Design 2 - Final Group Report

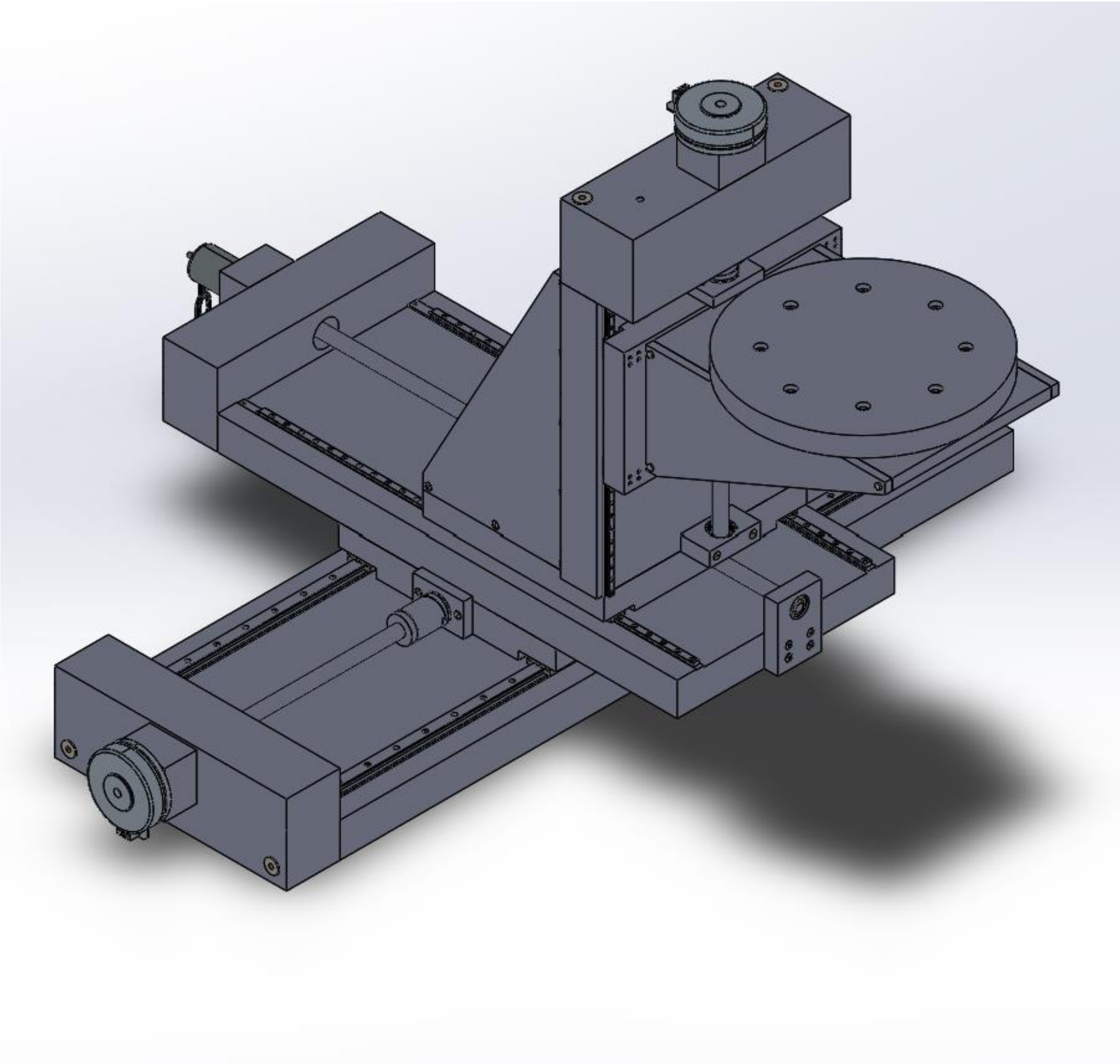

Figure 1 - Overall SolidWorks Model of 3-Axis Positioning System

Group members:

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Kojo Afriyie [redacted]
Mohammad Waseem Suleman [redacted]
Yeo Kiat Wee [redacted]

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Task 5 - Final Designed Assembly

The figures of the overall SolidWorks assembly of the model are presented below, along with the overall dimensions and the footprint of the device. There were also a number of key components which have been highlighted in the device, which are also presented below.

- The required distance of travel in the Z-axis was 150mm, the distance of travel in the Y-axis is 350mm and 600mm was needed in the X-axis. (Figure 2).

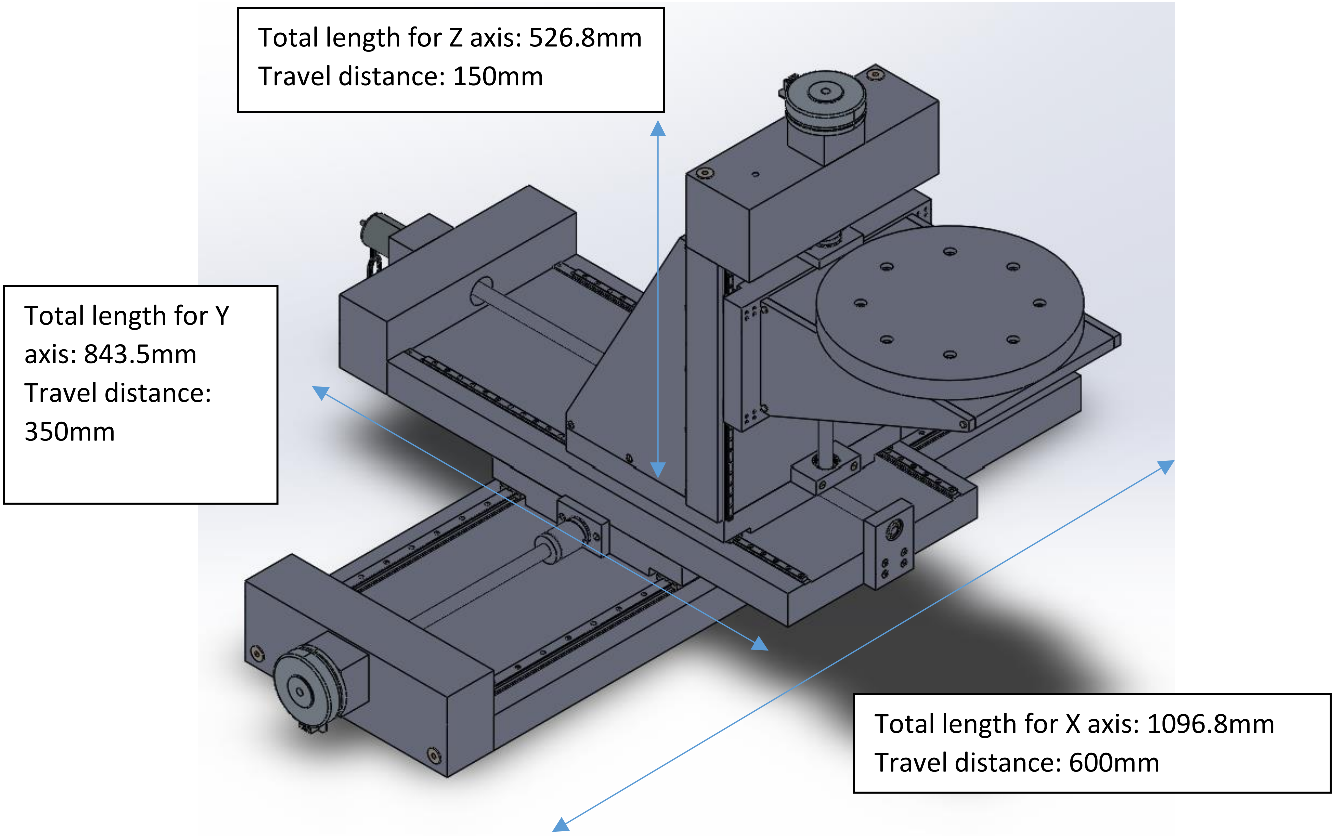

Figure 2 – Overall Assembly with the footprint for each axes

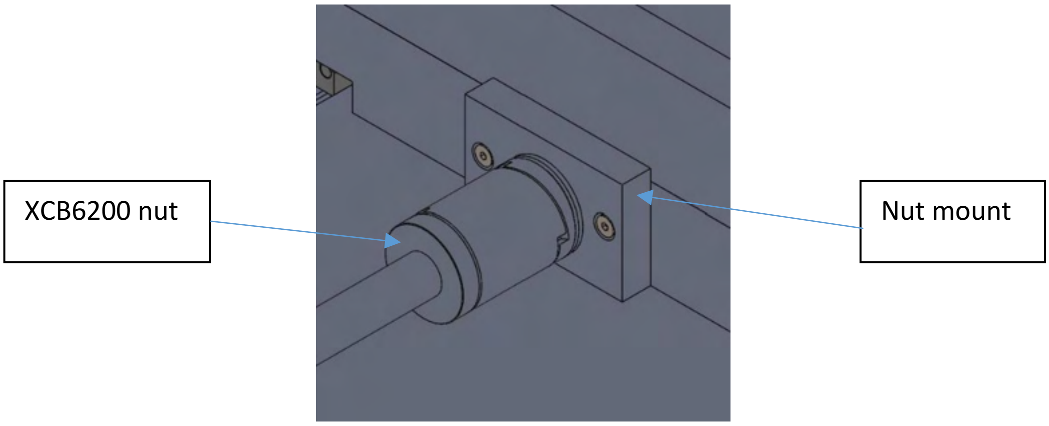

Figure 3 - Nut Mount

- The nut mount that houses the XCB6200 nut is applied as a method to connect the nut to the moving plate. It also functions as a barrier to protect the moving plate from colliding with the side plate. The same nut mount was used across all the axes as a similar nut was used in all three stages (Figure 3).

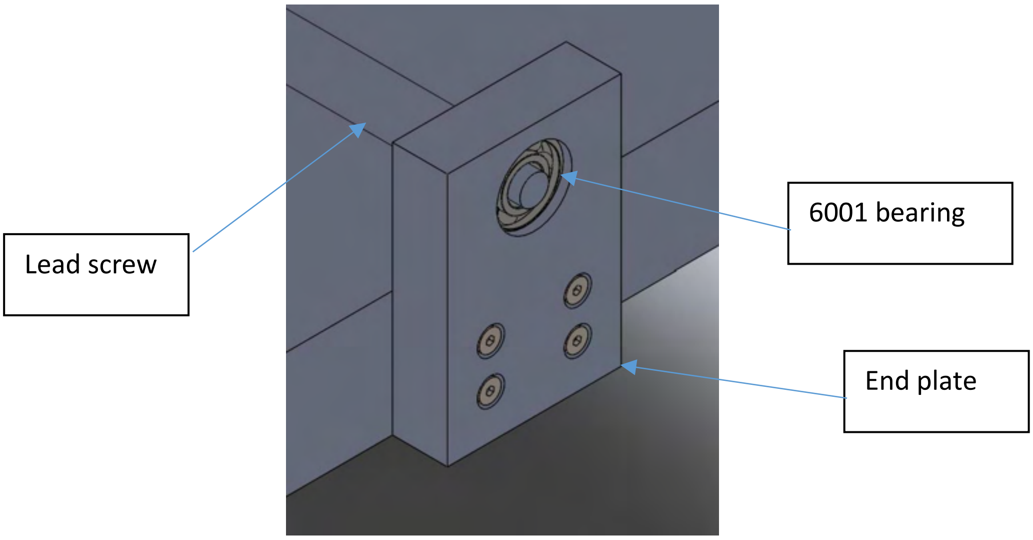

Figure 4 - End plate connected to the baseplate

- To prevent the moving plate from exceeding the required distance of travel, the model includes a small end plate attached to the baseplate which also houses the bearing along with the threaded ring. The reason for this was to provide a barrier that prevents the overrun of the moving plate as well as giving additional support to the lead screw thus reducing the deflection of the lead screw as well as dampening any additional vibrations which may occur due to the free end (Figure 4). Again, this was applied across all axes.

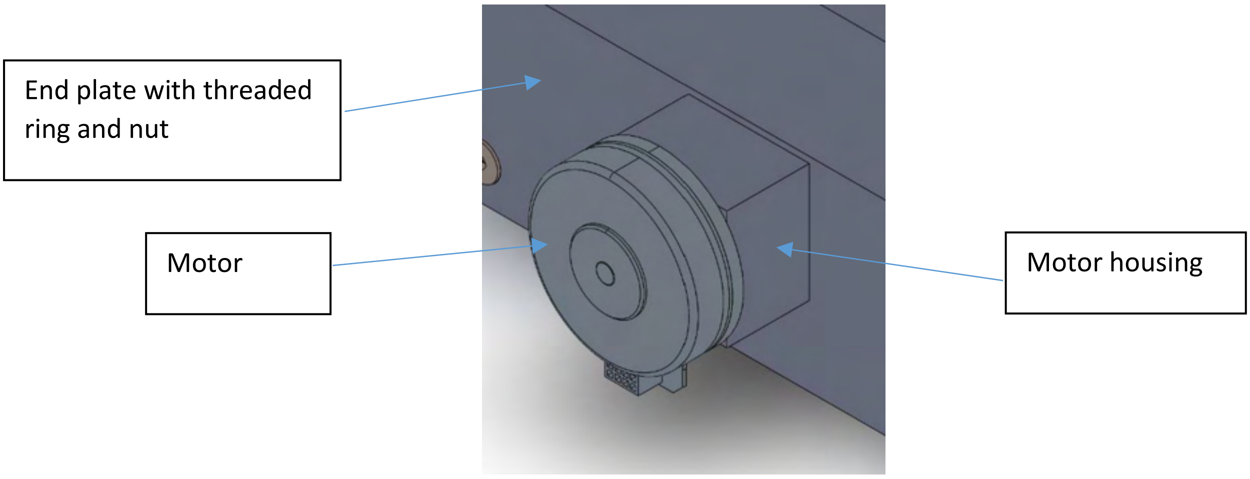

Figure 5 - Housing for the coupler

- Figure 5 shows the housing required to mount the motor onto the side plate. The mount also acts as a safety barrier because the coupler inside will be rotating along with the motor. It allows the motor to be mounted onto the 3-axis positioning system without causing any additional vibrations.

Task 6 - Final design of the Z-axis stage

The figure below shows the overall assembly of the Z-axis stage. All components are labelled.

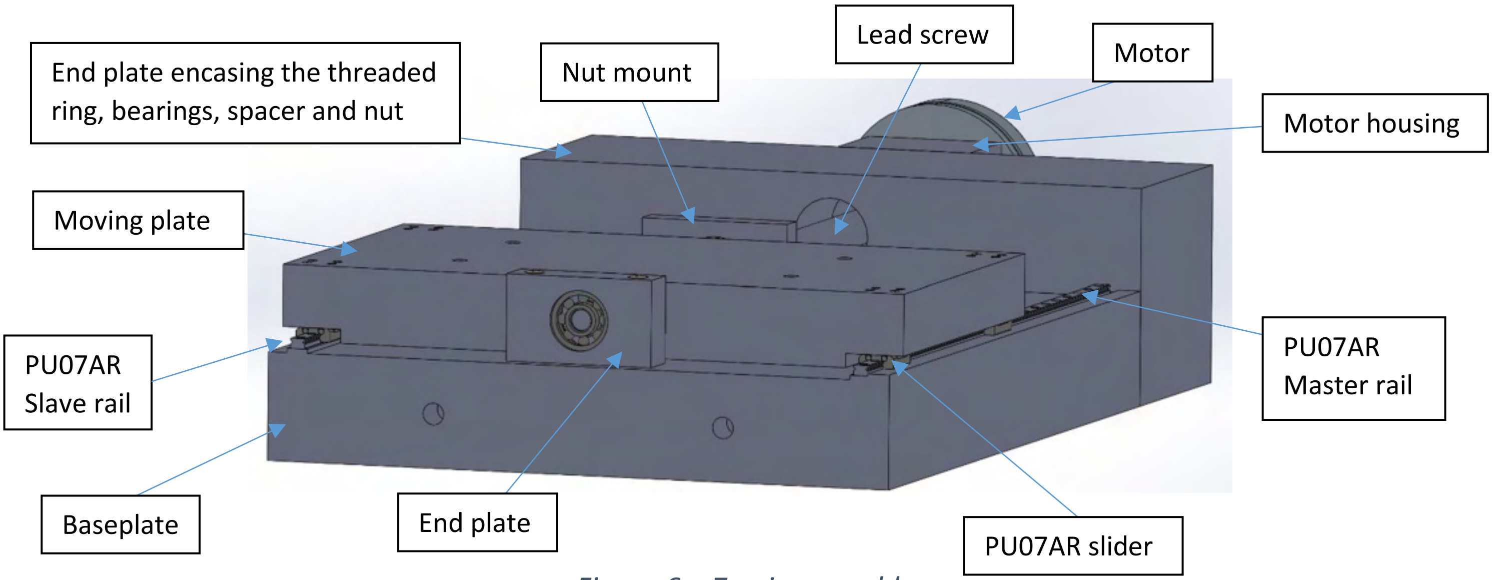

Figure 6 – Z-axis assembly

The figure below shows a cross-sectional view of the Z-axis stage, showcasing the pre-loading arrangements of the components of this stage.

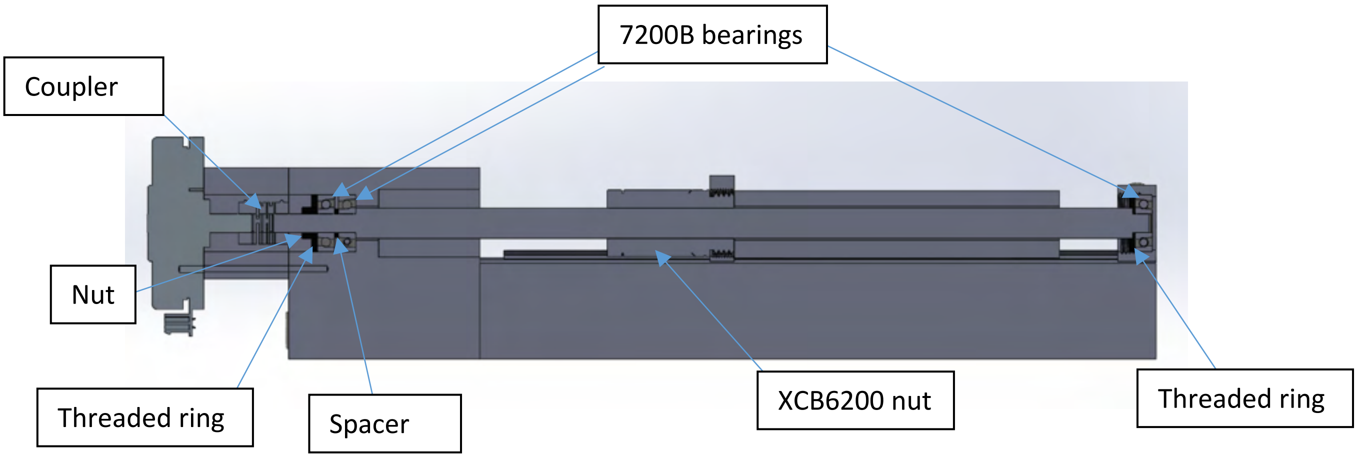

Figure 7 – Z-axis cross sectional view

The operation of the Z-axis stage is controlled using a linear encoder, which gives the machine real-time position feedback, otherwise the machine will not know its positional coordinates and this will hinder its operation. The linear encoder also allows the machine to move in the Z-direction whilst knowing its position within the Z-stage. This allows the work piece to move up or down within a travel range of 150mm. The linear encoder in the figure below sends its data via a cable which goes through a small hole from the top of the Z-axis side plate. (Figure 8).

