Critical Design Report

MUG FOR VETERANS WITH TREMORS SENIOR PROJECT

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ABSTRACT

This Critical Design Report outlines the senior design project being carried out by a team of mechanical engineering students attending California Polytechnic State University, San Luis Obispo for the McGuire Veterans Affairs Medical Center in Richmond, VA. The scope of the project is to design, build, and test a device for veterans with tremors that will allow them to enjoy their favorite drinks comfortably and easily, without worrying about spills. This final product must be lightweight, aesthetic, capable of handling various tremor types, and can be operated in multiple planes to allow the veterans full control over the device. This document details the overall steps taken to establish our final design direction, "The Reaction Wheel Mug." The following sections will include the background research conducted to define the scope of our problem, the objectives of the project, our ideation and concept selection process, and preliminary analysis and CAD modeling for our final design direction. It will also discuss our plans to manufacture and test the final prototype.

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1. INTRODUCTION

Hand tremors are involuntary oscillations or vibrations in the hands and wrists that are caused by many diseases [1]. Approximately 7 million people in the US across a wide age range have essential tremors, although essential tremors are more prevalent among older people [2]. Common tasks that require a steady hand, such as drinking from a cup, can become difficult or impossible for individuals with hand tremors.

The Mug for Veterans Senior Project is a collaboration between the Richmond McGuire Veterans Hospital and the California Polytechnic State University Mechanical Engineering Department. We are also receiving funding and support from the TECHE lab at Cal Poly, San Luis Obispo. Melissa Oliver, an occupational therapist at the hospital, works with many veterans and helps them navigate their daily lives. Current drinking solutions for veterans with hand tremors are either ineffective at mitigating the effects of hand tremors or employ lids and straws that appear childish.

The purpose of this project is to create a device to mitigate the effects of a wide variety of hand and wrist tremors while drinking. Ideally this device will also avoid the aesthetic shortcomings of current products so that users can enjoy their favorite drinks anytime, anywhere, comfortably, and without the worry of spilling their drink.

This preliminary design report describes our background research, project objectives, concept ideation and design, initial engineering analysis, and how we will manage the project moving forward.

2. BACKGROUND

To best understand the challenges associated with solving this problem, our team gathered personal testimony, researched existing products and patents, and met with our sponsors who are intimately familiar with this problem.

2.1 Sponsor Interview

We met with our project sponsor, Melissa Oliver of the Richmond McGuire VA Hospital (assisted by rehabilitation engineer John Miller), to gain a working knowledge of the problems faced by veterans with hand tremors and to define the desired outcome of this project. From these conversations with Ms. Oliver, we gained an understanding of the elements of the mug that were most important to her end users [3], mainly:

- The user needs to be confident in the ability of the cup to prevent the user from spilling while drinking.
- The final product must appear like a regular coffee cup or travel mug, as the willingness of the customer to use the product is paramount.
- The handle must not have an opening that would allow for the mug to slip from the user’s grasp.
- The final product must be capable of handling both hot and cold liquids, be lightweight, and not rely on a straw/lid to mitigate spills.

- Operating procedures for the mug must be simple and intuitive, with clear instruction provided for care and maintenance.

2.2 Previous Senior Project

Last year, a mechanical engineering senior project team at Cal Poly, San Luis Obispo, also worked on this project. Their final design was a mug with two motorized joints in the handle which were used to react to hand tremors as shown in Figure 1 below. Unfortunately, due to COVID-19 the previous senior project was not able to fully test their design and determine its effectiveness at reacting to tremors [4].

Figure 1. Previous senior project final mug design [4]

Our sponsor raised several concerns with this design, including its overall weight due to the electrical components and its inability to be microwaved. We were also concerned about the motor's ability to continue to stabilize the mug as it was tipped. We were also able to see the background research that the previous team had conducted, and this helped to expedite our research.

2.3 Veterans with Hand Tremors Interviews

Initially, we struggled to interview our end users, specifically veterans with medical tremors. A member of the team was able to have a brief conversation with a representative end user, Vernan Eppard, and from this talk learned the following:

- Durability is important to build confidence in the product.
- Being able to see how much liquid is left in the cup is very useful.

Eventually, we were able to host a full-length interview [5] with another veteran, Bruce Dodd, and his wife, Kitty Dodd. Mr. Dodd's tremors have motivated him to try and to use a variety of tremor mitigating technologies, such as the Liftware Steady, a set of binoculars manufactured by Cannon utilizing gimbal tech, and (relevant to us) the Jamber mug. The devices employing active control (the Liftware and

Cannon products) were relatively effective for Mr. Dodd, while the Jamber mug did nothing to mitigate his tremors or improve the act of drinking, though it did improve the ease of gripping the mug.

Regarding his experience with tremors, Mr. Dodd relayed to us that he noticed no correlation between the strength with which he must grip an object and the severity of his tremors, though he does note that his tremors increase proportionally with the amount of energy he exerts in taking a drink from his mug (I.e. when the mug is full, his tremors are worse). Additionally, it became apparent that the aesthetic of the mug would play a significant role in whether Mr. Dodd would feel comfortable using the mug out in public. Compromises to the normal appearance of the mug would likely result in him "...not taking the mug outside the home, say to the coffee house." The interview with Mr. Dodd added to the appeal of using methods of active control to improve the drinking experience for individuals with tremors. We also gained insight into the design features that would help mitigate tremors, as well as the times when the tremors are most prominent.

2.4 Technical Information

The research we performed can be broken into medical research on tremors and analogous systems focusing on mitigating a forced oscillation imparted on a system.

2.4.1 Tremor Research

From the research on tremors, we found a definition for medical tremors, that reads: "An involuntary oscillatory motion of a body part" [1]. Additionally, the same source contained a breakdown on common tremors, allowing us to identify two main categories: resting tremors and acting tremors. Acting tremors, those characterized by a tremor that starts small but grows exponentially worse as the target of a task is approached [1], comprise the major tremor category we will be addressing in this project. The typical frequency range of tremors of this variety is 4-8 Hz [1]. A study of clinicians' abilities to accurately assess the amplitude of tremors described several standards for measuring the severity and amplitude of hand tremors such as the Clinical Tremor Rating Scale (CTRS), Fahn-Tolosa-Marin Tremor Rating Scale (FTM TRS), and the Unified Parkinson's Disease Rating Scale (UPDRS) [6]. Understanding these different rating scales is useful for understanding clinical data on hand tremors. This same study also provided hand acceleration data from multiple individuals with tremors, which will be useful for characterizing and simulating hand tremors.

2.4.2 Systems Focused on Mitigating Oscillations

Regarding the forced input to the cup caused by tremors, the conservative option is to conclude that vibration patterns vary per the individual, and that there is no standard pattern for hand tremor among people, even for those with the same disease/affliction [7]. Additionally, A research paper describing the creation of a self-stabilizing scalpel [8] provided a useful method for separating intended motions from unintended hand tremors using advanced bandpass filters on the acceleration data from an inertial measurement unit. This methodology for isolating unintended motions could be useful if our final design involves active stabilization.

2.4.3 Reaction Wheel Research

NASA provides a useful overview of reaction wheels uses in spacecraft: Reaction wheels are commonly used in satellites to provide attitude control. They work by accelerating or decelerating a flywheel to apply torque to the spacecraft [9]. Reaction wheels provide a compact way of applying torque to a system without any external parts, which could be an effective way of generating reaction torques to counteract tremors.

2.5 Patent Research

As part of our background research, we also found patents that attempt to solve the same problem or used technology that may be relevant to a potential design. Appendix #1 provides detailed information about these patents. Two of the patents, patent EP3571992A1, and patent EP3237081B1, seek to minimize tremors by using a glove worn on the hand and wrist. If they effectively minimized tremors, these could both be valid solutions to our problem while not being a drinking vessel of any kind [10], [11].

Another patent, patent GB2491981A, is designed to solve our exact problem (including aesthetic considerations) without any moving parts. Effectively, it is a lid that can fit into a variety of cup sizes but remains below the lip of the cup so that it is not as visible, as shown in Figure 2 [12]. This design has several limitations, such as being visible in clear glasses and easily visible to anyone sitting nearby.

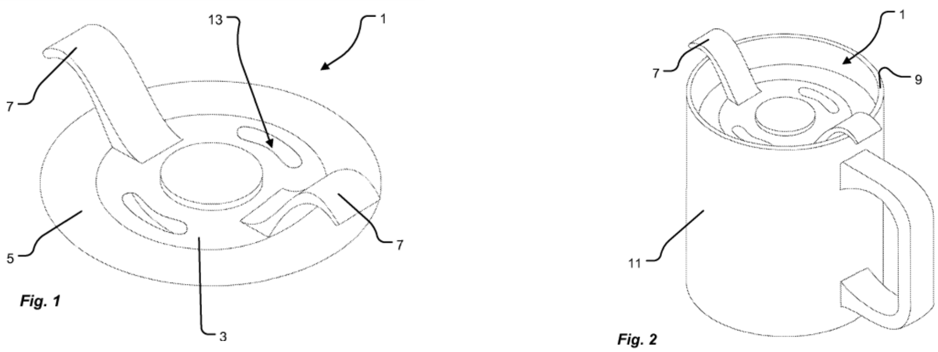


Figure 2. Anti-spill Device [12]

The Anti-spill Device patent also includes a detailed description of problems commonly faced by people with hand tremors. One challenge of particular note was the awkwardness of having to ask a waiter to fill a separate drinking container when eating out, which was one reason why this pattent is designed to work with a variety of different cups [12].

One other patent, patent US20200029710A1, for gyroscopically stabilized drinkware, seeks to mitigate rotations caused by tremors in one axis by using a gyroscope in the bottom of the mug [13]. This design has several issuses, including only mitigating tremors in one axis and requiring two hands to tilt the cup when drinking.

2.6 Product Research

Current products for individuals with tremors employ a number of different methods to minimize the effects of tremors on users' daily lives:
Liftware [14], an assistive spoon, senses the input tremor from the user and articulates the spoon end to counteract the tremor motion. In clinical trials Liftware devices, as seen in Figure 3, counteract approximately 70% of the affects of tremors, making their products some of the most popular for our end users; however, this technology does come at a price, as a Liftware Steady kit costs $195.00.

Figure 3. The Liftware Steady with the Control System Displayed [12]

The HandSteady Drinking Aid [15], as shown in Figure 4 below, is a simple, lightweight cup that makes use of a rotatable handle to allow the user to place their arm in a position that minimizes the effect of the tremors while drinking. Excluding its large handle this product looks like any other mug. It also has an easily removeable lid recessed into the mug so as to be out of sight. Some users appreciate having to use two hands as a result of the rotatable handle, while others consider it a deal breaker [16].

Figure 4. HandSteady Drinking Aid
A Lightweight Mug Featuring a Recessed Lid and a Rotatable Handle [15]

Another product, the Easy Grip-In Mug [17], seen below in Figure 5, is a travel mug with a hole through the middle that serves as a handle. The idea is that the lack of a clenching motion and the width of the exposed area will allow the user to have more control over their mug; however, this product seems to have a less than steady track record of mitigating spills, and even more detrimental, many users cannot fit their hand in as advertised. The mug's aesthetic, while not glaringly different when in use, is certainly distinguishable from a standard travel mug when the user sets it down.

Figure 5. Sammons Preston Easy Grip-In Mug
A Traveling Mug with a Center Slot to Remove the Need for a User to Grip [17]

Another product we researched was the Weighted Insulated Mug [18], shown in Figure 6. The weighted insulated mug includes a single closed handle, which looks like it may be uncomfortable to grip and may not fit all hand sizes. The added steel weight at the bottom of the mug also makes it non-microwaveable, but it is dishwasher safe. Some pros of the devices are that it stabilizes some individual's hand tremors, it works for both hot and cold liquids, and it includes a no-spill lid. According to our sponsor, weighted mugs have an inconsistent effect from person to person and can make tremors worse in some cases [3]. Finally, the aesthetic appeal of this device was very poor and looked childish and clunky.

Figure 6. Weighted Insulated Mug [18]

Lastly, we studied the Imagiroo [19], a device invented by a young girl to help her grandfather with Parkinson's disease, who would spill his drinks very frequently. The three-legged design of the Imagiroo seen in Figure 7 makes it hard to knock over and allows it to stay steady on uneven surfaces. The Imagiroo is also microwave safe, dishwasher safe, and BPA free. Users report the device being very effective for limiting knocking over and spilling drinks, but do not say much about it actually mitigating their hand tremors or making the act of drinking easier. It seems that the primary purpose of this device is to prevent the cup from knocking over, not to actually stabilize one's hand tremors.

