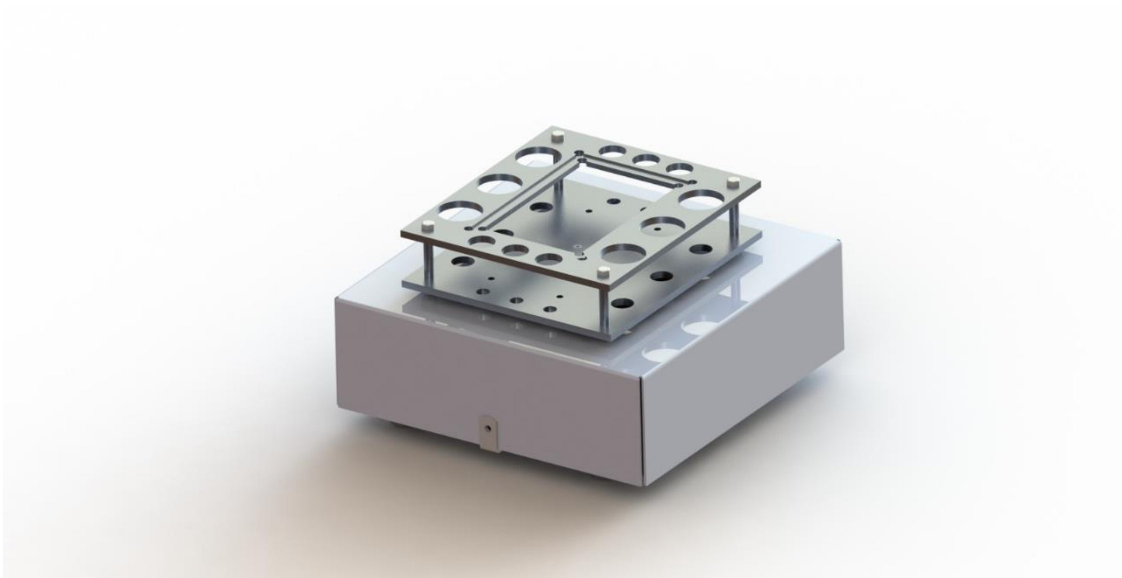
Final Design Report for Autonomous Microbioreactor Shaker Table with Integrated OD/FI



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5146-8077[5] *5912-1158*[6]

3135-4373[7]

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I. Executive Summary

A. Hedgehog Concept

The stated objective of this group is to create a competitive product in the industry that possesses a certain uniqueness to achieve that objective. There were three points of emphasis that ultimately combine to make our hedgehog concept (what we're really good at). First, our passion lies in our desire to standardize any dimension of our system to imperial units at a nominal dimension. Some parts, such as rods and bearing, were determined to be metric and, therefore, were left as such. But our group has experience working in the EML4502 lab and knows the availability of imperial tooling and fasteners compared to metric tooling and fasteners. Next, our formal education at the University of Florida has given us the confidence to achieve "best in the world" manufacturability. Finally, this will give our design an economic advantage over other products by minimizing part numbers and manufacturing costs. Ultimately, our hedgehog concept is simplicity by having, "A standardized shaker table that emphasizes manufacturability and reduces manufacturing time and assembly costs without compromising quality or performance."

B. Branding, Naming, and IP Protection

Although we have not created a logo for our project team, the name of our design is the "637 Shaker". This name is derived from our group name for the Mech 3 Design class. Actions have not been taken towards protecting our intellectual property because our design team believes our final design of the "637 Shaker" should be properly tested and certified for a full-scale production run of our product before we take actions to protect our intellectual property. Research has been done on the various IP protection methods available to us, and the method most effective in protecting our product is a patent. A patent will provide us the exclusive rights to sell our invention for 20 years although our shaker table design must be filed with the USPTO and disclosed to the public to receive our patent.

II. Prototyping Documentation

A. Down Selection & Engineering Analysis

Engineering analyses were performed for critical functions of the shaker table. Deflection for a fixed-fixed beam, two ends fixed and downward force on the center of the beam shown in Fig. X.

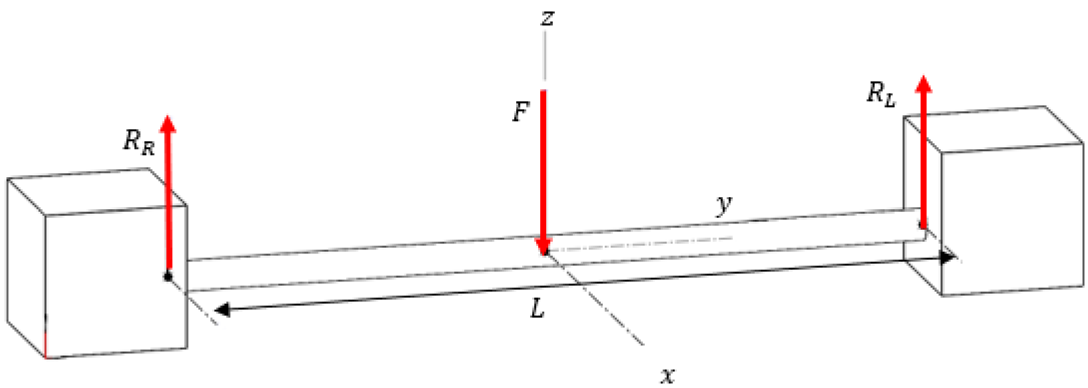


Fig. 1 - Free Body Diagram of a Fixed-Fixed Beam

The equation is given as,

$$\delta = -\frac{Fx^2}{48EI}(3L - 4x) \tag{1}$$

The variable x will equal L/2,

$$\delta = \frac{FL^3}{192EI} \tag{2}$$

This is max deflection on the rod if simulated as a fixed-fixed beam and the force of the weight of the shaker table supported by the rods is concentrated on the center of the beam.
Force is estimated from design reports of the previous teams, as 20.3 N where they calculate the resultant of the force exerted on the system during the shaking motion and the static force on the rods that need to support the weight of the center piece of the shaker table. Due to our increased amount of well plates and test tubes required to hold in the shaker table during one operation we decided to increase the resultant force to 30 N.
The length of the rod is 6 in. but the supports are the corner mounts which the rods are fitted through. We consider the corner mounts as acting fixed supports for the rod and the length becomes 4 in from corner mount to corner mount.
The Young's Modulus is 190 GPa for 304 Stainless Steel rods.
The moment of inertia is for a circular rod is,

$$I = \frac{\pi d^4}{64} \tag{3}$$

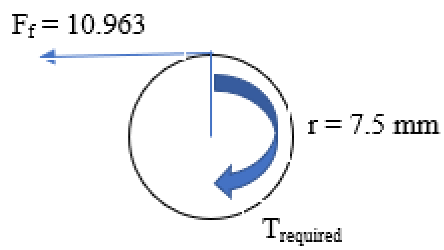
With all the variables characterized we can solve for the deflection in the rod and determine the displacement in the rods due to deformation and ensure the rods are strong enough to maintain the structure of the shaker table.
The diameter of the rods is 4 mm, so the moment of inertia is,

$$I = \frac{\pi \cdot 0.004^4}{64} = 1.26 \times 10^{-11}\ m^4 \tag{4}$$

The deflection can now be calculated as well,

$$\delta = \frac{(30\ N)(0.106\ m)^3}{192(1.9 \times 10^{11}\ Pa)(1.26\ \times\ 10^{-11}\ m^4)} = 6.86 \times 10^{-5}\ m = 0.0686\ mm \tag{5}$$

This is the max deflection if the whole weight of the centerpiece is concentrated on one rod, and since there are two guide rods in each direction to support the base, the force will be halved for each rod and the deflection will also be halved at 0.0343 mm for each rod. This is significantly smaller than the diameter of the guide rods, and we can deem the rods stiff enough for the functionality of the shaker table.



The selection of motors on the market was very limited when trying to consider cost, size and functionality. A 12V DC motor from Polulu was found with an operating speed of 1600 RPM and torque of 3.3 kg cm (42 oz in) [3]. To determine if this motor is powerful enough to move the well plate interface, a free body diagram can be drawn.

The weight of the well plate interface resists motion with a friction force on the aluminum rods which the motor needs to overcome. The normal force of the well plate interface is 20.3 N and the coefficient of friction between the aluminum rod and pulley is 0.54 which gives a friction force of 10.963 N [4].

$$F_f = \mu \cdot F_N \tag{6}$$

$$F_f = 0.54\ \cdot 20.3\ N = 10.963\ N \tag{7}$$

The motor needs to overcome a 10.963 N force at a distance of 7.5 mm. The resistive torque comes out to 11.64 in oz (0.822 N m). The motor is rated for 42 in oz so it is more than strong enough to move the well plate interface at the speeds necessary.

B. Engineering Design Changes

A major change that was made is the size of the rails that are used in the assembly. One of the initial observations was that the rails seemed larger than was needed and the corner mounts and rail mounts did not have a full major diameter of material on all sides of the mounting holes which could be failure locations during testing. According to the analysis performed above, the reduction in diameter from 6 mm to 4 mm rods would not affect the functionality of the shaker table.

During assembly and testing, a combination of 3D printed parts and manufactured aluminum parts were used. During some cycles, the collar blocks would not slide smoothly along the rails, and it was determined the problem stemmed from the rods not being completely perpendicular and horizontal. This was in part due to the 3D printed parts having low tolerances, however when using fully aluminum parts the issue persisted. To combat this issue, tolerances were tightened on the holes in the mounting blocks and surface finishes were added. This will keep the rods more perpendicular and horizontal and reduce the amount of friction the collars experience when sliding.

The original assembly included an array of UV lights in order to conduct the OD/FI measurements. The array of lights was to be mounted to the well plate interface and the sensor would hover above the samples using the robot arm to take measurements. During testing of the OD/FI system it became difficult to calibrate the measurements because the other lights in the array were interfering with the readings. It was decided that our OD/FI light and sensor would live completely on the robot arm and instead of having an array of lights, only one would be needed. The robot attachment could be adjusted to measure well plates or 15- and 50-mL test tubes and would maneuver around the well plate interface and take measurements of the samples one at a time. Using only a single light will remove the interference from other light sources and provide more accurate measurements. The OD/FI assembly will also include two photoresistors, one to measure optical density and the other to measure fluorescent intensity.

C. Electrical Modifications

The three biggest changes to the electrical system were the conversion from stepper motors to DC motors, the integration of the OD/FI system, and conversion from breadboard to a more permanent perf board. The conversion to DC motors allows for a simpler circuit requiring only one driver to power both motors. The driver used, an L298N model, also steps down the 12 V DC power to 5 V DC to power the rest of circuit eliminating another electrical component. The motors used also contain encoders and therefore there is almost no loss of function compared to the stepper motors. The integration of the OD/FI system called for a 365 nm UV light source to be added, as well as two photoresistors as sensors which were each wired in series with 10 kΩ resistors for proper function. One of the biggest changes was converting the circuit from a temporary breadboard to a fully soldered perf board. This allowed for a sleeker and more permanent design when moving towards a final functioning product as wires don’t easily detach when moving components or doing maintenance. Perf boards are also significantly smaller allowing for a smaller and sleeker control module.

D. Code Modifications

One main change to the software that was made involves the limit switches and handling drifting during use. The previous design did a position check when the machine was turned on and used the limit switches to center the well plate interface. The 637 Shaker table does not center the well plate at the beginning, but instead has active correction during cycles. If the well plate interface contacts one of the limit switches, it will correct the drift in real time during the cycle to recenter the well plate. So, the 637 Shaker can start at any position and will automatically correct itself if needed. An additional change that was made is after the parameters for the cycle are selected using the potentiometer, the user is prompted to confirm the cycle and parameters before starting. This way, if a parameter was incorrectly selected the user can return to the main menu and repeat the cycle selection with the correct values.

III. Testing Results

IP-X5 Infiltration Test

This was our first performance evaluation to ensure our shaker table could withstand water or liquid exposure and still maintain functionality. For our initial test the casing over the motors were 3D-printed which is not a waterproof material, so the motors and the wiring connected to the motors were compromised. Future tests will be done with motor casings made of the 6061 Aluminum that the rest of our components are made of.

Functional Demonstration

The functional demonstration required our shaker table could operate the three shaking patterns: linear, orbital, and double orbital. The shaker table must also be connected to a user interface that allows us to select variable speeds, durations, and radii of orbitals. Our functional demonstration was successful in all aspects with a functional user interface that could control the shaking patterns of our shaker table with precision.

Full Machine Demonstration

The full machine demonstration requires our interface that operates the shaker table, to be user friendly, allowing first-time operators to easily control the shaker table and its various functions. Our full machine demonstration was successful with an LED panel to show options available to the user, up and down buttons to select between the three shaking patterns, a potentiometer to adjust the various speeds, durations, and radii sizes of the shaking patterns, a start button to initiate the operation of the shaker table, and an emergency off switch to completely stop the shaker table operation.

Cold Soak Temperature Test

The cold soak temperature test was to ensure the shaker table can operate in extreme cold environments. The test requires that the shaker table is still operational after sitting in an environment of 4 degrees Celsius. We have not completed this test yet however we found the coldest temperature for each component before loss of function. Since the temperatures for each component are lower than the necessary temperature, we believe the shaker table will still function after being put in an extremely cold environment.

Overclock & High Temperature Test

For the overclock and high temperature test, a heat test is performed to ensure the shaker table can operate at extremely high heats without problems due to thermal expansion in the components of the shaker table. The test requires that the shaker table still be operational at temperatures up to 70 degrees Celsius. Although we have not performed the test yet, we found the maximum temperatures for each component before loss of function and found them to all be higher than the necessary requirement. Thus, we believe the shaker table will pass the test and be operational at temperatures up to 70 degrees Celsius.

Drop Test

The drop test performance eval requires that we drop our shaker table from a height of 75 cm to ensure that our shaker table can still operate after impact. We haven't done our test yet, but calculations have been performed to estimate the force and velocity that the shaker table will undergo. The force can be found from the mass times the acceleration due to gravity which is 20.3N. The impact velocity can be found from the initial velocity, the acceleration due to gravity and the height of the drop which is 3.84m/s. and with our material choice of 6061 aluminum for most of our components and use of sturdy fasteners to assemble our components together, we believe that our shaker table is sturdy enough withstand the impact force and velocity from the drop and remain functional.

IV. Improvement Plan

There are several ways to improve the design to ensure its functionality meets the customer's needs. Because of human error in the lab and unexpected hinderances during the manufacturing and assembly process, the current state of our prototype is not meeting our intended design, nor the intended functionality required by the customer.

After our performance tests, we derived an understanding of further improvements that can be made to the shaker table. First, steps towards noise reduction need to be made. A few improvements described below will help reduce the vibrations in the system that result in louder system performance. The table is currently averaging 70 dB and is required to be below 50 dB. A final note for this change is to consider adding some sound dampening padding or changing the material used for the casing. The steel sheet metal produces significant echoing in the system. Next, an issue proposed by the prior semester's FDR that was not addressed is motor drift. A solution that was implemented this semester was using limit switches to return the center block back to centered position using a fixed value. While this was effective to a degree, the encoders in the motors would allow the implementation of a PID controller to the system to allow for dynamic centering of the well plate interface to achieve high functioning orbitals.

One problem discovered during our performance tests of the shaker table was the interference between the limit switches on top of the corner mounts and the lower belt system. In the CAD model of our design no interference is present between the limit switches and belts but tolerance errors of components in our base subassembly caused the belt to be lowered and the limit switches raised to a point of interference between each other. The shaker table is not inoperable due to this problem, but improvements made for spacing between the limit switches and the belt will improve the performance of our shaker table.

Our initial prototype of our shaker table consisted of mainly 3D-printed parts, such as the center block, well plate interface, the corner and drive mounts, and a few of the guide rods. As the semester progressed, manufacturing TA's delivered parts composed of 6061 aluminum which would replace our 3D-printed parts. Thus, a gradual improvement in the strength and durability of components within our shaker table was seen. Issues with drawing submissions and manufacturing led to a few of our components that were 3D-printed for the initial prototype to not be replaced by aluminum parts. Earlier part submission from our design team would lead to proper replacement of 3D-printed parts.

To IPX5 waterproof certify our motors on the shaker table, motor casings were developed during our design process to cover the motors and protect from water or liquid exposure. Unfortunately, the motor casing interfered with the guide rods going through the center block. Fixing this will allow for smoother movement of the well plate interface. Improvements can be made by extending the length and width of the base plate, allowing our motors to be placed further outwards and removing the interference between the motor casings and the central guide rods. If this improvement were to be implemented the outward distance extended by the motors must not exceed the full length of the belts.

One of our design changes from the initial belt-driven design was to split the pulley mount into two separate mounts to simplify manufacturing and remove interferences with screws and fasteners of other components. Our prototype ended up only having one screw to fasten each of the pulley mounts meaning the pulley mount had no resistance to moment forces in the direction of the screw. This means our pulley mounts could not properly keep the belt in place during operation. Improvements were reflected in the final CAD model with two screws fastening each of the pulley mounts but actual changes to the prototype were not created and the two pulley mounts were instead fastened with glue.

The drive mounts along the outer guide rods were the components that would hit the limit switches during operation to ensure the code could realign the shaker table movement if drifting were to occur. Our design team discovered in testing our prototype that the drive mounts were not large enough to properly activate the limit switches when the shaker table would drift too far to the outer range of the shaking pattern. Improvements in the sizes of the drive mounts to ensure that limit switches will be properly activated during operation will allow for the shaker table to properly account for drifting problems in the shaking pattern.

Finally, a major design change for this semester was to reduce the diameter of the rods from 6 mm to 4 mm. The analysis performed on the change was a deflection calculation from the weight of the well pate interface on the rods with liquid samples present. However, an element to functionality that was not considered is a moment created by the lag and lack of parallelism between the driving guide rod and the guide rod opposite to it. This creates a significant bending of the rod in the XY plane that negatively affects the performance of the shaker table.

V. Bill of Material & Purchase Order

Purchase Order

REQUEST FOR ITEMS TO BE PURCHASED

Date Requested: 4/28/23

1. Purchase Order Number:	1
2. Group requesting item(s):	1
3. Account to be charged:	MAE Mechanical Design 3
4. Group member issuing PO:	Alexander Bailey

