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Rapid Configuration 3D Printer

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Abstract

Select industries have begun to adopt additive manufacturing as a viable alternative to traditional manufacturing methods. One of the major factors that has prevented the widespread adoption of additive manufacturing has been the cycle time required to produce a given object. In order to reduce cycle time, a novel method of additive manufacturing has been developed which employs a rapidly configurable mold cavity. The mold cavity is formed by an addressable pin array. The array is able to configure into a user defined shape, after which a polymer is dispensed and cured within the mold cavity. The part is ejected, and the mold cavity is ready to reconfigure itself. The examined methodology provided a reduction in cycle time and has opened the doors for alternative materials to be utilized. In order to determine the practicality of this method, a prototype has been assembled and tested.

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I. *Introduction*

Additive manufacturing has gone through many changes within the past decade – vast improvements to print quality and material properties have brought additive manufacturing (commonly called 3D printing) closer to widespread adoption than ever before. Even with decade of improvements, manufacturer's have been hesitant to fully embrace additive manufacturing as a viable alternative to traditional manufacturing methods. This is due in large part to the speed at which a given object can be generated (printed). Another important aspect of additive manufacturing that is missing in current methods is the ability to introduce additional objects such as fasteners and electronics into a print. The variety of material selection has improved since the introduction of additive manufacturing in the early 80's, however there is a large segment of materials still not offered commercially.

Luxx Enterprises acknowledges that improvements in the methods of additive manufacturing is a necessary step towards universal acceptance as a viable alternative to traditional manufacturing processes. It is with these goals in mind that a proof of concept prototype be designed in which improvements to print speed, breadth of material choices, and ability to insert mold objects, is achieved. In order to meet these goals a novel approach to additive manufacturing was needed.

Inspiration was found in an MIT paper by Leithinger, Et al. This paper documents a new approach to physical telepresence (Figure 1). A bed of pins adjust vertically in order to roughly render the shape of objects [1].

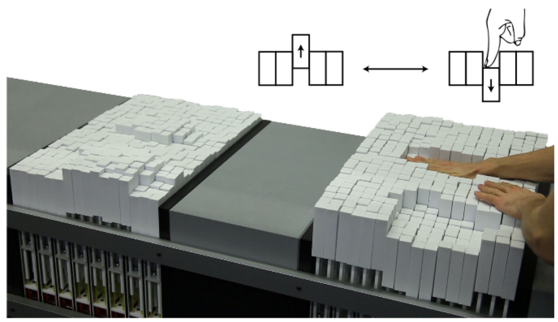


Fig. 1 A figure taken from the MIT paper showing the physical telepresence device [1].

This concept was adopted as the basis for a new method of additive manufacturing. This configuration allows for an open-pour method in which inserted objects can be over-molded and a variety of materials to be used. The proof of concept prototype is limited in resolution, however, improvements to resolution are feasible with currently available technologies.

A. Company Background

Luxx Enterprises has been involved in technology consulting for over 15 years, providing outsourced technology solutions for small and mid-sized companies in the Chicago-land region. During the early part of this decade Luxx Enterprises had begun to provide outsourced CAD and solid modeling solutions, as such opportunities in automated manufacturing consulting have appeared. With clients in cosmetic dentistry Luxx Enterprises was exposed to the paradigm shift that was occurring throughout the industry. Rapid manufacturing and 3D printing are finally coming to age. It is with that notion that Luxx Enterprises is looking to explore areas of advanced manufacturing technologies, specifically additive manufacturing, also known as 3D printing.

B. Design Criteria

A "proof-of-concept" prototype is to be produced that will consist of 9 electronically adjustable square pins, arranged in a 3x3 grid, able to self-configure to a minimum "z" depth of 1 inch.The pin array will rest inside a control guide with close tolerances, effectively creating a rapidly configurable mold cavity (Figure 2).

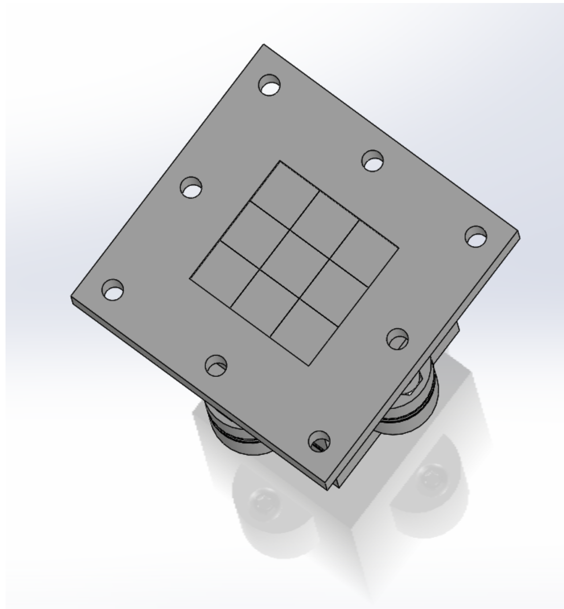


Fig. 2 Rapidly configurable mold cavity from 3x3 grid array of pins.

The square pegs will be adjusted to specific depths using a motion control system that consists of micro stepper-motors directly attached to linear screws. For demonstration purposes the motion control system will adjust the grid of pins to three predetermined configurations. Code written for an Arduino will direct stepper motors to adjust depths of each individually addressed pin (Figure 3).

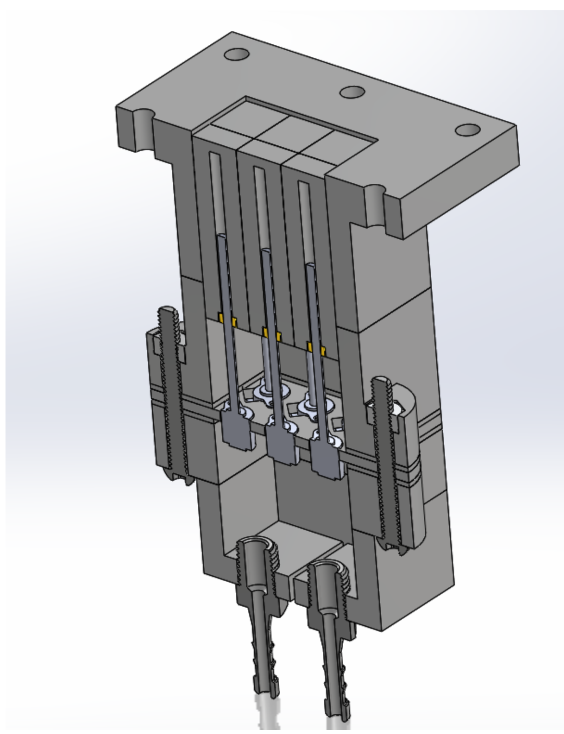


Fig. 3 Section view of the rapidly configurable mold cavity showing motors and linear screws.

Above the grid array lies a thin silicone sheet. After the pins are set into a position a pump will apply vacuum to the containment vessel surrounding the pin array. The pressure differential will cause the silicone sheet to conform to the shape of the cavity. A binary curing resin will be metered and dispensed into the cavity where an endothermic chemical reaction will take place. The overall product will have a modern and minimalist look for mass appeal.

C. Literature Survey

Before proceeding with the design process, the team performed a literature search of related patents and existing technologies so as to not infringe on intellectual property.

Although it has only started to become prevalent in households recently, 3D-printing – commonly known as additive manufacturing – has existed for a long time. In fact, the technology being used in this device, stereo-lithography, has been around since the early 1980s [4]. In 2014 the Massachusetts Institute of Technology (MIT) media lab had produced a physical telepresence system which utilizes arrays of linear actuators to move square pins up and down in order to convey a physical link between two of these systems [1]. While this idea was primarily for computer-mediated object manipulation, this project will implement this idea toward a programmable bed for 3D-printing applications. In essence, this will result in a customized mold to be used in stereo-lithography (Figure 4).

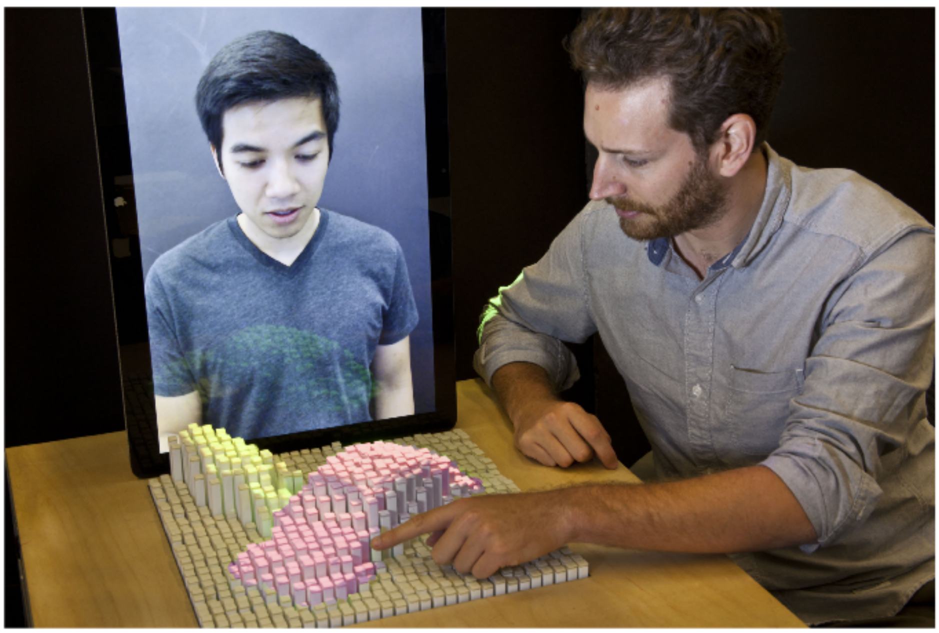


Fig. 4 Figure taken from MIT paper demonstrating physical telepresence technology [1].

Ultraviolet (UV) resin was considered for the project, the team aimed to ensure proper handling of UV light during the curing process if UV cure resin was used. The most common wavelength for various UV lights is 395 nm [2]. Scientists sort UV light into three different categories based on their wavelengths – UV-A, UV-B, and UV-C. UV-A has the longest wavelength, and UV-C has the shortest [5].

UV-C includes wavelengths from 100 nm to 280 nm, UV-B from 280 to 315 nm, and UV-A from 315 to 400 nm (Figure 5). Mercury vapor UV lamps were traditionally used to cure UV resin. However, to reduce risk of exposure to harmful mercury vapor fumes, a UV LED lamp can be used instead. These lamps are capable of producing the wavelength necessary for curing UV resin with a far narrower spectrum of radiation. Additionally, UV LED lamps last about 10 times as long as mercury vapor UV lamps [6].

Most UV resins will react in normal daylight. However, for rapid prototyping applications, UV wavelengths less than 400 nm would be preferred. Wavelengths below 365 nm will cure the resin instantaneously, but wavelengths above 385 will cure the resin more uniformly and allow for penetration into thicker sections [7].

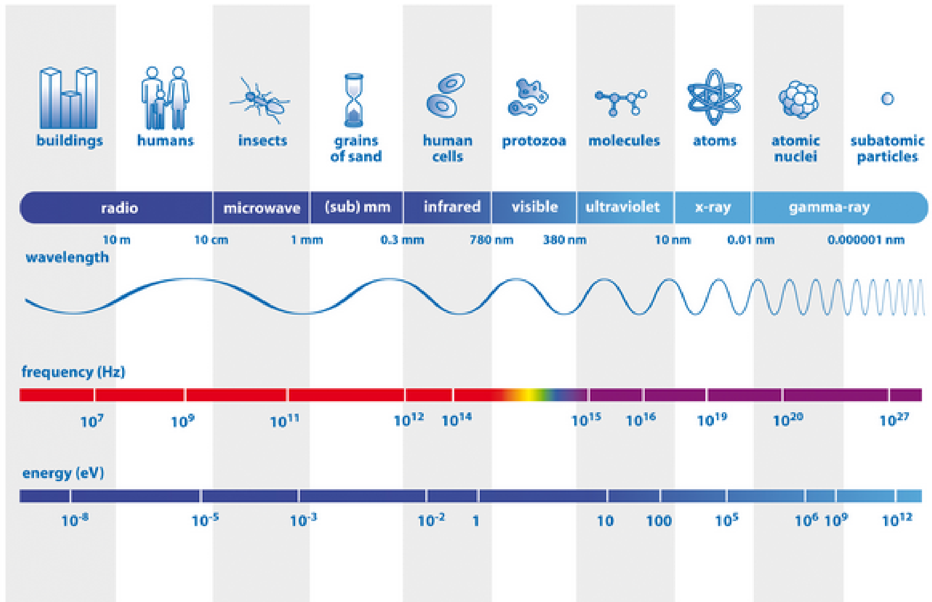


Fig. 5 Electromagnetic spectrum graph showing UV frequencies. [2]

Another resin has been considered, polyurethane. Smooth-On© provides four polyurethane resins that are bright white and virtually bubble free: Smooth-Cast 300Q, Smooth-Cast 300, Smooth-Cast 305 and Smooth-Cast 310. Since the prototype is meant to minimize print time, the Smooth-Cast 300Q resin will be considered. The pot life of this resin is only 30 seconds, but the cure time is 4 - 5 minutes, while the rest of the Smooth-On© resins have a cure time over 10 minutes. While it is not necessary for a prototype, if the Smooth-Cast 300Q is used in industry it may be important that the tensile strength is 3,000 psi and the tensile modulus is 139,500 psi. This resin has a shrinkage of approximately 0.01 in/in, which will be important for manufacturing accurate parts [8]. Since the polyurethane includes two liquids that need to be accurately measured and mixed, two peristaltic pumps and a mixing nozzle will be used.

Peristaltic pumps (Figure 6) are commonly used in applications in which it is undesirable for the pump mechanism to come in direct contact with the pumped fluid. The peristaltic pump utilizes a series of lubricated shoes which contact the exterior of a replaceable, compliant hose. Pumping action is similar to a piston style pump as the shoes separate small packets of pumping fluid, then force them towards the output creating pressure as a result. The result is a pumping system that requires no seals or packing and complete isolation from the pumped fluid [3].

Fig. 6 Schematic diagram for a peristaltic pump. [3]

Once the appropriate resin has been chosen, the next challenge is to actuate the motion control of the bed to fit the desired mold geometry. For this proof-of-concept design, the bed will consist of a 3x3 grid of "pins" controlled by stepper motors. The stepper motors being used in this device are bipolar stepper motors. These are controlled using a micro-controller, such as an Arduino board, which will require the use of an external DC power supply [9].

One of the desired features of the device is that the motors be individually addressable. For the proof-of-concept design, the device will have pre-determined geometry the motors will move to with the push of a button. This will also be programmed into the micro-controller and wired into the circuit using push buttons. The motor drivers are wired in parallel with the push buttons and will be programmed to move only when the appropriate push button is pressed [10]. Because the micro-controller will not only be controlling the nine motors (Figure 7), but also a vacuum pump, metering pumps and a fan, the device will have to include relays. This will allow the high-voltage devices to have the power delivered to them that they need without burning out the micro-controller [9].

Fig. 7 Micro stepper motor and linear screw used for pin motion.

II. *TechnicalContent*

A. Key Metrics

Without existing devices for comparison, prototype manufacturing relies on defined metrics (Table 1) to establish the terms for project success. In order to function as a proof of concept, the finished prototype must successfully present a cavity that is configured to a user defined shape and fill with a suitable compound. The prototype aimed to reduce additive manufacturing print time by using an articulating print base, it was thus necessary that the configuring of the pins take up no more than [5-10%] of the overall cycle time. Overall cycle times are ultimately defined by the cure times of the selected compound, however the metrics established by the sponsor have dictated a target print time of five minutes. The cycle time selected by the sponsor is for demonstration purposes. The composition of the final part is dictated by the needs of the customer, limited only by the chemical interactions between the compound and the membrane that seals the cavity.

Table 1 Key metrics as agreed upon in project charter.

Metric	Description
1. Pin Coordination	The pins must move in a coordinated fashion, the minimum Z distance
2. Print Time	Print time is under 5 minutes (not including post cure process)

Through meeting with the project sponsor a set of goals were developed in order to give the engineering team a target objective. The basic operation and construction of the machine were set forth. This set of goals (Table 2) was documented in the project charter and provides the foundation for the project.

Table 2 Goals and objectives as agreed upon in project charter

Goal
1. Adjustable molding section that consists of a 3x3 array of pins.
2. Minimum Z travel of ½", preferable travel of 1" for each pin.
3. Pins will move via cable and sheath or linear screw.
4. Vacuum enclosure and vacuum pump to pull down silicone, or another substrate, sheet to conform to pin array.

B. Pin Array

The prototype pins are constructed from 3D printed PLA, this method of manufacturing allowed for minimal post processing for the given geometry. The array of 9 square pins (Figure 8) that will form the print cavity are not subjected to a large amount of load, therefore PLA construction is sufficient. For a 0.625" square pin, a theoretical maximum load on each pin under full vacuum would not exceed 6 PSI, well below the 2600 PSI compression strength of a standard PLA 3D printed part [11].

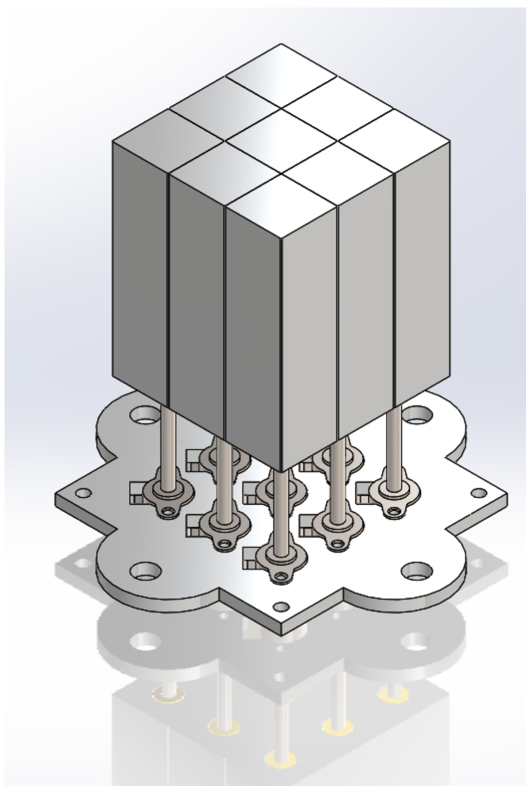


Fig. 8 Exposed pin array consisting of 9 pins mounted on linear screws.

Two methods were considered for the movement of the pin array, servo motors attached to sleeved cables or stepper motors with attached lead screws. Two types of servo motors were examined, linear and 60 degree. The type of motor used dictates the configuration of the pins, as well as the Arduino code needed. Determination of motor type defines the motion of the entire device, a mid-project change would result in substantial lost time, therefore a decision matrix was made. The decision matrix for the motors (Table 4) compares three types of motors: micro linear servos, two-phase four-wire micro steppers and a 60-degree hobby servo. Criteria such as cost, torque, speed of actuation, and precision were considered. Stepper motors were selected as their design inherently has greater positional accuracy and precision, while also benefiting from more widespread implementation in 3D printer construction. The large utilization of stepper motors for 3D printers has resulted in greater availability of components and support. The combination of stepper motor and lead screw comes with a penalty of slower movement speeds; however, it is sufficient for the small vertical displacement required for the prototype. The stepper motors used in the pin array are individually addressed such that the internal cavity volume is the product of each pin's controlled height.

C. Vacuum Canister

The pin array is covered by a thin silicone membrane that serves several purposes. The membrane separates the mechanisms of the prototype from the print compound being used, as well as functions as a release film once curing is complete. Additionally, the membrane provides the upper surface of a chamber that will contain negative pressure. An internal vacuum is required to pull the silicone membrane tight against the pin array after it has been positioned away from the uppermost surface. The first design consisted of an external container that would accept the pin array as a detachable cartridge. Having the pin array as a separate structure allowed for better control over vacuum leakage, as the pin array has numerous areas presenting risk of air infiltration. It was determined that the absolute control over vacuum was not necessary, as the overall cycle time was fast enough to negate the detrimental effects of vacuum leaks. The final pin array assembly (Figure 9) would contain the vacuum internally, and this structure would maintain vacuum long enough to complete curing of the print compound. Additional advantages of controlling vacuum within the pin array assembly were reduced size, manufacturing complexity, and cost.

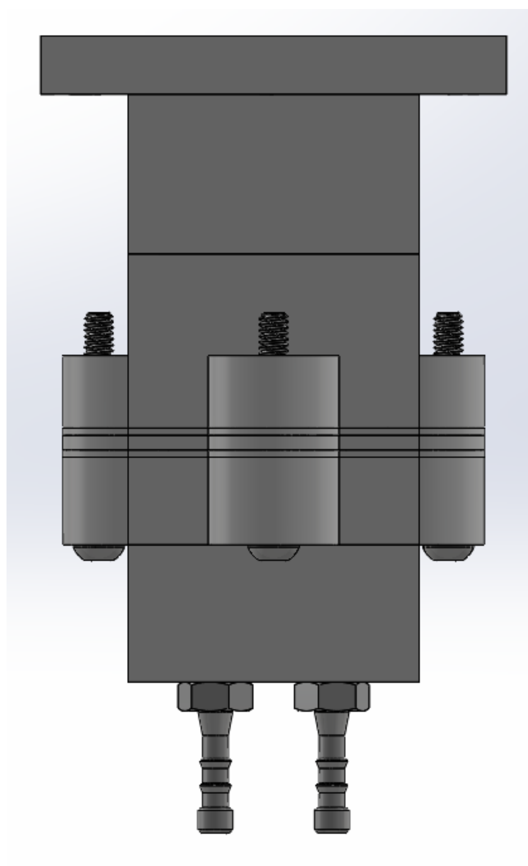


Fig. 9 Final pin assembly with integrated vacuum containment system.

D. Print Compound

The customer required overall cycle time to be minimized. Cycle times are predominantly determined by the material that is used for printing, thus special consideration was given to the selection of print compound and a decision matrix was created. Figure 5 compares various performance characteristics of UV resin, binary resin, thermoplastics and wax. Each of the material options were analyzed based on their respective cost, safety, estimated production time, strength, detail, and cleanliness. As a result of the decision matrix process, the first choice of print material was to be UV resin. UV resin produced almost instantaneous cure times during testing while being easy to handle, strong, and fluid enough to contour to complex shapes. Further research determined that the UV resins that were commonly available due to the usage in stereolithographic 3D printing were not suitable, as they become opaque to UV light after curing. Opacity to UV light in a cured portion of resin is a key benefit to stereolithographic prints, as it prevents UV passthrough that would cure resin past the part dimension. Typical layer thicknesses for stereolithographic prints range from 25-100 microns, or 0.001-0.004" [12]. The pin array developed has a maximum cavity depth of 1", for a maximum layer height of 0.004" a total of 250 layers was determined to be unacceptable for the desired cycle time.

The second option dictated by the decision matrix of Figure 3 was a binary resin. Binary resins consist of the family of materials known as thermosetting polymers. A urethane polymer, Smooth-Cast 300Q (SC300Q), was selected as a suitable alternative to a UV cured resin (Table 3). SC300Q features ultra-low viscosity resins that do not require degassing, meaning it can easily be pumped directly into the pin cavity. The pot life and cure time of SC300Q is 30 seconds and 5 minutes respectively, which is appropriate for the desired cycle time [8]. Binary resins in general provide superior part strength and lower cost as compared to UV cured resins, thus it is a superior print material once the production limitations of UV resins are taken into account.

Table 3 Technical specifications regarding Smooth-Cast 300Q polymer.

Smooth-Cast 300Q									
Pot Life (73F/23C)	Cure Time (73F/23C)	Tensile Strength	Tensile Modulus	Elongations at Break %	Flexural Strength	Flexural Modulus	Compressive Strength	Compressive Modulus	Shrinkage
30 Sec.	4 - 5 Min.	3,000 psi	139,500 psi	5%	4,510 psi	128,000 psi	4,000 psi	45,800 psi	0.01

E. Z-Axis

The prototype is a component section to a manufacturing cycle; thus, it becomes necessary to anticipate ancillary functionality needed to allow integration. A Z-axis was designed to allow vertical movement of the dispensing subsystem (Figure 10). By moving the dispensing system, space is provided to allow for part removal and gives the opportunity for additional manufacturing processes during the casting operation. Additional processes that may occur during casting would include the addition of fasteners or other componentry into the liquid resin. The Z-axis has a connected part shield that encloses the mold during casting in order to prevent splashing of resin or to facilitate fume extraction if required.

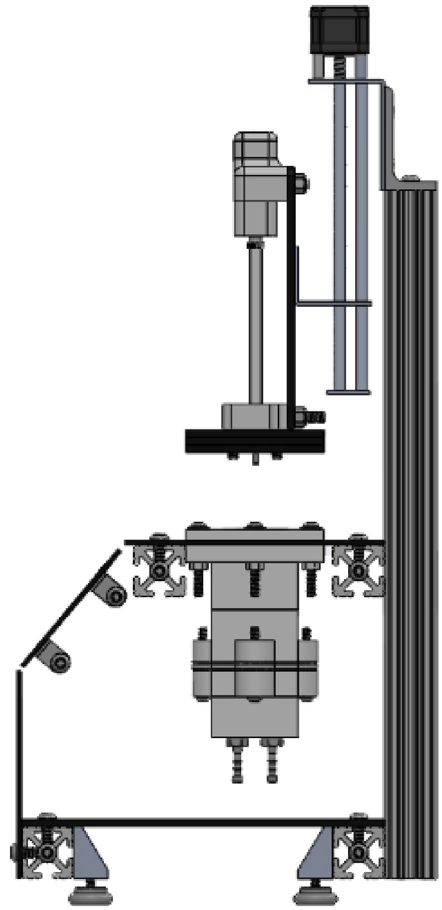


Fig. 10 A sideview of the machine - showing the z-axis on right.

The construction of the Z-axis consists of three linear rails with bronze bearings and movement is controlled by NEMA 17 stepper motors attached to ACME screws. The nozzle system attached to the Z-axis was designed to be disposable. Due to the fast cure time of the binary resin, it was considered too risky to have a permanent dispensing nozzle. The disposable nozzle facilitates internal mixing of the resin and an attached coupling keeps the supply hoses separated (Figure 11). The entire Z-axis system mounts to an aluminum extrusion that extends vertically above the casting surface.

Fig. 11 A view of the actual machine that shows the resin mixing assembly.

F. Electro-mechanical System

The system is composed of nine micro stepper motors, a vacuum pump, two peristaltic pumps, and a high-powered stepper motor. Each of the nine micro stepper motors comes equipped with a linear screw fitted with a pin. The micro stepper motors are arranged into a 3×3 pin array, which becomes the mold cavity. The vacuum pump is located below the micro stepper motors, and pulls the substrate down to create the part mold based on the configuration of the pin array. The peristaltic pumps comprise the dispensing system, which is located directly overhead of the pin array. They dispense the resin components into the mixing nozzle, which delivers the mixed resin into the mold cavity for curing. The high-powered stepper motor is used to change the vertical position of the dispensing system.

One of the customer requirements was that the prototype be fully automated. To meet this requirement, the prototype's components are all controlled by an Arduino Mega micro-controller (Figure 12). The components directly connected to the micro-controller are the pressure sensor, the motor driver modules, the relay module, the push buttons. The pressure sensor is connected to analog pins and draws 3.3 volts directly from the Arduino. The remaining components are connected to digital pins. The only other component to draw power directly from the Arduino is the relay module. It draws 5 volts from the Arduino to trigger the relay. All the other components draw power from the power supply. See Appendix for an enlarged schematic of the wiring.

