UNIVERSITY OF WATERLOO
Faculty of Engineering

DESIGN AND INSTALLATION OF INKJET PRINTING SYSTEM ON A FLATBED ROUTER

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Dr. Pearl Sullivan, Chair
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Dear Professor Sullivan,

The enclosed report entitled 'Design and Installation of Inkjet Printing System on a Flatbed Router' was written as my fourth work term report (3B) for my employment at the University of Waterloo.

Under the supervision of Dr. Kaan Erkorkmaz at the Precision Controls Laboratory my main responsibility was to integrate inkjet printing system on a flatbed router to build a combined cutting-printing system. The project was carried out to support the research of a master's student, Ms. Dayna Chan. This report documents the completed mechanical and electrical designs for the integration as well as the selection of necessary components purchased. This report was written entirely by me and has not received any previous academic credit at this or any other institution.

I would like to thank Mr. Jeffry Gorniak, Mr. Ammar Alzaydi, and Mr. Sui Gao for their help in machining mechanical components; Mr. Robert Wagner and Mr. Andy Barber for their technical assistance during the design and installation process; and Ms. Dayna Chan and Dr. Kaan Erkorkmaz for providing me with valuable feedback throughout the project.

Sincerely,

AJung Moon

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SUMMARY

This report focuses on mechanical and electrical design involved in retrofitting 4'x8' flatbed router into a combined cutting-printing system. This retrofitting operation contains three main design sections: selection of vertical axis drive components, electrical system design, and mechanical design of fixtures.

The first section compares a few common vertical axis drive systems available in the industries. These configurations include ACME screws, ball-screws, as well as belt and pulley system. Given the budgetary limit in addition to the requirements for positioning accuracy a DC servo motor and ball-screw stage is chosen.

The second section briefly describes the electrical design involved in this project. With emphasis on safe operation of the machine, a 24VDC power supply required to power the selected vertical axis is connected to the router's main power. This configuration ensures that both the router and the inkjet system will immediately halt when any one of the router's existing emergency stops are pressed.

The third section describes the mechanical design involved in mounting different components of the inkjet system. These designs include: mechanical connection between the new vertical axis and the router, fixture design involved in the components that travel along the new vertical axis, and modifications on the router's gantry for mounting of peripheral components.

All mechanical components have been built, assembled, and installed onto the router unit. After the retrofit the router's performance for the three axis of motion was tested using the machine's built-in controller.

It is recommended that covers or separators be installed between the router's spindle and the printhead mounting unit in order to protect the printhead nozzles from machined debris. It is also recommended that a sensor be installed near the printhead nozzles in order to detect the distance between the printing surface and the printhead nozzles and to avoid collision of the two objects. Upon completion of electrical work, CSA inspection should be done on both the Z'-axis components as well as the router. Control algorithms for the Z'-axis printing unit and re-characterization of router's control parameters should be implemented via PC and control system platforms such as dSpace.

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1 INTRODUCTION

It has been many years since computer numerical controlled (CNC) machines became widely used in industries. CNC machines have not only freed human machinists from laborious and repetitive work on mills, lathes, and routers, but also allowed rapid and precise manufacturing of products. Recent developments in the CNC technology and computer-aided manufacturing (CAM) software tools are constantly improving the complexity, accuracy and repeatability of the finished products.

The main advantage of a CNC machine is its ability to accurately position its end-effector. This high precision positioning is also highly-desired in other manufacturing processes. One such process is printing. If printing capability can be added onto a CNC machine, the machine would be able to cut and print on the same object. Such dual function machines can be useful in manufacturing large colourful objects such as signs or engraved doors with printed images. In addition, a combination of CNC and UV cure printing technology would produce a machine that can print and engrave on plastic or metal surfaces.

<*Company name omitted*> has become interested in the idea of a combined cutting-printing machine using the company's flatbed router. This project is being undertaken by the Precision Controls Laboratory at the University of Waterloo under the supervision of Dr. Kaan Erkorkmaz. The desired final outcome of the project is to retrofit <*Company name omitted*>'s router with UV cure printing technologies.

However, setting up UV cure printing method is in itself a challenging process due to the complex curing process involved. Hence, the quality of printing from the router would depend on two independent variables – the configuration of the print head system on the router as well as the UV curing process. To eliminate this complexity the initial stage of the project utilizes a solvent based inkjet printing method as a proof of concept for integrating general printing technology onto a CNC router. Solvent based inkjet printing is a relatively straight forward printing method that can eliminate the variables associated with the complex UV cure process. Once the retrofit of the router is deemed suitable then UV cure printing can be installed as the final step of the project. Figure 1 is a visual representation of the two approaches to the project.

The Xaar 126, the chosen printing system to be installed onto the router, is compatible to both solvent and UV based inks. This dual compatibility will allow the system to convert from solvent to UV based system without requiring any major modifications.

This report documents the initial stage of the project focusing on the mechanical and electrical design of components required to retrofit the router and integrate solvent based inkjet printing system.

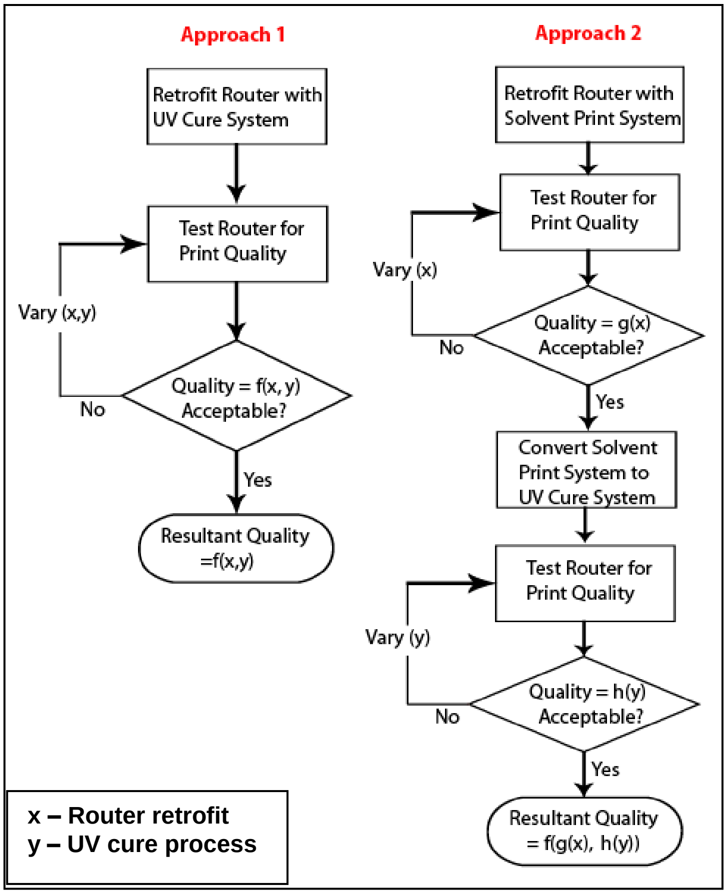


Figure 1 Two different approaches to the project

1.1 Router

<*Company name omitted*>'s router is a 4'x8' flatbed CNC machine with three axes of motion (X, Y, and Z). The picture of the router is shown in Figure 2.

Each of the three axes has ball-screw drive mechanisms powered by DC motors. The Y and Z axes have single ball-screw drives and the X-axis uses two ball-screw drives to support the ends (X_{Left}, and X_{Right}) of the gantry. Originally the machine only had

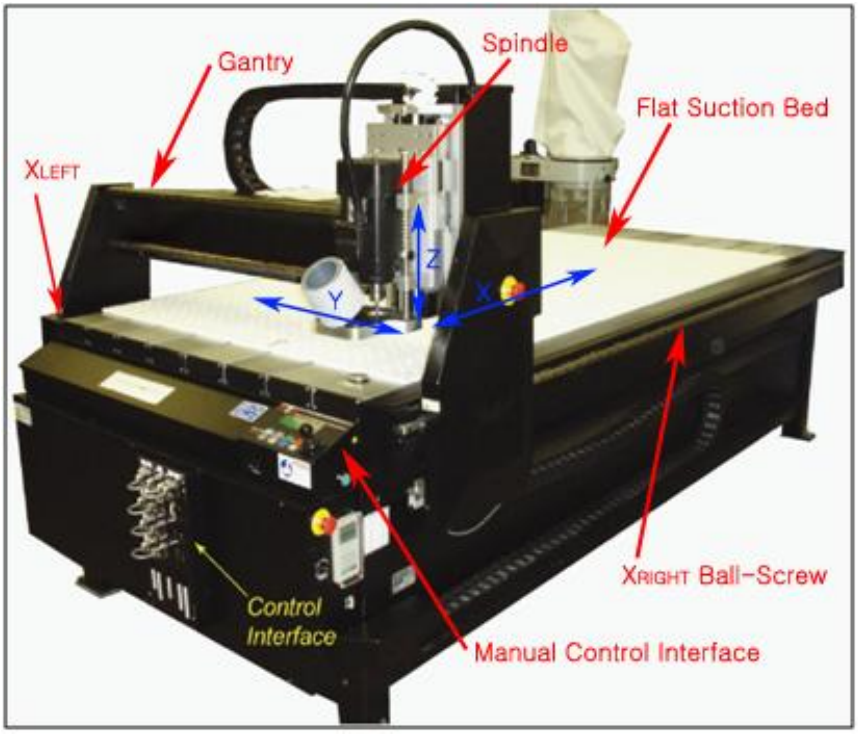


Figure 2 The 4'x8' router in isometric view

built-in rotary encoders on each motor. However, linear encoders were added for X_{Left}, X_{Right}, and Y axes for more accurate position measurement. Implementation of feed-forward compensation in combination with linear encoder retrofit has resulted in 127.09% improvement in overall 2D tracking error, making the position accuracy of the router to be ±28.53μm. This level of position accuracy is deemed acceptable for inkjet printing [1].

The functional work area of the CNC router is 2400mm x 1200mm, and the machine's maximum tool positioning speed is 250mm/s. A 3hp spindle is located on the Z-axis and is capable of cutting wood, plastics and metals.

The router can be controlled either by the built-in controller, or by PC and a control system platform (dSpace). The built-in controller allows basic control of the router such as performing homing routine and manual positioning of spindle via a joystick interface. Controls from the PC using RS232 serial interface and MATLAB software allows much more elaborate control of the router. This configuration will form the basis of controlling printing trajectory of the machine.

Implementation of Xaar 126 printing system requires a secondary Z-axis to be installed onto the router. Since the existing Z-axis drive is used for the spindle an additional vertical axis is required in order to keep the printhead nozzles at their optimum distance above the printing surface independent of vertical motions of the spindle. This additional Z-axis will be written as Z'-axis from hereafter, and its planned location is shown in Figure 3.

Figure 3 Z'-Axis drive installation location plan

1.2 XAAR 126 INKJET PRINTING SYSTEM

The Xaar 126 printing system has four XJ-126 printheads (Figure 4) each equipped with 126 nozzles. These printheads are capable of printing colour images at a resolution of 300dpi. Each printhead is designated to a single colour of ink – cyan, magenta, yellow, or black.

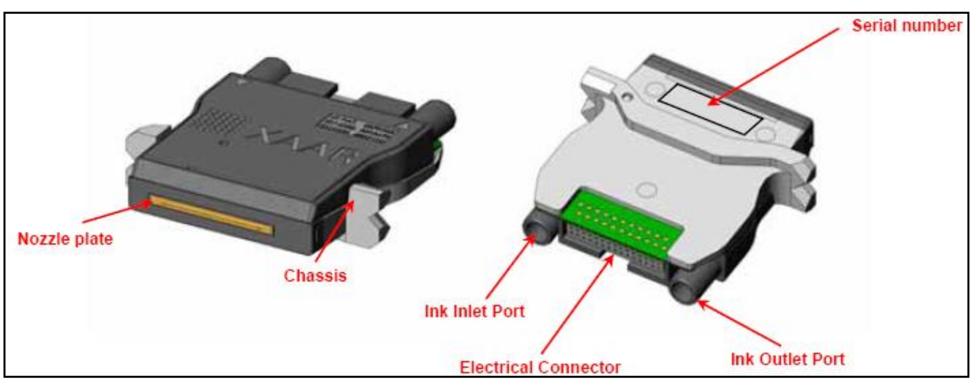


Figure 4 XJ-126 printhead

Each of the four ink reservoirs are fed into corresponding filters and connected to the respective ink pumps. Each pump is responsible for sending ink to the header tanks for maintaining a constant volume of ink in the vessels. Headers tanks supply ink to the printheads at a constant pressure. The Ink Supply Controller (ISC) controls the header tanks and ink pumps. ISC can be connected to a PC for real-time status monitoring of the header tanks and pumps. A typical ink supply schematic is visually represented in Figure 5.

In order to process an image, the computer sends image data to the XUSB controller via USB interface. Once the image data is received, the XUSB controller determines the required printing sequence and sends appropriate signals to all four of the printheads. Since the XJ-126 printhead is an older generation of component relative to the XUSB controller, the commands from XUSB cannot directly be understood by XJ-126. Hence, Head Personality Card is used to translate the commands from XUSB to signals understood by the four XJ-126 printheads. The Xaar 126 printing system comprises of ten main components. Table 1 provides a summary for their respective functions and installation notes.

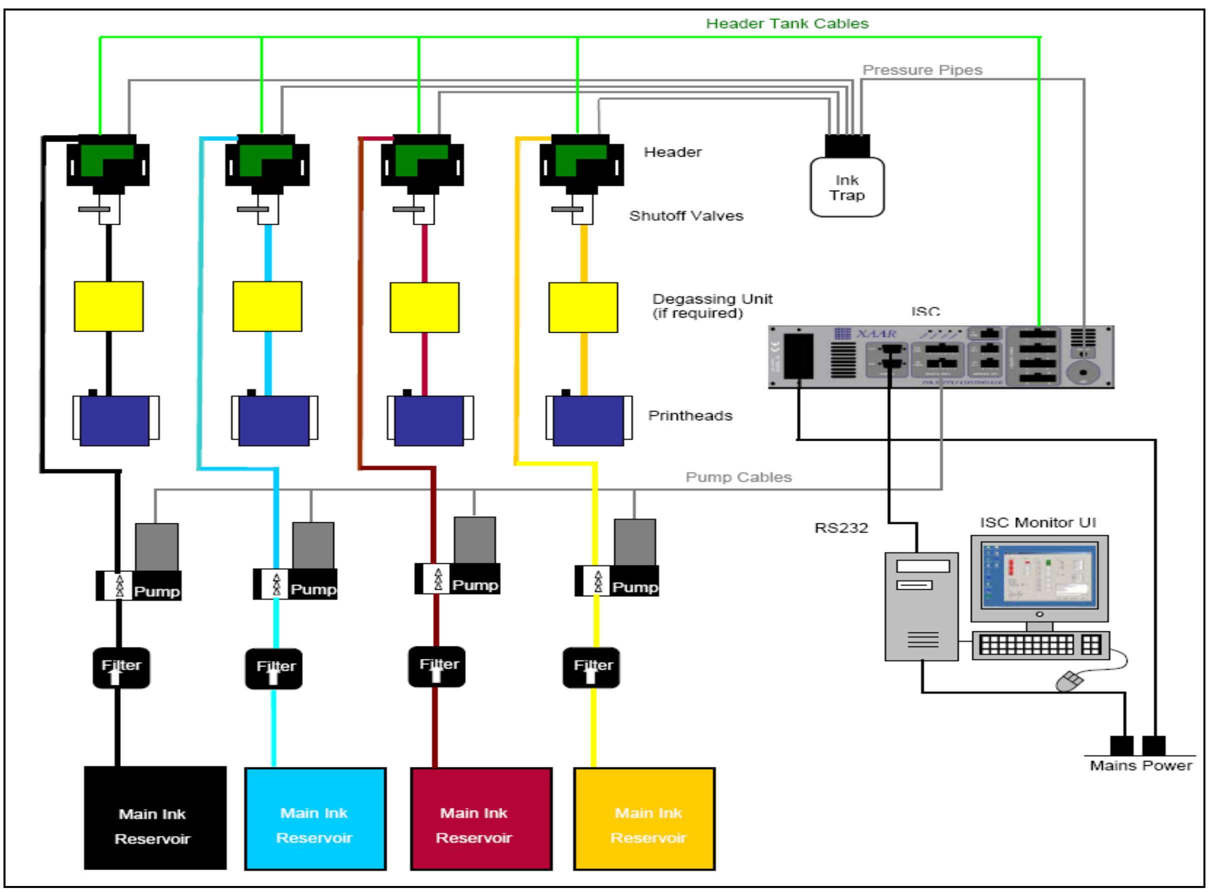
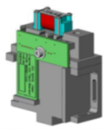
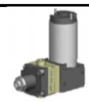


Figure 5 Typical Xaar 126 ink supply schematic [2]

Table 1 Xaar 126 printing system components function and installation notes

Component	Function	Quantity	Installation Notes
XJ-126 Printhead 	Printhead that receives ink from a header tank and dispenses onto printing surface via 126 nozzles. Achieves 300dpi resolution at 36.9 degrees of tilt angle.	4	Must be tilted at 36.9 degrees. Nozzle plate must be parallel to printing surface with 1mm optimum gap between printhead nozzles and printing surface.
Header Tank 	Receives ink from pump and supplies ink to the printhead at a correct pressure.	4	Vertical orientation required. Bottom of header tank must be 150mm to 350mm above the printhead nozzles. All tanks must be at the same height.
Ink Pump 	Pumps ink from filter to the header tank.	4	Vertical orientation required.
Filter 	Ink from the ink reservoir gets filtered as ink passes through the filter into the ink pump. Particles of size ≥5µm are filtered in order to prevent nozzle blockage.	4	Vertical orientation required. Vent of filter must face upwards. Minimum distance to ink pump is desired in order to minimize required tube length.
Ink Supply Controller (ISC) 	Generates the negative pressure required by the header tanks. Controls switching of ink pumps.	1	Can be mounted in any orientation. Must be in close proximity to a PC for communication.
XUSB Controller 	Receives image from computer and sends data to printheads at real time. Provides power to printheads.	1	Must be located near its power supply. Minimum distance to a computer is desirable in order to minimize length of cables.
Power Supply for XUSB 	Supplies 24VDC power to XUSB controller from 115VAC power source.	1	Must be located in close proximity from XUSB due to cable length limitation (2.5m).
Head Personality Card(HPC) 	Enables the use of XUSB controller on older versions of XAAR printheads such as XJ-126.	1	Must be mounted near printheads. Ribbon cables of length 30cm need to connect printheads to the HPC.
Ink Trap Bottle 	Prevents inks from being sucked into the ISC. Acts as a single air outlet from ISC to header tanks.	1	Vertical orientation required. Minimum distance to header tanks is desired in order to minimize required tube length.
Ink Reservoir 	Contains inks for printing.	1 of each colour (Total 4 bottles)	Vertical orientation required. Minimum distance to filter is desired in order to minimize required tube length.

2 Z'-Axis Stage Selection Process

As shown in Figure 3, an independent vertical axis needs to be installed beside the spindle. Since the vertical motion does not require any customization from what is available in the market different types of drive mechanisms were evaluated. This section documents the process of choosing the most appropriate Z'-axis drive system.

2.1 Selection Criteria

The following list of criteria/constraints for selecting Z'-axis drive was compiled based on the limited information available at the beginning of the project:

<u>**Criteria:**</u>

1. **Minimum vertical travel length of 7"**
2. **Must be able to carry minimum 3kg of weight vertically**
   Weight of four printheads is 120grams in total, and weight of printhead mounting plates is estimated to be 2kg.
3. **Positioning speed of 38mm/s or higher**
   Maximum positioning speed of the router is 250mm/s. 38mm/s is the minimum positioning speed of the Z'-axis that will not create bottleneck in the printing process.
4. **High repeatability**
   Quality of print will depend on the amount of gap between printhead nozzles and printing surface. The optimum gap of 1mm should consistently be achieved.
5. **Built-in or installable encoder with resolution of less than 10µm**
   Optimum 1mm gap between surface of print and nozzles is required by the printheads for optimum quality of print. With maximum 10µm of encoder resolution the maximum deviation from the optimum gap is ±10%. Tolerance information on the optimum gap is not provided by XAAR, and such deviation is assumed acceptable.
6. **Must not back-drive upon power-off**
7. **Must have minimum or constant backlash**

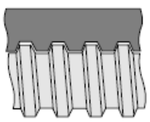
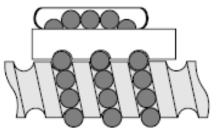
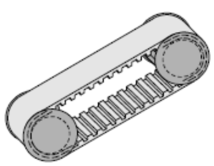
<u>**Constraints:**</u>

1. **Budget of under $3000 CAD**
2. **Delivery time of less than 6 weeks**
3. **Width of 6 inches or smaller**
   Since Z'-axis will be installed beside Z-axis of the spindle, width of Z'-axis drive system can become a limiting factor to the functional area of the router if it is greater than minimum width of carriage mounting plate (estimated width of 6").
4. **Maximum weight of 56.6kg**
   Assuming the linear guide bearings used to support other axes is used to support the weight of the Z'-axis and its components, 56.6kg is the maximum weight of Z'-axis a bearing can support. Calculation for this value is shown in Appendix A.

2.2 DRIVE SYSTEM COMPARISON AND Z'-AXIS STAGE SELECTION

Three different drive mechanisms were considered based on availability and budgetary limit: ACME screw, ball-screw, and belt & pulley system. Comparison between the different drive mechanisms is summarized in Table 2.

Table 2 Comparison of different drive mechanisms [3]

Drive Mechanism	Pros	Cons
ACME Screw 	-Low operating noise -High friction prevents back-driving - Good repeatability	-Low efficiency, high friction -Low speed -Low duty cycle -Low long term life -Backlash increases with wear
Ball-Screw 	-High efficiency -High speed -High duty cycle -High long term life -High accuracy and repeatability -Constant backlash	-Easily back-drivable -Significantly higher prices for increase in speed
Belt & Pulley 	-High efficiency -High speed -High duty cycle -Medium long term life -Good accuracy and repeatability -Provides consistent speed throughout its travel length -Great for long travel length applications	-Easily back-drivable -Backlash increases with stretching, tension, and wear of belt

Although ACME screw mechanism provides advantages of natural back-drive prevention, it was deemed inappropriate due to its low efficiency, speed, and duty cycle. Ball-screw and belt & pulley mechanism both offer high efficiency, speed, duty cycle as well as good repeatability. The ability of the belt & pulley to provide long travel lengths were negated for this particular application. Considering the cost differences, durability, and backlash of the two mechanisms, ball-screw was selected as the most appropriate candidate for this project.

A number of ball-screw driven stages were found. Each of these products were compared according to the list of criteria mentioned in section 2.1, and are summarized in Table 3. Of the five products compared, two met the budgetary constraints as well as the requirements for travel length and rated load. These products are LinTech Series 130, and Velmex BiSlide 10". With only $400 difference LinTech Series 130 product offers significantly faster positioning (127mm/sec) than BiSlide 10"(32mm/sec), can be equipped with a better resolution encoder (1.27 μm vs 1.6 μm) as well as larger ball-screw diameter for improvement in rigidity. Both products meet the criteria and constraints outlined in section 2.1, except BiSlide has slower positioning speed than what is desired (38mm/s). Hence LinTech Series 130 linear stage was chosen as the Z'-axis drive system. A layout of LinTech Series 130 is shown in Figure 6. The stage is equipped with a precision grade ball-screw of 0.625" diameter and 0.2" lead. Two linear bearings attached to one side of the carriage rides on a stainless steel rail and offers maximum travel length of 8".

In order to meet the encoder resolution requirement a rotary encoder of 1000ppr is added onto the stage. The encoder resolution, after taking into account the encoder quadrature decoding, can be calculated as follows:

$$l = 0.2''/rev = 5.08mm/rev \quad (1)$$

$$\mathrm{r} = 1000\ \frac{\mathrm{pulses}}{\mathrm{rev}} \times 4\,\frac{\mathrm{counts}}{\mathrm{pulses}} = 4000\,\frac{\mathrm{counts}}{\mathrm{rev}} \quad (2)$$

$$\mathrm{l/r} = 0.00127\ \mathrm{mm} = 1.27\mu\mathrm{m/count} \quad (3)$$

where l is the lead, and r is the encoder resolution in cpr. Resolution of 1.27μm satisfies the encoder resolution criteria.