BOM Part Number	BOM Part Name	Description of item to be purchased:	Part Number	Qty.	Unit	Price	Shipping	Sub Total	Vendor Name	Vendor Address	Vendor City/State/Zip	Vendor Phone Number
EML4502-OTS-01	10-24 1-3/4" Hex Head Screws	92314A313_18-8 Stainless Steel Hex Head Screws (5)	92314A313	4	1	$ 8.32	$8.62	$ 16.94	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3516/92314A313								
EML4502-OTS-02	10-24 Hex Nuts	91841A011_18-8 Stainless Steel Hex Nut (100)	91841A011	4	1	$ 5.24	$ 5.24	$ 10.48	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3582/91841A011								
EML4502-OTS-03	4-40 1" Hex Frive Flat Head Screws	92210A115_18-8 Stainless Steel Nex Drive Flat Head Screw (100)	92210A115	3	1	$ 7.59	$ 7.59	$ 15.18	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3424/92210A115								
EML4502-OTS-04	4mm Fixed Alignment Ball Bearing	Fixed Alignment High Temperature Linear Ball Bear for 4mm Shaft Diameter (1)	N/A	6	6	$ 5.55	$ 10.69	$ 43.99	Amazon	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/uxcell-Linear-Motion-Bearings-Printer/dp/B07H93TFBM?th=1								
EML4502-OTS-05	4mm Diameter, 3ft Multipurpose Rod	1272T13_Multipurpose 304 Stainless Steel Rod (1)	1272T13	2	2	$ 12.55	$ 12.55	$ 37.65	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/4235/1272T34								
EML4502-OTS-06	M3 Aluminum Washers	92334A109_Aluminum Washer (10)	92334A109	2	1	$ 10.49	$ 10.40	$ 20.89	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3628/92334A109								
EML4502-OTS-07	M3 x 6mm Pan Head Phillips Screws	90116A151_316 Stainless Steel Pan Head Philips Screw (100)	90116A151	2	1	$ 11.62	$ 11.62	$ 23.24	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3394/90116A151								
EML4502-OTS-08	M3.5 x 10mm Buttom Head Hex Drive Screws	92095A161_Button Head Hex Drive Screw (100)	92095A161	8	1	$ 5.52	$ 5.52	$ 11.04	McMaster-Carr	920 Pilot Rd.	Las Vegas, NV 89119	(702) 262 6648
			Web Site:	https://www.mcmaster.com/catalog/129/3385/92095A161								
EML4502-OTS-09	M2 x 8mm Black-Oxide Socket Head Screws	91290A015_M2 Black-Oxide Alloy Steel Socket Head Screw (100)	91290A015	8	1	$ 18.04	$ 18.04	$ 36.08	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3494/91290A015								
EML4502-OTS-10	M6 x 1mm Neoprene Bumpers	9546K212_Neoprene Bumper (Rubber Feet) (1)	9546K212	4	4	$ 4.09	$ 4.09	$ 20.45	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/4314/9546K212								
EML4502-OTS-11	M6 x 16 mm Socket Head Screws	95263A531_M6 X 1mm 16 mm Long Steel Socket Head Screw (25)	95263A531	14	1	$ 7.47	$ 7.47	$ 14.94	McMaster-Carr	701 Brooks Avenue South	Theif River Falls, MN 56701	1-800-344-4539
			Web Site:	https://www.mcmaster.com/catalog/129/3500/95263A531								
EML4502-OTS-12	M3 x 8mm Button Head Hex Drive Screws	92095A181_Button Head Hex Drive Screw (100)	92095A181	12	1	$ 8.00	$ 8.00	$ 16.00	McMaster-Carr	701 Brooks Avenue South	Theif River Falls, MN 56701	1-800-344-4539
			Web Site:	https://www.mcmaster.com/catalog/129/3385/92095A181								
EML4502-OTS-13	M2.5 x 4mm Button Head Hex Drive Screws	92095A456_Button Head Hex Drive Screw (25)	92095A456	8	1	$ 5.36	$5	$ 10.72	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3385/92095A456								
EML4502-OTS-14	Small Limit Switches	Small Limit Switches (5)	N/A	4	1	$ 12.98	$2	$ 14.97	Amazon	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/MXRS-Hinge-Momentary-Button-Switch/dp/B07MW2RPJY/ref=asc_df_B07MW2RPJY/?tag=hyprod-20&linkCode=df0&hvadid=385401161937&hvpos=&hvnetw=g&hvrand=8494385917865736959								
EML4502-OTS-15	Belt2/Belt4	Belt2/Belt4 (1)	1922V298	2	2	$ 24.21	$24	$ 72.63	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/products/belts/								
EML4502-OTS-16	High Strength HTD Timing Belt Idler Pulley	High Strength HTD Timing Belt Idler Pulley (1)	369N12	2	1	$ 7.25	$15	$ 21.75	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/products/timing-belt-idler-pulleys/for-belt-trade-size~htd/								
EML4502-OTS-17	HTD Timing Belt Pulleys	HTD Timing Belt Pulleys (1)	3693N11	2	1	$ 7.25	$15	$ 21.75	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3424/92210A112?s=stainless+steel+hex+drive+flat+head+screw								
EML4502-OTS-18	MXL Timing Belt Clamps	MXL Timing Belt Clamps (1)	92210A112	2	1	$ 21.38	$2	$ 23.27	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/products/timing-belt-clamps/belt-trade-size~mxl/								
EML4502-OTS-19	Plate Spacers	Plate Spacers (5)	N/A	4	1	$ 2.89	$2	$ 4.79	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/wall-plate-spacer/s?k=wall+plate+spacer								
EML4502-OTS-20	DC Motor	37d-gearmotor-6-10-encoder (1)	N/A	2	1	$ 103.90	$6	$ 110.35	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.pololu.com/product/4758								
EML4502-OTS-21	M4 Hex Nuts	90591A255_Zinc Plated Steel Hex Nut (100)	90591A255	4	1	$ 3.11	$3	$ 6.22	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3584/90591A255								
EML4502-OTS-22	M4 x 10mm Zinc-Plated Alloy Steel Socket Head Screws	90128A212_Zinc-Plated Alloy Steel Socket Head Screw (100)	90128A212	4	1	$ 9.49	$9	$ 18.98	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3499/90128A212								
EML4502-OTS-23	Zinc-Plated Steel Corner Brackets	1556A26_Zinc-Plated Steel Corner Bracket	1556A26	2	1	$ 14.38	$14	$ 28.76	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/2916/1556A26								
EML4502-OTS-24	Motor Drivers	Qunqi L298N Motor Drive Controller Board Module Dual H Bridge DC Stepper For Arduino	N/A	1	1	$ 16.99	$2	$ 18.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/Qunqi-Controller-Module-Stepper-Arduino/dp/B014KMHSW6/?tag=hyprod-20&linkCode=df0&hvadid=167139094796&hvpos=&hvnetw=g&hvrand=13171131084069081								
EML4502-OTS-25	LCD Module	SunFounder IIC I2C TWI Serial 2004 20x4 LCD Module Shield Compatible with Arduino R3 Mega2560	N/A	1	1	$ 12.89	$2	$ 14.78	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/SunFounder-Serial-Module-Arduino-Mega2560/dp/B01GPUMP9C/ref=asc_df_B01GPUMP9C/?tag=hyprod-20&linkCode=df0&hvadid=309777534894&hvpos=&hvnetw=g&hvrand=6338229128115								
EML4502-OTS-26	UV Detection Sensor	GUVA S12SD 200nm-370nm UV Detection Sensor Module Light Sensor for Arduino STM32	N/A	1	1	$ 14.99	$2	$ 16.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3424/92210A112?s=stainless+steel+hex+drive+flat+head+screw								
EML4502-OTS-27	UV LED Module	Everbeam 365nm 50W UV LED Black Light	N/A	1	1	$ 48.99	$49	$ 97.98	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3424/92210A112?s=stainless+steel+hex+drive+flat+head+screw								
EML4502-OTS-28	Electrical Wire M/M	Electrical Wire M/M	N/A	65	1	$ 1.99	$1	$ 2.99	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/Elegoo-EL-CP-004-Multicolored-Breadboard-arduino/dp/B01EV70C78/ref=asc_df_B01EV70C78/?tag=hyprod-20&linkCode=df0&hvadid=222785939698&hvpos=&hvnetw=g&hvrand=9722929112								
EML4502-OTS-29	Electrical Wire F/F	Electrical Wire F/F	N/A	65	1	$ 1.99	$1	$ 2.99	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/Elegoo-EL-CP-004-Multicolored-Breadboard-arduino/dp/B01EV70C78/ref=asc_df_B01EV70C78/?tag=hyprod-20&linkCode=df0&hvadid=222785939698&hvpos=&hvnetw=g&hvrand=9722929112								
EML4502-OTS-30	Push Button	Push Button	N/A	3	1	$ 2.89	$1	$ 3.43	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/Twidec-Normal-Momentary-Pre-soldered-PBS-110-XBK/dp/B07RW2YZ4W/ref=asc_df_B07RPS2ZY3/?tag=&linkCode=df0&hvadid=366352800385&hvpos=&hvnetw=g&hvrand=488417000185836								
EML4502-OTS-31	Power Switch	Power Switch	N/A	1	1	$ 5.36	$2	$ 7.25	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/DaierTek-Rocker-Switch-Household-Appliances/dp/B07S1MV462/ref=sr_1_7?hvadid=616931649073&hvdev=c&hvlocphy=9011699&hvnetw=g&hvqmt=e&hvrand=15750527718203799228&hvtar								
EML4502-OTS-32	Potentiometer	Potentiometer	N/A	1	1	$ 6.38	$2	$ 8.27	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com/catalog/129/3424/92210A112?s=stainless+steel+hex+drive+flat+head+screw								
EML4502-OTS-33	12V 5A Adaptor	ALITOVE DC 12V 5A Power Supply Adapter Converter Transformer AC 100-240V Input with 5.5x2.5mm DC Output Jack for 5050 3528 LED Strip Module Light	N/A	4	1	$ 12.84	$2	$ 14.73	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.amazon.com/ALITOVE-Adapter-Converter-100-240V-5-5x2-1mm/dp/B01GEA8PQA/ref=asc_df_B01GEA8PQA/?tag=hyprod-20&linkCode=df0&hvadid=167156299330&hvpos=&hvnetw=g&hvrand=111810491								
EML4502-1	Corner Mount	Corner Mount	N/A	4	1	$ 6.89	$2	$ 8.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-2	Rail Mount Tall	Rail Mount Tall	N/A	1	1	$ 5.30	$1	$ 6.60	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-3	Shaker Plate Case	Shaker Plate Case	N/A	1	1	$ 8.34	$3	$ 11.33	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-4	Rail Mount Short	Rail Mount Short	N/A	1	1	$ 5.30	$3	$ 8.73	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-5	Guide Rod	Guide Rod	N/A	6	1	$ 4.32	$1	$ 5.31	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-6	Base Plate	Base Plate	N/A	1	1	$ 14.99	$3	$ 17.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-7	Bottom Plate	Bottom Plate	N/A	1	1	$ 14.99	$3	$ 17.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-8	Top Plate	Top Plate	N/A	1	1	$ 14.99	$3	$ 17.88	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-9	Center Block	Center Block	N/A	1	1	$ 5.84	$1	$ 7.18	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-10	Pulley Mount Left	Pulley Mount Left	N/A	2	1	$ 10.40	$1	$ 11.40	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-11	Pulley Mount Right	Pulley Mount Right	N/A	2	1	$ 10.40	$1	$ 11.40	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-12	Motor Mount	Motor Mount	N/A	2	1	$ 11.68	$2	$ 13.57	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-13	Motor Mount Front Door	Motor Mount Front Door	N/A	2	1	$ 9.08	$2	$ 11.19	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-14	Pulley Rod	Puley Rod	N/A	1	1	$ 4.32	$1	$ 5.21	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-15	Short Motor Spacer	Short Motor Spacer	N/A	1	1	$ 5.44	$1	$ 6.33	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-16	Tall Motor Spacer	Tall Motor Spacer	N/A	1	1	$ 5.44	$1	$ 6.33	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								
EML4502-17	Motor Mount Back Door	Motor Mount Back Door	N/A	1	1	$ 9.11	$1	$ 10.02	McMaster-Carr	1901 Riverside Pkwy.	Douglasville, GA 30135-3150	(404) 346 7000
			Web Site:	https://www.mcmaster.com								

TOTAL: $ 886.67

Deliver to whom: Sean R. Niemi
Delivery location: Dept of Mech and Aero Eng.
Building B, Room 305

Denotes items to be filled in by preparer.

VI. Bill of Materials

Item No.	DWG Number	Part Description	Material (Individual Custom & Modified OTS Parts)	Qty.
1	EML4502-OTS-01	10-24 1-3/4" Hex Head Screws	18-8 Stainless Steel	4
2	EML4502-OTS-02	10-24 Hex Nuts	18-8 Stainless Steel	4
3	EML4502-OTS-03	4-40 1" Hex Drive Flat Head Screws	18-8 Stainless Steel	3
4	EML4502-OTS-04	4mm Fixed Alignment Ball Bearing	18-8 Stainless Steel	6
5	EML4502-OTS-05	4mm Diameter, 3ft Multipurpose Rod	18-8 Stainless Steel	2
6	EML4502-OTS-06	M3 Aluminum Washers	6061 Aluminum	2
7	EML4502-OTS-07	M3 x 6mm Pan Head Phillips Screws	18-8 Stainless Steel	2
8	EML4502-OTS-08	M3.5 x 10mm Buttom Head Hex Drive Screws	18-8 Stainless Steel	8
9	EML4502-OTS-09	M2 x 8mm Black-Oxide Socket Head Screws	18-8 Stainless Steel	8
10	EML4502-OTS-010	M6 x 1mm Neoprene Bumpers	Hard Neoprene	4
11	EML4502-OTS-11	M6 x 16 mm Socket Head Screws	Zinc-Plated Steel	14
12	EML4502-OTS-12	M3 x 8mm Button Head Hex Drive Screws	18-8 Stainless Steel	12
13	EML4502-OTS-13	M2.5 x 4mm Button Head Hex Drive Screws	18-8 Stainless Steel	8
14	EML4502-OTS-14	Small Limit Switches	Plastic/18-8 Stainless Steel	4
15	EML4502-OTS-15	Belt2/Belt4	Neoprene	2
16	EML4502-OTS-16	High Strength HTD Timing Belt Idler Pulley	6061 Aluminum	2
17	EML4502-OTS-17	HTD Timing Belt Pulleys	6061 Aluminum	2
18	EML4502-OTS-18	MXL Timing Belt Clamps	6061 Aluminum	2
19	EML4502-OTS-19	Plate Spacers	Low-Carbon Steel	4
20	EML4502-OTS-20	DC Motor	OEM	2
21	EML4502-OTS-21	M4 Hex Nuts	Zinc-Plated Steel	4
22	EML4502-OTS-22	M4 x 10mm Zinc-Plated Alloy Steel Socket Head Screws	Zinc-Plated Steel	4
23	EML4502-OTS-23	Zinc-Plated Steel Corner Brackets	Zinc-Plated Steel	2
24	EML4502-OTS-24	Motor Drivers	OEM	1
25	EML4502-OTS-25	LCD Module	OEM	1
26	EML4502-OTS-26	UV Detection Sensor	OEM	1
27	EML4502-OTS-27	UV LED Module	OEM	1
28	EML4502-OTS-28	Electrical Wire M/M	OEM, Copper	65
29	EML4502-OTS-29	Electrical Wire F/F	OEM, Copper	65
30	EML4502-OTS-30	Push Button	OEM, Plastic	3
31	EML4502-OTS-31	Power Switch	OEM, Plastic	1
32	EML4502-OTS-32	Potentiometer	OEM, Plastic	1
33	EML4502-OTS-33	12 V 5A Adaptor	OEM	1
34	EML4502-1	Corner Mount	6061 Aluminum	4
35	EML4502-2	Rail Mount Tall	6061 Aluminum	1
36	EML4502-3	Shaker Plate Case	6061 Aluminum	1
37	EML4502-4	Rail Mount Short	6061 Aluminum	1
38	EML4502-5	Guide Rod	304 Stainless Steel	6
39	EML4502-6	Base Plate	6061 Aluminum	1
40	EML4502-7	Bottom Plate	6061 Aluminum	1
41	EML4502-8	Top Plate	6061 Aluminum	1
42	EML4502-9	Center Block	6061 Aluminum	1
43	EML4502-10	Pulley Mount Left	6061 Aluminum	2
44	EML4502-11	Pulley Mount Right	6061 Aluminum	2
45	EML4502-12	Motor Mount	6061 Aluminum	2
46	EML4502-13	Motor Mount Front Door	6061 Aluminum	2
47	EML4502-14	Pulley Rod	6061 Aluminum	1
48	EML4502-15	Short Motor Spacer	6061 Aluminum	1
49	EML4502-16	Tall Motor Spacer	6061 Aluminum	1
50	EML4502-17	Motor Mount Back Door	6061 Aluminum	2

VII. Projected Manufacturing and Assembly Cost

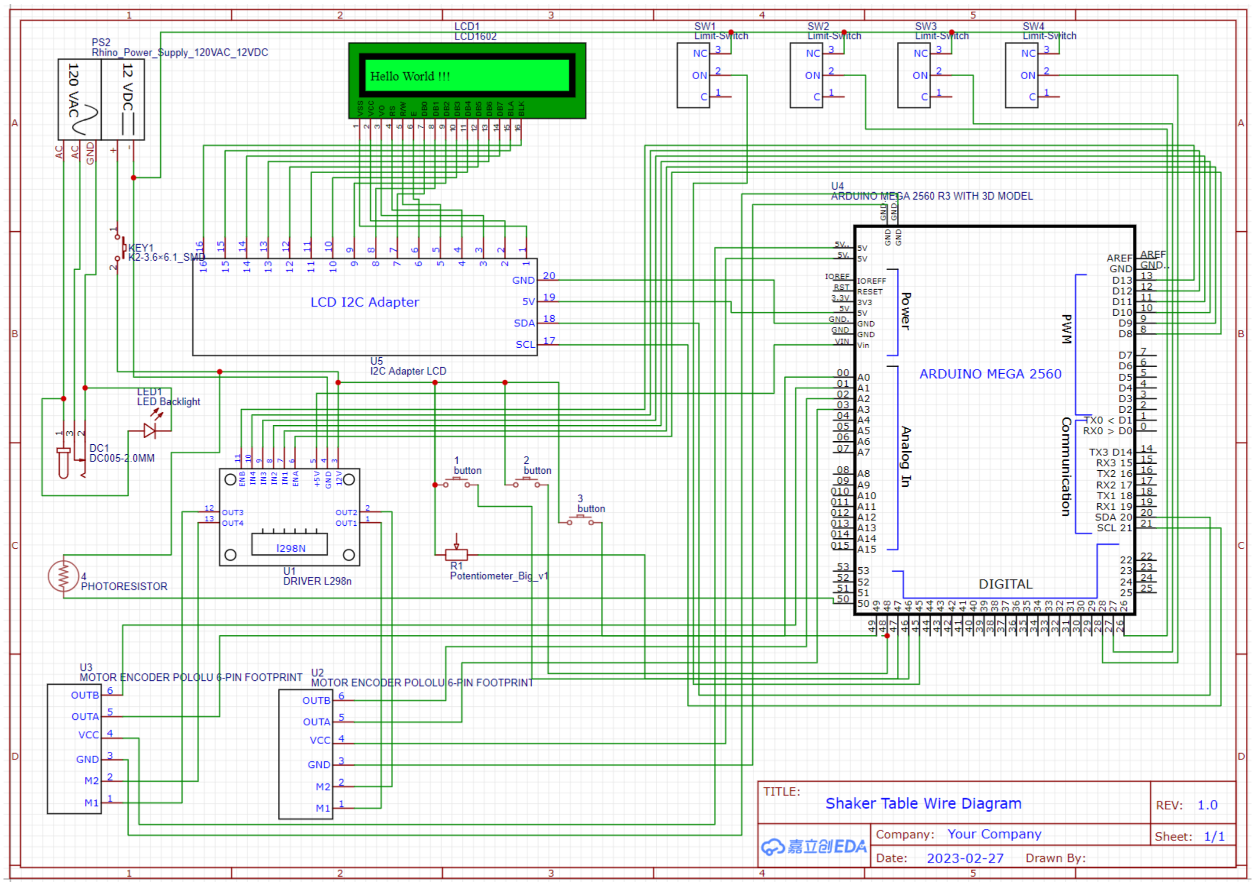
	Cost (per unit)
Prototyping Cost	**$886.87**
1000 Unit Production Scale Cost	**$362.29**

The prototyping and production total cost include raw material costs and manufacturing costs. The prototyping cost was over budget by $86.87 however the production scale cost for 1000 units was $37.71

under budget. The savings for the production run are for buying parts in bulk and manufacturing of the same parts.

VIII. Electrical Schematic

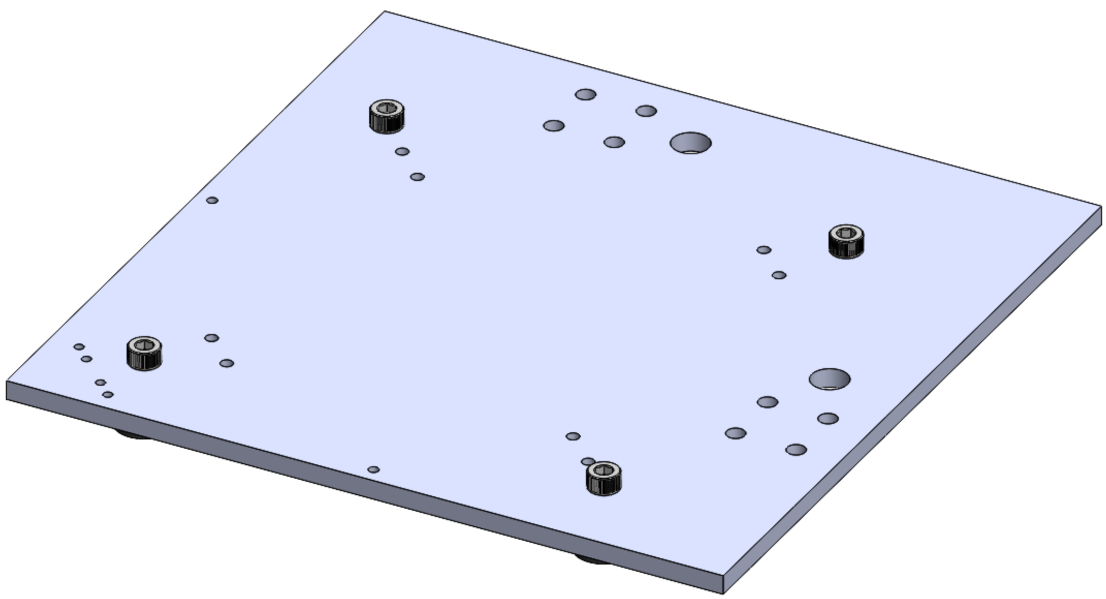
Electrical Schematic



The wiring schematic above details how all electrical components should be properly connected to achieve a functioning shaker table. 120 volt AC power is taken from a standard wall outlet and stepped down to 12 volts DC using an AC to DC converted. Immediately afterwards a power switch which doubles as an emergency cutoff switch is wired to power and ground. This switch is used to turn the circuit on and off and cut off all power to components in the case of an emergency. The now 12 volt DC power runs to an L298N DC motor driver that powers the two DC motors. The driver is also connected to an Arduino mega 2560 using the pulse width modulation pins to provide control to the motors. The 365 nm UV light source used for OD/FI also utilizes the 12 volt DC power. The L298N driver is capable of powering both the motors as well as further stepping down the 12 volt DC power to 5 volt DC power that will be used in the rest of the circuit. The 5 volt DC power from the driver powers the Arduino using its Vin pin. For OD/FI sensors, two photoresistors are wired to 5 volt DC and an analog pin on the Arduino. The photoresistors each use a 10 kΩ resistor wired in series. For control of the system, 3 buttons and a potentiometer are used. Each button is wired to ground and a digital pin on the Arduino. The potentiometer is wired to 5 volts, ground, and an analog pin on the Arduino. To prevent the well plate interface from drifting into the edges of motion, four limit switches were implemented by wiring one pin to ground, one pin to the digital pins on the Arduino and leaving the last pin open. As a user interface, a 16x2 LCD screen is wired to an I2C adapter. The I2C adapter uses 5 volt power, is grounded, and utilizes the Arduinos SDA and SCL pins. Lastly, the two motors each have four extra pins due to having a built-in encoder. These pins are wired to 5 volts, ground, and two analog pins on the Arduino. It should be noted that the schematic above does not include the perf board that is used in the physical product. The perf board only provides easy connection to 12 volt, 5 volt, and ground for components that need to share these power sources.