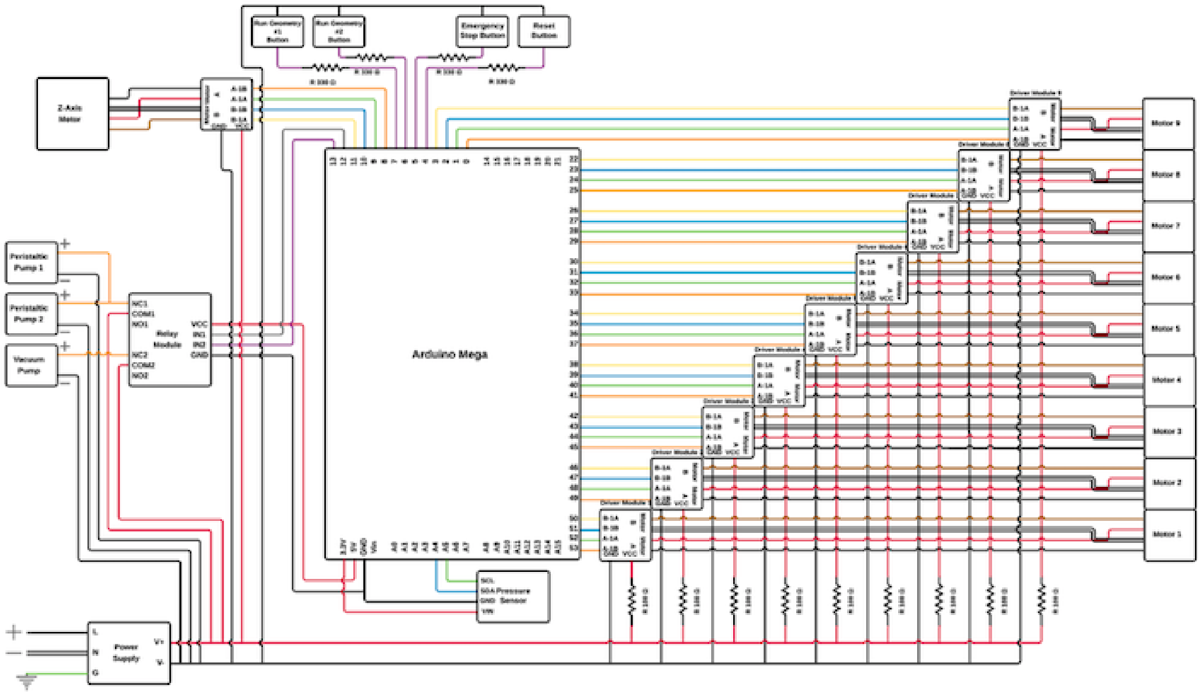


Fig. 12 Electrical wire diagram.

All objects are created in the beginning of the program, as is required in Arduino programs. Libraries used in this program are the Stepper, Wire, and SFE-BMP180. The Stepper library is required to control the stepper motors. The Wire and SFE-BMP180 libraries are used to communicate with the pressure sensor. Since push buttons are being used, volatile Boolean variables are used to check the status of each push button. Pins are assigned in the setup function.

The pressure sensor records pressure and temperature data the entire time the machine is on. To ensure that the pressure sensor does not depend on configuration it is written into a separate function, which is called continuously in the loop function of the program.

The machine only runs when one of the push buttons is pressed. For this prototype, there are three pre-defined geometries for the pin array, so the machine has three buttons to run the program. There is also an emergency stop button, which terminates the process at any point should problems arise, and a reset button, which returns the pins to their home position.

The loop function of the program begins by calling functions to check each push button's status. When one of the buttons is pressed, the machine performs the processes tailored for the specific geometry. The machine is programmed so that if one of the buttons is pressed, the program is not interrupted by any of the other buttons with the exception of the emergency stop button. If that button is pressed, the micro-controller goes into an infinite loop, stopping all processes (Figure 13). See Appendix A and B for code and enlarged logic diagram.

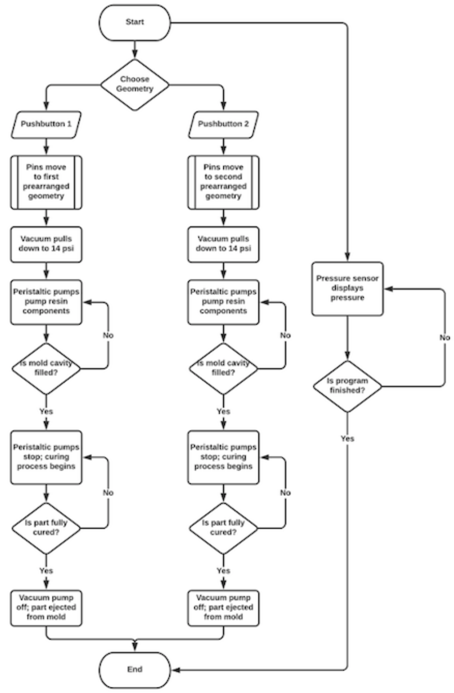


Fig. 13 Logic sequence for coding.

The process begins with the user choosing their desired geometry by push button. The pin array then conforms to that geometry. After the pin array is set, the vacuum pump turns on, pulling the substrate down to the pins and creating the mold cavity. The z-axis moves downward to begin the dispensing of resin. Once the z-axis is in position, the peristaltic pumps begin pumping the resin components, mixing together in the nozzle. The peristaltic pumps run until the mold cavity is filled. After the mold cavity is filled, the peristaltic pumps turn off and the resin is allowed to cure. Once curing is complete, the z-axis moves back up to its original position, the vacuum pump turns off, and the pins reset to their home position. See Appendix C for code.

III. *Methodology*

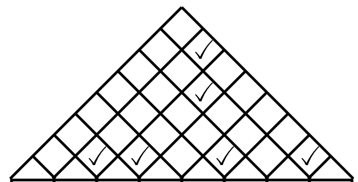
In order to create a successful prototype, many design aspects have to be analyzed. There are several engineering tools that guided the analysis that was used in order to decide the parts that will be needed within the design: the Quality Functional Deployment chart, Fishbone diagram, decision matrices and experiments. The engineering tools utilized provides balance between meeting engineering requirements and the desires of the customer.

A. Engineering Tools

The Quality Functional Deployment (QFD), or House of Quality, is used to focus on the requirements given by the customer and intertwines them with the design factors of the prototypes. Each customer requirement was given a ranking of importance on a scale from one to five, five being important. Since the prototype is being produced to try to improve the print time, the "quick print time" is considered extremely important. In order to also decrease overall print time, it would be beneficial to have a fully automated machine in order to reduce cycle time due to human error – causing it to receive a ranking of five (Figure 1). A characteristic that will always receive a high importance ranking is that the machine is safe to operate.

Since this machine is only a prototype, the quality of the print is not considered extremely important but should be considered. The aesthetic, durability and small size of the machine was also required by the customer, but those characteristics are not as important as the others leaving them to have a lower priority ranking. Several design factors had the relationship between each customer requirement determined. For example, as seen in Figure 1, the motion control system (Arduino) needs to be fully automated in order for the machine to be fully automated, resulting in a raking of five for the relationship. On the contrary, the attractiveness, durability and safety of the machine is not necessarily affected by the Arduino coding which is why a raking of zero was given for each. The most important design factors were determined based on final ratings, seen in Figure 14. A majority of the customer requirements are greatly affected by the resin, peristaltic pumps and the UV lighting, meaning that these three design factors were given high priority for the prototype.

Fig. 14 House of Quality - To focus engineering attention according to priority

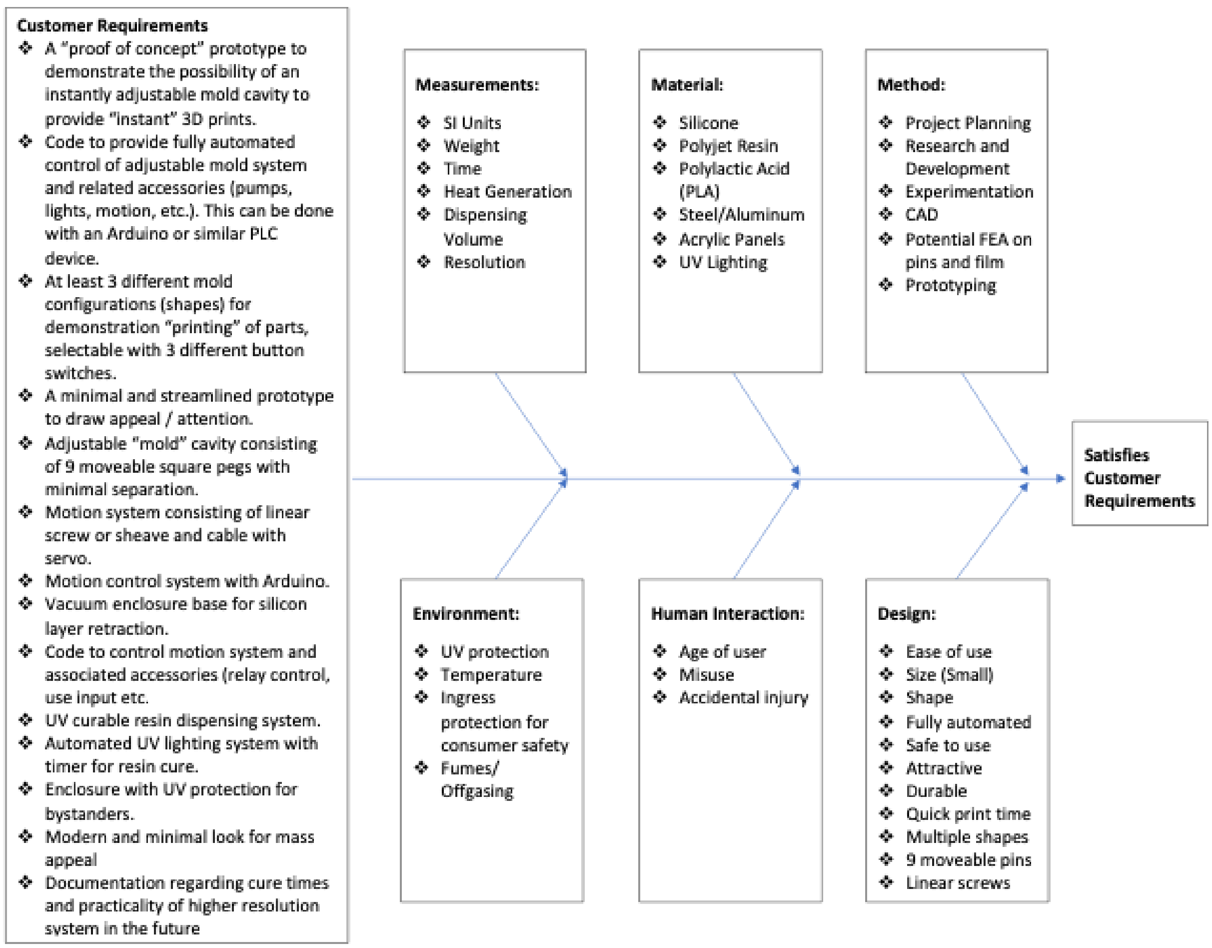


Customer Needs		Ranking	Digital Control Sys	UV Lighting	UV Protection	Modern Design	Desktop Size	Resin	Pumps
Customer Needs	Fully automated	5	5	5	0	0	5	5	5
	Safe to use	5	0	5	5	0	3	5	2
	Attractive	1	0	0	0	5	5	0	0
	Durable	3	0	0	0	0	3	5	0
	Small	3	2	0	5	5	5	0	5
	Quick print time	5	5	0	0	0	0	5	2
	High quality prints	2	5	0	0	0	0	5	5
		Ratings	69	81	25	20	44	100	70

The developing, design and production of the prototype are greatly affected by many characteristics. The Fishbone diagram (Figure 15) essentially mapped out all of the potential restrictions, considerations and solutions for the prototype. These characteristics were then placed into several categories: measurements, material, method, environment, human interaction and design. The measurements section highlights that characteristics such as weight, heat generation, time and resolution will be recorded. The potential materials used throughout the process were silicone for the vacuumed membrane, polylactic acid resin for the structure of the machine, two types of resin: UV cure resin and polyurethane resin.

Many methods were used to design the prototype, as seen in Figure 15, but the most commonly used methods were experimentation and prototyping. The environment section suggested that UV protection will be needed if a UV cure resin is used. Since there are chemical reactions that occur when the resin is cured it is important that the space is vented for the fumes to be exhausted from the building. Human interaction sometimes comes with individuals who are not correctly trained, allowing for the machine to be misused and accidental injuries to occur. Finally, the design aspect of the Fishbone diagram allowed each customer requirement to be accounted for on the overall design figure.

Fig. 15 Fishbone Diagram - Logical organization to determine root cause of problems



While the Fishbone diagram accounted for all possible outcomes for the design process, a decision matrix was used to evaluate and prioritize design options, such as the motors and print material that was used. In order to accurately rank the chosen motors, the cost, torque of the motor, design time, speed actuation, actuation force and precision were all considered. Each of these characteristics of the motors were given a weight of importance, allowing the summation of all of the weights to be one. Three motors were chosen: a micro linear servo, a two-phase four-wire micro stepper and a sixty-degree hobby servo (Table 4). The criteria were then assigned a score based on how much the design affected them, one hundred being the design completely affected the criteria. The total weighted score showed that the two-phase four-wire micro stepper was the best motor for this machine based on the given criteria.

Table 4 Decision Matrix - Weighing out options for motor control system

Motors		Design 1 Micro Linear Servo		Design 2 2-Phase 4-Wire Micro Stepper		Design 3 60 Degree Hobby Servo	
Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	0.15	40	6	90	13.5	70	10.5
Torque	0.25	50	12.5	90	22.5	30	7.5
Design Time	0.4	20	8	100	40	20	8
Speed of Actuation	0.05	60	3	90	4.5	30	1.5
Actuation Force	0.1	20	2	90	9	70	7
Precision	0.05	75	3.75	100	5	20	1
Total	1		35.25		94.5		35.5

The decision matrix for the print material had very little criteria in common with the decision matrix for the motors. Four print materials were compared in terms of cost, safety, production time, part strength, part detail and cleanliness (Table 5). The four materials considered for the prototype were UV cure resin, polyurethane resin, thermoplastics and wax. Since this prototype tried to enhance 3D printing technology by reducing the time, the production time was chosen to have the largest priority out of all of the other criteria for the print material. Similar to the decision matrix for the motors, the total weighted score determined that the UV cure resin and polyurethane resin were superior options.

Table 5 Decision Matrix - Weighing out options for print compound

Print Material		Design 1 UV Resin		Design 2 Thermoset Resin		Design 3 Thermoplastic		Design 4 Wax	
Criteria	Weight	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost	0.15	50	7.5	40	6	100	15	80	12
Safety	0.15	50	7.5	50	7.5	75	11.25	60	9
Production Time	0.3	90	13.5	90	13.5	20	3	25	3.75
Part Strength	0.1	90	13.5	100	15	20	3	10	1.5
Part Detail	0.15	90	13.5	90	13.5	80	12	90	13.5
Cleanliness	0.15	100	15	90	13.5	100	15	75	11.25
Total	1		70.5		69		59.25		51

B. Experimental Results

Since the UV cure resin and polyurethane resin were equally as useful for the experiment, the UV resin cure path was explored first. The vacuum pulls down a substrate material to make a cavity that the is filled with the resin. An experiment was performed to determine the best substrate material. Five different materials were compared using their flexibility and their likely hood to release UV cured resin. As seen in Table 6, there were only two substrates that were not resilient enough to be vacuumed: polyethylene and mold release film. The latex, mold bag and silicone materials were all viable materials for forming a mold cavity when a vacuum was applied.

Once it was determined that only three of the five substrate materials were flexible enough for the cavity, the three materials were then tested with the UV cure resin. A small amount of UV cure resin (10 mL) was poured onto each material and then was cured under the UV lighting. It can be seen in Table 6 that the mold bag material chemically combined with the UV cured resin and the resin could not be removed. The latex and silicone materials both released the UV cured resin; however, the silicone material required less force to remove the cured resin. Since the silicone material was extremely flexible and the UV cured resin could be easily removed from the sheet, the silicone material was used.

Table 6 Experimental results for substrate material analysis

Substrate Material	Is the material resilient?	Can UV cured resin be removed from substrate?	Notes
Polyethelyne	No	——	————————-
Mold Release Film	No	——	————————-
Latex	Yes	Yes	Cured resin can be removed but a bit of force needs to be applied
Mold Bag Material	Yes	No	Material chemically combined to the cured resin
Silicone	Yes	Yes	Cured resin easily peels off of the material

Analysis of the silicone sheet was needed to ensure that the selected material could deform sufficiently to copy the detail of the mold. Computational analysis using ANSYS software was not possible, as commonly available material properties for silicone did not accurately represent the sheet material used for this design. In order to collect meaningful results from computational methods, extensive material property analysis would be required to characterize the specifics of the silicone used in this design. Experimental procedures proved to be sufficiently accurate while minimizing time requirements. The silicone sheet was mounted in the device as was intended and calibrated weights were applied to the surface with deformation measurements being collected. Table 7 below shows the data collected during experimentation.

Table 7 Experimental results for membrane deformation.

Weight (g)	Deformation (in)
0	0.000
5	0.050
10	0.096
20	0.163
50	0.190
100	0.220

At 100g of applied weight, the silicone deflected 0.220 inches. Due to the relative size of the 100g weight to the mold cavity, an assumption is made that the weight roughly approximates a distributed load across the silicone sheet. With the assumption of a distributed load, it was extrapolated that this load is equivalent to 0.6 psi of pressure. The equivalent pressure represents just 4.1% of a complete vacuum. It was concluded that the amount of deformation was enough for the size of mold cavity intended and the levels of vacuum to be achieved.

An experiment regarding specifically the UV cure resin was performed (Table 8). The purpose of this experiment was to check if the UV cure resin is fully cured once exposed to the UV light since the resin cures nearly instantaneously. The experiment started with fifteen milliliters of resin in a small plastic cup, the resin was exposed to the UV light for approximately five seconds. After the resin was cured, it was determined that uncured resin was still in the middle of the abstract object. For the second trial, the amount of resin exposed to the UV light was decreased to ten milliliters, but after approximately five seconds under the light the resin in the middle was still left uncured. The amount of resin was decreased a second time, allowing only five milliliters of UV cure resin to be exposed to the UV light for about five seconds. The middle of the object was still uncured. Another sample of five milliliters was put under the UV light, but instead of remaining under the light for five seconds, the duration was quadrupled. The outcome of all of the trials remained constant, the object was not fully cured. However, when comparing the thickness of cured resin for each sample, the thickness of the cured resin seemed to be about 0.005”. Finally, five milliliters of resin was spread into a thin layer (0.005”) and cured almost instantaneously after the UV light was illuminated.

Table 8 Experimental results for UV resin cure testing

Trial	Volume of Resin (mL)	Duration of UV Light (sec)	Fully Cured?
1	15	5.14	No
2	10	5.16	No
3	5	5.23	No
4	5	20.21	No

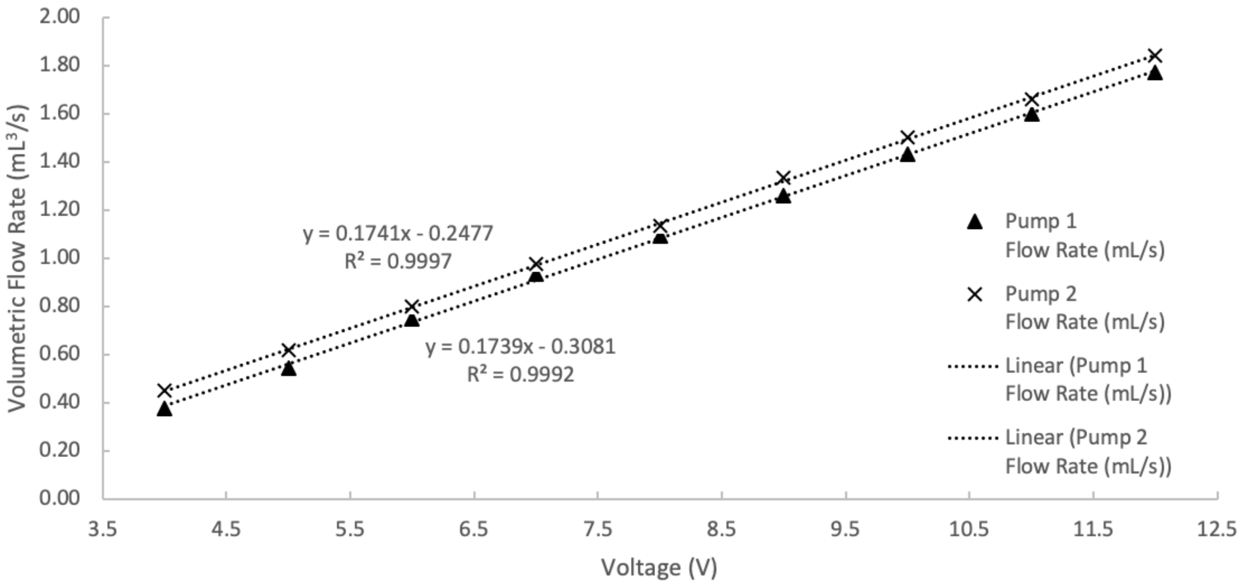
Following the previous experiment regarding UV cure resin, it was determined that a binary thermosetting resin would be of better use for this prototype. Binary thermosetting resins rely on correct mixing ratios to achieve their designed mechanical properties. The prototype will control mixing ratios by utilizing accurately calibrated peristaltic pumps. The pumps were characterized by defining flow rates as a function of input voltage. The voltage provided to the pumps can be altered to accommodate the mixing ratio required by the resin.

Peristaltic pumps are a type of positive displacement pump, meaning the volume of fluid pumped each cycle is the same. While positive displacement pumps have a predetermined volume, the system uses an electric drive motor that must be included in the device characterization. The peristaltic pumps were first characterized utilizing water and varied input voltages. The voltage input to the pumps was varied across a range of 4V to 12V, with 4V being the minimum voltage required to start pump movement and 12V being the maximum recommended voltage by the manufacturer. Water was collected in a graduated cylinder and the dispense time recorded (Table 9). The relationship between flow rate and input voltage is shown in Figure (16). Both pumps exhibited a linear relationship between input voltage and flow rate with coefficients of determination greater than 0.999. The linear relationship can be used to select input voltages to ensure even flow rates of resin.

Table 9 Experimental results for pump metering testing using water.

Volt (V)	Volume (mL)	Time (sec)	Pump 1 Flow Rate (mL/s)	Volume (mL)	Time (sec)	Pump 2 Flow Rate (mL/s)
4	30	80	0.38	27	60	0.45
5	38	70	0.54	37	60	0.62
6	45	60	0.75	48	60	0.80
7	56	60	0.93	58.5	60	0.98
8	65.5	60	1.09	68	60	1.13
9	75.5	60	1.26	80	60	1.33
10	71.5	50	1.43	75	50	1.50
11	70	50	1.60	83	50	1.66
12	88.5	50	1.77	92	50	1.84

Fig. 16 Relationship between input flow rate and input voltage of two peristaltic pumps(water).



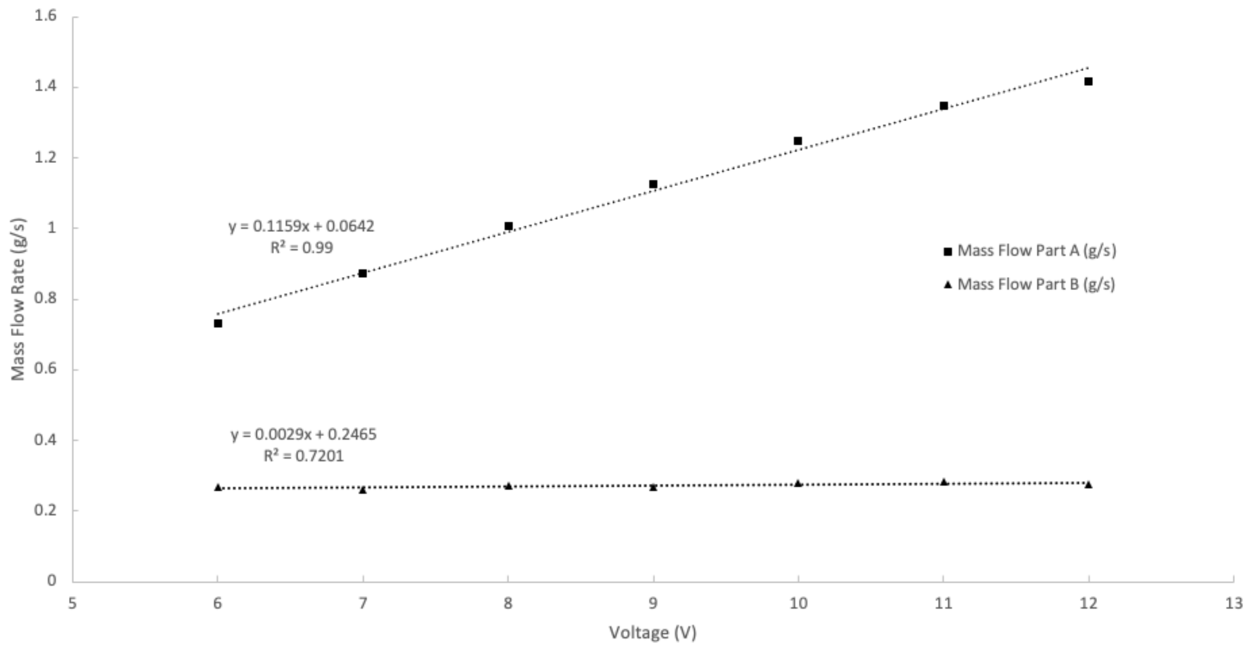
The testing of the volumetric flow rates demonstrated that the peristaltic pumps and their drive motors have a linear relationship between input voltage and flow rate. The next step for integrating the pumps was to analyze the pumping performance for the selected binary resin. The reactive nature of a binary resin system necessitated a change to mass flow rate testing. Analysis of mass flow was possible because the manufacturer specifies both a volumetric mixing ratio of 1:1 as well as mass ratio of 1:0.9. Mass flow rate testing was conducted using disposable cups to keep all components separated. A pumping time of 20 seconds was utilized, and the dispensed amounts measured using a scale. The measurement scale has a specified accuracy of +/- 0.01 grams. Table 10 below shows the experimental mass flow rates achieved for varying voltages.

Table 10 Experimental results for pump metering testing using resin.

Voltage (V)	Time (s)	Mass Cup (g)	Mass Component A (g)	Mass Flow Rate Part A (g/s)	Mass Cup (g)	Mass Component B (g)	Mass Flow Rate Part B (g/s)
6	20	1.73	16.36	0.7315	1.69	7.02	0.2665
7	20	1.69	19.12	0.8715	1.72	6.95	0.2615
8	20	1.72	21.89	1.0085	1.69	7.11	0.271
9	20	1.68	24.21	1.1265	1.7	7.08	0.269
10	20	1.7	26.69	1.2495	1.73	7.3	0.2785
11	20	1.69	28.64	1.3475	1.67	7.31	0.282
12	20	1.68	29.99	1.4155	1.69	7.23	0.277

As can be seen in Figure 17, the pumping of resin component B did not maintain an increasing and linear response to input voltage. Further examination of the two resin components determined that not only does component B have a greater density than component A, but also significantly higher viscosity. It was concluded that for the selected tubing and pump size, the system would not be able to accurately meter component B. A possible solution to an issue with liquid viscosity is to elevate the working temperature of component B to reduce cohesion and therefore viscosity. Introducing temperature control to the resin dispensing system means that matching flow rates between components becomes a function of both input voltage as well as temperature. A temperature control system could be implemented as a possible solution to this problem for the given pump size, however developing the temperature and voltage relationships for various resins is outside the scope of this design process. It is possible that a larger peristaltic pump may be less sensitive to fluid viscosity and is a more reasonable solution.

Fig. 17 Relationship between input flow rate and input voltage of two peristaltic pumps(resin).



Another experiment conducted involved the motors used to control the pin movement (Table 11). The experiment consists of several independent variables, each was tested holding the others constant. The machine may be heavily impacted by heat - meaning the heat of the motors should be monitored. The experiment controlled either the voltage (CV) or the current (CC), while adjusting the maximum force the motor withstood. Each of the trials allowed for the motor to move the pin, along with a known weight. Within the data it can be observed that as the weight was increased, the resulting temperature of the motor increased as well. It would be ideal to be able to keep the current constant, as it allows for an ambient temperature that does not rise. However, the temperature of the machine will be constantly considered - thermocouples will be placed throughout the machine to ensure no overheating will occur.

