

**Mug for Tremors
Team 183a1
Final Design Review**

Sponsored By: QL+

by

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Statement of Disclaimer

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Executive Summary

This document is a final design review for our senior project, establishing our final design and the overall steps we took to complete this project. This project, officially called Mug for Tremors is issued and sponsored by Quality of Life Plus, or QL+. Mug for Tremors aims to provide a reliable and aesthetically pleasing mug meant to be used by veterans who have developed different levels of hand tremors. Subsequent research was conducted to understand the concepts of this idea more thoroughly, primarily through research of similar products. Afterwards, a scope for this project is defined through understanding our target customer's needs and wants as well as an analysis of our quality function deployment, or QFD, process. A thorough description of our concept design is provided, including our selection process, CAD models, and preliminary analysis of our selected design. A final design, including detailed CAD models, a structural prototype, and descriptions of all structural and electrical components is included, followed by a manufacturing plan for the finalized mug. Safety concerns and possible modes of failure are identified and addressed. Additionally, a plan for testing the design to ensure it meets the necessary design specifications is established. Finally, an outline of our project timeline and further recommendations to improve our product in the future are included.

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1.0 Introduction

Quality of Life Plus was founded in 2008 by Jon Monett as a way to give back to wounded veterans in the community. Through QL+, unique engineering solutions are designed, developed, and produced to improve the quality of life of wounded veterans. Student teams at California Polytechnic State University, San Luis Obispo have completed over 100 engineering challenges since the creation of QL+.

Melissa Oliver, an occupational therapist at McGuire VA Medical Center, works extensively with veterans who struggle with certain daily activities due to their hand tremors. Hand tremors caused by essential tremor, Parkinson's Disease, or other physical or neurological impairments can greatly affect an individual's ability to perform daily tasks. One of these tasks include the ability to handle beverages, as hand tremors can cause excessive sloshing and spilling of liquid. Melissa reached out to find a way to help veterans with hand tremors easily consume liquids. Our team, consisting of Logan Smith, Allen Tecson, Jaret Wedow, and Kai Workman, was tasked with creating a stabilizing mug capable of resisting motion due to hand tremors. The following document details the design process our team took to research, design, prototype, and iterate our way to the final prototype that was created.

2.0 Background

To understand the challenge proposed to us, understand our project requirements, and decide on a reasonable scope for the project, we conducted research on products and concepts in the market or in development that are like our project. We can use these products to benchmark our mug, as well as use technology already developed. Along with product research, we also investigated various patents of products that could help with stabilization and not spilling the liquid. These include electrically controlled stabilizing systems and geometries that reduce tremors or liquid spillage.

2.1 Liftware™ Self-Stabilizing Fork & Spoon

Liftware™ is an electronic stabilizing handle with attachments that include a fork and spoon. The Liftware™ spoon, as shown in Figure 1, works by using an internal computer to detect small tremor motions from users with hand tremors. From there, motors located in the handle oppose the tremor motion to stabilize the spoon ("Liftware Steady™"). Our team plans to use electronics and stabilizing techniques very similar to those found in the Liftware™ product. These techniques will be applied to our mug guidelines rather than the eating utensil featured by the Liftware™.



Figure 1: Liftware™ Self-Stabilizing Spoon (Hagen)

2.2 HandSteady Cup

The HandSteady cup, shown in Figure 2, features a rotating handle, designed for people with tremors, pain, or limited dexterity (“Home”). While the HandSteady cup does satisfy a few criteria set by our sponsor, the design has several issues with solving drinking problems associated with hand tremors. The handle only pivots along one axis of rotation, so it does not reduce the effects of hand tremors in the other axis. The cup also has to be refilled frequently due its small carrying capacity of only 9 fluid ounces.

This ground breaking device that is changing the way people drink with less spills, more control and more comfort is called handSteady® - which is a cup with a unique Rotatable Handle™ and Hidden Lid™.



Figure 2: HandSteady Cup (“Home”)

2.3 Imagiroom

The Imagiroom, as shown in Figure 3, is a cup that features a wide three-legged base. It is designed to be comfortable to hold and difficult to spill for people with Parkinson’s Disease. However, once in the hand of the individual, the Imagiroom has no features to reduce the effect of hand tremors. Thus, it is not an effective way to prevent the sloshing and spilling of drinks during use (“Imagiroom”).



Figure 3: Imagiroom Cup (“Picture of Imagiroom Cup on a Table.”)

2.4 Technology

Different technologies exist that counteract many of the involuntary motions that come with hand tremors. For our project, we initially planned to take inspiration from the Liftware™, which bases its technology around motion sensing and motor actuation. The internal system of the Liftware™ spoon, shown in Figure 4, features different electronic parts, such as sensors, microcontrollers, and motors. Through these devices, any tremor motions that occur will be detected and corrected, reducing the shaking effects and improving the practicality of the mug.

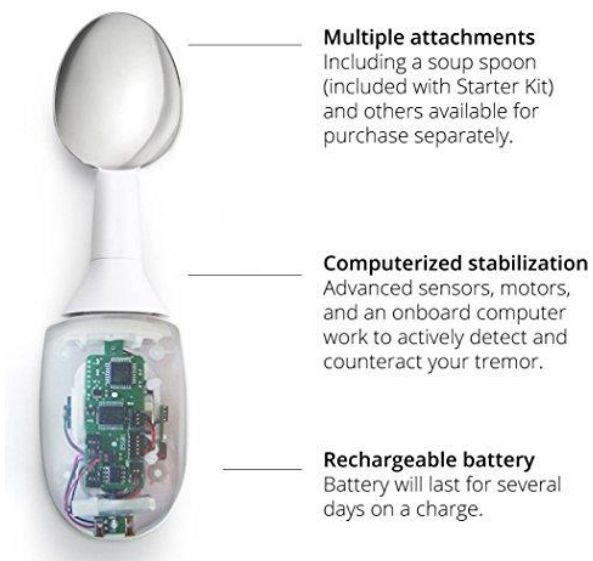


Figure 4: Internal System of Liftware (“Liftware™”)

Later during the project, we began looking into different technologies that would accomplish the same goals the Liftware™ spoon was accomplishing. The main type of technology we found was a slightly different application of gimbal technology, this time based on the design of camera stabilizers. These camera stabilizers feature linkages that branch out from the cup and that control one axis of rotation at a time. The purpose of a gimbal-type handle is very similar to the Liftware™ spoon, in which it provides a rotation to the handle without rotating the base cup in order to effectively counteract tremor motions that occur on the handle. The difference is in how and where the rotation is applied. Primarily, the design of a camera stabilizer features a longer handle that allows for more components to be utilized while not increasing the volume of the cup to a size that is not aesthetically pleasing or feasible to carry.

2.5 Patents

In order to find out if there are any products with the technology we need, we searched through patents that focused on passive and active solutions to preventing spillage or vibrations of any kind. The patents we examined are listed in Appendix A and showcase products and technologies that are already being used. The first patent focuses on an active gimbal that accounts for rotation in three axes. This would allow our mug to counteract tremors rotating about any axis. The patent also lists how to prevent different axes from becoming locked, which can often happen with gimbals if components rotate too far. The next three patents focus on geometrical or form factors to reduce tremors. The first one describes a specific type of handle that is larger and easier to grip so people with tremors have more control over a utensil. The second patent has physical obstructions on the inside of the cup that limit the amount of liquid that can come out. The third patent is similar to the second but has inner baffles to keep the fluid from spilling. The final patent in the list is one for decreasing vibrations for cameras on vehicles. It uses a two-gimbal system to counteract all vibrations while filming movie scenes shot from moving vehicles. All of these patents will prove useful in the ideation stage and can possibly be adapted to prevent the spillage of liquid in a cup.

3.0 Objectives

There are currently no cups or mugs on the commercial market that are effective for people with hand tremors. All cups aimed to help individuals with hand tremors are either not effective, carry too little of liquid, are too heavy, or are aesthetically displeasing. People that have hand tremors need a mug that reduces the effects of these tremors and make it easy to drink from while still looking like a traditional mug. We aim to develop a mug that reduces the effect of hand tremors, can carry at least 16 ounces of liquid, is lightweight, and is aesthetically pleasing.

Figure 5 depicts the area we wish to focus our project on, the mug itself and how it interacts with the user. There are many ways people are working to reduce the effects of tremors, but we are going to focus on developing a mug to be used by people with hand tremors. Because the user's

hand is included in the boundary diagram, we will need to make sure that the mug can be used by a variety of hand sizes.

BOUNDARY DIAGRAM

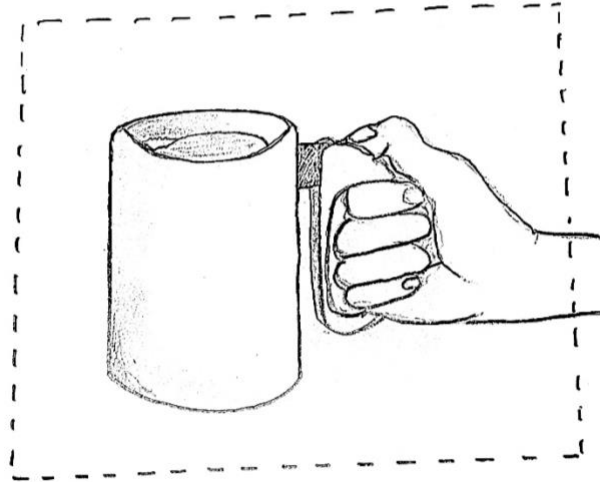


Figure 5: Gyro Mug Boundary Sketch

3.1 Customer Needs and Wants

After speaking with our sponsor, Melissa Oliver, we constructed a list of the needs and wants that the veterans have regarding mugs that are designed for people with hand tremors. From this conversation, we identified the functions that will be necessary in our mug design. These functions are a high liquid carrying capacity, effective tremor reduction, lightweight, portable, fits different hand sizes, and looks good. Some of the less necessary functions are that the mug should be durable, easy to clean, and is affordable. The complete list of need and wants can be seen in Table 1.

Table 1: Table of needs and wants for a mug designed for individuals with hand tremors.

NEEDS	WANTS
High Carrying Capacity	Durable
Effective Tremor Reduction	Easy to Clean
Lightweight	Low Cost
Good Aesthetics	Water Resistant
Portable	Ability to Sustain Hot and Cold Beverages
Fits Different Hand Sizes	

3.2 Quality Function Deployment

We applied the quality function deployment (QFD) process to ensure we have identified the correct problem and that we are meeting the necessary specifications. We created a house of quality diagram to highlight the specifications and requirements of the problem. The house of quality has sections for who, how, now, what, and how much, as well as the interaction between these elements. This diagram is included in Appendix B. The “who” section listed the parties that would benefit from this project: the veterans and other individuals who struggle to drink due to their hand tremors. The “what” section states customer requirements, in the form of needs and wants. Quantifiable, testable engineering specifications were stated in the “how” section. The interaction between these specifications and the customer needs is shown in the center of the house of quality.

Making the QFD challenged us to determine which engineering specifications were needed in order to have a way to quantifiably determine if the customer’s needs and wants were met. This allowed us to then clearly identify the objectives that our mug is going to have to be able to accomplish and be able to rank the importance of these objectives. From the QFD it is obvious that our main objective is to make sure that our mug effectively reduces the effects of hand tremors, otherwise it would be like any other mug currently on the market. The second most important objective will be making sure the mug stays relatively small. If the mug is too big than it will not be portable, lightweight, aesthetically pleasing, and overall effective.

The QFD also allowed us to compare how we want our mug to perform based on how products currently on the market perform. The HandSteady Cup and the Imagiroo Cup both performed quite bad because they are pretty much just normal cups that only benefit one function. The Liftware™ performed the best out of the products currently on the market, but its major drawback is that it is a spoon and not a mug. Because of this we want our mug to perform just as well as the Liftware™ but be able to carry the same amount of liquid as a mug.

3.3 Engineering Specifications

After creating our QFD, we tabulated the engineering specifications in the “how” section in Table 2. After talking with our sponsor, we were able to create target values for these engineering specifications with a tolerance or limit for these values. Carrying capacity refers to the amount of liquid that the mug will be able to hold. We decided on 16 ounces because this is the medium drink size at most restaurants and stores. When developing this mug, the engineering specification which we think has the highest risk (most difficult to achieve) is the tremor reduction due to its complex nature. Battery life refers to how long this mug will be able to be used one a single charge. A typical meal lasts about an hour, so we want our mug to be able to last the entirety of this. It is important we keep production cost down, so this mug is a viable solution. The cost of the Liftware™ spoon is about two hundred dollars so we chose this as a baseline price. Finally, it is important we keep the

overall weight of the mug to a minimum. We chose 5 pounds including liquid to be our baseline weight as it gives some room to experiment with different electronics and batteries. We believe this weight will be a challenge to meet because of all the different components we might need to incorporate in our mug. Our sponsor mentioned that if the mug is too heavy, she is worried that it will amplify the tremors we are hoping to counteract. We must also make sure that our handle can be used by a variety of users. According to an article about average reviewed by Doctor Weatherspoon, NASA and the CDC report that the average hand breadth size for adult males and females in the U.S. is 3.5 and 3.1 inches respectively. This means we need our mug’s handle to be at least 3.5 inches long, so we chose 4 inches to accommodate for veterans who may have larger hands. We decided that for our mug to be considered durable, it should be able to withstand a drop of at least 4 feet. This height is that from the top of a standard table onto the ground.

Table 2: Table of engineering specifications with target values, tolerance, risk, and compliance.
Compliance: Test, Analysis, Inspection, or Similarity

Spec.#	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Carrying Capacity	16 ounces	±2 oz	M	T
2	Tremor Reduction	50%	Min	H	T
3	Battery Life	1 hour	Min	M	T,A,S
4	Production Cost	\$200	Max	M	A
5	Weight	5 lbs	Max	H	T,A,S
6	Drop Height	4ft	Min	M	T
7	Overall Size	6” x 4” x 4”	Max	M	I
8	Handle Length	4”	±0.5”	L	I

We will need to have different tests in order to measure how well our mug satisfies these engineering specifications. To test the carrying capacity we will pour as much liquid as we can into our mug and measure how much fits. To test the tremor reduction capabilities, we will use a high-speed camera to measure how much the cup moves compared to how much movement is put into the handle. To test battery life, we will use the mug continuously and see how long it lasts before the battery dies. To test the weight of the mug we will weigh the final prototype full of water.

4.0 Concept Design

With our design requirements we began to create concept prototypes of the different functions our mug is expected to perform. The first thing our team did was apply functional decomposition to our project scope. To do this, we first thought of a general function that we wanted our mug to accomplish. In our case, we wanted our mug to reduce spillage. Afterwards, we broke down this established general function into small subfunctions that would accomplish the general function. We kept breaking down these subfunctions until we ended up with basic functions that we could then ideate concept models for. This process is shown in Figure 6. Despite the seemingly simplistic functional decomposition diagram, the basic functions were crucial to the success of our design. Along with that, the basic functions we found had numerous possible solutions, which we then narrowed down to one solution that was the most feasible option.

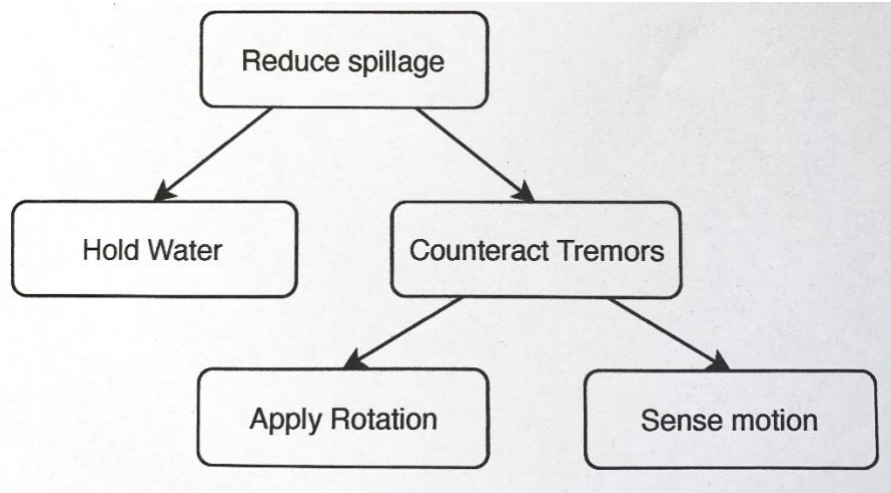


Figure 6: Functional Decomposition

Once basic functions were decided on, our group came up with concept models per basic function to ideate and physically represent potential solutions. The main functions we focused on were “hold water” and “apply rotation,” with “apply force” as a possibility, but our group recognized that applying a force is not as important (and may not even be needed) as applying a rotation.

We then created a morph matrix, shown in Table 3, to highlight different combinations of design characteristics. By comparing cup type, rotation method, type of handle, and handle connection location, we realized that the rotation type was the most important aspect of our design. We determined that some of the other characteristics, such as type of handle, were dependent on the rotation type selected.

Table 3: Morph Matrix

Cup Type	Rotation	Type of Handle	Handle Connection Location
Bottle	Gimbal	One Connection	Top
Coffee Mug	Bevel Gears	No Handle	Middle
Bowl	Gravity Mug	Two Connections	Bottom
	Ball & Socket		

Concept sketches, shown in Figure 7, were created of different ways to meet our basic functions. We treated a cup with a lid as a baseline, as it effectively reduces the spilling due to tremors but does nothing to reduce the cup movement due to hand tremors. Additionally, our sponsor specifically told us that a cup with a lid was not desirable to the veterans, so we quickly eliminated that option. One idea we generated was a ball and socket design. The handle would pivot in all directions inside a socket on the cup using a viscous fluid to dampen the movement. However, we determined this would be difficult to implement and control in order to effectively reduce tremors. We also considered using bevel gears, like a car differential. This would allow tremor reduction in two axes of rotation, but we determined it would be too bulky and difficult to integrate. A gravity mug was also proposed, which would suspend the mug from an outer casing using rubber bands

or other elastic suspenders to absorb the shock of the tremors. We decided that this would not be as effective as an actively powered device, so we eliminated this decision as well. The final concept generated was a gimbal device, like those used in camera stabilizers. We decided to move forward with this design, as it seemed feasible to design and implement along with being effective at reducing tremors. In order to help us make this decision to move forward with the gimbal design, we implemented a weighted decision matrix.



Figure 7: Concept Sketches

The weighted decision matrix, shown in Table 4, compares the various possible solutions using factors that are important to the design. By adding different weights to each of the factors, we could put more emphasis on the factors that were most important to the success of our final product. We determined that effectiveness in reducing tremors and feasibility of the design were the two most important factors in our decision-making process. Other factors we included were weight, aesthetics, manufacturability, and cost. We compared the four concept ideas we generated, along with our cup with lid baseline. The decision matrix resulted in the gimbal receiving the highest overall score, so we decided to continue with this design.

Table 4: Weighted Decision Matrix

Factors	Weights	Gimbal	Bevel Gears	Gravity Mug	Ball & Socket	Cup With Lid (Baseline)
Effectiveness	10	10	6	3	3	9
Weight	6	5	6	7	8	10
Aesthetics	4	7	5	5	7	3
Manufacturability	6	3	4	8	7	9
Feasibility	10	7	7	5	4	0
Cost	4	3	4	7	7	9
	Totals:	258	226	218	216	252

Once we decided to move forward with the gimbal design, we created concept CAD models of our design shown in Figure 8. We initially were focused on a 3-axis design, which would utilize 3 motors to reduce tremors in all 3 possible directions of rotation. After more consideration, we decided to also consider a 2-axis design for our mug. This would prevent rotation of the mug in 2 axes, but not along the vertical axis. Our group is considering this 2-axis design because hand tremors that result in the cup rotating in the vertical axis does not occur as often as rotation along the other two axes and rotation along the vertical axis does not result in as much liquid spillage in comparison to the other two axes of rotation. Moving forward, we need to compare the two possible solutions and determine which one will more effectively solve the issue we are faced with. The 2-axis design will be easier to implement, in addition to being more stable design due to the

weight of the cup being below the motors rather than above. If we can determine that losing the vertical axis of rotation will not have a significant effect on our tremor reduction, we feel that the 2-axis design will be a better design to pursue. We will be conducting tests on a mug full of water to see if we can eliminate the need for control over the vertical axis.

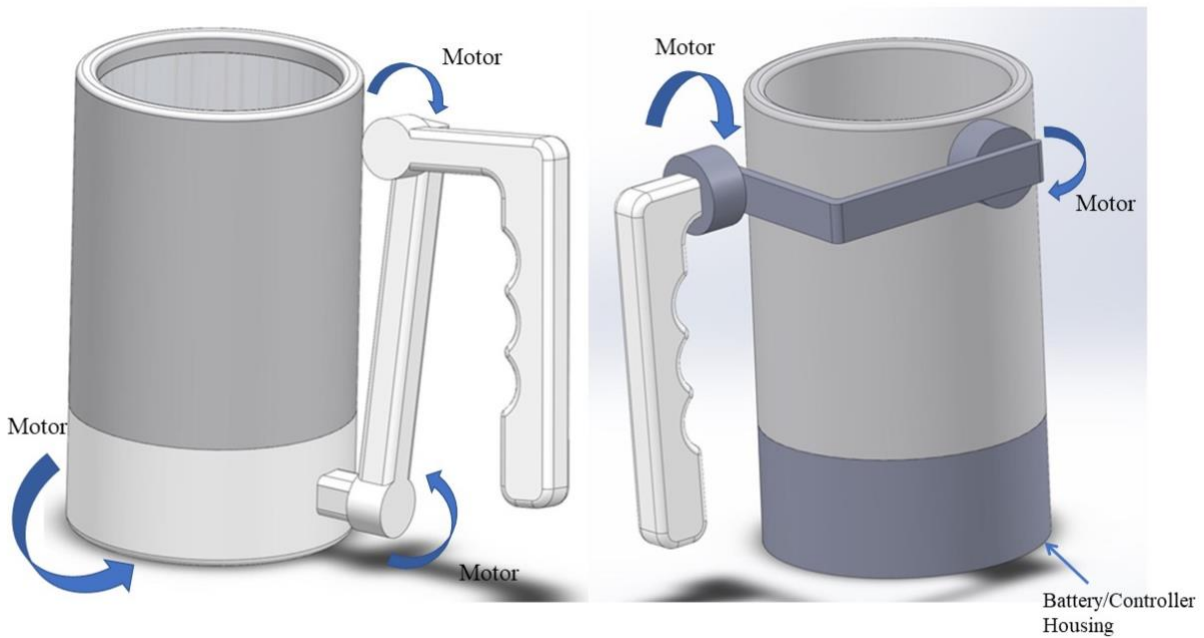


Figure 8: Concept CAD – 3 and 2-Axis Rotating Gimbal Designs

Regardless of whether the gimbal will be controlling 2 or 3 axes of rotation, the main components required will still be the same. We will need electric motors that will apply the rotation to brackets that are connected to the mug. An accelerometer is needed to communicate to a controller when and how much the mug is being moved. Given this data, the controller will have to be coded to then tell the motors how much to move in order to keep the mug stationary. Finally, a battery is needed to power all the components. These electrical components will need to be selected to be able to all work together and satisfy the requirements of our mug.

As we begin prototyping, we plan on 3D-printing most of the brackets and the mug itself. This will allow us to design them to be used with off-the-shelf electronic components that will save us time and money. In Appendix C, we performed a preliminary hand-calculation of the main bracket for the 2-axis design to determine some of the approximate forces that it will endure under static loading. This was a rough calculation with many estimations made, but it gave us an estimate of the expected loads on the bracket. The mug, water, and electronic components will most likely weigh less than three pounds, so the bracket will not be subjected to very high loads during normal use. From our initial hand calculations, the maximum stress that the bracket will be exposed to at

the connection to the handle will be 2 kilopounds per square inch (ksi). This is well under 4.8 ksi, the ultimate strength of the plastic we plan to print the bracket out of. Given this information, the bracket will be robust enough to not break. As we begin to finalize dimensions of the mug and determine which electrical components will be used, we will be able to construct more accurate loading scenarios.