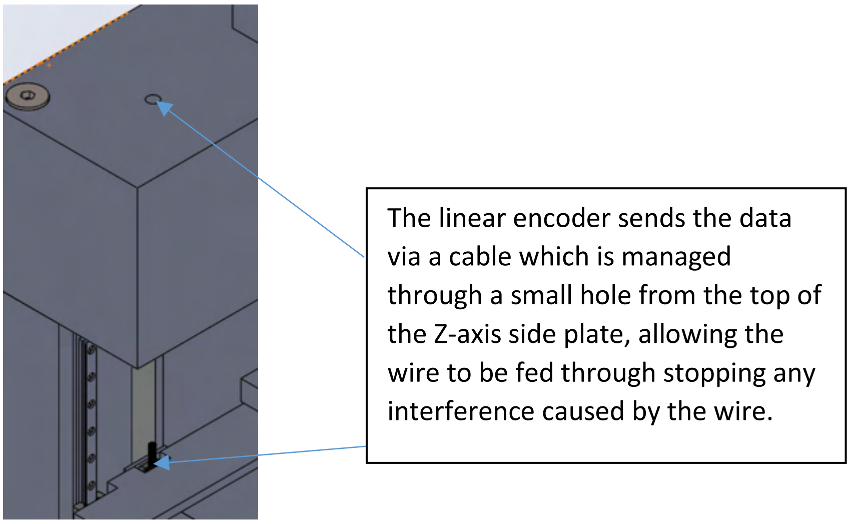

Figure 8 – Linear encoder arrangement with cable management

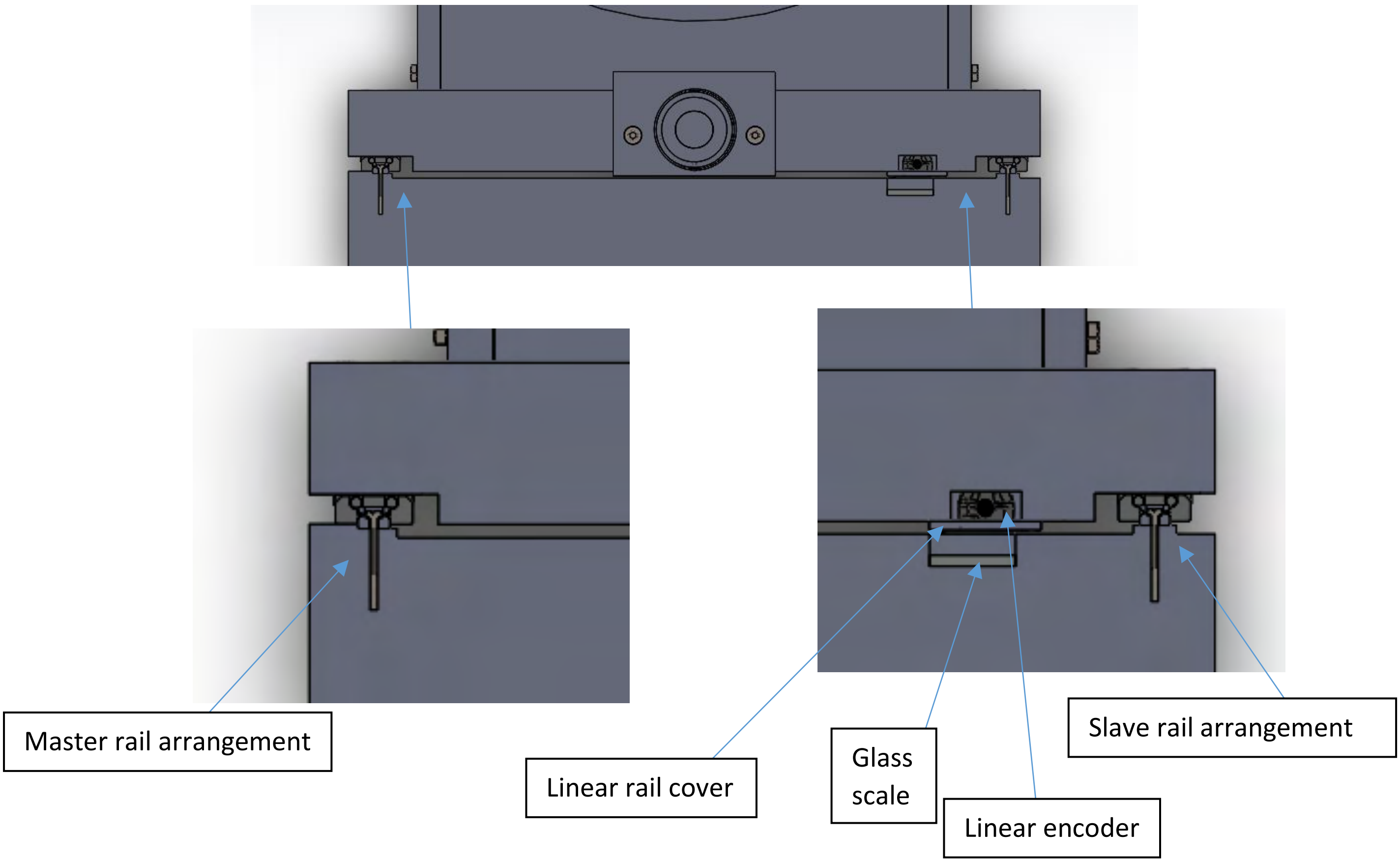

Figure 9 – Cross sectional view of linear rail arrangement

The purpose of the ribs is to reduce any potential deflection in the Z- axis stage which may arise due to moments produced from the work piece as well as increasing the structural integrity of the machine.

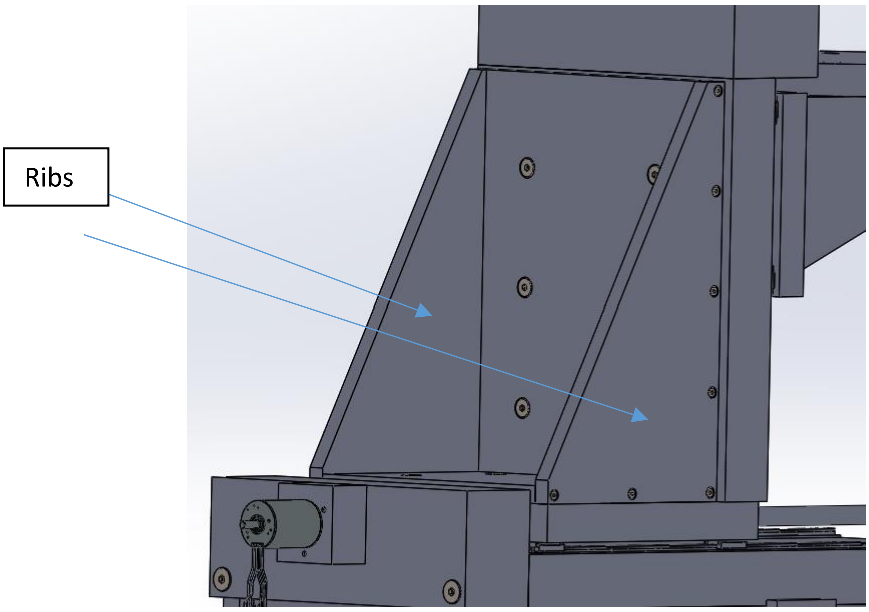

Figure 10 – Z-axis back view

In order to maintain the level of accuracy that the linear encoder can record, two bearings are mounted near the top of the stage as shown in Figure 11 as well as a single bearing arrangement on the opposite end. This is beneficial as it serves to dampen any vibrations which may occur but also allows a much more precise translation within the Z-axis stage allowing the data produced from the linear encoder to be more accurate. The side plate also provides a barrier to avoid the moving plate from exceeding its required travel range. The lead screw is chosen based on calculations produced earlier as well as meeting the design criteria to ensure torque is less than 0.8Nm.

The bearings used in the Z-stage are 7200B, this helps to reduce friction and allows a smoother operation. The bearings are required to be backlashed, this is done by a nut as well as a threaded ring. The nut produces a force on the hub of the bearing as it's threaded onto the lead screw as well as a threaded ring which is threaded to the interior of the Z-axis side plate, producing a force on the periphery of the bearing allowing it to be fixed in place.

The moving plate is moved up and down as it's connected to the XCB6200 nut via a nut mount which is threaded onto the bottom of the nut. The nut mount is fastened onto the moving plate causing the plate to move with the nut. When the lead screw rotates, the nut moves vertically causing the Z-axis moving plate to move accordingly.

The Z-axis side plate has a bore on the underside to allow the XCB6200 to fit inside, this allows the axis to meet its design specification of a travel range of 150mm.

Finally a coupling was used to join the shaft from the motor to the shoulder of the lead screw. The lead screw is milled down to 10mm to match the diameter of the motor shaft. Each shaft is fastened by grub screws on the perimeter of the coupling allowing the lead screw to rotate in sync with the motor shaft.

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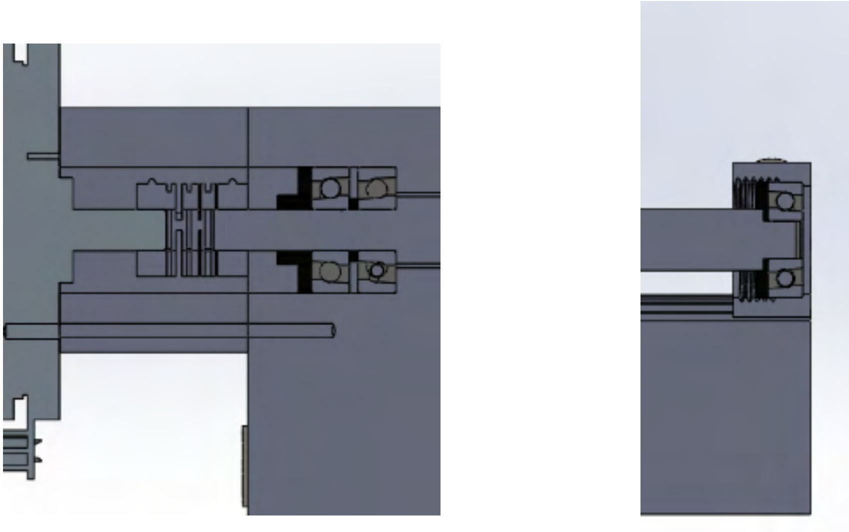


Figure 11 – Zoomed in cross sectional view of bearing arrangement

Task 7 - Selection of DC motors

One of the main tasks for this project was to choose the motor required for each of three axis stages. The main criteria to choose a motor were based upon the torques and angular velocities that were calculated based on the mass of each stage. The motors were chosen from MAXON motors and for such a heavy-duty machine, torque was a very important factor in the performance of the machine. Various factors were considered, such as the estimated linear line which shows the performance of the motor at the required speeds and torque. Another factor to consider is that the maximum torque must be no greater than 0.8Nm as stated in the design brief. The two main factors of speed and torque have an inverse relationship where a lower torque will produce a higher speed, and vice versa. With a torque specification given in the design brief, a motor with a lower RPM is recommended. Furthermore, the line of best fit takes into consideration factors such as stall torque, maximum operating RPM, and the nominal speed and torque point when producing the graph. The choice for the motor is based on the operating point which was calculated earlier. For the Z-axis the torque required is 501mNm with a speed of 375rpm.The motor is selected when the distance from the line of best fit is closets to the operating conditions for each stage, in this case motor number: 244879 is selected. A large distance between the line and required specifications indicates that the motor is too powerful. The operating point must lie underneath the speed-torque curve.

As shown in the graphs below each stage has slightly different operating requirements and to meet these, different motors were analysed and compared with the operating point to select the most suitable motor for each stage. The required torque for the Y-axis stage is 219mNm and a speed of 437.5 rpm and the line closest to the operating point is the motor number: 496656.

The operating conditions for the X-axis stage are: 539mNm of torque and 750 rpm. The motor most suited to the operating point of the X-stage is part number: 244879.As its line of best fit is the closest to the motors operating points as shown in the graphs below.

In order to transfer the torque and rotations from the motor to each corresponding stage a coupling is used. This allows the load to be transferred from one shaft to another linking the motor to the lead screw.

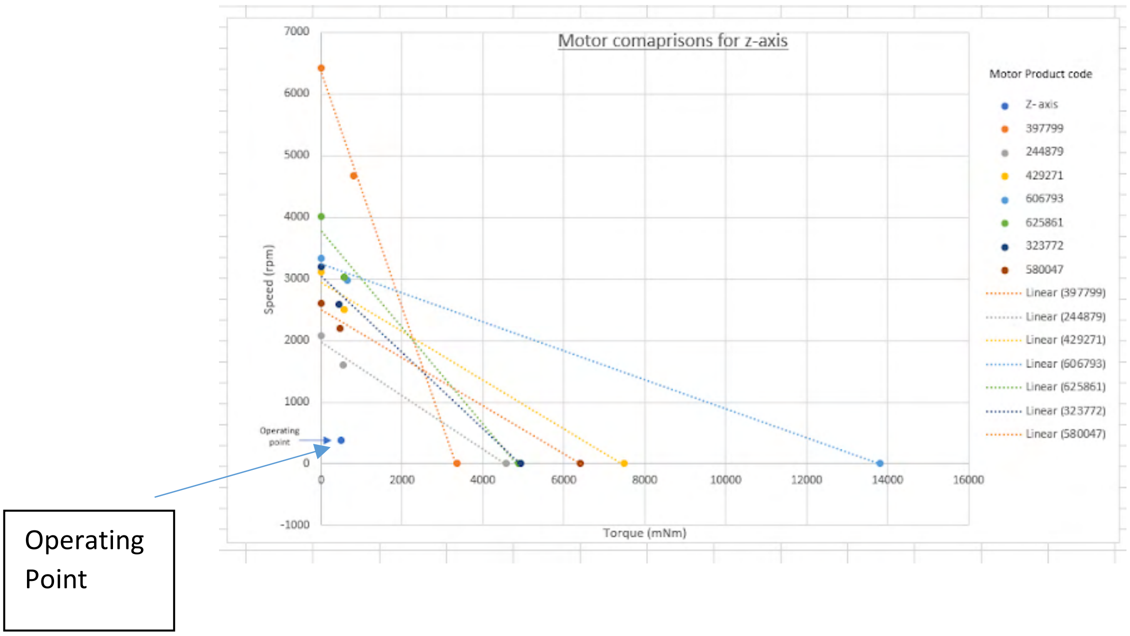


Figure 12 - Speed-Torque Diagram for Z axis Stage showing various motor choices

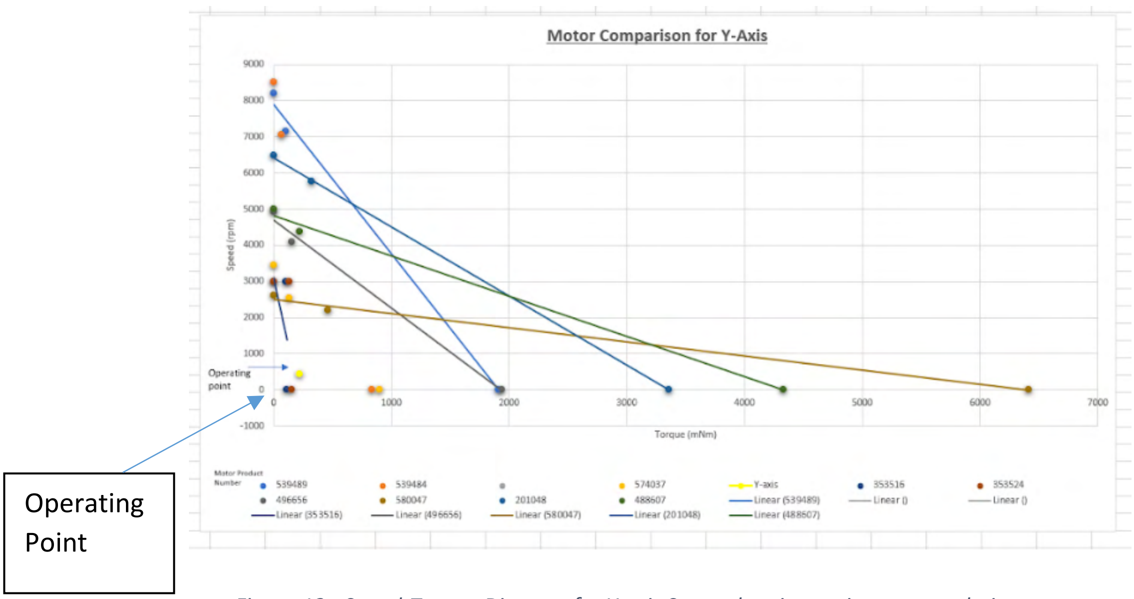


Figure 13 - Speed-Torque Diagram for Y axis Stage showing various motor choices

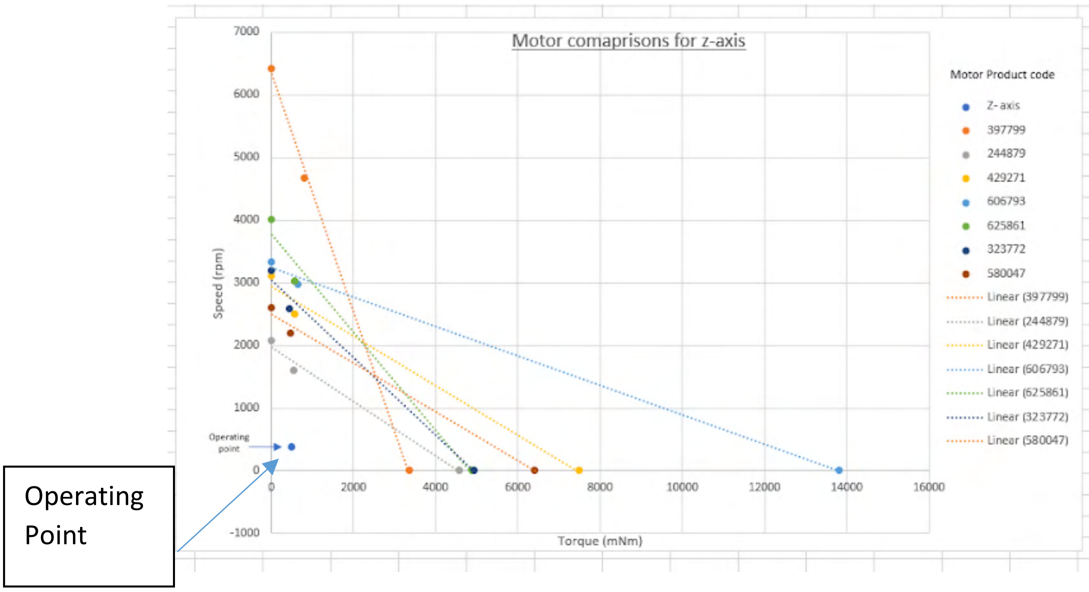


Figure 14 - Speed-Torque Diagram for Z axis Stage showing various motor choices

In the end, the motors chosen from MAXON were:
Z axis – EC 90 flat 90mm diameter, brushless, 90 Watt, with Hall sensors
Y axis – EC-I 40 40mm diameter, brushless, 100 Watt, with Hall sensors
X axis – EC 90 flat 90mm diameter, brushless, 90 Watt, with Hall sensors

