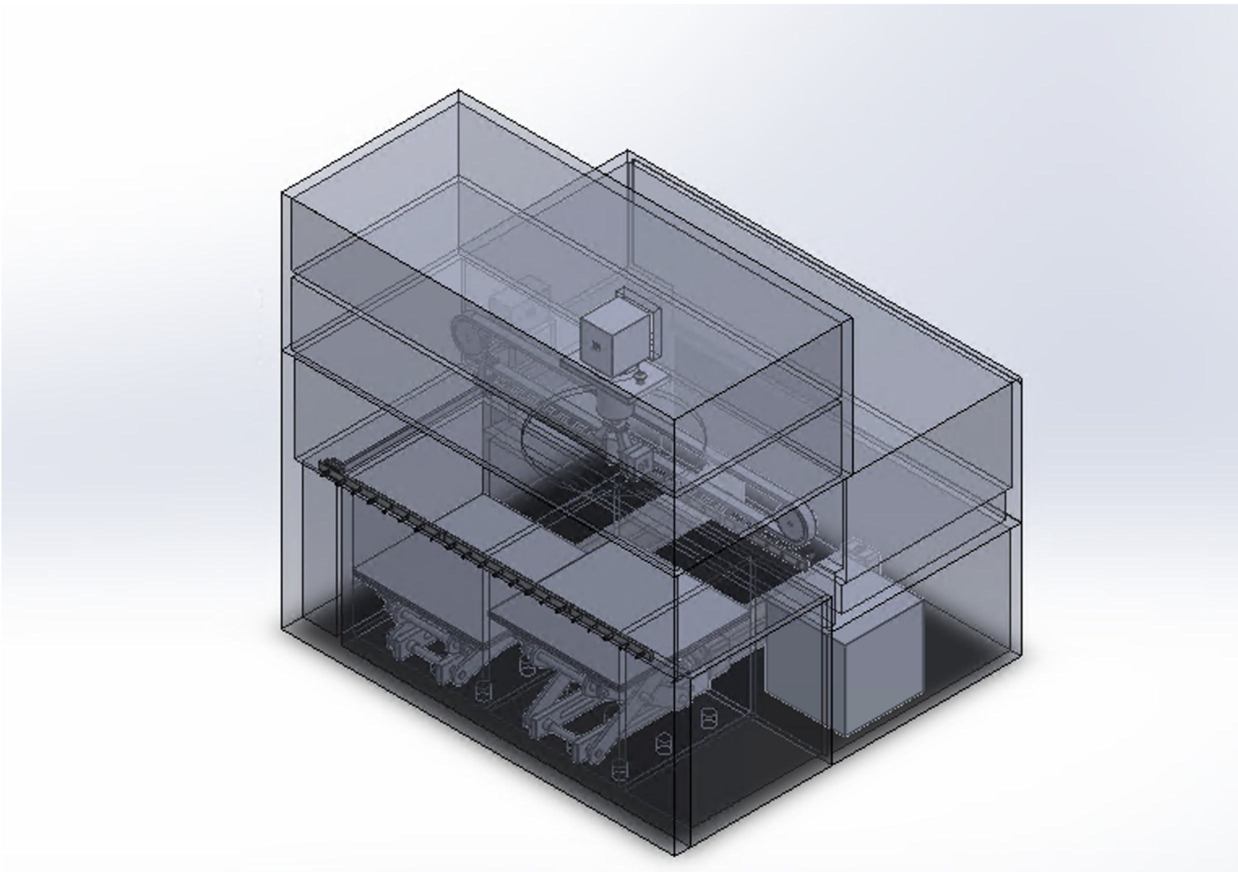
MIE243 Group Design Project- Entry-Level Professional 3-D Printer

Design Group 40



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Research:

3D printers create 3D models from 2D drawings. Some of the most notable 3D printers include fused deposition modeling (FDM), stereolithography (SLA), selective laser sintering (SLS) and material jetting. Through research, it was determined that FDM printers employ the cartesian x,y,z coordinate system and often range in size from 200x200x200mm to 1000x1000x1000mm [1]. FDM printers which extrude a thermoplastic filament are often referred to as the most common 3D printers available and are available at a relatively modest cost when compared to other printer types [1]. However, FDM printers require support structures for most 3D geometries, are not recommended for functional parts and may warp due to stress buildup while cooling [1]. SLA printers produce models through the use of a laser source which cures a liquid polymer located in a reservoir [2]. SLA printers often range in size from 145x145x175mm to 1500x750x500mm and utilize support structures [2]. SLA printers are capable of modeling fine details to high accuracy to create visually appealing prototypes but not functional prototypes due to their brittle nature [2]. Further, SLA models require post print processes and may curl and degrade from sun exposure [2]. SLS printers utilize a laser which outlines the cross sectional shape of the model on a powder covered build platform [3]. SLS printers do not require support structures and as a result, they are capable of printing more diverse geometries [3]. On average, SLS printers will range in size from 300x300x300mm to 750x550x550mm [3]. Even though SLS printers also face the issues of warping and shrinking, SLS printed models are isotropic as they have the same strength in all directions making them ideal functional parts [3]. Lastly, material jetting utilizes printheads which travel over the build platform dropping liquid polymer [4]. Material jetting printers are depicted as expensive and produce high accurate and resolution models that have poor mechanical properties making them best suited for visual appeal [4]. They often span dimensions of 380x250x200mm to 100x800x500mm [4]. The target audience for our 3D printer design will be engineers and architects with an approximate price range of $3000-$7000 CAD. After analysis of the printer types and their corresponding properties, this report will suggest the design of an SLS printer.

On the market, there are a variety of 3-D printers that range from low-end household printers to expensive high quality industrial printers. The ones relevant to this project are the ones in between which are entry level professional 3-D printers. The Ultimaker 2+ is a FDM printer with cost around $3000 and has a 12.5 micron precision [5]. The Formlabs Form 3 is a SLA printer that costs around $3500 and has a 25-300 micron precision depending on the resin used [6]. The Sinterit Lisa is an SLS printer that costs around $10,000 and has a 75-175 micron precision [7]. The ProJet MJP 2500 series is a material jetting printer that costs around $40,000 with most material jetting printers being this expensive or more, as many are for industrial use [8]. Overall, there are a number of different 3-D printers on the market, although not many are affordable for small engineering firms that need high quality functional printers but at a reasonable cost.

Engineering Specifications:

The following details outline the basic requirements and functions that a proposed design must fulfill in order to be considered suitable:

- The 3D printer must be able to produce a dimensional accuracy of ± 0.05mm.
- The 3D printer must be able to print parts that are at least 250 x 250 x 150mm large.
- The 3D printer must cost in the range of $8000-10000 (USD).
- The 3D printer must be able to resist a force of 140 newtons applied to the top of it, this will ensure the printer is not broken if weight is applied on it.
- The 3D printer must be able to print layers in the range of 75-150 microns thick.
- The printer must be compact and must not exceed dimensions of 750mmx750mmx650mm.
- The printer must have an interactive accessible user interface which interacts with the user.
- The 3d printer must not produce or transmit any hazardous or toxic materials into the surrounding area that pose health and safety concerns.
- The printer must achieve an average printer speed greater than 10mm/hr in the z-direction.
- After printing is complete the printer must remain closed until the temperature inside is 45°C or lower so harm isn't inflicted upon opening.
- The printer must work with standard 120V wall sockets found in the USA and Canada.
- The 3D printer must support ethernet and/or wifi connections.

Candidate Designs:

Candidate Design 1:

Laser:

Attached to swivel bearing to allow full 360 motion maximizing the diversity of possible prints

Swivel bearing attached rigidly to the top inside surface of the printer

Moving build platform downwards:

- 4 identical electric motors attached to identical gears.
- Gears are attached to a shaft with gear tooth cutouts.
- By the electric motors spinning the gears simultaneously on the shaft, the platform can move up or down.
- Build platform must be made of a metallic structure as operating temperatures are too high for most plastics.

Spreading powder:

Use a uniform belt with a rigid follower on top of it spanning the width of the build platform.

Moving the powder container upwards:

- Similar methods can be used.
- Excess powder container made of plastic.

Outer casing:

- Plastic

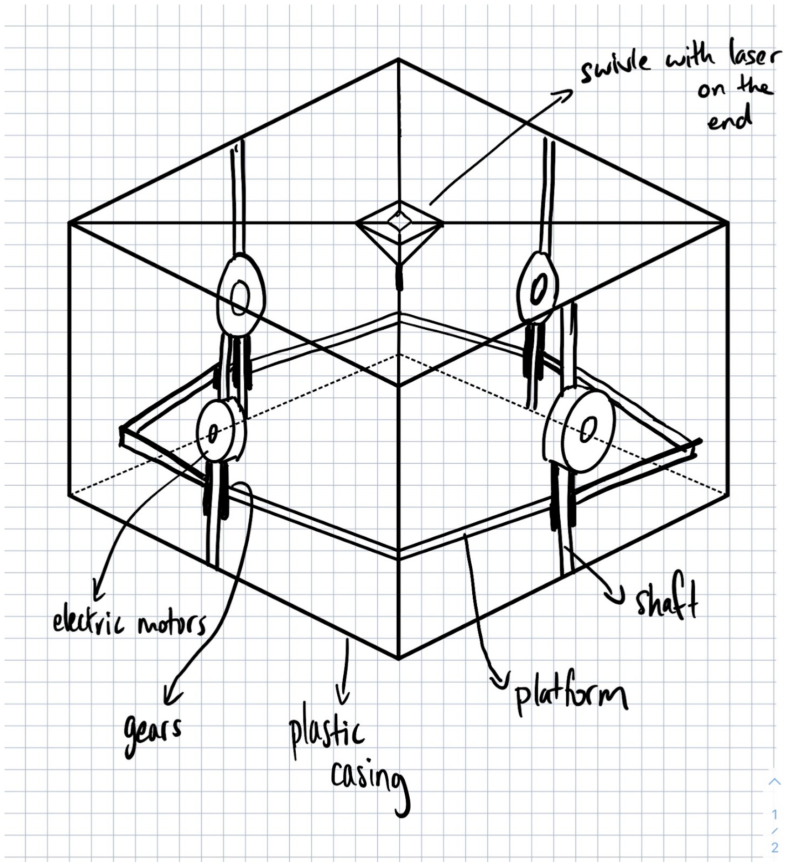


Figure 1. Sketch of Candidate Design 1

Potential Cons for Design 1:

The method of moving the build platform downwards may be too expensive as there are four motors. It also could be costly for this reason.

<u>Candidate Design 2:</u>

Laser:

Attached to swivel bearing to allow full 360 motion maximizing the diversity of possible prints

Swivel bearing attached rigidly to the top inside surface of the printer

Moving the build platform downwards:

- Can use two double hinge linkages attached to two identical electric motors, similar to a scissor lift. Linear motion is created by applying rotational motion to the two bottom links at the base of the printer.

- Build platform must be made of a metallic structure as operating temperatures are too high for most plastics.

Spreading powder:

Use a uniform belt with a rigid follower on top of it spanning the width of the build platform.

Moving the powder container downwards:

- Similar methods can be used.

Outer casing:

- Aluminum or other strong metal

Potential Cons for Design 2:

The design may be more difficult to facilitate precise movement as the movement is not linear at all heights of the scissors lift.

Potential Advantages of Design 2:

The scissor lift mechanism provides effective containment of the powder as the mechanism can be contained underneath the powder and build platforms.

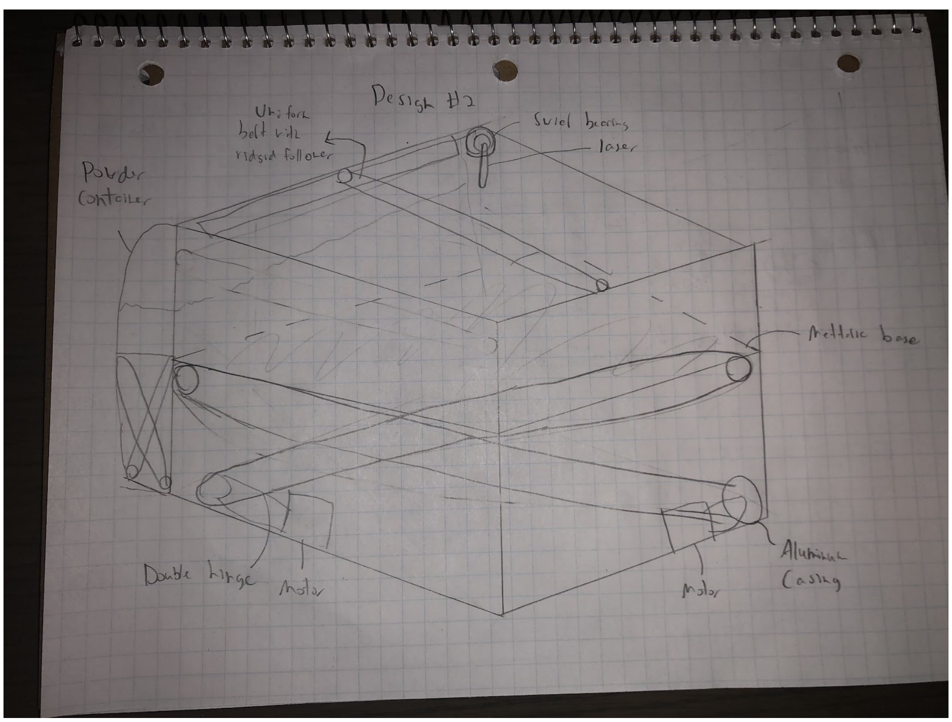


Figure 2. Sketch of Candidate Design 2

Candidate Design 3:

Laser:

Attached to swivel bearing to allow full 360 motion maximizing the diversity of possible prints

Swivel bearing attached rigidly to the top inside surface of the printer

(maybe could also use laser that reflects off of mirrors that are tilted in different directions)

Moving the build platform downwards:

- Hydraulic lift
- The use of actuators instead of gears, electronically controlled. Need high accuracy actuators as our print layers are aiming to be.
- Build platform must be made of a metallic structure as operating temperatures are too high for most plastics.