Figure 7. Imagiroo (Kangaroo Cup) [19]

3. OBJECTIVES

3.1 Problem Statement

Veterans with tremors have a difficult time drinking from mugs. Tremors can cause liquid to spill during the act of drinking leaving users frustrated. Veterans with tremors need a device that is lightweight, aesthetic, can adjust to various tremors, and can be operated in multiple planes to allow the veterans full control over the device. Such a device would allow users to enjoy their favorite drinks anytime, anywhere, comfortably, and without the worry of spilling their drink.

3.2 Boundary Diagram

Located below in Figure 8 is a schematic of the boundary diagram, which visually represents the problem. The area of the sketch enclosed by the dotted lines represents the situation that we can directly manipulate. The primary area of interest is the act of the veteran drinking (the veteran picking up the device and drinking from it). We do not need to design for the filling of the device with liquid or other activities associated with drinking, just the drinking motion itself (including the veteran's wrist and drinking device). Everything outside of the dotted enclosure represents aspects of the problem that we do not need to directly manipulate but should consider. For example, we want our device to be able to fit into common one-cup coffee makers, which constrains the overall dimensions of the final product.

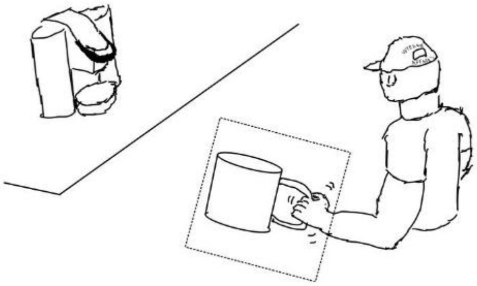


Figure 8. Boundary Diagram Sketch

3.3 Needs and Wants Table

The table below, Table 1, displays the customer needs and wants for the project. This information was gathered by talking with our sponsor, Melissa Oliver, about the project requirements. The “needs” represent aspects of the final design that are required, while the “wants” represent aspects of the final design that are not necessary but should be included to provide a more desirable solution. In order to create the best possible product, we are attempting to treat many of these wants as necessary inclusions.

Table 1. Customer Needs and Wants Table

Veteran Wants:
Dishwasher Safe
Microwave Safe
BPA free
Size: Fit in common one cup coffee maker
Ease of use: Simple and intuitive operating procedures
Sponsor Wants:
Geometry: Ability to hold 16 fluid oz, not clunky, handle sizing important, connected handle, and no lid and straw incorporated into the design if possible (or provide as add-ons to the design).
Motion/Kinematics: Ability to operate in all three planes (x, y, z)
Cleaning Instructions/Use Instructions (make simple if possible – drawings, captions, etc.)
Works for both hot and cold liquids (insulation isn’t super important)
Minimize weight
Documentation: Clear training instructions for care providers to train veterans
Aesthetics: Looks desirable to user (streamlined, not too clunky or childish)
Veteran Needs:
Prevent liquid from spilling while drinking
Sponsor Needs:
A product that instills confidence in user’s ability to drink without spilling

3.4 Quality Function Deployment:

The Quality Function Deployment, abbreviated QFD, is a method of defining an engineering problem with a house of quality, which consists of seven sections [20]. The QFD for this project is the first section of the house of quality is “Who”, which identifies the customers, in this case veterans with hand tremors, care providers, and non-veterans with hand tremors. Section two, titled “What”, details the needs and wants of the customers. The third section is “Who vs What”, which weighs the importance of the needs and wants for each customer. Section four documents benchmark testing of existing products against the customer needs and wants. Section five, titled “How”, contains the engineering specifications. In section six, “How vs. What”, we correlate the customer needs and wants to the engineering specifications. The final step, “How Much”, contains the target, maximum, or minimum values for each engineering specification.

3.5 Specifications Table

The engineering specifications table tabulates all the necessary requirements for a successful product, shown in Table 2 below. Each engineering specification must have a measurable way of determining success which will be measured through analysis, inspection, testing, or any combination thereof. We will use the engineering specifications and target values to determine where our product succeeds or needs improvement.

Table 2. Engineering Specifications Table

Spec. #	Specification Description	Requirement or Target	Tolerance	Risk*	Compliance**
1	Carrying capacity	12 oz	Min	L	A, I
2	Outside temperature range	40-120 °F	±5 °F	M	A, T
3	Total height	6 in	±0.5 in	M	A, I
4	Diameter (excluding handle)	4 in	±0.5 in	M	A, I
5	Vibration simulation	0 oz spilled	+.1 oz	H	A, T
6	Compliance with FDA standards and standards for assistive technology	Dishwasher, Microwave safe,	Min	M	A
7	Strength (drop test, no fracture)	6 ft	Min	H	A, T
8	Leakage	0 oz leaked	Max	L	I
9	Total weight	3 lbf	Max	M	A, I
10	Handle size	1in x 4in	±0.125 in	L	A, I
11	Instruction readability	95% comprehension	Min	L	T
12	Overall cost	$100	Max	L	A, I
13	Withstand hot liquids without degrading	212 °F	Min	L	T
14	Withstand cold liquids without degrading	32 °	Max	L	T
15	Battery Life	1 hr of operation time	Min	M	A, T

* Risk of meeting specification: (H) High, (M) Medium, (L) Low
** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

A brief description of each engineering specification is provided in the list below:

- The carrying capacity refers to the volume of liquid the product can safely carry, and while we would accept 12 oz as a minimum requirement, we will be targeting a capacity closer to 16 oz.
- The outside temperature range of the product is a necessary specification because users expect the product to comfortably hold hot and cold liquids, that in some instances will exceed the comfortable or safe temperatures of the human hand.
- The maximum height of the product is dictated by the maximum cup dimensions of common one-cup coffee makers.
- The maximum diameter of the product is dictated by the maximum cup dimensions of common one-cup coffee makers and the minimum hand size of users.
- Because a viable solution to this problem does not necessarily need to mitigate tremors, just the negative effects of tremors (i.e., liquid spilling), we will not be testing the product’s ability to

dampen the tremors; Instead, we will subject the product to a simulated hand tremor and measure the amount of liquid spilled.

- Several organizations, including the ISO, have created standards pertaining to the safety and functionality of assistive devices for persons with disabilities. It is important that our product meets these standards to promote user confidence and safety.
- The highest loading scenario which our product will be subjected to is if it is dropped while a user is drinking or knocked off a shelf. As such, we will perform a drop test to evaluate the real-world strength of our product.
- Any drinking device must hold liquid without leaking, so we will test our device for leaks.
- The total weight of the device includes the device itself and the liquid it holds. The target maximum of three pounds is a reasonable upper bound, but we will seek to minimize the weight.
- The handle size is dictated by the maximum hand size of users, so that the handle will fit all users.
- Instructions that are easy to comprehend is important to instill confidence in users when they are using the product. We will test such readability through a survey with a cross section of our end users, individuals with hand tremors and care providers.
- Designing a mug in such a way that would minimize the manufacturing cost will be important to maximize the number of people who can afford the product.
- Users will use our product with hot liquids, so it must be made from materials that can withstand boiling water.
- Users will use our product with cold liquids, so it must be made from materials that can withstand freezing water.
- If our product uses electronics and batteries, it must have an operational battery life greater than the amount of time a user would continuously use it for.

4. CONCEPT DESIGN

4.1 Concept Ideation

Having completed preliminary background research, established needs and wants with our sponsor, and refined our approach using a variety of project management tools, we began to develop basic concept models to address the functionality of the mug.

The concept models we created were derived from the function tree (Figure 9) displayed below. Each of the five functions were chosen to address an important ability our mug will have in order to achieve the main function of assisting the act of drinking of individuals with tremors. The subfunctions constitute the actions each of the higher order functions need to employ in order to be effective.

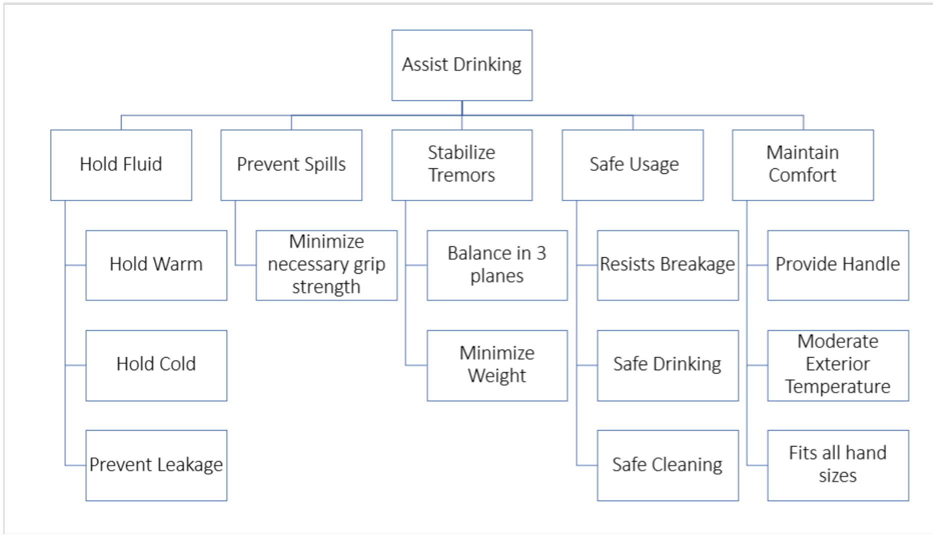


Figure 9. Functional Decomposition Tree

Each concept model was designed with a specific function of the mug in mind, and examples of these models can be found below. Included along with each model is the function they were designed to meet as well as a small description of how the model addresses the said function.

Function Addressed: Prevent Spills

The handle shown in Figure 10, is intended to address the prevent spills function by providing flexibility to the user while keeping the handle in a constant state of tension, thus securing it the cup frame. Integrating the handle elegantly will be difficult, as it will require manufacturing pathways for the tension bearing object to travel within the mug. The flexible handle will need to be able to rigidly fasten to the mug while allowing for slight rotations. If the handle were to translate away from the mug, the effect would have to be minimal, as that would be disconcerting to a user for the handle to appear to separate from the mug.

Figure 10: Handle in Tension/Flexible Handle

Function Addressed: Holds Fluid
To address holding fluid, it is important to consider the opposite of what holding fluid is. By allowing for external mugs to be the main method of holding fluid, this design, in Figure 11, addresses the personal side and the fluid storing methods in the specifications.

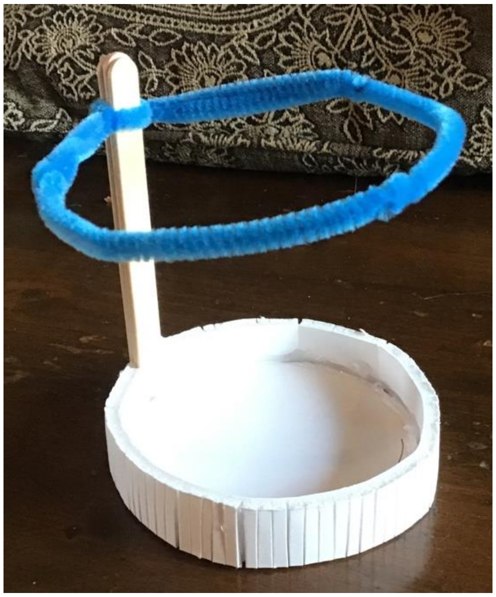


Figure 11: Vibration Mitigating External Handle

Function Addressed: Stabilize Tremors
Much like an earthquake mitigating spring-mass-damper employed by various skyscrapers, this cup, shown in Figure 12, would have a removable bottom portion with a spring-mass-damper system that could move in two axes specifically tuned to dampen tremors. This system could also be motorized to actively move the mass and provide a reaction force to the tremors without the use of the springs and dampers.

Figure 12 Moving Mass

Function Addressed: Maintain Comfort

The ideation model in Figure 13 is simply a soft outer wrapping, like that of a soft pencil grip, that encloses the drinking device. The material is soft and moldable to the user's fingers, requiring less grip strength to hold than usual. Ideally, the soft outer shell would help resist breakage and help to protect the user's hand from uncomfortable mug temperatures.

Figure 13: Compliant Exterior for Easier Gripping

4.2 System Level Designs

The various concept models that emerged from the ideation process were placed into a table, called a morphological matrix (Figure 14 below), that divided every idea into its resident function, with each function containing five ideas.