Task 8 - Discussion on the relative merits of lead screws, ball screws, and other types of drives

Lead screws have been specifically designed for long life and quiet operation. It is manufactured using a rolled process, a highly consistent method of production resulting in a cost-effective, quality product. (Reliance Precision Limited, 2019)

Lead screws are different in that there are no recirculating elements, and they are often used for simple transfer applications when speed, accuracy, precision, and rigidity are not as critical. On a positive note, more surface contact of the threads can make for a higher load rating of the nut over ball screws. (Machine Design, 2019)

Ball screws on the other hand have the ability to carry much higher loads, achieve faster speeds with continuous duty cycles can be well worth their added cost. For end users, the predictability of ball screws makes them the best choice for fast integration and reliability. A ball screw uses recirculating ball bearings to minimize friction and maximize efficiency. (A lead screw cannot). Ball screw technology allows balls to roll between the screw shaft and the nut to achieve high efficiency, usually above 90% depending on the lead angle. Its required driving torque is only a third of a conventional lead screw. As a result, ball screws are capable of converting rotational motion to straight motion and vice versa. This screw type is suitable when smooth motion, efficiency, accuracy, and precision are a priority. The rolling elements eliminate sliding friction, so smaller motors can be used to drive ball screws. And, because rolling motion is easier to control, accuracy and precision are also easier. (Machine Design, 2019)

In contrast, linear motors have no mechanical contact with the transmission force being generated in the air gap in addition to the linear motor rail without any other friction. The linear rail has a simple structure, small size, and has fewer parts. The linear motor operates in such a way that a wide range of speed can be used covering a few micrometres per second to several meters, especially in the high speed. Linear motors also have very high accuracy because the accuracy of the system depends on the position of the detection element Maintenance is simple, because it generally has less parts and no mechanical contact when moving, thus this greatly reduces the wear and tear.

Based on the accuracy and cost I would choose the recirculating ball screws as my new choice it is less expensive to maintain due to the ball bearings which minimize friction. Due to the smooth motion of the recirculating motor from its ball bearings I would rank it the most accurate.

Task 9 - Discussion on the relative merits of different types of motors

If this multi-axis system were to be redesigned, the type of motor used for the system would likely be the DC motor due to the following reasons:

When considering the accuracy of the motor for this redesign (which is considered to be the most important of the three criteria), stepper motors are more limited in their resolution due to the incremental size of its step (which is usually around 1.8°, or a 200th of a revolution). Therefore its accuracy is limited by a constant factor, whereas in the case of both DC motors and linear motors, they have a continuous displacement and therefore can be positioned accurately to the nearest 0.01mm.

When considering the speed of the motor, the DC motor is the fastest of the three potential contenders. Typical DC motors with shaft diameters of 10mm can reach rotational speeds as high as 5000 rpm which can be equivalent to a linear velocity of at least 2.5 m/s depending on the exact diameter of the motor shaft. Stepper motors rarely exceed a rotational speed of 1000 rpm and thus can rarely achieve a linear velocity greater than 0.5 m/s. Linear motors with similar specifications to the other two types of motors are generally able to reach a top speed of roughly 1.5m/s. Therefore DC motors offer the greatest speed for the redesign of this system.

When considering the cost of the motor, the price should be minimised without compromising on the quality of the motor. The cheapest available type of motor out of the three options is the DC motor, averaging roughly £180 for motors with a shaft diameter of 10mm. The second cheapest option is the stepper motor which costs around £320 for a motor with a shaft diameter of 10mm. Finally, the most expensive option for the redesign is the linear motor, which can cost up to £530 for a motor that is able to reach a similar linear velocity as the other motors. (RS, 2019)

To summarise; after considering each of the three motors against the given criteria, it is evident that the DC motor is the best choice as it has the highest speed, lowest cost, and joint-best accuracy. Therefore the DC motor should be used for the redesign. However if the motors were to be compared against additional criteria (such as efficiency, durability, or life span) then the DC motor may not be the most optimal choice.

Appendix

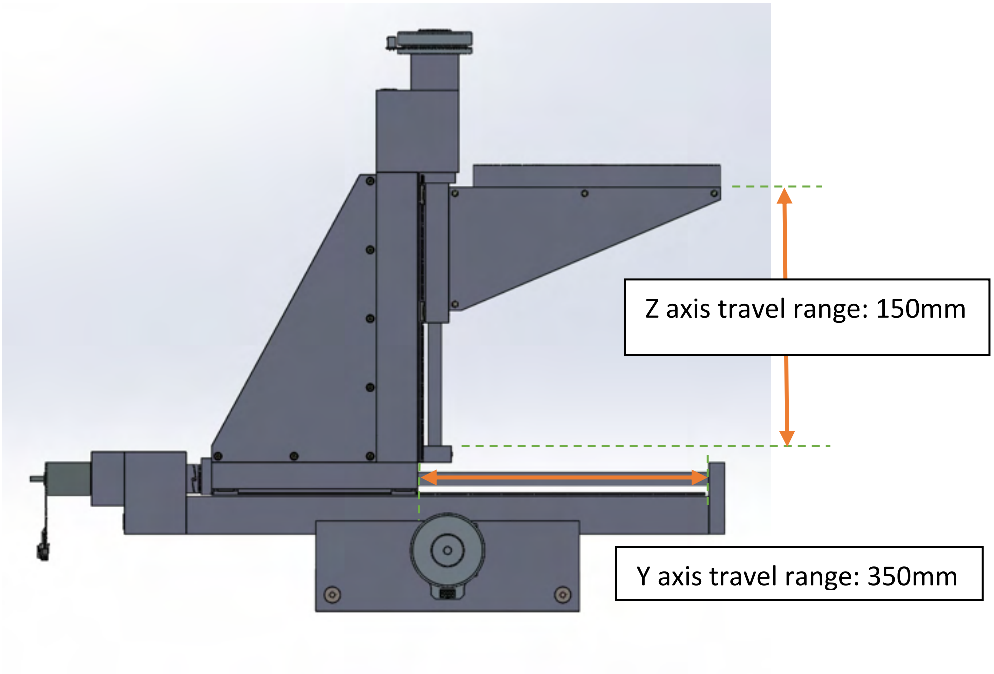


Figure 5 - Side View of Model

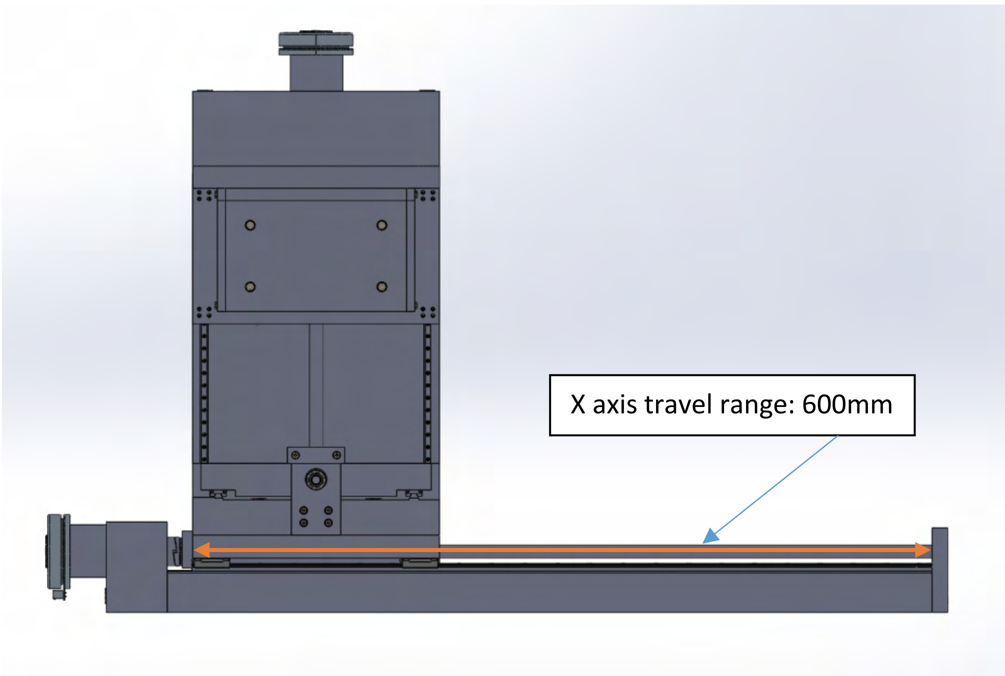
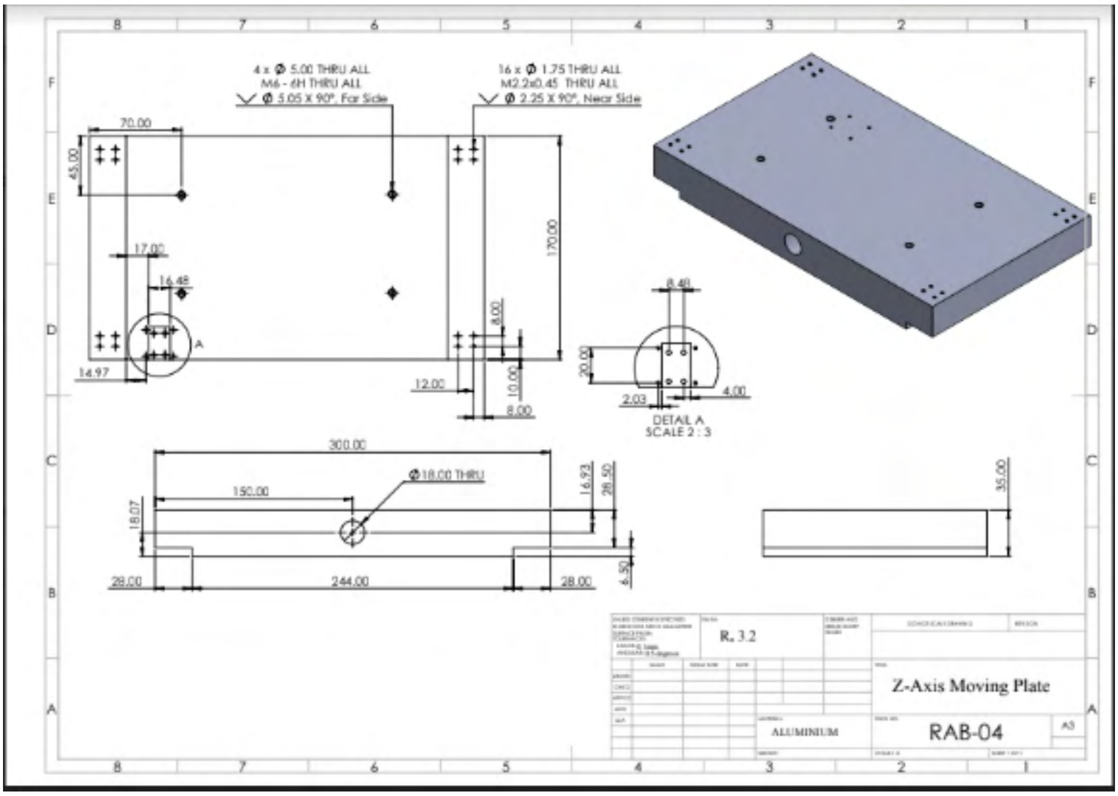
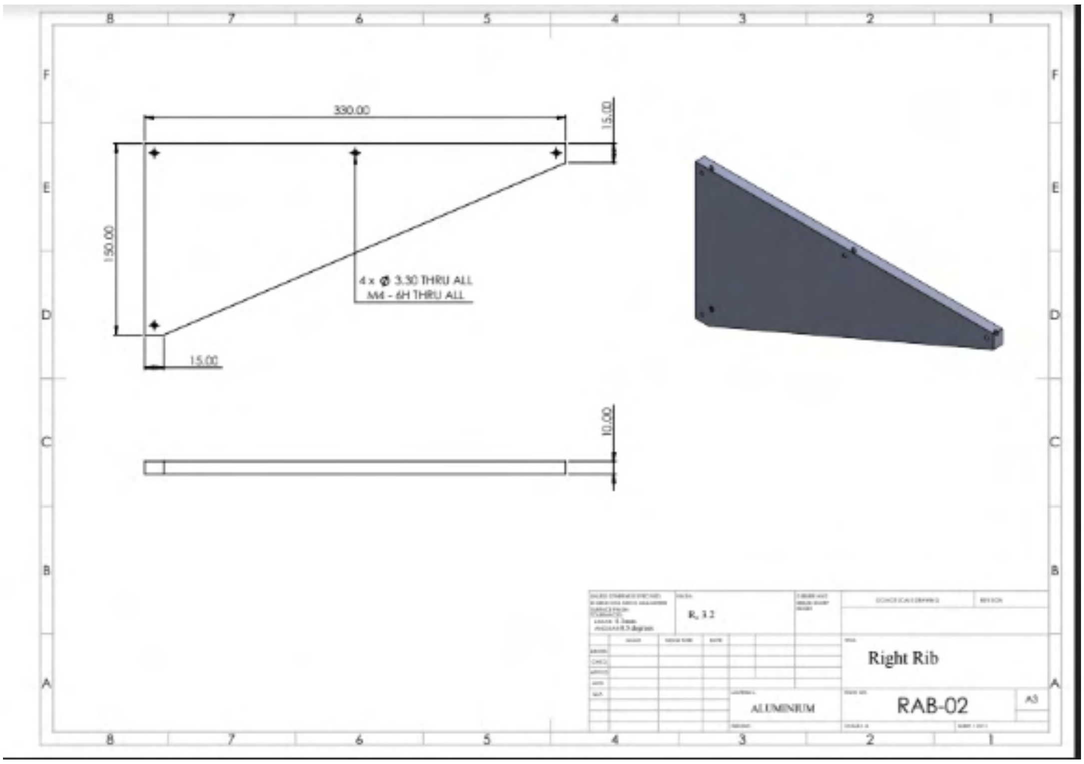
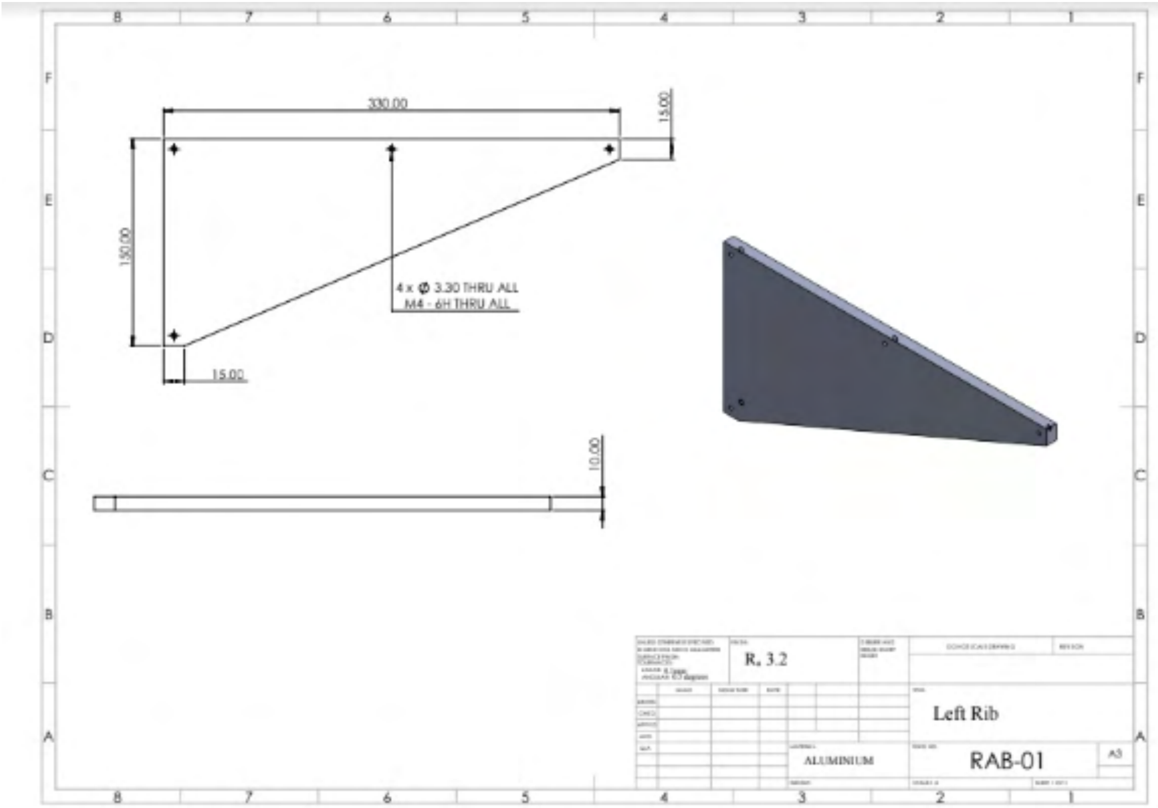