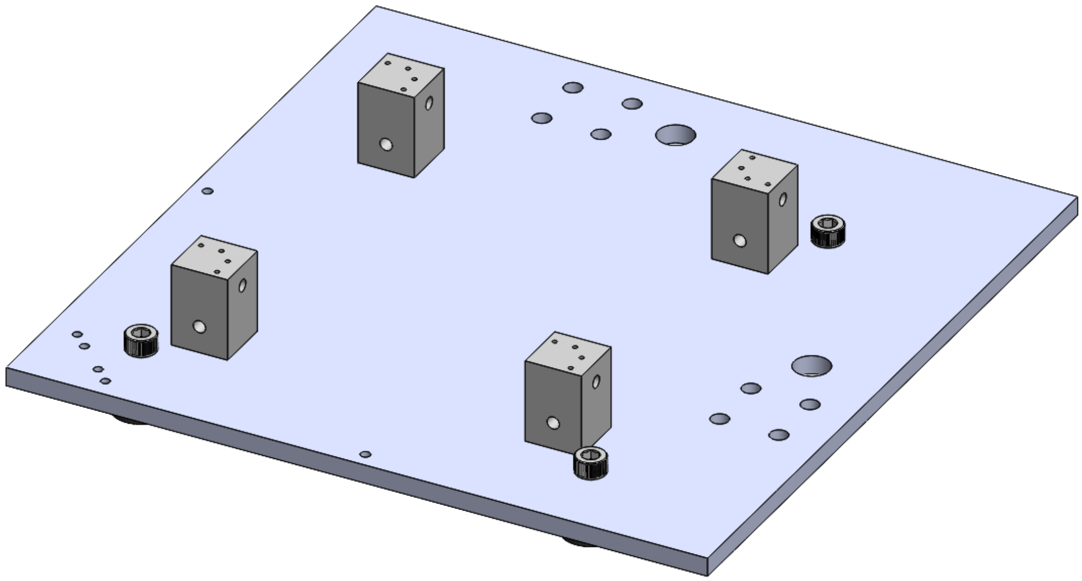
IX. Manual Assembly Plan

Step 1:
First, fasten the four rubber feet to the base plate using M6 cap screws.



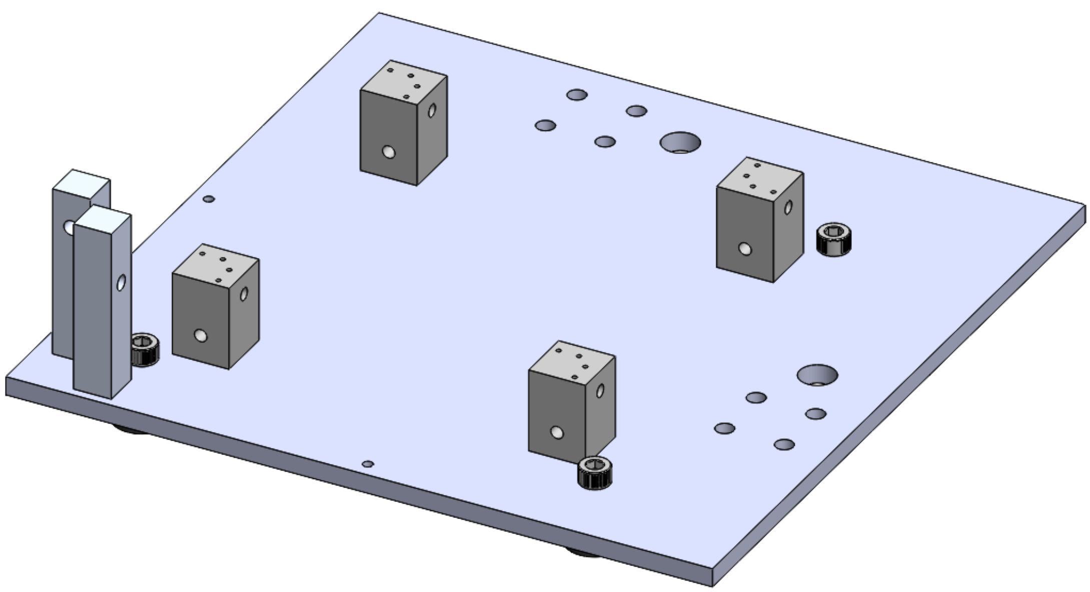
Step 2:

Next, fasten the four corner mounts onto the corners of the base plate, using 8 of the M4 cap screws (2 screws per corner mount). When securing the corner mounts, ensure that the holes for the guide rods are placed so that they align with the holes on the other corner mounts.



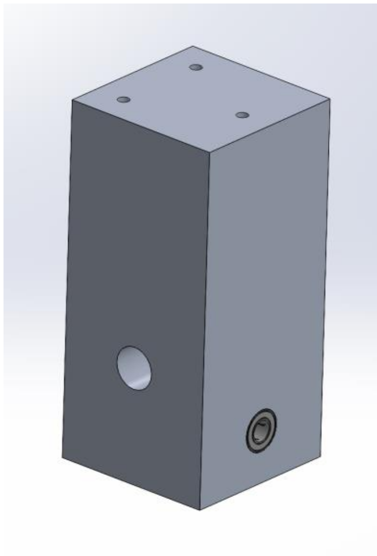
Step 3:

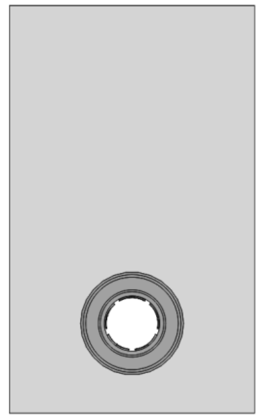
Fasten the pulley mounts to the corner of the base plate using 2 M3 socket head cap screws for each mount. Make sure that the mount with the higher hole location is to the left of the other mount, when looking directly at the corner of the base plate that the hole is being mounted to.



Step 4:

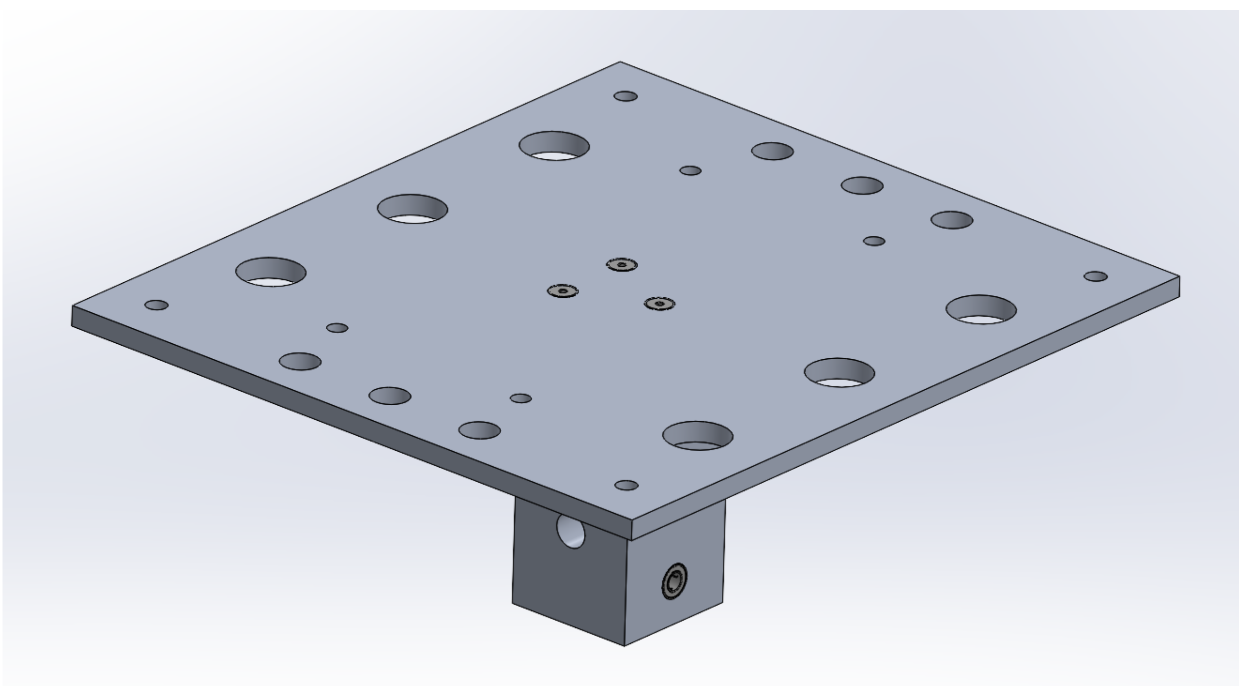
The four rail mounts each need a ball bearing as well as the center block in the control module. Place the 4 mm bore ball bearings into each rail mount and the two holes in the center block using a rubber mallet. The ball bearing should be fully in the lower hole of the rail mounts and the center block.





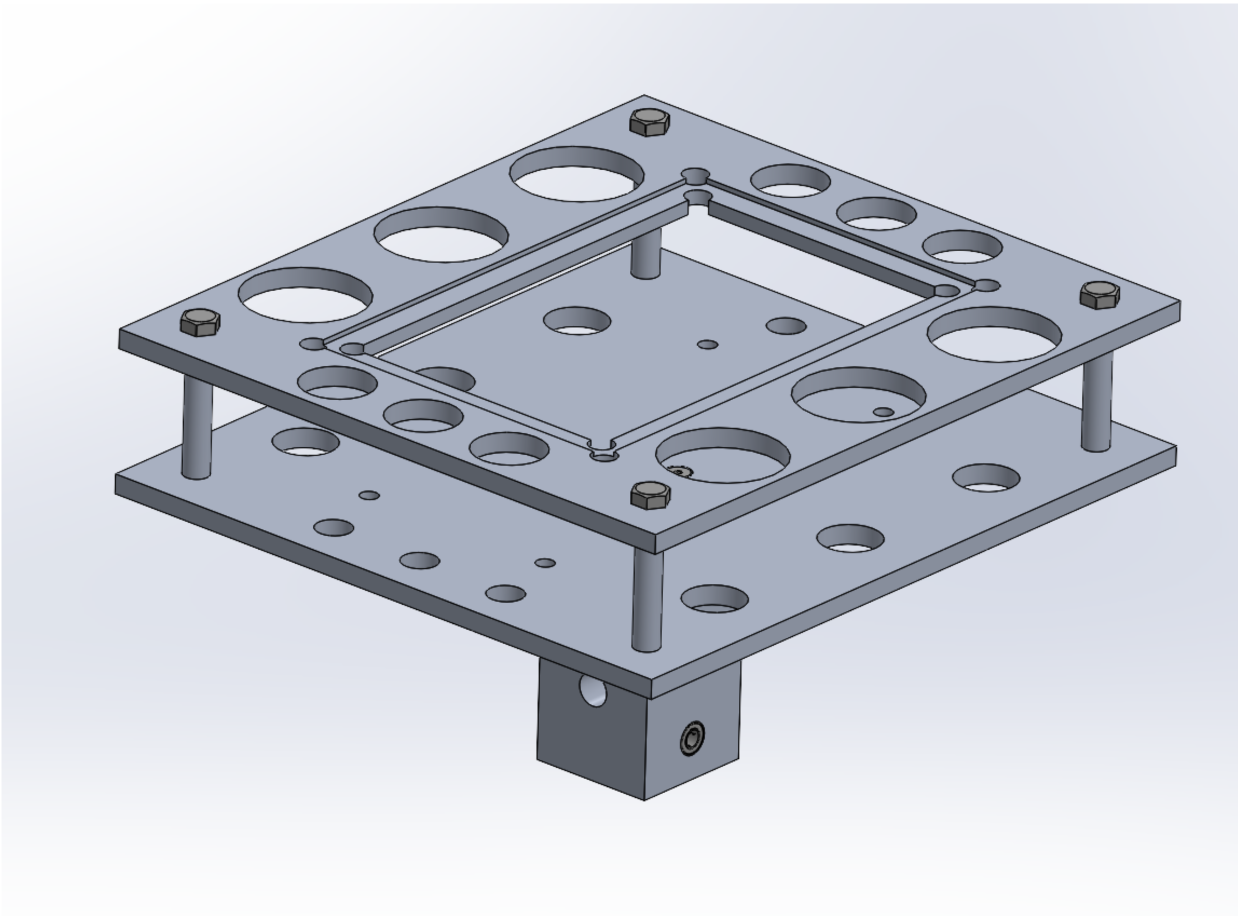
Step 5:

Fasten the bottom plate to the center block of the control module using 3 18-8 stainless steel hex drive flat head screws.



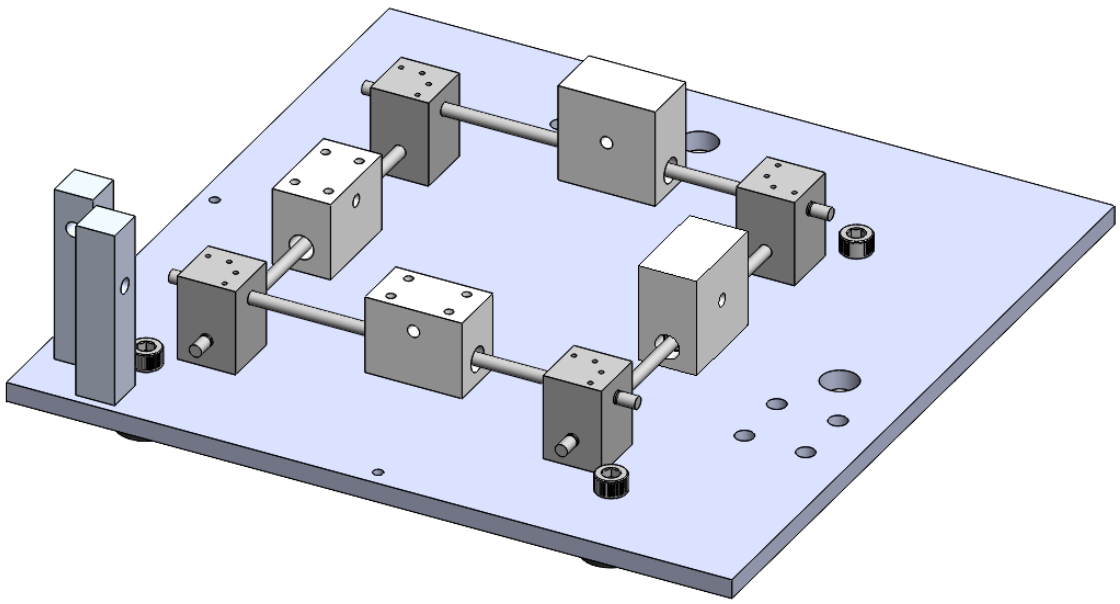
Step 6:

Put the plate spacers in each corner of the bottom plate and put the top plate on top of the plate spacers. Fasten the top plate and the plate spacers to the bottom plate using 4 18-8 stainless steel hex head screws and 4 18-8 stainless steel hex nuts.



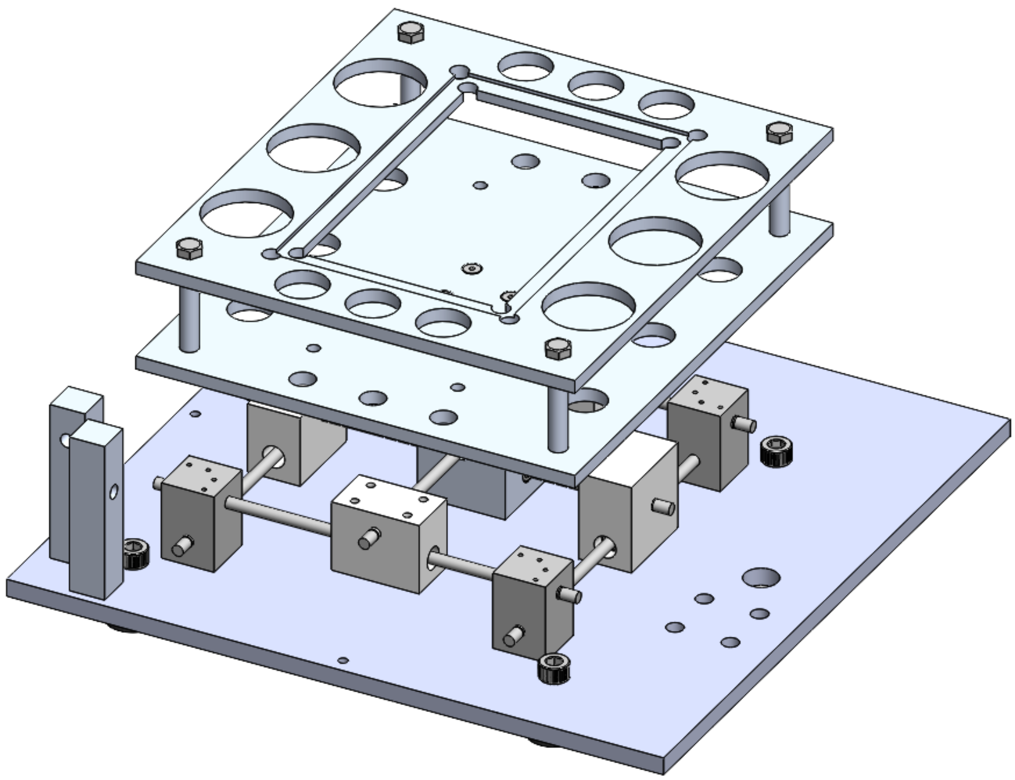
Step 7:

Put a rod through each of the corner mounts and before the rod goes through the opposite corner mount, put it through one of the rail mounts and then put it through the opposite corner mount. Make sure that the two mounts closest to the pulley mounts are the drive rail mounts, while the other two rods have normal rail mounts.



Step 8:

Put a rod through each of the rail mounts and before the rod goes through the opposite rail mount, put it through the center block in the control module and then put it through the opposite rail mount. Make sure that the higher hole in the center block is aligned with the higher rail mounts.

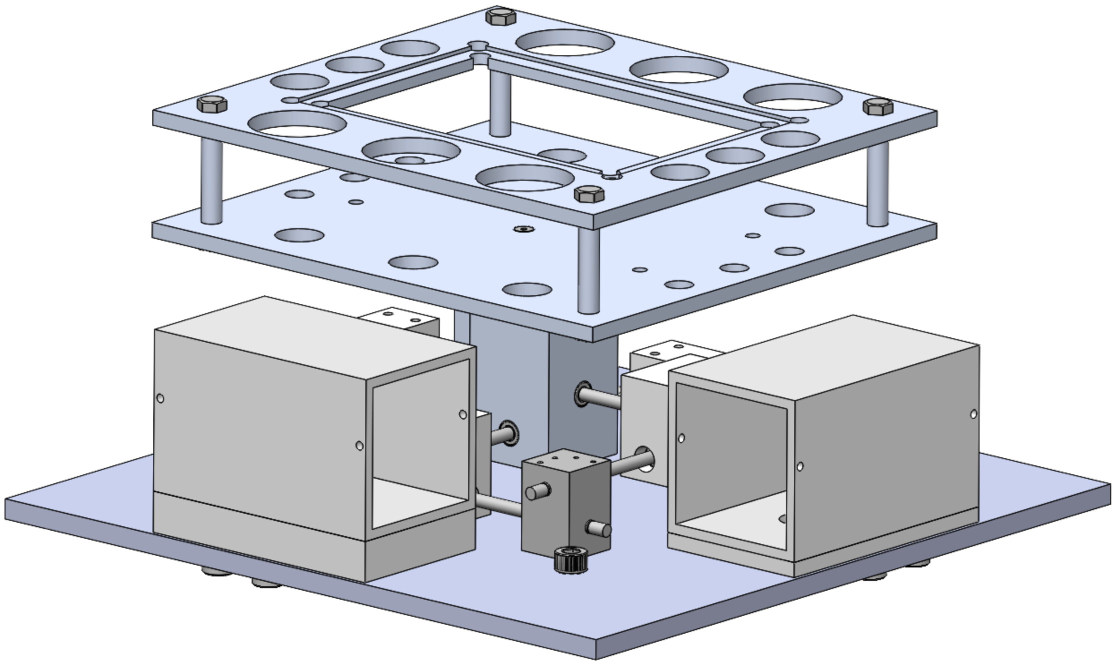


Step 9:

Put snap rings in the grooves on each of the six rods. Make sure that the grooves are outside of the corner mounts and rail mounts.