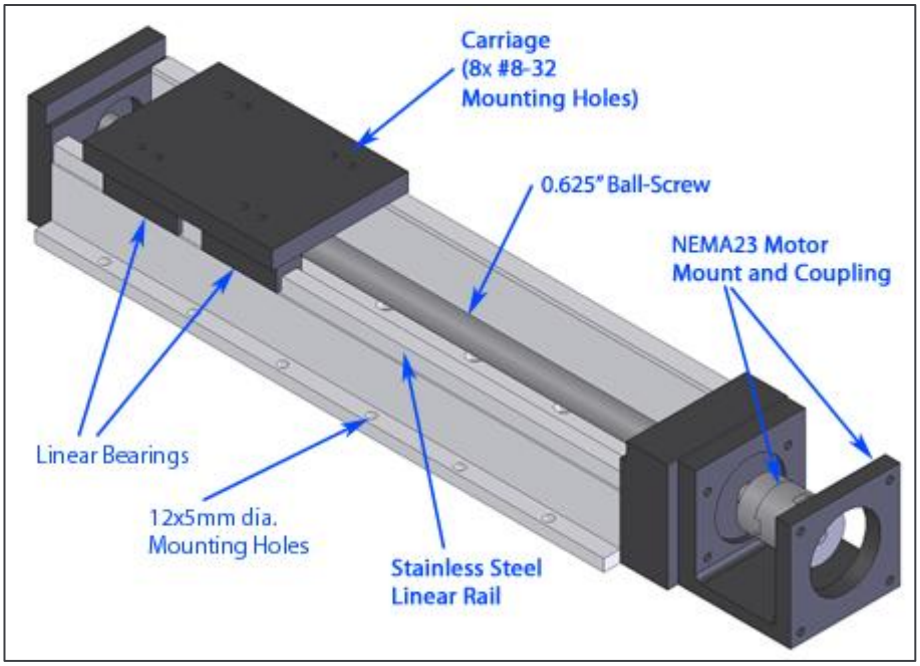


Figure 6 LinTech Series 130 linear stage layout

Table 3 Z'-Axis product comparison chart

Model Name	BiSlide 10"	Series 130	402XR Series	400XR Precision	400XR Standard
Manufacturer	Velmex	Lintech	Parker	Parker	Parker
Motor Details	DC Stepper (NEMA23, 1.8°/step)	DC Stepper (NEMA23, 1.8°/step) or DC Servo	DC Servo	DC Servo	DC Servo
Travel Length	254mm	203mm	200mm	200mm	200mm
Width	86mm	73mm	57mm	40.9mm	40.9mm
Overall Length	457mm	403mm	420mm	384.3mm	384.3mm
Mounting Holes	8	8	4	4	4
Encoder	Rotary (400 cpr, or 1.6µm) Linear (5µm)	Rotary (1000ppr->1.27 µm)	Rotary (1.0µm), Linear (1.0, 0.5, 0.1µm option)	Linear (0.5µm)	None
Rated Load	45kg	30kg	38 kg	15.5kg	15.5kg
Repeatability	4µm	Unknown	1.3µm	1.3µm	1.3µm
Max. Vel	32mm/sec	127mm/sec	700mm/sec	700mm/sec	700mm/sec
Actuator Weight	3.6kg + motor weight	2.9 kg	3.2kg	1.5kg + motor weight	1.5kg + motor weight
Brakes	Motor takes Brake commands from controller	Yes	No Mechanical brakes	No Mechanical brakes	No Mechanical brakes
Advance/Step for DC Stepper	0.1"(2.54mm) advance/rev. 0.0005"(12.6µm) per step.	0.2"(5.08mm) advance/rev. 0.001" (25.4µm) per step	N/A	N/A	N/A
Screw Diameter	0.5"	0.625"			
Price (CAD)	$1872.00	$2240.00	$6064.96 *Quoted for 0.5µm Linear Encoder	$5459.00	$3370.00
Notes	One week delivery time.	Need to assemble motor and slider.	May drop down upon power off.	Two week delivery.	Two week delivery.

2.3 POWER COMPONENT SELECTION

It is desirable to control Z'-axis with the same configuration of control as the router since this will allow both cutting and printing sequence of the machine to be controlled by a single controller. A DC servo motor with NEMA23 mounting, amplifier, and power supply achieves this configuration as shown in Figure 7.

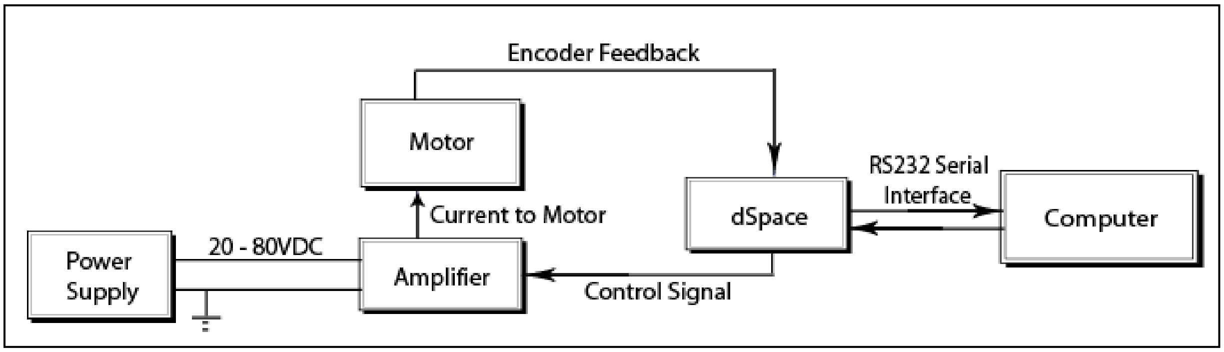


Figure 7 Control schematic of Z'-axis

A spare amplifier, 12A8 from Advanced Motion Controls, was available for the laboratory use. The 12A8 takes 20 to 80V unregulated DC power from a power supply, and has maximum continuous current of ± 6 Amps and peak current of ±12 Amps. The amplifier can receive ±10 VDC of analog input from dSpace and send corresponding amount of current to power the motor.

With the assumed 3kg of weight of the components on carriage, maximum torque required to move the carriage at maximum acceleration is calculated as below:

$$a_{max} = 127mm/s^2 \tag{4}$$

$$F = \left(9.81\frac{m}{s^2} + a_{max}\right)\cdot(3kg) = 29.8\ N \tag{5}$$

$$\mathrm{T_{Raise}} = \frac{\mathrm{Fd_m}}{2}\cdot\left(\frac{l+\pi \mathrm{fd_m}}{\pi \mathrm{fd_m} - fl}\right) = 0.0827\ \mathrm{Nm} \tag{6}$$

where a_{max} is the maximum rated acceleration of the stage, F is the force due to the weight of the load, T_{Raise} is the torque required to raise the carriage, d_m is the diameter of the ball screw (15.9mm), l is the lead of the ball screw, and f is the coefficient of friction of 0.3.

In order to ensure that the system will not back-drive upon power off, the calculated torque is used to check the self-locking condition via equation (7):

$$\pi\cdot \mathrm{f}\cdot \mathrm{d_m} - l = 0.0069 \tag{7}$$

According to Singley if the value of $(\pi \cdot f \cdot d_m - l) > 0$ then the system is self-locking [4]. The resultant value of the equation is very close to 0 indicating that the system may back-drive with 3kg of load. Hence, an electrical motor brake was deemed necessary.

Using the value of T_{Raise} calculated from above a DC brush servo motor, Motor Control Group ID23005, is chosen to raise the estimated load via the ball-screw mechanism. The motor's continuous rated torque is 0.402Nm, and peak torque is 2.825Nm with rated speed of 3400rpm. This achieves a safety factor ($T_{Continuous\_rated\_stall} / T_{Raise}$) of 5 assuming the estimated weight of the load is correct. The motor consumes 4.14 Amps and 25.90 Amps at stall torque and peak torque respectively.

Given,

$$R_m = 2.23\ \Omega; \qquad K_t = 0.121 \frac{Nm}{A}; \qquad K_e = 12.7 \frac{V}{kRPM};$$

$$T_{rms} = 0.58Nm; \qquad \omega = 1500rpm$$

where R_m is the motor impedance, K_t is the torque constant, K_e is the voltage constant, and T_{rms} is the root mean square torque, the requirement for the power supply was derived from the calculation below:

$$I_m = \frac{T_{rms}}{K_t} = 4.74\ Amp \tag{8}$$

$$V_{emf} = K_e \cdot \omega = 19.1V \tag{9}$$

$$V_t = I_m \cdot R_m + V_{emf} = 29.7\ V \tag{10}$$

$$P = V_t \cdot I_m = 140.6\ W \tag{11}$$

Here, I_m represents motor current, V_t indicates motor terminal voltage, V_{emf} represents back emf voltage, and P indicates the power required by the motor. The power required by an optional electrical motor brake is 4.4W and uses 24VDC. One 24VDC power supply for both the motor and brake has been sized. Since the total required power from the power supply is 145.0W, a 24VDC power supply capable of minimum 6.0Amps of current was sought. The 240W (24VDC, 10Amp) DLP240-24-1 power supply was chosen, resulting in a factor of safety of 1.7.

3 ELECTRICAL DESIGN

There are two options to providing AC power source to the 240W AC-DC power supply selected in section 2.3. One is to use the power outlet (115VAC) available on the walls of the laboratory, and the other is to use the main power (240VAC) available from the router. Although both options would provide enough AC power to the power supply, the latter option was deemed more desirable due to safety reasons.

If the power supply uses a power source other than that of the router's main power, then the entire Z'-axis control system shown in Figure 7 would run on a completely separate circuit from that of the router. This means that a separate emergency stop circuit will have to exist for the Z'-axis if the machine must halt immediately for safety reasons. If two different emergency stops are to be pressed at an urgent situation the purpose of having emergency stop is defeated. Hence, it has been decided that the power supply will take 240VAC power available from the router's main control panel such that the existing emergency stops on the router will halt both the router as well as the Z'-axis system when pressed.

According to the safety regulations of the CSA electrical code, the power supply needs to be mounted inside an electrical housing. Instead of building an electrical housing, the DLP 240-24-1 power supply (4.7"x4.3"x3.8") is mounted inside a 7"x7"x6" space available in the control panel at the front of the router. Mounted power supply inside the control panel is shown in Figure 8. Complete electrical connection schematic is shown in Appendix C.

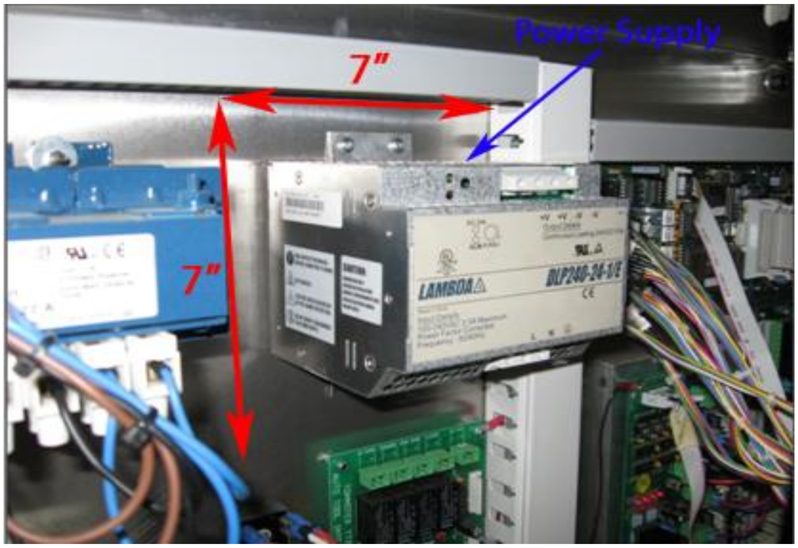


Figure 8 Power supply inside the router control panel

4 MECHANICAL DESIGN OF INKJET SYSTEM MOUNTING

Three main sections of mechanical design were involved in mounting all the required components of the inkjet system from Table 1. First, a mechanical interface for the Z'-axis was designed in order to link the Z'-axis to the router's gantry and Y-axis drive. Second, mountings for printheads and other components to be carried by the Z'-axis were designed. Lastly, other components that are not mounted on the Z'-axis carriage – such as filters, pumps, and inks – but need to be in a close proximity to the axis are mounted on the router gantry.

4.1 Z'-AXIS STAGE TO ROUTER INTERFACE

The simplest way to share the XY axes of the router between the two vertical axes is to connect the two axis drives with couplings. A set of couplings were designed and their dimensional parameters were calculated for safety factors. The linkages were designed to minimize the weight impact on the unit while providing the necessary structural rigidity. The parallel layout of the links ensures the orientation of the Z'-axis unit. Detailed calculation can be found in Appendix B.

These couplings were calculated with the assumption that a set of bearings will be implemented to take the thrust load of the Z'-axis. Otherwise, there will be moment created by the weight of the Z'-axis assembly as shown in Figure 9. The moment due

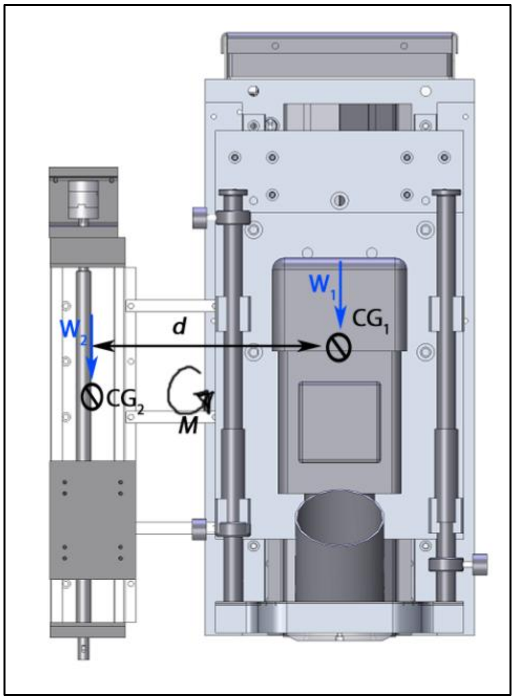


Figure 9 Z'-axis moment (M) diagram

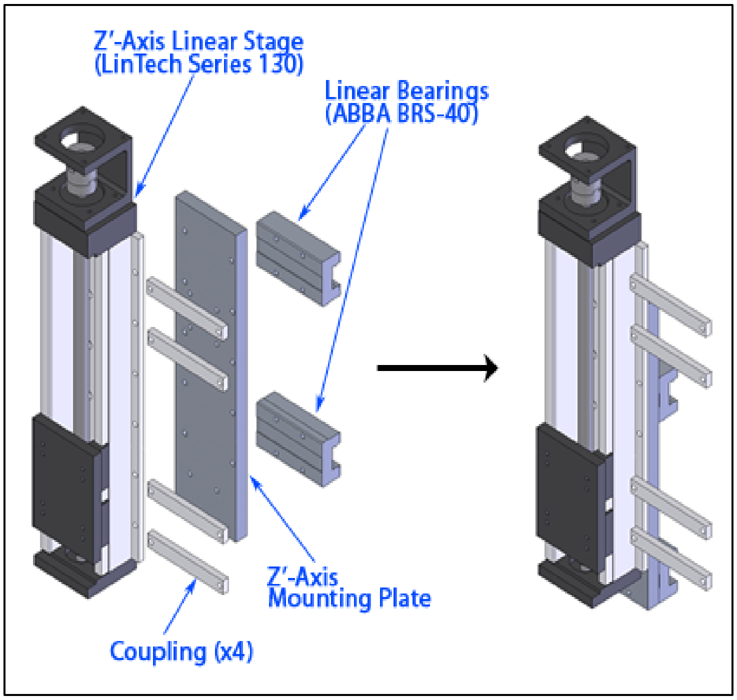


Figure 10 Z'-axis stage to router interface assembly

to the load (W_2 in Figure 9) may result in undesirable added dynamics to the router. Hence, a set of linear bearings (ABBA BRS-40) were implemented to eliminate the moment and support the weight of the Z'-axis assembly.

The length of the couplings was modified after the mountings on Z'-axis carrier had been designed such that there would be no interferences between the spindle and the inkjet printing system mounting assembly. The finalized mounting assembly for integrating the Z'-axis to Z-axis is shown in Figure 10.

4.2 MOUNTING INKJET PRINTING COMPONENTS ON Z'-AXIS CARRIAGE

A number of inkjet printing system components listed in Table 1 need to be mounted onto the Z'-axis carrier. Those components include: four printheads, four header tanks, a Head Personality Card (HPC), and an ink trap bottle. Printheads, header tanks, and ink trap bottle must be connected to each other via 3mm tubing. Figure 11 is an illustration of the assembly for the inkjet printing components.

Electrically, HPC and the printheads need to be connected via four 30cm ribbon cables. The HPC and header tanks must be connected to XUSB and ISC controller respectively, both of which are too heavy and large to be mounted on the Z'-axis carriage. These two electrical connections are mounted externally and the cables will be fed through the cable tracks from the carriage to their respective controllers. Electrical schematics between components can be found in Appendix C.

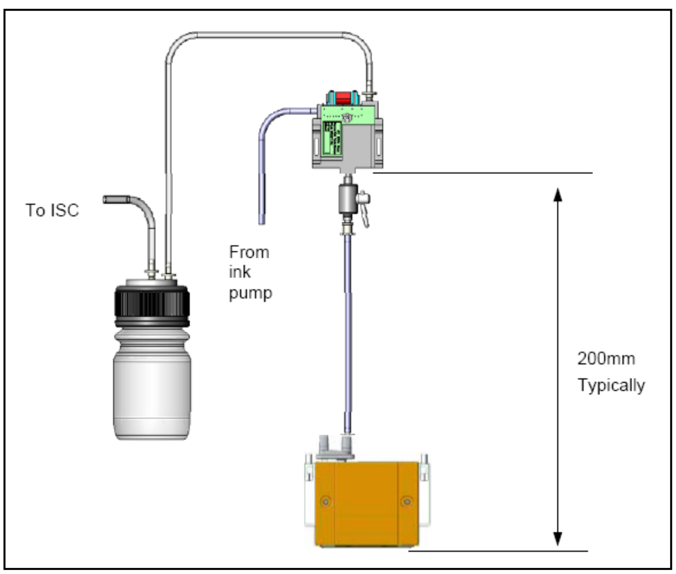


Figure 11 Header tank, printhead, and ink trap bottle tube connection [2]

4.2.1 BOTTOM PLATE FOR PRINTHEAD MOUNTING

Due to the fact that the XJ-126 printheads only have 126 nozzles, the printheads must be tilted at an angle of 36.9º in order to produce 300dpi resolution image. This configuration is shown in Figure 12.

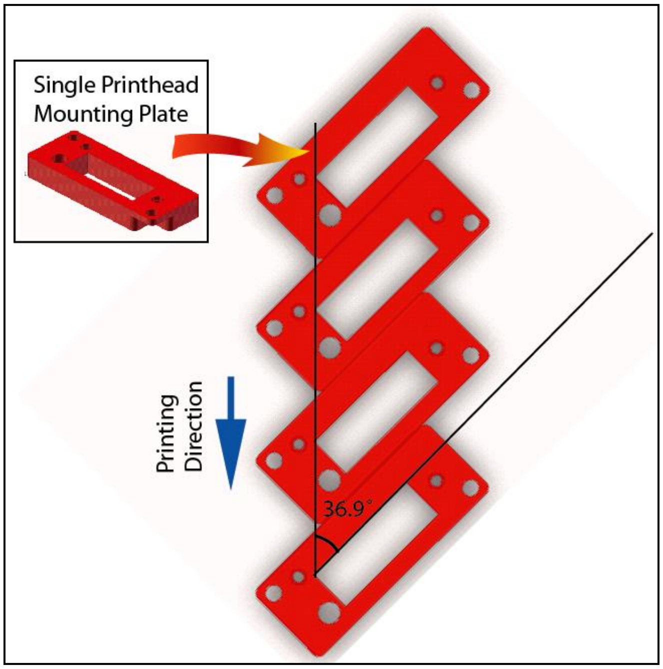


Figure 12 XJ-126 printhead mounting angle

In designing a horizontal mounting plate for printheads there were two options: a single unit mounting plate and individual printhead mouting plates. The individual mounting plates could be assembled on a larger mounting plate such that their tilt angle as well as the distance between each other can be fine-tuned. The other option involved fabricating one large mounting plate that would replace the single mounting plates.

Considering the latter option, a bottom mounting plate mimicking the dimensions of adjustment holes of single printhead mounting plates was designed. This design is shown in Figure 13. However, manufacturing such a mounting plate poses many problems. First, the angle of the rectangular printhead slots need to be manufactured at precisely 36.9 degrees. Second, the adjustment holes need to be threaded for the customized adjustment screw which requires special threading tools. Not only that, it is difficult to make adjustments to the printhead's orientation once the plate has been manufactured and allow for very tight tolerances in manufacturing the plate. Hence, the option of installing four individual mounting plates was chosen since it provides greater flexibility and ability to make final adjustments.

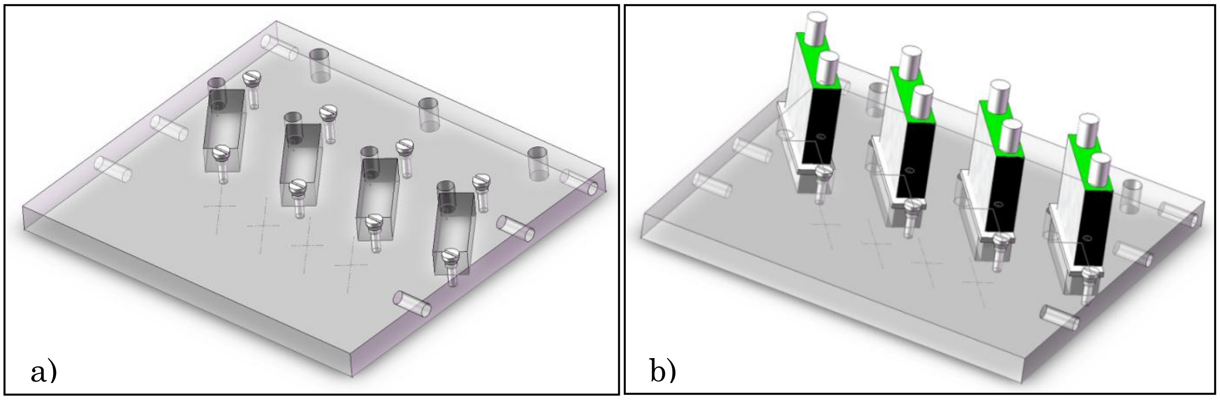


Figure 13 Single unit bottom plate (a. without printheads; b. with printheads)

To ensure the quality of the four single mounting plates to be installed, each of the plates were measured and inspected carefully. The dimension tolerances between the different mounting plates were within ±0.20mm deviation, and this was considered acceptable.

In order to allow maximum adjustment after the bottom plate has been manufactured, a plate shown in Figure 14 was designed, and was later manufactured. In this design the individual mounting plates are bolted from the bottom of the bottom plate through oval shaped holes. The oval shaped holes allow 1mm of shift and angle adjustment of individual printhead mounting plates. This design only requires simple X and Y axis machining operation on a milling machine to manufacture the plate.