Figure 6 - Front View of Model

Right Angle Bracket



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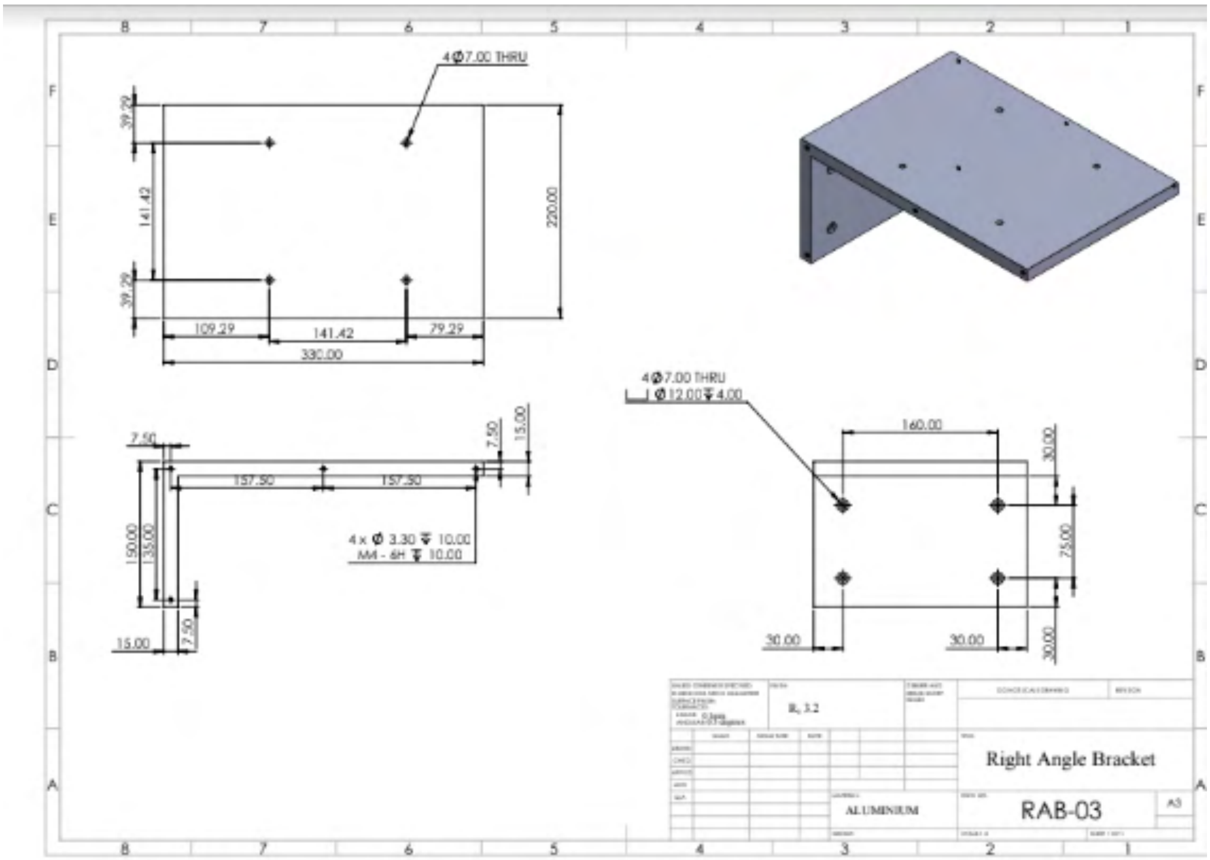
RAB-01
A3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150.00
135.00
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M4 - 6H ↧ 10.00
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7.50
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⌴ Ø 12.00 ↧ 4.00
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ALUMINIUM
RAB-03
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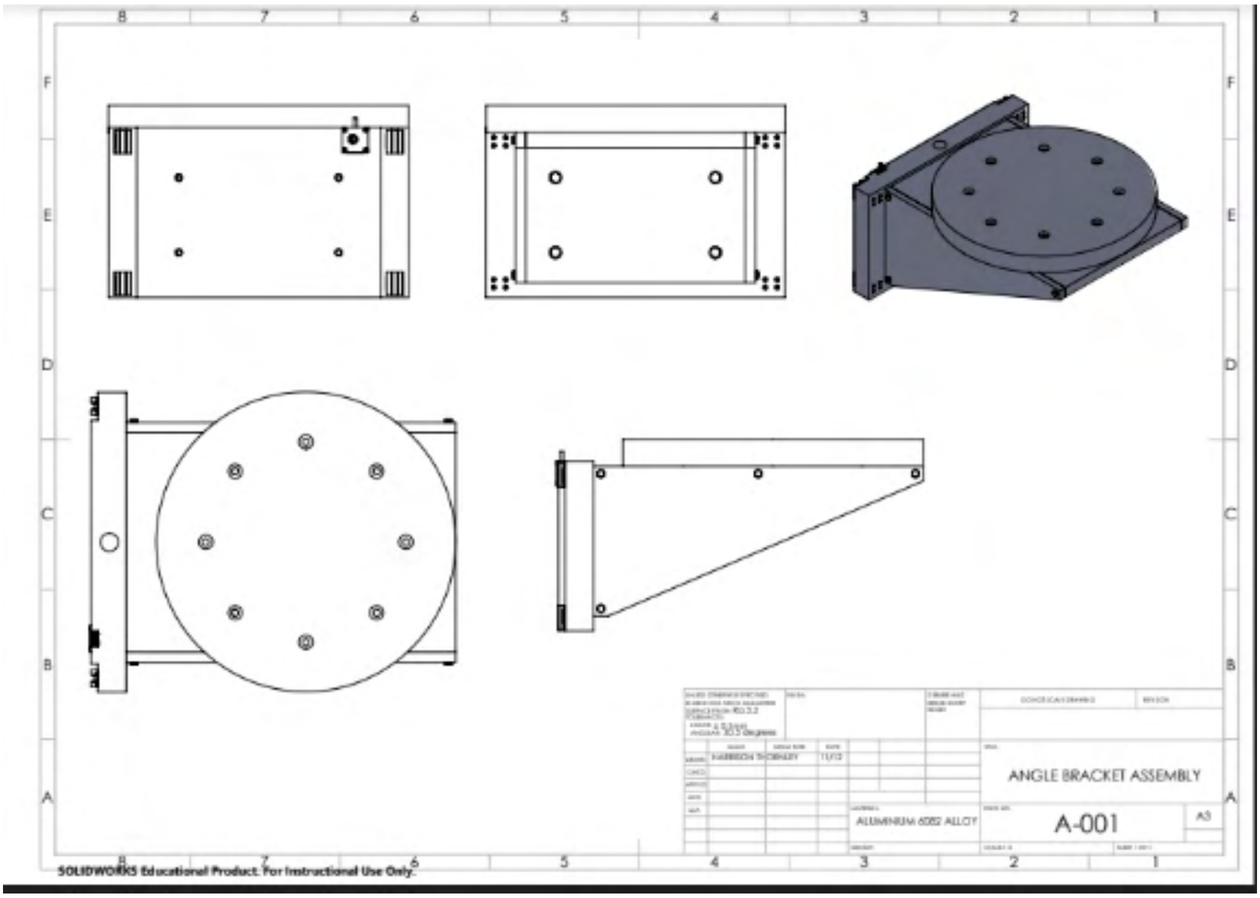
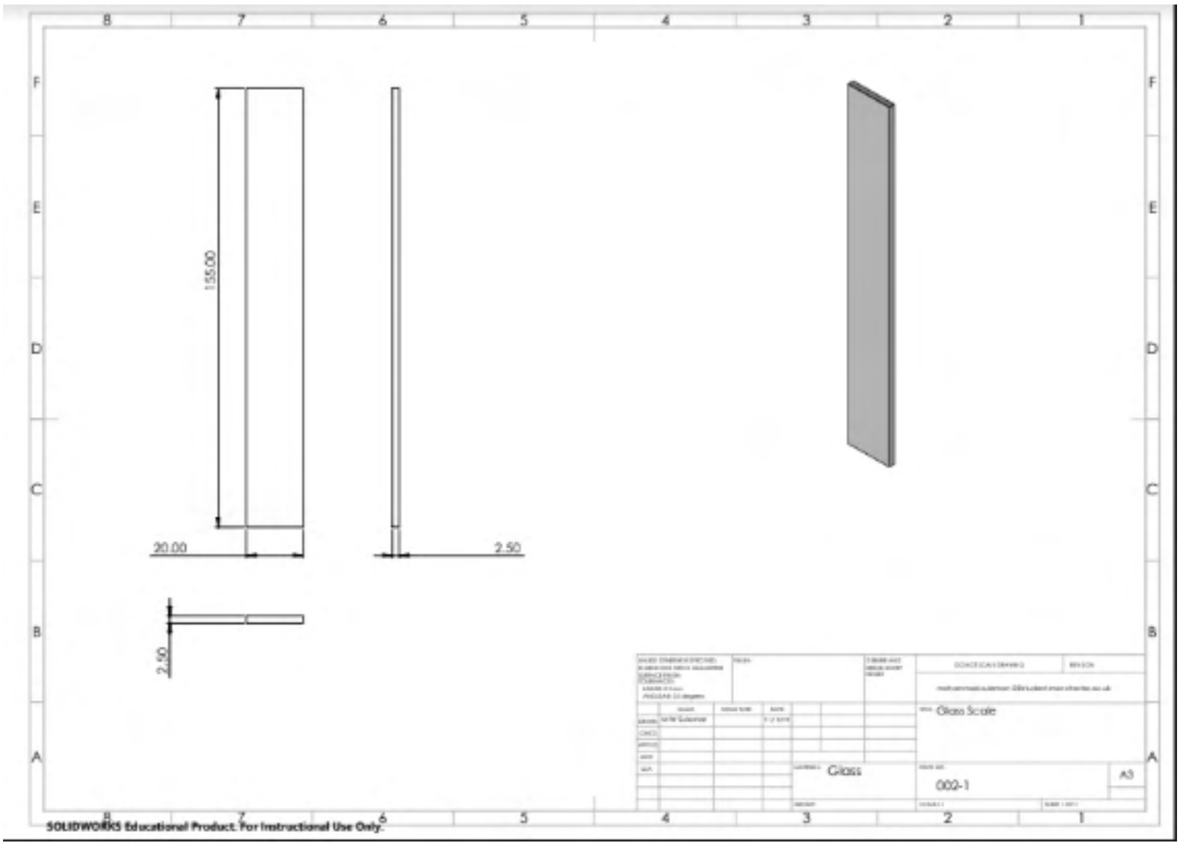
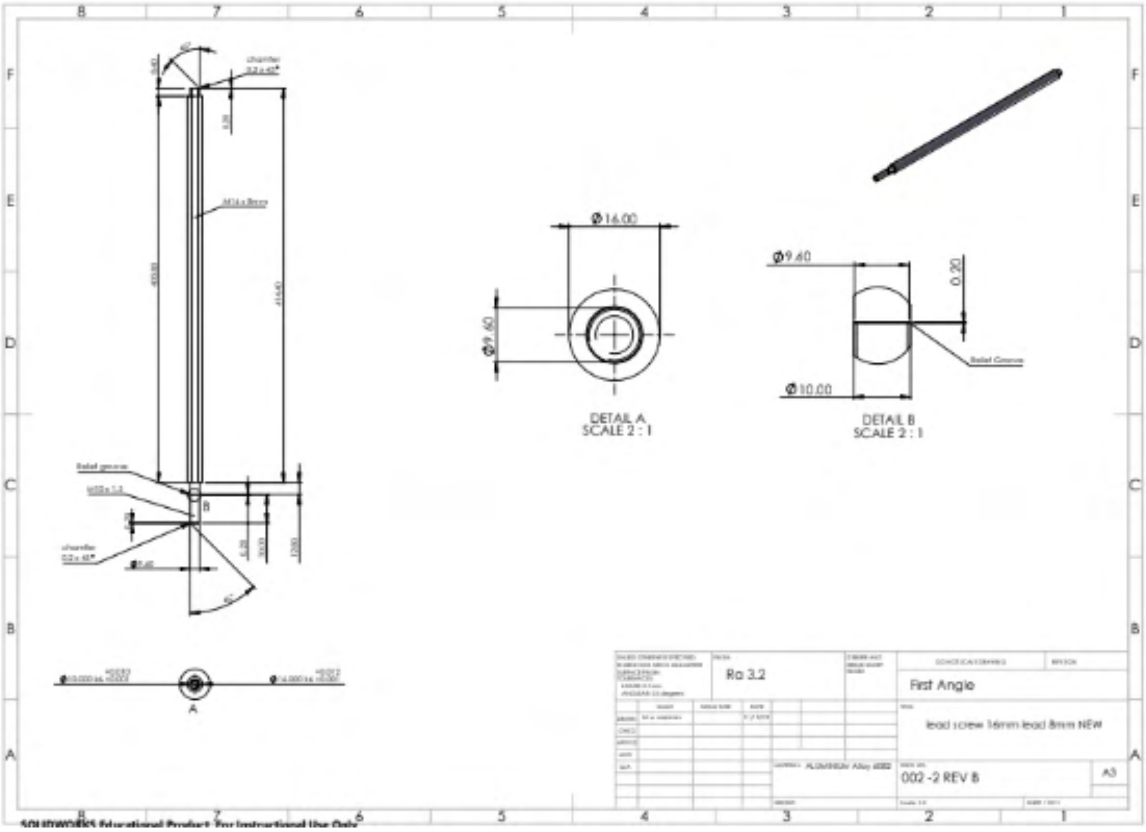


Z-Axis Drawings

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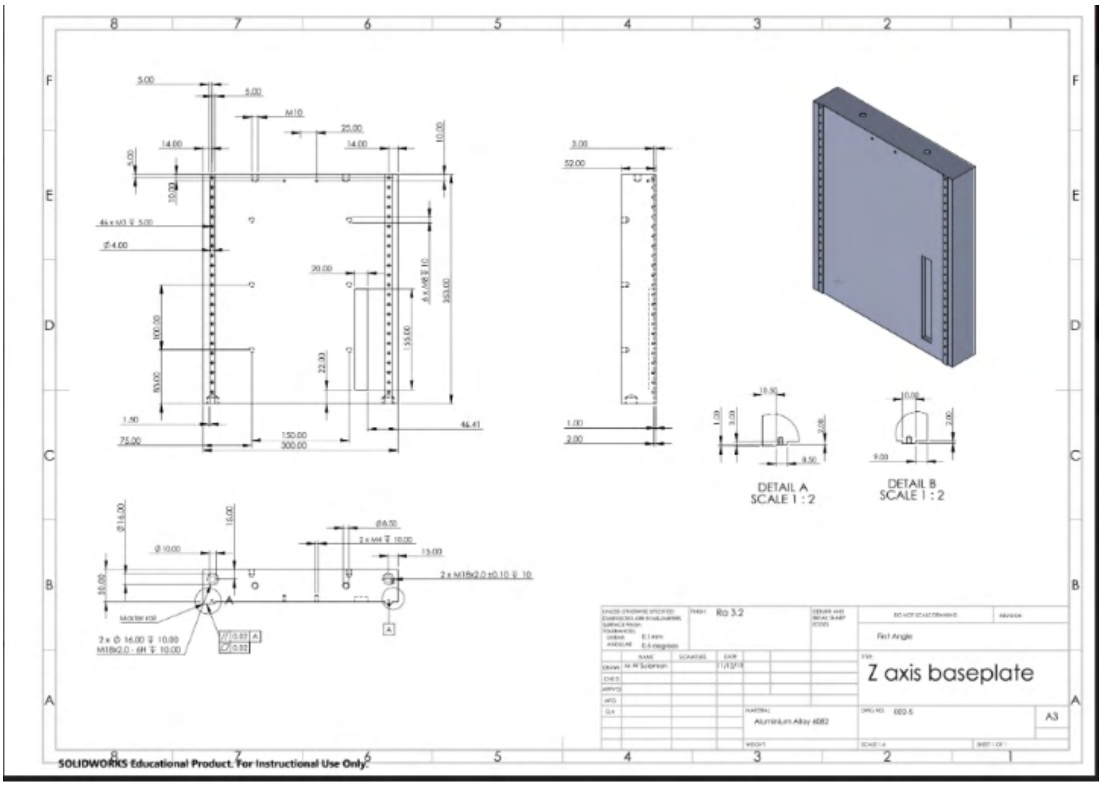
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SCALE 1 : 2
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Aluminium Alloy 6082
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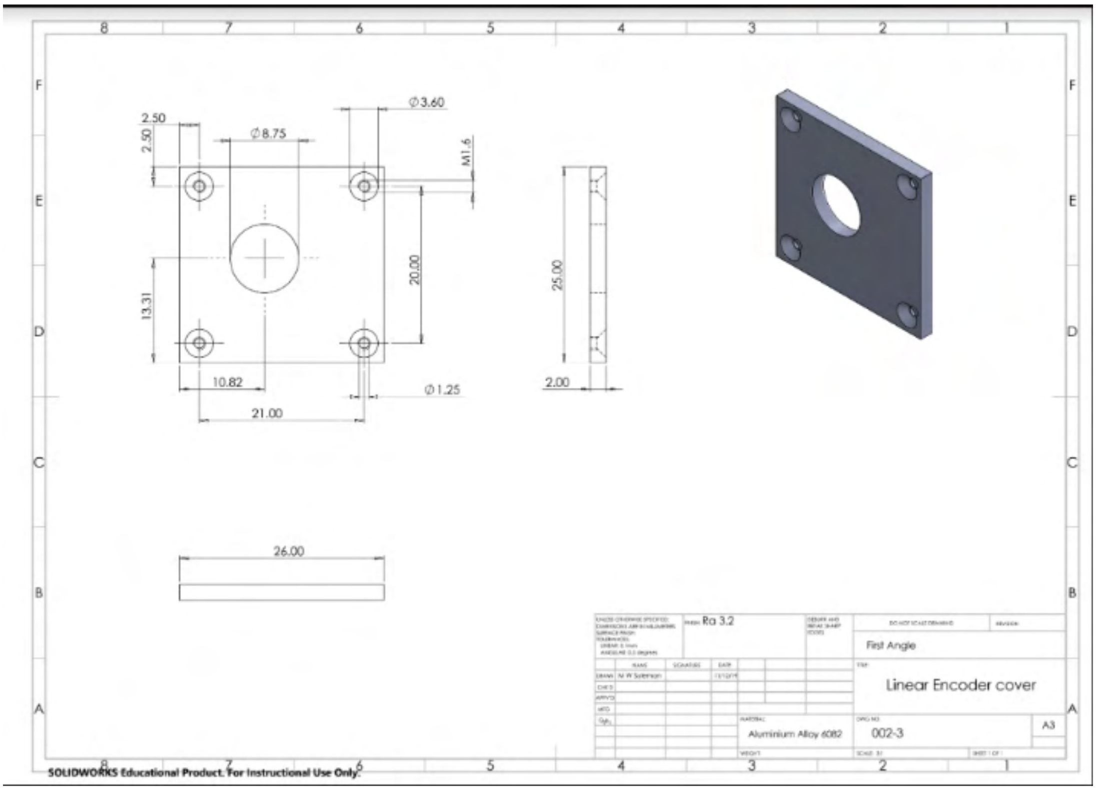
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Ra 3.2
First Angle
Linear Encoder cover
Aluminium Alloy 6082
002-3
A3
SOLIDWORKS Educational Product. For Instructional Use Only.