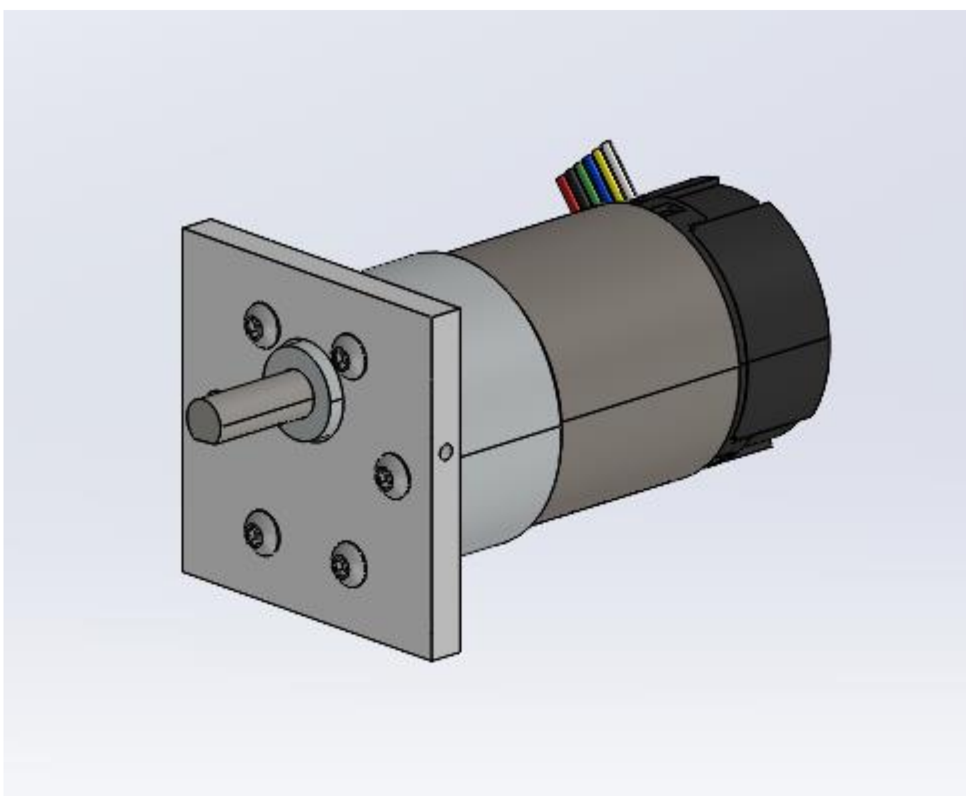
Step 10:

Fasten the 2 motor mount spacers and motor mounts to the base plate using 4 18-8 stainless steel socket head screws for each spacer and mount. Make sure that the motor mount spacer is placed under the motor mount before fastening. Make sure that the short motor mount spacer is on the side of the base plate closest to the higher up rail mount. Make sure that the motor mounts and motor mount spacers are aligned so that the holes are closer to the edge of the base plate.



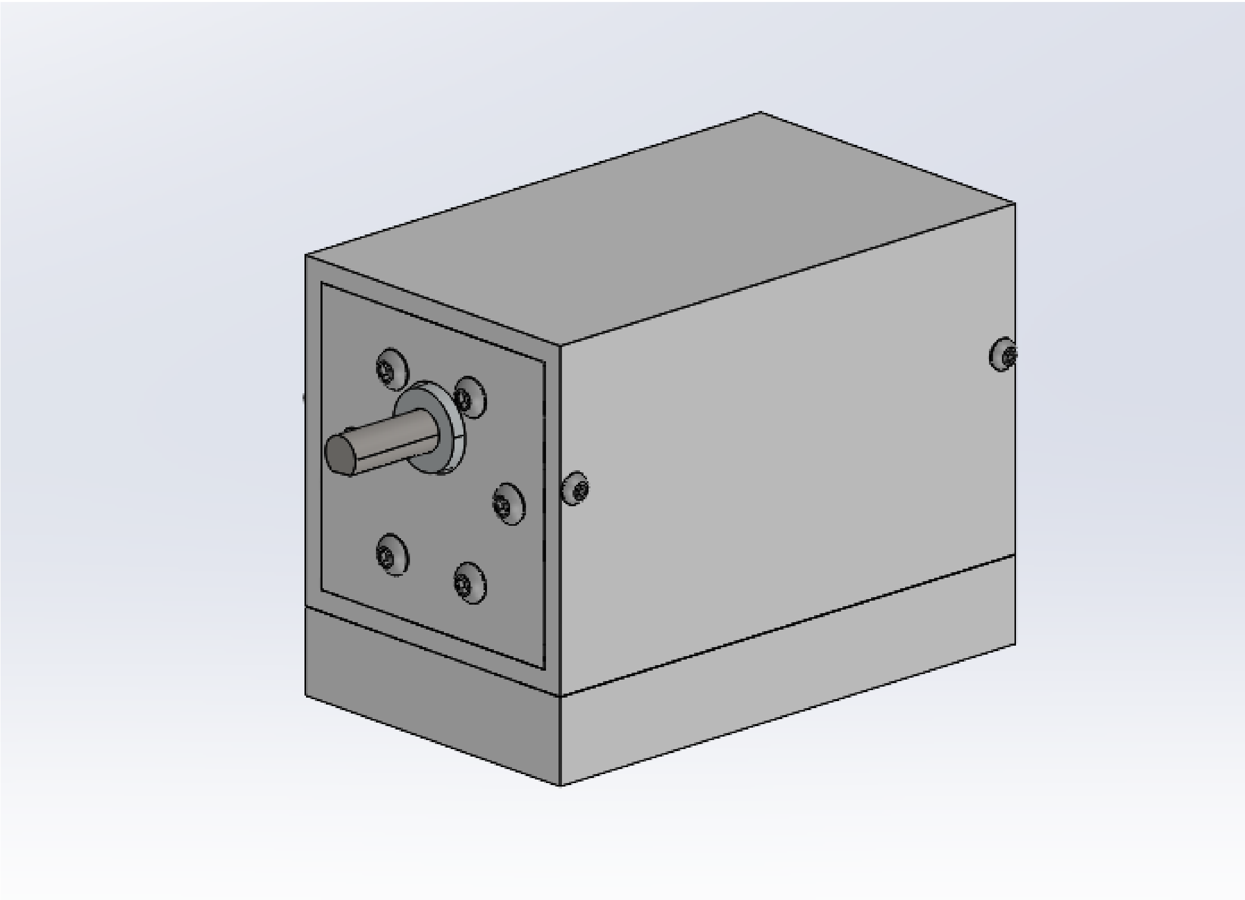
Step 11:

Fasten both front motor doors to the motors using 6 button head hex drive screws for each door.



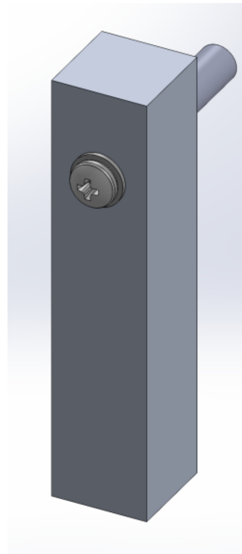
Step 12:

Fasten both front and back motor doors to the motor mounts using 2 button head hex drive screws for each door.



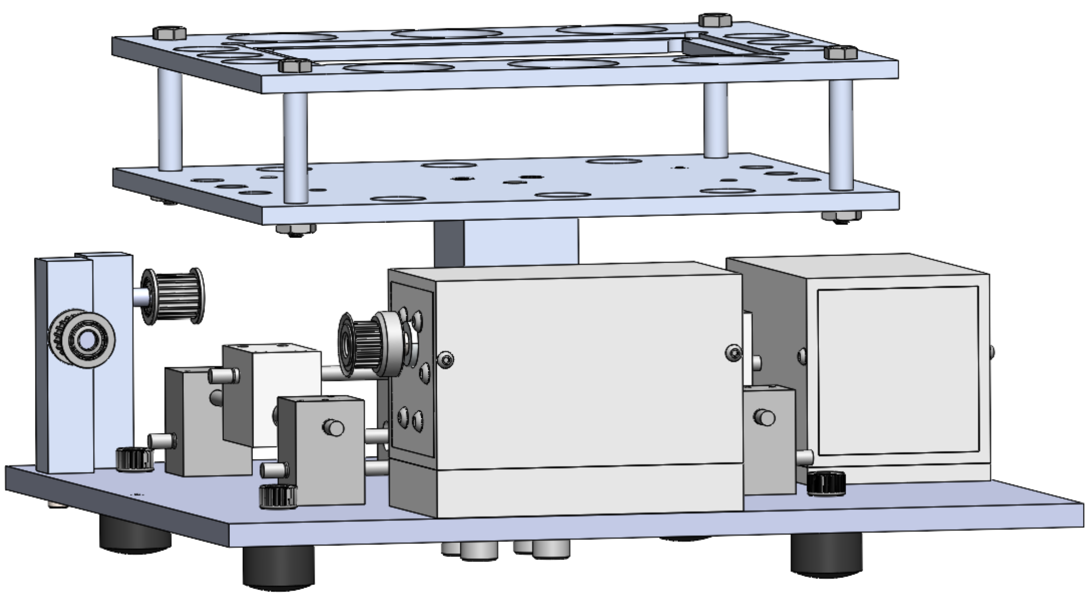
Step 13:

Insert the pulley rods into the pulley mounts and fasten them using a stainless steel pan head Phillips screw and an aluminum washer. Make sure that the fasteners are on the sides of the pulley mounts closest to the edge of the base plate.



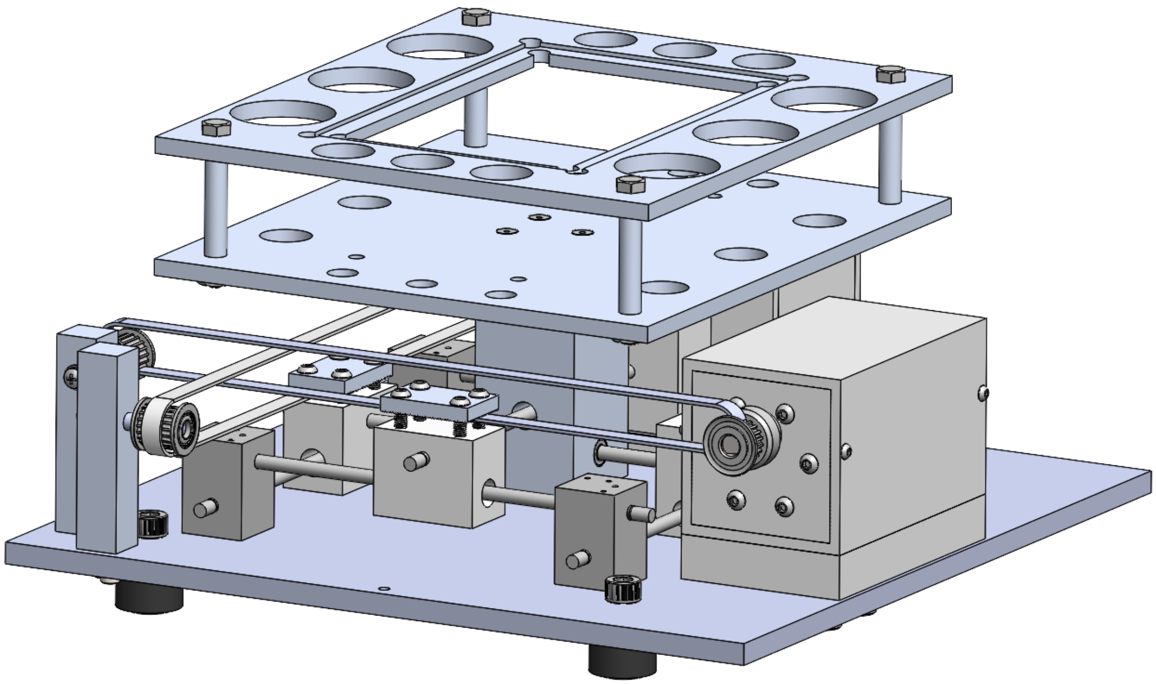
Step 14:

Fasten the pulleys to the pulley rods and the motor shafts using set screws. Make sure that the larger pulleys with a 6 mm bore are fastened to the motor shafts while the smaller pulleys with a 5 mm bore are fastened to the pulley rods.



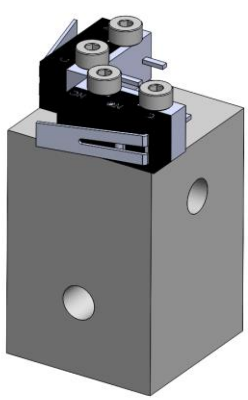
Step 15:

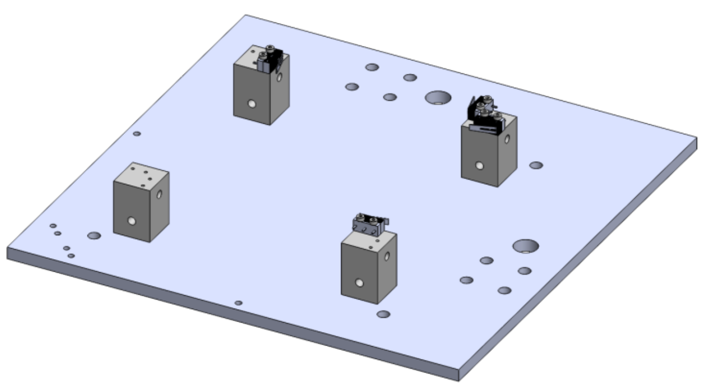
Wrap a belt from each motor shaft to the parallel pulley mount. The belts should intertwine with each other. Make sure that the open ends of the belt cross on the drive rail mount. Fasten the open ends of the belt to the drive rail mount using a timing belt clamp and 4 button head hex drive screws on each drive rail mount. The excess belt can now be cut off with scissors.



Step 16:

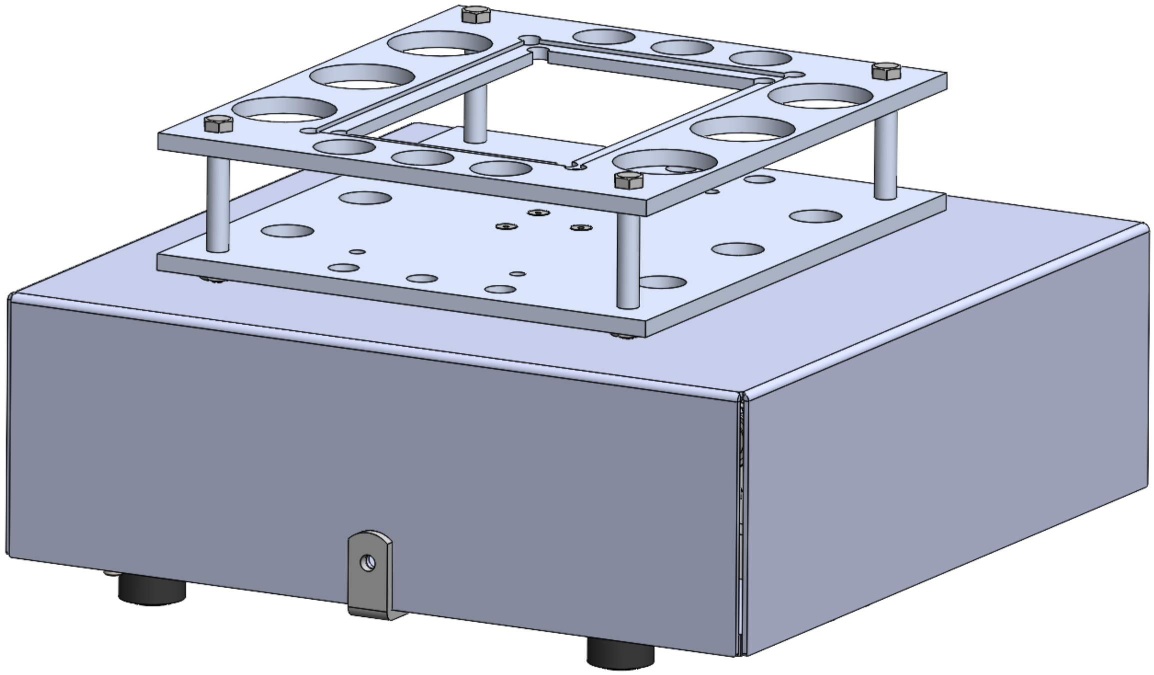
Fasten the four limit switches to the corner mounts using 2 M2 screws on for each limit switch. Make sure that there are 2 limit switches on the corner mount furthest from the pulley mounts. Make sure there is 1 limit switch on the 2 corner mounts parallel to this corner mount and make sure that they're facing away from the drive rail mounts.





Step 17:

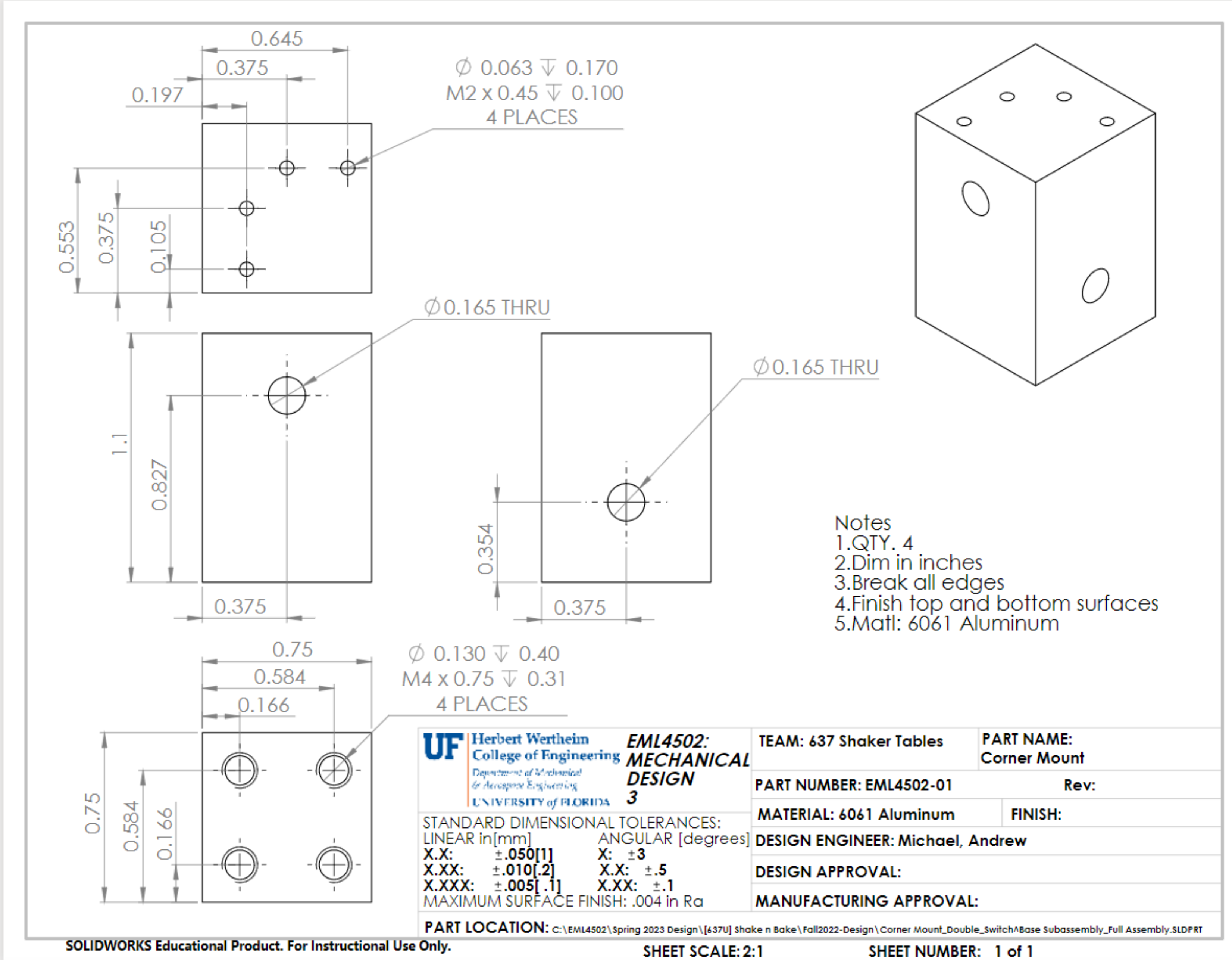
Fasten the shaker plate case to the shaker plate using 2 corner brackets and 2 M4 screws and nuts for each bracket. To fasten this case the screws should be put through the base plate and case before the case is put on the shaker table to make fastening easier.