Powder container moving downwards:

Powder container is composed of a vertical tube that is fed powder through the top of the printer and extends downward towards the build platform. Releases powder by opening the end of the tube. As the build platform moves toward, powder container stays stationary and just drops the powder on the build platform

Moving the powder container upwards

- Actuators connecting to the bottom of the container which will push the container upwards.

Spreading Powder:

Powder is spread periodically using a geneva mechanism that has a follower extension, creating a sweeping motion across the build platform. Similar to windshield wipers on the glass of a car. Excess powder that falls off the platform is collected below for reuse

Outer Casing:

- Steel to save costs because the machine will not be moving much once in use

Potential Advantages of Design 3:

The use of actuators may be able to provide highly accurate movement required to print small layers.

Potential Cons of Design 3:
Using geneva mechanism to spread powder will cause some powder to fall off the platform, and may not be uniformly spread near the edges of the platform.

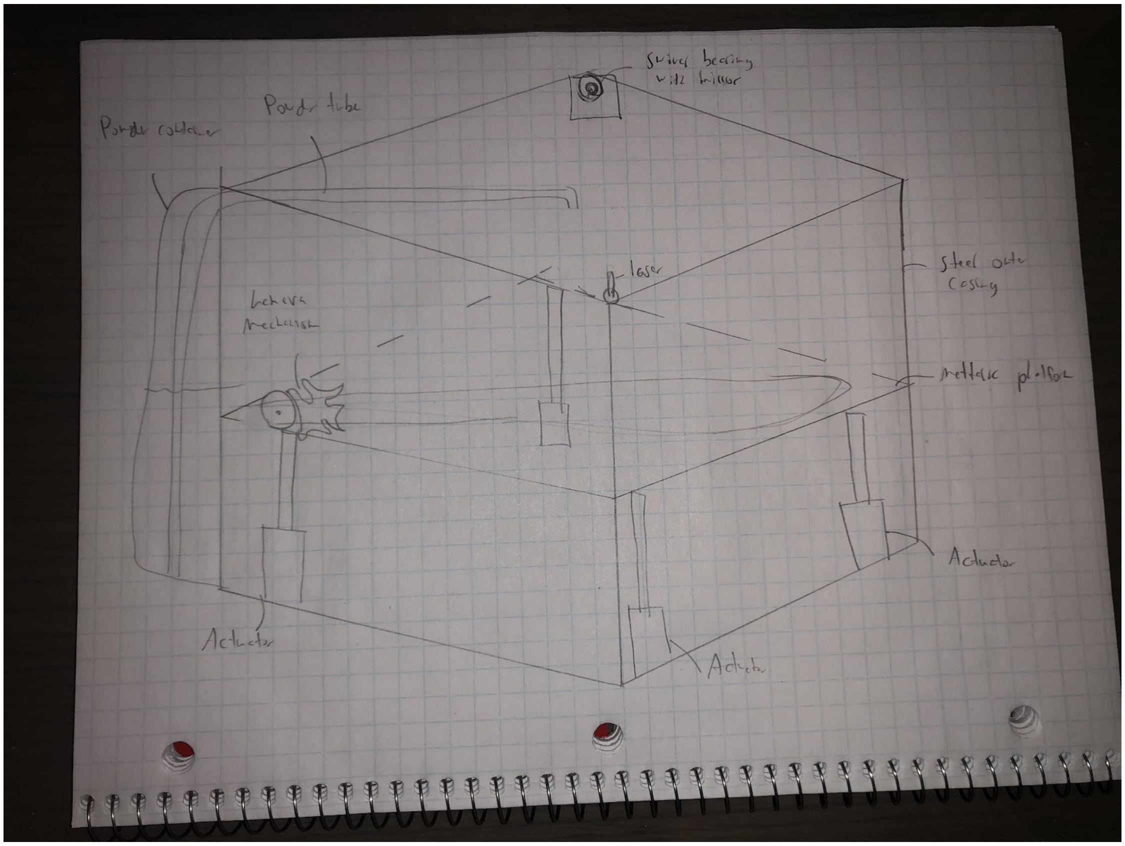


Figure 3. Sketch of Candidate Design 3

<u>Detailed Design:</u>

Explanation of Design Operation

First the overall design mechanism will be discussed of our choice of style of printer, SLS. After this the more specific details pertaining to our chosen design will be discussed.

SLS stands for Selective laser sintering, this mechanism of producing 3D models involves the dispersion of powder into the lower platform, this powder will be heated to just below the materials melting temperature by the laser based on the instructions generated to print the part. The direct heat provided by the laser allows for intricate parts to be built, the heat will then melt the powder and cause it to fuse together, this process is repeated on a layer by layer basis until the intended model is completed.

Now, pertaining to our design more specifically, the individual parts chosen to accomplish each function work together in harmony to produce the final 3-D models accurately and efficiently. Many helper/supporting parts such as bearings and gaskets are used to ensure the least friction possible is present in the system, thus ensuring a longer lifespan of all the individual parts and the design on a whole.

Two scissor lifts are used, one for the build platform and the powder platform. The scissors lift was chosen as the best method to accomplish this movement due to the effectiveness in containing the powder in the build container. Other mechanisms fall short in this regard and it is crucial to have the powder contained for the integrity of the parts being built. If the powder is allowed to shift and fall through cracks while in printing

A timing belt in conjunction with a stepper motor is used to spread powder across the build platform with a rigid follower. The timing belt is ideal for this situation as it provides one to one motion with the input, meaning as the stepper motor rotates the pulley, the timing belt does not slip. This increases the reliability of the mechanism as there will be no need to reposition the connection of the rigid follower to the belt due to slip.

An actuator is used in conjunction with a pump to actuate the hydraulic pistons precisely to lift the platform. Actuators offer adjustable movements with extremely high accuracy.

The laser is controlled via two electric stepper motors which both act in perpendicular axis to one another. One electric stepper motor is to be of a small size which allows for it to be attached beside the laser and rotate with the laser as well. This setup of motors allows the required motion for the laser to cover the entirety of the build platform to occur.

Justification of Component Selection

Laser:

The laser used in this printer should have 360 degree motion and therefore should be attached to part of a mechanism that allows rotational motion about all three axes. A swivel bearing will be attached to the laser to allow this 360 motion. The swivel bearing attached rigidly to the top inside surface of the printer. This motion however would be limited by the walls of the 3D printer. This 360 degree motion and chosen laser must be highly accurate and controlled since "the 3D printer must be able to print layers in the range of 75-150 microns large". The laser chosen should not cost over $1500.

Table 1: Potential Laser Selections and Mechanisms for Support and Movement of the Laser

Candidate Mechanism	**Analysis of Mechanism**
CO_2 Laser	This laser is very powerful with a 40-80 Watt power output. [9]. This power output makes the CO_2 laser ideal for fast laser cutting. This is the laser used for industrial production. However, this laser can't engrave metal (this is possible with the addition of cermark which is very expensive). Furthermore, these lasers are very large due to their high power output and will take up a lot of space which might not be ideal for our client. Finally these lasers are very fragile and usually degrade within 6-12 months.
Diode Laser	The diode laser is less powerful than its CO_2 alternative and therefore is slower at laser cutting. However, the diode laser doesn't take up much space. It is not as fragile as the CO_2 laser and has a longer lifespan. This laser is also cheaper than the CO_2 laser and can easily fit into a relatively compact 3D printer. [9]

KingPin Swivel Bearing	The kingpin Swivel bearing design utilizes load bearing as well as thrust bearing to transmit the load. This bearing can be tightened for different levels of swivel resistance which could increase the accuracy of the motion of the laser by preventing it from moving too much. However, this type of swivel bearing is likely to become a point of failure. [10]
Kingpinless Swivel Bearing	This bearing doesn't provide different levels of swivel resistance and therefore motion of the laser may not be as accurate. However, This bearing is better than the kingpin bearing for higher speed caster applications. This bearing doesn't require as much maintenance as the Kingpin bearing.
Galvanometric (Mirror) Mechanism	This mechanism is used in many SLS printers. In this case, the laser doesn't move but is reflected off a mirror that angles the beam to the "correct spot on the powder bed". However, when the laser is redirected toward the edge of the powder bed, the laser spot generated is an ellipse. Furthermore, in this position "the angle of the beam leads to a distorted metal spot" [11].

Moving Build Platform Downwards:

To move the build platform downwards, we require a mechanism which provides highly accurate linear output. The motion of the build platform (up and down) is linear, and due to the engineering specification of "the 3D printer must be able to print layers in the range of 75-150 microns large”, a highly accurate mechanism for providing this motion is required. While in operation, the mechanism will undergo low to moderate torque, speed and force.

Table 2: The following table suggests some candidate mechanisms with their corresponding analysis in conjunction with the applicable engineering specifications.

Candidate Mechanism	**Analysis of Mechanism**
Rack and pinion mechanism placed vertically which will facilitate the up and down linear motion. The pinion will be driven by an electric motor.	The rack and pinion mechanism is standardized which means that its cost will be lower than custom parts and can be replaced in the event of failure easily. Accuracy of 75-150 microns can be achieved with the rack and pinion, however this can incur a higher cost as it is presumed these high accuracy rack and pinions are not as standardized due to extra processes when being manufactured [12]. The mechanism can be integrated within the space requirements. Effective containment of powder may be an issue with this mechanism.
Two double hinge mechanisms which can extend vertically to raise or contract to lower the build platform. Similar to scissor lifts there will be an actuated hydraulic or pneumatic piston which can be actuated to facilitate this motion.	The double hinge mechanism will provide a high level of support for the platform. The accuracy of it may be difficult to judge, measure, and control compared to other mechanisms. The scissor lift mechanism does not come standardized in the dimensions we require (250mmx250mm) which will incur additional cost manufacturing the parts for this mechanism likely to be more expensive than other options. However, this mechanism is highly effective in containing the powder in the container.
Electronically actuated hydraulic or pneumatic lift which will vertically extend to raise the platform and contract to lower the platform.	The use of an actuated hydraulic cylinder can provide a high level of support for the build platform. The required accuracy is possible with this design, and it may contain the power in the build platform

	effectively. Alignment issues may hinder the operation of this mechanism.
Ball and screw mechanism placed vertically which will allow the build platform to move up and down.	Ball and screw mechanisms can provide excellent positioning accuracy with high repeatability. This makes them a potentially great candidate mechanism for this function. A potential drawback is the cost for a ball and screw mechanism which can be too high for our targeted cost range and effectiveness of containing the powder in the build platform.

The mechanism chosen to move the build platform up and down is the two double hinge (scissor lift) mechanism. It is capable of providing high quality motion and precision with the proper actuation for meeting the engineering specification of must be able to print layers in the range of 75-150 microns thick. It is chosen because it is the most effective mechanism for containing the powder in the build platform. Other mechanisms which are not positioned directly below the platform and protrude to the side (ball screw and rack and pinion) are more difficult to implement in terms of containing the powder effectively.

Spreading Powder:

To spread the powder on our 3D printer design, a mechanism that converts rotational to linear motion must be implemented. A linear output is required since this will enable the device to output a sweeping motion which will evenly layer the powder over the build platform. Further, to ensure an even spread of powder, the linear output will be of relatively low speeds. As a result, the corresponding rotational motion will be relatively low torque. When selecting the mechanism which will spread the powder over the build platform, multiple candidate mechanisms were considered prior to selecting the mechanism of interest that will ultimately be included in our final design.

Table 3: The following table suggests some candidate mechanism along corresponding analysis in conjunction with the engineering specification.