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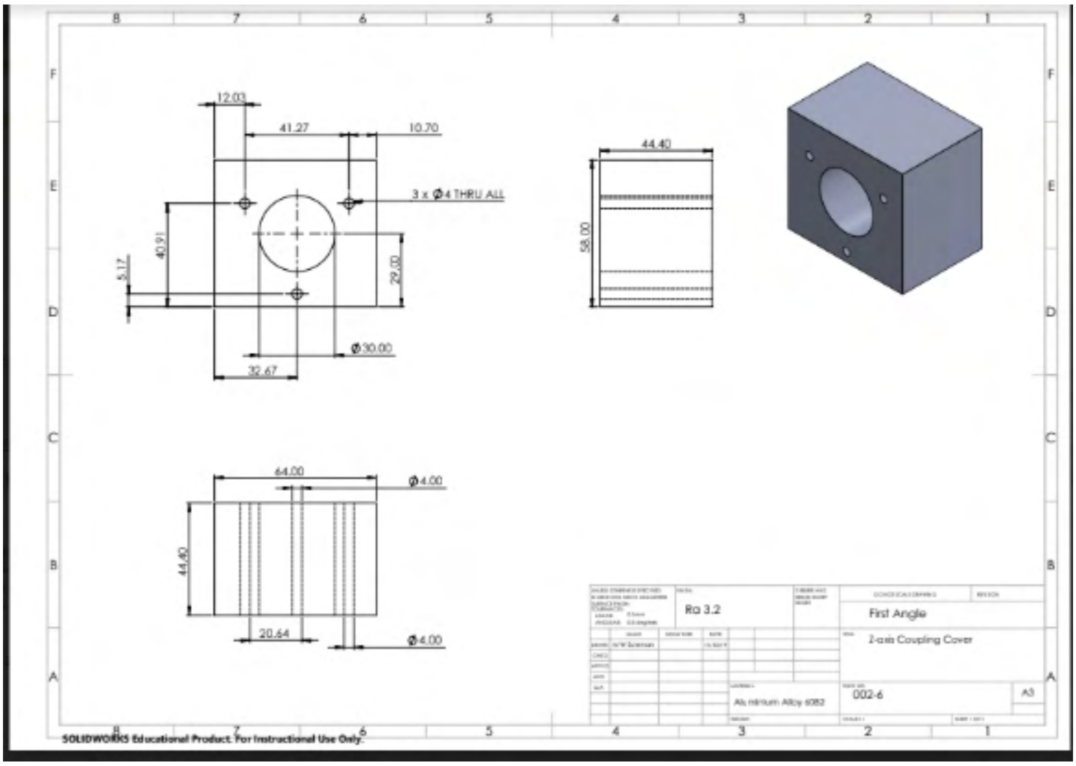
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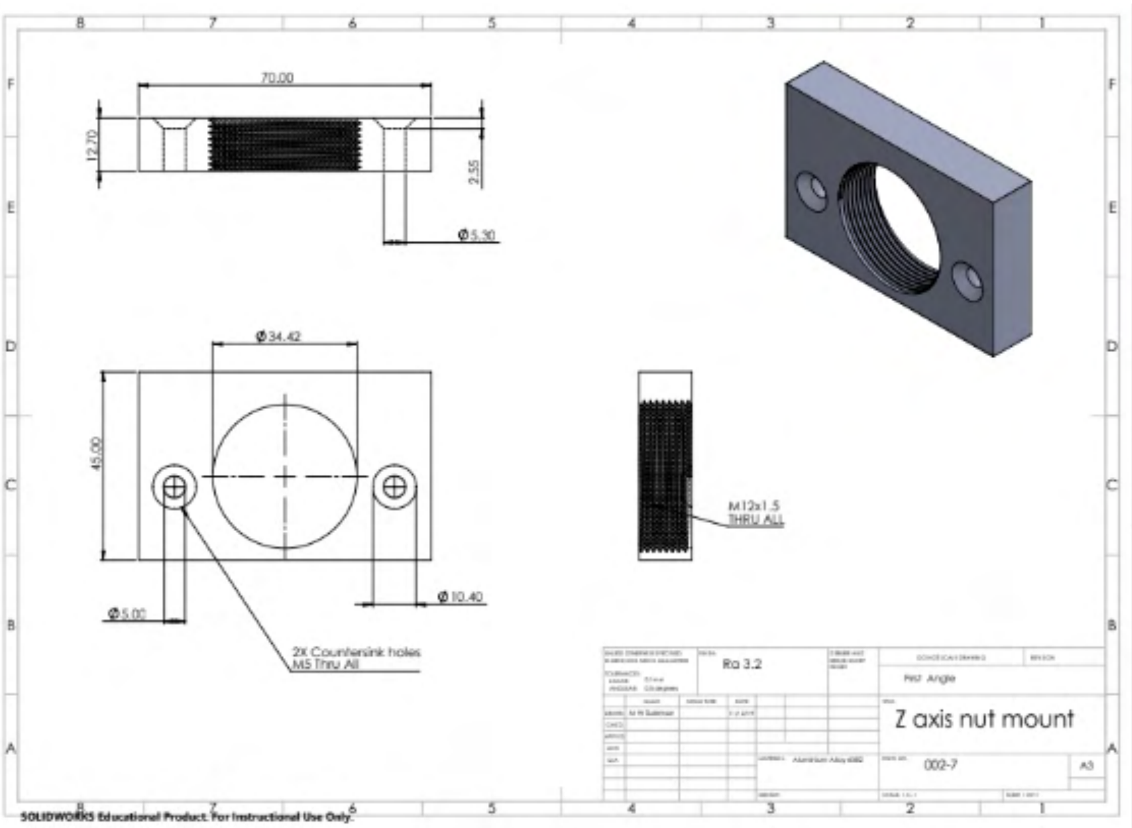
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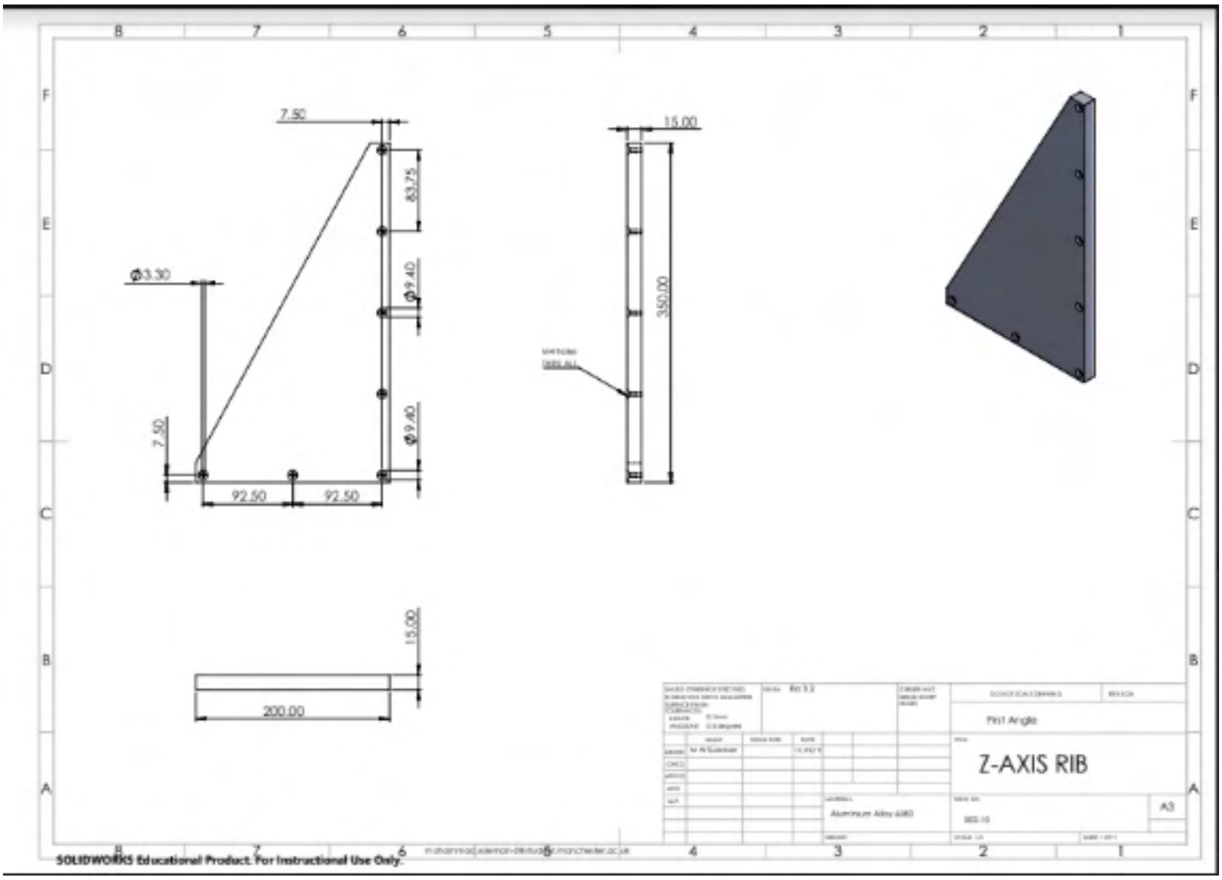
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Z-AXIS RIB
Aluminium Alloy 6082
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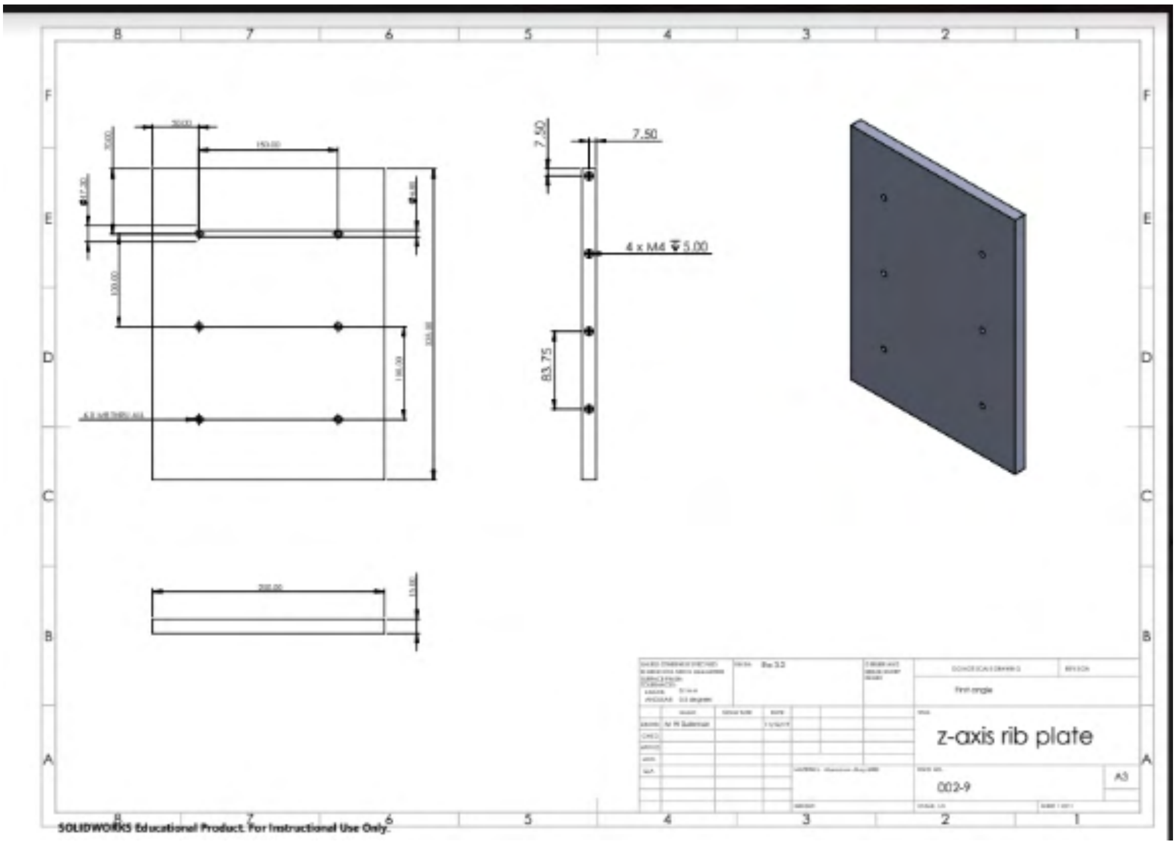
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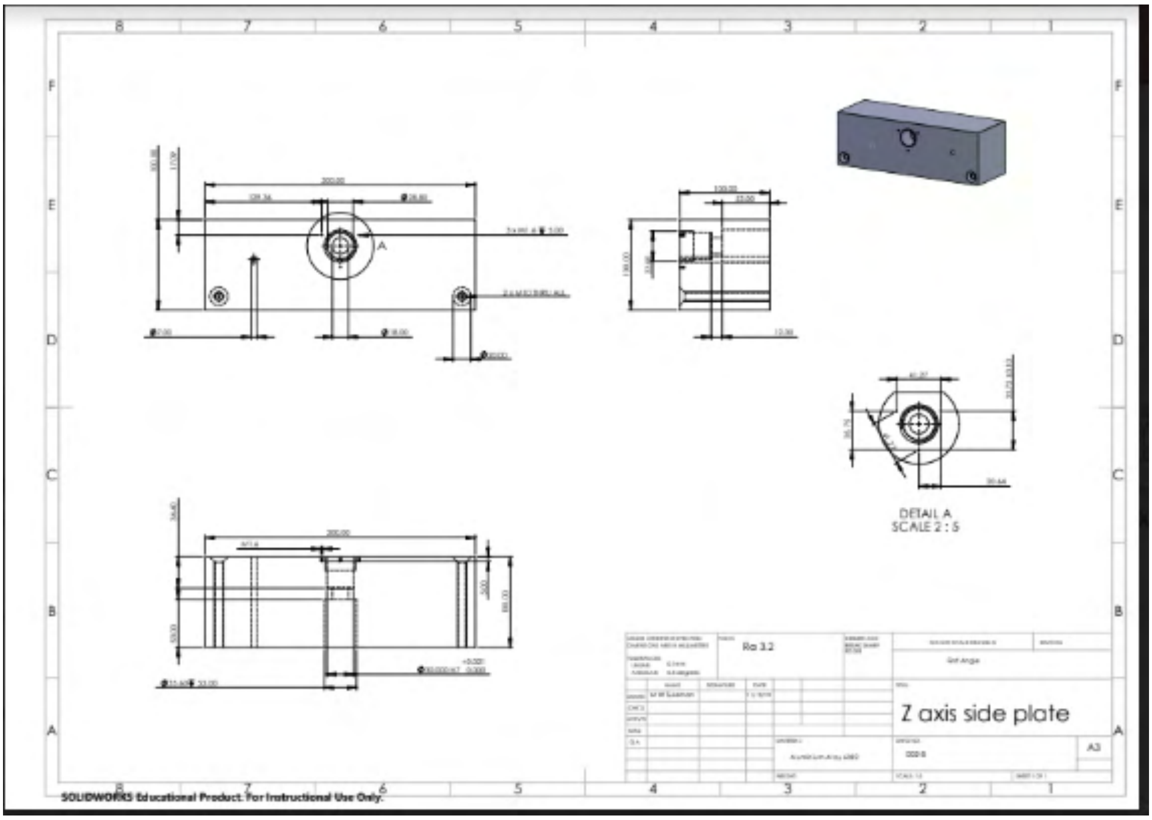
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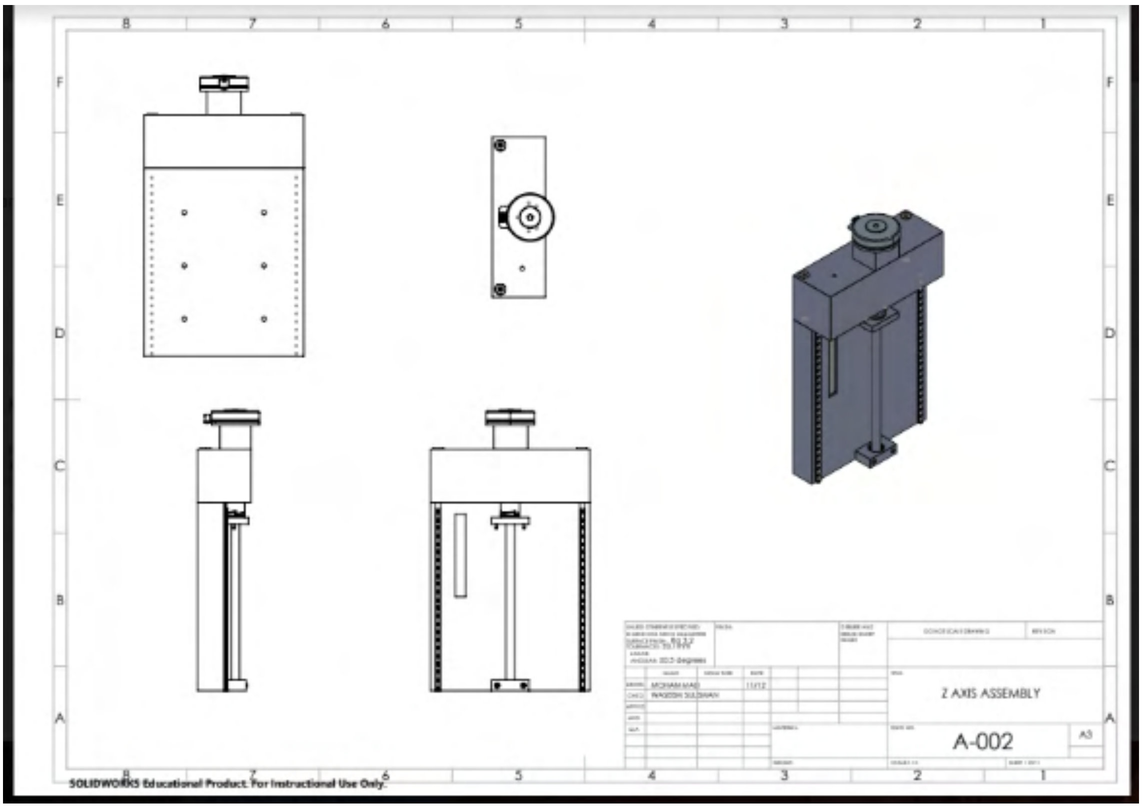
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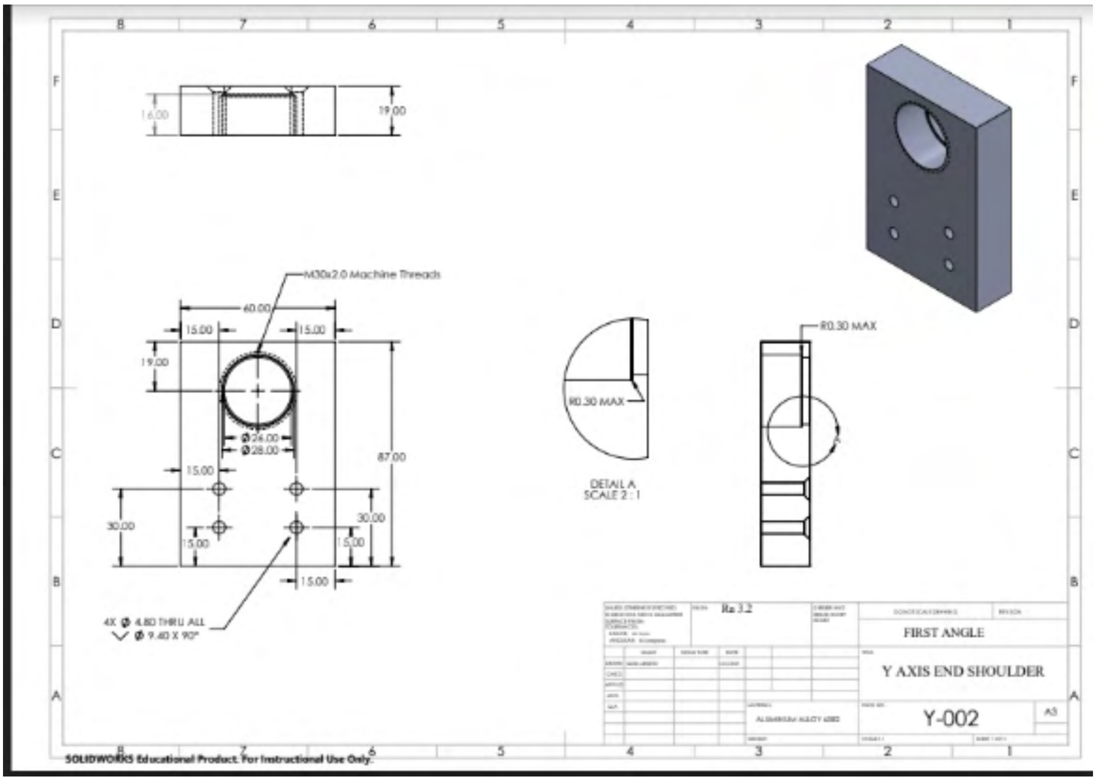
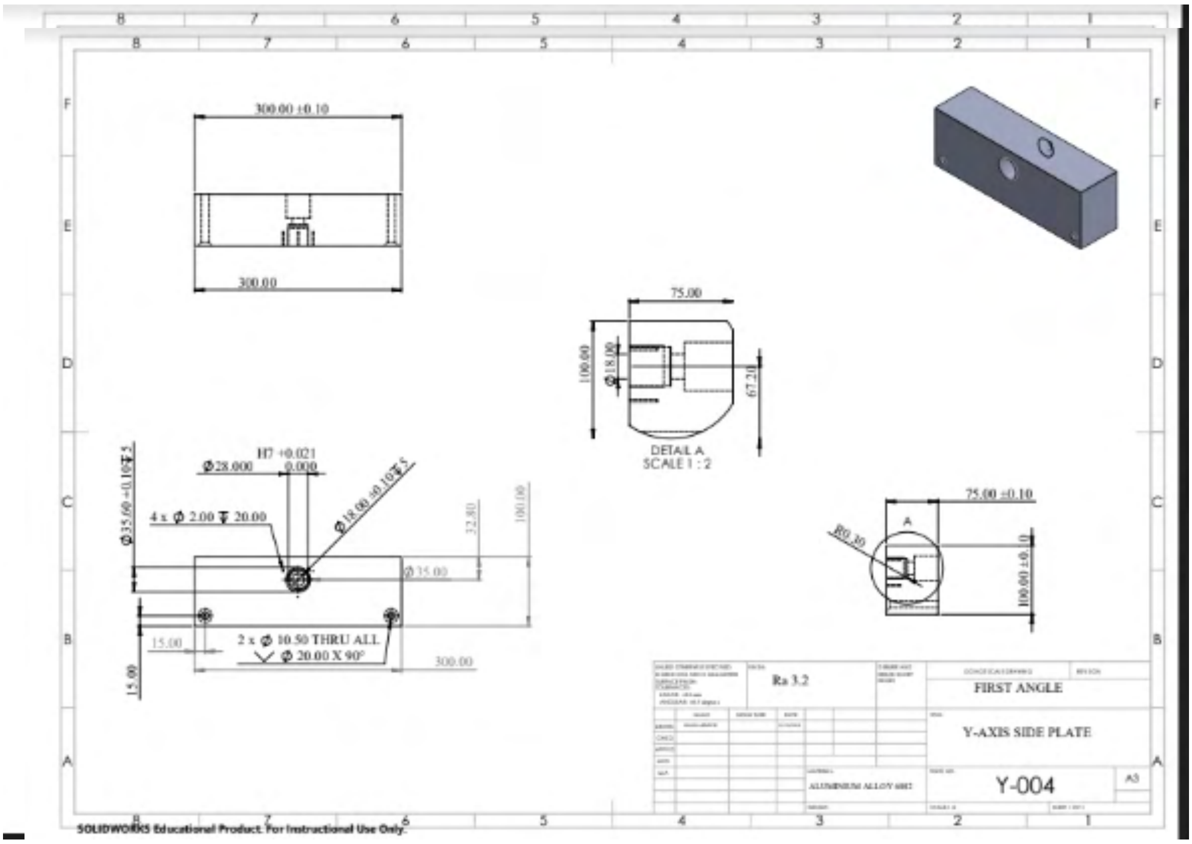
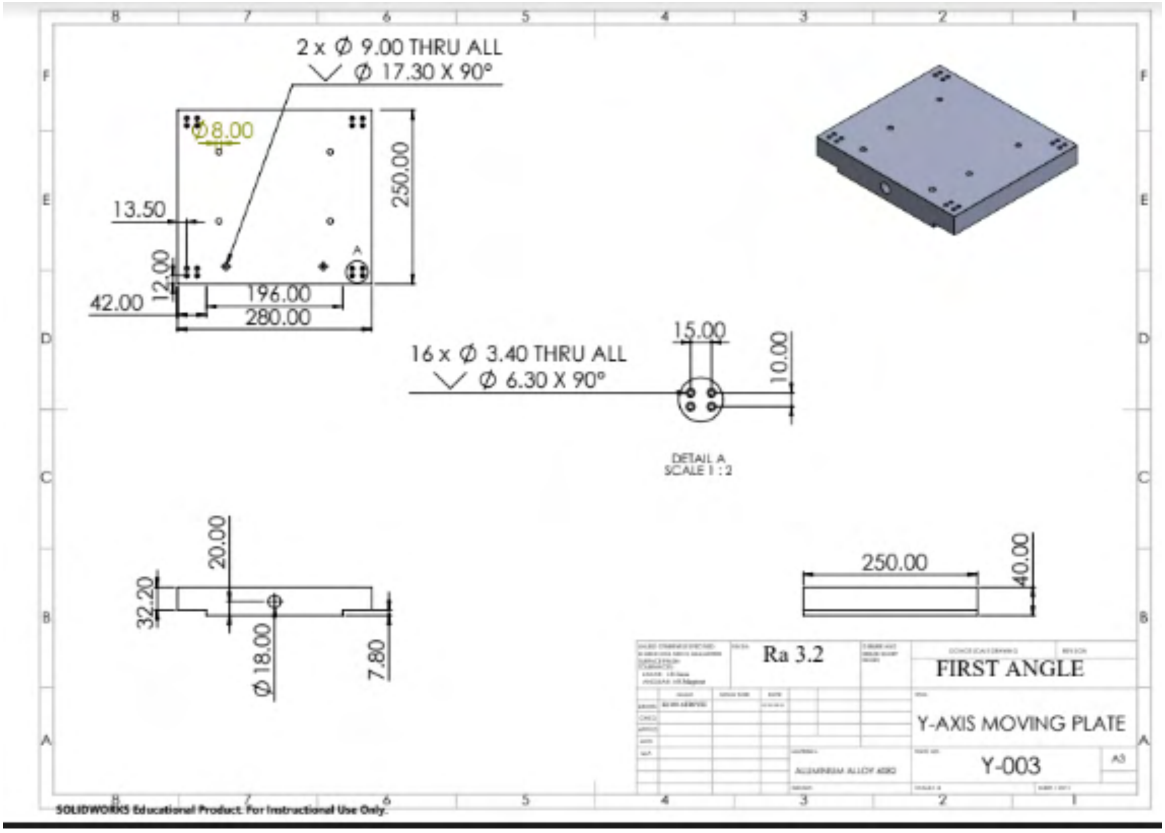
Y-Axis Drawings