There are several challenges we face moving forward with this project. Our team has little experience with gimbals and the coding and control systems that will be required to make them function properly. Fortunately, Cal Poly Mechanical Engineering professor, Dr. Siyuan Xing, has agreed to serve as a technical advisor for our team moving forward. He has experience with control systems, so we will approach him with any difficult technical issues we are working through. We also have a limited timeframe to complete this project. Since we began the project at a later date, we may not have time to iterate through to a final design that is as lightweight, compact, and aesthetically pleasing as possible. Our focus is to create a functioning prototype that effectively assists in tremor reduction for users, even if we do not reach a final marketable product. During our PDR Presentation, a few other design concerns were brought up. The 2-axis design would currently only allow for right-handed drinking, so we are looking into ways to alter the design to make it usable with either hand. Additionally, we will need a way to lock one axis of rotation in order for the user to tip the mug and drink from it. While we have not yet settled on a final solution for this, possible solutions include a button to lock rotation or a band pass filter to allow slow movements to occur without activating the motors.

5.0 Final Design

After taking into account the feedback we received during our PDR and CDR presentations, we were able to iterate and refine our design down to a final design, complete with a structural prototype. Our final design features a two-axis stabilizing system to actively reduce the motion of the cup due to hand tremors. It features five main 3D printed components, along with purchased electrical components. These five 3D printed components are composed of PLA.

5.1 3D Printed Components

The first designed component is the handle, which is shown in Figure 9. This serves as the interface between the user and the mug, and we designed it with an emphasis on comfort and aesthetics. By utilizing ergonomic principles to help define the diameter and curves on the handle, we created a handle that is easy to hold and comfortable to use regardless of hand strength or dexterity. The top of the handle has a radial cutout for one motor to rest in, along with mounting holes to securely fasten the handle to the motor.



Figure 9: Handle

The bracket, which is shown in Figure 10, connects the handle to the body of the mug. A motor is mounted on both sides of the bracket, with one side on the mug handle and the other side on the outer mug shell. To ensure proper alignment during mounting and account for any misalignments in bracket or motor dimensions, we implemented mounting slots rather than holes.

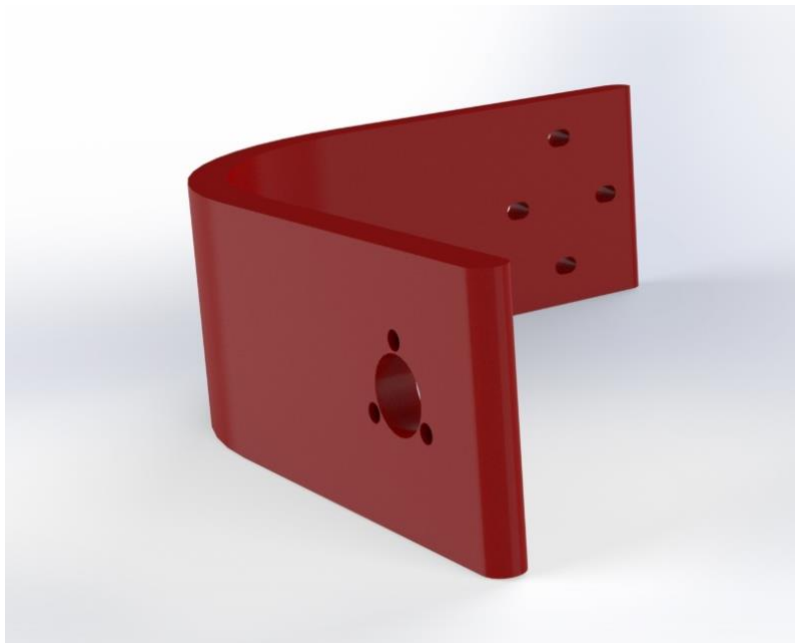


Figure 10: Bracket

The outer mug shell, shown in Figure 11, contains the mug liner, along with the Inertial Measurement Unit (IMU), controller board, and battery. It is the large overall structure that gives the mug its shape. We included small cutouts to allow for wire routing and management. The top of the mug features threads to allow for an easy interface with the mug liner. We designed the mug shell to have a gap of approximately 2 inches between the bottom of the shell and the bottom of the liner when it is fully installed. This gap is where the battery, controller board, and IMU are stored. These components are held in place by the mounting fixture shown in Figure 13. The wires are routed from the motors down along the mug shell wall, where they connect to the controller board.



Figure 11: Mug Shell

The mug liner, which is shown in Figure 12, is designed to sit within the outer mug shell, forming a watertight container that can be easily removed and cleaned. The mug liner has threads to allow for easy connection and removal from the rest of the mug assembly. The liner also features a slight taper from top to bottom, to ensure it can easily be inserted and removed without interfering with the walls of the mug shell or any other components.



Figure 12: Mug Liner

We designed a mounting fixture to hold the controller board, IMU, and battery secure in the bottom of the mug shell. These components need to be firmly held in place to ensure the mug does not experience any issues with connectivity or performance during usage. The mounting fixture, which is shown in Figure 13, also helps with easily removing the electronic components of the design if any issues arise that require troubleshooting. It attaches to the bottom of the mug shell with one mounting screw; removing this screw allows the mounting fixture assembly to be lifted and removed from the remainder of the mug assembly.

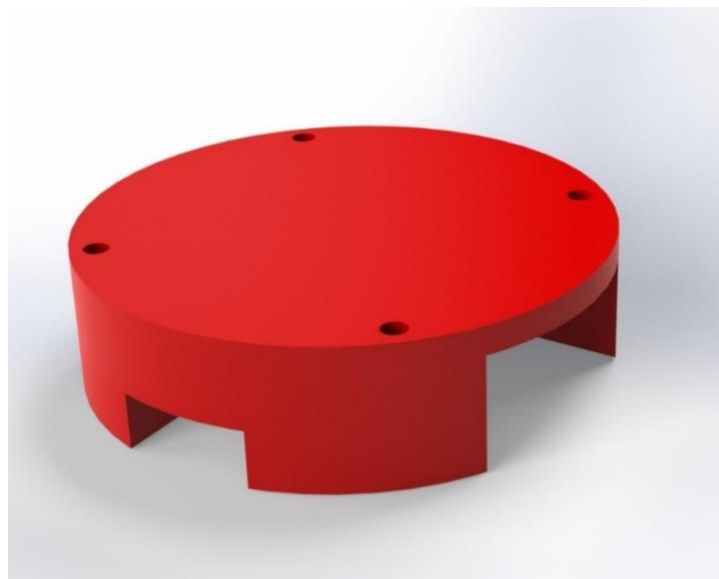


Figure 13: Mounting Fixture

5.2 Final Assembly

An exploded assembly view of our CAD model is shown in Figure 14. This highlights the various components of our final design and shows how the components fit together in relation to each other in the final product.

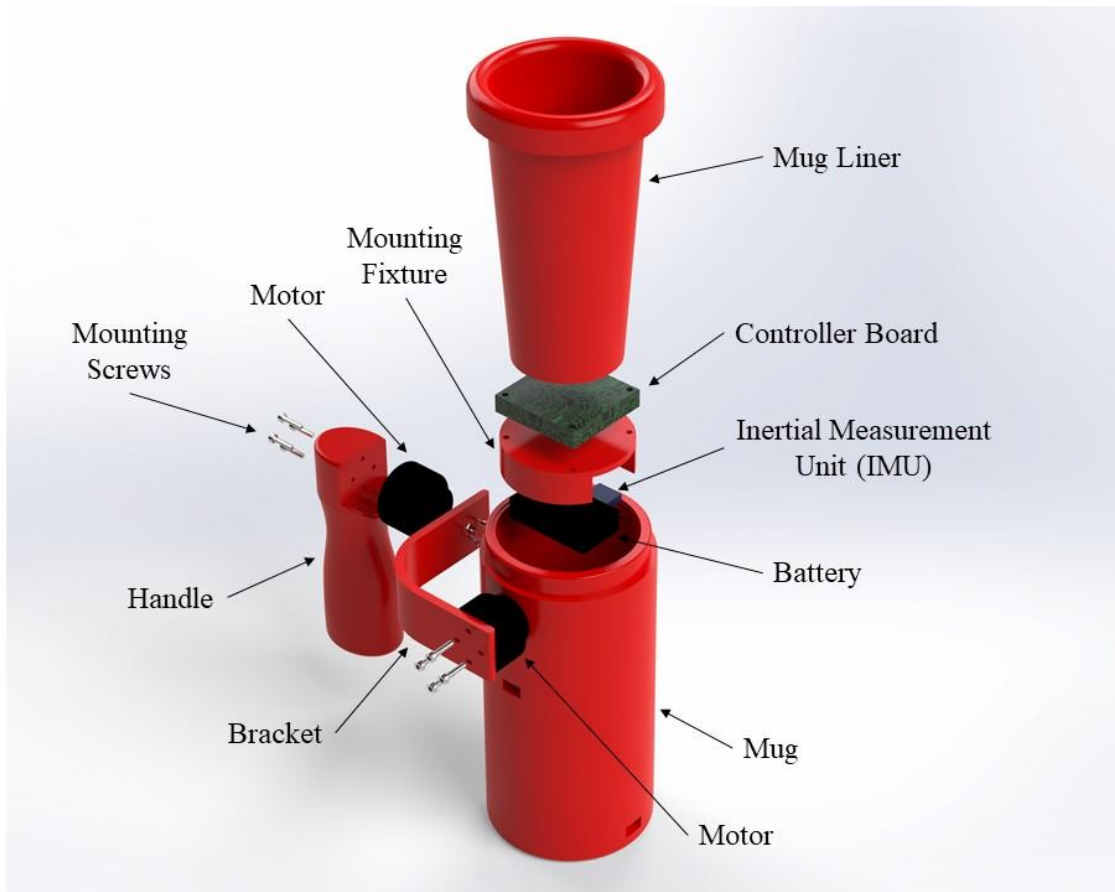


Figure 14: Exploded CAD Assembly

A completed, assembled CAD model is shown in Figure 15. This figure shows how the completed design looks when all components are fully assembled and integrated. After completing this CAD and finishing the necessary analysis to prove our design would succeed, we created a structural prototype, which is shown in Figure 16.



Figure 15: Mug Assembly

The image in Figure 16 was taken while the prototype was partially disassembled for testing, so not all of the wiring and electrical components are included. We constructed this structural prototype to prove that our final design was feasible and that we were able to incorporate the various structural and electrical components into a single product. While our finalized structural prototype currently utilizes brushless DC motors that we purchased along with our controller board, testing and analysis showed us that these motors do not provide enough torque to effectively reduce tremors. Therefore, motors with higher torques were tested and implemented into the mug design as we continued in our iterations towards a final prototype to deliver at Senior Project Expo.



Figure 16: Structural Prototype

5.3 Electronics

The electrical components of our design consist of a battery, two brushless motors, an inertial measurement unit (IMU), and a controller board. The motors, IMU, and controller board came from a GoPro camera stabilizer. These components were separated from their initial housing and linkages and integrated into our mug design.

The various electrical components in our design are connected through wires, which are routed through our mug shell. The wiring diagram, shown in Figure 17, highlights the connection between these electrical components. The controller board serves as a central hub for all electrical components, relaying acceleration information from the IMU to the motors to initialize motion. The battery, IMU, and motors are all wired to connect with the controller board.

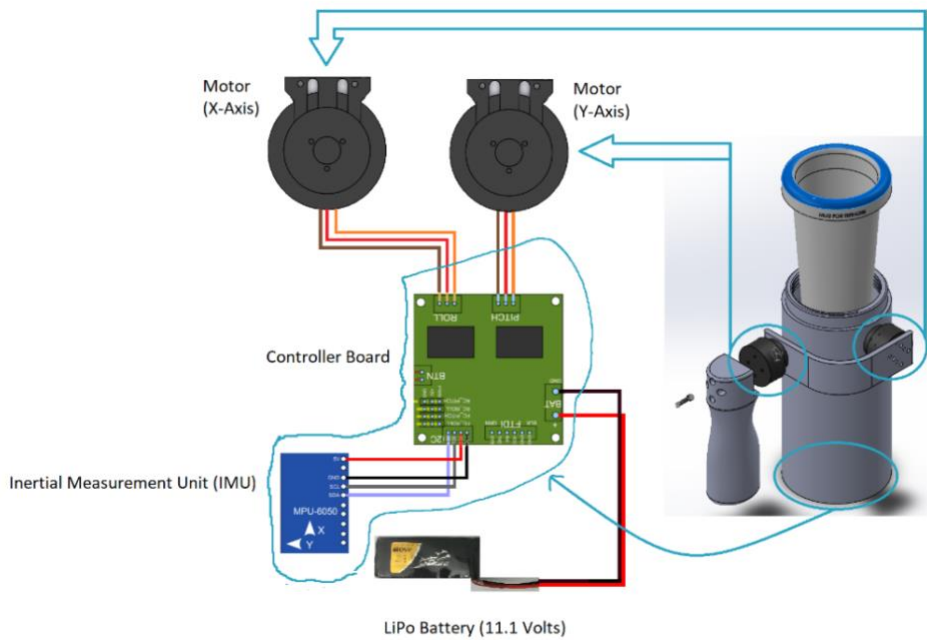


Figure 17: Wiring Diagram

5.4 Software

The controller board we purchased came with a software that allows for easy modifications, tuning, and adjustments. Rather than having to code the controller board ourselves, we were able to utilize this software to make the controller board effective for the application we needed. The software user interface, shown in Figure 18, allows us to view IMU movements in real time. Additionally, it allows us to adjust power, calibration, and make changes to the controller performance. We adjusted Proportional, Integral, and Derivative (PID) values to tune our system and alter the responses to input tremors.

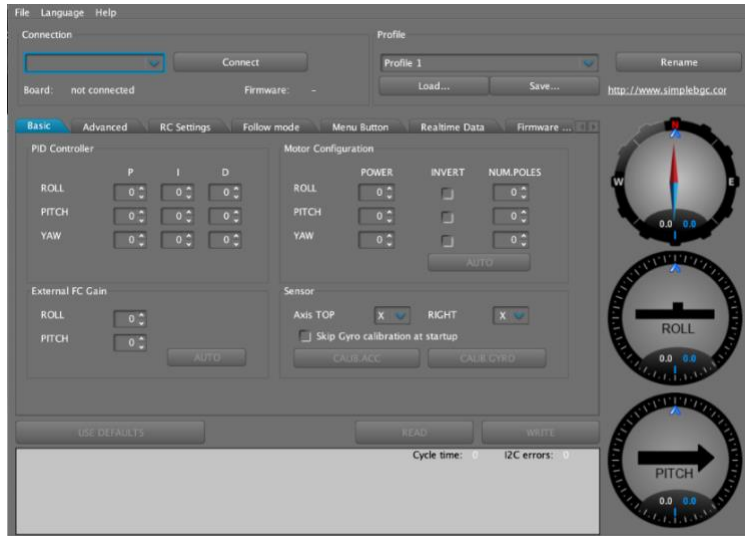


Figure 18: Controller Board Software Interface

The software also displays accelerations and gyro positions in real time on the grid space shown in Figure 19. This helped us in our calibration and tuning process. Viewing this data in real time, along with changing necessary values on the interface shown in Figure 18, allowed us to iterate control settings until we achieved desirable results from the controller.



Figure 19: Controller Board Real Time Data

5.5 Motors

The two motors, which control the two axes of rotation, are a critical component to the success of our design. We needed to ensure that our motors would be strong enough to effectively support and rotate the weight of the mug in order to reduce mug movement due

to hand tremors. We performed a three-dimensional dynamic analysis to solve for the required motor torque. Figure 20 shows the appropriate axis orientation and all length dimensions of each component in terms of variables (a , r , h , w , and b). During all the torque calculations, the axis in the XY plane is lined up with the centroid of the motors and bracket.

To determine the torques needed by the motors, we performed the following steps in our solution process. First, we applied a force representing the hand tremor force to the handle in the direction normal to both the x and y axes. We then calculated the corresponding angular acceleration in along the axis of the applied force. We used this angular acceleration to calculate the torque needed by the respective motor. All these calculations, in equation form, as well as the diagram and corresponding analysis are shown in Appendix D.

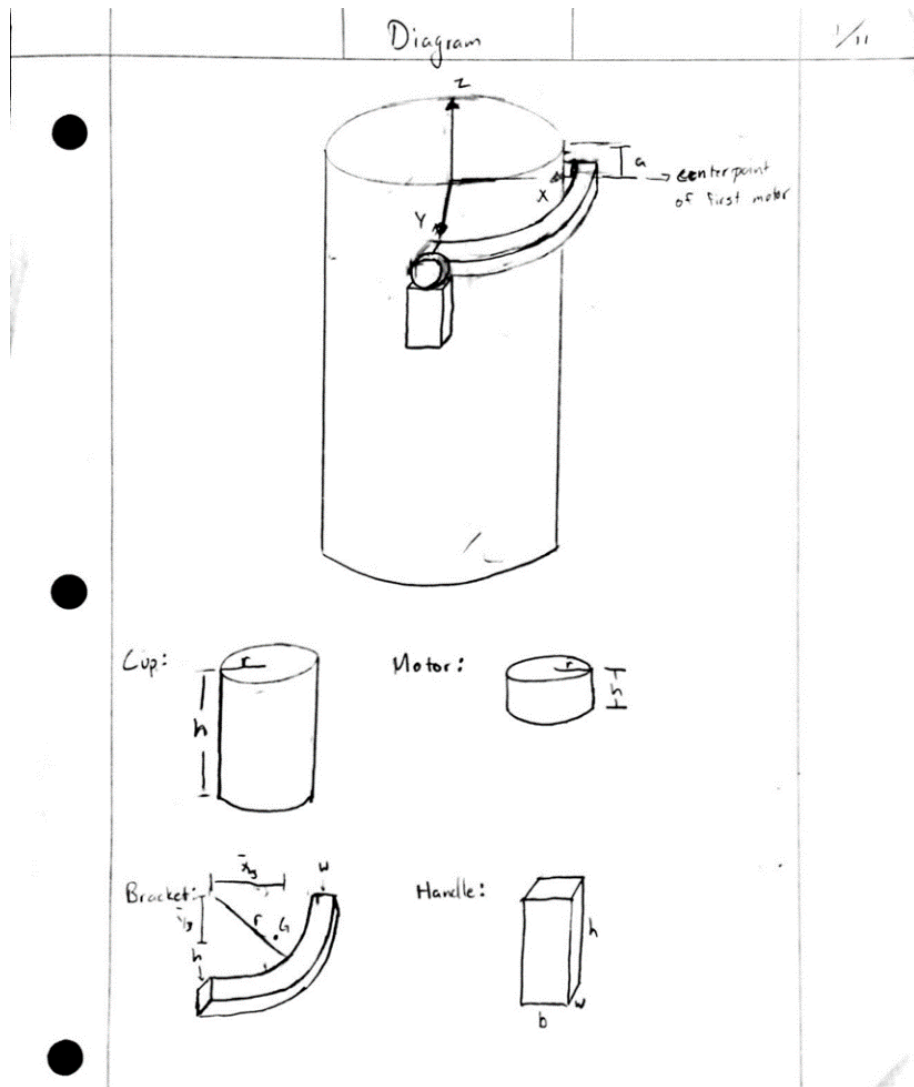


Figure 20: Diagram for 3D Dynamics Analysis

To complete these calculations, we simplified the physical components (mug, mug liner, motors, bracket, and handle) into basic geometry. We input exact values for length, masses, and moments of inertia into a MATLAB script for final calculations. As a result of this analysis, we determined that for a 5-pound tremor force applied to a handle, the two motors controlling the axes of rotation need to apply a torque of 2.94 N-m and 1.26 N-m respectively. We will use this knowledge to select motors rated for high enough torque as we iterate our design further.

5.6 Safety Analysis

We performed a safety analysis on our design to identify potential hazards and failures and plan how to overcome these hazards in our design process. We created a design hazard checklist, which is included in Appendix E, to identify the potential hazards. Main hazards we identified include electrical components being exposed to water and moving linkages creating pinch points for the user. To counteract these hazards, we planned corrective actions for each case. To prevent electrical components from being exposed to water and shorting out, we will conduct performance tests without liquid in the mug. We will also ensure there is no exposed wiring, and that the mug liner is properly installed and watertight before introducing any liquid to the system. To prevent pinch points from harming the user, we ensured that our design minimized pinch points and placed them in areas less likely to affect the user.

After completing our design hazard checklist, we moved on to identify possible failures our design could experience. To do this, we performed a Failure Mode and Effects Analysis (FMEA). The FMEA, which is in Appendix F, breaks down our design into systems and functions, then identifies potential failures of each system and function. By comparing the severity, likelihood, and ease of detection for each failure, we identified which require the most attention moving forward. After completing the FMEA, we determined the most important failure modes are the cup leaking, electronics shorting out, and the code for the controller not working properly. All three of these failures have the potential to injure the user, which is why we are taking steps to ensure the failures will not occur. To make sure the cup does not leak, we are incorporating the watertight cup liner. This will prevent water from leaking down into the electronics, which could result in the user getting shocked and the mug shutting down. We also ensured all cables are properly managed and routed to prevent any unnecessary exposures, which could result in a wire shorting out and delivering a shock to the user. If the code does not work properly, the cup could act abnormally, possibly pinching the user or impacting the user when the cup is lifted to drink. To prevent this, we took extra steps to ensure our controller will work as intended. Dr. Xing assisted our efforts in setting up and tuning our controller, and we were fortunate to be able to use the existing software integrated with our controller board.

5.7 Cost Analysis

Table 5 shows all items used in our structural prototype and the cost of each of them. Our structural prototype came out to be much cheaper than we anticipated because we were able to 3D print all of our custom components. We were able to print for free through the QL+ lab so this drastically brought cost down. Additionally, we found a 2-axis gimbal assembly for a drone on eBay that contained all of the necessary electrical hardware needed to make our mug work for a very low price. Note that in Table 5, Part numbers 10007-10012 were all included in the gimbal assembly purchased on eBay, so the price listed for 10007 is the overall gimbal assembly cost.

Table 5: Cost Analysis of Structural Prototype

Part #	Description	Quantity	Cost	Total Cost
10001	Mug Shell	1	\$0.00	\$0.00
10002	Mug Liner	1	\$0.00	\$0.00
10003	Bracket	1	\$0.00	\$0.00
10004	Handle	1	\$0.00	\$0.00
10005	Mounting Fixture	1	\$0.00	\$0.00
10006	11.1V LiPo Battery	1	\$16.14	\$16.14
10007	Brushless 2-8 Series Motor	2	\$35.72	\$35.72
10008	BGC 3.1 Brushless Gimbal Controller	1	-	-
10009	GY6050 Sensor (IMU)	1	-	-
10010	Motor Cable	2	-	-
10011	IMU Cable	1	-	-
10012	Power Cable	1	-	-
10013	M3x0.5-14mm Socket Head Cap Screw	8	\$0.11	\$0.85
10014	M2x0.4-10mm Socket Head Cap Screw	6	\$0.10	\$0.59
			Total	\$53.30

6.0 Product Implementation and Manufacturing

This chapter outlines the manufacturing and assembly process for all of our mug prototypes. Specifically, it highlights all the necessary materials and parts of our prototypes, as well as procedures for the procurement, manufacturing, and assembly processes. Initially, manufacturing and assembly was organized and carried out by the entire group on the Cal Poly campus, utilizing resources like the Mustang 60 machine shop and the QL+ lab. However, these resources were no longer available to us during the last few months of our project as a result of the COVID-19

pandemic. Fortunately for our group, one team member had access to his own 3D printer. Since the manufacturing of our mug relies on 3D printed parts, we were able to continue iterating and producing prototypes.

6.1 Initial Manufacturing Plan

Our initial plans for manufacturing our mug prototypes were outlined before we began making our structural prototype. We planned to acquire all the necessary parts for our mug from various sources. To manufacture our 3D printed parts, we used the QL+ lab on campus with a Ultimaker 3 printer.

Along with the printed components, we purchased some off the shelf parts to complete our design. The electronic components of the mug were extracted from an FPV 2-Axis Brushless Gimbal meant for GoPro cameras. These components include a controller board, an internal measurement unit (IMU), two motors, and wires to connect everything together. The entire gimbal was purchased online from eBay. The one electrical component not included in the gimbal system was the power supply. For this, we purchased a Tattu 11.1V LiPo battery from Amazon to power the entire system. Finally, to hold the mug together and to integrate the gimbal into our mug, we used M2.5 and M3 screws ordered online from McMaster Carr.