Candidate Mechanism	Analysis of Mechanism

Slider crank mechanism with rectangular rigid follower that lies flush with the build platform. The rectangular rigid follower would be connected at the end of the output link on the slider crank.	One drawback of using this mechanism is the required size of disk needed for the slider crank. Since the rigid follower must be able to spread powder over the entire build platform, the slider crank must have a stroke length that is equal to the length of the build platform. As a result, this will lead to the radius of the disk to be greater than or equal 250mm since the printer must be able to objects that are at least 250x250x150mm. A 250mm disk is relatively large and may lead to difficulties in achieving the requirement of dimensions less than 750x750x650mm and difficulties when selecting a suitable housing for the printer.
Chain drive that connects to a rigid follower. The rigid follower on top of the chain would span the width of the build platform.	Chain drives may be seen as a desirable mechanism since they produce non slip motion. However, due to their considerable amount of backlash, noise and vibration associated with chain drives, selecting a chain to spread the powder across the platform may have consequences. Any backlash or vibration that occurs when spreading the powder will lead to an uneven spread which will have potential to cause geometric inaccuracies of greater than 0.05mm when the following layer is sintered. To continue, relative to the other candidate mechanisms suggested, the chain drive is the most costly leading to difficulties of achieving the desired price range of $8000-10000.
Belt drive with a rigid follower connected across its width. The rigid follower would span the width of the build platform .	Belts are best functional under low speeds. One drawback associated with the belt drive is the possibility for slip during operation, however, with correct selection of the belt type, the possibility of slip can be eliminated. Belts are relatively low cost, however, they have a tendency to wear due to their strong dependence on tension and high vulnerability to the environment. As wear accumulates, the spreads will become uneven and may result in print inaccuracies of greater than 0.05mm.
Geneva Mechanism with a	Throughout every rotation, the pin on the geneva mechanism

rigid follower extension which creates a sweeping motion across the build platform at given time increments	continuously contacts the disk which is initially at rest. As a result, the pin is susceptible to wear. As the pin on the geneva mechanism wears, the motion quality will decrease drastically leading to uneven and inconsistent powder spreads which may lead to inaccuracies of greater than 0.05mm. Also, since the printer must be able to print at least 250x250x150mm, the device will require a large amount of space due to the large rotational paths occupied by the mechanism and the follower extension. This may lead to the requirement of compactness to not be met since overall printer dimensions may exceed 750x750x650mm and difficulties when selecting housing for the printer.

After analyzing the mechanism, a timing belt with a rigid follower on top of it spanning the width of the build platform will be used to spread powder across the build platform. The timing belt will be modelled as a flat belt in the CAD models, assemblies and drawings. The belt serves as a relatively low cost option for this function and the expected low speed and torque motion fall within the belt's ideal use case. It is expected that the extreme low speeds and torque subjected to the belt will mitigate its associated wear. A timing belt will be selected to maximize accuracy since they produce no slip. The output will always move relative to input movement. The rigid follower will be made of a lightweight metallic material to minimize the timing belts' load and to ensure there is no melting or degradation of the follower due to the high temperatures of the build platform.

Moving the Powder Container Upwards:

To move the powder container platform upwards, a mechanism that provides moderately accurate linear motion is required. The motion of the power container platform is strictly up and down linear motion. As stated in the specifications, "The 3D printer must be able to print layers in the range of 75-150 microns large" although the printing occurs on the build platform so the linear motion of the powder container platform does not necessarily need to be accurate to 75-150 microns. However, the powder container needs to provide enough powder to be spread across on the build platform and any excess powder will be pushed off the edge into an excess powder container. Therefore, it is prudent to regulate the motion of this platform in such a way that its movement is slightly larger relative to the build platform to ensure enough powder is spread.

Table 4: The following table suggests some candidate mechanism for linear motion of the powder container platform

Candidate Mechanism	**Analysis of Mechanism**
One ball screw with two linear rails	This mechanism would be very accurate as ball screws are accurate up to 75-150 microns. Ball screws are very efficient in converting rotational motion from a motor in accurate linear motion. Cheaper then using pneumatic and hydraulic actuators [13]. The two linear rails would allow support across the platform.
Scissor lift mechanism	The two double hinges can be placed parallel to each other and as they extend, motion is generated upward on the platform. The hinge motion would be powered by an actuated hydraulic.
Two-Slider cranks guided by two liner rails on either side of platform	The slider cranks would be powered by a motor that would rotate a gear which would push the shaft up along a slider on the linear rail. No wear at the pin like the scotch yoke. Large linear space needed for mechanism as linear motion is directly proportional to gear diameter, meaning the stroke length equal to the length needed to move the platform.

Two rack and pinions on either side of platform	The rack and pinion is a standardized part and because this platform does not need high accuracy a custom rack and pinion would not need to be needed, which would save costs. The rack and pinion does not take up much space and is very compact. Length of rack can be increased without much increase to price of mechanism.

After analyzing all the candidate mechanisms the mechanism chosen to move the powder container platform upward in the z-direction is the scissor lift mechanism. The scissor lift mechanism provides the ability for discrete height adjustments so the platform can move up a certain height at different times. The use of a scissor lift also allows the mechanism to be fully under the powder platform which ensures no powder falls underneath as it would with other mechanisms that are built along either side of the platform. The scissor lift is also very compact and takes up limited space which is important as stated in the specifications the printer "must not exceed dimensions of 750mmx550mmx550mm".

Outer Casing:

The outer casing is made from high density polyethylene sheets due to its high strength to density ratio. This is due to its little branching molecularly leading to it possessing much more strength. The strength it possesses can be altered depending on the thickness in which we make it. A thicker casing will be more rigid and sturdy but will cost more to produce. Thus, to keep costs down we will use modeling software with a margin for error inputted within the testing to see what are the possible maximum stresses it will have to support and from this find the thickness which is most optimized for this capacity using the least amount of material possible. Furthermore, we have to account for other external factors that will affect the choice of material such as heat produced by the printer and the environment in which the printer will be stored. HDPE also has a relatively high resistance to heat of about 120 °C for extended periods of time which will be sufficient for the outer casing. In the parts where the laser is in a closer vicinity to the laser, aluminum will be used instead to better withstand the higher temperatures in these areas.

So for this case we will need a material that has a very long working life, no need to be replaced, can withstand prolonged stress of 140N, resistant to potentially corrosive environments, able to maintain rigidity at very low and high room temperatures, able to withstand internal heat generated from the mechanisms within the printer.

For the container which will hold the powder container, build platform, and excess powder collector, aluminum will be used as in these specific areas a higher temperature than the HDPE sheets can withstand is likely to be encountered. Although aluminum is the most expensive option, by limiting its usage to only a portion of the overall structure, the impact on cost is minimized.

In the table below the materials considered are discussed.

Table 5: Discussion of Potential Material Selection

Candidate Material	**Analysis of Material**
Stainless Steel	Supports all the needs of the design but at a weight and a slight expense penalty. Offers more resistance to heat and can be formed into intricate forms to provide a unique design for the casing. Stainless steel is also readily available so supply of material would not be an issue. Although stainless steel is very resistant to corrosion in some environments corrosion can occur which is not ideal thus extra protection mechanisms would have to be added to ensure this does not happen because if corrosion occurs the load the steel can support will be less.
Aluminium	By far the most expensive option. Aluminium is a good choice for minimizing the weight of the design. It hit all our targets that have been

	previously discussed however as mentioned, may incur costs which are too large.
High density polyethylene sheets	The best overall option that was discovered through research satisfied our heat and stress requirements perfectly but also satisfied our crucial cost requirements too. This material can be formed into many shapes easily thus causes no additional constraints in terms of the actual design of the outer casing. This material also has an extremely long life span so there is no issue here for longevity. Due to this and facts stated above this was our chosen material for construction. Manufacturing is possible through injection molding, allowing for complex shapes to be created as well.

Motors:

Table 6: The following table suggests some candidate mechanism for motors to be used in the printer

Candidate Mechanism	**Analysis of Mechanism**
Stepper Motor	Electric motor that is able to move in discrete steps with an accuracy from 0.3-7.5 degrees. This accuracy is very important in our 3-D printer. Has torque of up to 10’s of feet per pound giving enough force to lift up and hold the powder. Is able to keep position between steps which is very important so the laser can print in the powder layer by layer.
Brushless DC Motor	High speed motor but has a low torque and platforms need a low speed moderate torque in

	order to hold the powder. Low wear and low noise, which is good so parts do not need replacement often and low noise is also important as it will be used in an office setting.
Permanent Magnet DC Motor	Moderate speed and has long life brushes so does not need replacement often. Moderate torque up to 50 pound per feet, which is enough to lift powder. Provides accurate positioning so the platform can be controlled.
Universal Motor	Provides good speed control although does not allow for accurate positioning, which is needed. Parts wear frequently and need replacement often.
Brushed DC Motor	Has high speed but not accurate positioning, and also wears easily so brushes need to be replaced. Very similar to universal but has simpler parts.

After analyzing the motors, the stepper motor will be used to power the build platform and the powder platform. As mentioned in the specifications the build platform needs “to produce a dimensional accuracy of ± 0.05mm” and the stepper motor will provide this greatest accuracy. Furthermore, the stepper motor can hold position which is important for both the build and powder platform as they need to be held at different levels and not constantly be in motion. The stepper motor also has a moderate torque which is needed to hold and lift the powder on both platforms. As mentioned in the specifications the stepper motors will run off of a 120 V power source.

Axis Choice

The axes coordinate system is a crucial consideration that must be made when designing a 3D printer. The axes system ultimately determines the mobility of the 3D printer which will have a direct effect on how 3D prints will be created.

In 3D SLS printers, the laser will outline and capture the details in each cross sectional layer. Once each cross section is completed, the build platform will be lowered enabling fresh powder to be released on top of the previous layer, enabling the laser to sinter new powder [14].

Table 7: The following table suggests some candidate axes system that may be implemented in 3D printer along with corresponding analysis

Candidate Coordinate System	**Analysis of Coordinate System**
Cartesian Coordinate System	Cartesian coordinates 3D printers outline and capture each cross section by moving rectangular in orthogonal x and y axes before the build platform moves downward in the z direction [14]. Cartesian coordinates are the most frequently found and simplified 3D printer axis system [14]. As a result, the cartesian coordinate printer system minimizes cost enabling the target price range of $8000-$10000 to be attained.
Polar Coordinate System	Polar coordinate printers move the laser with reference to one dimension and one angle and are known to produce effective circular prints [14]. Polar coordinate 3D printers are power efficient which will enable low power consumption, however, they are also limited

	on the market which may drive costs to accommodate printers of this nature [14]. Polar coordinates are compact which may enable the printer to not exceed the dimensions of 750mmx750mmx650mm [15].
Delta Coordinate System	The delta coordinated printers move the lazer within the plane of the build platform moves position in relation to an angle [14]. Most feasible for printing circular parts and features [14], [15]. Delta coordinates are associated with high speeds which will enable the requirement of 10 mm/hr in the z direction to be fulfilled and lead to fast print times [14], [15]. Delta coordinated 3D printer are less accurate which may lead to challenges in fulfilling a precision level of $+/-$ 0.05mm [14]. To continue, delta coordinate system printers are more complex than cartesian coordinates printers [14], [15]. This may cause more parts to be added to accommodate for the coordinate system which will lead to an increase in cost and increase the potential for wearing parts within the printer.

Overall, after analyzing potential candidate axes systems, our printer will implement a cartesian coordinate system which operates in 3 orthogonal directions. The implementation of a cartesian coordinate system will enable the 3D printer to achieve an accuracy of +/- 0.05mm and obtain layer heights in the range of 75-150 microcrons. To continue, a cartesian coordinate system will be able to maintain desired speeds and minimize costs since the concept of cartesian coordinates 3D printers are highly standardized [14].

Secondary Mechanisms (Fasteners/Bolts/shafts/bearings/mountings)

Table 8: Other part justifications

Part [16]	**Justification**
2423K410_HIGH-PRECISION STEEL NEEDLE-ROLLER BEARING	Need a small bearing to fit into the design of the laser holder. These bearings have a high accuracy as well for positioning of the laser.
23915T84_TAPERED-ROLLER BEARING	A tapered roller bear is required for the design of the laser holder for two reasons. One, a bearing is needed to facilitate rotation of the shaft rotating the laser and two because this bearing is placed vertically in this assembly.
2342K166_PERMANENTLY LUBRICATED BALL BEARING	No need for lubrication. The lubricants prevent dust and water from entering the part, therefore the part has a longer lifespan. This part is used to support and facilitate movement of the timing belt pulleys.
92453A130_BRASS DECORATIVE ROUND HEAD SLOTTED SCREW	Screws will be implemented to reinforce and join mechanisms together within the assemblies.
91251A344_BLACK-OXIDE ALLOY STEEL SOCKET HEAD CAP SCREW	Screws will be implemented to reinforce and join mechanisms together within the assemblies.