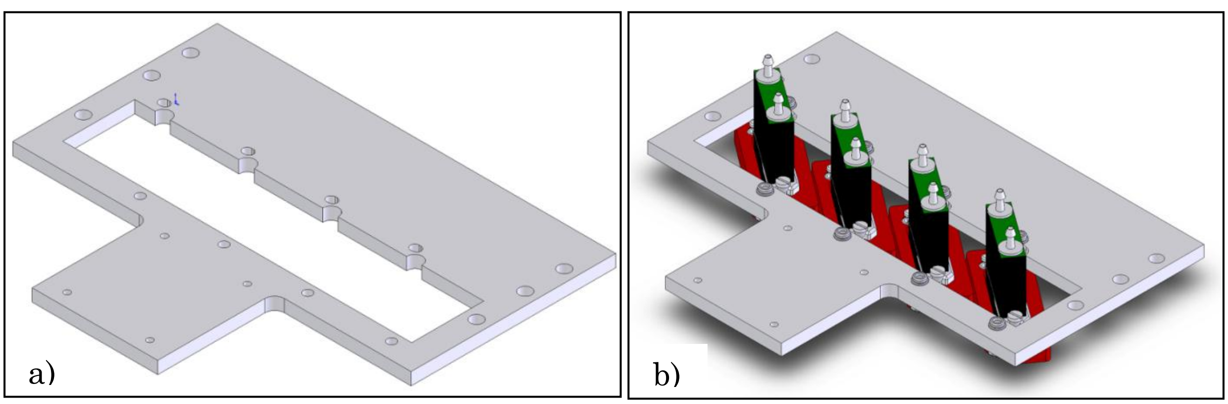


Figure 14 Multi-unit bottom plate (a. without printheads; b. with printheads)

4.2.2 *SUPPORTING PIECE FOR VERTICAL AND BOTTOM PLATE*

The orientation of the printhead nozzles with respect to the printing surface is critical to the quality of the prints. Therefore, it was crucial to create a mechanical design that ensures accurate horizontal orientation of the bottom plate designed in section 4.2.1. Three different designs were made, and they are shown in Figure 15.

The first design (Figure 15 a)) uses a standard size angle. It is the easiest to manufacture, and can produce an angle of nearly perfect 90 degrees. However, this design is the least rigid of the three designs.

The second design (Figure 15 b)) is similar to the first design, but has added rigidity in its structure. This design was aimed at providing rigidity while reducing the most weight from the supporting piece. Although weight reduction from mounting components is favourable, the efforts involved in machining and necessary structural analysis outweighs the benefits for the calculated weight reduction.

The third design (Figure 15 c)) offers the most amount of rigidity, and can ensure the vertical and bottom plates are linked at a accurate 90 degree angle. It is relatively easier to manufacture compared to the second design. Hence, the third design was chosen.

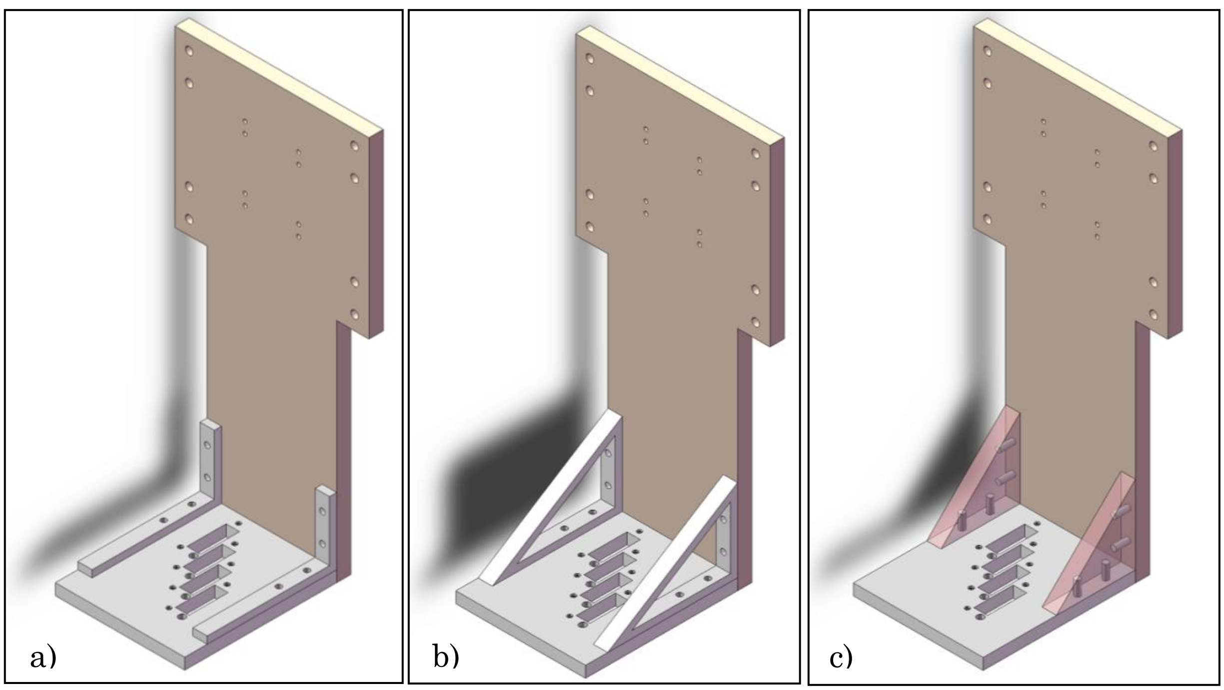


Figure 15 Three different designs of supporting piece

4.2.3 Z'-AXIS CARRIAGE OVERALL ASSEMBLY

In order to maintain maximum factor of safety while meeting all of component installation requirements, efforts were made to reduce the weight of the mounting plates. Also, additional mounting holes were put in place such that the same assembly can be easily taken off of the Z'-axis and installed onto the original spindle axis. This ensures that the assembly can be used for inkjet testing on the Z-axis when Z'-axis is not functional. The finalized assembly design is shown in Figure 16, and a breakdown of the components of the assembly is shown in Figure 17. The overall assembly mounted onto the Z-axis is shown in Figure 18.

This assembly was expected to weigh maximum 3kg in the beginning of the project. The actual weight measured was approximately 4kg while all components were dry of ink. Calculations from section 2.3 can be repeated with the new weight to ensure the motor can indeed drive the assembly upwards.

$$F = \left(9.81\frac{m}{s^2} + a_{max}\right) \cdot (4kg) = 39.8\,N \tag{12}$$

$$\mathrm{T}_{\mathrm{Raise}} = \frac{Fd_m}{2} \cdot \left(\frac{l+\pi f d_m}{\pi f d_m - fl}\right) = 0.112\ \mathrm{Nm} \tag{13}$$

$$\text{Factor of Safety} = \frac{\mathrm{T}_{\mathrm{Continuou}\ \ s\_rated\ \_stall}}{\mathrm{T}_{\mathrm{Raise}}} = 3.5 \tag{14}$$

The factor of safety of the motor is reduced from 5 to 3.5, however, this reduction is not expected to affect the performance of the Z'-axis system.

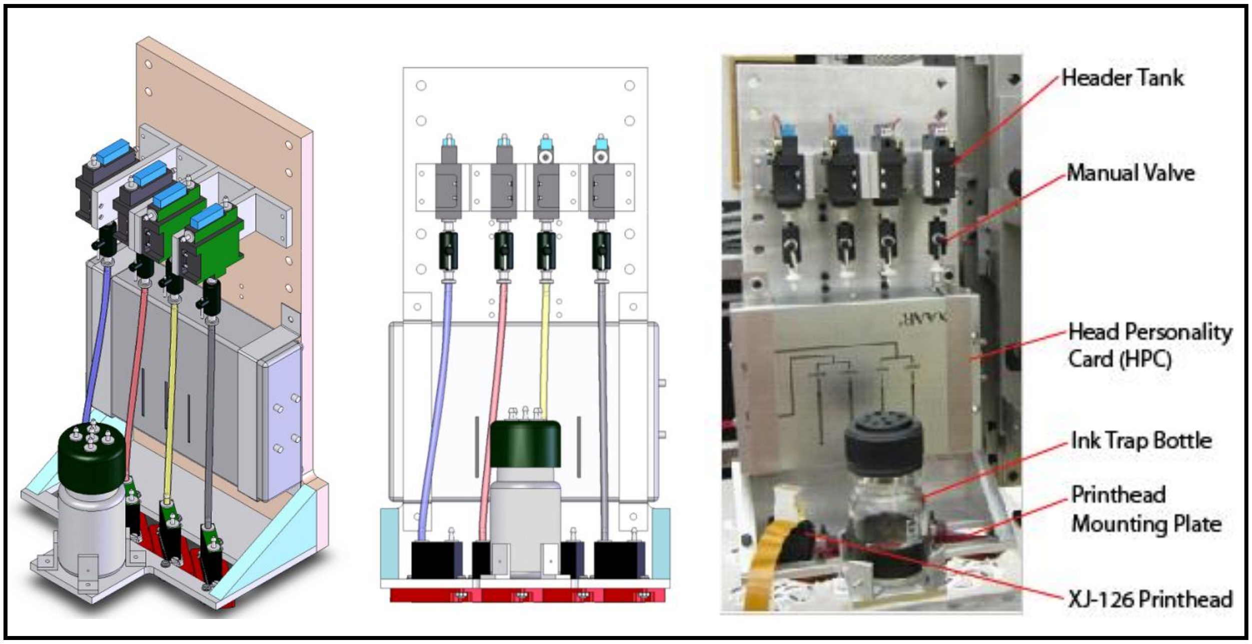


Figure 16 Final design of Z'-axis carrier assembly

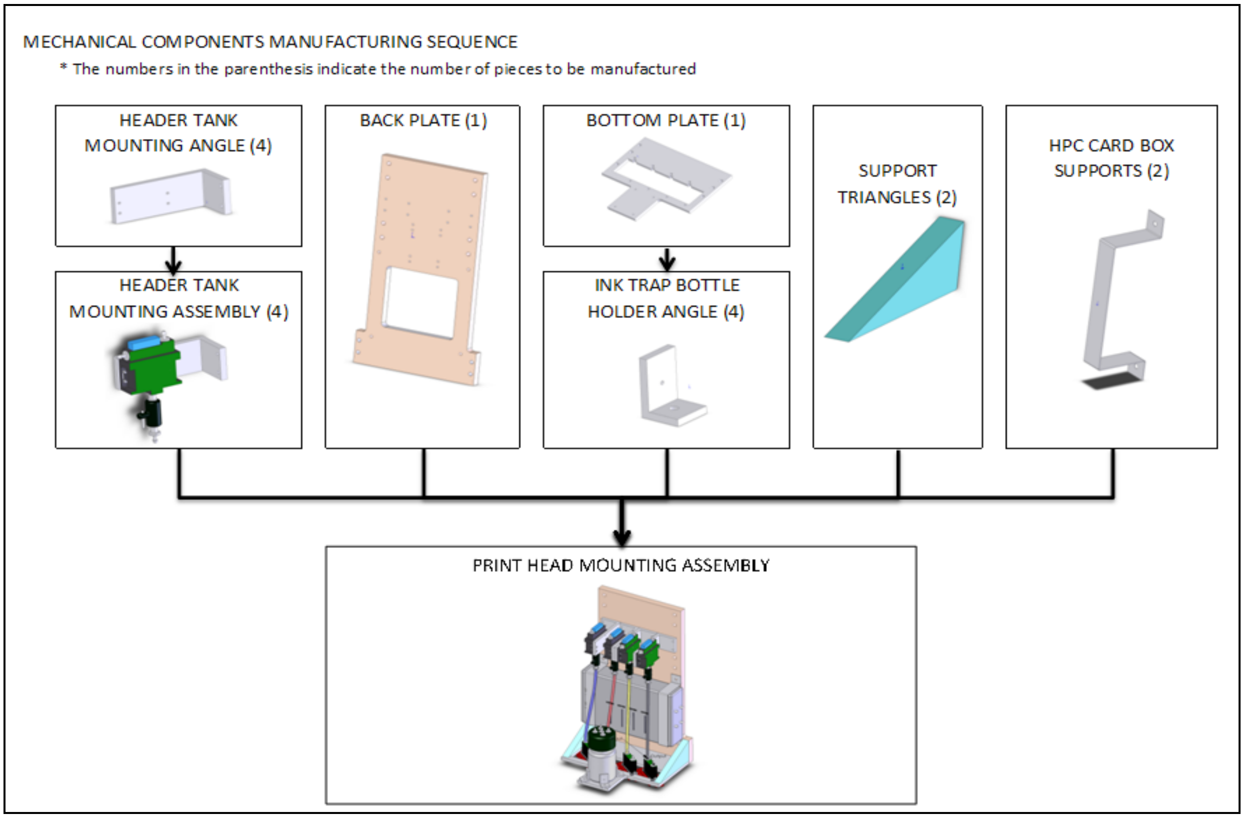


Figure 17 Carriage assembly mechanical component manufacturing sequence

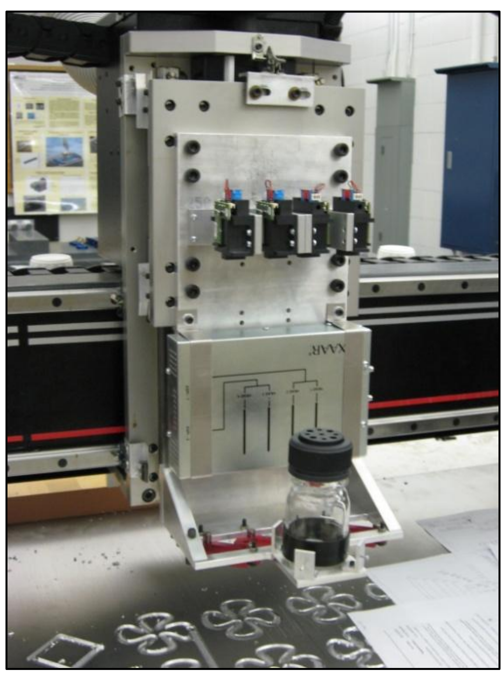


Figure 18 Carriage assembly mounted on Z-axis

4.3 Installation of Ink Supply Peripheral Components

The header tanks, installed on the Z'-axis carriage, receive inks from its respective ink pumps via 3mm tubes. It is desirable to maintain all tubes as short as possible since longer tube length means added hydraulic resistance of the inks. Four other peripheral components (ink reservoirs, filters, pumps and header tanks) need to be connected by tubes. Tubes required to connect filters to pumps is minimized by installing both components onto a single vertical mounting plate. The mounting plate is designed to keep the two components at the closest proximity and still taking into account the space required to access the tubes and fittings. A stand-alone version of the mounting plate complete with filter and pumps is shown in Figure 19.

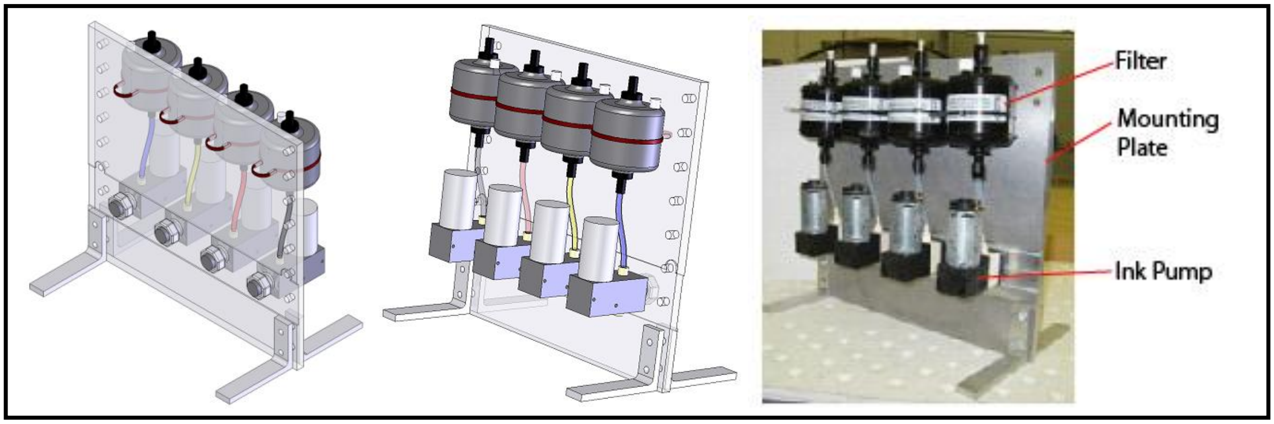


Figure 19 Stand-alone filter and pump mounting assembly

There were three options to minimizing the tube length between pumps and header tanks:

1) **Install inks, filters, and pump on the right side of gantry (Figure 20)** In this configuration tubes from pumps to header tanks can be easily fed through the existing cable track. The right side of the gantry is where the top cable track starts, and this ensures that there will be minimum turns in ink tubes from pump to header tank. A disadvantage of this configuration is that all ink reservoirs, pumps, and filters need to be installed on the same side of the gantry. This means there will be some undesirable weight imbalance on the gantry.

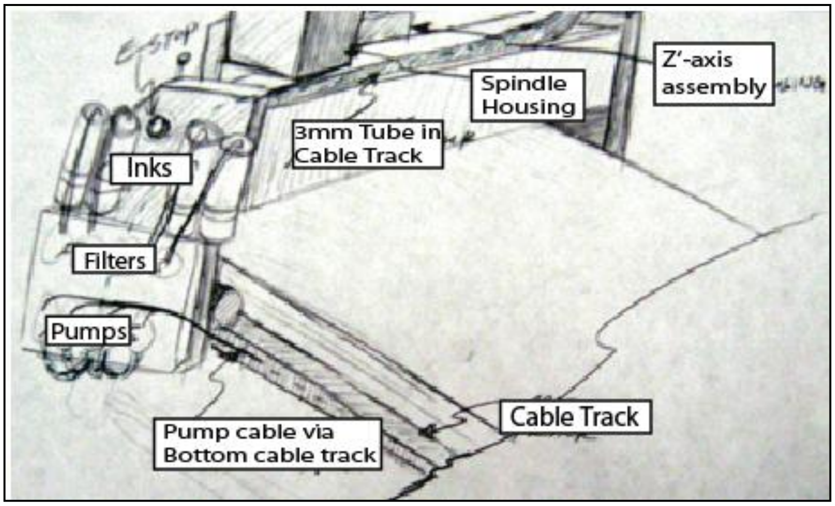


Figure 20 Filter, pump and ink mounting location proposal 1

2) Install inks, filters and pumps on the back of the gantry (Figure 21)

In this setup the tubes from pumps to header tanks can be fed from the middle of the cable track. This solution eliminates approximately 3 ft of tubing for each colour compared to option 1). When the components are installed in the centre of the gantry there is no weight imbalance issue. One disadvantage of this solution is that a longer electrical pump cable is required compared to option 1). The pump cables for this configuration need to be at least 3 ft longer than option 1), since the pumps are located farther away from the right of the gantry where the cable track starts.

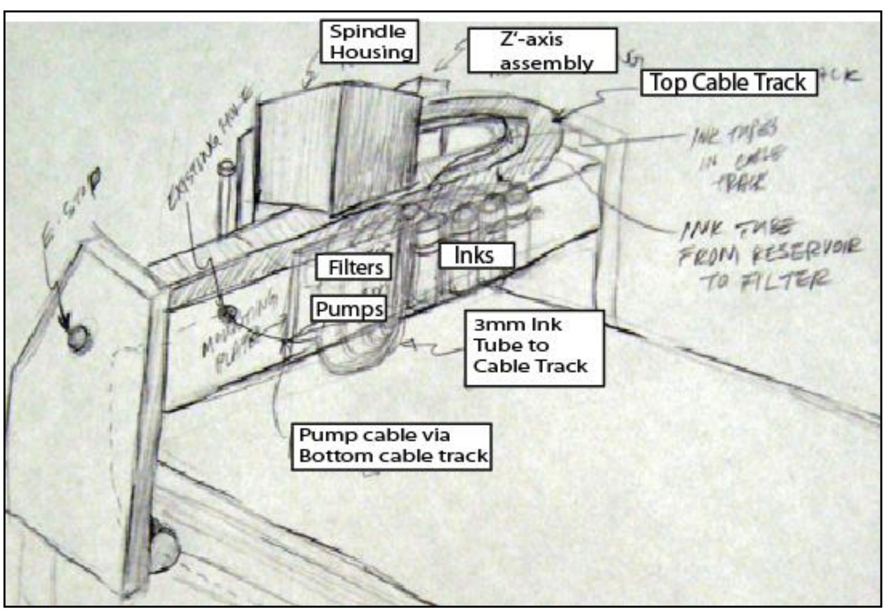


Figure 21 Filter, pump and ink mounting location proposal 2

3) **Install inks on the back of gantry, and filters and pumps on the spindle housing (Figure 22)**
   The mounting plate can be installed on the backside of the spindle housing. In this setup the tube length would be the shortest since the filter and pump assembly would travel both X and Y-axis with the Z'-axis assembly. However, the tubes from ink reservoirs to the filters need to be at least 5 ft long such that ink can be supplied to the filter even if ink reservoir does not travel along the Y-axis with filters and pumps.

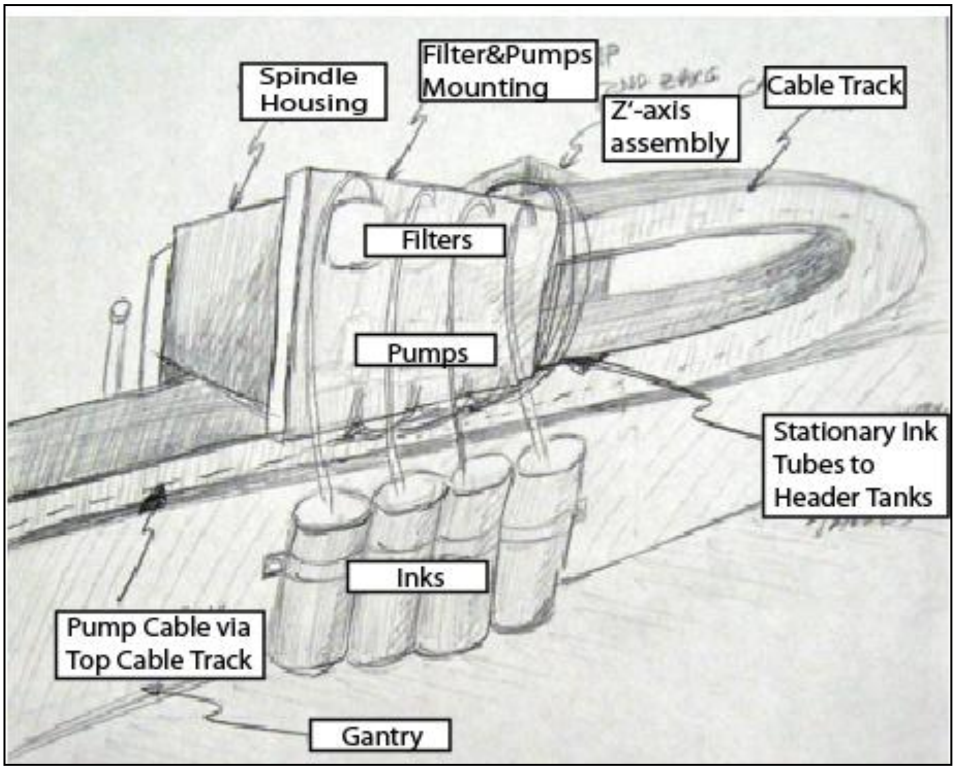


Figure 22 Filter, pump and ink mounting location proposal 3

Of the three options above, option 3) offered the shortest tube length between the pump and header tanks. However, while considering option 3) the width of spindle housing was found to be smaller than the width of the filter and pump mounting plate. Hence, for the structural stability and ease of installing the filter and pump mounting plate option 3) was eliminated.

The solution that offers the next shortest tube length is option 2). Although the difference in tube length between option 1) and 2) is 3 ft per colour, option 2) was highly preferred over option 1). This is because option 1) not only causes weight imbalance problem on the gantry, but also is harder to implement due to the non-flat surface of the mounting location. Hence, option 2) was chosen.

Mounting holes were drilled onto the back cover of the gantry in order to support the filter and pump assembly in the centre. To minimize the tube length between ink reservoirs to filters the inks were mounted on each side of the filter. The completed installation of the peripheral components is shown in Figure 23.