Table 11 Experimental results for motor behavior

Steps Per Revolution	RPM	Volts	Amps	CV/CC	Max Vertical Lifted Weight and Weight of Pin (g)	Motor Temp	Motor Temp T Infinity
200	60	5	0.250	CC	20	Ambient	Ambient
200	60	5	0.500	CV	50	Warm	Hot and Rising
20	300	3	0.250	CV	20	Ambient	Warm but stable
20	300	4	0.350	CC	50	Warm	Warm but stable
20	300	5	0.450	CV	50	Warm	Hot and Rising
20	300	5	0.550	CV	100	Hot	Very Hot and Rising

IV. *Results*

A. Failure Modes and Effects Analysis

Table 12 Failure Mode Analysis - Resin dispensing subsystem analysis

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recom.	Resp.	Actions Taken
Dispense resin into mold	No Dispense	No part made	7	Code runtime discrepancy	1	Effective code logic	10				
		Time spent troubleshooting	4	Poor maintenance	5	Defined reset process	5				
	Over Dispense	Wasted material	5	Part failure	2	None	7				
		Poor or incomplete cure	6	Pump inaccuracy	1	Selecting the correct part	3				
		Excess part heat	1	Code Calibration	5	Proper testing/ calibration	8				
	Under Dispense	Weak part	5	Part failure	2	None	7				
		Incomplete part/ wasted material	5	Pump inaccuracy	1	Selecting the correct part	3				
				Code Calibration	5	Proper testing/ calibration	8				

Table 13 Failure Mode Analysis - Vacuum subsystem failure analysis

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recom.	Resp.	Actions Taken
Internal vacuum	No Vacuum	Silicone sheet will not form to mold	4	No power to pump	3	Set up the procedure	10	120			
		Process halt	7	Faulty pump	1	Test runs	6	42			
	Partial vacuum	Incorrect part geometry	5	Leak in system	5	Proper material selection	6	150	seal	DS	sealed w/epoxy
		Wasted material	6	Faulty pump	1	Proper pump selection	6	30			

B. Cost Analysis

The original design was for a prototype that exhibited a proof of concept. For a realistic cost analysis, the design of the machine has been scaled from a 3x3 pin array to a 16x16 pin array. The Bill of Materials (BOM) for the prototype has been updated to reflect the resolution of the machine. The BOM has been separated into two categories: sourced parts and materials with estimated costs. The BOM is shown in Tables 14 and 15 below:

Table 14 Bill of Materials for sourced parts.

Sourced Parts			
Part Name	**Quantity**	**Cost per Unit**	**Total Cost**
Custom Motion System Control	1	$650.00	$650.00
Micro Stepper Motor	256	$3.00	$768.00
Extension Wires	1	$14.95	$14.95
Silicone Cover	1	$5.99	$5.99
Smooth-On Cast 300Q (2 Pints = 57.75in3)	1	$30.00	$30.00
SoftTouch Screw-in Leveling Glides, 1-1/16" (Quantity 4)	1	$3.08	$3.08
Camco 25573 Bullseye Level	1	$3.10	$3.10
1/4" DC 12V 2-way Solenoid Air Valve	1	$9.39	$9.39
2pcs 12V DC 2 Channel Relay Module w/Isolated OptocouplerHigh/Low Level Trigger Module	1	$6.99	$6.99
Vacuum Pump 12V Mini Diaphragm Air Compressor w/Silicone Tube	1	$22.99	$22.99
Peristaltic Liquid Pump 12V DC Hose Pump Dosing Head w/Silicone Tubing	2	$16.49	$32.98
1M 1.17mm 28AWG 40PIN Dupont Wire Flat Multicolored Flexible Rainbow Ribbon Jumper Cable	28	$6.99	$195.72
Thread-Forming Screws for Thin Plastic, Zinc-Plated Steel, M2.5 Size, 6mm Long, Packs of 25	1	$5.88	$5.88
Dowel Pin, Black-Oxide 114 Carbon Steel, 1/8" Diameter, 1/2" Long, Packs of 25	1	$6.41	$6.41
18-8 Stainless Steel Button Head Torx Screws, 1/4"-20 Thread, 2" Long, Packs of 10	1	$4.92	$9.84
Medium-Strength Steel Hex Nut, Grade 5, Black Oxide, 1/4"-20 Thread Size, Packs of 50	1	$4.88	$4.88
Gasket Material, Food-Grade Compressible Buna-N, 12" x 12", 1/16" Thick	1	$5.83	$5.83
Zinc-Plated Steel Barbed Hose Fitting for Air and Water, Adapter for 1/4" Hose ID, 1/4 NPT Male, Packs of 1	3	$2.01	$6.03
18-8 Stainless Steel Washer for 1/4" Screw Size, 0.281" ID, 0.625"OD, Packs of 100	1	$3.37	$3.37
		Total (USD)	$1,785.43

Table 15 Bill of Materials for manufactured parts.

Materials	Material with Estimated Costs	Quantity	Cost per Unit	Total Cost
Injection Molding	***Mold Cost***			
Pins	$15,123.00	256	$0.06	$15.10
Guide Block Bottom Cap	$7,356.00	1	$7.36	$7.36
Motor Mount Guide Base	$4,255.00	1	$4.26	$4.26
Motor Mount Gasket	$6,236.00	1	$6.24	$6.24
Guide Block Bottom Space	$6,236.00	1	$6.24	$6.24
Guide Block Top	$6,681.00	1	$6.68	$6.68
Guide Block Bottom	$6,904.00	1	$6.90	$6.90
Acrylic Panels	***Approximate Area (in2)***			
Top	92.6	1	$3.00	$3.00
Bottom	125.4	1	$4.00	$4.00
Front	55.6	1	$2.00	$2.00
Side	128.9	2	$4.00	$8.00
			Total (USD)	$69.77

The original design has several components printed using a 3D printer. The cost of these parts can be lowered by using injection molding. The BOM contains a section related to Materials with Estimated Costs (Table 15). The price of each injection mold is accounted for in this section. The price of each mold depends on the complexity of the piece. For example, the mold for the pins is approximately $15,000; however, this allows for 8 pins to be created each time the mold is used. This allows for the price of each pin to be only $0.06.

After adjusting the machine from being a proof of concept to a high-resolution printer, the cost per unit went from $559.12 to $1,979.99. There is a significant increase in cost per unit due to the increase of resolution. The number of parts needed for the motion control of the pins increased. There are now 256 pins to address rather than 9 pins. This will require a custom-made motion control system, which has been estimated to be $650.00. The cost per unit includes 0.1% of the developmental cost.

According to Forbes, the Wohler's Report 2019 is projecting a growth of the additive manufacturing market from a forecasted market size of $15.8 billion in 2020 to $35.6 billion in 2024 [13], so demand for this product should be expected. When comparing prices of 3D printers that have similar capabilities as this one, it was determined that a fair price for the machine is about $3,500. The price of this machine allows for approximately $1,500 in revenue. This will allow for the cumulative cash flow to turn into a profit during Year 2 (Table 16). The developmental cost for the machine includes several components: the duration and required materials of design and testing as well as the cost of the injection molds. While this machine has been redesigned for mass production a few assumptions for this cost analysis still have been considered:

- This new machine was developed by a team of four full-time engineers working at a rate of $40 per hour for 15 weeks.
- Marketing and support costs are fixed at $250,000 per year.
- Production volume is 1,000 machines per year.
- The cost of production for each machine is at $90.00/hour for 5 hours.
- For the purposes of net present value, the interest rate is assumed to be 10%.

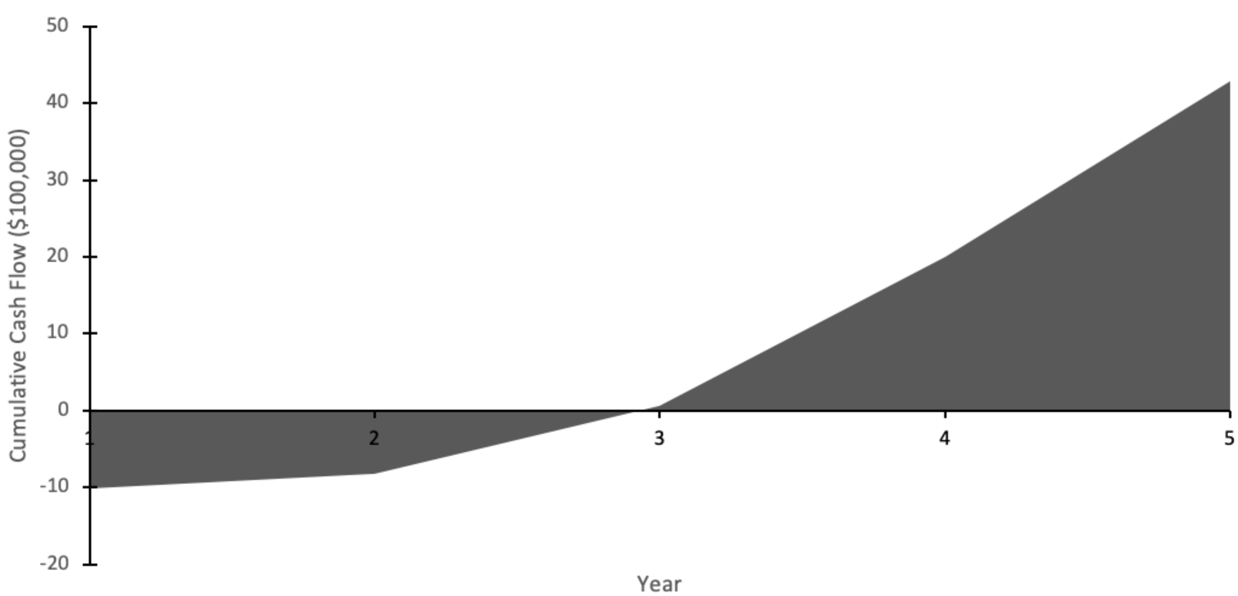
Based on these assumptions, the financial analysis performed over a five-year period is given below in Table 16:

Table 16 Financial analysis for 16x16 pin array.

	Year				
Description	**1**	**2**	**3**	**4**	**5**
Development Cost	$148,791.00				
Marketing	$83,600.00	$83,600.00	$83,600.00	$83,600.00	$83,600.00
Support	$166,400.00	$166,400.00	$166,400.00	$166,400.00	$166,400.00
Production Cost	$2,363,993.00	$2,363,993.00	$2,363,993.00	$2,363,993.00	$2,363,993.00
Cost per Unit	$2,363.99	$2,363.99	$2,363.99	$2,363.99	$2,363.99
Production Volume	1000	1000	1000	1000	1000
Sales Revenue	$1,750,000.00	$2,800,000.00	$3,500,000.00	$4,550,000.00	$4,900,000.00
Price per Unit	$3,500.00	$3,500.00	$3,500.00	$3,500.00	$3,500.00
Sales Volume	500	800	1,000	1,300	1,400
Period Cash Flow	($1,012,784.00)	$186,007.00	$886,007.00	$1,936,007.00	$2,286,007.00
PV	($1,012,784.00)	$169,097.27	$732,237.19	$1,454,550.71	$1,561,373.54
Cumulative Cash Flow	$(1,012,784.00)	$(826,777.00)	$59,230.00	$1,995,237.00	$4,281,244.00
Cumulative PV	($1,012,784.00)	($843,686.73)	($111,449.54)	$1,343,101.18	$2,904,474.72

The company originally put $148,791.00 into the design of this machine. The first year the machine is launched, it will be expected that the company will not be able to make enough to have a profit return. Since the product is not expected to sell out the first or second year, there will be a negative cash flow for each year. By Year 3, it is expected that the marketing will allow for higher sales volume. Consequently, the company will expect to see a profit at the end of Year 3 (Figure 18).

Fig. 18 Cumulative cash flow chart for 16x16 array machine.



V. *Conclusion*

A method of additive manufacturing was developed in an effort to minimize production cycle time relative to other available methods. The requirements set out at the start of the design process required a combined process time of 5 minutes and an object height of at least 1/2". The system utilized an array of pins that could be individually configured to create a desired shape. A prototype was developed that was capable of achieving the required print time of minimum vertical travel. Thermosetting resins became the primary material choice as they offered fast cure times with excellent mechanical properties. The modularity of the pin array system allows the prototype to be scaled up to larger or more detailed arrays depending on application.

A. Future Works

During the production of the prototype, some limitations of the the design and components were recognized. Some limitations directly impacted the performance of the prototype while others would need to be addressed only as the design was scaled for different applications.

The size and number of pins directly affects the types of shapes that can be printed by the Rapid Configuration 3D Printer. Print resolution for the prototype was set by the 3x3 array but the fundamental concept may find more application as the resolution increases with larger pin arrays or smaller pins. Increasing vertical pin travel would also improve resolution, allowing for a larger range of object heights to be printed. The primary factor that challenges increased print resolution is the finite channels of control offered by the Arduino Mega microcontroller. While the Arduino Mega worked well for generating a prototype design, a proprietary control system would need to be developed to control substantially larger pin arrays. In order to continue use of an Arduino control unit, motors would either have to be connected through multiple bridges or a collection of Arduino. The Arduino microcontroller architecture could be maintained with a customer PCB handling the interconnection of processors.

Performance of the direct drive stepper motors presented concerns for their viability as a long term solution. The sourced stepper motors were unable to provide their claimed torque and risked overheating during prolonged operation. High heat from the direct drive stepper motors degrades the performance of the motors over time and could cause damage to other components in the printer. Stepper motors with attached gear reduction were found to be a possible alternative that traded movement speed for greater torque. The geared stepper motors maintain the small form factor of the direct drive units and would still allow for smaller pins to be used.

The difference in viscosity between the two components of the thermosetting resin prevent the accurate metering of resins into the mixing system. Failure to mix the components of a thermosetting resin will result in diminished mechanical properties or incomplete cures. It was theorized that larger pumps would be less susceptible to the difference in viscosity. Another possible method for achieving the correct flow rates for fluids with different viscosity would be to heat the thicker component to make it more fluid. A side-effect in elevating the temperature of a thermosetting resin is typically reduced open time and cure time. Variable speed pumps like the peristaltic pumps used remain the best choice for fine tuned control of flow rates.

VI. *Bibliography*

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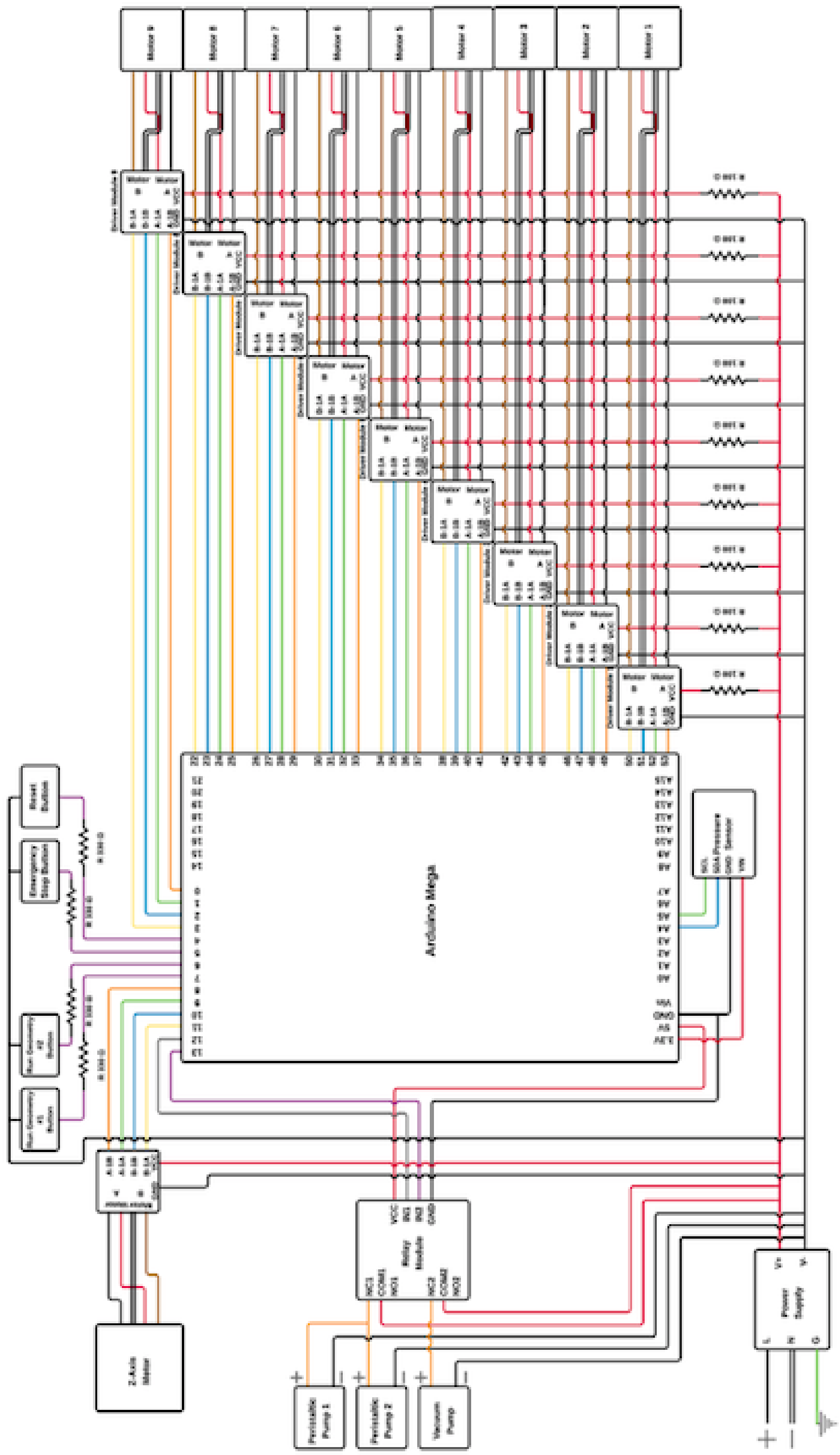
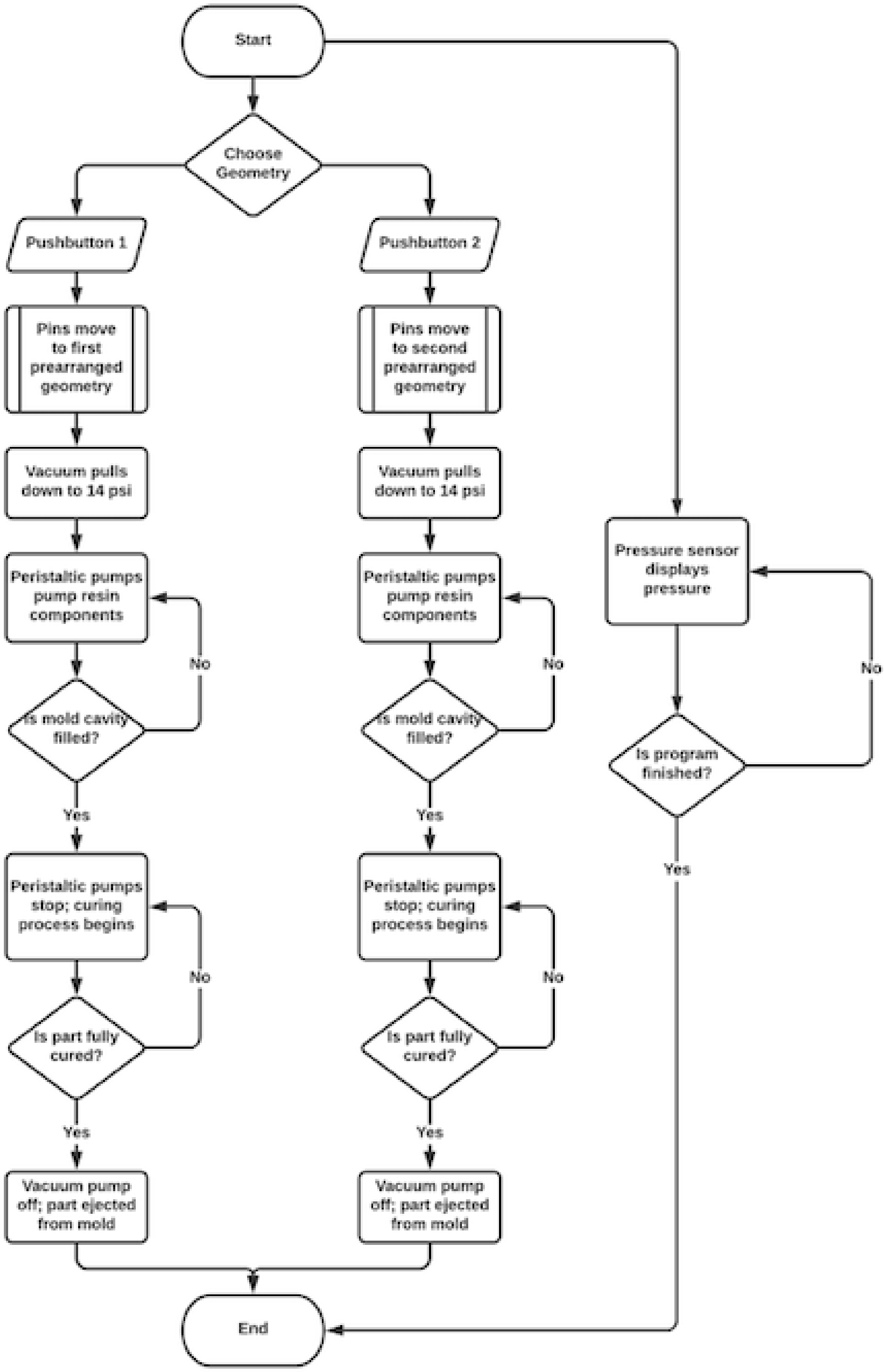
VII. *Appendix*

Appendices A: Wire Diagram Enlarged



Appendices B: Logic Sequence Enlarged



Appendices C: Coding

```
// This program controls the Rapid Configuration Instant 3D Printer's subsystems

#include <Stepper.h>                          // include Stepper library
#include <Wire.h>                             // include Wire library
#include <SFE_BMP180.h>                       // include pressure sensor library
const int StepNum = 200;                      // number of steps, equivalent to 360 degrees
const int speed = 20;                         // speed in RPM
Stepper stepmoto1(StepNum, 50, 51, 52, 53);  // create Stepper object 1 with associated pins
Stepper stepmoto2(StepNum, 46, 47, 48, 49);  // create Stepper object 2 with associated pins
Stepper stepmoto3(StepNum, 42, 43, 44, 45);  // create Stepper object 3 with associated pins
Stepper stepmoto4(StepNum, 38, 39, 40, 41);  // create Stepper object 4 with associated pins
Stepper stepmoto5(StepNum, 34, 35, 36, 37);  // create Stepper object 5 with associated pins
Stepper stepmoto6(StepNum, 30, 31, 32, 33);  // create Stepper object 6 with associated pins
Stepper stepmoto7(StepNum, 26, 27, 28, 29);  // create Stepper object 7 with associated pins
Stepper stepmoto8(StepNum, 22, 23, 24, 25);  // create Stepper object 8 with associated pins
Stepper stepmoto9(StepNum, 0, 1, 2, 3);      // create Stepper object 9 with associated pins
Stepper zaxis(StepNum, 8, 9, 10, 11);        // create Stepper object for z-axis motor
SFE_BMP180 pressure;                          // creates SFE_BMP180 (pressure sensor) object
#define sw1_pin 4                             // defines the "Geometry #1" button
#define sw2_pin 5                             // defines the "Geometry #2" button
#define sw3_pin 6                             // defines the "Emergency Stop" button
#define sw4_pin 7                             // defines the "Reset" button
#define ALTITUDE 225.0                        // altitude of Glen Ellyn, IL in meters

volatile boolean sw1 = false; // initialize sw1 status to "unpressed"
volatile boolean sw2 = false; // initialize sw2 status to "unpressed"
volatile boolean sw3 = false; // initialize sw3 status to "unpressed"
volatile boolean sw4 = false; // initialize sw4 status to "unpressed"

uint8_t sw1ButtonState = 0; // initialize sw1ButtonState to "unpressed"
uint8_t sw2ButtonState = 0; // initialize sw2ButtonState to "unpressed"
uint8_t sw3ButtonState = 0; // initialize sw3ButtonState to "unpressed"
uint8_t sw4ButtonState = 0; // initialize sw4ButtonState to "unpressed"

uint8_t lastsw1ButtonState = 0; // initialize lastsw1ButtonState to "unpressed"
uint8_t lastsw2ButtonState = 0; // initialize lastsw2ButtonState to "unpressed"
uint8_t lastsw3ButtonState = 0; // initialize lastsw3ButtonState to "unpressed"
uint8_t lastsw4ButtonState = 0; // initialize lastsw4ButtonState to "unpressed"

void setup()
{
  Serial.begin(9600);
  Serial.println("REBOOT");

  // Initialize pressure sensor to store calibration values
  if (pressure.begin())
  {
    Serial.println("BMP180 initialization success");
  }
```

```
else
{
  Serial.println("BMP180 initialization failed\n\n");
  while(1); // Pauses forever
}

// pin assignments
pinMode(0, OUTPUT);
pinMode(1, OUTPUT);
pinMode(2, OUTPUT);
pinMode(3, OUTPUT);
pinMode(8, OUTPUT);
pinMode(9, OUTPUT);
pinMode(10, OUTPUT);
pinMode(11, OUTPUT);
pinMode(12, OUTPUT);
pinMode(13, OUTPUT);
pinMode(22, OUTPUT);
pinMode(23, OUTPUT);
pinMode(24, OUTPUT);
pinMode(25, OUTPUT);
pinMode(26, OUTPUT);
pinMode(27, OUTPUT);
pinMode(28, OUTPUT);
pinMode(29, OUTPUT);
pinMode(30, OUTPUT);
pinMode(31, OUTPUT);
pinMode(32, OUTPUT);
pinMode(33, OUTPUT);
pinMode(34, OUTPUT);
pinMode(35, OUTPUT);
pinMode(36, OUTPUT);
pinMode(37, OUTPUT);
pinMode(38, OUTPUT);
pinMode(39, OUTPUT);
pinMode(40, OUTPUT);
pinMode(41, OUTPUT);
pinMode(42, OUTPUT);
pinMode(43, OUTPUT);
pinMode(44, OUTPUT);
pinMode(45, OUTPUT);
pinMode(46, OUTPUT);
pinMode(47, OUTPUT);
pinMode(48, OUTPUT);
pinMode(49, OUTPUT);
pinMode(50, OUTPUT);
pinMode(51, OUTPUT);
pinMode(52, OUTPUT);
pinMode(53, OUTPUT);
```

```
  pinMode(sw1_pin, INPUT_PULLUP); // attaches "Run Geometry #1" button to pin 4 on Arduino board
  pinMode(sw2_pin, INPUT_PULLUP); // attaches "Run Geometry #2" button to pin 5 on Arduino board
  pinMode(sw3_pin, INPUT_PULLUP); // attaches "Emergency Stop" button to pin 6 on Arduino board
  pinMode(sw4_pin, INPUT_PULLUP); // attaches "Reset" button to pin 7 on Arduino board

  stepmoto1.setSpeed(speed);  // sets speed of motor 1 in RPM
  stepmoto2.setSpeed(speed);  // sets speed of motor 2 in RPM
  stepmoto3.setSpeed(speed);  // sets speed of motor 3 in RPM
  stepmoto4.setSpeed(speed);  // sets speed of motor 4 in RPM
  stepmoto5.setSpeed(speed);  // sets speed of motor 5 in RPM
  stepmoto6.setSpeed(speed);  // sets speed of motor 6 in RPM
  stepmoto7.setSpeed(speed);  // sets speed of motor 7 in RPM
  stepmoto8.setSpeed(speed);  // sets speed of motor 8 in RPM
  stepmoto9.setSpeed(speed);  // sets speed of motor 9 in RPM
  zaxis.setSpeed(speed);      // sets speed of z-axis motor in RPM


  digitalWrite(12, HIGH); //initialize peristaltic pumps relay switch to close
  digitalWrite(13, HIGH); //initialize vacuum pump relay switch to close
}

void loop()
{
  // This only commands the system if any of the buttons are pressed
  checkIfSw1ButtonIsPressed(); // updates "Geometry 1" button status
  checkIfSw2ButtonIsPressed(); // updates "Geometry 2" button status
  checkIfSw3ButtonIsPressed(); // updates "Emergency Stop" button status
  checkIfSw4ButtonIsPressed(); // updates "Reset" button status

  // This runs the machine based on the sloping geometry (Geometry 1)
  if (sw1)                       // if first button status is "pressed"
  {
    while(sw1)
    {
      sw2 = true;                // Geometry 2 blocked from running
      sw4 = true;                // Reset blocked from running
    }
    sw1 = false;                 // completes circuit for first button
    stepmoto1.step(-StepNum);    // reverse 200 steps, or 360 degrees
    stepmoto2.step(-2*StepNum);  // reverse 400 steps, or 720 degrees
    stepmoto3.step(-3*StepNum);  // reverse 600 steps, or 1080 degrees
    stepmoto4.step(-2*StepNum);  // reverse 400 steps, or 720 degrees
    stepmoto5.step(-3*StepNum);  // reverse 600 steps, or 1080 degrees
    stepmoto6.step(-4*StepNum);  // reverse 800 steps, or 1440 degrees
    stepmoto7.step(-3*StepNum);  // reverse 600 steps, or 1080 degrees
    stepmoto8.step(-4*StepNum);  // reverse 800 steps, or 1440 degrees
    stepmoto9.step(-5*StepNum);  // reverse 1000 steps, or 1800 degrees
    delay(15);                   // waits for 15 ms
```

```
    digitalWrite(13, LOW);       // turns on vacuum pump
    zaxis.step(-10*StepNum);     // lowers z-axis into dispensing position
    delay(20000);                // pauses for 20 seconds while z-axis gets into position
    digitalWrite(12, LOW);       // turns on peristaltic pumps to dispense resin
    delay(20000);                // allows for mold cavity to fill with resin
    digitalWrite(12, HIGH);      // turns off peristaltic pumps to stop dispensing of resin
    delay(600000);               // Stops for 10 minutes while part cures
    zaxis.step(10*StepNum);      // z-axis returns to idle position

    // Part ejection
    stepmoto1.step(StepNum);     // forward 200 steps, or 360 degrees
    stepmoto2.step(2*StepNum);   // forward 400 steps, or 720 degrees
    stepmoto3.step(3*StepNum);   // forward 600 steps, or 1080 degrees
    stepmoto4.step(2*StepNum);   // forward 400 steps, or 720 degrees
    stepmoto5.step(3*StepNum);   // forward 600 steps, or 1080 degrees
    stepmoto6.step(4*StepNum);   // forward 800 steps, or 1440 degrees
    stepmoto7.step(3*StepNum);   // forward 600 steps, or 1080 degrees
    stepmoto8.step(4*StepNum);   // forward 800 steps, or 1440 degrees
    stepmoto9.step(5*StepNum);   // forward 1000 steps, or 1800 degrees

    delay(2000);
  }
  // This runs the machine based on the stairstep geometry
  else if (sw2)                  // if second button status is "pressed"
  {
    while(sw2)
    {
      sw1 = true;                // Geometry 1 blocked from running
      sw4 = true;                // Reset blocked from running
    }

    sw2 = false;                 // completes circuit for second button
    stepmoto1.step(-StepNum);    // reverse 200 steps, or 360 degrees
    stepmoto2.step(-1.5*StepNum);// reverse 400 steps, or 540 degrees
    stepmoto3.step(-2*StepNum);  // reverse 600 steps, or 720 degrees
    stepmoto4.step(-3.5*StepNum);// reverse 400 steps, or 1260 degrees
    stepmoto5.step(-3*StepNum);  // reverse 600 steps, or 1080 degrees
    stepmoto6.step(-2.5*StepNum);// reverse 800 steps, or 900 degrees
    stepmoto7.step(-4*StepNum);  // reverse 800 steps, or 1440 degrees
    stepmoto8.step(-4.5*StepNum);// reverse 900 steps, or 1620 degrees
    stepmoto9.step(-5*StepNum);  // reverse 1000 steps, or 1800 degrees
    delay(15);                   // waits for 15 ms
```

```
    digitalWrite(13, LOW);       // turns on vacuum pump
    zaxis.step(-10*StepNum);     // lowers z-axis into dispensing position
    delay(20000);                // pauses for 20 seconds while z-axis gets into position
    digitalWrite(12, LOW);       // turns on peristaltic pumps to dispense resin
    delay(20000);                // allows for mold cavity to fill with resin
    digitalWrite(12, HIGH);      // turns off peristaltic pumps to stop dispensing of resin
    delay(600000);               // Stops for 10 minutes while part cures
    zaxis.step(10*StepNum);      // z-axis returns to idle position

    // Part ejection
    stepmoto1.step(StepNum);     // forward 200 steps, or 360 degrees
    stepmoto2.step(1.5*StepNum); // forward 300 steps, or 540 degrees
    stepmoto3.step(2*StepNum);   // forward 400 steps, or 720 degrees
    stepmoto4.step(3.5*StepNum); // forward 700 steps, or 1260 degrees
    stepmoto5.step(3*StepNum);   // forward 600 steps, or 1080 degrees
    stepmoto6.step(2.5*StepNum); // forward 500 steps, or 900 degrees
    stepmoto7.step(4*StepNum);   // forward 800 steps, or 1440 degrees
    stepmoto8.step(4.5*StepNum); // forward 900 steps, or 1620 degrees
    stepmoto9.step(5*StepNum);   // forward 1000 steps, or 1800 degrees

    delay(2000);
  }

  // Emergency stop button
  if (sw3) // if third button status is "pressed"
  {
    while(1)
    {
      // infinite loop to stop all processes
    }
  }
  // Resets pins to starting position
  if (sw4) // if fourth button status is "pressed"
  {
    while(sw4)
    {
      sw1 = true;                // Geometry 1 blocked from running
      sw2 = true;                // Geometry 2 blocked from running
    }

    sw4 = false;                 // completes circuit for Reset button
    stepmoto1.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto2.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto3.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto4.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto5.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto6.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto7.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto8.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
    stepmoto9.step(10*StepNum);  // forward 2000 steps, or 3600 degrees
```