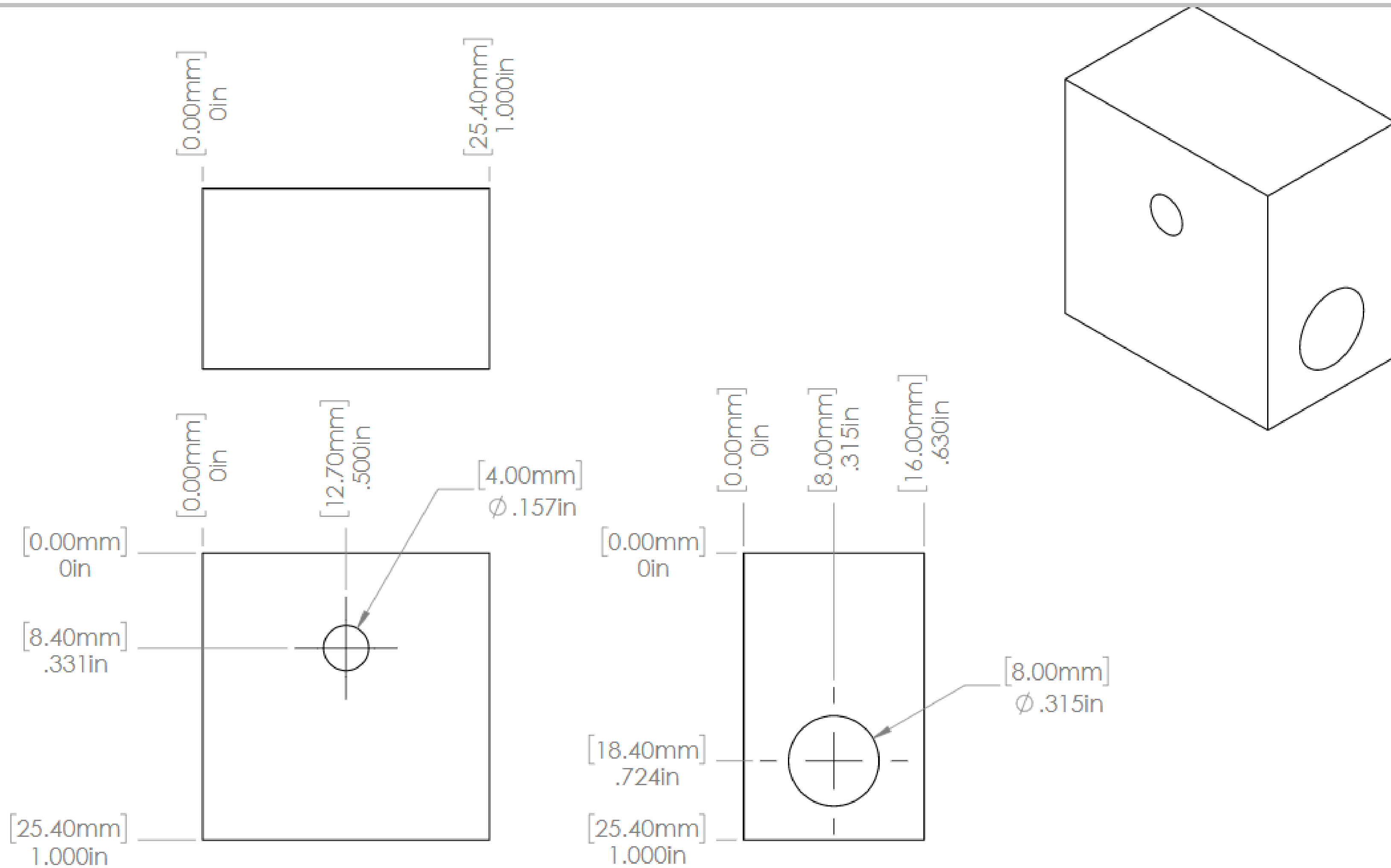


X. Manual Handling and Insertion Time

Step #	Handling/Insertion	Code	Time (s)	Description of operation
1	Handling	(3,0)	1.69	Grab 4 rubber feet
2	Handling	(3,0)	1.69	Grab M6 cap screws
3	Handling	(0,0)	1.13	Grab the base plate
4	Insertion	(0,0)	1.5	Insert screw through base plate and rubber foot
5	Insertion	(0,2)	2.5	Screw in M6 cap screw for each rubber foot
6	Handling	(3,0)	1.69	Grab 8 M4 cap screws
7	Handling	(0,0)	1.13	Grab the 4 corner mounts
8	Handling	(0,0)	1.13	Place the corner mounts over their designated holes on the base plate
9	Insertion	(0,2)	2.5	Screw in the M4 cap screws for each corener mount (2 per corner mount)
10	Handling	(0,0)	1.13	Grab the 2 pulley mounts
11	Handling	(3,0)	1.69	Grab the 4 M3 socket head cap screws
12	Handling	(0,1)	1.5	Place the pulley mounts in the correct orientation on the base plate
13	Insertion	(0,2)	2.5	Screw in the pulley mounts using the M3 screws (2 per pulley mount)
14	Handling	(0,0)	1.13	Grab all the rail mounts
15	Handling	(0,0)	1.13	Grab the 4 mm ball bearings
16	Handling	(0,0)	1.13	Grab a mallet
17	Insertion	(1,1)	5	Press the ball bearings into the rail mounts using a mallet
18	Handling	(0,0)	1.13	Grab the center block
19	Insertion	(1,1)	5	Press the ball bearing into the holes on the bottom of the center block
20	Handling	(3,0)	1.69	Grab 3 18-8 Stainless steel Hex drive flat head screws
21	Handling	(0,0)	1.13	Grab the bottom plate
22	Insertion	(0,2)	2.5	Screw the bottom plate on top of the center block
23	Handling	(3,0)	1.69	Grab 4 of the plate spacers
24	Handling	(0,0)	1.13	Place the plate spacer on the 4 corners of the bottom plate
25	Handling	(0,0)	1.13	Grab the top plate
26	Handling	(3,0)	1.69	Grab 4 18-8 staineless steel hex head screws
27	Insertion	(0,2)	2.5	Screw the bottom plate , plate placers and top plate together
28	Handling	(0,0)	1.13	Grab the guide rails
29	Handling	(1,0)	1.5	Place the rail mounts in between the corner mounts on the base plate
30	Insertion	(0,6)	5.5	Place the guide rails through each of the 4 corner mounts while also going throught the rail mounts.
31	Handling	(0,0)	1.13	Grab additional guide rods
32	Handling	(0,0)	1.13	Grab the drive rail mounts
33	Handling	(1,0)	1.5	Place the center block in the center of the base plate
34	Insertion	(0,6)	5.5	Place the guide rodes through the rail mount, drive rail mount and center block
35	Handling	(2,0)	1.88	Grab snap rings
36	Insertion	(0,9)	7.5	Place the snap rings on the ends of all guide rods
37	Handling	(3,0)	1.69	Grab 4 18-8 stianless steel socket head screws
38	Handling	(1,0)	1.5	Grab the motor spacers
39	Insertion	(0,2)	2.5	Screw the motor spacers to the base plate with the 18-8 screws
40	Handling	(1,0)	1.5	Grab the motor mounts
41	Handling	(1,0)	1.5	Grab the front motor doors
42	Handling	(3,0)	1.69	Grab 6 button head hex drive screws
43	Insertion	(0,2)	2.5	Screw the front motor doors to the motor mounts
44	Handling	(3,0)	1.69	Grab 18-8 stianless steel socket head screws
45	Handling	(1,0)	1.5	Place the motor mount on top of the spacers
46	Insertion	(0,2)	2.5	Fasten the motor mount to the spacer
47	Handling	(0,0)	1.13	Grab the motor
48	Insertion	(2,0)	1.88	Place the motors in the motor mounts
49	Handling	(3,0)	1.69	Grab M2 screws
50	Insertion	(0,2)	2.5	Screw the motor into the front door of the motor mount
51	Handling	(0,0)	1.13	Grab the pulley rods
52	Insertion	(0,0)	1.5	Place the pulley rods into the pulley mounts
53	Handling	(3,0)	1.69	Grab stainless steel pan head philips screws and aluminum washers
54	Insertion	(0,2)	2.5	Fasten the pulley rods into the pulley mounts
55	Handling	(2,0)	1.88	Grab the belts
56	Handling	(6,8)	5.25	Wrap the belts around the pulley mount and motor
57	Handling	(0,0)	1.3	Grab the timing belt clamp
58	Insertion	(1,9)	10	Secure the belt with the timing belt clamp
59	Handling	(3,0)	1.69	Grab M2 screws
60	Handling	(1,2)	2.25	Grab limit switches
61	Insertion	(1,1)	5	Fasten the limit switches with the M2 screws to the corner mounts
62	Handling	(1,0)	1.5	Grab the shaker plate case
63	Handling	(1,0)	1.5	Grab the corner brackets
64	Handling	(3,0)	1.69	Grab M4 screws and nuts
65	Insertion	(0,2)	2.5	Fasten the shaker plate case to the base plate
	Total		**143.68**	

XI. Part Drawings





1. DEBURR ALL SHARP EDGES

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	***EML4502: MECHANICAL DESIGN 3***	**TEAM: 637 Shaker Table**	**PART NAME: Rail Mount Tall**
STANDARD DIMENSIONAL TOLERANCES:		**PART NUMBER: EML4502-02**	**Rev:**
LINEAR in[mm]	ANGULAR [degrees]	**MATERIAL: Aluminum 6061**	**FINISH: As machined**
X.X: ±.050[1]	**X: ±3**	**DESIGN ENGINEER: Adam Paroff**	
X.XX: ±.010[.2]	**X.X: ±.5**	**DESIGN APPROVAL:**	
X.XXX: ±.005[.1]	**X.XX: ±.1**	**MANUFACTURING APPROVAL:**	
MAXIMUM SURFACE FINISH: .004 in Ra			

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\Copy of Rail Mount Tall^Copy of Tall Collar Assembly_Base Subassembly_Full Ass

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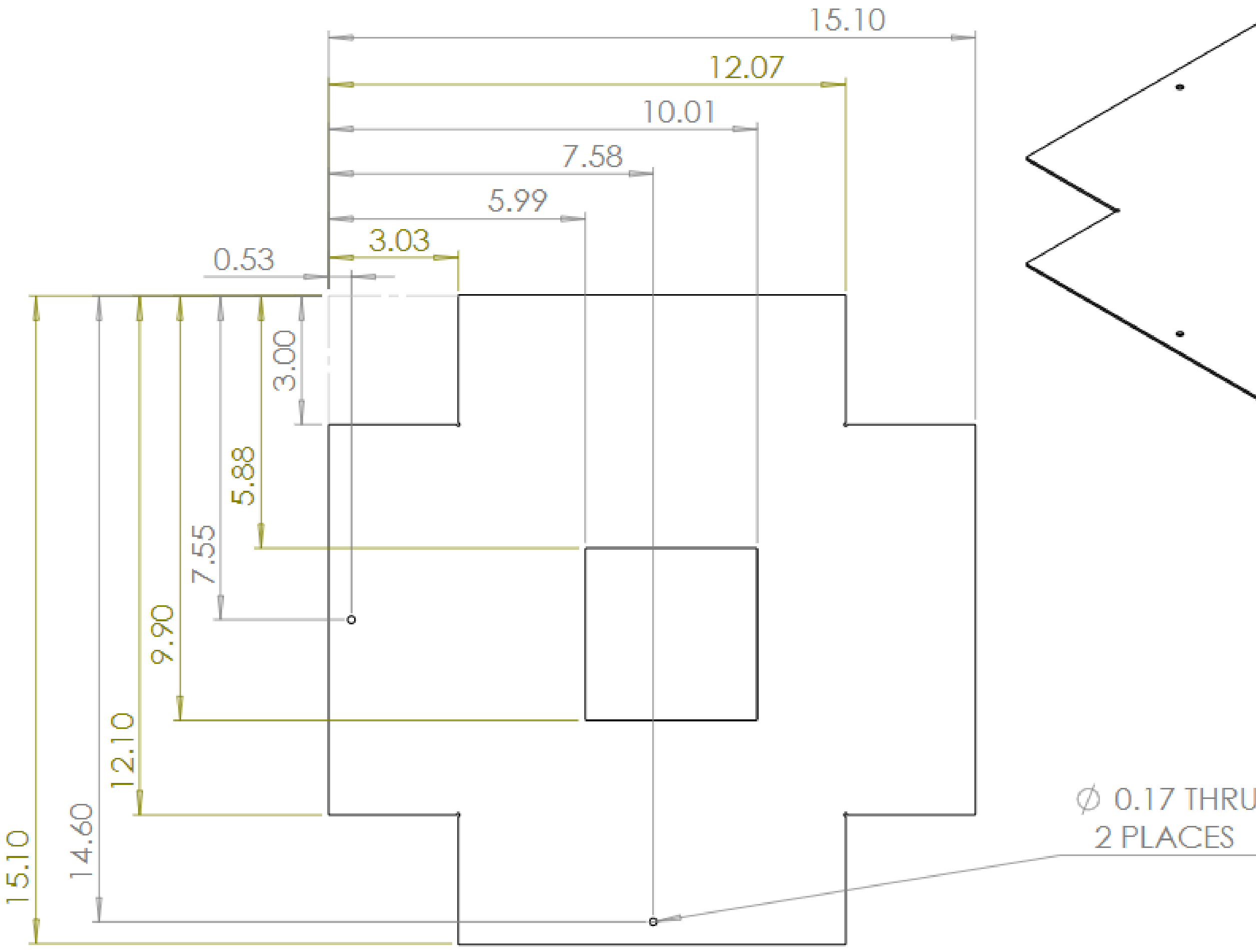
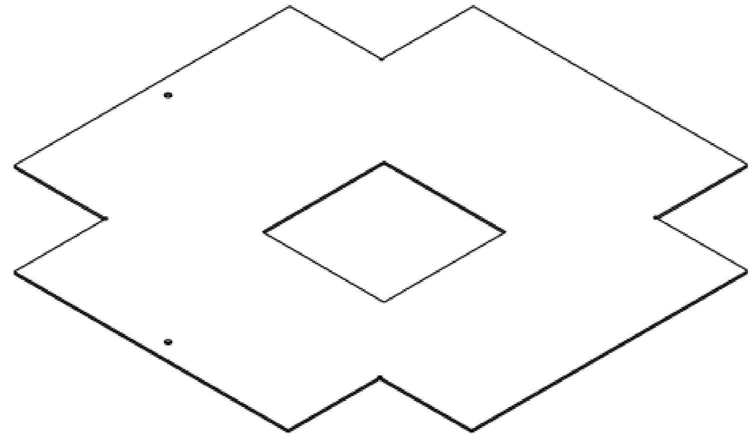
SHEET SCALE: 2:1 **SHEET NUMBER: 1 of 1**





Notes:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: 18-GAUGE PLAIN ALUMINUM SHEET METAL
5. FINISH: AS MACHINED
6. ALL CORNERS FILLETED AT .03 IN

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Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: ShakerPlateCaseNewFlat

PART NUMBER: EML4502-03

Rev:

MATERIAL: Aluminum Sheet Metal

FINISH: As machined

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

DESIGN ENGINEER: Paroff,Adam

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\ShakerPlateCaseNewFlat.SLDPRT

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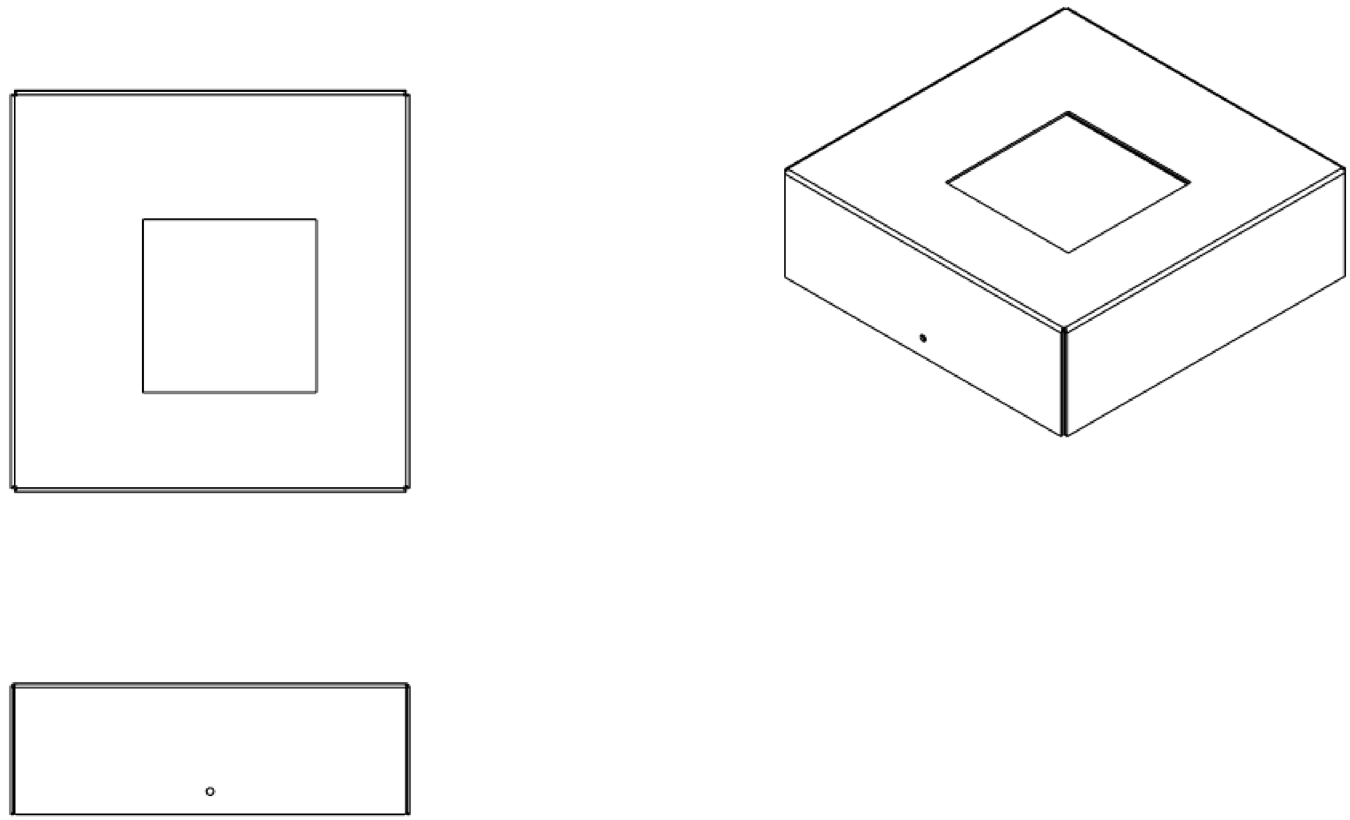
SHEET SCALE: 1:4

SHEET NUMBER: 1 of 2



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Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: ShakerPlateCaseNewFlat

PART NUMBER: EML4502-03

Rev:

MATERIAL: Aluminum Sheet Metal

FINISH: As machined

DESIGN ENGINEER: Paroff,Adam

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

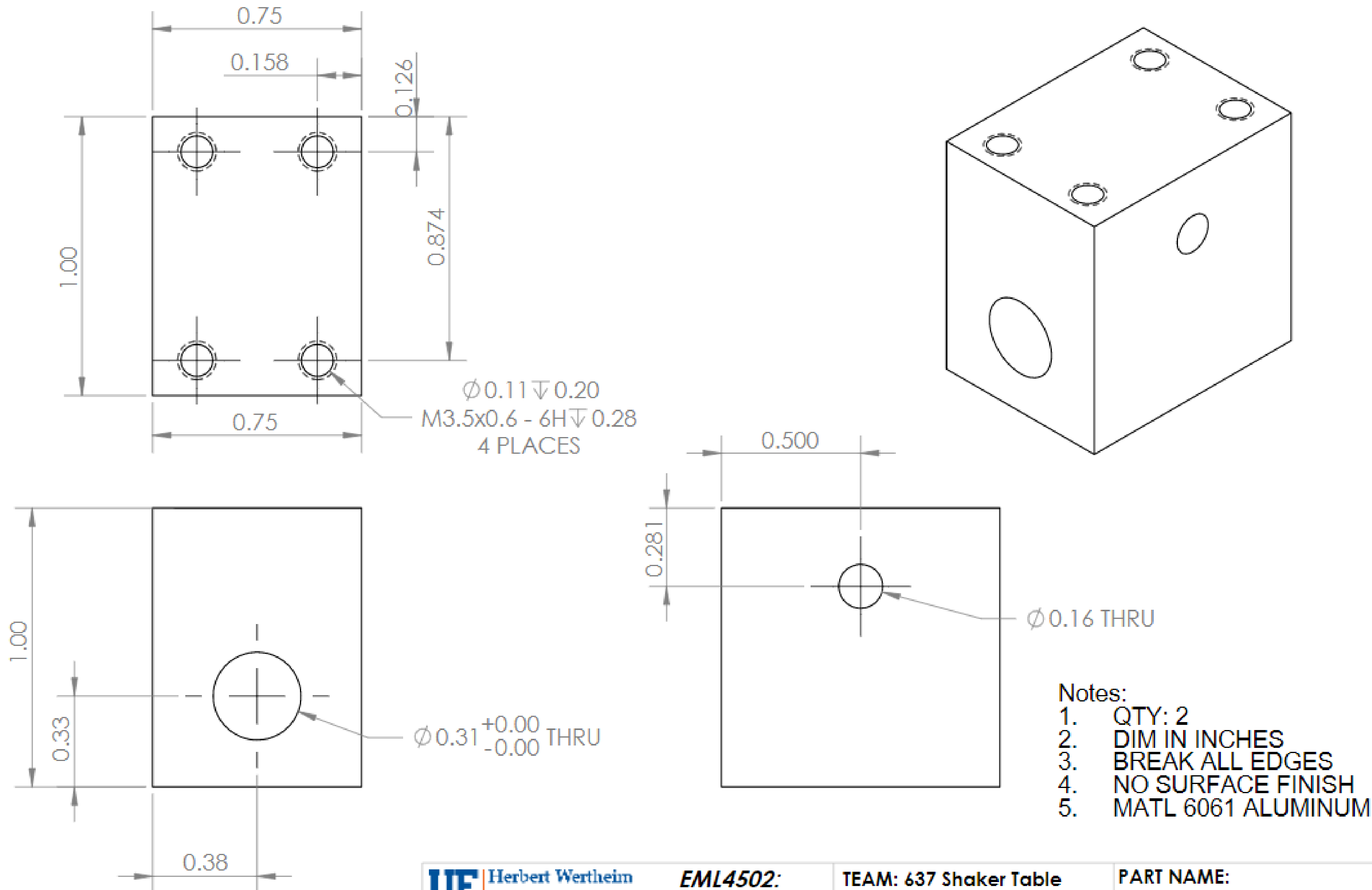
LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\ShakerPlateCaseNewFlat.SLDPRT

SOLIDWORKS Educational Product. For Instructional Use Only.

