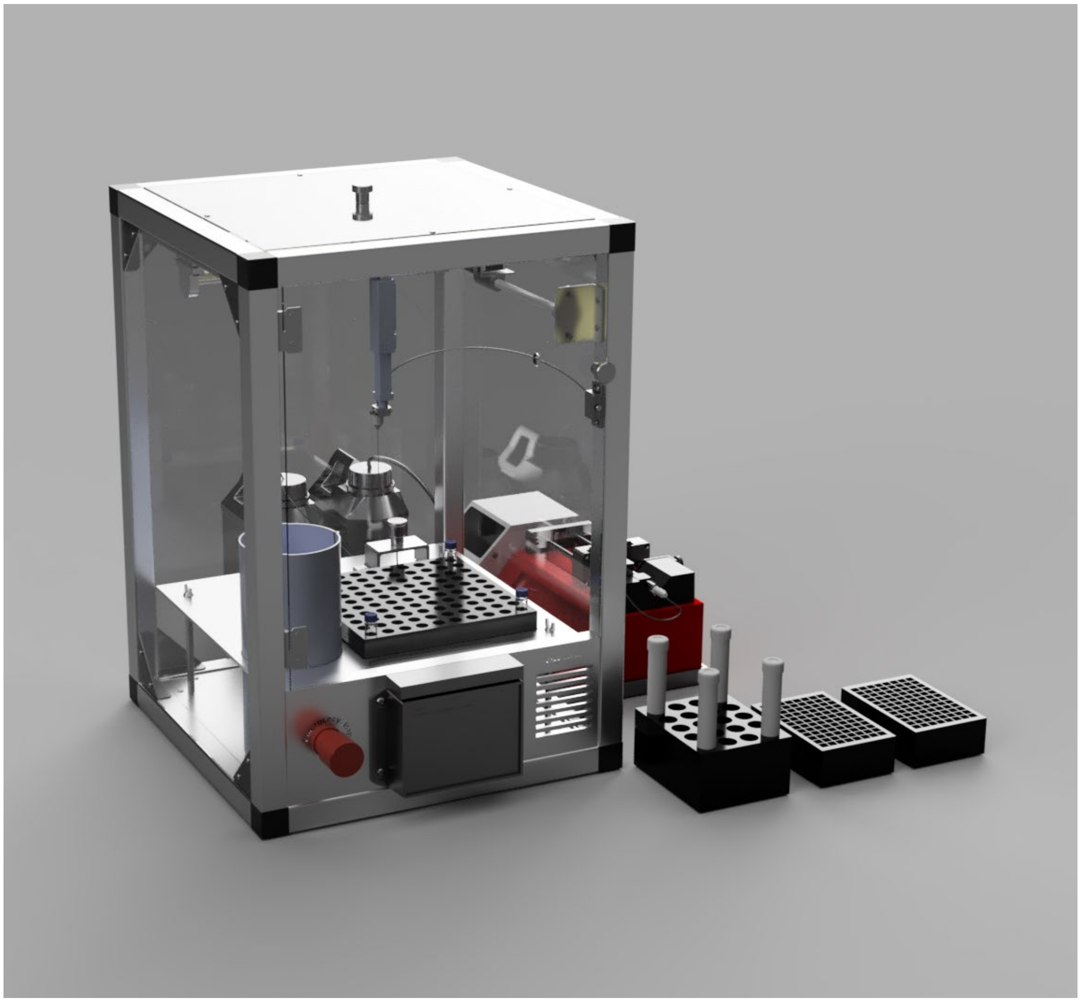
EML4501 Mechanical Engineering Design 2 | Group Project Report

Biofluid Autosampler



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Executive Summary

Autosamplers have seen massive gains in popularity in recent years, with the market expected to grow by 187% by 2032 [1]. By automating the process of sampling injection and preparation, they are not only a much faster alternative to manual injection, but they also minimize human error and ensure greater accuracy of injected volumes. However, many autosamplers found on the market do not offer some highly desirable features, such as compact size, temperature control, adequate sample storage, intuitive user interface, error checking and warning, and low processing times. The ones that do are accompanied by a hefty price tag.

Our client at the University of Florida has expressed the need for an autosampler that offers high speed, high accuracy, and active temperature control at a total cost of under $5,000, including manufacturing costs. While the report details all of the requirements, some of the main ones are to be stated here. This autosampler needs to be capable of injecting sample volumes in the range from 0.5 to 500 microliters, with accuracies of under 20% and 0.5%, respectively. The user should also be able to vary the temperature between 4 °C to 37 °C. These capabilities allow the user to address a wide span of conditions present in real-world applications. With a proper business plan, this autosampler could find use across many research and clinical environments.

Our design consists of 4 subsystems that collectively work to deliver the sample from a vial to an analytical instrument for analysis. These include the enclosure, movement system, temperature control system, and fluids system. A picture showing an overview of each subsystem is included for clarity (Fig. 1.1).

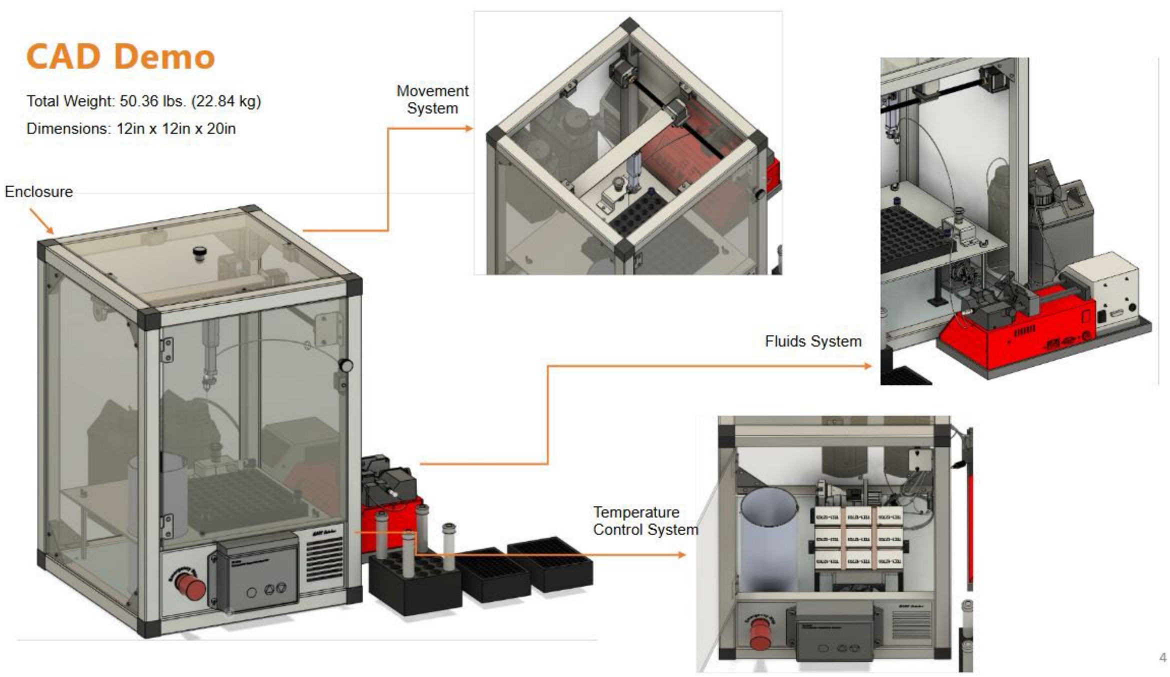


FIGURE 1.1: CAD DEMONSTRATION OF EACH SUBSYSTEM

The enclosure uses aluminum tubing connected by 3-way nylon, press-fit corners to house most of the components. An aluminum sheet is placed between the bottom four aluminum tubes to provide a base to hold everything together. The remaining sides are covered by polycarbonate sheets, locked in place using rivets and steel corner brackets, which also further secure the aluminum tubing in place. The enclosure also has an upper compartment supported by threaded standoffs, which elevates the sample trays and contains a hole for fluid beaker stability. This autosampler allows the user to store either two 96 well plates, a test tube rack with a hundred 1.5 mL test tubes, or a test tube rack with twenty 15 mL test tubes, all of which are to be 3D-printed. An aluminum front panel is included to serve as both a vent and the mount for the emergency stop button and the temperature controller. Magnetic latches are used to secure the polycarbonate lid that can be lifted for maintence and hold the front door closed that is hinged to act as the door.

The heating and cooling is performed by a combination of thermoelectric plates and a copper heat sink located beneath the enclosure deck. The thermoelectric plates are placed on top of the heat sink and are controlled by a PWM temperature controller on the front panel. These plates generate a thermal gradient across their two faces, thus heating one side and cooling the other. If, for example, the cool side is placed along the test tube rack, the sample temperature will go down. In this case, the bottom side will experience heating, so to cool it off, a copper heat sink is used. A heat sink utilizes its large surface area to absorb and dissipate the heat generated by the plates. To vent the remaining heat out of the system, a DC cooling fan is added as well.

The movement system contains two lead screws with stepper motors that move the linear actuator in the x- and y-directions, allowing the user to position the needle right above the desired location. The linear actuator enables the needle to move in the z-direction, i.e. up and down. Thanks to this, the needle can both reach and freely move between the test tubes containing the samples and the beaker containing the cleaning solution.

The fluids system uses the push-to-fill mode of injection to ensure precise volume delivery. It contains two pumps, a syringe pump and a peristaltic pump, placed outside of the enclosure. The former uses a stepper motor to aspirate the liquid from a test tube. The liquid is then dispensed through a needle seat, mounted on top of enclosure’s upper compartment, and enters a 6-port injection valve. Once the fluid reaches this position, the peristaltic pump helps push the sample over to the analytical instrument with the help of a mobile phase liquid stored in one of the jugs. The extra sample ends up in one of the waste jugs. Once the sampling is over, the needle moves over to the beaker with a cleaning solution to rinse the needle and then clean the entire pathway by repeating the same process as before.

Failure analyses are performed for both the enclosure and movement systems to ensure that they can withstand the expected loading conditions. It is found that the system satisfies these requirements, consistently with factors of safety of above 2. Moreover, the enclosure is so sturdy that it can endure the impact of a 200 lb man falling directly onto one of its corners with a factor of safety of 9.56. A pressure evaluation reveals that each of the fluids system components can endure the expected pressures, with the lowest factor of safety being 2.2 for the syringe pump. A time analysis for the temperature control system reveals that the time to cool the system after use is 4.5 minutes. Lastly, it is determined that the total sampling time adds up to 20 seconds for a 0.5 µL sample and 92 seconds for a 500 µL sample. Building an autosampler with this level of performance would result in a total price of $3,355.12, which accounts for manufacturing costs.

1 Design Methodology

1.1 Design Process

The team utilized the Double Diamond Method to arrive at a solution to the problem at hand. This method parses the design process into four major phases: discover, define, develop, and deliver. Each phase is denoted as convergent or divergent. Divergent phases involve broad research from the team, and convergent phases involve bringing the research from divergent phases together to arrive at a solution. This process is depicted visually in Figure 1.1.1.

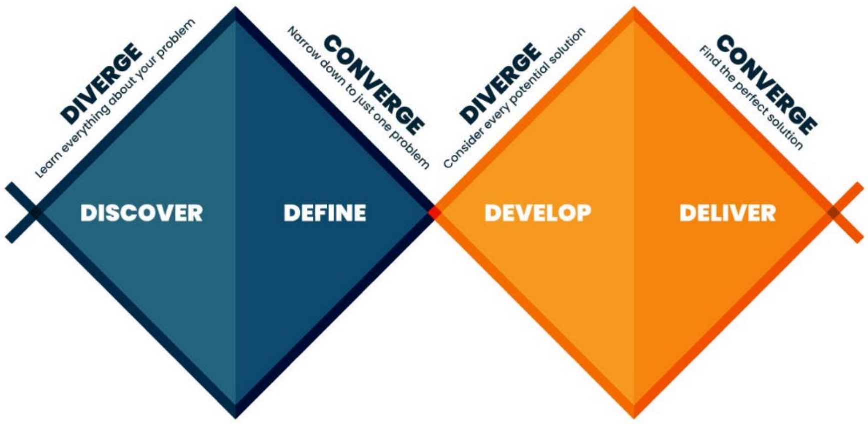


FIGURE 1.1.1: VISUAL REPRESENTATION OF THE DOUBLE DIAMOND METHOD

Discover:

The task at hand called to design an autosampler that can hold >100 1.5-mL centrifuge tubes and >20 15-mL tubes with a total manufacturing cost under $5,000. The first step was to research existing autosamplers to obtain a grasp of their functionality, maintenance, and cost. This exploration allowed the team to consider industry-standard systems when making selections for materials, components, and subsystem functions. This phase also included the development of a need statement, which allowed the team to home in on what issue the user needed to resolve the most. This need statement was supplemented by market and user research which gave a deeper insight into autosamplers in an industrial context as well as their typical clientele. The research helped to create two personas, which were the most likely archetypes for consumers looking for an autosampler. Furthermore, reviews of existing products and patents were performed to be better informed on professionally applied systems and how they cater to the ideated personas. Finally, the design opportunities were evaluated to assess what innovative change could be made to the design of an autosampler in order to make it unique, integrous, and useful.

Define:

Research showed that the most major issue with designing an autosampler was the high manufacturing cost; these machines are intricate and require the utmost accuracy when being used. This high cost was due to the generally large size of the machines and expensive materials/components used in professional industries; given the design requirements, it was less necessary to consider the size in the design process as the enclosure would not need to be large to house the required number of samples. As such, a larger emphasis was placed on material and component selections in order to minimize the manufacturing cost while upholding the integrity of the design. Additionally, both the use and function models were developed in this phase. These models are flow charts that map a prospective user's interaction with the system (use model) and the process that the autosampler performs as it runs (function model).

Develop:

The aforementioned considerations led to a compilation of potential materials and functions to use for each major component and furthermore the subsystems those selections applied to. Each consideration is detailed and compared in Section 4.1; to avoid redundancy, only the materials considered for each subsystem will be stated here. For the enclosure, mild steel, polycarbonate, and aluminum were considered. Polypropylene, aluminum-filled PLA, and polycarbonate were considered for the test tube racks. The motion system considered stainless steel, carbon steel, and aluminum. For the temperature control system, stainless steel, nickel alloy, and titanium were considered. Finally, the materials considered for the tubing were PFA, PTFE, and carbon fiber. Based on all options, team members developed conceptual designs for an autosampler. These concepts were then evaluated in two phases for their benefits and drawbacks using a Qualitative Pugh Chart in the first phase and a Quantitative Pugh Chart in the second phase. Between the first and second phase, an additional conceptual design was added to analyze due to drawbacks found in the first round of design evaluation. Based on the Quantitative Pugh Chart containing two designs from the first round of design evaluation and the design added in for the second round, a single design was decided on to move forward with.

Deliver:

These comparisons from the Develop Phase led to a final design selection. All final design selections are found in Section 5.1 with the CAD model, design calculations, reasons for design choices, and future design improvements also being discussed in detail. This final design was created by iterating through multiple designs of the subsystems to reach the function of the initial sketch decided during the develop phase. These iterations also occurred due to updated requirements from the client and to stay within all the requirements detailed in the project brief.

1.2 Design Process Management

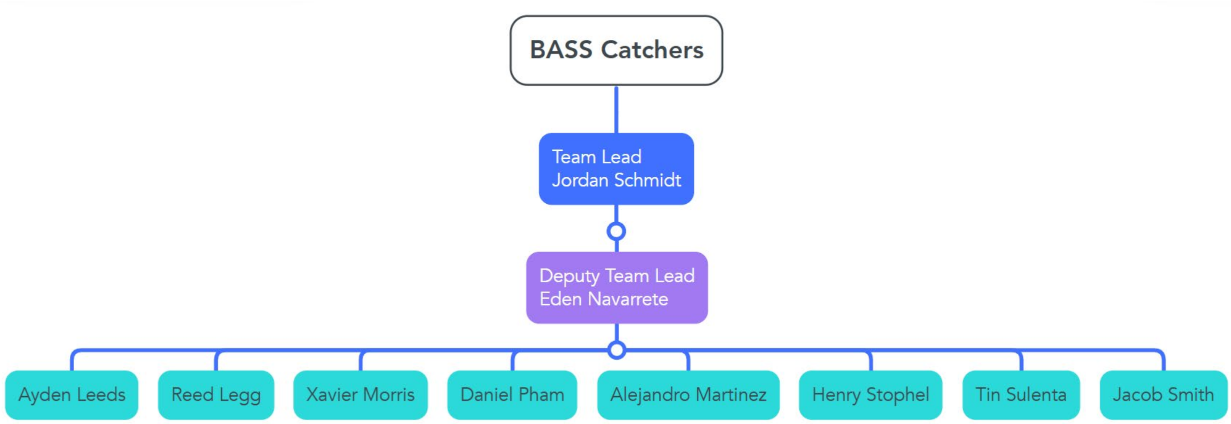


FIGURE 1.2.1: BASS CATCHERS ORGANIZATIONAL CHART – DISCOVER & DEFINE PHASES

The Team Lead and Deputy Team Lead were established at the start of the project to be Jordan Schmidt and Eden Navarrete respectively. The Team Lead's duties included managing team members, tasks, and schedule and leading team meetings. The Deputy Team Lead aided with these tasks by making announcements to the team, ensuring deliverables meet project requirements, and leading team meetings when the team lead was not present. Every team member worked together on all parts of the design through the discover and define phase, as shown in Figure 1.2.1.

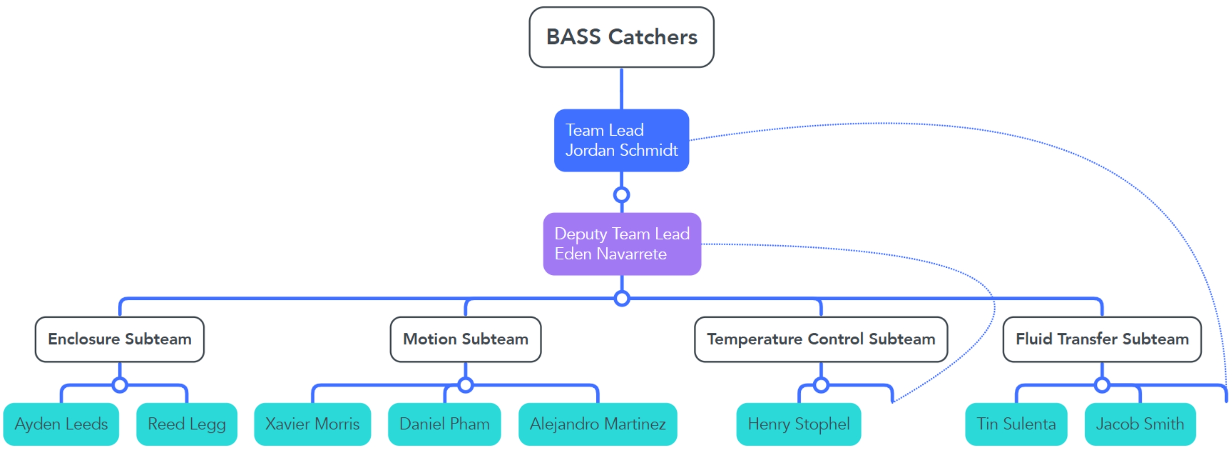


FIGURE 1.2.2: BASS CATCHERS ORGANIZATIONAL CHART – DEVELOP & DELIVER PHASES

Starting at the develop phase and through the end of the project, the team was split into four subteams based on the four subsystems incorporated into the overall design. The Enclosure Subteam was responsible for the enclosure of the autosampler and all connection points to the other subsystems. The Motion Subteam was responsible for the system that moves the needle to where it needs to be within the autosampler enclosure. The Temperature Control Subteam was responsible for ensuring the autosampler can keep the samples at the temperatures required by our client. The Fluid Transfer Subteam was responsible for designing the sample loop that controlled when and how the fluid moved from the vials placed in the autosampler to the analytical device that acted as the output of the autosampler. Which team member is part of which subteam is shown in Figure with the team lead also supporting the Fluid Transfer Subteam and the Deputy Team Lead also supporting the Temperature Control Subteam.

1.3 Project Gantt Charts

The project's schedule was designed using a Gantt Chart. The initial schedule had 5 weeks of float should delays occur in the project. This float turned out to be very valuable due to a couple weeks being delayed from hurricanes and additional delays during the deliver phase.

Task Name	Duration	Start	Finish
Discovery Phase	**21 days**	**Thu 8/22/24**	**Thu 9/19/24**
Background Research	21 days	Thu 8/22/24	Thu 9/19/24
Write-Up	**5 days**	**Tue 9/3/24**	**Mon 9/9/24**
2.1 General Background	5 days	Tue 9/3/24	Mon 9/9/24
2.2 Need Statement	5 days	Tue 9/3/24	Mon 9/9/24
2.3 Users and Target Market	5 days	Tue 9/3/24	Mon 9/9/24
2.4 Product and Patent Review	5 days	Tue 9/3/24	Mon 9/9/24
2.5 Design Opportunity Descriptio	5 days	Tue 9/3/24	Mon 9/9/24
Define Phase	**10 days**	**Tue 9/3/24**	**Mon 9/16/24**
Write-Up	**10 days**	**Tue 9/3/24**	**Mon 9/16/24**
3.1 Design Requirements	5 days	Tue 9/3/24	Mon 9/9/24
3.2.1 Use Model	5 days	Tue 9/3/24	Mon 9/9/24
3.2.2 Function Model	7 days	Sat 9/7/24	Mon 9/16/24
Develop Phase	**15 days**	**Tue 9/10/24**	**Tue 10/1/24**
Combination Charts	1 day	Tue 9/10/24	Tue 9/10/24
Solution Sketches	4 days	Wed 9/11/24	Mon 9/16/24
Concept Evaluation	0 days	Tue 9/17/24	Tue 9/17/24
Prototyping	5 days	Tue 9/17/24	Mon 9/23/24
Design & Prototyping Analysis	0 days	Tue 9/24/24	Tue 9/24/24
Design Review Deck	5 days	Tue 9/24/24	Mon 9/30/24
Design Review	0 days	Tue 10/1/24	Tue 10/1/24
Write-Up	**9 days**	**Wed 9/11/24**	**Mon 9/23/24**
4.1 Combination Charts	4 days	Wed 9/11/24	Mon 9/16/24
4.2 Design Alternatives	5 days	Tue 9/17/24	Mon 9/23/24
4.3 Design Evaluation	5 days	Tue 9/17/24	Mon 9/23/24

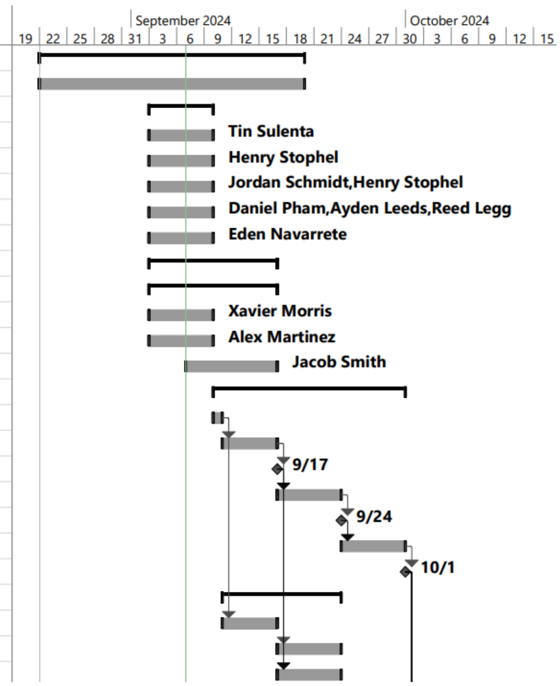


FIGURE 1.3.1: INITIAL GANTT CHARTS FOR DISCOVERY, DEFINE, AND DEVELOP PHASES

Task Name	Duration	Start	Finish
Discovery Phase	**21 days**	**Thu 8/22/24**	**Thu 9/19/24**
Background Research	21 days	Thu 8/22/24	Thu 9/19/24
Write-Up	**8 days**	**Tue 9/3/24**	**Thu 9/12/24**
2.1 General Background	8 days	Tue 9/3/24	Thu 9/12/24
2.2 Need Statement	8 days	Tue 9/3/24	Thu 9/12/24
2.3 Users and Target Market	8 days	Tue 9/3/24	Thu 9/12/24
2.4 Product and Patent Review	8 days	Tue 9/3/24	Thu 9/12/24
2.5 Design Opportunity Descriptio	8 days	Tue 9/3/24	Thu 9/12/24
Define Phase	**10 days**	**Tue 9/3/24**	**Mon 9/16/24**
Write-Up	**10 days**	**Tue 9/3/24**	**Mon 9/16/24**
3.1 Design Requirements	8 days	Tue 9/3/24	Thu 9/12/24
3.2.1 Use Model	8 days	Tue 9/3/24	Thu 9/12/24
3.2.2 Function Model	7 days	Sat 9/7/24	Mon 9/16/24
Develop Phase	**18 days**	**Thu 9/12/24**	**Tue 10/8/24**
Combination Charts	3 days	Thu 9/12/24	Mon 9/16/24
Design Review Deck	10 days	Tue 9/17/24	Mon 9/30/24
Solution Sketches	2 days	Tue 9/17/24	Wed 9/18/24
Concept Evaluation 1	0 days	Thu 9/19/24	Thu 9/19/24
Add'l. Design Research & Sketching	8 days	Thu 9/19/24	Sat 9/28/24
Concept Evaluation 2	0 days	Mon 9/30/24	Mon 9/30/24
Design Review	0 days	Tue 10/8/24	Tue 10/8/24
Write-Up: 4.1 Combination Charts	3 days	Thu 9/19/24	Mon 9/23/24
Write-Up: 4.2 Design Alternatives	1 day	Tue 10/1/24	Tue 10/1/24
Write-Up: 4.3 Design Evaluation	5 days	Tue 10/1/24	Mon 10/7/24

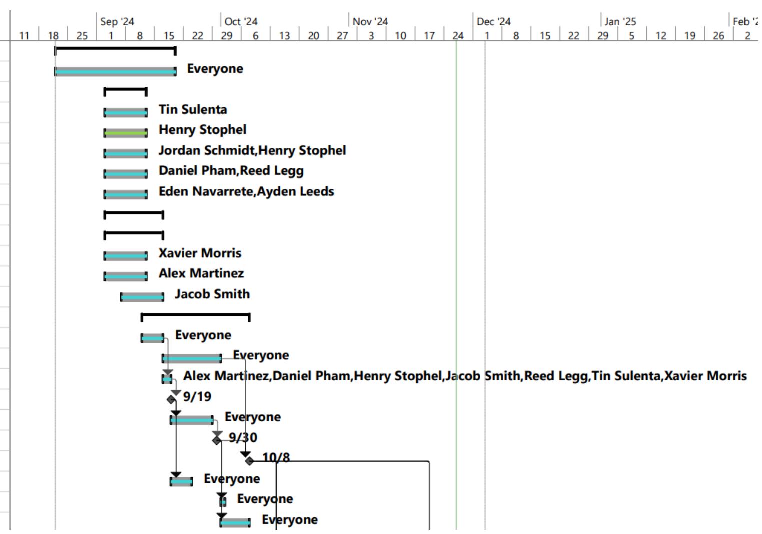
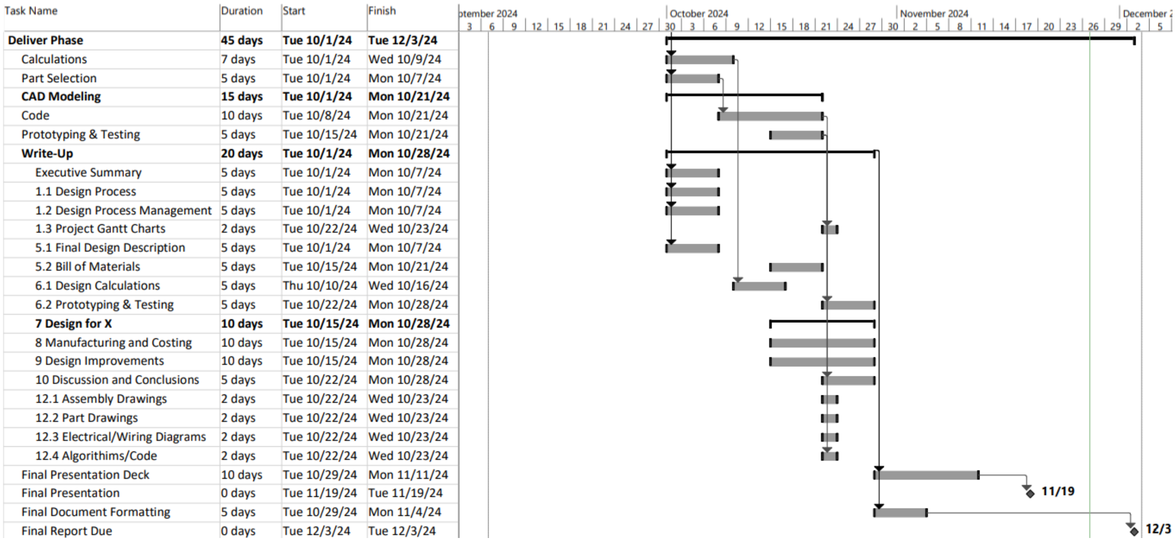


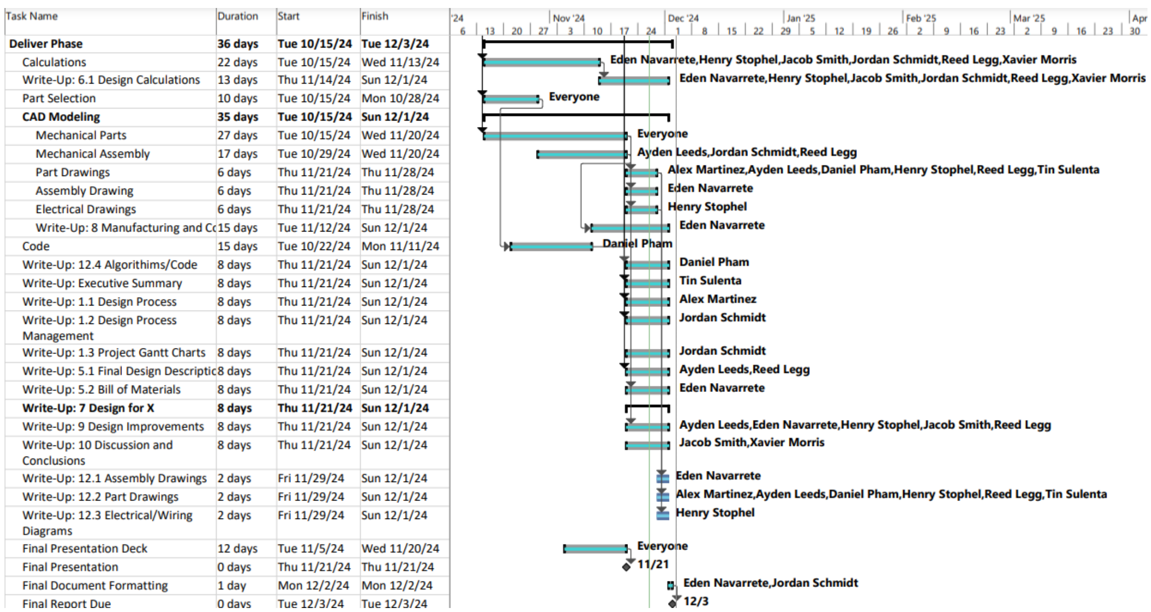
FIGURE 1.3.2: FINAL GANTT CHARTS FOR DISCOVERY, DEFINE, AND DEVELOP PHASES

The Gantt Charts shown in Figure 1.3.1 and Figure 1.3.2 show the initial and final schedules for the Discovery, Define, and Develop phases of our design process. With the Design Review milestone being the final milestone of these three phases, it is a good point to reference to compare the schedules at the beginning and at the end of the project. Initially, the Design Review was scheduled for 10/1/24, but it was pushed back (along with some tasks leading up to it and dependent on it) to 10/8/24 due to a hurricane which canceled school and left many team members without power. Due to the float built into the schedule, the team was still on track to complete the project on time.



Task Name	Duration	Start	Finish
Deliver Phase	**45 days**	**Tue 10/1/24**	**Tue 12/3/24**
Calculations	7 days	Tue 10/1/24	Wed 10/9/24
Part Selection	5 days	Tue 10/1/24	Mon 10/7/24
CAD Modeling	**15 days**	**Tue 10/1/24**	**Mon 10/21/24**
Code	10 days	Tue 10/8/24	Mon 10/21/24
Prototyping & Testing	5 days	Tue 10/15/24	Mon 10/21/24
Write-Up	**20 days**	**Tue 10/1/24**	**Mon 10/28/24**
Executive Summary	5 days	Tue 10/1/24	Mon 10/7/24
1.1 Design Process	5 days	Tue 10/1/24	Mon 10/7/24
1.2 Design Process Management	5 days	Tue 10/1/24	Mon 10/7/24
1.3 Project Gantt Charts	2 days	Tue 10/22/24	Wed 10/23/24
5.1 Final Design Description	5 days	Tue 10/1/24	Mon 10/7/24
5.2 Bill of Materials	5 days	Tue 10/15/24	Mon 10/21/24
6.1 Design Calculations	5 days	Thu 10/10/24	Wed 10/16/24
6.2 Prototyping & Testing	5 days	Tue 10/22/24	Mon 10/28/24
7 Design for X	**10 days**	**Tue 10/15/24**	**Mon 10/28/24**
8 Manufacturing and Costing	10 days	Tue 10/15/24	Mon 10/28/24
9 Design Improvements	10 days	Tue 10/15/24	Mon 10/28/24
10 Discussion and Conclusions	5 days	Tue 10/22/24	Mon 10/28/24
12.1 Assembly Drawings	2 days	Tue 10/22/24	Wed 10/23/24
12.2 Part Drawings	2 days	Tue 10/22/24	Wed 10/23/24
12.3 Electrical/Wiring Diagrams	2 days	Tue 10/22/24	Wed 10/23/24
12.4 Algorithims/Code	2 days	Tue 10/22/24	Wed 10/23/24
Final Presentation Deck	10 days	Tue 10/29/24	Mon 11/11/24
Final Presentation	0 days	Tue 11/19/24	Tue 11/19/24
Final Document Formatting	5 days	Tue 10/29/24	Mon 11/4/24
Final Report Due	0 days	Tue 12/3/24	Tue 12/3/24

FIGURE 1.3.3: INITIAL GANTT CHART FOR DELIVER PHASE



Task Name	Duration	Start	Finish
Deliver Phase	**36 days**	**Tue 10/15/24**	**Tue 12/3/24**
Calculations	22 days	Tue 10/15/24	Wed 11/13/24
Write-Up: 6.1 Design Calculations	13 days	Thu 11/14/24	Sun 12/1/24
Part Selection	10 days	Tue 10/15/24	Mon 10/28/24
CAD Modeling	**35 days**	**Tue 10/15/24**	**Sun 12/1/24**
Mechanical Parts	27 days	Tue 10/15/24	Wed 11/20/24
Mechanical Assembly	17 days	Tue 10/29/24	Wed 11/20/24
Part Drawings	6 days	Thu 11/21/24	Thu 11/28/24
Assembly Drawing	6 days	Thu 11/21/24	Thu 11/28/24
Electrical Drawings	6 days	Thu 11/21/24	Thu 11/28/24
Write-Up: 8 Manufacturing and Cc	15 days	Tue 11/12/24	Sun 12/1/24
Code	15 days	Tue 10/22/24	Mon 11/11/24
Write-Up: 12.4 Algorithms/Code	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: Executive Summary	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 1.1 Design Process	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 1.2 Design Process Management	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 1.3 Project Gantt Charts	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 5.1 Final Design Descriptic	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 5.2 Bill of Materials	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 7 Design for X	**8 days**	**Thu 11/21/24**	**Sun 12/1/24**
Write-Up: 9 Design Improvements	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 10 Discussion and Conclusions	8 days	Thu 11/21/24	Sun 12/1/24
Write-Up: 12.1 Assembly Drawings	2 days	Fri 11/29/24	Sun 12/1/24
Write-Up: 12.2 Part Drawings	2 days	Fri 11/29/24	Sun 12/1/24
Write-Up: 12.3 Electrical/Wiring Diagrams	2 days	Fri 11/29/24	Sun 12/1/24
Final Presentation Deck	12 days	Tue 11/5/24	Wed 11/20/24
Final Presentation	0 days	Thu 11/21/24	Thu 11/21/24
Final Document Formatting	1 day	Mon 12/2/24	Mon 12/2/24
Final Report Due	0 days	Tue 12/3/24	Tue 12/3/24

FIGURE 1.3.4: FINAL GANTT CHART FOR DELIVER PHASE

The Gantt Charts shown in Figure 1.3.3 and Figure 1.3.4 show the initial and final schedules for the Deliver phase of our design process. Due to a second hurricane delay, this phase did not begin until two weeks after it was initially planned. Once the work of this phase was approaching and the team was restructured into subteams, tasks were assigned to specific people and subteams. Subteams pushed forward on their tasks and communicated with other subteams during weekly team meetings. Delays occurred during the assembly process of the subsystems but, once again due to the built in float in the schedule, allowed the project to be completed on time.

2 Discover Phase

2.1 General Background

An autosampler is an automation device that extracts a precise amount of sample from a sample container and carries it over to an analytical instrument for analysis, ensuring speed and accuracy of the process [2]. It is commonly used in chemical and medical industries to perform processes like liquid and gas chromatography, mass spectrometry, capillary electrophoresis, and flow injection analysis [3].

An autosampler typically comprises two main elements, a sample storage compartment and a sampling and distribution apparatus. As the name suggests, the storage compartment is used to store the samples at a set of controlled conditions, most importantly temperature. Within the storage compartment, samples are kept in rectangular vial racks, vial carousels, or well plates [2]. Vials are glass or plastic containers with several enclosure options, such as snap caps, crimp caps, and screw caps [4]. Depending on the enclosure type, the sample may be drawn with or without taking off the enclosure. Well plates, on the other hand, are containers consisting of multiple cavities, each of which serves the same purpose as a single vial.

The sampling and distribution apparatus is used to draw the sample from the tubes, carry it over to the analytical instrument, and clean the entire pathway before the next run [2]. Its primary component is an injector, which comprises an injection valve, a metering device, and a moving sampling needle. An injection valve facilitates the extraction of the sample solution and its travel to the analytical instrument under high pressure. Its components typically include a needle port, a sample loop, and a rotor and stator combination [2]. A sample loop represents the path the sample solution and wash solvent can travel within the sampling and distribution apparatus. A rotor and stator combination is implemented to control the flow of both the sample solution and the wash solvent through the sample loop. The sample is usually packed into the sample loop first as this can be done at atmospheric pressure. The rotor then rotates around from the load to inject position and directs the sample towards the analytical instrument [5].

There are three main approaches to sample introduction designs: split-loop, pulled-loop, and pushed-loop designs [6]. In the split-loop design, the needle directly connects to the part of the sample loop that goes over to the analytical instrument. The needle aspires the sample into the sample loop and then goes back to a high-pressure needle port. Once the injection valve switches to the inject position, the sample is taken towards the analytical instrument. The main advantage of the split-loop design is waste elimination since all the sample loaded into the sample loop is carried over to the column for analysis, which is particularly useful for small sample sizes. Moreover, this design tends to have faster injection cycles than the other two designs. In the pulled-loop design, the sample is aspirated into the sample loop via a needle attached to the sample port [7]. On the other side of the sample loop stands an external syringe attached to the waste port, which can be drawn back to facilitate suction of the sample solution. The injection valve is then rotated to carry the sample over to the column. The main advantage of the pulled-loop design is its simplicity, usually resulting in a lower price than the other two approaches [6]. However, its disadvantages include higher waste generation and carryover, i.e. remnants of the former sample found in the new sample due to improper cleaning [6]. Lastly, in the pushed-loop autosamplers, the syringe goes directly into the sample unit and pulls up a desired sample volume, which is then dispenses into the sample loop through an injection port [7]. Each of these processes are controlled by stepper motors, cutting imprecision to no more than 0.5%. Furthermore, this design produces significantly less waste and carryover than the pulled-loop design.

Pulled- and pushed-loop autosamplers use one of two injection modes, full-loop mode or partial-loop mode [2]. In the former, the sample solution fills out the entire sample loop, which renders it more precise and thus more suitable to deal with small sample sizes. However, it creates more waste as the process of filling out the entire sample loop usually requires three times its volume worth of sample solution. Conversely, only a fraction of the sample loop volume is filled in the partial-loop mode, usually between 10% and 50% [2]. While less precise, this mode can be used to inject varying sample volumes without having to change out the sample loop, thus offering more flexibility.

To aspire a precise dose of sample solution, a sample syringe or metering device are used [2]. In the case of pushed-loop autosamplers, the sampling needle pulls the sample into the sample loop through an orifice called a needle port. As for the split-loop autosamplers, the process is similar, but the needle port must be counterpart to seal to the maximum system pressure level. Lastly, pulled-loop autosamplers do not require needle ports.

Once the sample is drawn, the sampling needle is usually taken through a needle wash port for needle wash. Needle wash refers to placing the needle into the sample solvent to rinse the carryover from the former sample. Typically, the solvent is provided to the cleaning station using either a peristaltic pump or the sampling syringe.

2.2 Need Statement

TABLE 2.2.1: 5WH ANALYSIS

5WH Question	Answers
Who has the problem?	Dr. Jing Pan has brought up this design challenge.
What is the problem?	High-throughput fluid analysis samplers cost in the range of $10,000-50,000. There is a need to devise a cost-effective method to automatically and efficiently collect, prepare, and deliver fluid samples.
Where is the problem?	In laboratory environments, where high volumes of fluid samples must be safely collected and stored for later use.
When is the problem?	The problem is continuous, whenever samples need to be collected and stored in a lab.
Why is there a problem?	The current autosampler market only provides expensive commercial options, which may be unreasonable for many labs to include in the budget. Using core technologies found in other devices such as 3D-printers and CNC machines can allow for the creation of an open-source, scalable version that can be more reasonable for more wide-spread use.

Dr. Pan needs a device to collect, store, and prepare biological fluid samples with high-speed and accuracy. The device should contain both a storage module and a sampling apparatus. The sampling and distribution apparatus must have a capacity capability of 0.5 to 50 µL, with a precision within 0.5% for sampling volume. Between each sampling cycle, all collecting lines must be rinsed, and the entire sampling and cleaning cycle must take less than 1 minute. The storage module should be able to hold at least 100 1.5 mL vials, at least 20 15mL tubes, and at least 2 96 well plates. The storage module must have an adjustable temperature of 4ºC to 37ºC, with an alarm to indicate if the maximum allowable temperature is exceeded. Another feature that is not required but desirable, the storage module should be capable of sliding in and out of the device for easy retrieval. Overall, the device needs to draw power from a standard American 120 V outlet, not exceeding a 15 A current draw. It also needs a physical emergency stop to cease function of all subsystems, and a user interface for control and to display task progress. Any heating, electrical, or other hazardous elements should be stored within a protective housing. The device as a whole must cost under $5,000 to manufacture, and under $3,000 to prototype and test.

A 5WH analysis (as shown in Table 2.2.1) was conducted to simplify the approach to the solution and keep this need statement in mind as the project develops. Based on this analysis, there is a clear need to create an autosampler that is cost-effective, capable, and user-friendly for use in a laboratory environment.

2.3 Users and Target Market

2.3.1 User Observation Process

The user observation process comprised of touring facilities at the University of Florida with autosamplers to interview the staff and observe their usage of the autosampler. Two facilities were toured: a biomedical-focused laboratory and a soils-focused laboratory.

During these tours, we first learned about how the researchers interact with autosamplers that have planar movement (as opposed to a rotary autosampler). We observed the process of loading the autosampler, which involves placing trays in the sampling area and ensuring proper alignment with the sampling apparatus. This alignment step was found to be one of the biggest issues for the user, as the autosampler sometimes may become unaligned during or between sampling, which can cause the probe or needle to break on the sample tubes. Once alignment was completed, the user can start the autosampler and let it run through its cycles. Each cycle consists of the autosampler moving the needle to a sample, lowering the needle into the sample, pumping a set amount of the sample to the testing device, raising the needle, moving to a washing station, and rinsing the needle to prepare for the next sample. Devices observed in the soils-focused laboratory are shown in Figure 2.3.1.1, Figure 2.3.1.2, and Figure 2.3.1.3 and a device observed in the biomedical-focused laboratory is shown in Figure 2.3.1.4

Another major issue that was described by the researchers during the tour was how lead screw on many of the autosamplers is prone to rust, which can often change the alignment of the needle. This rust occurs especially when acidic samples, sometimes with fumes, are being tested.

FIGURE 2.3.1.1: SOILS LAB LARGE AUTOSAMPLER

FIGURE 2.3.1.2: SOILS LAB SMALL AUTOSAMPLER

FIGURE 2.3.1.3: SOILS LAB TEMPERATURE CONTROLLED DEVICE

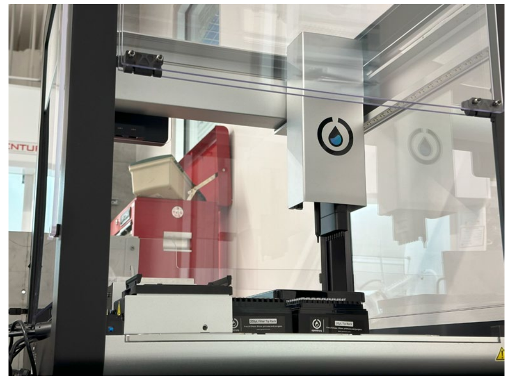


FIGURE 2.3.1.4: BIOMEDICAL LAB AUTOSAMPLER

2.3.2 Persona Creation

Two personas were developed from this research. Both include researchers with or pursuing doctoral degrees and comprise of a researcher focused on biotechnology and a researcher focused on soils. These personas match the laboratories observed and, thus, have the same successes and issues with current autosamplers in their respective laboratories.

The researcher focused on biotechnology can be depicted as Cheryl Nicholson, a 34-year-old professor at the University of Washington. She earned her bachelor's degree in biomedical engineering from the University of Oregon, and obtained her PhD in neural engineering from San Jose State University. She now has her own lab at UW, where she has been for two years. In that time, she has been working on neural implants to remedy nerve damage for trauma patients. Still in the early stages of her project, her lab has reached a point where they are implanting rodents with a prototype version of their design. She deals with large quantities of blood samples, as they must analyze several samples for each implant to ensure the blood chemistry is remaining at acceptable levels. Therefore, it is crucial for her lab to have highly functioning autosamplers at a high throughput level. Her project is heavily funded, so she has top of the line autosamplers that are effectively serving their purpose. However, she would like to have an option that is cheaper so the funds can be allocated elsewhere when needed. Additionally, an option using fundamental, open-source technologies will allow for the high maintenance subscriptions to be reduced or even eliminated, and repairs can be performed in-house.

The researcher focused on soils can be depicted as Frank Helsing, a 54-year-old professor at University of Southern Missouri. He obtained both his bachelors degree and PhD in soil sciences from Mississippi State, and has served in several assistant roles around the country before getting his own lab at USM. He relies on autosamplers in his own lab to handle the large volumes of soil he needs sorted into his machines used for analysis on the silt content of each sample. Due to a lack of funding, his autosamplers are outdated and facing high maintenance and upkeep costs. He needs a simple autosampler that can be easily repaired and obtained at a low price, while also reliably controlling and storing his samples. One note in particular he had was how the rods the sampling device travels on was made of stainless steel. Due to often dealing with acidic solutions, corrosion on the rod occurs quickly. This can be remedied by lubricating the rod with Vaseline weekly, but in order to reduce labor, another material would be more suitable for this component. An additional complaint that was noted was the alignment can be difficult, especially if the sample vials of interest are of small volume. Any external disruption will throw off the alignment, and as a result the autosampler will not be able to effectively retrieve samples.

2.3.3 Jobs to be Done

Based on this research, a "jobs to be done" framework was developed as shown in Table 2.3.1.

TABLE 2.3.1: JOBS TO BE DONE

Phase	Researcher...	BASS Catchers innovate by...	Example
1. Define	Decides what samples and amount of samples need to be tested in autosampler.	Ensuring autosampler can house needed samples.	Have an autosampler that is climate controlled, can hold large trays, and can house appropriately sized test tubes.
2. Locate	Obtains trays and samples.	Providing materials that integrate easily with autosampler.	Create trays that integrate easily with autosampler.
3. Prepare	Adds trays to autosampler and align autosampler. Set autosampler temperature if needed.	Making the preparation process easy and quick.	Improve alignment times via probes and software and provide an intuitive UI to adjust temperature of the enclosure.
4. Confirm	Verify autosampler alignment and temperature is correct.	Having software verify alignment and temperature.	Show on a UI the alignment and temperature of the autosampler and provide and over-temperature alarm.
5. Execute	Runs autosampler.	Only allowing autosampler to run if prepared to run.	Autosampler will not run if not aligned or temperature is not properly controlled.
6. Monitor	Ensures autosampler does not became misaligned while running and that temperature stays consistent.	Provides software to check alignment and temperature during process.	Autosampler stops and alerts user if it becomes misaligned while sampling or if temperature leaves intended range.
7. Modify	Manually realigns autosampler if it becomes misaligned during use and adjusts temperature as needed.	Making the autosampler adjust as needed during sampling process.	Autosampler realigns during sampling process and adjusts temperature should it leave the ideal range.
8. Conclude	Removes trays from autosampler and prepare to realign with new tray.	Make process to prepare for new samples as quick as possible.	Ensure trays can be easily removed and reduce the need for realignment between sampling trays.

2.3.4 Market Size Estimation

The global market size for autosamplers has been estimated at $1,660.23 million in 2023 [1]. Over the next 10 years to 2032, the market is expected to grow to a size of $3,112.02 million (Figure 2.3.4.1). Since autosamplers are becoming an increasingly crucial component in the medical, environmental, and chemical industries, continued research funding and pursuits will power this growth. The amount of repetitive labor at a precise level autosamplers can eliminate will increasingly make them a necessary part of productive and profitable lab environments.

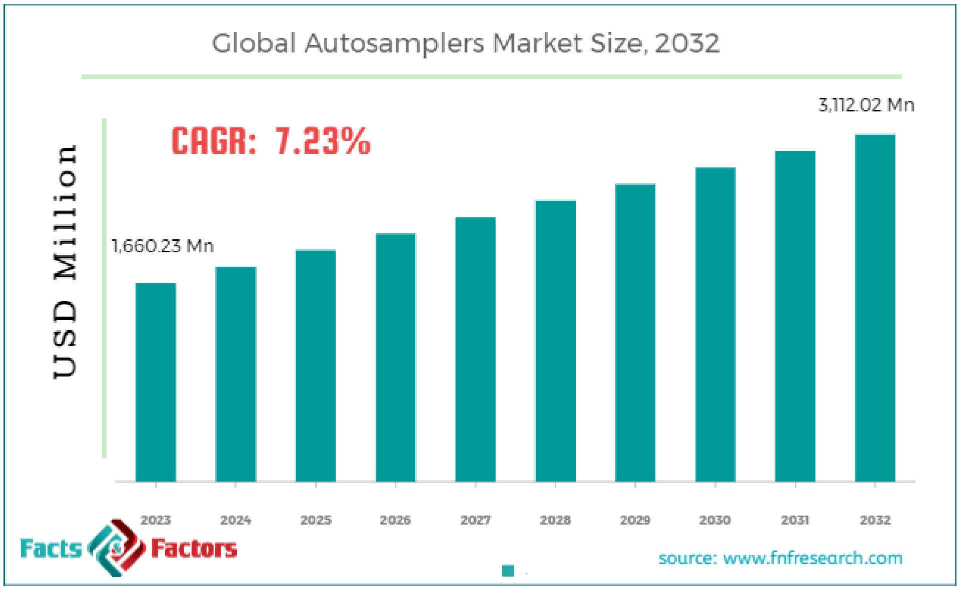


FIGURE 2.3.4.1: GLOBAL AUTOSAMPLER MARKET SIZE FOR THE CURRENT YEAR, AND PREDICTIONS FOR GROWTH OVER THE NEXT TEN YEARS [8].

The initial target market for this concept will be smaller labs who are unable to afford the steep baseline price for most autosamplers, as well as the expensive maintenance packages that accompany them. Even though this can be expected to open a door for many labs and organizations previously unable to utilize autosamplers, a conservative estimate of the serviceable addressable market size is 25% of the total market, equivalent to $415.06 million. If we estimate that we can win 10% of this addressable market, the serviceable obtainable market can be seen as $41.5 million.

TABLE 2.3.2 SOM/SAM/TAM BREAKDOWN

Serviceable Obtainable Market (SOM)	Serviceable Addressable Market (SAM)	Total Addressable Market (TAM)
We believe we can win 10% of the addressable market SOM = 10%*SAM = $41.5 million	Initial target market = smaller labs or labs seeking new equipment = 25% of the total market SAM = 25%*TAM = $415.06 million	Total size of autosampler market in 2023, TAM = $1,660.23 million

2.4 Product and Patent Review

From the results of the product review (Table 2.4.1, Table 2.4.2, and Table 2.4.3) and patent review (Table 2.4.4, Table 2.4.5, and Table 2.4.6), it was found that there are very few autosamplers in the industry that combine features of compact size, adequate sample storage, active temperature control, and quick sample processing for a cost of $5000. Most autosamplers found were either very simple with very few features and long processing times, or they were very high-end autosamplers that contained all the above features and more for a large price tag. The patent review shows important patents from three of the products evaluated. The Ultraclean autosampler employs multiple rotary valves and syringe pumps for precise fluid handling. The OT-2 autosampler enhances precision and operational efficiency using a motorized XYZ gantry and automated calibration. Lastly, the Automated system uses a combination of mechanical and software-driven components to rinse sample loops, fluid connections and purge residual rinse fluid.

TABLE 2.4.1: PRODUCT REVIEW PART 1

	ASX-280 Compact Autosampler	OI Analytical 3180 Sampler
Image		
Size	24.4 x 14 x 22 inches, 17.8 lbs	14 x 19.5 x 20 inches, weight unavailable
Movement	XYZ	XYZ
Samples	180 samples, 10 standards positions for 50 mL vials	180 samples + 10 standards
Price	$12210	$5000-10200
Temperature Control	None	None

Table 2.4.2: Product Review Part 2

	Amuza HPLC Autosampler “Insight” AS-700	**Hanna Instruments Autosampler HI921**
Image		
Size	11.8 x 22.6 x 14.2 inches, 46 lbs	Unavailable, appears larger
Movement	XYZ	Carousel
Samples	2 x 96 well plates	16 or 18 beaker tray (150mL or 100mL)
Price	$18000	$11019
Temperature Control	Yes, 4°C to room temperature across Peltier cooler	None

Table 2.4.3: Product Review Part 3

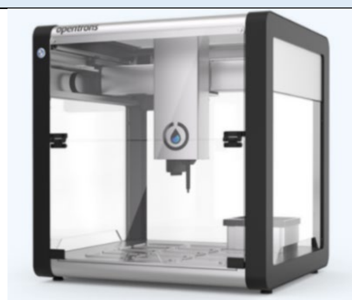
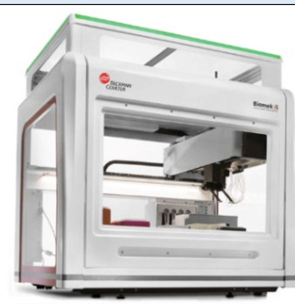
	Opentrons OT-2 Autosampler	**Beckman Coulter Biomek i5 Autosampler**
Image	 [9]	 [10]
Size	25 x 57 x 66 inches, 105.8 lbs (half of your standard lab bench)	44.1 x 31.9 x 44.1 inches, 399 lbs
Movement	XYZ	XYZ
Samples	11 deck slots, uses a modular system	25 deck positions
Price	$8950-$15450, large variation since everything is sold separately	$166000
Temperature Control	Can have with temperature module sold separately	Yes, 10-30 deg. Celsius

TABLE 2.4.4: PATENT REVIEW PART 1

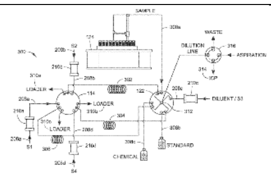
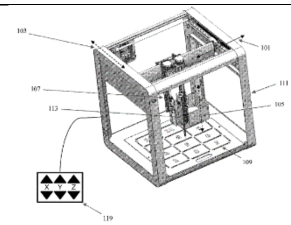
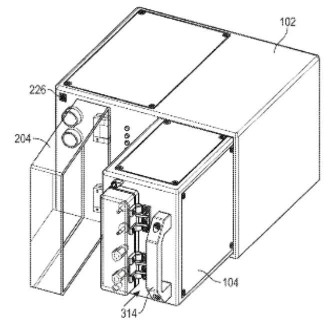
	US11566755 [11]	**US11506677B2** [12]	**US11493523** [13]
Description	Ultraclean autosampler with syringe delivery for mass spectrometry	Systems and Methods for Pipette Robots	Automated System for Safe Sample Collection, Transfer and Analysis
Image			
Patent Overview	The patent details an autosampler system with multiple rotary valves and syringe pumps designed to manage the flow of a sample, a chemical, and a standard. The system can process these fluids through one or more syringe pumps while maintaining physical separation between them.	This patent features a pipette robot system designed to enhance precision and overcome deficiencies found in conventional pipette robot approaches. It features the ability to adjust the deck during liquid handling operations enabling precise pipette operations.	This patent covers an automated system for an autosampler, which efficiently prepares and dispenses samples for analysis in lab environments. The system uses a combination of mechanical and software-driven components to rinse sample loops, fluid connections and purge residual rinse fluid. The system retains the ability to rinse the fluid connections while preserving the sample inside the sample loop.

TABLE 2.4.5: PATENT REVIEW PART 2

	US11566755 [11]	**US11506677B2** [12]	**US11493523** [13]
Mechanical and Operational Characteristics	This system's modularity and expandability allowing an additional third rotary valve and multiple fluid loops make it versatile for different fluid handling applications. In addition, the system's support for features such as cleanup columns enable purification and preparation of the sample before further analysis, enhancing overall system functionality and flexibility.	The robot uses an XYZ gantry, pipette, and calibration points on a fixed deck to perform detailed operations such as pipette tip pickup, ejection, and liquid handling. The system features motorized control, enabling precise movements in response to calibration points. Various sensors, switches, and electronic controls are integrated to ensure accurate pipette positioning during deck and tip calibration. The system also accounts for variations in manufacturing and setup to maintain accuracy.	The system features a an enclosed sample loop and automated valves that control fluid flow for both sampling and rinsing operations. The filling station directs rinse fluids through dedicated input ports, with pumps and actuators managing fluid movement. During rinsing, the system's valves can bypass the sample loop to clean external fluid lines while keeping the sample isolated. Locking mechanisms and interlocks ensure safe operation, and software automates the entire process, including valve control, fluid flow, and sequence management. Sensors monitor pressure and leaks, while RFID tags or barcodes track each sample, ensuring accurate, contamination-free handling.
Performance and Reliability	The multiple rotary valves and syringe pumps ensure accurate sampling and improved sample integrity with included cleanup columns. However, this can make the challenging to maintain and repair.	The calibration of the pipette ensures high accuracy and reliability for both the deck and the pipette tip. This also includes functionalities relating to accurate tip pickup and ejection.	The performance relies on the smooth interaction between key components such as the sample module, sample loop, and valves. The sample loop within the module handles precise fluid transfers, while the valve alternates between flow paths. The system enhances reliability with automated procedures for cleaning and sample integrity checks.

TABLE 2.4.6: PATENT REVIEW PART 3

	US11566755 [11]	**US11506677B2** [12]	**US11493523** [13]
Cost-effectiveness and Scalability	While the system’s increased automation can lower manual labor costs, the use of multiple complex components can drive up production costs. This complexity may impact overall cost-effectiveness and scalability.	The automated calibration system reduces the need for manual intervention, potentially lowering setup costs and improving operational efficiency. By using open-loop stepper motors instead of more expensive closed-loop systems, it maintains affordability while providing high precision. The modular nature allows for scalability, but its advanced calibration features may increase complexity, requiring more effort for setup and maintenance.	The system's modular design enables it to be scaled according to different laboratory needs. While initial investment may be significant, the reduction in labor costs and increased output offer long-term cost savings making it a practical solution for labs of various sizes.

2.5 Design Opportunity Description

For our design opportunity mapping, we first considered the functionality of the autosampler versus the price (Figure 2.5.1). For this map, we evaluated functionality as the autosampler’s speed, user interface, error management, and diversity of features. Our research revealed highly functional autosamplers often come with a great cost, with prices as high as $166,000. Additionally, even for simpler autosamplers with lower functionality, the prices are often greater than $10,000. This research reveals that there is a market opportunity for autosamplers with a low cost and high functionality. With our target budget of $5000, the target area for our design is lowest cost and a moderate-to-high functionality.

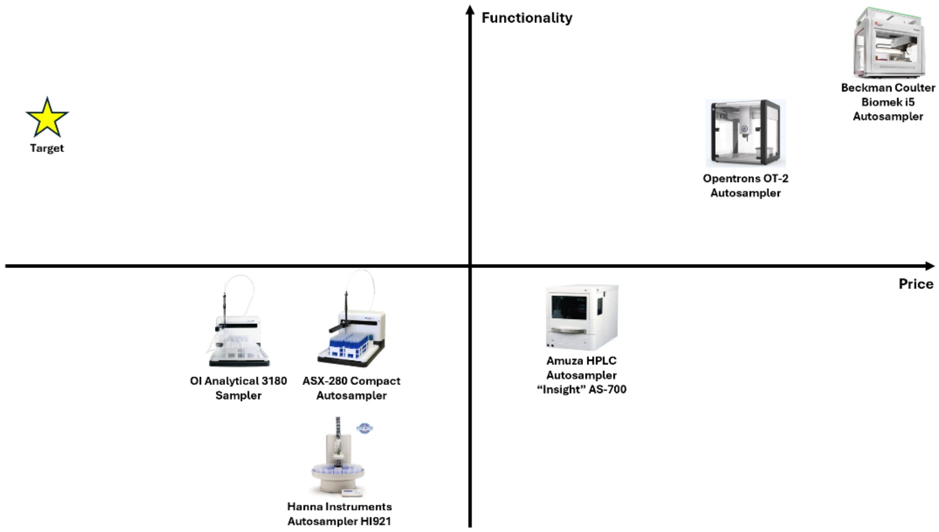


FIGURE 2.5.1: COST VS. FUNCTIONALITY OPPORTUNITY MAP

Another feature that we considered during our product research was current autosamplers' ability for temperature management (Figure 2.5.2). Our research revealed that most accessible autosamplers do not come with temperature management capabilities, and many may price the capability as an add-on. Additionally, our research revealed that autosamplers with efficient, controllable temperature management were very large in size, which may not be ideal for a non-commercial, university research laboratory. The design goals for our project include a size around that of a shoebox and the ability to control the temperature the samples are stored at. With these goals and our product research in mind, we found our design opportunity target area to be a product with a relatively small size and controllable temperature management.

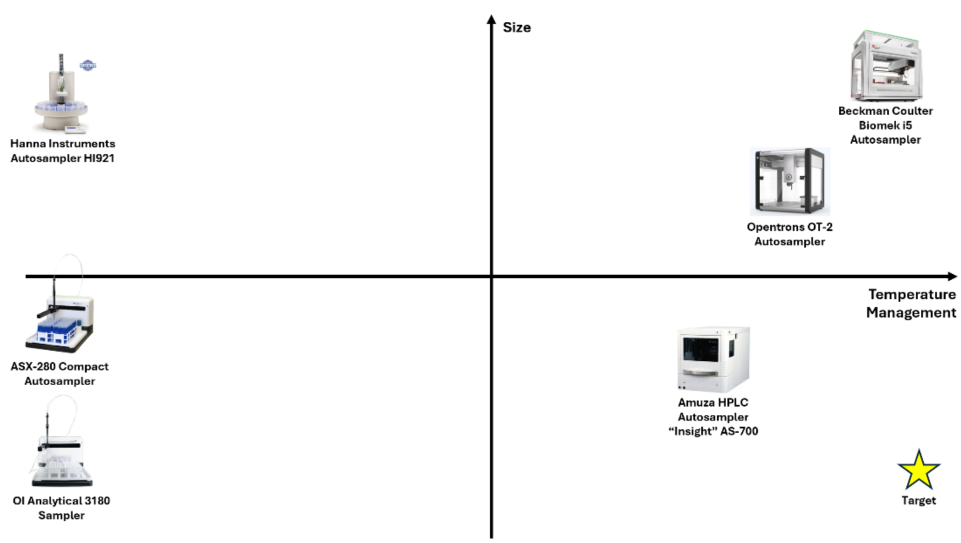


FIGURE 2.5.2: TEMPERATURE MANAGEMENT VS. SIZE OPPORTUNITY MAP

The Kano Model (Figure 2.5.3) was created to illustrate the importance of the desired features and components for the biofluid autosampler. The features of the autosampler were divided up into three different curves on the diagram, with curve 1 representing the basic requirements of the autosampler (shown in red), curve 2 representing the performance aspects (shown in yellow), and curve 3 representing the desirable features (shown in purple). The axis of the Kano model represents satisfaction vs execution of the autosampler. This is used in combination with the three types of feature curves to prioritize while designing, this allows for the best features possible with the budget given. From the Kano model, it was determined that some basic characteristics like speed and precision should be prioritized from curve 1. It was demonstrated by curve 2 that performance characteristics like storage, temperature control, and cleaning should be prioritized. It was also found that some small features like an alarm and emergency stop would be desirable for marketability from curve 3.

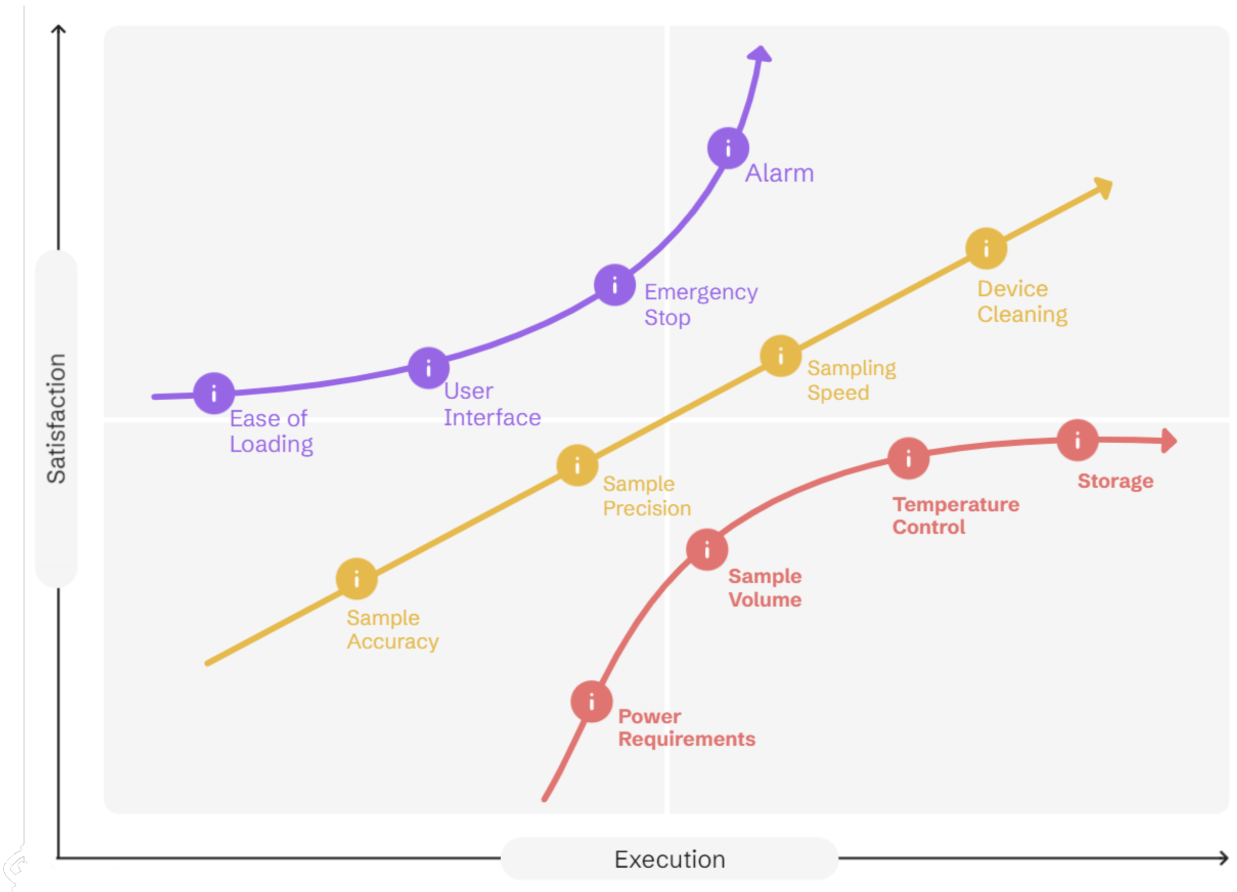


FIGURE 2.5.3: KANO MODEL

Overall, our research has revealed design opportunity exists in delivering an autosampler that is user-friendly, capable, and low cost. Our tours of the lab facilities at the University of Florida that utilize autosamplers revealed many insights to how researchers interact with these machines. Based on our conversations with them, we have decided that some of the features that are important to include are automated sample selection, temperature control, line rinsing, error management, and an emergency stop. We also must also consider our design's price, size, sample time, and accuracy in the final product. All of these considerations will lead to a design that has a lot of desirability in the greater scientific market.

3 Define Phase

3.1 Design Requirements

Following discussion with the client, Dr. Jing Pan, the team was able to create a list of requirements that the final biofluid autosampler design must meet based on the client's needs. These requirements were used to create an initial design, which was then improved iteratively until a final design was reached. The list was referenced constantly throughout the design process to ensure that the team did not design something incapable of meeting the client's needs. The requirements for the design process based on customer needs are listed below and further detailed in a specification table shown in Table 3.1.1 and Table 3.1.2. The standard that would be most relevant to this product and these requirements is ISO 23783-1:2023 [14].

TABLE 3.1.1: SPECIFICATION LIST

The final design must include:

General Requirements

1. Production Cost: Total cost to manufacture the full machine, including labor, must not exceed $5000
2. Prototype Cost: The material cost to fabricate and test the functional prototype (no labor included) must not exceed $3000
3. Device Housing: Machine should have a housing to protect user from pinch points, heating elements, and any other safety or operational hazards
4. Connection to Power: Each sub-component must obtain power by plugging into a standard American 120 VAC receptacle outlet, with a peak current draw of 15 amps
5. Emergency Stop: The system should have a physical emergency stop that will cut power to all sub system functions
6. User interface: The system should contain a user interface for choosing workflow and showing task progress

Sample Storage Compartment

1. Number of Samples: >100 1.5-mL vials, >20 15-mL test tubes, and at least 2 96-well plates
2. Temperature: Adjustable 4°C~37°C with over temperature alarm
3. (Optional): Capable of slide in/out of the device housing for easy sample placement/retrieval

Sampling and Distribution Apparatus

1. Sampling Volume: 0.5 micro liter to 50 micro liter
2. Sampling Precision: <0.5% variations in sampling volume
3. Sampling Speed: < 1 min for each sampling and cleaning cycle
4. Cleaning: Must be able to rinse all lines before or after sampling

TABLE 3.1.2: SPECIFICATION TABLE

Category	#	Item	Units	Acceptable	Test	Notes
1. Cost	1.1	Production Cost	USD	< 5000	Estimation	
	1.2	Prototype Cost	USD	< 3000	Estimation	
2. User inputs	2.1	User interface	N/A	Easy-to-learn and intuitive	Physical testing	Workflow can be chosen, and task progress is displayed
	2.2	Emergency Stop	N/A	Visible and accessible	Physical testing	System will cut power to all sub system functions
3. Sample Storage Compartment	3.1	Storage Capacity	N/A	>100 1.5mL vials >20 15mL test tubes At least 2 96-well plates	Physical Testing	Centrifuge tubes typically held in test tube racks
	3.2	Storage Temperature Range	°C	4~37 °C	Temperature sensors/gages	Must have over temperature alarm
4. Sampling and Distribution Apparatus	4.1	Sampling Volume	µL	0.5 to 500 µL	Volumetric measurement	
	4.2	Sampling Precision	%	<20% variations at 0.5 µL <0.5% variations at 500 µL	Volumetric measurement	
	4.3	Sampling Speed	min	< 1 for sampling and cleaning cycle	Timer/Stopwatch	
	4.4	Cleaning	N/A	Must be able to rinse all lines before or after sampling	Visual inspection	
	4.5	Delivery speed	µL/min	1 to 1000	Timer/Stopwatch	

3.2 Product Modeling

3.2.1 Use Model

A use model was created to visually display the use process of the device and to understand what process the team should design for. It is shown in Figure 3.2.1.1 and details each step of the use process with repeated steps when needed (as shown in yellow).

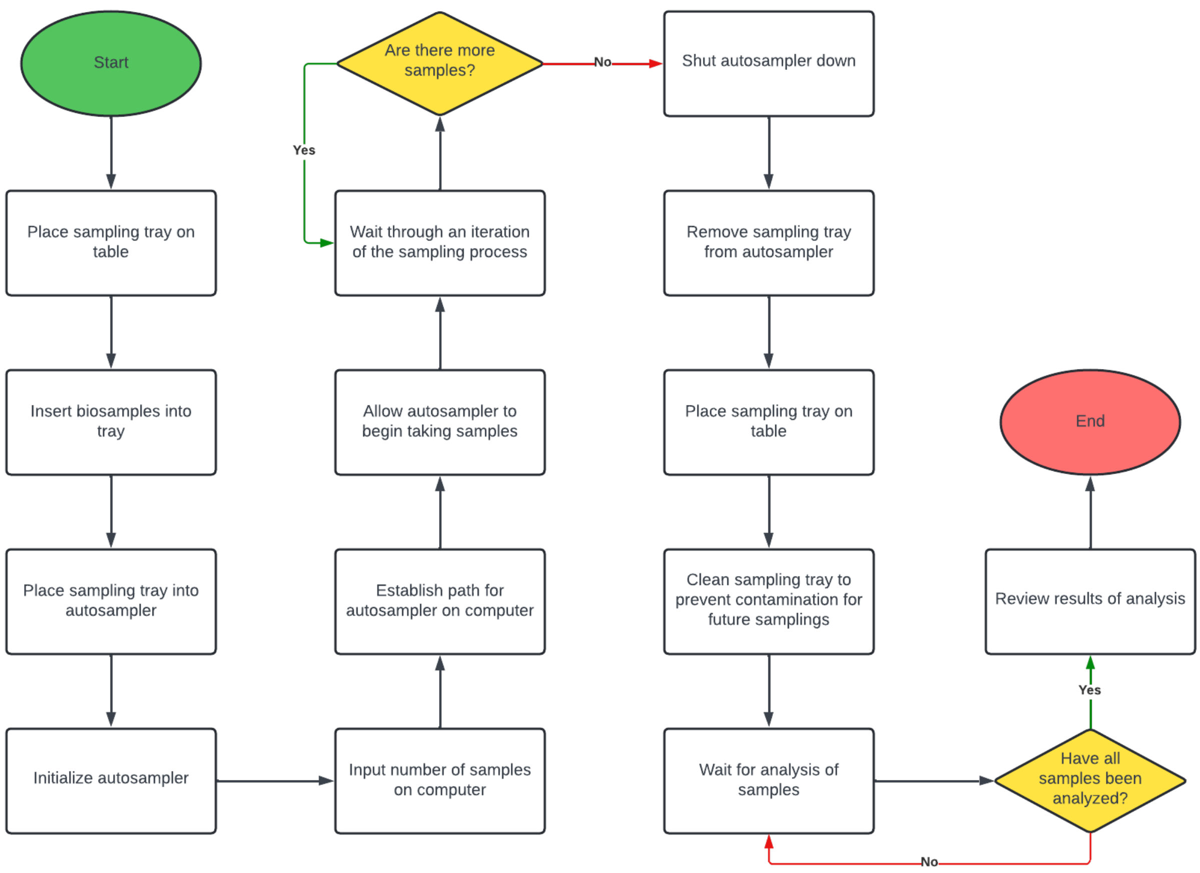


FIGURE 3.2.1.1 USE MODEL

3.2.2 Function Model

A function model was created to visually display the functional analysis of the product. The functional analysis specifically details what occurs within the autosampler as it is being used. An overall functional analysis is shown in A visual depiction of the overall functional analysis is shown in Figure 3.2.2.1 while a version detailing subfunctions is shown in Figure 3.2.2.2

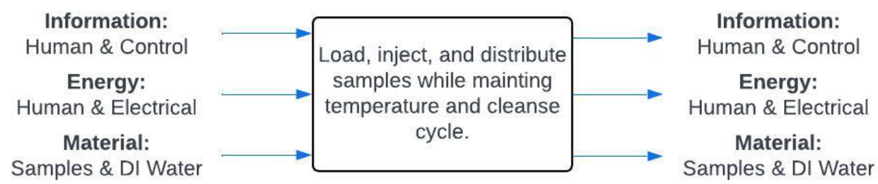


FIGURE 3.2.2.1 OVERALL FUNCTION MODEL

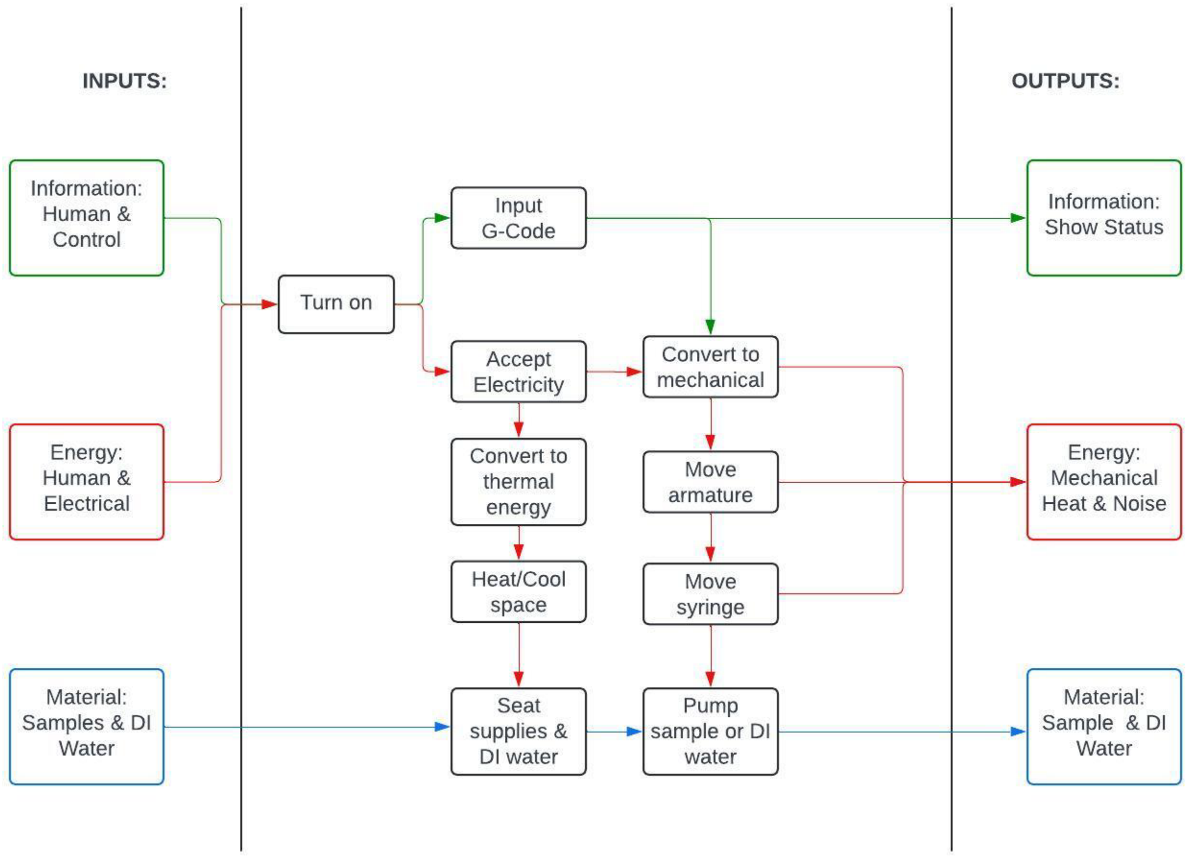


FIGURE 3.2.2.2 FUNCTION MODEL WITH SUBFUNCTIONS

4 Develop Phase

4.1 Combination Charts

Combination charts were used to find solutions to sub-functions by listing potential solutions for each subfunction in Table 4.1.1 and Table 4.1.2 for the enclosure, sample trays, and movement, Table 4.1.3 for the sample heating and cooling system, and Table 4.1.4 for the fluid transfer system.