Once we completed building our structural prototype, we were able to test our mug for basic functionality and inspection purposes. After being able to test our design in use and receive feedback, we identified different components of the mug that could be improved on. As a result, a second iteration of our prototype was developed. The changes included in the final prototype are highlighted in the next section.

6.2 Changes for Final Prototype

After the completion of our Critical Design Review (CDR), our first prototype design was iterated to incorporate feedback received during our review, along with implementing certain design changes we felt were necessary for the success of the project. The general design was kept the same, but the new prototype saw changes in the individual parts of the mug. Major design changes included incorporating stronger motors, stabilizing the IMU, and replacing the threaded liner with a key-lock mechanism to simplify manufacturing and product use.

6.2.1 New Motors

Our initial prototype featured two brushless DC motors measuring approximately 22 mm in diameter. Unfortunately, the vendor that provided the GoPro gimbal did not include a specification sheet, so most of the properties of these motors, including voltage, speed, and torque, are not known. However, testing showed us

that these motors did not provide enough torque to support and move the weight of the mug assembly. When the mug was subjected to slight tremors, the motors applied a little bit of power, but were unable to move the mug.

To overcome this problem, we upgraded to larger motors with higher torque outputs. Since we were buying these new motors as a standalone product rather than part of a gimbal system, we were able to look more closely into the specifications of the motors online. The motors we selected for our final design are Tiger GB36-1 Brushless Gimbal Motors, shown in Figure 21. These motors are much more powerful than the initial motors we used, rated at a payload of up to 4.2 pounds each. Due to the different dimensions of these motors, the fitting and sizing holes in our mug body, bracket, and handle were also changed.



Figure 21: Tiger GB36-1 Brushless Gimbal Motors (“Tiger GB36-1 Brushless Gimbal Motor (Hollow Shaft).”)

6.2.2 New 3D Printed Parts

After receiving feedback for our first prototype, the individual components of the mug were updated to reflect the feedback. The bracket, which is shown in Figure 22, was redesigned to have a cleaner interface with the motors it attaches to. Shallow cutouts and radial edges ensure a seamless connection is made, while also improving the aesthetics of the mug and improving user safety. The geometry and dimensions of the bracket were also updated after completing testing on the structural prototype to improve the function of the bracket.



Figure 22: Updated Bracket Design for Final Prototype

As a result of feedback to make the handle more ergonomic and user friendly, the handle experienced another redesign after the completion of CDR. One of the recommendations for our handle was to utilize a horizontal overhang to allow the mug to rest on the hand. This idea was implemented in our new handle, shown in Figure 23, as an enclosed area to grip, similar to a coffee mug. This allows users with limited grip strength to easily pick up and hold the mug. The connection to the motor was changed to allow the edges to sit flush with the motors. The mounting holes were repositioned to align with the new motors, and the resulting bracket was more streamlined and ergonomically pleasing than the original.

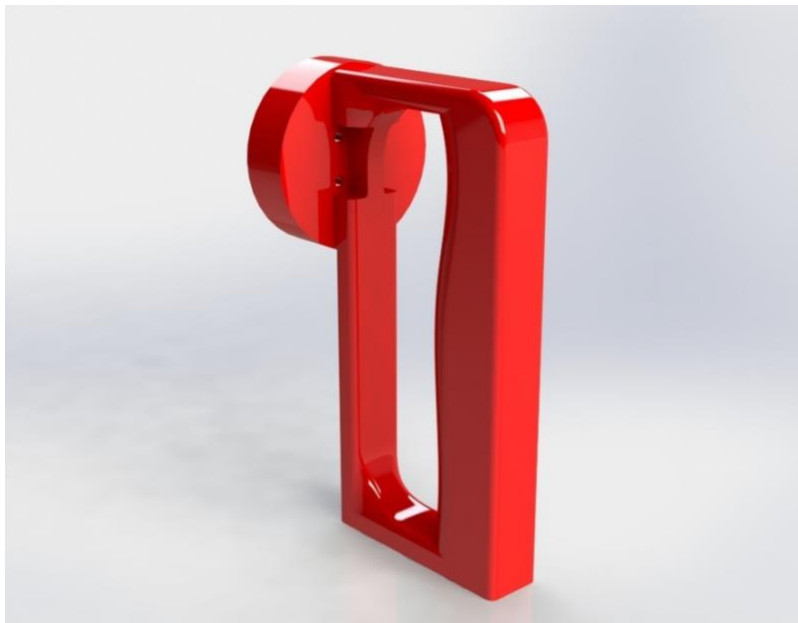


Figure 23: Updated Handle Design for Final Prototype

We decided to improve the detachable liner, specifically the method in which the liner would attach and detach from the mug. The utilization of threads in our structural prototype caused a few problems. First, due to how the liner and base mug were 3D printed, there was an excessive amount of support material printed around the threads. This resulted in the required removal of the support material; a process that was time consuming, labor intensive, and even unsafe depending on the method of removal. Also, the practical use of threads brought up problems. Depending on the quality of print and the quality of removing the support material, the interface of the threads could end up being inadequate for commercial use. Rough edges would cause the threads to be get caught on themselves and due to the material being made of PLA, the thin threads would be susceptible to chip damage or full fracture. As a result of these issues, a new key-lock was designed and implemented. The CAD model of the new liner design are shown in Figure 24. This mechanism is much simpler to use and will be easier to 3D print with high quality. Our final prototype proved these improvements when in use, as the liner is now easier to attach and detach.



Figure 24: Updated Mug Liner Design for Final Prototype

The mug shell geometry was also updated, resulting in thinner walls and the addition of a key-lock notch to allow for easy attachment and removal of the liner. This new mug shell design is shown in Figure 25.



Figure 25: Updated Mug Shell Design for Final Prototype

The mounting fixture, shown in Figure 26, also experienced some major changes. While troubleshooting performance issues with the structural prototype, we discovered a possible solution to the unstable vibrations was to ensure proper alignment and secure fastening of the IMU. To secure the IMU, a secondary structure was designed to attach to the top of the fixture. The remainder of the mounting fixture also featured some geometry updates to ensure it fit within our new mug shell design.



Figure 26: Updated Mounting Fixture Design for Final Prototype

6.2.3 New Final Assembly

An exploded assembly view of our final CAD model is shown in Figure 27, with all major parts and components labeled. It shows how the various components fit together in relation to each other to create our final product.

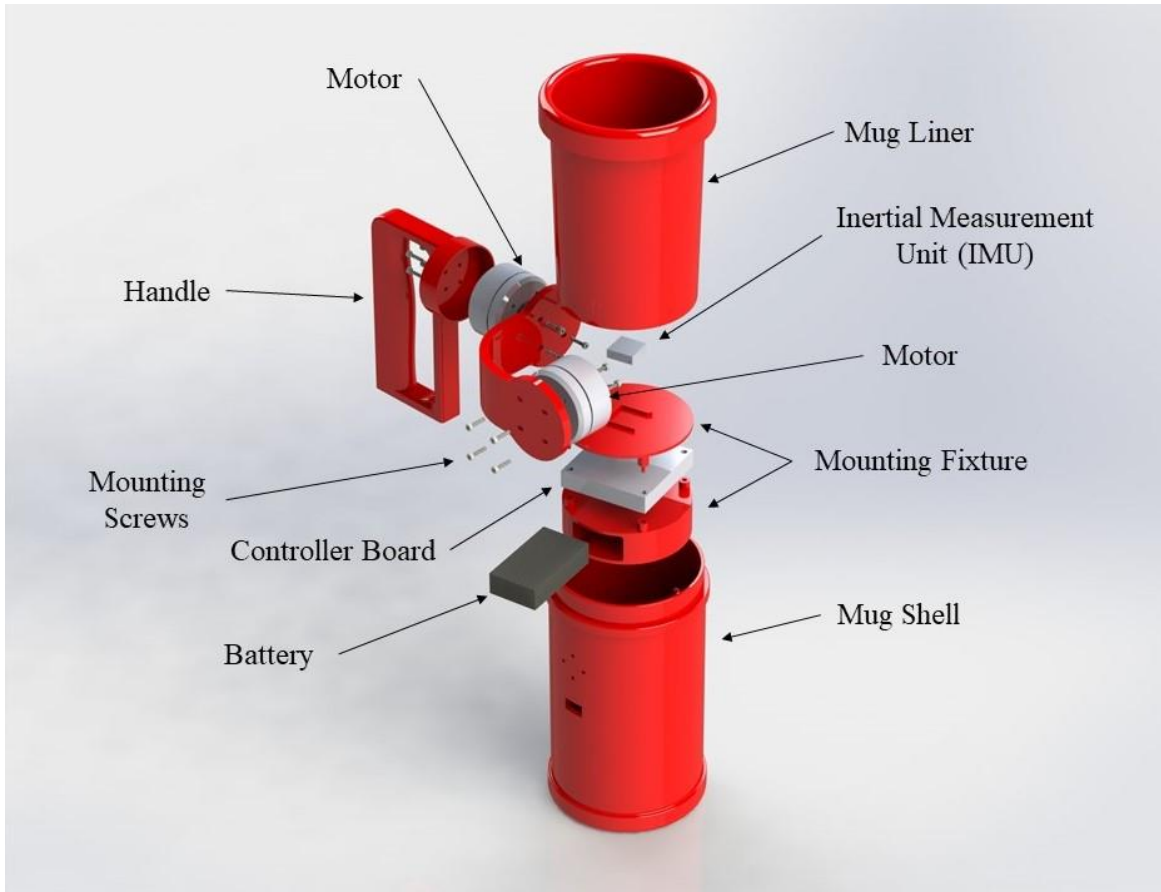


Figure 27: Exploded CAD Assembly View of Final Design

Figure 28 shows the completed, fully assembled CAD model. This shows how the completed design looks when fully integrated.



Figure 28: Completed CAD Assembly for Final Design

Once the final components were all redesigned and 3D printed, they were assembled into the final prototype shown in Figure 29.



Figure 29: Final Prototype of Mug

6.3 3D Printing Process

To produce the custom components needed for our mug design, we utilized a 3D printer. The material we used and designed our model around was 1.75mm PLA as it is easily accessible to many 3D printers. As mentioned previously, two different printers were used in the making of our prototypes. The first is an Ultimaker 3 printer provided by the QL+ Lab. The second printer is the Monoprice Maker Ultimate provided by one of our group mates. Due to the size of our mug components, any printer with at least a 215x215x200mm build volume will work for printing. A picture of the Monoprice Maker Ultimate is provided in Figure 30.

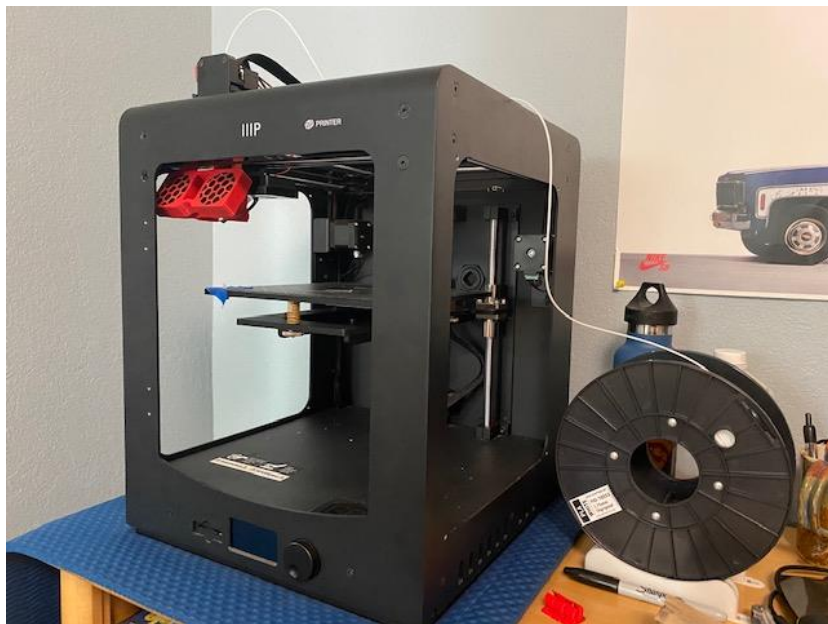


Figure 30: Monoprice Maker Ultimate in Kai's bedroom

Due to the size of our parts, the printing process took about 79.9 hours total to complete all necessary components. This time could be reduced if a larger layer height were used, but we did 0.1mm for better surface finish and part quality. The parts were orientated diagonally when needed for the 3D printing to take up less time as well as use up less support material. A temperature of 205 degrees Celsius was used for the hot end and 70 degrees Celsius for the bed temperature. We upgraded the fans and installed an all metal extruder from micro swiss to make the print quality higher using the Monoprice Maker Ultimate. The process of 3D printing our parts is documented through pictures via Figures 31-33.

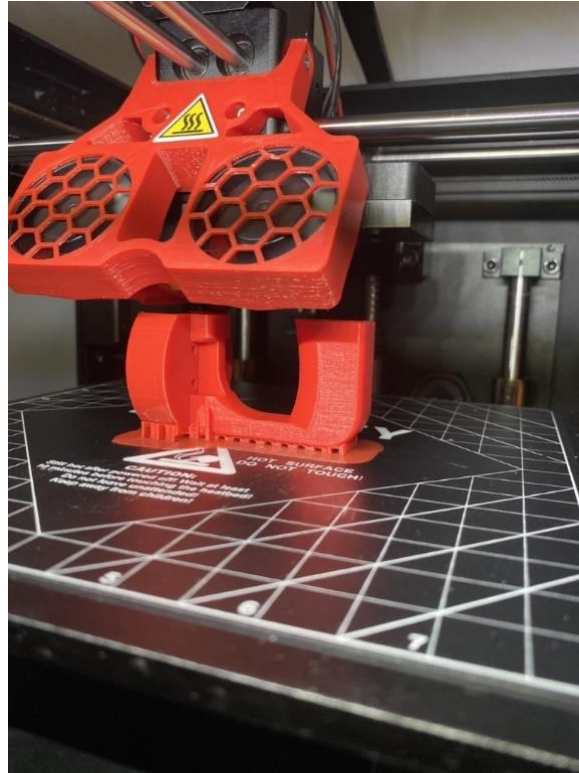


Figure 31. 3D Printer in Process of Printing Mug Handle

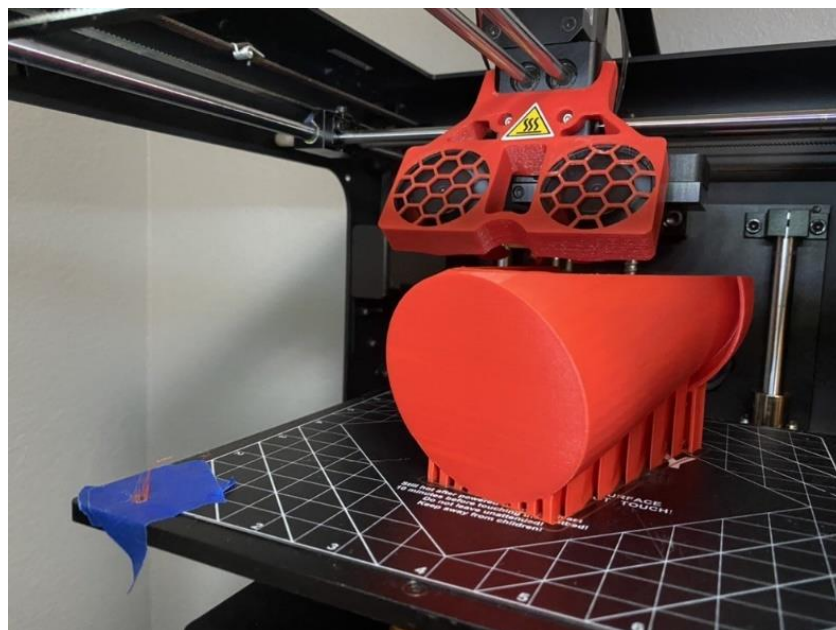


Figure 32. 3D Printer in Process of Printing Mug Body

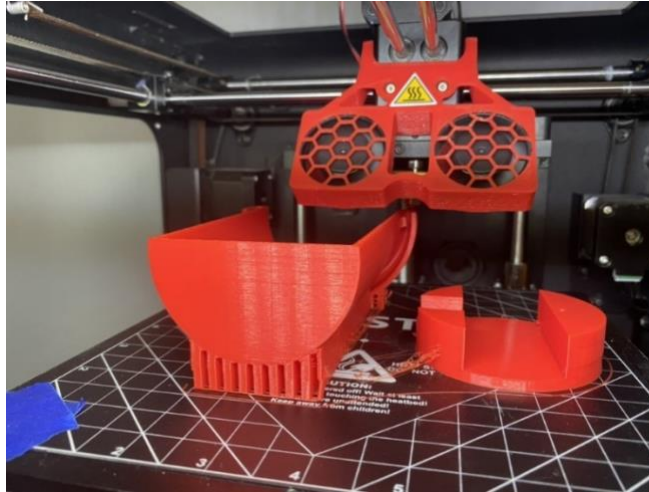


Figure 33. 3D Printer in Process of Printing Mug Liner and Bottom of Mounting Fixture

6.4 Bill of Materials

A final bill of materials is displayed in Table 6. This includes the cost for all components, both purchased and manufactured, that were used in our final prototype. The total cost for manufacturing our final prototype was \$123.28.

Table 6: Bill of Materials

Part #	Description	Quantity	Cost	Total Cost
10001	Mug Shell	1	\$3.66	\$3.66
10002	Mug Liner	1	\$2.89	\$2.89
10003	Bracket	1	\$0.54	\$0.54
10004	Handle	1	\$1.34	\$1.34
10005	Mounting Fixture	1	\$1.15	\$1.15
10006	11.1V LiPo Battery	1	\$16.14	\$16.14
10007	Brushless 2-8 Series Motor	2	\$29.88	\$59.76
10008	BGC 3.1 Brushless Gimbal Controller	1	\$35.72	\$35.72
10009	GY6050 Sensor (IMU)	1	-	-
10010	Motor Cable	2	-	-
10011	IMU Cable	1	-	-
10012	Power Cable	1	-	-
10013	M2.5x0.45-6mm Socket Head Cap Screw	8	\$0.05	\$0.37
10014	M3x0.5-6mm Socket Head Cap Screw	8	\$0.21	\$1.71
			Total	\$123.28

6.5 Operators Manual

We created a detailed operators manual to help with using the mug. It includes instructions for important tasks such as calibrating, using, and cleaning the device. The operator's manual is in Appendix G.

6.6 Assembly Instructions

Due to the flexibility of 3D printing the models we designed, the assembly of the mug only required screws. Detailed drawings for all custom manufactured components and exploded views to aid assembly are in Appendix H. The procedure to put the entire mug together is as follows:

To assemble:

1. Attach 1 of the Tiger Brushless Gimbal Motors to the handle using 4 M2.5x0.45-6mm screws.



Figure 34: Attaching Motor to Handle

2. Attach the other side of the motor to the bracket using 4 M3x0.5-6mm screws.

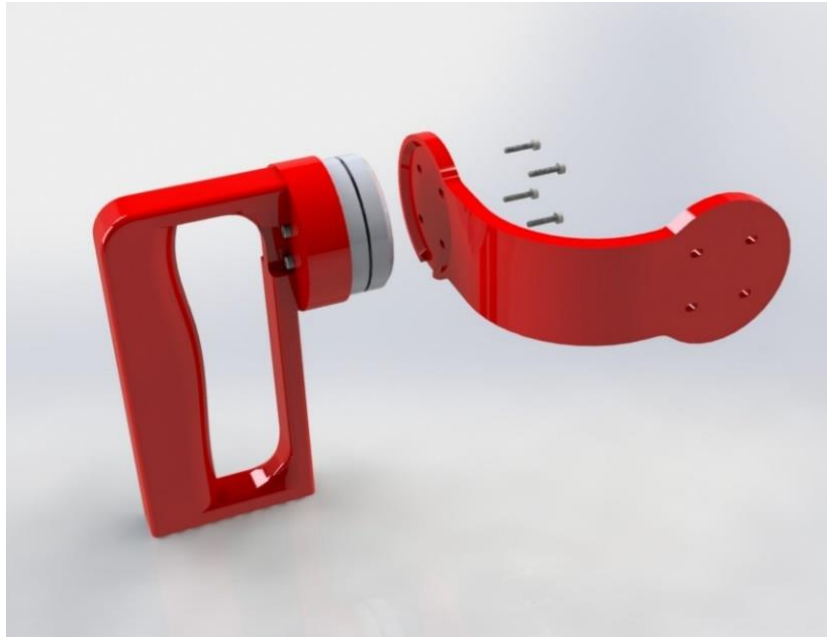


Figure 35: Attaching Bracket to Motor

3. Attach the second motor to the mug body using 4 M2.5x0.45-6mm screws



Figure 36: Attaching Motor to Mug Shell

4. Attach the other side of the motor to the bracket using 4 M3x0.5-6mm screws



Figure 37: Attaching Bracket to Mug Shell

5. Assemble the mounting fixture assembly:
 - a. Secure the battery in the bottom slot of the mounting fixture using tape or other adhesive underneath the battery.
 - b. Secure the controller board in the mounting fixture by attaching the two mounting fixture halves together, with the mounting tabs passing through the controller board mounting holes.
 - c. Secure the IMU to the top of the mounting fixture using tape or other adhesive

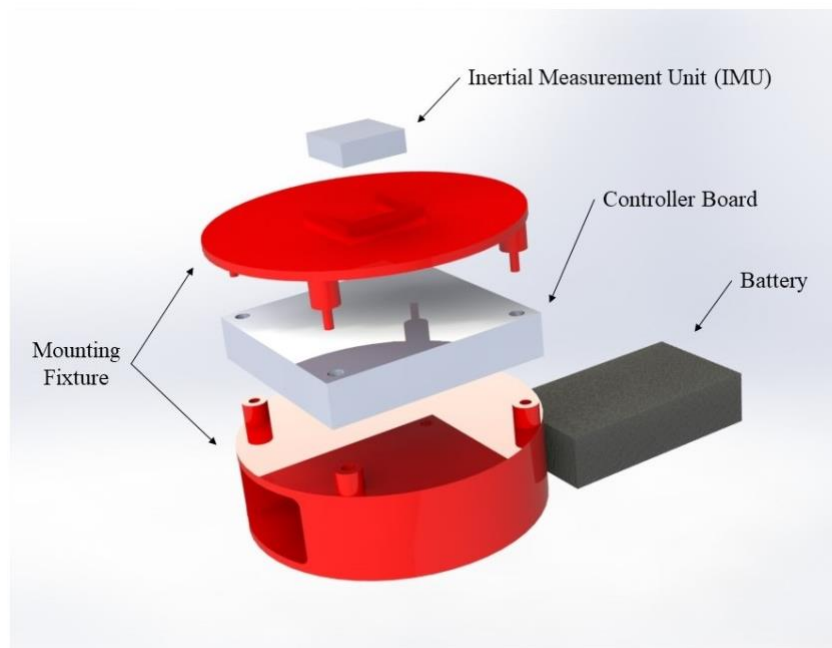


Figure 38: Assembling Mounting Fixture Components

6. Lower the mounting fixture into the mug body. Secure to the bottom of the mug shell by using 1 M3x0.5-6mm screw passing through the bottom of the mug shell and self-tapping into the mounting fixture. Hot glue can be used to secure the fixture into the bottom of the mug as well.



Figure 39: Placing Mounting Fixture Assembly in Mug Shell

7. Use the rectangular cutouts in the mug body to route the wires from the motors to the interior of the body, then attach the motor wires to the corresponding connection pins on the controller board.
8. Insert the mug liner into the mug body, lining up the key-lock tab on the liner with the key-lock cutout on the mug body. Rotate the liner clockwise to secure it in place.