6211K759_NFPA TIE ROD AIR CYLINDER Shorter	It should be noted that in the 3D-printer a hydraulic cylinder will be used while this is only used in the model as a representation of size in the 3D-printer model (this model is an air cylinder). A hydraulic cylinder was chosen over an air cylinder because hydraulic fluid is less compressible than air, meaning the hydraulic cylinder has higher positional accuracy.
92949A451 - 18-8 Stainless Steel Button Head Hex Drive Screw	Screws will be implemented to reinforce and join mechanisms together within the assemblies.
92453A124 - Brass Decorative Round Head Slotted Screw	Screws will be implemented to reinforce and join mechanisms together within the assemblies.
7917N64_HIGH-CYCLE LOW-PROFILE BALL BEARING CARRIAGE	Linear guide rails are used in the design to constrain and support motion in a linear direction. This is important for moving the rigid follower to spread powder and moving the platforms up and down.
7917N180_ HI-CYCLE LOW-PROFILE BALL BEARING CARRIAGE	These carriages are used to attach parts to the linear guide rails for movement.

All above parts are taken from McMaster-Carr and their downloadable part models are used in the Solidworks assembly of the 3D-printer.

Additional Considerations

The printer will have a touchpad with graphics to make the training process for employees quicker and make the user interface interactive. The printer will support ethernet and/or wifi connections making it easier for users to print parts/designs remotely. The Wifi setup will be easy due to the user friendly UIUX.

Cost Analysis of Design

Our design has implemented various cost saving measures to ensure the 3D printer does not come over our estimated budget. The extensive use of standardized parts such as bearings and bolts helps reduce cost as these do not need to be specifically built for our usage thus can be bought from manufacturers existing stock. Furthermore, the use of materials that are easy to source and readily in abundance such as high density polyethylene sheets for the outer casing and aluminum for the powder and build platform containers help keep costs down. Relatively expensive parts such the laser being used were unavoidable due to its necessity in the design and lack of cheaper alternatives that can satisfy our requirements. The abilities which individual parts could achieve were always weighed against the cost of such material and thus the optimum parts/materials were chosen. In some situations less complex and thus cheaper parts were chosen to be used as this not only reduced the overall cost of the printer but aided in not over complicating the design. Below you will find the costs of some components used in our 3D printer:

Table 9: Estimated Cost for Parts [16]

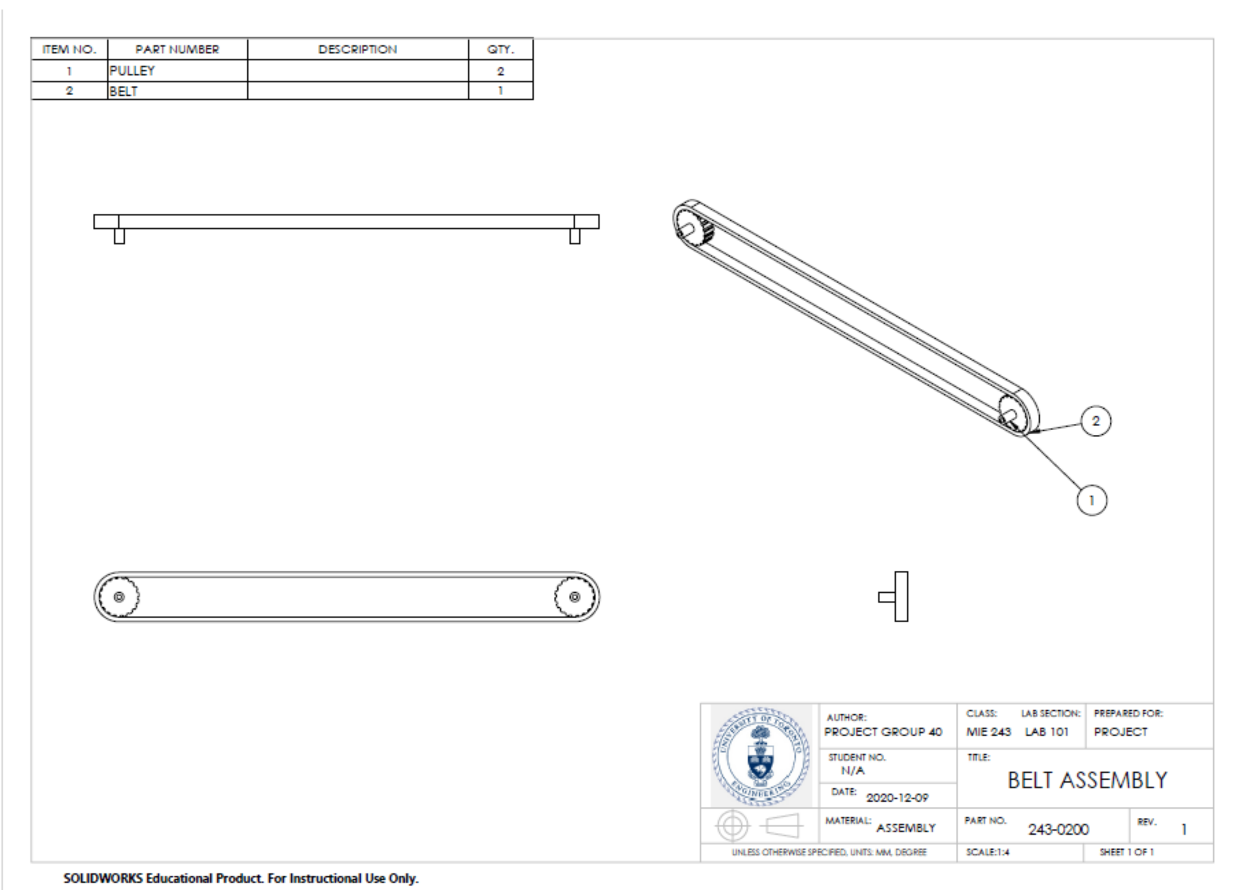
Part	**Cost (USD)**
Stepper motor	~$1200 (for three)
Outer casing	~$500
Actuators	~$500
Laser	~$1000
Bearings	$91.26
Screws	$33.33
Scissor lift	~$300 each (two used)

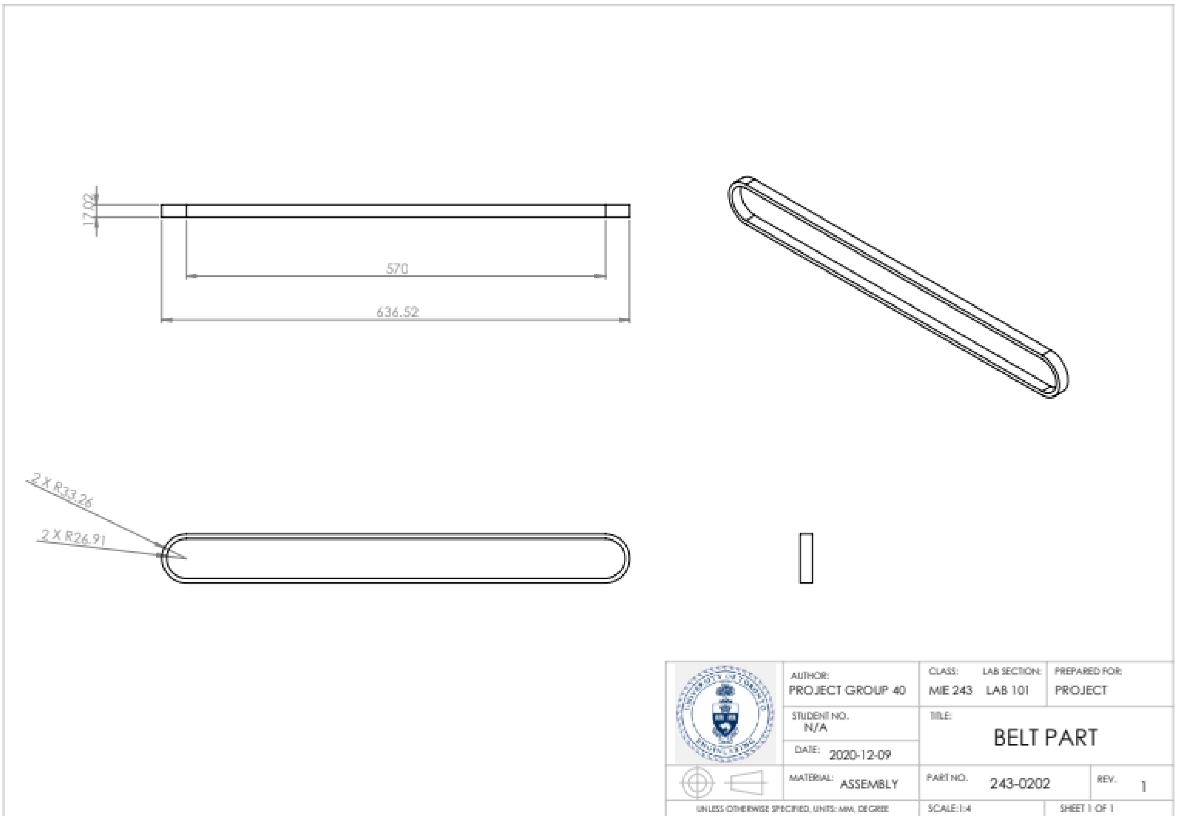
Timing Belt	$62.63
Platform	~$400
Guide Rails	$1638.00 (for ten)
Carriages for Guide Rails	$471.14 (for six)
Hydraulic Cylinder	$600 each (two used)
Pump for Hydraulic Cylinder	~$600 (for two)

Total: **$8,296.36**

Prices with a ~ in front of them represent prices which are estimated without reference to McMaster-Carr prices.