Morphological Matrix		Ideas				
Functions		Idea 1	Idea 2	Idea 3	Idea 4	Idea 5
Function 1	Hold Fluid	External Mug	Hourglass	Inner removeable Cup	Mug Liner	Regular mug shape
Function 2	Prevent Spills	Tilting cup	Mug w/inner lip	Tilting Bottom	Recessed Lid	Fluid Dampening Mug
Function 3	Stabilize Tremors	Two axis Gimbal	Half Weighted cup	Tuned Mass Spring Damper	Gyroscope in bottom	Motorized mass in bottom
Function 4	Safe Usage	Wireless Charging	Detachable Electronics	Padding/compliant exterior	Thermal Insulation	Spring Loaded Tripod
Function 5	Maintain Comfort	Adjustable Handle	Hourglass Covered Handle	Finger Groove Handle	Handle in Tension	Closed Handle

Figure 14: Morphological Matrix

Using the morphological matrix, each team member incorporated ideas from each function into a systems-level design. These designs represent comprehensive final products, weaving in the functional decomposition, the concept models addressing those particular functions, and the morphological matrix which presented the full range of ideas per function.

By combining different ideas from each function of the morphological matrix, we created five system level concept sketches to best meet the required functions. Our first concept sketch, seen in Figure 15, was of the previous senior project's design. This design features a two-axis gimbal (controlled by an IMU/controller-board stored in the bottom of the device) to counteract the input motions produced by the user's tremors and stabilize the device while drinking. The two-axis gimbal is connected to a handle with finger grooves to minimize the necessary grip strength needed to operate the device. The device also features a removable mug liner that can be used in a dishwasher or be microwaved, which maintains the electrical integrity of the device and minimizes the chance of the device being damaged. Lastly, the cup also has an inner lip to minimize spilling.

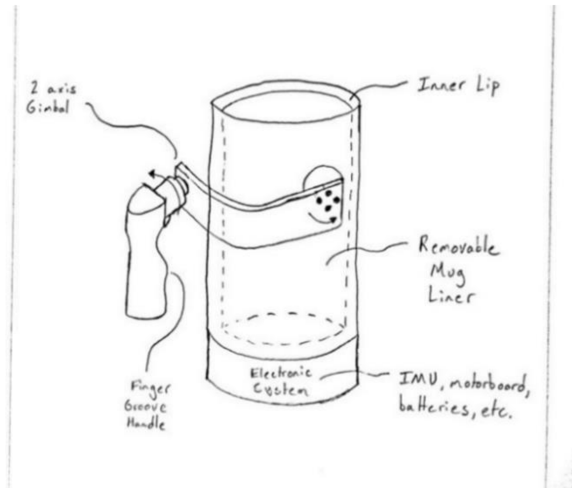


Figure 15. Previous Senior Project

The next concept we came up with was the “moving mass,” seen below in Figure 16. This idea uses an internal moving mass to generate reaction forces to counteract the tremors. This design allows for the user to grip the exterior of the mug as well as the handle and still be effective at stabilizing the tremors. The diagram below shows masses on linear actuators placed in the bottom of the mug to generate reaction moments (although non-coupled forces would also be generated, which is a possible problem with this implementation). Another implementation would use reaction wheels, much like the control system on a spacecraft, to generate reaction moments to counteract the tremor forces. Using reaction wheels would eliminate several problems with using linear moving masses, including the very limited range of motion of the linear moving masses.

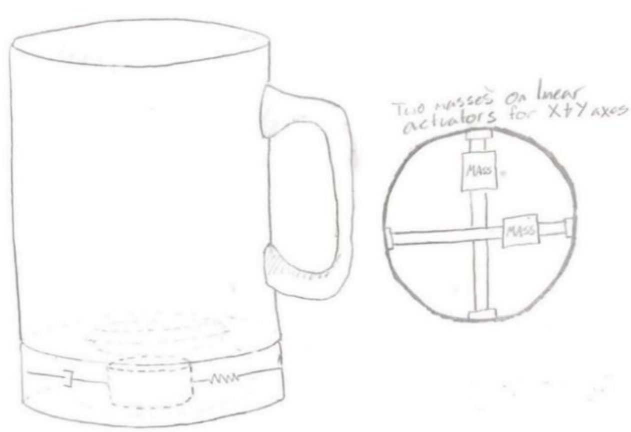


Figure 16. Moving Mass

The idea below in Figure 17, called the suspended inner cup, mitigates vibrations through a sequence of tuned spring-mass dampers that suspend a mug liner inside of an outer shell, which serves as both the holster for the mug liner and a part of the system's mass. The pronounced mug lip will serve to disrupt the standing wave oscillations that develop from fluid perturbations and can exacerbate the amount of liquid spilled should the oscillations reach a resonance frequency. An adjustable handle will allow for fitting the mug comfortably to many different hand sizes.

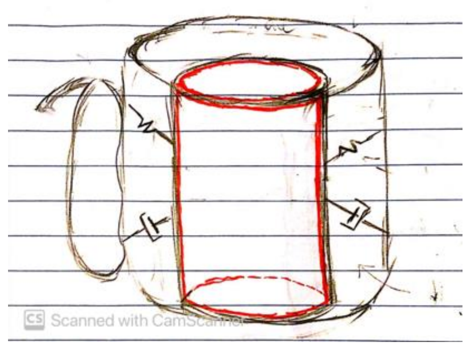


Figure 17. Suspended Inner Cup

The idea below in Figure 18, focuses on use of an external mug. By using an external mug, the design becomes focused on the stabilization of the tremors rather than the effectiveness of the cup. This also allows for preference of a certain mug based on different likes and dislikes of the user. Once an external mug is secured to the two-axis gyro, the control system and motors help reduce the effect of tremors on the mug. The use of a large handle is ideal for our target users of Veterans. The gyro skeleton is similar to the previous senior project design, as it is controlled by an IMU/controller-board stored in the bottom of the device.

Figure 18. External Mug/Handle

4.3 Design Selection

These systems-level designs (4 per team member) were evaluated based upon the sponsor's specifications. Those that best addressed these parameters were included in a final table, the weighted decision matrix, seen in Figure 19. Each specification was assigned a weight corresponding to its importance to the final design (0-10 scale), and each final design was assigned a score (also a 0-10 scale) based upon how well it addressed the specification in question. By multiplying the weight by the design's score, repeating this operation for every specification, and summing up the final scores per design, each system received a final number whose importance is in comparison to that of the other mug designs. In this manner, the mug design with the largest score theoretically addresses the specifications of the sponsor to the highest degree.

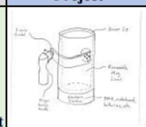
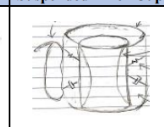
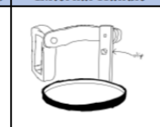
Team W15: Mug for Veterans with Tremors Decision Matrix		**Previous Senior Project**	**Moving Mass**	**Suspended Inner Cup**	**External Handle**	**Tilting Inner Cup**
Specification	**Weight**					
Prevent Liquid Spills	8	8	7	6	8	5
Instill Confidence while Drinking	10	8	8	7	8	4
Dishwasher Safe	4	4	6	10	6	10
Microwave Safe	5	3	6	3	5	3
Fit in Common Coffee Makers	8	4	7	7	8	6
Mitigates Vibrations	7	8	9	6	8	5
Hold 16 fl oz	5	7	7	6	5	8
Fits different Hand Sizes	8	9	9	9	9	9
Stabilize in all Three Axes	6	7	7	5	7	3
Minimize Weight	5	3	3	4	3	8
Work with cold and hot liquids	8	10	8	9	8	10
Look "normal" or desirable	6	5	9	7	4	8
Affordable for veterans	5	4	4	6	4	9
Total	85	557	611	567	575	561
Average on 10pt Scale		6.55	7.19	6.67	6.76	6.6

Figure 19. Weighted Decision Matrix

From the weighted decision matrix, the top scoring design was the moving mass design, while the design with the second-highest score was the external handle design. These two ideas are still in the developmental phase, as we are figuring out how to address the spatial and weight constraints of each design. Until further calculations and analysis are done, we are pursuing the moving mass as our primary design while having the external handle design as a failsafe.

The moving mass design and external handle design both rely on active electronic control. The intuition of the group motivated us to move ahead with mug designs that utilized active control systems for generating reaction forces. Purely mechanical designs, while inherently more reliable, are not likely to be as suited for the random and rapid waveforms that define hand tremors. With an electronic system, if the mug can directly sense the tremors, and prompt an instantaneous response from the mechanical system, the tremors can be directly mitigated to the degree necessary. Purely mechanical methods of vibration damping, such as spring-mass-dampers, are also most effective with a constant mass system. This makes tuning a purely mechanical system over the weight range of the mug (from completely full to completely empty) difficult or impossible, while an electronically controlled system with closed loop feedback can remain effective over a wide range of operating conditions.

In moving forward with an electronics solution, our sponsor, Melissa Oliver, provided her sentiments on a previous iteration of this project that pursued a similar avenue. Their design ultimately did not meet the criteria she felt had been established for the project, in particular the aesthetics of the mug and the rigid, mechanical operation of the handle. In our own design, we must strive to balance the technical ability of the mug while designing a platform with which the user wants to interact.

Our current intent is to further study the efficacy of using reaction wheels to generate reaction moments to stabilize tremors, along with improving and optimizing the control system used by the previous senior project. Regarding the use of reaction wheels, our primary concerns are available space, torque generation, motor capabilities, and battery energy density. This design is heavily constrained by physics, and there is a significant risk that a viable reaction wheel design does not exist within the size constraints of a mug. As such, we are continuing to further the work of the previous senior project and are investigating solutions to the aesthetic and functional drawbacks of the design.

4.4 Conceptual Prototypes

To further assess the functionality and feasibility of our system level designs we built concept prototypes based on the previous senior project design and reaction wheel design. We upgraded these concepts using feedback from our sponsor and our engineering judgement to better meet the needs and wants of our design.

The concept prototype seen in Figure 20 below is of a recessed two-axis gimbal mug design. We feel that the idea behind this design is effective in the mitigation of tremors in two axes and that with an upgraded controller board and gimbal software this design could perform its intended purpose. Due to the concern of our sponsor that the handle on the previous senior project design was too clunky and made the mug look unusual, we chose to recess the gimbal arm mechanism into the mug shell to improve the aesthetic appeal of the device while maintaining its functionality.

This design would also include an electronics box located in the base of the mug to hold the IMU (inertial measurement unit), controller board, and battery. The IMU would actively detect shifts in the mugs position due to the user’s input tremors, while the controller would rotate the gimbal motors opposite to the input motion to counteract this motion and stabilize the device. The battery would power these components and allow the device to be rechargeable.

Additionally, we are thinking of ways to make this device dishwasher and microwave safe. This could be accomplished by creating a removable inner mug liner that is microwave and dishwasher safe or we could find ways to make the electronics removable from the device. Furthermore, there are some concerns over a few aspects of this design. Our primary concern is that recessing the gimbal mechanism into the mug will limit the volume available for holding our intended target of 12 fluid oz. We are also concerned with attaching the motor securely to the mug in the recessed track and would need to design both a left-hand and right-hand model for users due to the mechanical layout of the gimbal arm. If we can find ways to effectively design around these constraints, we feel that this concept could adequately solve our design problem.

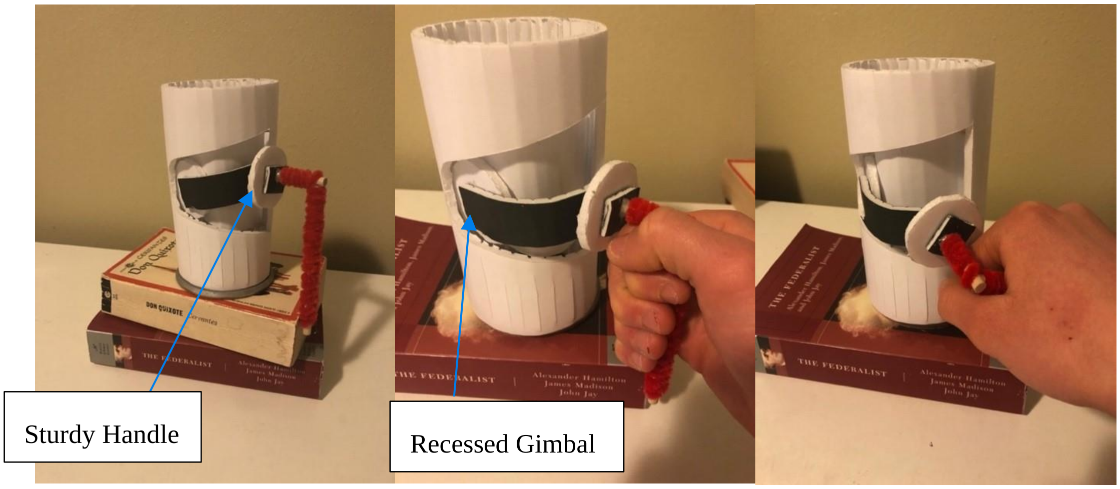


Figure 20. Recessed Two-Axis Gimbal Concept Prototype

In addition to the recessed two-axis gimbal concept, we also developed a reaction wheel mug concept prototype as seen in Figure 21. The reaction wheel mug consists of two reaction wheels oriented perpendicular to each other and contained within the bottom of the cup. These reaction wheels will be powered by motors and accelerate and decelerate to create reaction torques to counteract the tremors. This design is intended to be as visually similar to a normal mug as possible, while still actively stabilizing tremors. While creating this concept prototype we gained a better understanding of the space constraints associated with packaging all of the electronics into the form factor of a mug. Specifically, we learned that a large diameter mug will allow more space for the battery and controller to fit next to the reaction wheels. We also learned that the handle would need to be positioned opposite the reaction wheels so that the mug is balanced side to side and to allow the electronics to slide out of the side of the mug.