Mounting components seen from inside the gantry cover is shown in Figure 24 a. As shown in the picture all mounting bolts and nuts have minimum 2mm gap from the Y-axis ball-screw assembly to avoid interferences (Figure 24 b). This design also allows for easy access and removal of nuts during disassembly of pumps.

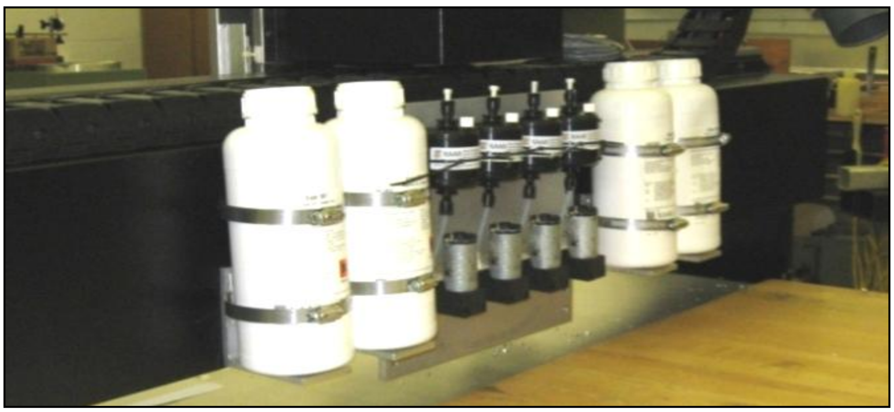


Figure 23 Isometric view of peripheral component mounting on gantry

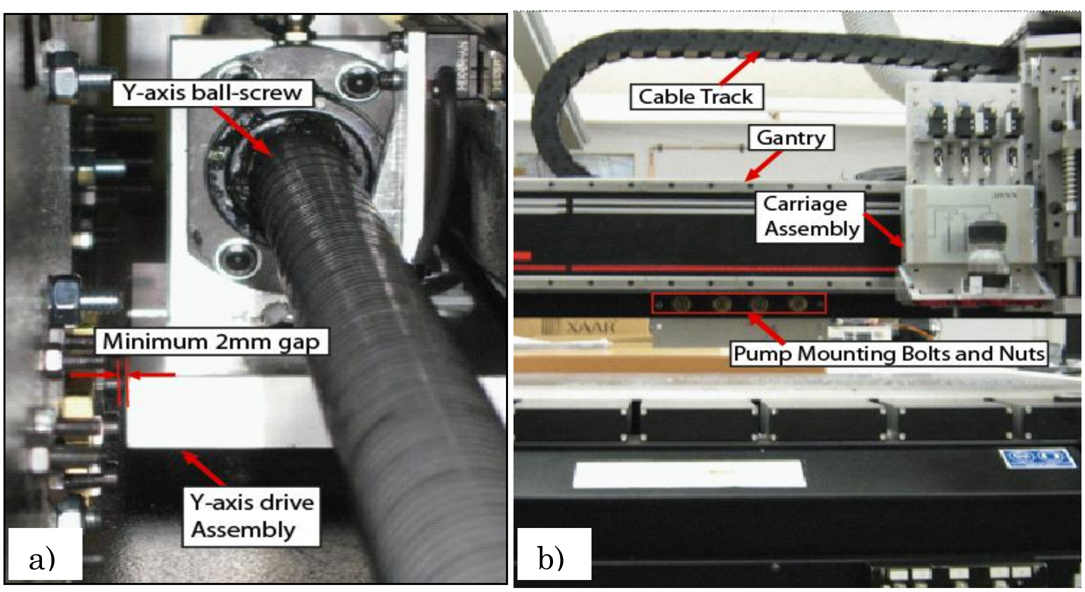


Figure 24 Peripheral component mounting (a. inside gantry cover; b. front of router)

4.4 Completed Mechanical Retrofit Overview

Shown in Figure 25 is the completed retrofit seen from front and back of the router. Upon completion of the mechanical installation, the router was tested for its X and Y axis motion using the built-in controller's joy-stick interface. No problems were found in router's X and Y axis motion during testing. In-depth testing needs to be done using the PC and dSpace controller in order to determine the changes in the axis control parameters.

The overall width of the added Z'-axis components is 198.2mm. This means the overall functional area of the router is reduced from 2400mm X 1200mm to 2400 mm X 1002mm. This more reduction in working area of the router than was expected (6" or 152.4mm) in the beginning of the project. However, this was inevitable due to the required spacing of the header tanks and printheads which were learned later in the project.

Mechanical drawings of all components installed onto the router can be found in Appendix D. Due to the time constraint of the project, tubes connecting the inkjet components, and the motor and amplifier for Z'-axis have not been installed yet.

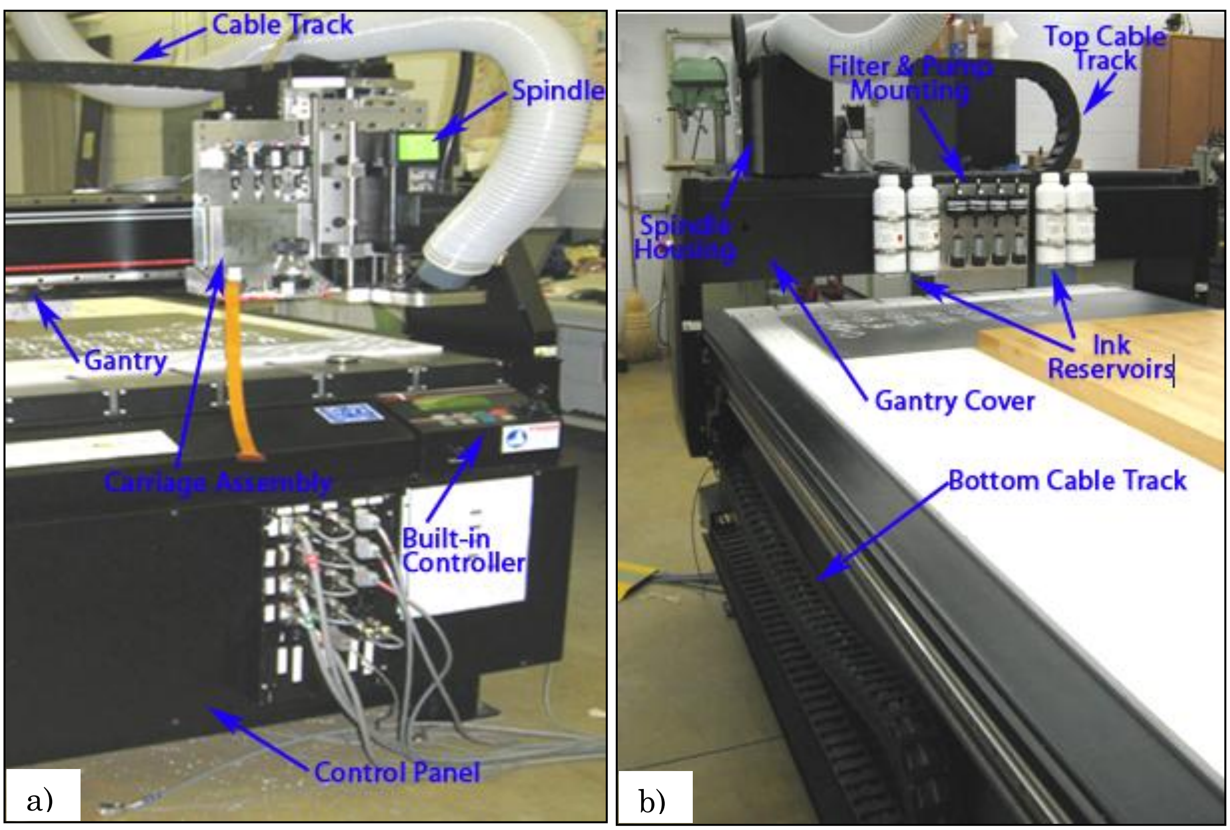


Figure 25 Completed retrofit (a. front; b. back)

5 CONCLUSION

In this project, a flatbed CNC router was retrofitted with Xaar 126 inkjet printing system in order to combine cutting and printing capabilities. A LinTech Series 130 linear stage was selected to provide the additional vertical axis of motion required for the retrofit. A mechanical linkage between the stage and the router was made using two linear guide bearings and four coupling plates that connect the two vertical axes.

Due to the possibility of the carriage back-driving with a 3kg weight, a 24VDC electrical brake was implemented. DC servo motor (MCG ID23005) was chosen to drive the carriage. With the resultant weight of 4kg on the carriage, the factor of safety calculated by the maximum torque the motor can generate versus maximum torque required by the linear stage is 3.5.

An amplifier that supplies required current to the motor can be powered by 24VDC of unregulated power. A 24VDC, 10Amp power supply was chosen for both the motor and the electrical brake. The power supply's input power is to come from the router's 240VAC main power. This ensures a safe and simple way to share the existing router emergency stop with the Z'-axis drive system.

Mechanical mounting for components that need to travel along the Z'-axis throughout the printing operation are mounted onto the carriage of Z'-axis stage. As a result of the retrofit, the functional width of the router was reduced by 198.2mm. This reduction in area was inevitable due to the minimum space required by each of the key components of the assembly, especially the header tanks and printheads.

Lastly, the cover of the gantry was modified to accommodate the filters, pumps, and ink reservoirs. These components were carefully arranged on the gantry cover in order to minimize the connecting tube lengths; and hence, ensure minimum hydraulic resistance in the tubes.

Due to the time constraint of the project, necessary tubing and wiring has not been finished. However, all mechanical designs were manufactured and installed onto the router, and did not cause any problems when the router's three axis of motion were tested via the machine's built-in controller.

6 RECOMMENDATION

There are a number of points to be considered before the router becomes fully functional as a combined cutting-printing machine. They are listed as follows:

1. **Cover or separator for printhead nozzles**
   The printhead nozzles are the most delicate part of the printhead which needs to be clean of debris at all times. Hence, it would be wise to install a cover or separator for printhead nozzles such that the debris from cutting process does not damage the printhead nozzles.
2. **Implementation of sensor to meet optimum 1mm distance from surface**
   With the installed Z'-axis carriage assembly there is no way of determining whether the printhead nozzles are 1mm above the printing surface. Installation of a touch or proximity sensor to determine the distance between the bottom plate and the printing surface would prevent possible collision between the carriage assembly and the surface.
3. **CSA approval of the overall system once power supply is connected to the main power of router**
   It is required that the entire router's electrical system is inspected by a CSA agent after it is modified. Once the 24VDC power supply is connected to the main power of the router the Z'-axis electrical drive components as well as the router's electrical system should be inspected and approved by a CSA agent.
4. **Testing of the router's positioning performance with PC and dSpace to identify changes in control parameter**
   Since the mechanical components installed on the router adds some mass to the gantry, the value of parameters used in the control algorithm may need to be changed. Hence, the router's position controller should be modified to accommodate the changes made to the router.
5. **Testing of Z'-axis positioning using PC and dSpace controller**
   Due to the time constraint of the project, installation and wiring of motor and amplifier was not finished. This will be completed by an electrician, Andy Barber. Once this is completed, the Z'-axis must be tested using a PC and dSpace in order to develop a suitable control algorithm for the axis.

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1. Hang Dong, *Improving Gantry Style Router Tracking Accuracy Through Optical Linear Encoder Retrofit and Error Compensation Using Laser Interferometry*, September 2007
2. Xaar plc, *Xaar 126 User Manual: Document D010928009 Version I*, 2001, Accessed July 2008
3. LinTech , *Positioning Systems*, 2000, Accessed June 2008
4. Singley J. *Mechanical Engineering Design*. New York: McGraw-Hill. 2003

APPENDIX A: Z'-AXIS MAXIMUM WEIGHT ESTIMATION

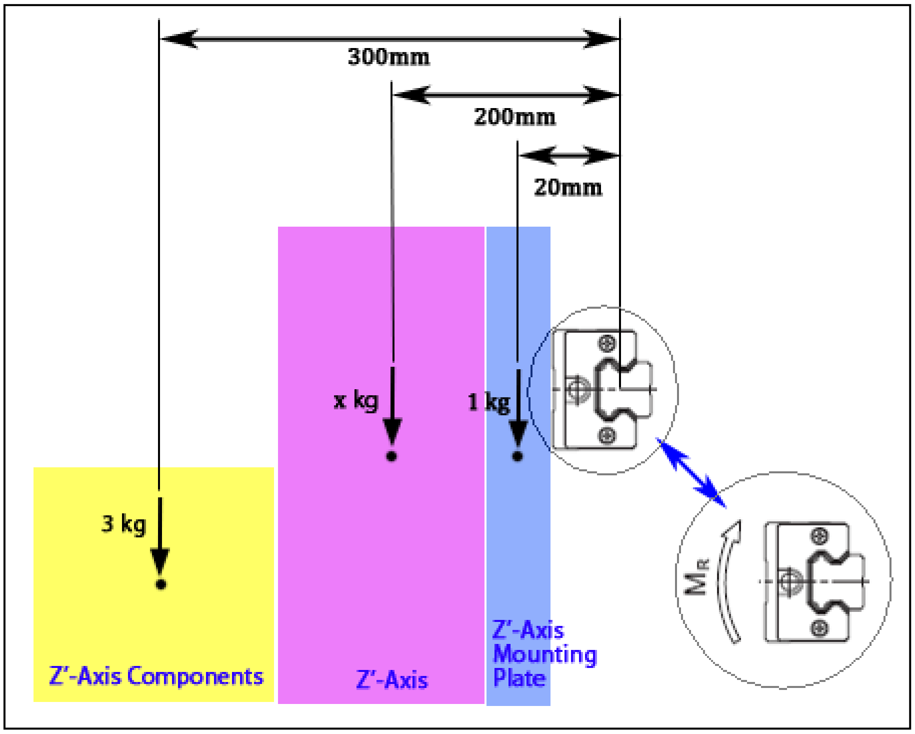


Figure 26 Z'-axis maximum weight estimation diagram

Given the assumed weights shown in Figure 26 and $\mathrm{M_R} = 0.12\ \mathrm{kN} \cdot \mathrm{m}$ (ABBA BRS-20 linear guide bearing technical specification),

$$\mathrm{M_R} = 9.81(1 \cdot 0.02 + 3 \cdot 0.3 + x \cdot 0.2)$$

$$0.12 \times 10^3 = 9.03 + 1.96x$$

$$\boldsymbol{x = 56.6\ \mathbf{kg}}$$

where x is the maximum allowable weight of the stage.

APPENDIX B: COUPLING CALCULATION

Assume,

$$t = 6.35mm; \qquad w = 10mm; \qquad d = 4.9mm; \quad S_y = 296MPa$$

where t is thickness, w is width, and d is the diameter of the coupling hole.

Then the stress concentration factor $K_t = 2.2$.

$$\sigma_{max} = K_t \cdot S_{\mathrm{y}} = 652MPa$$

Hence, the coupling will fail upon 652Mpa or higher stress. With $F_{max} = 12.8N$ from free body diagram the expected stress on two couplings connecting the two vertical axes can be calculated as follows:

$$\sigma_{expected} = \frac{F_{max}}{\pi \mathrm{dt}(2 \times 2)} = 32.67 \text{ kPa}$$

Therefore, the factor of safety for having two couplings with area of 6.35mm × 10 mm is:

$$\frac{\sigma_{max}}{\sigma_{expected}} = 19957$$

Such a large number indicates that even having two coupling to link the two vertical axes would be fail-safe.