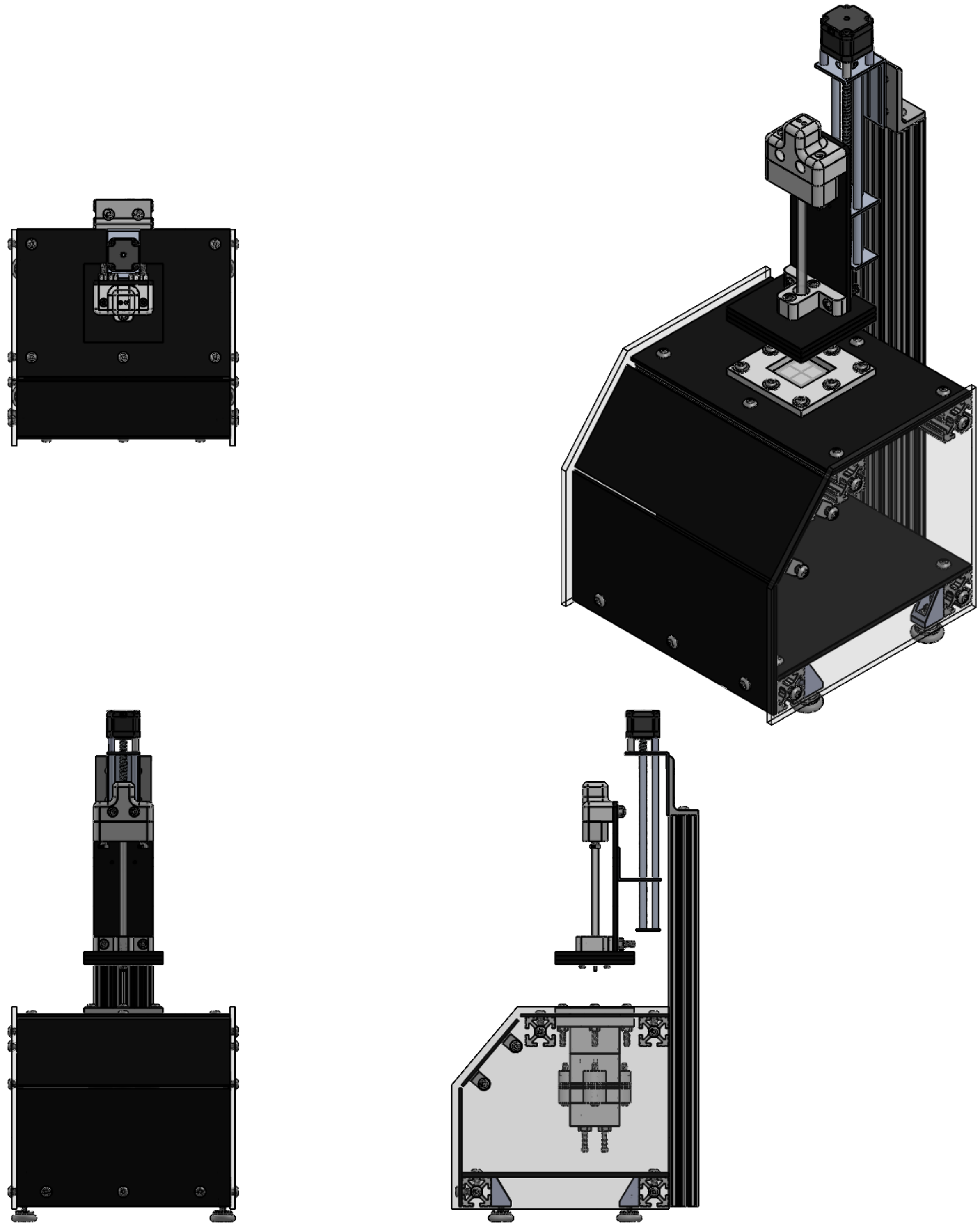
```
    delay(15);              // waits for 15 ms

  }
  // waits for the Stepper to get there

  getPressureReading();     // displays temperature and pressure info
}

void checkIfSw1ButtonIsPressed()  // checks to see if the first button is pressed
{
  sw1ButtonState = digitalRead(sw1_pin);  // receives signal from first button

  if (sw1ButtonState != lastsw1ButtonState) // if signal changes
  {
    if ( sw1ButtonState == 0) // if no signal
    {
      sw1 = true; // button considered unpressed
    }
    delay(50);  // runs every 50 ms
  }
  lastsw1ButtonState = sw1ButtonState; // updates button status
}

void checkIfSw2ButtonIsPressed()  // checks to see if the second button is pressed
{
  sw2ButtonState   = digitalRead(sw2_pin);  // receives signal from second button

  if (sw2ButtonState != lastsw2ButtonState) // if signal changes
  {
    if ( sw2ButtonState == 0) // if no signal
    {
      sw2 = true; // button considered unpressed
    }
    delay(50);  // runs every 50 ms
  }
  lastsw2ButtonState = sw2ButtonState;  // updates button status
}

void checkIfSw3ButtonIsPressed()  // checks to see if the third button is pressed
{
  sw3ButtonState   = digitalRead(sw3_pin);  // receives signal from third button

  if (sw3ButtonState != lastsw3ButtonState) // if signal changes
  {
    if ( sw3ButtonState == 0) // if no signal
    {
      sw3 = true; // button considered unpressed
    }
    delay(50);  // runs every 50 ms
  }
```

```
  lastsw3ButtonState = sw3ButtonState;  // updates button status
}

void checkIfSw4ButtonIsPressed()  // checks to see if the fourth button is pressed
{
  sw4ButtonState   = digitalRead(sw4_pin);  // receives signal from second button

  if (sw4ButtonState != lastsw4ButtonState) // if signal changes
  {
    if ( sw4ButtonState == 0) // if no signal
    {
      sw4 = true; // button considered unpressed
    }
    delay(50);  // runs every 50 ms
  }
  lastsw4ButtonState = sw4ButtonState;  // updates button status
}

void getPressureReading()
{
  char status;
  double T, P, P0, a;

  // This loop gets readings every 10 seconds
  Serial.println();
  Serial.print("Altitude: ");
  Serial.print(ALTITUDE, 0);
  Serial.print(" meters, ");
  Serial.print(ALTITUDE*3.28084, 0);
  Serial.println(" feet.");

  // Start of temperature measurement
  status = pressure.startTemperature();
```

```
    if (status != 0)
    {
      // Wait for measurement
      delay(status);

      // Retreive completed temperature measurement
      status = pressure.getTemperature(T);
      if (status != 0)
      {
        // Print measurement
        Serial.print("Temperature: ");
        Serial.print(T, 2);
        Serial.print(" degrees C, ");
        Serial.print((9.0/5.0)*T + 32.0, 2);
        Serial.println(" degrees F.");

        // Start of pressure measurement
        status = pressure.startPressure(3);
        if (status != 0)
        {
          // Wait for measurement to complete
          delay(status);

          // Retrieve completed measurement
          status = pressure.getPressure(P, T);
          if (status != 0)
          {
            // Print absolute pressure measurement
            Serial.print("Absolute pressure: ");
            Serial.print(P, 2);
            Serial.print(" millibar, ");
            Serial.print(P*0.0295333727, 2);
            Serial.println(" inHg.");

            // Adjusts for altitude
            P0 = pressure.sealevel(P, ALTITUDE);
            Serial.print("Relative (sea-level) pressure: ");
            Serial.print(P0, 2);
            Serial.print(" millibar, ");
            Serial.print(P0*0.0295333727, 2);
            Serial.println(" inHg");
          }
          else Serial.println("Error retrieving pressure measurement.\n");
        }
        else Serial.println("Error starting pressure measurement.\n");
      }
      else Serial.println("Error retrieving temperature measurement.\n");
    }
    else Serial.println("Error starting temperature measurement.\n");

    delay(1000);  // Pause for 1 second
  }
```

2 1

B B



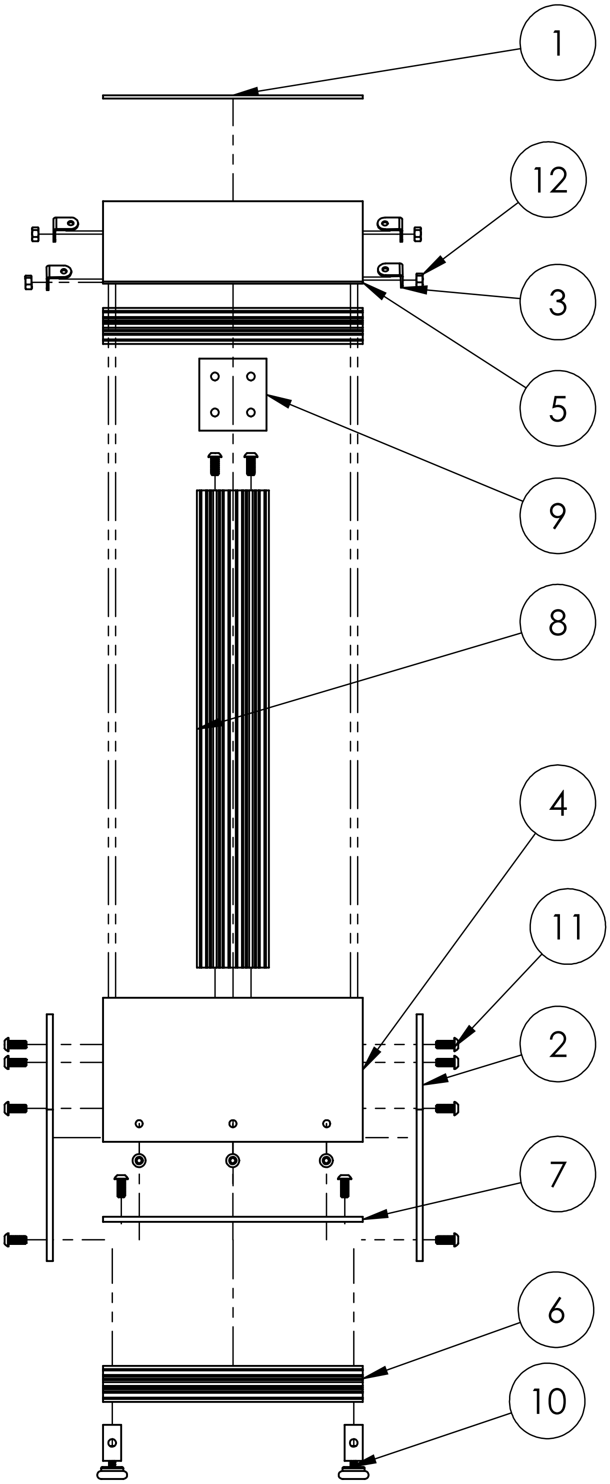
A A

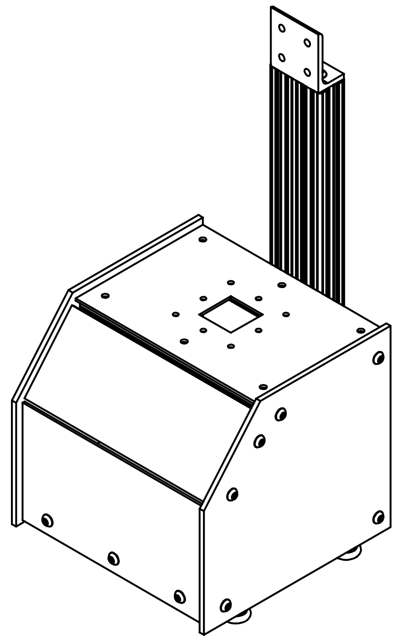
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE	
			DRAWN			
			CHECKED			Rapid Configuration 3D Printer
			ENG APPR.			
			MFG APPR.			
		MATERIAL	Q.A.			
			COMMENTS:			
NEXT ASSY	USED ON	FINISH				SIZE A · DWG. NO. · REV.
APPLICATION		DO NOT SCALE DRAWING				SCALE:1:8 · WEIGHT: · SHEET 1 OF 1

2 1

2 1

B B





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Acrylic Enclosure Mid Plate		1
2	Acrylic Enclosure Right Panel		2
3	1556A24		4
4	Acrylic Front Panel		1
5	Acrylic Front Control Panel		1
6	1515-BLACK X 72		4
7	Acrylic Bottom Electronic Panel		1
8	1515-BLACK X 72		2
9	47065T498_T-SLOTTED FRAMING (Aluminum L)		1
10	Leveling Feet		4
11	96452A581		21
12	95479A115		4

A A

NEXT ASSY | USED ON

APPLICATION

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

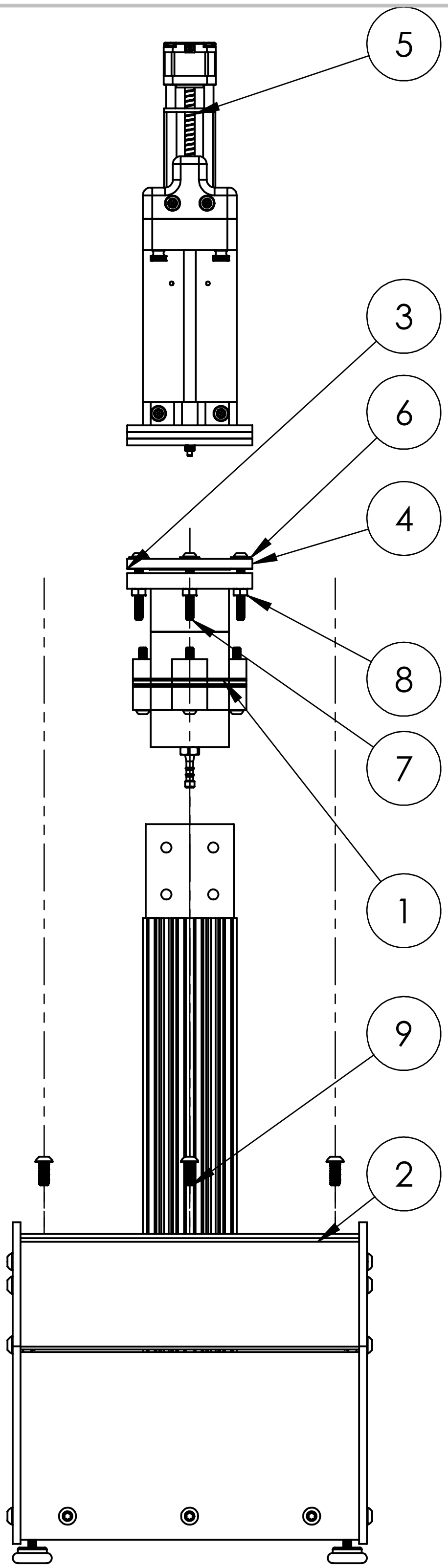
COMMENTS:

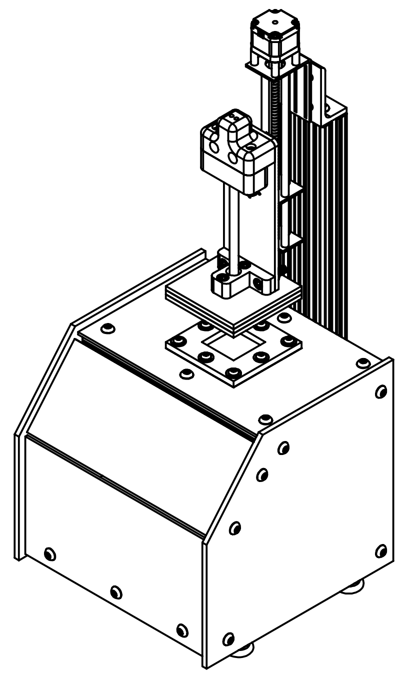
Machine Enclosure

SIZE A | DWG. NO. | REV.

SCALE:1:8 | WEIGHT: | SHEET 1 OF 1

2 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Central Pin Array Assembly		1
2	Machine Enclosure		1
3	Silicon Sheet		1
4	Top Square Ring		1
5	Z Axis Assembly		1
6	92141A029		8
7	90600A629		8
8	95479A111		8
9	96452A581		6

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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL

FINISH

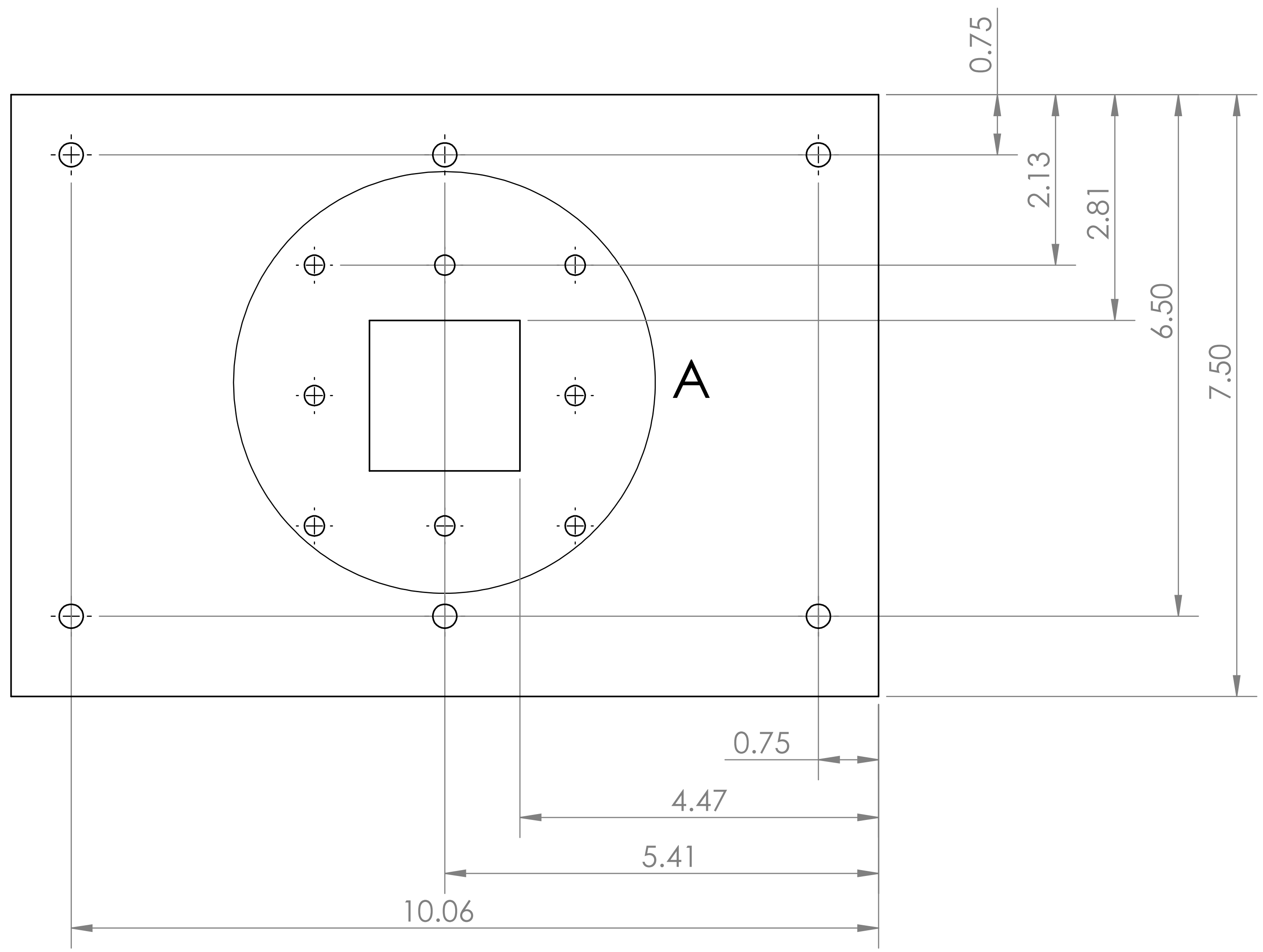
NEXT ASSY | USED ON

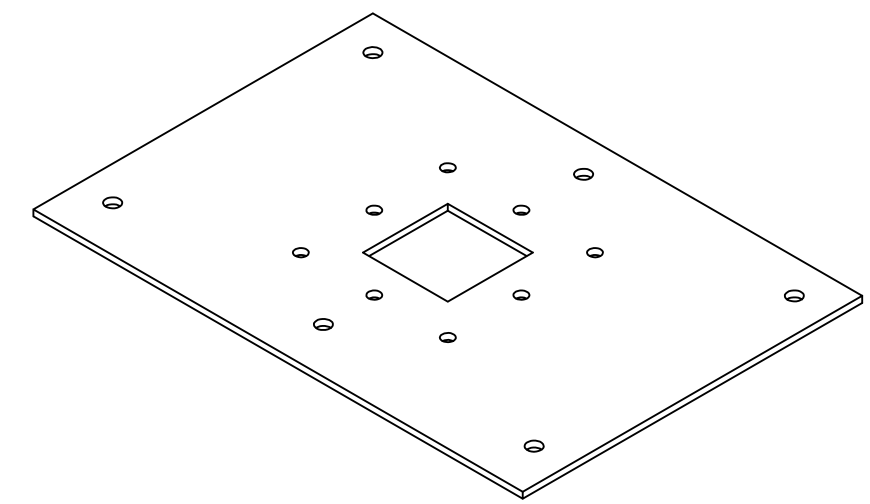
APPLICATION

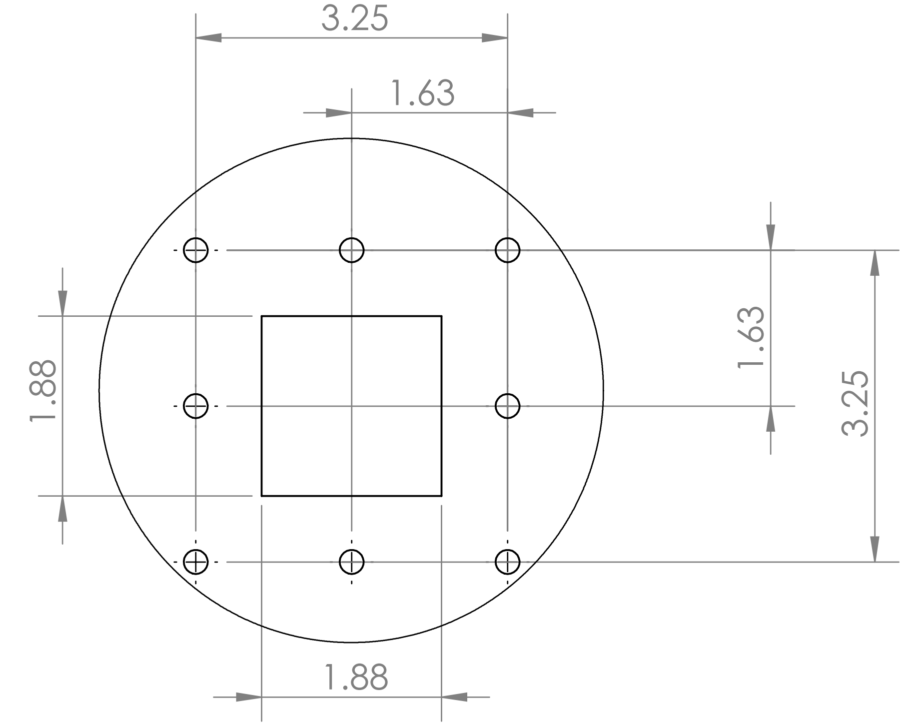
DO NOT SCALE DRAWING

SIZE A | DWG. NO. Rapid Configuration 3D Printer | REV.