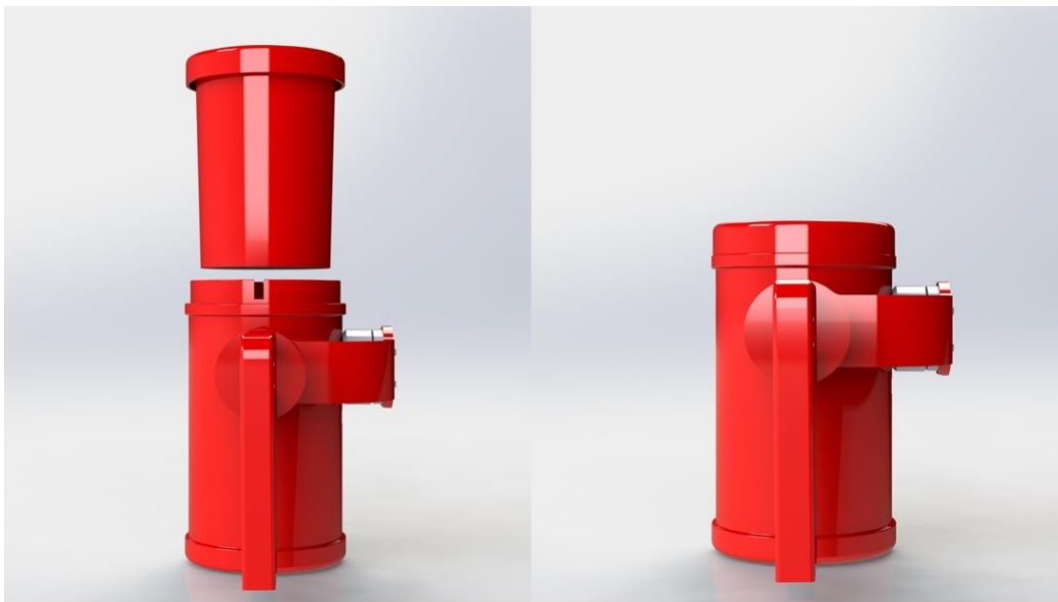


Figure 40: Inserting Mug Liner

Purchased components used in our final prototype:

- 9x M3x0.5-6mm and 8x M2.5x0.45-6mm screws from McMaster Carr
- BGC 3.1 Brushless Drone Gimbal kit from eBay, which was disassembled for its controller board and Inertial Measurement Unit (IMU)
- 11.1 Volt LiPo Battery from Amazon
- 2x Tiger GB36-1 Brushless Gimbal Motors from GetFPV

7.0 Design Verification

As outlined in the Objectives section, we created eight engineering specifications that our design was required to meet. The first one is the overall liquid carrying capacity of 16 ounces. We also wanted to be able to reduce the effect of tremors by 50%. Next, our battery life was set to last for a minimum of one hour and our total production cost at a maximum of \$200. The mug was required to weigh less than five pounds with liquid since weight can impact tremors negatively. The mug was also designed to survive a four-foot drop test and fit within a 6"x4"x4" envelope. Finally, the handle length was required to be 4" to allow for all hand sizes.

Due to COVID-19, our initial design verification plan had to be modified as our project came close to completion. Initially, we had plans to test or verify seven of our engineering specifications. However, due to time and resource restrictions placed on our team due to the uncertainties surrounding the spread of COVID-19, not all of our tests were able to be completed.

The first test completed was mug carrying capacity. We filled the mug liner with water and poured it into a Pyrex liquid measuring cup to ensure we met our requirement of a 16-ounce carrying capacity. Simultaneously, we were confirming that our design did not leak, and successfully contained the water. Both of these checks were successful, so the mug met our first design requirement.

The next test performed was for battery life. By leaving the mug powered on and providing input tremors through hand movements, we were able to verify that our mug could last through a whole meal without becoming dysfunctional. During our test, the mug battery lasted through one hour of continuous use, so it met this design requirement.

The weight of the system was determined by performing a simple inspection using a digital scale. We filled the mug with 16 ounces of water and verified that the mug, water, and all other components weighed less than five pounds collectively. This test was successful, as the mug assembly came out to a total weight of 1.9 pounds.

The last two tests that were performed involved inspections on the size of our design. First, we measured the largest dimensions for length, width, and height using a tape measure. Our specification called for the mug to fit within an envelope of 6"x4"x4". However, due to design changes we made to improve both performance and aesthetics, our final prototype dimensions are 6.15"x7.3"x4.5". Thus, we did not meet this initial design requirement. We also measured the

handle to ensure the grip area is large enough to accommodate most hand sizes. We used calipers to measure the height of the grip to compare to our 4-inch specification. Since the measured height was within 0.25 inches of our target 4 inches, we considered this specification met.

The two remaining design specifications were unable to be tested and verified due to the changing circumstances we faced as the project neared completion. Both tremor reduction tests and a structural drop test relied on access to materials or resources that we were unable to obtain.

To test the tremor reduction of our system, we planned on using a high-speed camera to record an input into the handle and measure the angle that the mug itself moves. We were planning on using Cal Poly faculty member Dr. John Chen's high-speed camera to run this test. However, due to campus being shut down, we were unable to gain access to this high-speed camera or any other one.

We planned on performing a drop test to ensure structural rigidity. By dropping the mug on a smooth concrete floor from a height of four feet and then powering the device on, we would be able to ensure it still works properly after experiencing a shock impact, which is a possible situation to occur during actual use. However, due to time restraints and the challenges of working remotely, we were unable to perform the drop test. We had limited access to supplies, so our team did not want to break a controller board or other component, which would prevent us from having a working prototype at the time of the senior project expo.

Our Design Verification Plan and Report can be seen in Appendix I. This document outlines each specification, the acceptance criteria, and the dates that each test was performed.

8.0 Project Management

While designing the mug for tremors our biggest task was making it compact, attractive, and effective. The technology used to stabilize objects is already well engineered. Accelerometers are found in devices from drones to cell phones; however, getting all the electrical and mechanical components in a lightweight device that contains liquid is the main challenge. After understanding all of the electrical workings of accelerometers, motors, and computer chips used, we began to design a mug that can effectively conceal these components and reduce the effect of the tremors. Rapid prototyping was key in iterating our design and finding clever space saving solutions. Once we find a suitable design that holds the electronics and is aesthetically pleasing, we continued to fine tune the controller in order to reduce tremors as effectively as possible. As we iterated the design to reduce more tremors and cut down on weight, we narrowed down to the final device that is being presented to our challenger.

As we went through the design process, many deliverables were created to ensure our sponsor, Melissa Oliver, knew our progress and could approve our design choices. Descriptions and submission dates for the major reports are in Table 7. A more detailed plan for what we have accomplished this year can be seen in our final Gantt Chart in Appendix J. This chart helped us break down our project into smaller steps and keep track of our progress along the way.

Table 7: Project Timeline

Deliverable	Description	Date
Preliminary Design Review	Initial design direction for approval	1/27/2020
Critical Design Review	Detailed design of updated solution with part drawings and costs	3/6/2020
Manufacture and Testing Review	Manufacturing plan, test manuals, and updated status of project	3/12/2020
Operational Manual	Document safety hazards and how to operate effectively	5/8/2020
Final Design Review	Final design, prototype, and report for presentation	6/5/2020

Due to the unfortunate events caused by COVID-19, we were unable to implement all of our design ideas. If we had been able to meet in person and have access to Cal Poly’s resources, we would have included a power button, an even better-looking design, and understand the software better in order to make our mug effective. We would have also liked to include a button or lever to be pushed while drinking to allow the mug to tip in one axis. If this project is extended to future teams, these are the new implementations that should be added and improved upon.

9.0 Conclusion

When we started this project, we were tasked with delivering an effective, lightweight, and aesthetically pleasing product to solve the current issues veterans with hand tremors face when drinking liquids. This document outlines our background research, specification development, and concept design process, along with the iterations we took to reach a final design. Due to changing circumstances regarding COVID-19, we were unable to deliver a fully calibrated product that is as effective as we hoped to our sponsor. However, we finalized a compact, aesthetically pleasing design with all the hardware and electronic components needed to make this mug an effective solution to reducing hand tremors.

After completing this project, there are several design changes and improvements our team would make if given more time, or if COVID-19 did not drastically change the final few months of our design time.

Unfortunately, our team was unable to tune the system as well as we would like. While the hardware and electrical components are integrated in a cohesive unit, the software that came installed on the controller board does not yet properly stabilize the mug. Since none of our team has experience with gimbals or software of this kind, we were unable to properly calibrate and set up the software. Additionally, our team was working remotely the last few months of the design process and we were unable to bring the product to Cal Poly faculty because campus was shut

down. Thus, we were not able to get technical advice from someone with more knowledge on the subject. We feel that properly calibrating and setting up the software for the mug would be a relatively simple and quick task for someone with experience, so we hope in the future that this design can be easily replicated and improved upon.

Additionally, if given more time to iterate until reaching a final design, our team would have optimized the motors to be more compact. More time for testing and feedback would have allowed us to find motors that were smaller than the ones currently selected, but still able to handle the loads imposed on the mug during use. If more compact motors were selected in the future, mounting holes on the bracket, handle, and mug shell would need to be updated to interface with the new motors.

Currently, the design does not feature a button or lever to disengage the motors. Adding this feature and disengaging the motors in one axis of rotation would make it much easier for users to tilt and drink from the mug. The software we currently use for tuning and calibrating the system has a parameter to add input signals from buttons and switches, so we feel it would be very straightforward to incorporate a small button on the handle that locks the rotation of the mug along one axis when pressed.

Another improvement that could be made is the addition of dishwasher safe mug liners. Our team researched using silicone molds to create mug liners that were effective, cheap to manufacture, and easier to clean than the existing 3D printed liner. However, due to time restraints and COVID-19, we were unable to pursue this any further. This could be a great way to turn the mug into a more polished, consumer ready product that is easy for users of all abilities to maintain and use.

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Appendices

- A. Table of Patents
- B. Quality Function Deployment (QFD)
- C. Bracket Stress Calculations
- D. Motor Torque Calculations
- E. Design Hazard Checklist
- F. FMEA
- G. Operators Manual
- H. Drawing Package
- I. Design Verification Plan
- J. Gantt Chart

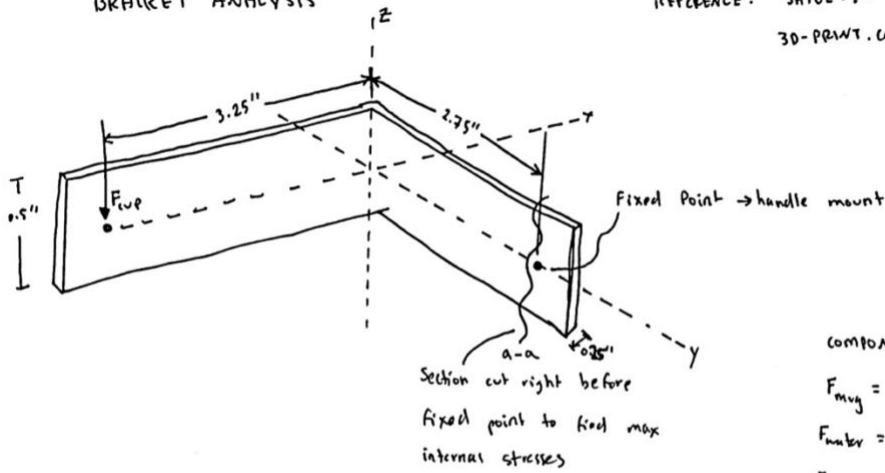
Appendix A: Table of Patents

Patent Number	Patent Title	Description
US4052654A	Gyro stabilized inertial reference system with gimbal lock prevention means	This patent is about how a gyro allows freedom of rotation around the three axes and how to lock certain axes of rotations.
US20110005085A1	Eating Devices Which Reduce Tremors of the Hand	This patent changes the grip of how you hold silverware to help reduce tremors. It has a larger handle so someone could have more control of the silverware and not need to bend their wrist at strange angles
WO2007077009A2	Device for preventing undesired spilling of liquids from a container	A patent for a device that won't spill using physical barriers instead of electronics. A mechanical/geometric solution to no spillage.
US4130215A	No spill beverage cup	This cup uses inner baffles that prevent liquid from splashing out. These baffles have holes to allow liquid to flow through for drinking but not allow water to spill out of the cup when jostled.
US8179078B2	Handheld or vehicle-mounted platform stabilization system	This patent is about the technology used to stabilize cameras for movies, TV, and other purposes. It uses two gimbal frames to keep the camera from shaking.

Appendix C: Bracket Stress Calculations

BRACKET ANALYSIS

REFERENCE: SHIBLY'S
3D-PRINT.COM

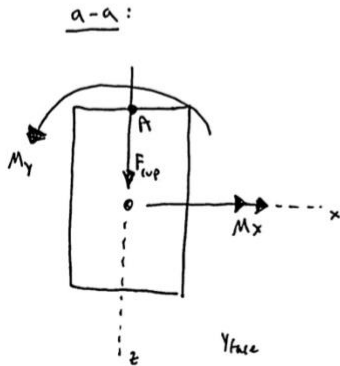


COMPONENTS:

$$F_{mug} = 1lb$$

$$F_{handle} = 1lb$$

$$F_{electronics} = 1lb$$



$$F_{cup} = F_{mug} + F_{handle} + F_{electronics}$$

$$F_{cup} = 3lb$$

$$M_y = (F_{cup})(3.25in)$$

$$M_y = 9.75 lb \cdot in$$

$$M_x = (F_{cup})(2.75in)$$

$$M_x = 8.25 lb \cdot in$$

STRESS MATRIX @ A

$$\begin{bmatrix} 0 & 1169 & 0 \\ 1169 & 793 & 36 \\ 0 & 36 & 0 \end{bmatrix}$$

$$\tau_{xy} = \frac{-M_y}{(0.267)(0.5)(0.15)^2} = 1169.05 lb/in^2$$

$$I = \frac{1}{12}(0.25)(0.5)^3$$

$$\tau_{zy} = \frac{3F_{cup}}{2(0.5)(0.25)} = 36 lb/in^2$$

$$I = 0.0026 in^4$$

$$\sigma_{yy} = \frac{(M_x)(0.25)}{0.0026} = 793.27 lb/in^2$$

VON MISES

$$\sigma' = \frac{1}{\sqrt{2}} \left[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2) \right]^{1/2}$$

For PLA Plastic:

$$S_u = 4771 lb/in^2$$

$$\sigma' = \frac{1}{\sqrt{2}} \left[2\sigma_y^2 + 6(\tau_{xy}^2 + \tau_{zy}^2) \right]^{1/2}$$

FACTOR OF SAFETY:

$$F.S. = \frac{S_u}{\sigma'} = 2.2$$

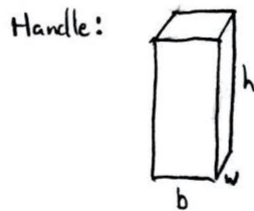
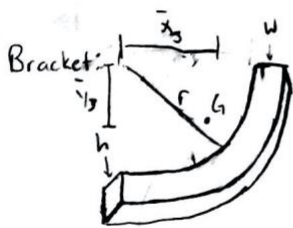
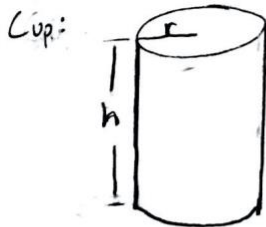
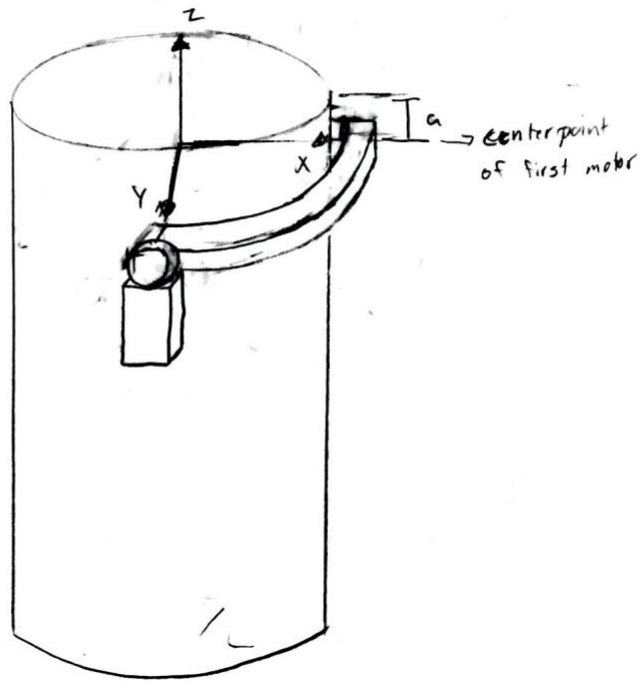
$$\sigma' = 2174.7 \text{ psi max stress}$$

$$FS = 2.2$$

Appendix D: Motor Torque Calculations

Diagram

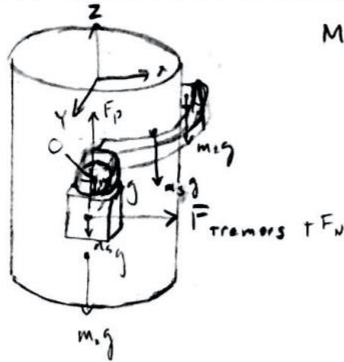
1/11



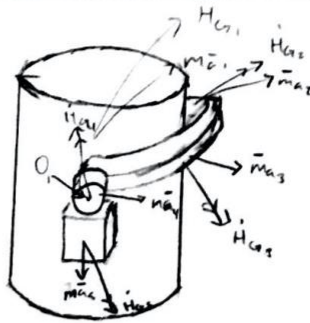
α - Motor γ - P_2 axis

2/11

FBD:



MAD:



$$\left(\sum \vec{M}_O \right)_{FBD} = \left(\sum \vec{M}_O \right)_{MAD}$$

$\rightarrow F_N$ at a value that negates $m_2 g$ force, so $\vec{M}_{F_N} = \vec{M}_{m_2 g}$

* Only care about α in γ -axis (simplifying)

$$\hat{j} : \left(F_p \times \phi \right) \hat{j} + \left(F_T \times \left(\frac{h_2}{2} + r_4 \right) \right) \hat{j} + \left(m_1 g \times \phi \right) \hat{j} + \left(m_2 g \times \left(r_1 + \frac{h_2}{2} \right) \right) \hat{j}$$

$$- \left(m_3 g \times \bar{x}_3 \right) - \left(m_4 g \times \phi \right) + \left(m_5 g \times \phi \right) + \left(F_N \times \left(\frac{h_2}{2} + r_4 \right) \right) \hat{j}$$

$$= \sum \left[\dot{H}_G \right]_{xyz} + \vec{Q} \times \vec{H}_G + \vec{r}_{G_i/O} \times m_i \vec{a}_i \quad \left| \quad \dot{H}_G \right]_{xyz} = [\bar{I}_G] \alpha$$

$$\vec{a} = \alpha \times \vec{r}_{G_i/O} + \omega \times \omega \times \vec{r}$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} 0 \\ \alpha_y \\ 0 \end{bmatrix} + \left\langle - \left(\frac{h_2}{2} + r_3 + w_3 \right) \hat{j} - \left(\frac{h_2}{2} - a \right) \hat{k} \right\rangle \times m_1 \left(\alpha_y \hat{j} \times \left\langle - \left(\frac{h_2}{2} + r_3 + w_3 \right) \hat{j} - \left(\frac{h_2}{2} - a \right) \hat{k} \right\rangle \right)$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} 0 \\ \alpha_y \\ 0 \end{bmatrix} + \left\langle r_1 + \frac{h_2}{2} \right\rangle \hat{i} - \left\langle \frac{h_2}{2} + r_3 + w_3 \right\rangle \hat{j} \times m_2 \left(\alpha_y \hat{j} \times \left\langle r_1 + \frac{h_2}{2} \right\rangle \hat{i} - \left\langle \frac{h_2}{2} + r_3 + w_3 \right\rangle \hat{j} \right)$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} 0 \\ \alpha_y \\ 0 \end{bmatrix} + \left\langle \bar{x}_3 \hat{i} - \left(\frac{h_2}{2} + r_3 + w_3 \right) \hat{j} \right\rangle \times m_3 \left(\alpha_y \hat{j} \times \left\langle \bar{x}_3 \hat{i} - \left(\frac{h_2}{2} + r_3 + w_3 \right) \hat{j} \right\rangle \right)$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} 0 \\ \alpha_y \\ 0 \end{bmatrix} + \phi \times m_4 \left(\alpha \times \phi \right)$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{xy} & I_{yy} & I_{yz} \\ I_{xz} & I_{yz} & I_{zz} \end{bmatrix} \begin{bmatrix} 0 \\ \alpha_y \\ 0 \end{bmatrix} + \left\langle - \left(r_4 + \frac{h_2}{2} \right) \hat{k} \right\rangle \times m_5 \left(\alpha_y \hat{j} \times \left\langle - \left(r_4 + \frac{h_2}{2} \right) \hat{k} \right\rangle \right)$$

α - Motor y-axis Pg 2 > 0 (check if $\sum M_F = 0$)

$$\left(\frac{F_1 h_5}{2} + F_1 r_4 \right) \hat{j} - \left[(m_2 g r_1 + \frac{m_2 g h_2}{2}) \hat{j} + (m_3 g \bar{x}_3) \hat{j} + (F_N (\frac{h_5}{2} + r_4)) \hat{k} \right]$$

$\sum M_F = 0$
assum
is valid

$$I_{yy_1} \alpha_y \hat{j} + \bar{m}_1 \alpha_y (\frac{h_1}{2} - a)^2 \hat{j} - \bar{m}_1 \alpha_y (\frac{h_1}{2} - a) (\frac{h_1}{2} + r_3 + w_3) \hat{k}$$

$$+ \bar{m}_2 \alpha_y (\frac{h_2}{2} + r_3 + w_3) (r_1 + \frac{h_2}{2}) \hat{i} + I_{yy_2} \alpha_y \hat{j} + m \alpha_y (r_1 + \frac{h_2}{2})^2 \hat{j}$$

$$+ \alpha_y \bar{x}_3 (\frac{h_3}{2} + \bar{r}_3) \hat{i} + [I_{yy_3} + I_{yy_3} + I_{yy_3}] \alpha_y \hat{j} + \alpha_y \bar{x}_3^2 \hat{j}$$

$$+ I_{yy_4} \alpha_y \hat{j} + I_{yy_5} \alpha_y \hat{j} + m \alpha_y (r_4 + \frac{h_5}{2})^2 \hat{j} + m_5 \alpha_y (r_4 + \frac{h_5}{2}) (r_3 + w_3 + \frac{h_4}{2}) \hat{k}$$

$$\hat{j} : \frac{F_1 h_5}{2} + F_1 r_4 + m_2 g r_1 + \frac{m_2 g h_2}{2} + m_3 g \bar{x}_3 = I_{yy_5}$$

$$I_{yy_1} \alpha_y + \bar{m}_1 \alpha_y (\frac{h_1}{2} - a)^2 + I_{yy_2} \alpha_y + m_2 \alpha_y (r_1 + \frac{h_2}{2})^2$$

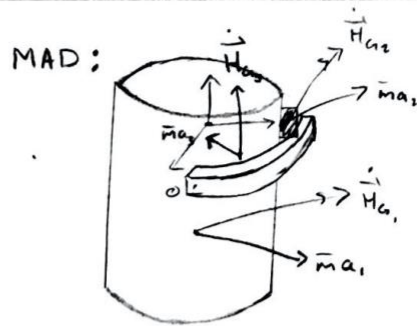
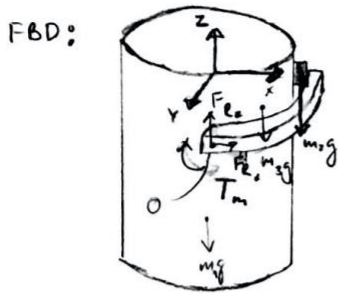
$$+ [I_{yy_3} + I_{yy_3} + I_{yy_3}] \alpha_y + \alpha_y \bar{x}_3^2 + I_{yy_4} \alpha_y + I_{yy_5} \alpha_y$$

$$+ m \alpha_y (r_4 + \frac{h_5}{2})^2 + m_5 \alpha_y (r_4 + \frac{h_5}{2}) (r_3 + w_3 + \frac{h_4}{2})$$

$$F_1 (\frac{h_5}{2} + r_4) = \alpha_y \left[I_{yy_1} + \bar{m}_1 (\frac{h_1}{2} - a)^2 + I_{yy_2} + \bar{m}_2 (r_1 + \frac{h_2}{2})^2 \right. \\ \left. + (I_{yy_3} + I_{yy_3} + I_{yy_3}) + \bar{x}_3^2 + I_{yy_4} + I_{yy_5} + m_5 (r_4 + \frac{h_5}{2})^2 \right]$$