APPENDIX C: ELECTRICAL CONNECTION SCHEMATIC

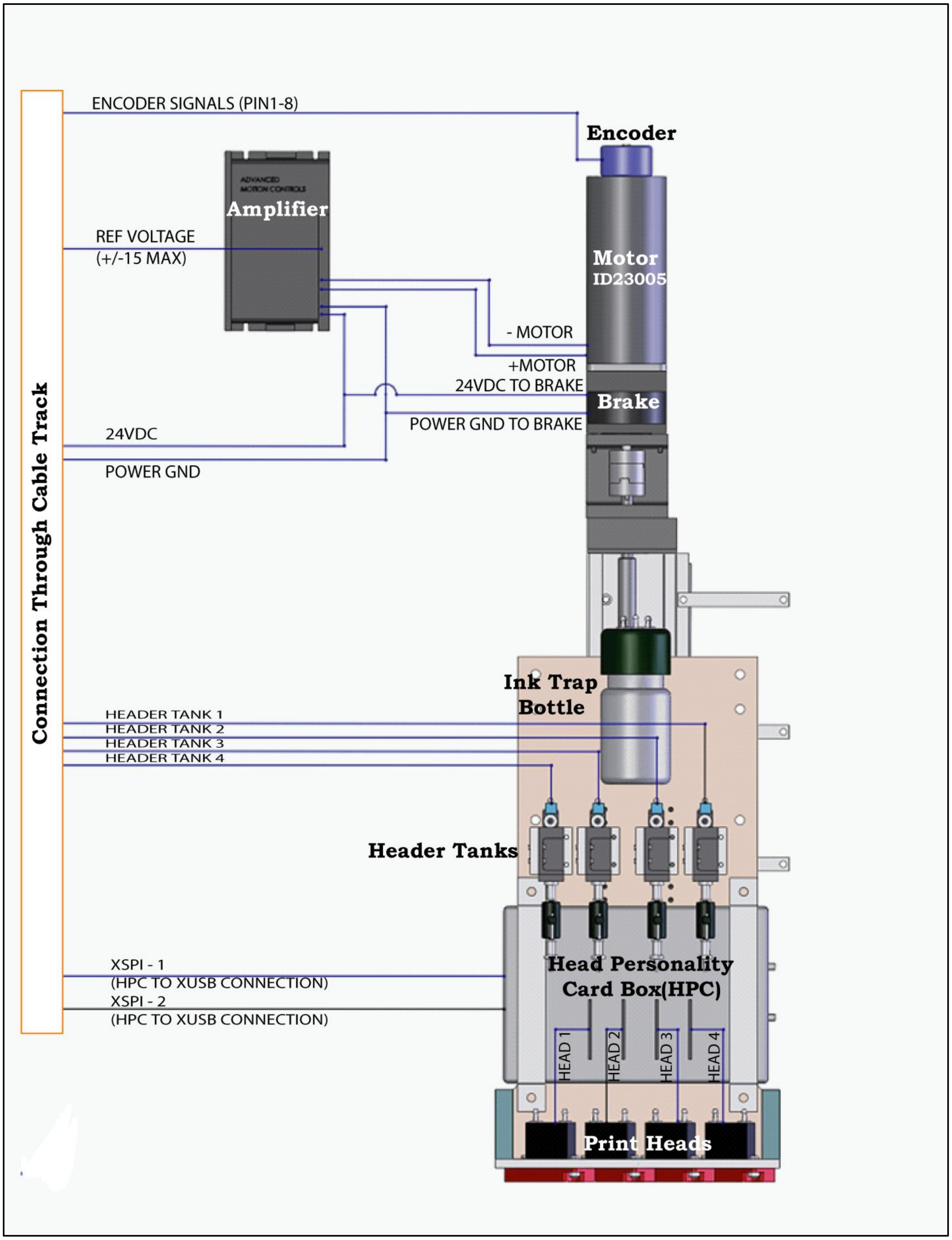


Figure 27 Electrical connection schematic 1

Appendix C continued

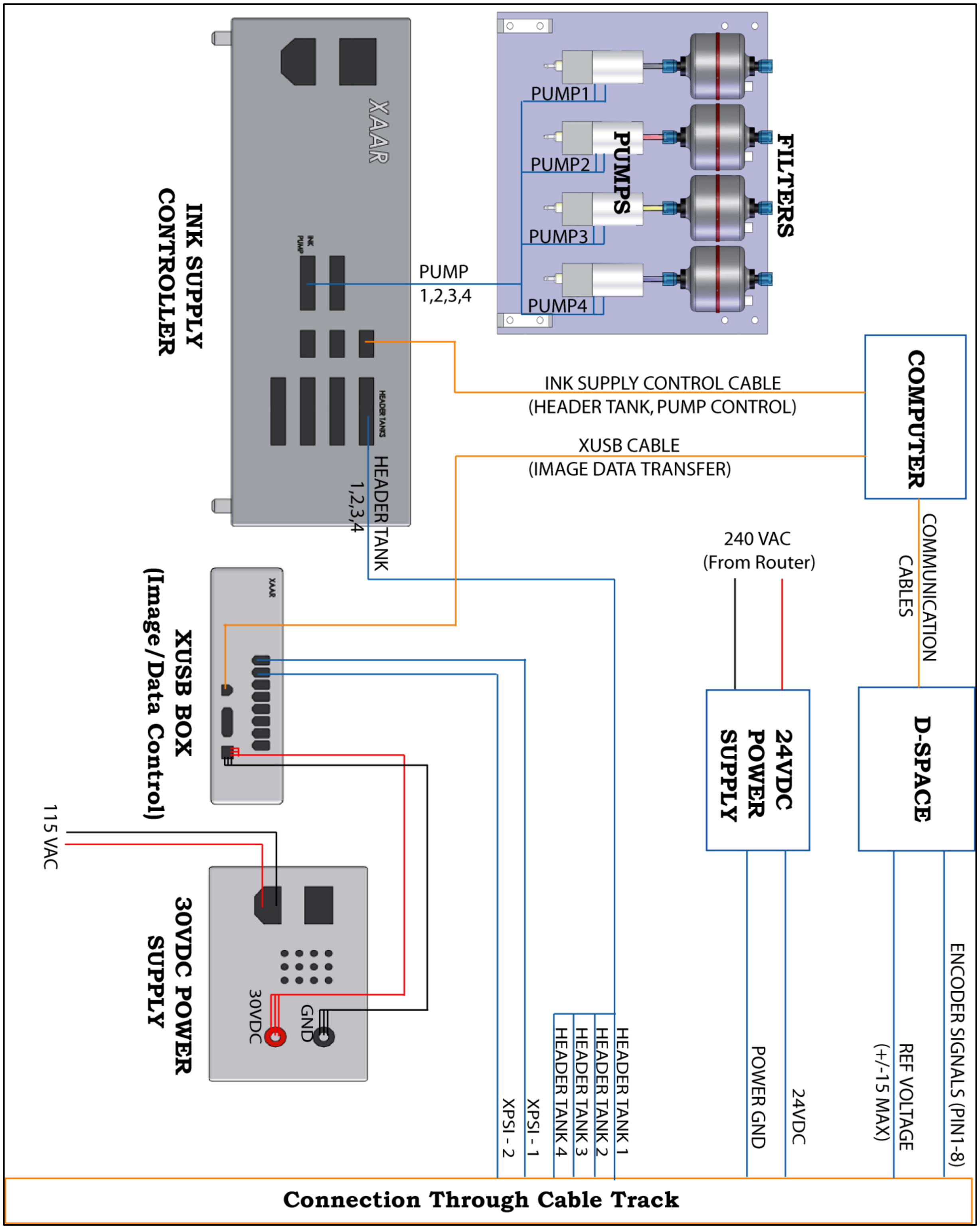
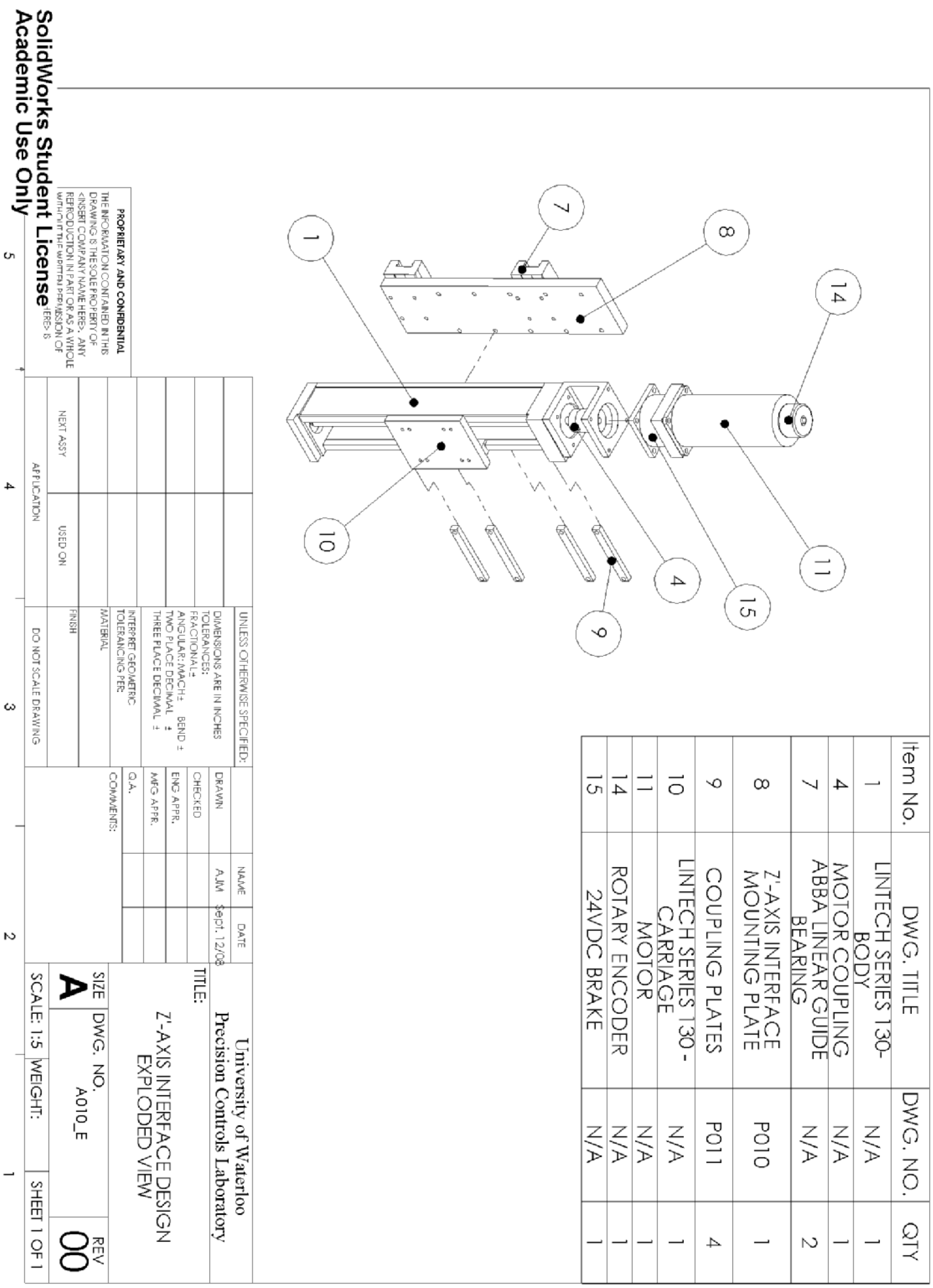
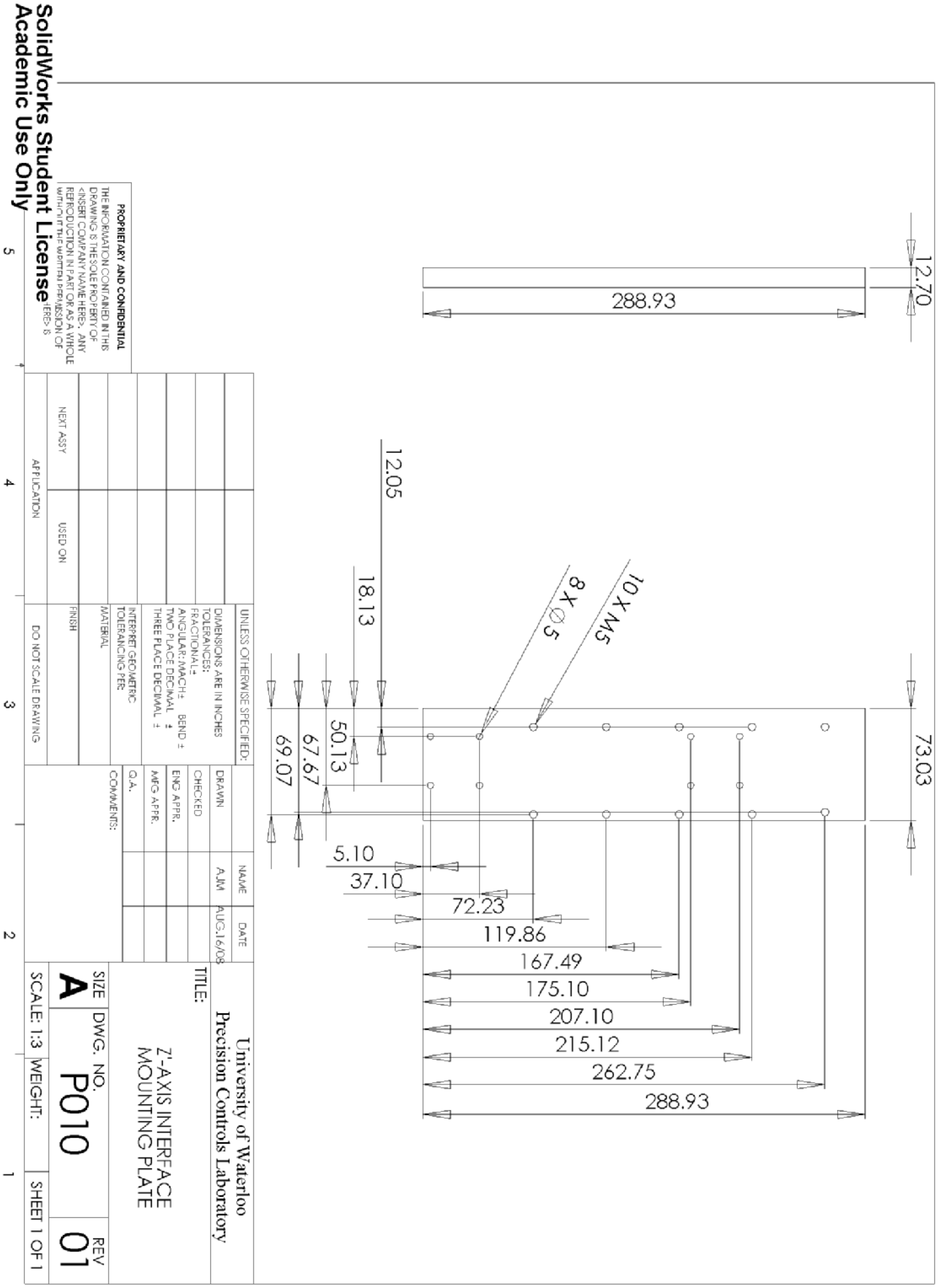


Figure 28 Electrical connection schematic 2

APPENDIX D: MECHANICAL DRAWINGS

1. Z'-Axis Interface Design

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University of Waterloo
Precision Controls Laboratory
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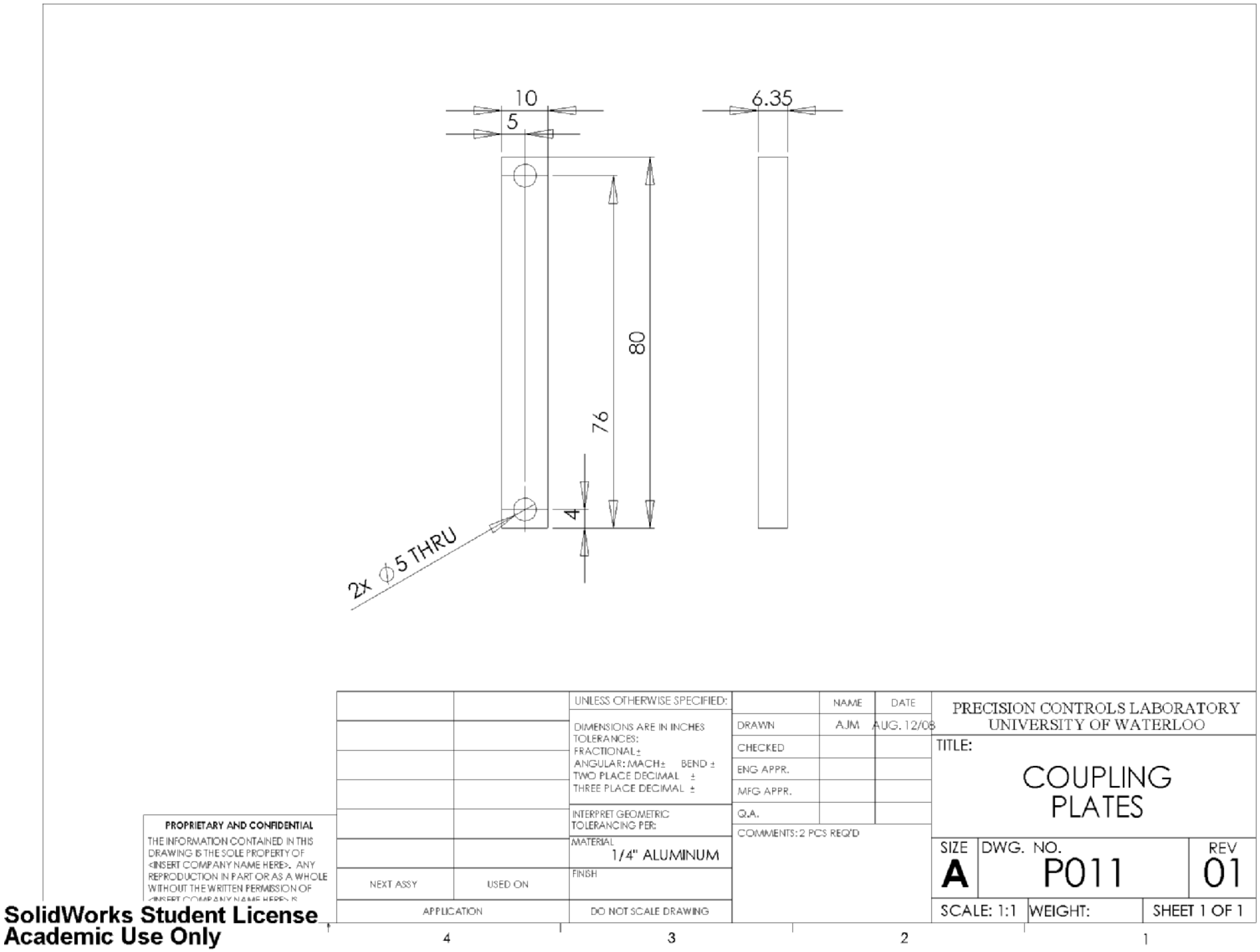
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COUPLING PLATES
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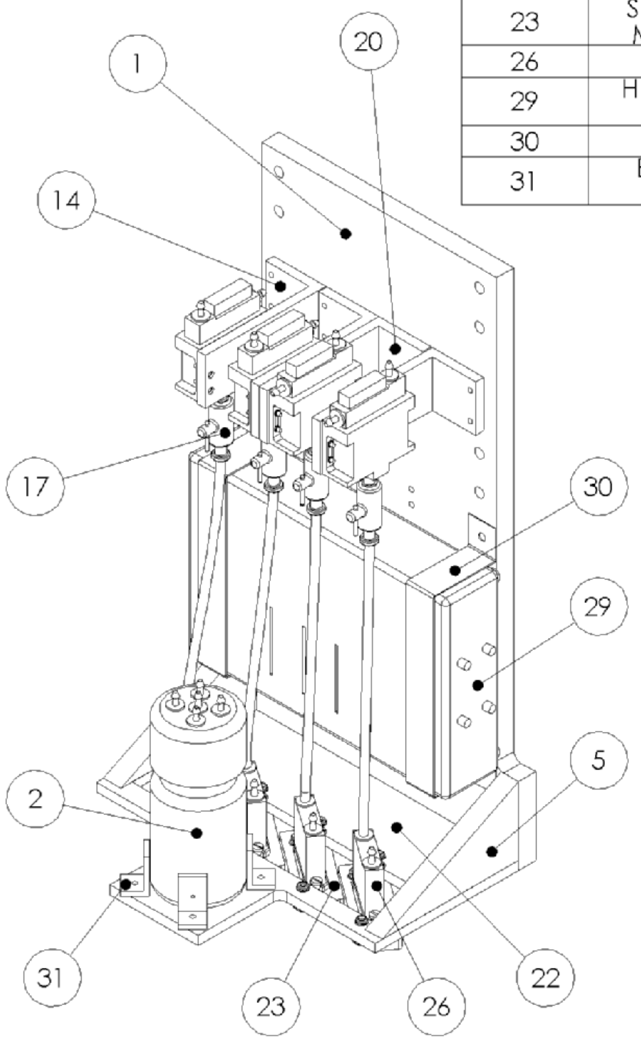
2. **Z'-Axis Carriage Assembly**

ITEM NO.	DWG. TITLE	DWG. NO.	QTY
1	VERTICAL PLATE	P020	1
2	INK TRAP BOTTLE	N/A	1
5	SUPPORT TRIANGLE	P024	2
14	HEADER TANK MOUNT 1	P022	2
17	MANUAL VALVE	N/A	4
20	HEADER TANK MOUNT 2	P023	2
22	BOTTOM PLATE	P021	1
23	SINGLE PRINTHEAD MOUNTING PLATE	N/A	4
26	PRINTHEAD	N/A	4
29	HEAD PERSONALITY CARD (HPC)	N/A	1
30	HPC MOUNTING	P025	2
31	BOTTLE HOLDER L BRACKET	P026	4



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

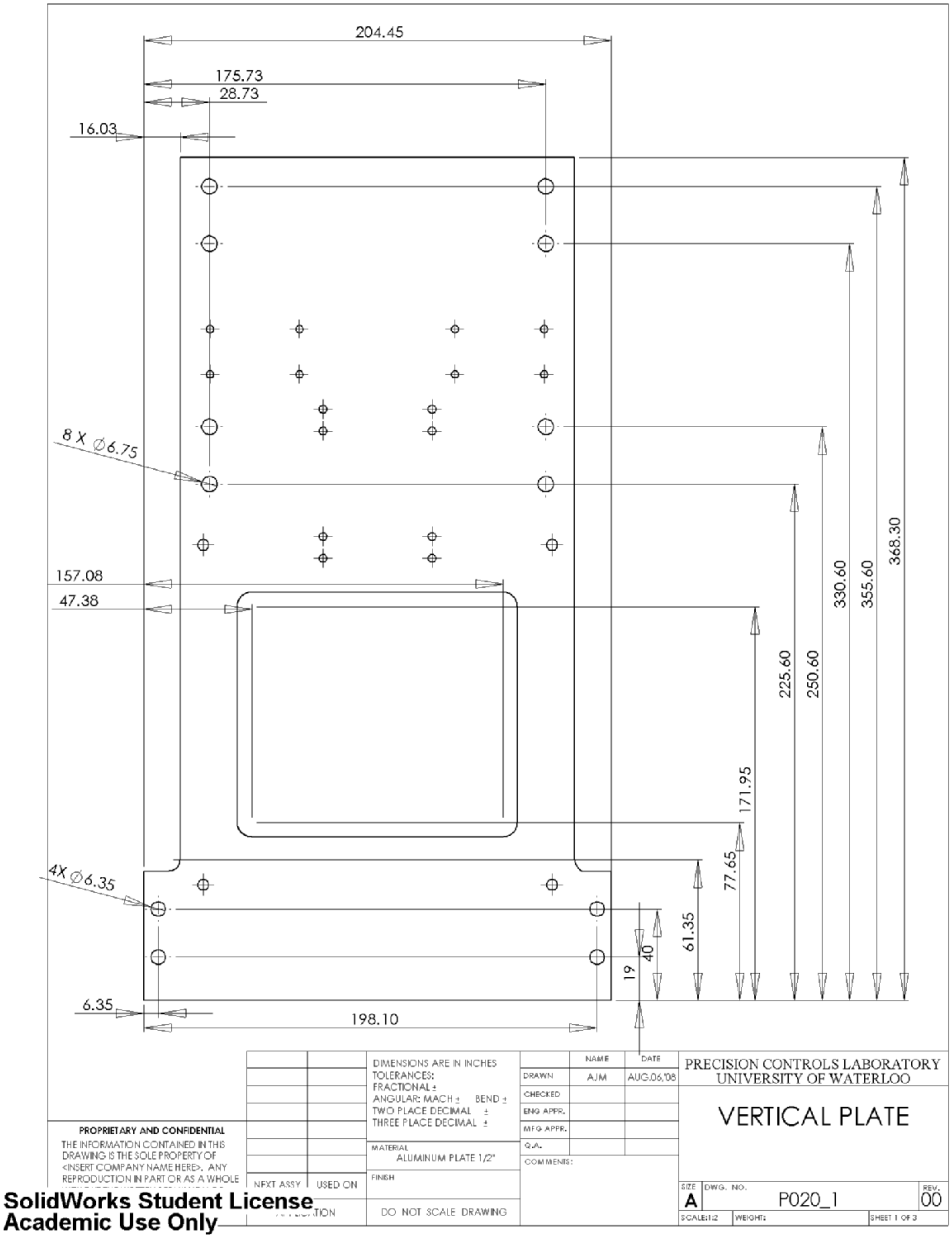
	NAME	DATE
DRAWN	AJM	Sept.12/08
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

University of Waterloo
Precision Controls Laboratory

Z'-AXIS CARRIAGE ASSEMBLY

SIZE A | DWG. NO. A020 | REV. 03

SCALE:1:3 | WEIGHT: | SHEET 1 OF 1


204.45
175.73
28.73
16.03
8 X ∅6.75
157.08
47.38
368.30
355.60
330.60
250.60
225.60
171.95
77.65
61.35
40
19
4X ∅6.35
6.35
198.10
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
MATERIAL
ALUMINUM PLATE 1/2"
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
NAME
DATE
DRAWN
AJM
AUG.06,'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
VERTICAL PLATE
SIZE
A
DWG. NO.
P020_1
REV.
00
SCALE:1:2
WEIGHT:
SHEET 1 OF 3
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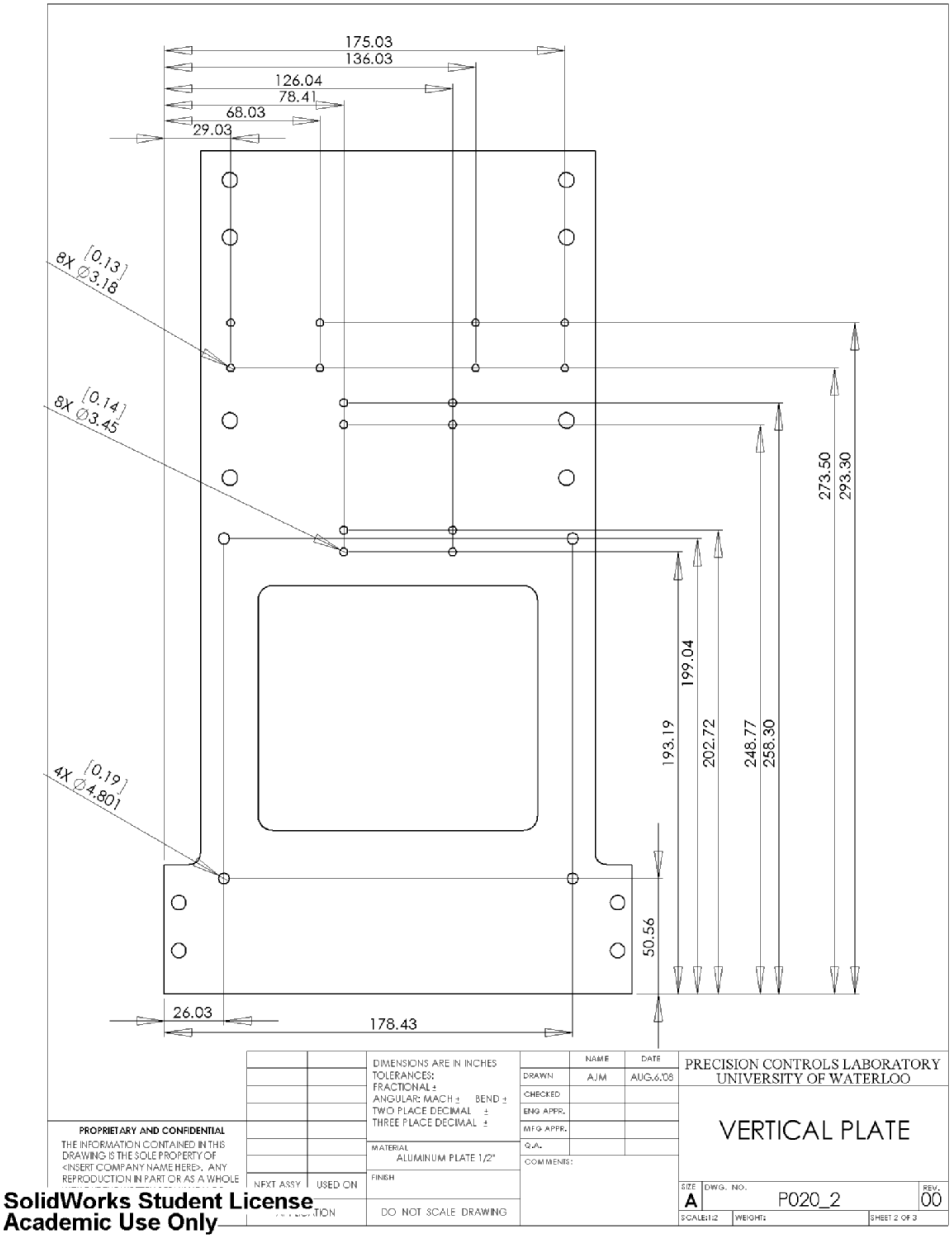
175.03
136.03
126.04
78.41
68.03
29.03
8X [0.13] ∅3.18
8X [0.14] ∅3.45
4X [0.19] ∅4.801
273.50
293.30
199.04
193.19
202.72
248.77
258.30
50.56
26.03
178.43
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
AJM
AUG.6.'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
VERTICAL PLATE
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MATERIAL
ALUMINUM PLATE 1/2"
FINISH
NEXT ASSY
USED ON
DO NOT SCALE DRAWING
SIZE A
DWG. NO.
P020_2
REV. 00
SCALE:1:2
WEIGHT:
SHEET 2 OF 3
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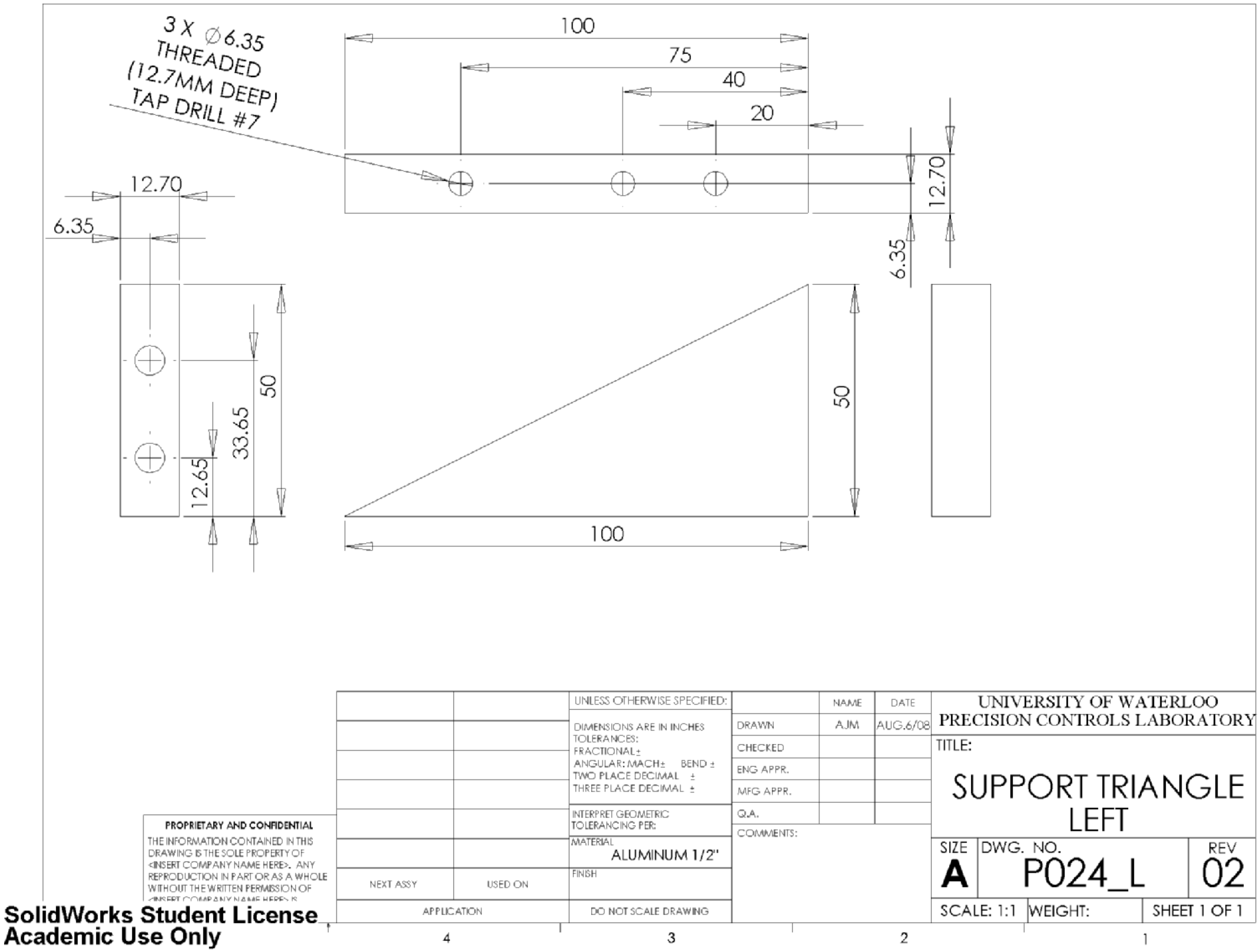
3 X ∅6.35
THREADED
(12.7MM DEEP)
TAP DRILL #7
100
75
40
20
12.70
6.35
12.70
6.35
50
33.65
12.65
50
100
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
ALUMINUM 1/2"
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
AJM
AUG.6/08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNIVERSITY OF WATERLOO
PRECISION CONTROLS LABORATORY
TITLE:
SUPPORT TRIANGLE
LEFT
SIZE
A
DWG. NO.
P024_L
REV
02
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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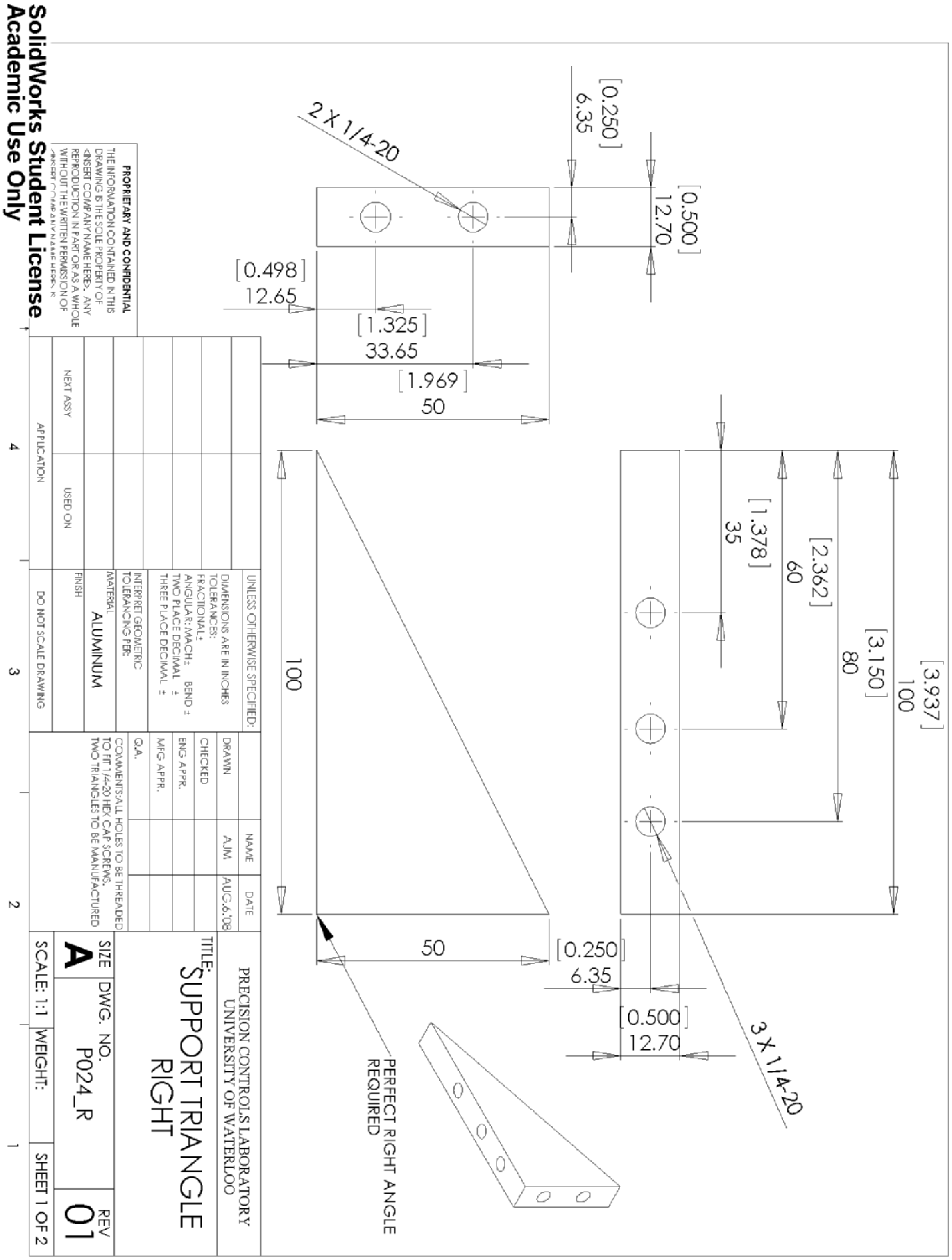
4
3
2
1