SHEET SCALE: 1:4



Notes:
1. QTY: 2
2. DIM IN INCHES
3. BREAK ALL EDGES
4. NO SURFACE FINISH
5. MATL 6061 ALUMINUM

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UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Table

PART NAME: Drive Rail Mount Short New

PART NUMBER: EMl4502-04 | Rev:

MATERIAL: 6061 Aluminum | FINISH: No surface finish

DESIGN ENGINEER: Kaio Bui

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\Drive Rail Mount Short New.SLDPRT

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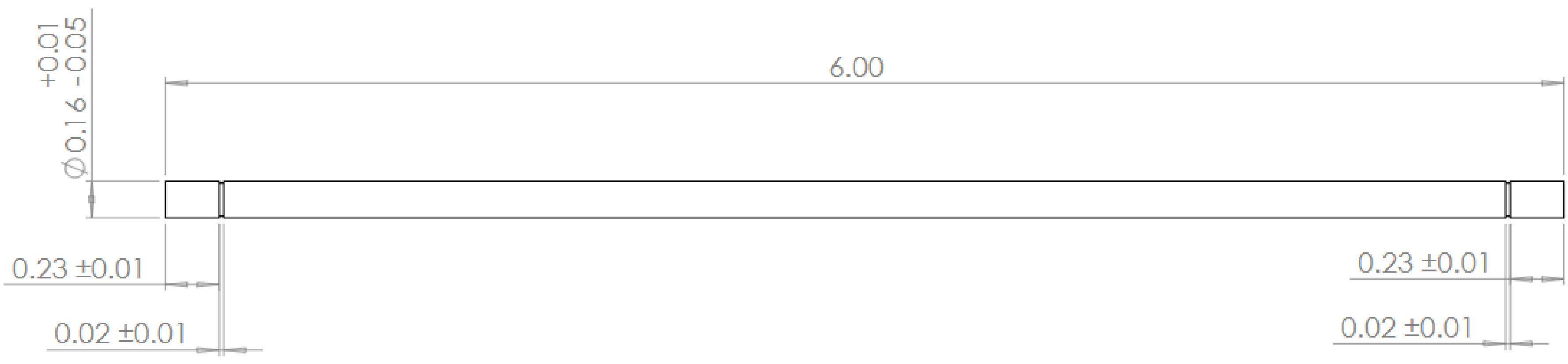
SHEET SCALE: 2:1 SHEET NUMBER: 1 of 1



Notes:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 6
4. FINISH: AS MACHINED

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UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: Guide Rod

PART NUMBER: EML4502-05 **Rev:**

MATERIAL: 304 Stainless Steel **FINISH:**

DESIGN ENGINEER: Paroff,Adam

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\1272T13_Multipurpose 304 Stainless Steel Rod (1).SLDPRT

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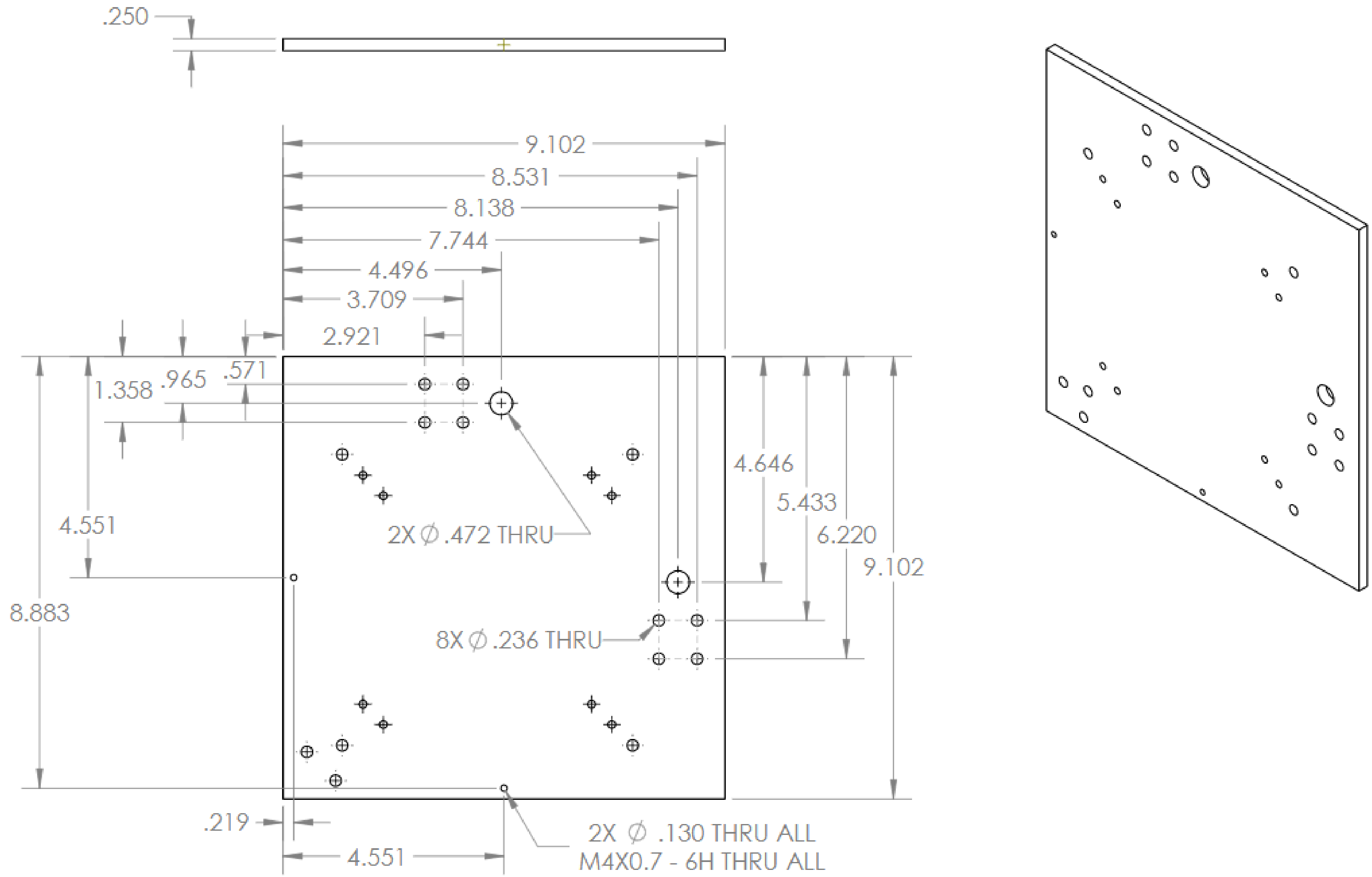
SHEET SCALE: 1:4 **SHEET NUMBER:** 1 of 1



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: Base Plate

PART NUMBER: EML4502-06

Rev:

MATERIAL: Aluminum 6061

FINISH: As machined

DESIGN ENGINEER: Christopher Crouch

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	**±.050[1]**	**X:**	**±3**
X.XX:	**±.010[.2]**	**X.X:**	**±.5**
X.XXX:	**±.005[.1]**	**X.XX:**	**±.1**

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\BasePlateRedone.SLDPRT

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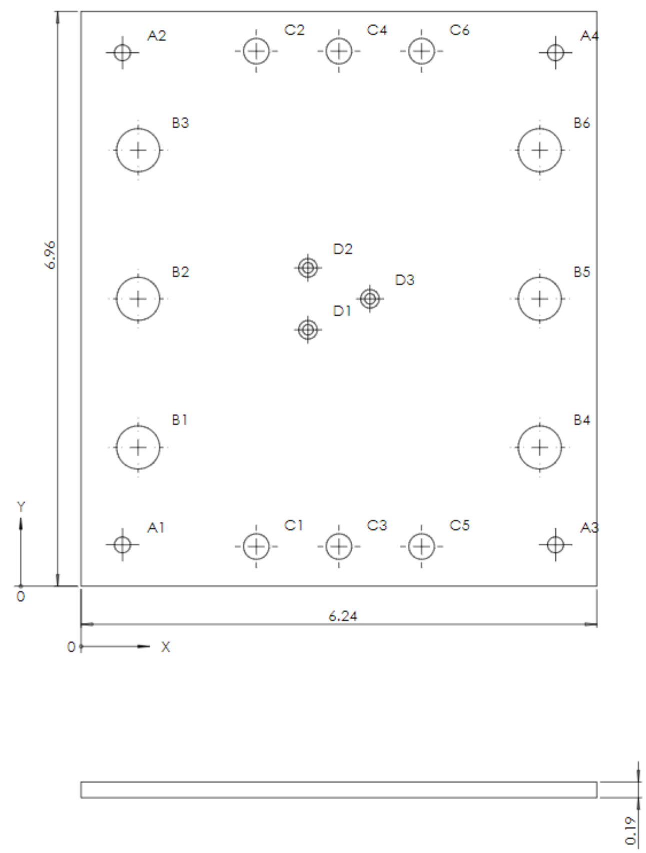
SHEET SCALE: 1:3

SHEET NUMBER: 1 of 2



TAG	X LOC	Y LOC	SIZE
A1	0.50	0.50	Ø 0.19 THRU ALL
A2	0.50	6.46	Ø 0.19 THRU ALL
A3	5.74	0.50	Ø 0.19 THRU ALL
A4	5.74	6.46	Ø 0.19 THRU ALL
B1	0.69	1.68	Ø0.52 THRU
B2	0.69	3.48	Ø0.52 THRU
B3	0.69	5.28	Ø0.52 THRU
B4	5.55	1.68	Ø0.52 THRU
B5	5.55	3.48	Ø0.52 THRU
B6	5.55	5.28	Ø0.52 THRU
C1	2.12	0.48	Ø0.31 THRU
C2	2.12	6.48	Ø0.31 THRU
C3	3.12	0.48	Ø0.31 THRU
C4	3.12	6.48	Ø0.31 THRU
C5	4.12	0.48	Ø0.31 THRU
C6	4.12	6.48	Ø0.31 THRU
D1	2.75	3.11	Ø 0.13 THRU ALL ⌵ Ø 0.23 X 100°
D2	2.75	3.86	Ø 0.13 THRU ALL ⌵ Ø 0.23 X 100°
D3	3.50	3.48	Ø 0.13 THRU ALL ⌵ Ø 0.23 X 100°

Notes:

1. All dims in inches
2. Debur all edges
3. Material: 3/16" Aluminum plate

Sample Interfac
Bottom Plate

Group
#: 637U

SampleInterface Bottom Plate

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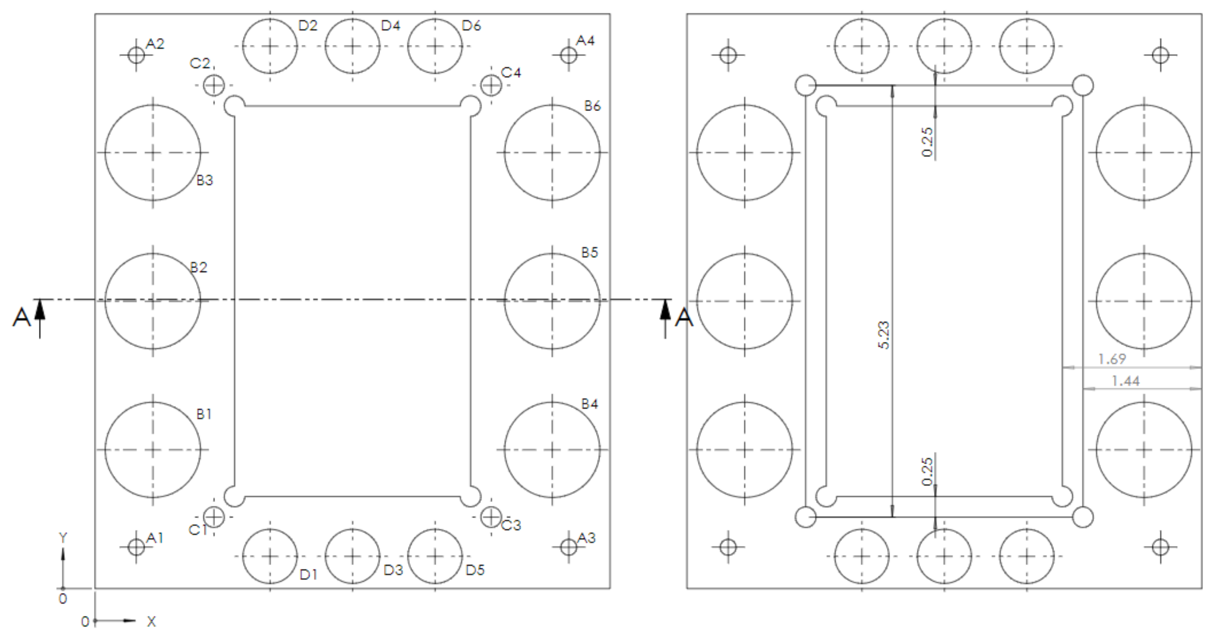
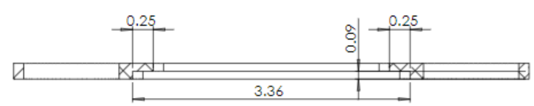
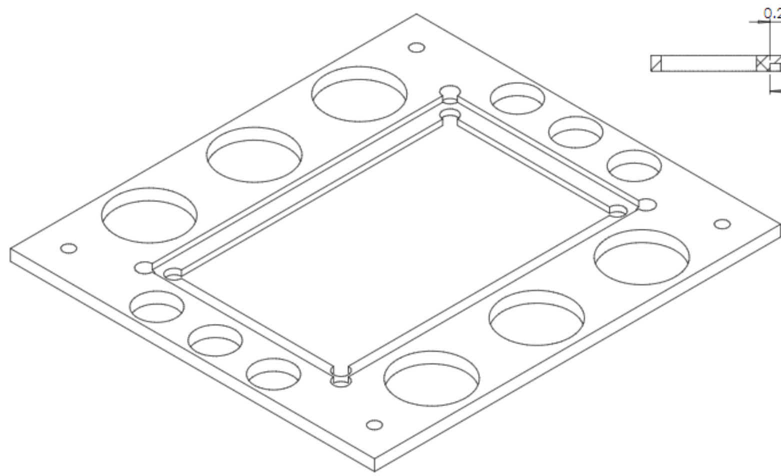
TAG	X LOC	Y LOC	SIZE
A1	0.50	0.50	∅ 0.19 THRU ALL
A2	0.50	6.46	∅ 0.19 THRU ALL
A3	5.74	0.50	∅ 0.19 THRU ALL
A4	5.74	6.46	∅ 0.19 THRU ALL
B1	0.70	1.68	∅1.16 THRU
B2	0.70	3.48	∅1.16 THRU
B3	0.70	5.28	∅1.16 THRU
B4	5.54	1.68	∅1.16 THRU
B5	5.54	3.48	∅1.16 THRU
B6	5.54	5.28	∅1.16 THRU
C1	1.44	0.87	∅ 0.25 THRU ALL
C2	1.44	6.10	∅ 0.25 THRU ALL
C3	4.80	0.87	∅ 0.25 THRU ALL
C4	4.80	6.10	∅ 0.25 THRU ALL
D1	2.12	0.39	∅0.66 THRU
D2	2.12	6.57	∅0.66 THRU
D3	3.12	0.39	∅0.66 THRU
D4	3.12	6.57	∅0.66 THRU
D5	4.12	0.39	∅0.66 THRU
D6	4.12	6.57	∅0.66 THRU





SECTION A-A



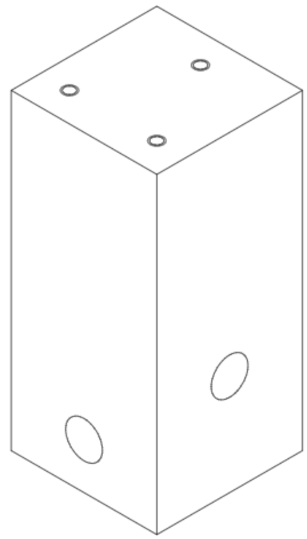
Notes:
1. All dims in inches
2. Debur all edges
3. Material: 3/16" Aluminum plate

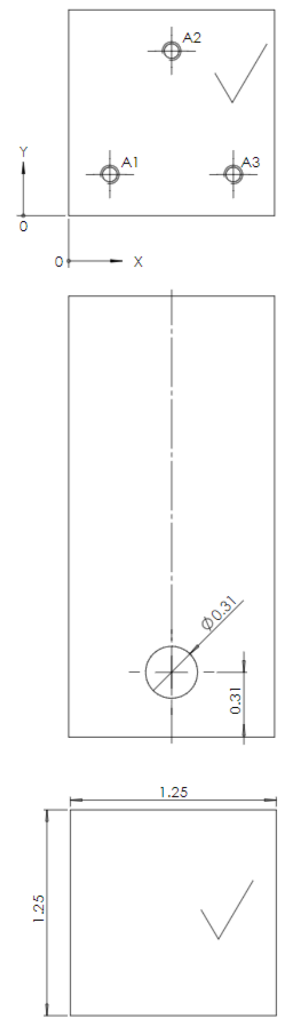
TITLE: Sample Interface Top Plate

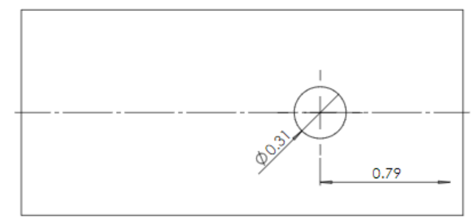
DWG NO. Sample Interface Top Plate

SOLIDWORKS Educational Product. For Instructional Use Only.

