

AUTHOR: Shu Wen	CLASS: MIE 243	LAB SECTION: LAB 103	PREPARED FOR: 3D PRINTER	
STUDENT NO. 1008753920	TITLE: TOP SUPPORT PLATE			
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UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:2		SHEET 1 OF 1	

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