TABLE 4.1.1: ENCLOSURE, TEST TUBE RACKS, AND MOVEMENT COMBINATION CHART PART 1

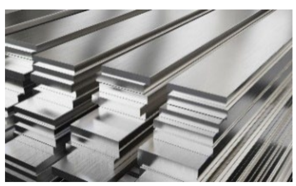
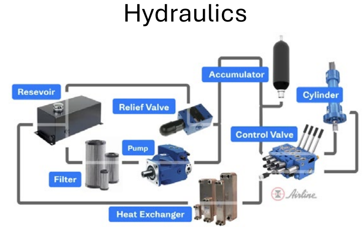
Topic	1	2	3
Enclosure Material	Mild Steel 	Polycarbonate 	Aluminum 
Test Tube Racks Material	Polypropylene 	Aluminum-Filled PLA 	Polycarbonate 
Movement System Material	Stainless Steel 	Carbon Steel 	Aluminum 
Energy Supply	Electrical 	Pneumatics 	Hydraulics 

Table 4.1.2: Enclosure, Test Tube Racks, and Movement Combination Chart Part 2

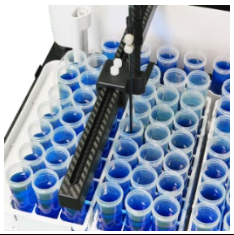
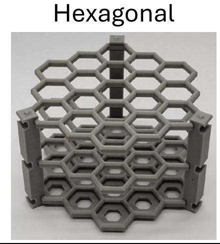
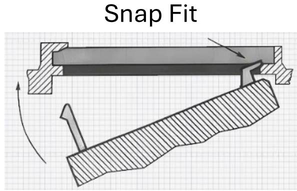
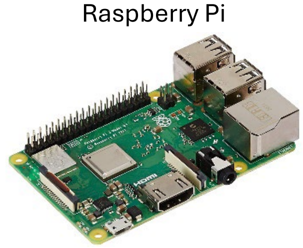
Topic	1	2	3
Enclosure Shape	Cube 	Rectangular 	Shaped Rectangular 
Movement Mechanism	Lead Screw 	Rack & Pinion 	Rotary 
Test Tube Rack Cavity Shape	Circle 	Square 	Hexagonal 
Test Tube Rack Connection	Snap Fit 	Alignment Pins 	
Computer	Arduino 	Raspberry Pi 	None (uses user's computer) 
User Interface	Touch Screen 	LCD 	Digital (on user's computer) 

TABLE 4.1.3: SAMPLE HEATING AND COOLING SYSTEM

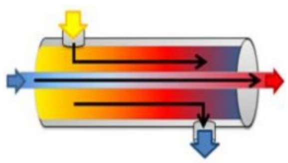
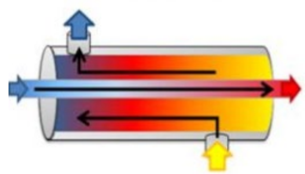
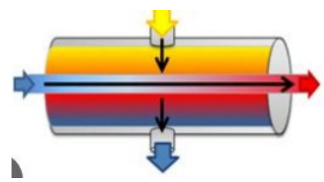
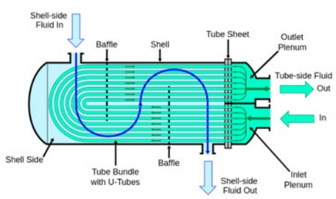
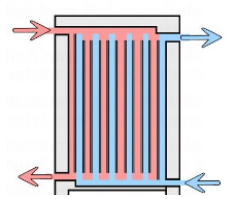
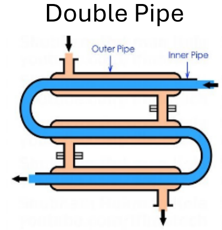
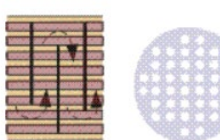
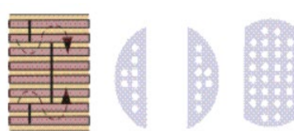
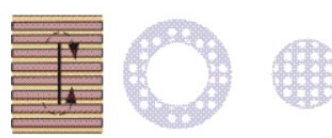
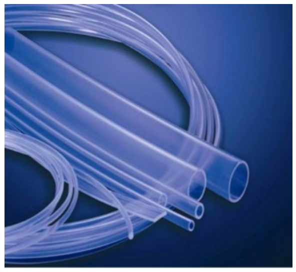
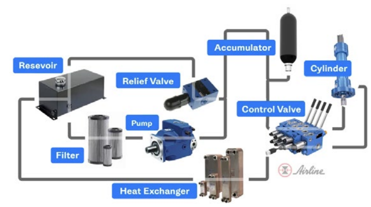
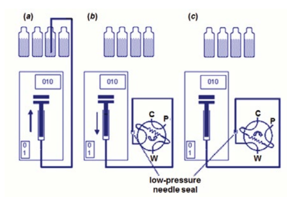
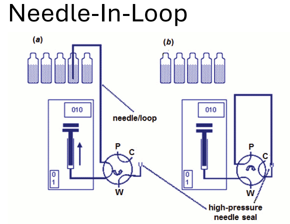
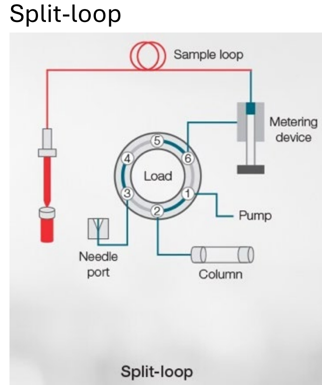
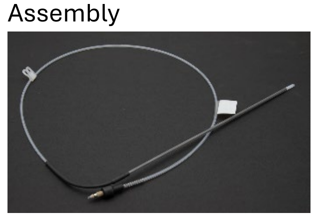
Topic	1	2	3
Material	Stainless Steel 	Nickel Alloy 	Titanium 
Energy Supply	Electrical 	Natural Gas  (can be used to power cooling systems)	Solar Panels  (for powering thermoelectric coolers)
Coolant	Water 	R32 	R-290 
Flow	Parallel Flow 	Countercurrent Flow 	Cross Flow 
Heat Exchanger	Shell and Tube 	Plate 	Double Pipe 
Baffle Structure	Single Segmental 	Double Segmental 	Doughnut 
Temperature Sensor	Thermocouple 	Infrared sensor 	Thermistor 

TABLE 4.1.4: FLUID TRANSFER SYSTEM

Topic	1	2	3
Material	PFA 	PTFE 	Carbon fiber 
Energy Supply	Electrical 	Pneumatics 	Hydraulics 
Sample Injection	Push-to-fill 	Needle-In-Loop 	Split-loop 
Sampling Needles	Sciencix Needle, SS 	Autosampler Needle Assembly 	Hamilton 1700 Series 1701 Model Cemented Needle Syringe, 10μL, 22s ga 

4.2 Design Alternatives

4.2.1 Design A: Reed Legg Design

The autosampler shown in Figure 4.2.1 is housed in a cube-shaped enclosure made from mild steel and polycarbonate to provide durability and visibility. Inside is the polypropylene test tube racks which have circular fittings for vial security and alignment pins for precise fluid transfer. The system uses an aluminum rack and pinion system for smooth and controlled movement powered by electrical motors. The user interface is managed through a laptop, which connects to the system. The stainless-steel heating and cooling system rely on natural gas for heating and water for cooling using a parallel flow system with a thermocouple to monitor the temperature. PFA tubing is paired with autosampler needle assembly and a split-loop injection system for fluid transfer and analysis.

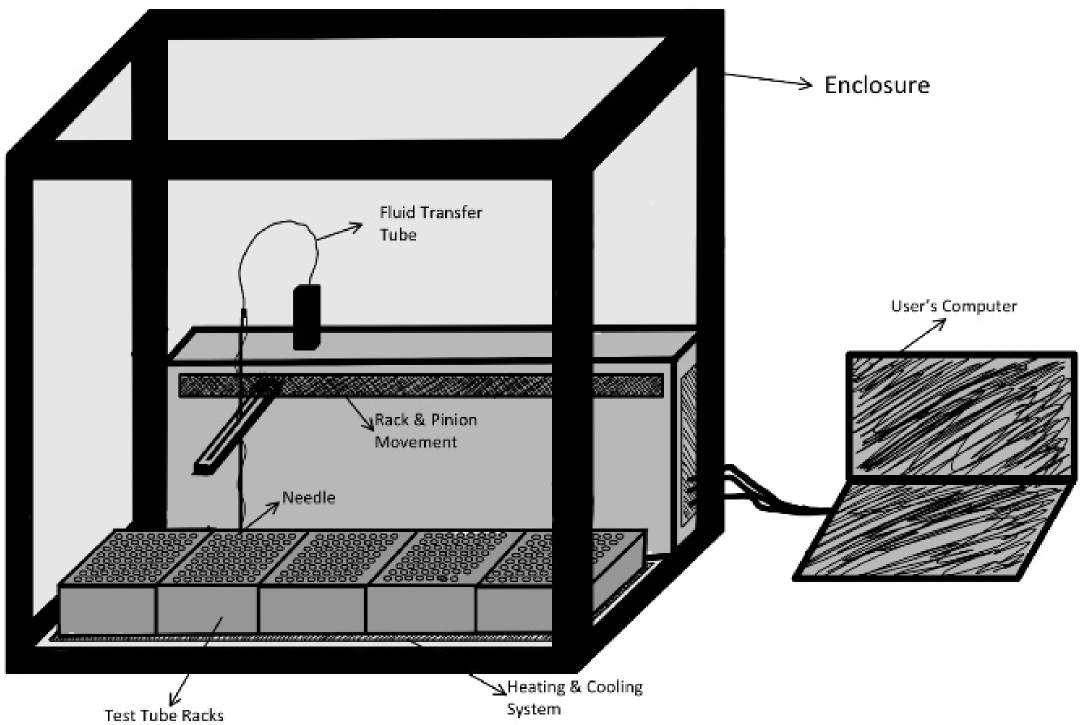


FIGURE 4.2.1: AUTOSAMPLER SKETCH DESIGNED BY REED LEGG

4.2.2 Design B: Alex Martinez

This autosampler concept shown in Figure 4.2.2 was designed to minimize production cost. It has a rectangular enclosure shape made of polycarbonate and sampling racks made of polypropylene. The decision to incorporate plastics into the design helps to reduce the expense of production as they are typically cheaper materials than metals. Additionally, the UI was chosen as a user's computer, as it would be cheaper to use an existing device rather than integrating a UI into the autosampler. An electric power supply was chosen to reduce its finitude (as opposed to using a more consumable supply like natural gas) and therefore minimize the cost of fueling/powering the system. This power supply also increases the practicality of the design. For parts susceptible to fatigue (temperature control and movement), stainless steel was chosen as the material. This ensures the integrity of those components while also keeping costs relatively low. The movement system was chosen to be rotary, as this allows for the most efficient use of the limited space in the enclosure by allowing for more samples to be carried at a time. A plate was chosen as the element for heat transfer as it is a simple yet effective mechanism, which upholds the validity of the design while reducing costs and complications. For this same reason, water was chosen as the coolant for its ease of access and minimal cost. Finally, PTFE was chosen as the tubing material, and this tube connects to an autosampler needle assembly. PTFE was chosen for its high flexibility and relatively low cost; the autosampler needle assembly was chosen for its design being centered around this specific system.

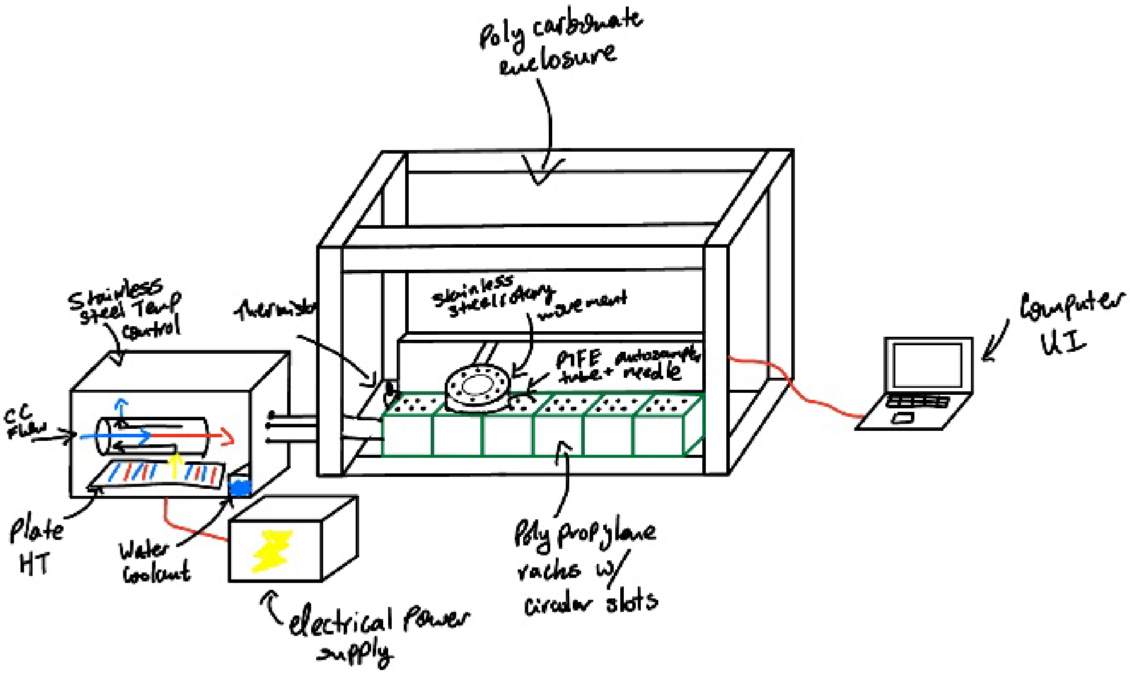


FIGURE 4.2.2: AUTOSAMPLER SKETCH DESIGNED BY ALEX MARTINEZ

4.2.3 Design C: Tin Sulenta

This autosampler shown in Figure 4.2.3 is enclosed in a structure made of 80-20 aluminum extrusions and polycarbonate, where aluminum is anodized to provide corrosion resistance. The aluminum structure provides the necessary strength and stability, whereas polycarbonate provides visibility, giving the user extra confidence when performing tests and improving the device's overall look. This system uses a lead screw mechanism powered by stepper motors to achieve x-y motion for the arm containing a needle that can move in the z direction. Motion in the z direction allows the needle to go in and out of the samples contained within the test tube racks with circular cavities. This autosampler operates with the push-to-fill mode, with the syringe and injection valve enclosed in the large rectangular box that is also used for arm movement. In the push-to-fill mode, a syringe is first pulled backwards to aspirate the sample through the needle into the buffer line. The needle is taken to the injection port to transfer the sample from the buffer line into the sample loop, and the sample is then carried to an analytical instrument for analysis. After each iteration of sample collection, the needle is cleaned at the wash port, and the sample loop is cleaned from within with the help of a wash liquid line. Waste goes through a waste line to the waste port, which brings it to a waste tray contained underneath it. Alongside a thermistor used to sense temperature, sample temperature is controlled using a double pipe heat exchanger with a single-segmental baffle structure in a parallel flow arrangement, powered by an electrical power supply. Water is used as coolant. The user interface includes a laptop, which can be programmed to automate sample collection.

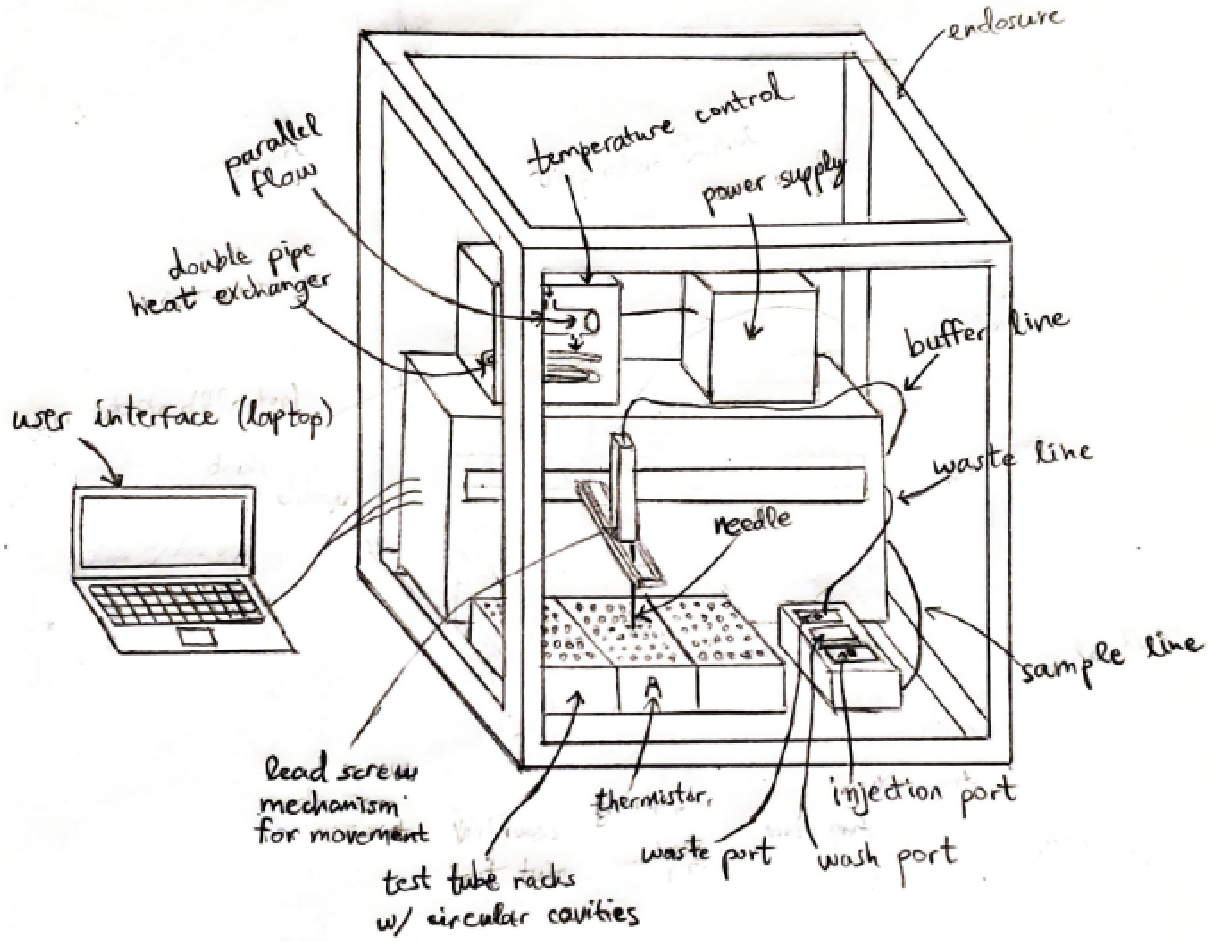


FIGURE 4.2.3: AUTOSAMPLER SKETCH DESIGNED BY TIN SULENTA

4.2.4 Design D: Henry Stophel

This autosampler concept shown in Figure 4.2.4 is enclosed in a mild steel frame enclosure. This chosen material increases weight and helps maintain alignment for the autosampler. The polycarbonate walls allow for visibility inside the enclosure as well as insulation for the inner environment. A rack and pinion guiding system is used to direct the needle in two planar x and y axes. This needle can plunge into the cylindrical test tubes to collect necessary samples. The front face of the enclosure has a LCD display and an attached Arduino to control the autosampler. Fixed to the side of the autosampler is a shell and tube heat exchanger using R32 coolant due to its excellent cooling properties. The opposing fluids travel in counter current. The other fluid travels within the base of the test tube rack to ensure the samples are maintained at a constant desirable temperature within the acceptable range. The collected fluid samples travel through PFA tubes, and are collected by a needle-in-loop system, that uses a high-pressure seal to ensure all of the fluid the needle collects is evacuated to the next step.

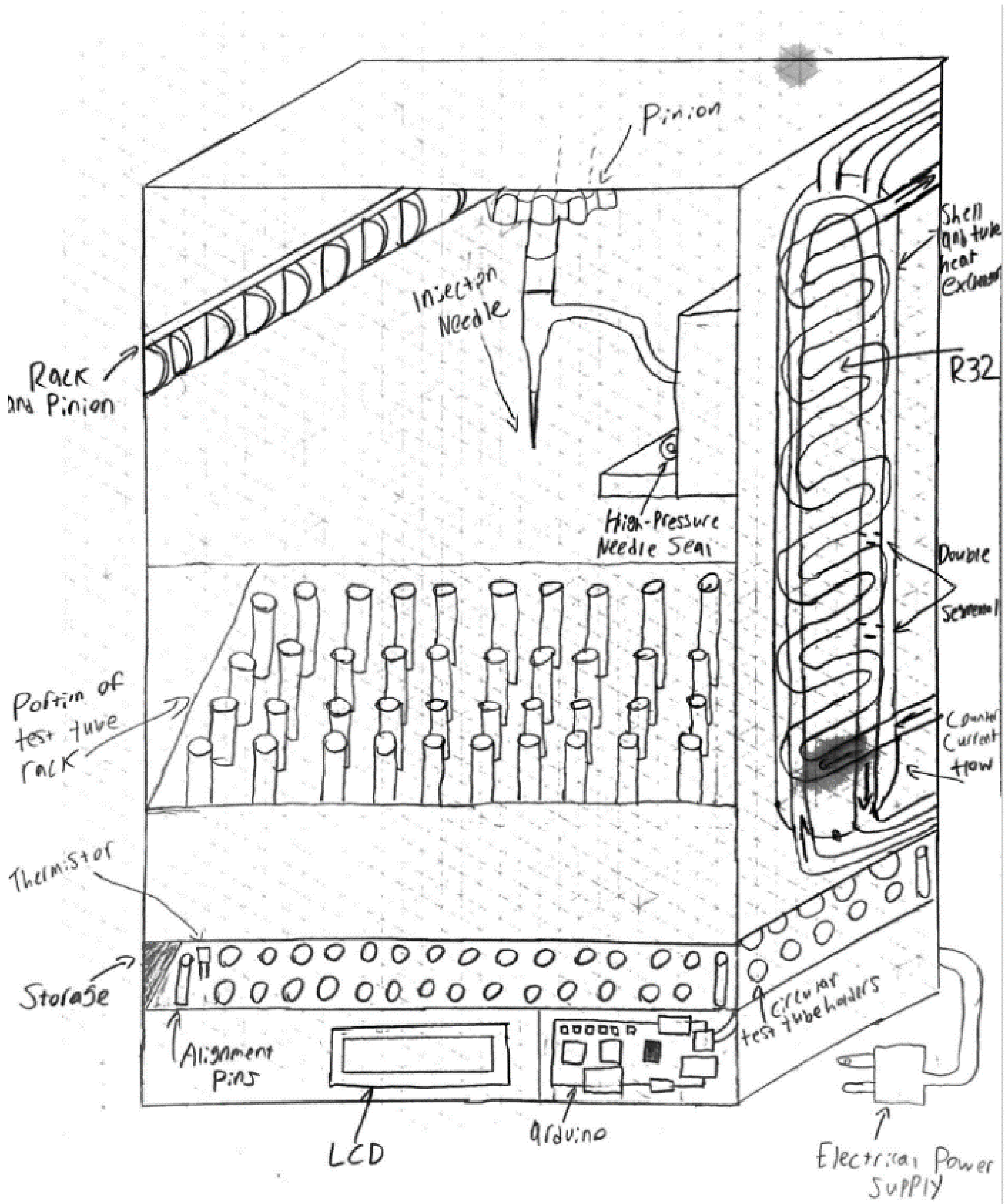


FIGURE 4.2.4: AUTOSAMPLER SKETCH DESIGNED BY HENRY STOPHEL

4.2.5 Design E: Daniel Pham

The autosampler shown in Figure 4.2.5 is housed in a polycarbonate enclosure (for visibility) with an aluminum L shape acting as the base and structural component for the needle's movement. It uses a thermoelectric cooler (Peltier cooler) to maintain the required temperature control using a thermocouple to ensure regulated temperature. There is the inclusion of the emergency stop button that simultaneously acts as a progression light for the user. There is a concealed pull handle of a draw like sliding system to allow the user to access the test tube rack. This also contains alignment pins to ensure correct alignment within the system. The system also features a drip cup using a pneumatic system to prevent cross contamination between samples. The X-Y movement are both controlled by a lead screw. An electric peristaltic pump is used for fluid movement and utilizes a needle-in-loop. The user interface relies on the user computer with the autosampler controlled by an Arduino.

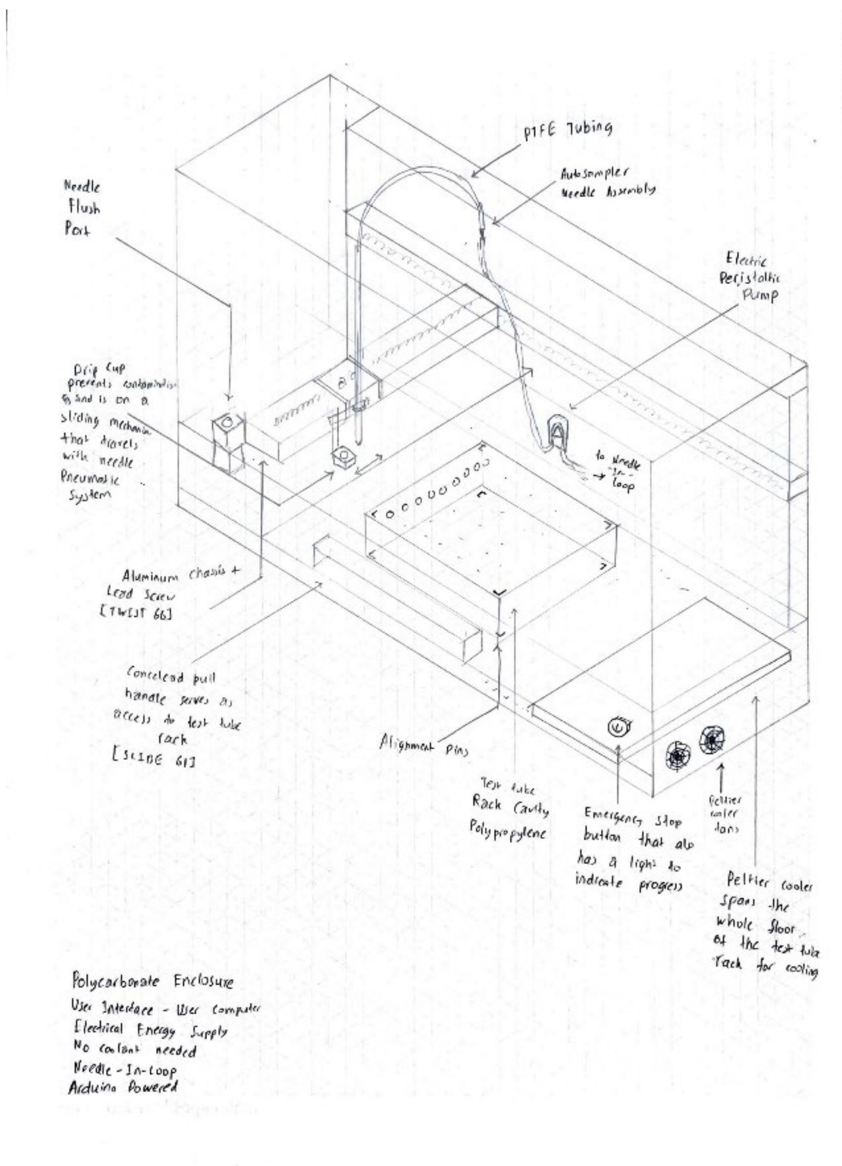


FIGURE 4.2.5: AUTOSAMPLER SKETCH DESIGNED BY DANIEL PHAM

4.2.6 Design F: Jacob Smith

This autosampler shown in Figure 4.2.6 is enclosed in a rectangular frame made from 80-20 aluminum. The frame encloses multiple polypropylene plates of various sizes with circular cavities, as well as a tray for DI-water, used during the cleansing cycle. The plates are fitted in place with snap-to-fit connectors. The protruding aluminum arm has a rack & pinion design to allow for 2 degrees of movement. The arm operates off G-code run through the autosampler's raspberry pie, and progress is displayed on an external digital UI (computer software). The heating & cooling system is housed in a stainless-steel body that uses a parallel flow plate heat exchangers and a double segmental baffle. R-290 is used in the heat exchanger and flow is controlled by an internal power supply. This is also controlled by the UI device and a thermocouple. The fluid transfer system is also run off the power supply and uses a push-to-fill autosampler needle assembly and PFA tubing.

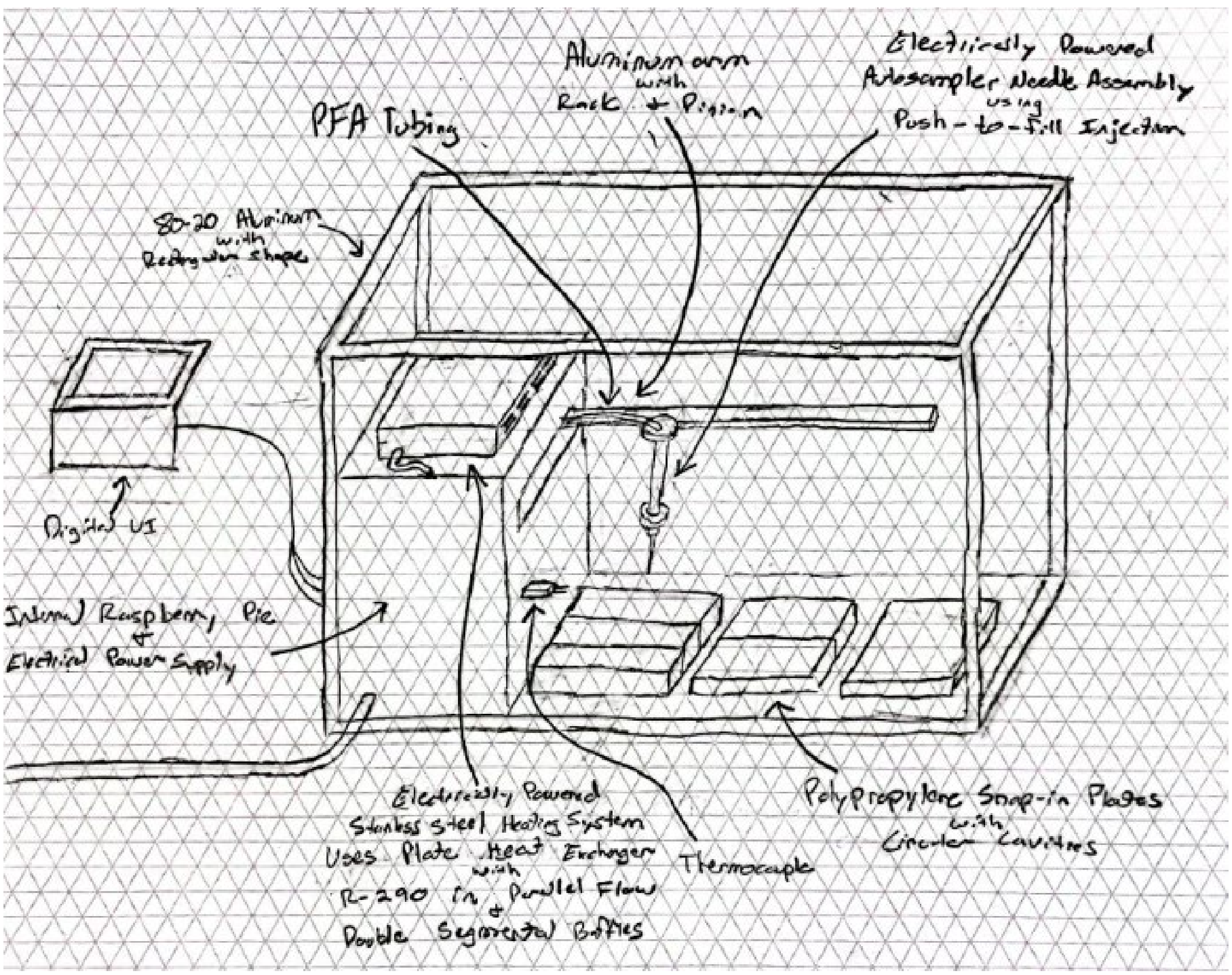


FIGURE 4.2.6: AUTOSAMPLER SKETCH DESIGNED BY JACOB SMITH

4.2.7 Design G: Xavier Morris

The autosampler shown in Figure 4.2.7 uses a rectangular-shaped enclosure made from polycarbonate. The PETG test tube racks are placed inside and secured using alignment pins. The racks utilize circular fittings for higher test tube stability. The movement mechanism uses a stainless-steel lead screw system for controlled movement powered by electrical motors. The user interface is done through a laptop, which can be connected to the system. The titanium heating and cooling system relies on an electrical power supply for heating and water for cooling using a cross flow system. Additionally, a thermocouple is used to monitor the temperature of the entire system. PFA tubing is paired with sciencix needle and a split-loop injection system for fluid transfer and analysis.

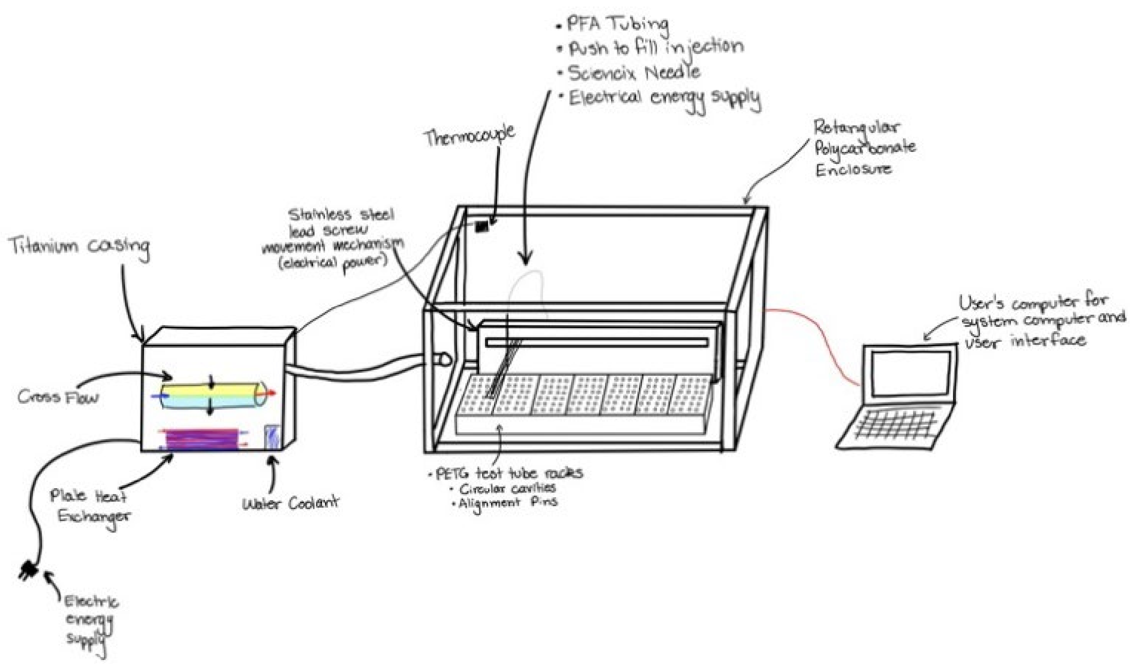


FIGURE 4.2.7: AUTOSAMPLER SKETCH DESIGNED BY XAVIER MORRIS

4.3 Design Evaluation

Design alternatives were evaluated using a Qualitative Pugh Chart as shown in Table 4.3.1 and further evaluated in a second round using a Quantitative Pugh Chart as shown in Table 4.3.2. Designs were evaluated based on seven selection criteria: cost, manufacturability, weight, volume, keeps alignment, upkeep, and heating/cooling. A low cost, easy manufacturability, high weight, low volume, ability to keep alignment, easy upkeep, and fast and effective heating/cooling were preferred.

In the first round of design evaluation, designs were compared to an existing product found during Product and Patent Review. If a design did better than the existing product in one of the selection criteria, it would get a plus sign in the chart. If it did worse, it would get a minus sign. If it matched the selection criteria about the same, it would get a zero. These were then summed up with a plus sign acting as a “+1”, a zero acting as a “0”, and a minus sign acting as a “-1”. The team deliberated over each value to see which designs would move to the next round of design evaluation.

Table 4.3.1 Qualitative Pugh Chart

	A	B	C	D	E	F	G	Ref.
Selection Criteria	Reed	Alex	Tin	Henry	Daniel	Jacob	Xavier	Existing Product
Cost	+	+	+	+	+	+	+	0
Manufacturability	-	-	0	-	0	-	0	0
Weight	-	+	-	+	-	-	+	0
Volume	-	-	-	-	-	-	-	0
Keeps Alignment	-	-	0	0	0	0	0	0
Upkeep	-	0	+	-	-	-	0	0
Heating/Cooling	+	+	+	+	+	+	+	0
Plusses	2	3	3	3	2	2	3	0
0s	0	1	2	1	2	1	3	6
Minuses	5	3	2	3	3	4	1	0
Net	-3	0	1	0	-1	-2	2	
Rank	7	3	2	3	5	6	1	
Cont.?	No	No	Yes	No	No	No	Yes	

In the first round of design evaluation in Table 4.3.1, designs C and G moved forward as the best potential solutions due to their net scores. However, these net scores were not as high as desired, so a third option was sketched for the second round of design evaluations. This design was created by iterating off of all the previous designs. Weak points of the previous designs were improved upon by either adding a new component or combining ideas from multiple sketches. The design's sketch can be seen in Figure 4.3.1.

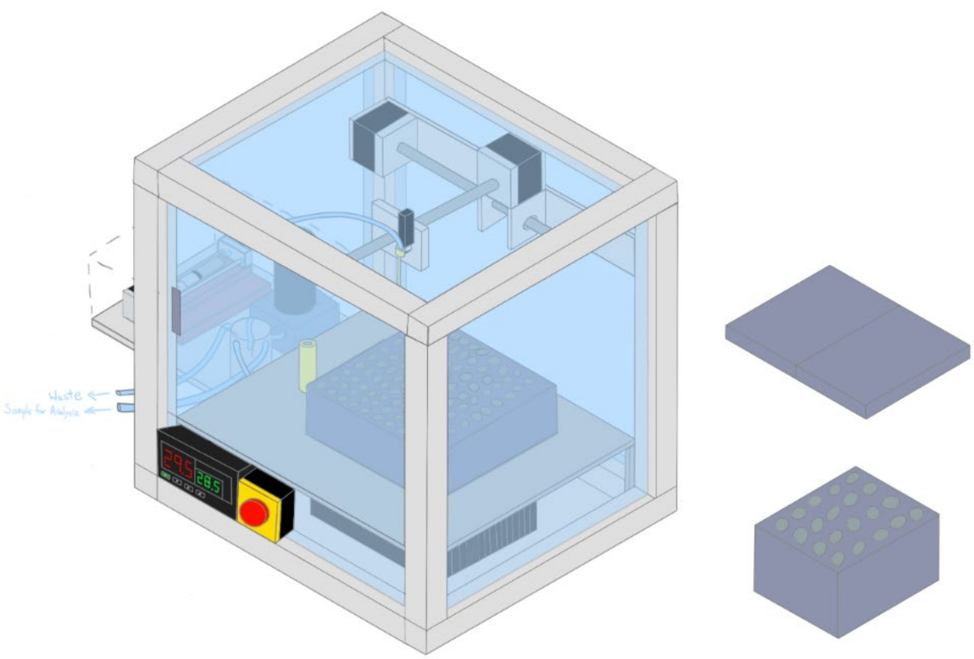


Figure 4.3.1 Sketch H for Second Round of Design Evaluation

Table 4.3.2 details the results of the second round of design evaluation via a Quantitative Pugh Chart. In this round, the two selected designs from round 1 and the new design for round 2 were analyzed in relation to the same selection criteria as the first round. This time, each selection criterion was also given a weight to it to inform how much the value given to a design for that criterion affects the overall score of the design. These weights were selected by the group based on the design requirements and the client's emphasis on certain requirements in conversations. Values were then selected as a team to determine which design should be used moving forward.

Designs C and G turned out to have similar final weighted scores, coming out ahead in upkeep and weight respectively. However, while C outperformed H in upkeep and G outperformed H in weight, H overall greatly outperformed the other two designs. Thus, it was chosen as the design to move forward with.

TABLE 4.3.2 QUANTITATIVE PUGH CHART

		C		G		H (New)	
		Tin		**Xavier**		**Jordan**	
Selection Criteria	**Weight (%)**	Value	Score	Value	Score	Value	Score
Cost	20	4	0.8	4	0.8	5	1
Manufacturability	15	3	0.45	3	0.45	4	0.6
Weight	5	1	0.05	4	0.2	3	0.15
Volume	20	1	0.2	1	0.2	5	1
Keeps Alignment	15	2	0.3	2	0.3	5	0.75
Upkeep	10	4	0.4	2	0.2	3	0.3
Heating/Cooling	15	2	0.3	2	0.3	5	0.75
	Total Score	2.5		2.45		4.55	
	Rank	2		3		1	
	Cont.?	No		No		Yes	

5 Deliver Phase

5.1 Final Design Description

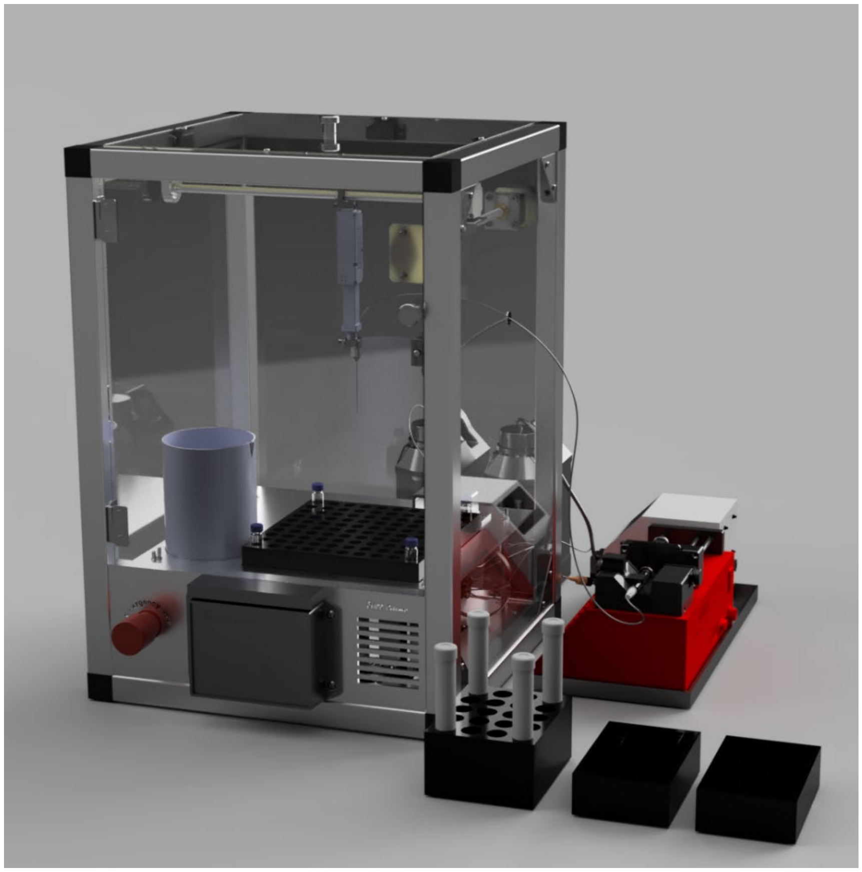


FIGURE 5.1.1: FINAL RENDERED CAD ASSEMBLY OF THE AUTOSAMPLER

The autosampler CAD model features four subsystems, the enclosure, the temperature control system, the fluids system, and the movement system. The enclosure (Figure 5.1.2) simply consists of 5052 aluminum tubing that is connected with the corresponding nylon, press-fit corners. The sides of the enclosure consist of polycarbonate panels that are secured with rivets through corner brackets into the tubing. The bottom of the enclosure features a 5052-aluminum pan that serves both to hold everything inside as long as a surface for mounting holes. The upper compartment of the enclosure uses threaded standoffs to elevate the sample trays and provide an opening for the fluid beaker to surface. The enclosure also features an aluminum front panel to mount an emergency stop button, the temperature controller, as well as providing a vent. Finally, the enclosure uses magnetic latches to secure the hinged polycarbonate front door and the top polycarbonate lid, which simply lifts off to allow for service of the machine.

The motion system of the autosampler (Figure 5.1.3) consists of two lead screws with corresponding stepper motors to move a needle on a linear actuator in the x and y directions. A guiderail parallel to the bottom lead screw ensures the system is supported on both sides while an alignment rail parallel to the top lead screw keep the linear actuator vertical as it moves along the lead screw. The linear actuator moves the needle in the z-direction, allowing it to reach both the inside of the vials or samples as well as the beaker for the cleaning solution.

The fluids system of the autosampler (Figure 5.1.4) includes both a syringe pump and peristaltic pump located outside the enclosure. These pumps use hoses to connect to the needle assembly and a six-port injection valve located underneath the enclosure deck, creating a push-to-fill sample loop. The fluids system also includes a needle seat, mounted on top of the enclosure deck in the home position of the of the movement system (back right). The microsyringe pump collects the sample when the needle is lowed into a vial and pushes the sample into the sample loop via the needle seat and six-port injection valve once the needle is back at its home position above the needle seat. The six-port injection valve then switches positions to allow the peristaltic pump to push mobile phase through the sample loop and send the sample to the output of the system to be analyzed. This occurs again to clean the fluid lines, but this time with the excess cleaning fluid going to waste instead of to the output of the system via the six-port injection valve's waste port.

The final subsystem of the autosampler is the temperature control system (Figure 5.1.5). This system includes a raised heat sink located underneath the enclosure deck. The heat sink has an array of thermoelectric plates that are controlled via the temperature controller on the front panel of the enclosure. The underside of the heat sink includes a fan as well, which is used to vent the extra heat out the front vent of the enclosure.

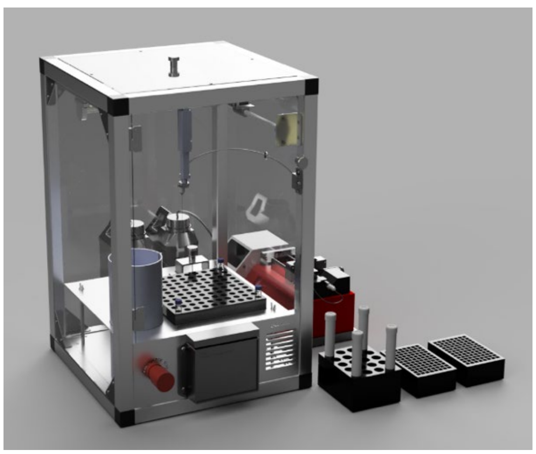


FIGURE 5.1.2: VIEW OF AUTOSAMPLER ENCLOSURE

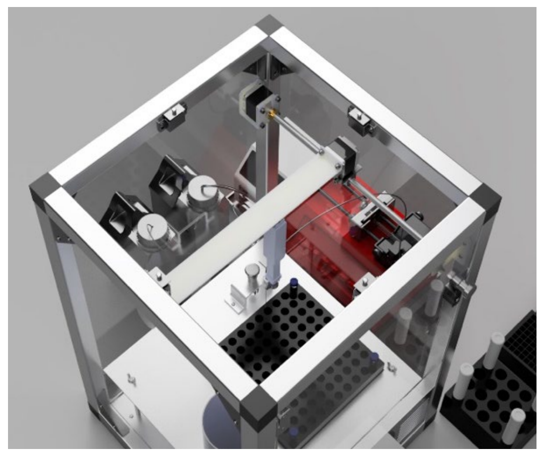


FIGURE 5.1.3: VIEW OF AUTOSAMPLER MOTION SYSTEM

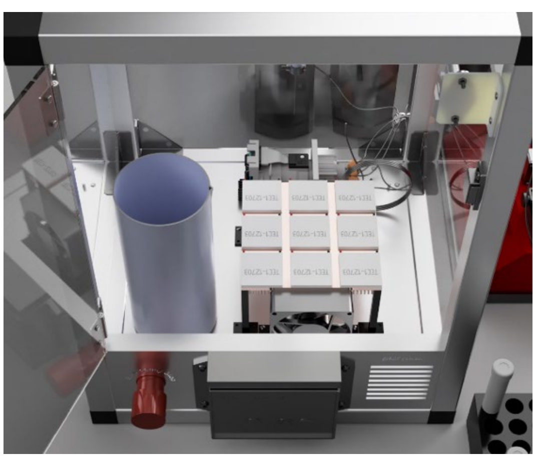


FIGURE 5.1.4: VIEW OF AUTOSAMPLER TEMPERATURE CONTROL SYSTEM

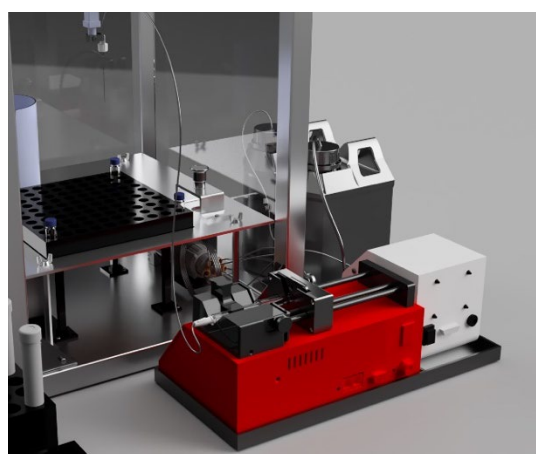


FIGURE 5.1.5: VIEW OF AUTOSAMPLER FLUIDS SYSTEM

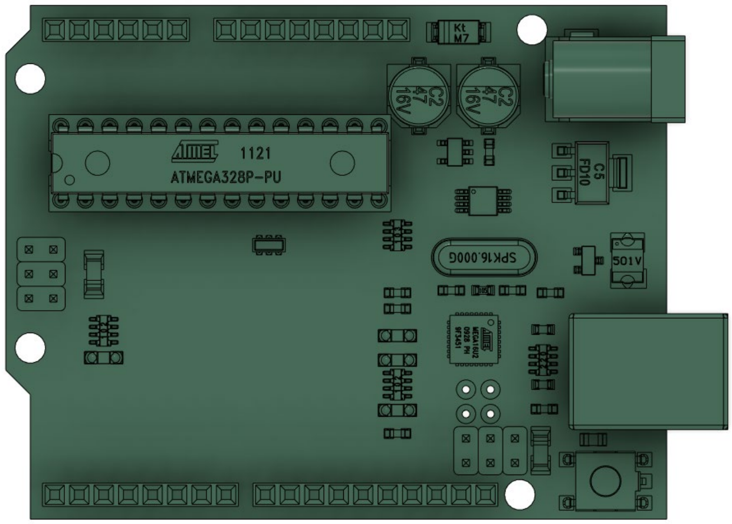


FIGURE 5.1.6: ARDUINO CONTROL CIRCUIT BOARD FOR THE AUTOSAMPLER

The Arduino controller for the autosampler will be conveniently located under the sample platform, next to the base of the six port injection valve. Therefore, there is ample room to connect the circuit board to wall power, by routing wires out the side of the autosampler and passing through a hole in the wall of the autosampler.

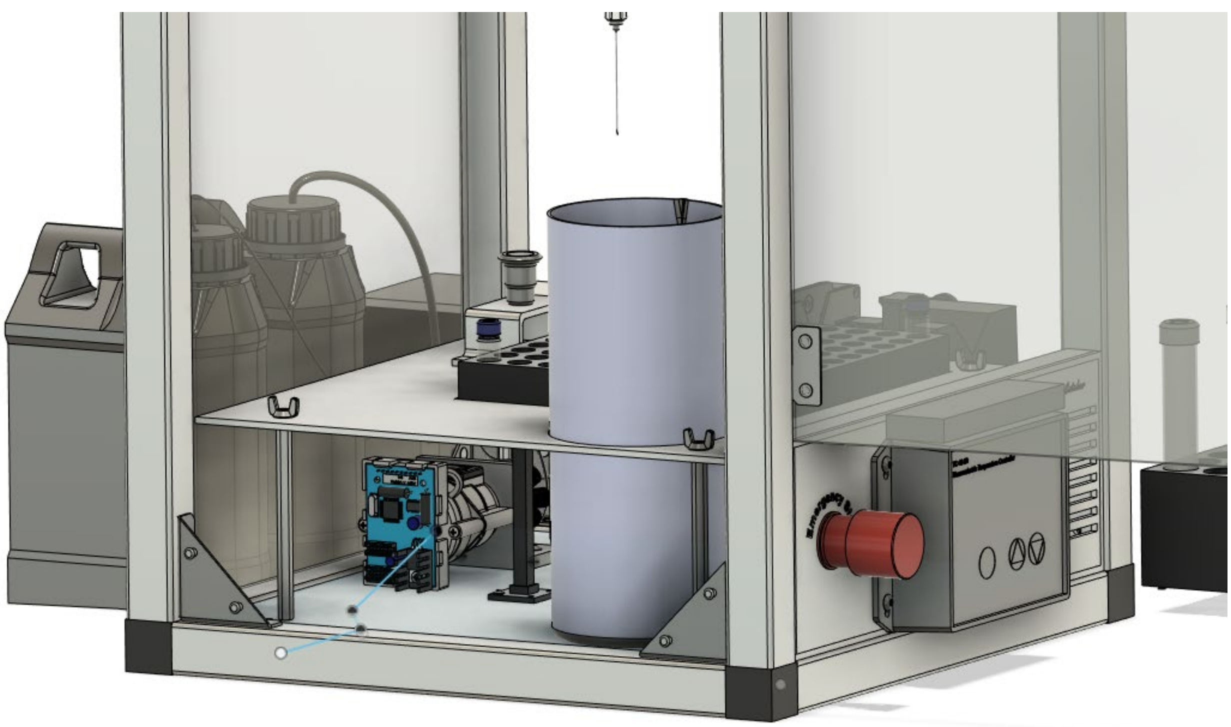


FIGURE 5.1.7: ARDUINO CIRCUIT BOARD TO WALL POWER WIRE PATH

Connections between power and the motors involved in movement of the autosampler also follow a relatively simple path. The Arduino is already connected to wall power, so the motors can be connected to the circuit board for power. Therefore, the wiring from the Arduino to the motors can be considered both the power and control connections for the motors and actuators. The wires can then be routed along the back inner face of the autosampler, up to the ceiling. Wire bundles can then be connected to each respective motor, for movement in each axis.

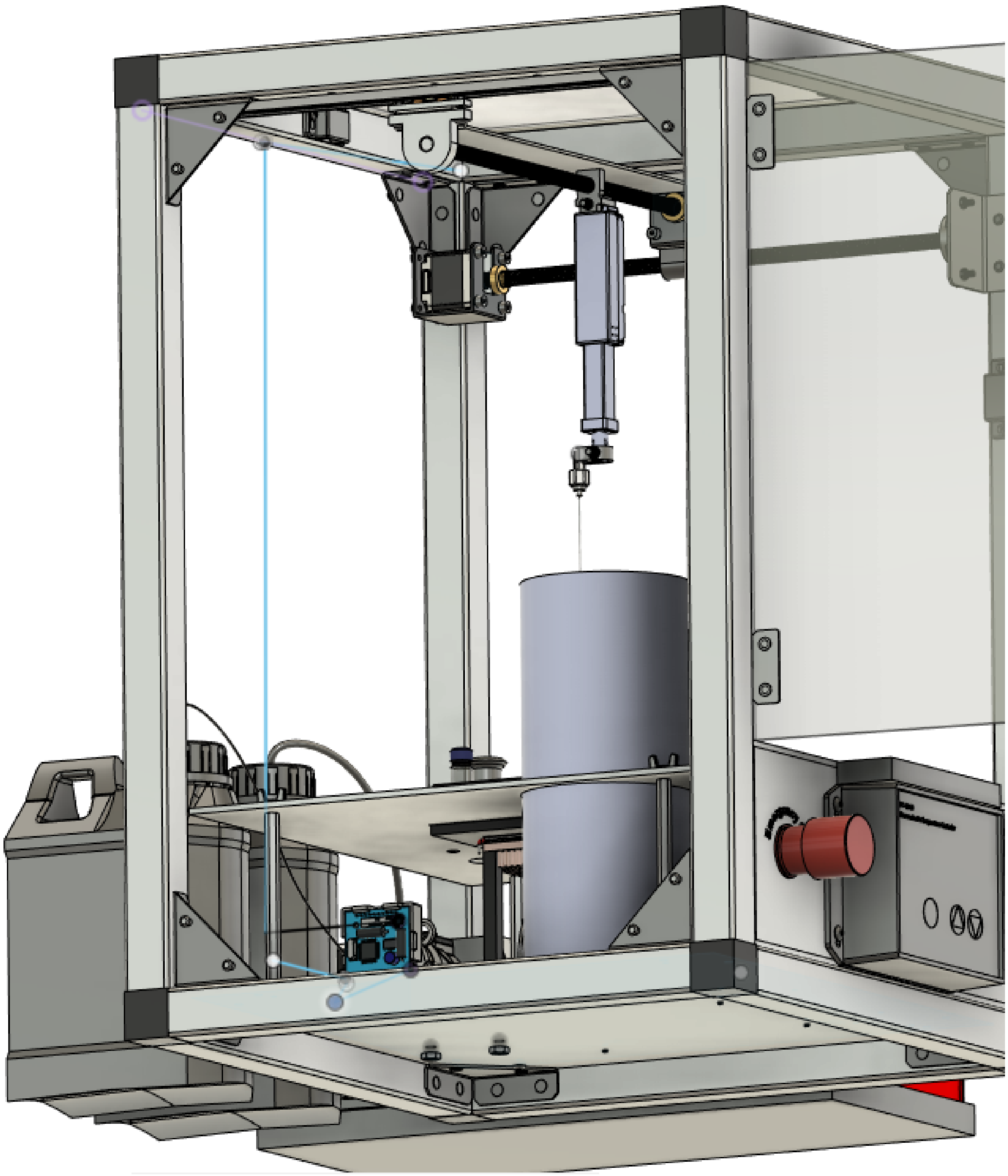


FIGURE 5.1.8: WIRING PATH OF INTEREST CONNECTING TO THE MOTORS RESPONSIBLE FOR MOVING THE NEEDLE AND CARRIAGE

5.2 Bill of Materials

Assemblies				
Person Requesting	Item No.	Part No.	Description	Qty.
Ayden Leeds	1	EML4501-A01	Enclosure Subsystem and Final Assembly	1
Alejandro Martinez	2	EML4501-A02	Motion Subsystem Assembly	1
Henry Stophel	3	EML4501-A03	Temperature Control Subsystem Assembly	1
Tin Sulenta	4	EML4501-A04	Fluids Subsystem Assembly	1
Tin Sulenta	5	EML4501-A05	6-Port Injection Valve Assembly	1
Ayden Leeds	6	EML4501-A06	Deck Assembly	1
Ayden Leeds	7	EML4501-A07	Front Panel Assembly	1

Enclosure Subsystem and Final Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Ayden Leeds	1	EML4501-E01	Polycarbonate Front Door	1
Ayden Leeds	2	EML4501-E02	Polycarbonate Side Panels	3
Ayden Leeds	3	EML4501-E03	Polycarbonate Lid	1
Ayden Leeds	4	EML4501-E04	Aluminum Tubing Sides	2
Ayden Leeds	5	EML4501-E05	Aluminum Tubing Side FL	1
Ayden Leeds	6	EML4501-E06	Aluminum Tubing Side FR	1
Ayden Leeds	7	EML4501-E07	Aluminum Base Sheet	1
Ayden Leeds	8	EML4501-E08	Aluminum Tubing Base	1
Ayden Leeds	9	EML4501-E09	Aluminum Tubing Top	1
Ayden Leeds	10	EML4501-E10	Aluminum Unthreaded Spacer, 4.500 mm OD, 2 mm Long	5
Ayden Leeds	11	EML4501-E11	3-Way Corner Connector 2 1/8 in x 2 1/8 in	8
Ayden Leeds	12	EML4501-E12	Steel Inside Corner Bracket, 2 in Sides for No. 8 Screw Size	16
Ayden Leeds	13	EML4501-E13	304 Stainless Steel Lift-Off Hinge 1-1/2 in High x 23/32 in Wide	2
Ayden Leeds	14	EML4501-E14	Surface-Mount Plastic 3 lb. Pull Magnetic Latch	5
Ayden Leeds	15	EML4501-E15	303 Stainless Steel Knob 10-24 Thread, 3/4 in Head	2
Ayden Leeds	16	EML4501-E16	18-8 Stainless Steel Button Head Screw	2
Ayden Leeds	17	EML4501-E17	18-8 Stainless Steel Button Head Screw	8
Ayden Leeds	18	EML4501-E18	18-8 Stainless Steel Hex Nut	6
Ayden Leeds	19	EML4501-E19	18-8 Stainless Steel Washer, No. 8 Screw Size	2
Reed Legg	20	EML4501-E20	1.5ml Test Tube Rack	1
Reed Legg	21	EML4501-E21	15ml Test Tube Rack	1
Reed Legg	22	EML4501-E22	96 Well Plate	2
Reed Legg	23	EML4501-E23	1.5ml Vial	100
Reed Legg	24	EML4501-E24	15ml Tube	20
Reed Legg	25	EML4501-E25	Test Tube Rack Pin Plate	1

Motion Subsystem Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Alejandro Martinez	1	EML4501-M01	Lead Screw Motor Bracket	1
Alejandro Martinez	2	EML4501-M02	Motor Carrier	1
Alejandro Martinez	3	EML4501-M03	Linear Actuator Holder	1
Alejandro Martinez	4	EML4501-M04	Actuator Holder Guide	1
Alejandro Martinez	5	EML4501-M05	Front Motion Bracket	1
Alejandro Martinez	6	EML4501-M06	300mm T8 Lead Screw with NEMA 17 Stepper Motor	2
Alejandro Martinez	7	EML4501-M07	300mm Linear Guide Rail with 4 Slide Blocks (2 pieces)	2
Alejandro Martinez	8	EML4501-M08	Linear Actuator with 4-inch stroke	1
Alejandro Martinez	9	EML4501-M09	8mm T8 Lead Screw Support Set Ball Bearing Pillow Block	2
Alejandro Martinez	10	EML4501-M10	M3 10mm Long Screw Phillips Drive Stainless Steel	12
Alejandro Martinez	11	EML4501-M11	M3 8mm Long Screw Phillips Drive Stainless Steel	2
Alejandro Martinez	12	EML4501-M12	M3 14mm Long Screw Phillips Drive Stainless Steel	2
Alejandro Martinez	13	EML4501-M13	Flanged Bearing 8x16x5	2

Temperature Control Subsystem Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Eden Navarrete	1	EML4501-T01	Heat Sink Columns	4
Eden Navarrete	2	EML4501-T02	Fan Base	1
Henry Stophel	3	EML4501-T03	Thermoelectric Cooler Cooling Peltier Plate Module	6
Henry Stophel	4	EML4501-T04	80mm 12V Brushless DC Cooling Fan	1
Henry Stophel	5	EML4501-T05	Copper Heat Sink	1
Eden Navarrete	6	EML4501-T06	Temperature Sensor	1
Eden Navarrete	7	EML4501-T07	18-8 Stainless Steel Pan Head Phillips Screws	16

Fluids Subsystem Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Tin Sulenta	1	EML4501-F01	Fluids System 3D-Printed Pump Tray	1
Tin Sulenta	2	EML4501-F02	Bevel Tip Needle for Luer Lock Syringes	1
Tin Sulenta	3	EML4501-F03	Luer Lock Syringe with Interchangeable Pistons and Barrels	1
Tin Sulenta	4	EML4501-F04	NE-1000 Single Syringe Pump	1
Tin Sulenta	5	EML4501-F05	0.03 inch - 0.063 inch PVC Connector	1
Tin Sulenta	6	EML4501-F06	0.029 inch - 0.03 inch ID PC Connector	1
Tin Sulenta	7	EML4501-F07	Needle Seat, PEEK, 0.17 mm ID, 2.3 µL	1
Tin Sulenta	8	EML4501-F08	ETFE Tubing Natural 1/16" OD x .030" ID x 5ft	2
Tin Sulenta	9	EML4501-F09	One-Piece Fitting, 1/4-28 Flat-Bottom, for 1/16" OD	2
Tin Sulenta	10	EML4501-F10	3-Roller Micro Flow Laboratory Peristaltic Pump	1
Tin Sulenta	11	EML4501-F11	Borosilicate Graduated Beaker, 1000ml, Autoclavable	1
Tin Sulenta	12	EML4501-F12	32 oz. White HDPE F-Style Jug	2
Tin Sulenta	13	EML4501-F13	33/400 White Ribbed Polypropylene Cap with F217 Liner	2
Tin Sulenta	14	EML4501-F14	Swivel Barb Adapter For 3/32" ID Tubing	1
Tin Sulenta	15	EML4501-F15	Adapter - 1/4-28 x 10-32, PEEK	1
Tin Sulenta	16	EML4501-F16	Needle Seat Bracket	1

6-Port Injection Valve Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Tin Sulenta	1	EML4501-P01	PEEK 2-Position, 6-Port Motorized Injection Valve	1
Tin Sulenta	2	EML4501-P02	Fitting for Tubing of Sizes Varying from 1/8”OD to 3/16”OD	6
Tin Sulenta	3	EML4501-P03	Injection Port Bracket	1

Deck Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Ayden Leeds	1	EML4501-D01	Aluminum Upper Deck Sheet	1
Ayden Leeds	2	EML4501-D02	18-8 Stainless Steel Threaded Hex Standoff 3-3/4 in Long, 6-32 Thread	4
Ayden Leeds	3	EML4501-D03	316 Stainless Steel Wingnut, 6-32 Thread	4

Front Panel Assembly				
Person Requesting	Item No.	Part No.	Description	Qty.
Ayden Leeds	1	EML4501-C01	Front Panel Sheet	1
Eden Navarrete	2	EML4501-C02	PWM Temperature Controller	1
Ayden Leeds	3	EML4501-C03	Emergency Stop	1
Ayden Leeds	4	EML4501-C04	18-8 Stainless Steel Pan Head Phillips Screws	4

6 Design Analysis

6.1 Design Calculations

6.1.1 Sampling Time

Motion:

To solve for the overall sampling time, a series of calculations must be made for each of the tubes and sample phases. As an example, for the sample loop tube in the initial load phase, the following was performed. First, the tube length and velocity of the fluid were needed to be solved for. Starting with the maximum sampling volume of 500 µL and the inner diameter of the tube used, the required length of tubing was able to be solved for using the equation for volume of a cylinder.

$$V = \pi r^2 l \rightarrow l = \frac{V}{\pi r^2} = \frac{5x10^{-7}}{\pi(3.81x10^{-4})^2} = 1.096\ m$$

Additionally, the overall area of the inside of the tube is solved so that it can be combined with the flowrate equation. In this manner of combining the two equations, a velocity can be calculated for the fluid. The flow rate used is given in requirements by the customer and is specified to not exceed 1 µL/min.

$$A = \pi r^2 = \pi(3.81x10^{-4})^2 = 4.56x10^{-7}\ m^2$$

$$Q = Av \rightarrow v = \frac{Q}{A} = \frac{6.22x10^{-8}}{4.56x10^{-7}} = 0.136\frac{m}{s}$$

From this, the time can be calculated using the velocity equation. Note, this is only the time for a maximum sampling volume load phase within the sample loop.

$$v = \frac{l}{t} \rightarrow t = \frac{l}{v} = \frac{1.096}{0.136} = 8.039\ s$$

This process must be repeated for each section of tubing and for each phase of the sampling process. Then, the times are all added together in conjunction with the movement time calculated below to find the total sampling time of a max volume sample. Movement 1 is the system's motion from the needle seat to the furthest sampling vial. This distance is 10 inches in the x-direction and 6.5 inches in the y-direction, totaling 33 inches of movement when considering movement there and back. Movement 2 is system's motion from the needle seat to the water reservoir and back. This distance is 10 inches in the x-direction and 10 inches in the y-direction, totaling 40 inches of movement when considering movement there and back. Knowing that the stepper motors used in the motion system have a linear movement speed of 4.27 in/s along with the total distances of the two movements, total movement time calculations can be completed. In the equations below, *d* is the total distance of the respective movement and *v* is the linear speed of the stepper motors.

$$t_{movement\ 1} = \frac{d}{v} = \frac{33\ in}{4.17\frac{in}{s}} = 7.914\ s \approx 7.9\ s$$

$$t_{movement\ 2} = \frac{d}{v} = \frac{40\ in}{4.17\frac{in}{s}} = 9.592\ s \approx 9.6\ s$$

$$t_{motion,max} = t_{movement\ 1} + t_{movement\ 1} = 7.9 + 9.6 = \mathbf{17.5\ s}$$

Fluids:

In our system there are eight different sections of tubing: needle, aspiration capillary, sample transfer line, sample loop, Peristaltic pump line, column line, microfluidic line, and the waste line. Additionally, the phases of sampling and cleansing can be broken down into their respective loading and injection cycles: sample aspiration part a, sample aspiration part b, injection, cleanse cycle part a, and cleanse cycle part b.

Sample aspiration part a is the process of the sample going through the needle, through the aspiration capillary; it is all pressurized by the vacuum created by the micro syringe pump. Sample aspiration part b is the flow of the fluid back through the aspiration capillary and needle, and then through the sample transfer line and finally to the sample loop. This is also pressurized by the micro syringe pump and uses the same flow rate previously shown in the pressure calculations. The injection phase is the path of the fluid back through the sample loop, to the column, and finally out to the microfluidic line. The fluid in this phase is pressurized by the peristaltic pump operating at the maximum flow rate given in the requirements. While this is happening, cleanse cycle part a occurs. This is the process of DI water flowing through the needle into the aspiration capillary and then back out all the way to the waste line. Finally, after all the sample has been pumped into the analytical device, the pump can start cleansing cycle b and continue to pump DI water as a mobile phase through the sample loop, column, and microfluidic line.

$$t_{total\ sampling} = t_{aspiration\ (a)} + t_{aspiration\ (b)} + t_{injection} + t_{cleanse\ (a)} + t_{cleanse\ (b)}$$

The times for a half sample of 250 µL and the smallest sample size of 0.5 µL were also solved for. Being that the length of tube required changes drastically with the different sample sizes, it is also evident that the overall sampling times will likewise greatly change. Note that cleanse loop 2 occurs simultaneously with cleanse loop 1, the sample injection, and movement of the needle. When performing the calculations, it was found that the longest time was the sample injection due to the it using the slower flow rate of 1 mL/min from the peristaltic pump. This allows us to eliminate cleanse loop 2 from the overall time because it occurs continuously while the other processes take place. Results can be found in Table 6.1.1.1.

TABLE 6.1.1 TOTAL FLUIDS SAMPLING TIMES

Cycle	Times for 500 µL (s)	Times for 250 µL (s)	Times for 1 µL (s)
Sample Aspiration (a)	8.046	4.026	0.023
Sample Aspiration (b)	16.121	8.083	0.077
Sample Injection	32.743	4.019	0.016
Cleanse Loop 1	16.129	8.090	0.084
Cleanse Loop 2	N/A	N/A	N/A
Total	73.038	24.219	0.199

Total:

When adding the times for the movement system, the final total times were found to be:

$$\boldsymbol{t_{500\ \mu L} = 90.538\ s}$$

$$\boldsymbol{t_{250\ \mu L} = 41.719\ s}$$

$$\boldsymbol{t_{0.5\ \mu L} = 17.699\ s}$$

6.1.2 Enclosure

Vertical Beams:

The strength requirements for the enclosure were discussed with the client and it was determined that a 200lb man should be able to fall on the enclosure and not crush it. Thus, a failure analysis was done for the vertical beams in buckling due to a vertical distributed load. The buckling force is in terms of elastic modulus (E), the moment of inertia (I), the end conditions factor (k), and the length of the beam (L). The force of impact is the approximate force the 200lb man falling onto the enclosure. This number is approximate as it is dependent on how the man falls. The factor of safety (F.O.S.) is used to confirm the man will not crush the enclosure with extra security. The buckling calculations ensure that the vertical aluminum beams can support a 200lb man falling directly onto one corner with a **factor of safety of 9.56**.

FIGURE 6.1.2.1: FREE BODY DIAGRAM OF COLUMN BUCKLING.

$$F_{buckling} = \frac{\pi^2 EI}{kL^2} = \frac{\pi^2(1e7)(0.0334)}{1(18.07^2)} = 10095.55\ lbf$$

$$F_{impact} \approx 1056 lbf$$

$$F.O.S. = \frac{F_{buckling}}{F_{impact}} = 9.56$$

Rivets:

Another failure mode determined to be critical to the enclosure system was the possible shear failure of the bottom aluminum base plate rivets. The enclosure base plate is fastened with 16 rivets. This baseplate holds the entirety of the components within the enclosure including the liter of water, the thermal system, the sample trays, the tray platform, and other small components. The bearing stress is in terms of the applied force, the thickness (t), and the diameter of the rivet (d). The factor of safety for the rivets was determined using the ultimate stress of the rivet material compared to the bearing stress. The calculations done show that the rivets can support the entirety of components on the base plate with an extremely large **factor of safety of 284**.

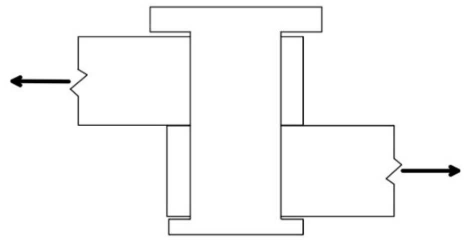


FIGURE 6.1.2.2: FREE BODY DIAGRAM OF THE BASE PLATE RIVET

$$\sigma_{bearing} = \frac{F_{applied}}{t * d} = \frac{0.81lb}{0.16in * 0.033in} = 153.4\frac{lb}{in^2}$$

$$F.O.S. = \frac{\sigma_{ultimate}}{\sigma_{bearing}} = \frac{43511\frac{lb}{in^2}}{153.4\frac{lb}{in^2}} = 284$$

6.1.3 Motion System

Assumptions:

- The lead screws utilized for the motion system will be composed of a stepper motor with an integrated 11.811-in Aluminum T8 lead screw and will be purchased off the shelf from a third-party vendor.
- The guide rail utilized along the y-axis is 11.811-in in length and 0.669-in thick and is composed of clear anodized aluminum. This is purchased from a third-party vendor.
- A chrome steel bearing with a radius of 0.158-in and thickness of 0.197-in is utilized to support the end of the lead screw opposite to the motor on X-axis. This part is purchased off the shelf from a third-party vendor.
- All fasteners utilized in the motion system are 10-mm M3 Stainless Steel Pan Head Screws. These components are purchased off the shelf from a third-party vendor.
- The bracket utilized to support the x-axis lead screw motor will be manufactured using ABS Plastic via 3D printing.

Factor of Safety: All components utilized for the motion system of the autosampler should achieve a minimum factor of safety of 2.