Theorizing: α_y should be positive

$$\alpha_y = F_1 \frac{(\frac{h_5}{2} + r_4)}{[I_{yy_1} + I_{yy_2} + I_{yy_3} + I_{yy_4} + I_{yy_5} + I_{yy_3} + I_{yy_3} \\ + \bar{m}_1 (\frac{h_1}{2} - a)^2 + \bar{m}_2 (r_1 + \frac{h_2}{2})^2 + \bar{x}_3^2 + m_5 (r_4 + \frac{h_5}{2})^2 \\ + m_5 (r_4 + \frac{h_5}{2}) (r_3 + w_3 + \frac{h_4}{2})]}$$



$$(\sum \vec{M}_o)_{FBD} = (\sum \vec{M}_o)_{MAD}$$

* α solved, so solve for T_m

* α going in negative direction to counteract acc. caused by tremors

$$\hat{j}: -T_m \hat{j} - (m_3 g \bar{x}_3) \hat{j} - m_2 g (r_1 + \frac{h_2}{2}) \hat{j} = \sum \left[(\dot{H}_{c1})_{xyz} + \vec{r}_{c1/o} \times \vec{m} \dot{a}_1 \right]$$

$$- [T_m + m_3 g \bar{x}_3 + m_2 g (r_1 + \frac{h_2}{2})] \hat{j} =$$

$$\left[\begin{array}{ccc} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{array} \right] \begin{bmatrix} 0 \\ -\alpha_y \\ 0 \end{bmatrix}_1 + \langle -(\frac{h_1}{2} + r_1 + w_3) \hat{j} - (\frac{h_1}{2} - a) \hat{k} \rangle \times \bar{m}_1 \langle -\alpha_y \hat{j} \rangle \times \langle -(\frac{h_1}{2} + r_1 + w_3) \hat{j} - (\frac{h_1}{2} - a) \hat{k} \rangle$$

$$\left[\begin{array}{ccc} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{array} \right] \begin{bmatrix} 0 \\ -\alpha_y \\ 0 \end{bmatrix}_2 + \langle (r_1 + \frac{h_2}{2}) \hat{j} - (\frac{h_1}{2} r_1 + w_3) \hat{j} \rangle \times \bar{m}_2 \langle -\alpha_y \hat{j} \rangle \times \langle (r_1 + \frac{h_2}{2}) \hat{j} - (\frac{h_1}{2} + r_1 + w_3) \hat{j} \rangle$$

$$\left[\begin{array}{ccc} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{array} \right] \begin{bmatrix} 0 \\ -\alpha_y \\ 0 \end{bmatrix}_3 + \langle \bar{x}_3 \hat{i} - (\frac{h_1}{2} + \bar{y}_3) \hat{j} \rangle \times \bar{m}_3 \langle -\alpha_y \hat{j} \rangle \times \langle \bar{x}_3 \hat{i} - (\frac{h_1}{2} + \bar{y}_3) \hat{j} \rangle$$

$$- [T_m + m_3 g \bar{x}_3 + m_2 g (r_1 + \frac{h_2}{2})] \hat{j} = -\alpha_y [I_{yy1} + I_{yy2} + I_{yy3} + I_{yy4} + I_{yy5}]$$

$$+ [-m_1 \alpha_y (\frac{h_1}{2} - a)^2 \hat{j} - m_2 \alpha_y (r_1 + \frac{h_2}{2})^2 \hat{j} - m_3 \alpha_y \bar{x}_3^2 \hat{j}]$$

$$T_m = \left[\alpha_y \left(I_{yy1} + I_{yy2} + I_{yy3} + I_{yy4} + I_{yy5} + m_1 (\frac{h_1}{2} - a)^2 + m_2 (r_1 + \frac{h_2}{2})^2 + m_3 \bar{x}_3^2 \right) \right] - \left[m_2 g (r_1 + \frac{h_2}{2}) + m_3 g \bar{x}_3 \right]$$

Y-axis

$$1: \begin{pmatrix} 0 & \alpha_y & 0 & 0 & \alpha_y \\ 0 & \frac{h_y}{2} - (\frac{h_x}{2} - a) & 0 & -h_y & 0 \\ 0 & -(\frac{h_y}{2} + r_3 + w_3) & -(\frac{h_x}{2} - a) & a & -(\frac{h_y}{2} + r_3 + w_3) \\ -\bar{m}_1 \alpha_y (\frac{h_x}{2} - a) & 0 & 0 & -\bar{m}_1 \alpha_y (\frac{h_x}{2} - a) & 0 \end{pmatrix} \Rightarrow -\bar{m}_1 \alpha_y (\frac{h_x}{2} - a) \hat{i}$$

$$0 \hat{i} + \bar{m}_1 \alpha_y (\frac{h_x}{2} - a)^2 \hat{j} - \bar{m}_1 \alpha_y (\frac{h_x}{2} - a) (\frac{h_y}{2} + r_3 + w_3) \hat{k}$$

$$2: \begin{pmatrix} 0 & \alpha_y & 0 & 0 & \alpha_y \\ r_1 + \frac{h_x}{2} & \frac{h_y}{2} & 0 & r_1 + \frac{h_x}{2} & -(\frac{h_y}{2} + r_3 + w_3) \\ r_1 + \frac{h_x}{2} & -(\frac{h_y}{2} + r_3 + w_3) & 0 & r_1 + \frac{h_x}{2} & -(\frac{h_y}{2} + r_3 + w_3) \\ 0 & 0 & -m_2 \alpha_y (r_1 + \frac{h_x}{2}) & 0 & 0 \end{pmatrix} - \alpha_y (r_1 + \frac{h_x}{2}) \hat{k}$$

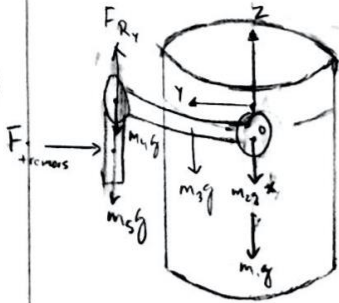
$$m \alpha_y (\frac{h_y}{2} + r_3 + w_3) (r_1 + \frac{h_x}{2}) \hat{i} + m \alpha_y (r_1 + \frac{h_x}{2})^2 \hat{j} + 0 \hat{k}$$

$$3: \begin{pmatrix} 0 & \alpha_y & 0 & 0 & \alpha_y \\ \bar{x}_3 & -(\frac{h_y}{2} + \bar{y}_3) & 0 & \bar{x}_3 & -(\frac{h_y}{2} + \bar{y}_3) \\ \bar{x}_3 & -(\frac{h_y}{2} + \bar{y}_3) & 0 & \bar{x}_3 & -(\frac{h_y}{2} + \bar{y}_3) \\ 0 & 0 & -\alpha_y \bar{x}_3 & 0 & 0 \end{pmatrix} \Rightarrow -\alpha_y \bar{x}_3 \hat{k}$$

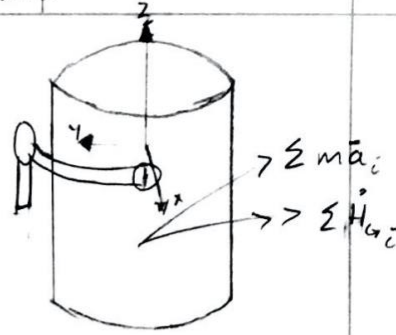
$$\alpha_y \bar{x}_3 (\frac{h_y}{2} + r_3 + w_3) \hat{i} + \alpha_y \bar{x}_3^2 \hat{j} + 0 \hat{k}$$

$$5: \begin{pmatrix} 0 & \alpha_y & 0 & 0 & \alpha_y \\ 0 & 0 & -(r_4 + \frac{h_x}{2}) & 0 & 0 \\ 0 & 0 & -(r_4 + \frac{h_x}{2}) & 0 & 0 \\ -m \alpha_y (r_4 + \frac{h_x}{2}) & 0 & 0 & -m \alpha_y (r_4 + \frac{h_x}{2}) & 0 \end{pmatrix} \Rightarrow -\alpha_y (r_4 + \frac{h_x}{2}) \hat{i}$$

$$0 \hat{i} + m \alpha_y (r_4 + \frac{h_x}{2})^2 \hat{j} + 0 \hat{k}$$



* Actual Drawing Attached



$$(\sum \vec{M}_0)_{FBD} = (\sum \vec{M}_0)_{MAD} \quad \left\{ \begin{array}{l} \text{only care for dynamic forces (F}_{FRy}\text{),} \\ \text{so } \sum M_{FRy} - \sum M_{mg_i} = 0 \text{ (i.o. ignore } FRy\text{ /} \\ \text{mg}_i \text{ for calcs)} \end{array} \right.$$

$$F_c \left(\frac{h_1}{2} + r_1 \right) \hat{i} = \sum \left[(\dot{H}_G)_{x,y,z} + \vec{\omega} \times \vec{H}_G + \vec{r}_{G_i/0} \times m \ddot{\vec{a}}_i \right] \quad \left(\dot{H}_G \right)_{x,y,z} = [I_G] \alpha$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha_x \\ 0 \\ 0 \end{bmatrix} + \langle -(r_1 + \frac{h_2}{2}) \hat{i} - (\frac{h_1}{2} - a) \hat{k} \rangle \times \langle \bar{m}_1 (\alpha_x \hat{i} \times \langle -(r_1 + \frac{h_2}{2}) \hat{i} - (\frac{h_1}{2} - a) \hat{k} \rangle) \rangle$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha_x \\ 0 \\ 0 \end{bmatrix} + \vec{r} \times m (\alpha \vec{r})$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha_x \\ 0 \\ 0 \end{bmatrix} + \langle -(\frac{h_2}{2} + r_1 - \bar{x}_3) \hat{i} + \bar{y}_3 \hat{j} \rangle \times \langle \bar{m}_3 (\alpha_x \hat{i} \times \langle -(\frac{h_2}{2} + r_1 - \bar{x}_3) \hat{i} + \bar{y}_3 \hat{j} \rangle) \rangle$$

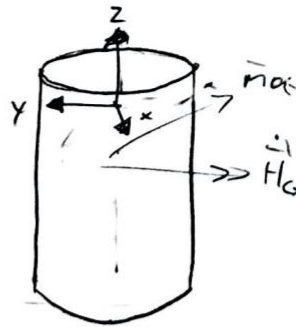
$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha_x \\ 0 \\ 0 \end{bmatrix} + \langle -(r_1 + \frac{h_2}{2}) \hat{i} + (r_3 + w_3 + \frac{h_4}{2}) \hat{j} \rangle \times \langle \bar{m}_4 (\alpha_x \hat{i} \times \langle -(r_1 + \frac{h_2}{2}) \hat{i} + (r_3 + w_3 + \frac{h_4}{2}) \hat{j} \rangle) \rangle$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \begin{bmatrix} \alpha_x \\ 0 \\ 0 \end{bmatrix} + \langle -(r_1 + \frac{h_2}{2}) \hat{i} + (r_3 + w_3 + \frac{h_4}{2}) \hat{j} - (r_2 + \frac{h_5}{2}) \hat{k} \rangle \times \langle \bar{m}_5 (\alpha_x \hat{i} \times \langle -(r_1 + \frac{h_2}{2}) \hat{i} + (r_3 + w_3 + \frac{h_4}{2}) \hat{j} - (r_2 + \frac{h_5}{2}) \hat{k} \rangle) \rangle$$

$$\hat{i}: F_c \left(\frac{h_1}{2} + r_1 \right) = \alpha_x \left[\frac{I_{xx_1} + I_{xx_2} + I_{xx_3} + I_{xx_4} + I_{xx_5} + I_{yy_3} + I_{zz_3}}{+ m_1 \left(\frac{h_1}{2} - a \right)^2 + m_3 \bar{y}_3^2 + m_4 \left(r_3 + w_3 + \frac{h_4}{2} \right)^2 + m_5 \left(r_2 + \frac{h_5}{2} \right)^2} \right]$$



* Dynamic Forces Only



$$(\sum \vec{M}_O)_{FBD} = (\sum \vec{M}_O)_{MAD}$$

$$-T_m \hat{i} = \sum \left[(\dot{\vec{H}}_G)_{xyz} + \vec{\omega} \times \vec{H}_G + \vec{r}_{G/O} \times m \vec{a}_G \right]$$

$$= \begin{bmatrix} I_{xx} & I_{xy} & I_{yz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{xz} & I_{yx} & I_{zz} \end{bmatrix} \begin{bmatrix} -\alpha_x \\ 0 \\ 0 \end{bmatrix} + \langle -r_1 \hat{i} - \frac{h_1}{2} \hat{k} \rangle \times m \langle \alpha_x \hat{i} \times (-r_1 \hat{i} - \frac{h_1}{2} \hat{k}) \rangle$$

$$\begin{aligned} & \begin{bmatrix} -\alpha_x & 0 & 0 & -\alpha_x & 0 \\ -r_1 & 0 & -\frac{h_1}{2} & -r_1 & 0 \\ -r_1 & 0 & -\frac{h_1}{2} & -r_1 & 0 \\ 0 & -\alpha_x \frac{h_1}{2} & 0 & 0 & -\alpha_x \frac{h_1}{2} \end{bmatrix} \Rightarrow -\alpha_x \frac{h_1}{2} \hat{j} \\ & = -\alpha_x \left(\frac{h_1}{2} \right) \hat{i} + \alpha_x r_1 \frac{h_1}{2} \hat{k} \end{aligned}$$

$$\hat{i}: -T_m = -\alpha_x I_{xx_1} = \frac{m_1 \alpha_x h_1^2}{4}$$

$$I_{xx_1} = \frac{m r_1^2}{4} + \frac{m h_1^2}{12} + m \left(\frac{h_1}{2} - a \right)^2$$

$$T_m = \alpha_x \left[\frac{m r_1^2}{4} + \frac{m h_1^2}{12} + m \left(\frac{h_1}{2} - a \right)^2 + \frac{m h_1^2}{4} \right]$$

$$\begin{aligned}
 1: & \alpha_x \quad 0 \quad 0 \quad \alpha_x \quad 0 \\
 & -(r_1 + \frac{h_2}{2}) \quad 0 \quad -(\frac{h_1}{2} - a) - (r_1 + \frac{h_2}{2}) \quad 0 \\
 & -(r_1 + \frac{h_2}{2}) \quad 0 \quad -(\frac{h_1}{2} - a) \quad - (r_1 + \frac{h_2}{2}) \quad 0 \\
 & 0 \quad \alpha_x (\frac{h_1}{2} - a) \quad 0 \quad 0 \quad \alpha_x (\frac{h_1}{2} - a) \Rightarrow \alpha_x (\frac{h_1}{2} - a)^2 \hat{i} - \alpha_x (r_1 + \frac{h_2}{2}) (\frac{h_1}{2} - a) \hat{k}
 \end{aligned}$$

$$\begin{aligned}
 3: & \alpha_x \quad 0 \quad 0 \quad \alpha_x \quad 0 \\
 & -(\frac{h_2}{2} + r_1 - \bar{x}_3) \bar{y}_3 \quad 0 \quad -(\frac{h_2}{2} + r_1 - \bar{x}_3) \bar{y}_3 \Rightarrow \alpha_x \bar{y}_3 \hat{k} \\
 & -(\frac{h_2}{2} + r_1 - \bar{x}_3) \bar{y}_3 \quad 0 \quad -(\frac{h_2}{2} + r_1 - \bar{x}_3) \quad 0 \\
 & 0 \quad 0 \quad \alpha_x \bar{y}_3 \quad 0 \quad 0 \Rightarrow \frac{\alpha_x \bar{y}_3^2}{2} \hat{i} + \alpha_x \bar{y}_3 (\frac{h_2}{2} + r_1 - \bar{x}_3) \hat{j}
 \end{aligned}$$

$$\begin{aligned}
 4: & \alpha_x \quad 0 \quad 0 \quad \alpha_x \quad 0 \\
 & -(r_1 + \frac{h_2}{2}) (r_3 + w_3 + \frac{h_4}{2}) \quad 0 \quad -(r_1 + \frac{h_2}{2}) (r_3 + w_3 + \frac{h_4}{2}) \Rightarrow \alpha_x (r_3 + w_3 + \frac{h_4}{2}) \hat{k} \\
 & -(r_1 + \frac{h_2}{2}) (r_3 + w_3 + \frac{h_4}{2}) \quad 0 \quad -(r_1 + \frac{h_2}{2}) (r_3 + w_3 + \frac{h_4}{2}) \\
 & 0 \quad 0 \quad \alpha_x (r_3 + w_3 + \frac{h_4}{2}) \quad 0 \quad 0 \\
 & \alpha_x (r_3 + w_3 + \frac{h_4}{2})^2 \hat{i} + \alpha_x (r_3 + w_3 + \frac{h_4}{2}) (r_1 + \frac{h_2}{2}) \hat{j}
 \end{aligned}$$

$$\begin{aligned}
 5: & \alpha_x \quad 0 \quad 0 \quad \alpha_x \quad 0 \\
 & -(r_1 + \frac{h_2}{2}) (r_2 + w_2 + \frac{h_5}{2}) - (r_2 + \frac{h_5}{2}) - (r_1 + \frac{h_2}{2}) (r_2 + w_2 + \frac{h_5}{2}) \Rightarrow \alpha_x (r_2 + \frac{h_5}{2}) \hat{j} + \alpha_x (r_2 + w_2 + \frac{h_5}{2}) \hat{k} \\
 & -(r_1 + \frac{h_2}{2}) (r_2 + w_2 + \frac{h_5}{2}) - (r_2 + \frac{h_5}{2}) - (r_1 + \frac{h_2}{2}) (r_2 + w_2 + \frac{h_5}{2}) \\
 & 0 \quad \alpha_x (r_2 + \frac{h_5}{2}) \quad \alpha_x (r_2 + w_2 + \frac{h_5}{2}) \quad 0 \quad \alpha_x (r_2 + \frac{h_5}{2}) \\
 & \left[\alpha_x (r_2 + w_2 + \frac{h_5}{2})^2 + \alpha_x (r_2 + \frac{h_5}{2})^2 \right] \hat{i} + \alpha_x (r_1 + \frac{h_2}{2}) (r_2 + w_2 + \frac{h_5}{2}) \hat{j} \\
 & - \alpha_x (r_1 + \frac{h_2}{2}) (r_2 + \frac{h_5}{2}) \hat{k}
 \end{aligned}$$

Moments of Inertia

9/11

$$1: \bar{I}_{xx_1} = \bar{I}_{xx_1} + mr_1^2 \quad \left| \quad I_{xx_1} = \frac{1}{12} m_1 (3r_1^2 + h_1^2) \quad r_1 = \left(\frac{h_1}{2} - a\right)$$

$$\bar{I}_{yy_1} = \bar{I}_{yy_1} + mr_1^2 \quad \left| \quad I_{yy_1} = \frac{1}{12} m_1 (3r_1^2 + h_1^2) \quad r_1 = \left(\frac{h_1}{2} - a\right)$$

$$2: I_{xx_2} = \bar{I}_{xx_2} + mr^2 \quad \left| \quad I_{xx_2} = \frac{1}{2} m_2 r_2^2 \quad r = 0$$

$$I_{yy_2} = \bar{I}_{yy_2} + mr^2 \quad \left| \quad I_{yy_2} = \frac{1}{12} m_2 (3r_2^2 + h_2^2) \quad r = \left(r_1 + \frac{h_2}{2}\right)$$

$$3: I_{xx_3} = \bar{I}_{xx_3} + mr^2 \quad \left| \quad \bar{I}_{xx_3} = \quad r = \frac{1}{3}$$

$$I_{yy_3} = \bar{I}_{yy_3} + mr^2 \quad \left| \quad \bar{I}_{yy_3} = \quad r = x_3$$

$$4: I_{xx_4} = \bar{I}_{xx_4} + mr^2 \quad \left| \quad \bar{I}_{xx_4} = \frac{1}{12} m_4 (3r_4^2 + h_4^2) \quad r = r_3 + w_3 + \frac{b_4}{2}$$

$$I_{yy_4} = \bar{I}_{yy_4} + mr^2 \quad \left| \quad I_{yy_4} = \frac{1}{2} m_4 r_4^2 \quad r = 0$$

$$5: I_{xx_5} = \bar{I}_{xx_5} + mr^2 \quad \left| \quad \bar{I}_{xx_5} = \frac{1}{12} m_5 (w_5^2 + h_5^2) \quad r = r_3 + w_3 + \frac{h_4}{2}$$

$$I_{yy_5} = \bar{I}_{yy_5} + mr^2 \quad \left| \quad \bar{I}_{yy_5} = \frac{1}{12} m_5 (b_5^2 + h_5^2) \quad r = r_4 + \frac{h_5}{2}$$

$$1: \begin{cases} I_{xy} = \bar{I}_{xy} + m d_x d_y \\ I_{zy} = \bar{I}_{zy} + m d_z d_y \end{cases} \left| \begin{array}{l} d_x = 0 \\ d_y = 0 \\ d_z = \frac{h_1}{2} - a \end{array} \right. \begin{array}{l} I_{xy_1} = 0 \\ I_{zy_1} = 0 \end{array}$$

$$2: \begin{cases} I_{xy} = \bar{I}_{xy} + m d_x d_y \\ I_{zy} = \bar{I}_{zy} + m d_x d_y \end{cases} \left| \begin{array}{l} d_x = r_1 + \frac{h_1}{2} \\ d_y = 0 \\ d_z = 0 \end{array} \right. \begin{array}{l} I_{xy_2} = 0 \\ I_{zy_2} = 0 \end{array}$$

$$3: \begin{array}{l} I_{xy} = \bar{I}_{xy} \neq 0 \\ I_{zy} = \bar{I}_{zy} \neq 0 \end{array}$$

↓
Value found in SolidWorks

$$4: \begin{cases} I_{xy} = \bar{I}_{xy} + m d_x d_y \\ I_{zy} = \bar{I}_{zy} + m d_z d_y \end{cases} \left| \begin{array}{l} d_x = 0 \\ d_y = r_3 + w_3 + \frac{h_w}{2} \\ d_z = 0 \end{array} \right. \begin{array}{l} I_{xy_4} = 0 \\ I_{zy_4} = 0 \end{array}$$

$$5: \begin{cases} I_{xy} = \bar{I}_{xy} + m d_x d_y \\ I_{zy} = \bar{I}_{zy} + m d_z d_y \end{cases} \left| \begin{array}{l} d_x = 0 \\ d_y = r_3 + w_3 + \frac{h_w}{2} \\ d_z = r_4 + \frac{h_5}{2} \end{array} \right.$$

$$I_{zy} = m_5 \left(r_4 + \frac{h_5}{2} \right) \left(r_3 + w_3 + \frac{h_w}{2} \right)$$

Motor (Y-Axis)

Angular Acceleration -

$$\alpha_y = \frac{\bar{F}_{\text{tremors}} \left(\frac{h_5}{2} + r_4 \right)}{\left[\begin{array}{l} I_{yy_1} + I_{yy_2} + I_{yy_3} + I_{yy_4} + I_{yy_5} + I_{yy_3} + I_{yy_3} \\ + \bar{m}_1 \left(\frac{h_1}{2} - a \right)^2 + \bar{m}_2 \left(r_1 + \frac{h_2}{2} \right)^2 + \bar{m}_3 \bar{x}_3^2 \\ + m_5 \left(r_4 + \frac{h_5}{2} \right)^2 + m_5 \left(r_4 + \frac{h_5}{2} \right) \left(r_3 + w_3 + \frac{h_4}{2} \right) \end{array} \right]}$$

$$\begin{aligned} T_y = & \left[\alpha_y \left(I_{yy_1} + I_{yy_2} + I_{yy_3} + I_{yy_3} + I_{yy_3} + \bar{m}_1 \left(\frac{h_1}{2} - a \right)^2 + \bar{m}_2 \left(r_1 + \frac{h_2}{2} \right)^2 + \bar{m}_3 \bar{x}_3^2 \right) \right. \\ & \left. - \left[m_2 g \left(r_1 + \frac{h_2}{2} \right) + m_3 g \bar{x}_3 \right] \right] \end{aligned}$$