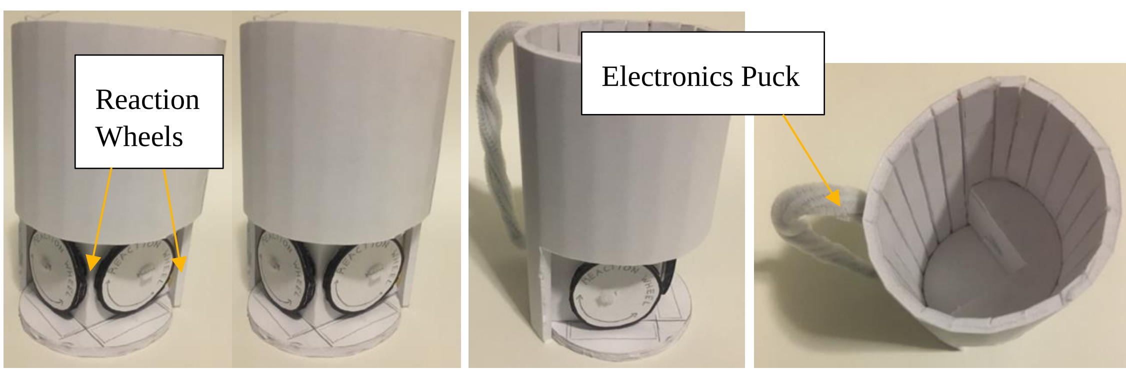


Figure 21. Reaction Wheel Mug Concept Prototype

We intend to move forward with analysis on both concepts, with the reaction wheel mug being our primary design direction. Further analysis is needed for the reaction wheel concept to determine its feasibility, but if analysis proves this idea to be feasible, we will move forward with detailed design of this concept. The recessed gimbal design will be our secondary design, should further analysis prove the reaction wheel mug concept to be unreasonable to implement.

4.4.1 Concept CAD

To illustrate the functionality of the updated moving mass concept, which employs reaction wheels as an active counterbalance, detailed drawings in the CAD software Fusion 360 were created (Figure 22 – 23 below).

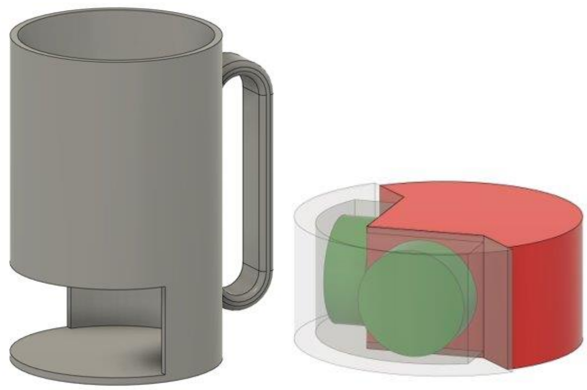


Figure 22: Reaction wheel design mug shell (left) and electronics puck (right).

The figures above illustrate the main components of the mug design, a mug shell to carry the liquid and house the electronics puck. The figure of the puck shows two reaction wheels (green) set perpendicular to one another in order to generate reaction torques in the two axes we principally associate with tremors (that of pitch and roll). Within the red portion of the puck, a controller, IMU, motors, motor drivers, and battery are housed. Together, these components comprise the network that delivers appropriate power to each reaction wheel depending upon the forced input (the tremor, in this case) from the user.

The puck slides into the base of the mug and is (tentatively) affixed by a “snap-on” mechanism that can be easily released at the push of a button, or perhaps by employing a spring-activated attachment on the puck, which can be released by simply pushing on the puck. The interface of the puck and mug shell is displayed below in Figure 23.

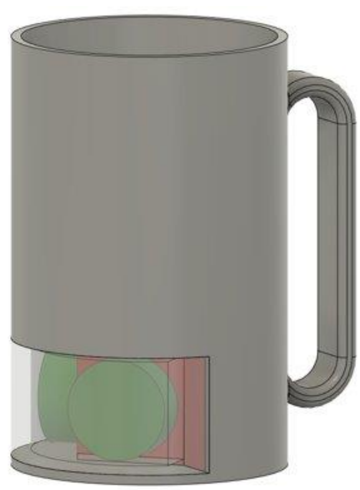


Figure 23: Reaction wheel design with electronics puck installed in mug shell.

4.5 Initial Modeling and Analysis

Stabilizing tremors is ultimately a problem of dynamic control and vibration damping. As such, it is critical that we can simulate the dynamics of both the reaction wheel system and the recessed gimbal design. Moving forward, we will split the simulation and analysis into three components: modeling tremor input forces, developing a sizing tool for motors and reaction wheels, and creating a full system, three-dimensional dynamics simulation. We plan to create these models using Matlab and Simulink.

4.5.1 Modeling Tremors

Currently, we have developed a simplified model of a tremor in one axis as a sinusoidal input torque, shown in Equation 1 below. While real tremors are random and vary widely from person to person, this simplified model is useful for sizing the motors and reaction wheels.

$$M_{tremor}(t) = M_{max} \sin 2\pi f t$$

Eq 1: 1D Tremor Forcing Function

In Equation 1, M_{max} is the amplitude of the tremor torque, and f is the frequency of the tremor, which typically ranges from 4-8 Hz [1]. Since we were not able to find any good information on the force of hand tremors in our technical research, we can work our way backwards from typical tremor amplitudes (which are well defined), Equation 1, and the mass-moment of inertia of the mug to find M_{max}. We performed this calculation in Matlab, which is shown in Appendix 5. This analysis resulted in Equation 2, shown below, which relates M_{max} to the tremor frequency, tremor amplitude (in radians), and physical properties of the mug.

$$M_{max} = \frac{1}{3} f^2 m \theta_{max} \pi^2 (0.75D^2 + H^2)$$

Eq 2: Amplitude of tremor forcing function.

In Equation 2, θ_{max} is the tremor amplitude in radians, D is the mug diameter, H is the mug height, and m is the mug mass (all units are base SI). This equation models the mug as a solid cylinder of uniform density, which is highly simplified, but still useful for initial feasibility studies and motor sizing. Plugging in a reasonable range of values for θ_{max} and f we came up with an expected range of values for M_{max} between 0.3 and 2 Nm, with the upper bound being a high amplitude (±15°) and high frequency tremor (8 Hz).

4.5.2 Initial Sizing Methodology

For sizing the motors and reaction wheels there are two main parameters to consider: the maximum torque the system can generate, and the angular impulse the system can impart. The maximum torque of a motor occurs at zero rpm [23] and should be greater than M_{max}.

The angular impulse, or torque applied over time [24], is a function of the motor torque curve and the moment of inertia of the reaction wheel. As the reaction wheel speed increases, the motor torque will drop until the motor reaches its maximum speed and the torque applied to the mug drops to zero, which is called saturation [25]. Increasing the moment of inertia of the reaction wheel would decrease the acceleration of the motor and allow it to operate for longer periods of time without saturating.

For initial sizing of the motors and reaction wheels we sought to find a combination that fits within the size constraints of the mug and could impart a greater angular impulse than the angular impulse of one-half cycle of a worst-case scenario tremor. For more detailed sizing and final verification of the reaction wheel design we will need to develop a more detailed system model with a controller, feedback, and random tremor input; However, we believe the methodology described above provides a good jumping off point for sizing the motors and reaction wheels and confirming the feasibility of this design.

4.6 Risks per Design Selection

Both the concept designs we considered have several major risks associated with them, which are detailed in the sections below. Comparing these risks helped us to come to a final design decision, which we discus in Chapter 5 of this report.

4.6.1 Risks with Reaction Wheel Mug

The reaction wheel design poses several serious design challenges and is heavily physics constrained. Namely, we are most concerned with packaging the motors and reaction wheels within the size constraints of a regular looking mug. This system would also require an advanced controller design since motor torque changes with RPM and it is possible to max out the rpm of the motor, at which point the system would no longer be able to create torque in one direction. Additionally, the presence of removable electronics creates the potential for users to misuse the mug, such as accidentally microwaving the mug with the electronics still attached.

4.6.2 Risks with Recessed Gimbal Mug

The current risks associated with the recessed gimbal mug are the ability to incorporate the recessed track inside the mug. The motor sizing will be dependent on the output of our motors which could lead to a larger and bulkier design. Creating removable and washable parts that can easily be fit correctly and are sturdy enough to mitigate tremors every time is an important challenge for this design. We are also concerned with the aesthetic look issues, as this design should be very functional, however has the issue of not being a normal enough looking mug. This design also has an issue with the handle positioning as the mug is dependent on which hand holds the mug. Designs for both left and right-handed users would have to be made, however the electronic software and code would be extremely similar.

4.7 Design Hazard Checklist

The Design Hazard Checklist in Appendix 4 is a way for our team to identify potential safety hazards and incorporate solutions to prevent them. Evaluating both of our designs allowed us to identify hazards that were apparent in both solutions and plan a corrective action to fix/ mitigate these dangers. These safety hazards range from moving parts, potential issues with electronic components, misusage of the designs. These hazards will be kept in mind as we pursue our final design for the Interim Design Review.

4.8 Design Direction: Reaction Wheel Mug vs. Recessed Gimbal Mug

In chapter 4.4 (Conceptual Prototypes) we establish our intended design direction as the reaction wheel mug, with the recessed gimbal mug serving as our Plan B design direction. The reaction wheel concept was selected to be our primary design focus because of the possibility for an aesthetic final product and as it provided a clear path to mitigate tremors while not counteracting voluntary motion. However, the reaction wheel concept was a novel idea without much analysis to back-up the approach, hence our decision to initially proceed with two designs. Through further analysis and testing (detailed in Chapter 5. Final Design), our goal was to determine whether the reaction wheel mechanism would be capable of generating sufficient torque in a small enough package to counteract a user's tremors. After designing a lumped parameter model, developing kinematic and kinetic equations of motion in MATLAB, and building a structural prototype that qualitatively demonstrated the torque capacity of a medium sized motor, we were confident in proceeding with the reaction wheel design.

5. FINAL DESIGN

5.1 Final Design Summary

The main purpose of the mug we develop is to ensure that the user with tremors feels comfortable and in control of the mug throughout the action of taking a drink. In order to do this, the mug must feel durable, have an aesthetic appearance, and mitigate the effect of the tremors during drinking. To address the mitigation of tremors, we have developed a reaction wheel mechanism capable of reacting to rotations about the pitch and roll axes, the two axes we have identified as contributing the most to spillage. Our design is broken up into two subsystems, the mug shell and the electronics puck. These are shown below in Figure 24.