Drawings





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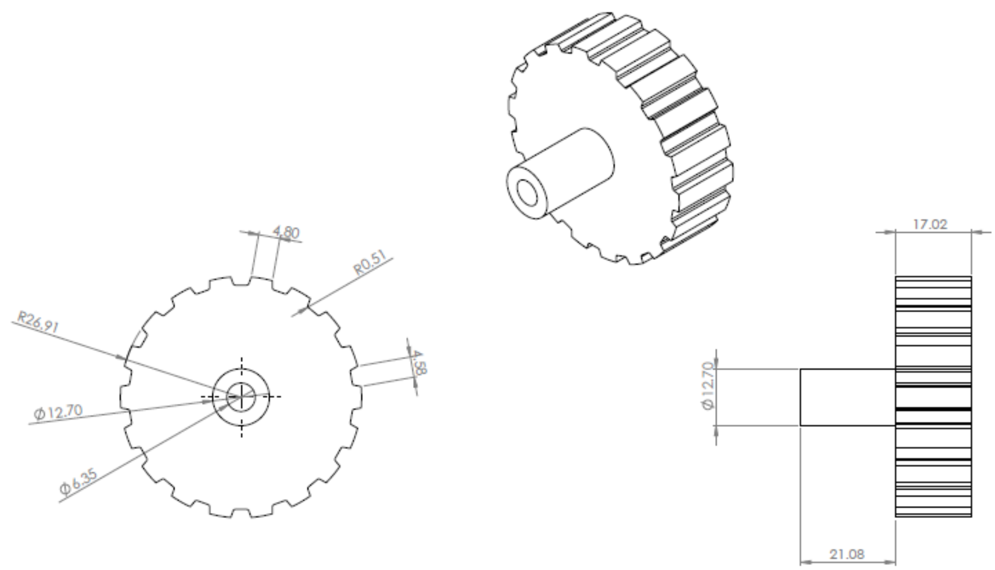
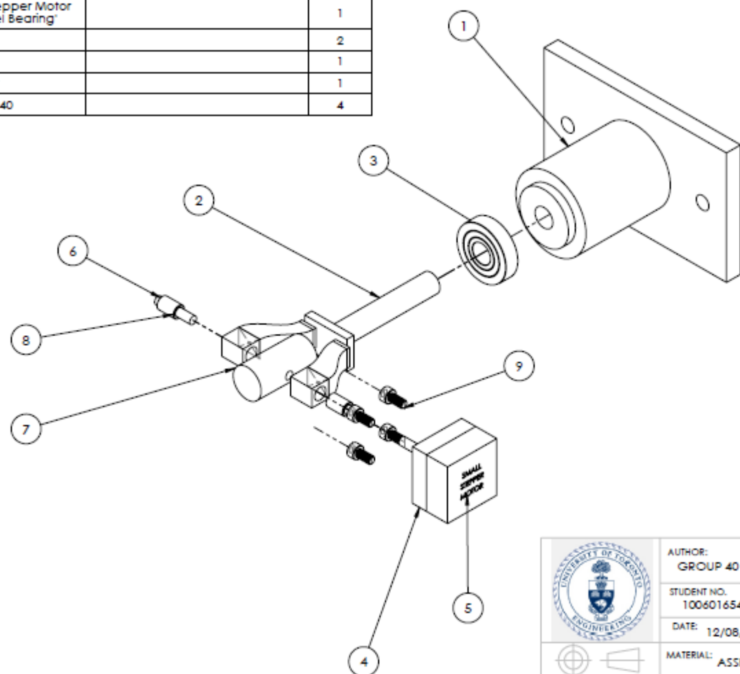
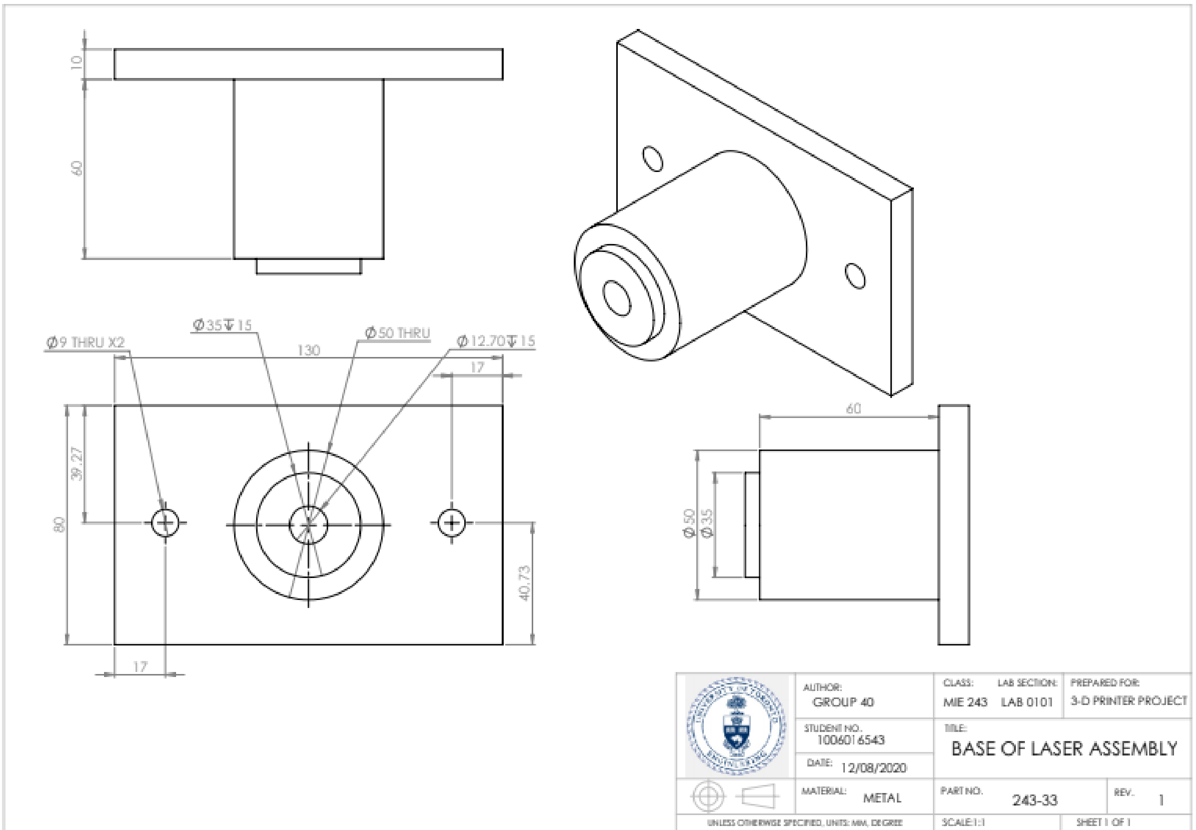


AUTHOR: PROJECT GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 101	PREPARED FOR: PROJECT GROUP 40
STUDENT NO. N/A	TITLE: PULLEY		
DATE: 2020-12-08			
MATERIAL: METAL	PART NO. 243-008-030		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:3:2	SHEET 1 OF 1	

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base of Laser Assembly		1
2	Laser Holder		1
3	23915T84		1
4	Swivel Bearing Electric Motor Holder		1
5	Small Stepper Motor for Swivel Bearing'		1
6	2423K41		2
7	Laser		1
8	Cylinder		1
9	91251A340		4



AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: LASER ASSEMBLY		
DATE: 12/08/2020			
MATERIAL: ASSEMBLY	PART NO. 243-30		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:2:3		SHEET 1 OF 1



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60
Ø9 THRU X2
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Ø50 THRU
Ø12.70 ↧ 15
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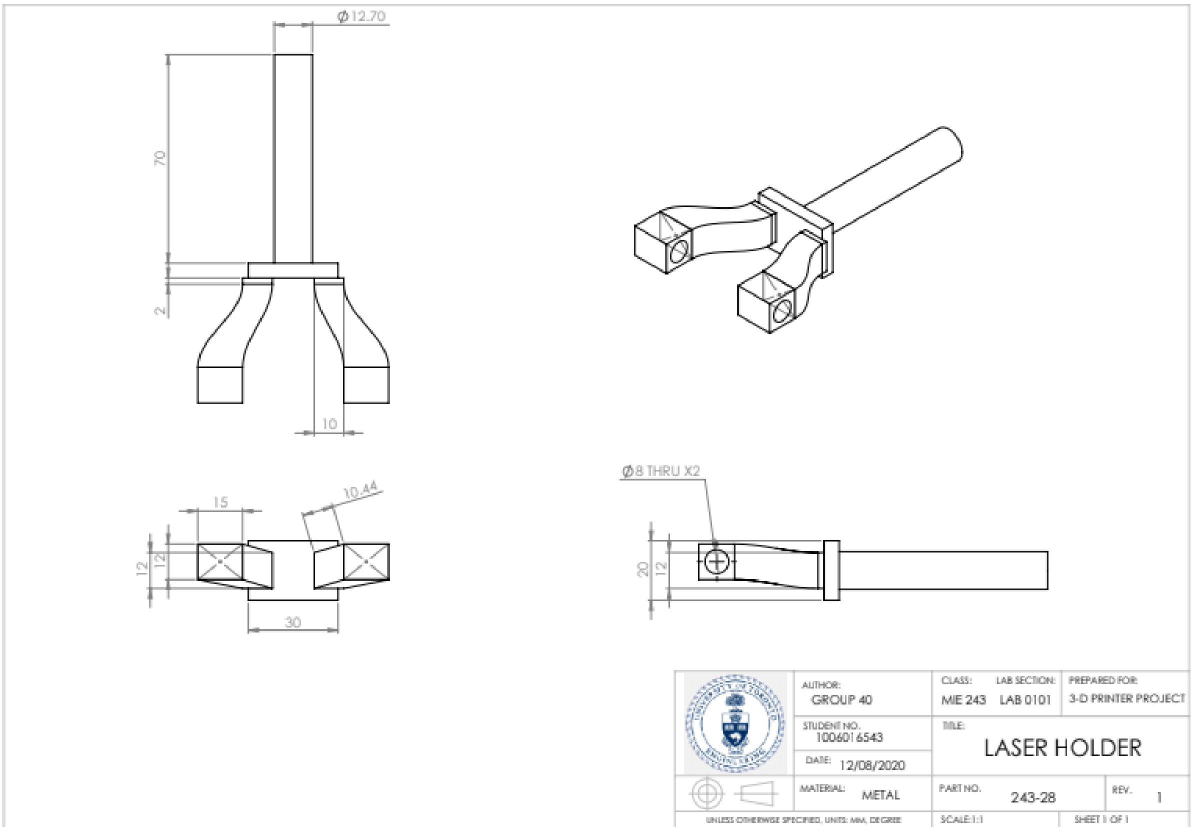
Ø35
AUTHOR:
GROUP 40
STUDENT NO.
1006016543
DATE: 12/08/2020
CLASS: MIE 243
LAB SECTION: LAB 0101
PREPARED FOR: 3-D PRINTER PROJECT
TITLE:
BASE OF LASER ASSEMBLY
MATERIAL: METAL
PART NO. 243-33
REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE
SCALE:1:1
SHEET 1 OF 1



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Ø8 THRU X2
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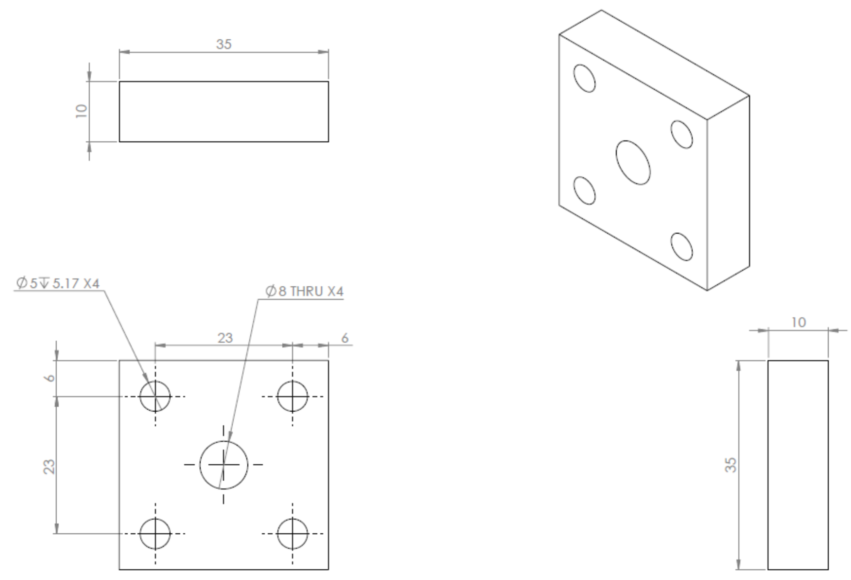
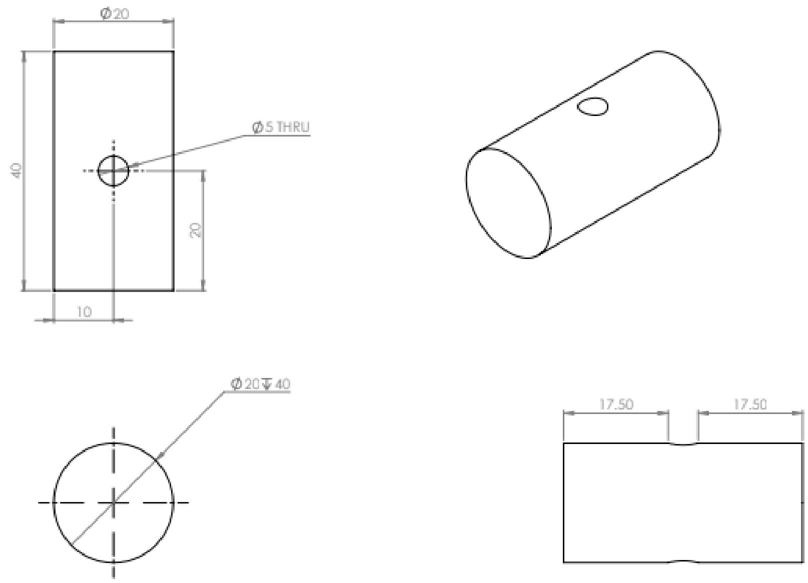
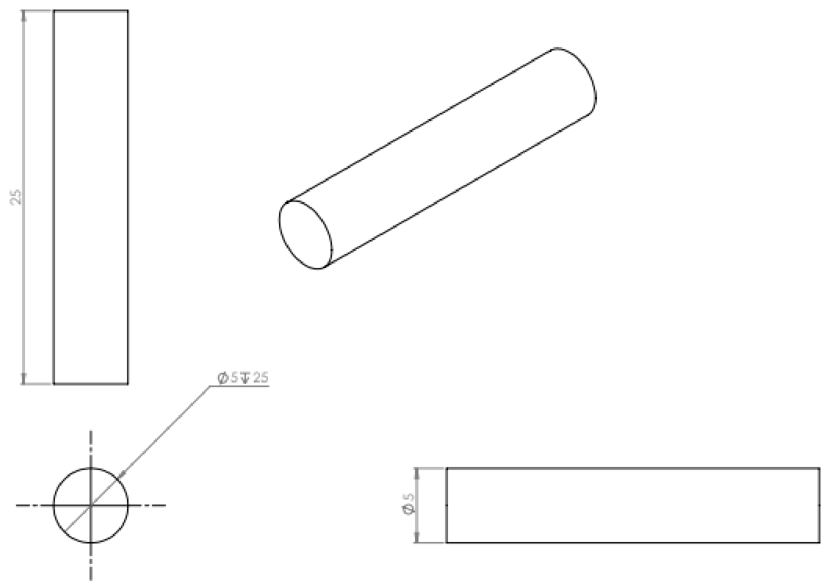
AUTHOR:
GROUP 40
STUDENT NO.
1006016543
DATE: 12/08/2020
CLASS:
MIE 243
LAB SECTION:
LAB 0101
PREPARED FOR:
3-D PRINTER PROJECT
TITLE:
LASER HOLDER
MATERIAL:
METAL
PART NO.
243-28
REV.
1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE
SCALE:1:1
SHEET 1 OF 1