Motor (X-Axis)

$$\alpha_x = \frac{\bar{F}_{\text{tremors}} \left(\frac{h_3}{2} + r_4 \right)}{\left[\begin{array}{l} I_{xx_1} + I_{xx_2} + I_{xx_3} + I_{xx_4} + I_{xx_5} + I_{yy_3} + I_{zz_3} \\ + m_1 \left(\frac{h_1}{2} - a \right)^2 + m_3 \bar{y}_3^2 + m_4 \left(r_3 + w_3 + \frac{h_4}{2} \right)^2 + m_5 \left(r_3 + w_3 + \frac{h_4}{2} \right)^2 \\ + m_5 \left(r_2 + \frac{h_3}{2} \right)^2 \end{array} \right]}$$

$$T_x = \alpha_x \left[\frac{m_1 r_1^2}{4} + \frac{m_1 h_1^2}{12} + m_1 \left(\frac{h_1}{2} - a \right)^2 - \frac{h_1^2}{4} \right]$$

Table of Contents

Variables	1
Product of Ineritas	2
Y-Axis Motor	2
X-Axis Motor	2

Variables

```
% Force of Tremors
Ft= 5; % [ lbf ]

% Dimension from top of mug to centerpoint of motors
a= 1.25; % [in]

% Gravity
g=32.174; % [ft/s^2]

% Masses
m1= 0.445334; % [lbm]
m2= 0.11464;
m3= 0.0220462;
m4= 0.11464;
m5= 0.116845;

sum_of_mass=m1+m2+m3+m4+m5; % [lbm]

% Cup
r1=3.68/2; % [in]
h1= 8;

% Motor (x-axis)
r2=.75; % [in]
h2=1;

% Bracket
x3bar=2.5; % [in]
y3bar=2.5; % From solidworks

r3= 4; % [in]
w3= .25;
h3= 1.25;

% Motor (y-axis)
r4= .75; % [in]
h4= 1;

% Handle
b5= 1.65; % [in]
w5= 2;
```


h5= 5.25;

Product of Ineritas

```
Ixx1=(1/12)*m1*(3*r1^2+h1^2)+m1*(h1/2-a)^2; % [lbm-in^2]
Iyy1=(1/12)*m1*(3*r1^2+h1^2)+m1*(h1/2-a)^2;

Ixx2=(1/2)*m2*r2^2; % [lbm-in^2]
Iyy2=(1/12)*m2*(3*r2^2+h2^2)+m2*(h2/2+r1)^2;

Ixx3=.1; % [lbm-in^2]
Iyx3=-.6; % From SolidWorks
Izx3=0;

Ixy3=Iyx3; % [lbm-in^2]
Iyy3=.1; % From SolidWorks
Izy3=0;

Ixx4=(1/12)*m4*(3*r4^2+h4^2)+m4*(r3+w3+h4/2)^2; % [lbm-in^2]
Iyy4=(1/2)*m4*r4^2;

Ixx5=(1/12)*m5*(w5^2+h5^2)+m5*(r3+w3+h4/2)^2; % [lbm-in^2]
Iyy5=(1/12)*m5*(b5^2+h5^2)+m5*(r4+h5/2)^2;
```

Y-Axis Motor

Angular Acceleration Equations

```
Alpha_Y = 32.174*12* Ft * ( ((h5/2)+r4) /
((Iyy1+Iyy2+Iyy3+Iyy4+Iyy5+Ixy3+Izy3) + ((m1*(h1/2-
a)^2)+(m2*(h2/2+r1)^2)+(m3*x3bar^2)+(m5*(h5/2+r4)^2) +
m5*(r4+h5/2)*(r3+w3+h4/2))) );
% [rad/s^2]

% Torque of Motor
Torque_Y = Alpha_Y * ( (Iyy1+Iyy2+Iyy3+Ixy3+Izy3)+((m1*(h1/2-
a)^2)+(m2*(h2/2+r1)^2)+(m3*x3bar^2)) ) -
( m2*12*g*(r1+(h2/2))+m3*12*g*x3bar );
% [lbm-in^2/sec^2]

% Torque in lbf-in
Torque_Y_lbf_in = Torque_Y/(32.174*12)
```

Torque_Y_lbf_in =

11.1780

X-Axis Motor

Angular Acceleration Equations

```

Alpha_X = 32.174*12*Ft * ( ((h5/2)+r4) /
  ((Ixx1+Ixx2+Ixx3+Ixx4+Ixx5+Iyx3+Izx3) + ( m1*(h1/2-a)^2) +
  (m3*y3bar^2) + (m4*(r3+w3+(h4/2))^2) + (m5*(r3+w3+(h4/2))^2) +
  (m5*(h5/2+r2)^2) )) );
% [rad/s^2]

Torque_X = Alpha_X * ( (m1*r1^2/4) + (m1*h1^2/12) + (m1*((h1/2)-a)^2)
  + m1*(h1^2-4));
% [lbf-in^2/sec^2]

% Torque in lbf-in
Torque_X_lbf_in=Torque_X/(32.174*12)

Torque_X_lbf_in =

    26.0574

```

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Appendix E: Design Hazard Checklist

ME 428/429/430 Senior Design Project

2019

DESIGN HAZARD CHECKLIST	
Team: XXXXXXXXXX <u>Mug For Tremors</u> Faculty Coach: <u>Harding</u>	
Y N	
<input checked="" type="checkbox"/> <input type="checkbox"/>	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and shear points?
<input type="checkbox"/> <input checked="" type="checkbox"/>	2. Can any part of the design undergo high accelerations/decelerations?
<input type="checkbox"/> <input checked="" type="checkbox"/>	3. Will the system have any large moving masses or large forces?
<input type="checkbox"/> <input checked="" type="checkbox"/>	4. Will the system produce a projectile?
<input type="checkbox"/> <input checked="" type="checkbox"/>	5. Would it be possible for the system to fall under gravity creating injury?
<input type="checkbox"/> <input checked="" type="checkbox"/>	6. Will a user be exposed to overhanging weights as part of the design?
<input type="checkbox"/> <input checked="" type="checkbox"/>	7. Will the system have any sharp edges?
<input checked="" type="checkbox"/> <input type="checkbox"/>	8. Will any part of the electrical systems not be grounded?
<input type="checkbox"/> <input checked="" type="checkbox"/>	9. Will there be any large batteries or electrical voltage in the system above 40 V?
<input checked="" type="checkbox"/> <input type="checkbox"/>	10. Will there be any stored energy in the system such as <u>batteries</u> , flywheels, hanging weights or pressurized fluids?
<input type="checkbox"/> <input checked="" type="checkbox"/>	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
<input type="checkbox"/> <input checked="" type="checkbox"/>	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
<input checked="" type="checkbox"/> <input type="checkbox"/>	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
<input type="checkbox"/> <input checked="" type="checkbox"/>	14. Can the system generate high levels of noise?
<input type="checkbox"/> <input checked="" type="checkbox"/>	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
<input checked="" type="checkbox"/> <input type="checkbox"/>	16. Is it possible for the system to be used in an unsafe manner?
<input checked="" type="checkbox"/> <input type="checkbox"/>	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.
For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.	

Figure 4: Design Hazard Checklist, Page 1

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Liquid spilling onto electrical components	<ul style="list-style-type: none"> • test without liquid in cup • no exposed wiring 		
Moving linkages	<ul style="list-style-type: none"> • anticipate where pinch points will occur and keep furthest away from handle 		
Electrical system will not be grounded	<ul style="list-style-type: none"> • make sure there are no exposed wires 		
Batteries will have stored energy in them	<ul style="list-style-type: none"> • make sure there are no exposed wires and batteries are handled safely 		
Lithium-Ion Batteries are known to be hazardous	<ul style="list-style-type: none"> • don't cut them • make sure they are stored in safe conditions 		
Dangerous if not handled correctly	<ul style="list-style-type: none"> • mug should only be used as directed 		

Figure 5: Design Hazard Checklist, Page 2

Appendix F: FMEA
Design Failure Mode and Effects Analysis

Product: Stabilizing Mug

Prepared by: Jaret Wedow

Team: Mug For Tremors

Date: 6/4/2020

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurrence	Current Detection Activities	Detection	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
												Actions Taken	Severity	Occurrence	Criticality	RPN
Water Containment System / Water tight	Cup leaks	- Electronics short, user is dissatisfied/wet	5	- 3D printed container not secured, Gap between liner and cup frame	- Check CAD model, test material	3	- Normal use test (put water in the cup)	4	60	- Check 3D printing process (primarily the final product before implementing it with electronics)	Kai - Mid May	Mug liner tested before intergrating with electronics	5	2	2	20
Water Containment System / Water tight	Cup breaks	- User is injured, water is not contained, product does not function	4	- 3D printed container not secured, 3D material weak/not waterproof, Impact from drop fractrues container, Gap between liner and cup frame	- Check CAD model (stress analysis/FEA), test material	3	- Normal use test (max load test)	2	24	-	-	-	4	3	2	24
Electronics / Power the motor	Electronics short circuits	- User is shocked, prodcut does not function	5	- Poor wire management (wire exposed/wire faulty/etc.)	- Insulate wires	2	- Checking circuit after construction	3	30	-	-	-	5	2	3	30
Electronics / Power the motor	Runs out of power	- Product does not function	2	- Runs out of battery power, Battery power drains faster than expected	- Include option to replace battery	7	- Test battery life of our battery	1	14	-	-	-	2	7	1	14
Electronics / Transfer tremor signal into motors	Loses communication	- Product does not function	2	- Poor wire management (wires broken/wires pinched)	- Check wiring installation, check coding	4	- Normal use test	2	16	-	-	-	2	4	2	16
Electronics / Transfer tremor signal into motors	Code does not work properly	- Product does not function, code could amplify tremors	3	- Code written wrong, test case failed/not accounted for	- Check coding (debug a lot)	5	- Debug a lot/Normal use test	5	75	- Confer with CS/CPE/ME faculty/students	Allen - March/ April	Professor Xing assisted with our coding and debugging	3	3	5	45
Electronics / Actuate Motor	Motor stops functioning	- Product does not function	2	- Motor overheated/burnt out, faulty wiring, battery power out	- Select suitable motors/batteries	3	- Motor use test	2	12	-	-	-	2	3	2	12
	No power/not strong enough	- Product does not satisfy user/meet needs	2	- Motor overheated/burnt out, faulty wiring, battery power out	- Select suitable motors/batteries	4	- Motor use test	3	24	-	-	-	2	4	3	24
Linkage / Transmit motion to cup	Linkage break	- Product does not function, water is not contained, user may be injured	4	- Poor design (not enough analysis), material fracture (drop impact/poor 3D printing)	- Stress analysis	2	- Normal use test (max load test)	2	16	-	-	-	4	2	2	16
	Linkage deforms	- Product may fail, product may not be as effective, not aesthetically pleasing	3	- Poor design (not enough analysis), material fracture (drop impact/poor 3D printing)	- Stress analysis	2	- Normal use test (max load test)	3	18	-	-	-	3	2	3	18
Linkage / Handle to user interface	Handle not comfortable	- User is displeased	2	- Poor design, poor choice of material	- Ergonomic research/analysis, material research/analysis	4	- User test (have people hold it)	2	16	-	-	-	2	4	2	16
	Handle flimsy/bending	- Water spills out of mug, handle may break from mug	3	- Poor design (strength analysis), poor choice of material	- Stress analysis, material research/analysis	2	- Normal use test (max load test)	2	12	-	-	-	3	2	2	12
Housing / Contain electronics saftey	Not watertight	- Electronics short, user is wet/shocked	5	- 3D printed container not secured, 3D material weak/not waterproof, Impact from drop fractrues container, Gap between liner and cup frame	- Check CAD model, test material	3	- Normal use test (fill up mug with water)	4	60	- Check 3D printing process (primarily the final product before implementing it with electronics)	Kai - Mid May	Mug Components tested before integrated with electronics	5	2	3	30
	Faulty wiring	- Electronics short, user is wet/shocked	5	- Poor instillation/design of wiring, wear and tear	- Wire management/insulation	2	- Checking circuit after construction	3	30	-	-	-	5	2	3	30

Mug for Tremors User Guide



Caution: Do not expose electrical components to water.

This can cause the user to experience an electric shock and can damage the product. Make sure that the liner is properly secured before adding water.

Warning: This mug features moving components which can lead to pinch points

While design considerations have been made to minimize pinch points, connections between the bracket and handle, along with the bracket and mug body present the chance for the user to get pinched while using the device.

Operation

To turn on the device, connect the battery to the controller board using the small plug-in connector. The liner must be removed to gain access to the battery cables. If the device has not been calibrated, follow the calibration guidelines. Once powered on and calibrated, the mug will actively reduce hand tremors at all times until powered off.

NOTE: The current version of the device does not have a power button, so the only way to activate and deactivate the power to the motors is to unplug the battery.

Calibration

Power on the device, then press and hold the small black button on the microcontroller for 3 seconds. Note that the Liner must be removed to have access to the controller board. Upon release, the controller indicator light will flash, and the motors will disengage. Position the assembly in the desired orientation, with the mug upright and handle oriented vertically. After 5 seconds, the controller board indicator light will stop flashing and the motors will start functioning again. The mug is now calibrated to the orientation introduced by the user, and will resist tremors to maintain the calibrated orientation.



Maintenance

No active maintenance is required to keep the mug assembly working properly. Although the device is designed for repeated use, if 3D printed components wear out over time, they can be replaced by repeating the necessary manufacturing and assembly steps. The mug should not be exposed to extreme temperatures, as this can damage the electrical components.

Cleaning

The Mug features a removable liner, designed to quickly and easily be detached for cleaning. Twist the liner to disengage the Key Insert that holds it in place, then lift the liner to separate it from the rest of the assembly. To sanitize the handle, bracket, or mug body, wipe down with a disinfectant wipe.

Charging

The Mug contains a rechargeable battery to allow it to function for extended periods of time without being close to a power source. To recharge the battery, first remove the liner. Twist the liner to disengage the Key Insert that holds it in place, then lift the liner to separate it from the rest of the assembly. Inside the remaining mug assembly, plug the rechargeable battery cable into a power source to charge. It may take a few hours to fully charge the battery for use. After the battery is fully charged, unplug and reinstall the mug liner so the device is ready for use again.

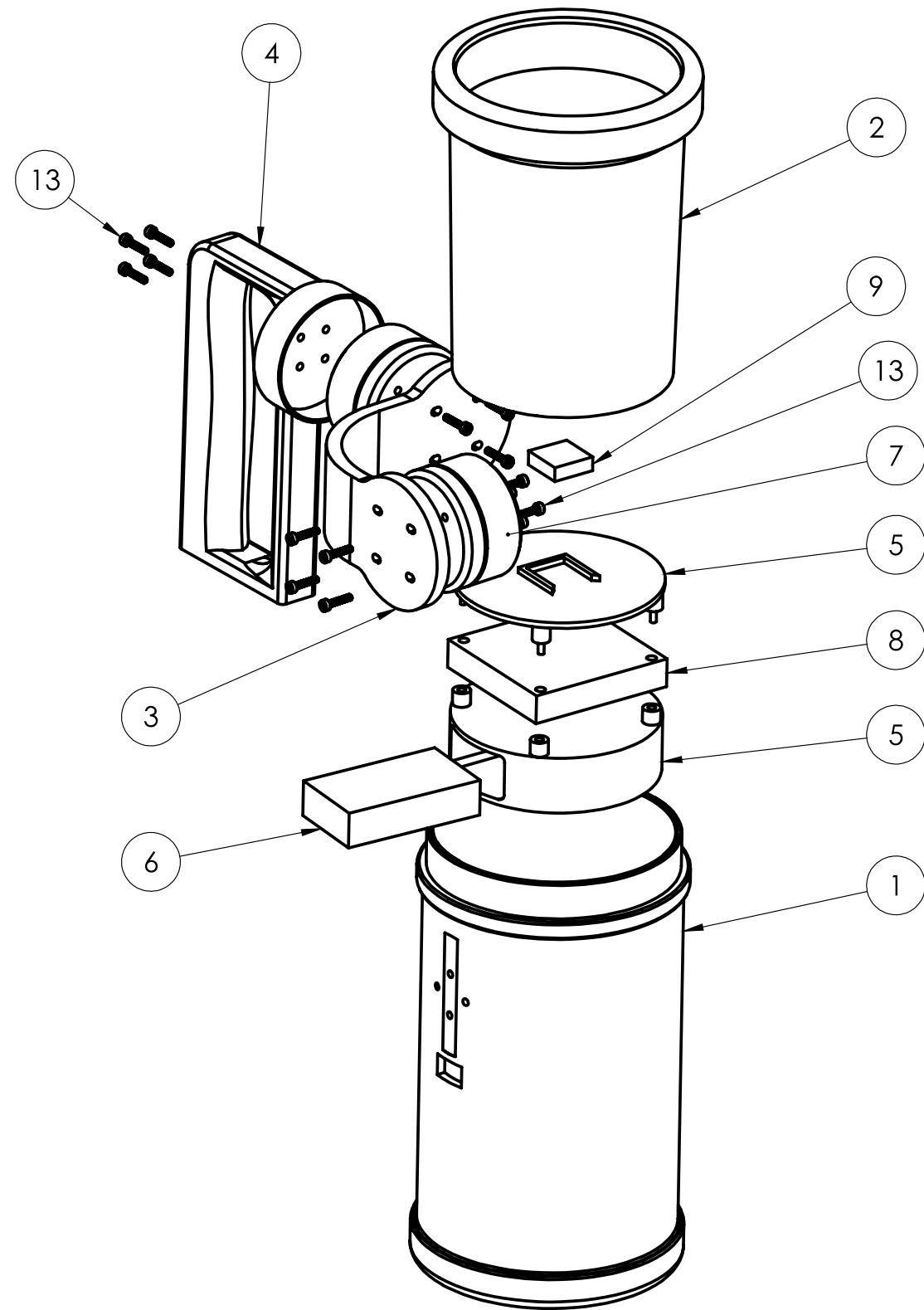
Appendix H: Drawing Package

Part #	Description	Quantity	Cost	Total Cost	Source	More Info
10000	Mug For Tremors Assy					
10001	Mug Shell	1	\$3.66	\$3.66	Custom	3D PRINTED
10002	Mug Liner	1	\$2.89	\$2.89	Custom	3D PRINTED
10003	Bracket	1	\$0.54	\$0.54	Custom	3D PRINTED
10004	Handle	1	\$1.34	\$1.34	Custom	3D PRINTED
10005	Mounting Fixture	1	\$1.15	\$1.15	Custom	3D PRINTED
10006	11.1V LiPo Battery	1	\$16.14	\$16.14	AMAZON	
10007	GB36-1 Motor	2	\$29.88	\$59.76	EBAY	
10008	BGC 3.1 Brushless Gimbal Controller	1	\$35.72	\$35.72	EBAY	
10009	GY6050 Sensor (IMU)	1	-	-	EBAY	
10010	Motor Cable	2	-	-	EBAY	LENGTHENED
10011	IMU Cable	1	-	-	EBAY	LENGTHENED
10012	Power Cable	1	-	-	EBAY	LENGTHENED
10013	M2.5x0.45-6mm Socket Head Cap Screw	8	\$0.05	\$0.37	McMaster	Pack of 25, Item 92290A056
10014	M3x0.5-6mm Socket Head Cap Screw	8	\$0.21	\$1.71	McMaster	Pack of 50, Item 92290A111
			Total	\$123.28		

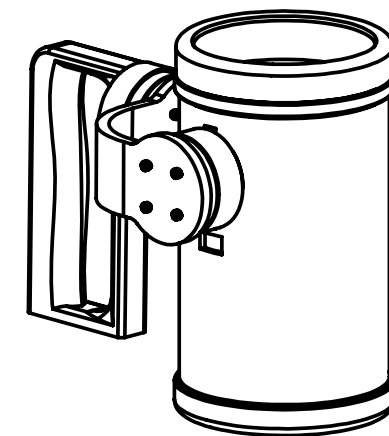
* All of the ebay parts sold as a kit

* IMU = Inertial Measurement Unit

* 3D printed parts cost calculated based on weight



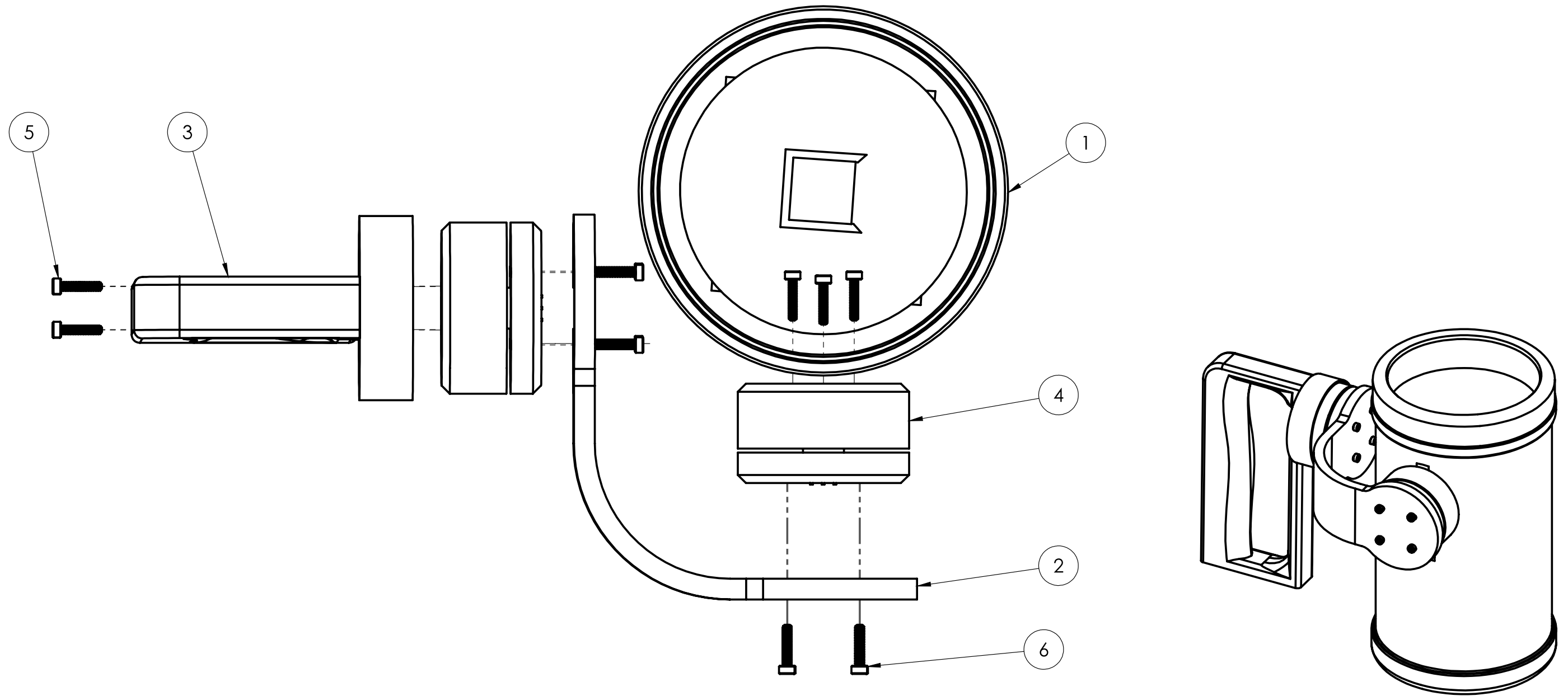
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10001	MUG SHELL	1
2	10002	MUG LINER	1
3	10003	BRACKET	1
4	10004	HANDLE	1
5	10005	MOUNTING FIXTURE	1
6	10006	11.1V BATTERY	1
7	10007	GB36-1 MOTOR	2
8	10008	BGC 3.1 BRUSHLESS GIMBAL CONTROLLER	1
9	10009	GY6050 SENSOR (IMU)	1
10	10010	MOTOR CABLE	2
11	10011	IMU CABLE	1
12	10012	POWER CABLE	1
13	10013	M2.5X0.45-6MM SOCKET HEAD CAP SCREW	8
14	10014	M3X0.5-6MM SOCKET HEAD CAP SCREW	8