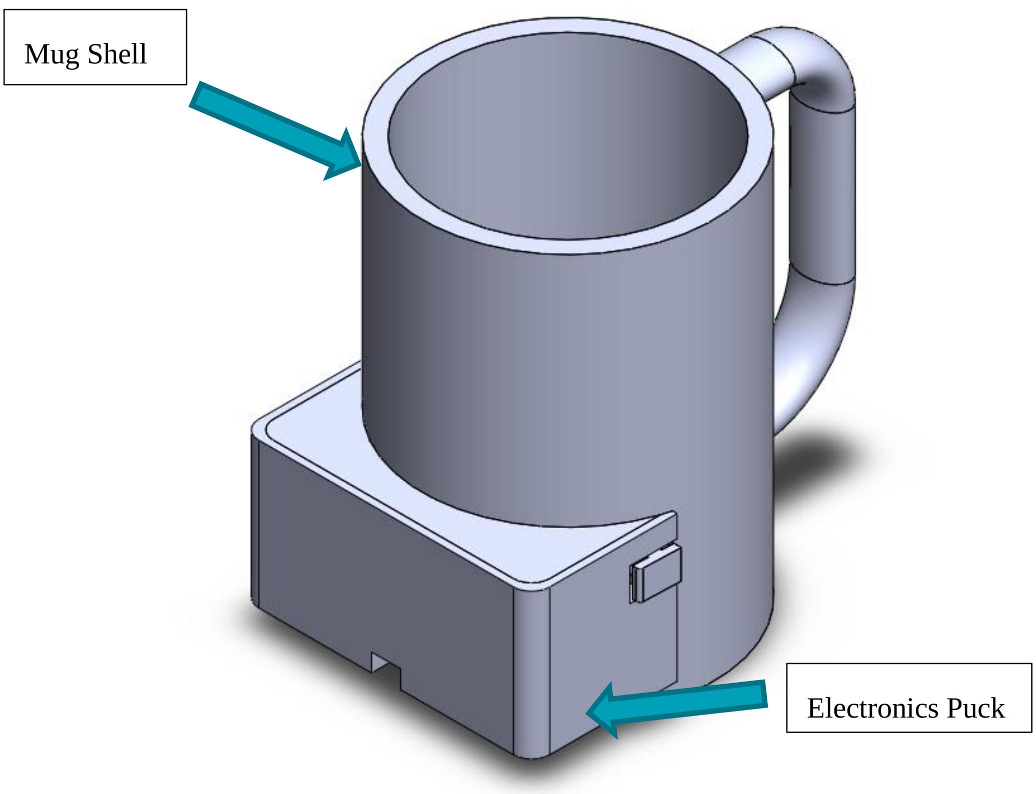


Figure 24: Full CAD model

5.1.1 Functional Diagrams

The functionality of the reaction wheel mechanism begins with the input of a continuous tremor. A tremor input from the user will displace the mug from an established datum of the IMU and will be mitigated through the operation of our linear, setpoint control loop. The displacements caused by the tremor will cause changes in the angular velocity of the mug, which will be captured by an Inertial Measurement Unit (IMU) that then conveys this "disturbance" to the microcontroller (MCU). Before the signal from the IMU reaches the MCU though, the signal will have to pass through a software-implemented bandpass filter. The purpose of the bandpass filter is to remove the frequencies that the reaction wheel mechanism ought to ignore. The main contributors to this category are electronic component noise and, more importantly, the frequencies corresponding to voluntary motions, such as raising one's hand to take a drink. The MCU will interpret the adjusted signal and convey an appropriate voltage input to the ESC, which will spin up the motor with an appropriate PWM signal, and the flywheel being directly driven by the motor, to the required speed. The flywheel will spin in the same direction as the tremor that induces the disturbance from the setpoint because the equal and opposite reaction the flywheel's rotation on the motor (which is mounted to the base of the mug), will cause the mug to rotate in the opposite direction as the tremor input. This moment translated to the user should help counteract the tremors.

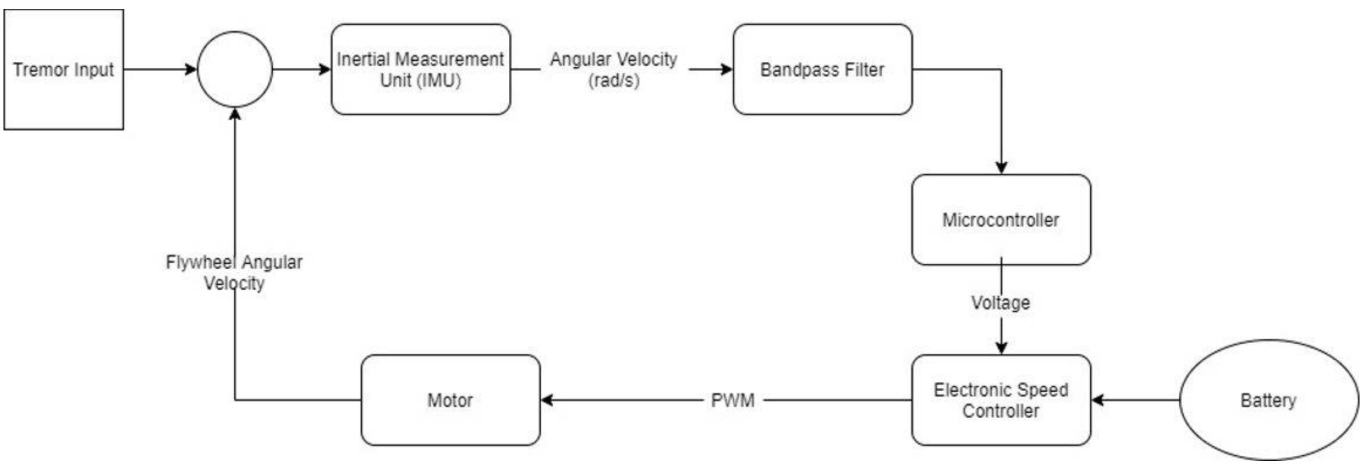


Figure 25: Tremor Mitigation Functional Diagram

Sizing for various electronic components was due to our motor selection process, which is highlighted in Section 5.2 Structural Prototype. In Figure 26 below, we can visually see how power (enabling component motion) and data (signals between sensors, controllers, and the microcontroller) flow between our electronics components.

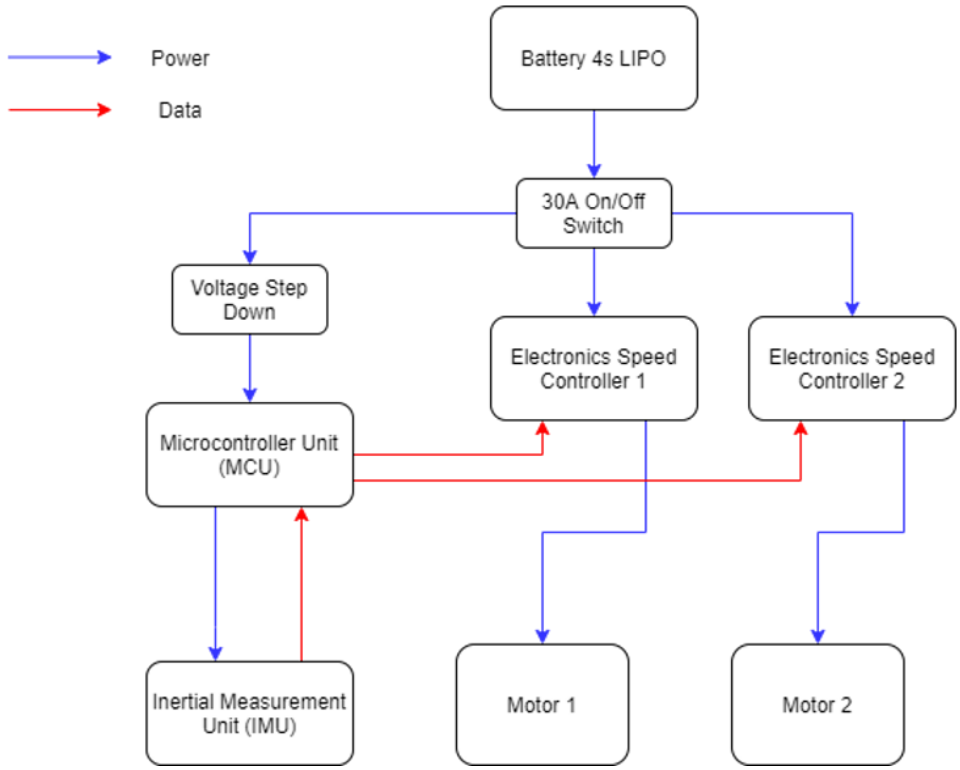


Figure 26: Electronics Function Breakdown

5.1.2 Systems Breakdown

In Figure 27 below we can see the part-by-part breakdown of the electronics puck. This includes all the components necessary for our system to run. The parts we have modeled have been correctly sized for our chosen electronics. These final electronics are highlighted in Section 5.2.2

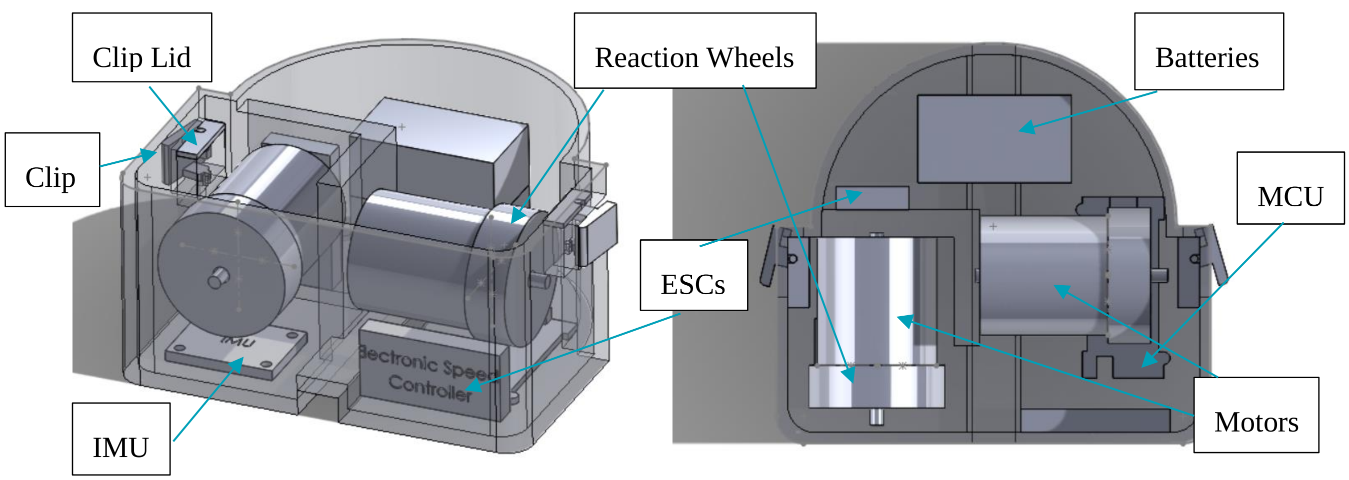


Figure 27: Piece by Piece breakdown of Electronics Puck

Another important aspect of our design was the Mug Body. As the mug body is the presentation to the user, a normal looking mug was our design intent. A sturdy handle is an integral addition to the functionality of the design to mitigate tremors for our mug. Based upon a hand size analysis conducted by NASA [26], we designed our mug handle to fit up to the 95th-percentile of users, which will allow for a large percentage of potential end users to have sufficient space between the handle and the cup. In Figure 28 below you can see how the gentle curve of the handle is both appealing and functional.

Figure 28: Profile of Mug

The electronics puck is integral to the functionality of mitigating tremors. However, without a method of attaching to the mug shell, our design will not work. Therefore, we designed the puck and mug body interface to ensure that these two pieces act as one body when connected. A large rail centered along the floor of the mug body cavity serves to align puck for easy sliding action. Once the puck is slid in fully, two spring-loaded tab mechanisms on either side of the mug will interlock with their corresponding hooks, which are attached to the mug body. To slide the puck out of the body both clips on the sides will need to be depressed. These clips are designed to be easy to unclip, but sturdy enough in addition with the center alignment beam to not allow movement of the puck while in use. The center alignment beam and clip mechanisms are shown in Figure 29 below. The springs selected for the clip mechanism were calculated to function in our design, and are included in our drawing package (Appendix 11). They are highlighted in section 5.4.

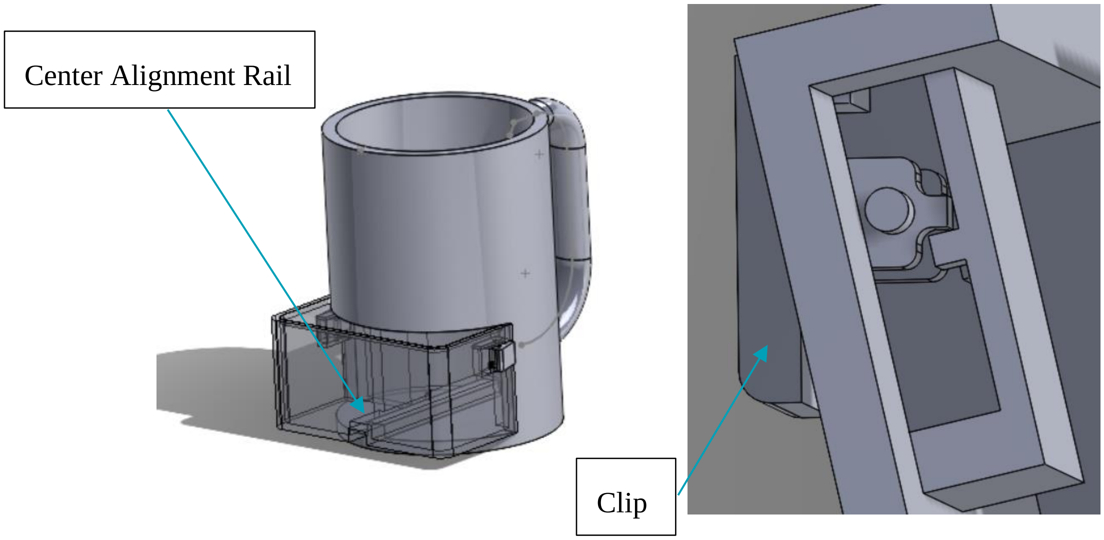


Figure 29: Center Alignment Beam and Clip Mechanism

5.1.3 Weight of Mug

Located in Table 3 below is a breakdown of our final estimated design mass. The final estimated mass is 710 g or 1.18 kg (holding 16 fluid oz). This is below our maximum allowable mass of 1.36 kg (3lb) from our engineering specifications table. The final mass is something we will continuously be trying to reduce in order to decrease the severity of the user's tremors when using the device.