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Ø 18.00
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Y-003
A3
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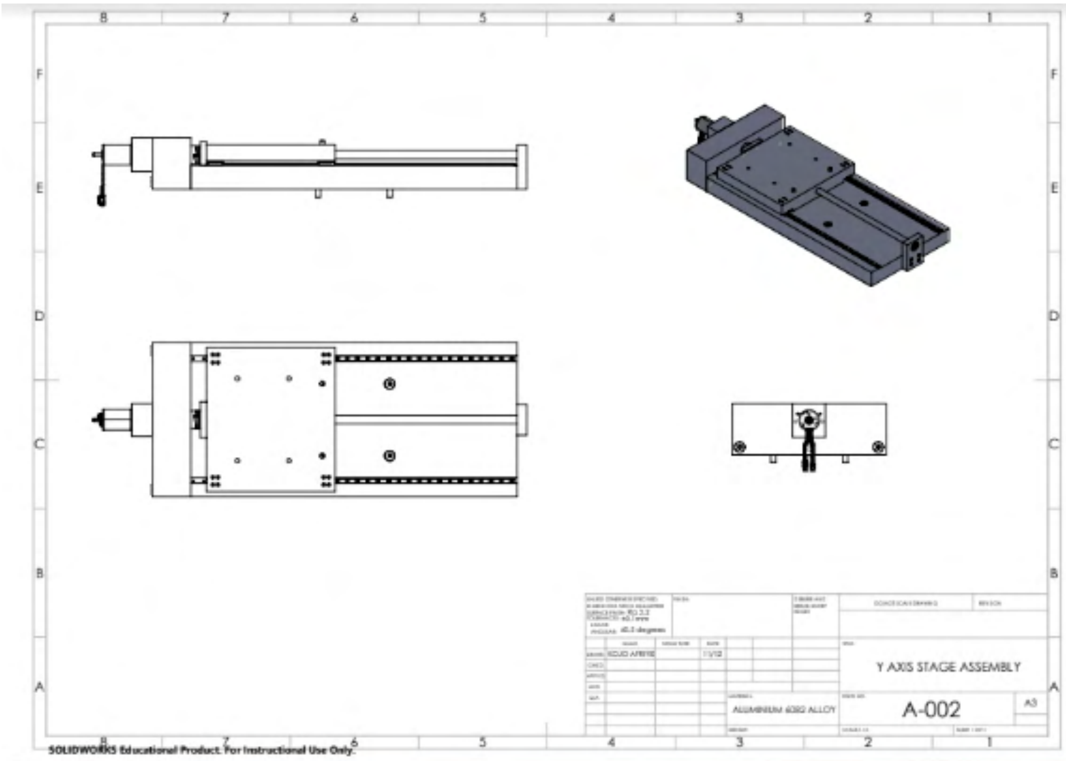
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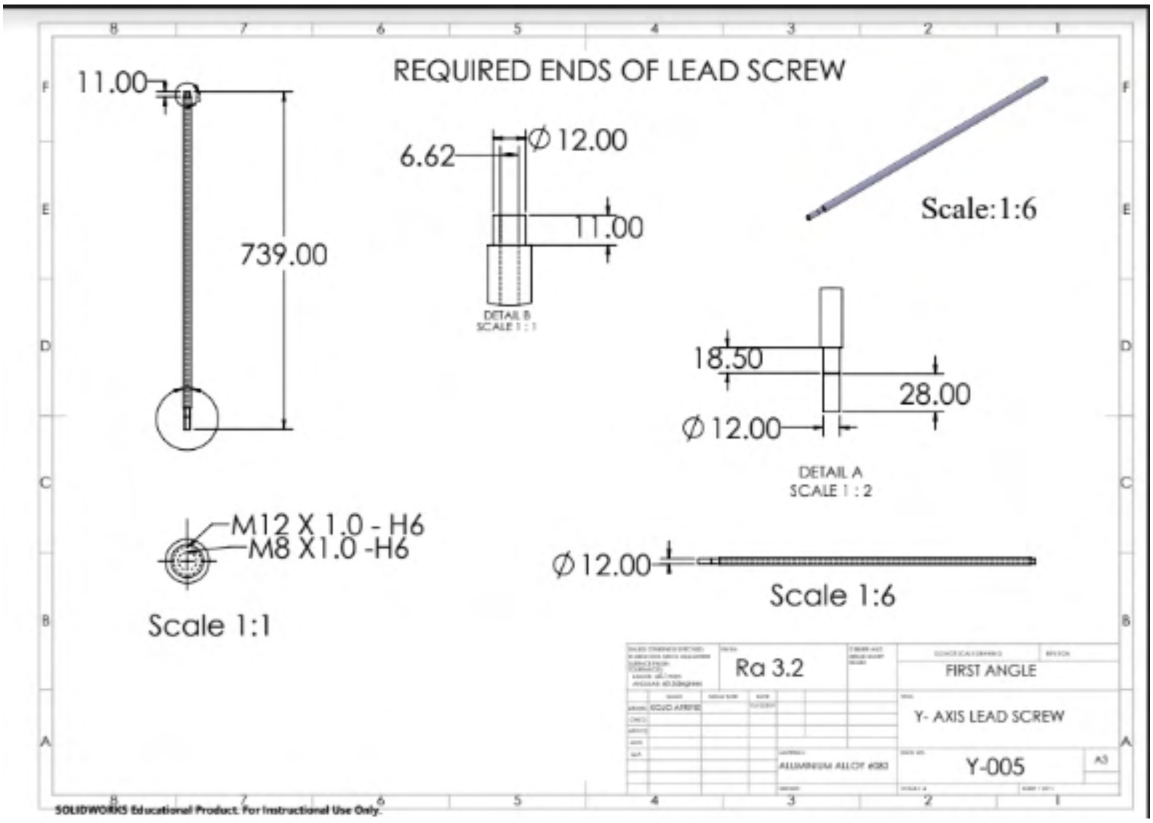
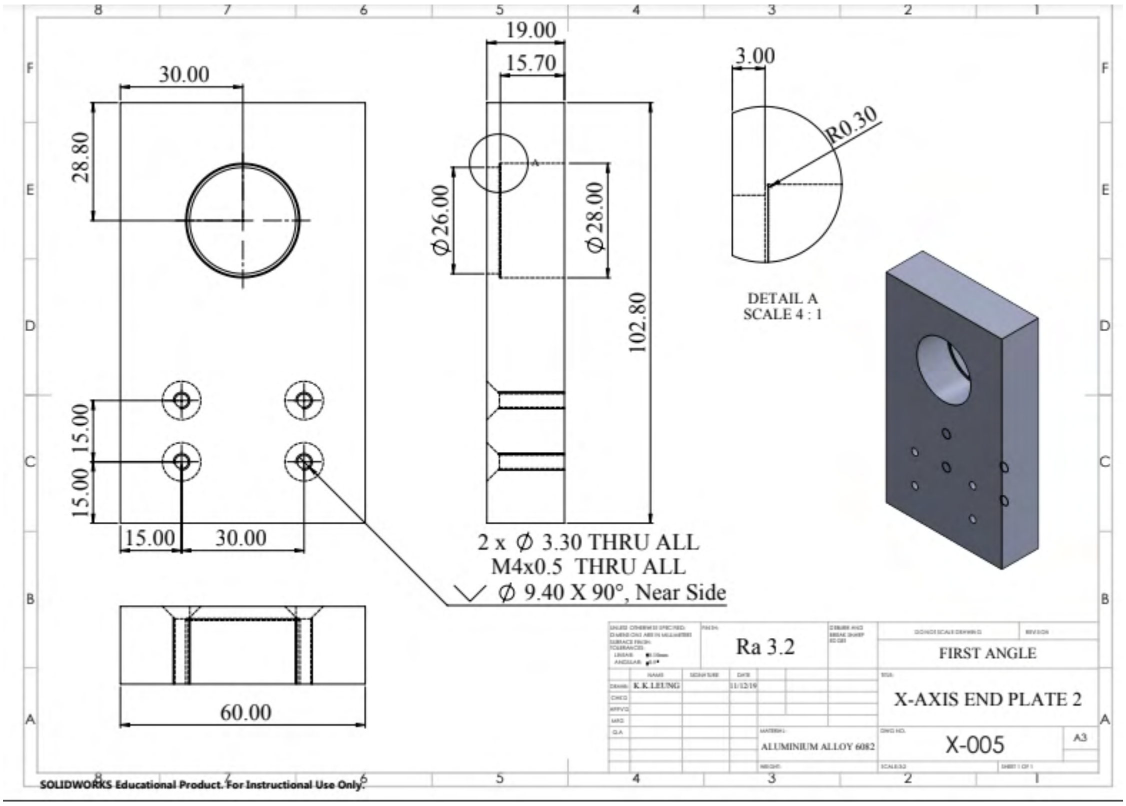
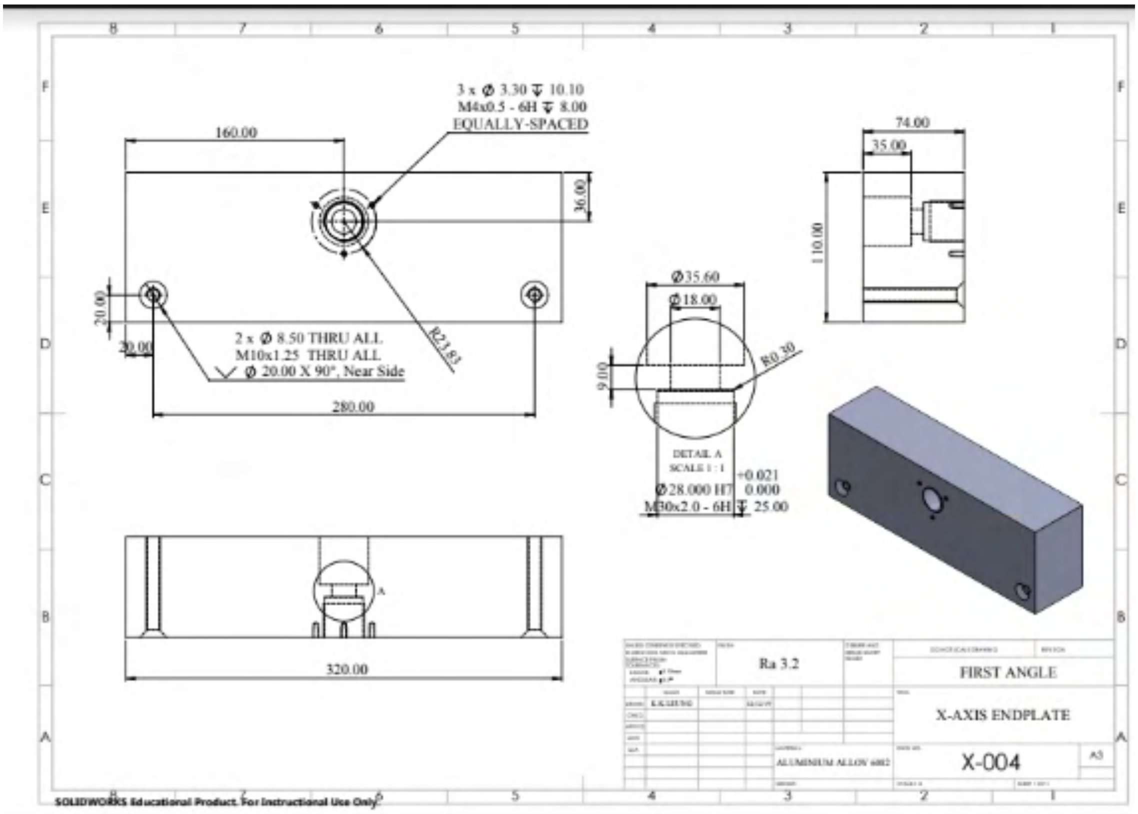
X-Axis Drawings