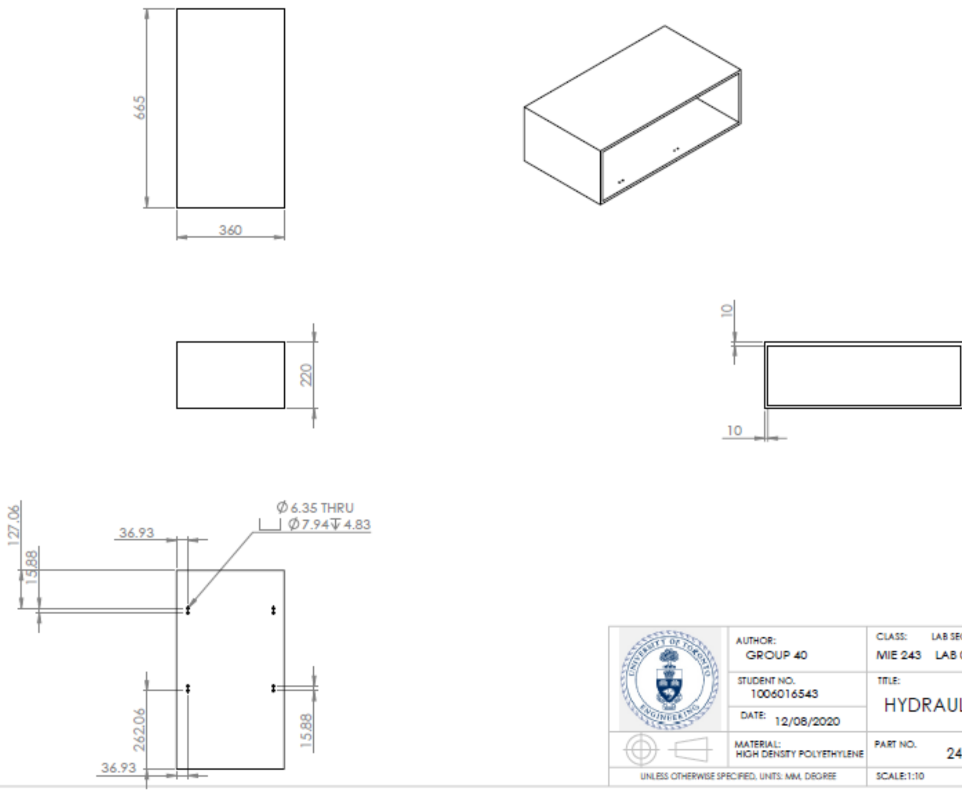
AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: MOTOR HOLDER		
DATE: 12/08/2020			
MATERIAL: METAL	PART NO. 243-35		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:2:1	SHEET 1 OF 1	



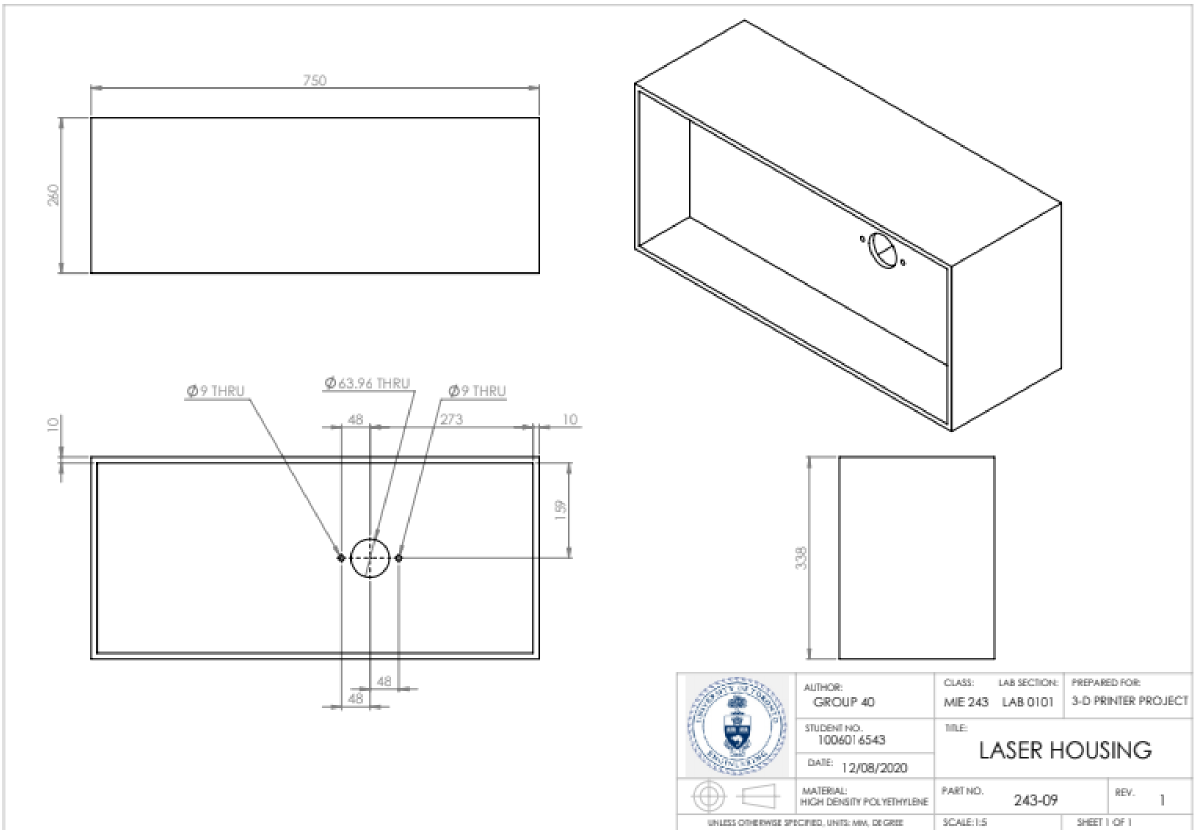
AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: LASER		
DATE: 12/08/2020			
MATERIAL: METAL	PART NO. 243-39		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:2:1	SHEET 1 OF 1	



	AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
	STUDENT NO. 1006016543	TITLE: CYLINDER		
	DATE: 12/08/2020			
	MATERIAL: METAL	PART NO. 243-41		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE		SCALE:5:1	SHEET 1 OF 1	



AUTHOR: GROUP 40	CLASS: MIE 243 / LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: HYDRAULICS CONTAINER	
DATE: 12/08/2020		
MATERIAL: HIGH DENSITY POLYETHYLENE	PART NO. 243-10	REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:10	SHEET 1 OF 1



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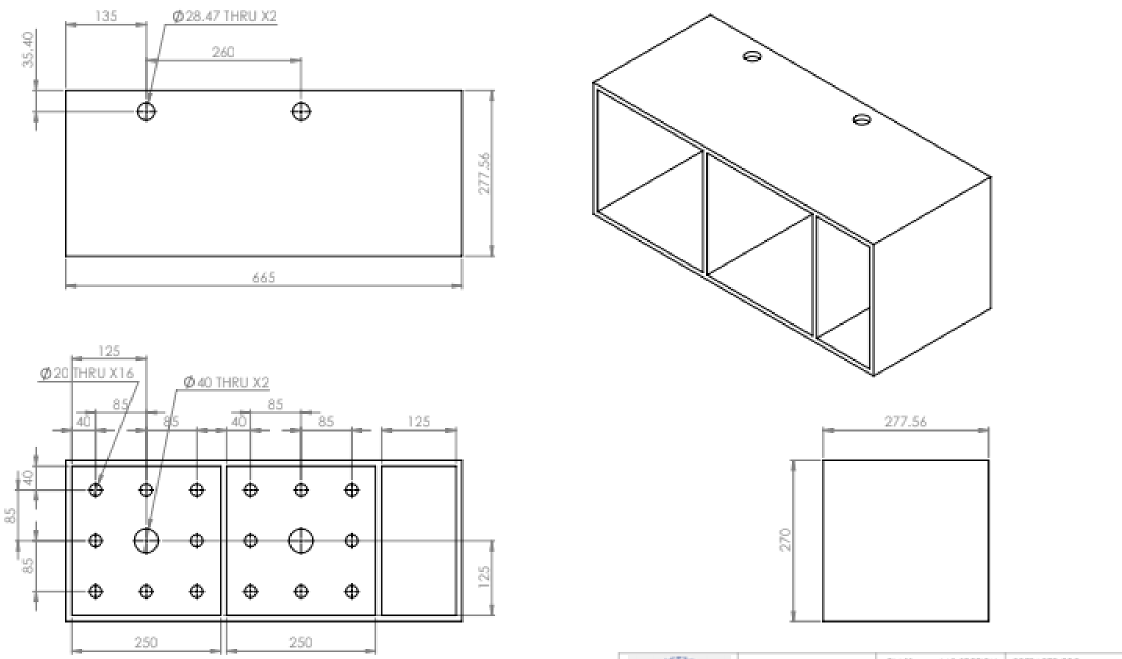
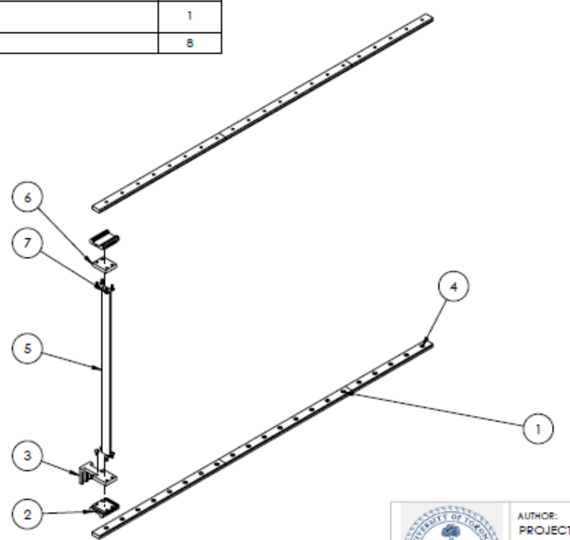
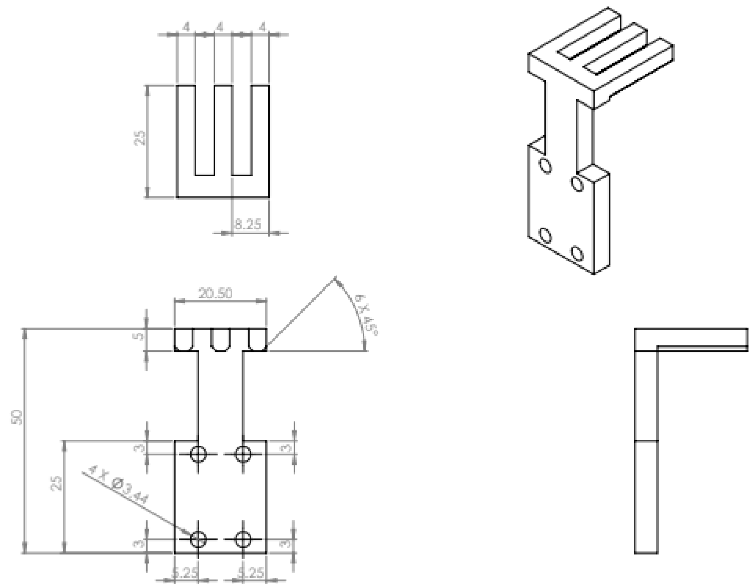


AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: BASE BOX		
DATE: 12/08/2020			
MATERIAL: HIGH DENSITY POLYETHYLENE	PART NO. 243-11		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:5		SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	7917N64	Guide Rail for High-Cycle Low-Profile Ball Bearing Carriage	4
2	7917N18	High-Cycle Low-Profile Ball Bearing Carriage	2
3	Attachment to Timing Belt		1
4	7917N64	Guide Rail for High-Cycle Low-Profile Ball Bearing Carriage	2
5	Rigid Follower		1
6	Attachment to Rail for Rigid Follower		1
7	92453A124		8



AUTHOR: PROJECT GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 101	PREPARED FOR: PROJECT
STUDENT NO. N/A	TITLE: RIGID FOLLOWER ASSEMBLY		
DATE: 2020-12-09			
MATERIAL: ASSEMBLY	PART NO. 243-0500		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:4		SHEET 1 OF 1



AUTHOR: PROJECT GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 101	PREPARED FOR: PROJECT	
STUDENT NO. N/A	TITLE: ATTACHMENT TO TIMING BELT			
DATE: 2017-10-06				
MATERIAL: ALUMINUM	PART NO. 243-0501			REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:3:2		SHEET 1 OF 1	