Lead Screws:

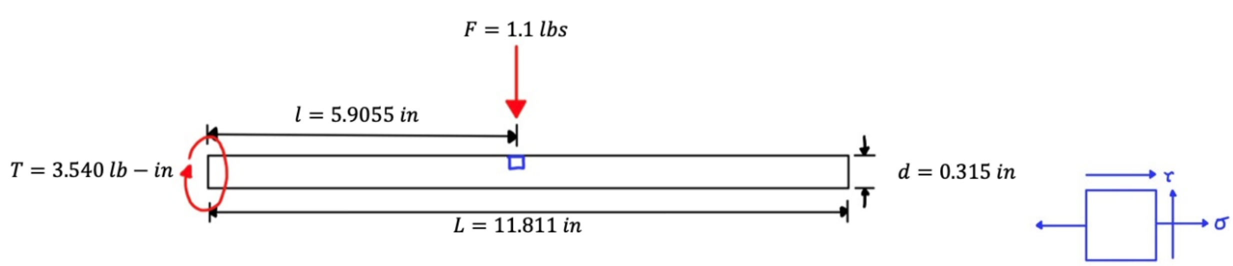


FIGURE 6.1.3.1: FREE BODY DIAGRAM AND VON MISES STRESS SQUARE OF LEAD SCREW

For the horizontal motion of the autosampler sampling system, two identical lead screws with integrated stepper motors are used. The lead screws use the rotational input of the motor to translate to a linear output of a component on the screw itself, which in the case of this product is a carrier for the y-axis motor and a linear actuator mount. Due to the rotational nature of the lead screws as well as the load experienced on the x-axis lead screw from carrying the y-axis motor, both bending and torsional stresses should be evaluated for failure. Selection information and failure modes are as follows:

- Materials Selection: Aluminum 6061-T8 Lead Screw with brass nut was used for both its strength and anti-corrosive properties (Yield Strength = 40,000 psi).
- Sizing Selection:
    - 11.811-inch length (lead screw plus motor) ensures that the part will reach completely across the enclosure for proper mounting and support.
    - 0.315-inch lead screw diameter ensures that the lead screw resists bending due to a 1.1-pound vertical load.
- Potential Modes of Failure: Bending and Torsional

In order to determine the values for the bending stress, σ, and torsional stress, τ, we need both information of the motor and the lead screw. This includes the motor torque, *T*, the lead screw radius, *r*, diameter, *d*, overall length, *L*, length to the location of the highest load, *l*, and force acting on the lead screw, *F*.

$$\tau_{tor} = \frac{T * r}{\frac{\pi d^4}{64}} = \frac{(3.5043\ lb - in)(0.1575\ in)}{\frac{\pi(0.315\ in)^4}{64}} = 1142.01\ psi$$

$$\sigma_{bend} = \frac{F * d * l}{\frac{\pi d^4}{64}} = \frac{(1.1\ lbs)(0.315\ in)(5.9055\ in))}{\frac{\pi(0.315\ in)^4}{64}} = 4233.97\ psi$$

Due to the lead screw having potential failure due to both bending and torsional stresses, it is logical to calculate the Von Misses stress, σ', of the component. This is done using both of the previously calculated bending and torsional stress values.

$$\sigma' = \sqrt{\sigma^2 + 3\tau^2} = \sqrt{(4233.97\ psi)^2 + 3(1142.01\ pdsi)^2} = 4673.23\ psi$$

With the Von Mises stress now determined, the factor of safety for the selected part can be determined. This is done by fractional comparison of the yield strength of the material used, S_y,and the determined Von Mises stress.

$$N = \frac{S_y}{\sigma'} = \frac{40000\ psi}{4673.23\ psi} = 8.56$$

With a design factor of safety of 2, it can be stated that the lead screw factor of safety of 8.56 exceeds the design requirements. With the factor of safety now determined, the margin of safety of the utilized component can be calculated. This is done using the max strength of the material, σ_{max}, design factor of safety, N_d, and Von Mises stress, σ'. Margin of safety was then calculated.

$$MOS = \frac{\sigma_{max}}{N_d * \sigma'} - 1 = \frac{40000\ psi}{2 * 4673.23\ psi} - 1 \approx 3.28$$

While a **margin of safety of 3.28** is often referred to as high, it would be rather difficult to reduce by using differently sized parts. If the material of the lead screw was changed, it would lose its anti-corrosive properties, leading to the part needing replacement more frequently. This was a main complaint of autosampler users. Additionally, the diameter of the lead screw could be reduced, however, in reducing the diameter of the part, it would lose its rigidity and become more like a wire. With these complications in mind, the determined margin of safety is acceptable for this part. Nonetheless, the von mises stress, resulting from the torsional and bending stresses acting on the lead screw, is not a possible mode of failure of the motion system.

Guide Rail:

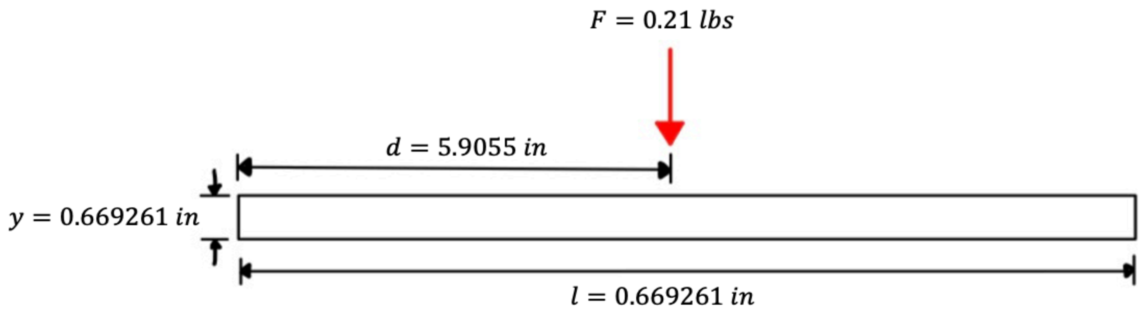


FIGURE 6.1.3.2: FREE BODY DIAGRAM OF THE GUIDE RAIL.

Selection information and failure modes are as follows:

- Materials Selection:
  - Clear anodized aluminum guide rail (Yield Strength = 40,000 psi)
  - Solid plastic carriage for guide rail (Yield Strength = 21,000 psi).
- Sizing Selection:
  - 11.811-inch guide rail length utilized to ensures that the part will reach completely across the enclosure for proper mounting and support of the y-axis lead screw.
  - 0.669261-inch guide rail thickness to help ensure bending strength of the part.
- Potential Modes of Failure: Bending

One potential concern for the autosampler's motion system is support of the system's lead screws. To ensure the proper support of the y-axis lead screw, a guide rail was put in place. This guide rail uses a carriage that moves with the free end of the y-axis lead screw as it moves in the x-direction. While the load on the guiderail is minimal, it is still important to consider its potential cause of failure. With this in mind, the guide rail's bending stress can be determined. The calculation utilizes the vertical load, *F*, guide rail length, *l*, and guide rail thickness, *y*. First, the moment acting on the guiderail, *M*, must be determined.

$$M = \frac{Fl}{8} = \frac{(0.21\ lb)(11.811\ in)}{8} = 0.31\ lb - in$$

With the moment acting on the guiderail, the bending stress of the guide rail can be calculated. To do this calculation, the moment of inertia around the neutral axis, *I*, is used.

$$\sigma_{bend} = \frac{My}{I} = \frac{(0.31\ lb - in)(0.6693\ in)}{\frac{\pi(0.6693\ in)^4}{64}} = 21.07\ psi$$

With the newly determined bending stress of the guide rail, the factor of safety for the selected part can be determined. This is done by fractional comparison of the yield strength of the material used, S_y ,and the determined bending stress.

$$N_{bend} = \frac{S_y}{\sigma_{bend}} = \frac{40000\ psi}{21.07\ psi} = 1898.46$$

With a design factor of safety of 2, it can be stated that the guide rail factor of safety of 1898.46 greatly exceeds the design requirements. With the factor of safety now determined, the margin of safety of the utilized component can be calculated. This is done using the max strength of the material, σ_{max}, design factor of safety, N_d, and bending stress, σ_{bend}. Margin of safety was then calculated.

$$MOS = \frac{\sigma_{max}}{N_d * \sigma_{design}} - 1 = \frac{40000\ psi}{2 * 21.07\ psi} - 1 \approx 949$$

A **margin of safety of 949** is rather large, but nonetheless proves that the selected part meets the design requirements set forth for the autosampler. It is important to note that with such high values for both factor of safety and margin of safety, bending stress of the guide rail is not a possible mode of failure of the motion system.

Bearing:

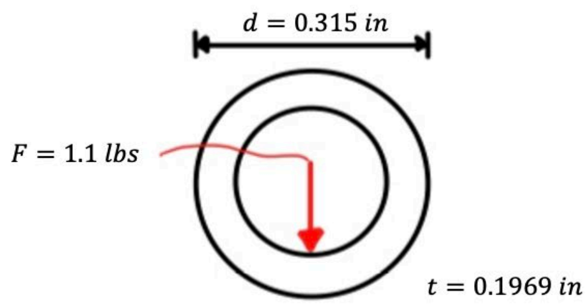


FIGURE 6.1.2.3: FREE BODY DIAGRAM OF THE X-AXIS BEARING.

Selection information and failure modes are as follows:

- Materials Selection: Chrome-moly Steel (Yield Strength = 39,900 psi).
- Sizing Selection:
  - 0.315-inch bore to ensure free end of x-axis lead screw can fit properly into the bearing.
  - 0.1969-inch thickness for proper fit into selected bearing pillow block.
  - 0.63-inch outer diameter for proper fit into selected bearing pillow block.
- Potential Modes of Failure: Bearing

In addition to the guide rail supporting the y-axis lead screw, a bearing and pillow block were mounted to the enclosure columns to secure the x-axis lead screw in place. With the bearing being used, it is important to evaluate the system for possible bearing failure. This can be done by first determining the bearing stress using the vertical load of the lead screw, *F*, bore radius of the bearing, *r*, and thickness of the bearing, *t*. Bearing stress is calculated by dividing the load by the contact area of the applied load. Considering the lead screw will be resting in the bearing, we can assume the load is only applied to the lower half of the bearing, therefore the overall contact area can be divided by two. The resulting calculation can be seen below.

$$\sigma_{bearing} = \frac{2F}{\pi r^2 t} = \frac{2(1.1\ lbs)}{\pi(0.1575\ in)^2(0.1969\ in)} = 143.38\ psi$$

With the newly determined bearing stress, the factor of safety for the selected part can be determined. This is done by fractional comparison of the yield strength of the material used, S_y, and the determined bearing stress, $\sigma_{bearing}$.

$$N_{bearing} = \frac{S_y}{\sigma_{bearing}} = \frac{39900\ psi}{143.38\ psi} = 278.3$$

With a design factor of safety of 2, it can be stated that the bearing factor of safety of 278.3 greatly exceeds the design requirements. With the factor of safety now determined, the margin of safety of the utilized component can be calculated. This is done using the max strength of the material, σ_{max}, design factor of safety, N_d, and bending stress, $\sigma_{bearing}$. Margin of safety was then calculated.

$$MOS = \frac{\sigma_{max}}{N_d * \sigma_{design}} - 1 = \frac{39900\ psi}{2 * 143.38psi} - 1 \approx 138$$

A **margin of safety of 138** is quite large, but nonetheless proves that the selected bearing meets the design requirements set forth for the autosampler. It is important to note that with such high values for both factor of safety and margin of safety, bearing stress is not a possible mode of failure of the motion system.

Fasteners:

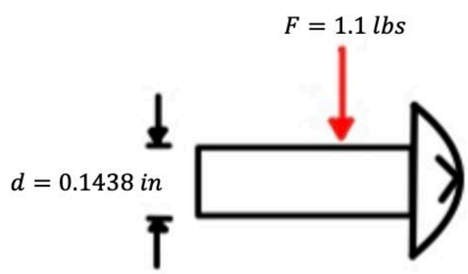


FIGURE 6.1.3.4: FREE BODY DIAGRAM OF THE FASTENERS.

Selection information and failure modes are as follows:

- Materials Selection: Stainless Steel (Yield Strength = 80,000 psi)
- Sizing Selection:
    - 0.1438-inch fastener diameter.
    - 50.8 threads per inch
- Potential Modes of Failure: Shear

Frequently, the failures of systems occur as a result of fasteners either being tightened incorrectly or being selected incorrectly. Because of this, the motion system evaluated its fasteners for shear failure. In order to properly determine if this is a possible failure mode for the autosampler, the shear stress, τ, must first be calculated. This is done by dividing the load on the fastener, *F*, by the cross-sectional area of the fastener, A_t. The value of the cross-sectional area requires knowledge of the threads per inch of the fastener, *n*, and the diameter of the fastener, *d*.

$$A_t = 0.7854\left(d - \left(\frac{0.9743}{n}\right)\right)^2 = 0.7854\left(0.1438 - \left(\frac{0.9743}{50.8}\right)\right)^2 = 0.0122\ in^2$$

$$\tau = \frac{F}{A_t} = \frac{1.1\ lbs}{0.0122\ in^2} = 90.2\ psi$$

With the newly determined shear stress, the factor of safety for the selected fastener can be determined. This is done by fractional comparison of the yield strength of the material used, S_y, and the determined shear stress, τ.

$$N = \frac{S_y}{\tau} = \frac{80000\ psi}{90.2\ psi} = 887$$

With a design factor of safety of 2, it can be stated that the bearing factor of safety of 887 greatly exceeds the design requirements. With the factor of safety now determined, the margin of safety of the utilized component can be calculated. This is done using the max strength of the material, σ_{max}, design factor of safety, N_d, and shear stress, τ.

<u>Margin of Safety:</u>

$$MOS = \frac{\sigma_{max}}{N_d * \sigma_{design}} - 1 = \frac{80000\ psi}{2 * 90.2psi} - 1 \approx 442$$

A **margin of safety of 442** is extremely large, but nonetheless proves that the selected fasteners meet the design requirements set forth for the autosampler. It is important to note that with such high values for both factor of safety and margin of safety, shear stress of the fasteners is not a possible mode of failure of the motion system.

Motor Bracket:

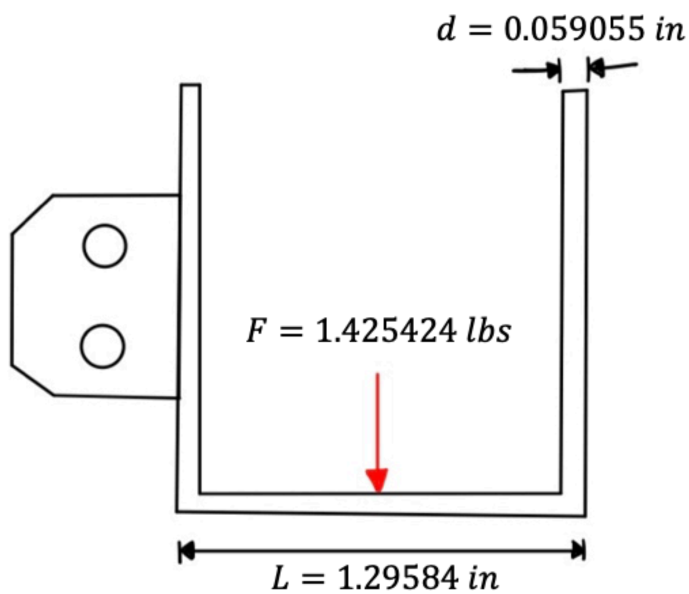


FIGURE 6.1.3.5: FREE BODY DIAGRAM OF THE MOTOR BRACKET.

Selection information and failure modes are as follows:

- <u>Materials Selection</u>: ABS plastic (Yield Strength = 29,600 psi)
- <u>Sizing Selection</u>:
    - 1.29584-inch overall length to ensure lead screw motor fits properly inside bracket
    - 0.059055-inch thickness on all three supporting sides gives bracket higher strength and more rigidity
- <u>Potential Modes of Failure</u>: Bending

The final potential concern for the autosampler's motion system is the bracket that supports the system's x-axis lead screw motor. The bracket is 3D printed and is rather thin, so it is important to consider its potential cause of failure due to bending. The bracket's bending stress can be determined utilizing the vertical load, *F*, bracket length, *L*, and bracket thickness, *y*. First, the moment acting on the bracket, *M*, must be determined. This calculation is shown below.

$$M = \frac{F * \frac{L}{2}}{8} = \frac{(1.425424\ lb)(0.629921\ in)}{8} = 0.1029\ lb - in$$

With the moment acting on the bracket found, the bending stress can be calculated. To do this calculation, the moment of inertia around the neutral axis, *I*, is used.

$$\sigma_{bend} = \frac{My}{I} = \frac{(0.1029\ lb - in)(0.059055\ in)}{\frac{\pi(0.059055\ in)^4}{64}} = 11{,}101\ psi$$

With the newly determined bending stress of the bracket, the factor of safety for the manufactured part can be determined. This is done by fractional comparison of the yield strength of the material used, S_y, and the determined bending stress.

$$N_{bend} = \frac{S_y}{\sigma_{bend}} = \frac{29600\ psi}{11101\ psi} = 2.67$$

With a design factor of safety of 2, it can be stated that the bracket factor of safety of 2.67 exceeds the design requirements while remaining quite close to the desired value. With the factor of safety now determined, the margin of safety of the system's component can be calculated. This is done using the max strength of the material, σ_{max}, design factor of safety, N_d, and bending stress, σ_{bend}. Margin of safety was then calculated.

$$MOS = \frac{\sigma_{max}}{N_d * \sigma_{design}} - 1 = \frac{29600\ psi}{2 * 11101\ psi} - 1 \approx 0.33$$

A **margin of safety of 0.33** is small but not zero, meaning that the selected part meets the design requirements set forth for the autosampler without being overdesigned. It is important to note that by having the smallest values for both factor of safety and margin of safety of all parts evaluated for the motion system, the motor bracket is the part that will be closest to failure. While the determined factor of safety is still greater than the design factor of safety, it is relatively close, therefore meaning that the bracket should be evaluated for any potential abnormalities from time-to-time to ensure integrity of the motion system.

6.1.4 Fluids System

Requirements:

The sampling requirements for the autosampler included being able to sample volumes from 0.5 μL to 500 μL, sampling precision < 20% in sampling volume at 0.5 μL and < 0.5% in sampling volume at 500 μL, delivery flowrate between 1 μL/min and 1 mL/min. During discussions with our client, we were also told that the systems in the client's lab typically operate at 100 kPa and at a pressure difference no more than 300 kPa.

Sampling Volume:

A 3 mL syringe and appropriately sized tubes were used to be able to accommodate this full range of sampling volumes. A 3 mL syringe was used over a 500 μL syringe in order to have a faster flowrate in the first two steps of the sampling loop, helping us meet the time requirements discussed in Section 6.1.1.

Sampling Precision:

Sampling precision was accounted for with the syringe pump which has a dispensing precision of 1%. Due to our use of a push-to-fill sample loop with a 6-port-injection valve, this should be the major cause of any imprecision in sampling volume. This meets the requirement for the smaller sample volume, but not the larger sample volume. However, **our precision would be within requirements for all sampling volumes below about 487 μL** assuming a linear relationship between the requirements for sampling volumes and precisions. This is shown in Figure 6.1.4.1 where, for example, there is a minimum precision requirement of about 10.3% for a sampling volume of 250 μL. Based on conversations with the client, this would be sufficient for most cases since it is more rare for the client to use the higher end of the sampling volume range given.

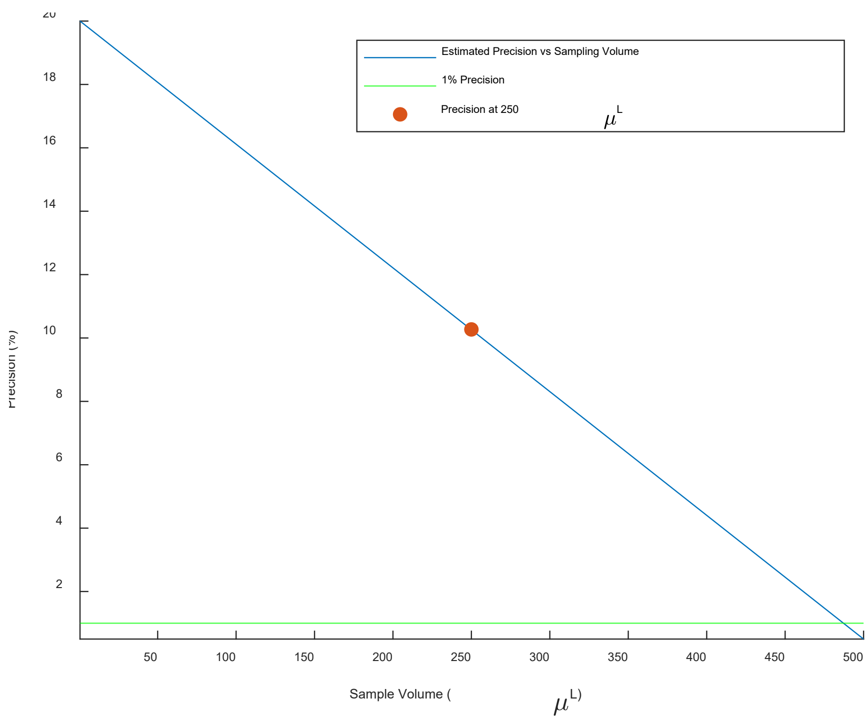


FIGURE 6.1.4.1: PRECISION VS. SAMPLING VOLUME REQUIREMENTS

Delivery Flowrate:

To meet the delivery flowrate requirement, we **run the peristaltic pump at a flowrate of 1 mL/min**. We use the maximum of the desired range to meet the time requirements discussed in section 6.1.1

Pressure and Factor of Safety:

Finally, pressure calculations were run on the syringe, 6-port-injection valve, peristaltic pump, and all tubes enclosed in the system. Starting at the syringe pump, a force of 66.7 N is required to achieve a flowrate of 3730 μL/min. Given that the syringe has an inner diameter of 8.24 mm, the pressure in the syringe during sample input and output was found.

$$P_{syringe} = \frac{F_{syringe\ pump}}{A_{syringe}} = \frac{F_{syringe\ pump}}{\pi\left(\frac{D}{4}\right)^2} = \frac{66.7\ N}{\pi\left(\frac{0.00824\ m}{4}\right)^2} \approx 1250.8\ kPa$$

Given that the syringe has a pressure rating of 2758 kPa, the syringe is within a safe pressure range during use with a factor of safety of 2.2. From here, the pressure in the sample loop during sample injection via the syringe pump and needle seat was calculated using Bernoulli's equation to account for the change in pressure from the change in diameter from the syringe to the tube and the Hagen-Poiseuille equation to account for the pressure drop due to tube drag. Due to the relatively small heigh of the device, height in the former was neglected and assumed to have a negligible effect on the pressure.

$$P_{sample\ loop} = P_{syr} + \frac{1}{2}\rho v_1 - \frac{1}{2}\rho v_2 - \frac{8\mu LQ}{\pi\left(\frac{D_{tube}}{2}\right)^4}$$

The velocities were calculated using the following equation, given the flow rate from the syringe pump and the inner diameter of the tube being 0.03". The length of tubing from the syringe through the sample loop is 2.437 m and the viscosity and rho were retrieved assuming water at 310.15 K, the highest temperature given in the project requirements which would result in the lowest viscosity and lowest pressure drop.

$$v_1 = \frac{Q}{A_{syringe}}, v_2 = \frac{Q}{A_{tube}}$$

These calculations turned out to show that the change in tube lengths and drag from the tubes had a negligible impact on the pressure in the system. This is most likely due to the fairly high starting pressure within the syringe and the fairly small tube diameters and lengths that were used. Thus, the pressure in the sample loop is roughly equal to the pressure in the syringe.

$$\boldsymbol{P_{syringe} \approx P_{sample\ loop} \approx 1250.8\ kPa}$$

Given that the pressure rating for the 6-port injection valve is about 34,473 kPa and the pressure rating for the tubing is about 13,789 kPa, this pressure is well below what these components can handle. These values result in **factors of safety of about 28 and 11** respectively.

Once the fluid is injected into the sample loop, the peristaltic pump takes over at the previously established flowrate of 1 mL/min to pump out the sample to the analytical device. Since pressure and flowrate are directly related, starting pressure within the peristaltic pump was estimated by interpolating. Minimum pressure was estimated at 0 and maximum pressure was estimated at the pressure rating of 200 kPa. Minimum flowrate and maximum flowrate were given by the manufacturer as 0.003 mL/min and 28 mL/min respectively.

$$P_{persitaltic\ pump} = P_{min} + \frac{Q_{actual} - Q_{\min}}{Q_{max} - Q_{\min}}(P_{max} - P_{min}) = 0 + \frac{1 - 0.003}{28 - 0.003}(200\ kPa - 0) \approx 7.12\ kPa$$

Based on the nature of these calculations, the pressure is clearly under the pressure rating of the peristaltic pump, resulting in a **factor of safety of about 4**. Once again, calculations using Bernoulli's equation and the Hagen-Poiseuille equation were done with a negligible effect to the pressure. Thus, the pressure at the output of the peristaltic pump is roughly equal to the pressure at the output of the system to the analytical device.

$$\boldsymbol{P_{peristaltic\ pump} \approx P_{out} \approx 7.12\ kPa}$$

Since the ideal max pressure for the system is 100 kPa, this pressure output meets this additional requirement given in conversations with the client.

6.1.5 Temperature Control System

The temperature requirements for the autosampler are to store the samples between 4°C to 37°C. The temperature requirements were met utilizing thermoelectric plates, a heat sink, a fan, a temperature controller, and temperature sensor.

Thermoelectric plates operate by creating a temperature gradient. The plates have a hot side with temperature T_H and a cold side with temperature T_C. The temperature difference between the hot and cold sides is represented by ΔT. The maximum temperature difference between the hot and cold sides is given by the manufacturer as ΔT_{max}hen cooling, the thermoelectric module ejects heat, which is represented by Q_C, also known as the cooling capacity. The cooling capacity can be determined from the performance curves for the thermoelectric module using the desired ΔT.

The maximum cooling capacity is given by the manufacturer as $Q_{C,max}$ = 26 W.

The total amount of heat to be dissipated Q is the sum of the cooling capacity and the maximum voltage V times the maximum current I. The equation for the calculation of Q can be shown below.

$$Q = Q_C + IR$$

In order to store samples at the desired temperatures, the conduction of the test-tube racks must be considered. The material of the test tube racks is composed of 30% aluminum and 70% PLA. The thermal conductivity k of the mixture of these materials is calculated considering their volume fractions as shown below.

$$k = V_{alum}k_{alum} + V_{PLA}k_{PLA} = 0.3 \cdot 237 + 0.7 \cdot 0.13 = 71.191\ \frac{W}{m \cdot K}$$

Based on **the conductivity of the material as 71.191 W/(m·K)**, the requirement for the temperature of the plate can be calculated considering this conductivity. With this k calculated, the difference between the required temperature of the plate to achieve the desired temperature at the test tube was less than 0.5%, so the temperature difference was deemed not significant. In order to achieve the desired temperature, the temperature of the cold side of the plate will be set directly to that desired temperature.

An example calculation for the amount of heat ejected when cooling to 4°C is shown below, when the temperature of the hot plate when cooling is set to T_H = 50°C. The Q_C determined from the chart was 18 W.

$$Q = 18 + (3)(12) = 54\ W$$

For optimal performance of the thermoelectric plates, Q must be completely dissipated from the system. This was achieved using a heat sink and fan. The system was calculated to be able to dissipate heat for the maximum requirement, when $Q_C = Q_{C,max}$hich is given by the manufacture as 26 W. The Q for this situation is **62 W**.

The required thermal resistance of the heat sink was calculated using the equation below, where ΔT is the difference between T_H and the desired exit temperature, or room temperature.

$$R = \frac{\Delta T}{Q}$$

For the most extreme case, when $Q_C = Q_{C,max}$he thermal resistance was calculated as shown below. For the calculation of ΔT, 21°C was used as room temperature.

$$R = \frac{50 - 21}{62} = 0.468\ \frac{°C}{W}$$

The heat sink selected has a thermal resistance of 0.21°C/W at 3 m/s of airflow. The airflow created by the fan selected is 3.2 m/s, so the 0.21°C/W will be achievable. This thermal resistance gives **a factor of safety of 2.23**.

The temperature control unit selected operates at a maximum voltage of 50 V and maximum current of 20 A. The above calculations were for the thermoelectric plates were done at 12 V, 3 A operation for each plate. The temperature controller will be connected to all thermoelectric plates in parallel. A temperature sensor will be attached to one plate for the feedback loop, and the control signal will be sent to all plates to control the temperature. With this configuration, there is a safety factor of 1.11 in the operation of the temperature controller.

In consideration of failure modes for the temperature control system, the operating temperatures of the thermoelectric plates was considered. The operating range for the plates is -55°C to 83°C, which is far outside of the predicted operational temperature of the autosampler. The ability of the thermoelectric plates to perform is not an expected failure mode of the temperature control system.

Another potential failure mode of the temperature control system may include the operation of the temperature control unit. The expected current running through the temperature controller is very close to the maximum operating point. Should failure occur in the temperature control unit, the result would be that the thermoelectric plates are not able to meet the set temperature.

The time to cool a desired sample can be determined using a lumped capacitance assumption for the test tube trays. The below equation can be utilized considering the lower temperature bound case. Initial and environmental temperatures are considered, as well as material properties of the ambient air and geometrical quantities of the sample trays.

$$t \ = \ \left(\ln\frac{(T_f - T_\infty)}{(T_i - T_\infty)}\right)\cdot\left(\frac{\rho V c}{hA}\right) = \left(\ln\frac{(25-21)}{(21-4)}\right)\cdot\left(\frac{-1.225\cdot 0.0273\cdot 72787}{25\cdot 0.875}\right) = 161\ sec$$

Therefore, the time needed to cool samples from an initial temperature of 25°C to 4°C is around **161 seconds**, or just under 3 minutes.

6.1.6 Margin of Safety Summary

With all subsystems for the autosampler now analyzed for potential modes of failure, it is important to note the critical margin for each component of the overall system. The margin considers the maximum strength of the part used, the design factor of safety, and the calculated stress on the part. Tabulated below in Table 6.1.6.1 are the critical margins for each component of the designed autosampler, separated by subsystem, with the load case and failure mode identified for each.

TABLE 6.1.6.1: MARGIN OF SAFETY SUMMARY BY SUBSYSTEM

Subsystem	Part	Load Case	Failure Mode	Design FOS	Actual FOS	MOS
Enclosure	Side Tube	Vertical load of 1056 pounds at the top of the tube.	Buckling	2	9.56	2.77
	Rivet	Bearing stress of 153.4 pounds at the center of the rivet.	Shear	2	284	142
Motion	Lead Screw	Vertical load of 1.1 pounds at the midpoint of the lead screw	Bending and Torsion	2	8.56	3.28
	Guide Rail	Vertical load of 0.21 pounds at the midpoint of the guide rail	Bending	2	1898.46	949
	Bearing	Vertical load of 1.1 pounds acting across the lower half of the bearing bore	Bearing	2	278.3	138
	Fasteners	Vertical load of 1.1 pounds acting on the cross-sectional area of the fasteners	Shear	2	887	442
	Motor Bracket	Distributed vertical load of 1.1 pounds acting across the bottom surface of the bracket	Bending	2	2.67	0.33
Fluids	Syringe	Pressure exceeds pressure rating of 2758 kPa	Pressure	2	2.2	0.1
	Tubing	Pressure exceeds pressure rating of 13,790 kPa	Pressure	2	11	4.5
	6-Port Injection Valve	Pressure exceeds pressure rating of 34,474 kPa	Pressure	2	28	13
Temperature Control	Heat Sink Module	Necessary dissipation through the heat sink module of the maximum heat produced, or 62 W.	Thermal	2	2.23	1.12

7 Design for X

7.1 Design for People and Safety

Hierarchical task analysis is a useful method for defining tasks from the user's perspective. Its approach aids in understanding how users complete tasks when using a product or system. Hierarchical task analysis tables (Table 7.1.1 and Table 7.1.2) were used to showcase how the product was designed for people and safety and breaks down user interaction with the product into easily understandable tasks.

The autosampler design focused heavily on the product being ergonomic, usable, accessible, and safe to ensure the user interaction was easy and efficient. The use of a simple power switch as well as computer interface allowed for the user to easily power on and use the autosampler with minimal confusion or learning needed. These features aid in proving both the ergonomic and usable nature of the product. A notable requirement for the design process was minimizing the system's size and weight. The autosampler introduced in this report achieved just that, minimizing size and weight, making the ability to move the system extremely easy for any user, if ever needed. The added handle to the enclosure's door also allows for ease of access for any user. Both of these factors contribute to the accessibility of the design. Finally, safety was at the forefront of the design process. The enclosure of the autosampler was designed with safety of the user in mind, ensuring that the entirety of the motion, fluidic, and temperature control systems were covered, protecting the user from potential malfunctions. Located near the bottom of the enclosure is an emergency shutoff switch, purposefully placed to make sure that if anything begins to go wrong with the autosampling system that the user can easily and quickly shut down the product. Each component of the overall product was additionally evaluated for failure modes, ensuring the autosampler's integrity and safety.

7.2 Design for Aesthetics

The temperature control subsystem is easily packaged as a single subassembly within the enclosure. The main components, the thermoelectric plate array, heat sink, and cooling fan, are secured together and neatly positioned under the test tube racks. This still ensures that the heat exchange and dissipation can effectively occur, while making the subsystem visually pleasing.

The autosampler enclosure is also designed to be appealing to users. The enclosure features aluminum tubing to provide a sleek and seamless appearance with the use of rivets and nylon corners to reduce any sharp edges. Accessories like stainless steel door hinges and knobs were used for both the front door and the top lid in order to provide good appeal and corrosion resistance.

Precision T8 lead screws, a linear actuator, and custom 3D-printed mounts are seamlessly integrated to create a clean and professional appearance. The components are arranged for optimal functionality while maintaining a tidy look, with 3D-printed parts enhancing alignment and stability.

TABLE 7.1.1: HIERARCHICAL TASK ANALYSIS TABLE PART 1 – SET-UP

#	Task	Product Feature	Feature Properties	Sensory Demands	Cognitive Demands	Motor Demands	Likely Errors/ Safety	Improvements
1. Set-up								
1.1	Turn on autosampler via power button	• Power switch	• Shape, switch force	• Feel when switch has engaged	• Verify correct switch and all the way down	• Use light force to push switch in	• User accidently hits emergency stop instead	• Better labels for on/off
1.2	Place samples into tray	• Pin plate • Vials	• Alignment holes	• Feel when alignment pins are in pin plate	• Verify correct orientation of vials	• Drop vials/samples gently in tray	• User spills samples	• Softer trays
1.3	Place tray into autosampler	• Hinged door with handle and pin plate	• Alignment holes, door magnet force	• Align the pin holes and ensure tray drops in	• Visually locate where the tray should sit in the enclosure	• Hold tray and drop in	• User spills samples • User bumps into needle with hand	• Provide "Sharp Object" warnings on the enclosure
1.4	Enter needed information on computer	• Personal computer and dedicated temperature controller	• Shape, dimensions, button force	• Read the display and ensure the correct parameters are entered	• Know the necessary parameters and how to reach those through each interface	• Physically plug Arduino from autosampler into computer	• Computer typos/errors	• Create a dedicated console for all operations on the front of the autosampler
1.5	Fill cleaning solution beaker if empty	• Removable, open top beaker	• Shape, dimensions	• See where the needle is in the enclosure	•Visually inspect level of solution already in beaker	• Dexterity to maneuver hand within enclosure	• User attempts to fill the beaker in the enclosure and spills • User hits needle while maneuvering in the enclosure	• Ensure the user realizes via product instructions that the beaker can be removed to fill outside of the enclosure • Provide "Sharp Object" warnings on the enclosure
1.6	Empty waste jug if full	• Jug with screw cap	• Shape, dimensions, opening torque	• Locate back exterior of enclosure to find jugs	•Recognize you must twist the cap off	• Dexterity and strength to twist cap off	•User confuses waste jug with phase jug	•Clear labels for jugs
1.7	Fill mobile phase jug if empty	• Jug with screw cap	• Shape, dimensions, opening torque	• Locate back exterior of enclosure and find jugs	•Recognize you must twist the cap off	• Dexterity and strength to twist cap off	•User confuses waste jug with phase jug	•Clear labels for jugs
1.8	Align Needle	• Needle holder	• Shape, dimensions, tightening torque, alignment holes	• Locate linear actuator • Feel resistance when tightening nuts	• Ensure needle is straight and understand alignment process	• Precise hand movements to align needle • Apply light but firm force to not bend needle	• User overtightens the nuts leading to needle misalignment	• Provide clear visual alignment markers • Provide recommended tightening torque

Table 7.1.2: Hierarchical Task Analysis Table Part 2 – Run, Analyze & Repeat

#	Task	Product Feature	Feature Properties	Sensory Demands	Cognitive Demands	Motor Demands	Likely Errors/ Safety	Improvements
2. Run								
2.1	Run autosampler	• Start button on program	• Shape, dimensions	• Locate button	• Know correct start process	• Click of a mouse	• User starts without inputting correct inputs	• Provide a confirmation screen that verifies input parameters
2.2	Needle Moves	• Motion mechanism	• Shape, dimensions	• Observe needle movement	• Recognize any problems		• Motion movement stalls	• Include audible and visual warnings if needle encounters resistance
2.3	Sample run through sample loop	• Peristaltic pump, microsyringe pump, push to fill sample loop	• Tube length, pressure, flow rate					
3. Analyze & Reset								
3.1	Analyze results	• Output sample to analytical device	• Tube length, pressure, flow rate		• Ensure sample has been studied by analytical device		• Sample has not made it to analytical device	• Provide maintenance instructions for autosampler in product instructions
3.2	Remove tray from autosampler	• Hinged door with handle	• Alignment holes, door magnet force	• Align the pin holes and ensure tray gently lifts	•Visually locate where the tray sits	•Hold tray and gently lift	•User spills samples • User bumps into needle with hand	• Provide “Sharp Object” warnings on the enclosure
3.3	Repeat from 1.2							

7.3 Design for Maintainability

The fluids subsystem accounts for ease of maintenance by having the peristaltic pump and microsyringe pump outside of the enclosure. Also, should the needle break or be bent at any point, it can be easily replaced due to it using a Luer Lock connection. This industry standard connection allows the needle to be easily removed and reattached from the bracket that connects it to the motion system.

The enclosure of the autosampler was designed with ease of sanitizing and maintenance in mind. The top polycarbonate panel was designed to be removable with magnets and a stainless-steel knob to allow for easy maintenance or repair of the movement system. The front door also utilizes the same stainless-steel knob to allow for easy access to samples, while the top deck of the interior is also easily removable via wingnuts for easy access or maintenance to the fluids system or temperature control system.

The temperature control system ensures an ease of maintenance by primarily consisting of easy individual parts to replace and positioning of crucial components. The heat sink and temperature controller are unlikely to fail at any point during reasonable operation. However, the temperature controller is positioned on the front exterior of the autosampler, so it can be easily accessed for maintenance or replaced if necessary. For the thermoelectric plates, the array of 9 plates allows for individual plates to be replaced if failure were to occur in any of them, rather than the entire array. The cooling fan is positioned in an easily accessible spot under the test tube racks, so if the fan were to require service it could easily be reached.

The motion subsystem is designed for ease of maintenance with removable brackets that provide quick access to the T8 lead screws and linear actuator for servicing. The system incorporates standardized fasteners throughout, which simplifies the replacement or adjustment of components. This standardization reduces the need to source unique parts, ensuring faster repairs and reducing the risk of errors when reassembling components and improve the overall serviceability of the system, as replacement parts are readily available, minimizing downtime. The consistent use of these fasteners also promotes a more organized, streamlined assembly process, which ultimately enhances both the design and the ease with which the system can be maintained over its lifecycle.

7.4 Design for Robustness

The autosampler enclosure was specifically designed with robustness in mind. The skeleton of the enclosure was designed with everything having factors of safety well over two, so it can support a lot more weight than necessary to prevent failure from accidents. The skeleton of the enclosure uses 5052 aluminum square tubing with nylon corners to provide the best buckling strength available while also providing a light weight and crack-resistant corners. The hardware used for supporting the internals of the autosampler on the bottom aluminum panel includes aluminum rivets. More rivets were used than necessary to provide a high factor of safety in order to prevent the bottom from collapsing or falling out, even if over-loaded.

The fluids subsystem would fail via pressure exceeding the pressure rating of components or by the needle bending due to hitting a vial. The former failure mode could only potentially occur if the peristaltic pump outputted the mobile phase at a high flowrate since the microsyringe pump’s highest flowrate would not result in a pressure that exceeds the pressure rating of any of the system’s components. Thus, a software limit on the output flowrate of the peristaltic pump was implemented to prevent this failure from occurring. For the latter failure, a visual alignment check before running the autosampler is currently used to align the motion system to the vials and prevent the needle from hitting the vials. An additional action to further mitigate this failure would be to add in a software-based alignment check to check for this needle-vial interference.

For the temperature control subsystem, failure of either the cooling plates or heat dissipation module could result in the samples no longer being viable. In the future, the easiest way to remedy this would be to include a software-based control mechanism to shut off the thermal system rather than strictly a manual emergency stop button. This would result in an automatic cessation of heating or cooling if the samples are not effectively being held within the temperature bound, and make sure that the autosampler is not run if the samples are not continually held in an acceptable state.

The motion subsystem is designed with a fixed-beam setup to enhance stability and ensure reliable, precise movement. By using T8 lead screws paired with linear guide rails, the system minimizes wobbling and flexing, ensuring that the motion remains steady even under varying loads. The fixed-beam configuration supports the lead screws and linear actuator, reducing the risk of misalignment and enhancing the overall structural integrity. This robust design ensures the motion subsystem operates consistently, even in demanding environments, while minimizing the need for frequent adjustments or replacements.

These qualities are further outlined in Table 7.4.1 and Table 7.4.2 which discuss Design Failure Modes and Analysis (DFMEA) and the actions that correspond to the DFMEA.

7.5 Design for Public Health and Safety

Although this design factor is not directly relevant to our device since this autosampler will not be used in public spaces, it was designed to remain sanitary and have minimal issues with corrosion and contamination. All hardware and structural materials used were either corrosion resistant 5052 aluminum or stainless steel. The polycarbonate panels used not only protect almost all air gaps from contamination and sanitary issues, but they also protect any users from moving parts inside. All surfaces normally interacted with by users like the pull knobs for the front door and top lid or even the emergency stop button were chosen with minimal grooves and crevices to maximize ease of cleanliness.

Autosamplers are often used in lab environments, where biological testing is being conducted. They add a great deal of ease to analysis of samples, such as blood. The strong presence of autosamplers in these medical lab applications means the effectiveness of this device will have a great impact on development public health. The easier these devices are to use, the more likely a greater number of labs are to use them, and they will play a greater role in public health safety.

7.6 Design for Global and Social Factors

The fluids subsystem might be affected by global distribution if there are different regulations on high-pressure systems used in private spaces. More research would need to be conducted to see what these regulations might be and what parts in all subsystems would be available in other countries.

The temperature control subsystem might vary in price based on the country that the autosampler is being sent to. The most expensive component of the subassembly, the temperature control module, is made in the United States. Therefore, if the autosampler is being sent for an application outside of the USA, the price for consumers will likely be greater due to increased shipping costs and export tariffs falling on the buyer.

TABLE 7.4.1: DESIGN FAILURE MODES AND EFFECTS ANALYSIS (DFMEA)

PART/ASSEMBLY	FUNCTION	REQUIREMENTS	POTENTIAL FAILURE MODE	POTENTIAL FAILURE EFFECTS	SEVERITY	POTENTIAL CAUSES	CURRENT DESIGN CONTROLS (PREVENTION)	OCCURANCE	CURRENT DESIGN CONTROLS (DETECTION)	DETECTION	RPN
Fluids Subassembly Tubing and Components	**Transfers the fluid sample from the vials to the analytical device.**	• Sampling volume between 0.5 µL and 500 µL • Sampling precision < 20% at 0.5 µL and < 0.5% at 500 µL • Output flowrate between 1 µL/min and 1 mL/min • Must be able to clean all lines between each sampling	Pressure	System can no longer transfer the sample to the analytical device.	10	Pressure in system surpases pressure rating for one of the components due to peristaltic pump flowrate being set to max.	All components at the flow rates required for the system have a pressure rating higher than the expected pressure.	1	Visual inspection	3	30
Needle	**Connects fluid system to vials during sampling to obtain samples.**	Must be able to reach into samples and needle seat to transfer fluid.	Bending	System can no longer obtain samples.	8	Motion system is misaligned causing needle to hit a vial when lowered to a sample.	The user is expected to align the motion system before each use of the autosampler.	3	Visual inspection	1	24
Temperature Control System	**Transfer heat through the test tube rack to samples to hold them at a desired inputted temperature.**	• Lower temperature bound of 4 degrees Celsius • Upper temperature bound of 37 degrees Celsius • Precision of ± 2 degrees Celsius in temperature stability • Over and under temperature alarm	Inability to reach desired temperatures	Samples are no longer viable or in good condition.	8	Failure of any of the thermoelectric plates in the array, or failure of the cooling fan to fail to allow for adequate temperature dissipation.	Routinely check performance and connections of the critical heating and cooling components.	4	Visual inspection and checking thermistors.	1	32
Enclosure	**Provides support to hold and mount all components of the autosampler together while also providing a protective housing from moving parts.**	Must be capable of withstanding general falling and striking hazards that are possible in a laboratory environment	Buckling	Various other subsystem components could be damaged	7	Any user or persons around the autosampler could potentially knock it over, drop something on it, or even fall on it.	Autosampler was made very visible with as few exterior sharp edges as possible and was built very tough to withstand these possibilities	3	Visual inspection for any cracks or bends in structural components	1	21
Motion Subsystem	**Enables precise movement of the needle to facilitate accurate sampling and fluid transfer.**	• Needle can reach and access the samples and cleaning solution • Sampling and cleaning cycle must take less than 1 minute	Misalignment of assembly	A misalignment of the assembly could result in a collision with components, potentially damaging them.	8	The incorrect installation of the assembly or overtightening of components during setup	Tightening torque is specified to prevent overtightening or loosening of fasteners	3	Visual inspection of the alignment components to check for any gaps and observing the motion of the system during operation	2	48

TABLE 7.4.2: ACTIONS RECOMMENDED FOR DFMEA

ACTIONS RECOMMENDED	RESP. & TARGET COMPLETION DATE	ACTIONS TAKEN & EFFECTIVE DATE	SEVERITY	OCCURANCE	DETECTION	RPN
Add in software limit for output flowrate to only be at the desired value.	Daniel Pham (12/1/24)	Software keeps flow rate within the desired range and, thus, pressure in the desired pressure. (11/14/24)	10	1	3	**30**
Add in a software based (as opposed to a human-visual based) alignment check	Potential future improvement	N/A	8	3	1	**24**
Add in a software based shutoff if a consistent over/under temperature is detected, rather than the manual shutoff switch.	Potential future improvement	N/A	8	4	1	**32**
Ensure autosampler is placed in a safe location and add signage around it.	Potential future improvement	N/A	7	3	1	**21**
Incorporate alignment pins, guides, or keyed slots to ensure precise alignment	Potential future improvement	N/A	8	3	2	**48**

7.7 Design for Cultural Factors

Although the autosampler is to be used in a primarily lab-based environment, it will ideally be used in many different countries, with different accompanying cultures. One factor to be considered is the instruction manuals and other text-related features on the autosamplers. Instruction labels will be printed in differing languages based on the target country. Any displayed text on the device will be able to be customized for the primary language in the target country, so that it can be effectively understood and utilized by the user. Additionally, it is important to recognize the different forms of outlet power and wall connections in different countries. Ensuring that any reasonable wall power supply can be paired with an adapter to power the autosampler is crucial to ensuring customer satisfaction.

7.8 Design for Environmental Factors

Should the autosampler be deconstructed, many of the fluid subsystem components could be reused in other applications in a lab, notably the peristaltic pump and the microsyringe pump. Since the syringe in the microsyringe pump is glass, it can also be reused in other applications as well.

The temperature control subsystem has may components that could be recycled or used in different situations for other labs. Each of the components has value in other applications, and would likely not simply become waste.

Components such as the T8 lead screws and linear actuator can be repurposed for other applications. The durable lead screws are well-suited for use in various motion control systems, while the linear actuator can be applied to other lab equipment or automated setups that require precise movement. Reusing these parts helps minimize waste and promotes sustainability by extending the lifespan of valuable components.

7.9 Design for Economic Factors

The temperature control subsystem price could be directly affected by the economic systems in its target market. Equilibrium prices for each of the components as well as the inflation at a given time would affect the price of components between certain points in time. Additionally, the raw material prices would affect the prices. For example, the heat sink is composed exclusively of copper, so it would likely either rise or fall with the price of copper.

7.10 Ethical Considerations

While there are no ethical issues in the design of this project, the ASME Engineering Ethics Canon was referenced for this design [15]. Ethics related to safety were especially taken into consideration given that sharp and moving objects were used in this device. Specific canons that were especially considered for this design are as follows.

A canon outlining how engineers must primarily consider the health and safety of the general public can be seen in this design in the care taken to prevent user injury. Any components designed to be moved or repositioned either have easy magnetic or snap removal, so that they can be easily put into place and easily removed when the need arises. This ensures that users will not exert unnecessary force during routine operation of the autosampler, and greatly reduces the risk of any operational related injury.

An additional canon outlines how engineers should only perform services throughout their areas of expertise. This was considered and enacted by this group by splitting up team members onto sub teams that fit their strengths the best. By designating tasks to each subsystem where each member is confident in the work that they're doing, it is ensured that they will only be producing quality work.

One final canon that was specifically considered was how engineers must act through sustainable practices in their work. As previously mentioned, this autosampler is designed with many parts that can be reused and recycled, or even repurposed into different applications if the autosampler were to no longer be used. This greatly reduces the number of new materials being extracted and used, and lessens the environmental footprint that the autosampler has. Having recyclable parts means that any autosamplers no longer being used can have their parts used in another autosampler. Therefore, this would reduce the costs for manufacturing autosamplers as well.

8 Manufacturing and Costing

In the autosampler design, there are 36 total manufactured parts. For our specialized designs and manufacturing simplicity, many of these parts are 3D-printed. There are seven subassemblies for the autosampler design which can be seen in the Bill of Materials. The manufacturing processes for all manufactured parts can be seen below.

8.1 Enclosure Subsystem

TABLE 8.1.1: ENCLOSURE MANUFACTURING PART E01/2

Polycarbonate Side Panels/Door (EML4501-E01/2)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panels from stock	10	1	10	0.2
Drill holes	5	1	5	0.1
			Total	0.3

TABLE 8.1.2: ENCLOSURE MANUFACTURING PART E03

Polycarbonate Lid (EML4501-E03)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panel from stock	10	1	10	0.2
Drill holes	5	1	5	0.1
			Total	0.3

TABLE 8.1.3: ENCLOSURE MANUFACTURING PARTS E05

Aluminum Upper Deck Sheet (EML4501-E05)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panel from stock	10	1	10	0.2
Drill holes	5	1	5	0.1
			Total	0.3

TABLE 8.1.4: ENCLOSURE MANUFACTURING PART E04/5/6/8/9

Aluminum Tubing (EML4501-E04/5/6/8/9)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut base/top and side beams from stock	10	1	10	0.2
Drill holes	5	1	5	0.1
			Total	0.3

Table 8.1.5: Enclosure Manufacturing Part E07

Aluminum Base Sheet (EML4501-E07)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panel from stock	10	1	10	0.2
Drill holes	5	1	5	0.1
			Total	0.3

Table 8.1.6: Enclosure Manufacturing Part E16

1.5ml Test Tube Rack (EML4501-E16)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D printer	10	1	10	0.2
Print part	2872	1	2872	47.9
			Total	48.0

Table 8.1.7: Enclosure Manufacturing Part E17

15ml Test Tube Rack (EML4501-E17)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D printer	10	1	10	0.2
Print part	2453	1	2453	40.9
			Total	41.0

Table 8.1.8: Enclosure Manufacturing Part E18

96 Well Plate (EML4501-E18)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D printer	10	1	10	0.2
Print part	955	2	1911	31.8
			Total	32.0

8.2 Motion Subsystem

TABLE 8.2.1: MOTION MANUFACTURING PART M01

Lead Screw Motor Bracket (EML4501-M01)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D Printer	10	1	10	0.2
Print Part	35	1	35	0.6
			Total	0.8

TABLE 8.2.2: MOTION MANUFACTURING PART M02

Motor Carrier (EML4501-M02)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D Printer	10	1	10	0.2
Print Part	52	1	52	0.9
			Total	1.0

TABLE 8.2.3: MOTION MANUFACTURING PART M03

Linear Actuator Holder (EML4501-M03)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D Printer	10	1	10	0.2
Print Part	6	1	6	0.1
			Total	0.3

TABLE 8.2.4: MOTION MANUFACTURING PART M04

Actuator Holder Guide (EML4501-M04)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D Printer	10	1	10	0.2
Print Part	101	1	101	1.7
			Total	1.8

TABLE 8.2.5: MOTION MANUFACTURING PART M05

Front Motion Bracket (EML4501-M05)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Bend the sheet using a press brake	7	1	7	0.1
Punch a hole	5	4	20	0.3
			Total	0.5

8.3 Temperature Control Subsystem

TABLE 8.3.1: TEMPERATURE CONTROL MANUFACTURING PART T01

Heat Sink Columns (EML4501-T01)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D printer	10	4	40	0.7
Print part	34	4	135	2.3
			Total	2.9

TABLE 8.3.2: TEMPERATURE CONTROL MANUFACTURING PART T02

Fan Base (EML4501-T02)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D printer	10	1	10	0.2
Print part	105	1	105	1.8
			Total	1.9

8.4 Fluids Subsystem

TABLE 8.4.1: FLUIDS MANUFACTURING PART F01

Fluids System 3D-Printed Pump Tray (EML4501-F01)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Prepare 3D Printer	10	1	10	0.2
Print Part	1293	1	1293	21.6
			Total	21.7

8.5 6-Port Injection Valve Subsystem

Table 8.5.1: 6-Port Injection Valve Manufacturing Part P03

Injection Port Bracket (EML4501-P03)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Bend the sheet using a press brake	7	1	7	0.1
Punch holes	5	1	5	0.1
			Total	0.2

8.6 Deck

Table 8.6.1: Deck Manufacturing Part D01

Aluminum Upper Deck Sheet (EML4501-D01)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panel from stock	10	1	10	0.2
Drill holes	45	1	45	0.8
			Total	0.9

8.7 Front Panel

Table 8.4.1: Front Panel Manufacturing Part C01

Front Panel Sheet (EML4501-C01)				
Manufacturing Process	Est. Time (min)	Qty (#)	Subtotal (min)	(hr)
Cut panel from stock	10	1	10	0.2
Drill vents	5	8	40	0.7
Drill holes	4	1	4	0.1
			Total	0.9

8.8 Assembly Times

The assembly process and times for all subsystems and the final subsystem is shown below based on the Boothroyd and Dewhurst Charts. The total assembly time given from this analysis is 697 seconds, or approximately 11 minutes for assembly. This assembly time only accounts for the mechanical components of the system – there are a number of electrical components that must be wired and hooked up for the final prototype, including the Arduino, temperature controller, thermoelectric plates, and the fan. One hour of time was added to the total assembly labor to account for the wiring time in order to complete a working prototype.

TABLE 8.8.1 MOTION SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Motor Bracket (2)	360	0	360	12/38	15.6
2	Lead Screw Carrier (1)	360	0	360	12/38	7.8
3	Actuator Holder Guide (1)	360	0	360	12/38	7.8
4	Slider Carriage Guide Rail (1)	360	0	360	00/06	6.63
5	Front Motion Bracket (2)	360	0	360	12/38	7.8
6	Linear Actuator (1)	360	0	360	11/38	7.8
7	Actuator Holder (2)	180	0	180	02/38	15.76
8	Horizontal Support (1)	360	0	360	02/38	7.88
					Total Time	77.07

TABLE 8.8.2 TEMPERATURE CONTROL SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Heat Sink Columns (2)	360	90	450	10/40	12
2	Thermoelectric Plates (6)	360	90	450	10/00	6
					Total Time	18

TABLE 8.8.3 FLUIDS SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Peristaltic Pump (1)	360	360	720	91/00	4.5
2	Syringe Pump (1)	360	360	720	91/00	4.5
					Total Time	9

TABLE 8.8.4 6-PORT INJECTION VALVE SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	6-Port Injection Valve (1)	360	360	720	91/00	4.5
2	Fittings (6)	360	0	360	11/38	46.8
					Total Time	51.3

TABLE 8.8.5 DECK SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Deck Plate (4)	180	90	270	00/00	10.52
2	Deck Standoffs (4)	360	0	360	10/38	30
					Total Time	40.52

TABLE 8.8.6 FRONT PANEL SUBASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Temperature Controller (4)	360	0	360	10/38	30
2	Emergency Stop (1)	360	0	360	10/38	7.5
					Total Time	37.5

TABLE 8.8.7 ENCLOSURE AND FINAL ASSEMBLY TIME

Step #	H / I Process	α Angle	β Angle	α + β Sum	H / I Code	Process Time (s)
1	Aluminum Tubing Base Brackets (4)	360	90	450	10/39	38
2	Aluminimum Bottom Sheet (1)	180	90	270	90/30	4
3	Temperature Control Subsystem (16)	360	360	720	10/38	120
4	Fan Base (4)	360	0	360	10/38	30
5	Fan (1)	360	180	540	10/00	3
6	6-Port Injection Valve Subassembly (2)	360	360	720	10/38	15
7	Deck Subassembly (1)	360	360	720	30/30	3.95
8	Beaker (1)	360	0	360	30/00	3.45
9	Aluminum Tubing Side Brackets (4)	360	90	450	10/49	48
10	Front Panel Assembly (4)	360	360	720	10/38	30
11	Needle Seat Bracket (2)	360	360	720	10/39	19
12	Needle Seat (1)	360	180	540	20/00	3.3
13	Horizontal Support Bracket (1)	360	0	360	10/49	12
14	Aluminum Tubing Top (4)	360	90	450	90/49	50
15	Motion Guide Rail (1)	360	360	720	91/41	10.5
16	Magnetic Latch (1)	180	360	540	20/39	9.8
17	Front Door Hinge (4)	180	360	540	20/38	31.2
18	Polycarbonate Panels (5)	180	90	270	90/40	32.5
					Total Time	463.7

8.9 OTS Parts

The total costs for all OTS parts is $3136.72. There are a few items required for our prototype which contribute to this large price, including the microsyringe pump, the 6-port injection valve, and the temperature controller, which alone cost more than half of the total price.

OTS Parts							
Part Name	Part Number	Description	Qty	Vendor	Total Units	Unit Price	Subtotal
Enclosure Subsystem							
Guide Rail Washer	94669A212	Aluminum Unthreaded Spacer, 4.500 mm OD, 2 mm Long	5	McMaster-Carr	5	$ 0.47	$ 2.35
Nylon Frame Corner	18G639	3-Way Corner Connector 2 1/8 in x 2 1/8 in	8	McMaster-Carr	8	$ 4.52	$ 36.16
Panel Corner Bracket	1088A31	Steel Inside Corner Bracket, 2 in Sides for No. 8 Screw Size	16	McMaster-Carr	16	$ 3.92	$ 62.72
Door Hinge	1151A51	304 Stainless Steel Lift-Off Hinge 1-1/2 in High x 23/32 in Wide	2	McMaster-Carr	2	$ 5.38	$ 10.76
Magnetic Latches	4096N226	Surface-Mount Plastic 3 lb. Pull Magnetic Latch	5	McMaster-Carr	5	$ 1.87	$ 9.35
Knurled Knob	60205K64	303 Stainless Steel Knob 10-24 Thread, 3/4 in Head	2	McMaster-Carr	2	$ 7.36	$ 14.72
10-24 Screws (7/16 in Long)	91772A241	18-8 Stainless Steel Pan Head Phillips Screw, 10-24 Thread, 7/16 in Long	2	McMaster-Carr	2	$ 0.14	$ 0.28
No. 10 Washer	91860A047	17-7 PH Stainless Steel Washer, No. 10 Screw Size	2	McMaster-Carr	2	$ 2.41	$ 4.82
Threaded Hex Standoff	91075A309	18-8 Stainless Steel Threaded Hex Standoff 3-3/4 in Long, 6-32 Thread	4	McMaster-Carr	4	$ 7.16	$ 28.64
Wingnuts	93575A201	316 Stainless Steel Wingnut, 6-32 Thread	4	McMaster-Carr	4	$ 0.74	$ 2.96
6-32 Screw (3/8 in Long)	92949A146	18-8 Stainless Steel Button Head Screw	4	McMaster-Carr	4	$ 0.05	$ 0.20
8-32 Screw (1/2 in Long)	92949A194	18-8 Stainless Steel Button Head Screw	4	McMaster-Carr	4	$ 0.08	$ 0.32
8-32 Nut	91841A009	18-8 Stainless Steel Hex Nut	4	McMaster-Carr	4	$ 0.05	$ 0.20
No. 8 Washer	92141A009	18-8 Stainless Steel Washer, No. 8 Screw Size	4	McMaster-Carr	4	$ 0.02	$ 0.08
1.5ml Vial	B0CMQ6W5LJ	Transparent Autosampler Vial with Cap Liner	100	StonyLab	100	$ 0.21	$ 21.00
15ml Tube	B003T3V7VG	Polypropylene Centrifuge Tube with Flat Top Screw Cap	20	Amazon	20	$ 0.16	$ 3.20
Emergency Stop Button	6741K41	Emergency Stop Button For Enclosure	1	McMaster-Carr	1	$ 41.73	$ 41.73
					Subsystem Total		$ 239.49
Motion Subsystem							
Stepper Motor with Integrated Lead Screw	AW030	300mm T8 Lead Screw with NEMA 17 Stepper Motor	2	Iverntech	2	$ 28.99	$ 57.98
Linear Guide Rail	SBR12-300	300mm Linear Guide Rail with 4 Slide Blocks (2 pieces)	1	Guwanji	2	$ 11.65	$ 23.30
Linear Actuator	B0D4Z3VSVN	Linear Actuator with 4-inch stroke	1	LCVXYERQ	1	$ 25.99	$ 25.99

Lead Screw Support Set	KP08	8mm T8 Lead Screw Support Set Ball Bearing Pillow Block	2	CHG Store	2	$	1.91	$	3.82
M3 Screws (10mm long)	RM3X10MM 2701	M3 10mm Long Screw Phillips Drive Stainless Steel	12	DigiKey	12	$	0.33	$	3.94
M3 Screws (8mm long)	RM3X8MM 2701	M3 8mm Long Screw Phillips Drive Stainless Steel	2	DigiKey	2	$	0.63	$	1.26
M3 Screws (14mm long)	SIP-M3-14-A2	M3 14mm Long Screw Phillips Drive Stainless Steel	2	Accu	2	$	1.02	$	2.04
Bearings	688ZZ	Flanged Bearing 8x16x5	2	Open Builds Part Store	2	$	1.49	$	2.98
					Subsystem Total			$	121.31
Fluid Transfer Subsystem									
23GA Needle	26270-U	Bevel Tip Needle for Luer Lock Syringes	1	MilliporeSigma	1	$	11.78	$	11.78
3mL Syringe	80089-548	Luer Lock Syringe with Interchangeable Pistons and Barrels	1	Avantor	1	$	13.10	$	13.10
Microsyringe Pump	new-era-ne1000	NE-1000 Single Syringe Pump	1	Spectra Services	1	$	774.25	$	774.25
Female Luer Lock Connector	11203	0.03 inch - 0.063 inch PVC Connector	1	Qosina	1	$	0.52	$	0.52
Male Luer Lock Connector	62000	0.029 inch - 0.03 inch ID PC Connector	1	Qosina	1	$	1.39	$	1.39
6-Port Injection Valve	MHP9900-500-1	PEEK 2-Position, 6-Port Motorized Injection Valve	1	IDEX	1	$	499.99	$	499.99
10-32 Fitting	P-636	Fitting for Tubing of Sizes Varying from 1/8"OD to 3/16"OD	6	IDEX	6	$	29.85	$	179.10
Needle Seat	25767	Needle Seat, PEEK, 0.17 mm ID, 2.3 µL	1	Restek	1	$	213.00	$	213.00
Tubing	1528	ETFE Tubing Natural 1/16" OD x .030" ID x 5ft	2	IDEX	2	$	24.86	$	49.72
¼-28 Fitting	P-249	One-Piece Fitting, 1/4-28 Flat-Bottom, for 1/16" OD	2	IDEX	2	$	12.53	$	25.06
Peristaltic Pump	BW100	3-Roller Micro Flow Laboratory Peristaltic Pump	1	Chonry	1	$	160.00	$	160.00
1L Beaker	EIS-CH0127I	Borosilicate Graduated Beaker, 1000ml, Autoclavable	1	Eisco Labs	1	$	22.99	$	22.99
1L Jug	66954	32 oz. White HDPE F-Style Jug	2	U.S. Plastic Corp.	2	$	1.59	$	3.18
Cap for 1L Jug	66508	33/400 White Ribbed Polypropylene Cap with F217 Liner	2	U.S. Plastic Corp.	2	$	0.12	$	0.24
Swivel Barb Adapter	D-646	Swivel Barb Adapter For 3/32" ID Tubing	1	IDEX	1	$	5.76	$	5.76
Adapter	P-652	Adapter - 1/4-28 x 10-32, PEEK	1	IDEX	1	$	19.46	$	19.46
					Subsystem Total			$	1,979.54
Temperature Control Subsystem									
Thermoelectric Plates	TEC1-12703	Thermoelectric Cooler Cooling Peltier Plate Module	2	Alinan	6	$	5.00	$	30.00
Fan	GDT8025S	80mm 12V Brushless DC Cooling Fan	1	GDSTime	1	$	8.99	$	8.99
Heat Sink	4-535305U	Copper Heat Sink	1	Cool Innovations	1	$	50.00	$	50.00

Temperature Controller	TC-48-20	PWM Temperature Controller	1	TE Technology	1	$ 477.00	$ 477.00
Temperature Sensor	MP-3193	Temperature Sensor	1	TE Technology	1	$ 34.50	$ 34.50
4-48 Screws	91772A741	18-8 Stainless Steel Pan Head Phillips Screws	1	McMaster-Carr	20	$ 0.09	$ 1.85
-	-	-	-	-	**Subsystem Total**		$ 602.34
Raw Materials							
Aluminum Square Tubing	18G633	1in x 1in Square Tubing, Aluminum 6106-T5 (12 ft Stock)	1	McMaster-Carr	1	$ 32.13	$ 32.13
Aluminum Square Tubing	18G632	1in x 1in Square Tubing, Aluminum 6106-T5 (6 ft Stock)	1	McMaster-Carr	1	$ 18.59	$ 18.59
Polycarbonate Sheet	8574K21	Clear Impact Resistant Polycarbonate 24" x 48" x 1/8"	1	McMaster-Carr	1	$ 49.44	$ 49.44
5052 Aluminum Sheet	88895K46	12 in x 24 in x 1/8 in 5052 Aluminum Sheet	1	McMaster-Carr	1	$ 56.23	$ 56.23
0.249'' Aluminum Sheet	8096	12'' x 12'' Aluminum Sheet, 0.249'' Thick	1	Online Metals	1	$ 37.65	$ 37.65
					Subtotal		$ 194.04
					TOTAL		$ 3,136.72

8.10 Cost Model

The cost model gives an overview of the production cost to construct one prototype of the autosampler. The energy cost rate is calculated from a cost per kilowatt-hour of energy. While there are many hours of manufacturing time, much of that time is 3D printing time, which can be done consecutively and does not require active manufacturing labor. Therefore, only 11.1 hours of active manufacturing labor were calculated. Based on all assembly steps, there is a total of 1.2 hours to assemble the autosampler. All labor hours were charged at a rate of $15/hour. The total cost for one prototype is $3,325.61, which is less than the $5000 maximum production cost requirement.

TABLE 8.10.1: COST MODEL FOR MANUFACTURING AND PRODUCTION

Item	Qty.	Unit	Unit Price	Item Total
Energy	31.6	Hour	$ 0.15	$ 4.74
Manufacturing Labor	11.1	Hour	$ 15.00	$ 166.25
Assembly Labor	1.2	Hour	$ 15.00	$ 17.90
OTS Costs	-	-	$ 3,136.72	$ 3,136.72
Total				**$ 3,325.61**

9 Design Improvements

9.1 Temperature Control

If this product were to be scaled up for greater manufacturing, several key changes would be made concerning the temperature control system. These changes would target improved effectiveness of the autosamplers performance, cheaper price, a greater ease of manufacturing, and similar improvement metrics.

One targeted improvement could be to source more powerful thermoelectric plates. Selecting plates with a greater cooling capacity will allow for the desired upper and lower temperature bounds to be reached in less time. Additionally, larger thermoelectric plates could be sourced. This would allow for a reduction in components of the subassembly, which would help decrease manufacturing time, maintenance difficulty, and wiring paths. Particularly, the reduced amount of components will bode well for large-scale manufacturing of the assembly, as the labor costs will fall and more products can be created in a shorter amount of time.

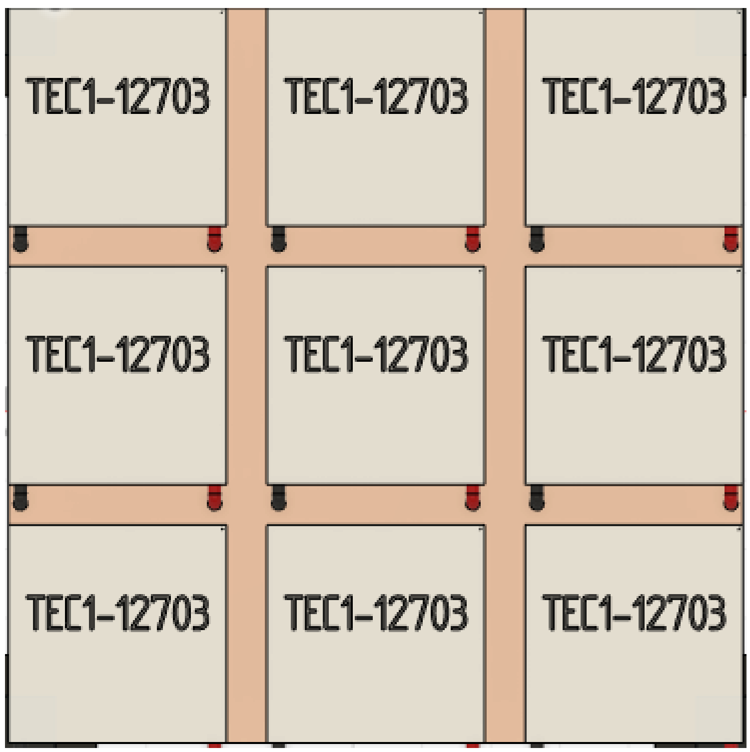


FIGURE 9.1.1: THE CURRENT ARRANGEMENT OF THE THERMOELECTRIC PLATES IN THEIR ARRAY

Additionally, a more powerful cooling fan could be utilized. This would provide the option of using a heat sink with a higher thermal resistance due to the greater linear air speed with forced convection. As a result, this would open up the possible portfolio of heat sinks that could be used, and a cheaper heat sink could be included in the subassembly, making repairs easier and most cost-effective.

9.2 Enclosure

Another critical improvement that can be made to the autosampler is manufacturability, specifically with the enclosure. The enclosure features a lot of structural parts like the aluminum tubing for the skeleton of it that could all be made simpler to manufacture. Due to the location of different parts in the enclosure, like the movement system brackets and the door hinges and magnet latches, it is very difficult to just make each side and top beam the same exact part by having the same length and same hole locations. As the enclosure sits in the prototype, there are three different aluminum side beams as well as three different aluminum top/bottom beams. This makes manufacturing time significantly longer and more expensive compared to what it could be if these beams were all the same part. One improvement that could be made is by using accessories that can be attached either without hardware, via adhesive or a similar method, or even by using hardware like self-tapping/drilling screws that can be installed without a preexisting hole. Unfortunately, larger components like the movement system brackets may not have this option as they have to support a larger amount of weight. Two of the different side beams are provided in the figures below, displaying the different hole locations, making them separate parts.

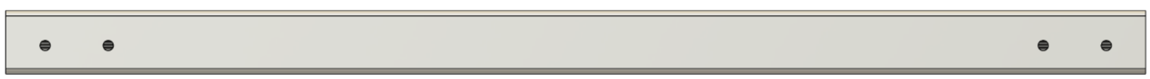


FIGURE 9.2.1: THE 5052 ALUMINUM SIDE BEAMS WITH NO HINGES OR OTHER ATTACHMENTS

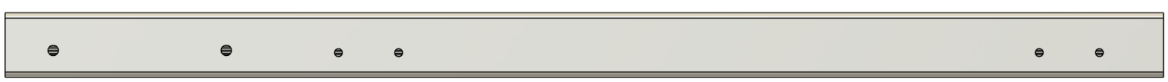


FIGURE 9.2.2: THE 5052 ALUMINUM SIDE BEAMS WITH HOLES FOR THE HINGES AND THE FRONT CONTROL PANEL

9.3 Fluid System

The maximum sampling time for our system exceeded the 60 second requirement. However, this is in part due to another requirement given by the customer; the max flowrate must not exceed 1 mL/min. When this flowrate is combined with the max sampling volume of 500 µL, the time it takes solely to pump the sample out of the sample loop is 30 seconds. This only leaves 30 seconds for the movement system and the rest of the sampling process. The peristaltic pump chosen in this design is capable of pumping fluid at greater flow rates and is variable and controllable based on the voltage supplied to it. This means that a simple design improvement to cut down on the overall sampling time would be to increase the flow rate of the peristaltic pump. It should be noted that if the analytical device still requires a max flow rate of 1 mL/min to process the fluid correctly, there could be a flow rate adapter added right before the microfluidic line to decrease it to this point. This would solve both problems of the time taking too long for a max sampling and still stay within the 1 mL/min requirement for the analytical device. For the purposes of this design, going over the 60 second sampling time requirement was deemed acceptable because this is only the time for a maximum sample volume from the farthest vial away. In most sampling cases, these extremes will not be the norm. The time calculations were also performed for a half sample of volume 250 µL and 0.5 µL. For both of these sampling sizes, the times were well within the given time requirement.

FIGURE 9.3.1: PERISTALTIC PUMP WITH VARIABLE FLOW RATE

9.4 Motion System

Currently, the autosampler features a single-point attachment of the needle to the linear actuator, which may result in issues in stability and reliability during the X and Y motion. Given the system's requirements to operate within a 60-second time requirement, the lateral forces from the high acceleration and deceleration may cause the needle to wobble or bend, potentially leading to misalignment and wear at the attachment point. Additionally, with the needle exposed, there is an increased risk of injury when the user handles samples or when adding or removing the sample tray. While the needle is designed to be replaced after the sampling process is complete, the vibrations and instability from the rapid motion may affect the sample handling.

To mitigate these issues, adding a secondary support located at the tip of the needle such as a needle guide would help stabilize the needle, minimizing lateral movement whilst providing protection to the user. This additional support would reduce the effects of vibration and prevent unwanted bending, ensuring the needle remains aligned during operation. Furthermore, a multi-point attachment system such as a clamping mechanism could also be considered to reinforce the stability of the needle throughout its movement, distributing the forces more evenly. While the small form factor of the needle makes it difficult to effectively clamp the needle, these potential improvements would dramatically improve performance and safety. A combination of these improvements are shown in Figure 9.4.1 with the parts colored bright orange to enhance visibility of the location of the needle.

FIGURE 9.4.1: EXAMPLE OF NEEDLE CLAMP AND NEEDLE GUIDE IMPROVEMENTS

9.5 Market Readiness

This product is complete for the purposes of our client assuming students wanting to do research will manufacture the product, especially if the design improvements stated in sections 0 through 9.4 were to be implemented. If this product were to be prepared for market readiness in the sense that it would be bought pre-manufactured and pre-assembled, additional improvements would need to be made to improve the aesthetics to look sleeker and more fitting of its reliability. Improvements would include adding covers to the lead screws and solid sides to the enclosure deck covering the heat transfer subsystem. This would hide many loose parts such as tubes and electrical components as shown in Figure 9.5.1. While this would improve how the product would be perceived in a mass production setting and encourage people to buy it, this would also increase the cost of the product.

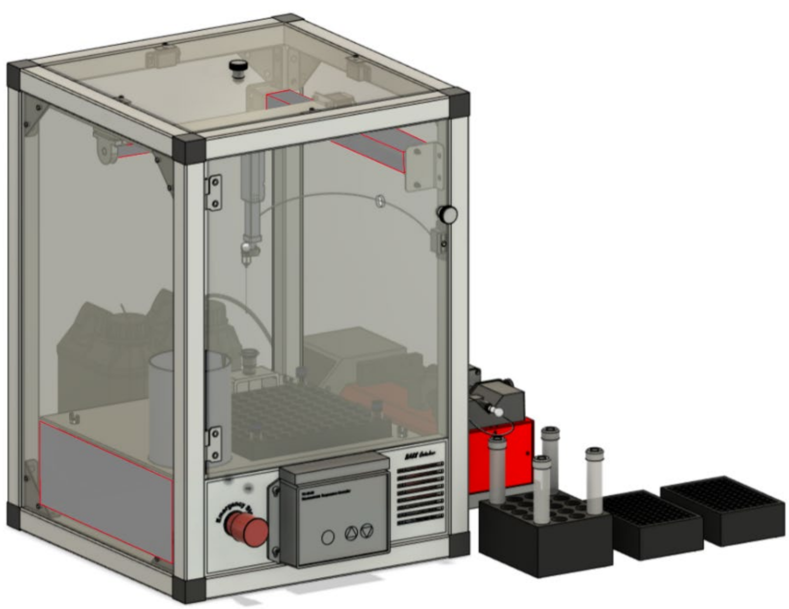


FIGURE 9.5.1: MARKET READINESS IMPROVEMENTS (OUTLINED IN RED)

10 Discussion and Conclusion

In order to break down the design process into a manageable and organized set of tasks, four phases were put into effect to separate the different stages of the design cycle. Namely, these phases are discover, define, develop, and delivery and they make up what is known as the Double Diamond Model. The Double Diamond Model is an iterative approach to the design process that helps create a flow from the generation of a concept all the way through to its delivery. The discover phase of the model consists of initial research into a problem. The define phase is where the discovered problem is refined into different requirements, which are addressed in the following phases. The develop phase involves the creation of potential solutions to the problem. The last phase, delivery, involves narrowing down the solutions and producing the best one. The iteration in the model is apparent when going through the different phases. For example, when in the develop phase, it may become apparent that there is a need for further research, and one must circle back to the discover and define phases to gain better understanding before moving forward with development.

For initial planning and overall arrangement of the project, both an organizational chart and a Gantt chart were created. The organizational chart allocated the team members to their respective sub-teams and the Gantt chart created an overall schedule which included multiple sub schedules for each phase of design. This was a crucial step in ensuring team management and team communication throughout the duration of the project.