19.00
15.70
30.00
3.00
R0.30
28.80
Ø26.00
Ø28.00
102.80
DETAIL A
SCALE 4 : 1
15.00 15.00
15.00
15.00 30.00
2 x Ø 3.30 THRU ALL
M4x0.5 THRU ALL
Ø 9.40 X 90°, Near Side
60.00
Ra 3.2
FIRST ANGLE
K.K.LEUNG
11/12/19
X-AXIS END PLATE 2
ALUMINIUM ALLOY 6082
X-005
A3
SOLIDWORKS Educational Product. For Instructional Use Only.


3 x Ø 3.30 ⌴ 10.10
M4x0.5 - 6H ⌴ 8.00
EQUALLY-SPACED
160.00
36.00
74.00
35.00
110.00
20.00
20.00
2 x Ø 8.50 THRU ALL
M10x1.25 THRU ALL
Ø 20.00 X 90°, Near Side
R23.83
280.00
Ø35.60
Ø18.00
R0.30
9.00
DETAIL A
SCALE 1 : 1
+0.021
Ø28.000 H7 0.000
M30x2.0 - 6H ⌴ 25.00
320.00
Ra 3.2
FIRST ANGLE
K.K.LEUNG
X-AXIS ENDPLATE
ALUMINIUM ALLOY 6082
X-004
A3
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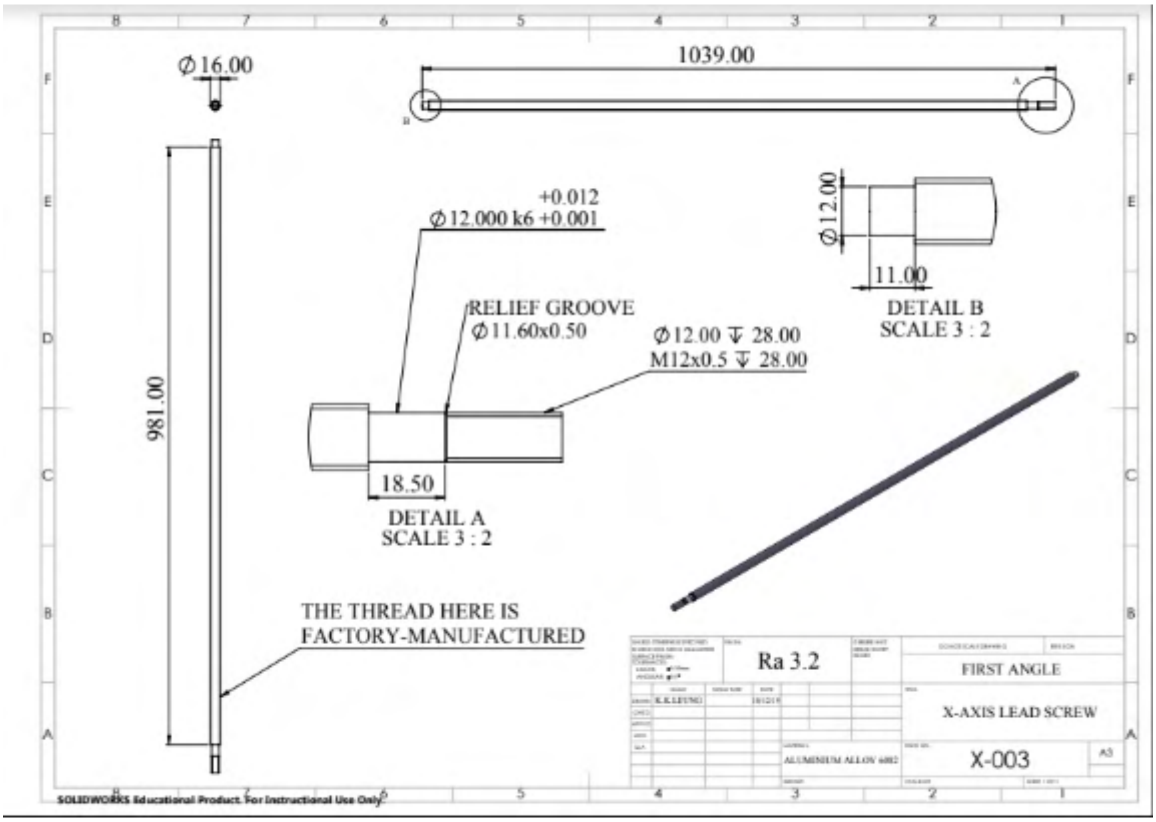

Ø16.00
1039.00
981.00
+0.012
Ø12.000 k6 +0.001
RELIEF GROOVE
Ø11.60x0.50
Ø12.00 ↧ 28.00
M12x0.5 ↧ 28.00
18.50
DETAIL A
SCALE 3 : 2
Ø12.00
11.00
DETAIL B
SCALE 3 : 2
THE THREAD HERE IS
FACTORY-MANUFACTURED
Ra 3.2
FIRST ANGLE
K.K.LEUNG
X-AXIS LEAD SCREW
ALUMINIUM ALLOY 6082
X-003
A3
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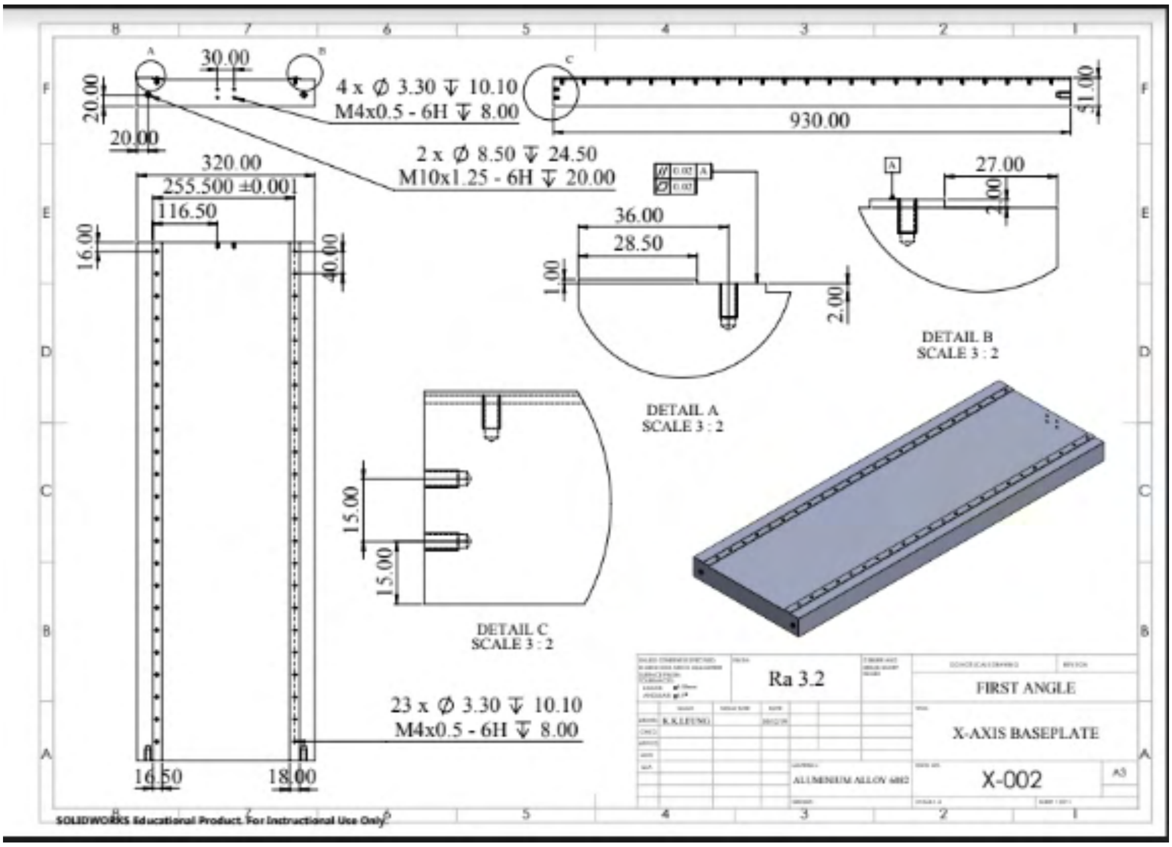

30.00
20.00
20.00
4 x Ø 3.30 ↧ 10.10
M4x0.5 - 6H ↧ 8.00
930.00
41.00
2 x Ø 8.50 ↧ 24.50
M10x1.25 - 6H ↧ 20.00
320.00
255.500 ±0.001
116.50
16.00
40.00
36.00
28.50
1.00
2.00
27.00
3.00
DETAIL B
SCALE 3 : 2
DETAIL A
SCALE 3 : 2
15.00
15.00
DETAIL C
SCALE 3 : 2
23 x Ø 3.30 ↧ 10.10
M4x0.5 - 6H ↧ 8.00
16.50
18.00
Ra 3.2
FIRST ANGLE
K.K.LEUNG
X-AXIS BASEPLATE
ALUMINIUM ALLOY 6082
X-002
A3
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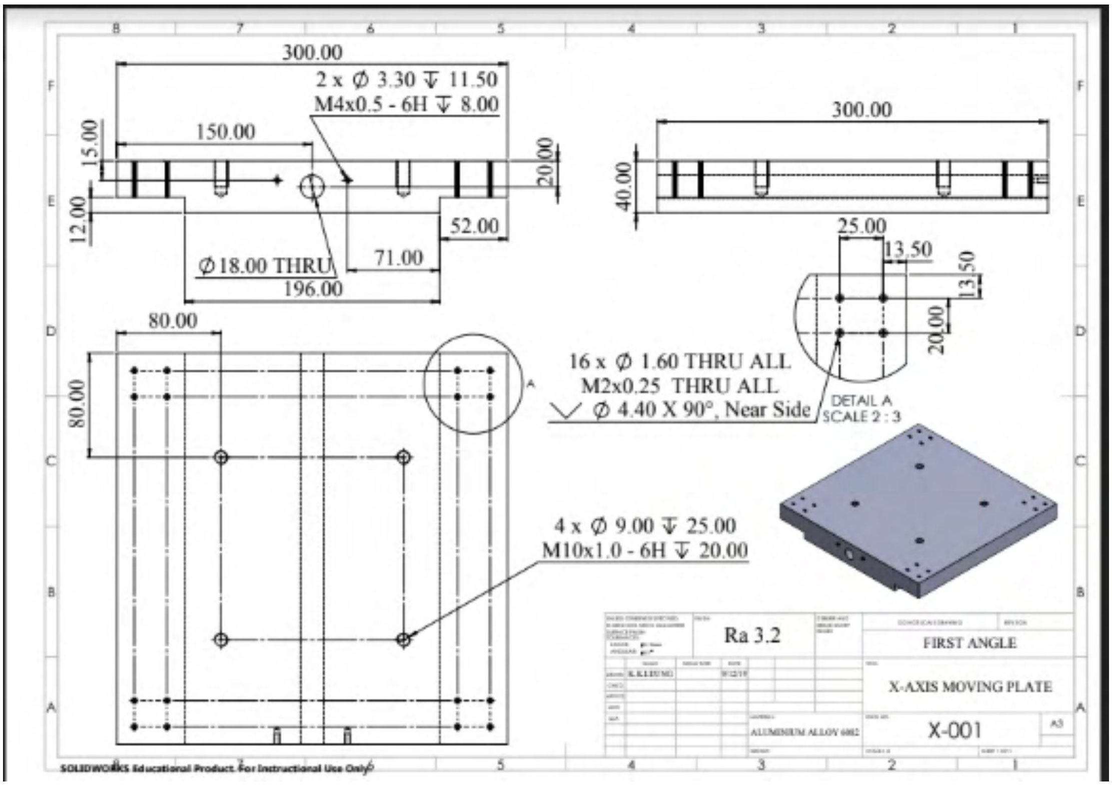

300.00
2 x Ø 3.30 ↧ 11.50
M4x0.5 - 6H ↧ 8.00
150.00
15.00
20.00
12.00
52.00
71.00
Ø18.00 THRU
196.00
300.00
40.00
25.00
13.50
13.50
20.00
80.00
80.00
16 x Ø 1.60 THRU ALL
M2x0.25 THRU ALL
⌵ Ø 4.40 X 90°, Near Side
DETAIL A
SCALE 2 : 3
4 x Ø 9.00 ↧ 25.00
M10x1.0 - 6H ↧ 20.00
Ra 3.2
FIRST ANGLE
X-AXIS MOVING PLATE
ALUMINIUM ALLOY 6082
X-001
A3
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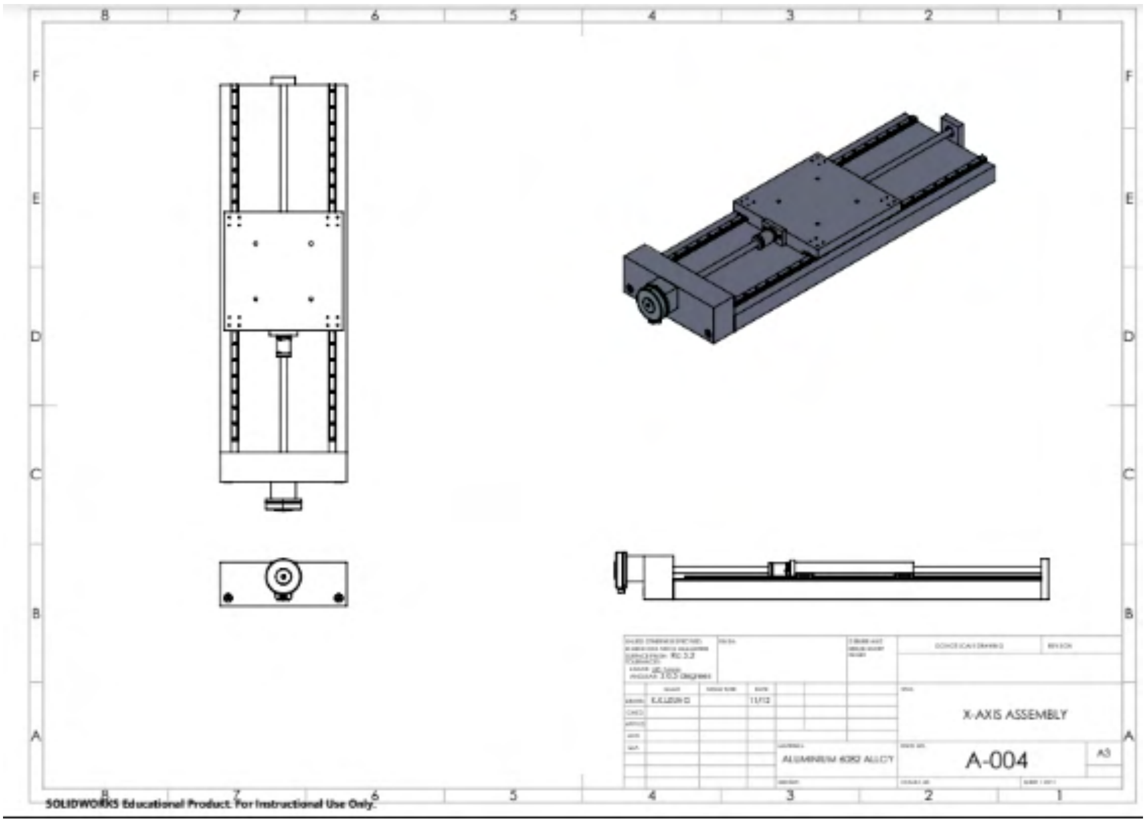