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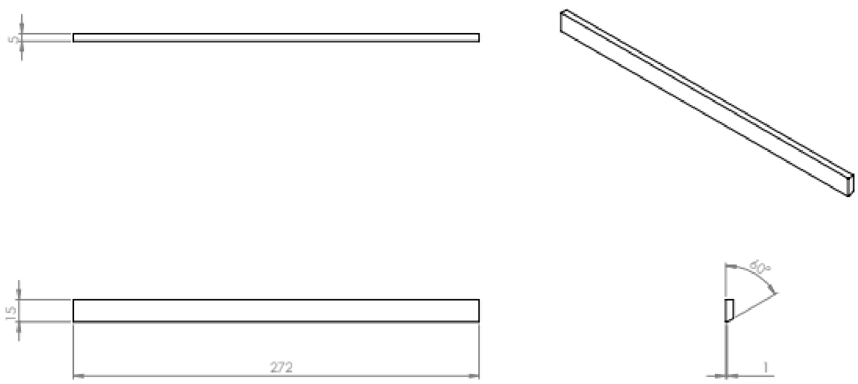
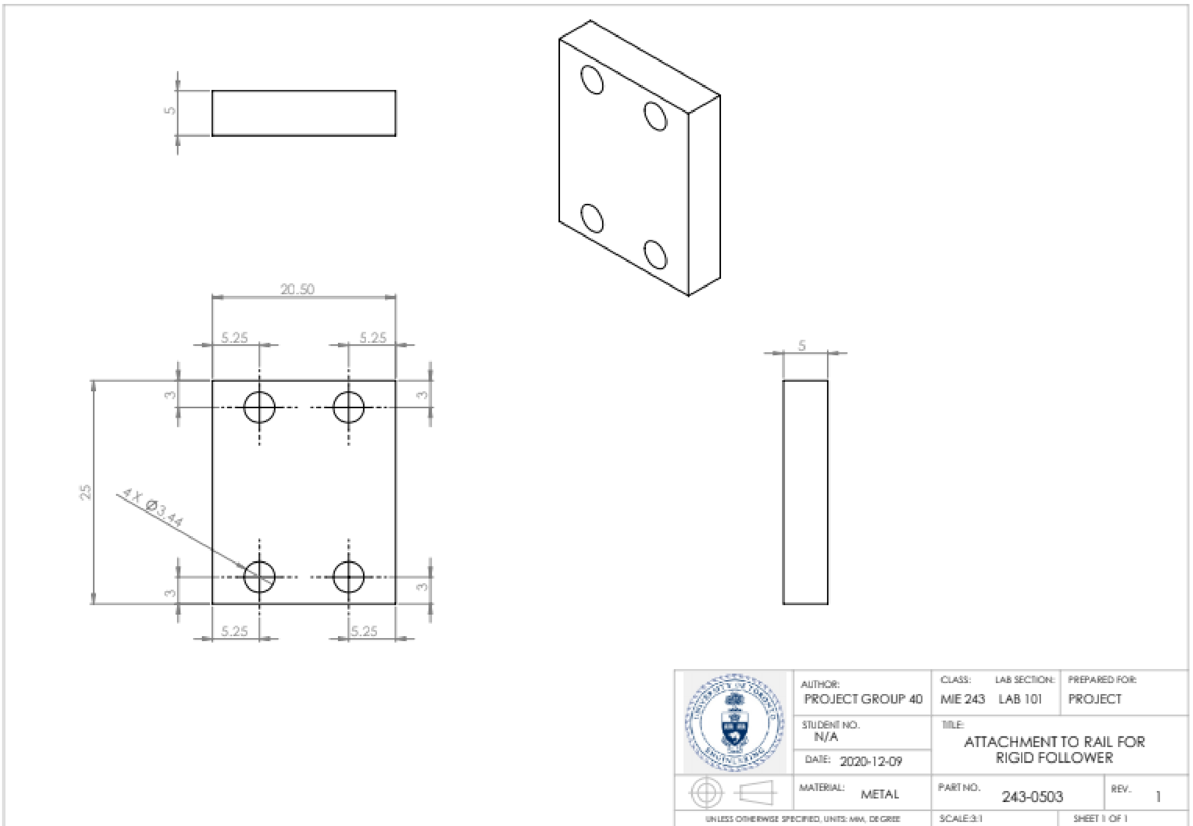


	AUTHOR: PROJECT GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 101	PREPARED FOR: PROJECT
	STUDENT NO. N/A	TITLE: RIGID FOLLOWER		
	DATE: 2020-12-09			
	MATERIAL: METAL	PART NO. 243-009-022		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE		SCALE:1:2	SHEET 1 OF 1	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AUTHOR:
PROJECT GROUP 40
CLASS:
MIE 243
LAB SECTION:
LAB 101
PREPARED FOR:
PROJECT
STUDENT NO.
N/A
TITLE:
ATTACHMENT TO RAIL FOR RIGID FOLLOWER
DATE: 2020-12-09
MATERIAL:
METAL
PART NO.
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REV.
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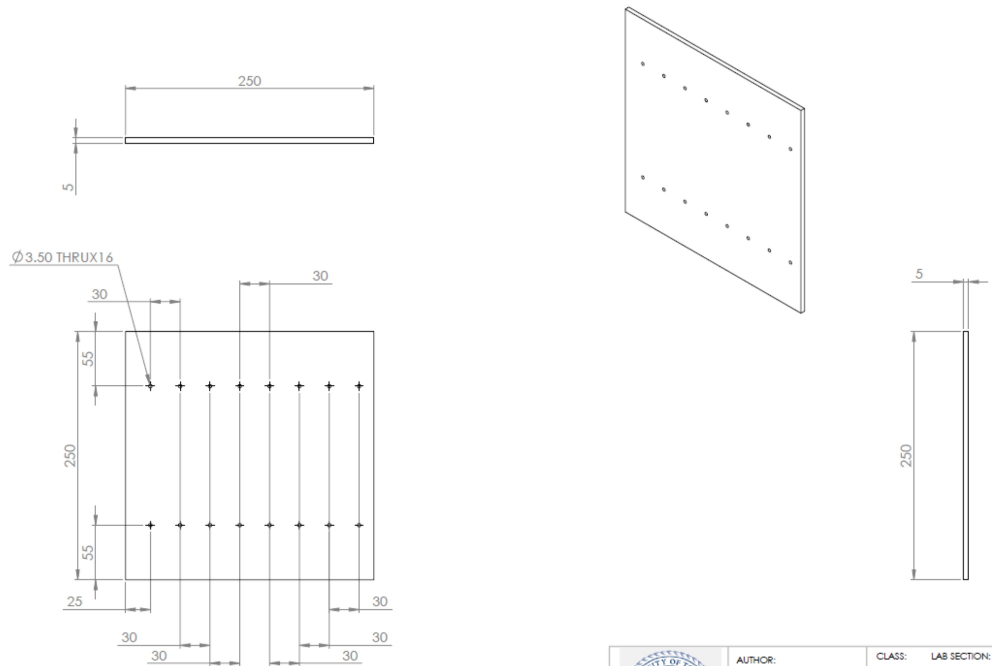
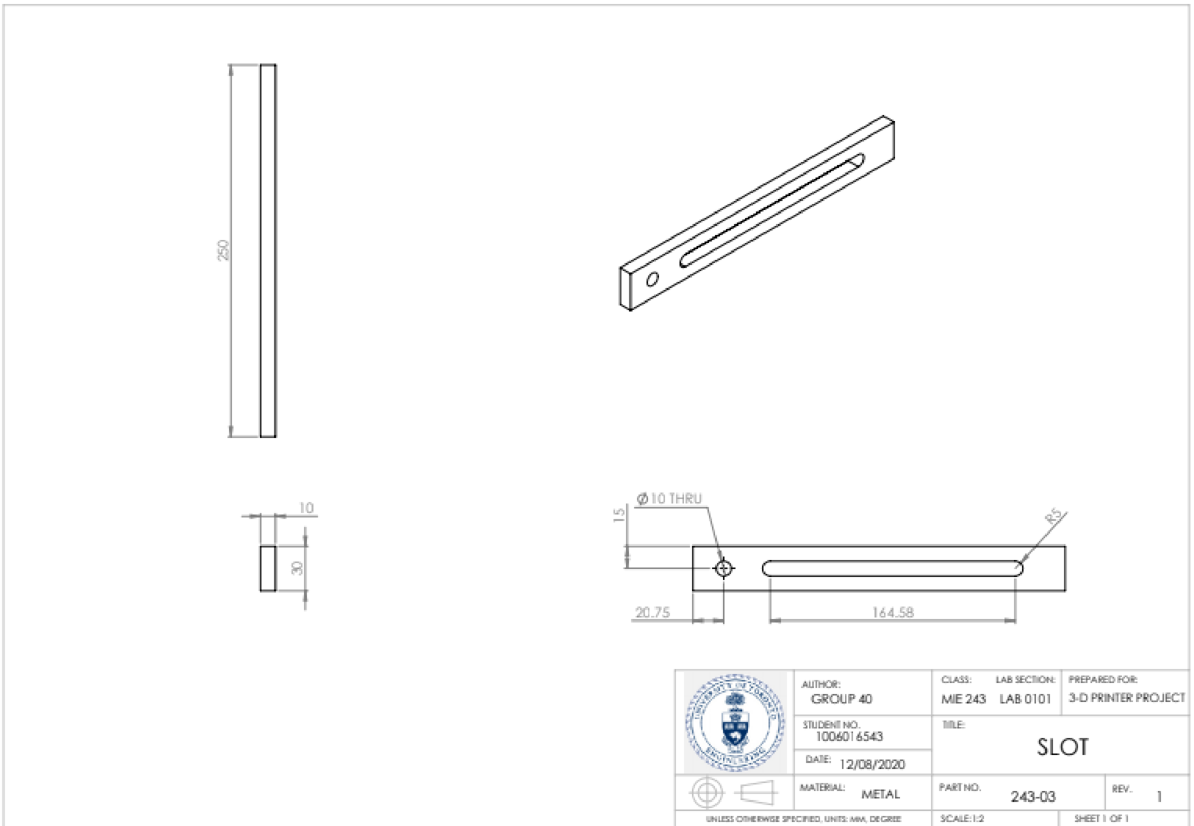
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE
SCALE:3:1
SHEET 1 OF 1



AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: BUILD PLATFORM		
DATE: 12/08/2020			
MATERIAL: METAL	PART NO. 243-35		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:3		SHEET 1 OF 1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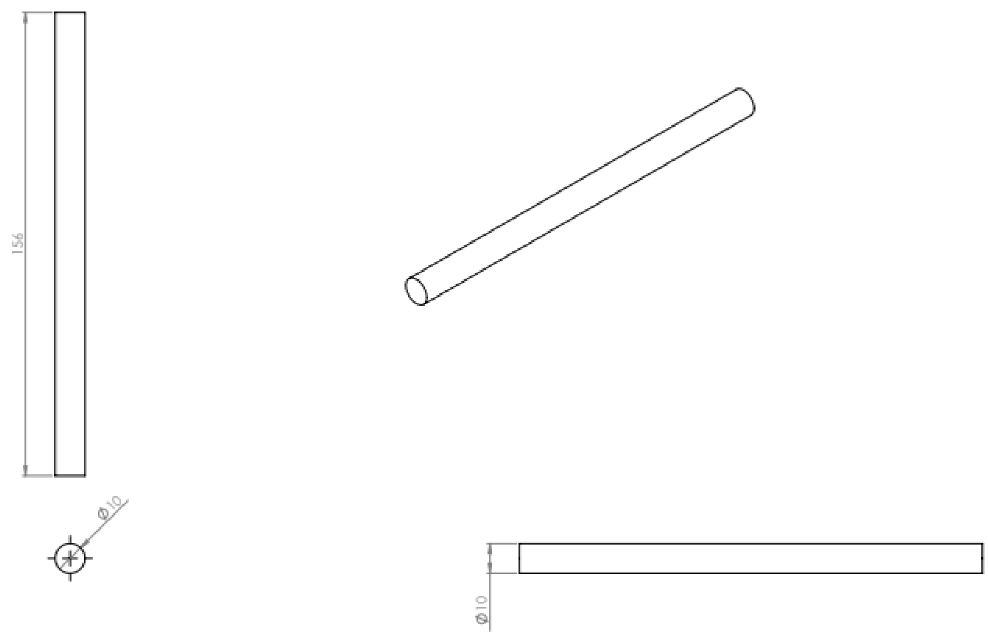
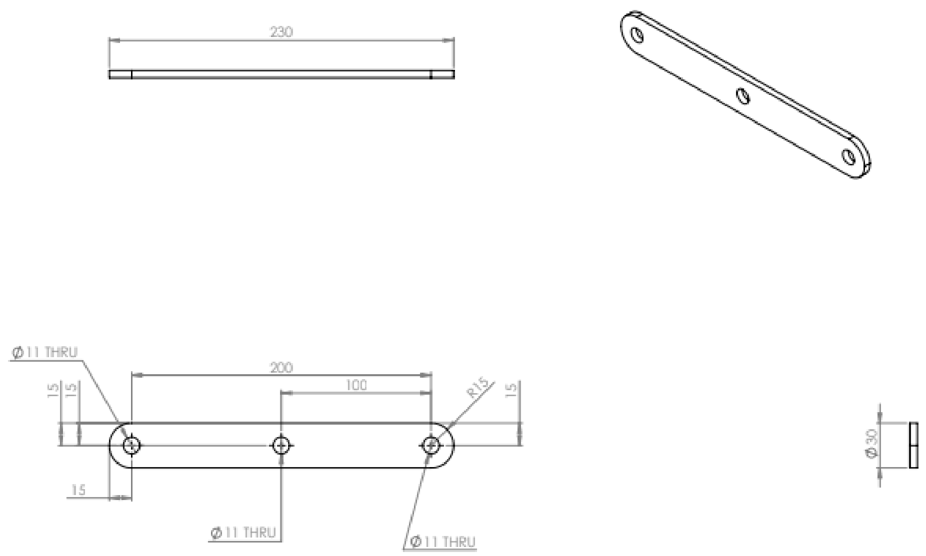
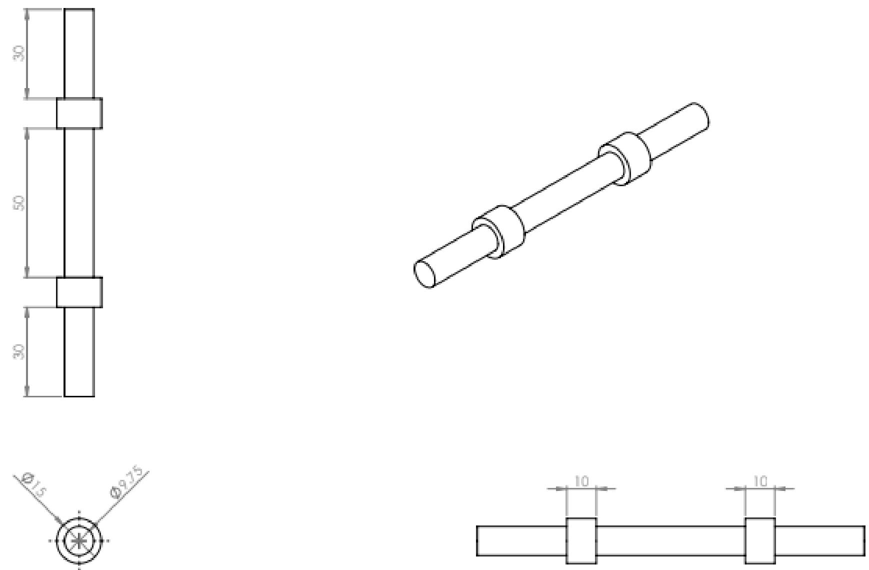
AUTHOR:
GROUP 40
STUDENT NO.
1006016543
DATE: 12/08/2020
CLASS:
MIE 243
LAB SECTION:
LAB 0101
PREPARED FOR:
3-D PRINTER PROJECT
TITLE:
SLOT
MATERIAL:
METAL
PART NO.
243-03
REV.
1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE
SCALE: 1:2
SHEET 1 OF 1



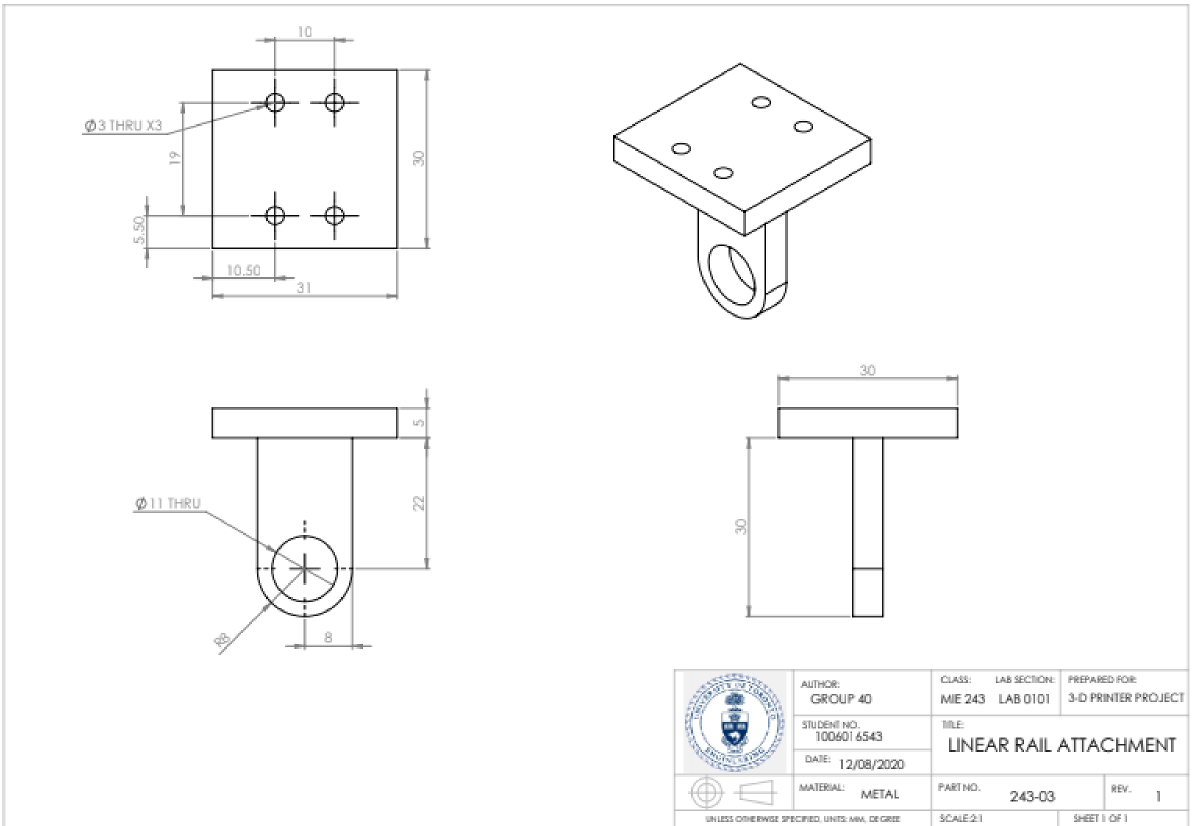
AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT	
STUDENT NO. 1006016543	TITLE: SCISSOR LIFT ATTACHMENT			
DATE: 12/08/2020				
MATERIAL: METAL	PART NO. 243-04		REV. 1	
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:1	SHEET 1 OF 1		



AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT
STUDENT NO. 1006016543	TITLE: SCISSOR LIFT ARMS		
DATE: 12/08/2020			
MATERIAL: METAL	PART NO. 243-05		REV. 1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:2		SHEET 1 OF 1



AUTHOR: GROUP 40	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: 3-D PRINTER PROJECT	
STUDENT NO. 1006016543	TITLE: SCISSOR LIFT SLIDING SHAFT			
DATE: 12/08/2020				
MATERIAL: METAL	PART NO. 243-03		REV. 1	
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE:1:1		SHEET 1 OF 1	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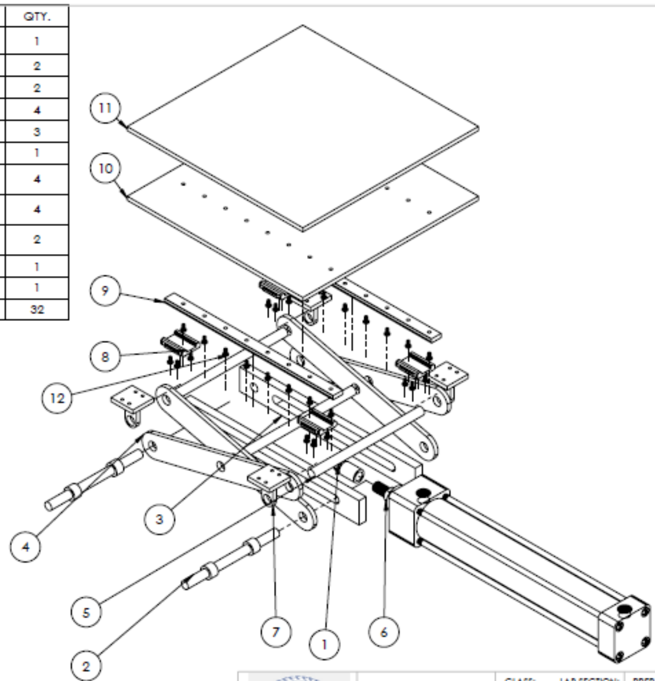
Ø11 THRU
22
R8
8
30
30
AUTHOR:
GROUP 40
STUDENT NO.
100601 6543
DATE: 12/08/2020
CLASS:
MIE 243
LAB SECTION:
LAB 0101
PREPARED FOR:
3-D PRINTER PROJECT
TITLE:
LINEAR RAIL ATTACHMENT
MATERIAL:
METAL
PART NO.
243-03
REV.
1
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE
SCALE:2:1
SHEET 1 OF 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tie Rod Shaft Attachment		1
2	Shaft		2
3	Slot		2
4	Scissor Lift Arms		4
5	Scissor Lift Atachment		3
6	6211K759		1
7	Attachment to Linear Rail Carriage		4
8	7917N18	High-Cycle Low-Profile Ball Bearing Carriage	4
9	7917N64	Guide Rail for High-Cycle Low-Profile Ball Bearing Carriage	2
10	Build Platform		1
11	Build Platform Top		1
12	92453A124		32



AUTHOR: GROUP 40

STUDENT NO. 1006016543

DATE: 12/08/2020

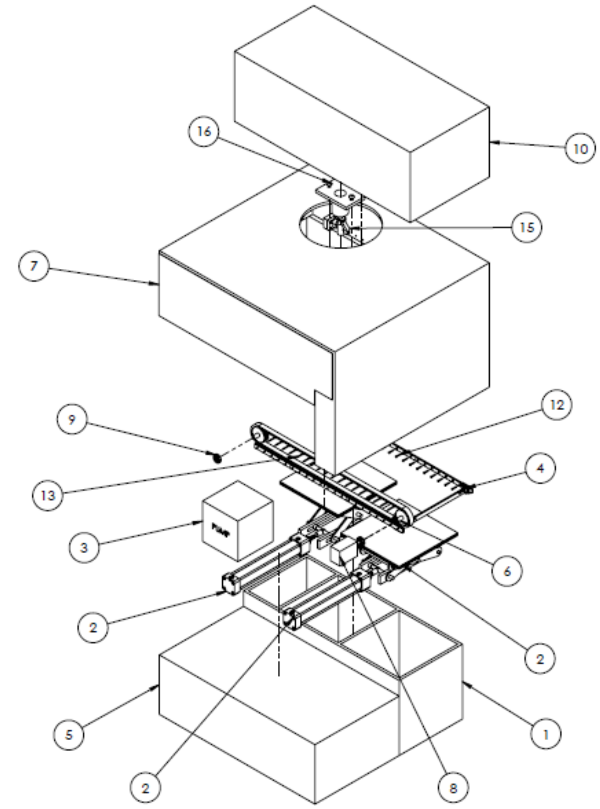
MATERIAL: ASSEMBLY

CLASS: MIE 243 | LAB SECTION: LAB 0101 | PREPARED FOR: 3-D PRINTER PROJECT

TITLE: SCISSOR LIFT ASSEMBLY

PART NO. 243-35 | REV. 1

UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE | SCALE:1:3 | SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Box		1
2	Scissor Lift Assembly		2
3	Representation of Pump		1
4	Rigid Follower Assembly		1
5	Hydraulics Container		1
6	BELT DRIVE		1
7	External Covering and Belt Drive Attachment		1
8	Stepper Motor Model		1
9	2342K166	MCMASTER-CARR	2
10	Laser Housing		1
11	Larger Stepper Motor for Swivel		1
12	92453A130	MCMASTER-CARR	21
13	92453A133	MCMASTER-CARR	21
14	91251A344	MCMASTER-CARR	8
15	Swivel Bearing Assembly		1
16	92949A451	MCMASTER-CARR	2

AUTHOR: NORBERT TANACS	CLASS: MIE 243	LAB SECTION: LAB 0101	PREPARED FOR: FINAL PROJECT
STUDENT NO. 1006020529	TITLE: FULL ASSEMBLY DRAWING		
DATE: 2020-12-09			
MATERIAL: VARIOUS	PART NO. 243-0000	REV. 1	
UNLESS OTHERWISE SPECIFIED, UNITS: MM, DEGREE	SCALE: 1:9	SHEET 1 OF 1	

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