With a team schedule in place, the design process began. In the discover phase, the goal was to better understand the problem and the market environment surrounding similar products. Background research was conducted on what autosamplers are and how they work. This was broken down into steps to see what jobs the autosampler must perform in order to meet user satisfaction. In addition to this, a need statement was created to outline the wants and needs of the customer. This would be useful in the define phase as a way to narrow in on what requirements were to be met. User and market research were conducted to find out how users interact with the machine and what some characteristics of these users are. The market size was then estimated, and the design opportunity was analyzed for any overlooked potential within the market. Multiple products already available on the market were also analyzed to see what patents existed and what the competition was doing. From this, a cost vs functionality opportunity map was drawn up. Upon analyzation, it was evident that there was a large target area for products with relatively small size and controllable temperature features.

The define phase organized all information collected during the discover phase, allowing specifications to be set for the design. Initially, the needs, general requirements, and universal standards were listed and imported into a tabular format to be easier to understand and eventually achieve. Moreover, a use model and functional model were developed to show the process of functionality of a system as well as the inputs, outputs, and flow of information, energy, and materials through the product.

Once the target market was determined and the need was defined, the develop phase was able to begin. The phase was broken down into three sections: combination charts, design alternatives, and design evaluation. The combination charts sought to list potential solutions for each subfunction already described. It enabled a clear view of different design possibilities and creative solutions. From these potential selections, multiple design alternatives were sketched and described. The alternatives attempted to include different combinations of parts and system ideas so that they could later be compared with one another. Lastly, in this phase, design evaluation was performed using a Qualitative Pugh Chart. This chart graded different aspects of the various alternative designs with respect to select criteria. Each design was given either a “+1”, “-1”, or “0” and their total was summed to see which showed the most potential. After this, an additional round of grading was performed taking the best parts of the two highest ranked designs to further improve on the weaknesses that were uncovered. This winning design, and its chosen attributes and specifications, would be the foundation of the final design going forward.

The final phase of the Double Diamond Model, the deliver phase, sought to create sketches and drawings for the final design. Here, OTS parts were selected and manufactured parts were created. These parts were then organized into a complete bill of materials and finally combined into a CAD assembly. The CAD assembly was then described and elaborated on to show the implementation and inner workings of the various subsystems. Additionally, in the design analysis, calculations were conducted to prove the design was capable of meeting requirements as intended and was indeed a viable solution to the customer's problem.

As is common for any design process, each sub team experienced rapid achievements as well as numerous setbacks that contributed to the overall completed design. Despite the ups and downs of the design process, numerous lessons were learned from each step, allowing for the entire team to move forward with minimal repeated errors.

The temperature control team found that in designing the temperature control subsystem for the autosampler, using the idea for heating the base of the test tube racks, and conducting heat through them to either heat or cool the samples worked extremely well. This setup allowed for an easy control with minimal extenuating variables, and it also introduced an easy way to dissipate the waste heat through a heat sink and cooling fan module. In order to determine what worked well, it also had to be determined what did not work well. For this subteam, the initial thermoelectric plate that was considered for use proved to not achieve its desired purpose. While the plate itself would have been convenient to use, it was priced at $700, which was an unreasonably high budget to assign to just one component of the product. Purchasing several thermoelectric plates at a much cheaper price would greatly reduce the overall cost of the subsystem, while maintaining adequate performance metrics. The main takeaway for this system's design was that in general, module assembly opens more doors that are potentially cheaper and not significantly harder to access, rather than strictly purchasing a completed assembly from off the shelf.

The enclosure subsystem successfully achieved several key objectives in its design. It securely fastened all other subsystems together, providing strong protection from external hazards while maintaining user safety by shielding moving parts. At the same time, the enclosure was designed to allow easy user access for essential tasks such as tray exchange, beaker refills, and maintenance. However, challenges arose with the initial snap-fit pins used to secure the sample trays. The pins were too rigid, resulting in excessive resistance and potential jerking during tray removal. This issue was resolved by replacing the snap-fit design with simpler pins, as only lateral stability during sampling was required. Throughout the design process, a critical lesson was learned about the importance of evaluating the necessary strength of components before selection. Many parts were initially over-specified, leading to higher costs. By optimizing part selection to meet rather than exceed the performance requirements, future designs could save on cost without compromising functionality or reliability.

Two main problems arose in the design process of the fluidic system: the cost and compatibility of the various OTS parts. When researching manufactured parts that fit the customer requirements, it became very clear that the go-to-replacement parts for on the market autosamplers were quite expensive and often time, exceeded the parameters in scope with this design. Additionally, most of these replacement parts only worked with select autosamplers already offered by the vendor, and when attempting to find information on the parts, most of it was proprietary. To counter this, extensive exploration into other industries that use fluidic systems was carried out. A few wholesalers were found that offered fluidic system parts that met requirements, offered more compatibility, and were within budget. Although the parts were intended for industries such as medical devices, pharmacology, and biotech, they were adequate for the intended purposes of the design. A key component of success with the fluidic system was the already available mappings of different sampling loops and configurations. Such configurations included the push to fill loop, the pull to fill loop, and the split loop designs. When analyzing the different options, it became apparent that the best system implementation for this design was the push to fill loop. Using sources from other autosamplers enabled the team to copy the mappings of the loop and match our parts to that layout. From what was learned throughout this design process, if the development of an improved design was pursued, the knowledge of existing OTS parts and configurations could allow for a quicker and more optimized fluid delivery.

The motion subsystem experienced a few setbacks during the design process. More specifically, supporting the y-axis leadscrew and coordination with other sub teams proved to be problematic for the design process. Initially, the y-axis lead screw was designed to be cantilevered, having no support on its free end. This was thought to help ensure nothing was blocking the autosampler's access door at the front of the enclosure. Following the initial design review, iterative design processes were followed to determine a solution. It was decided that a guide rail could be implemented into the system without posing problems for access through the enclosure door. The guide rail proved to properly support the y-axis linear actuator throughout its entire range of motion. In addition to support issues, coordination amongst sub teams proved to be problematic with the motion system design. As iterations of the motion system were completed, alterations to the autosampler enclosure had to be done in order to fit the sub system. While this may seem like an easy change, it required coordination of all sub teams. The size changes in the motion system required confirmation that all samples were still able to be reached and in a timely manner, requiring coordination with the fluids and enclosure teams. Despite the setbacks posed in the motion system design, there were numerous wins as well. The system's most notable achievement was utilizing a linear actuator for motion in the z-direction, reducing the need for a third lead screw or a gantry movement system. This helped keep the cost of the motion system minimalized. Iterative design teaches a team valuable lessons, and the most important lesson learned by the motion team was that coordination and communication greatly impacts the success of both a group and a design.

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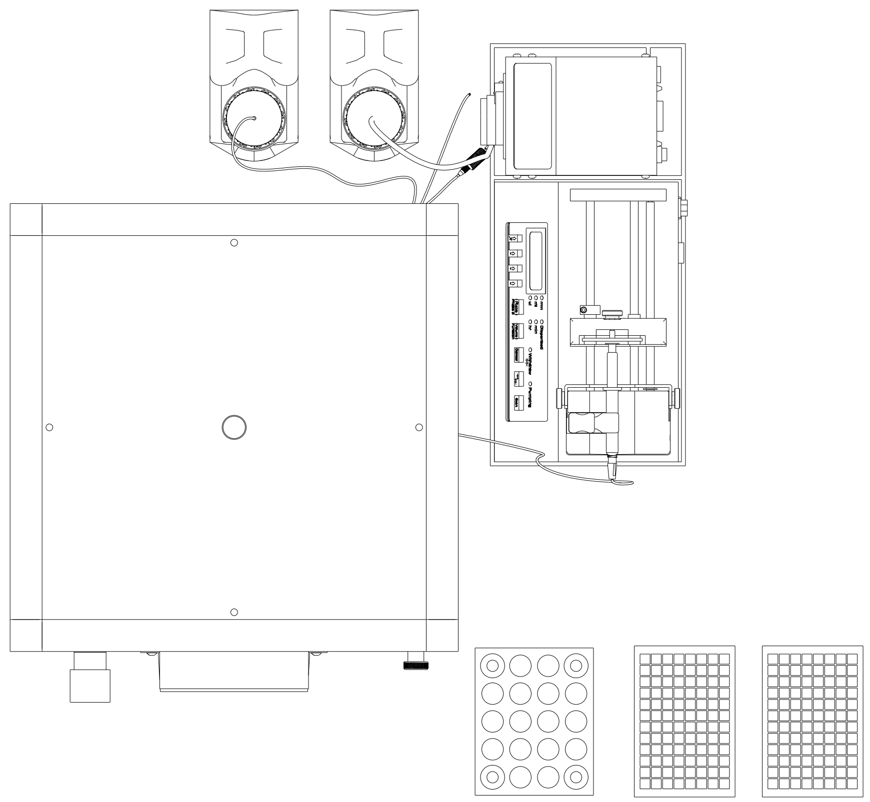
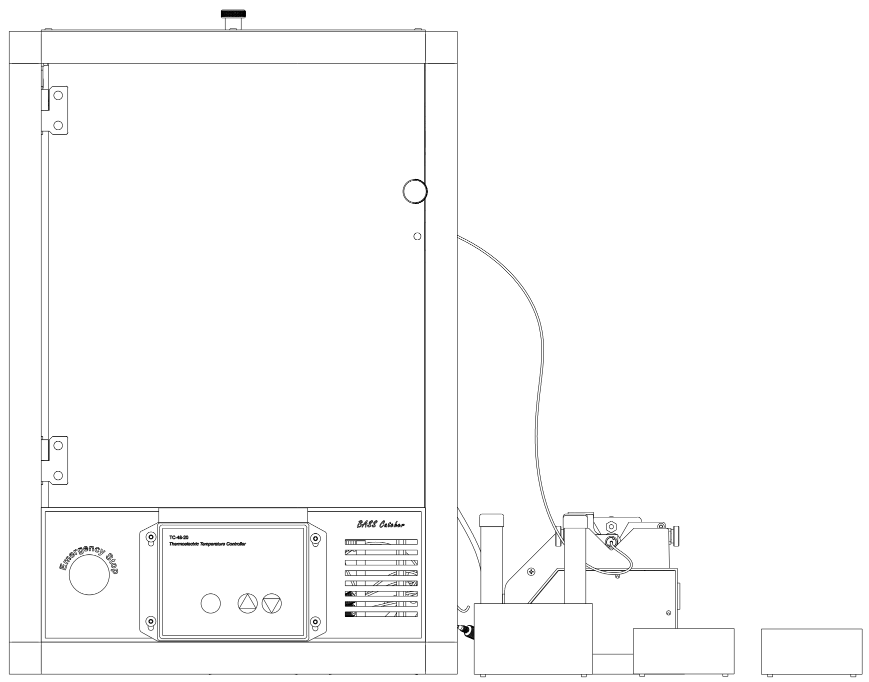
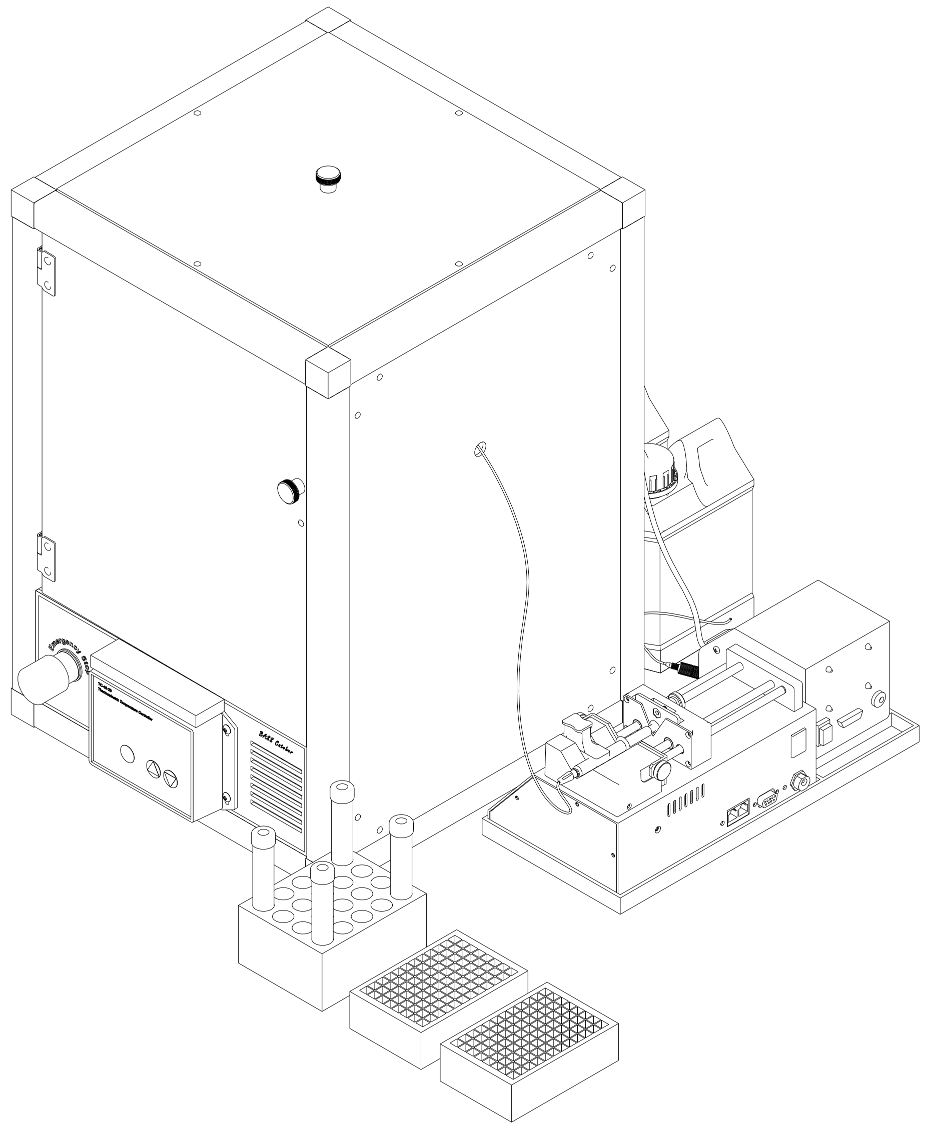
12 Appendices

12.1 Assembly Drawings







TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
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LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

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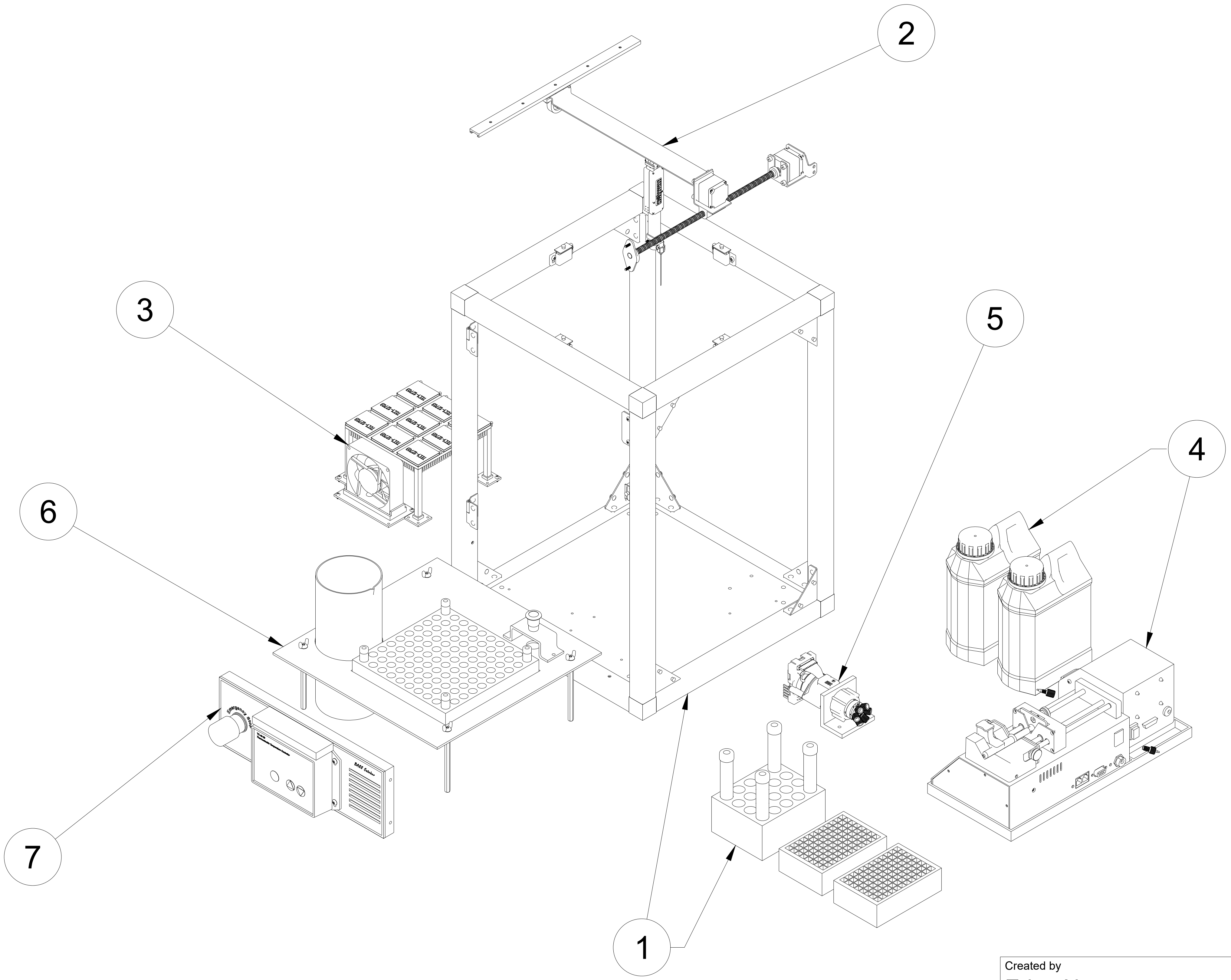
Created on: 11/26/2024	Material: N/A
Title: Enclosure Subsystem and Final Assembly	Part Number: EML4501-A01
	Scale: 1:6 · Sheet: 1/2

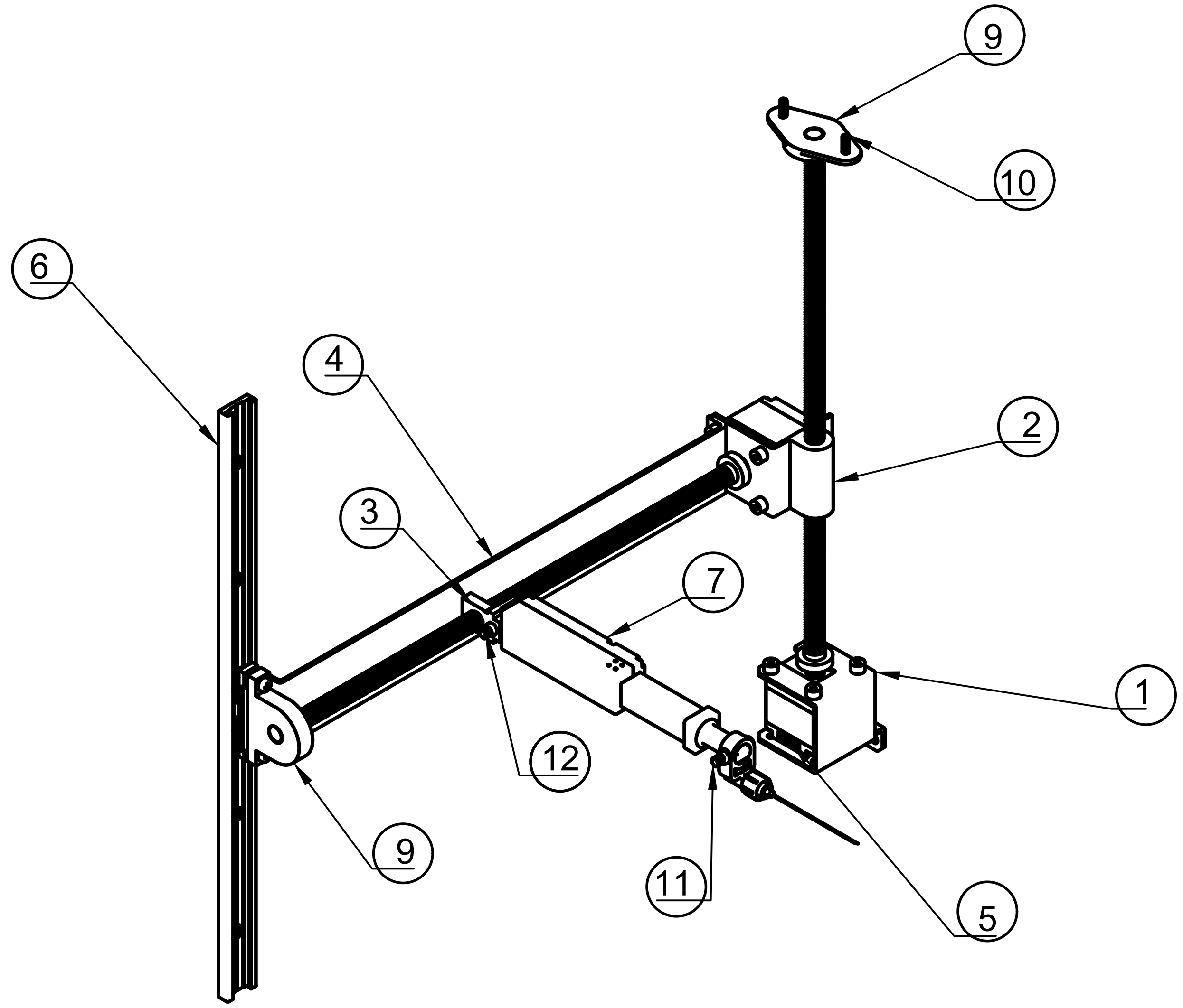


NOTES:
1. PANELS AND SOME FASTENERS HIDDEN FOR VISIBILITY

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Created by Eden Navarrete	Project BASS Catchers
Created on 11/26/2024	Material N/A
Title Encolsure Subsystem and Final Assembly	Part Number EML4501-A01
	Scale 1:6
	Sheet 2/2

Parts List			
Item	Qty	Part Number	Material
1	1	EML4501-M01	ABS Plastic
2	1	EML4501-M02	Steel
3	1	EML4501-M03	Steel
4	1	EML4501-M04	ABS Plastic
5	2	EML4501-M06	T8, Brass
6	2	EML4501-M07	Aluminum, Adonized Silver
7	1	EML4501-M08	Steel
8	2	EML4501-M09	Stainless Steel
9	12	EML4501-M10	T8
10	2	EML4501-M11	T8
11	2	EML4501-M12	T8
12	2	EML4501-M12	Steel



TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
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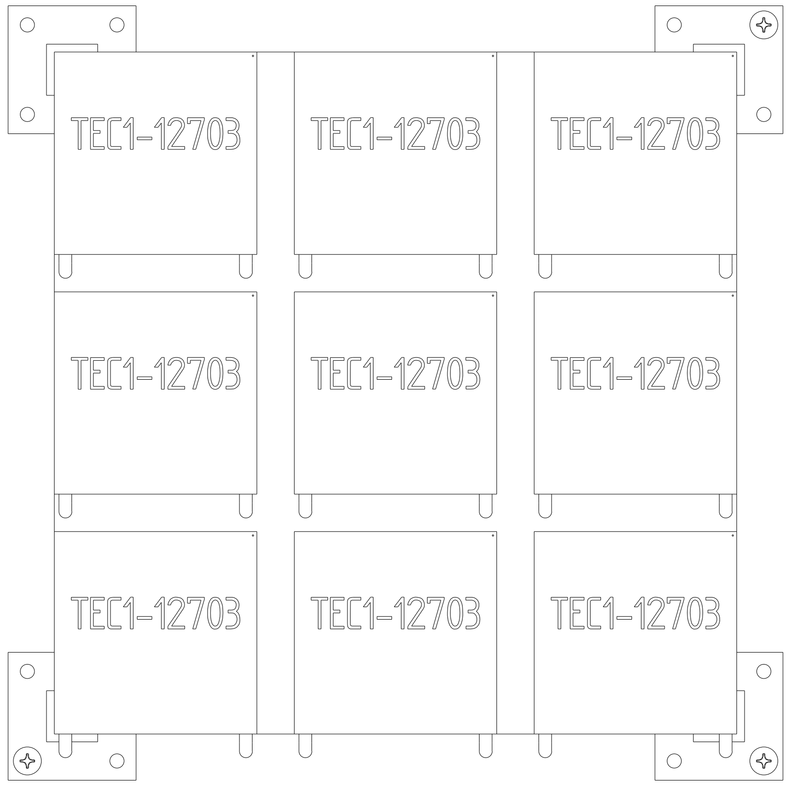
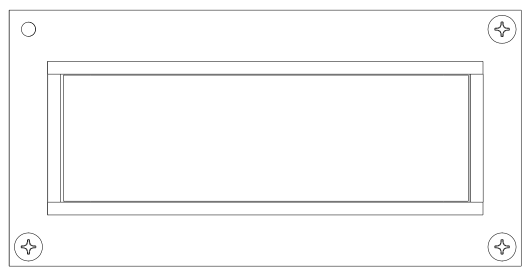
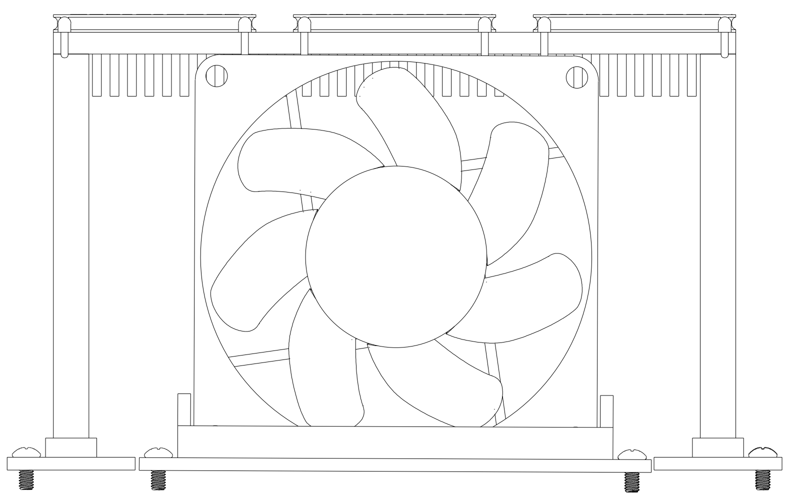
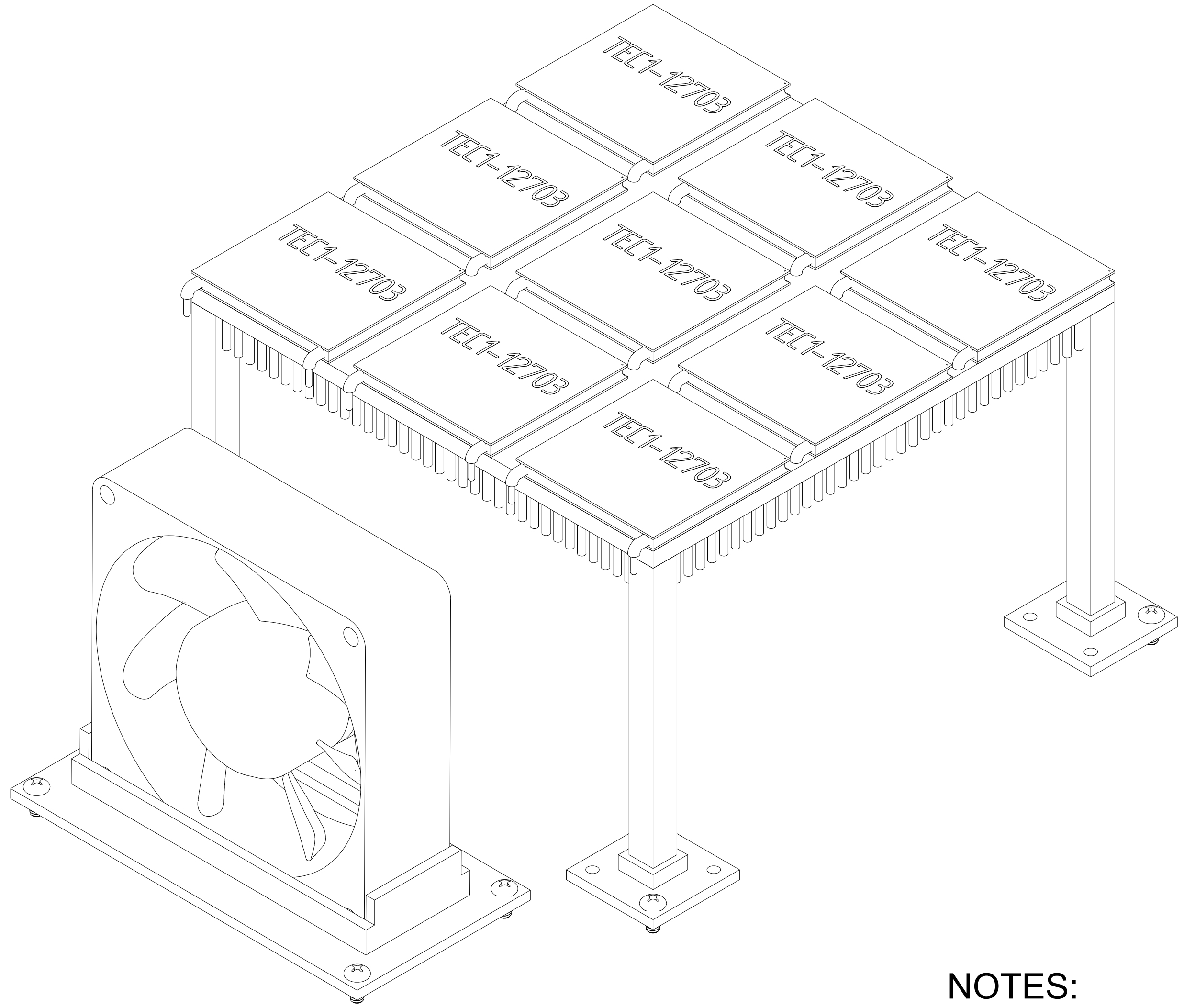
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Created by Alejandro Martinez	Project BASS Catchers
Created on 12/5/2024	Material N/A
Title Motion Assembly	Part Number A02
	Scale 1:3 / Sheet 1/1







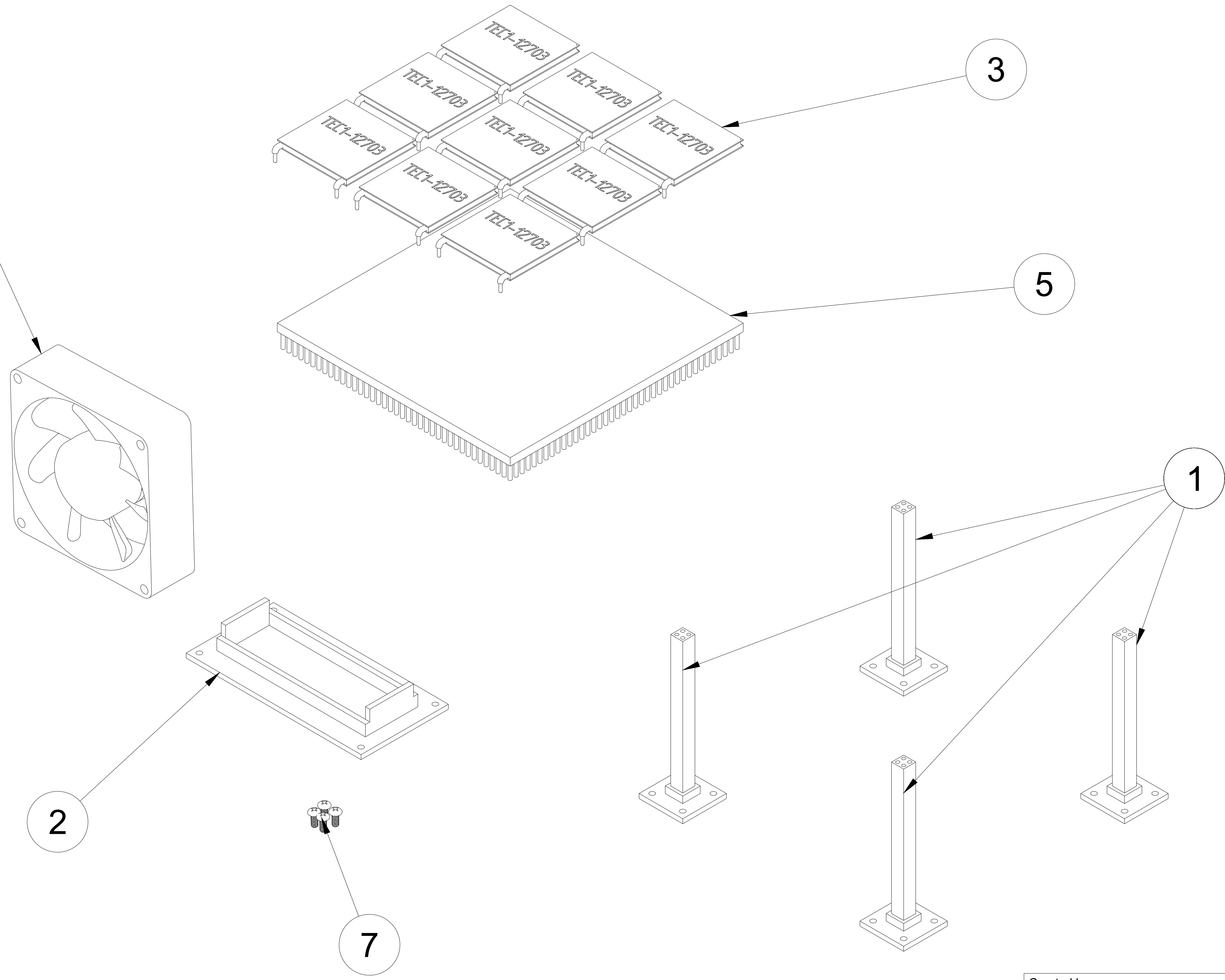


NOTES:

1. NOT ALL FASTENERS SHOWN
2. TEMPERATURE SENSOR NOT SHOWN

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Created by: Eden Navarrete	Project: BASS Catchers
Created on: 11/26/2024	Material: N/A
Title: Temperature Control Subsystem Assembly	Part Number: EML4501-A03
	Scale: 1:1.5
	Sheet: 1/2



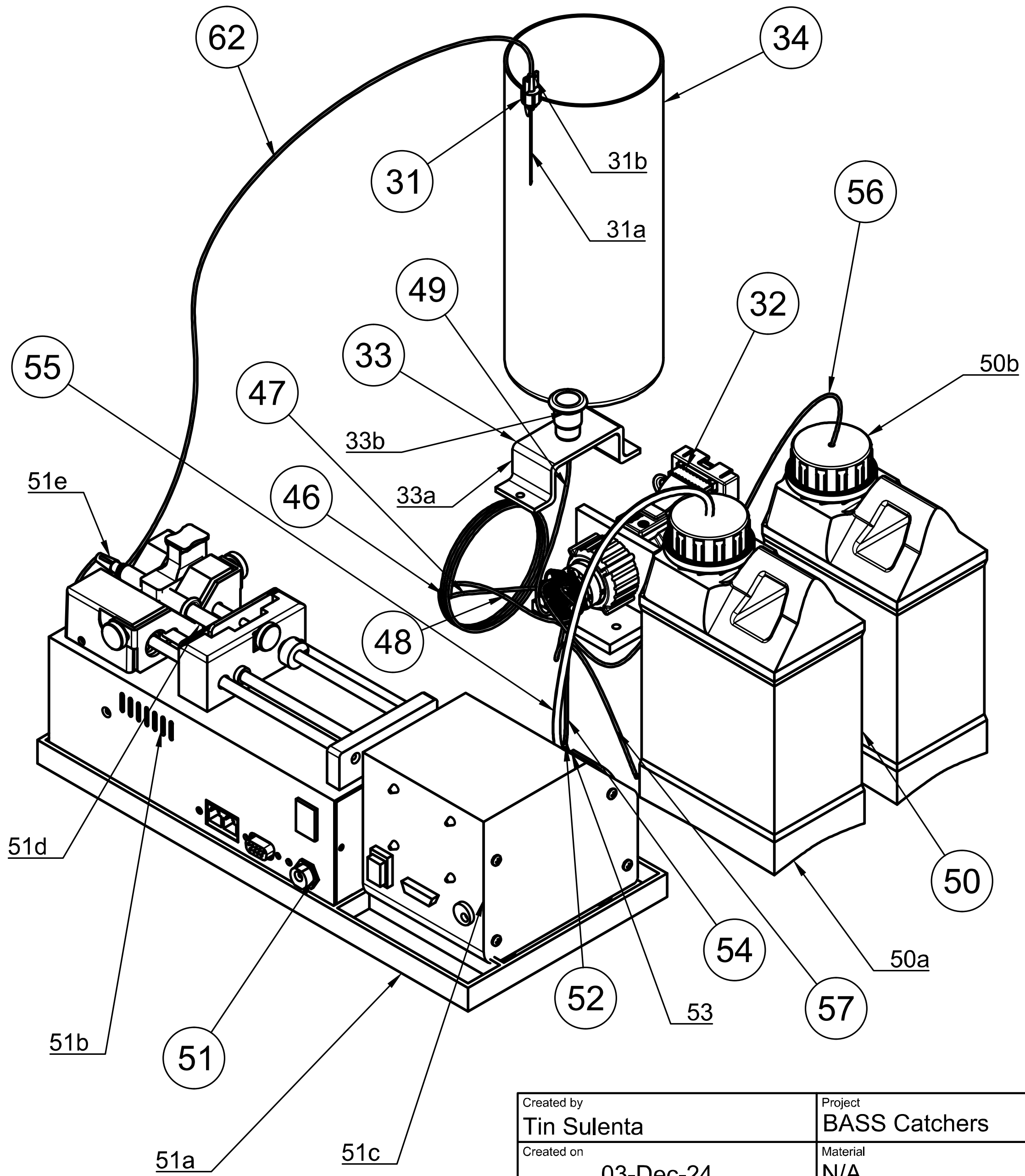
NOTES:
1. NOT ALL FASTENERS SHOWN
2. TEMPERATURE SENSOR NOT SHOWN

TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

Created by: Eden Navarrete	Project: BASS Catchers
Created on: 11/26/2024	Material: N/A
Title: Temperature Control Subsystem Assembly	Part Number: EML4501-A03
	Scale: 1:2
	Sheet: 2/2

Parts List			
Item	Qty	Part Number	Part Name
31	1	N/A	Motion Subsystem Assembly
31a	1	EML4501-F02	23GA Needle
31b	1	EML4501-F06	Male Luer Lock
32	1	EML4501-A05	*6-Port Injection Valve Assembly
33	1	N/A	Needle Seat Assembly
33a	1	EML4501-F16	Needle Seat Bracket
33b	1	EML4501-F07	Needle Seat
34	1	EML4501-F11	1L Beaker
46	1	EML4501-F08	Sample Loop Tube
47	1	EML4501-F08	Sample Loop In Tube
48	1	EML4501-F08	Sample Loop Out Tube
49	1	EML4501-F08	Fluid Transfer Line Tube
50	2	N/A	Jug Assembly
50a	2	EML4501-F12	32 oz. Jug
50b	2	EML4501-F13	Jug Cap
51	1	N/A	Fluids Equipment Tray Assembly
51a	1	EML4501-F01	Fluids System Pump Tray
51b	1	EML4501-F04	Microsyringe Pump
51c	1	EML4501-F10	Peristaltic Pump
51d	1	EML4501-F03	Luer Lock Syringe
51e	1	EML4501-F05	Female Luer Lock
52	1	EML4501-F15	Adapter - 1/4-28 x 10-32
53	1	EML4501-F08	Peristaltic to 6-Port Tube 1
54	1	EML4501-F08	Peristaltic to 6-Port Tube 2
55	1	EML4501-F08	Peristaltic to Mobile Phase Jug Tube
56	1	EML4501-F08	Waste Line Jug Tube
57	1	EML4501-F08	Output Tube
62	1	EML4501-F08	Aspiration Capillary Tube

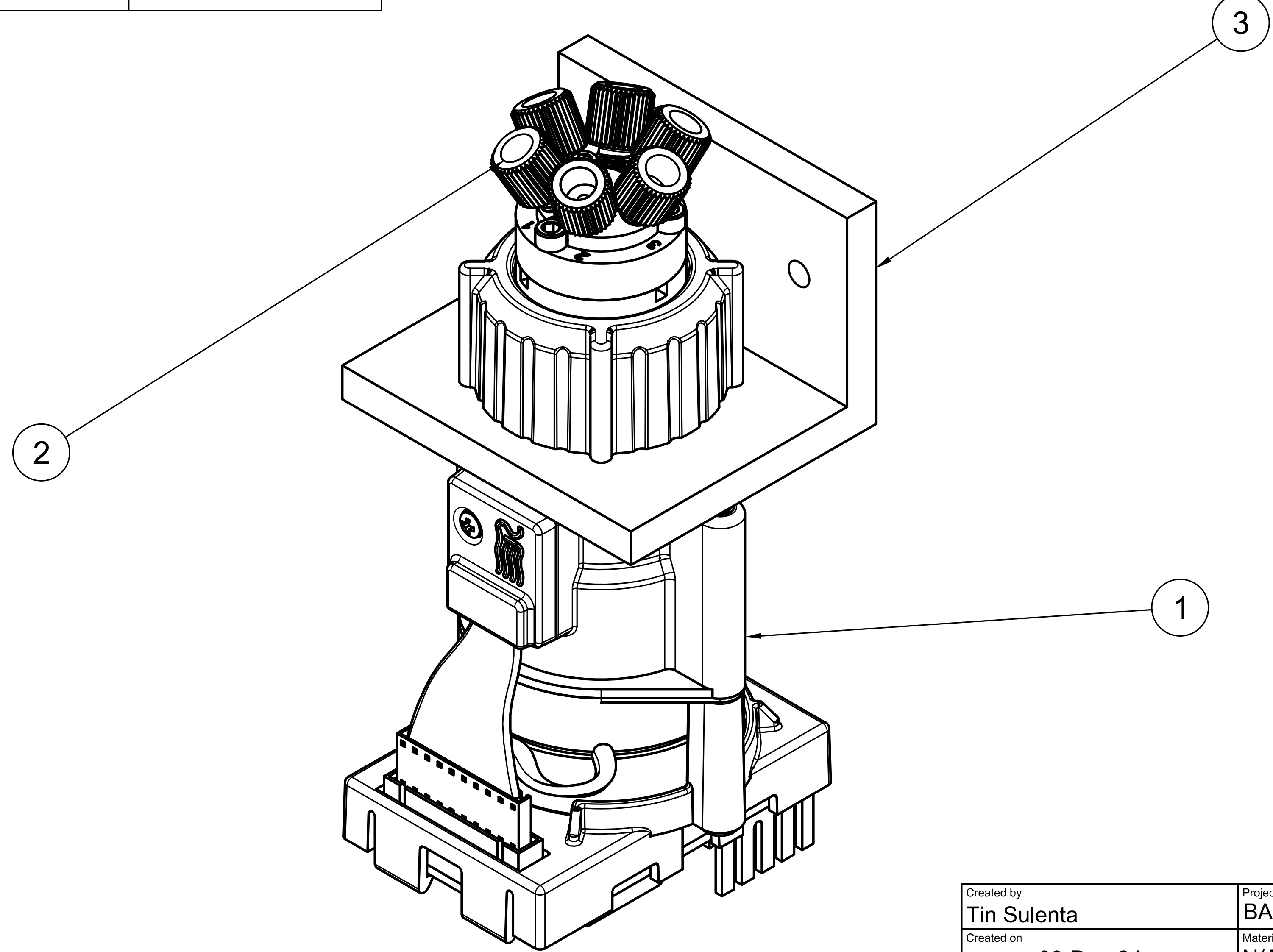
***Note:** The 6-Port Injection Valve Assembly is presented in a separate drawing.



TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

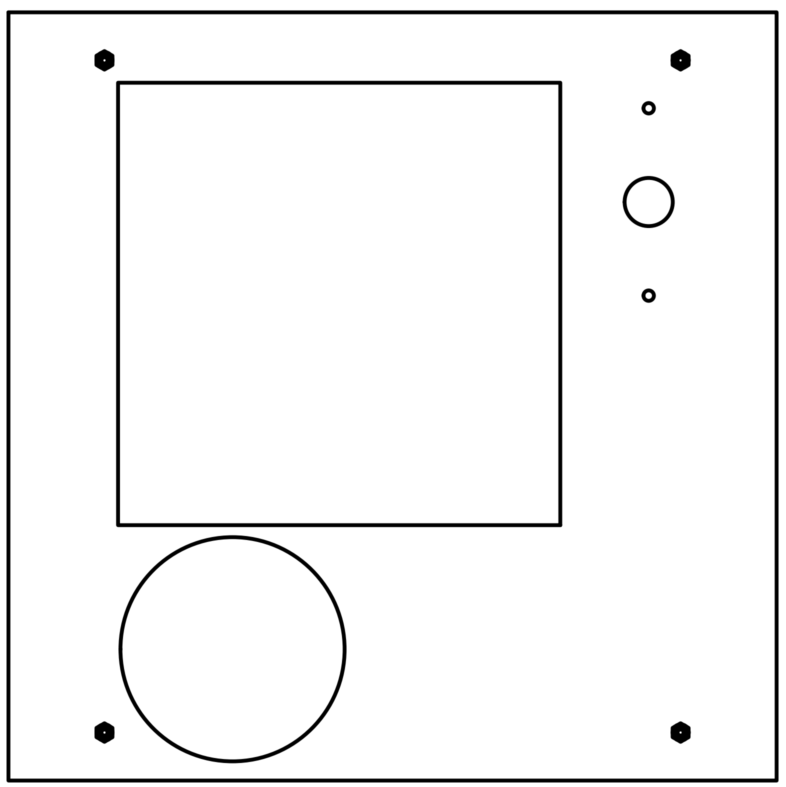
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 03-Dec-24	Material: N/A
Title: Fluids System Assembly	Part Number: EML4501-A04
	Scale: 1:2.7 / Sheet: 1/1

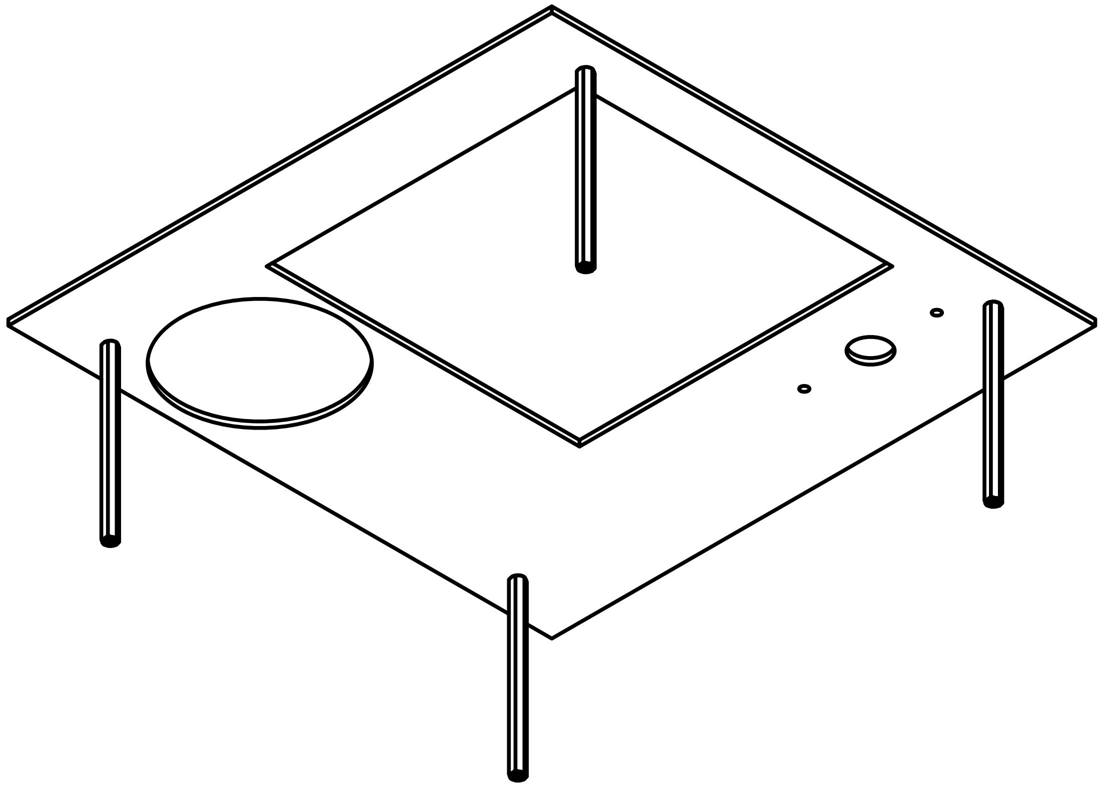
Parts List			
Item	Qty	Part Number	Part Name
1	1	EML4501-P01	6-Port-Injection Valve
2	6	EML4501-P02	10-32 Fitting
3	1	EML4501-P03	6-Port Bracket



TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

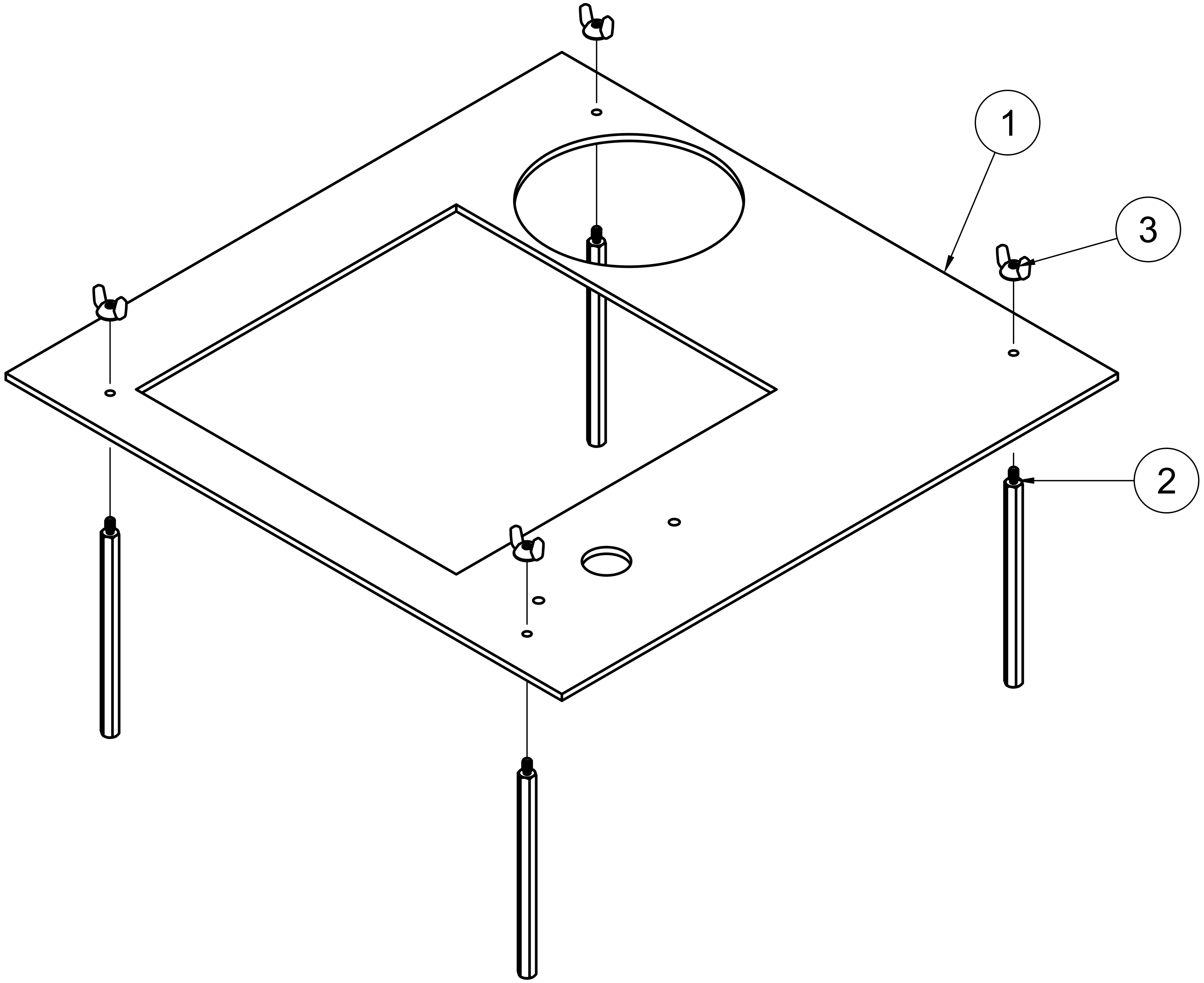
Created by Tin Sulenta	Project BASS Catchers
Created on 03-Dec-24	Material N/A
Title 6-Port Injection Valve Assembly	Part Number EML4501-A05
	Scale 1.5:1 / Sheet 1/1





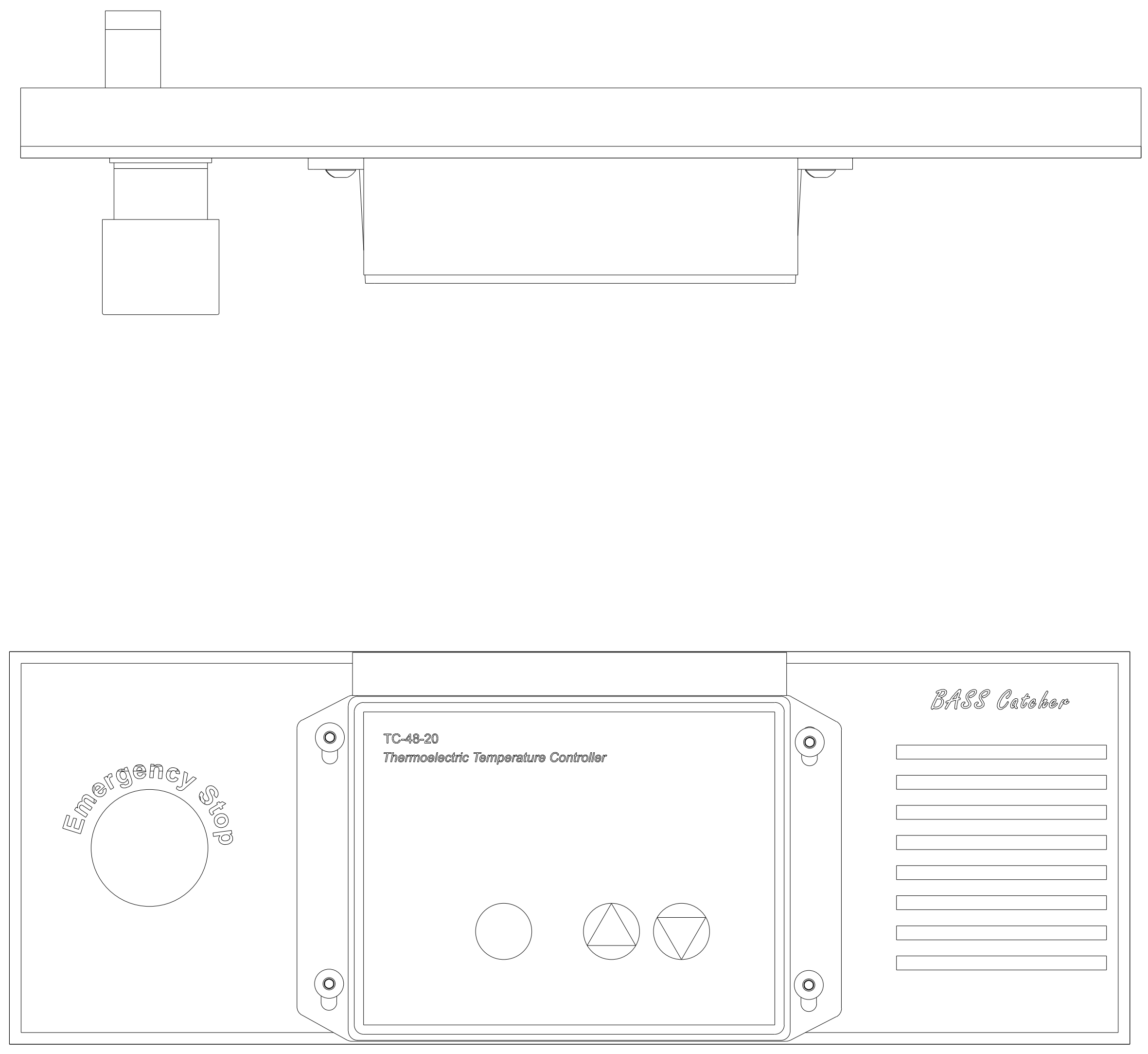
TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

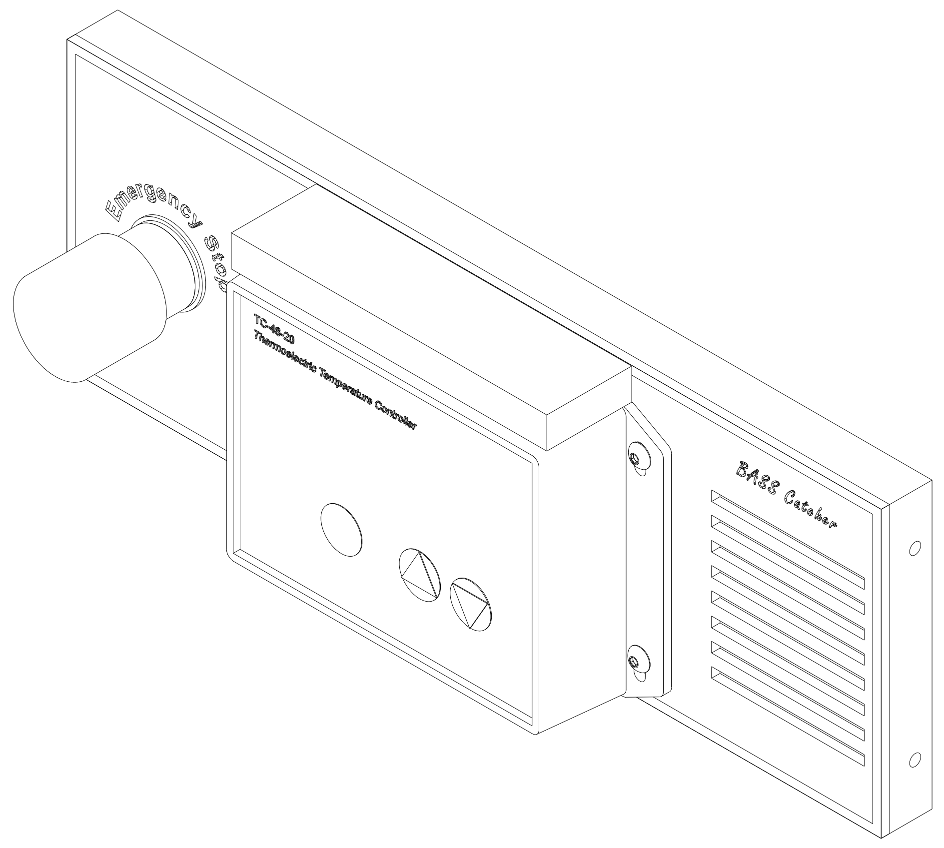
Created by Ayden Leeds	Project BASS Catchers
Created on 11/27/2024	Material N/A
Title Deck Assembly	Part Number A06
	Scale 1:3 / Sheet 1/2



TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

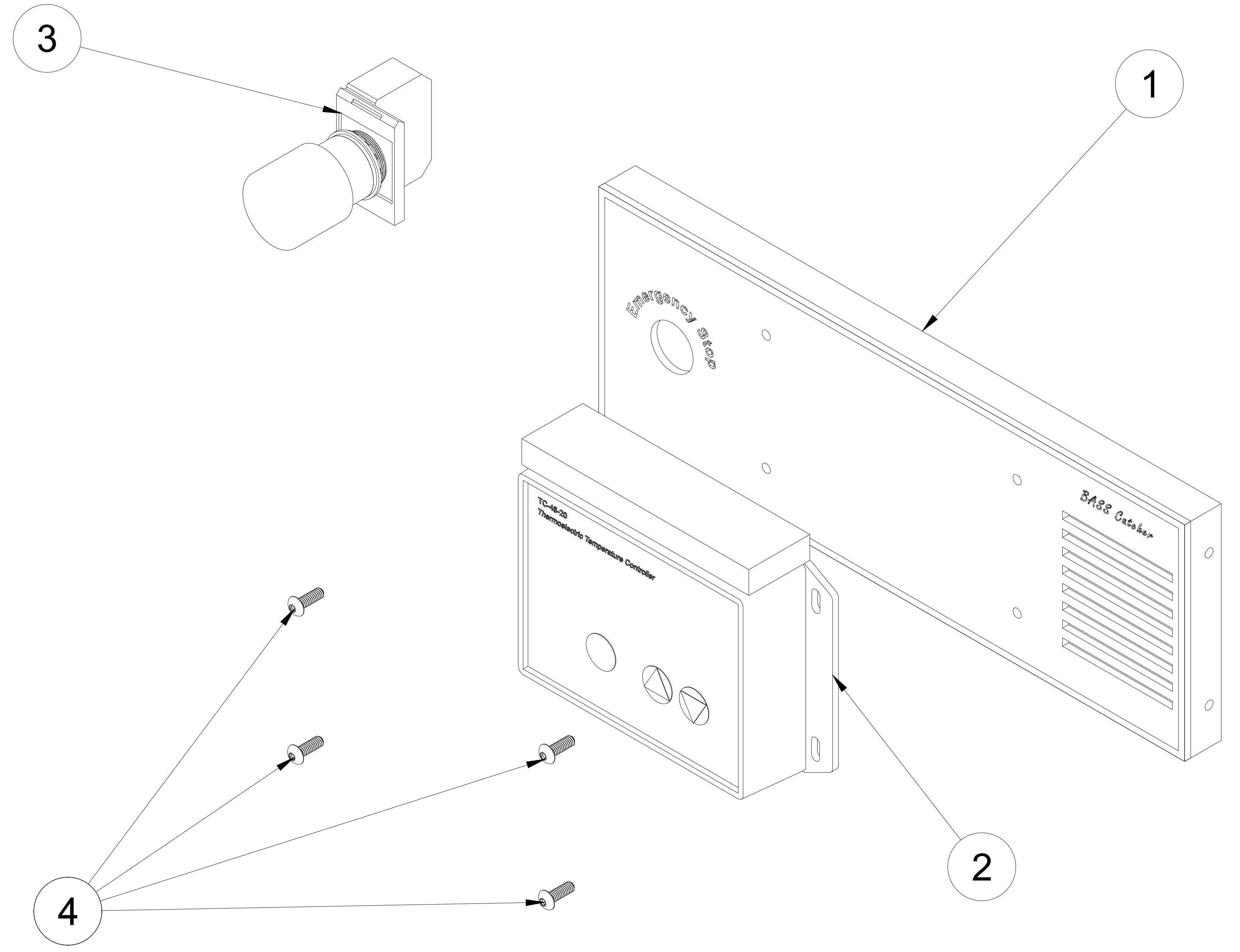
Created by Ayden Leeds	Project BASS Catchers
Created on 11/27/2024	Material N/A
Title Deck Assembly	Part Number A06
	Scale 1:3 — Sheet 2/2





TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

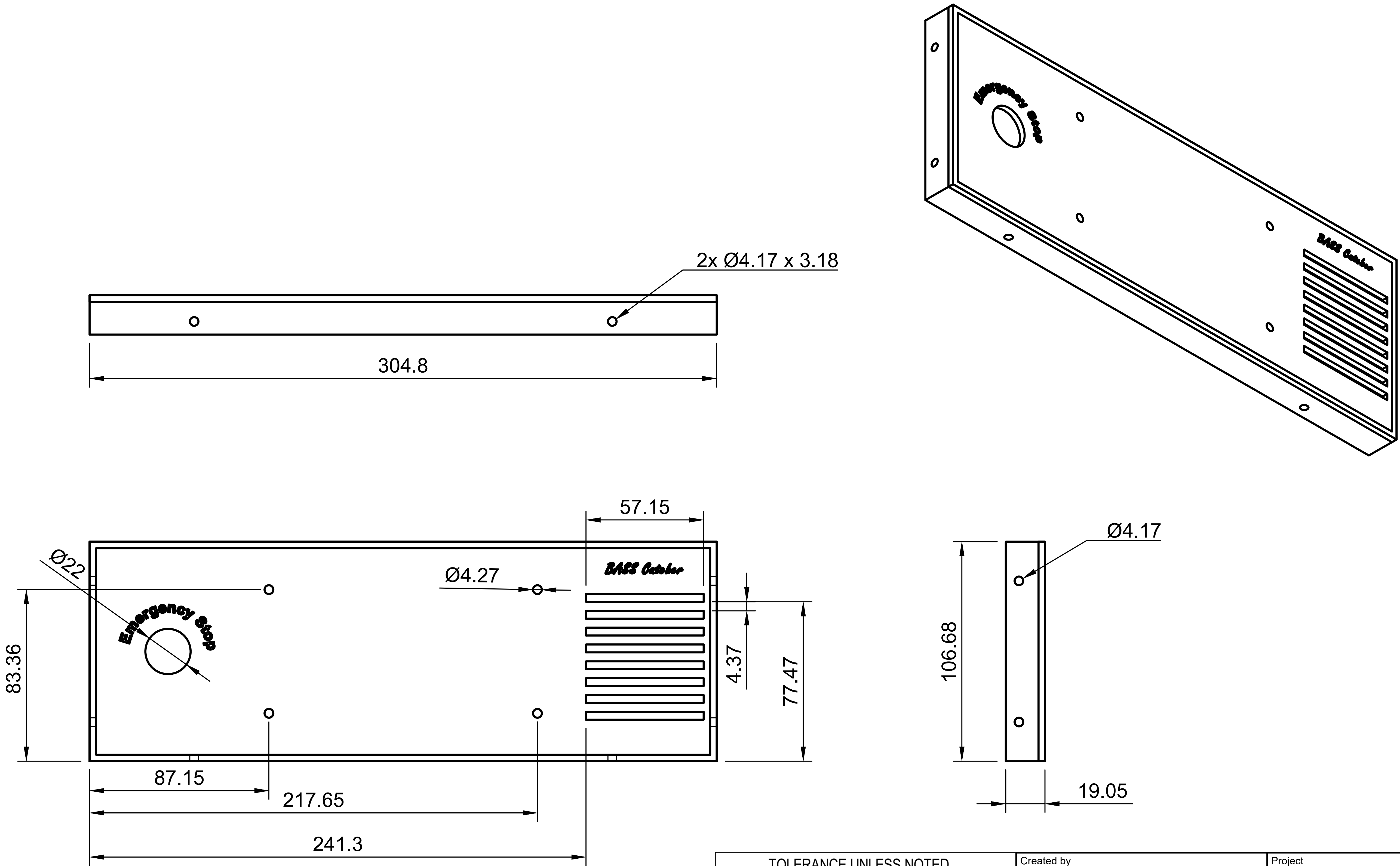
Created by Eden Navarrete	Project BASS Catchers
Created on 11/26/2024	Material N/A
Title Front Panel Assembly	Part Number EML4501-A07
	Scale 1:2 · Sheet 1/2



Created by Eden Navarrete	Project BASS Catchers	
Created on 11/26/2024	Material N/A	
Title Front Panel Assembly	Part Number EML4501-A07	
	Scale 1:2	Sheet 2/2

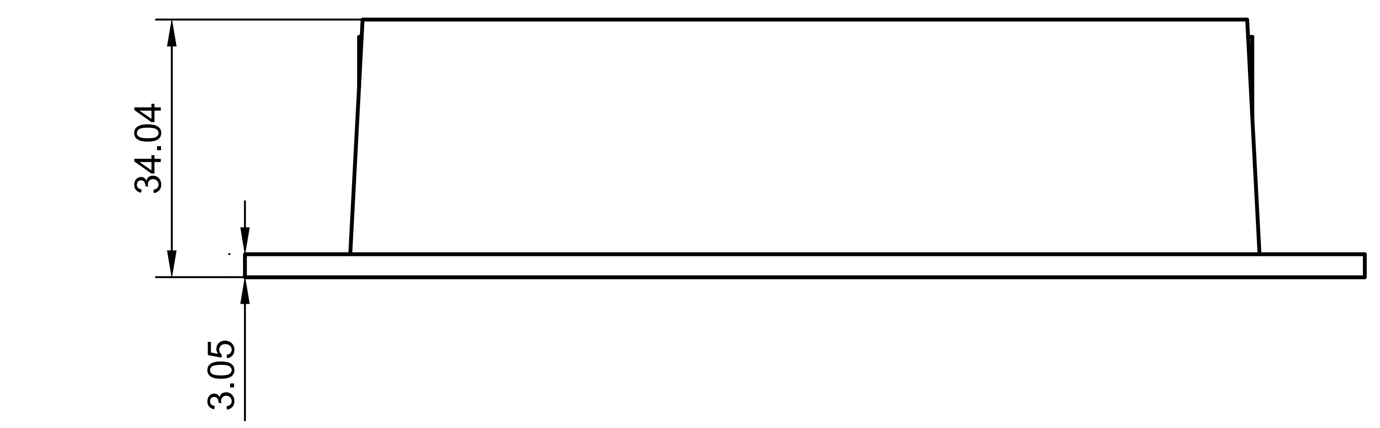
TOLERANCE UNLESS NOTED			
DIMENSION TYPE	PLACES IN DIMENSION		
	0.0	0.00	0.000
LOCATIONAL	±0.050	±0.020	±0.005
ANGULAR	±5	±2	±0.5

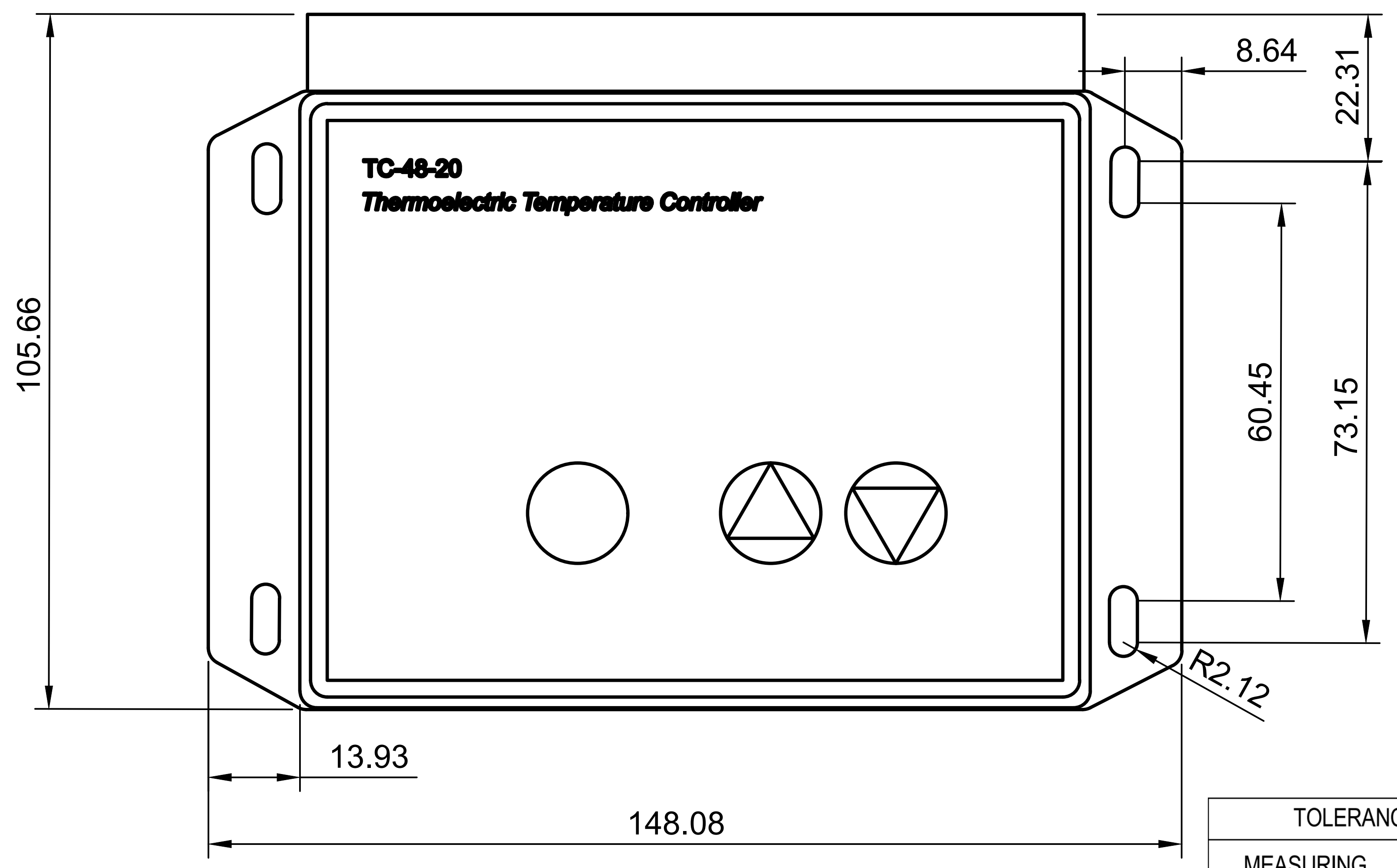
12.2 Part Drawings

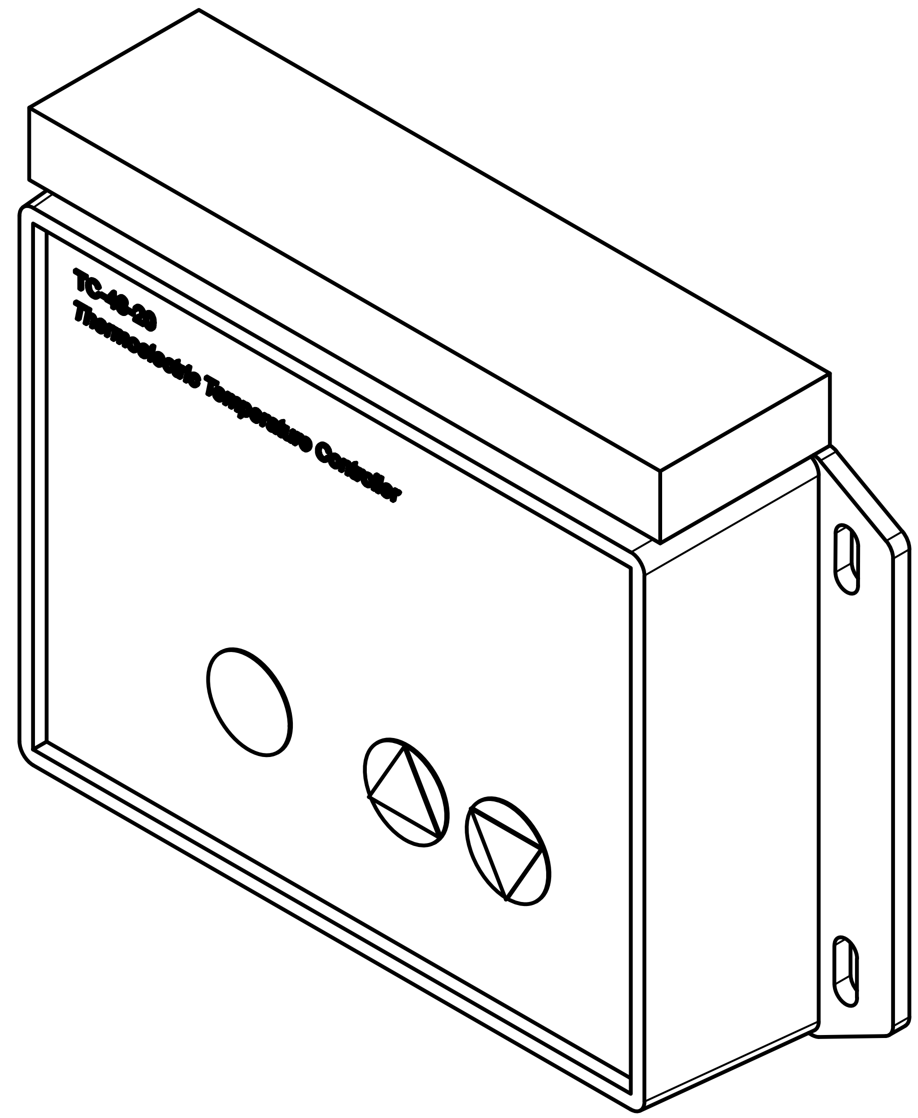


TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds	Project: BASS Catchers	
Created on: 11/27/2024	Material: 5052 Aluminum	
Title: Controls Front Panel	Part Number: C01	
	Scale: 1:2	Sheet: 1/1