X-AXIS ASSEMBLY
ALUMINIUM 6082 ALLOY
A-004
A3
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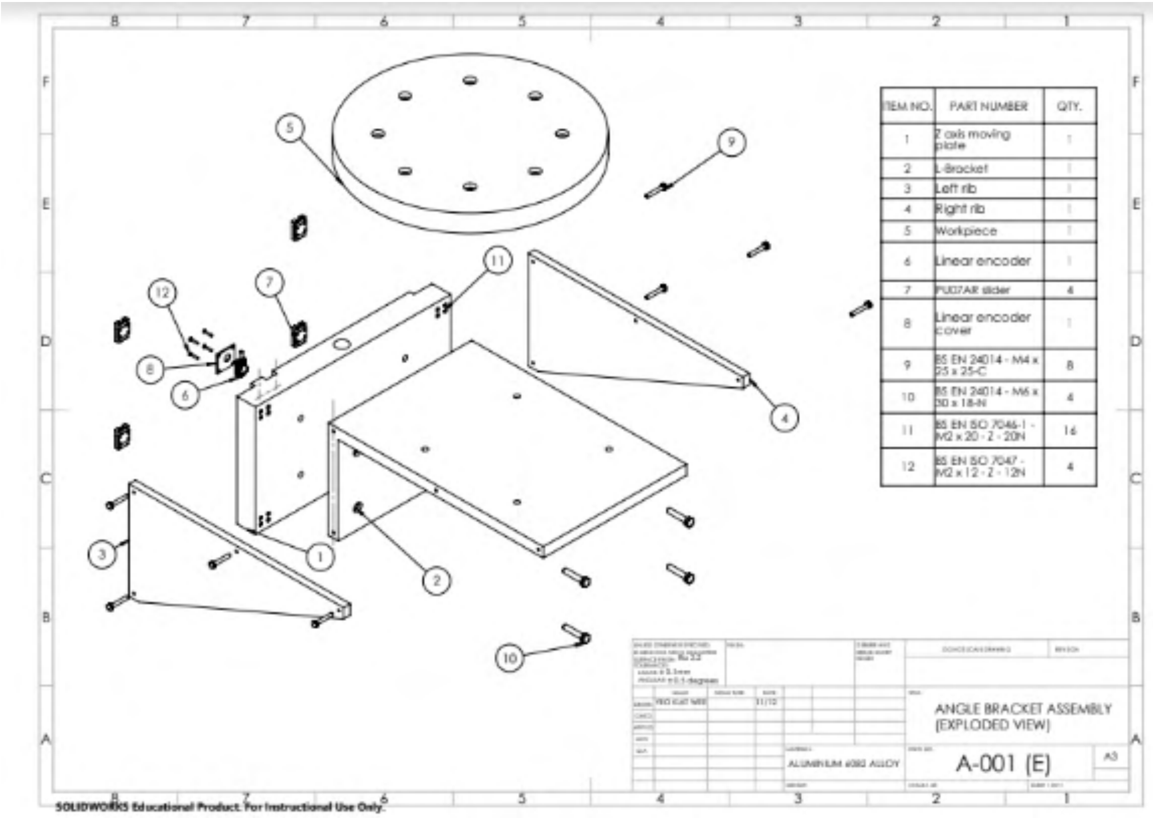
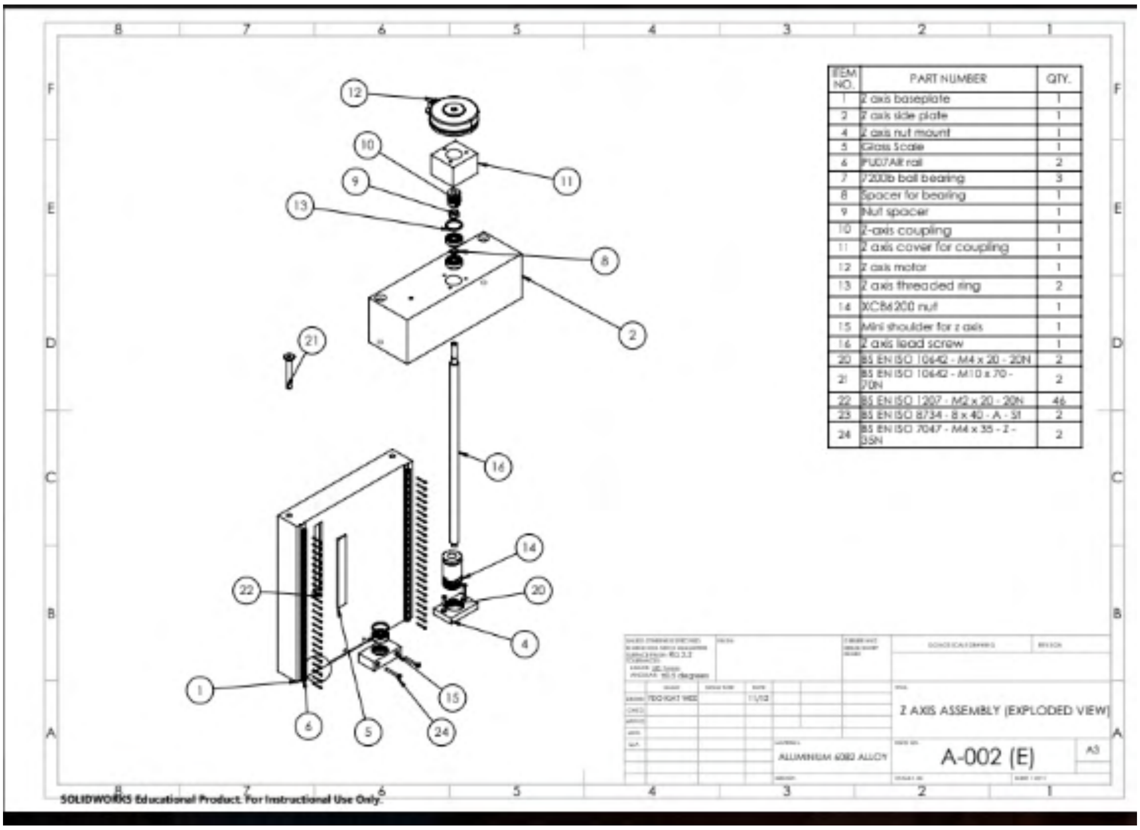
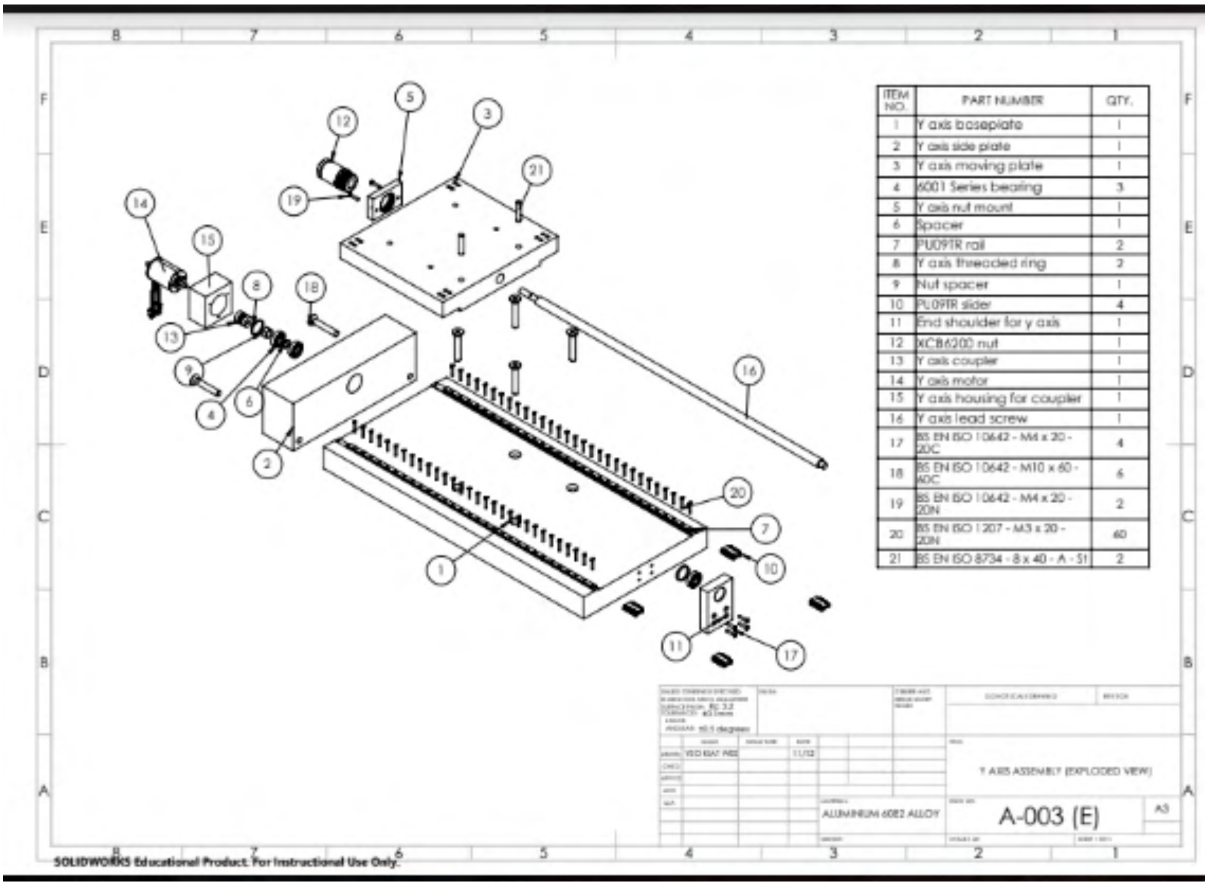
Overall Model Drawings






ITEM NO. | PART NUMBER | QTY.
1 Y axis baseplate 1
2 Y axis side plate 1
3 Y axis moving plate 1
4 6001 Series bearing 3
5 Y axis nut mount 1
6 Spacer 1
7 PU09TR rail 2
8 Y axis threaded ring 2
9 Nut spacer 1
10 PU09TR slider 4
11 End shoulder for y axis 1
12 XCB6200 nut 1
13 Y axis coupler 1
14 Y axis motor 1
15 Y axis housing for coupler 1
16 Y axis lead screw 1
17 BS EN ISO 10642 - M4 x 20 - 20C 4
18 BS EN ISO 10642 - M10 x 60 - 60C 6
19 BS EN ISO 10642 - M4 x 20 - 20N 2
20 BS EN ISO 1207 - M3 x 20 - 20N 60
21 BS EN ISO 8734 - 8 x 40 - A - St 2
YEO KIAT WEE
Y AXIS ASSEMBLY (EXPLODED VIEW)
ALUMINIUM 6082 ALLOY
A-003 (E)
A3
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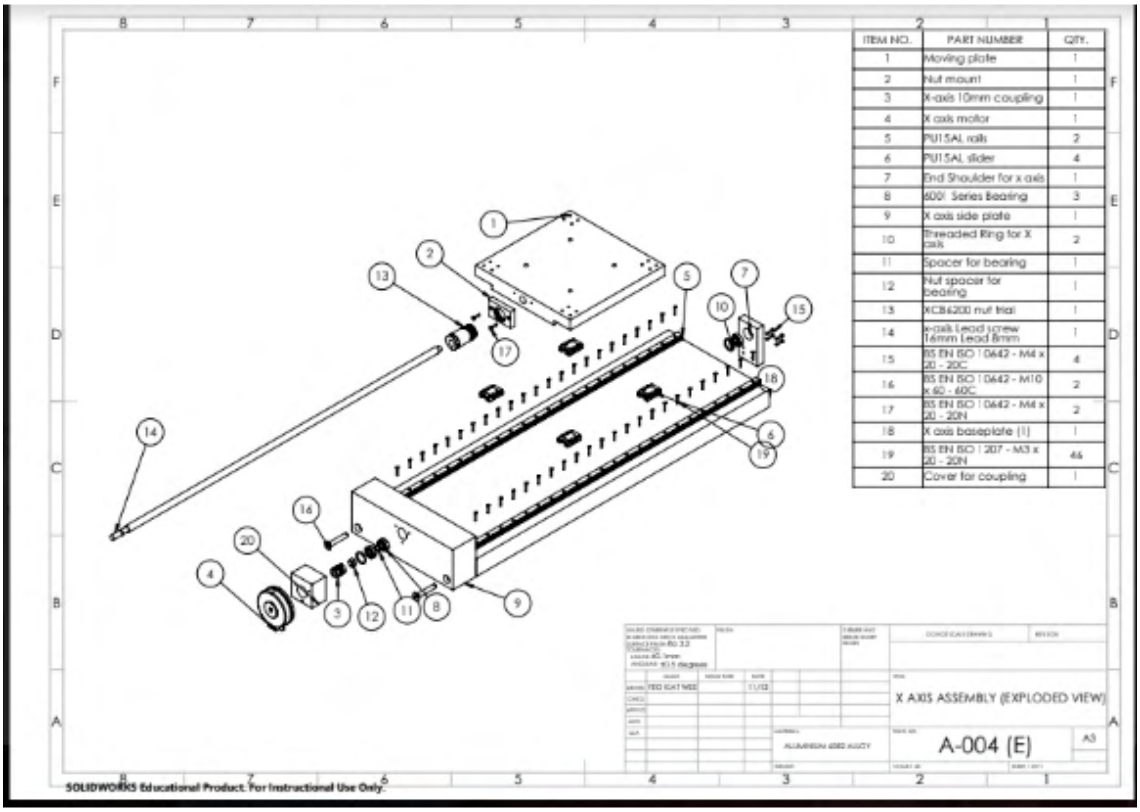
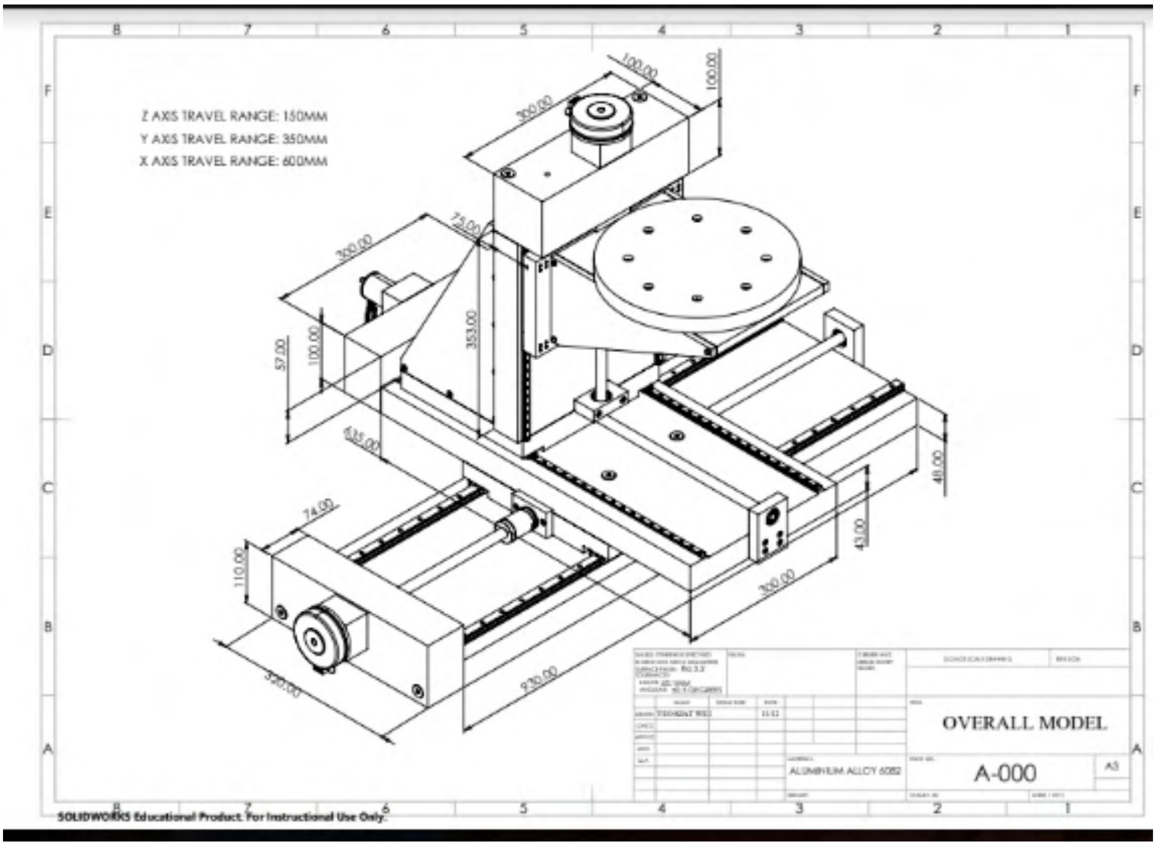

ITEM NO. | PART NUMBER | QTY.
1 Moving plate 1
2 Nut mount 1
3 X-axis 10mm coupling 1
4 X axis motor 1
5 PU15AL rails 2
6 PU15AL slider 4
7 End Shoulder for x axis 1
8 6001 Series Bearing 3
9 X axis side plate 1
10 Threaded Ring for X axis 2
11 Spacer for bearing 1
12 Nut spacer for bearing 1
13 XCB6200 nut trial 1
14 x-axis Lead screw 16mm Lead 8mm 1
15 BS EN ISO 10642 - M4 x 20 - 20C 4
16 BS EN ISO 10642 - M10 x 60 - 60C 2
17 BS EN ISO 10642 - M4 x 20 - 20N 2
18 X axis baseplate (1) 1
19 BS EN ISO 1207 - M3 x 20 - 20N 46
20 Cover for coupling 1
YEO KIAT WEE
X AXIS ASSEMBLY (EXPLODED VIEW)
ALUMINIUM 6082 ALLOY
A-004 (E)
A3
SOLIDWORKS Educational Product. For Instructional Use Only.


Z AXIS TRAVEL RANGE: 150MM
Y AXIS TRAVEL RANGE: 350MM
X AXIS TRAVEL RANGE: 600MM
OVERALL MODEL
ALUMINIUM ALLOY 6082
A-000
A3
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