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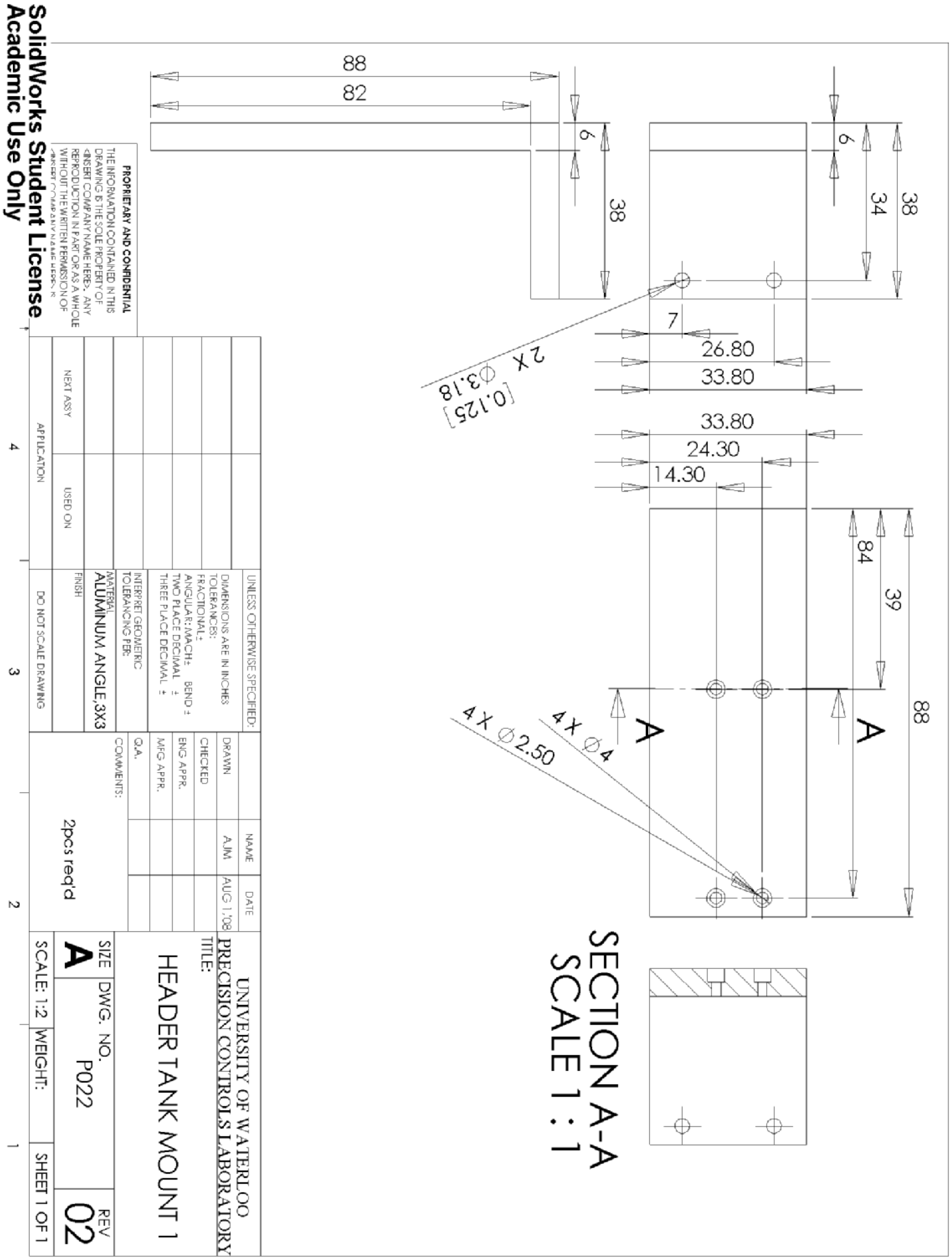
2 X 1/4-20
[0.250]
6.35
[0.500]
12.70
[0.498]
12.65
[1.325]
33.65
[1.969]
50
100
50
PERFECT RIGHT ANGLE REQUIRED
[1.378]
35
[2.362]
60
[3.150]
80
[3.937]
100
[0.250]
6.35
[0.500]
12.70
3 X 1/4-20
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AJM
AUG.6.'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:ALL HOLES TO BE THREADED TO FIT 1/4-20 HEX CAP SCREWS. TWO TRIANGLES TO BE MANUFACTURED
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
SUPPORT TRIANGLE RIGHT
SIZE
A
DWG. NO.
P024_R
REV
01
SCALE: 1:1
WEIGHT:
SHEET 1 OF 2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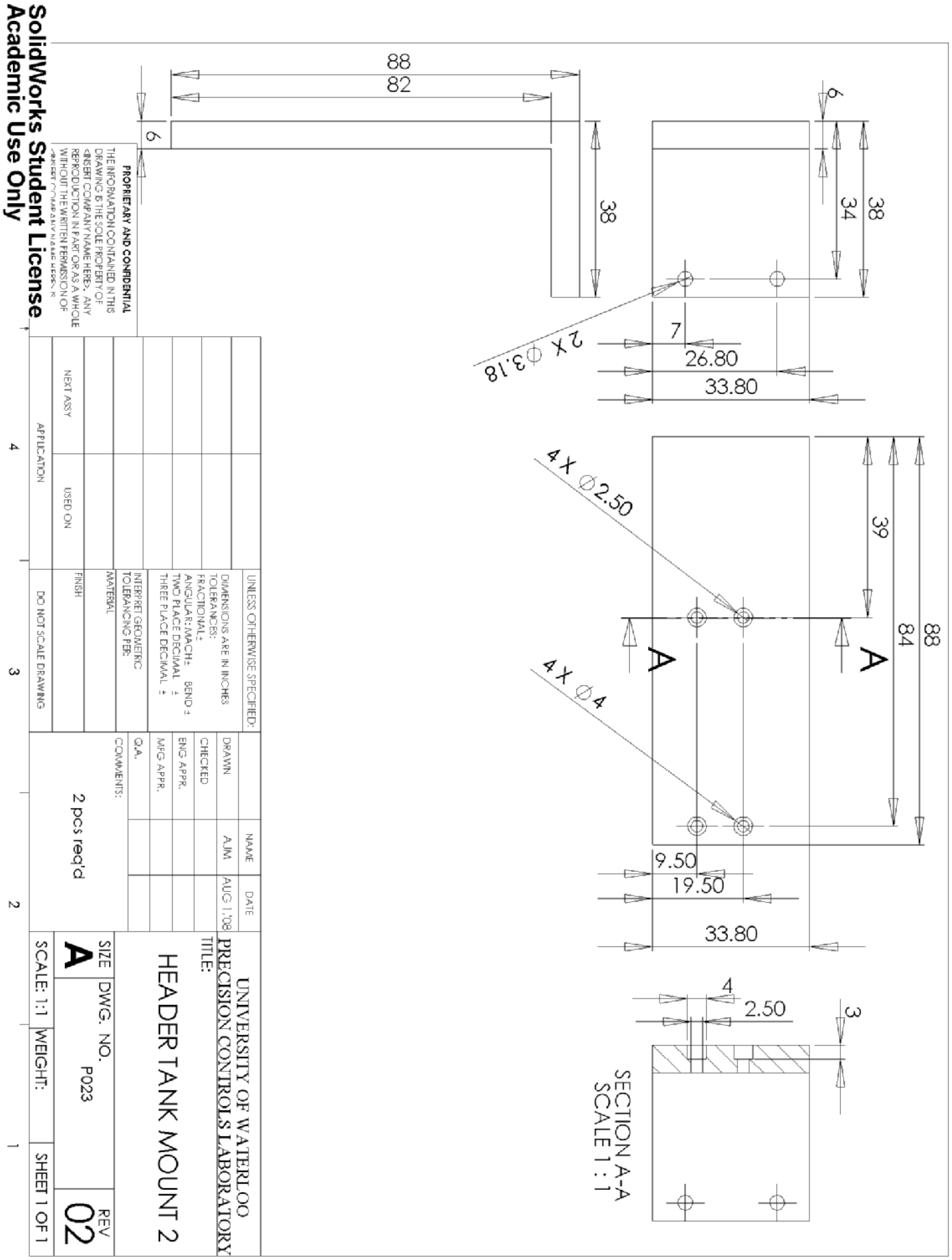
88
82
6
38
34
7
26.80
33.80
24.30
14.30
84
39
2 X ⌀3.18 [0.125]
4 X ⌀4
4 X ⌀2.50
A
SECTION A-A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
MATERIAL
ALUMINUM ANGLE,3X3
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
AJM
AUG 1,'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2pcs req'd
UNIVERSITY OF WATERLOO
PRECISION CONTROLS LABORATORY
TITLE:
HEADER TANK MOUNT 1
SIZE
A
DWG. NO.
P022
REV
02
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1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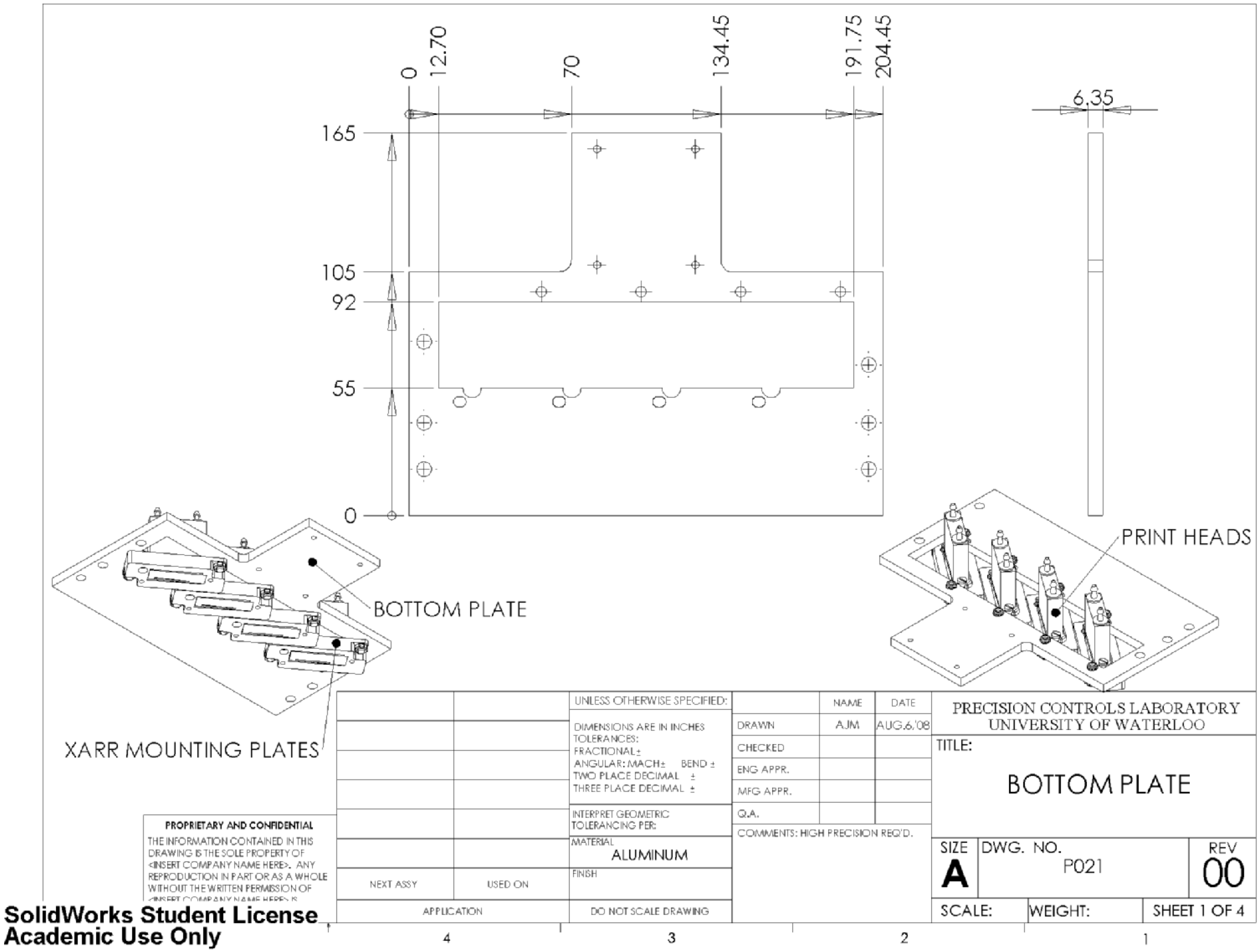
88
82
6
38
34
38
2 X ⌀3.18
7
26.80
33.80
4 X ⌀2.50
39
84
88
A
A
4 X ⌀4
9.50
19.50
33.80
4
2.50
3
SECTION A-A
SCALE 1 : 1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AJM
AUG 1,'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
2 pcs req'd
UNIVERSITY OF WATERLOO
PRECISION CONTROLS LABORATORY
TITLE:
HEADER TANK MOUNT 2
SIZE
A
DWG. NO.
P023
REV
02
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
4
3
2
1



0
12.70
70
134.45
191.75
204.45
165
105
92
55
0
6.35
BOTTOM PLATE
XARR MOUNTING PLATES
PRINT HEADS
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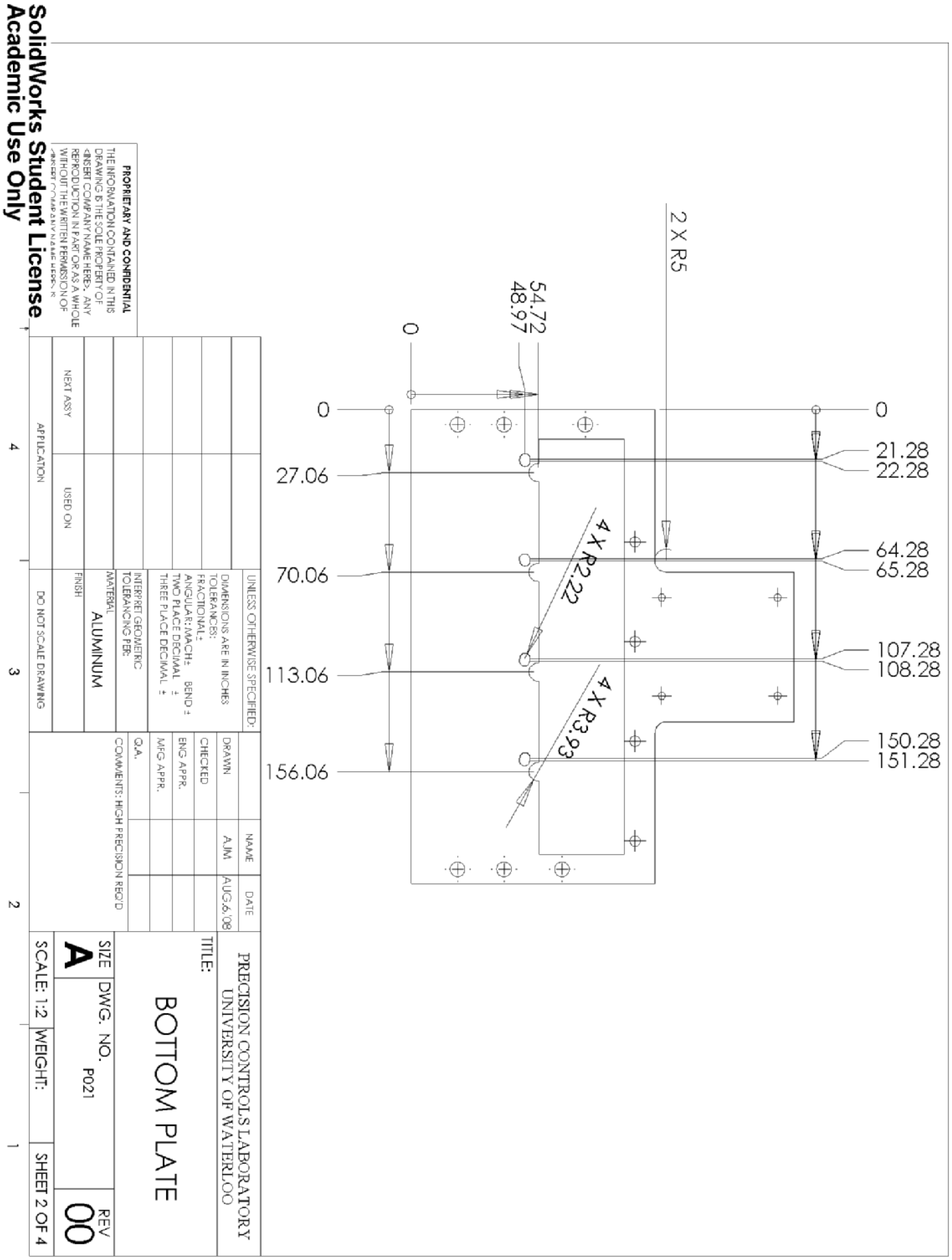
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
AJM
AUG.6.'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS: HIGH PRECISION REQ'D.
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
BOTTOM PLATE
SIZE
A
DWG. NO.
P021
REV
00
SCALE:
WEIGHT:
SHEET 1 OF 4
4
3
2
1