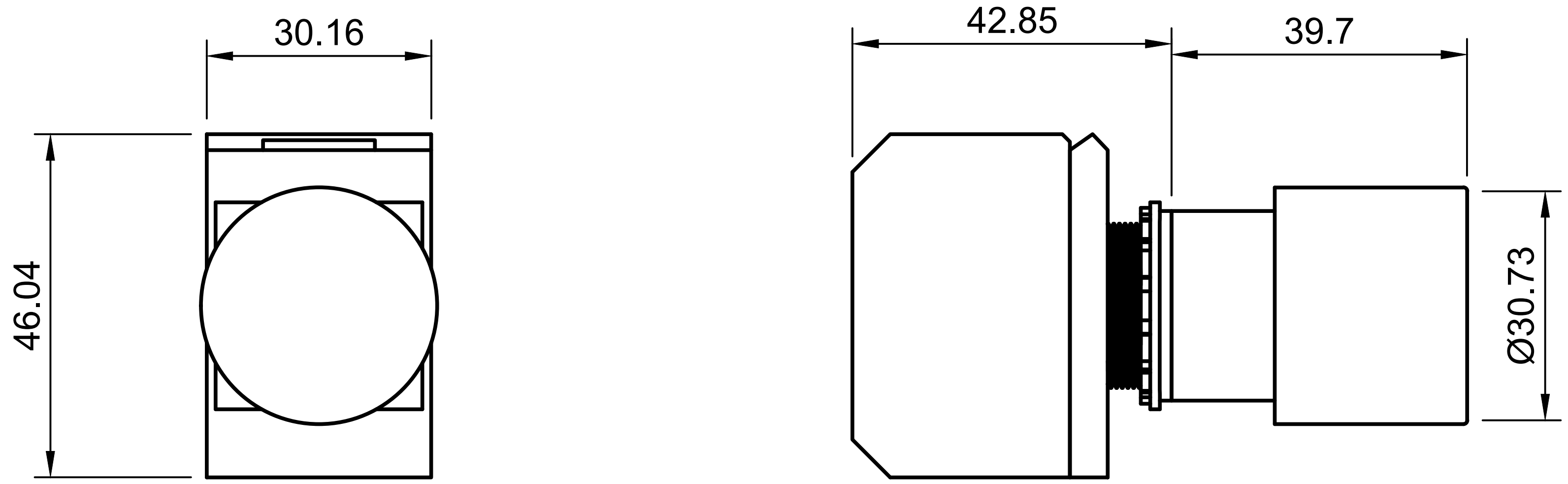






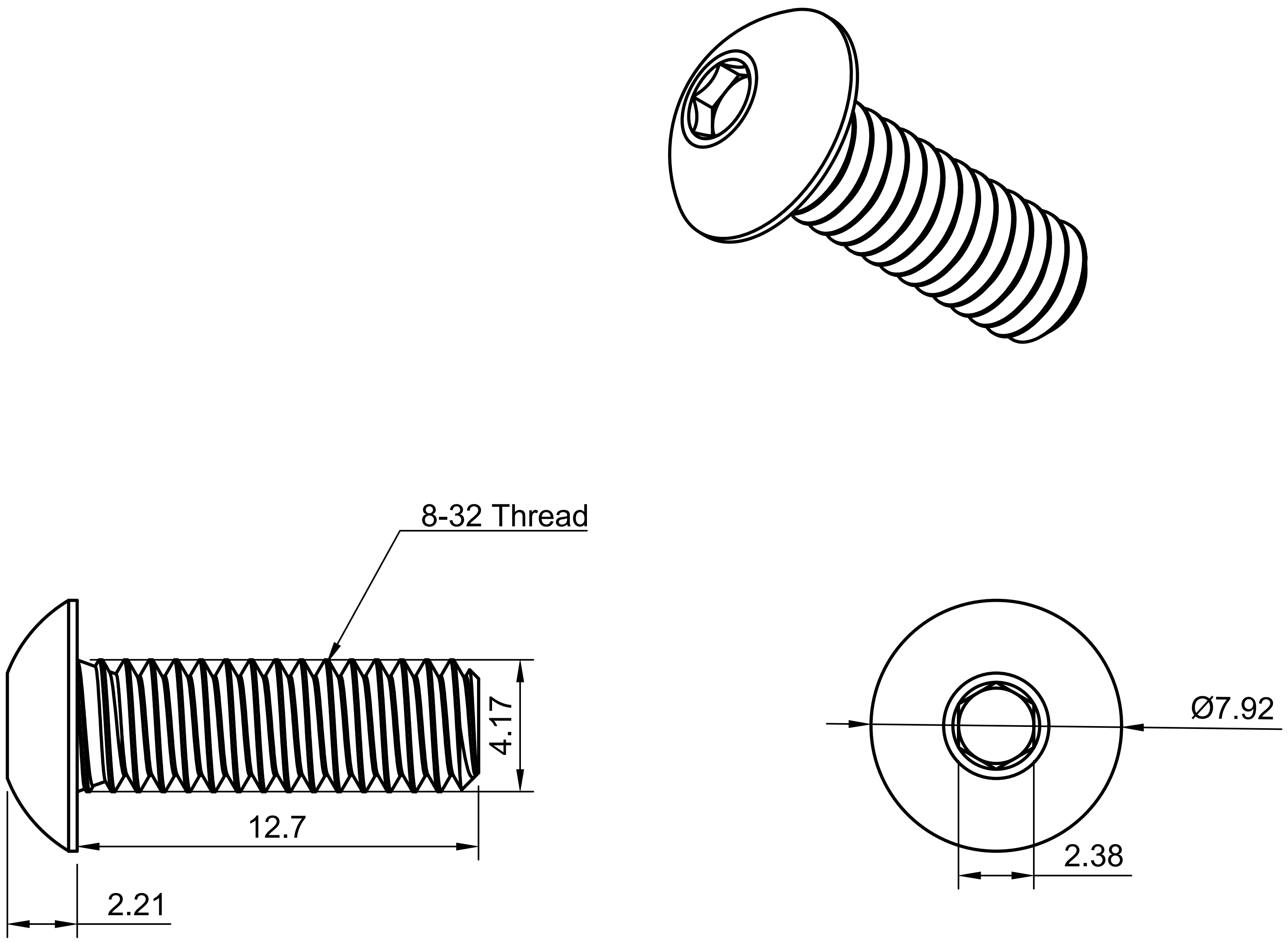
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 12/3/2024	Material: Aluminum
Title: Temperature Controller	Part Number: C02
	Scale: 1:1
	Sheet: 1/1



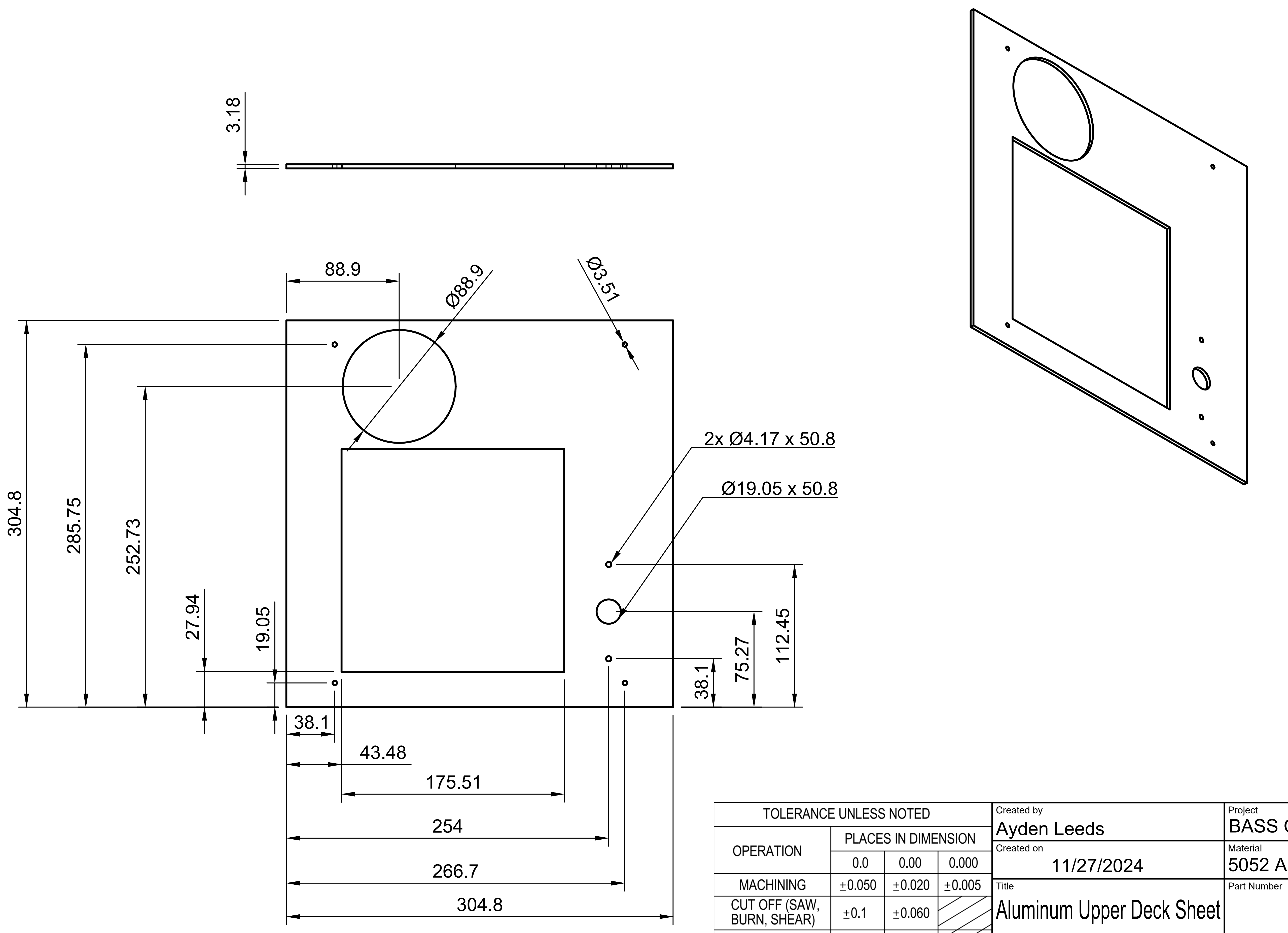
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: Plastic
Title: Emergency Stop Button	Part Number: C03
	Scale: 2:1 · Sheet: 1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 12/3/2024	Material: 18-8 Stainless Steel
Title: Front Panel Screw	Part Number: C04
	Scale: 5:1
	Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by
Ayden Leeds

Created on
11/27/2024

Title
Aluminum Upper Deck Sheet

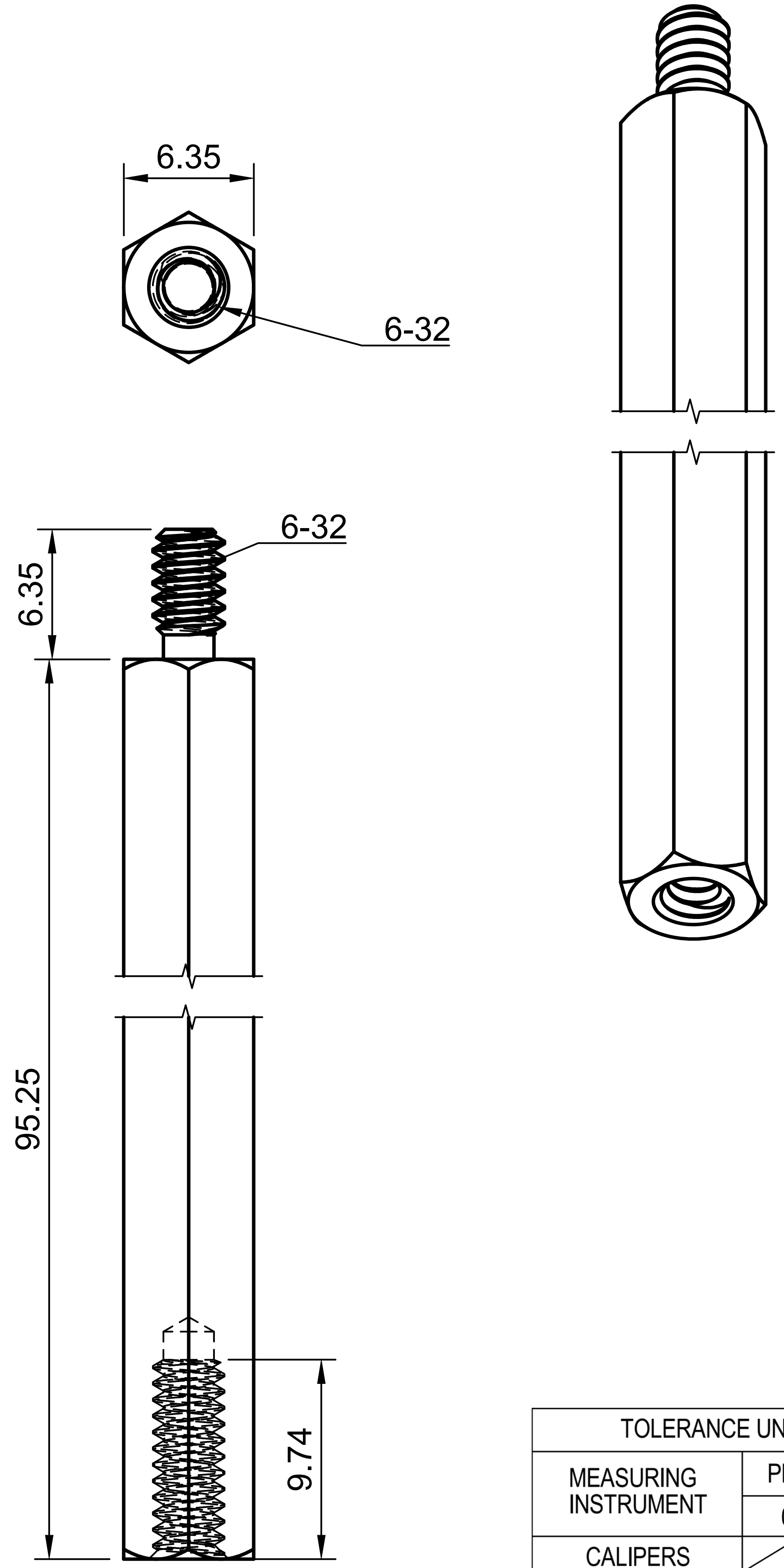
Project
BASS Catchers

Material
5052 Aluminum

Part Number
D01

Scale
1:3

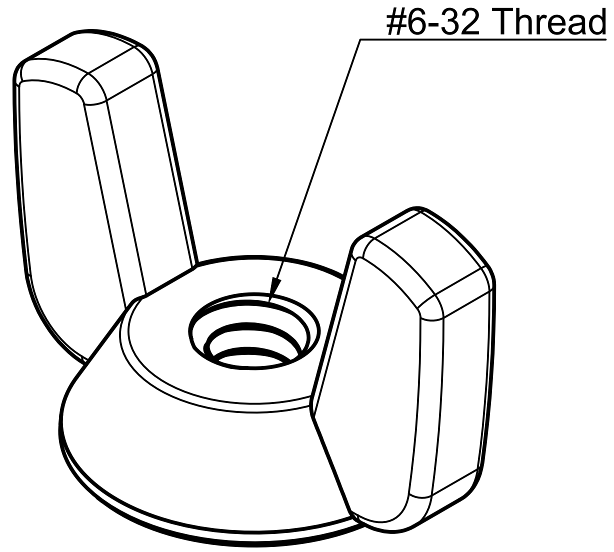
Sheet
1/1

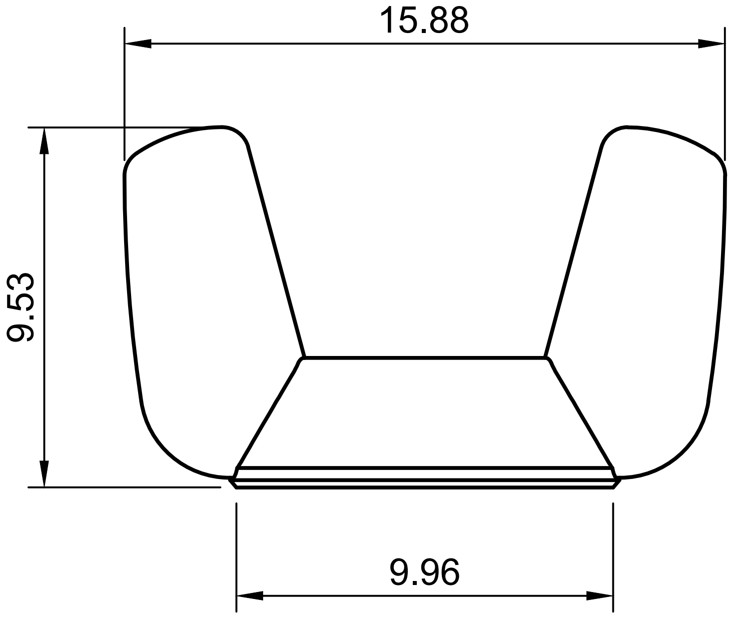


TOLERANCE UNLESS NOTED

MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

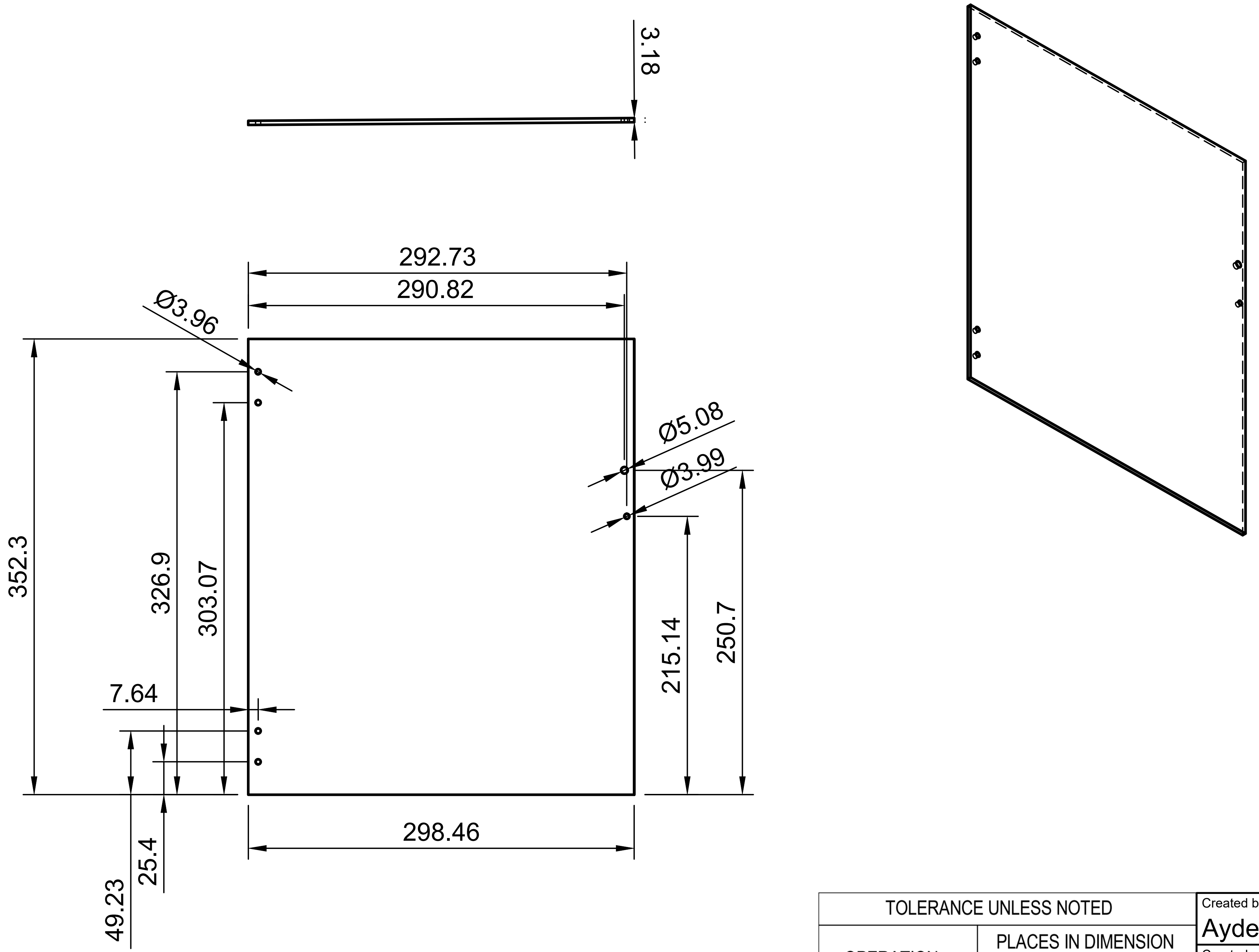
Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 18-8 Stainless Steel
Title: Deck Hex Standoff	Part Number: D02
	Scale: 3:1
	Sheet: 1/1





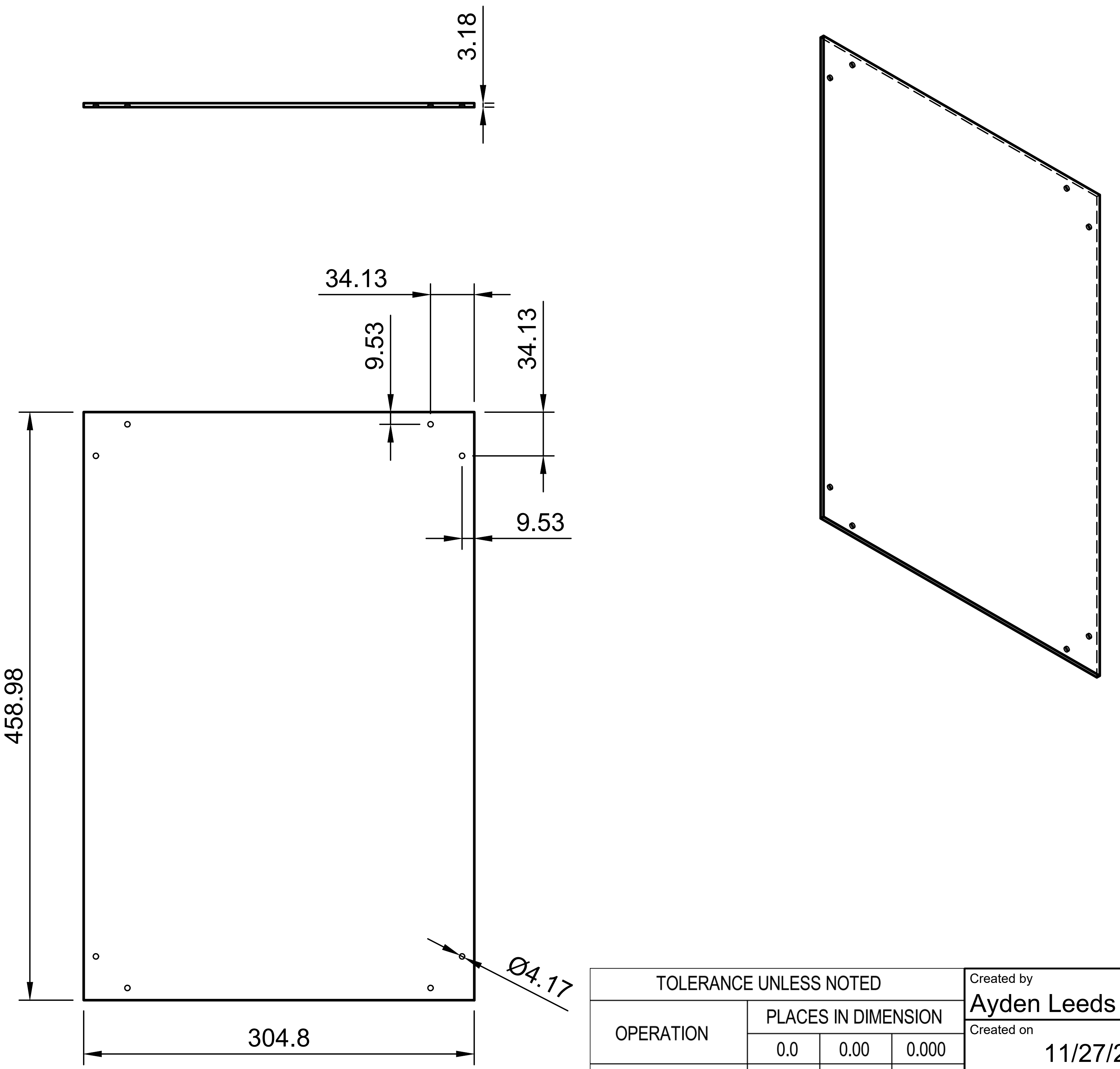
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 316 Stainless Steel
Title: Deck Standoff Wingnut	Part Number: D03
	Scale: 5:1
	Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: Polycarbonate
Title: Polycarbonate Front Door	Part Number: E01
	Scale: 1:4 — Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by
Ayden Leeds

Created on
11/27/2024

Title
Polycarbonate Side Panel

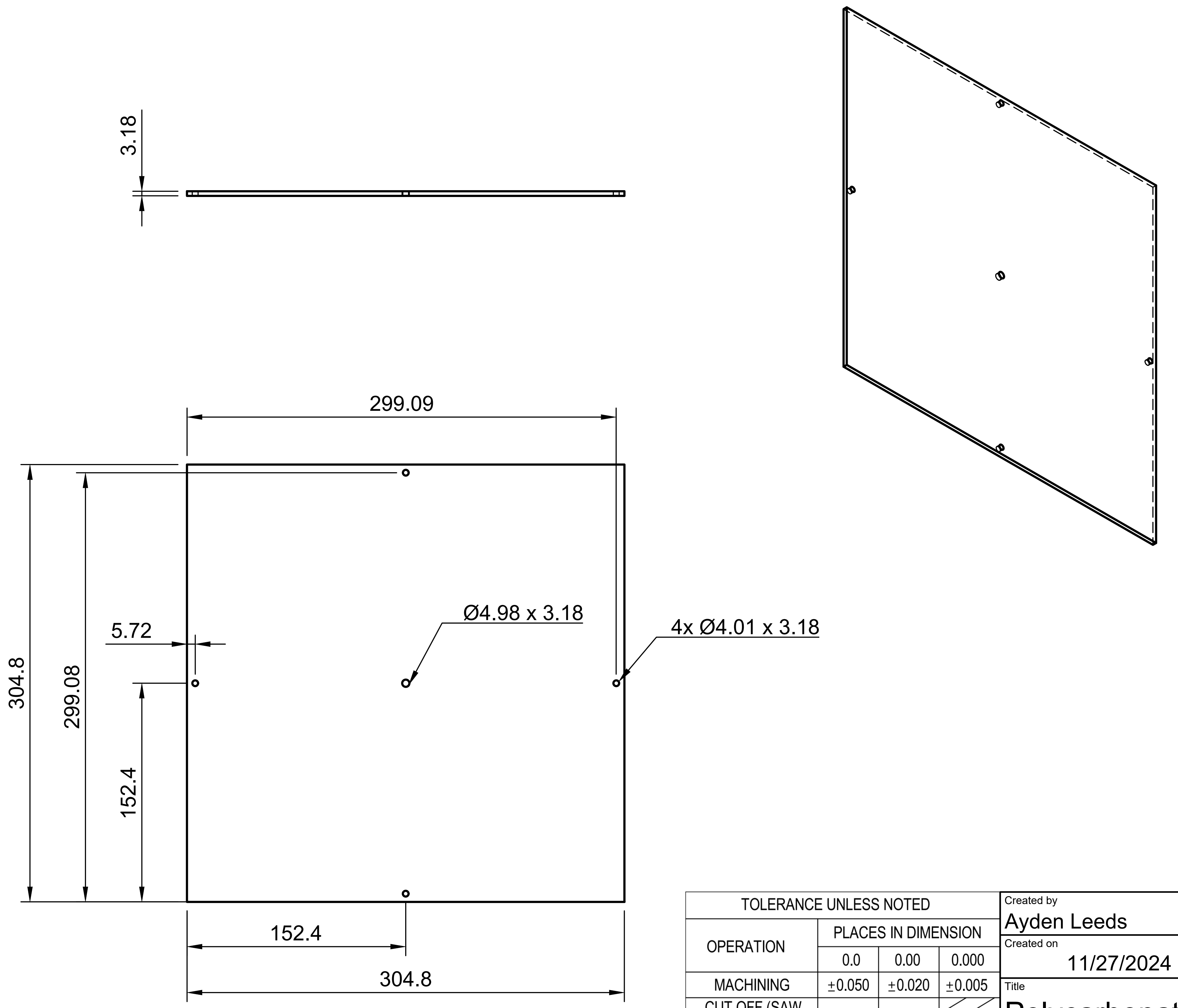
Project
BASS Catchers

Material
Polycarbonate

Part Number
E02

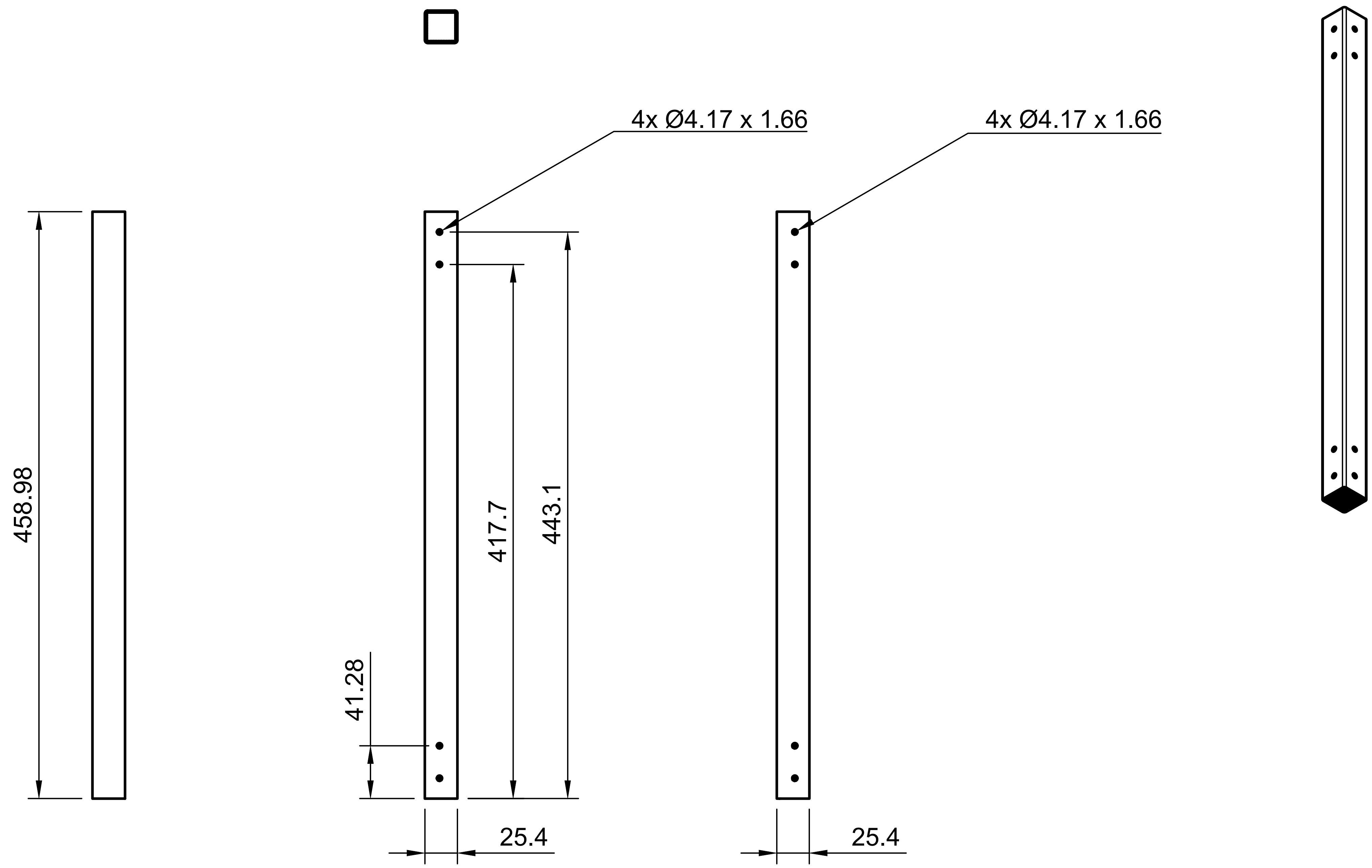
Scale
1:4

Sheet
1/1



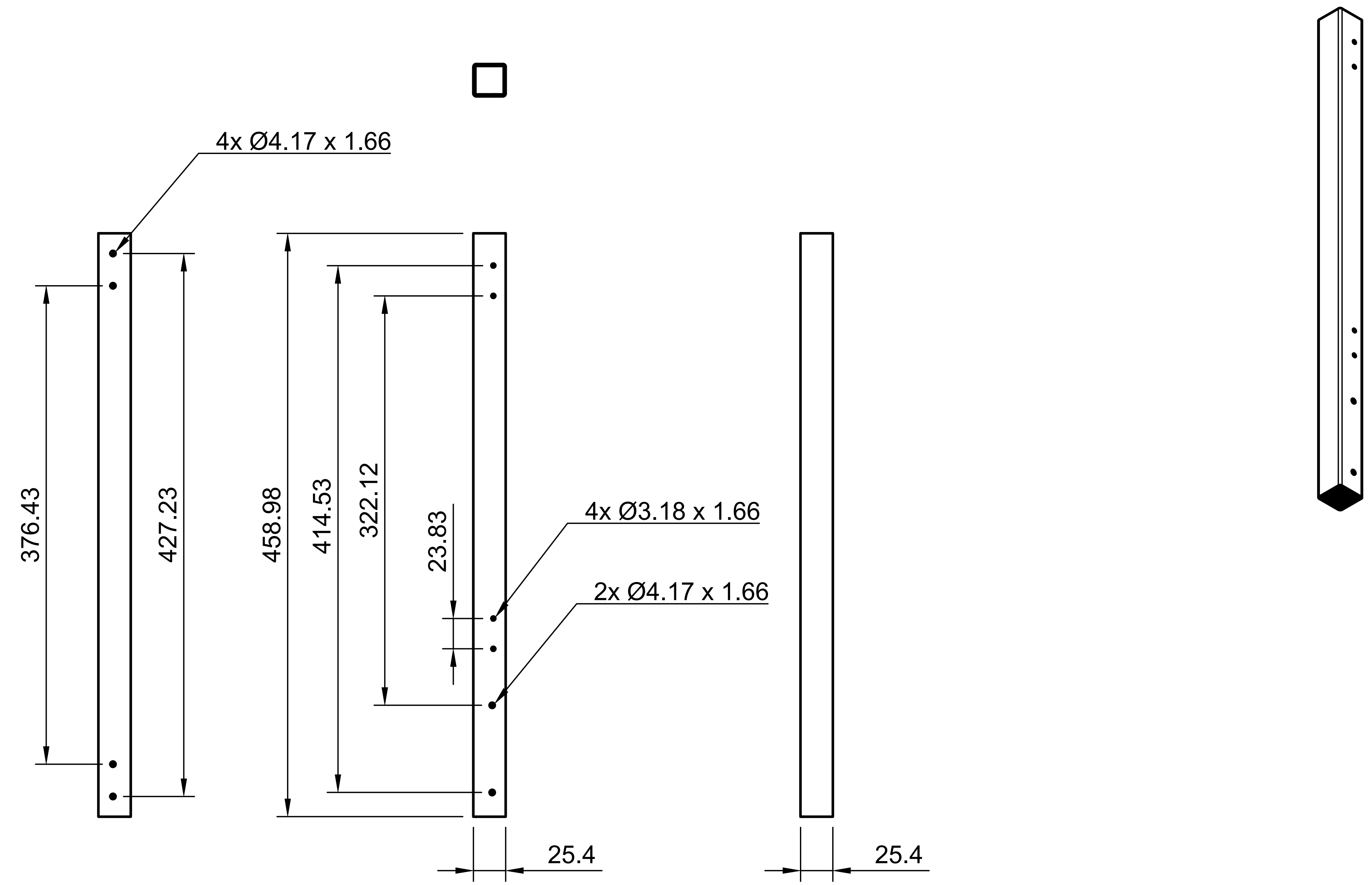
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by Ayden Leeds	Project BASS Catchers
Created on 11/27/2024	Material Polycarbonate
Title Polycarbonate Lid	Part Number E03
	Scale 1:3
	Sheet 1/1



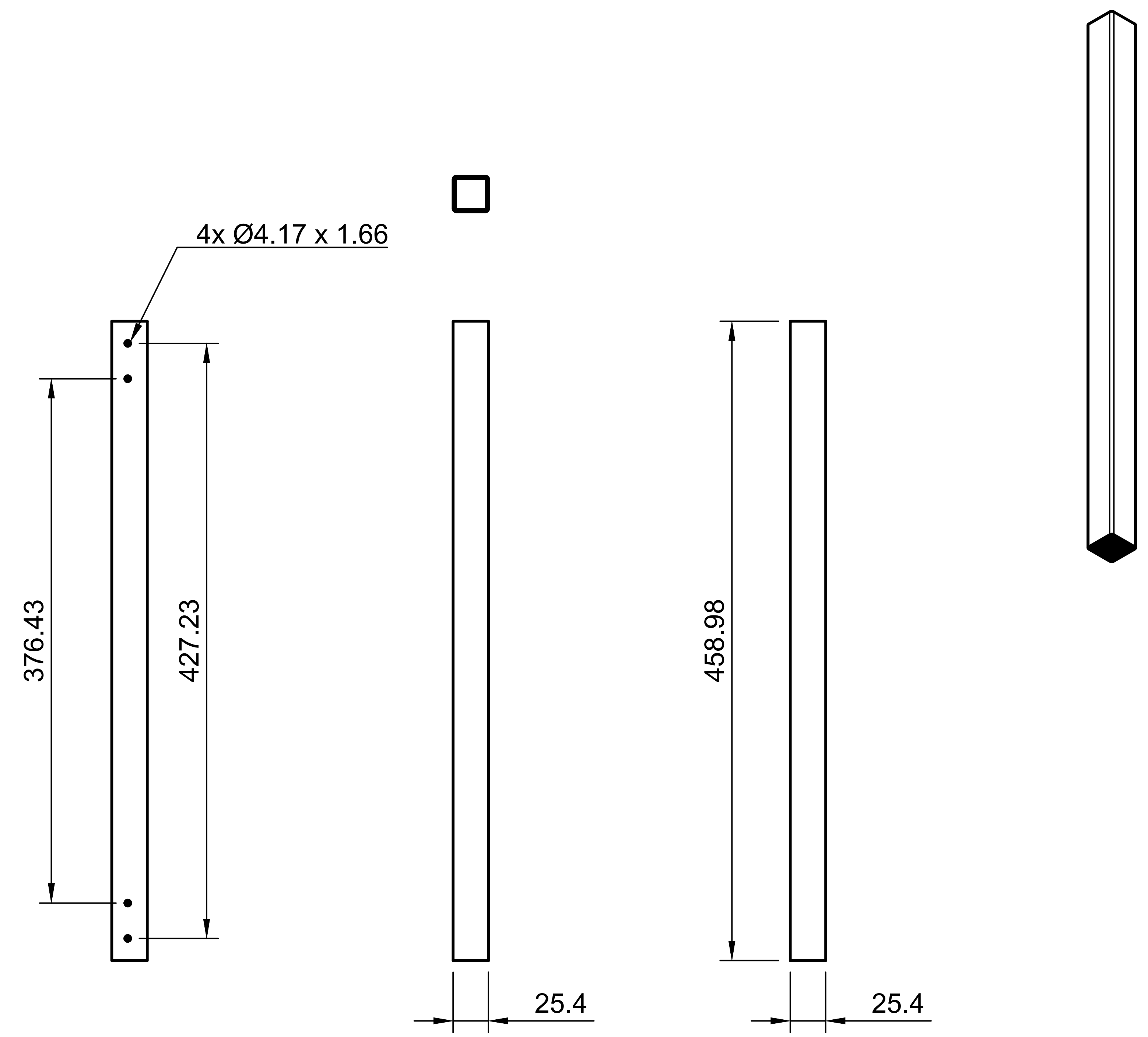
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 5052 Aluminum
Title: Aluminum Tubing Sides	Part Number: E04
	Scale: 1:4
	Sheet: 1/1



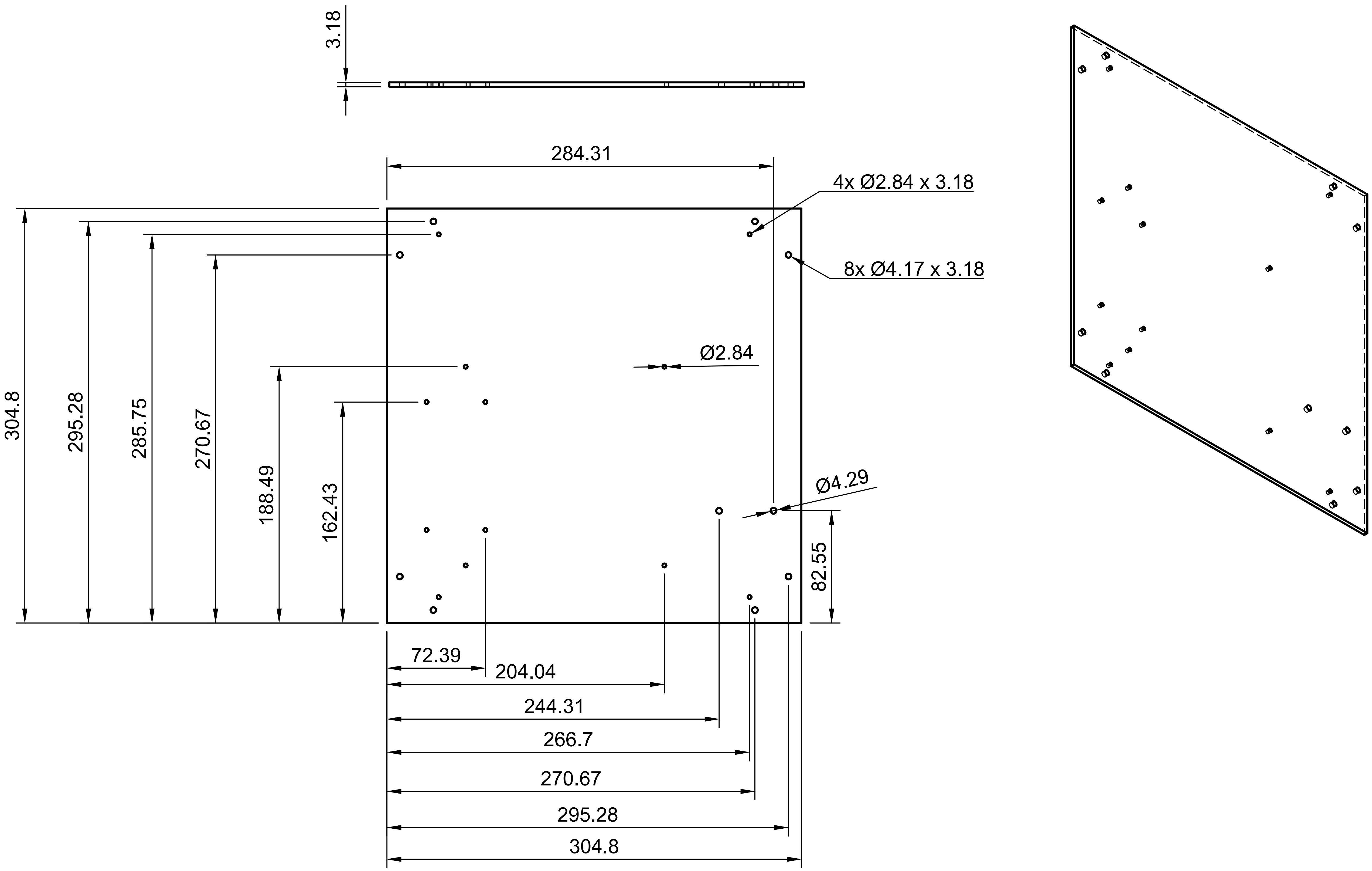
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 5052 Aluminum
Title: Aluminum Tubing FL	Part Number: E05
	Scale: 1:4 — Sheet: 1/1



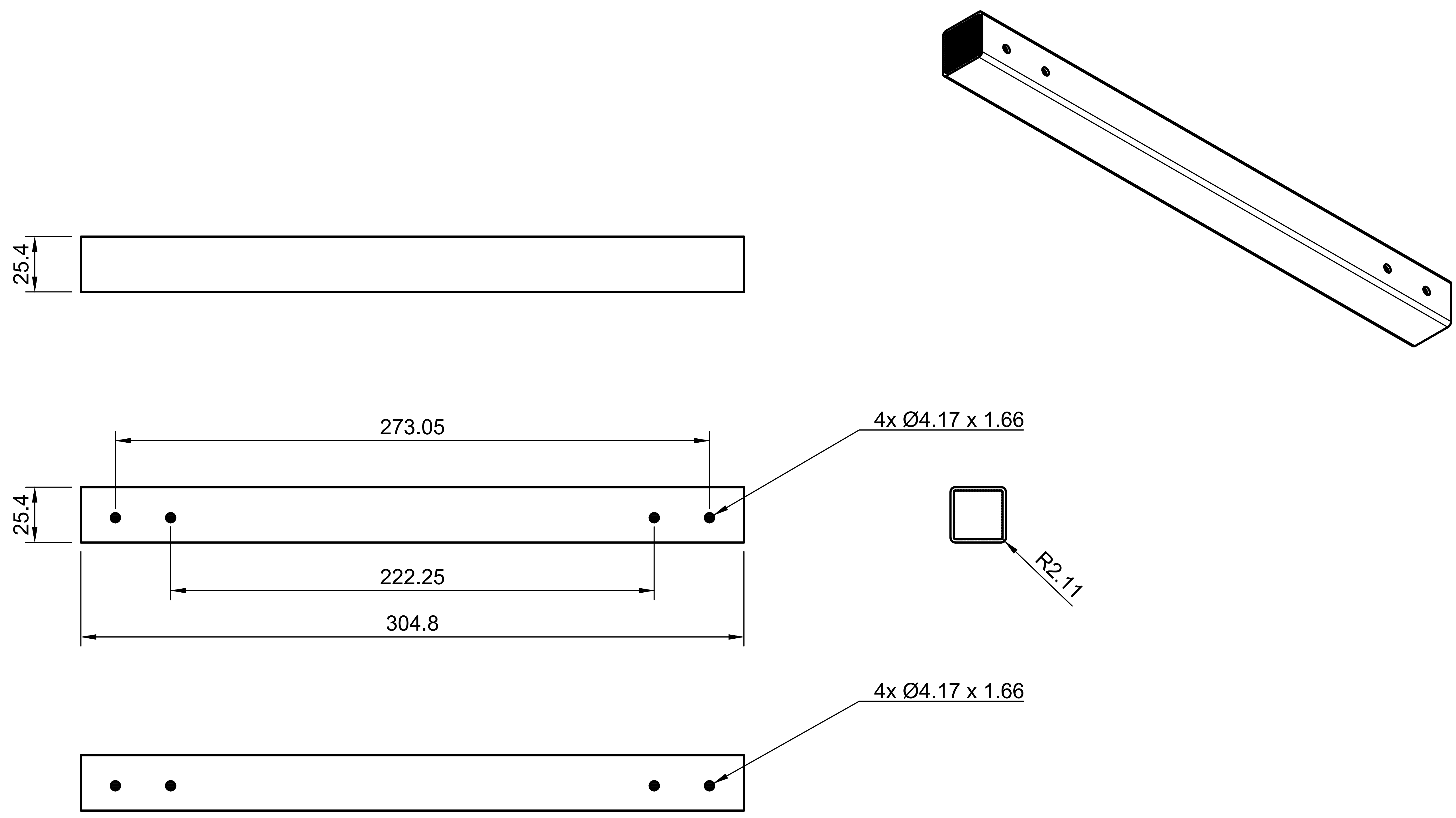
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 5052 Aluminum
Title: Aluminum Tubing FR	Part Number: E06
	Scale: 1:4 — Sheet: 1/1



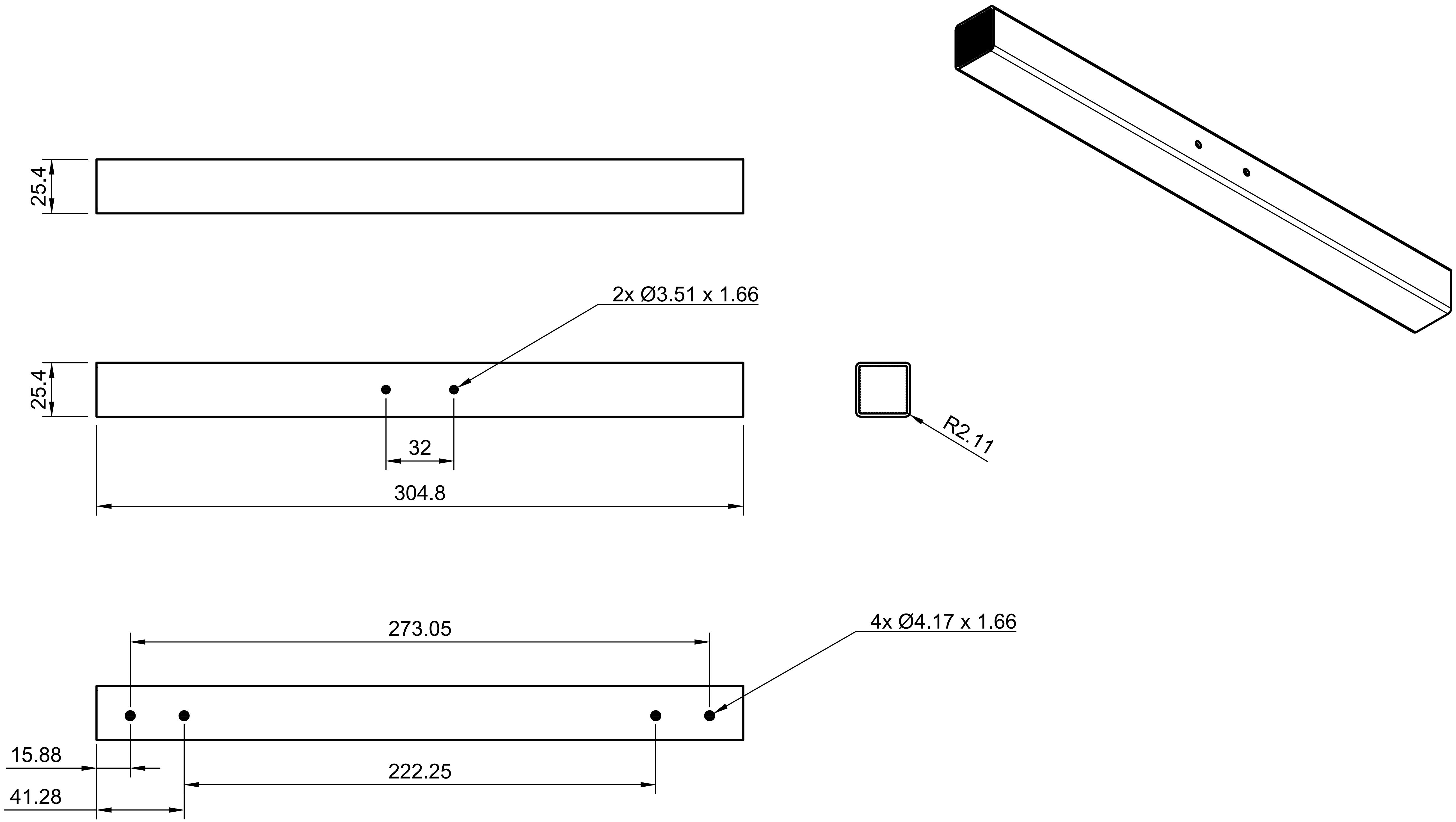
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Ayden Leeds
Created on: 11/27/2024
Title: Aluminum Base Sheet
Project: BASS Catchers
Material: 5052 Aluminum
Part Number: E07
Scale: 1:3
Sheet: 1/1



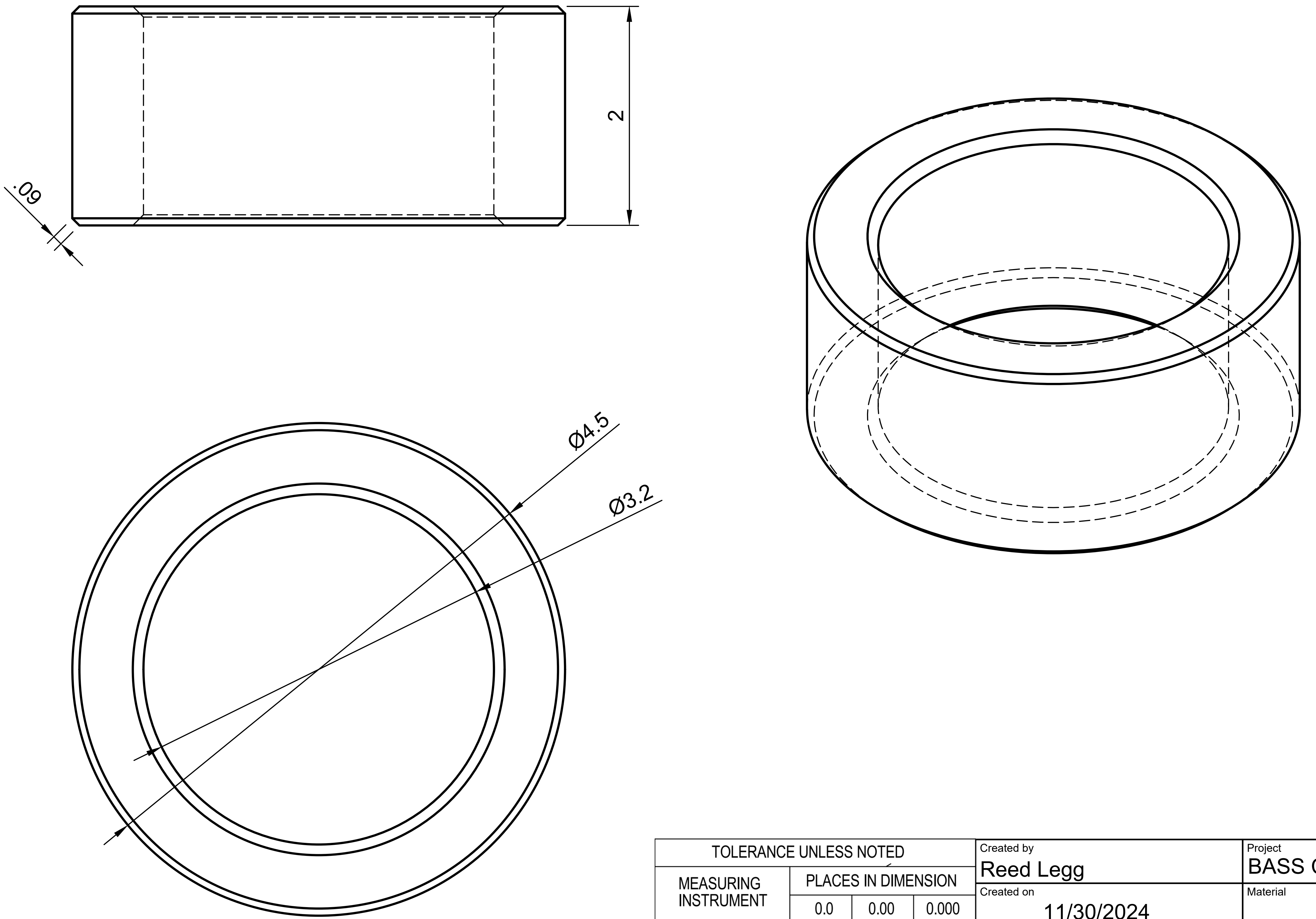
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by Ayden Leeds	Project BASS Catchers	
Created on 11/27/2024	Material 5052 Aluminum	
Title Aluminum Tubing Base	Part Number E08	
	Scale 1:2	Sheet 1/1



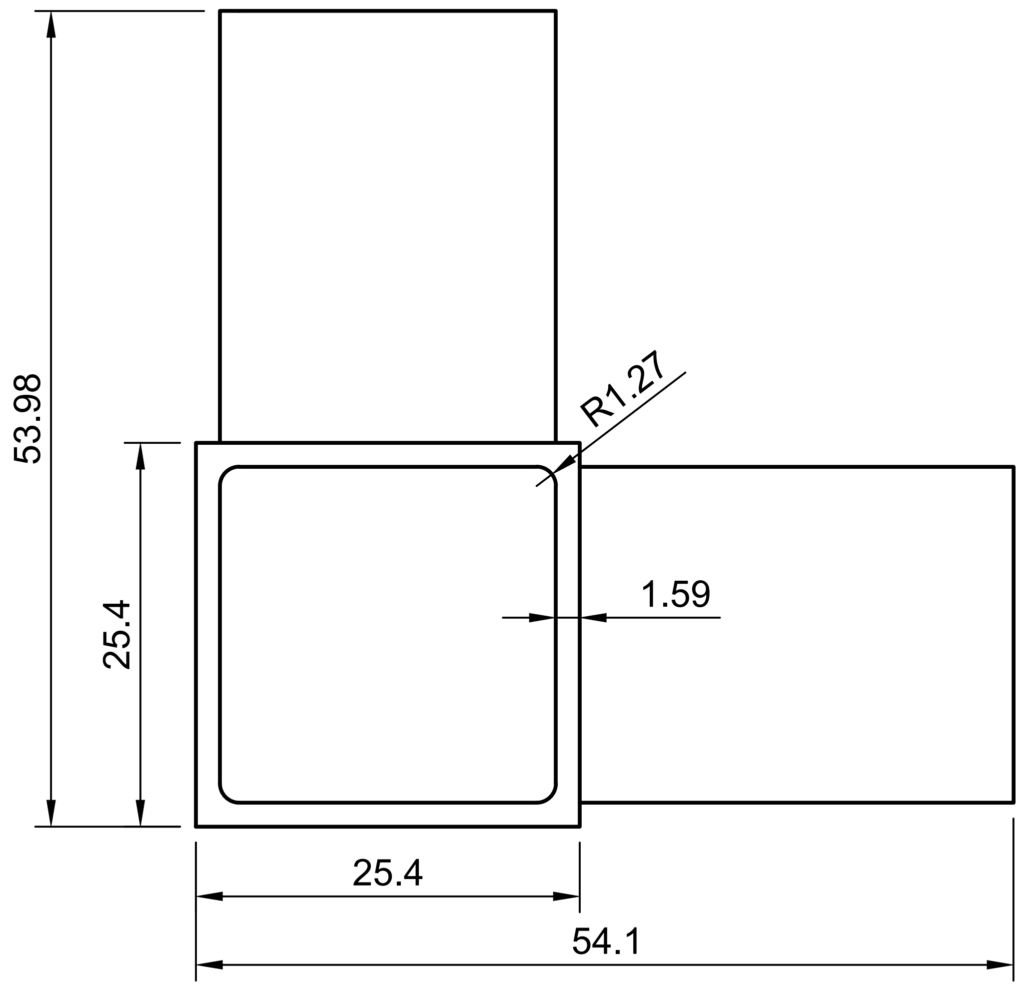
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

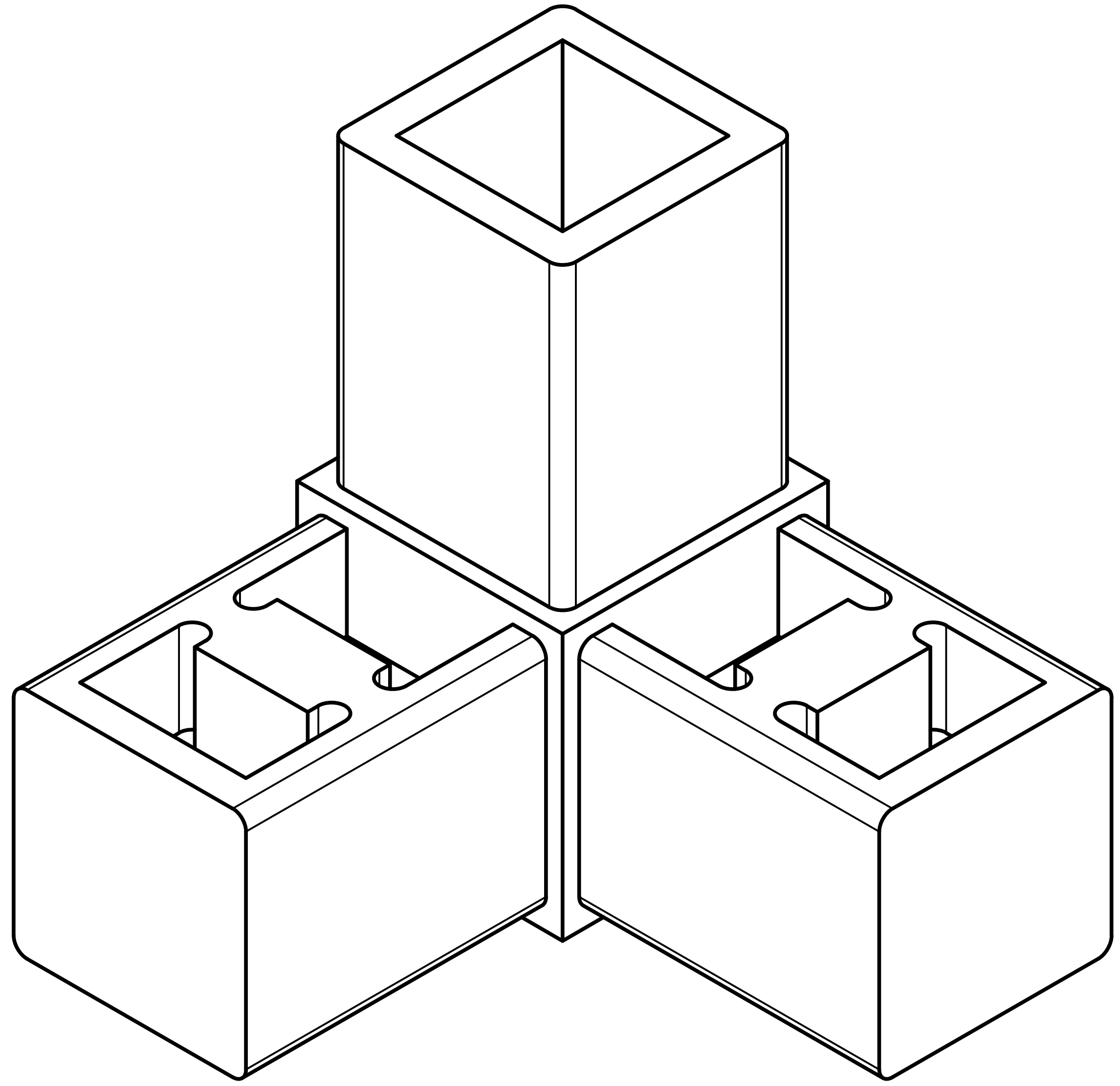
Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 5052 Aluminum
Title: Aluminum Tubing Top	Part Number: E09
	Scale: 1:2
	Sheet: 1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

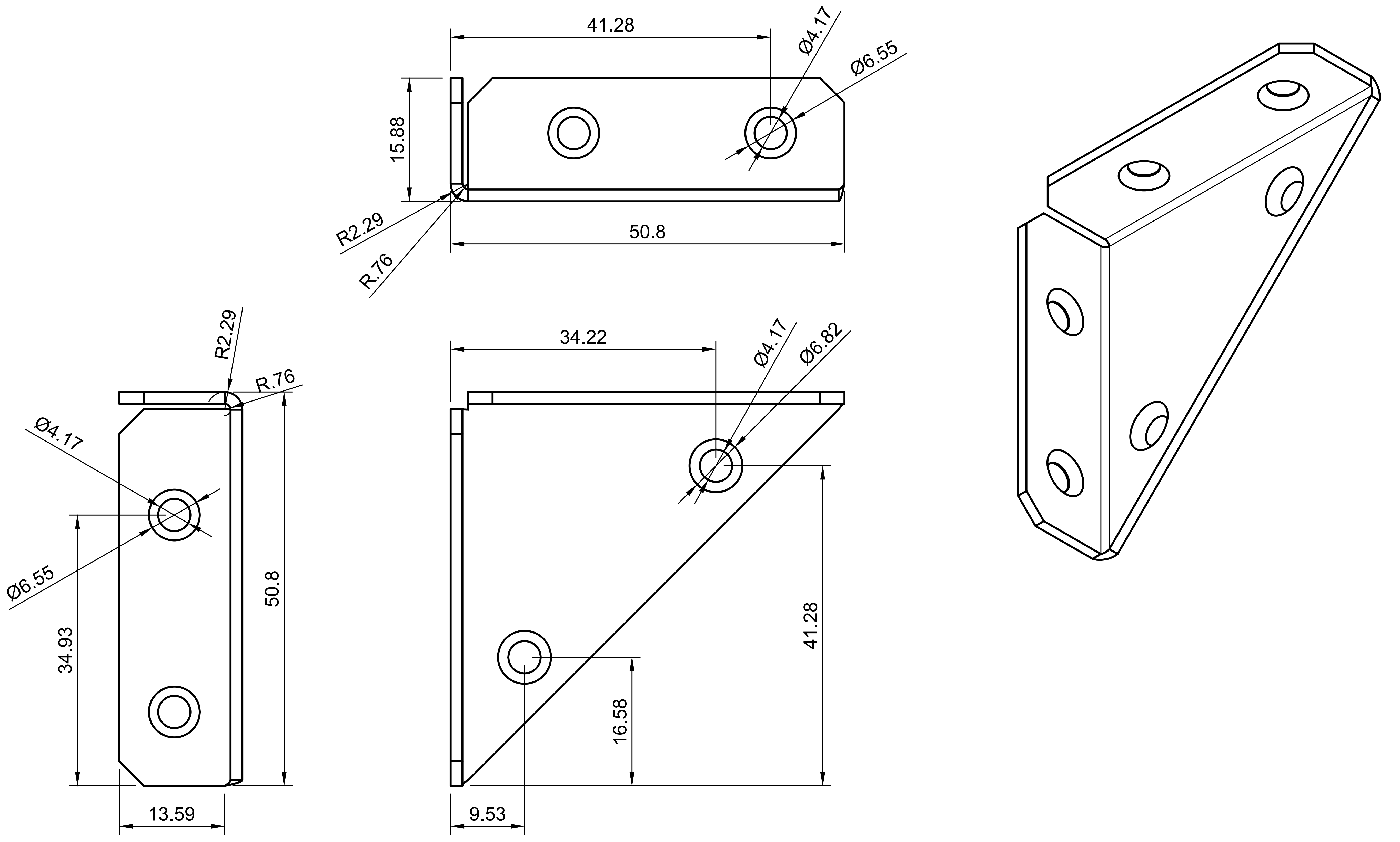
Created by: Reed Legg	Project: BASS Catchers
Created on: 11/30/2024	Material:
Title: Guide Rail Washer	Part Number: E10
	Scale: 25:1 / Sheet: 1/1





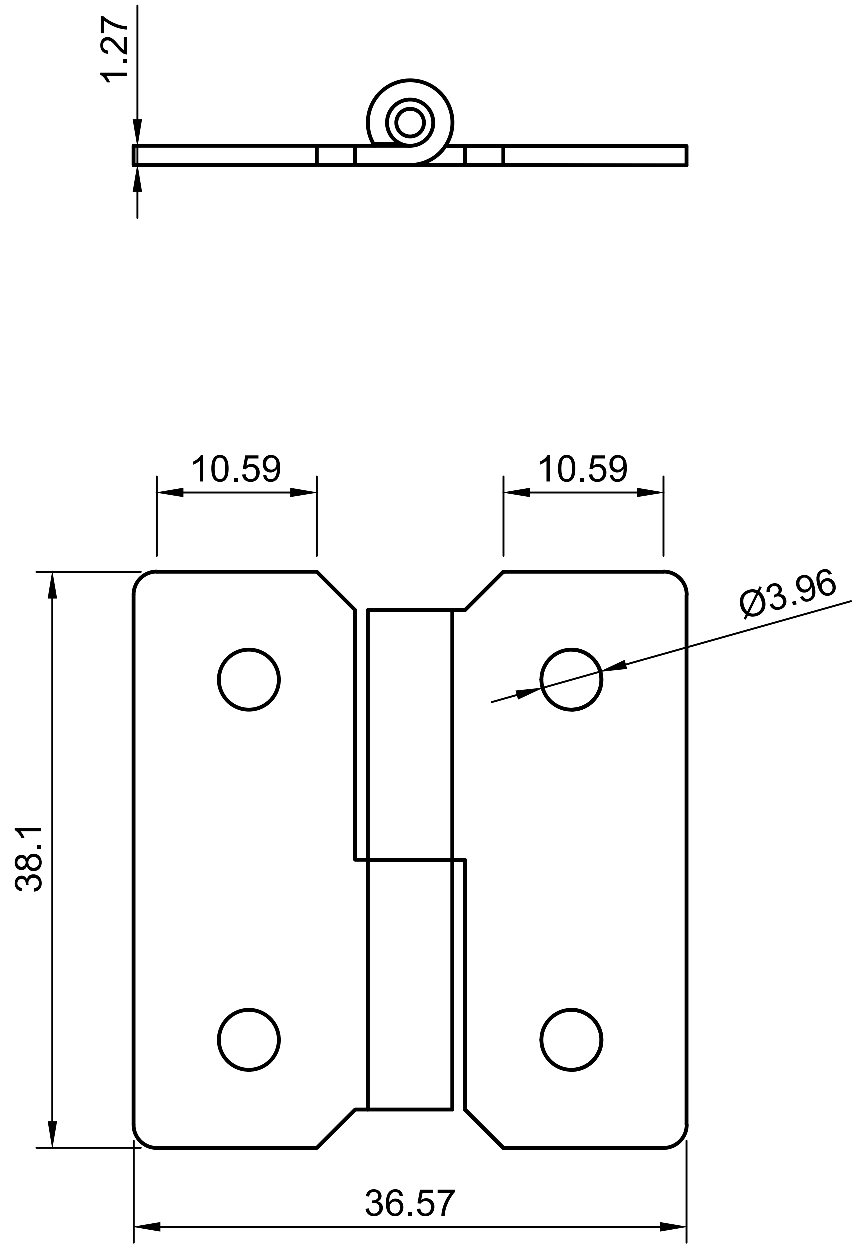
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

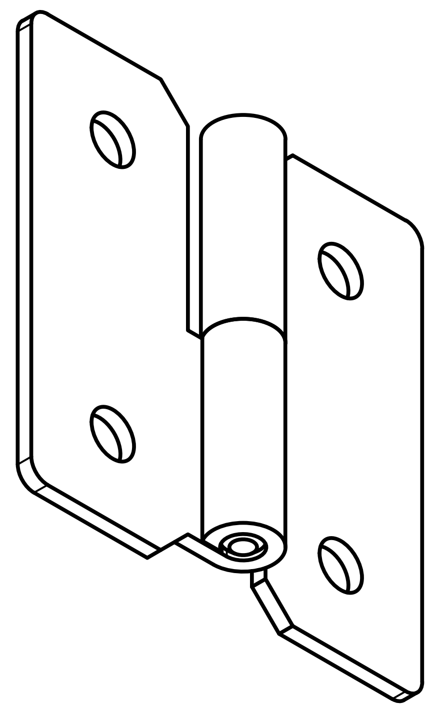
Created by	Ayden Leeds
Created on	11/27/2024
Title	3-Way Nylon Corner
Project	BASS Catchers
Material	Nylon
Part Number	E11
Scale	1:1
Sheet	1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

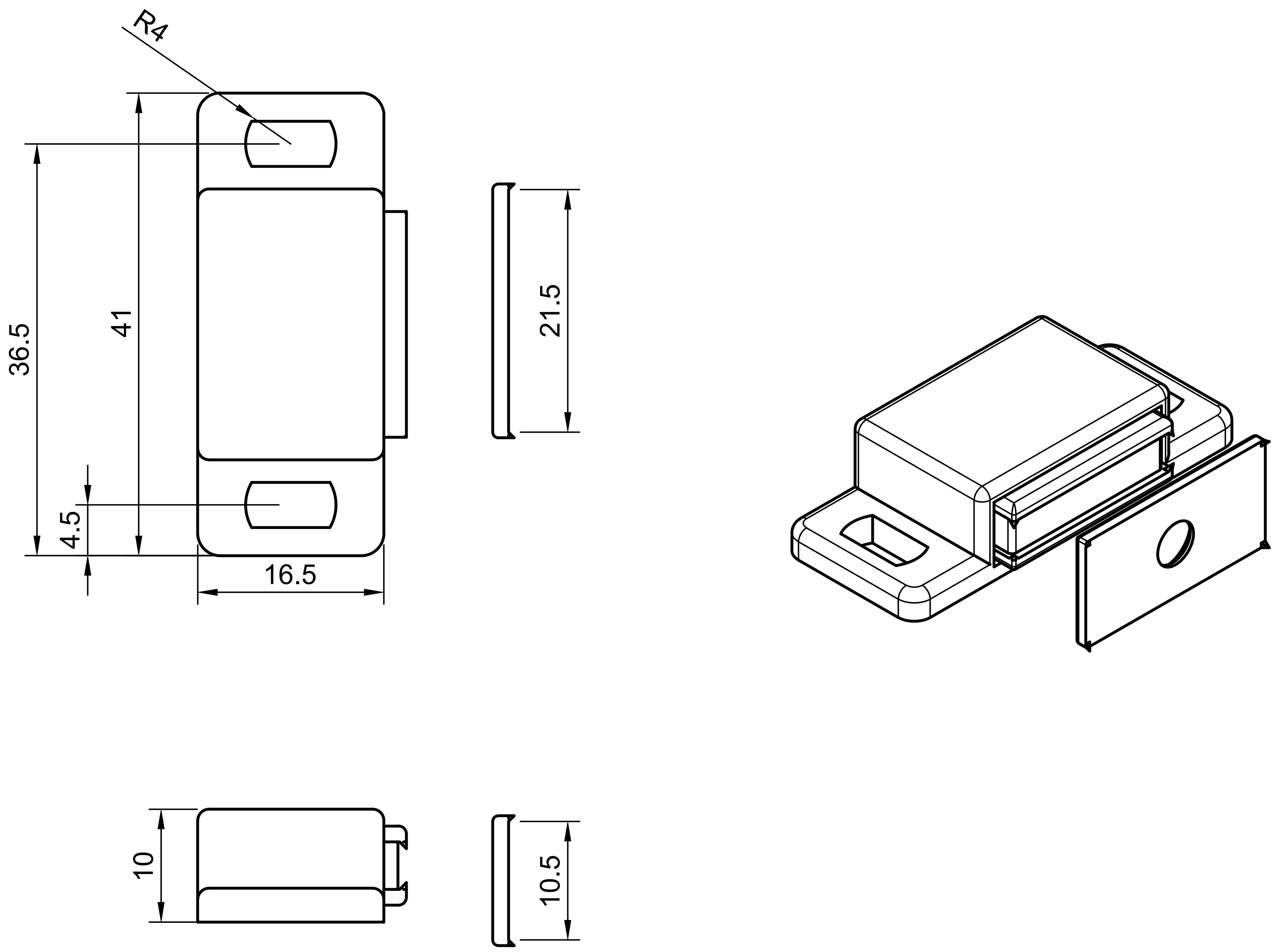
Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: Zinc Plated Steel
Title: Corner Bracket	Part Number: E12
	Scale: 1:1
	Sheet: 1/1





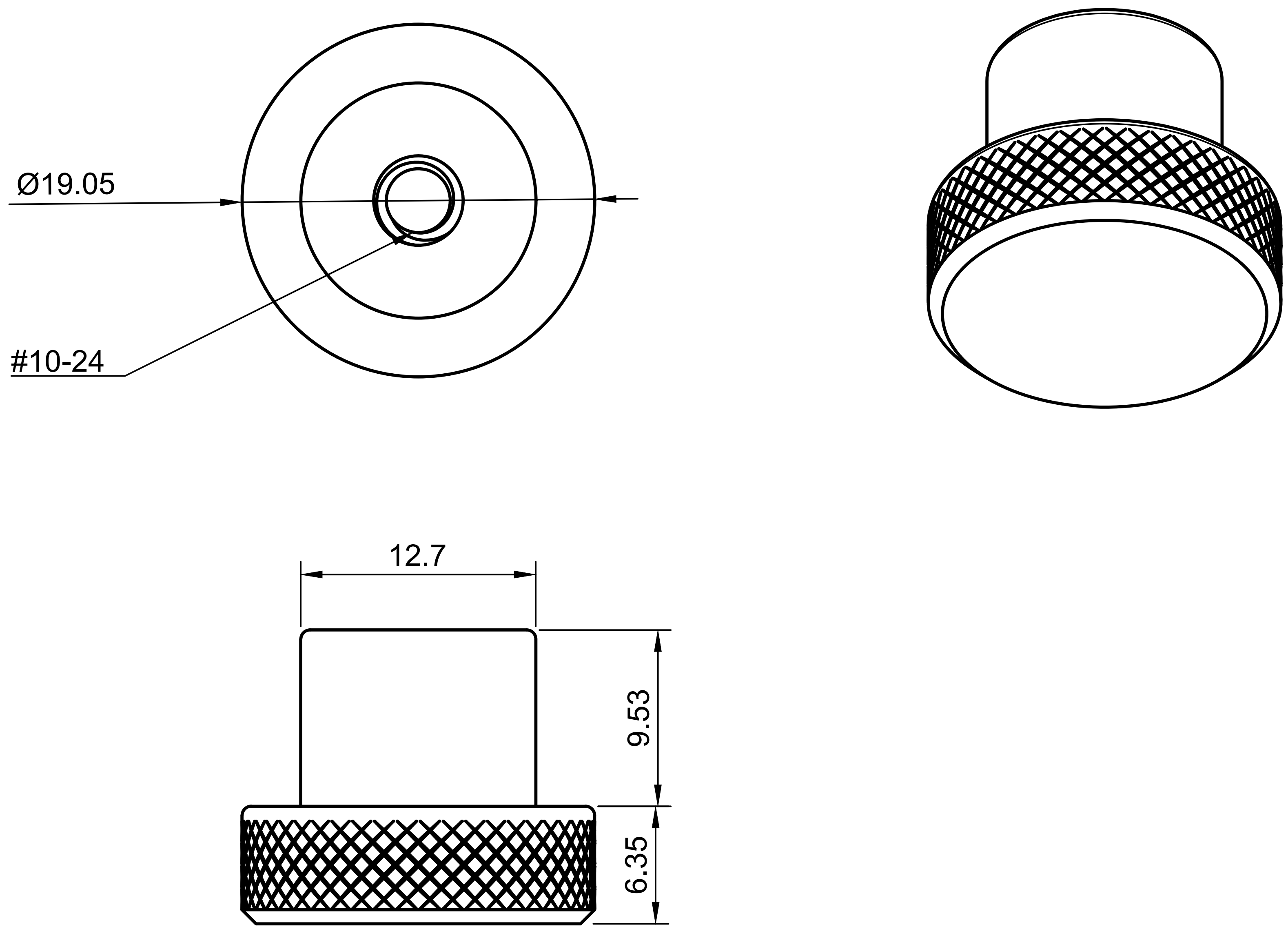
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: 304 Stainless Steel
Title: Front Door Hinge	Part Number: E13
	Scale: 2:1
	Sheet: 1/1