NOTE: CABLES NOT SHOWN ON DIAGRAM

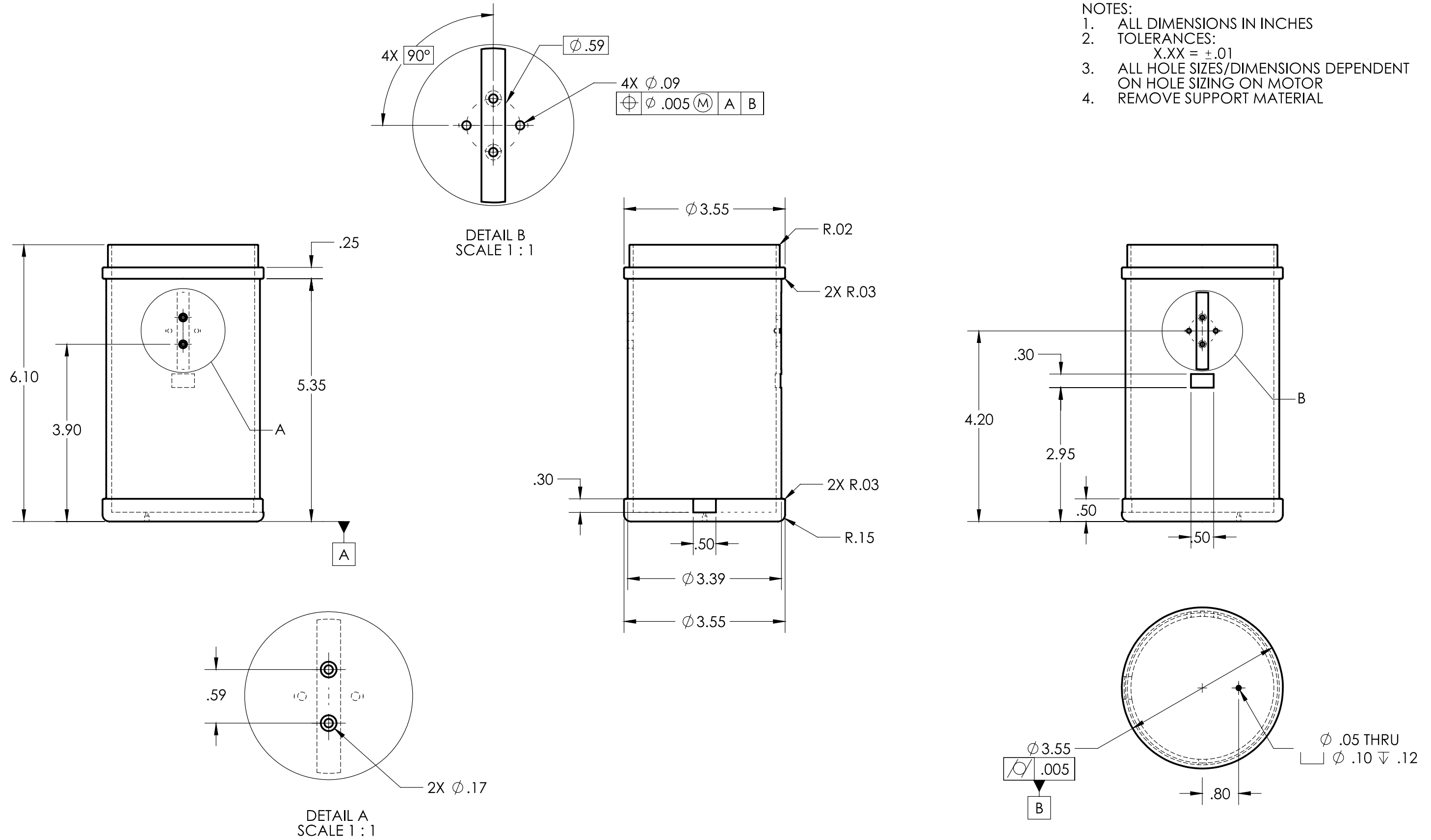
Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material:	Part #: 10000	Title: MUG FOR TREMORS ASSY	Drwn. By: JARET WEDOW
	Dwg. #: 1000	Nxt Asb:	Date: 6/3/20	Scale: 1:2
				Chkd. By: LOGAN SMITH

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10001	MUG SHELL	1
2	10003	BRACKET	1
3	10004	HANDLE	1
4	10007	GB36-1 MOTOR	1
5	10013	M2.5X0.45-6MM SOCKET HEAD CAP SCREW	8
6	10014	M3X0.5-6MM SOCKET HEAD CAP SCREW	8



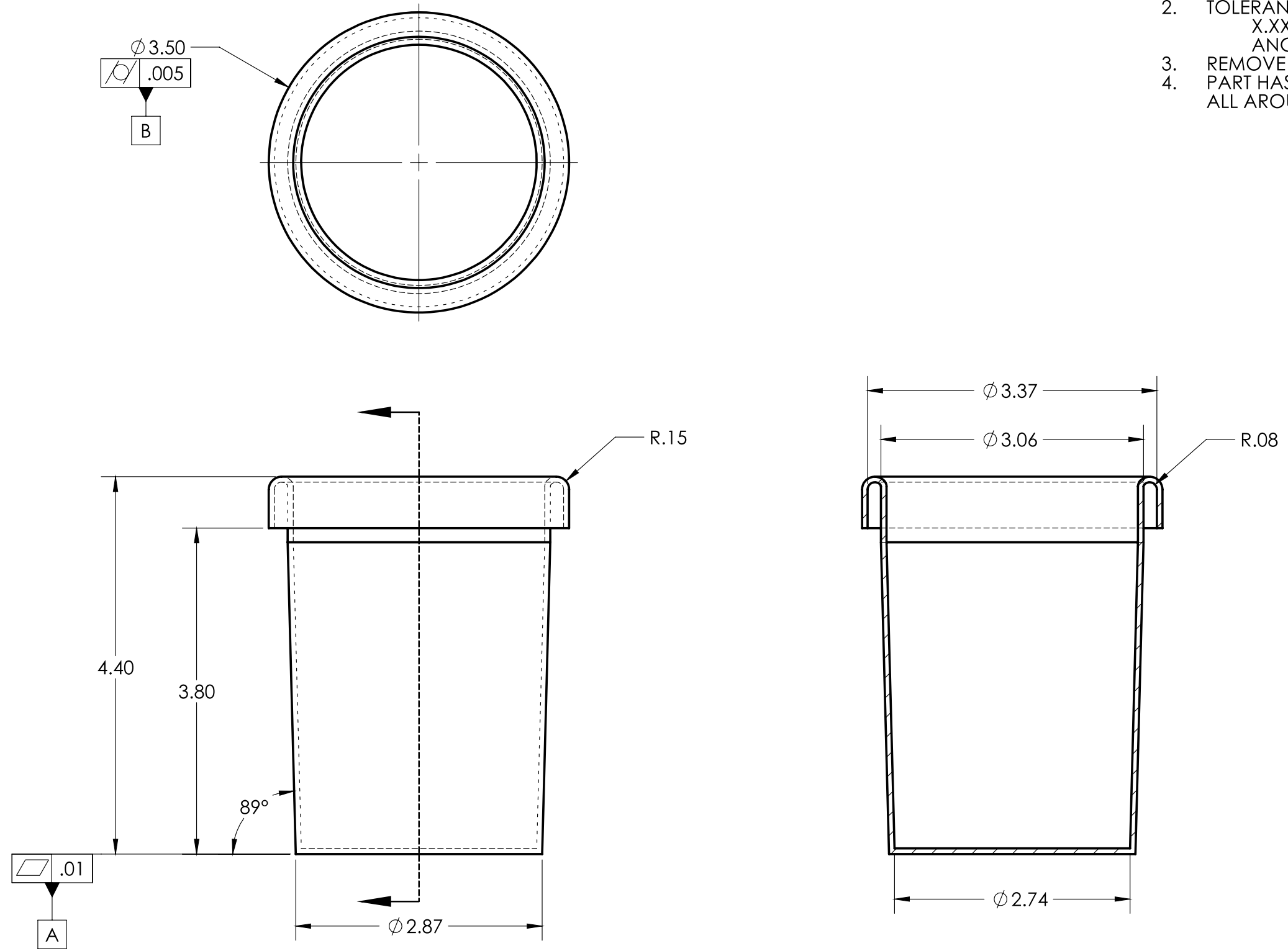
Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material:	Part #: 10000	Title: MUG FOR TREMORS ASSY TOP	Drwn. By: JARET WEDOW
	Dwg. #: 1001	Nxt Asb:	Date: 6/3/20	Scale: 1:1
				Chkd. By: LOGAN SMITH

- NOTES:
1. ALL DIMENSIONS IN INCHES
 2. TOLERANCES:
X.XX = ±.01
 3. ALL HOLE SIZES/DIMENSIONS DEPENDENT ON HOLE SIZING ON MOTOR
 4. REMOVE SUPPORT MATERIAL

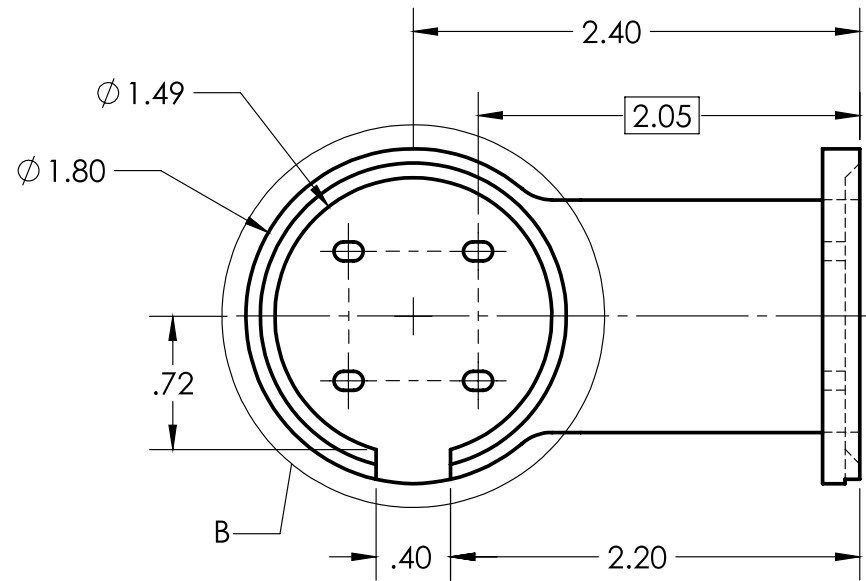


Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material: PLA Dwg. #: 100	Part #: 10001 Nxt Asb: 1000	Title: MUG SHELL Date: 6/3/20	Scale: 1=2	Drwn. By: JARET WEDOW Chkd. By: LOGAN SMITH
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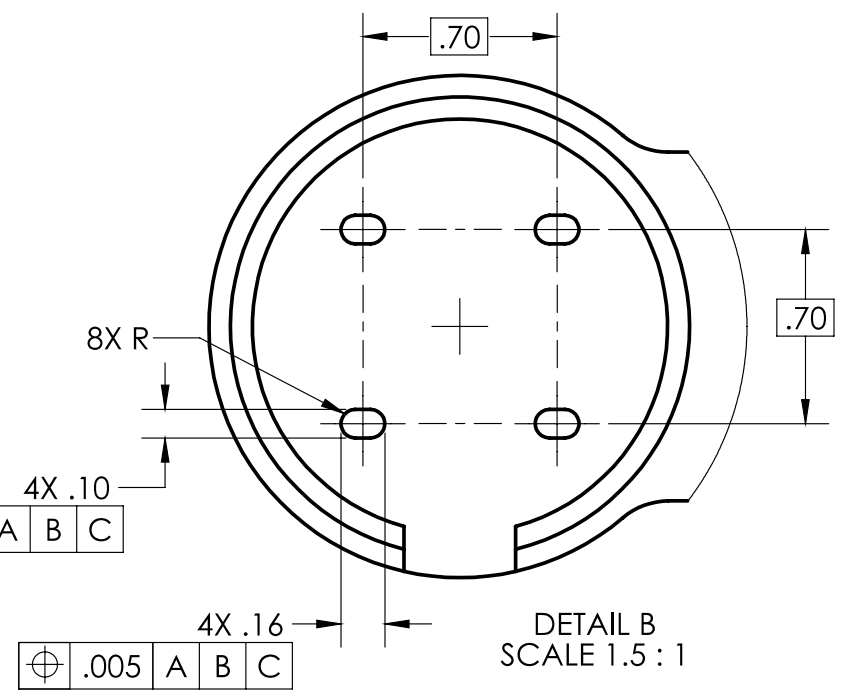
- NOTES:
1. ALL DIMENSIONS IN INCHES
 2. TOLERANCES:
X.XX = $\pm .01$
ANGLES = $\pm 1^\circ$
 3. REMOVE SUPPORT MATERIAL
 4. PART HAS THICKNESS OF .07 INCHES ALL AROUND



Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material: PLA Dwg. #: 200	Part #: 10002 Nxt Asb: 1000	Title: MUG LINER Date: 6/3/20	Scale: 3=4	Drwn. By: JARET WEDOW Chkd. By: LOGAN SMITH
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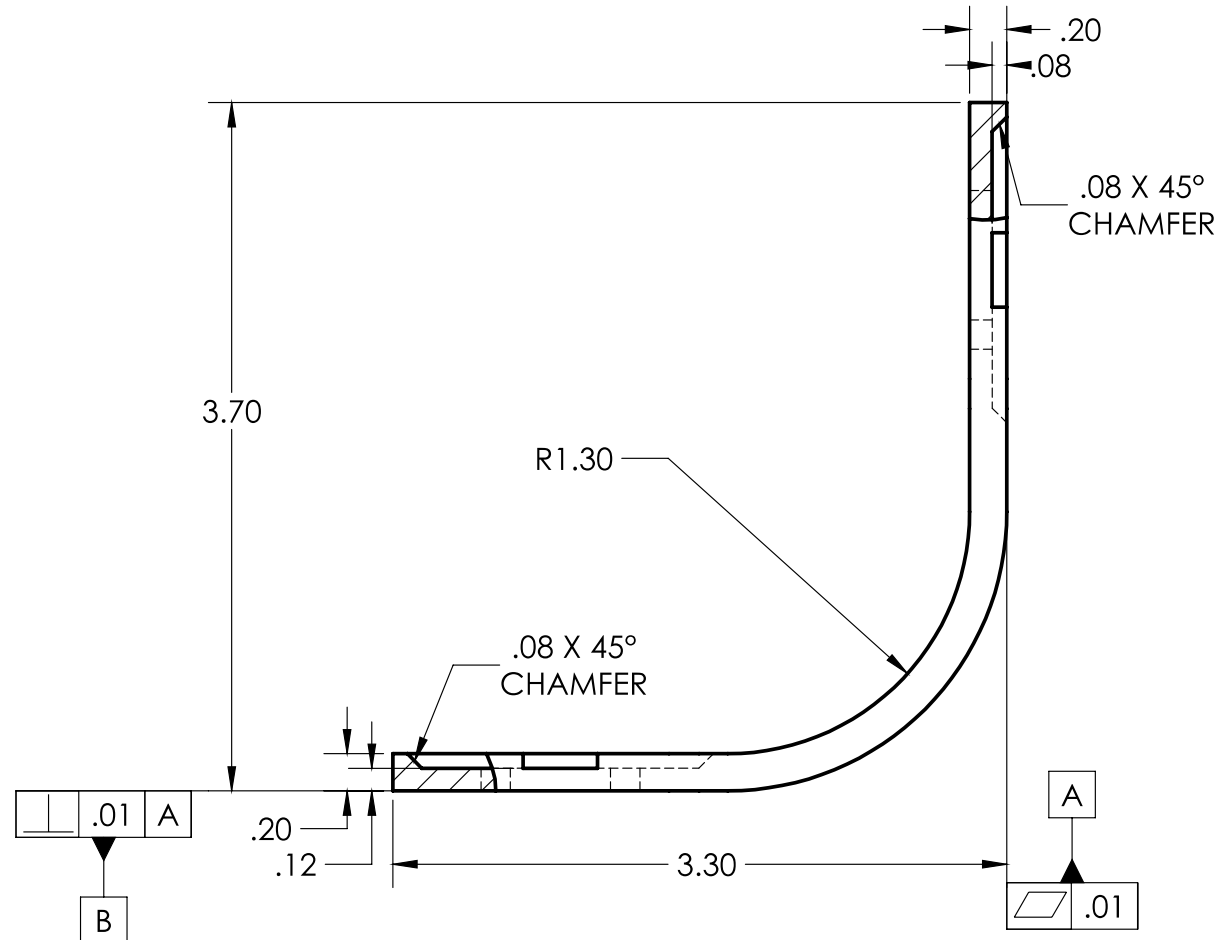


4X .10
 ⊕ .005 (M) A B C



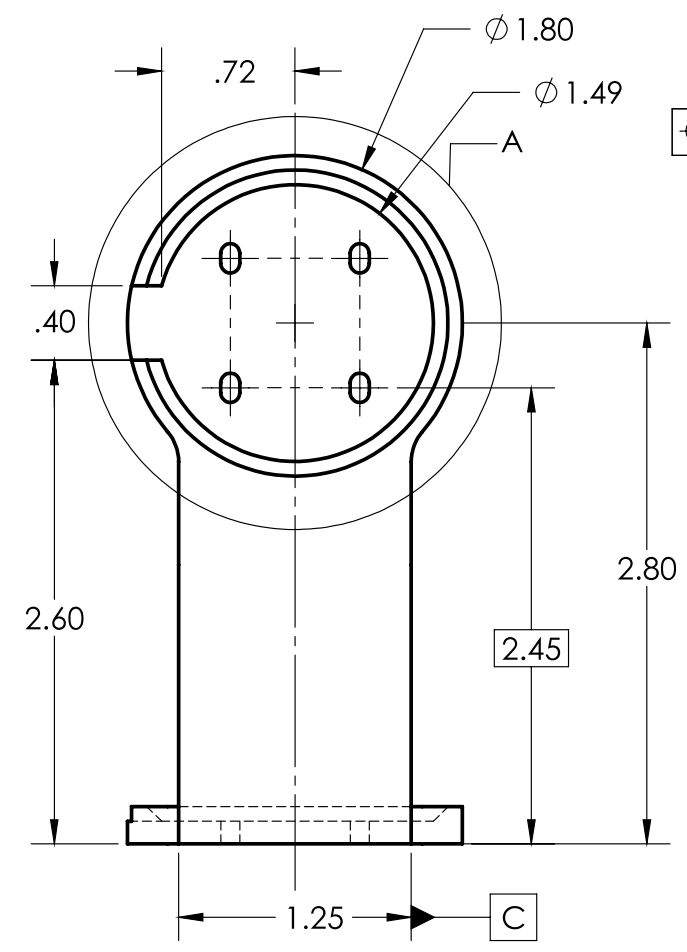
4X .16
 ⊕ .005 A B C

- NOTES:
 1. ALL DIMENSIONS IN INCHES
 2. TOLERANCES:
 X.XX = ±.01
 3. ALL HOLE SIZES/DIMENSIONS DEPENDENT ON HOLE SIZING ON MOTOR
 4. REMOVE SUPPORT MATERIAL