Table 3 – Final Design Mass (Estimated)

Final Design Weights		
Component	**Weight [g]**	**Quantity**
Microcontroller	43.2	1
ESC	16.2	2
Motor	52	2
Flywheel	56	2
IMU	3	1
Battery	18.2	2
3.3V regulator	1	1
Mug Body	410	1
Electronics Shell	80	1
Total:	**710**	

5.1.4 State Space Model

To develop the controller software for reacting to tremors, we need a dynamic model of the entire design. We decided to create a state space model of our system using linear graph theory [27]. State space models are particularly useful because they are easy to simulate using a computer. As the first step, we created a lumped parameter model of the mug and reaction wheel system, which is shown below in Figure 30.

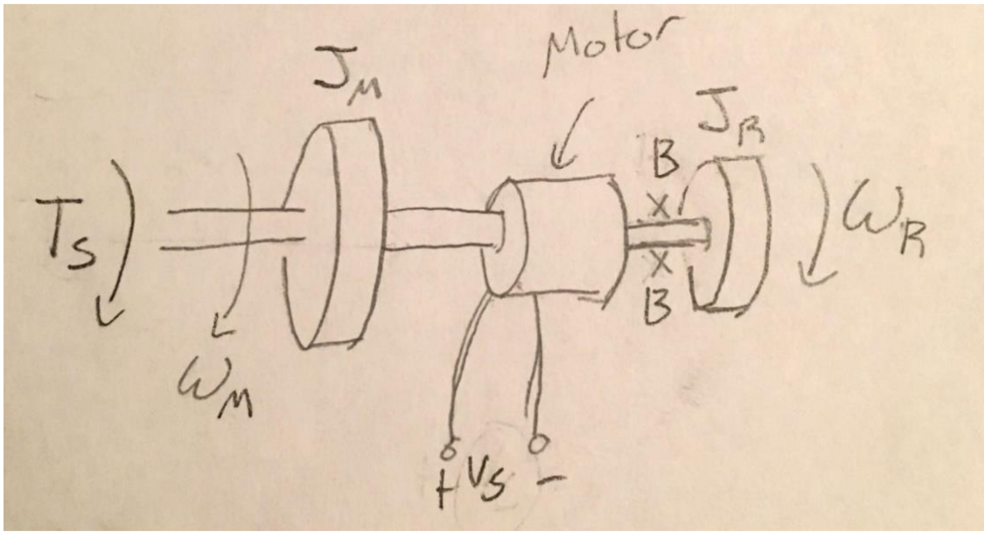


Figure 30. Lumped parameter model of the mug and reaction wheel system.

The inputs to our lumped parameter model are T_s, the tremor input torque, and V_s, the voltage to the motor from the ESC. Our system parameters are J_M(the total moment of inertia of the whole system), (the moment of the reaction wheels and motor rotor), and *B (*the viscous damping of the bearings in the motor). Next, we processed the lumped parameter model into a linear graph and normal tree to create the elemental equations. Equation 3 shows the resulting differential equations arranged in state-space form, which describe the dynamic behavior of our system. For a complete derivation refer to Appendix 6.

$$\begin{bmatrix} J_M & 0 & 0 \\ 0 & J_R & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \dot{\omega}_M \\ \dot{\omega}_R \\ \dot{i}_L \end{bmatrix} = \begin{bmatrix} -B & B & K_V \\ B & -B & -K_V \\ -K_V & K_V & -R \end{bmatrix} \begin{bmatrix} \omega_M \\ \omega_R \\ i_L \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_s \\ V_s \end{bmatrix}$$

Eq 3. State space model of mug and reaction wheel.

Our state space model also includes motor parameters K_V(the motor speed constant), *R (*the terminal resistance), and *L* (the motor inductance). While the motor manufacturer publishes the speed constant for their motors (750 RPM/Volt for our final motor), they do not publish the terminal resistance, inductance, or damping coefficient. We measured the terminal resistance of the motor from our structural prototype to be 2.7 Ω, but still need to get access to a multimeter that can measure inductance.

We have implemented this state space model in MATLAB, also shown in Appendix 6. Once we have purchased our final motors, we will be able to fully characterize the system and use our MATLAB model to run time domain dynamic simulations of the mug reacting to tremor inputs. This will allow us to develop and tune our controller software before building the final mug, as well as predict the degree to which the mug can reduce the amplitude of random tremmors.

5.2 Structural Prototype

The purpose of the structural prototype was mainly to test communication between major electrical components of our design, namely the microcontroller, ESC, and motor/reaction wheel, with the intention of causing a motor to spin. The structural prototype allowed us to test the output torque of various motors and confirm that Nucleo microcontrollers running MicroPython can communicate with the ESC to control the motor. From the testing different motors (3 total), the medium-sized Flash Hobby D2380 BLDC motor was selected owing to its sufficient torque (approximately 0.35 N-m) to jerk the user's hand. The major components of the structural prototype are shown below in Figure 30.

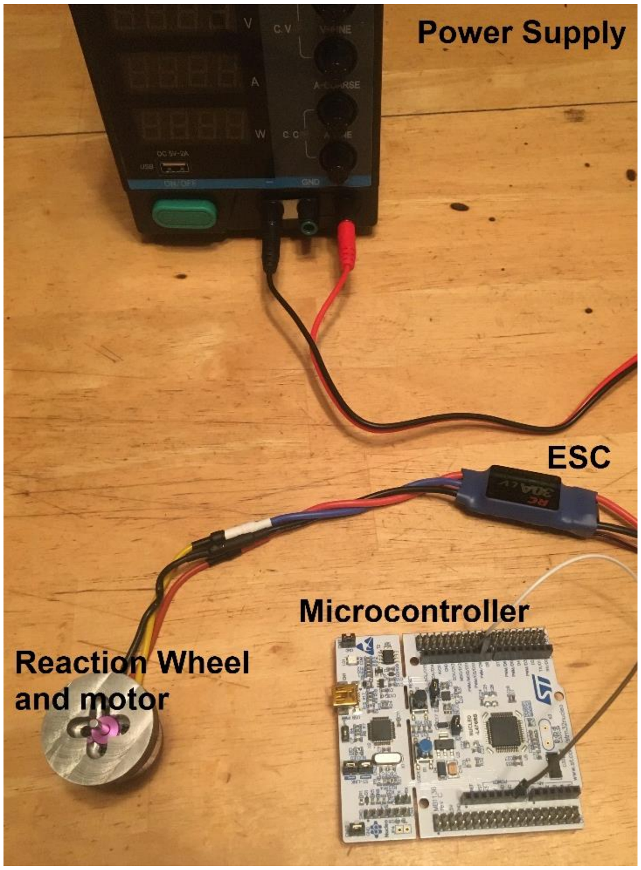


Figure 31. Structural prototype

5.2.1 Design and Build

For the structural prototype we used an off the shelf 30A hobby grade ESC from RC Electric Parts and a Nucleo-L47RG Micro Controller. The 30A ESC is deliberately oversized for our application so that we can test a wide range of motors without fear of damaging the ESC. Once we characterize the actual power requirements of the motors while actively stabilizing tremors, we will be able to select a smaller ESC for the final prototype. Likewise, the Nucleo microcontroller we used for the structural prototype is designed for prototyping, with Arduino style pinouts and ST-link USB communication for simple debugging. The microcontroller we will use in the final prototype will use the same STMicroelectronics microprocessor in a much smaller form factor with soldered connections and no ST-link, which will allow it to fit in the electronics puck., The reaction wheel was machined out of low carbon steel due to its high density, low cost, and ease of machining. The process of machining the reaction wheel is discussed in more detail in Section 6.3 of this report. By creating the reaction wheel for the structural prototype, we were able to verify our manufacturing plan for the reaction wheels.

5.2.2 Structural Prototype Results and Further Testing

From our initial testing with the structural prototype, we were able to verify that the conceptual basis for our design was sound and physically possible. Even at only 75% of the rated voltage, the D2830 1000KV motor made by DYS with the reaction wheel attached generates enough sustained torque to jerk a user's hand back and forth when held in the hand. We plan on performing further testing to measure the motor's stall torque and no-load RPM to more accurately characterize the motor for our controller design. We also learned that the ESC we used for the structural prototype is not reversible, meaning that it will only spin the motor in one direction. While the motor is still able to generate torque in both directions by accelerating and decelerating, its capacity to absorb momentum is cut in half, so for the final prototype we will use a similar, but reversible, ESC that can drive the motor in both directions.

The structural prototype also provides us with a test bed to test and tune our controller software on. Moving forward we plan on permanently mounting the electronics of the structural prototype to a base board so that we can test our controller designs by rotating the whole system. We also plan on integrating the battery and IMU into the structural prototype before creating the final prototype, which will give us an idea as to whether or not sufficient torque can be generated by the motor to counteract a user's hand tremors.

The structural prototype also has allowed us to finalize our electronics components. For our final design we chose a similar model of the purple motor from our structural prototype, however with a lower KV rating which should lead to a higher torque. The final electronics are shown below in Table 4.

Table 4: Final Electronics

Component	Manufacturer and Part Number
IMU	Adafruit 9DOF BNO055
MCU	NUCLEO-L432KC
Motors	Flash Hobby D2380 750Kv BLDC Motor
ESCs	Blue Robotics 30A ESC
Batteries	Turnigy nanotech 260mAh 2S 35~70C Lipo Battery
Voltage Stepdown	Pololu 5V, 1A Step-Down Voltage Regulator D24V10F5

5.3 Safety, Maintenance, and Repair Considerations

User safety is the number one priority in our design. To identify potential failure modes and how they would affect the user we created a Failure Modes and Effects Analysis (FMEA), attached in Appendix 6. The FMEA identifies all of the possible failure modes of our design and how each failure mode would affect the user. For each failure mode we also identify the potential sources of failure and how we will detect if failure occurs. This allows us to identify the most critical failure points and alter our design to minimize the chances of failure and ensure that it fails in a manner that does not put the user at risk of harm. The failure modes of the mug can be broken up into two main groups: Failures that could potentially cause physical harm to the user, such as burns or electrical shock, and failure modes that would affect the mug's ability to stabilize tremors, which would affect the users experience and confidence in the mug.

The first type of failure, where the user is at risk of electrocution, occurs when the electronics puck shell is breached either by water due to a seal failure or by cracks occurring from a drop. To minimize the risk of electrical shock we plan to make the electronics puck waterproof and will test for leaks without the electronics inserted. We will also include a fuse connected to the battery to cut power in the event of an electrical short caused by water intrusion or electrical component failure. The ESC already has thermal protection built in and will shut off all power if the battery temperature reaches unsafe levels. To minimize the risk of cracks occurring when the mug is dropped, we will drop the electronics puck shell (with weight added to simulate the electronics) from varying heights and inspect it for cracks or deformation.

Most of the failure modes that impact the mug's ability to mitigate tremors, such as running out of battery, cannot be fully eliminated. Instead, we must ensure that these potential failures are clearly communicated to the user and that the user is taught to use the mug in such a way that the risk of these failures is minimized. In the event that the mug runs out of battery during operation, the mug will make an audible beep and turn on an LED to indicate to the user that it needs to be charged. Our user manual will also emphasize use habits to prolong the mug's battery life, such as setting the mug down between sips so that the mug is not actively mitigating tremors. It is also possible that the IMU could send a onetime erroneous reading or fail in such a way that it measures a large acceleration. This could cause the mug to jerk unexpectedly or suddenly stop mitigating tremors. To minimize this risk, we will design our controller to reject acceleration measurements above a set threshold. The mug will also turn off the motors and make an audible beep and turn on an LED if it loses communication with the IMU or measures an acceleration above the maximum threshold.