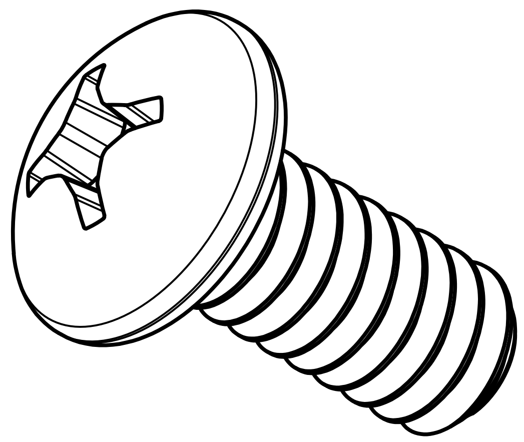
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

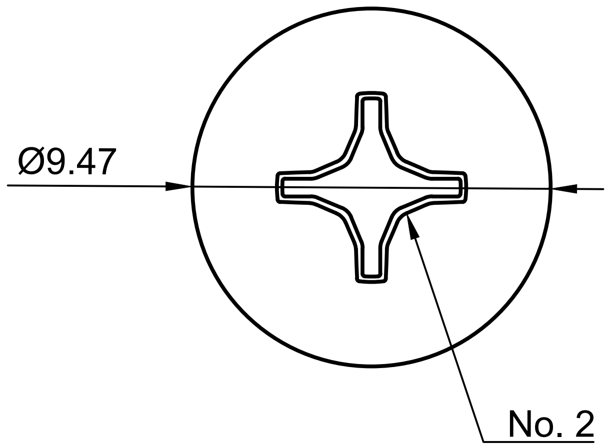
Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/27/2024	Material: Plastic
Title: Magnetic Latch	Part Number: E14
	Scale: 2:1 / Sheet: 1/1

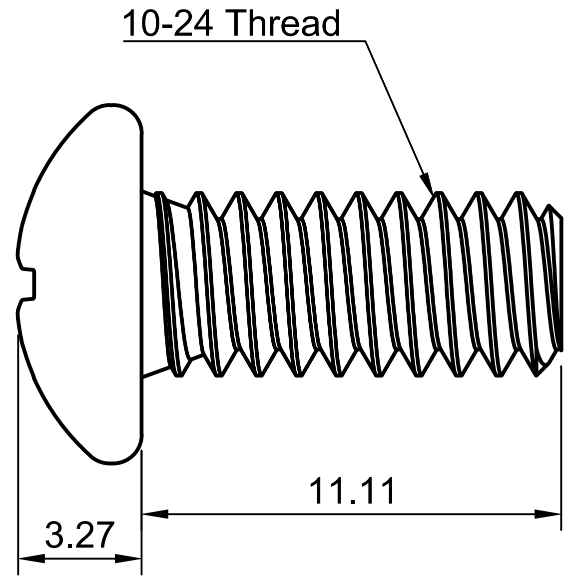


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/28/2024	Material: 303 Stainless Steel
Title: Stainless Steel Knurled Knob	Part Number: E15
	Scale: 2:1 — Sheet: 1/1

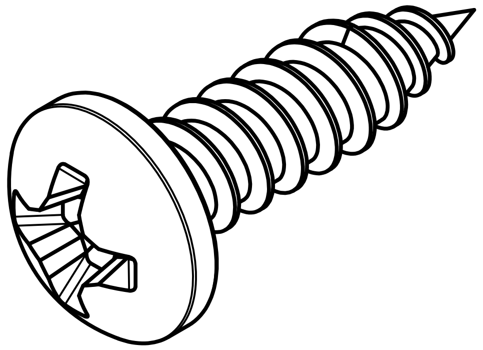


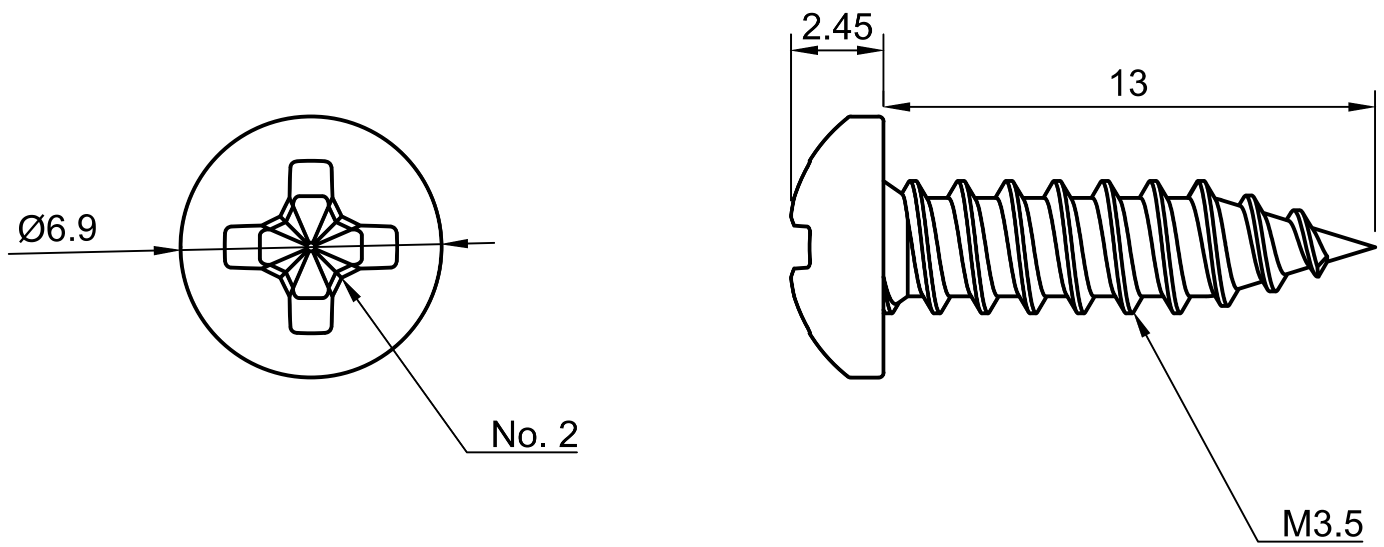




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

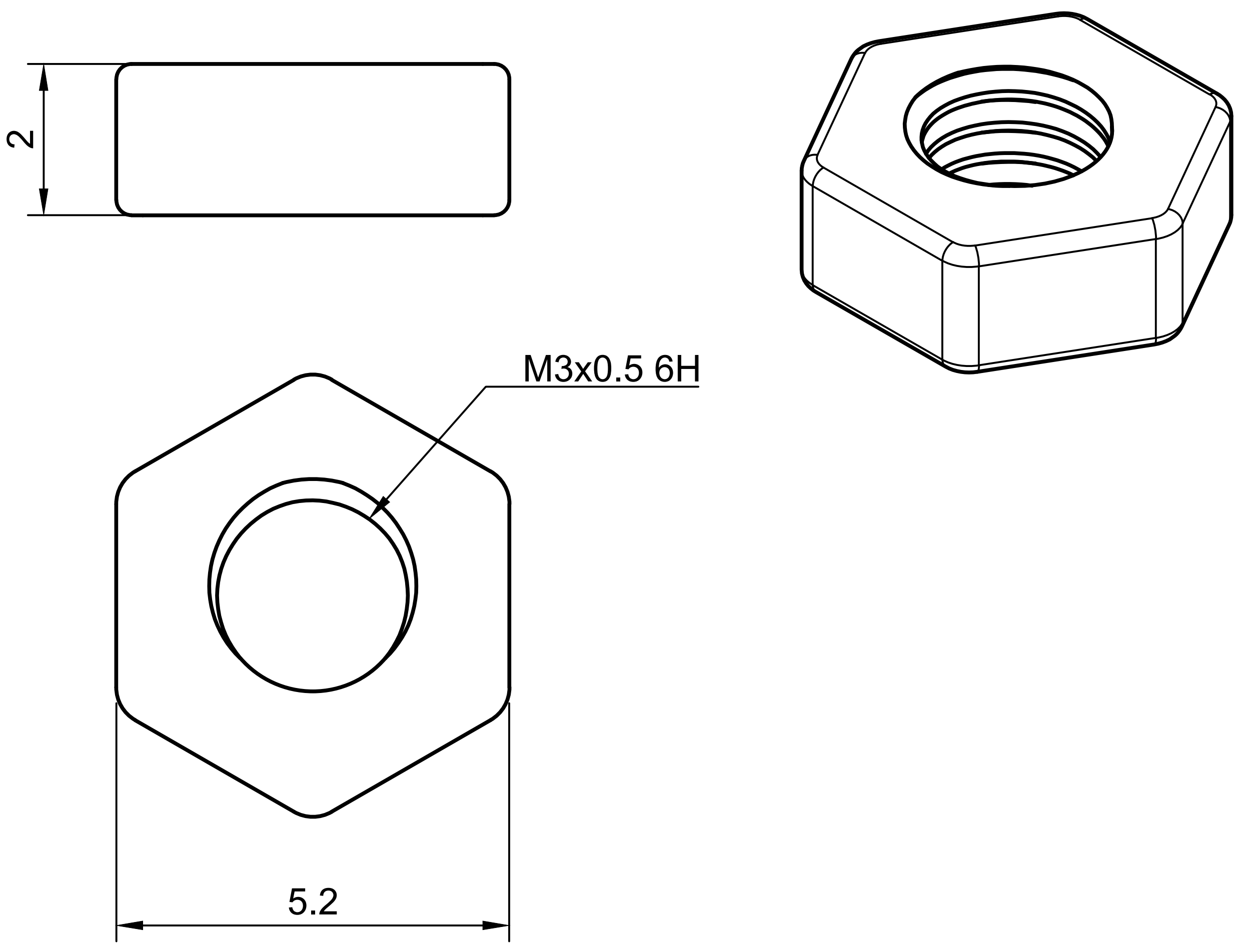
Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/28/2024	Material: 18-8 Stainless Steel
Title: Pan Head Phillips Screw	Part Number: E16
	Scale: 5:1 / Sheet: 1/1





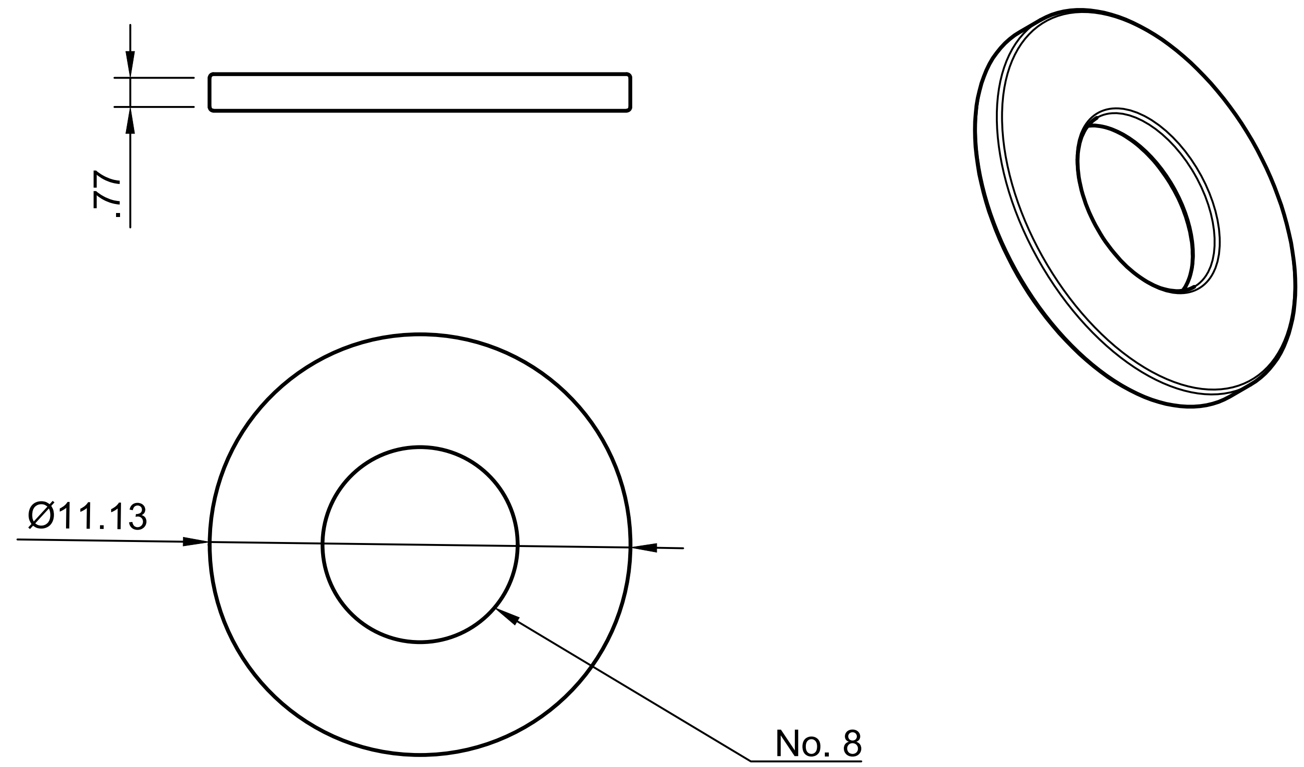
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/28/2024	Material: 18-8 Stainless Steel
Title: Passivated Pan Head Phillips Screw	Part Number: E17
	Scale: 5:1 · Sheet: 1/1



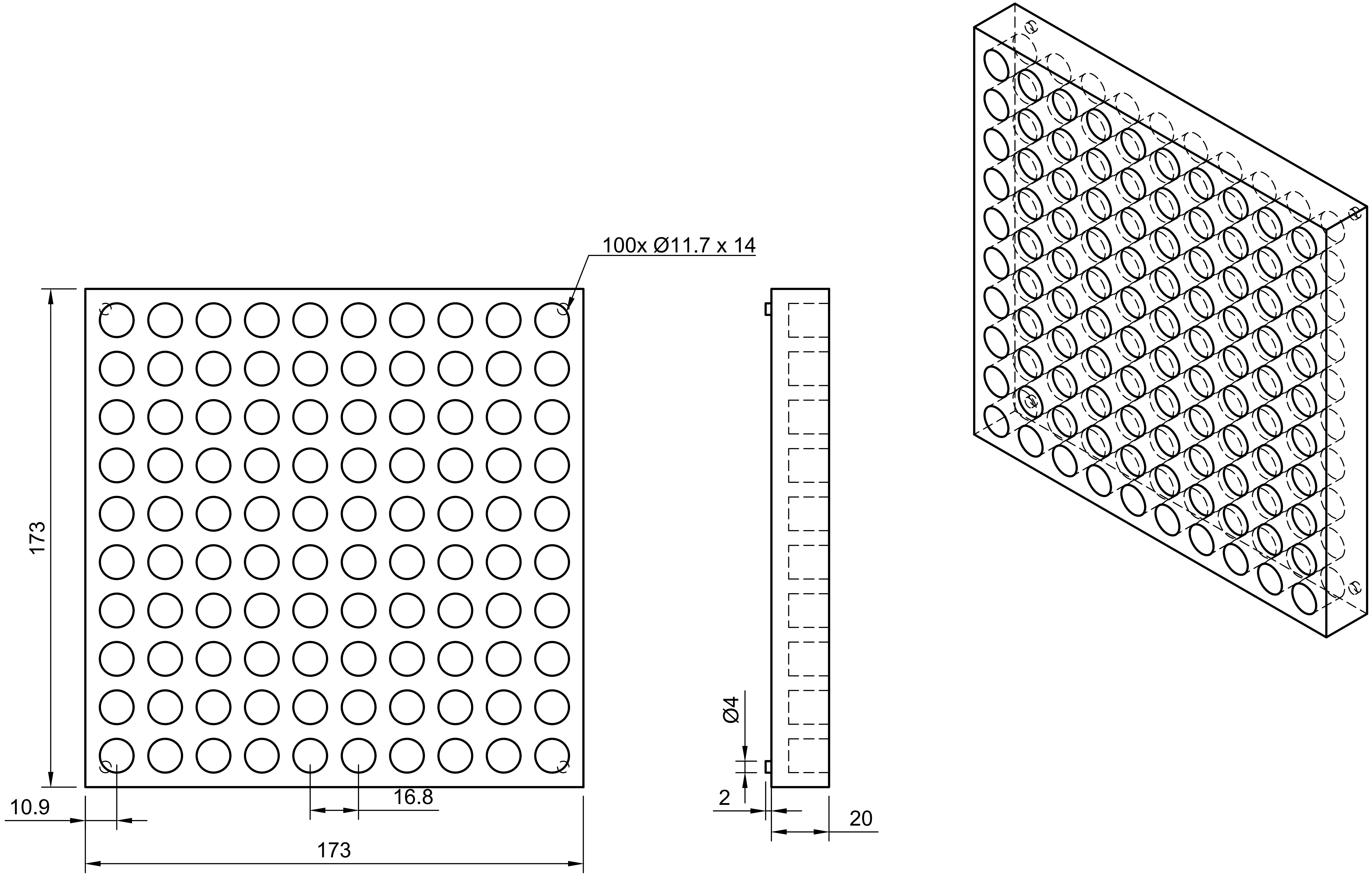
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/28/2024	Material: 18-8 Stainless Steel
Title: Hex Nut	Part Number: E18
	Scale: 10:1 / Sheet: 1/1



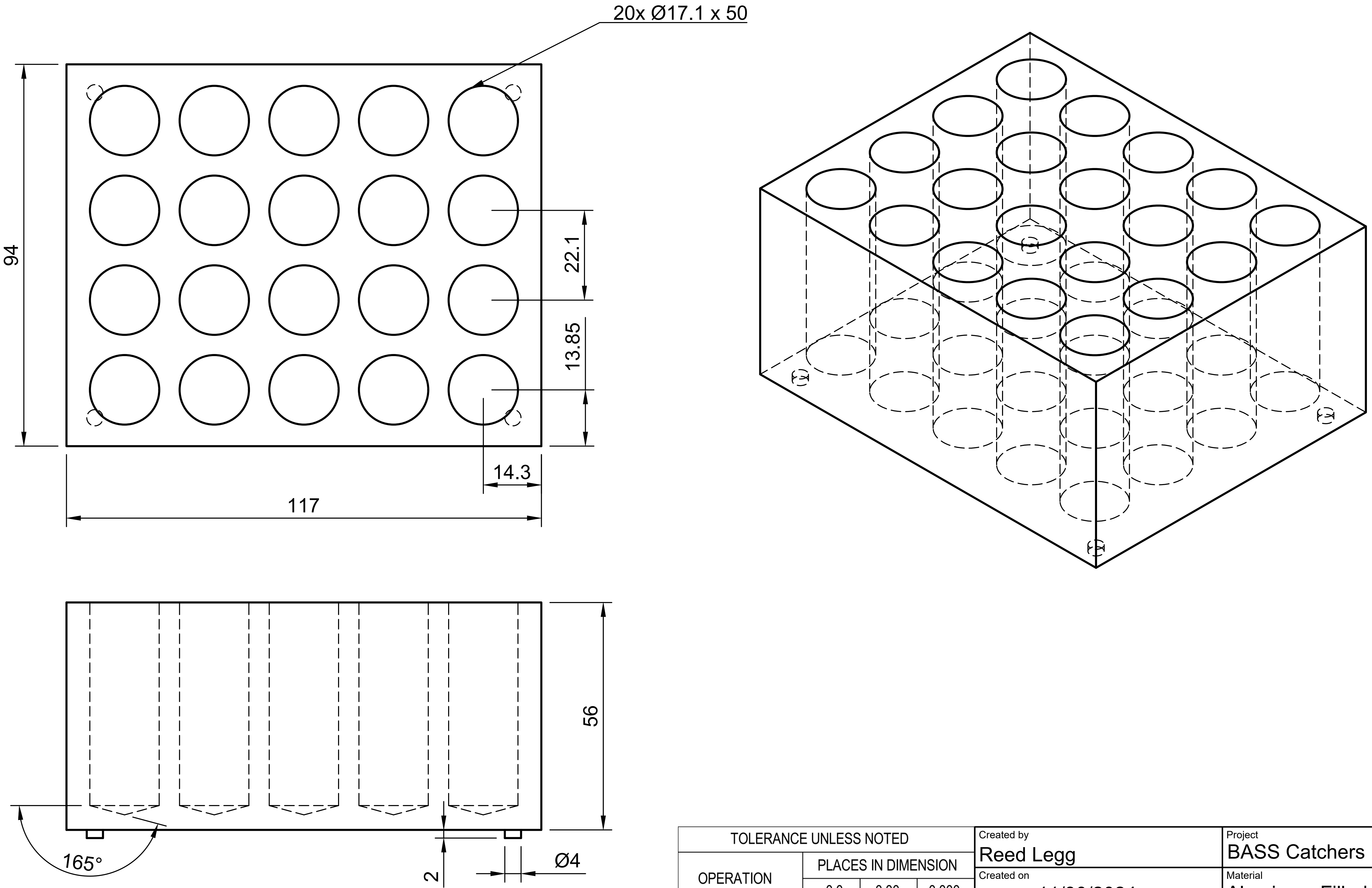
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Ayden Leeds	Project: BASS Catchers
Created on: 11/28/2024	Material: 17-7 PH Stainless Steel
Title: 17-7 PH Stainless Steel Washer	Part Number: E19
	Scale: 5:1
	Sheet: 1/1



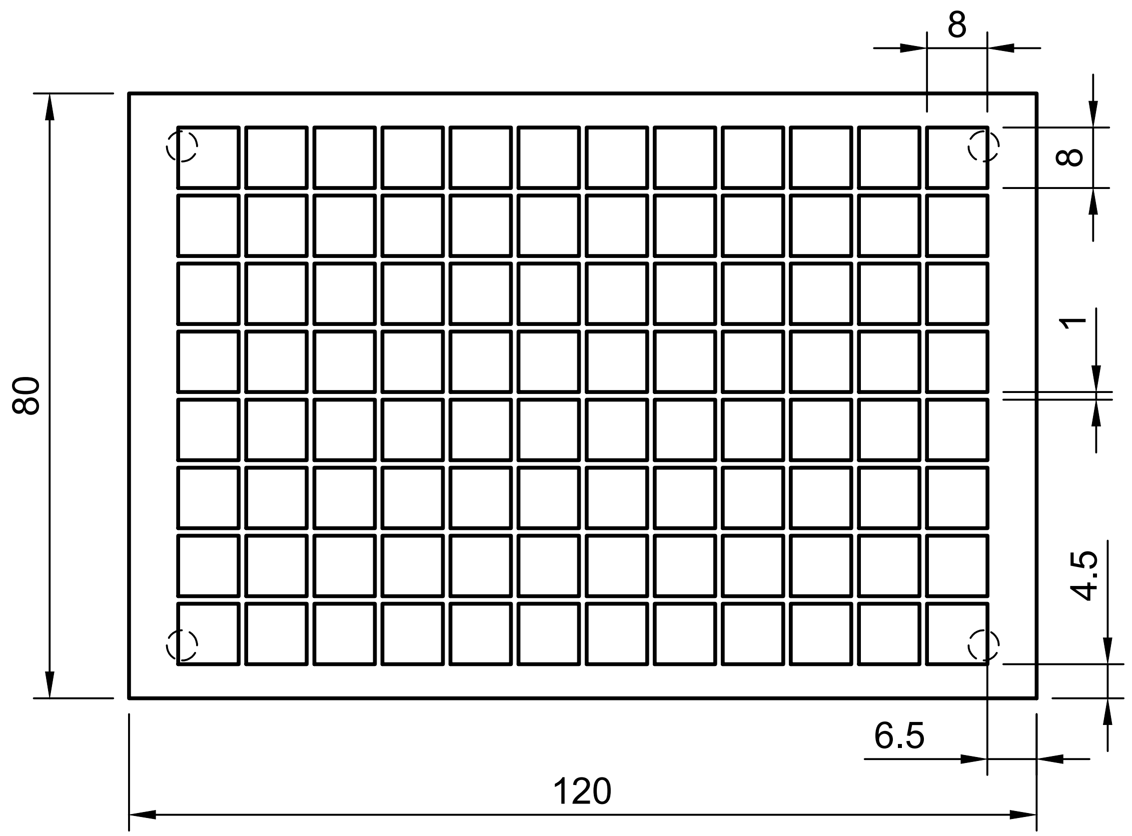
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

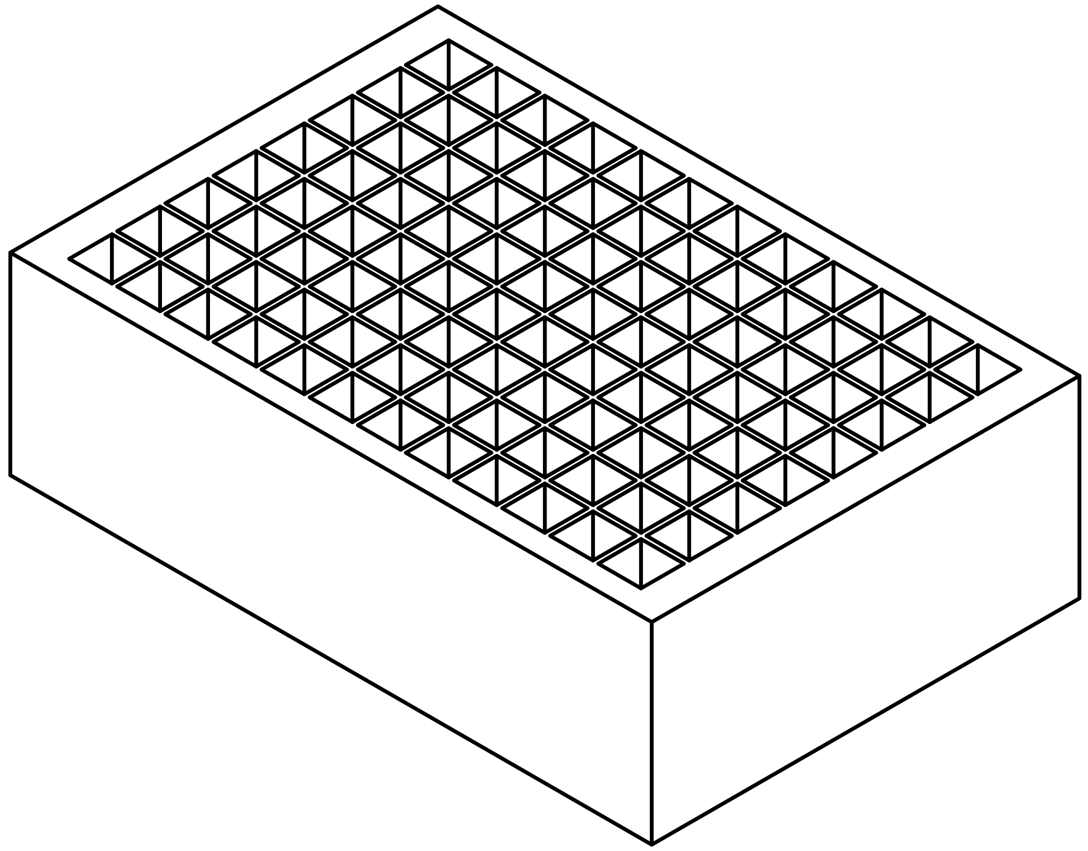
Created by Reed Legg	Project BASS Catchers
Created on 11/30/2024	Material Aluminum Filled PLA
Title 1.5ml Rack	Part Number E20
	Scale 1:1.5
	Sheet 1/1

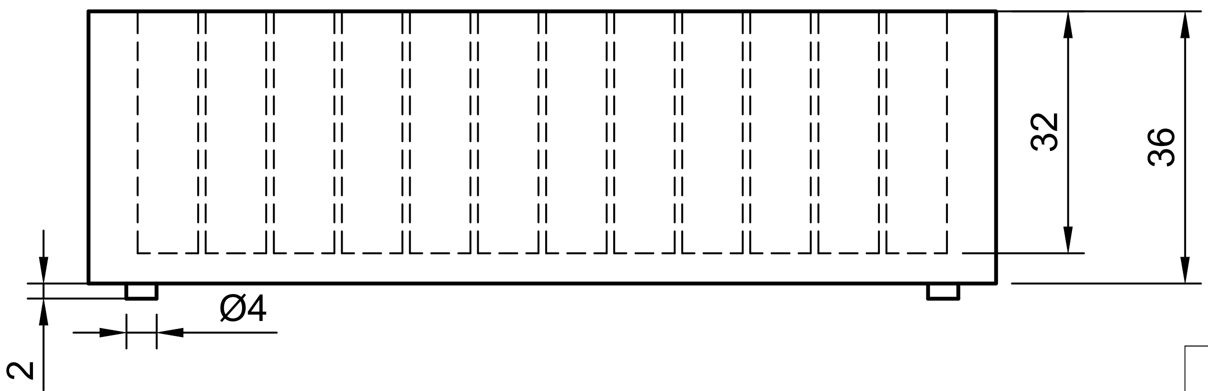


TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Reed Legg	Project: BASS Catchers
Created on: 11/30/2024	Material: Aluminum Filled PLA
Title: 15ml tray	Part Number: E21
	Scale: 1:1
	Sheet: 1/1

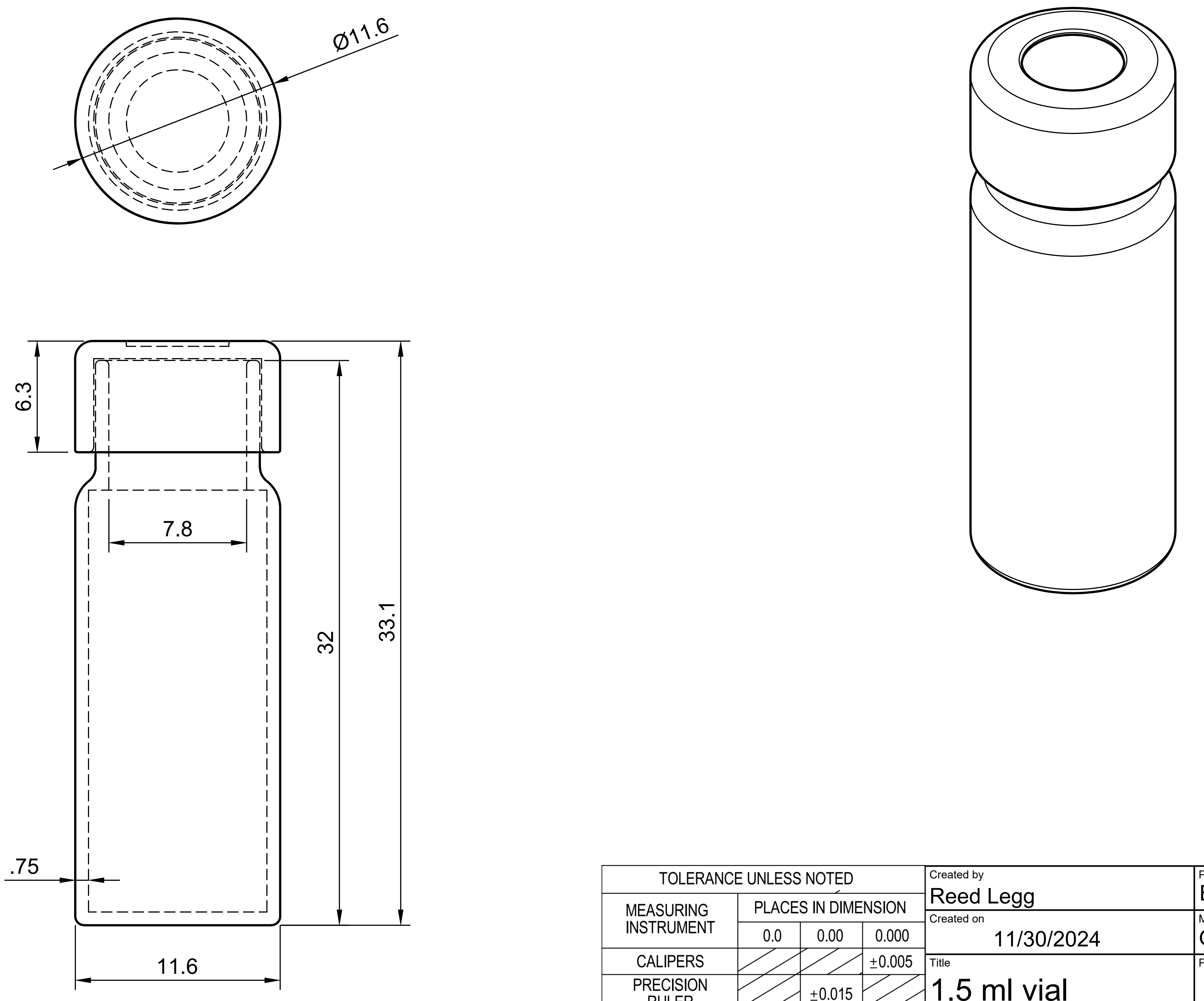






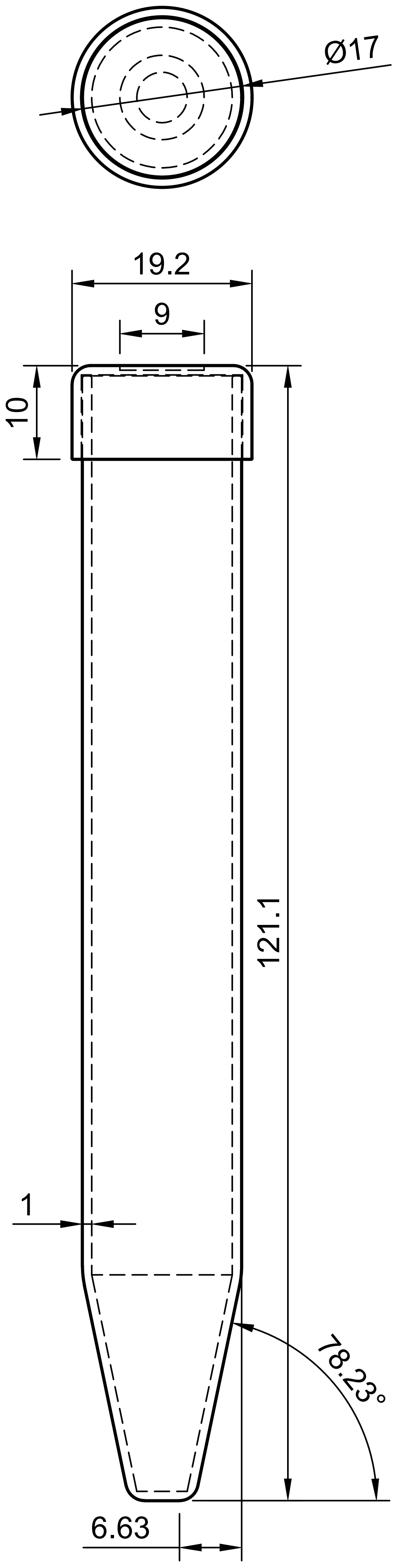
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

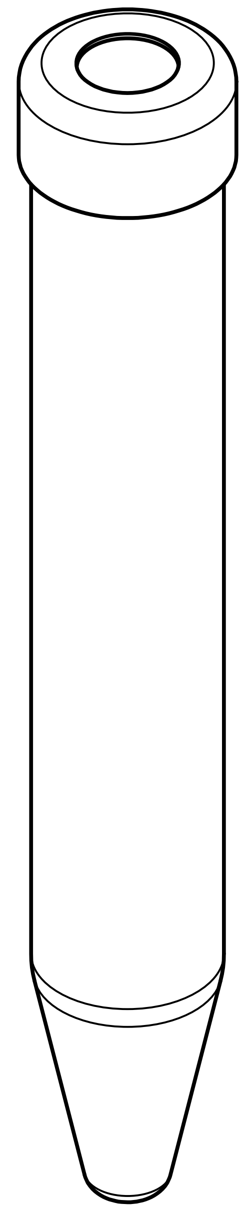
Created by Reed Legg	Project BASS Catchers
Created on 11/30/2024	Material Aluminum Filled PLA
Title 96 Well plate	Part Number E22
	Scale 1:1 · Sheet 1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

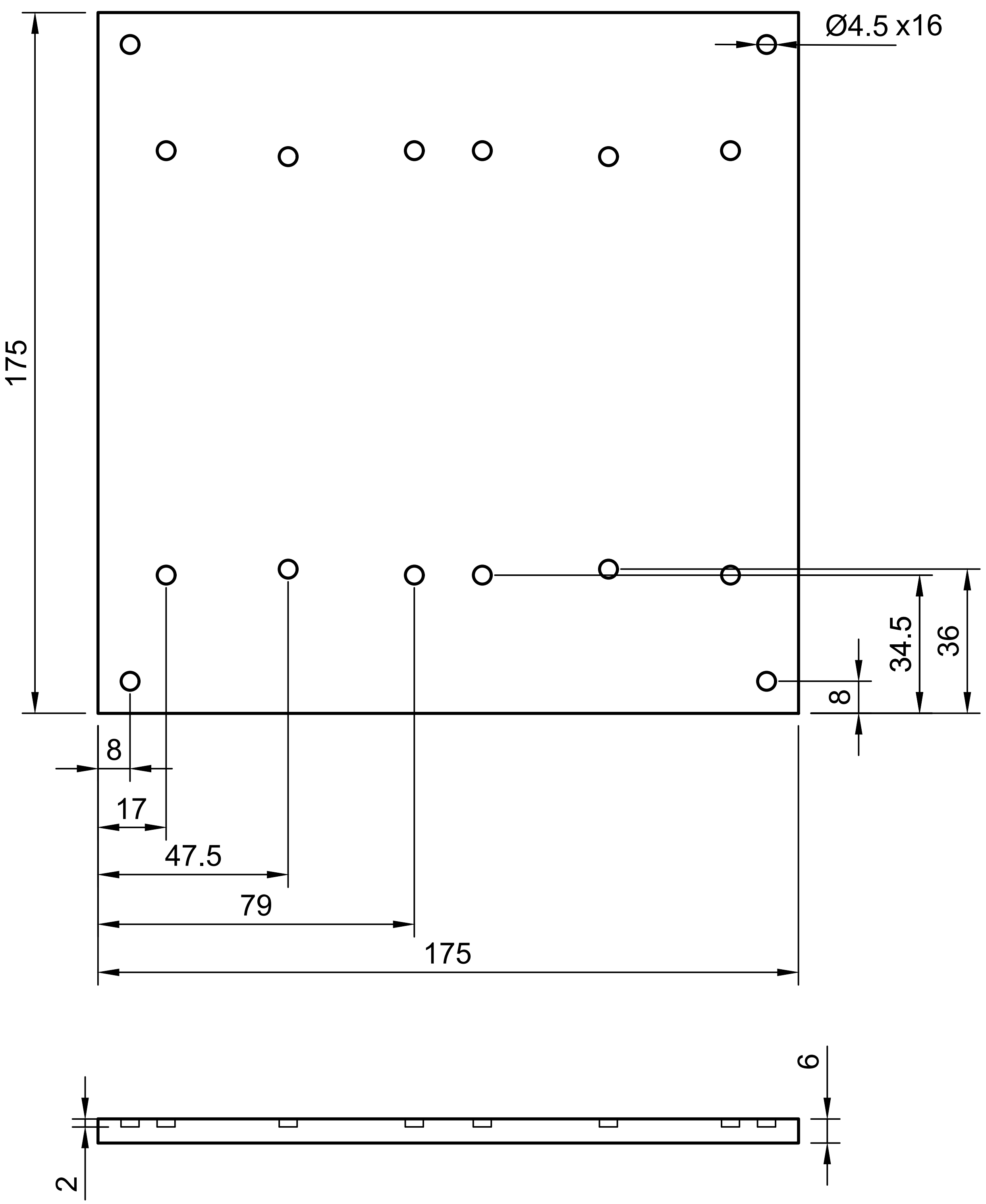
Created by: Reed Legg	Project: BASS Catchers
Created on: 11/30/2024	Material: Glass
Title: 1.5 ml vial	Part Number: E23
	Scale: 4:1 / Sheet: 1/1

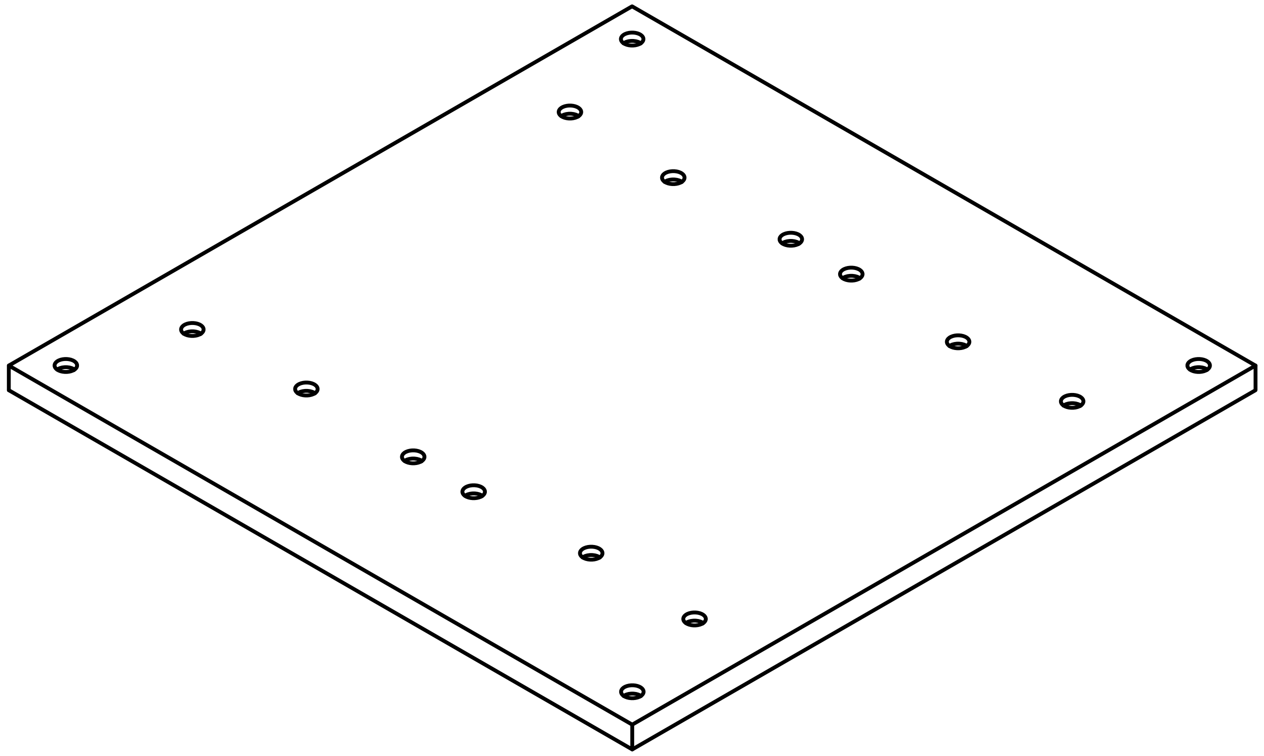




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

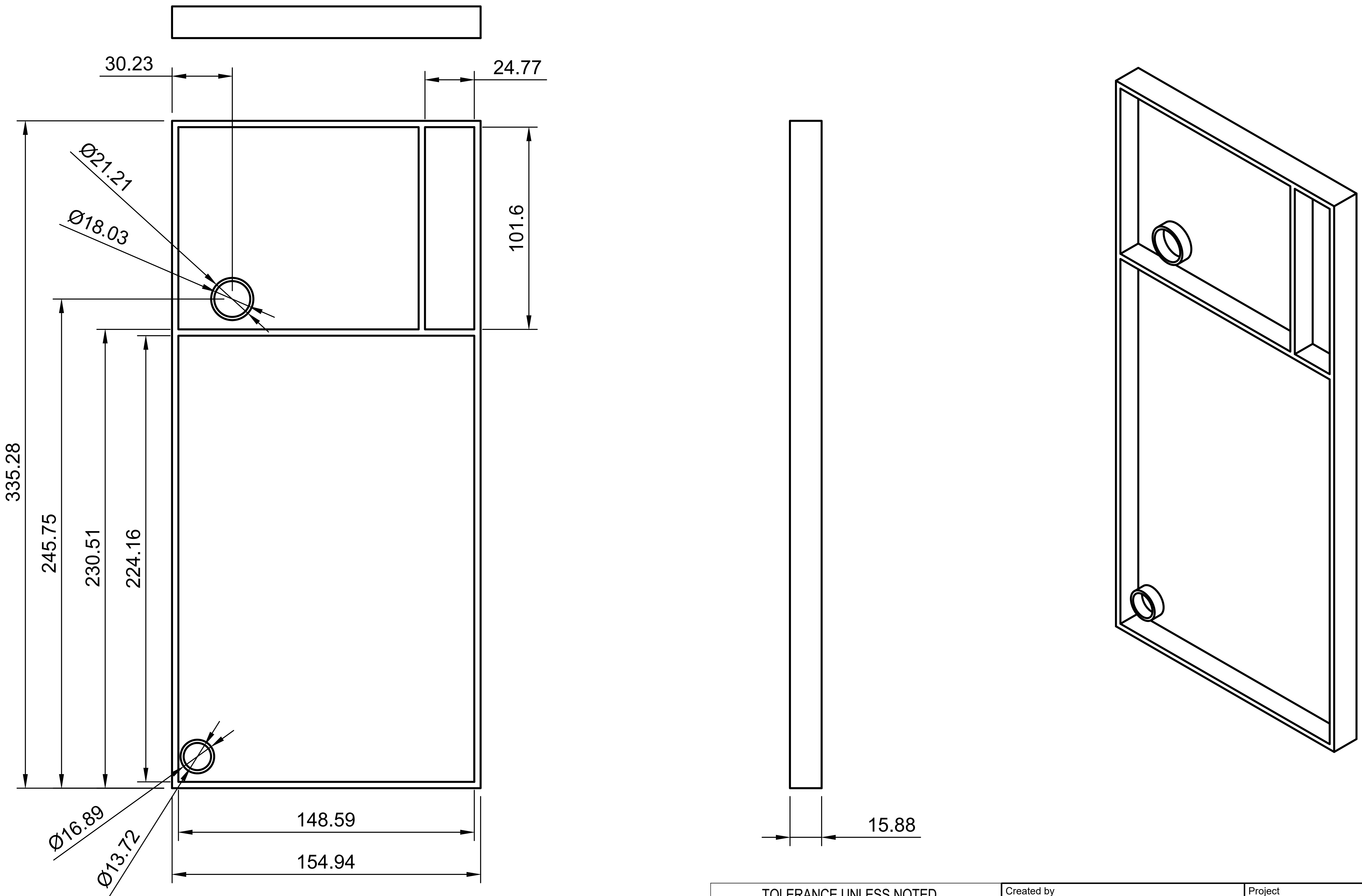
Created by: Reed Legg	Project: BASS Catchers
Created on: 11/30/2024	Material: Polypropylene
Title: 15ml vial	Part Number: E24
	Scale: 1.5:1 — Sheet: 1/1





TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Reed Legg	Project: BASS Catchers
Created on: 11/30/2024	Material: Aluminum Filled PLA
Title: pin plate	Part Number: E25
	Scale: 1:1 / Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by
Tin Sulenta

Created on
01-Dec-24

Title
Fluids System Pump Tray

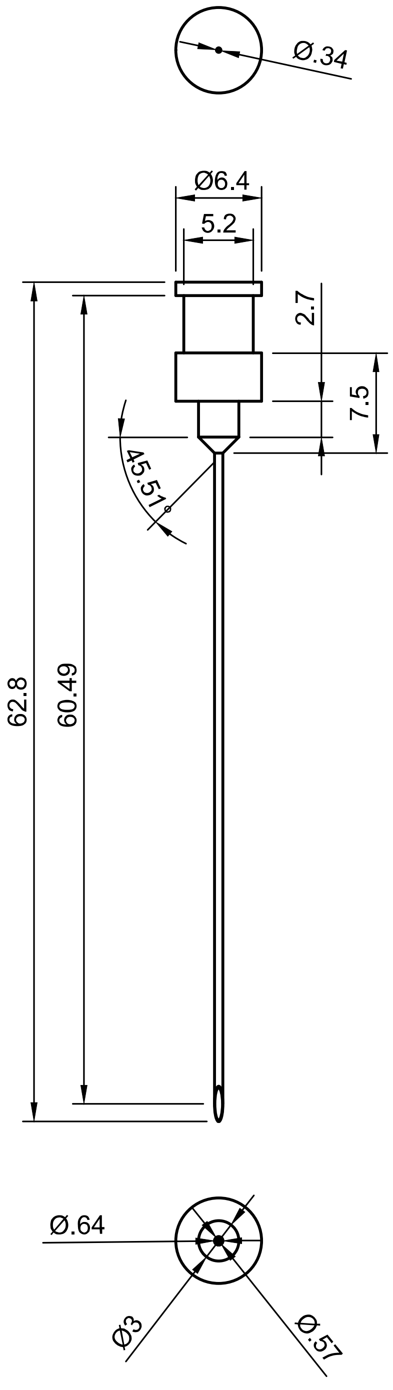
Project
BASS Catchers

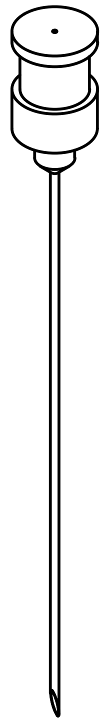
Material
PLA

Part Number
EML4501-F01

Scale
1:2

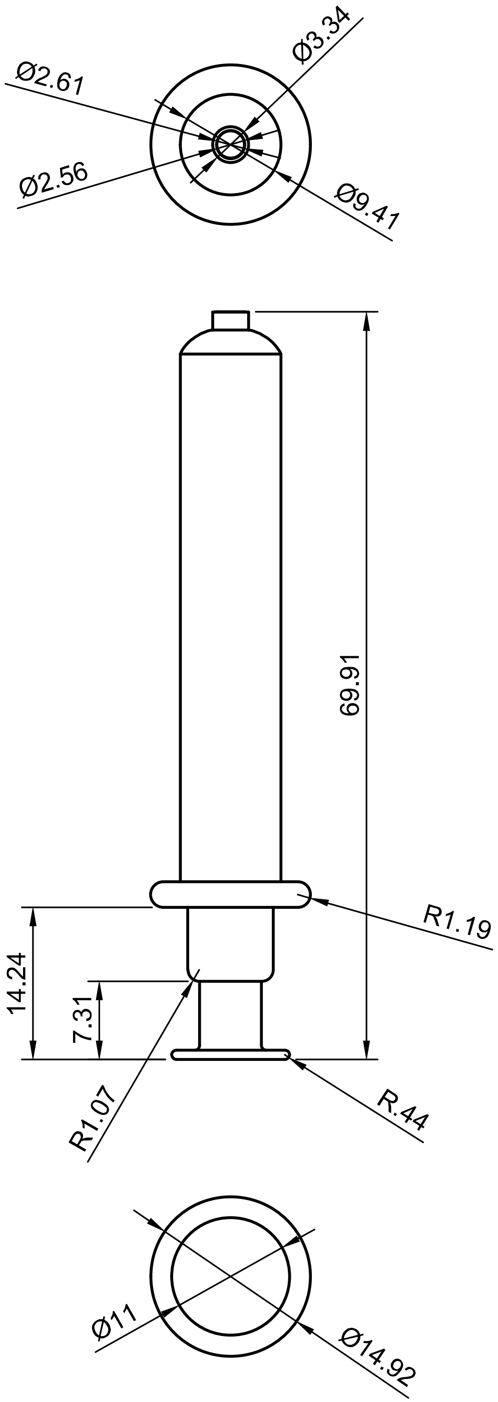
Sheet
1/1

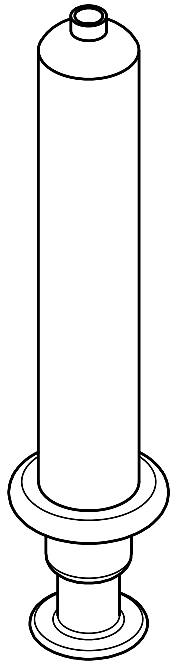




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

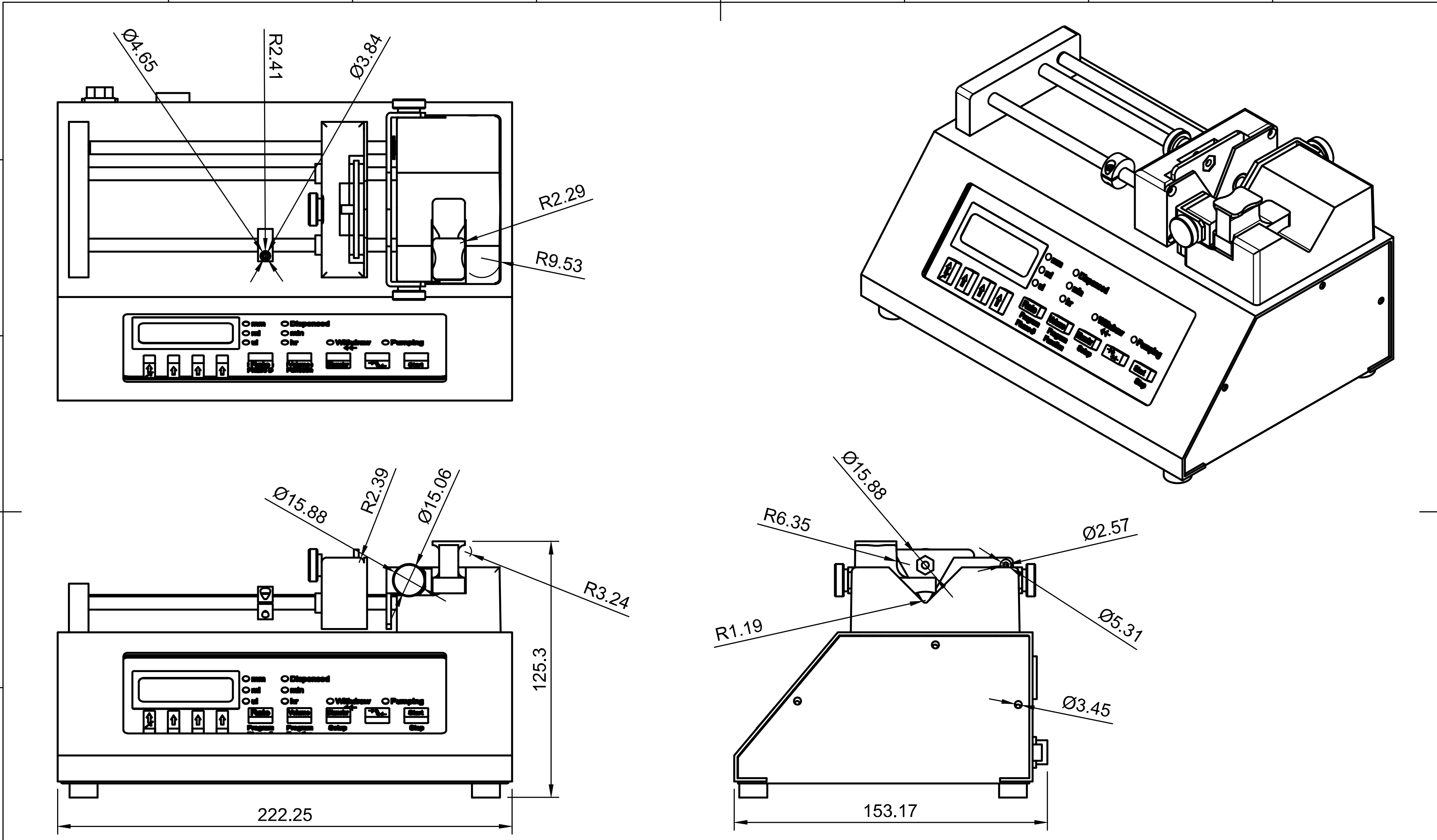
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: Stainless Steel
Title: 23GA Needle	Part Number: EML4501-F02
	Scale: 1.7:1 / Sheet: 1/1





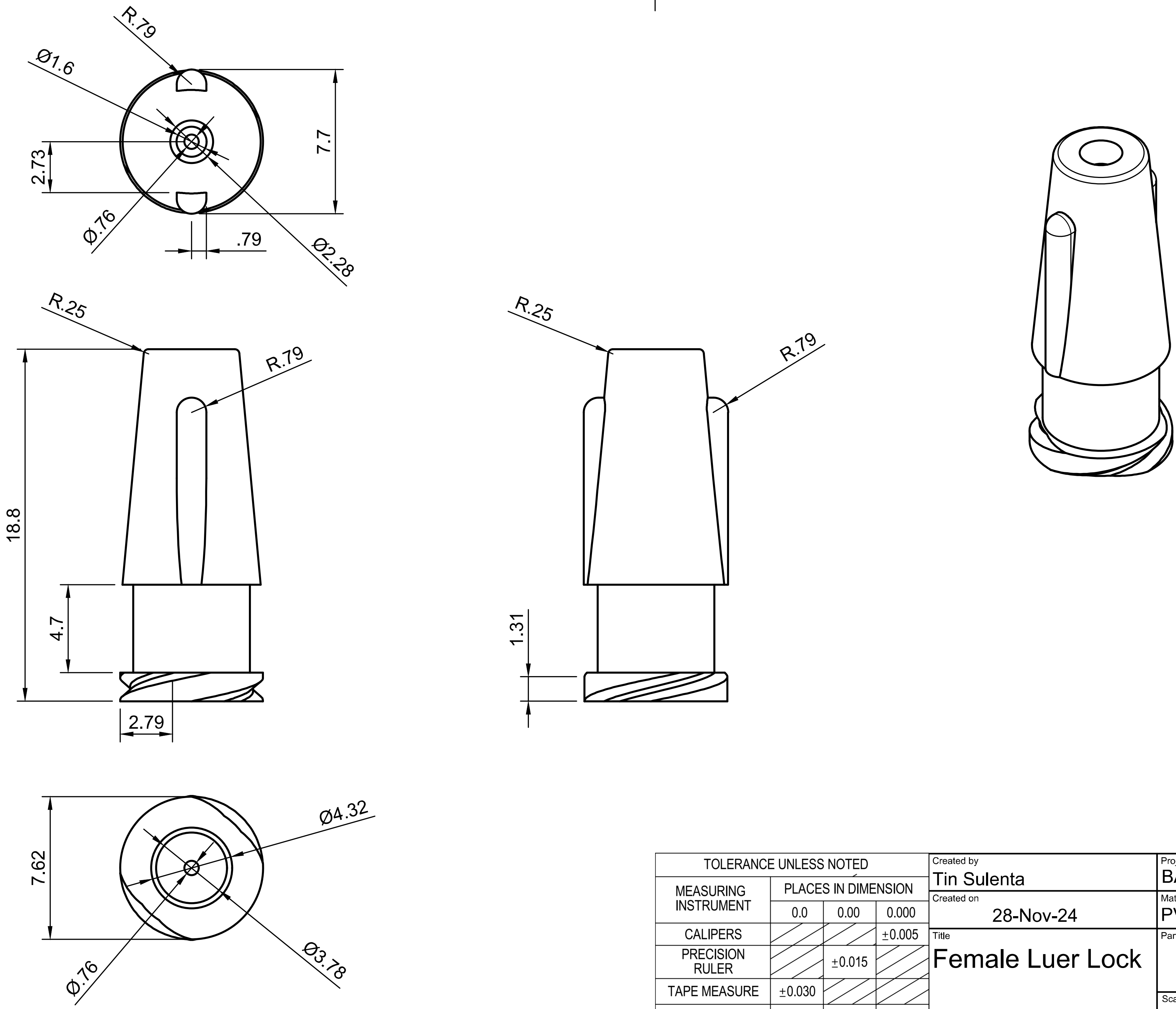
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: Borosilicate Glass
Title: Luer Lock Syringe	Part Number: EML4501-F03
	Scale: 2:1 / Sheet: 1/1



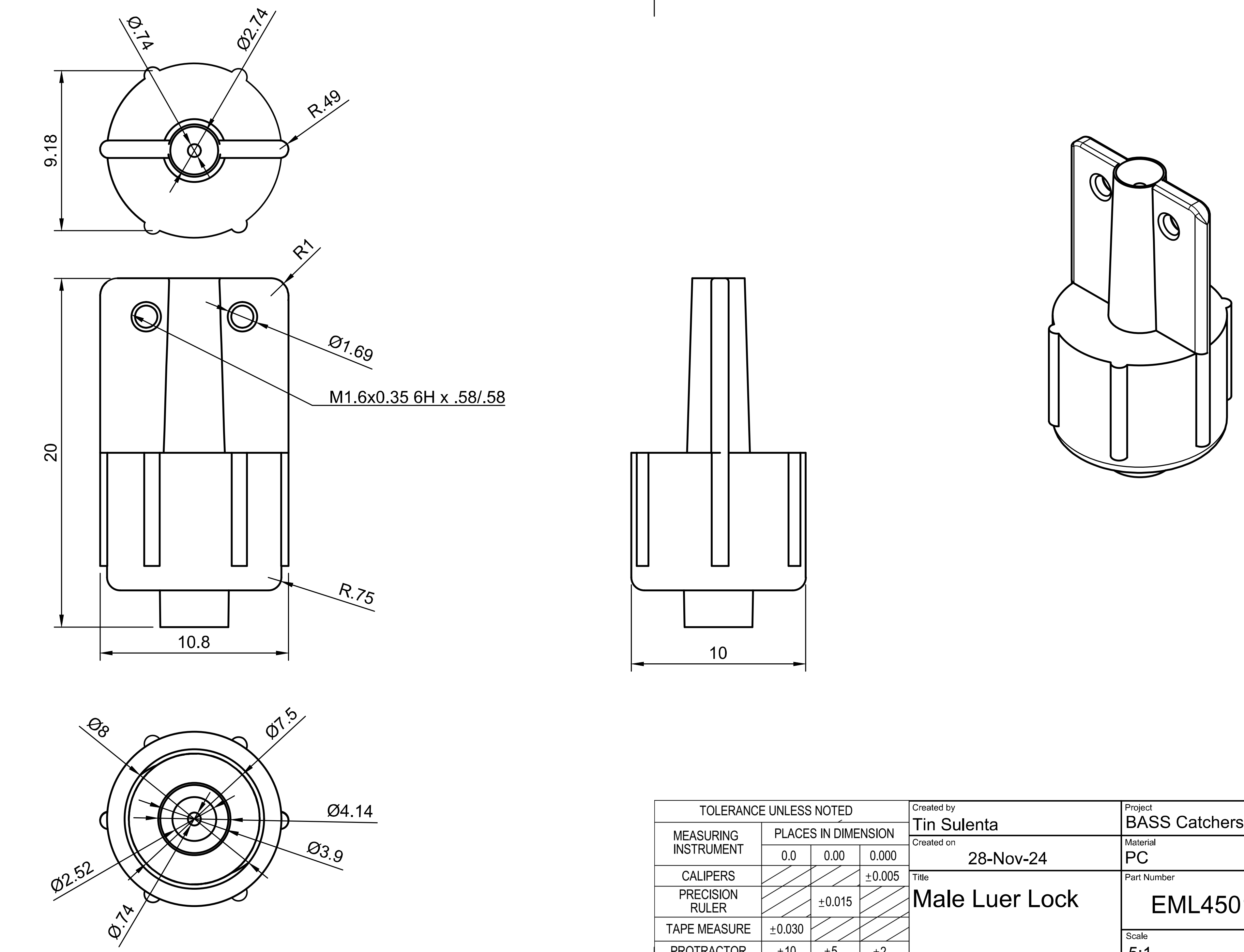
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: Aluminum
Title: Microsyringe Pump	Part Number: EML4501-F04
	Scale: 1:1.8
	Sheet: 1/1



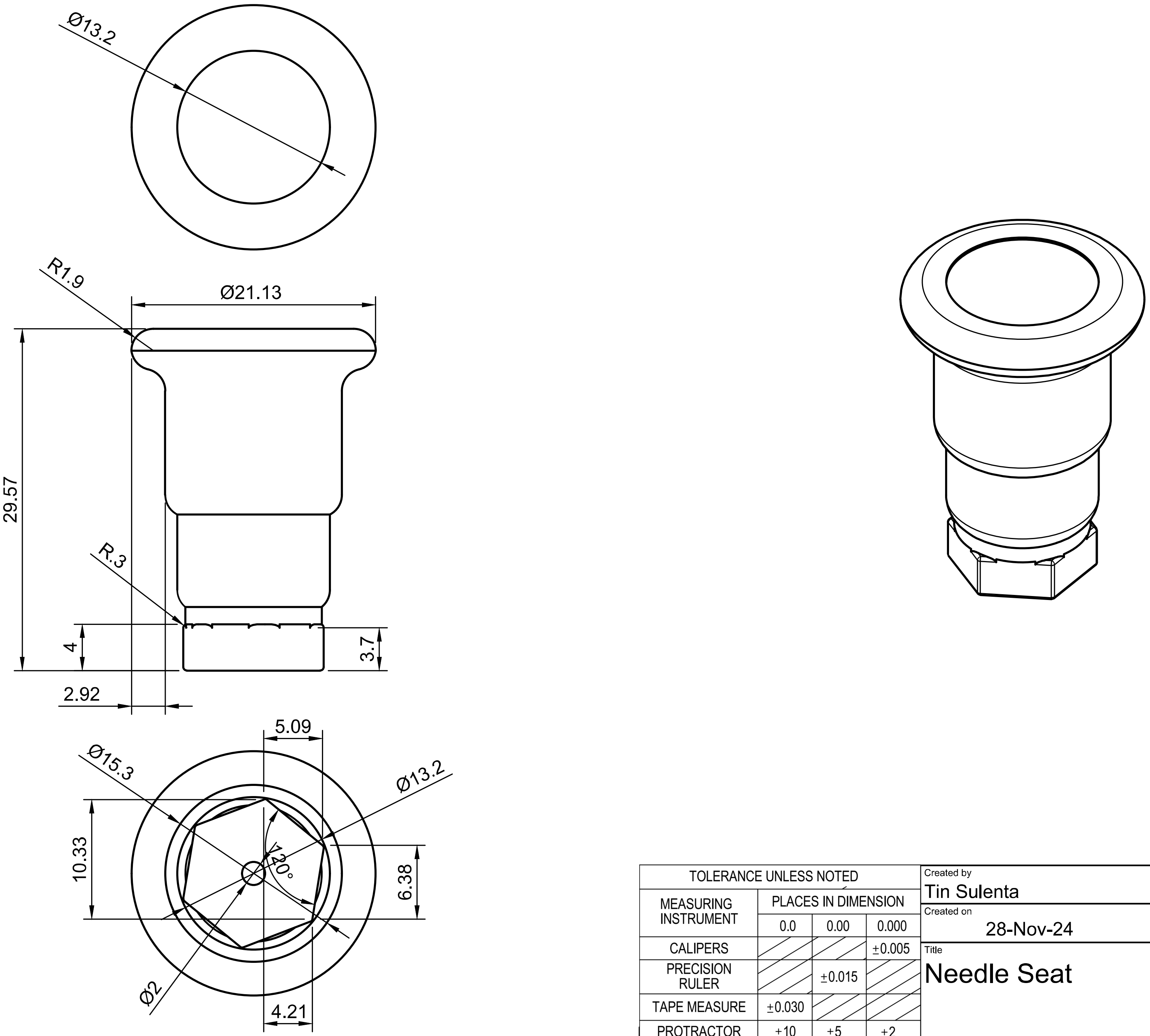
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: PVC
Title: Female Luer Lock	Part Number: EML4501-F05
	Scale: 5:1 — Sheet: 1/1



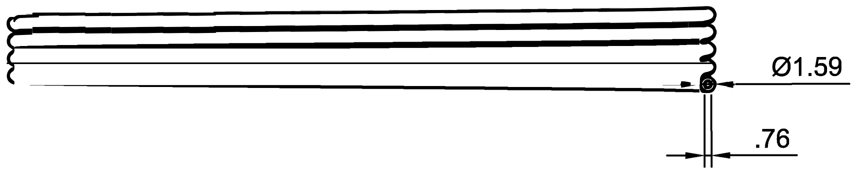
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

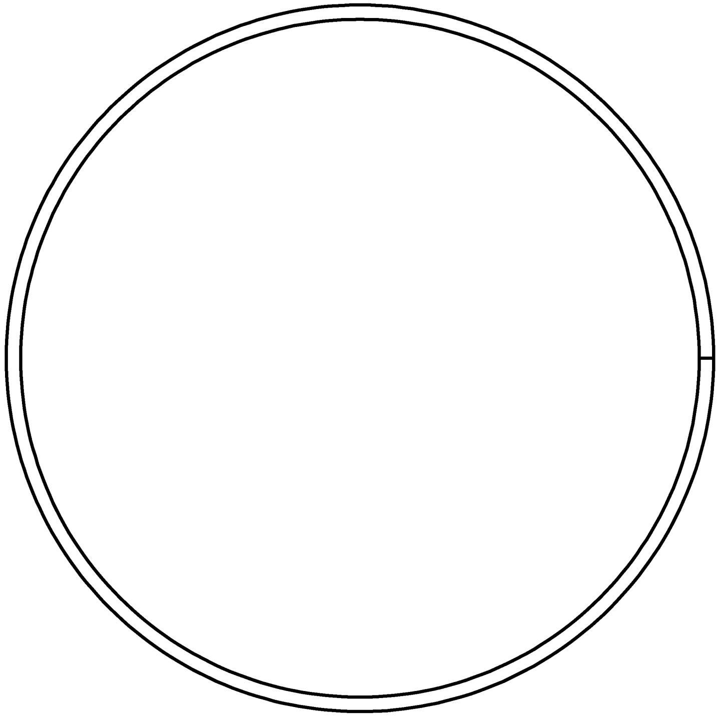
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: PC
Title: Male Luer Lock	Part Number: EML4501-F06
	Scale: 5:1 · Sheet: 1/1

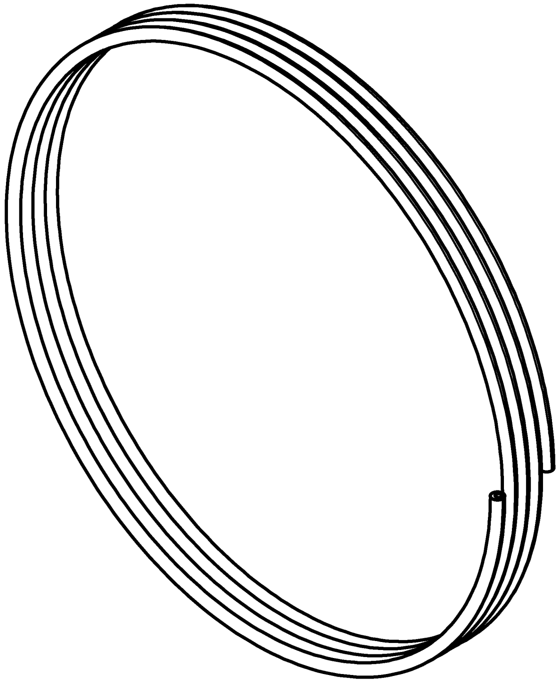


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: PEEK
Title: Needle Seat	Part Number: EML4501-F07
	Scale: 3:1 / Sheet: 1/1



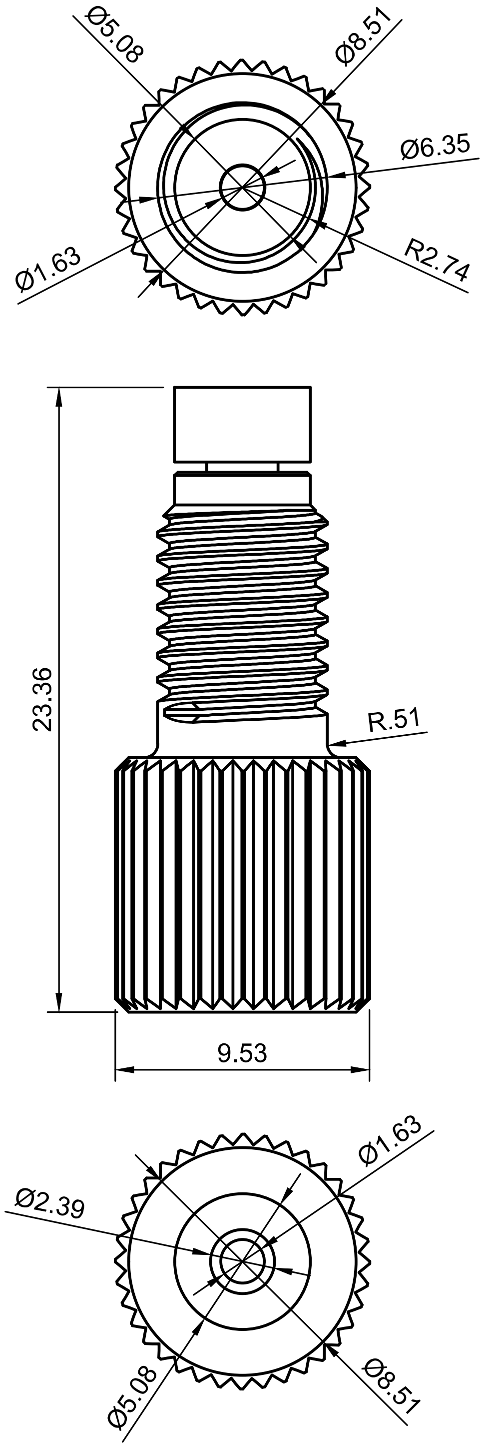


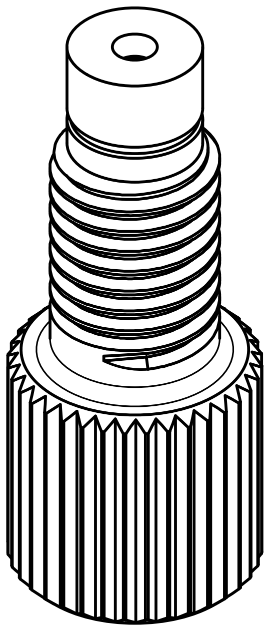


Sample loop length	1,340.03 mm
Aspiration capillary length, between the needle and the microsyringe pump	1,130.66 mm
Waste line, from the 6-port injection valve to the jug	371.42 mm
Mobile phase line 1 length, from the other jug to the peristaltic pump	449.35 mm
Mobile phase line 2 length, from the peristaltic pump to the 6-port injection valve	146.81 mm
Fluid transfer line length, from the needle seat to the 6-port injection valve	245.21 mm
Output line length	432.16 mm

TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

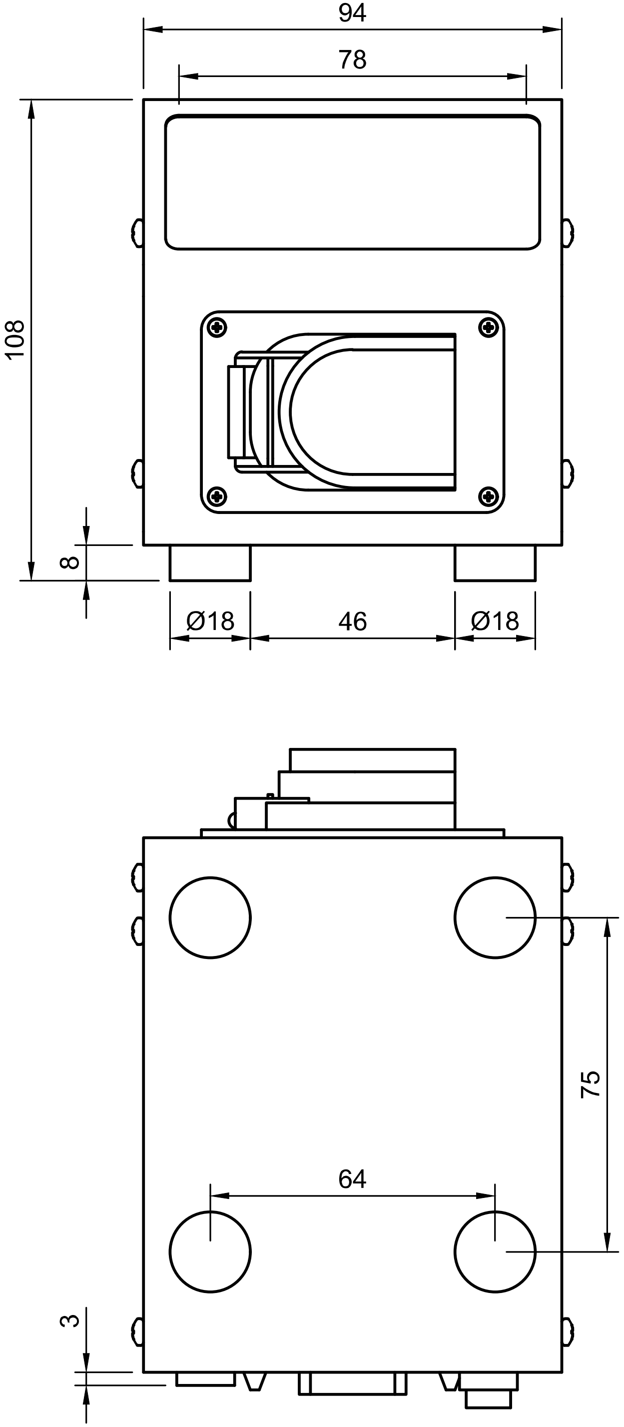
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: ETFE
Title: Sample Loop Tube	Part Number: EML4501-F08
	Scale: 1.7:1 — Sheet: 1/1