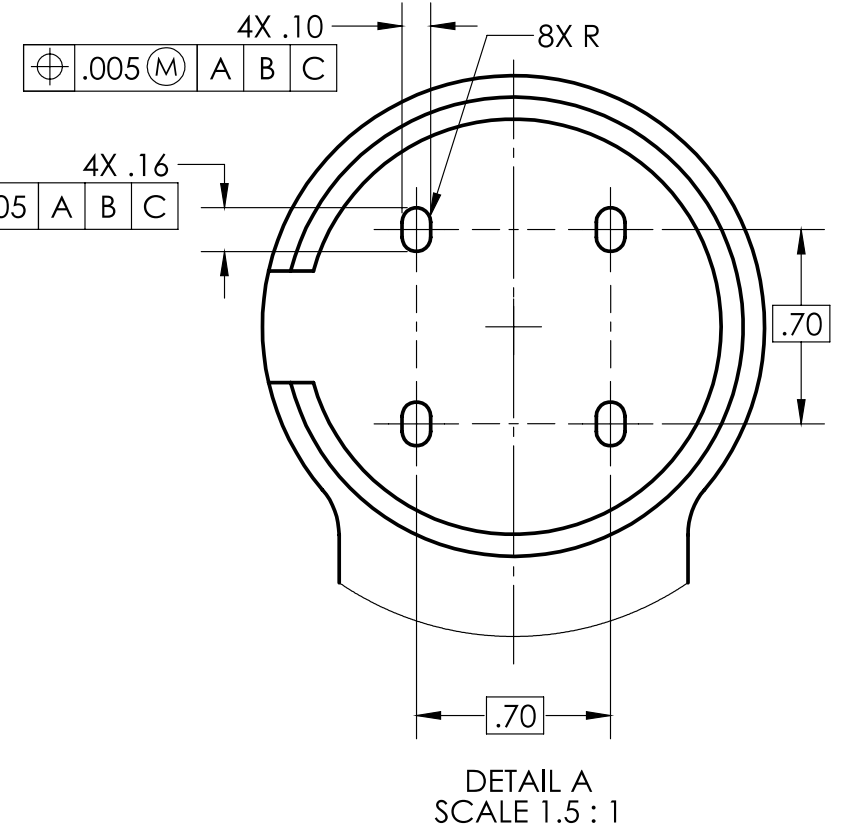


.01 A
 B

A
 .01

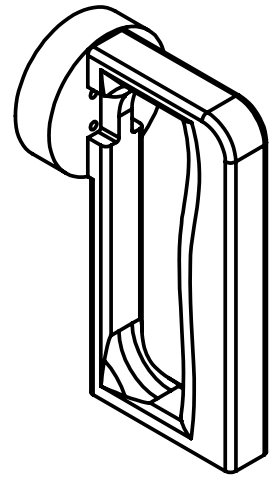


4X .16
 ⊕ .005 A B C




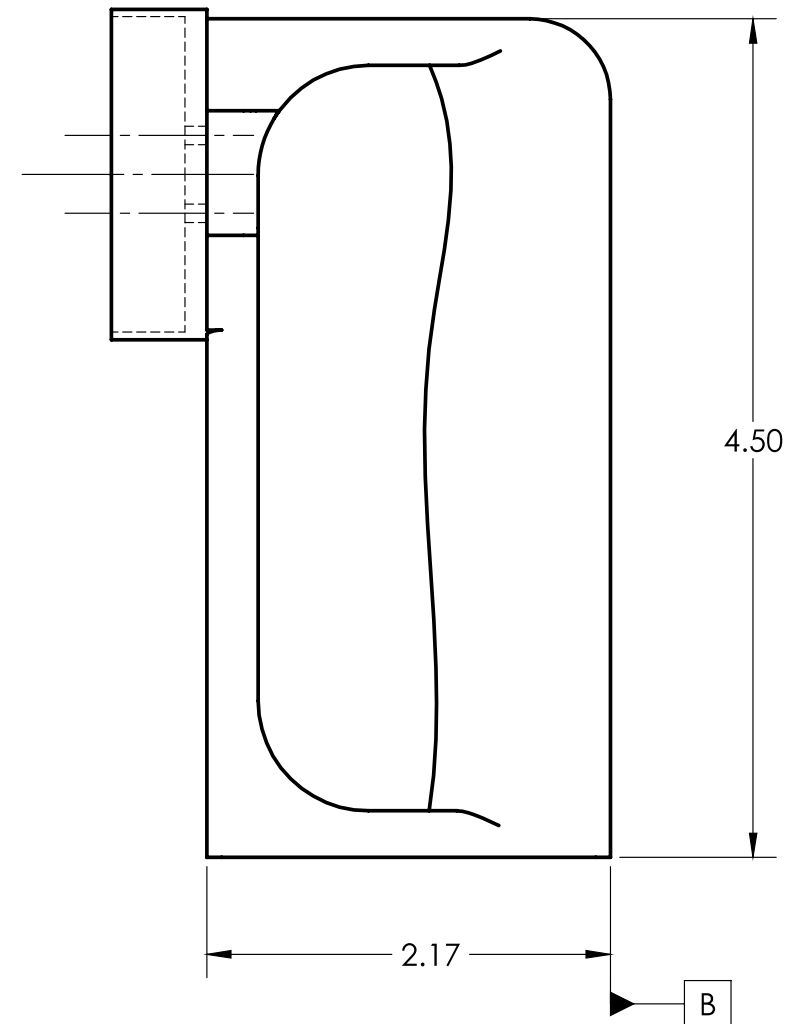
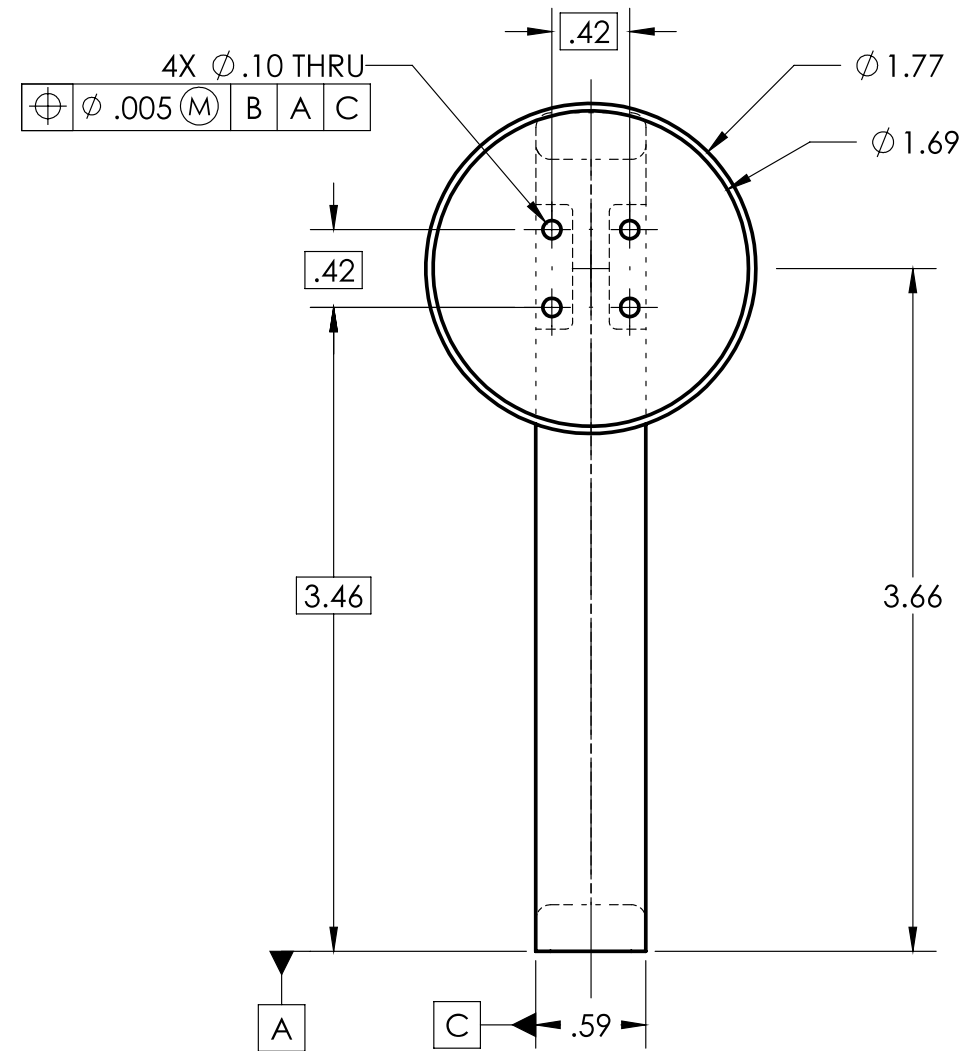
4X .10
 ⊕ .005 (M) A B C

Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material: PLA Dwg. #: 300	Part #: 10003 Nxt Asb: 1000	Title: BRACKET Date: 6/3/20	Scale: 1=1	Drwn. By: JARET WEDOW Chkd. By: LOGAN SMITH
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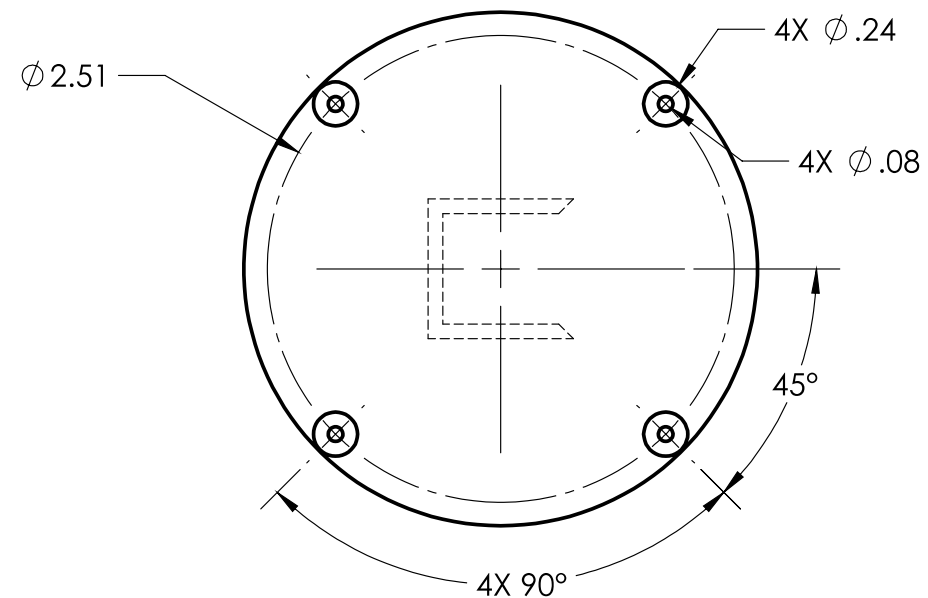
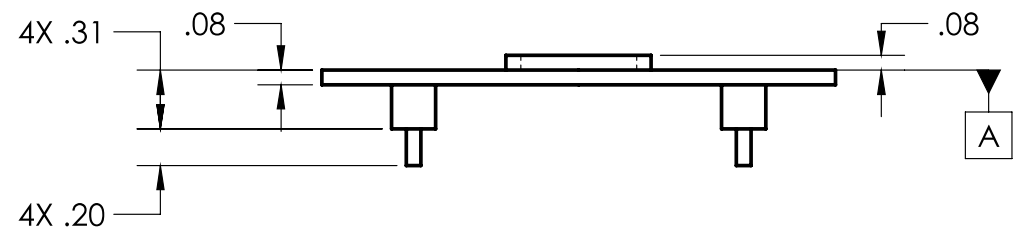
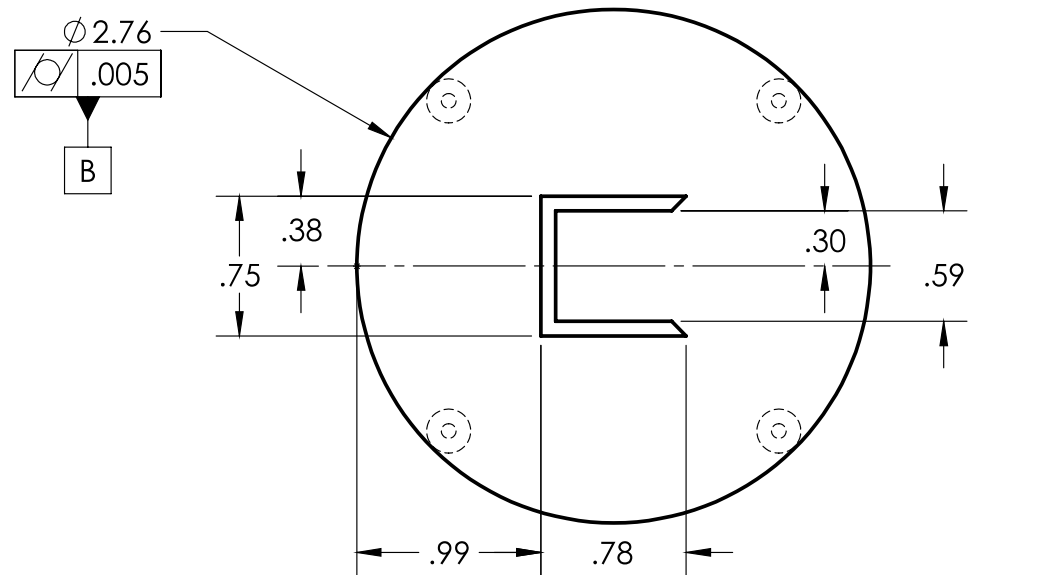
NOTES:

1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
X.XX = ±.01
3. ALL HOLE SIZES/DIMENSIONS DEPENDENT ON HOLE SIZING ON MOTOR
4. THIS IS A MINIMALLY DIMENSIONED DRAWING. THE CAD MODEL IS THE MASTER FOR ALL DIMENSIONS NOT SHOWN ON THE DRAWING. PART PROFILE
5.  .020 B A C UNLESS OTHERWISE NOTED.
REMOVE SUPPORT MATERIAL

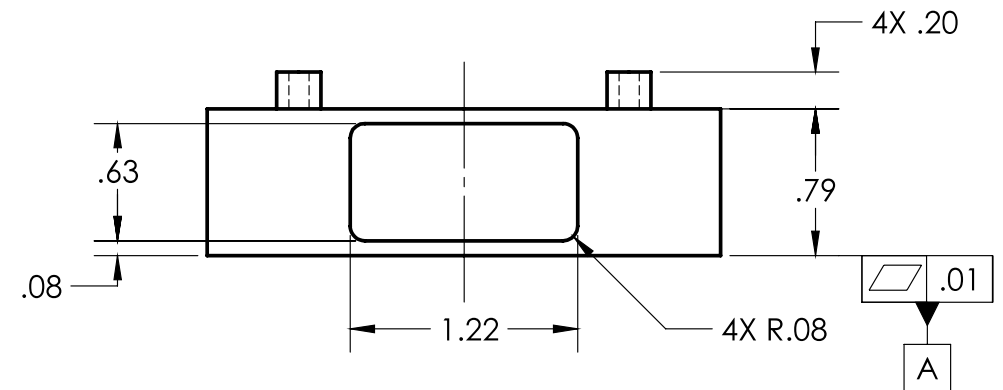
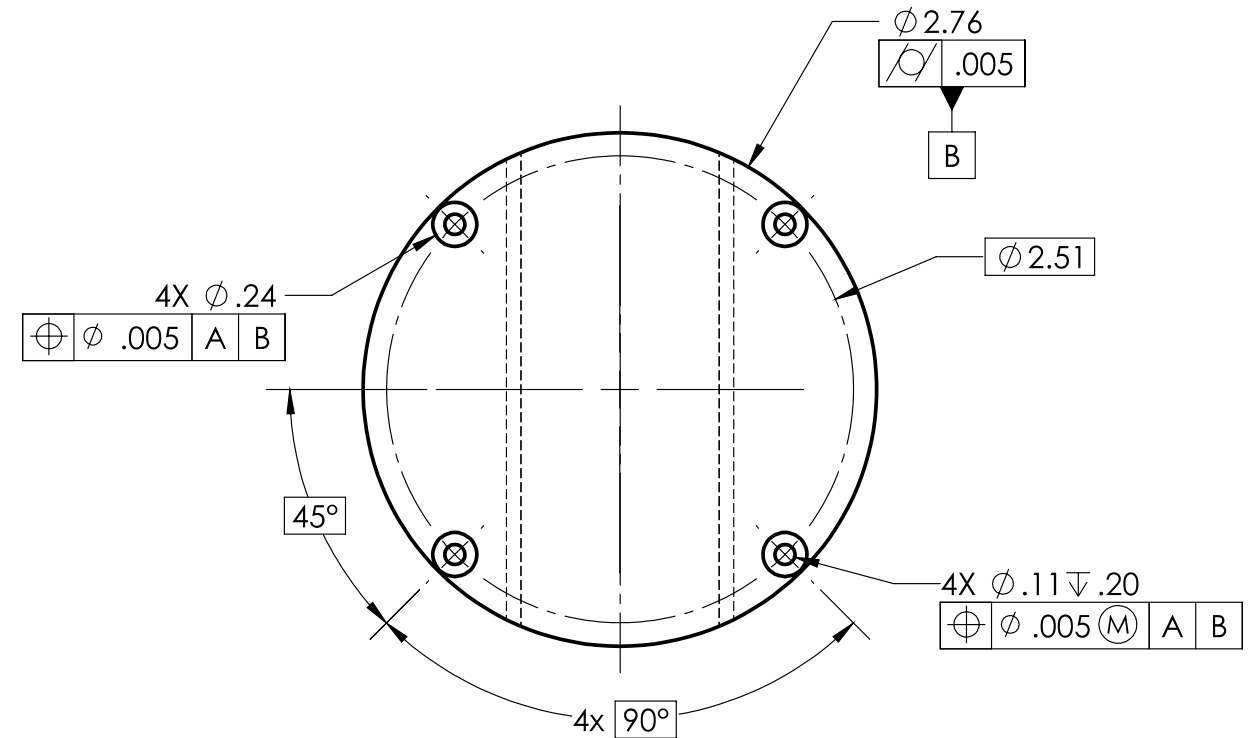


Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material: PLA Dwg. #: 400	Part #: 10004 Nxt Asb: 1000	Title: HANDLE Date: 6/3/20	Scale: 1:1	Drwn. By: JARET WEDOW Chkd. By: LOGAN SMITH
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- NOTES:
1. ALL DIMENSIONS IN INCHES
 2. TOLERANCES:
X.XX = ±.01
ANGLES = ±1°
 3. ALL HOLE SIZES/DIMENSIONS DEPENDENT ON HOLE SIZING ON MOTOR
 4. REMOVE SUPPORT MATERIAL



MOUNTING FIXTURE TOP HALF



MOUNTING FIXTURE BOTTOM HALF

Cal Poly Mechanical Engineering ME 430 - SPRING 2020	Material: PLA Dwg. #: 500	Part #: 10005 Nxt Asb: 1000	Title: MOUNTING FIXTURE Date: 6/3/20	Scale: 1=1	Drwn. By: JARET WEDOW Chkd. By: LOGAN SMITH
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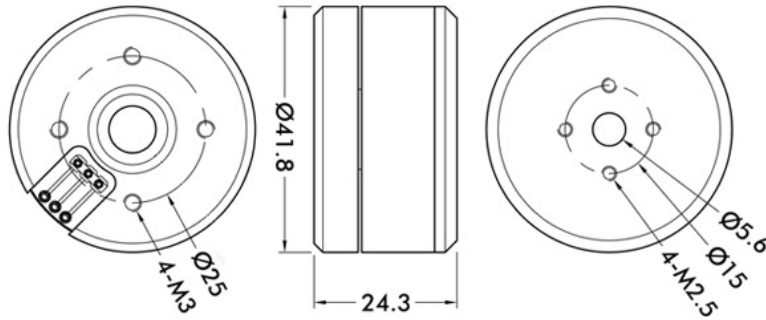
Part No: 10006
11.1V LiPo Battery

Brand:	Tattu
Capacity(mAh):	450mAh
Voltage(V):	11.1V
Discharge Rate (C):	45C
Max Burst discharge Rate (C):	90C
Configuration:	3S1P
Net Weight(dev.20g):	40.5g
Length(dev.5mm):	55mm
Width(dev.2mm):	30.5mm
Height(dev.2mm):	16mm
Connector Type:	JST-SYP-2P Plug
Wire Length(mm):	100mm
Balancer Connector Type:	JST-XHR
Amazon Product Name:	Tattu 11.1V 450mAh 3S LiPo Battery Pack 45C with JST Plug for Small Size FPV E-flite Blade 180 CFX Torrent 110 Baby Hawk Micro 2
ASIN:	B0714GN73V
Item model number:	TA-45C-450-3S1P-JST



Part No: 10007
GB36-1 Motor

Brand:	Tiger Motors
Motor Dimensions (mm):	41.8x24.3
Shaft Size (mm):	5.6 hollow
Stator Bore:	25x25mm 4-M3
Rotor Bore:	15x15mm 4-M2.5
Kv Constant:	50
Motor Weight:	88g
Cable Length:	35cm
Configuration:	12N14P
Motor Torque:	1.5kg/4S
Internal Resistance:	15.6 Ω
Rated Voltage	3-6S
Item model number:	GB36-1



Part No: 10008, 10009,10010, 10011, 10012
2 Axis Brushless Gimbal, Controller & Sensor

Item Name:	Brushless camera gimbal
Color:	Black
Flight controller:	BGC 2.2b2
Battery plug:	JST
Weight:	212g / 7.5oz
Number of stabilization axes:	2
Power supply voltage:	8.18V (3s-4s LiPo)
Maximum DC current to each motor:	2.8A
Limiting short-time current (with the inclusion of protection) to each motor:	7.1A
Output current regulation:	8 or 32 KHz PWM
Sensor connection:	I2C
Supported sensors:	MPU6050
PC communication for configuration and upgrade:	on-board USB
Overcurrent protection:	Yes
Overheat protection:	Yes
Undervoltage protection:	Yes
Reverse polarity protection:	Yes
Dimensions:	50mm x 50mm
Mounting holes:	M3, 45mm

Note: 8 Bit BGC Board is no longer produced but is still found in the marketplace. 32 Bit BGC Board would work and is completely backward compatible with all other software and hardware but is more expensive than the discontinued 8 Bit board.



Part No: 10013
M2.5x0.45-6mm Socket Head Cap Screw



Super-Corrosion-Resistant 316 Stainless Steel Socket Head Screw
M2.5 x 0.45 mm Thread, 6 mm Long

\$2.33 per pack of 25
92290A056

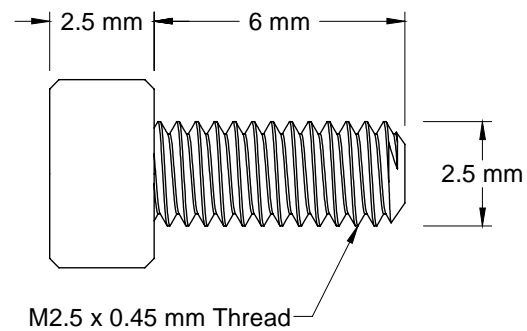
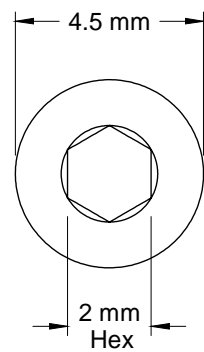
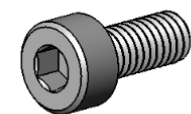


Head Type	Socket
Socket Head Profile	Standard
Drive Style	Hex
System of Measurement	Metric
Thread Direction	Right Hand
Thread Size	M2.5
Thread Pitch	0.45 mm
Thread Type	Metric
Thread Fit	Class 6g
Length	6mm
Threading	Fully Threaded
Thread Spacing	Coarse
Head	
Diameter	4.5mm
Height	2.5mm
Drive Size	2 mm
Material	316 Stainless Steel
Tensile Strength	70,000 psi
Hardness	Not Rated
Specifications Met	DIN 912, ISO 4762
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	Peoples Republic Of China, or Taiwan

These screws are corrosion resistant in wet environments, nonmagnetic, and electrically conductive. Length is measured from under the head.

Coarse threads are the industry standard; choose these screws if you don't know the pitch or threads per inch.

Screws that meet ISO 4762 (formerly DIN 912) comply with specifications for dimensional standards.



McMASTER-CARR <small>CAD</small>	PART NUMBER	92290A056
http://www.mcmaster.com		Stainless Steel
© 2014 McMaster-Carr Supply Company		Socket Head Cap Screw
<small>Information in this drawing is provided for reference only.</small>		

Part No: 10014
M3x0.5-6mm Socket Head Cap Screw



Super-Corrosion-Resistant 316 Stainless Steel Socket Head Screw
M3 x 0.5 mm Thread, 6 mm Long

\$10.67 per pack of 50
92290A111

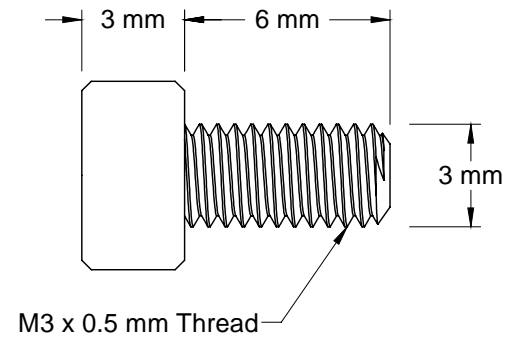
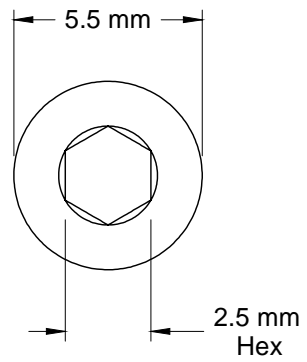
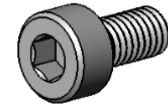


Head Type	Socket
Socket Head Profile	Standard
Drive Style	Hex
System of Measurement	Metric
Thread Direction	Right Hand
Thread Size	M3
Thread Pitch	0.5 mm
Thread Type	Metric
Thread Fit	Class 6g
Length	6mm
Threading	Fully Threaded
Thread Spacing	Coarse
Head	
Diameter	5.5mm
Height	3mm
Drive Size	2.5 mm
Material	316 Stainless Steel
Tensile Strength	70,000 psi
Hardness	Not Rated
Specifications Met	DIN 912, ISO 4762
RoHS	RoHS 3 (2015/863/EU) Compliant
REACH	REACH (EC 1907/2006) (01/16/2020, 205 SVHC) Compliant
Country of Origin	Belgium, France, Germany, India, Indonesia, Italy, Japan, Malaysia, Peoples Republic Of China, Philippines, Poland, South Korea, Switzerland, Taiwan, Thailand, or Vietnam

These screws are corrosion resistant in wet environments, nonmagnetic, and electrically conductive. Length is measured from under the head.

Coarse threads are the industry standard; choose these screws if you don't know the pitch or threads per inch.

Screws that meet ISO 4762 (formerly DIN 912) comply with specifications for dimensional standards.



McMASTER-CARR CAD

<http://www.mcmaster.com>
© 2014 McMaster-Carr Supply Company

Information in this drawing is provided for reference only.

PART NUMBER **92290A111**

Stainless Steel
Socket Head Cap Screw

Appendix I: Design Verification Plan

Senior Project DVP&R													
Date: 6/3/2020		Team: Mug for Tremors		Sponsor: QL+, Melissa Oliver			Description of System: Mug that counteracts tremors to reduce spillage for people with essential tremors				DVP&R Engineer: Logan Smith		
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1	Fill Mug Liner with liquid and measure using liquid measuring cup	16 ± 2 ounces	Kai Workman	SP, FP	1	C	5/26/20	5/26/20	16 ounces	1	0	
2	2	Measure input and output angles using high speed camera and computer software	50% reduction of rotation	Logan Smith	SP, FP	1	Sys	N/A	N/A	Did Not Complete	-	-	Did not complete due to COVID-19
3	3	Keep mug on and apply rotation to determine battery life	1 hour minimum	Kai Workman	FP	1	Sys	5/27/20	5/27/20	1 hour	1	0	Did not test maximum battery life
4	5	Weigh whole assembly on a digital scale	5 lbs maximum	Kai Workman	SP, FP	1	Sys	5/27/20	5/27/20	1.9 pounds	1	0	Including weight of water
5	6	Drop whole assembly from 4 feet to analyze structural integrity	No failures of components	Jaret Wedow	FP	1	Sys	N/A	N/A	Did Not Complete	-	-	Did not complete due to COVID-19
6	7	Measure the envelope of the assembly for height, width, and length	6"x4"x4" maximum	Kai Workman	FP	1	Sys	5/27/20	5/27/20	6.15"x7.3"x4.5"	0	1	
7	8	Measure height of handle	4" ± 0.5"	Kai Workman	FP	1	C	5/27/20	5/27/20	4"	1	0	

Appendix J: Gantt Chart