5.4 Cost Analysis

Located below in Figure 31 is a cost breakdown of our structural prototype. For our structural prototype we purchased an ESC and three motors (all other materials were previously owned). The total cost for our structural prototype came out to be $105. We initially started with a budget of $750, leaving us $645 remaining for our final design and any other necessary costs.

Materials Budget for Senior Project

Title of Senior Project:	W15 - Mug for Veterans with tremors		
Team members:	Eliot Briefer, Tiernan Kehoe, Nicholas Greco, Lucas Martos-Repath		
Designated Team Treasurer:	Nick Greco		
Faculty Advisor:	Eileen Rossman		
Sponsor:	Oliver, Melissa RICVAMC McGuire VA Medical Center, Richmond, Virginia		
Quarter and year project began:	Fall 2020		
Materials budget given for this project:	$750.00		
Remaining budget for this project:	$645.00		
Date purchased	**Vendor**	**Description of items purchased**	**Transaction amount**
04/12/21	Amazon	Electronic speed controller	$ 20.00
04/12/21	Amazon	DYS D2830 1000KV Brushless Motor for Multicopters RC Plane Helicopter	$ 25.00
04/12/21	DF Robot	MTO1804 Brushless DC Motor (CW) with 20A ESC	$ 25.00
04/12/21	Amazon	Ginyia Brushless Motor, 5010-360KV 1PCS Metal Outdoor Big Load Multiaxis Thick Line Hollow Cover Double Bearing Brushless Motor	$ 35.00

Figure 32. Structural Prototype Cost Breakdown

After assessing our structural prototyping costs, we estimated the cost of our final design to ensure that we would have enough money left for our final design in our project budget. The bulk of our final design cost is going to be related to effective motor control and motor operation. Generating sufficient torque to counteract tremors with such a small package will require high performance motors, likely of a widespread commercial availability (in other words, high-end hobbyist equipment will be necessary). As stated in our budget list (Attachment X), the two motors required will cost $40.00 each, with the ESCs controlling the motors each costing approximately $20.00 a piece. The remaining electronics required to complete the control loop include the IMU ($39.95), the breadboard wires, a 4S LiPo battery pack (between $20-$30), and a D-series microcontroller ($10-20 if using ST's Nucleo, $40-45 if MicroPython's pyboard). Raw materials such as steel stock for the flywheels and 3D printing plastics are supplied by Cal Poly facilities. Of our two major subsystems (the mug body and the electronics puck), the puck subsystem incurs all of the material cost as it is the subsystem housing the "brains" of the mechanism. Additionally, when it comes to ensuring the mug can be used to safely drink liquid from, we chose a two-part food grade epoxy ($54.99), intended to be applied to the basin of a 3D printed material. Lastly, M2 and M3 mounting screws will be purchased to mount the electronics inside the electronics puck and springs will be needed for the electronics puck clipping mechanism. A component cost breakdown of our purchased items for the final design are included in Table 5 below.

Table 5 - List of Purchased Components for the Final Product

Component	Cost
2 Motors	$80
2 Escs	$40
IMU	$40
4s Lipo Battery	$20
D series Microcontroller	$11
Food grade Epoxy	$55
M3 Mounting Screws	$7.88
M2 Mounting Screws	$12.89
3.3 Voltage Regulator	$7.49
Assorted Wires	$6.98
Springs	$5.66
Battery Charger	$30
Total Estimated Cost	$316.90

After structural prototyping costs, we were left with $645 remaining in our project budget. As seen in Table 5 above, the total estimated cost for our final design is $316.90. In case we need to spend any money on testing or manufacturing we are also allocating $100 each to testing and manufacturing. This results in a final estimated design cost of $516.90, leaving us about $128 to spare, given our initial project budget.

5.5 Expected Challenges and Remaining Concerns

The most pertinent remaining concern centers on our tremor mitigation model. Assuming a classical controller design can effectively mitigate an inherently nonlinear input is a big assumption. Consequently, early testing is important so that if our model should prove insufficient, we can make necessary tweaks as early as possible. As discussed in Section 5.1.4 our dynamic model requires several motor parameters that we will need to measure once we have purchased our final motors. This has prevented us from making accurate predictions about our design's ability to mitigate random tremors. Due to this constraint, we will be ordering the final motors as soon as possible. Additionally, the current selection of products for our final mug has forced our electronic puck geometry to protrude, giving the overall mug profile an unorthodox look. Though our sponsor is willing to accept the current appearance of the mug as we pursue functionality, if our end users' aesthetic concerns are to be mitigated along with their tremors (and thus allow them to enjoy using the mug), electronics of a more reasonable size will need to be selected. Durability considerations are especially important due to the compromised motor functions of our user group. As such we plan on attempting a version of a dynamic impact analysis to come up with a robust mug design capable of withstanding significant drops. Ultimately, eliminating these aesthetic concerns may require the development of custom motors and other electronics, as motors and controllers specifically optimized for our application do not currently exist on the market. While custom electronics design is not within the scope of our project, we plan on making recommendations for further research and development based on our test results.

6. MANUFACTURING PLAN

6.1 Procurement

The electronic components of our final design are entirely off-the-shelf, hobby-grade electronics. Consequently, all the electronics are available from many resellers. The Microcontroller is produced by STMicroelectronics. The motors are manufactured by Turnigy. The IMU is manufactured by Adafruit. We will order all these parts online as they are all widely available and do not require special orders or quotes.

6.2 Mug Body and Electronics Puck Shell

Both the mug body and shell of the electronics puck will be 3D printed on a selective laser activation (SLA) resin 3D printer. This printing method offers finer resolution and more temperature and chemical resistant plastics than fused deposition modeling (FDM) 3D printing. We plan on collaborating with our sponsor to print these parts at the McGuire VA Medical Center, however if this option doesn't work out for any reason, there are many online SLA printing services that offer reasonable prices. Since these parts will not be printed in house, we have accounted for a two week manufacturing and shipping lead time in our Gantt chart, shown in Appendix 3.

Step 1. Print mug body and electronics puck shell using an SLA 3d printer.

Step 2. Cure mug body and electronics puck shell using UV curing station.

Step 3. Insert clip mechanisms and glue clip top mounting piece to the puck shell.

Step 4. Coat the inside of the mug shell with a thin layer of food grade epoxy resin.

6.3 Reaction Wheels

The reaction wheels are the cylindrical disks mounted to the motors to increase their rotational moment of inertia. We will machine the reaction wheels from low carbon steel. The reaction wheels are nearly identical to the reaction wheel we machined for the structural prototype. The machining for the structural prototype only took 3 hours, so we are not concerned about limited shop time.

Step 1. Turn the outer diameter of the cylindrical bar stock down to final diameter using a lathe.

Step 2. Drill clearance hole for motor shaft using a lathe.

Step 3. Cut bar stock 0.2 in oversized using a horizontal band saw. (2x)

Step 4. Face both sides of each reaction wheel down to final size using a lathe (2x)

Step 5. Drill 4 1/8" clearance holes for mounting reaction wheels onto the motor using a mill. (x2)

Step 6. Countersink mounting holes for bolt heads with a ¼" endmill using a mill. (x8)

Step 7. Break all edges using a file.

6.4 Electronics Wiring

All the electronics are contained within the electronics puck. Except for the battery to ESC connection and the ESC to motor connection all electrical connections are soldered. The maximum battery voltage is 15.3V, well under the maximum 40V we are permitted to work with by Cal Poly. We are permitted by Cal Poly to soldier at home, so wiring the electronics components will not be constrained by limited shop time.

Step 1. Solder the IMU outputs to the corresponding microcontroller input pins and solder the power inputs to the microcontroller 5V output and ground. Verify that the IMU is receiving power and sending data to the microcontroller before proceeding.

Step2. Solder the microcontroller power input pins to the voltage step down.

Step 3. Connect the ESC PWM signal wire to the corresponding output pin on the micro controller. (x2)

Step 4. Plug in the three motor leads to the ESC. (x2)

Step 5. Connect the battery to the ESC's using the two XT60 connectors.

Step 6. Test the rotation direction of each motor and switch any two motor leads to reverse direction if necessary.

Step 7. Disconnect the battery and motors from the ESCs.

6.5 Final Assembly

For the final assembly we will mount the reaction wheels onto the motors and assemble all the electronics into the electronics puck.

Step 1. Bolt the reaction wheels onto the motors. Using a dial indicator and spinning the motors by hand, adjust the position of the reaction wheels until they are concentric with the motors' axis of rotation.

Step 2. Bolt the motors into the electronics puck.

Step 3. Screw the IMU into the electronics puck.

Step 4. Using Velcro mount the Motor Controller Unit, Voltage step down, and the ESCs

Step 5. Reconnect the motors and battery to the ESC's.

Step 6. Insert the battery into the electronics puck.

Step 7. Check that both motors are functioning and that the IMU is reading correctly.

Step 8. Screw the electronics puck lid over the electronics.

Step 9. Slide the electronics puck into the mug shell, ensuring the clips fully engage.

7. DESIGN VERIFICATION PLAN

To ensure that each engineering specification established in the House of Quality (Attachment 2) is addressed by our testing processes, the following test procedures have been drawn up.

In order to assess the viability of the tremor mitigating mechanism within the mug (aka. the reaction wheels), we will drive a shake table in the range of most tremor frequencies (a range of 5-8 Hz). Our analysis will consist of measuring the amount of liquid that spills from the mug, which could be accomplished either by measuring initial weight and final weight, or by measuring initial and final heights in the mug and using geometry to analyze volume losses. The liquid lost during the vibration test cannot exceed 0.5 oz.

The external temperature of the mug will allow us to prove the mug can be safely handled for a range of different liquid temperatures. To assess this temperature range, Type K or Type J thermocouples will be attached directly to the mug body and to the handle. The thermocouples will be attached to a voltmeter that will return a collection of voltages from which data on the temperature of the mug body itself can be interpreted. The test will be conducted for the extremes of what liquids may reasonably be put into the mug: chilled water (less than 40 °F) or boiling water (212 °F). The mug body itself cannot dip below 40 °F or rise above 110 °F. For this test, we will perform data analysis and uncertainty propagation on the voltages recorded by the multiple thermocouples.

We will also perform a leakage test to ensure that our mug is waterproof. This consists of filling the mug with liquids occupying the reasonable temperature extremes that may be poured into the mug. The mug will be left untouched overnight and observed in the morning to ensure that no water was lost due to any means other than evaporation, with the assumption being that any channel that develops to allow fluid to leak out of the mug will allow significantly more fluid to exit than by evaporation.

Our sponsor indicated that one of the most important elements of any product that requires the end user to operate the product is a clear set of instructions for usage. Thus, after creating a set of instructions to operate the final product, we will distribute these instructions to a sample group of individuals to ensure that the instructions are easy to interpret and could be carried out with ease. Positive responses to both of these points must be in excess of 95 % for this test to be considered successful.

Mugs can easily be dropped and broken, which can potentially cause harm to individuals or result in an unusable product. Our sponsor made sure to highlight the importance of this test during a discussion of the DVP, reaffirming its importance. To assess the strength of our mug we will perform a drop test on the mug body from increasing heights up to six feet, with the idea that six feet represents the mug being dropped from cupboard or microwave height. For this test we will exclude the electronics puck, so that we do not damage any valuable electronics components, and choose instead to simulate the weight of the electronics puck by inserting a round weight into the opening for the electronics puck. To measure the weight of the electronics puck and simulated weight we will need a digital scale. We will test the strength of the mug by ensuring that there are no visible cracks after the drop test and by measuring if the mug has deformed by more than 1/8”. Additionally, we will run FEA tests in Solidworks to predict the performance of the mug before actual testing. This will help us decide whether to implement design and/or material selection changes.

From our customer research we found that the severity of one’s tremors usually increases, the heavier an object is that they are trying to hold. To make our mug easier to hold and drink from, we will try to optimize the weight of the mug as much as possible. We will perform a weight test using a digital scale to ensure that our fully assembled mug design is under 1.36 kg.

It is important that our users can operate the mug for extended periods of time without having to recharge the battery continuously or have the battery die during use. We will perform a test on the battery life of our mug, to ensure that users can operate their mug for 20 minutes or longer without having to recharge it. For this test, we will use a shake table to simulate a tremor input to the mug. Starting at full battery charge, we will then shake the mug until the battery reaches low voltage cutoff and the mug is no longer able to mitigate tremors.

Lastly, we will be performing two tests to ensure that our mug will withstand hot liquids and cold liquids without degrading. Our mug design must be able to withstand 212 F temperature liquid on the hot side and 32 F liquid on the cold side without deforming more than an 1/8” and without showing any visible cracking. We will use a thermocouple to measure the temperature of the liquid and a boiler and freezer to bring the water to the desired temperatures for testing.