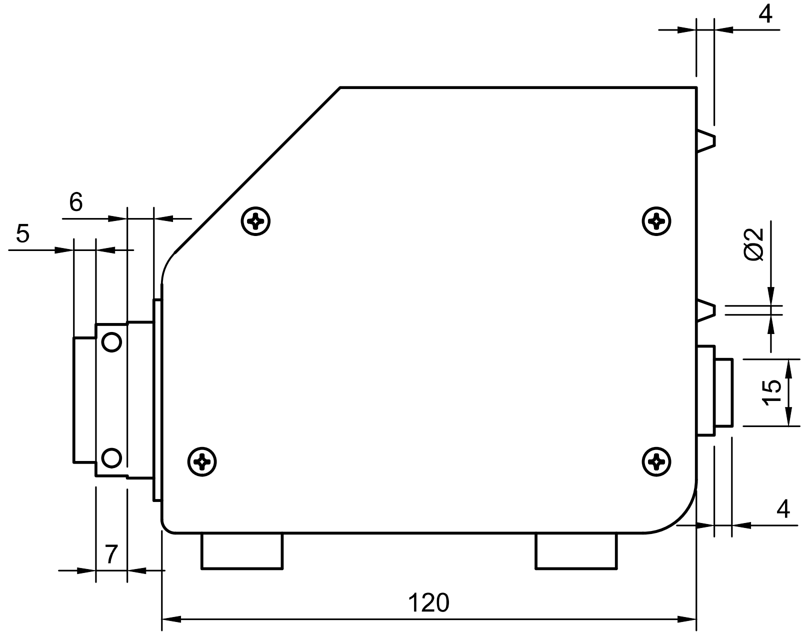




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

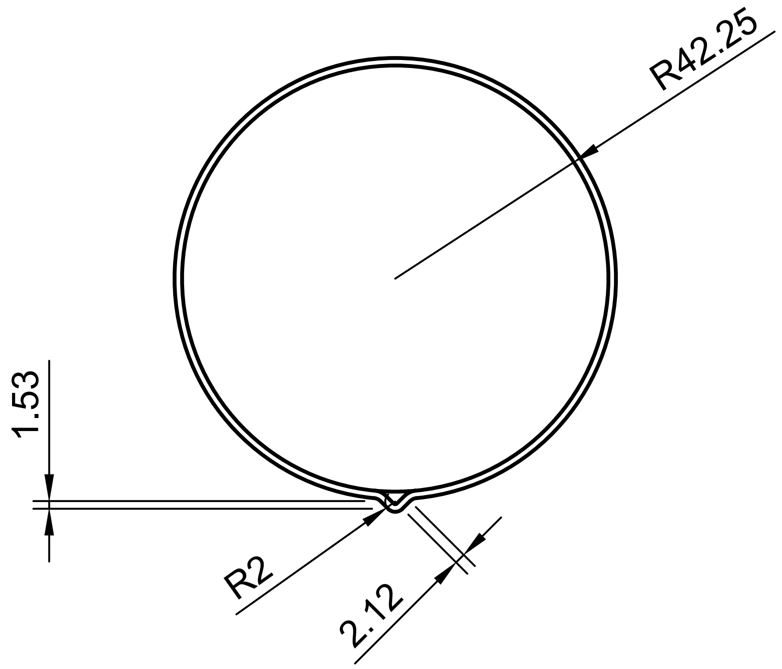
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 27-Nov-24	Material: PEEK
Title: 1/4-28 Flat Bottom Connector	Part Number: EML4501-F09
	Scale: 5:1
	Sheet: 1/1

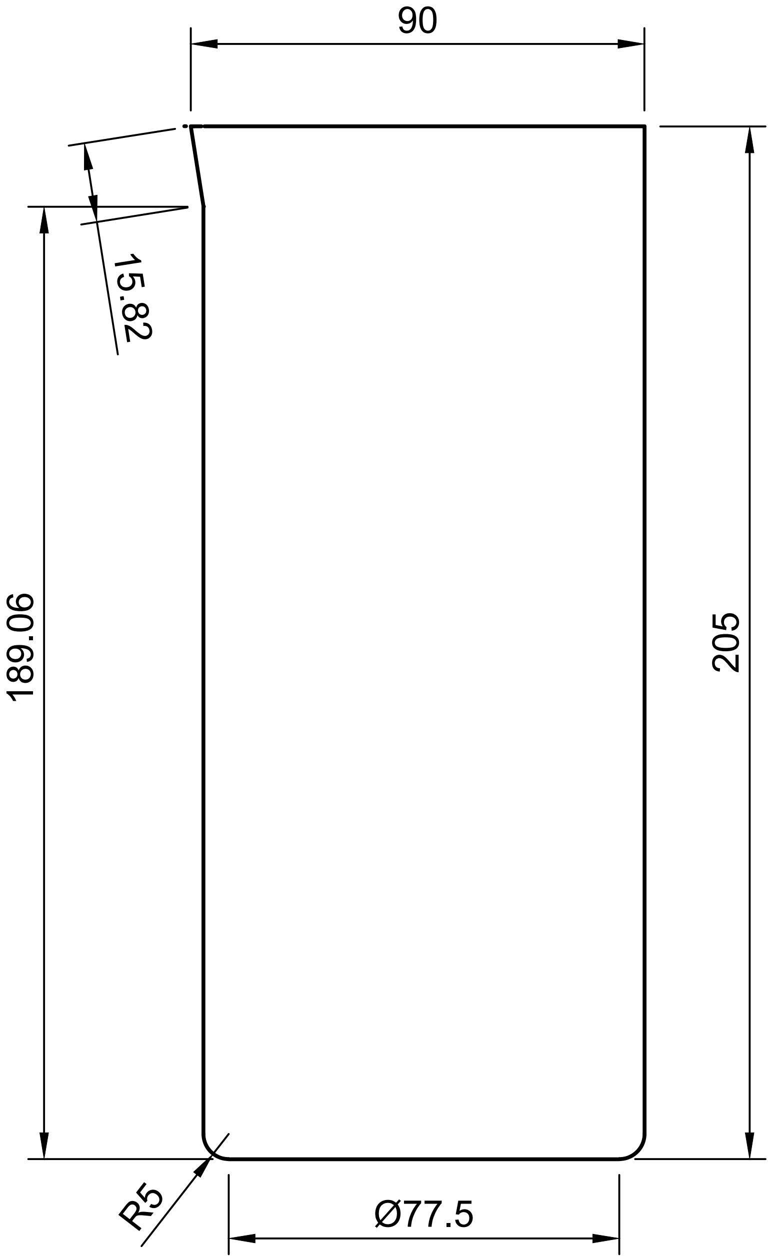


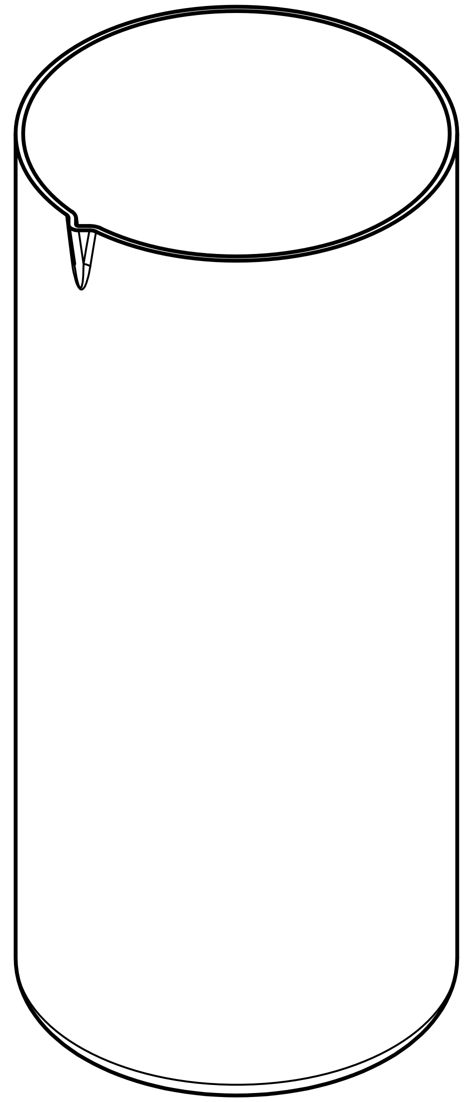


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 27-Nov-24	Material: N/A
Title: Peristaltic Pump	Part Number: EML4501-F10
	Scale: 1:1.2 — Sheet: 1/1

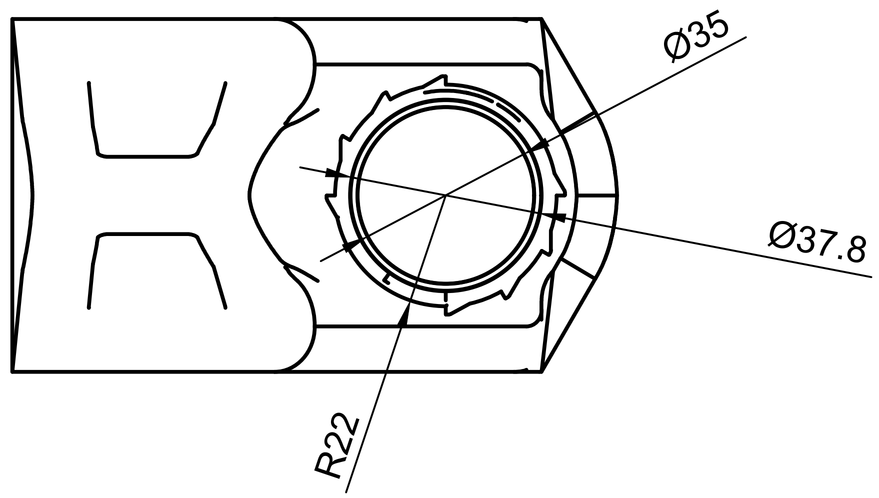


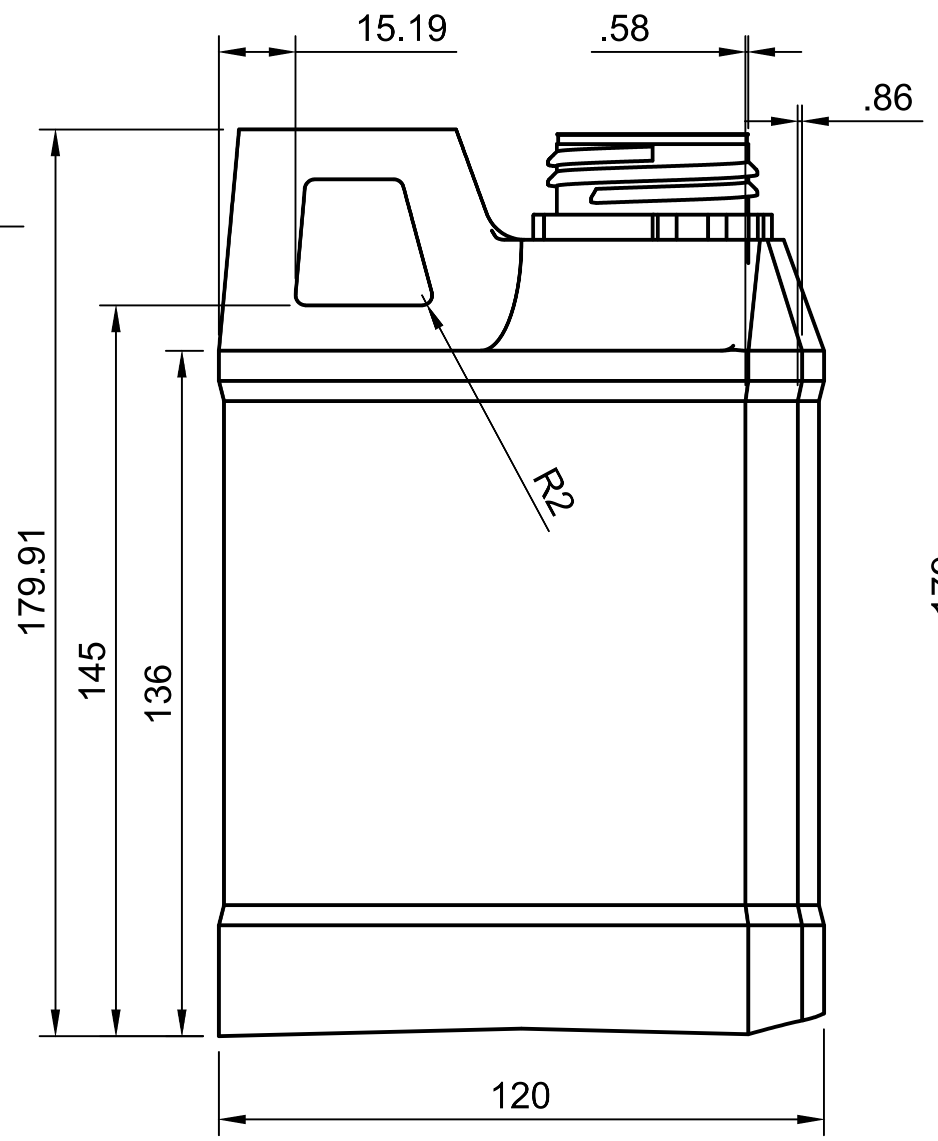


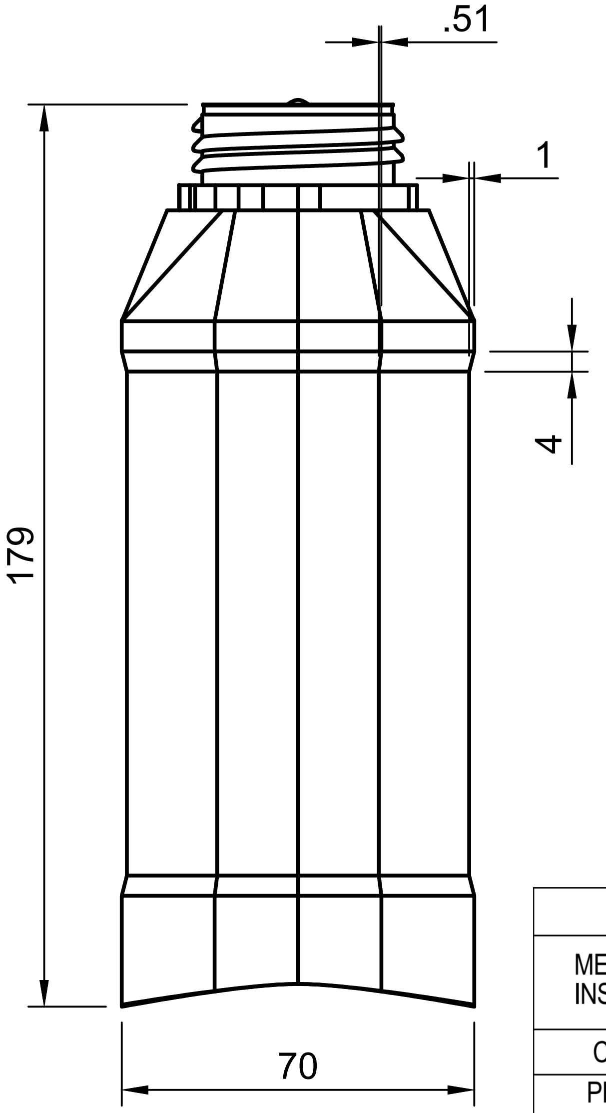


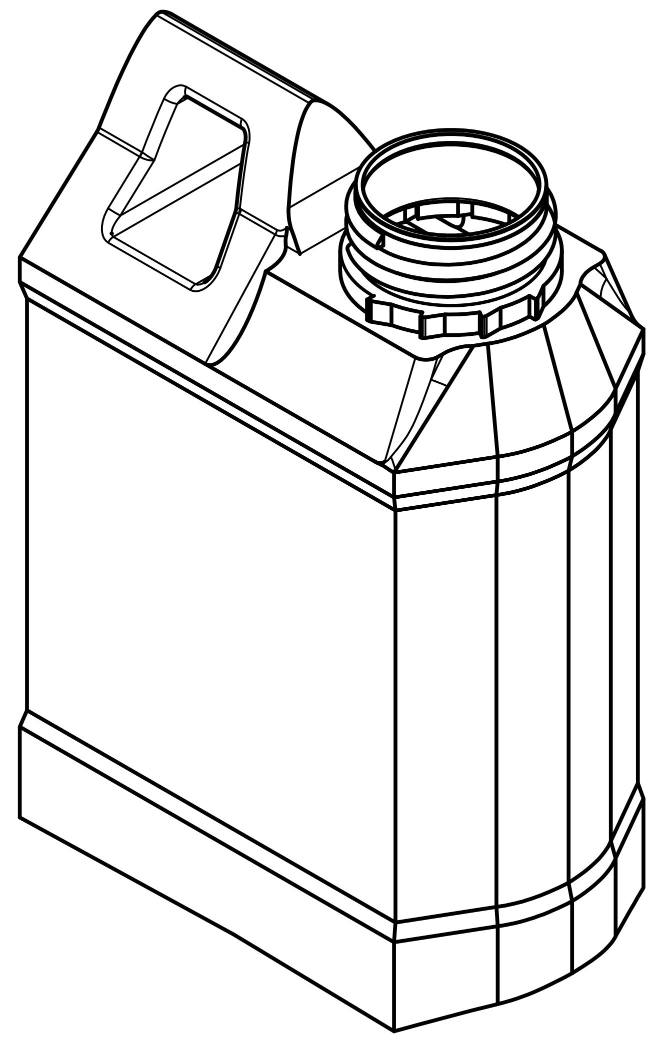
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by Tin Sulenta	Project BASS Catchers
Created on 28-Nov-24	Material Borosilicate Glass
Title 1L Beaker	Part Number EML4501-F11
	Scale 1:1.5
	Sheet 1/1



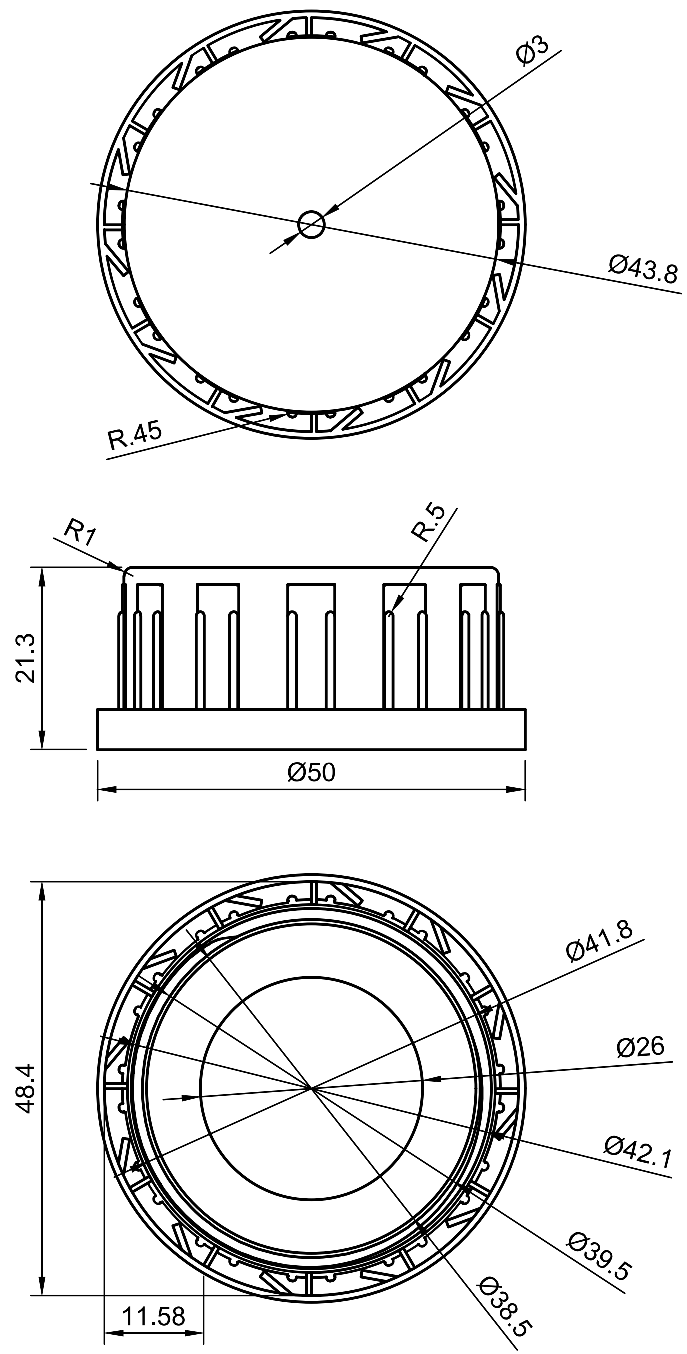


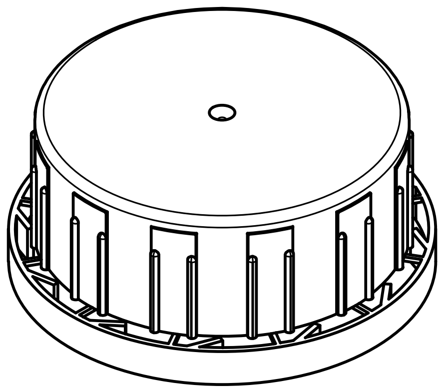




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: HDPE
Title: 32 oz. Jug	Part Number: EML4501-F12
	Scale: 1:1.5 — Sheet: 1/1





TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by
Tin Sulenta

Created on
28-Nov-24

Title
Jug Cap

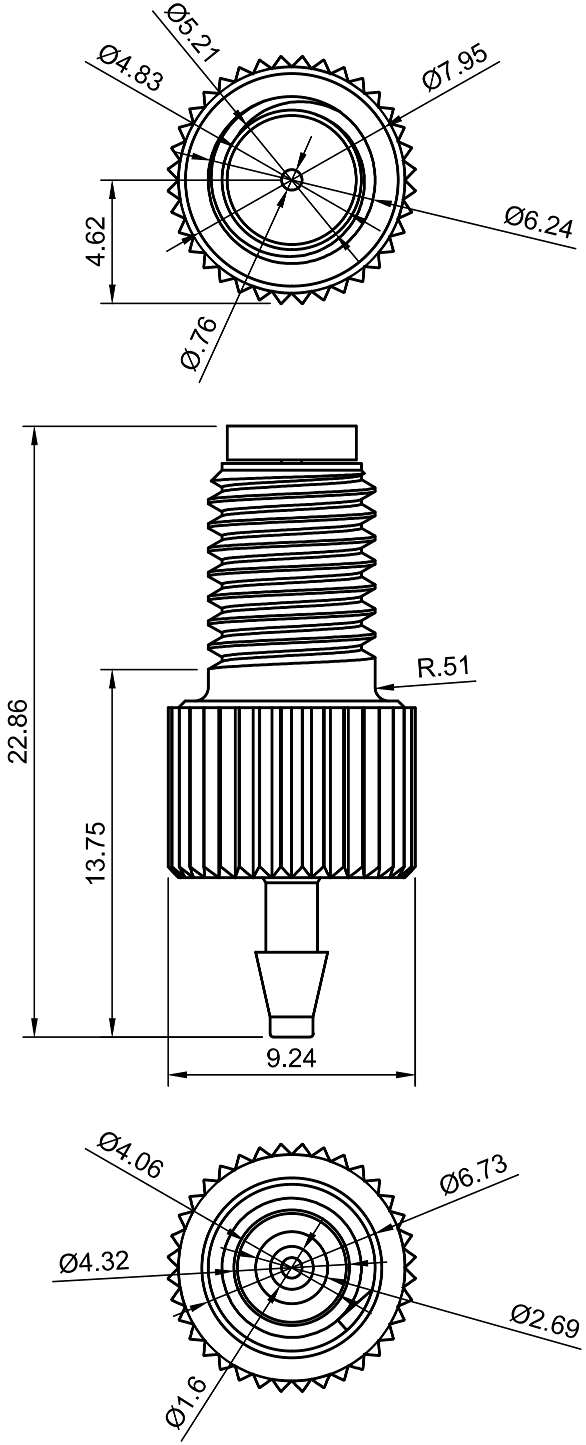
Project
BASS Catchers

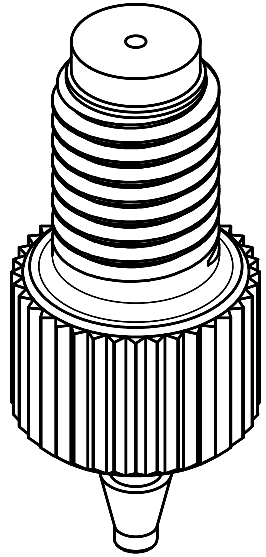
Material
Polypropylene

Part Number
EML4501-F13

Scale
1.6:1

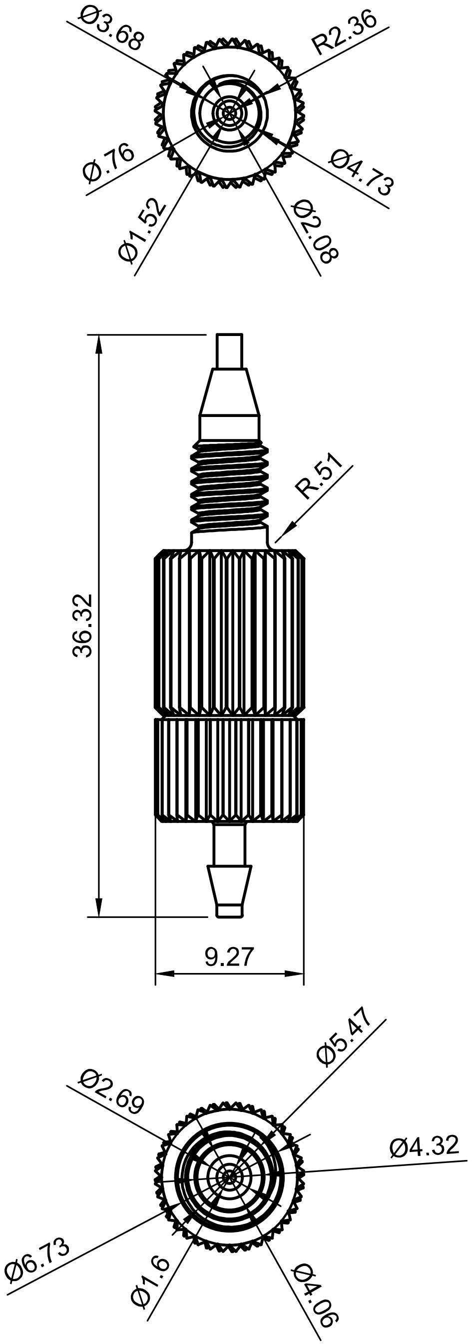
Sheet
1/1

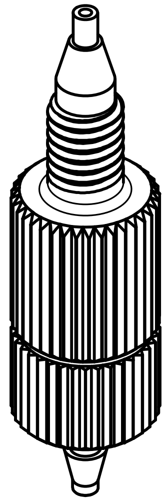




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

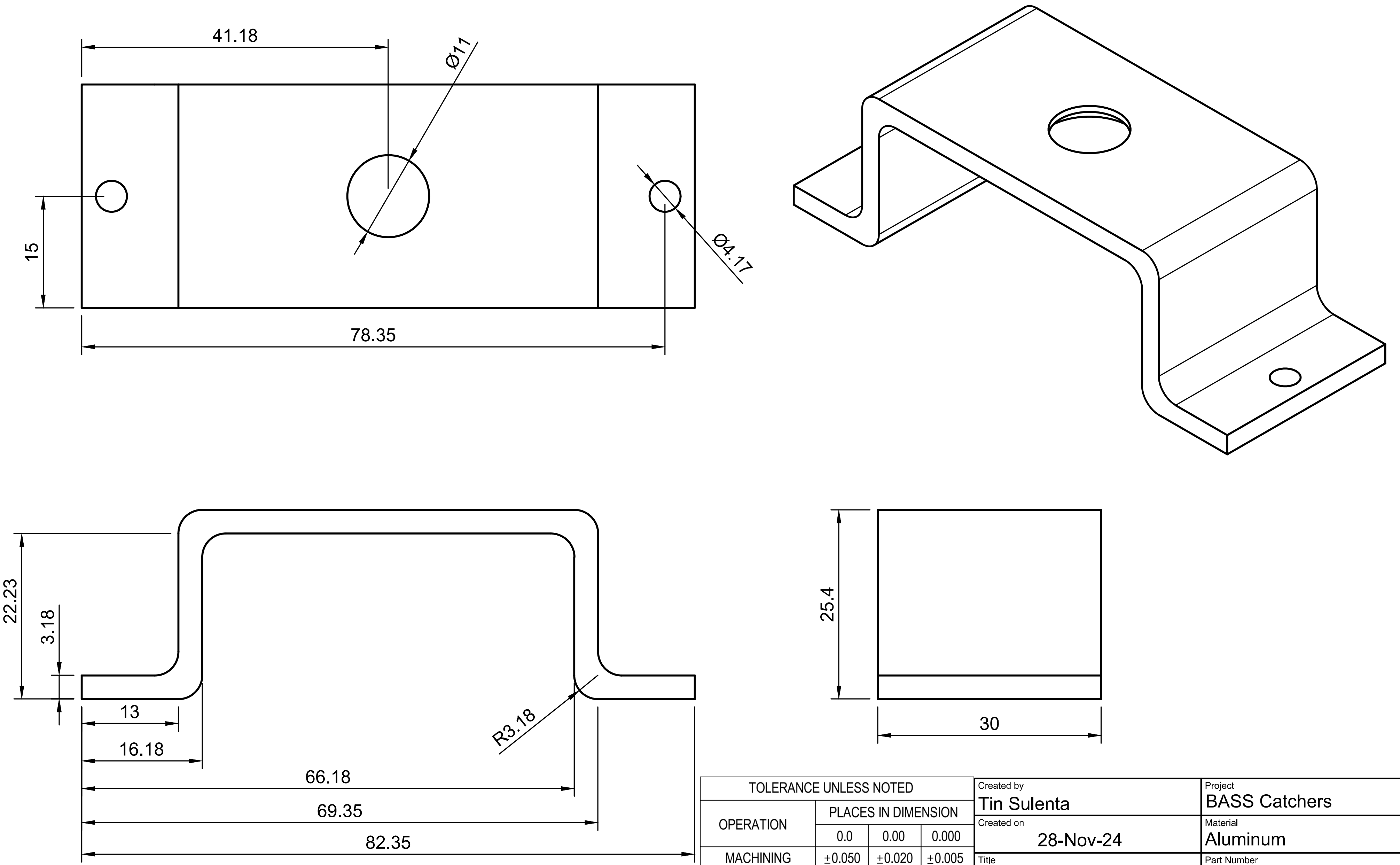
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: Polypropylene
Title: Swivel Barb Adapter	Part Number: EML4501-F14
	Scale: 5:1 / Sheet: 1/1





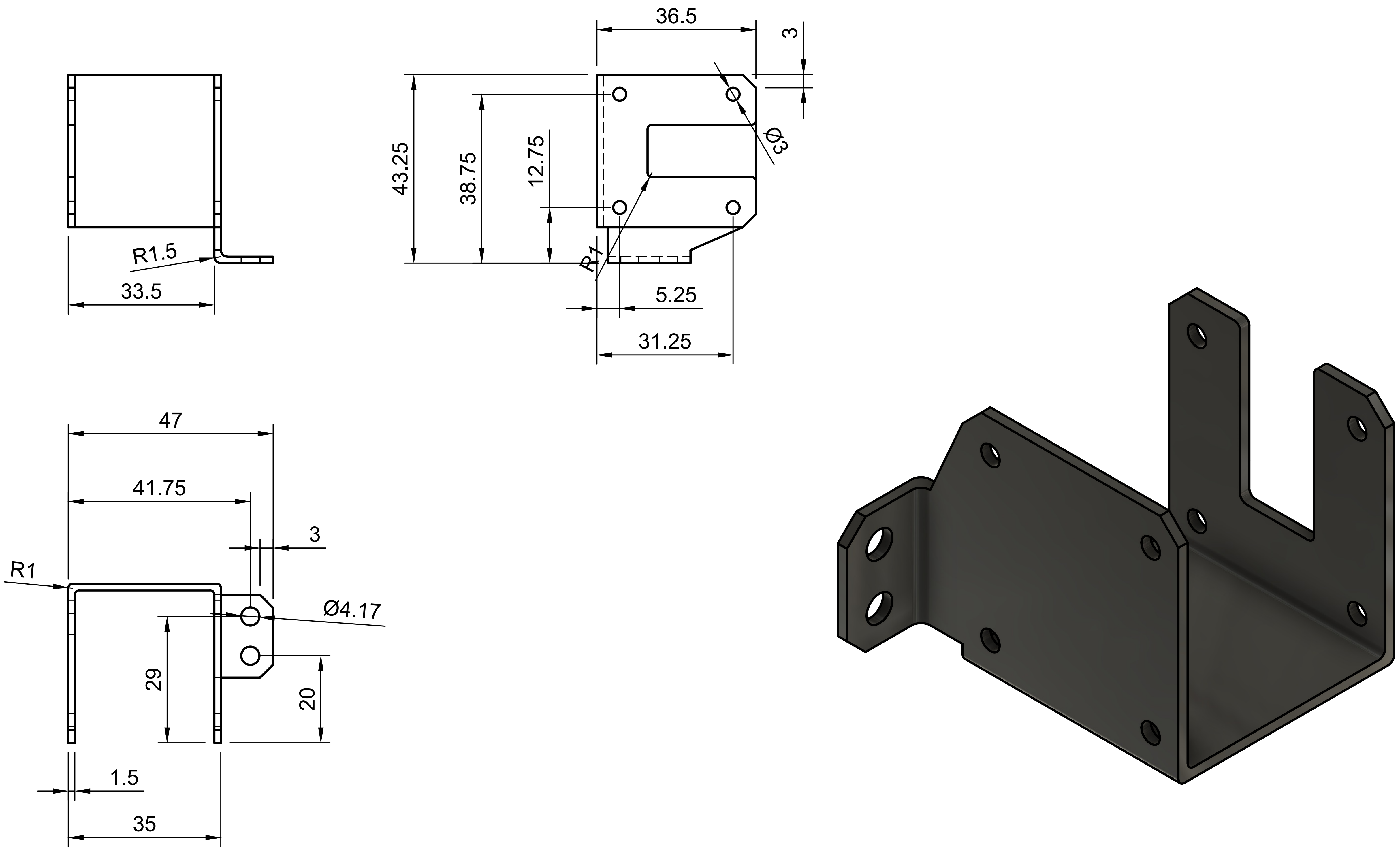
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by	Tin Sulenta
Created on	03-Dec-24
Title	Adapter - 1/4-28 x 10-32
Project	BASS Catchers
Material	PEEK
Part Number	EML4501-F15
Scale	3:1
Sheet	1/1



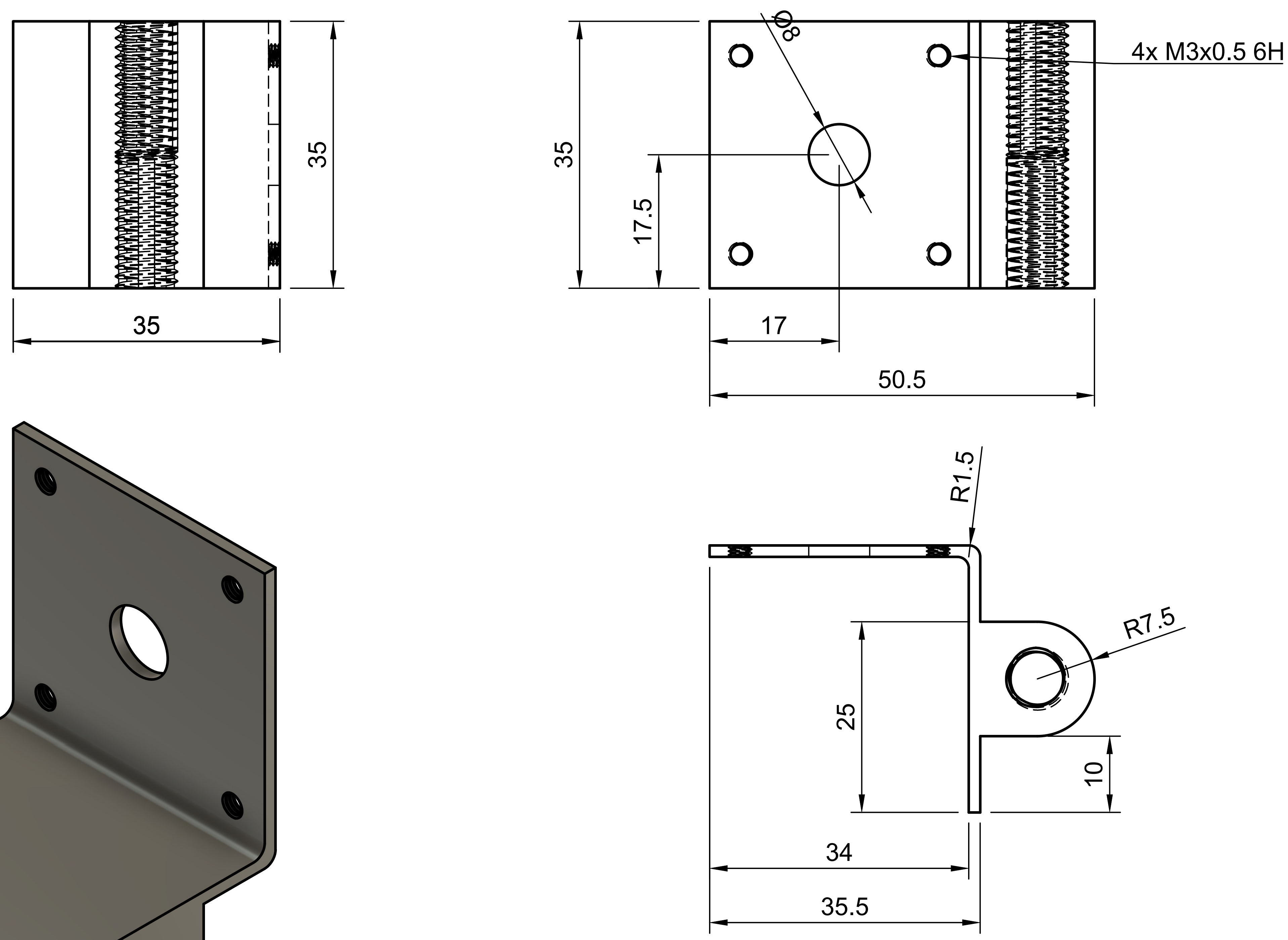
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

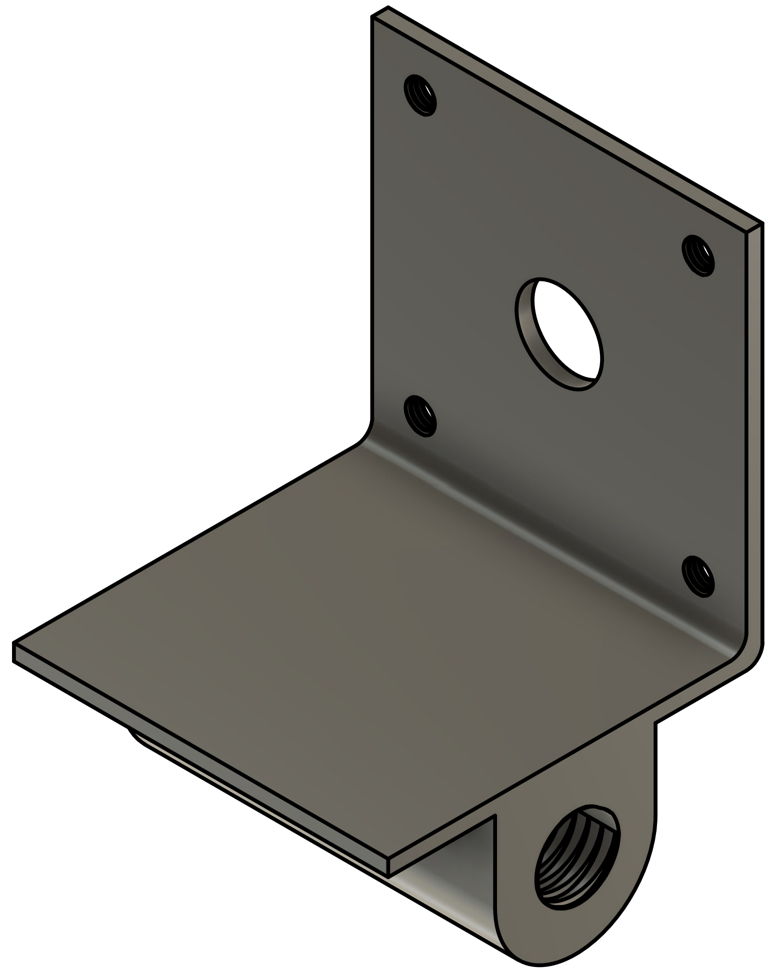
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: Aluminum
Title: Needle Seat Bracket	Part Number: EML4501-F16
	Scale: 2:1 — Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

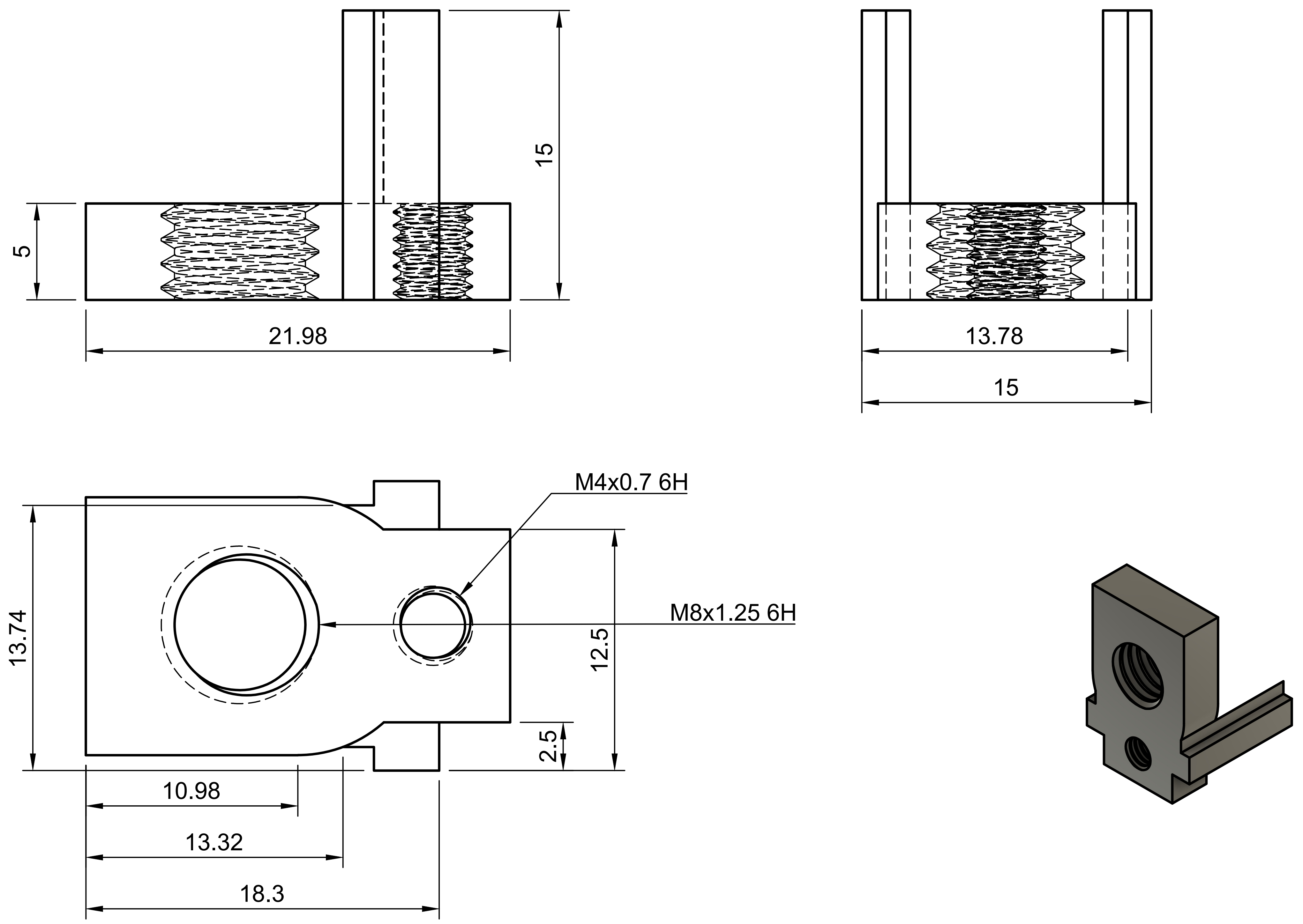
Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: ABS Plastic
Title: Lead Screw Motor Bracket	Part Number: M01
	Scale: 1:1 / Sheet: 1/1





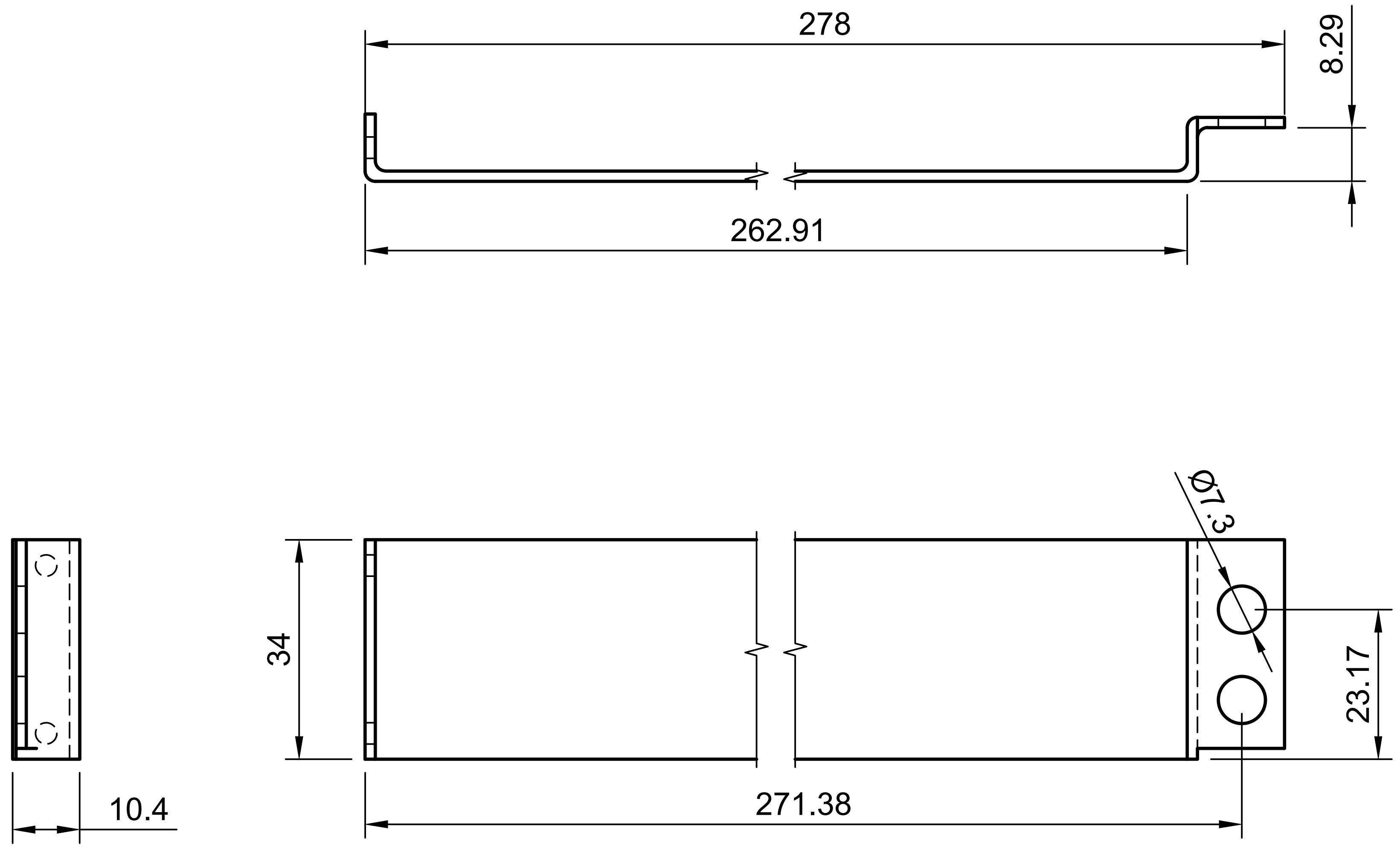
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

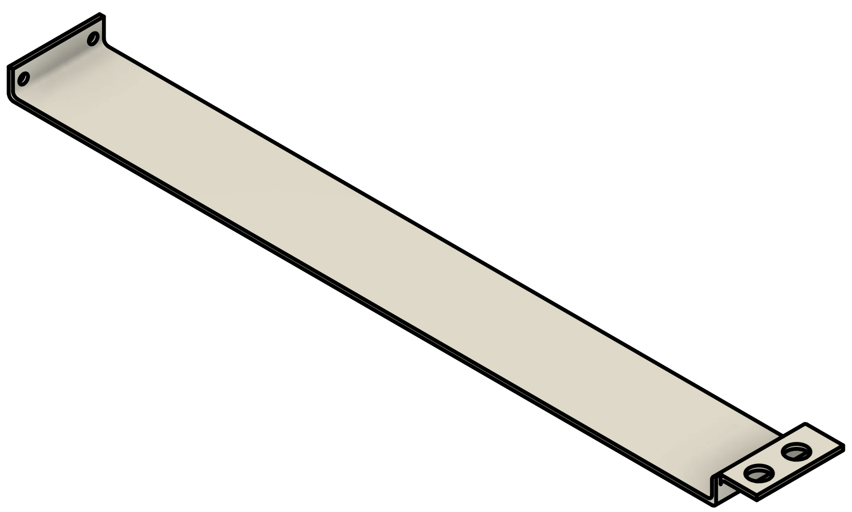
Created by	Alejandro Martinez
Created on	12/5/2024
Title	Motor Carrier
Project	BASS Catchers
Material	Steel
Part Number	M02
Scale	1:1
Sheet	1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

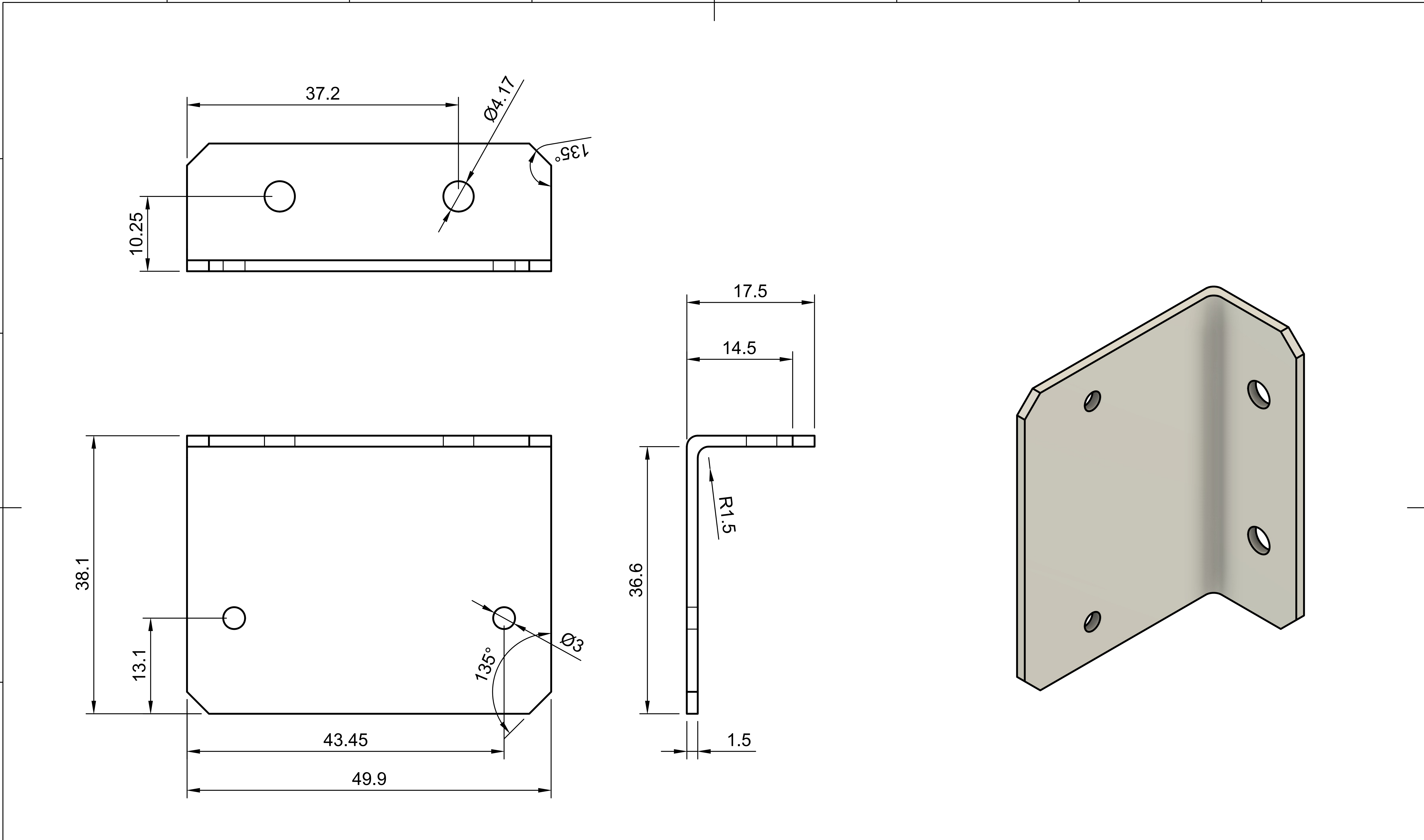
Created by	Alejandro Martinez
Created on	12/5/2024
Title	Linear Actuator Holder
Project	BASS Catchers
Material	Steel
Part Number	M03
Scale	4:1
Sheet	1/1





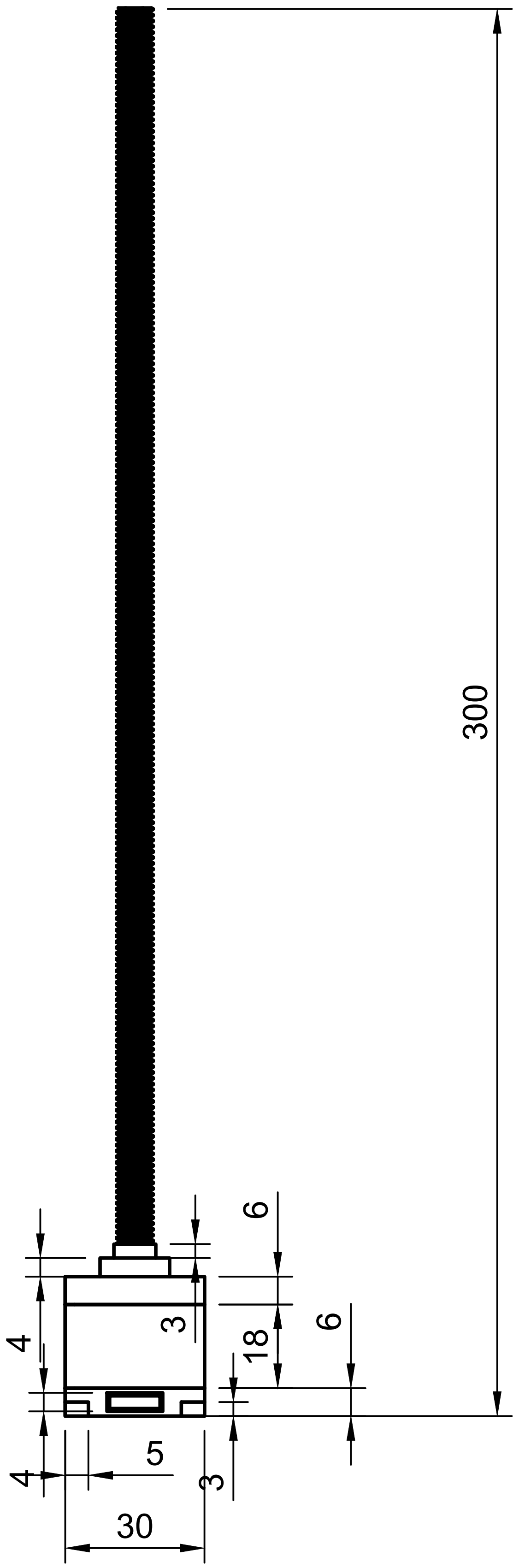
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

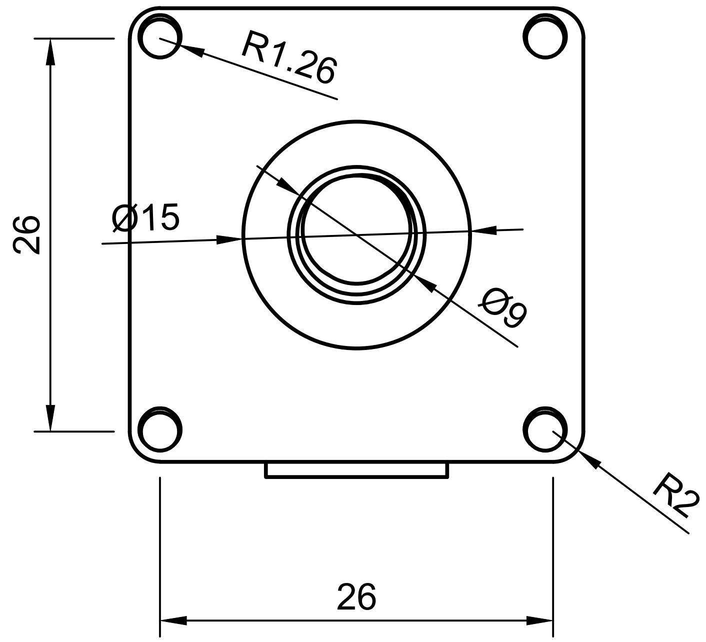
Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: ABS Plastic
Title: Actuator Holder Guide	Part Number: M04
	Scale: 1:1 — Sheet: 1/1

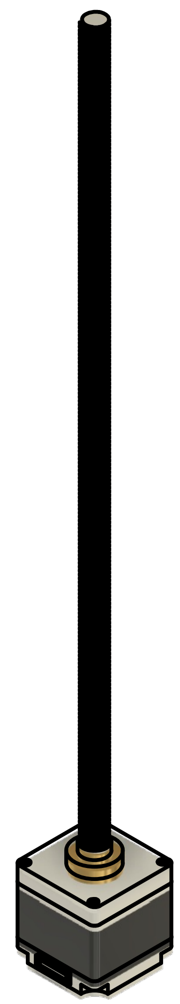


TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: ABS Plastic
Title: Front Motion Bracket	Part Number: M05
	Scale: 2:1 — Sheet: 1/1

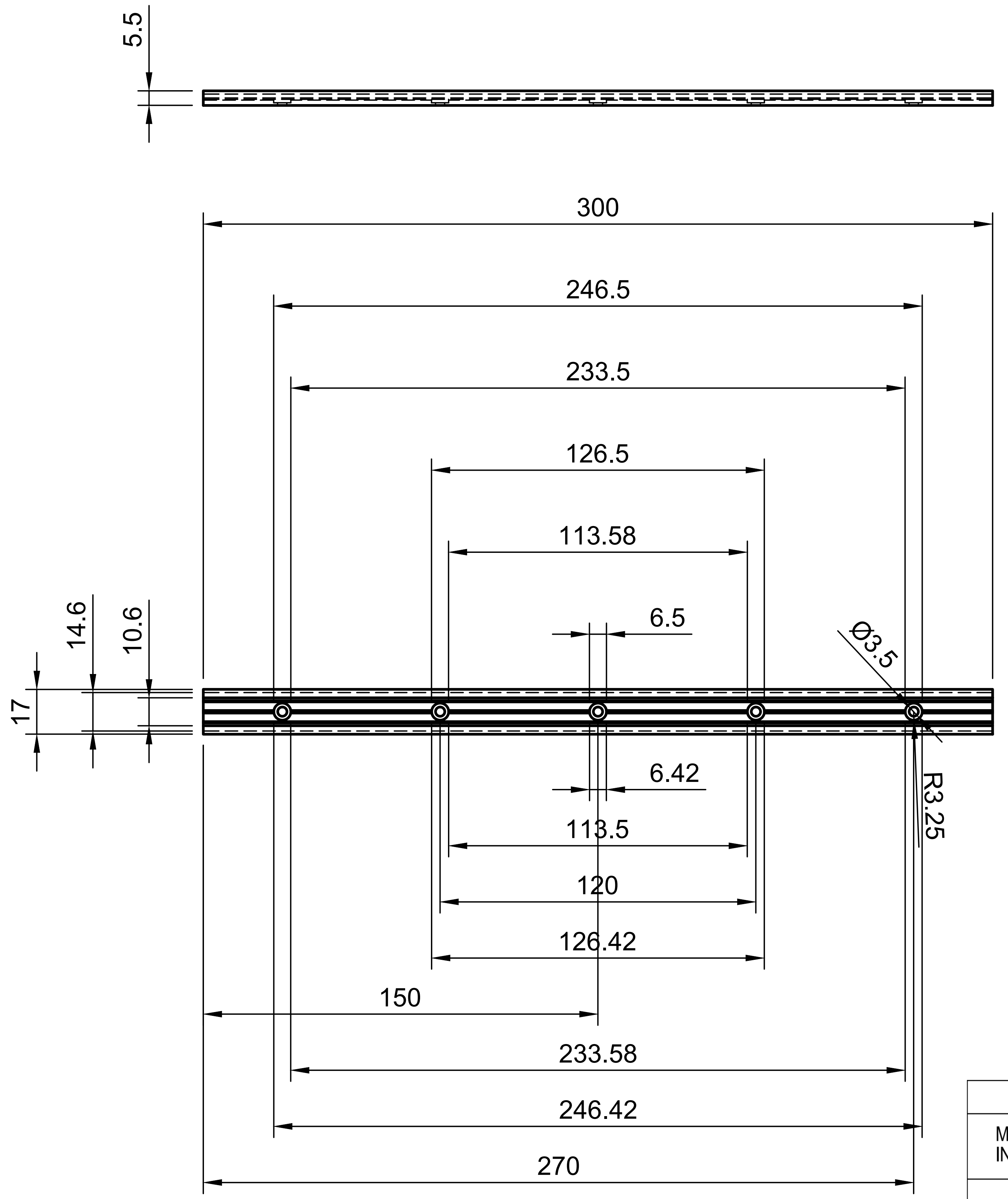


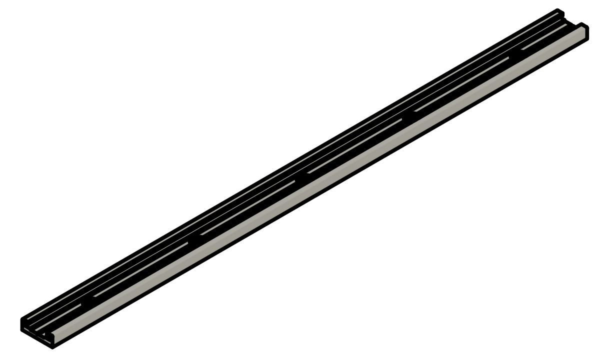


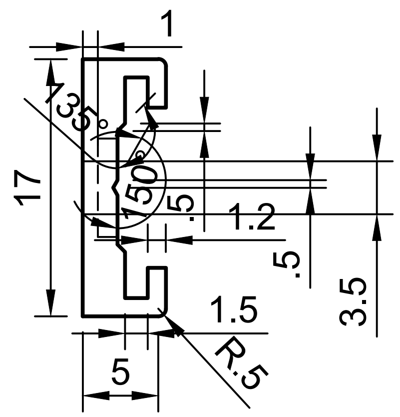


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: T8, Brass, Steel
Title: 300mm T8 Lead Screw with NEMA 17 Stepper Motor	Part Number: M06
	Scale: 1:1.5 — Sheet: 1/1

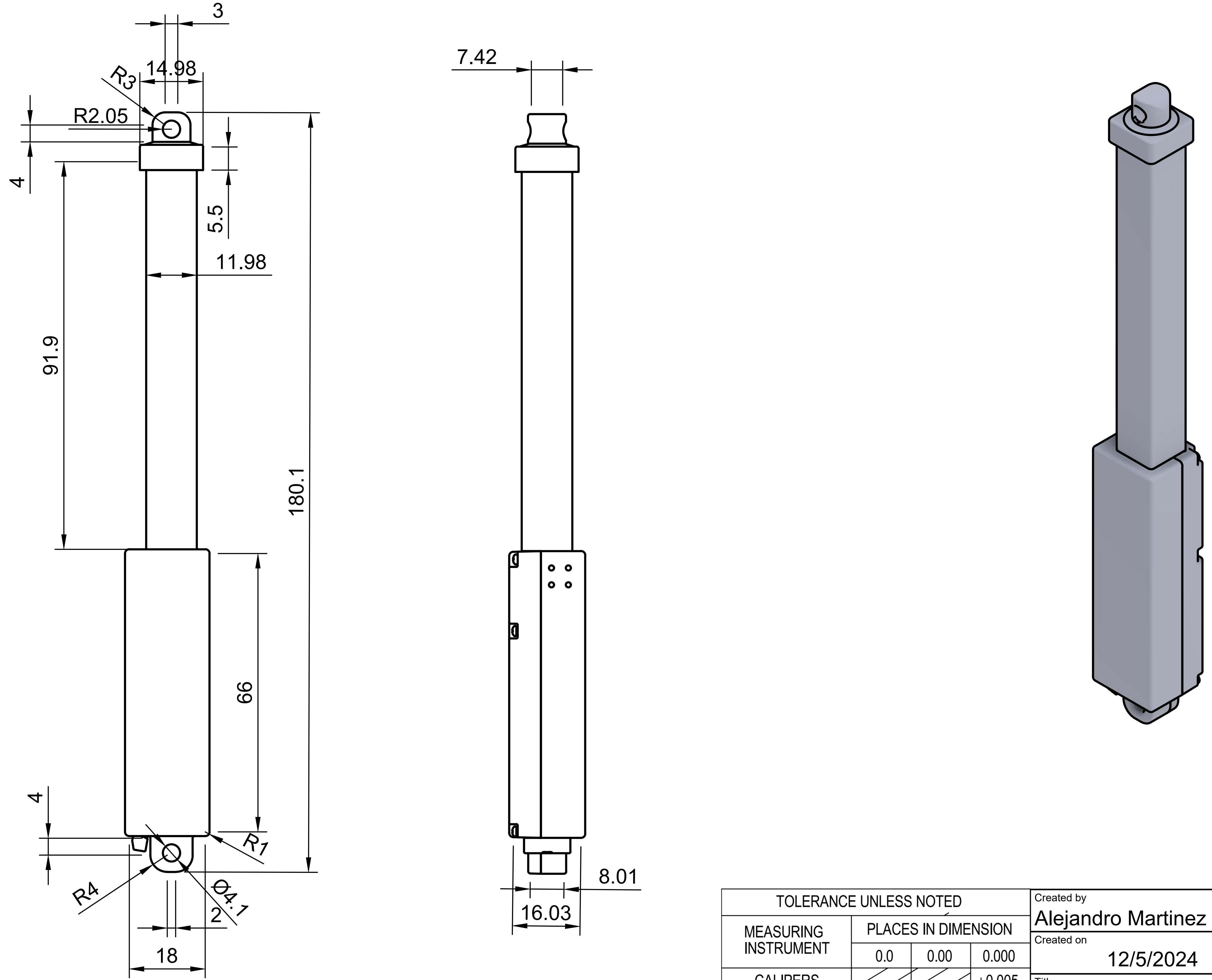






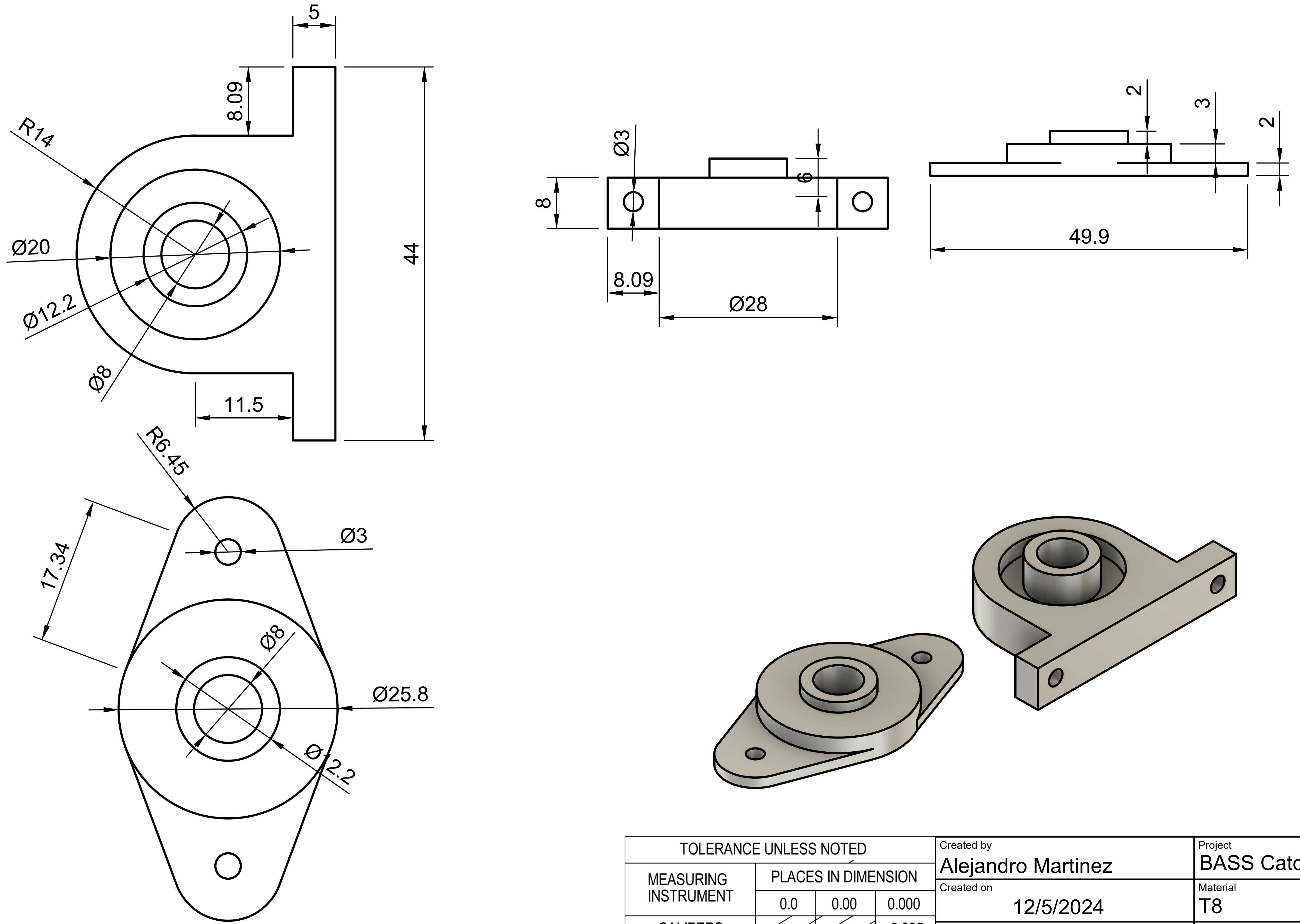
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: Aluminum, Anodized Silver
Title: 300mm Linear Guide Rail with 4 Slide Blocks (2 pieces)	Part Number: M07
	Scale: 1:2
	Sheet: 1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by	Alejandro Martinez
Created on	12/5/2024
Title	Linear Actuator with 4-inch stroke
Project	BASS Catchers
Material	Steel
Part Number	M08
Scale	1:1
Sheet	1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by
Alejandro Martinez

Created on
12/5/2024

Title
8mm T8 Lead Screw Support Set Ball Bearing Pillow Block

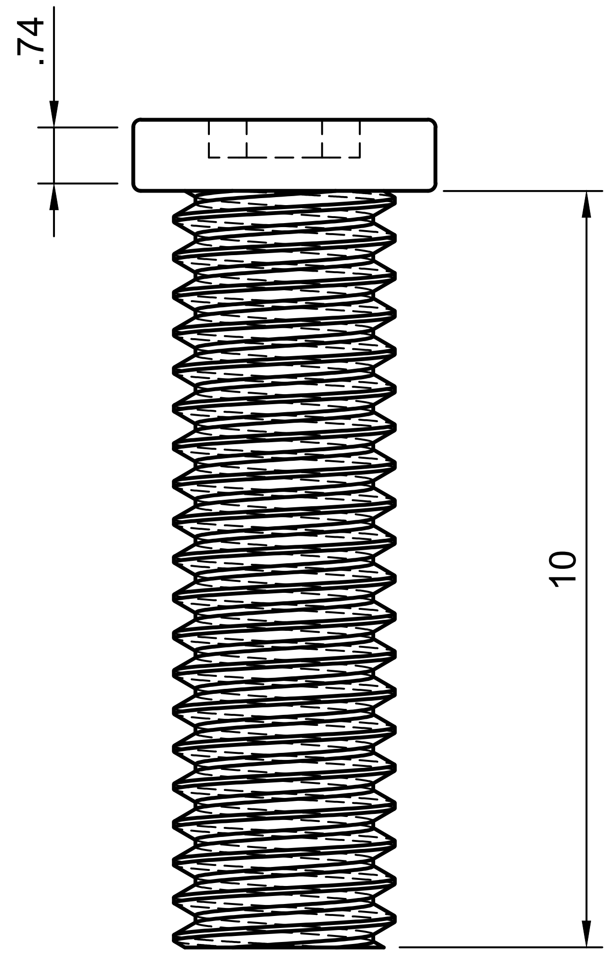
Project
BASS Catchers

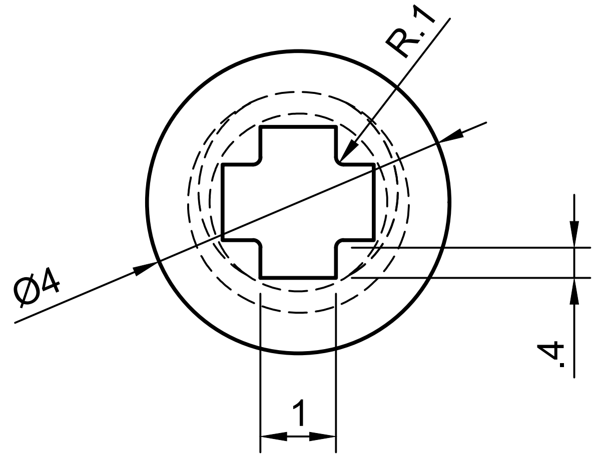
Material
T8

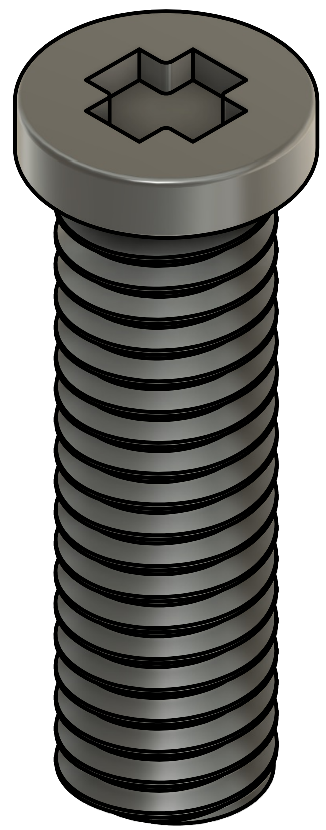
Part Number
M09

Scale
2:1

Sheet
1/1

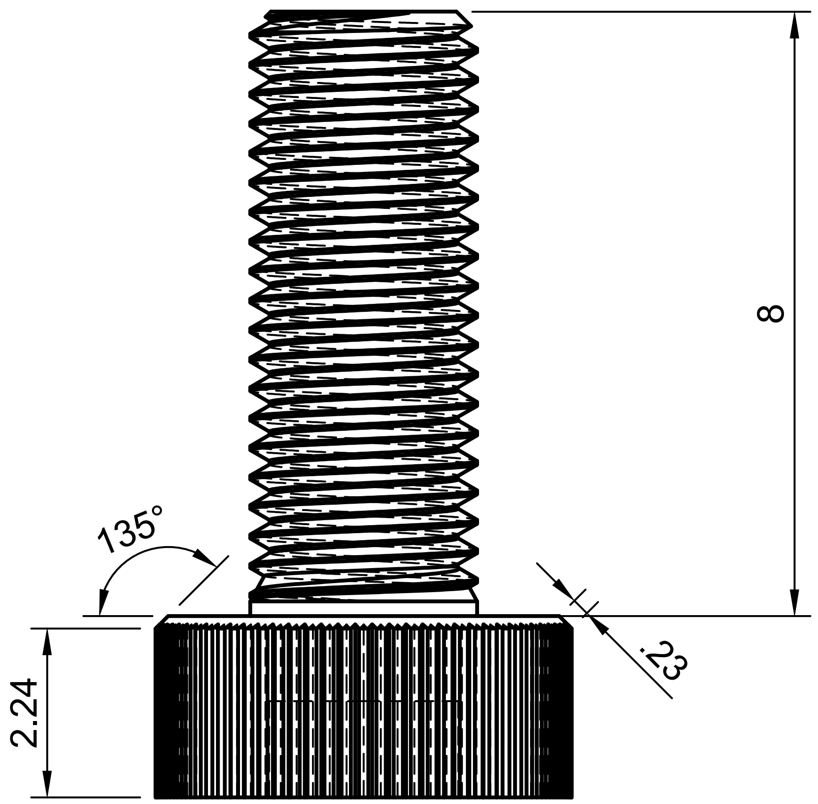


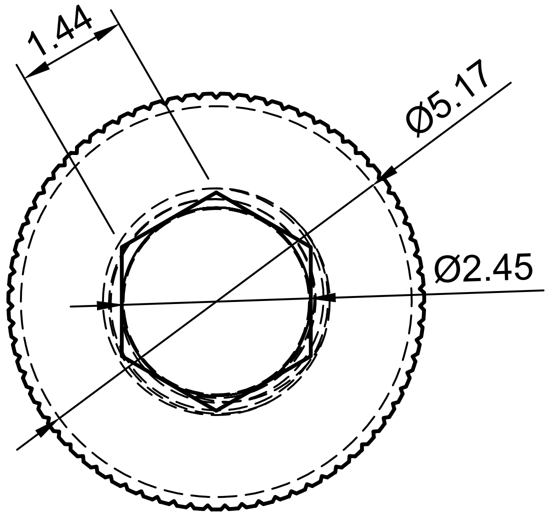


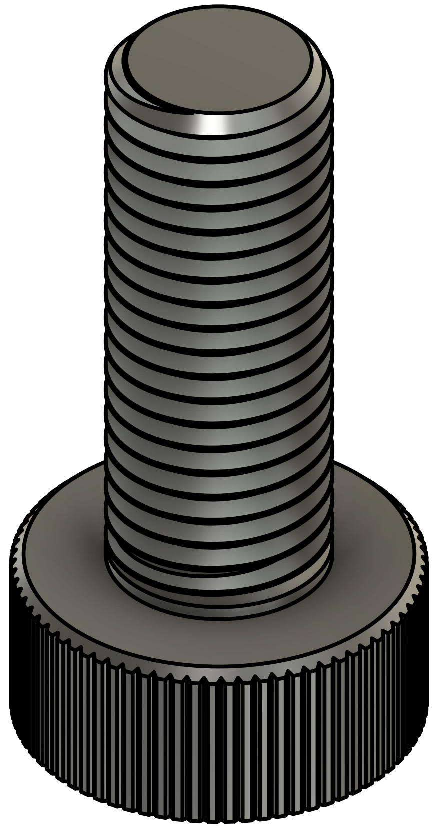


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: Stainless Steel
Title: M3 10mm Long ScrewPhillips Drive Stainless Steel	Part Number: M10
	Scale: 10:1 — Sheet: 1/1