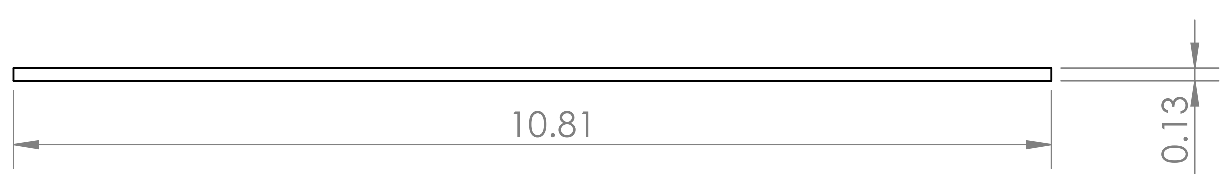
SCALE:1:12 | WEIGHT: | SHEET 1 OF 1







DETAIL A



PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

TITLE:

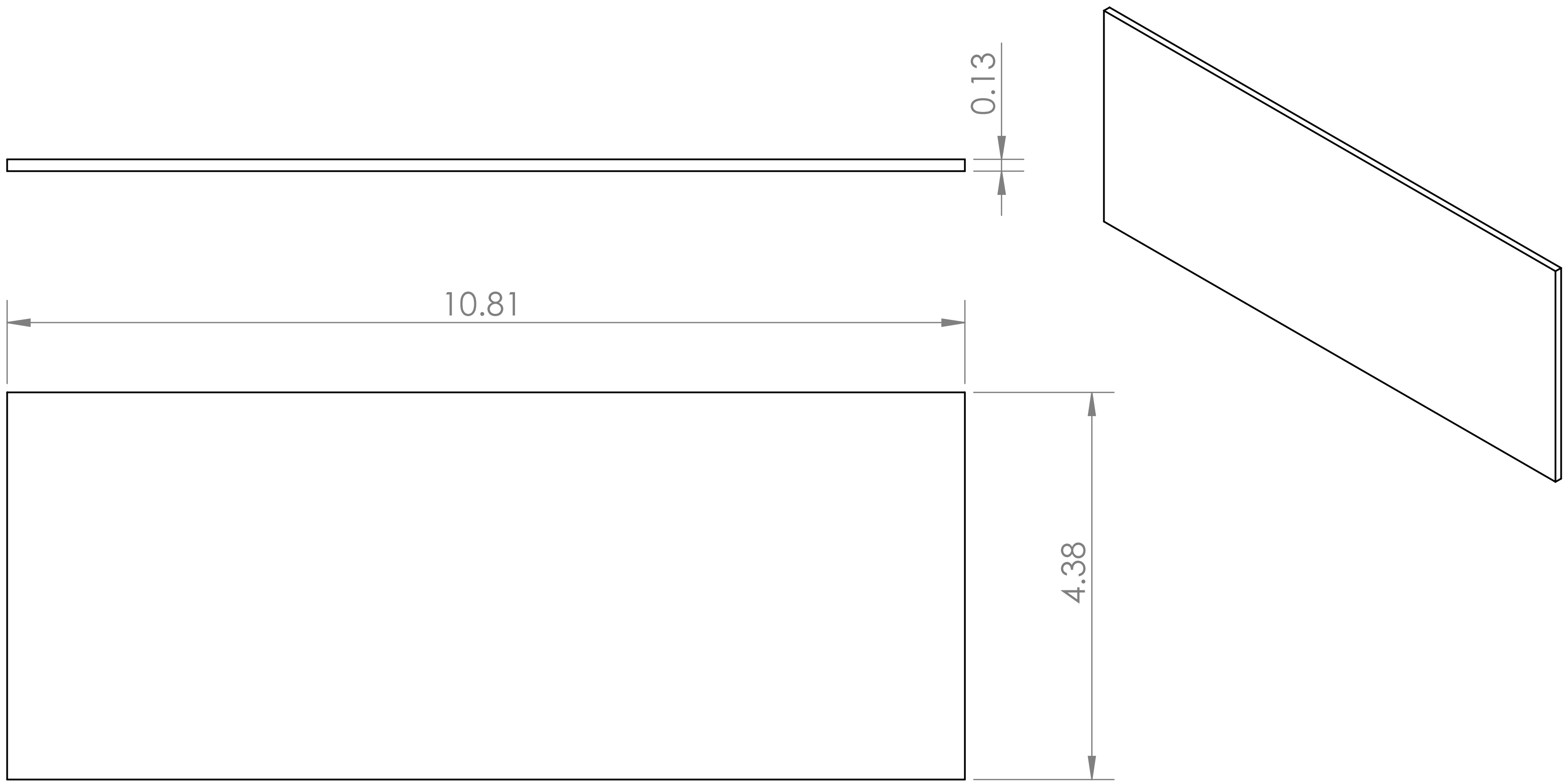
Acrylic Enclosure Mid Plate

SIZE	DWG. NO.	REV
B		

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

		NAME	DATE

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

Acrylic Front Control Panel

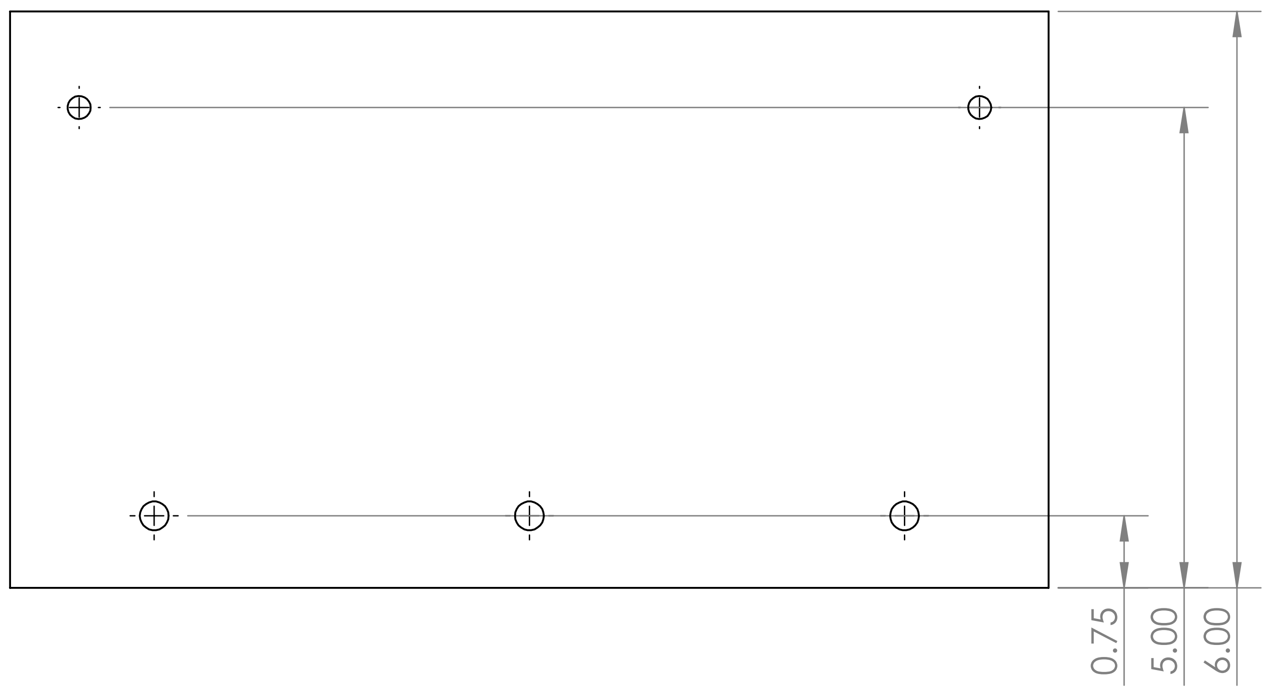
SIZE	DWG. NO.	REV
A		

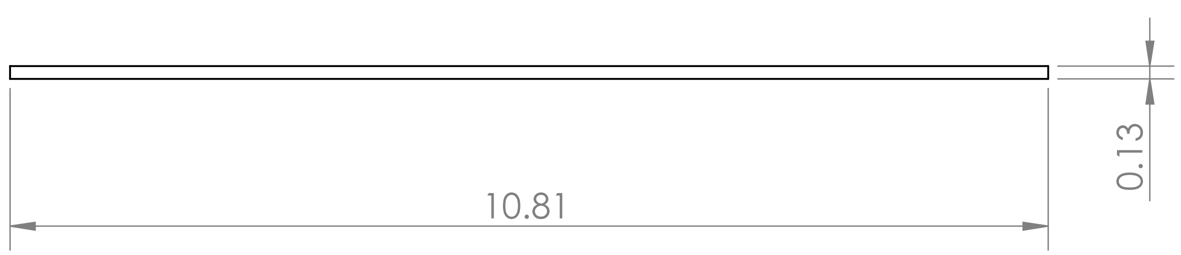
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

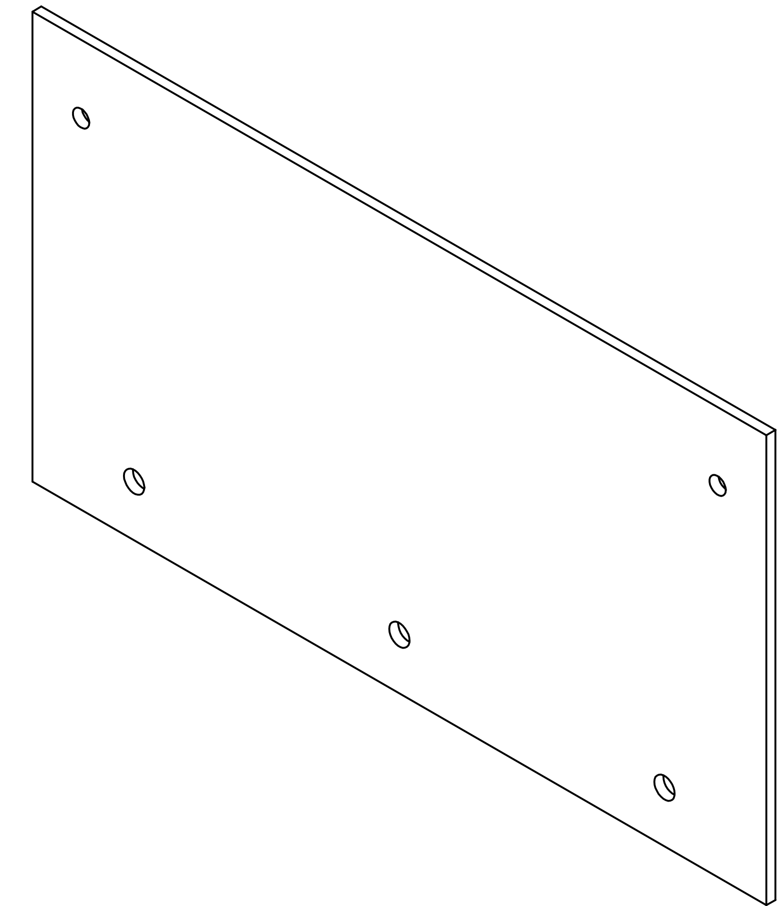
NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

2 1







		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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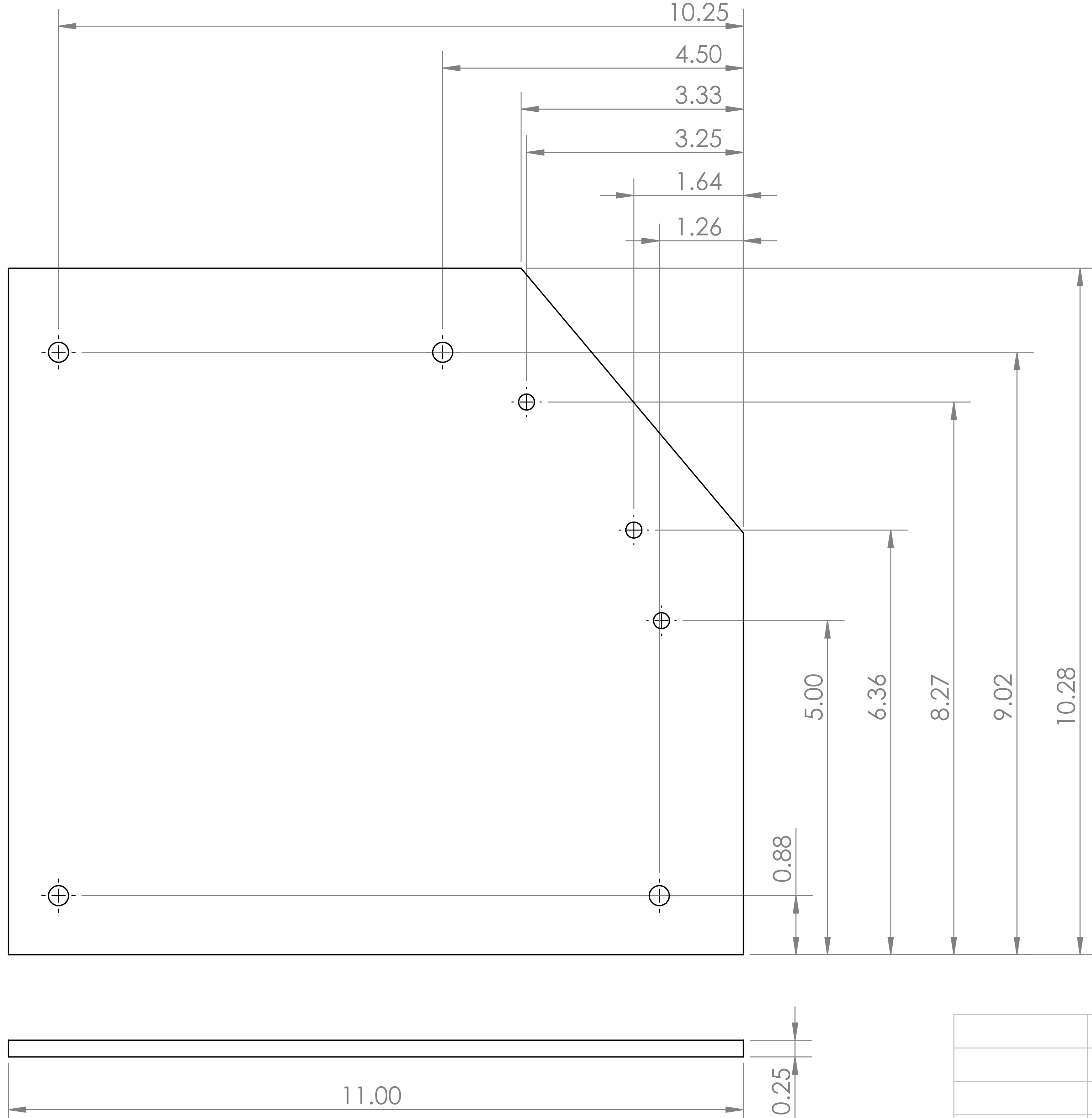
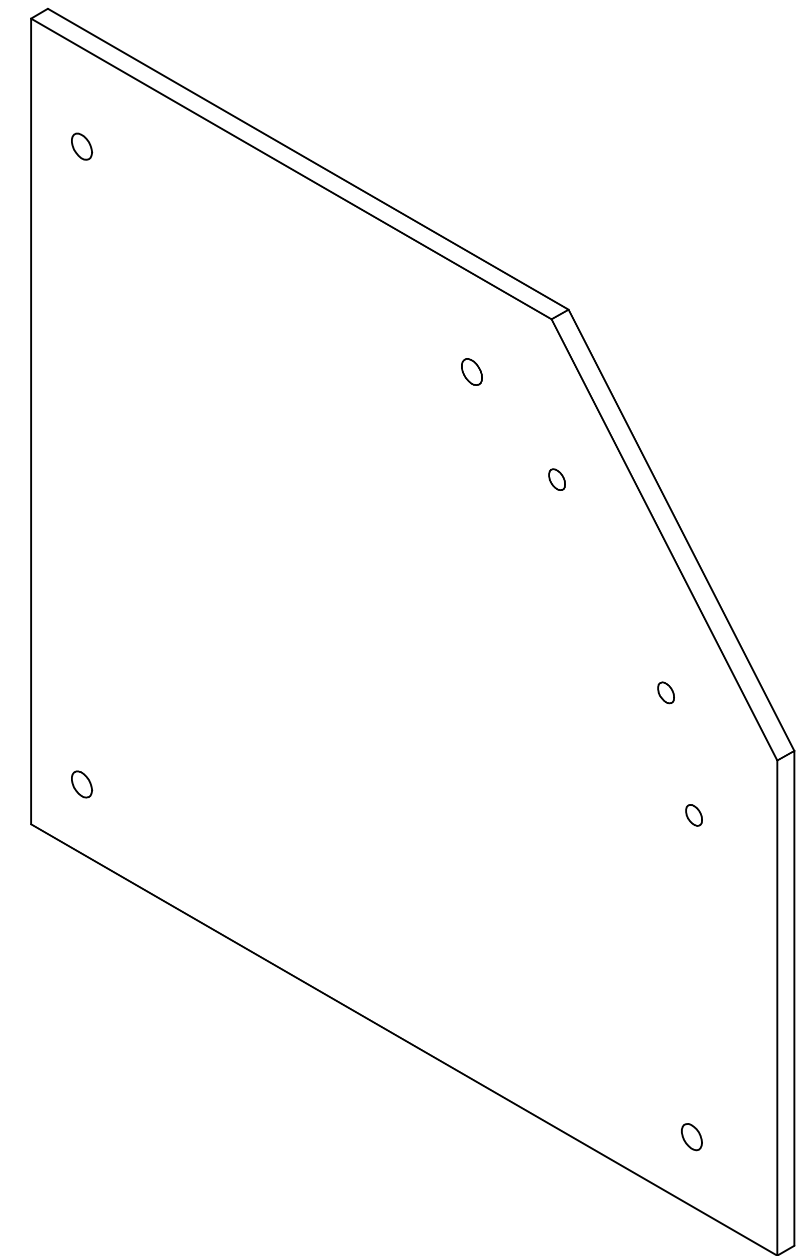
TITLE:

Acrylic Front Panel

SIZE B | DWG. NO. | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1





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NEXT ASSY	USED ON
APPLICATION	

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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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

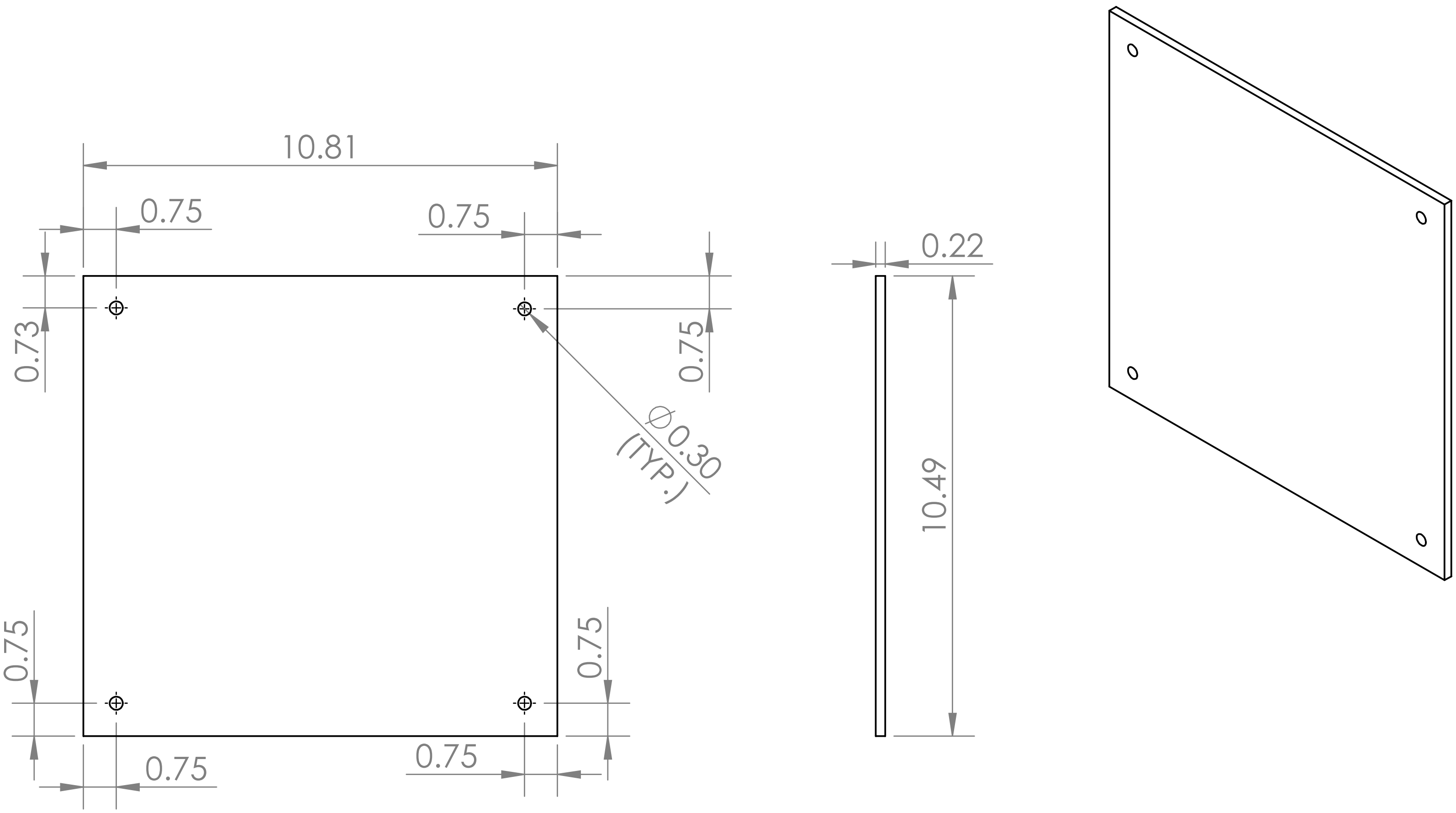
Acrylic Enclosure Right Panel

SIZE B | DWG. NO. | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

2 1

B B



A A

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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

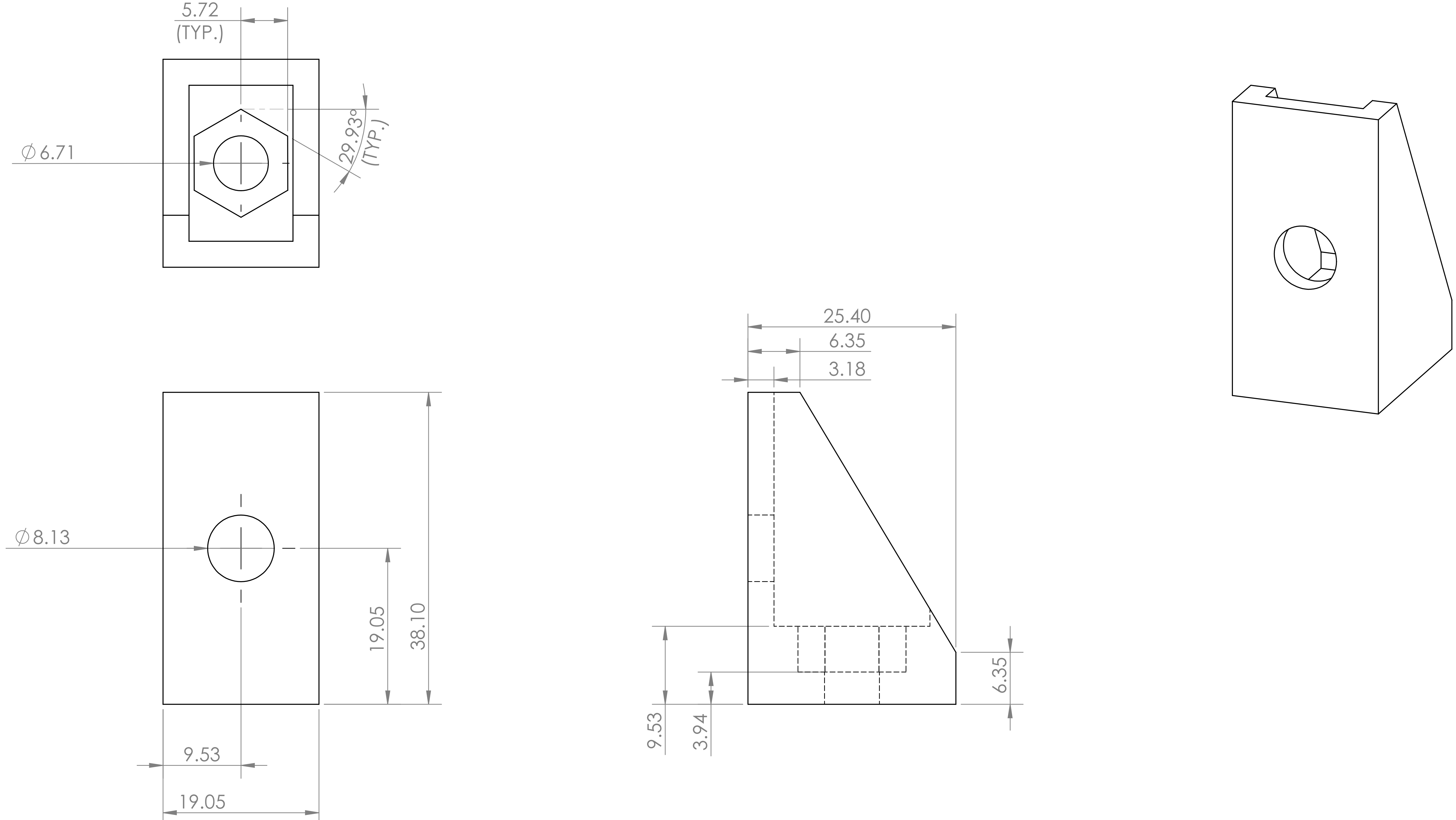
TITLE:

Acrylic Bottom Electronic Panel

SIZE	DWG. NO.	REV
A		

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

2 1



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APPLICATION	

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

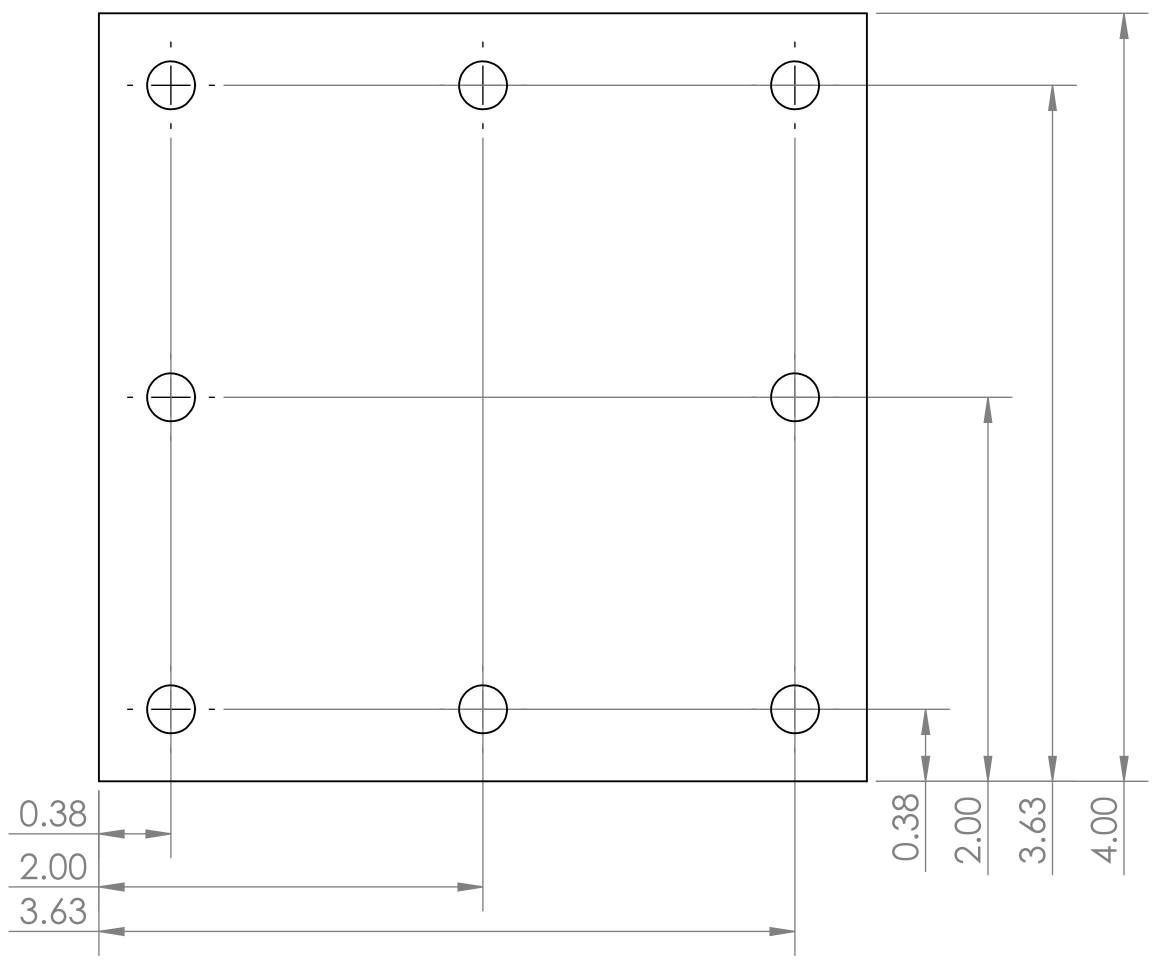
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

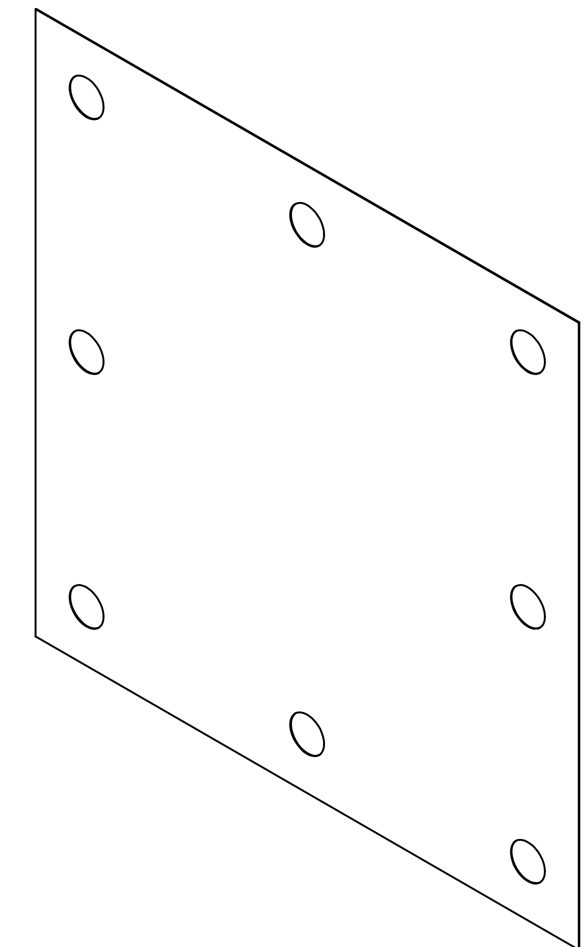
COMMENTS:

TITLE: Adjustment Feet Brackets

SIZE B | DWG. NO. | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1





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NEXT ASSY	USED ON
APPLICATION	

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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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

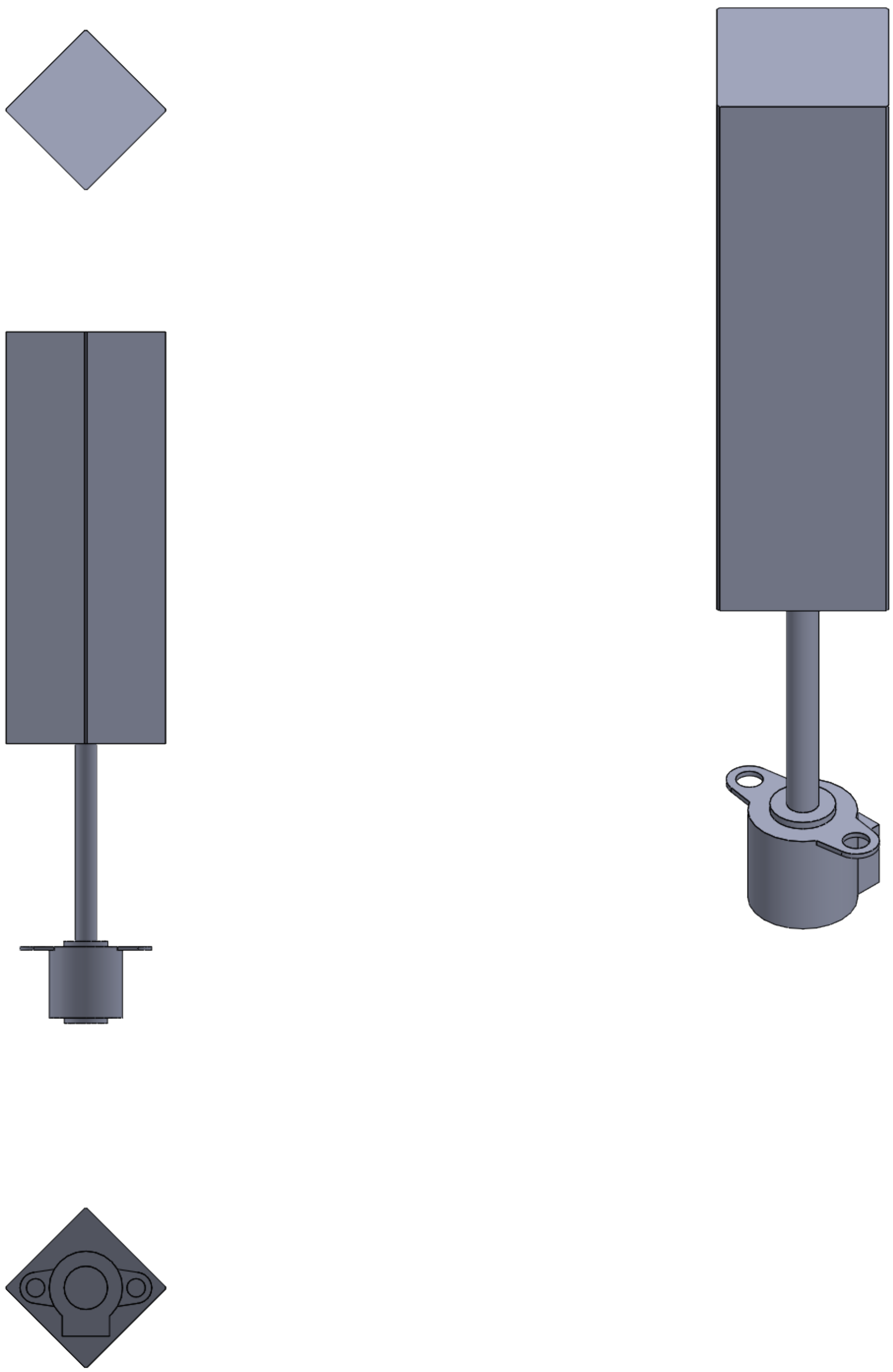
Silicon Sheet

SIZE B | DWG. NO. | REV

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

2 1

B B



A A

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APPLICATION	

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

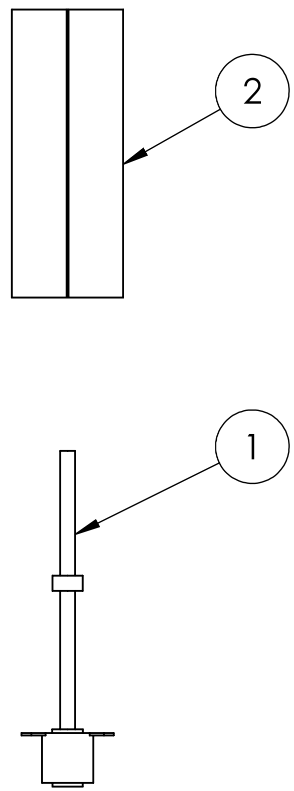
COMMENTS:

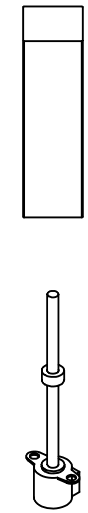
Motorized Pin Assembly

SIZE	DWG. NO.	REV.
A		

SCALE:1:1 WEIGHT: SHEET 1 OF 1

2 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor Assembly		1
2	Mold Pin		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

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

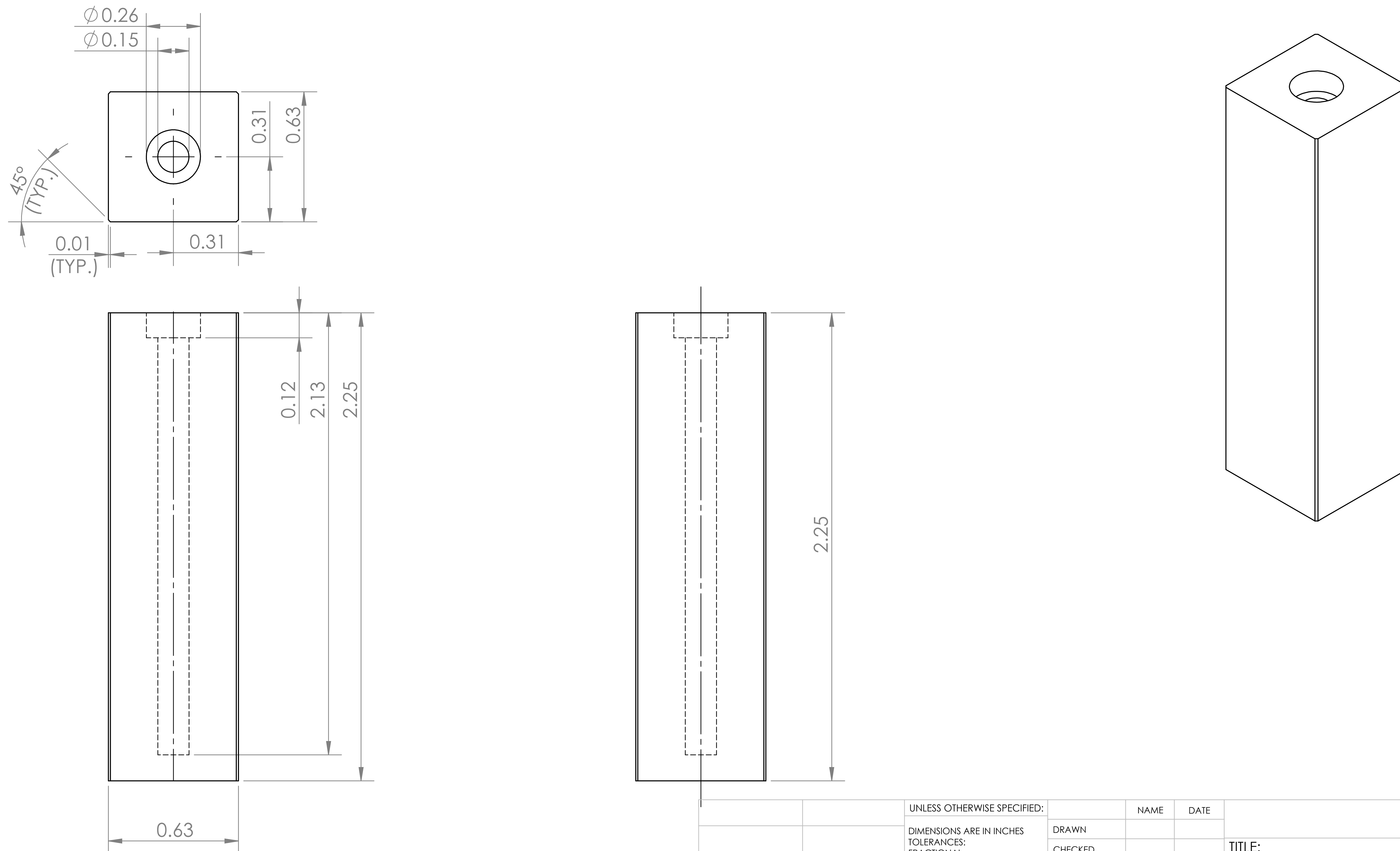
NEXT ASSY	USED ON
APPLICATION	

TITLE:

Motorized Pin Assembly

SIZE A | DWG. NO. | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:

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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

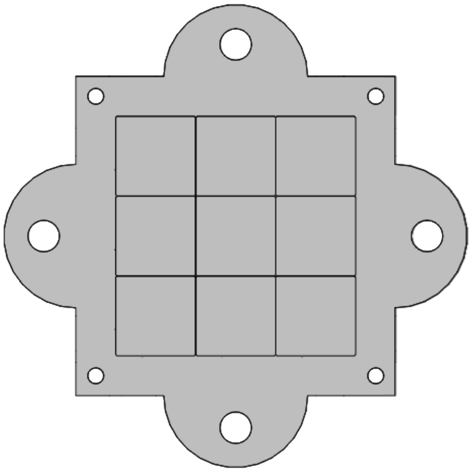
TITLE:

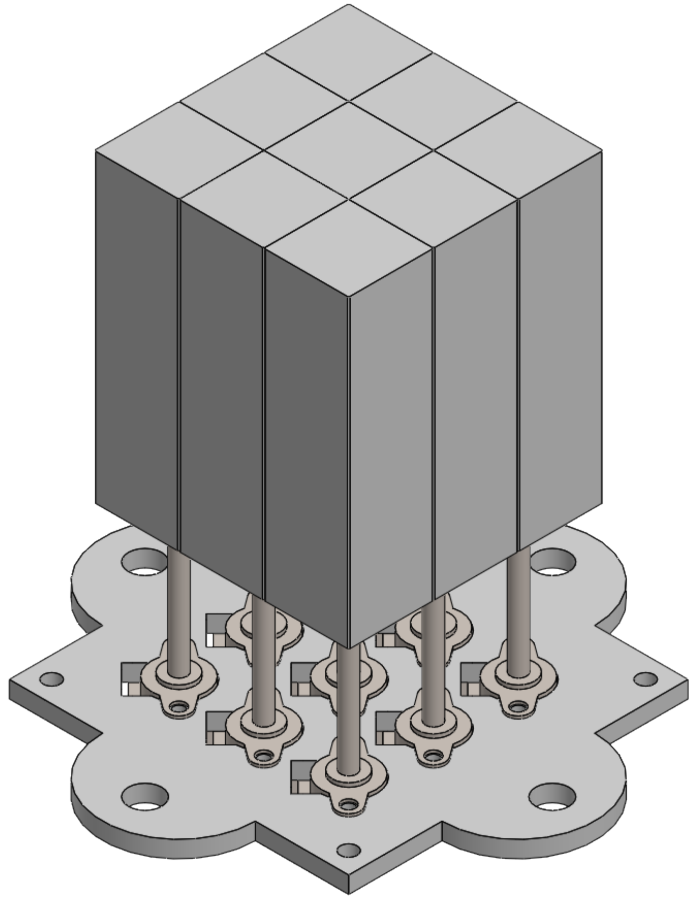
Mold Pin

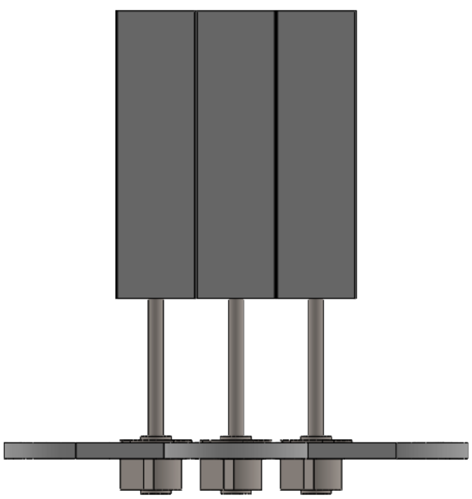
SIZE B | DWG. NO. | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	







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NEXT ASSY | USED ON

APPLICATION

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

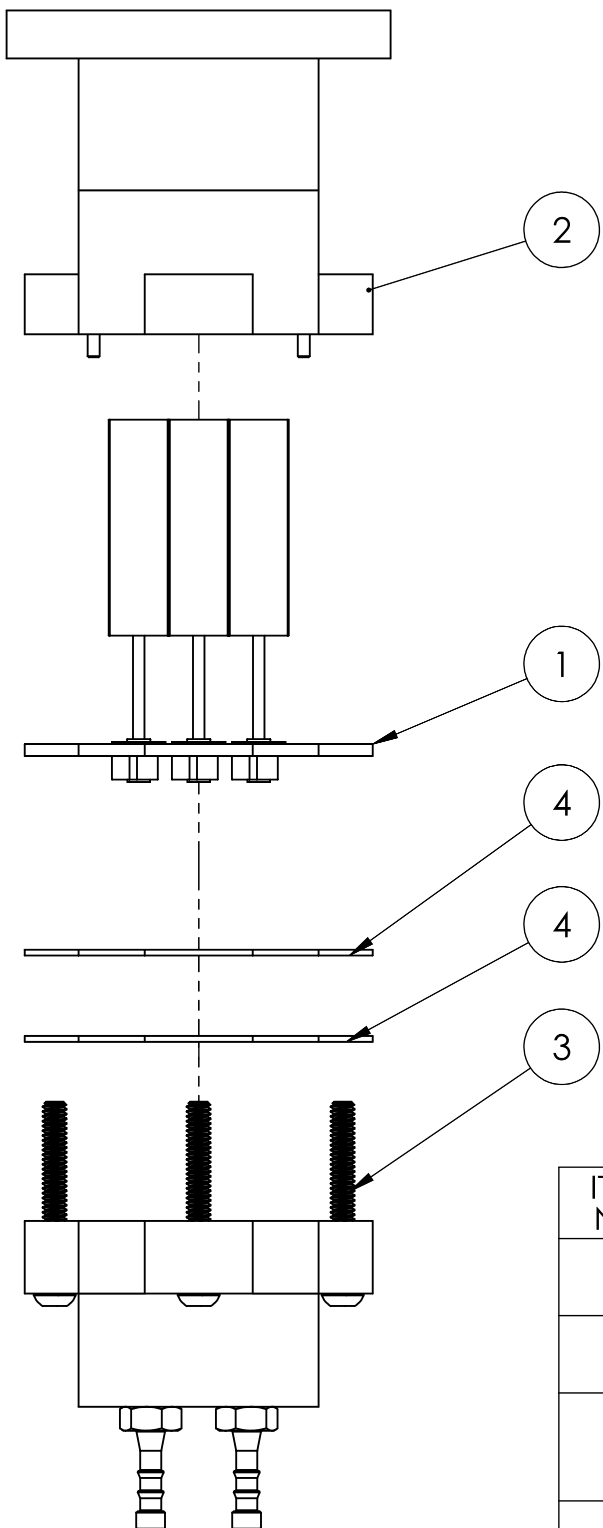
COMMENTS:

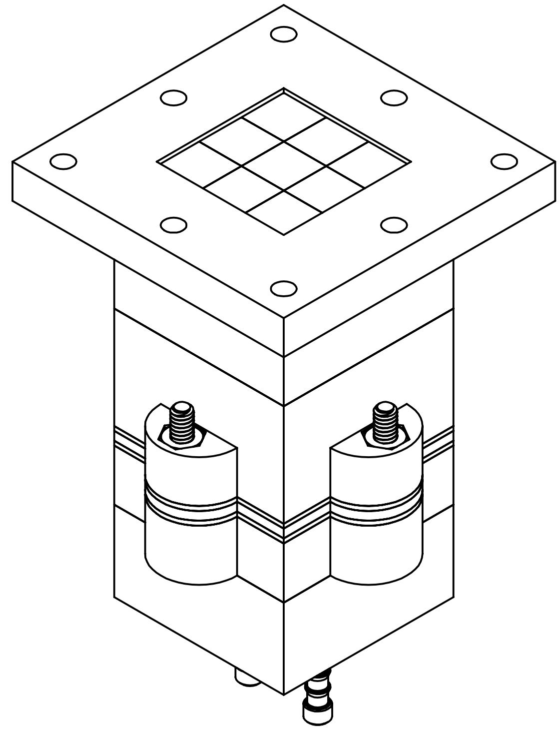
Base Pin Assembly

SIZE A | DWG. NO. | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1

B





B

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Pin Assembly		1
2	Guide Block Assembly		1
3	Guide Block Base Cap Assembly		1
4	Motor Mount Gasket		2

A A

NEXT ASSY	USED ON
APPLICATION	

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

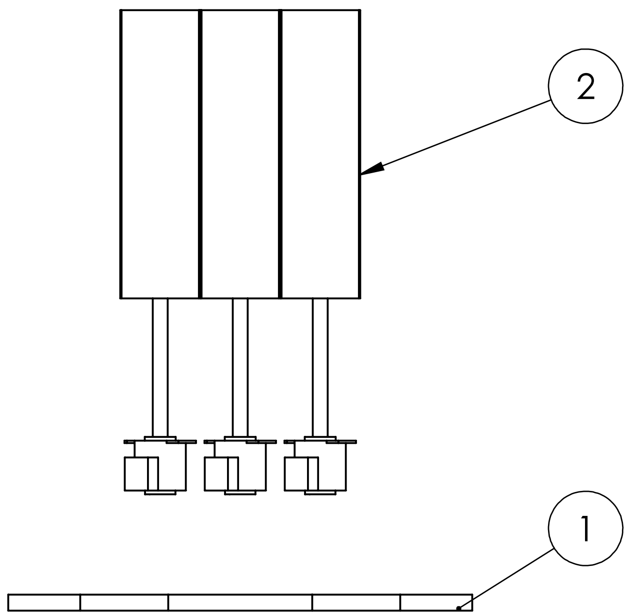
Central Pin Array Assembly

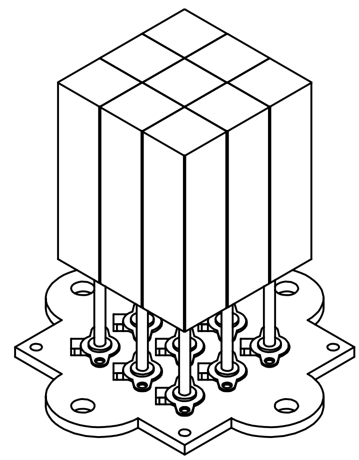
SIZE	DWG. NO.	REV.
A		

SCALE:1:2 WEIGHT: SHEET 1 OF 1

2 1

B B





A A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Motor Mount Guide Base		1
2	Motorized Pin Assembly		9

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NEXT ASSY	USED ON
APPLICATION	

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

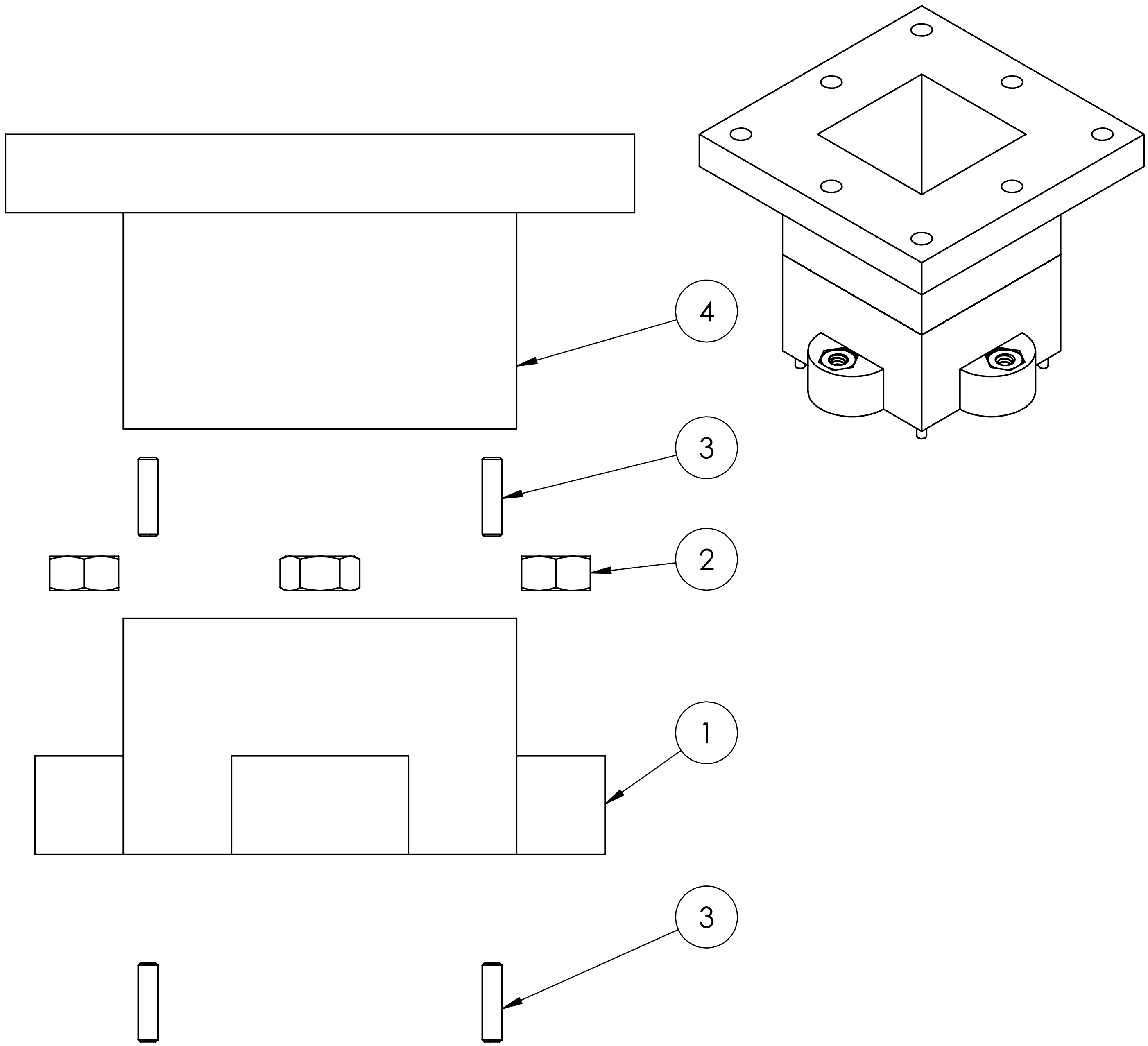
COMMENTS:

SIZE A DWG. NO. Base Pin Assembly REV.