2 X R5
54.72
48.97
0
0
27.06
70.06
113.06
156.06
0
21.28
22.28
64.28
65.28
107.28
108.28
150.28
151.28
4 X R2.22
4 X R3.93
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS: HIGH PRECISION REQ'D
NAME
DATE
AJM
AUG.6.'08
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
BOTTOM PLATE
SIZE
A
DWG. NO.
P021
REV
00
SCALE: 1:2
WEIGHT:
SHEET 2 OF 4
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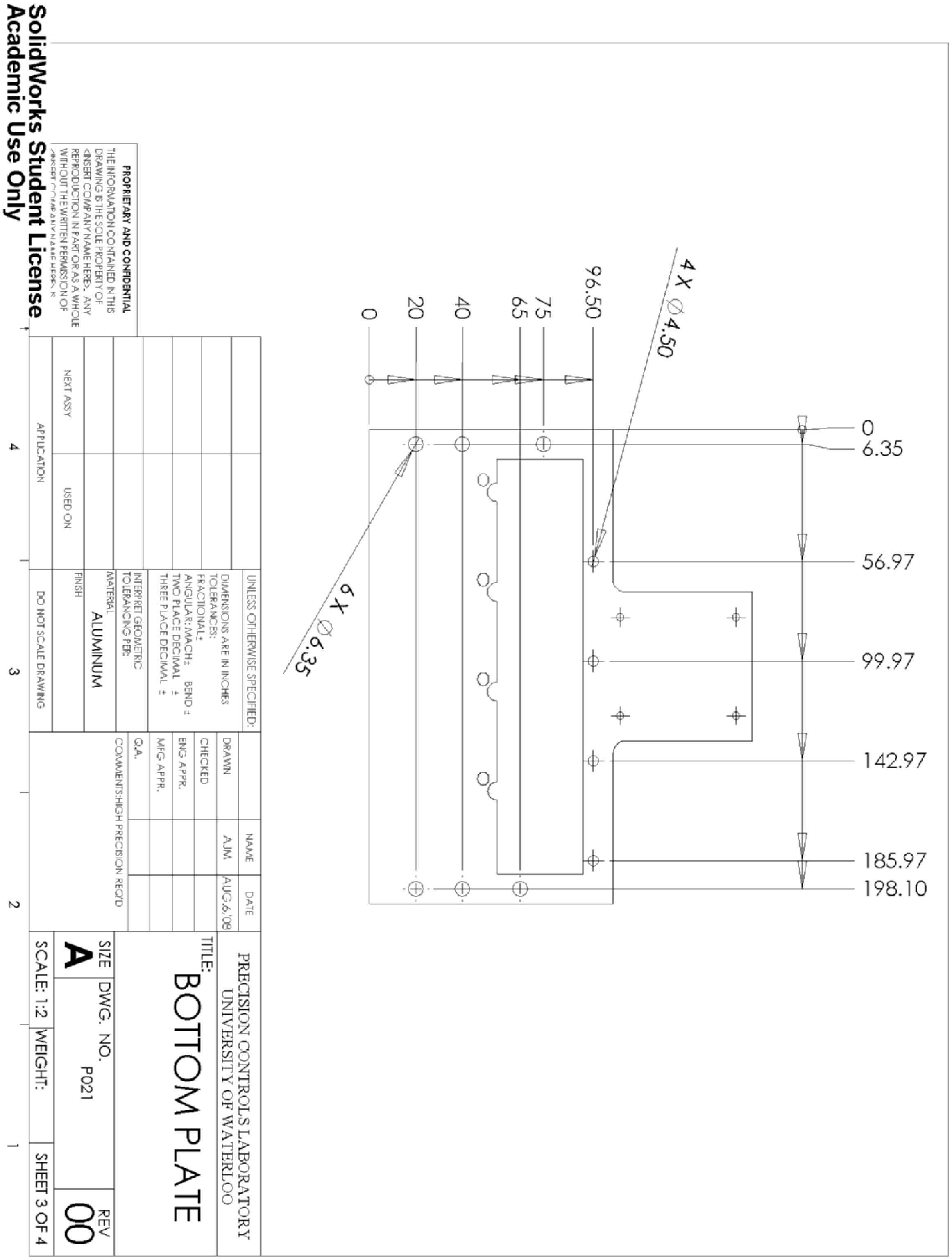
4 X Ø4.50
6 X Ø6.35
0
20
40
65
75
96.50
0
6.35
56.97
99.97
142.97
185.97
198.10
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NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM
FINISH
NAME
DATE
DRAWN
AJM
AUG.6.'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS: HIGH PRECISION REQ'D
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
BOTTOM PLATE
SIZE
A
DWG. NO.
P021
REV
00
SCALE: 1:2
WEIGHT:
SHEET 3 OF 4
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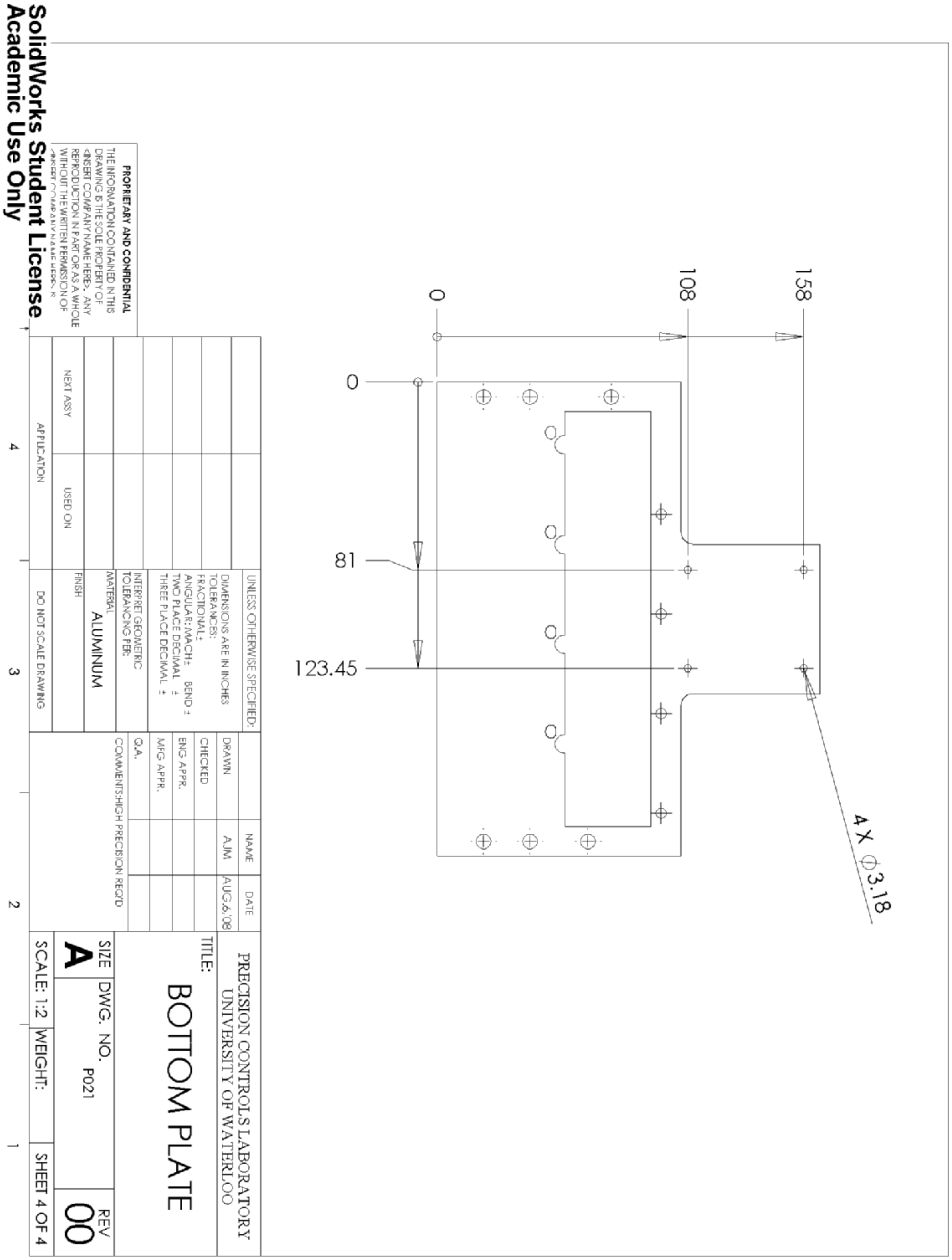

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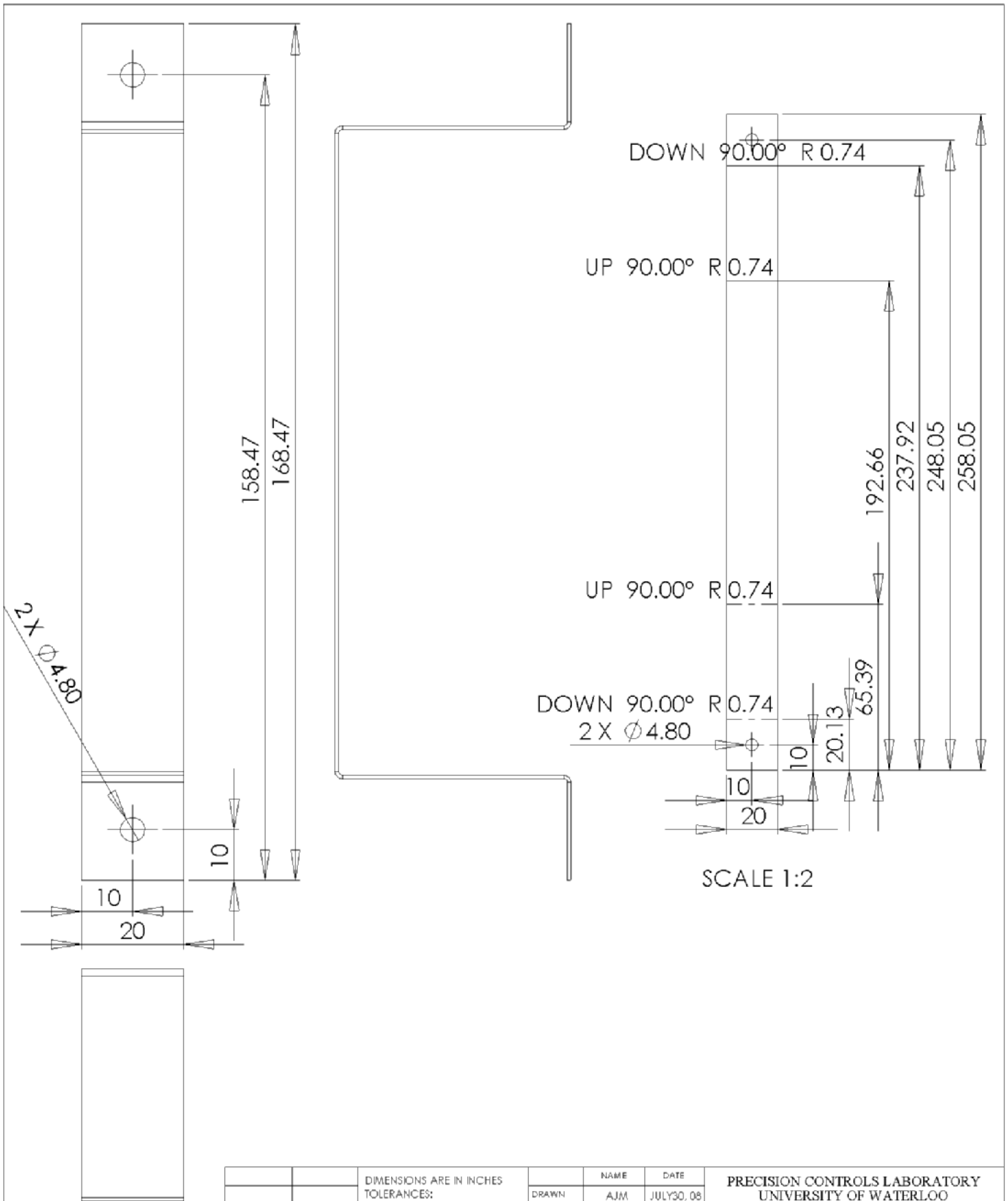
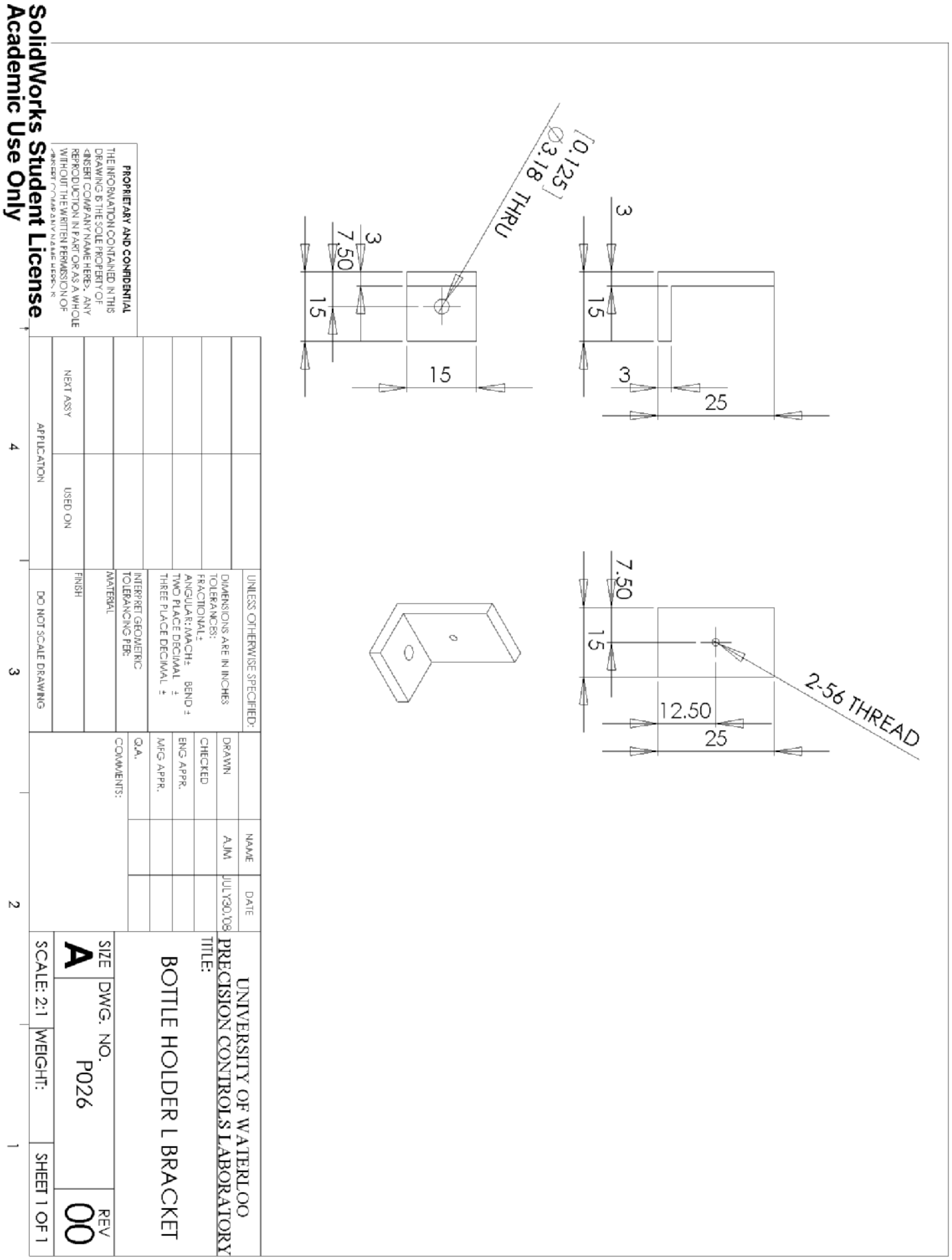
0
108
158
0
81
123.45
4 X ϕ3.18
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
ALUMINUM
FINISH
NAME
DATE
DRAWN
AJM
AUG.6.'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS: HIGH PRECISION REQ'D
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
BOTTOM PLATE
SIZE
A
DWG. NO.
P021
REV
00
SCALE: 1:2
WEIGHT:
SHEET 4 OF 4
4
3
2
1



DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE	PRECISION CONTROLS LABORATORY UNIVERSITY OF WATERLOO
	DRAWN	AJM	JULY30, 08	
	CHECKED			HPC MOUNTING
	ENG APPR.			
	MFG APPR.			
MATERIAL	Q.A.			
FINISH	COMMENTS: 2 PCS REQ'D			SIZE DWG. NO. P025 REV. 01
DO NOT SCALE DRAWING				SCALE:1:2 WEIGHT: SHEET 1 OF 1

NEXT ASSY | USED ON
APPLICATION



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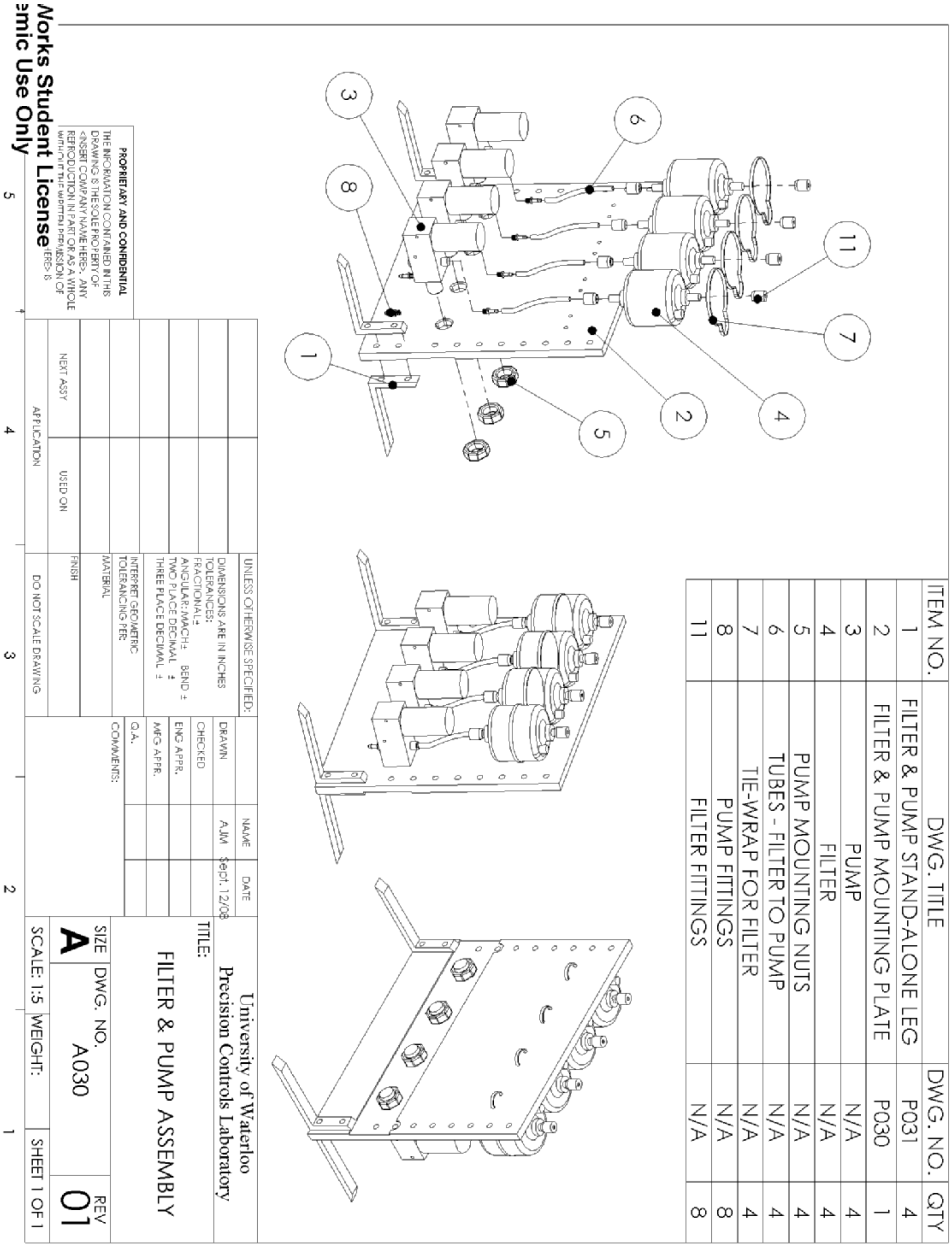
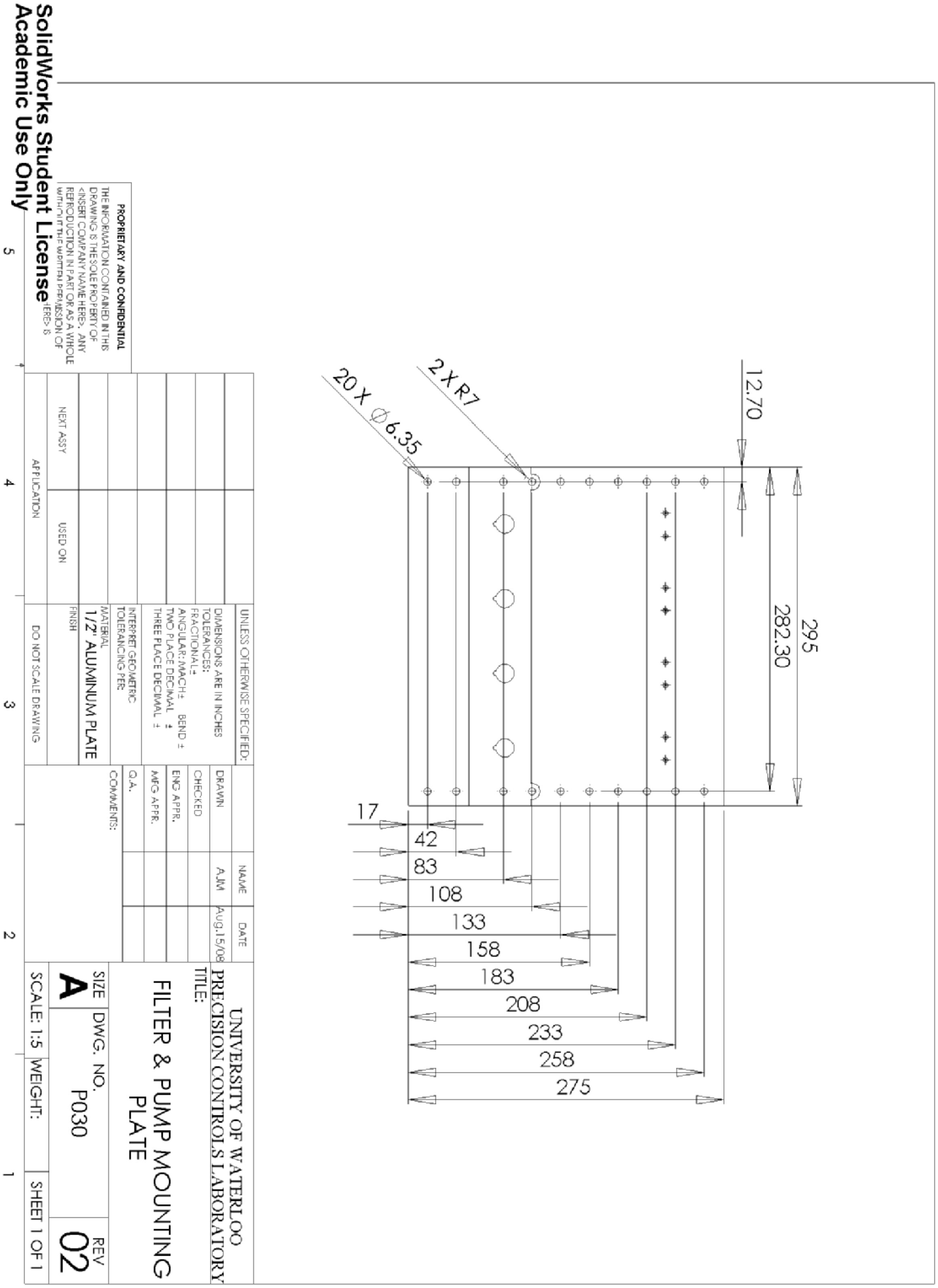
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
AJM
JULY30,'08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
UNIVERSITY OF WATERLOO
PRECISION CONTROLS LABORATORY
TITLE:
BOTTLE HOLDER L BRACKET
SIZE
A
DWG. NO.
P026
REV
00
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
[0.125]
⌀3.18 THRU
2-56 THREAD
3
7.50
15
25
12.50