TAG	X LOC	Y LOC	SIZE
A1	0.25	0.25	∅ 0.09 ↧ 0.30 4-40 UNC ↧ 0.22
A2	0.63	1.00	∅ 0.09 ↧ 0.30 4-40 UNC ↧ 0.22
A3	1.00	0.25	∅ 0.09 ↧ 0.30 4-40 UNC ↧ 0.22







Notes:
1. All dims in inches
2. Debur all edges
3. Material: 1.25" x 1.25" Aluminum square bar stock
4. Surface finishes noted

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

REVISION

	NAME	SIGNATURE	DATE
DRAWN			
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE: Center Block

DWG NO. Center Block

SCALE:2:1

SHEET 1 OF 1

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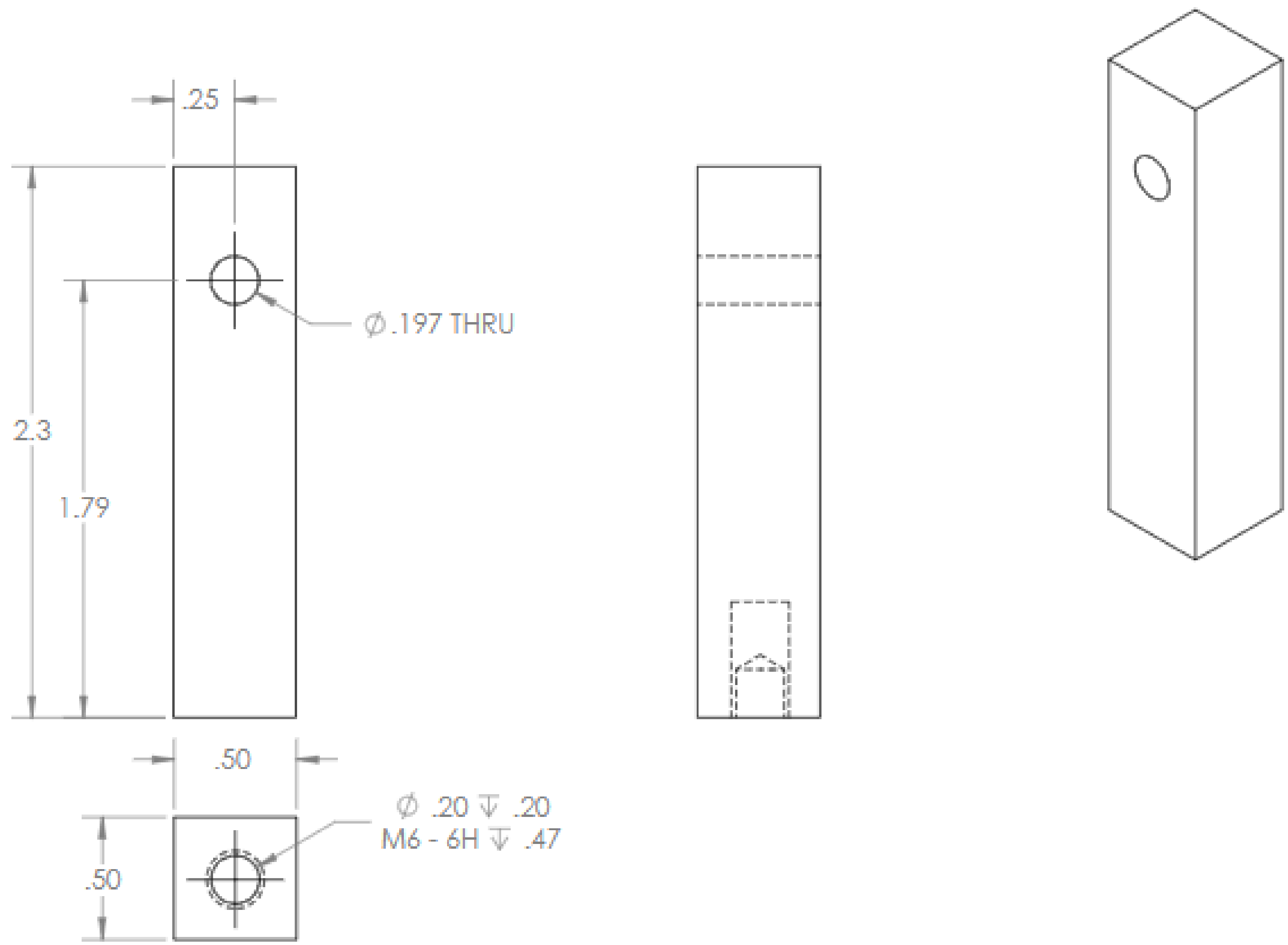
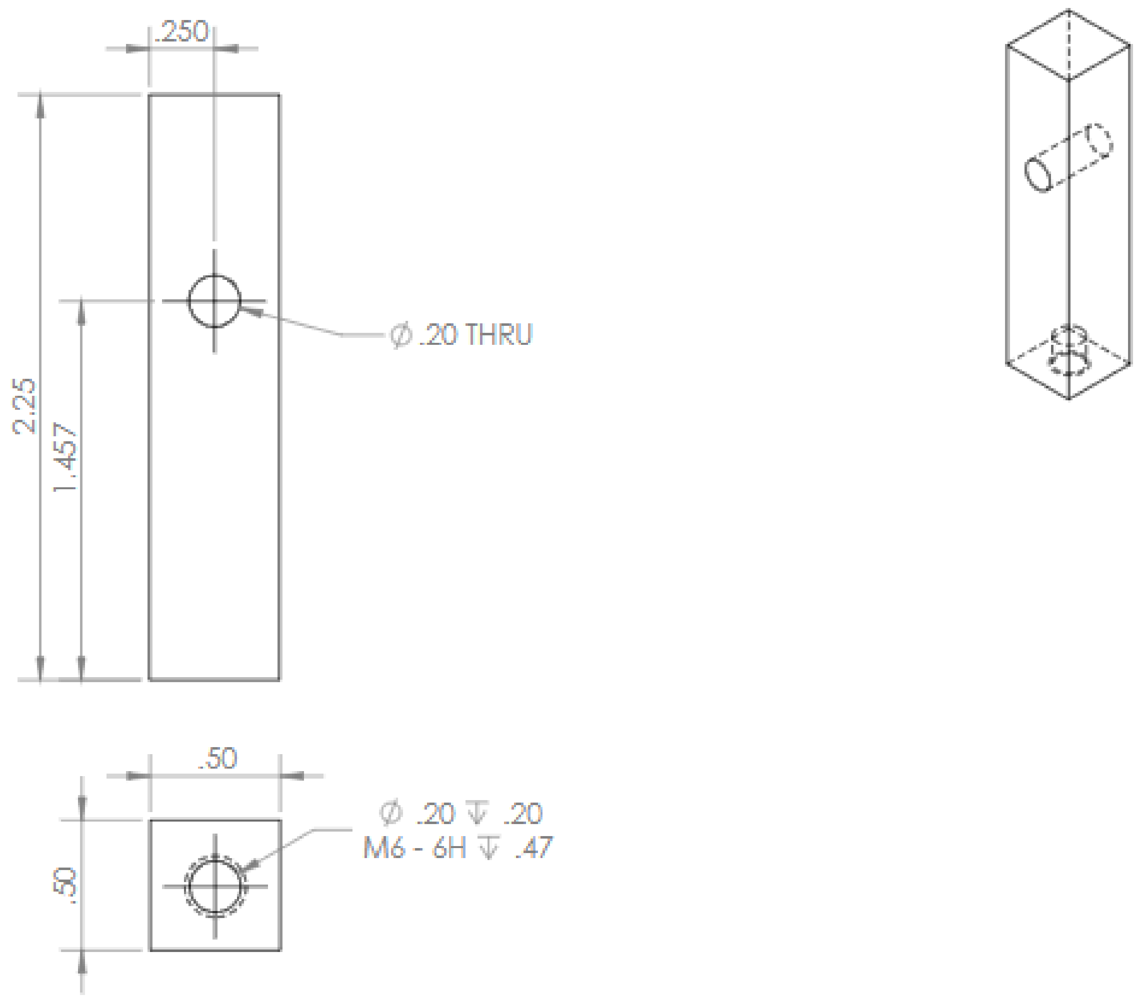


NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

UF Herbert Wertheim College of Engineering Department of Mechanical & Aerospace Engineering UNIVERSITY of FLORIDA	*EML4502: MECHANICAL DESIGN 3*	TEAM: 637 Shaker Tables	PART NAME: Pulley Mount
		PART NUMBER: EML4502-10	Rev:
STANDARD DIMENSIONAL TOLERANCES:		MATERIAL: 6061 Aluminum Aloy	FINISH: As machined
LINEAR in[mm]	ANGULAR [degrees]	DESIGN ENGINEER: Taylor Fisher	
X.X: ±.050[1]	X: ±3		
X.XX: ±.010[.2]	X.X: ±.5	DESIGN APPROVAL:	
X.XXX: ±.005[.1]	X.XX: ±.1		
MAXIMUM SURFACE FINISH: .004 in Ra		MANUFACTURING APPROVAL:	
PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\Pulley Mount.SLDPRT			

SOLIDWORKS Educational Product. For Instructional Use Only.

SHEET SCALE: 1:1 SHEET NUMBER: 1 of 1



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: Pulley Mount Right

PART NUMBER: ENL4502-11

Rev:

MATERIAL: 6061 Aluminum Alloy

FINISH: As machined

DESIGN ENGINEER: Taylor Fisher

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

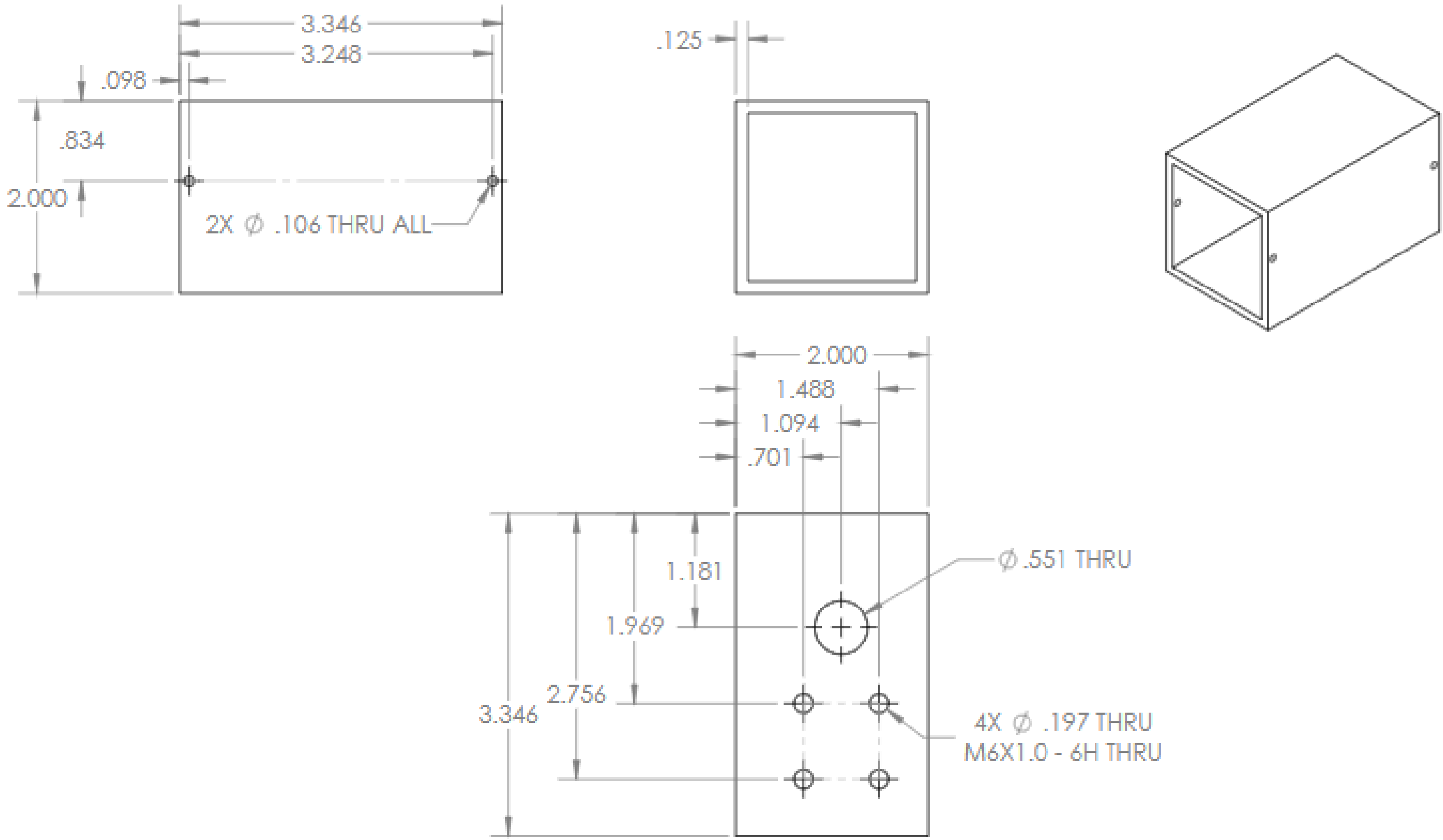
MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\Pulley Mount Right.SLDPRT

SOLIDWORKS Educational Product. For Instructional Use Only.

SHEET SCALE: 1:1

SHEET NUMBER: 1 of 1



NOTES:

1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

Herbert Wertheim College of Engineering
Department of Mechanical & Aerospace Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM: Shaker Table

PART NAME: MotorMount 37D

PART NUMBER: EML4502-12

Rev:

MATERIAL: Aluminum 6061

FINISH: As machined

DESIGN ENGINEER: Christopher Crouch

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\MotorMount_37D.SLDPRT

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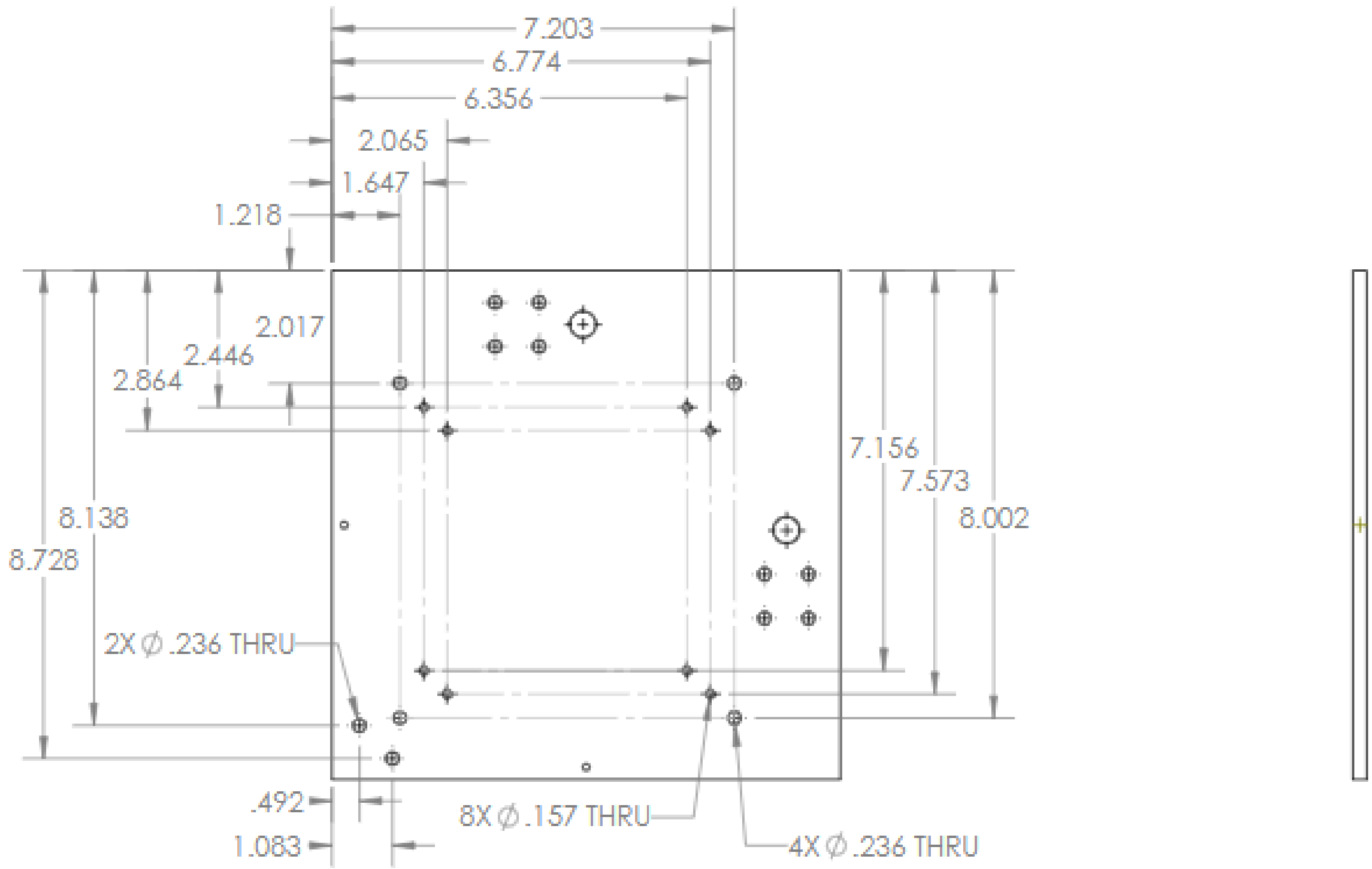
SHEET SCALE: 1:1.5

SHEET NUMBER: 1 of 2



NOTES:

1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

UF Herbert Wertheim College of Engineering
UNIVERSITY of FLORIDA

EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM: Shaker Table

PART NAME: Base Plate

PART NUMBER: EML4502-12

Rev:

MATERIAL: Aluminum 6061

FINISH: As machined

DESIGN ENGINEER: Christopher Crouch

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[6370] Shake n Bake\MotorMount_37D.SLDPRT

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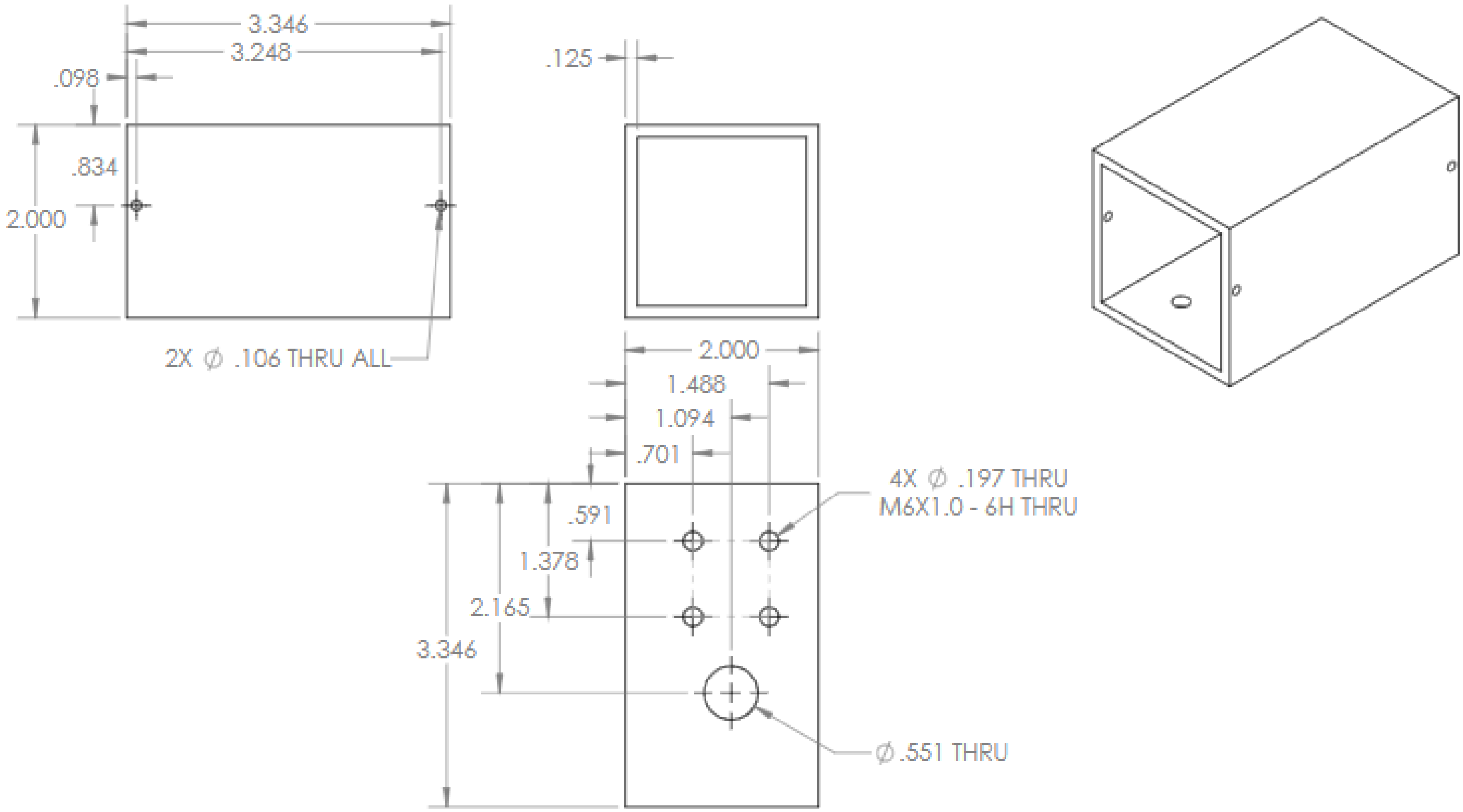
SHEET SCALE: 1:3



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637Shaker Tables	PART NAME: Motor Mount Tall
PART NUMBER: EML4502-23-02-10317	Rev:
MATERIAL: Aluminum 6061	FINISH: As machined
DESIGN ENGINEER: Christopher Crouch	
DESIGN APPROVAL:	
MANUFACTURING APPROVAL:	