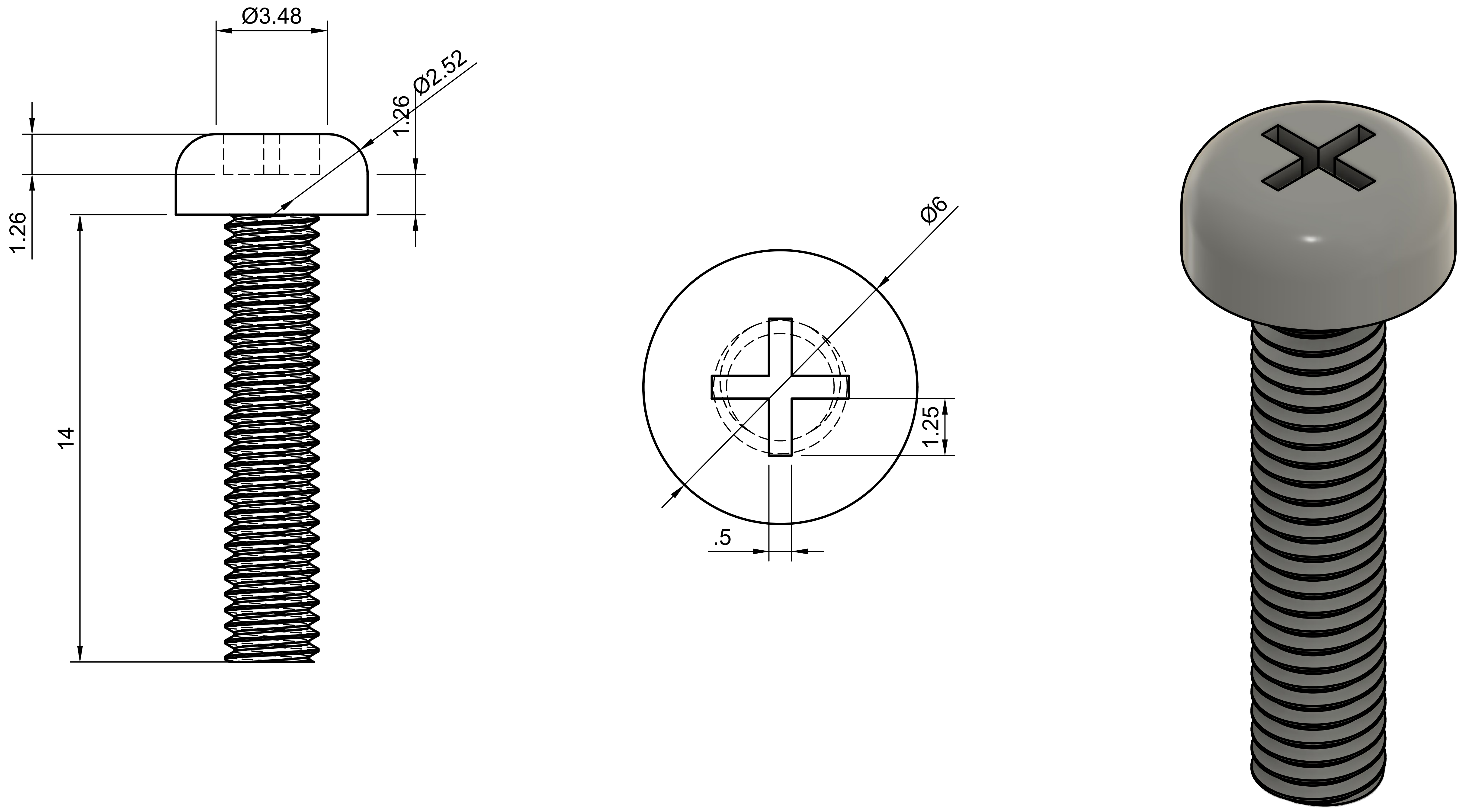






TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: Stainless Steel
Title: M3 8mm Long Screw Phillips Drive Stainless Steel	Part Number: M11
	Scale: 10:1
	Sheet: 1/1



TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by
Alejandro Martinez

Created on
12/5/2024

Title
M3 14mm Long Screw Phillips Drive Stainless Steel

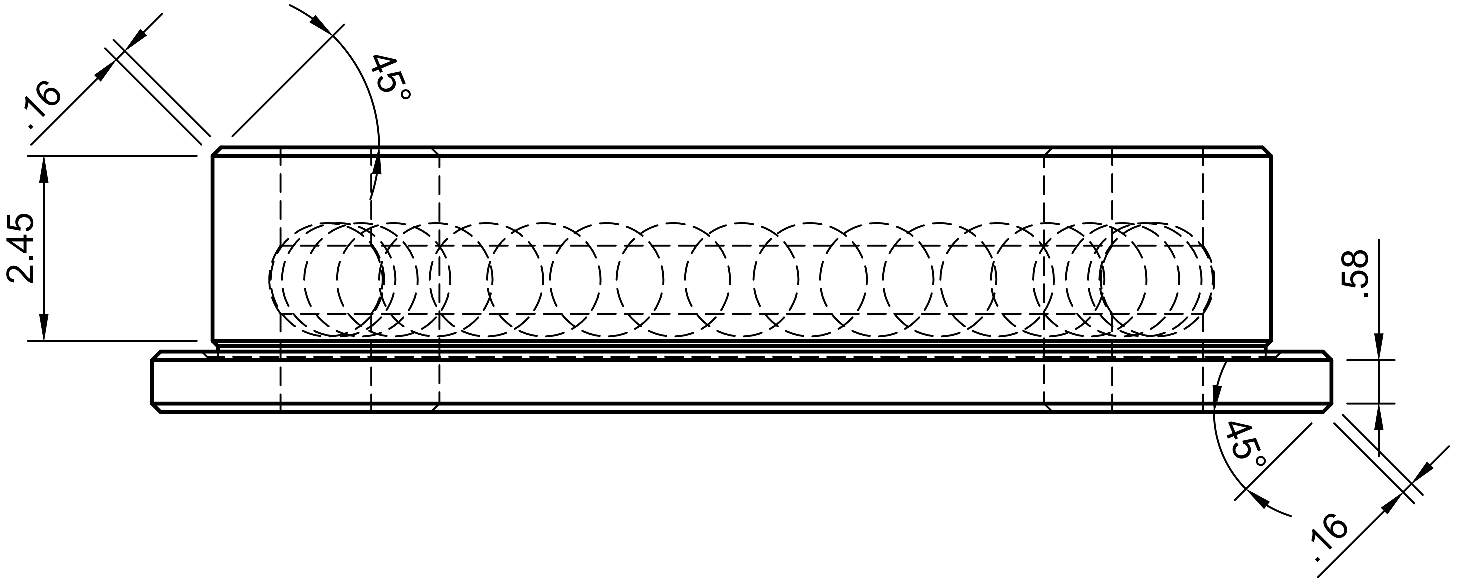
Project
BASS Catchers

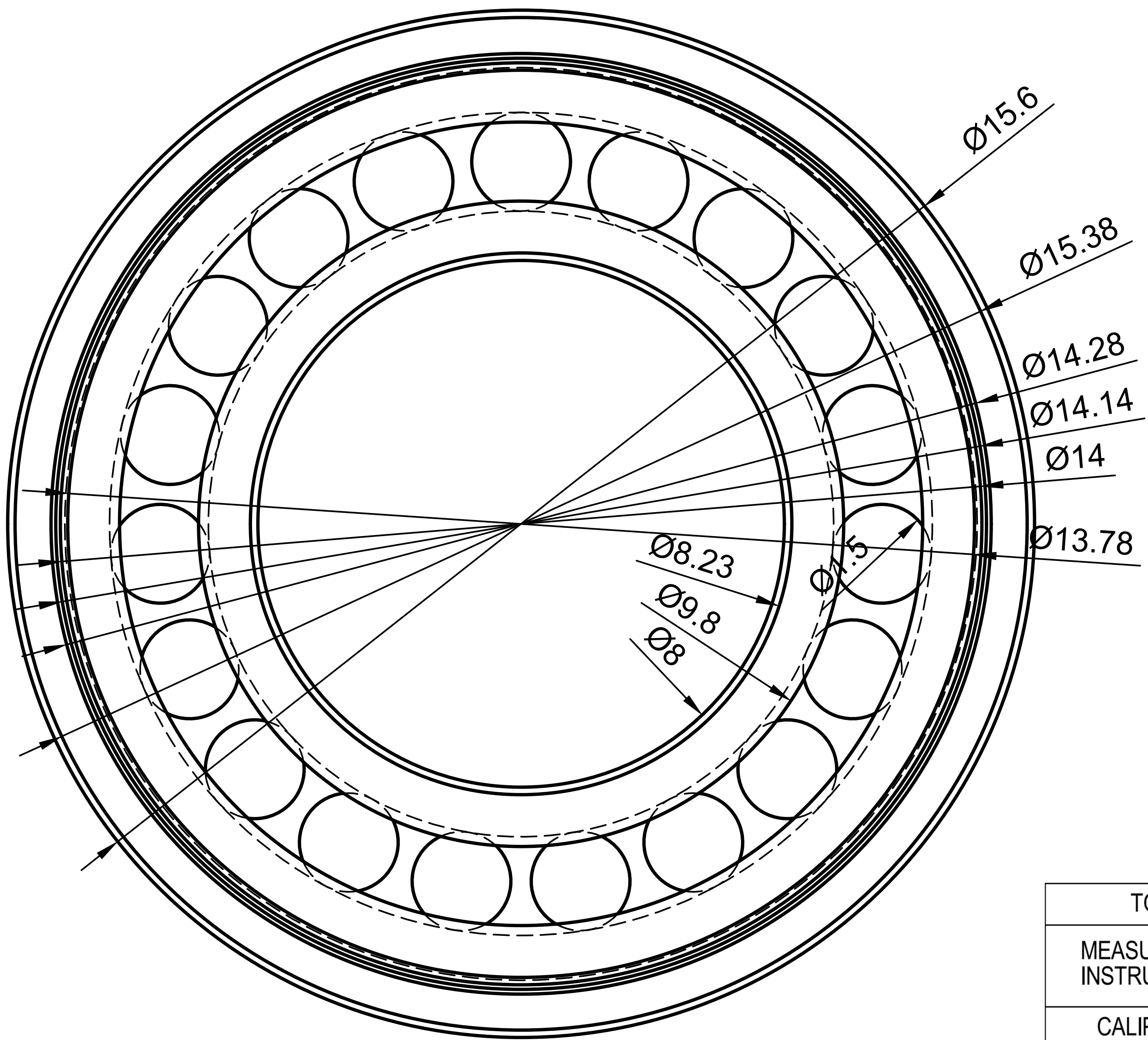
Material
Stainless Steel

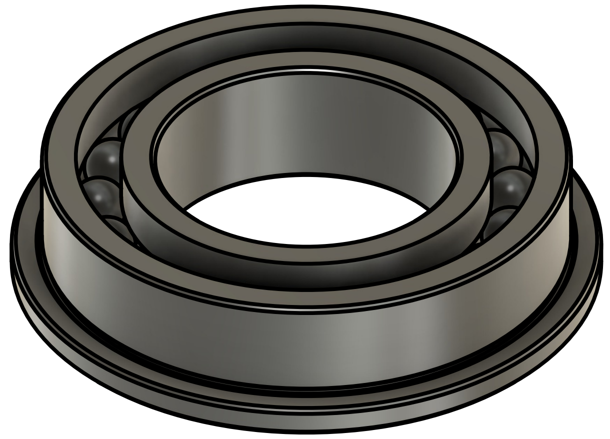
Part Number
M12

Scale
7:1

Sheet
1/1

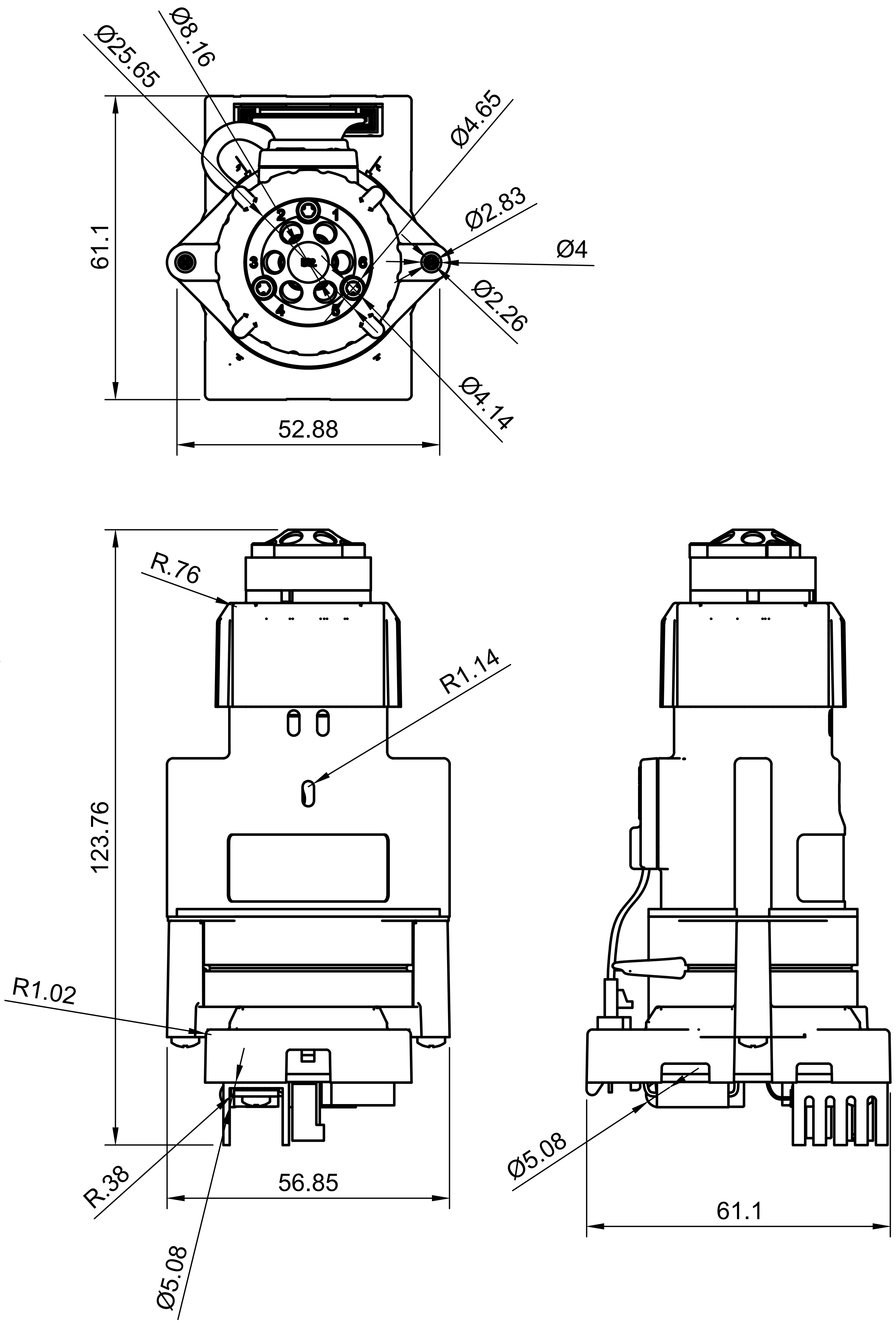


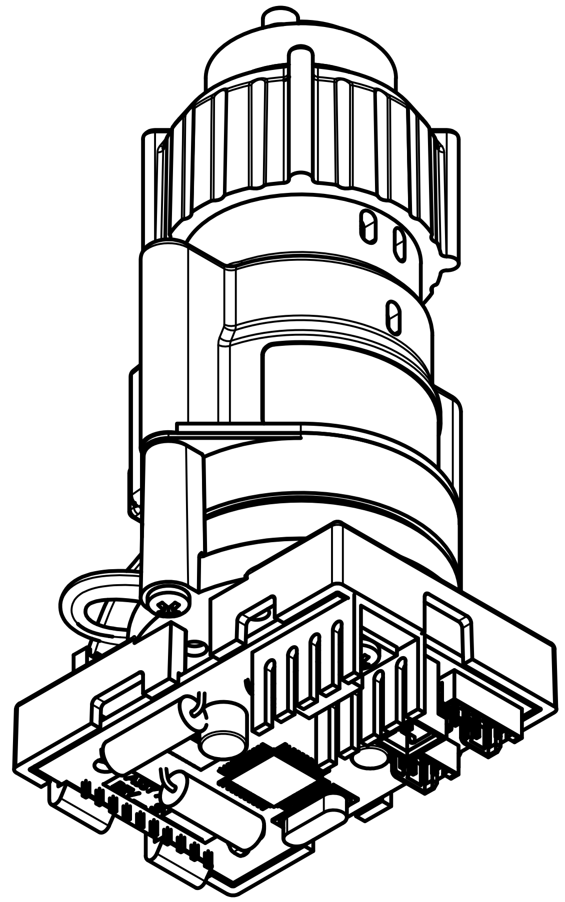




TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Alejandro Martinez	Project: BASS Catchers
Created on: 12/5/2024	Material: Steel
Title: Flanged Bearing 8x16x5	Part Number: M13
	Scale: 10:1
	Sheet: 1/1





TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by
Tin Sulenta

Created on
27-Nov-24

Title
6-Port Injection Valve

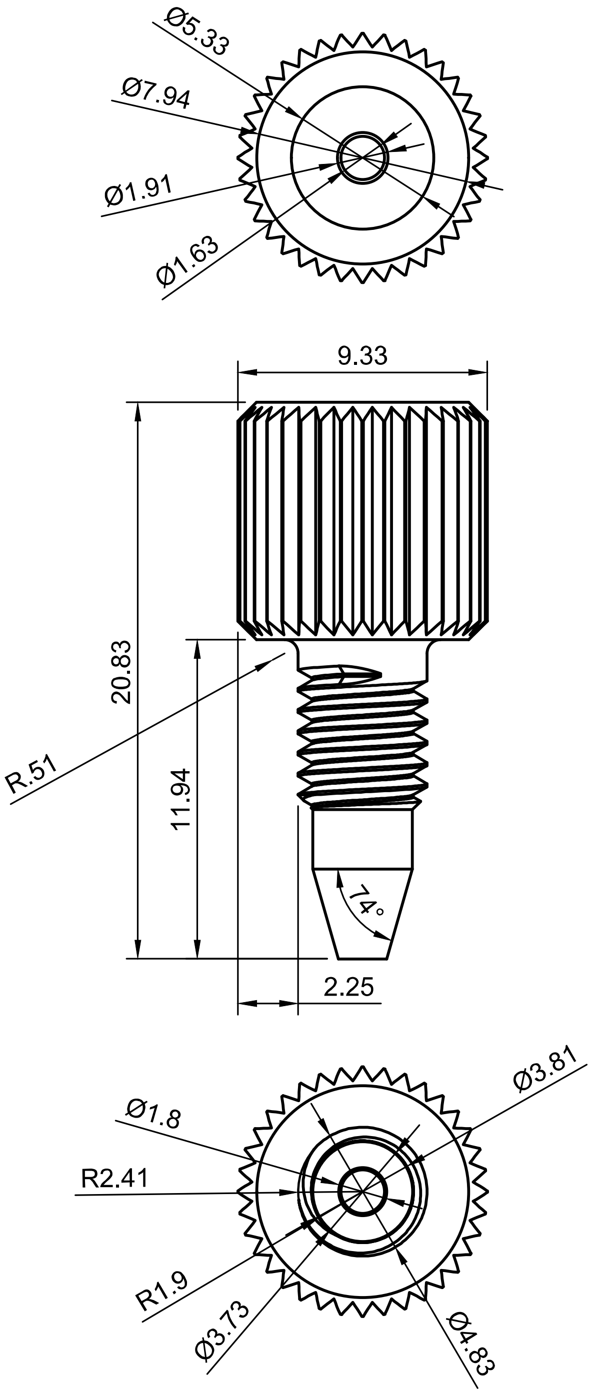
Project
BASS Catchers

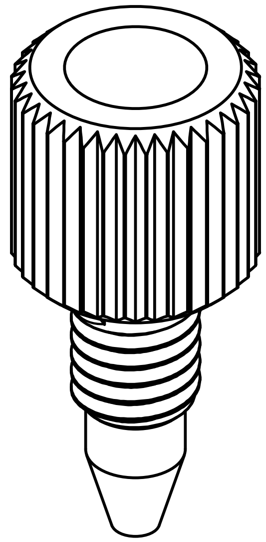
Material
PEEK

Part Number
EML4501-P01

Scale
1:1

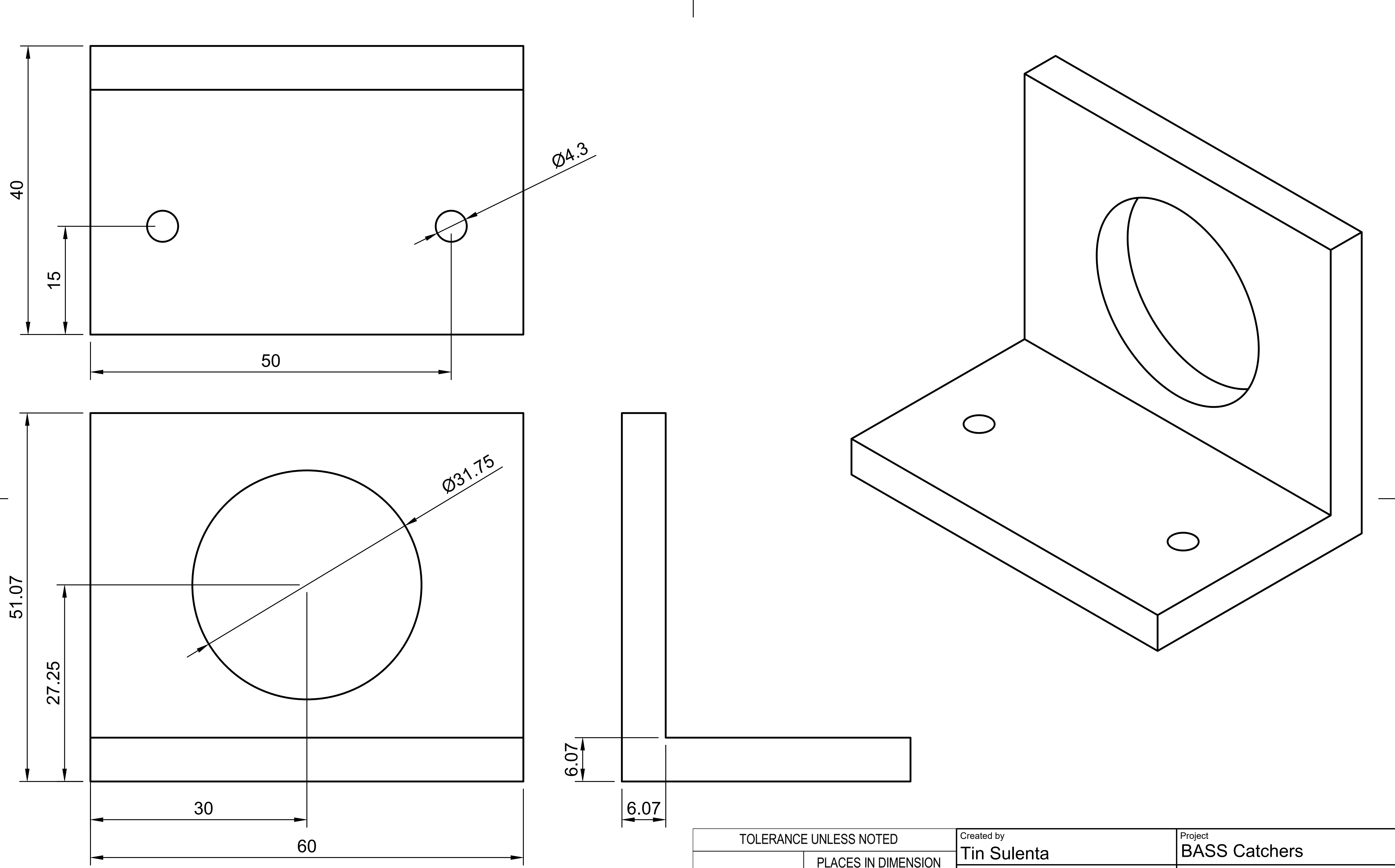
Sheet
1/1





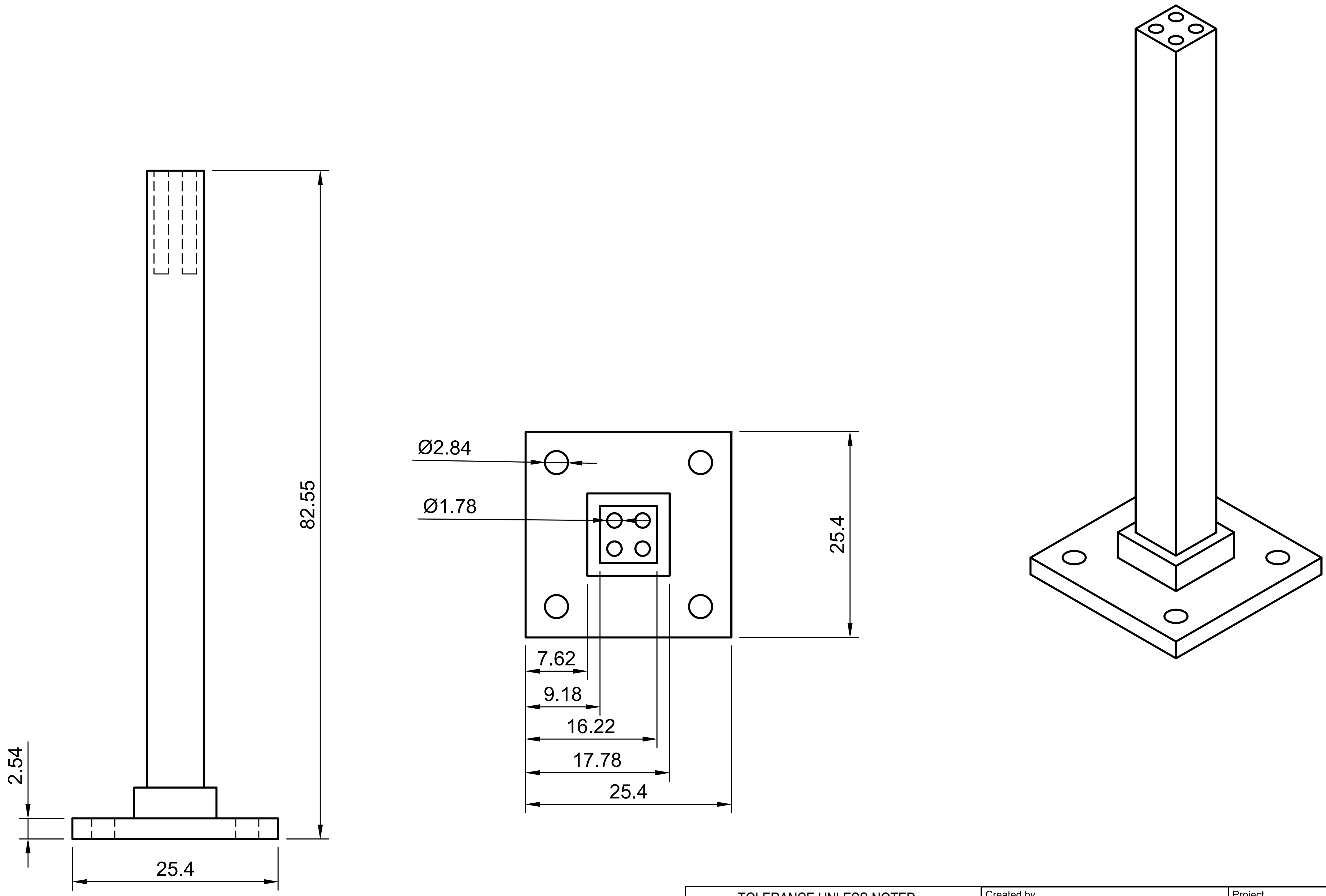
TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Tin Sulenta	Project: BASS Catchers
Created on: 28-Nov-24	Material: PEEK
Title: 10-32 Fitting	Part Number: EML4501-P02
	Scale: 5:1
	Sheet: 1/1



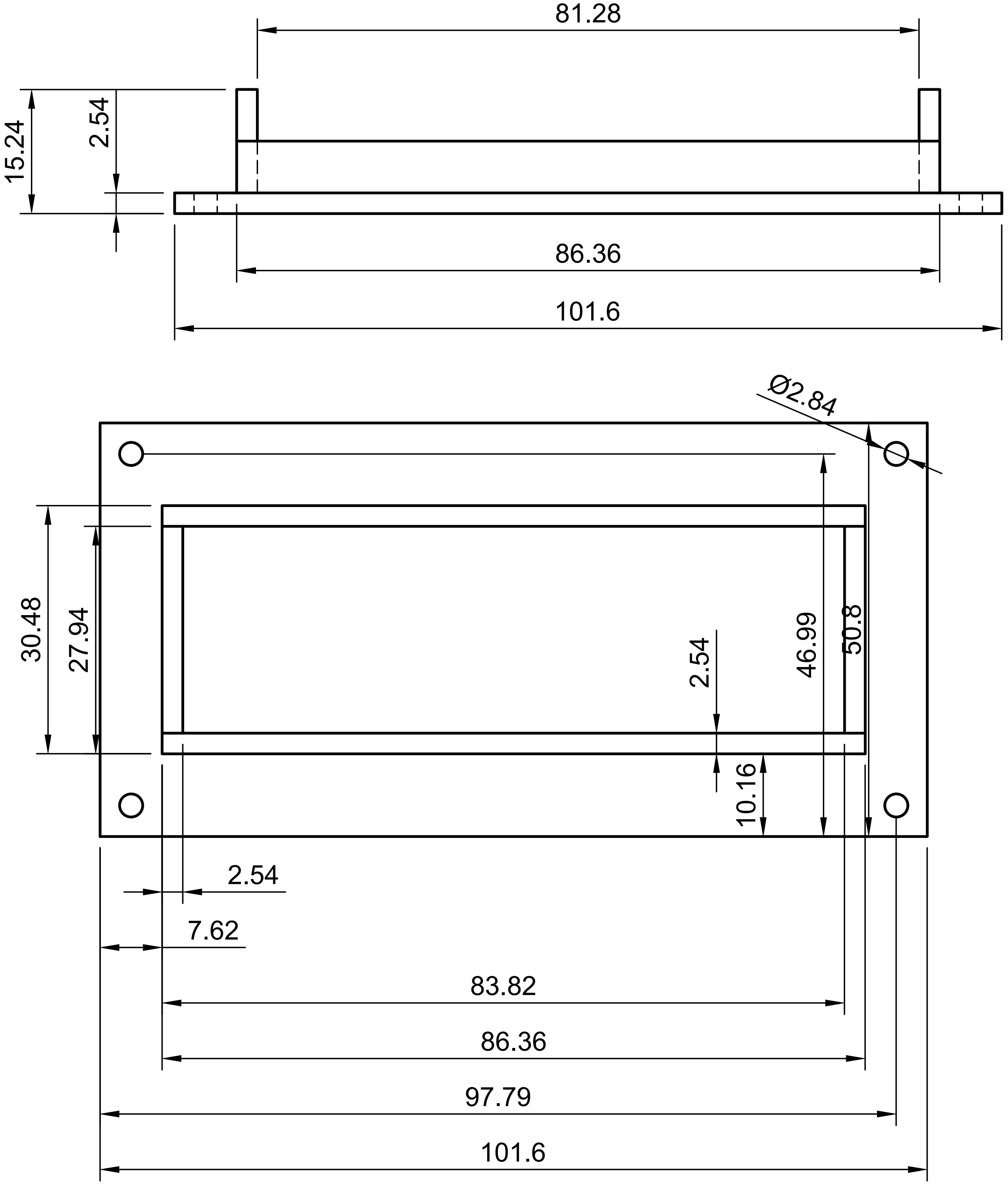
TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

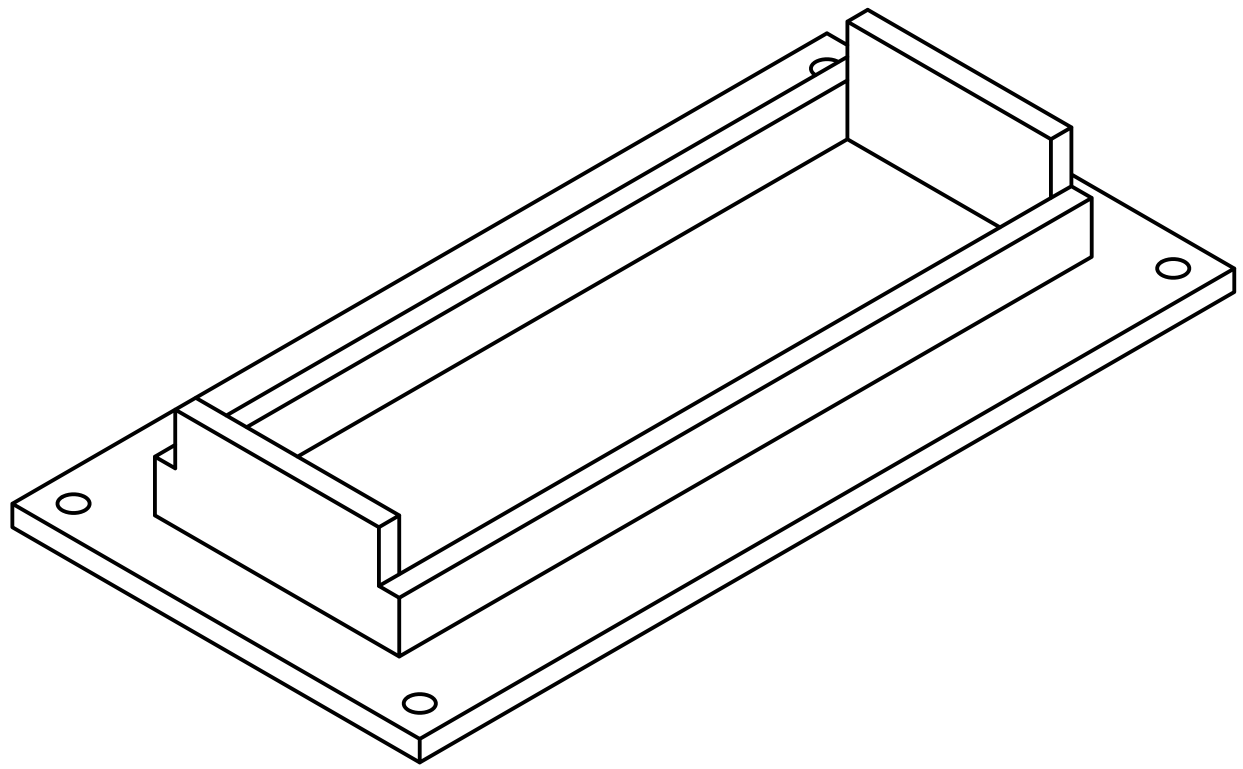
Created by: Tin Sulenta	Project: BASS Catchers
Created on: 27-Nov-24	Material: Aluminum 6061
Title: 6-Port Bracket	Part Number: EML4501-P03
	Scale: 2:1 / Sheet: 1/1



TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

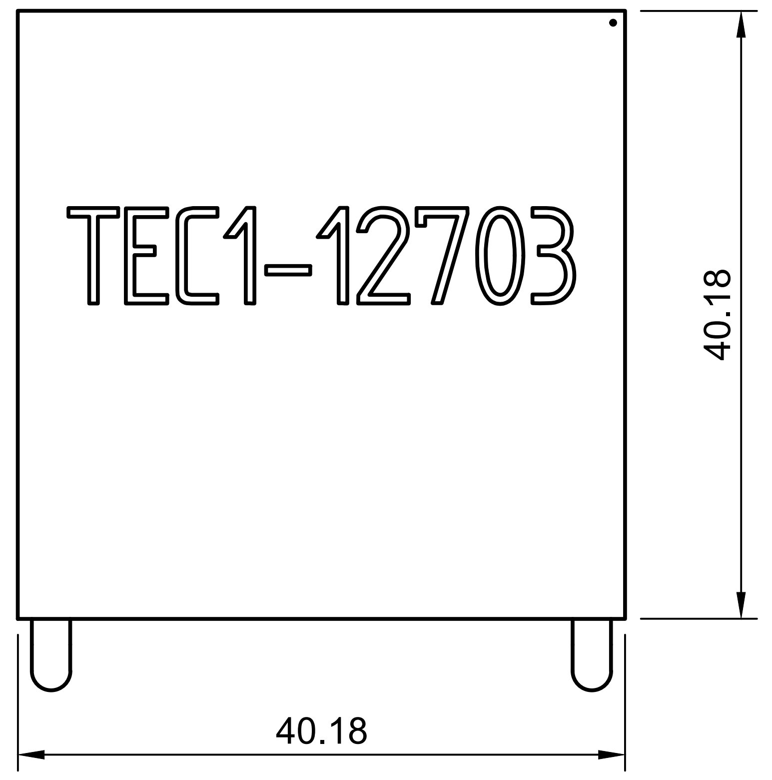
Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/1/2024	Material: Acetal Resin, Black
Title: **Heat Sink Support**	Part Number: EML4501-T01
	Scale: 1:1 — Sheet: 1/1

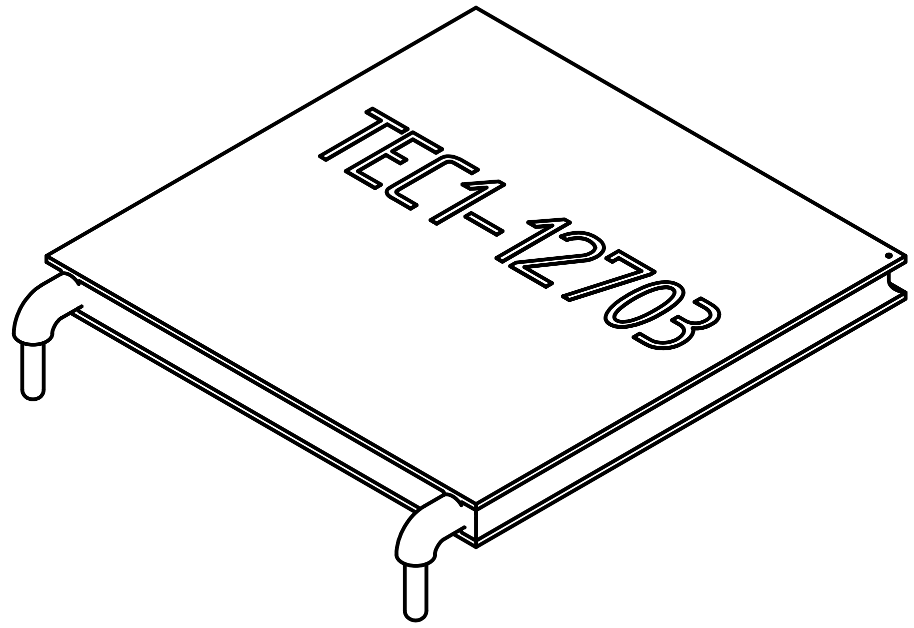


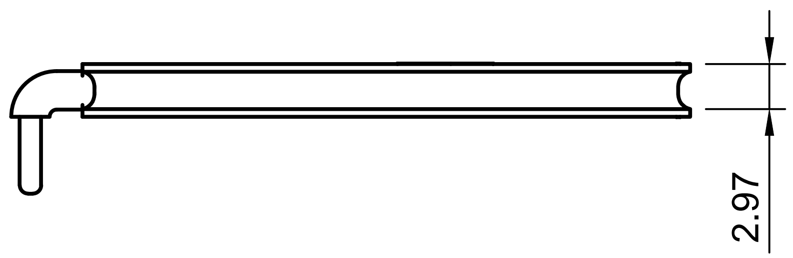


TOLERANCE UNLESS NOTED			
OPERATION	PLACES IN DIMENSION		
	0.0	0.00	0.000
MACHINING	±0.050	±0.020	±0.005
CUT OFF (SAW, BURN, SHEAR)	±0.1	±0.060	
WELDING	±0.1	±0.060	
ANGULAR DIMS	±5	±2	±0.5

Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/2/2024	Material: Acetal Resin, Black
Title: Fan Base	Part Number: EML4501-T02
	Scale: 2:1 / Sheet: 1/1







TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
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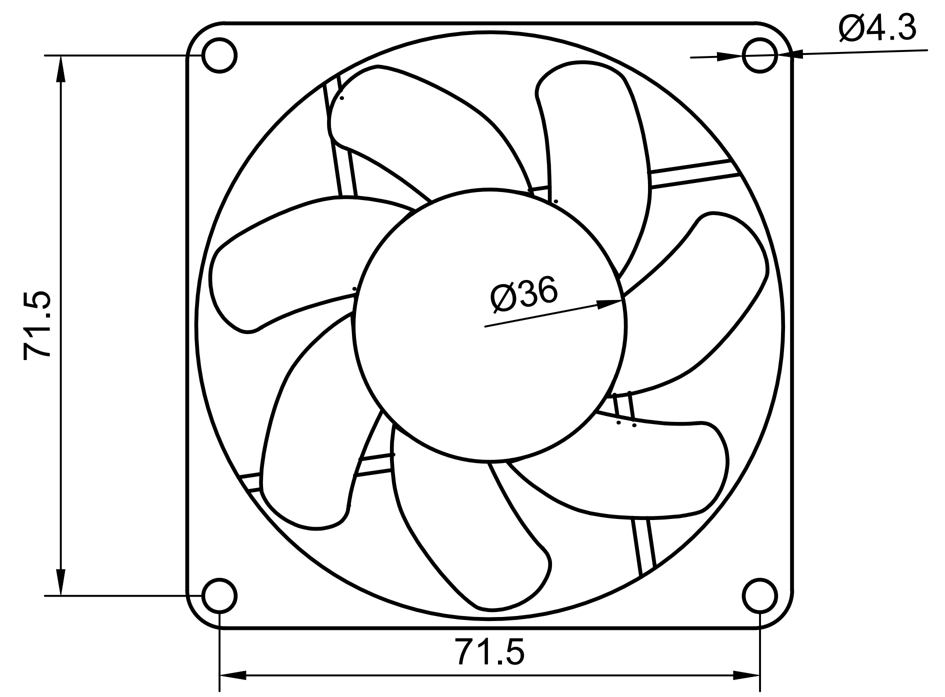
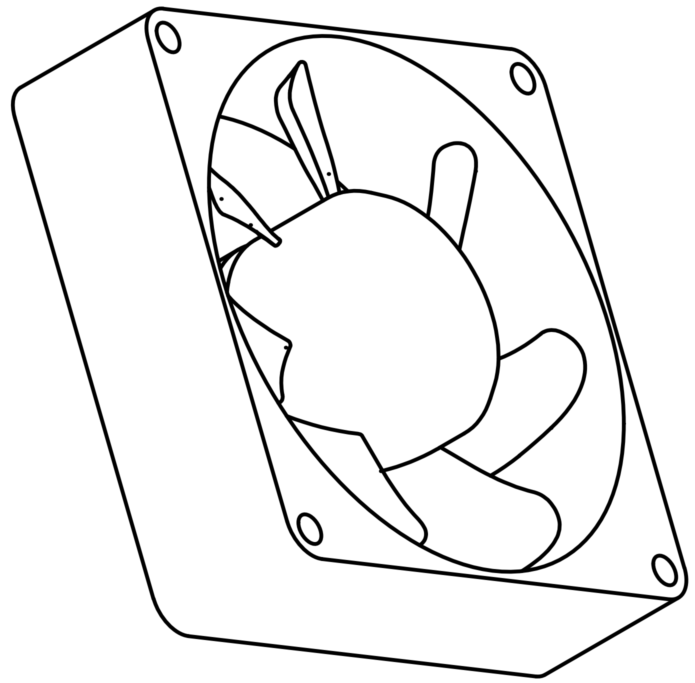
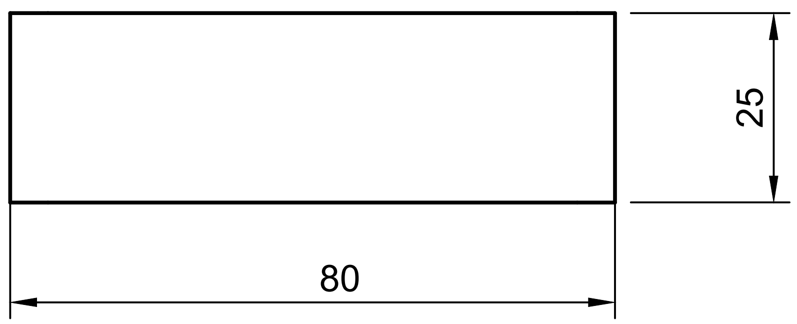
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Henry Stophel	Project: BASS Catchers	
Created on: 12/2/2024	Material: N/A	
Title: TEC1-12703 Plate	Part Number: EML4501-T03	
	Scale: 2:1	Sheet: 1/1







TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
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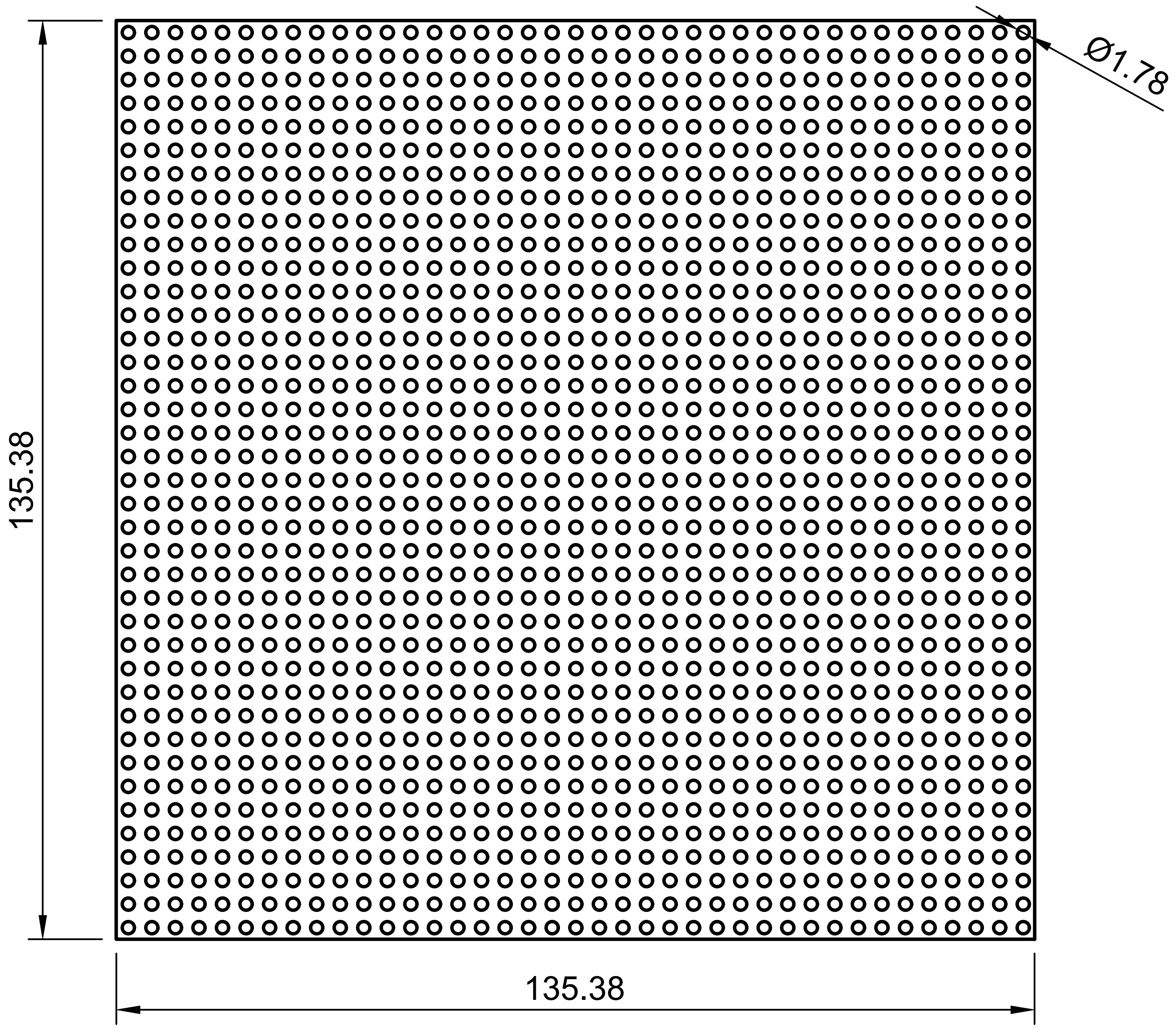
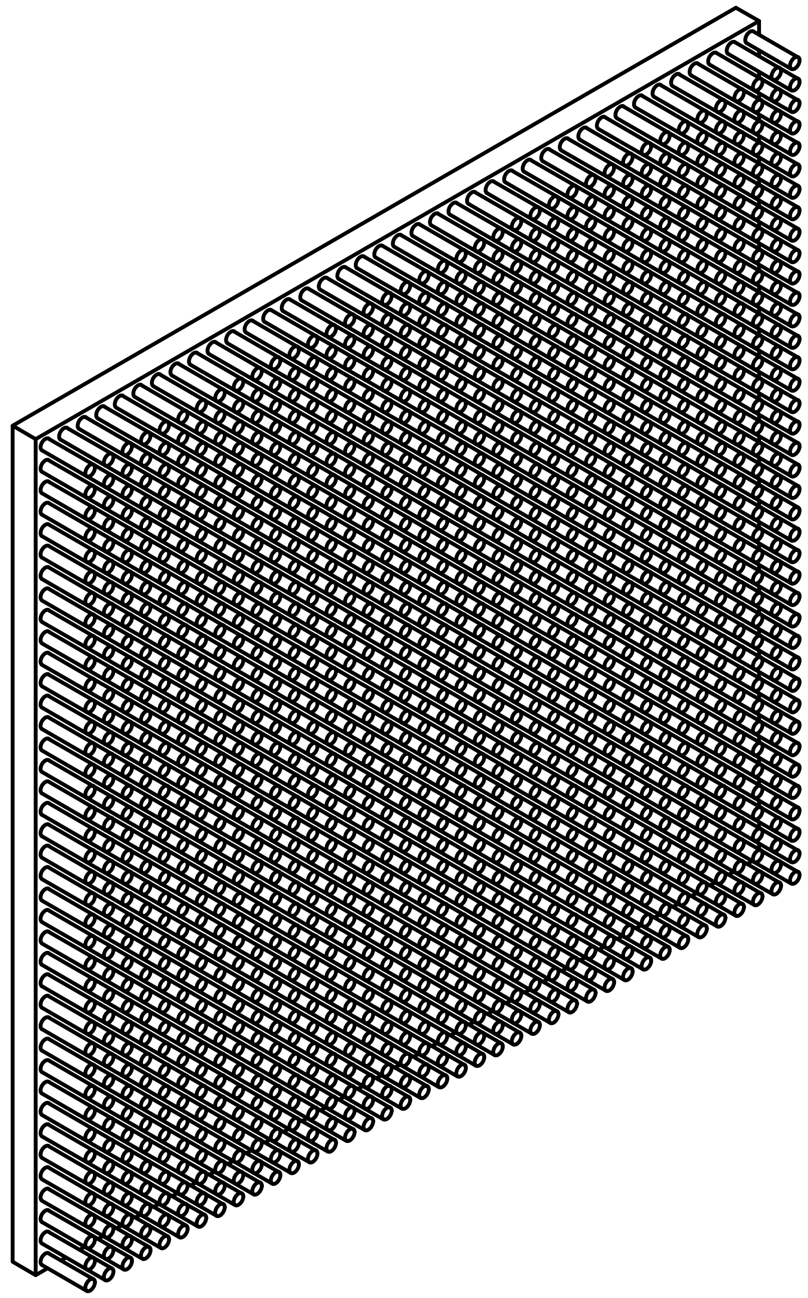
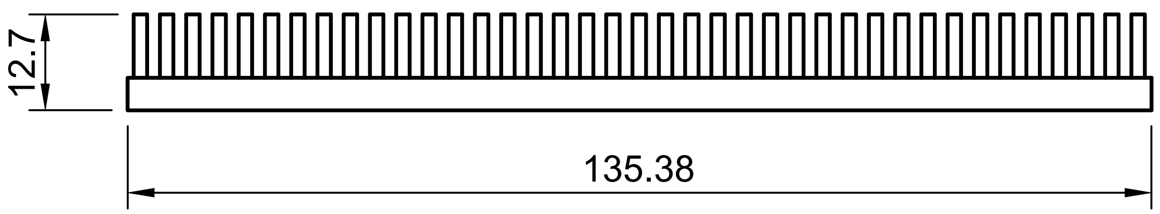
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/2/2024	Material: Steel and Plastic
Title: Fan Housing and Rotor	Part Number: EML4501-T04
	Scale: 1:1
	Sheet: 1/1

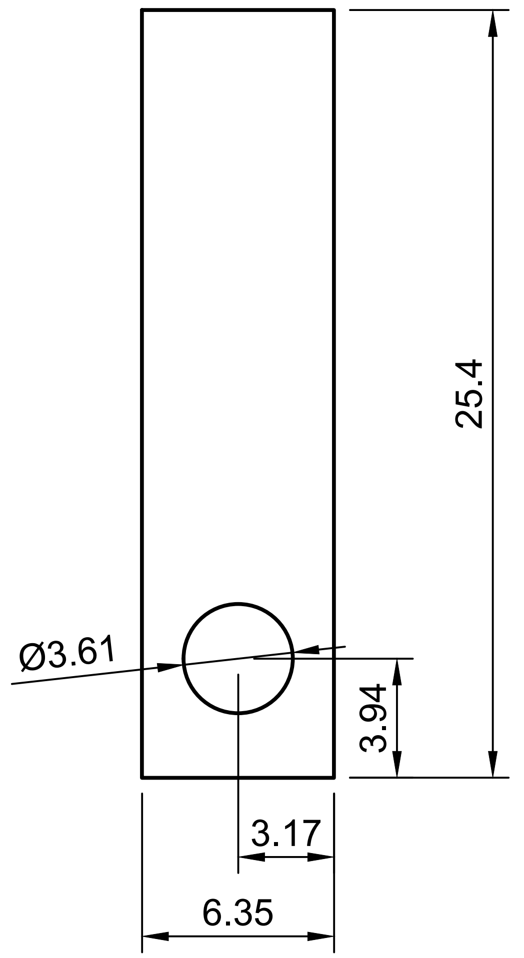


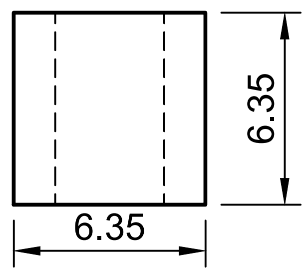


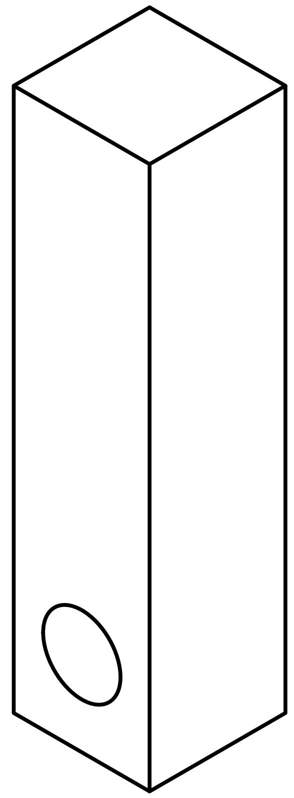


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/1/2024	Material: Copper
Title: Heat Sink	Part Number: EML4501-T05
	Scale: 1:1
	Sheet: 1/1

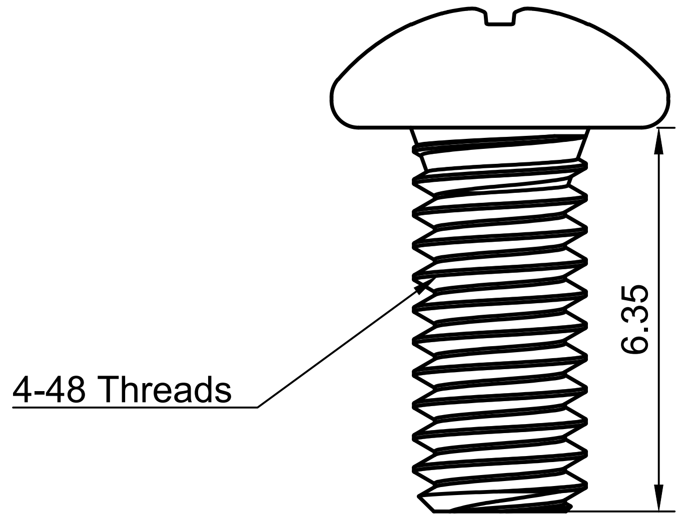


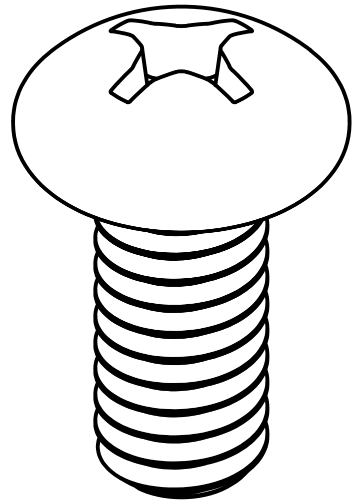


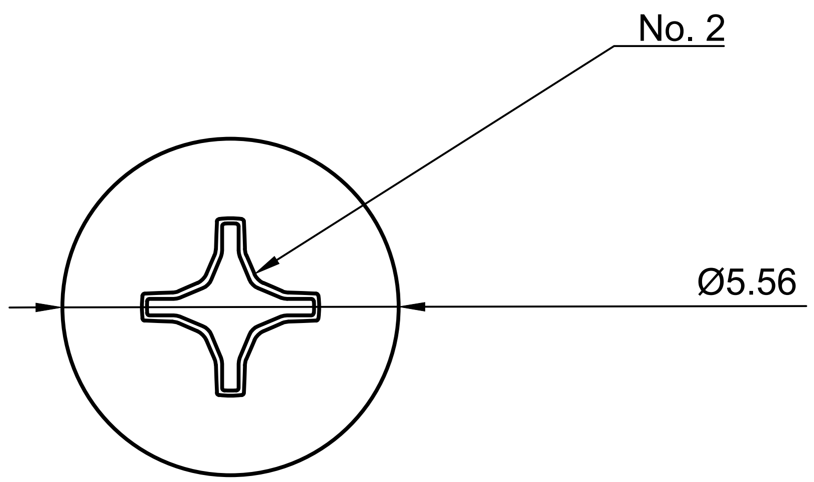


TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/2/2024	Material: Aluminum
Title: Temperature Sensor	Part Number: EML4501-T06
	Scale: 4:1 / Sheet: 1/1







TOLERANCE UNLESS NOTED			
MEASURING INSTRUMENT	PLACES IN DIMENSION		
	0.0	0.00	0.000
CALIPERS			±0.005
PRECISION RULER		±0.015	
TAPE MEASURE	±0.030		
PROTRACTOR	±10	±5	±2

Created by: Henry Stophel	Project: BASS Catchers
Created on: 12/2/2024	Material: Steel
Title: 91772A741_Passivated 18-8 Stainless Steel Pan Head Phillips Screw	Part Number: EML4501-T07
	Scale: 8:1
	Sheet: 1/1

12.2.1 Tolerance Loops

TABLE 12.2.1: FUNCTIONAL SURFACES AND TYPES OF FIT

Functional Surface	Type of Fit
Fan & Fan Base	Clearance
Heat Sink & Heat Sink Columns	Clearance
Rivet & Side Tube	Interference
Bracket & Screw	Clearance
Actuator Holder & Actuator Holder Guide	Sliding
Lead Screw Slider	Sliding

Fan & Fan Base:

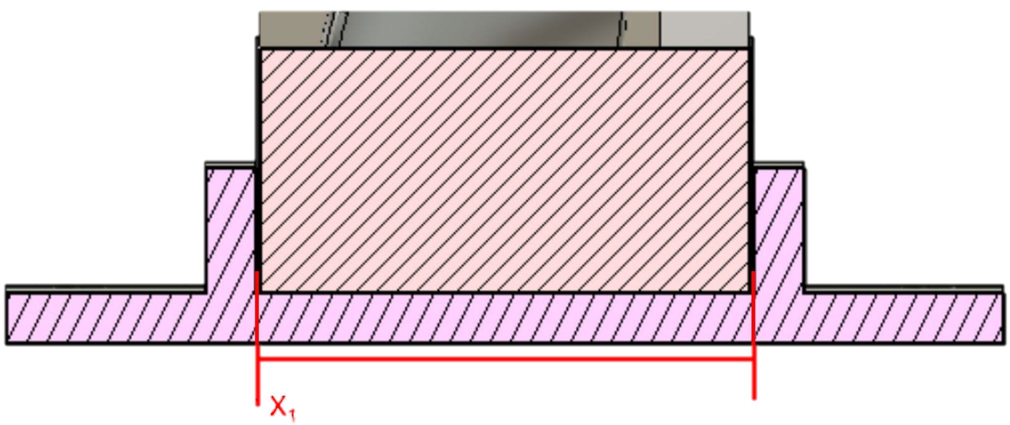


FIGURE 12.2.1.1: FAN AND FAN BASE FIT REFERENCE

The purpose of the fan base is to provide support for the fan to stand up underneath the deck in the autosampler. The fan is not load-bearing, and its position is not required to be precise. Therefore, a clearance fit was selected between the fan and fan base to ease the manufacturing precision requirement of the fabrication of the fan base.

Vector Name	Nominal Dimension (in)	Tolerances (in)	Max/Min Dimension (in)	References
X_1	1.00	+.05	1.05	Fan Base
		-.00	1.00	

Heat Sink & Heat Sink Columns:

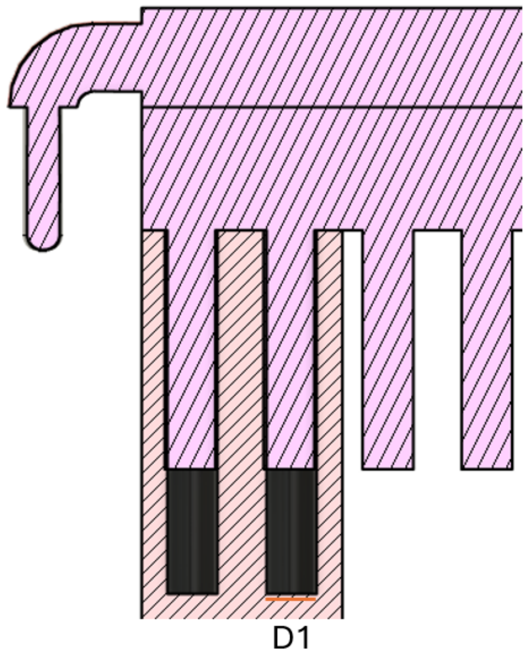


FIGURE 12.2.1.2: HEAT SINK & HEAT SINK COLUMNS FIT REFERENCE

The heat sink columns serve to support the heat sink in each of its four corners at a desired height. Each of the columns will support four pin fins in each corner. It is important that the pins and the holes in the support columns have clearance, as the most important function of the supports are to constrain the heat sink vertically. A secondary function is to axially constrain the heat sink, but that is less critical as the planar movement of the heat sink is less of a concern. D_1 refers to the diameter of the hole in the support. As long as the maximum diameter of the pins is smaller than the minimum diameter of the support post holes, there will be adequate clearance to support the heat sink.

Vector Name	Nominal Dimension (mm)	Tolerances (mm)	Max/Min Dimension	References
D_1	1.778	+0.5	2.278	Support Post
		-0	1.778	

Rivet & Side Tube:

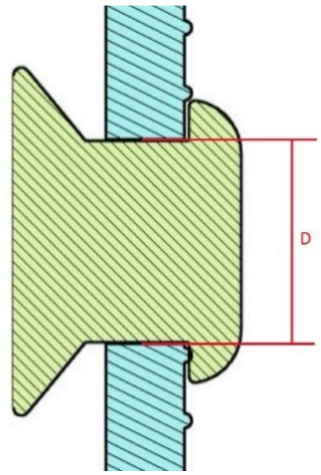


FIGURE 12.2.1.3: RIVET AND SIDE TUBE FIT REFERENCE

The purpose of the Rivet is to hold the base plate to the side tubing in order to support the majority of the components within the enclosure. The Rivet is load bearing and must not move during sampling so an interference fit that a rivet has is needed. The diameter (D) of the rivet expands as the rivet is inserted in order to give the required interference fit to secure the parts together.

Vector Name	Nominal Dimension (in)	Tolerances (in)	Max/Min Dimension (in)	References
D	0.164	+.0005	1.0005	Rivet
		-.0005	0.9995	

Bracket & Screw:

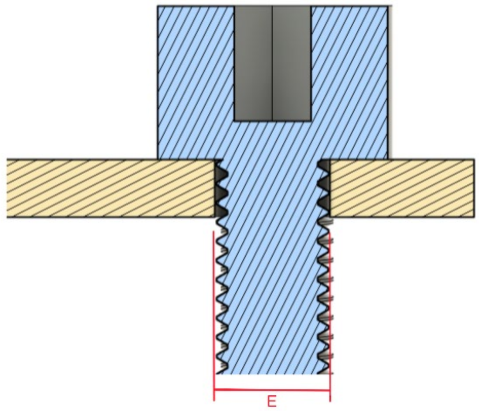


FIGURE 12.2.1.4: BRACKET & SCREW FIT REFERENCE

The purpose of the screw is to connect a part that the screw screws into to a bracket. While the screw is load bearing, since it screws into a different part with the bracket placed in between the screw head and the part, a clearance fit was selected between the bracket and the screw. This eases the manufacturing precision requirement of the fabrication of the brackets.

Vector Name	Nominal Dimension (mm)	Tolerances (mm)	Max/Min Dimension (mm)	References
E	3.15	+.15	3.30	Screw
		-.15	3.00	

Actuator Holder & Actuator Holder Guide:

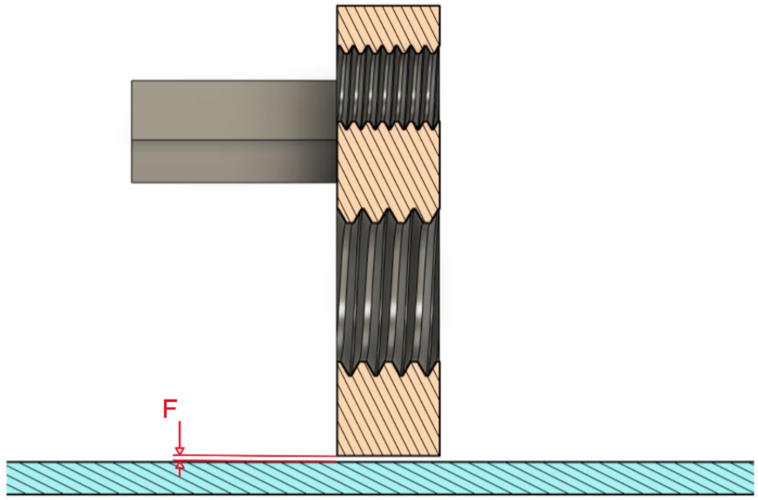


FIGURE 12.2.1.5: ACTUATOR HOLDER & ACTUATOR HOLDER GUIDE FIT REFERENCE

The purpose of the actuator holder guide is to keep the actuator holder, and thus the linear actuator and needle, vertical. The actuator holder is meant to slide against the actuator holder guide as the actuator holder moves along the lead screw, meaning the actuator guide is not load bearing. Therefore, a sliding fit was selected between the actuator holder and the actuator holder guide.

Vector Name	Nominal Dimension (mm)	Tolerances (mm)	Max/Min Dimension (mm)	References
F	0.30	+.05	0.35	Actuator Holder Guide
		-.05	0.25	

Lead Screw Slider:

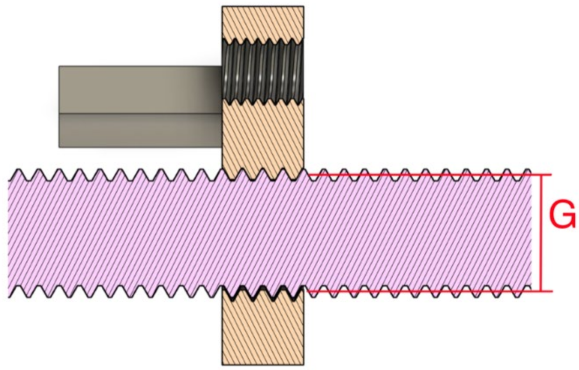


FIGURE 12.2.1.6: LEAD SCREW SLIDER FIT REFERENCE

The lead screw slider is designed to facilitate the smooth linear motion along the lead screw while maintaining precise alignment. The slider must move freely along the lead screw but also stay securely in place to prevent wobble or misalignment during operation. Therefore, a sliding fit is chosen between the lead screw and the lead screw slider. The slider itself should have minimal clearance from the lead screw to avoid any axial play while allowing easy movement.

Vector Name	Nominal Dimension (mm)	Tolerances (mm)	Max/Min Dimension (mm)	References
G	8.0	+.05	8.05	Lead Screw
		-.05	7.95	

12.3 Electrical/Wiring Diagrams

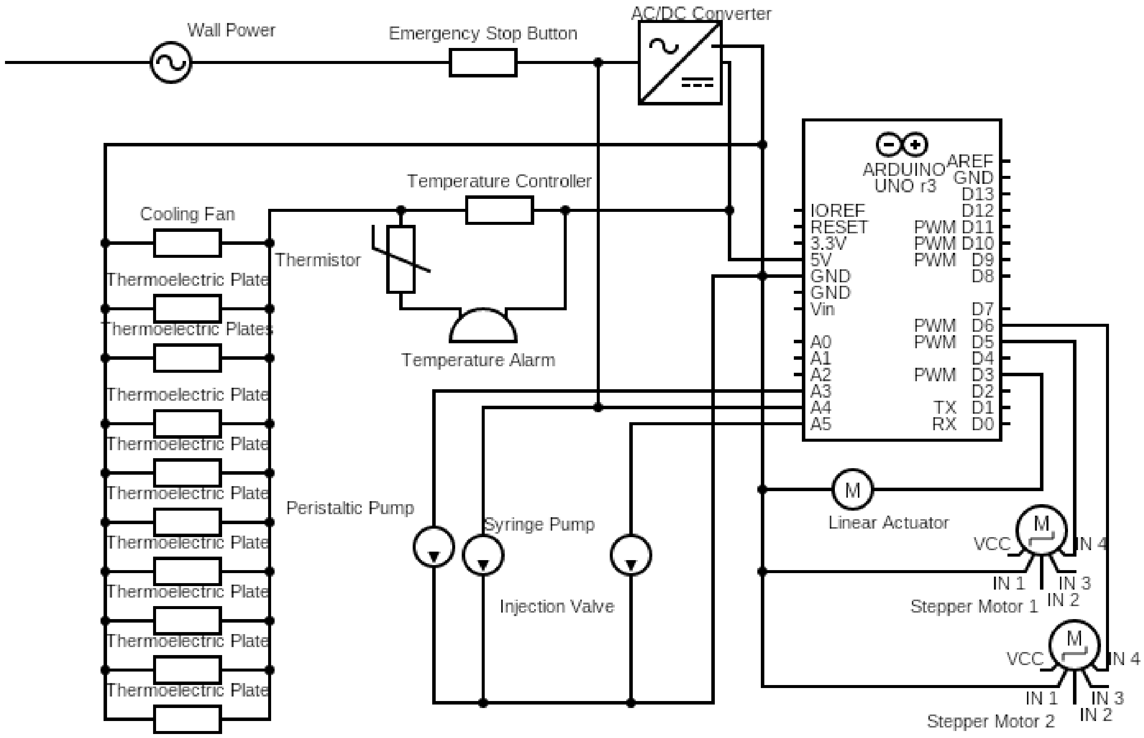


FIGURE 12.3.1: ELECTRICAL/WIRING DIAGRAM FOR AUTOSAMPLER

12.4 Algorithms/Code

```
# Initialize lead screw controls, actuator, and temperature system
Initialize X_leadscrew_control
Initialize Y_leadscrew_control
Initialize Z_actuator_control
Initialize cooling_system
Initialize temperature_sensor

# Function to calibrate the system
FUNCTION calibrate_system():
  # Home X, Y, and Z axes to corner position (home positions)
  retract_actuator()
  Set current_z_position to 0

  Move X_leadscrew_control to home position
  Set current_x_position to 0

  Move Y_leadscrew_control to home position
  Set current_y_position to 0

  Set position of beaker
  beaker_position = Get position of rinsing beaker (X, Y)
END FUNCTION

# Function to move to a sample position, perform sampling, and move to the beaker for rinsing
FUNCTION move_to_sample_and_rinse(sample_position, beaker_position, intermediate_position):
  # Move X and Y axes to intermediate position (between samples)
  Start moving X_leadscrew_control to intermediate_position.x
  Start moving Y_leadscrew_control to intermediate_position.y
  Wait until X_leadscrew_control reaches intermediate_position.x
  Wait until Y_leadscrew_control reaches intermediate_position.y

  # Move X and Y axes to target sample position
  Start moving X_leadscrew_control to sample_position.x
  Start moving Y_leadscrew_control to sample_position.y
  Wait until X_leadscrew_control reaches sample_position.x
  Wait until Y_leadscrew_control reaches sample_position.y

  # Extend the actuator to perform sampling operation
  extend_actuator()
  Perform sampling operation

  # Retract the actuator after the sampling operation
  retract_actuator()

  # Move to intermediate position (preventing drips on other samples)
  Start moving X_leadscrew_control to intermediate_position.x
  Start moving Y_leadscrew_control to intermediate_position.y
  Wait until X_leadscrew_control reaches intermediate_position.x
  Wait until Y_leadscrew_control reaches intermediate_position.y
```

FIGURE 12.4.1: PSEUDOCODE FOR SYSTEM PART 1

```
  # Move to the beaker position (for rinsing)
  Start moving X_leadscrew_control to beaker_position.x
  Start moving Y_leadscrew_control to beaker_position.y
  Wait until X_leadscrew_control reaches beaker_position.x
  Wait until Y_leadscrew_control reaches beaker_position.y

  # Rinse process
  rinse()
END FUNCTION

# Function to extend linear actuator (for sample collection)
FUNCTION extend_actuator():
  Extend Z_actuator_control to sample collection position
  Wait until Z_actuator_control is extended
END FUNCTION

# Function to retract linear actuator after sample collection
FUNCTION retract_actuator():
  Retract Z_actuator_control
  Wait until Z_actuator_control is retracted
END FUNCTION

# Function to rinse between samples (move to beaker position)
FUNCTION rinse():
  extend_actuator()
  Wait until rinsing is complete
  retract_actuator()
END FUNCTION

# Function to initialize the temperature control system
FUNCTION initialize_temperature_control(target_temperature, tolerance):
  Set target_temperature
  Set temperature_tolerance to tolerance
  Initialize cooling_system
  Initialize temperature_sensor
  RETURN success_code
END FUNCTION

# Function to monitor and control temperature
FUNCTION control_temperature():
  WHILE autosampler is running:
    # Read current temperature from sensor
    current_temperature = Read temperature_sensor

    # Check if current temperature is within acceptable range
    IF current_temperature > (target_temperature + temperature_tolerance):
      Activate cooling_system
      Wait until current_temperature <= target_temperature
      Deactivate cooling_system
```

FIGURE 12.4.2: PSEUDOCODE FOR SYSTEM PART 2

```
    ELSE IF current_temperature < (target_temperature - temperature_tolerance):
      Activate heating_system (if applicable)
      Wait until current_temperature >= target_temperature
      Deactivate heating_system

    ELSE:
      # Temperature is within range; system is idle
      Keep system idle

    END IF
    # Add delay to prevent continuous polling
    Wait for 1 second
  END WHILE
END FUNCTION

# Function to stop the temperature control system
FUNCTION stop_temperature_control():
  Deactivate cooling_system
  Deactivate heating_system (if applicable)
  RETURN success_code
END FUNCTION

# Main control loop
WHILE autosampler is running:
  # Calibrate the system initially
  calibrate_system()

  # Initialize temperature control
  temperature_target = Get target temperature for samples
  temperature_tolerance = Get allowable temperature range
  initialize_temperature_control(temperature_target, temperature_tolerance)

  # Start controlling temperature in a separate thread/process
  Start control_temperature()

  # Loop through the samples on the tray
  FOR each sample in grid:
    # Get target positions for the sample (X, Y)
    sample_position = Get sample position (X, Y)
    z_position = 0  # Linear actuator starts retracted
    intermediate_position = Calculate intermediate position between sample rows/columns

    # Move to the sample, perform sampling, and rinse
    move_to_sample_and_rinse(sample_position, beaker_position, intermediate_position)
  END FOR

  # Stop temperature control when autosampler stops
  stop_temperature_control()
END WHILE
```

FIGURE 12.4.3: PSEUDOCODE FOR SYSTEM PART 3

This pseudocode integrates the control of lead screws, the linear actuator, temperature control system and the sampling to automate the operation of the autosampler. Initially, the system calibrates by homing the X, Y, and Z axes to their starting positions and setting the rinsing beaker's coordinates. During operation, the autosampler loops through a grid of samples. For each sample, it moves the X and Y lead screws to an intermediate position between the samples to prevent contamination from possible drops from the needle. It will then move to the sample position for collection using the Z-actuated sampling mechanism. After collecting the sample, it moves back to the intermediate position and then to the rinsing beaker for cleaning. Simultaneously, a temperature control subsystem monitors and maintains the sample environment within a specified range using cooling or heating mechanisms as necessary. The system runs the sampling and temperature control processes concurrently, ensuring optimal sample handling while maintaining environmental stability.