3. Filter & Pump Assembly

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NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
1/2" ALUMINUM PLATE
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
AJM
Aug.15/08
UNIVERSITY OF WATERLOO
PRECISION CONTROLS LABORATORY
TITLE:
FILTER & PUMP MOUNTING PLATE
SIZE
A
DWG. NO.
P030
REV
02
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
20 X ⌀6.35
2 X R7
12.70
282.30
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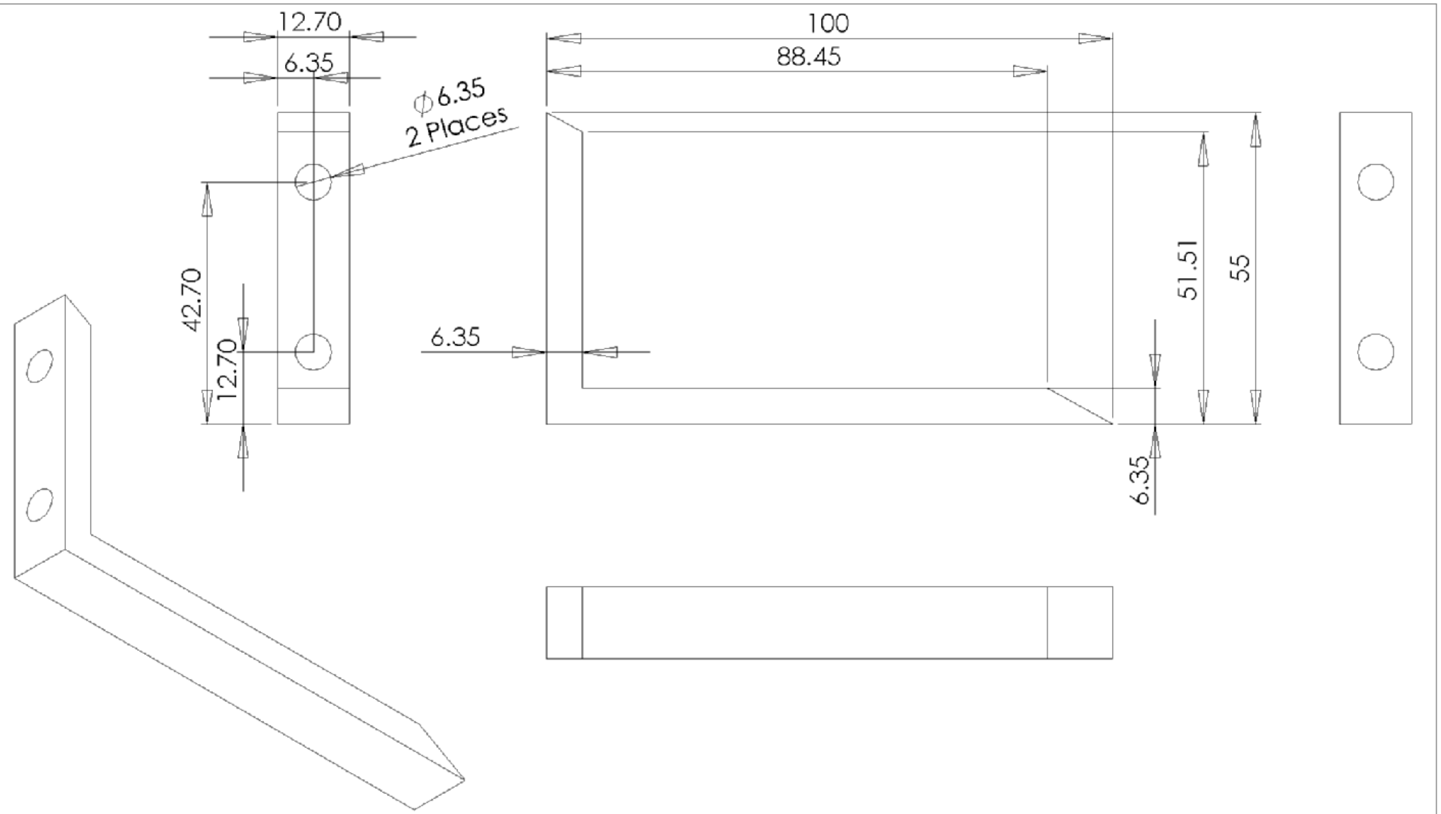
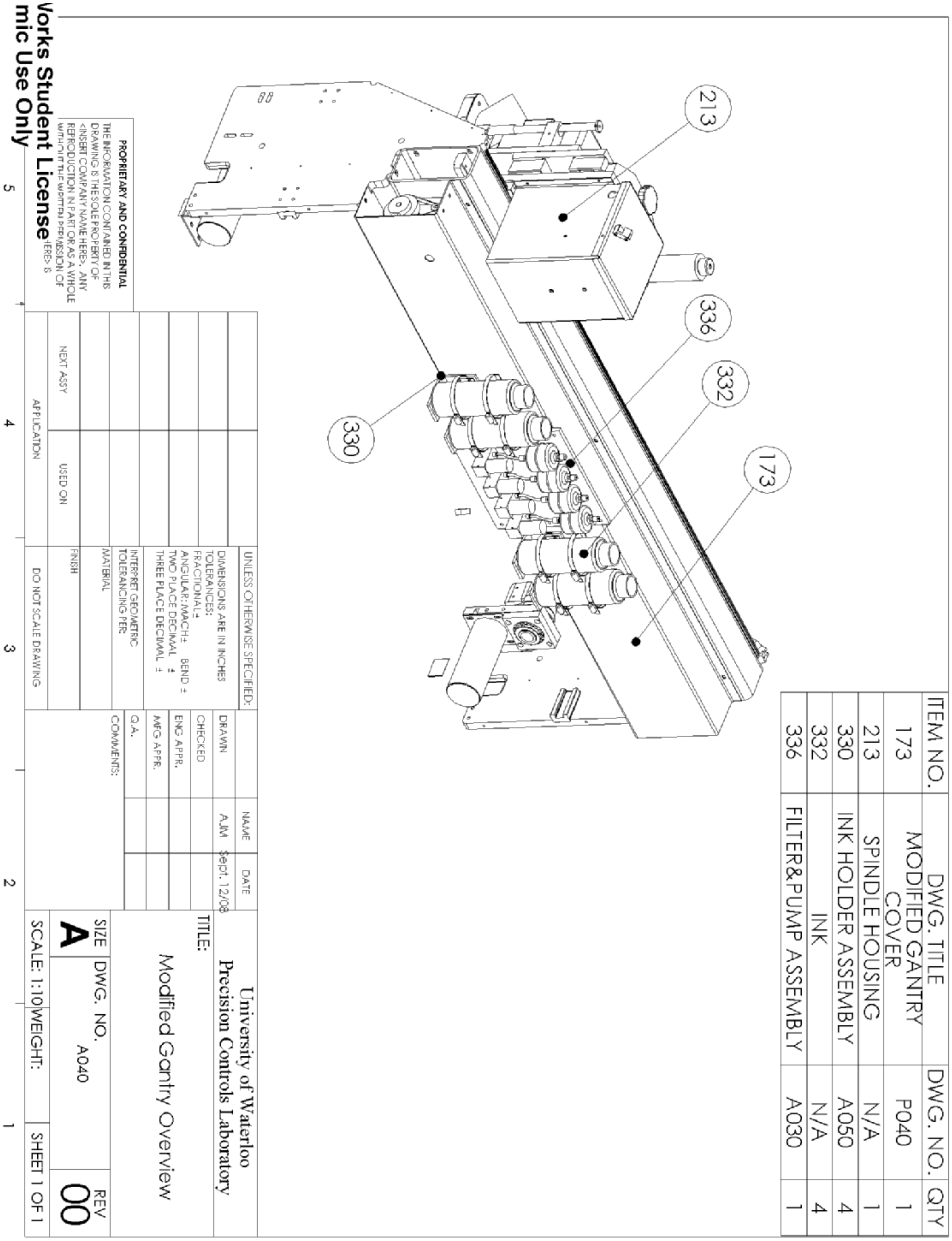
275
5
4
3
2
1

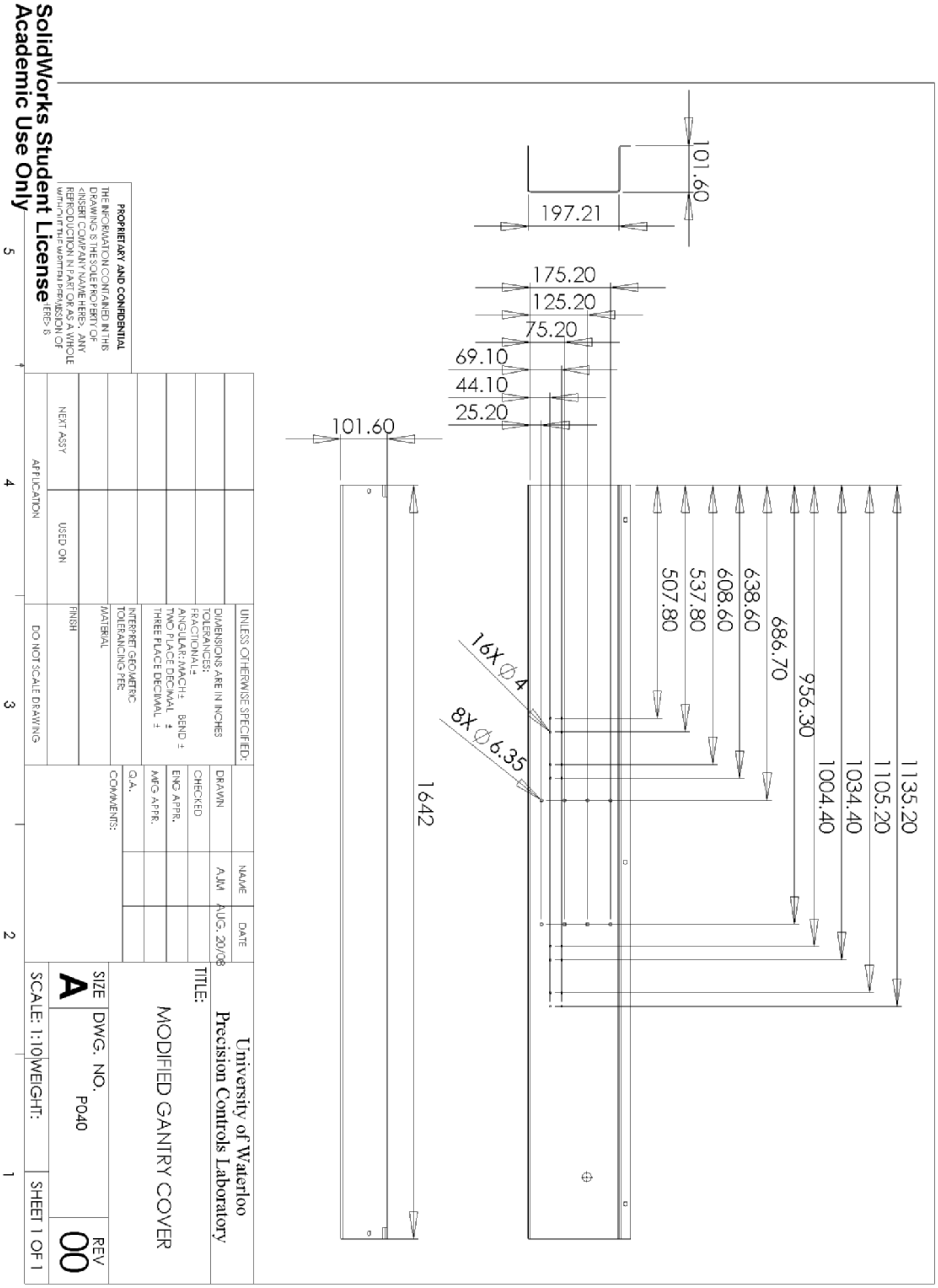


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	UNIVERSITY OF WATERLOO PRECISION CONTROLS LABORATORY	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	AJM	JULY 25/08	TITLE: FILTER & PUMP MOUNTING STAND-ALONE LEG	
	CHECKED				
	ENG APPR.				
	MFG APPR.				
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.				
MATERIAL 3X3 ALUMINUM ANGLE	COMMENTS:			SIZE A	DWG. NO. P031 REV 00
FINISH					
NEXT ASSY / USED ON / APPLICATION					
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT:	SHEET 1 OF 1

4 3 2 1

4. Modified Gantry

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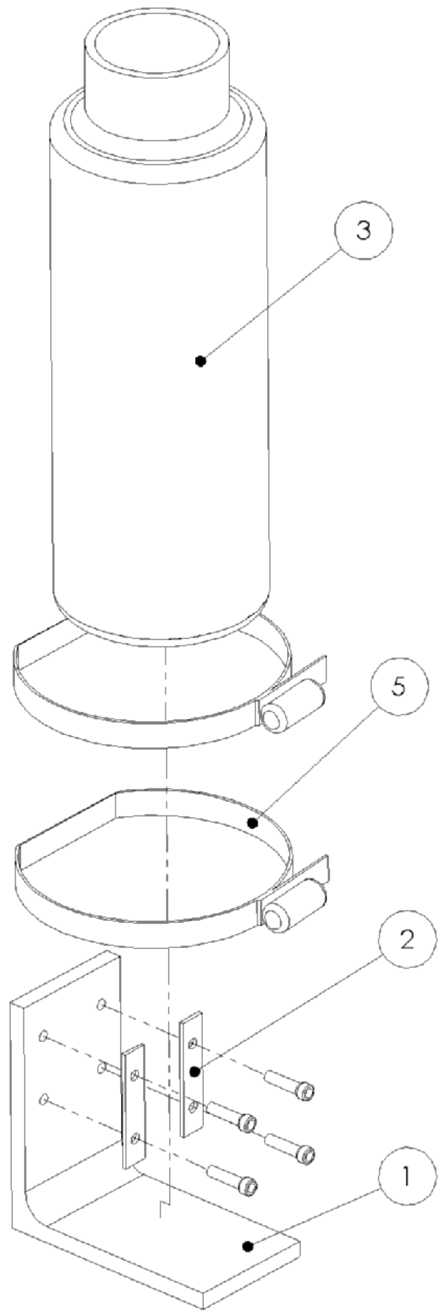
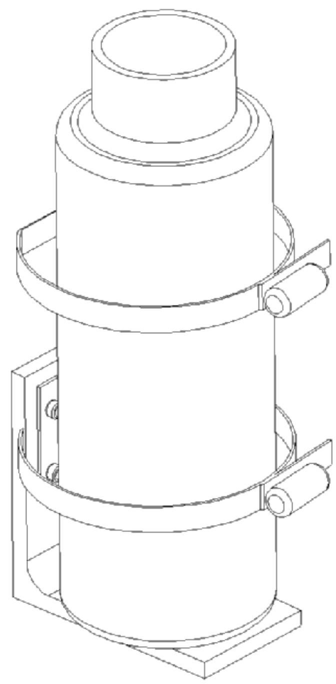
101.60
197.21
175.20
125.20
75.20
69.10
44.10
25.20
101.60
507.80
537.80
608.60
638.60
686.70
956.30
1004.40
1034.40
1105.20
1135.20
16X Ø 4
8X Ø 6.35
1642
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NAME
DATE
DRAWN
AJM
AUG. 20/08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
University of Waterloo
Precision Controls Laboratory
TITLE:
MODIFIED GANTRY COVER
SIZE
A
DWG. NO.
P040
REV
00
SCALE: 1:10
WEIGHT:
SHEET 1 OF 1
5
4
3
2
1

ITEM NO.	DWG. TITLE	DWG. NO.	QTY
1	INK SUPPORT ANGLE	P050	1
2	RING SUPPORT SHEET METAL	P051	2
3	INK RESERVOIR	N/A	1
5	ADJUSTABLE MOUNTING RING	N/A	2





DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

	NAME	DATE
DRAWN	AJM	AUG.16/08
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

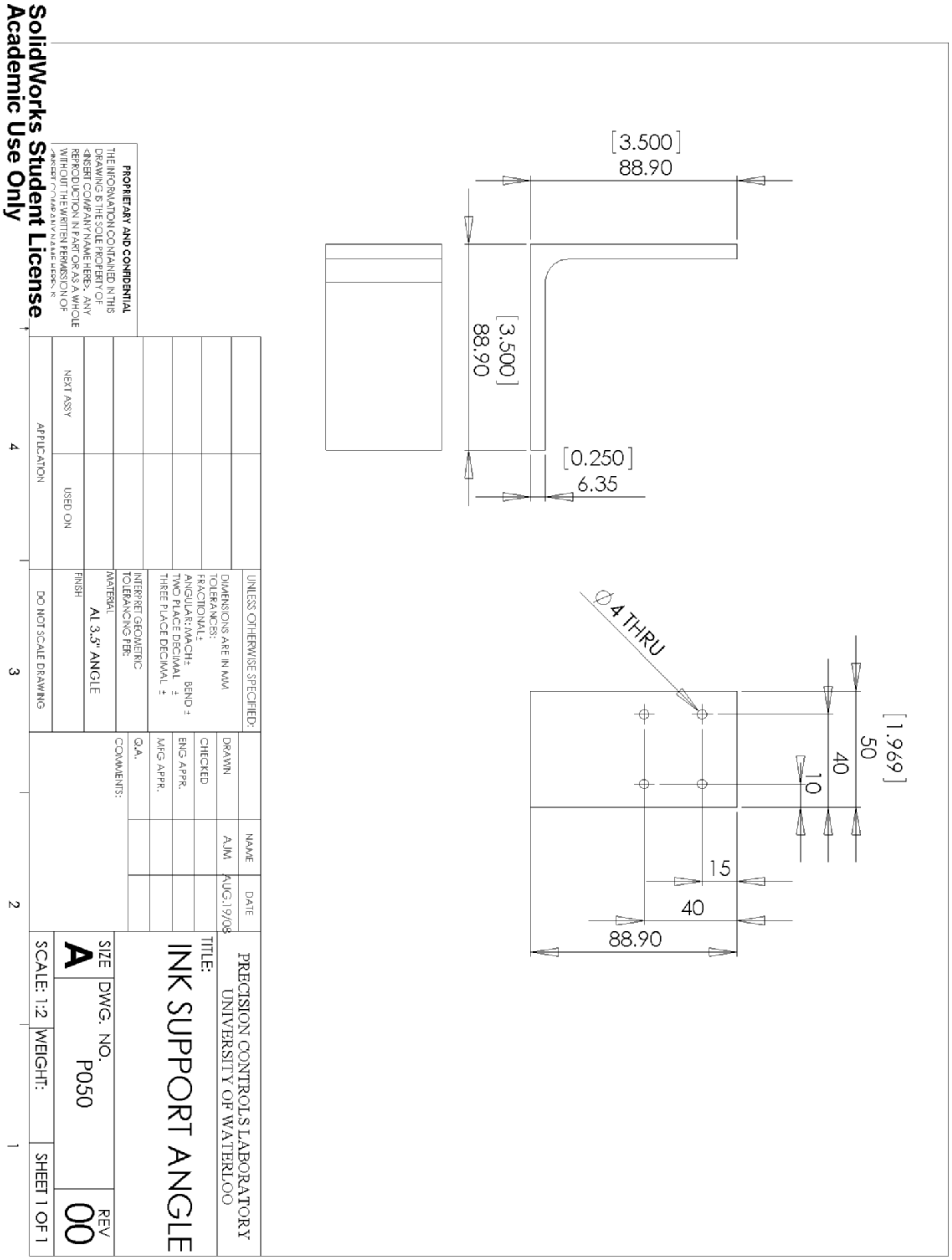
COMMENTS:

University of Waterloo
Precision Controls Laboratory

INK HOLDER ASSEMBLY

SIZE A | DWG. NO. A050 | REV. 03

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1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ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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APPLICATION
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NAME
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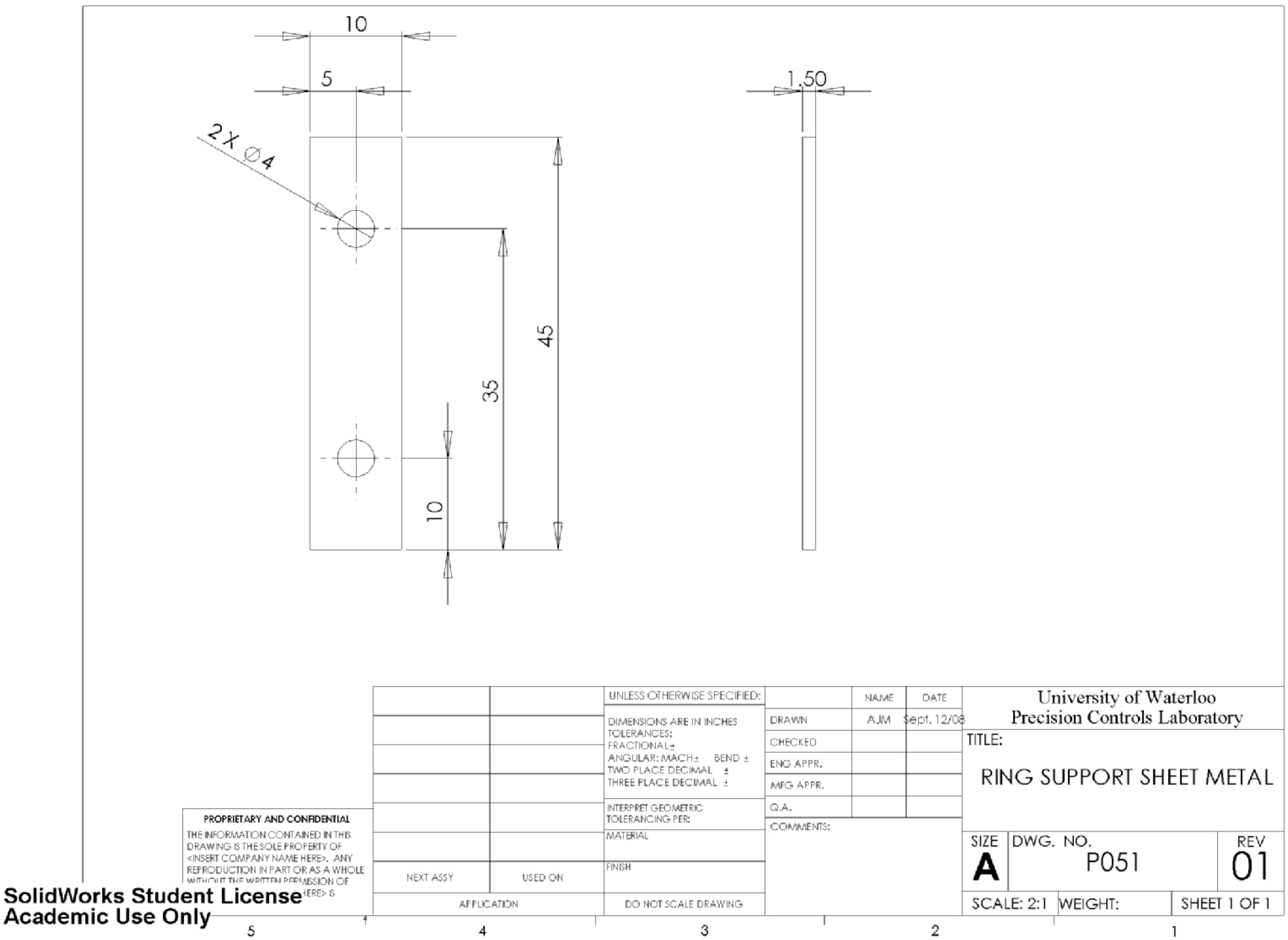
DRAWN
AJM
AUG.19/08
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PRECISION CONTROLS LABORATORY
UNIVERSITY OF WATERLOO
TITLE:
INK SUPPORT ANGLE
SIZE
A
DWG. NO.
P050
REV
00
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
AJM
Sept. 12/08
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
University of Waterloo
Precision Controls Laboratory
TITLE:
RING SUPPORT SHEET METAL
SIZE
A
DWG. NO.
P051
REV
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SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
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