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\MotorMount_Tall.SLDPRT

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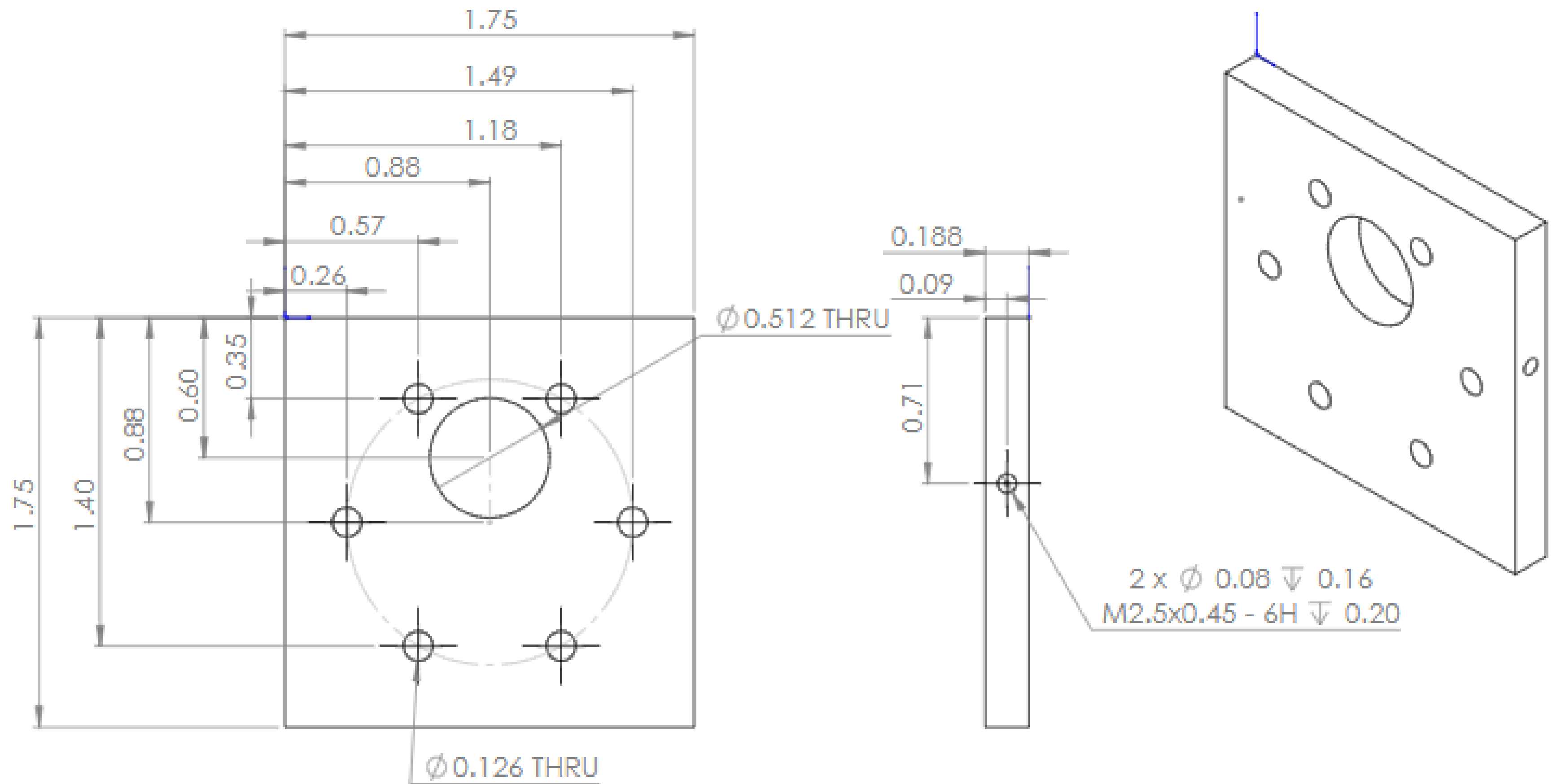
SHEET SCALE: 1:1.5 SHEET NUMBER: 1 of 1



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 2
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: MotorMountDoorShort

PART NUMBER: EML4502-14

Rev:

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

MATERIAL: Choose your Material

FINISH: As machined

DESIGN ENGINEER: Crouch,Christopher R

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\MotorMountDoorShort.SLDPRT

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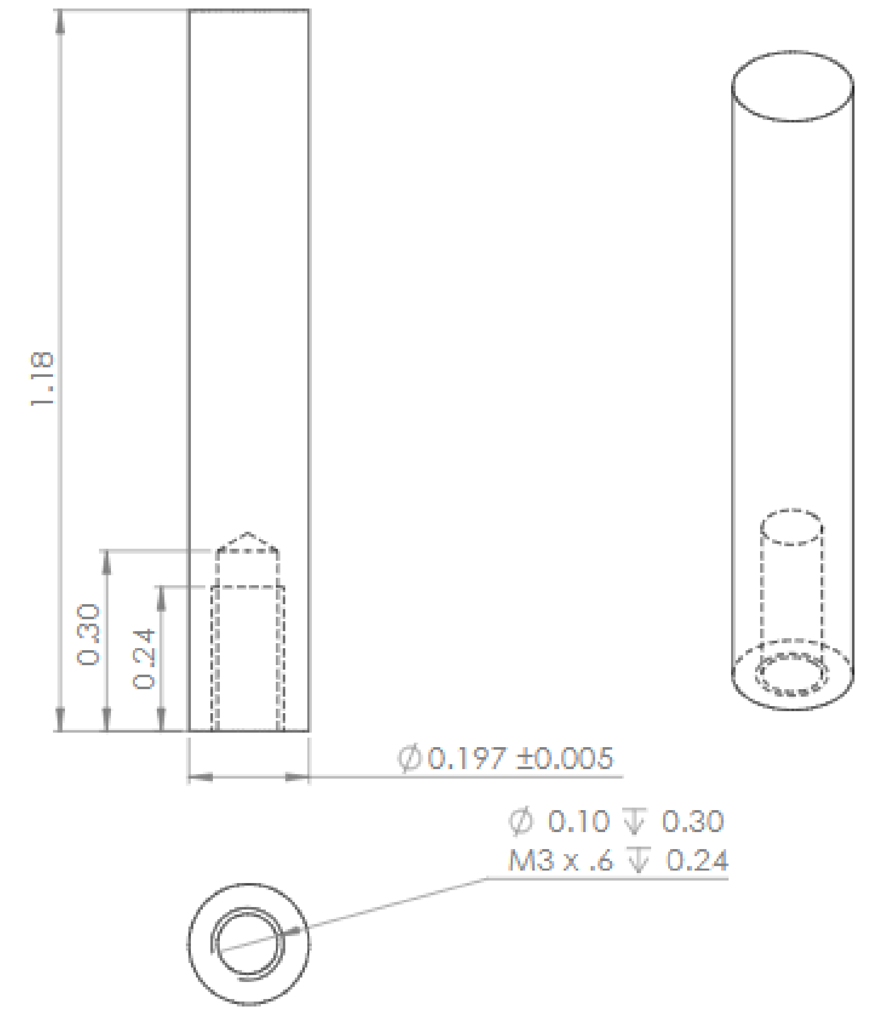
SHEET SCALE: 1.5:1

SHEET NUMBER: 1 of 1



Notes
1.Qty. 2
2.Dim in inches
3.Break all edges
4.Finish top and bottom surfaces
5.Matl: 6061 Aluminum

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EML4502: MECHANICAL DESIGN 3

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

TEAM: 637 Shaker Tables

PART NAME: Pulley Rod

PART NUMBER: EML4502-15

Rev:

MATERIAL: 6061 Aluminum

FINISH:

DESIGN ENGINEER: Paroff, Adam

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\Fully Rod.SLDPRT

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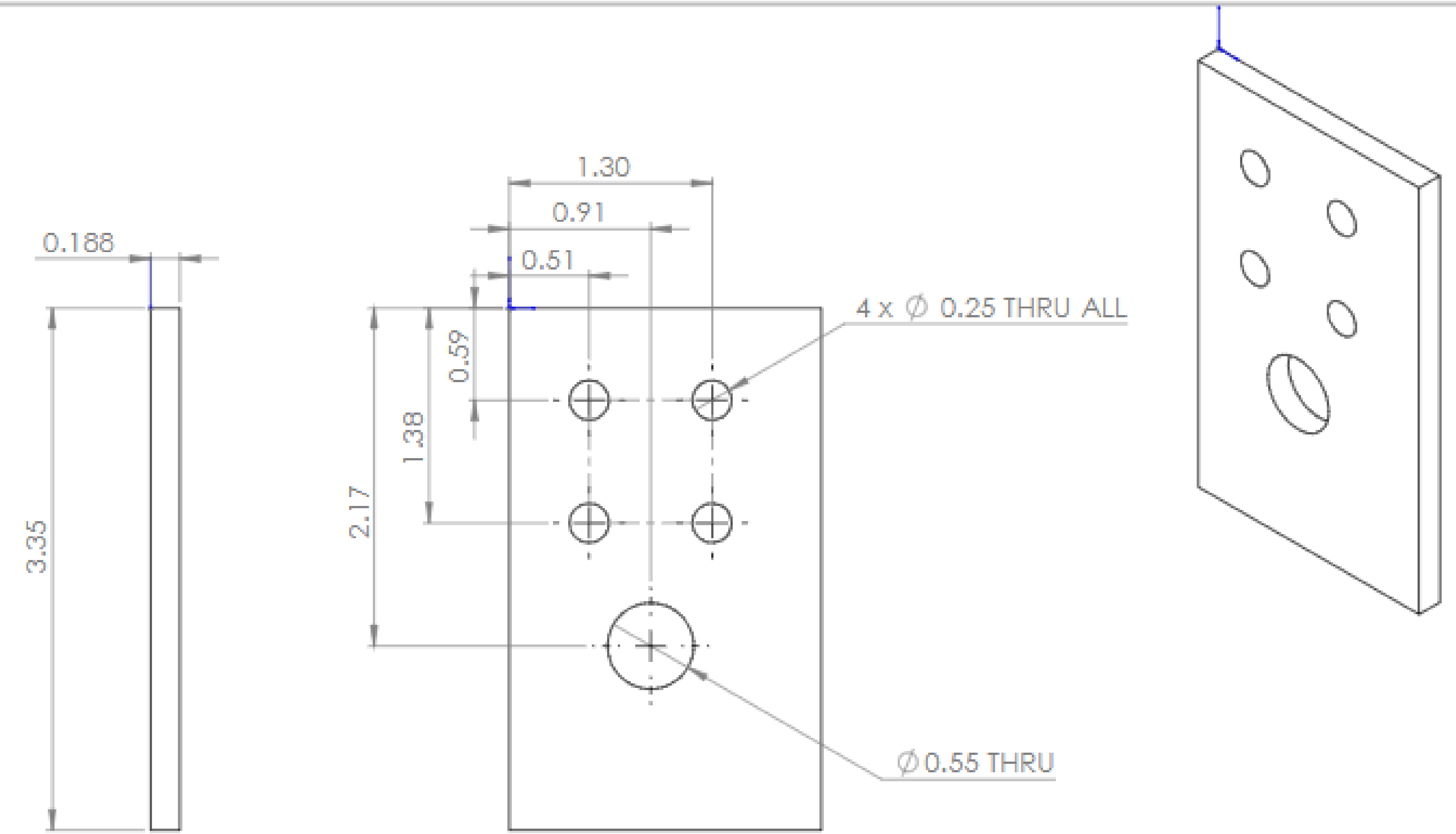
SHEET SCALE: 2:1

SHEET NUMBER: 1 of 1



NOTES:

1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

UF Herbert Wertheim College of Engineering, Department of Mechanical & Aerospace Engineering, UNIVERSITY of FLORIDA	*EML4502: MECHANICAL DESIGN 3*	TEAM: 637 Shaker Tables / PART NAME: ShortMotorSpacer
		PART NUMBER: EML4502-16 / Rev:
STANDARD DIMENSIONAL TOLERANCES: LINEAR in[mm] — X.X: ±.050[1]; X.XX: ±.010[.2]; X.XXX: ±.005[.1]. ANGULAR [degrees] — X: ±3; X.X: ±.5; X.XX: ±.1. MAXIMUM SURFACE FINISH: .004 in Ra		MATERIAL: 6061 Aluminum / FINISH: As machined
		DESIGN ENGINEER: Crouch,Christopher R
		DESIGN APPROVAL:
		MANUFACTURING APPROVAL:
PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\ShortMotorSpacer.SLDPRT		

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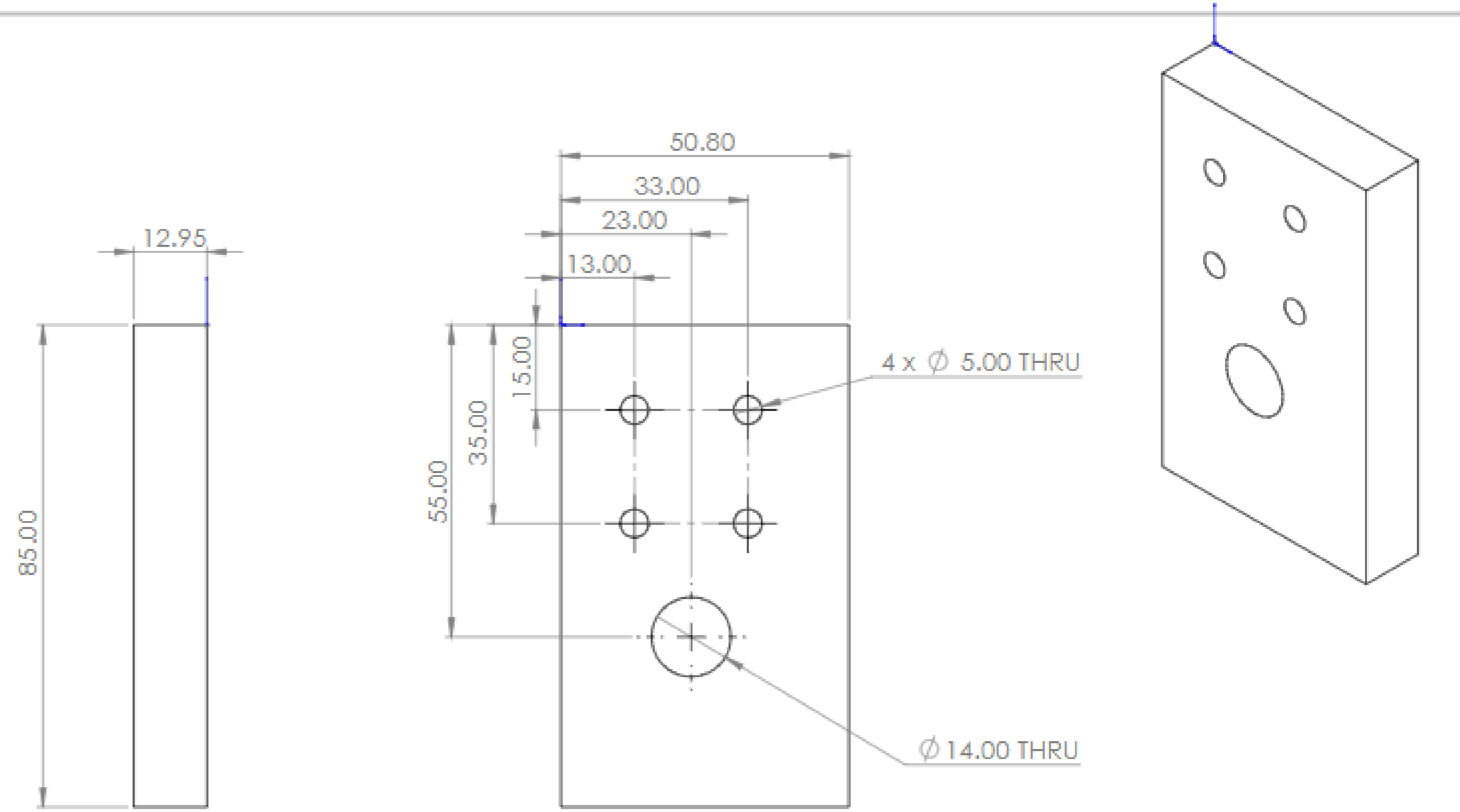
SHEET SCALE: 1:1 SHEET NUMBER: 1 of 1



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 1
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: TallMotorSpacer

PART NUMBER: EML4502-17

Rev:

MATERIAL: Aluminum 6061

FINISH: As machined

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

DESIGN ENGINEER: Crouch,Christopher R

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: C:\EML4502\Spring 2023 Design\[637U] Shake n Bake\TallMotorSpacer.SLDPRT

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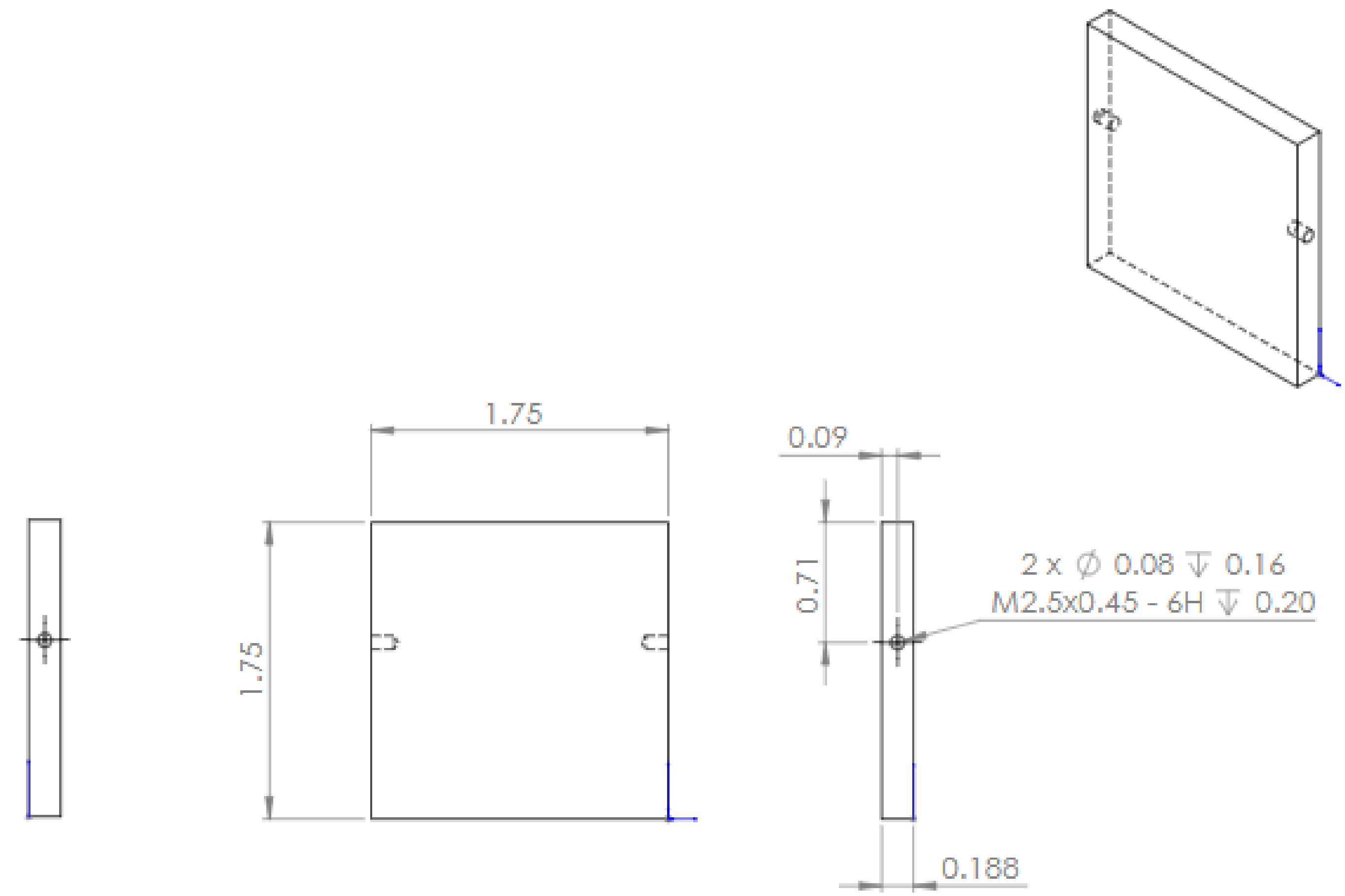
SHEET SCALE: 1:1

SHEET NUMBER: 1 of 1



NOTES:
1. DEBURR/BREAKALL SHARP EDGES
2. ALL DIMS IN INCHES
3. QTY: 2
4. MATL: Aluminum 6061
5. FINISH: AS MACHINED

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EML4502: MECHANICAL DESIGN 3

TEAM: 637 Shaker Tables

PART NAME: MountDoor_Tall

PART NUMBER: EML4502-18

Rev:

MATERIAL: Aluminum 6061

FINISH: As machined

STANDARD DIMENSIONAL TOLERANCES:

LINEAR in[mm]		ANGULAR [degrees]	
X.X:	±.050[1]	X:	±3
X.XX:	±.010[.2]	X.X:	±.5
X.XXX:	±.005[.1]	X.XX:	±.1

MAXIMUM SURFACE FINISH: .004 in Ra

DESIGN ENGINEER: Crouch,Christopher R

DESIGN APPROVAL:

MANUFACTURING APPROVAL:

PART LOCATION: c:\EML4502\Spring 2023 Design\[637U] Shake n Bake\Fall2022-Design\MountDoor_Tall.SLDPRT

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SHEET SCALE: 1:1

SHEET NUMBER: 1 of 1

XII. References

[1] Ravindran, S., Singh, P., Nene, S., Rale, V., Mhetras, N., & Vaidya, A. (2019, November 6). *Microbioreactors and perfusion bioreactors for microbial and Mammalian Cell Culture*. IntechOpen. Retrieved February 20, 2023, from https://www.intechopen.com/chapters/66188

[2] Seotechwriter. (2022, April 28). *Laboratory shakers: What are they?* Wiltronics. Retrieved February 20, 2023, from https://www.wiltronics.com.au/wiltronics-knowledge-base/laboratory-shakers-guide/

[3] "Pololu - 6.3:1 metal gearmotor 37Dx65L mm 12V with 64 CPR encoder (helical pinion)," *Pololu Robotics & Electronics*. [Online]. Available: https://www.pololu.com/product/4757/specs.

[4] "Friction - friction coefficients and calculator," *Engineering ToolBox*. [Online]. Available: https://www.engineeringtoolbox.com/friction-coefficients-d_778.html.