SCALE:1:2 WEIGHT: SHEET 1 OF 1

2 1

B B



A A

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Guide Block Bottom		1
2	95479A111		4
3	98381A304		8
4	Guide Block Top		1

NEXT ASSY | USED ON

APPLICATION

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

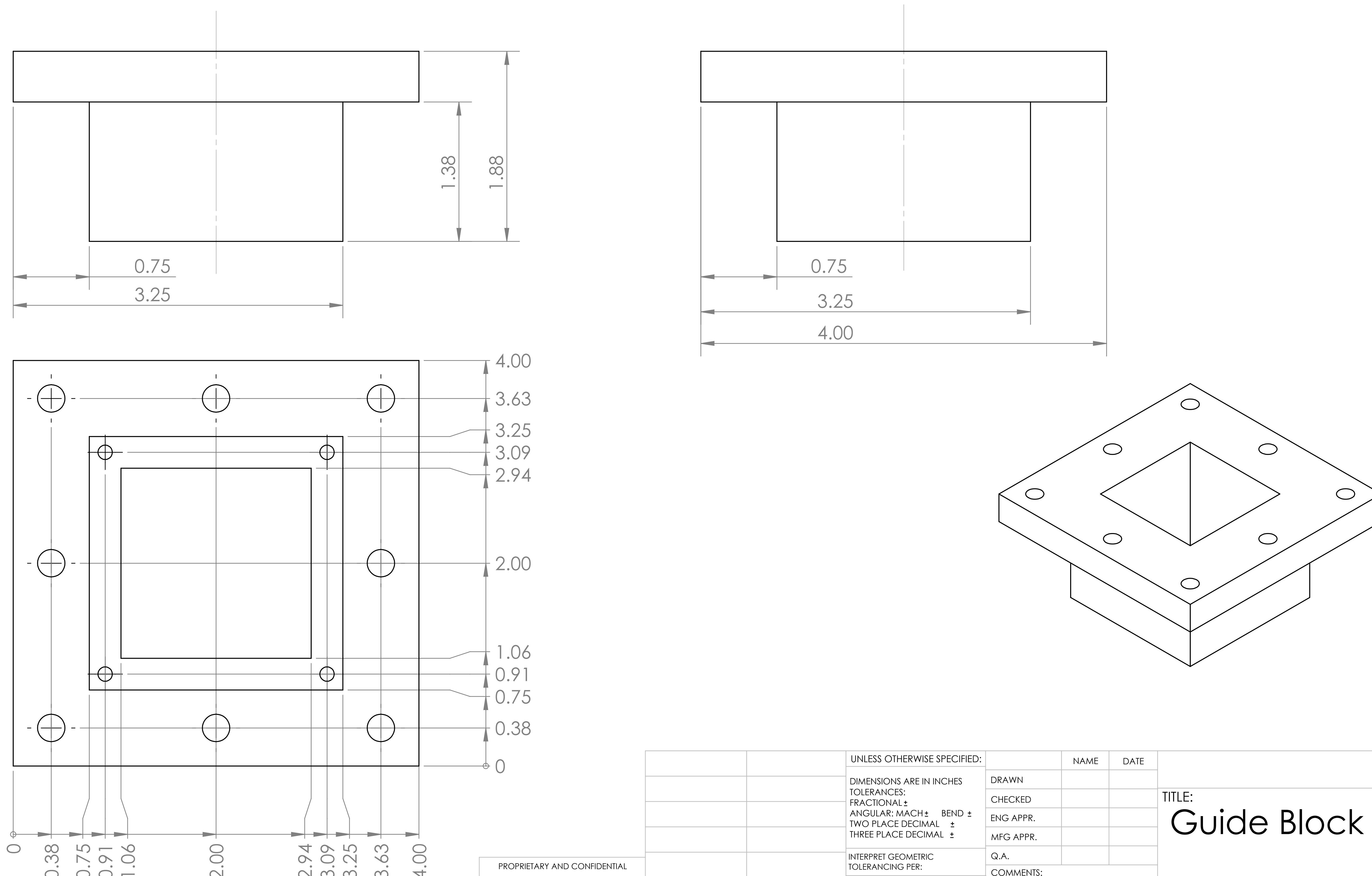
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Guide Block Assembly

SIZE A | DWG. NO. | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 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

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

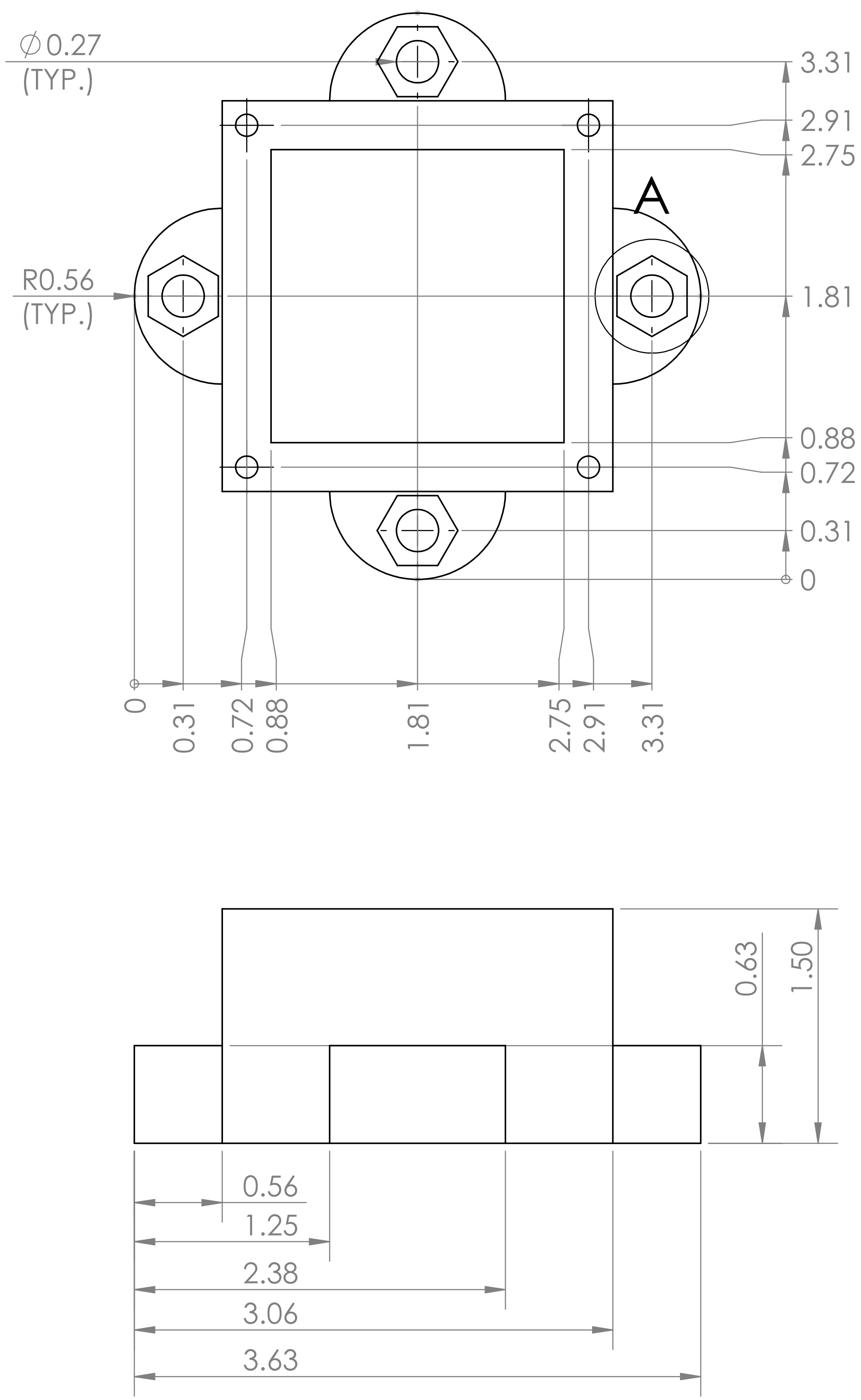
TITLE:

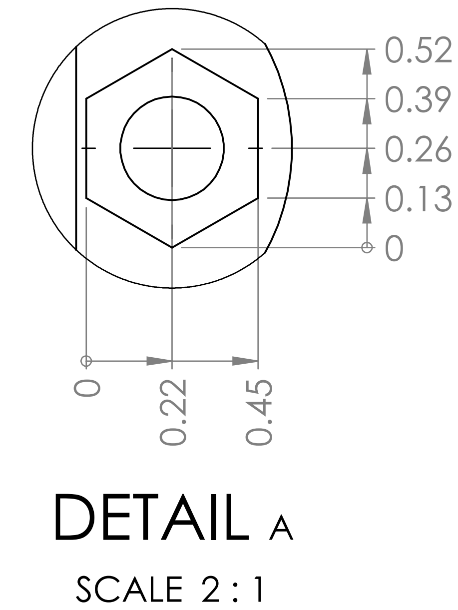
Guide Block Top

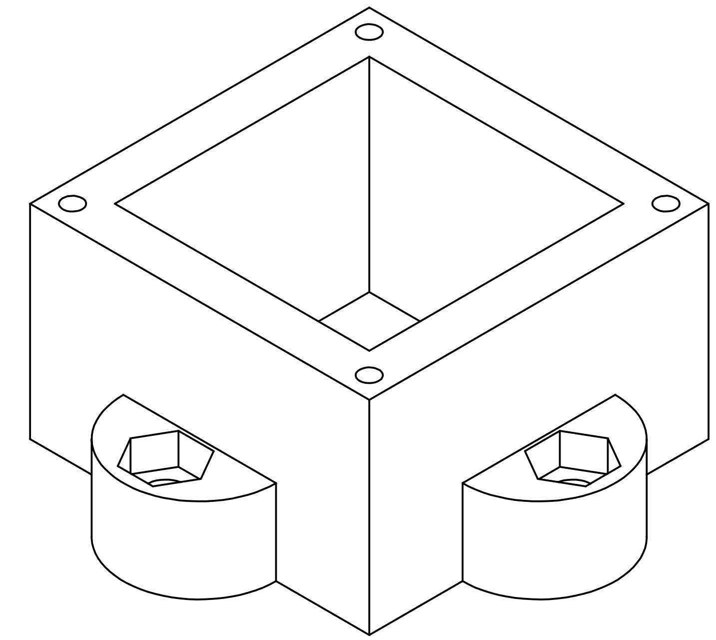
SIZE	DWG. NO.	REV
B		

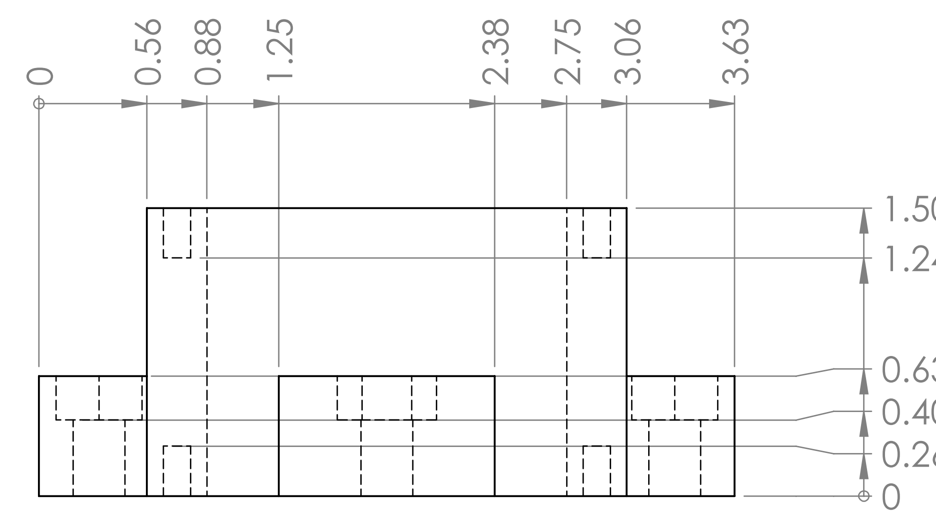
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	









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APPLICATION	

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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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

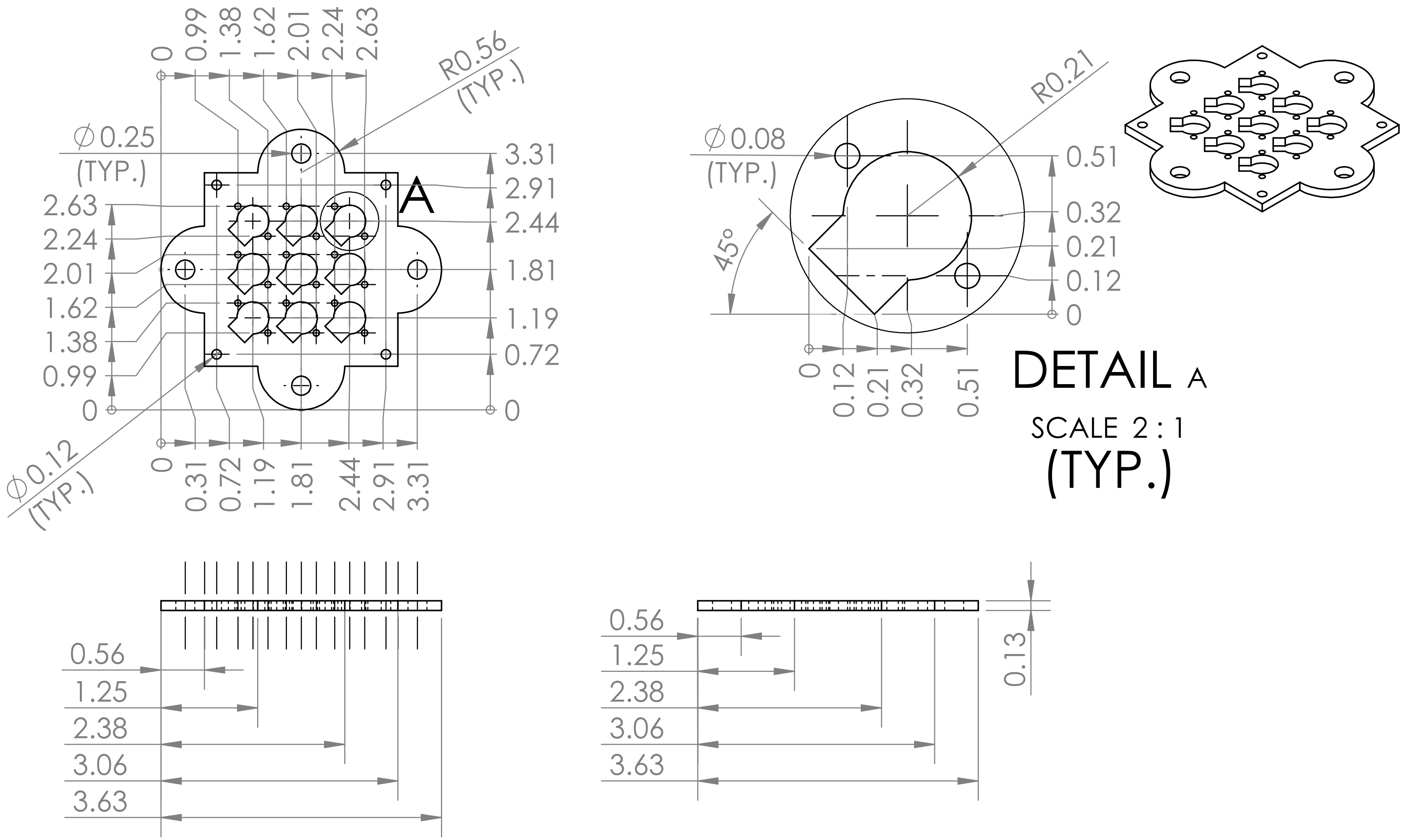
COMMENTS:

TITLE:

Guide Block Bottom

SIZE B | DWG. NO. | REV

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

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

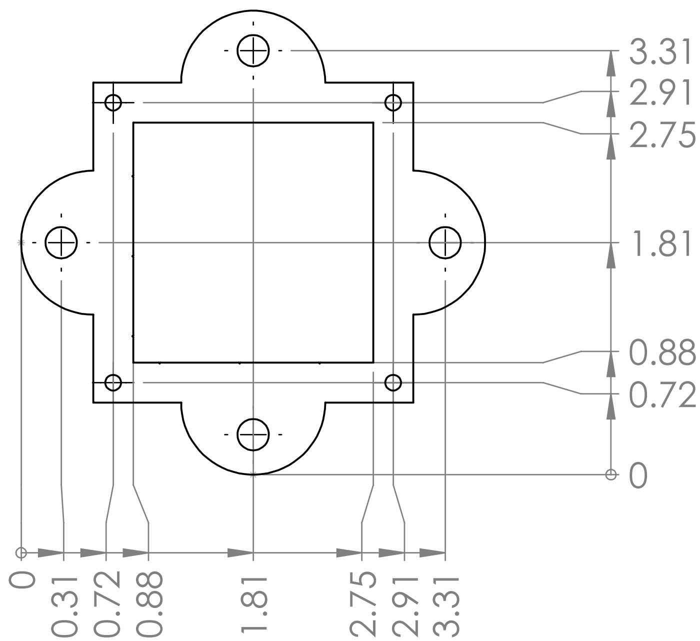
COMMENTS:

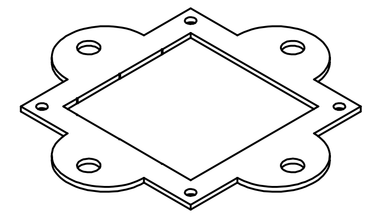
TITLE: Motor Mount Guide Base

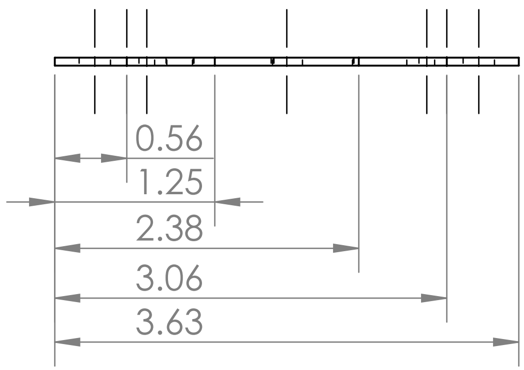
SIZE A | DWG. NO. | REV

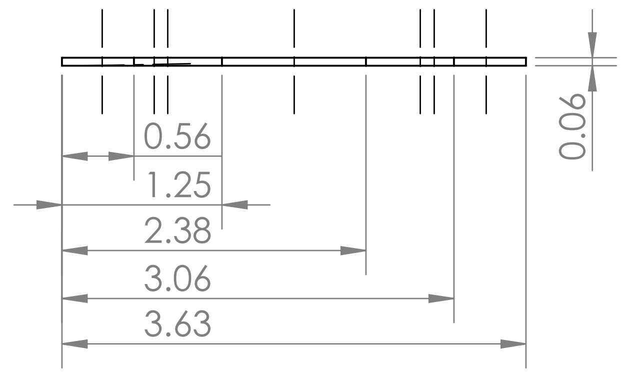
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	









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APPLICATION	

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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

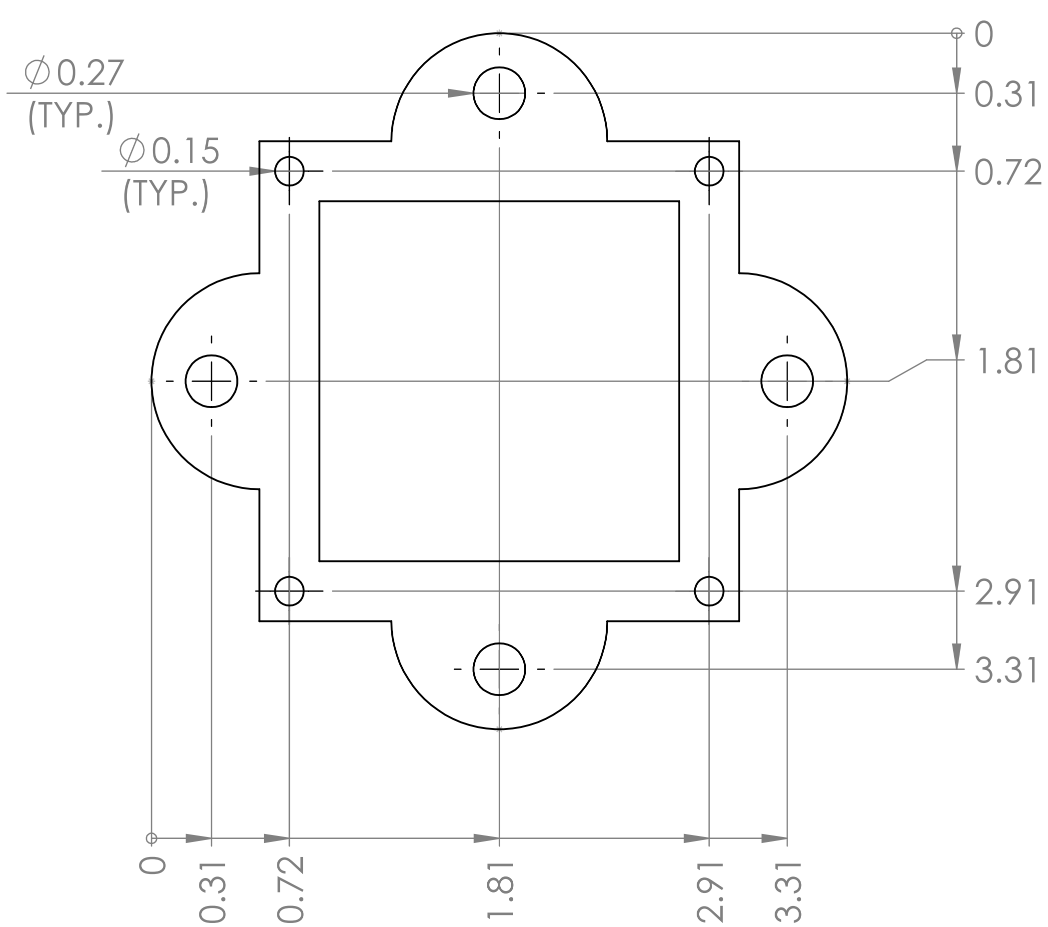
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

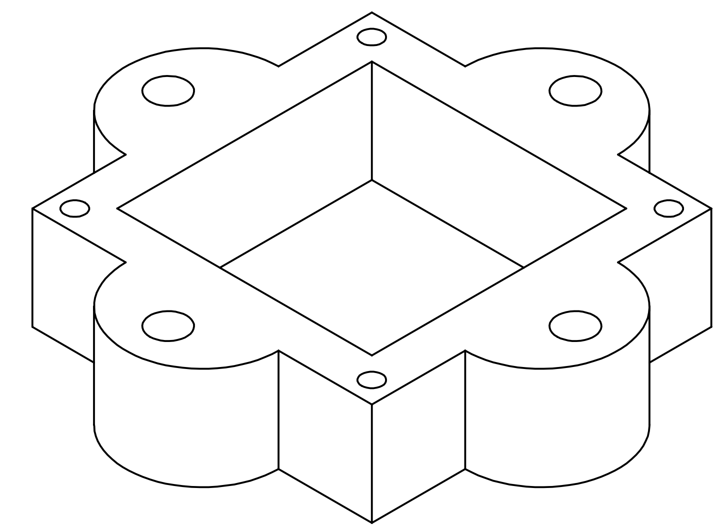
COMMENTS:

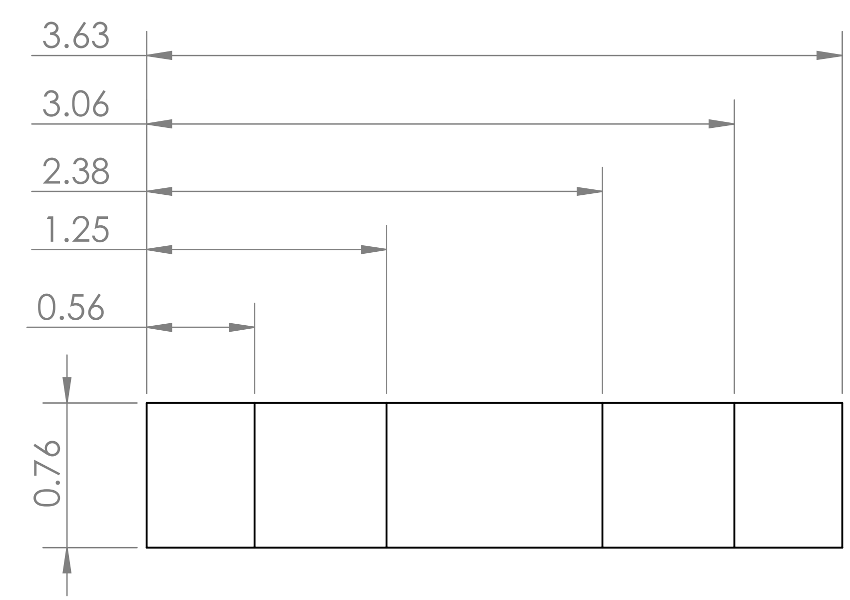
TITLE:
Motor Mount Gasket

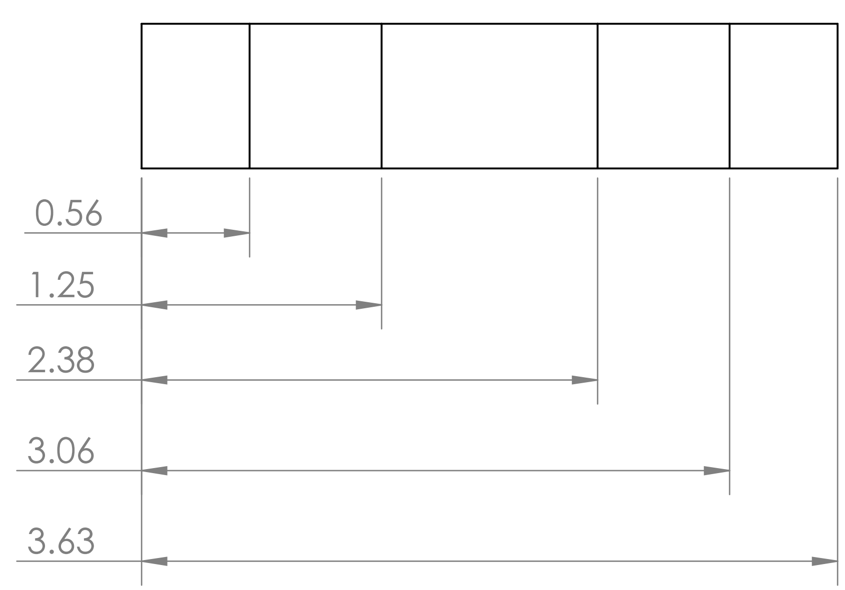
SIZE	DWG. NO.	REV
A		

SCALE: 1:2 WEIGHT: SHEET 1 OF 1









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APPLICATION	

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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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

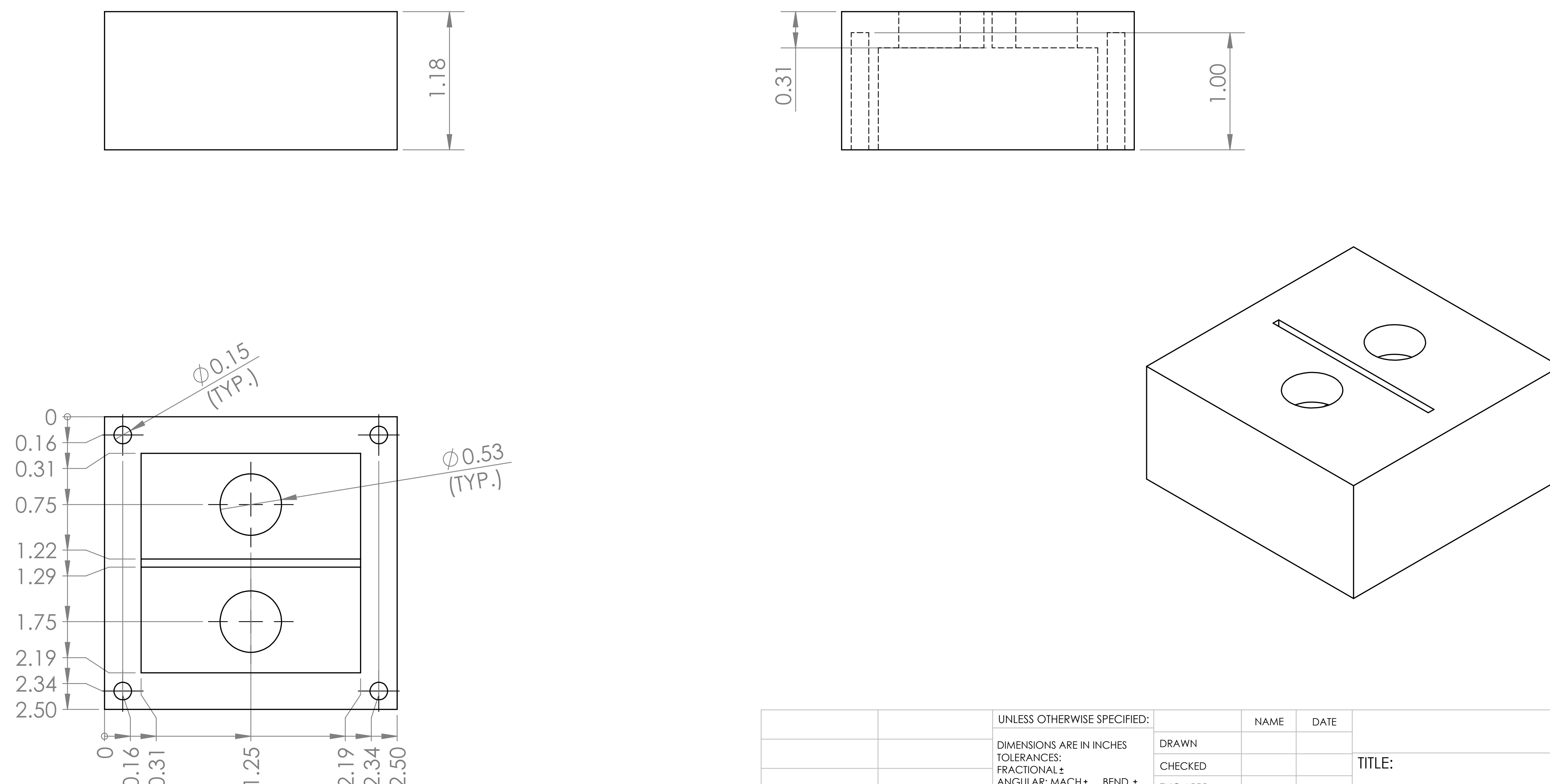
COMMENTS:

TITLE:

SIZE B DWG. NO. REV

Guide Block Bottom Space

SCALE: 1:1 WEIGHT: SHEET 1 OF 1



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APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

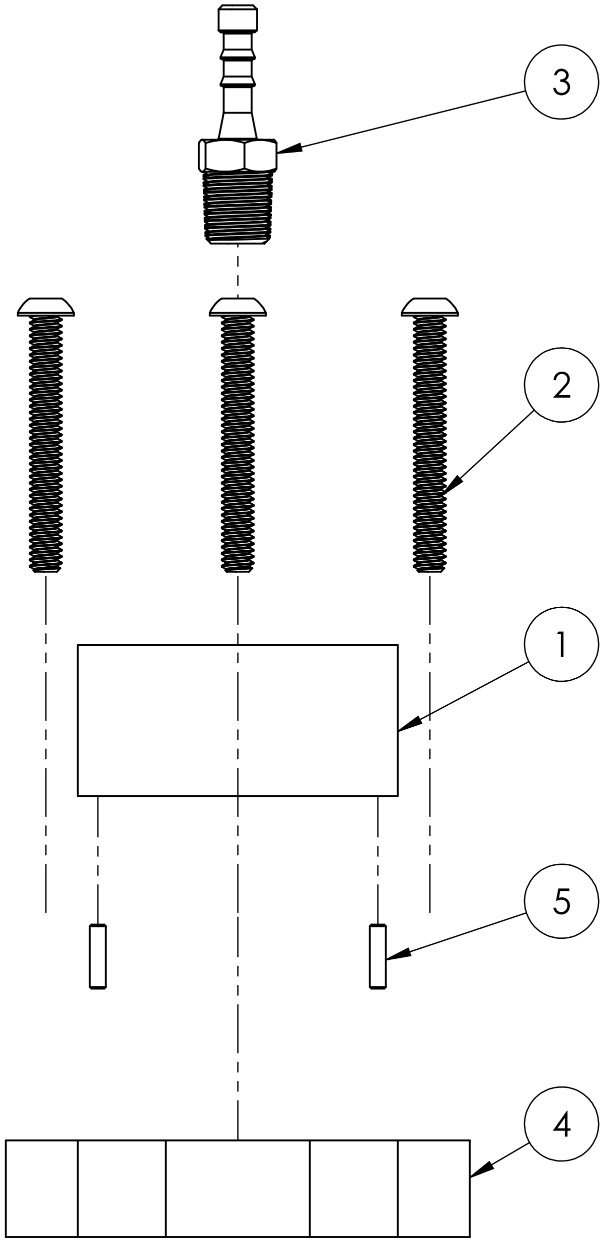
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

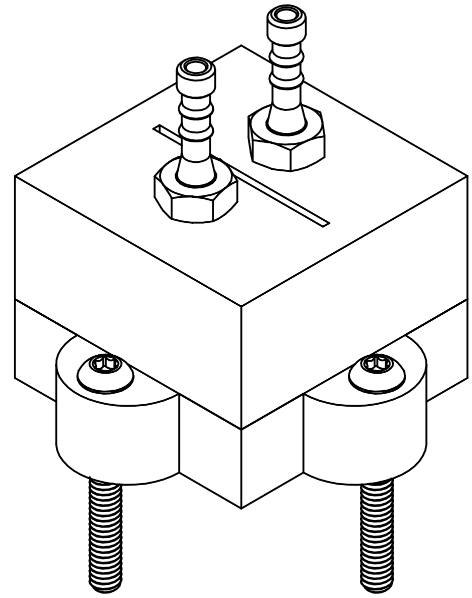
COMMENTS:

TITLE:

SIZE B DWG. NO. Guide Block Bottom Cap REV

SCALE: 1:1 WEIGHT: SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Guide Block Bottom Cap		1
2	90600A629		4
3	5350K32		2
4	Guide Block Bottom Spacer		1
5	98381A304		4

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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL

FINISH

NEXT ASSY | USED ON

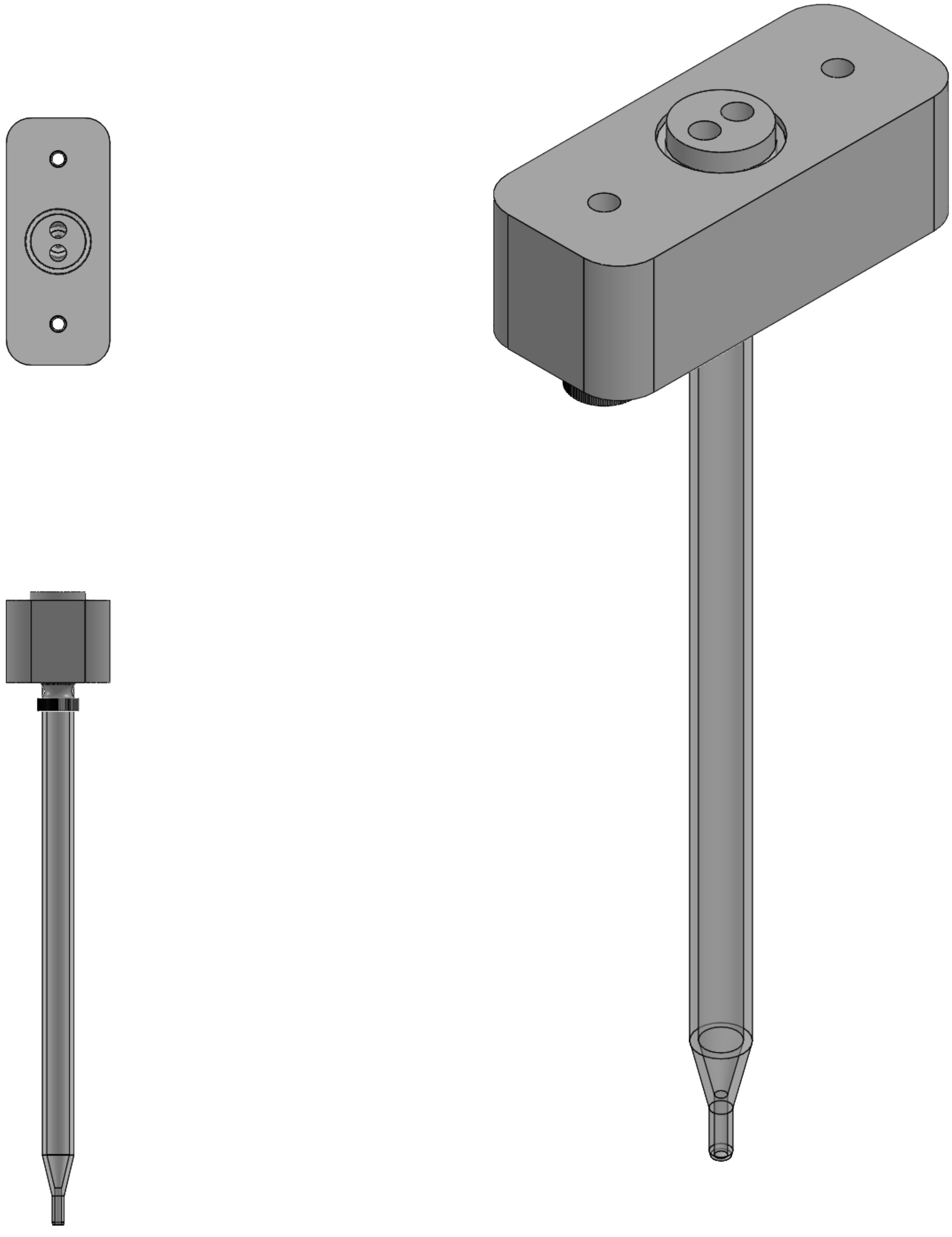
APPLICATION

DO NOT SCALE DRAWING

Guide Block Base Cap Assembly

SIZE A | DWG. NO. | REV.

SCALE:1:4 | WEIGHT: | SHEET 1 OF 1



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APPLICATION	

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

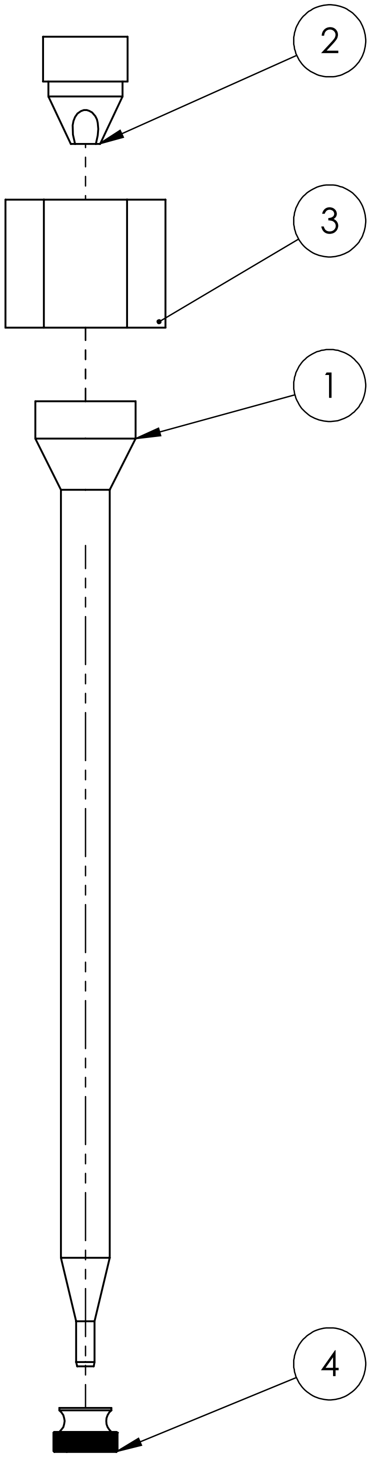
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

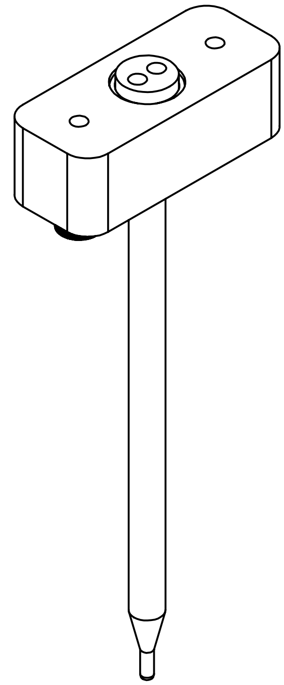
COMMENTS:

Mixing Nozzel Assemby

SIZE A | DWG. NO. | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Mixxing Nozzle		1
2	Nozzle Adapter		1
3	Nozzle Adapter Retainer		1
4	95150A160		2

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

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

MATERIAL

FINISH

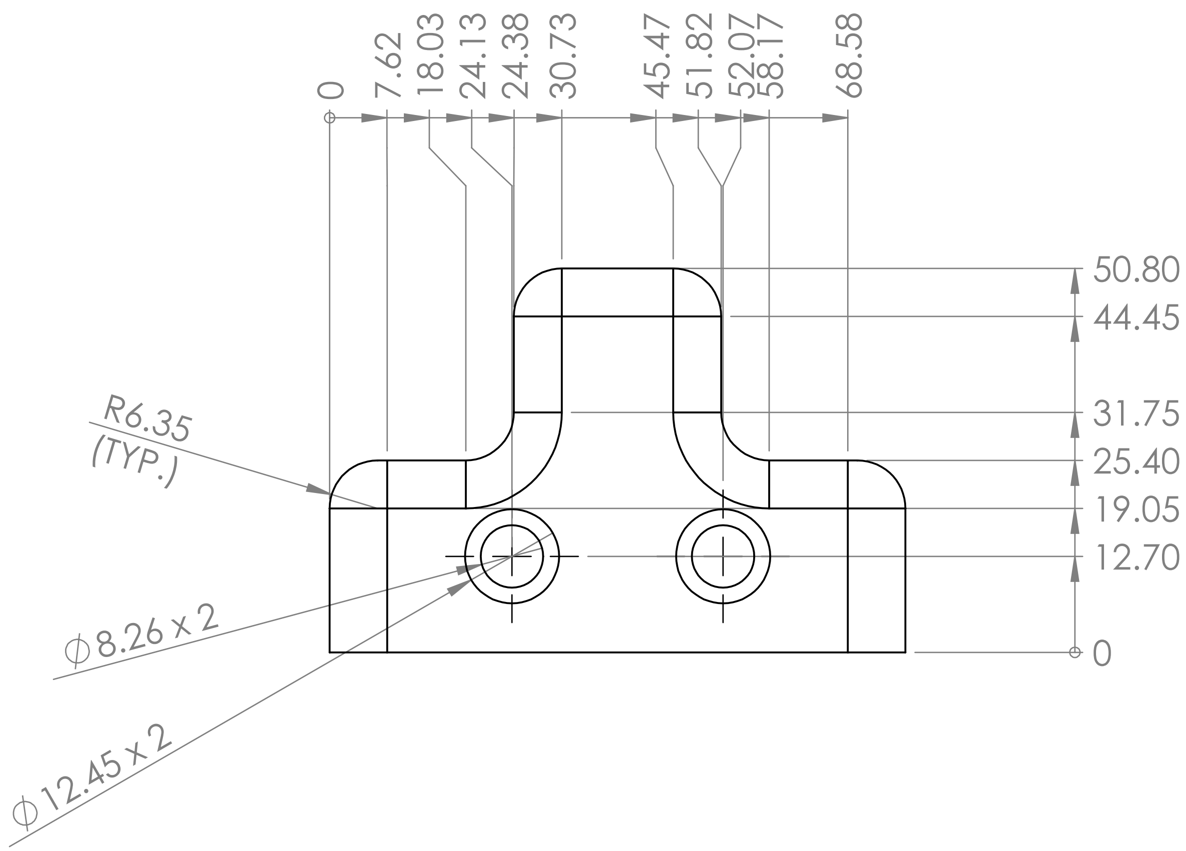
NEXT ASSY | USED ON

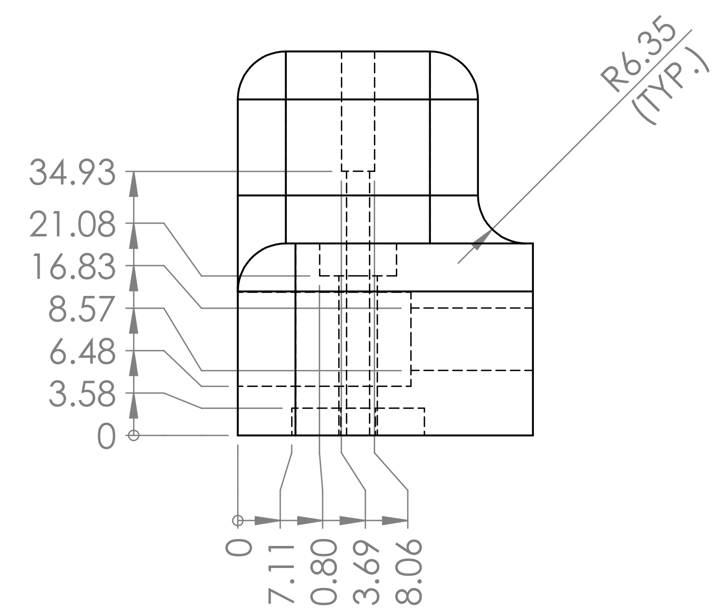
APPLICATION

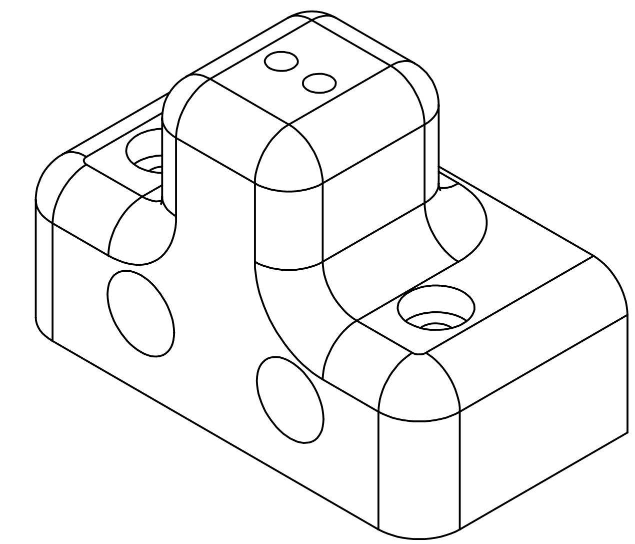
DO NOT SCALE DRAWING

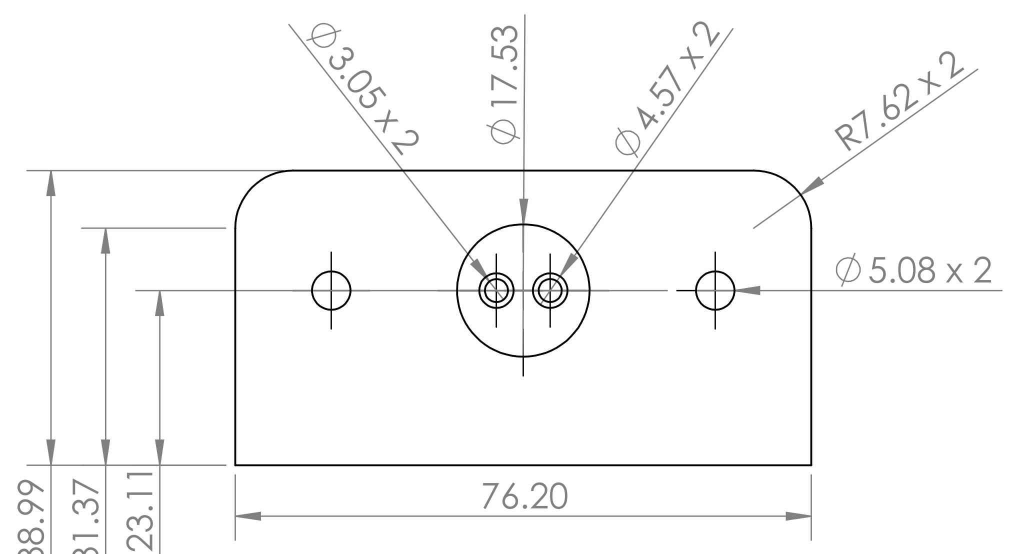
SIZE A DWG. NO. Mixing Nozzel Assemby REV.

SCALE:1:2 WEIGHT: SHEET 1 OF 1









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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

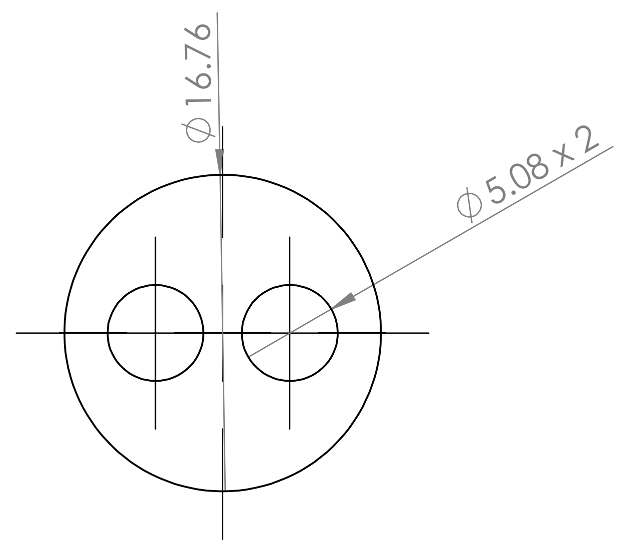
COMMENTS:

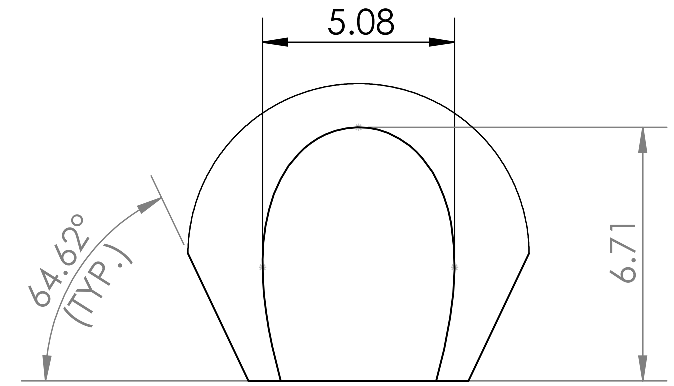
TITLE:

Nozzle Adapter Mount

SIZE	DWG. NO.	REV
B		

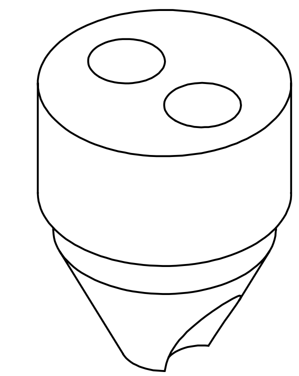
SCALE: 1:1 WEIGHT: SHEET 1 OF 1

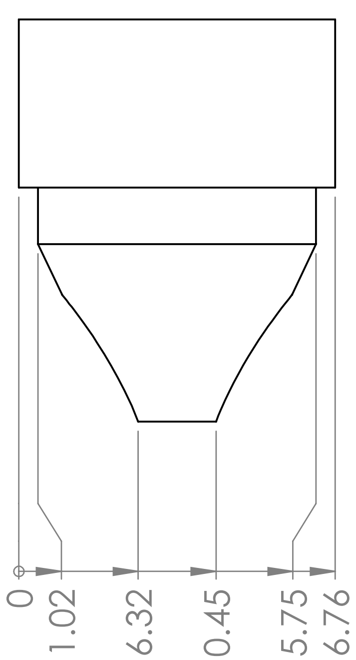


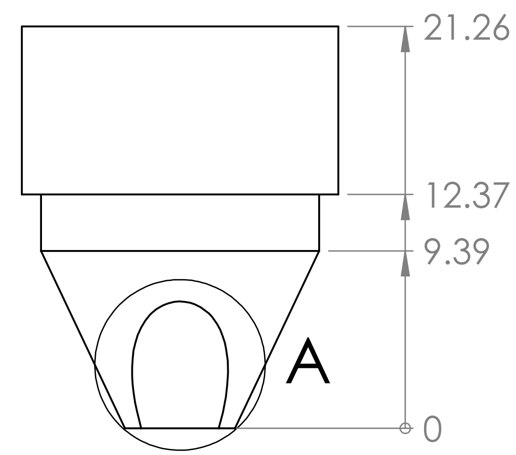


DETAIL A

SCALE 5 : 1







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TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

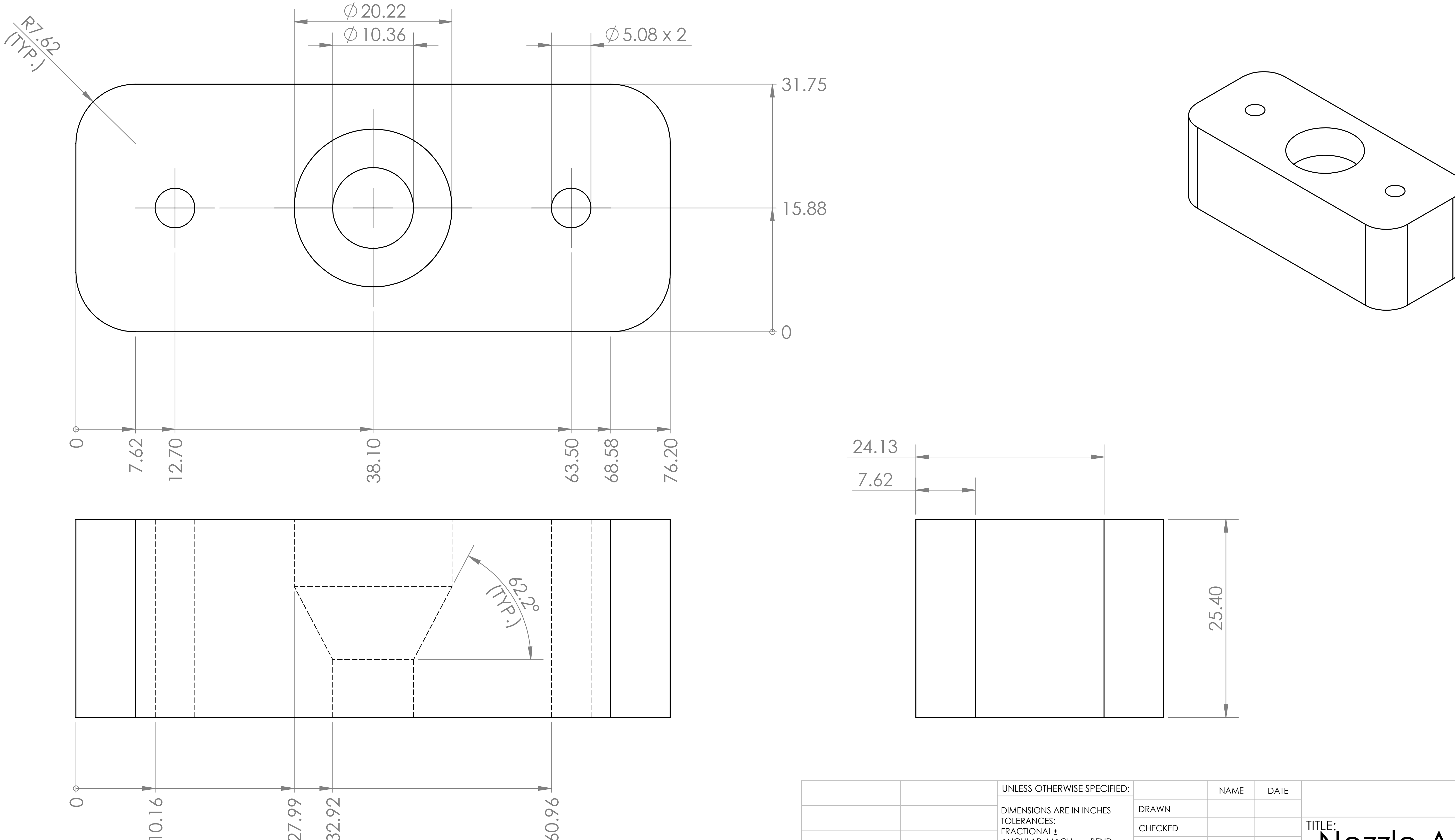
COMMENTS:

TITLE:

Nozzle Adapter

SIZE B | DWG. NO. | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1



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APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Nozzle Adapter Retainer

SIZE B | DWG. NO. | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1