All specifications and test requirements, including preliminary testing dates, are included in the Design Verification Plan in Appendix 7.

8. PROJECT MANAGEMENT

8.1 Design Process

Our design process can be broken down to a six-step approach with the following chronological order: Define, Create, Evaluate, Specify, Build, Test. This process, while appearing linear, has some stages intertwined, as the effects of one stage may lead to re-evaluating work from an older stage. During the Define Stage, we analyzed how the drinking habits for people with tremors are changed. Additionally, we gained a better understanding of the scope of the project and the needs and wants of our customer group and sponsor. Combining the information gained from these elements, we created a Quality Function Deployment (QFD) House of Quality as shown in Appendix 2. After the submission of the Scope of Work, we transitioned into the Create and Evaluate stages. Starting from our functional decomposition, we developed concept models designed per mug function, grouped these into a matrix that represented our best efforts, created systems level designs from these functions, and came up with two system level concept designs to present to Melissa for approval. Concept prototypes, equations for modelling the systems presented, and CAD models accompanying these final two models are introduced to justify our intended design direction. After crunching our analytical data, creating SolidWorks models, and ensuring all additional engineering specifications had been met, we selected a model to proceed with and began to obtain materials based upon the intended functionality of the mechanism. For preliminary prototype manufacturing and testing, our goals were to demonstrate basic functionality (i.e., wheel spinning). These tests gave qualitative data about the efficacy of our design.

Once approval of our final design direction is received, planned further analyses on the current design can be carried out. These include an FEA analysis on the mug for a from a height of 6 feet. Improving and implementing the tests specified in our DVP to ensure our product meets the engineering specifications agreed upon is another priority, and one that will require preparing a more complete prototype model to test. Many of the tests outlined in our DVP will be completed early in the Fall Quarter. It is our responsibility this quarter that all necessary materials, test set-up plans, and manufactured parts are ready for testing Day 1 of the Fall 2021 quarter.

8.2 Planned Analyses, Builds, and Tests

The analyses that we will be performing in the immediate future are the completed Simulink model for entire range of components that will be included in our final control loop, and a FEA for the mug to simulate stresses and deflections within the mug if the user were to drop their mug from a height of six feet. This latter test is in preparation for the strength (drop) tests that will be conducted Fall quarter, as the mug design and material selection may need to change based upon the results of the FEA simulation.

Additionally, updated prototypes will allow us to sequentially combine more components until we have a functional, albeit deconstructed, version of the electronics that will provide the power and data to the reaction wheel device carrying out the physical tremor mitigation. These prototypes will likely involve adding additional components, such as the IMU, bandpass filter, and second motor, one at a time until successful operation is achieved. For preliminary testing of the prototype, we might need to develop some test fixtures, namely those that might be capable of simulating the weight of the mug, or that might accommodate two motors for mock pitch-and-roll testing.

The tests we plan to run will be outlined in our manufacturing and test review, to be ready for presentation on June 3rd. The most important of these are the vibration mitigation test, the strength (drop) test, and the battery life test. Certain smaller tests, the weight and leakage tests, will be natural accompaniments to the larger scale tests. The thermal tests involving the cups resilience to temperature and the outside mug temperature tests will be conducted subsequent to the mechanical design and mechatronic tests. Finally, an instruction readability survey will be written and distributed to ensure that the mug can be appropriately operated and cared for by the end user group.

Verification of our system will be based around its ability to accurately mitigate input vibrations. We plan to create a simulated tremor response once the IMU can record data and use that data as an input to our control loop. We also plan to use the vibrations laboratory to run some tests after our critical design review once our prototype is completed. In Table 6 below, the dates of several Key Deliverables are listed to show the next steps in our process.

Table 6: Key Deliverables

Date	**Deliverable**
05/06/21	Critical Design Review
05/13/21	Safety Review
06/03/21	Manufacturing & Test Review
11/04/21	Final Testing Completed
11/18/21	Senior Expo
12/02/21	Final Design Report

8.3 Time Management

Our team currently meets two times a week for 6 hours total in class period. We also have a weekly meeting with our Sponsor Melissa, and any colleagues who might provide valuable input to the project and background information. On top of that our team meets twice a week to work on tasks for milestones. These tasks and milestones are highlighted in our team's Gantt Chart, Appendix 3, which allows us to progress towards each milestone through various tasks that are pre-requisites for completion. Appendix 3, Gantt Chart, shows the tasks needing to be done leading up to the Final Design Review.

9. CONCLUSION

The purpose of the Critical Design Review Report is to fully outline our design development to our final design. This report is intended on receiving final prototype approval from our sponsor for our Reaction Wheel Mug design. This design narrative starts with how we used the background material to define the functions of the mug. The narrative evolves with the subsequent transforming of those ideas into concept models addressing specific functions, and then to systems level designs encompassing the entire challenge. Next, the story continues with a selection of our systems level design and a collection of conceptual and technical justifications. Then it shows our final design with critical analysis of the choices we made moving forward. Our narrative shows how our structural prototype leads to final component selection. It goes on to explain how to create our product and what steps need to be taken next to verify our design. Finally, we discuss our next steps as a team as we head into the final quarter of our project.

The Critical Design Review Report includes all necessary deliverables, figures, and tables utilized in the project so far. Upon receiving approval for our intended final design, detailed tests will follow. The intention is to prove the efficacy of our Reaction Wheel Mug.

Additional Documents:
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Additional Documents:
APPENDICES

1. Relevant Patents
2. Quality Function Deployment
3. Gantt Chart
4. Design Hazard Checklists
5. Matlab Initial Modeling
6. State Space Time Domain Model
7. Failure Modes and Effects Analysis
8. Design Verification Plan
9. Project Budget
10. Indented Bill of Materials
11. Drawing package

Appendix 1: Relevant Patents

Patent Number	Patent Name	Key Characteristics
US20200029710A1	Gyroscopically Stabilized Drinkware [11]	- An attempt to use gimbal technology for stabilizing purposes
GB2491981A	Anti-Spill device [10]	- Attempt to create an anti-spill mug that appears normal - Example of solving problem by purely mechanical means - Compatibility with standard containers for eating/drinking
US6705580B1	Cup holder for a motor vehicle [19]	- Arms extend for stabilization - Adjustable arms depending on the size of the cup they hold
EP3571992A1	Mitigating effects of neuro-muscular ailments [8]	[1] Mitigation of tremors using predictive analysis and sensors mounted on the subject's hand [2] Electronic actuators interface w/ software to mitigate unintended movement
EP3237081B1	Tremor stabilization apparat us and methods [9]	**4** Attempts to minimize tremors by attaching a gyroscope to the back of the user's hand **5** Example of a solution to a more general problem (mitigating hand tremors) that could also solve our problem

Appendix 2: Quality Function Deployment

Correlations	
Positive	+
Negative	–
No Correlation	

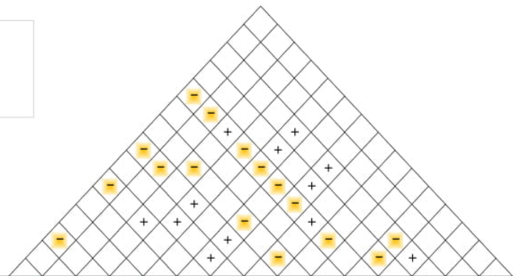
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: Mug for Veterans with Tremors

Revision Date: 1/28/21

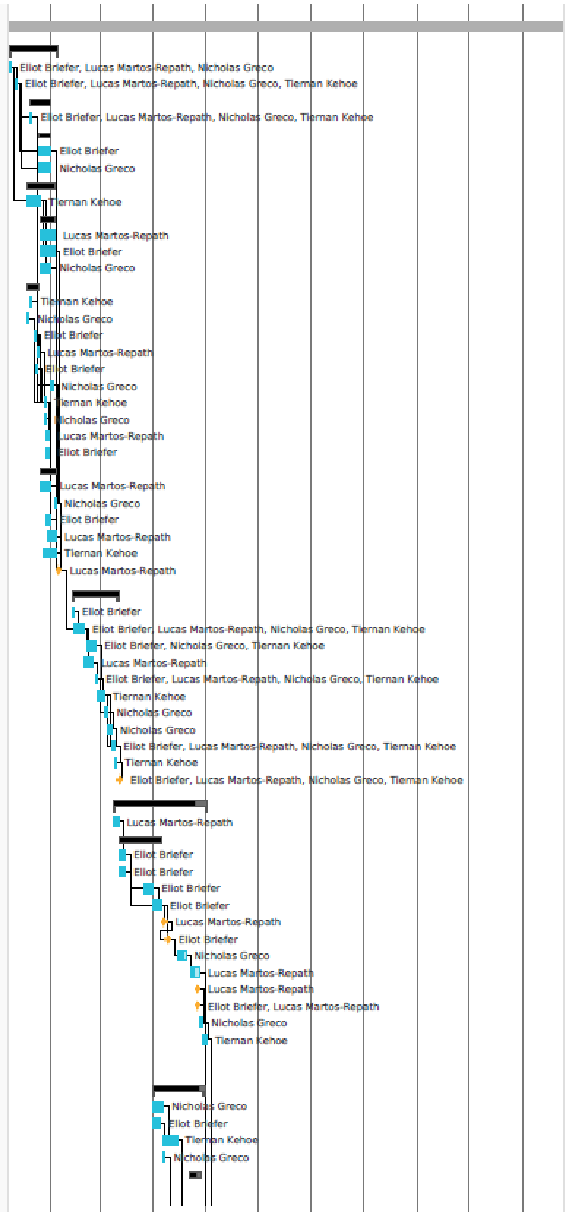


						Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15							
WHO: Customers						Direction of Improvement	▲	▼	▼	◇	▲	▼	▼	▼	◇	◇	▼	◇	◇			NOW: Curr. Products						
Row #	Weight Chart	Relative Weight	Veterans with hand tremors	Care Providers	Non-Veterans with hand tremors	Maximum Relationship / WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Carrying Capacity	Outside Temperature Range	Overall Size	Vibration Simulation Test	Compliant with all necessary FDA Standards (BI	Strength Test	Leakage	Weight	Handle Size	Instruction Readability Survey	Overall Cost	Withstand hot liquids without Degrading	Withstand cold liquids without Degrading			Our Current Product	Competitor #1: Liftware Spoon	Competitor #2: Weighted Cup	Competitor #3: Imagiroo	Hand-Through Mug	Competitor #4: Handsteady Drinking Aid	Row #
1		7%	8	8	8	9 Prevent Liquid Spills	▽		▽	●	▽	○	●	○	○	○	○						4	3	2	2	2	1
2		9%	10	10	10	9 Instill Confidence while Drinking	▽	▽	○	●	▽	●	○	○	○	●	▽	○	▽				2	2	2	2	2	2
3		4%	4	4	4	9 Dishwasher Safe		○			●	○	▽	▽	▽		○	●	●				5	5	5	5	5	3
4		5%	5	5	5	9 Microwave Safe		○			●		▽	▽	▽		○	●	●				0	0	5	0	5	4
5		7%	7	8	7	9 BPA free					●						○	●					5	5	5	5	5	5
6		7%	8	8	8	9 Fit in Common Coffee Makers	○		●						○								0	1	1	0	5	6
7		6%	6	7	6	9 Mitigates Vibrations	▽		▽	●				○	○		▽						5	2	1	1	2	7
8		6%	8	5	8	9 Hold 16 fl oz	●	▽	○	▽		▽	●	○	▽		▽	▽	▽				0	3	1	5	2	8
9		7%	8	8	8	9 Fits different Hand Sizes	▽		○		▽	▽		▽	●		▽						4	4	4	1	2	9
10		6%	6	8	6	9 Stabalize in all Three Axes			▽	●		▽		▽	○		▽						2	2	2	1	2	10
11		5%	5	5	5	9 Clear Cleaning Instructions					▽					●		○	○				4	5	5	3	4	11
12		5%	4	8	4	9 Minimize Weight	▽	▽	○	○		○	○	●	○		▽	▽	▽				3	0	3	3	4	12
13		5%	4	7	4	9 Training Instructions					▽					●		▽	▽				5	2	3	1	3	13
14		7%	8	8	8	9 Work with cold and hot liquids		●	▽		○	▽	○	▽			▽	●	●				5	5	3	4	5	14
15		8%	9	9	9	9 Look "normal" or desirable	▽	▽	●			▽	▽	○	○		▽	▽	▽				3	3	1	2	3	15
16		3%	4	5	4	9 Afordable for veterans	▽	▽	▽	▽	▽	▽	▽	▽	▽		●	▽	▽				2	5	5	5	5	16

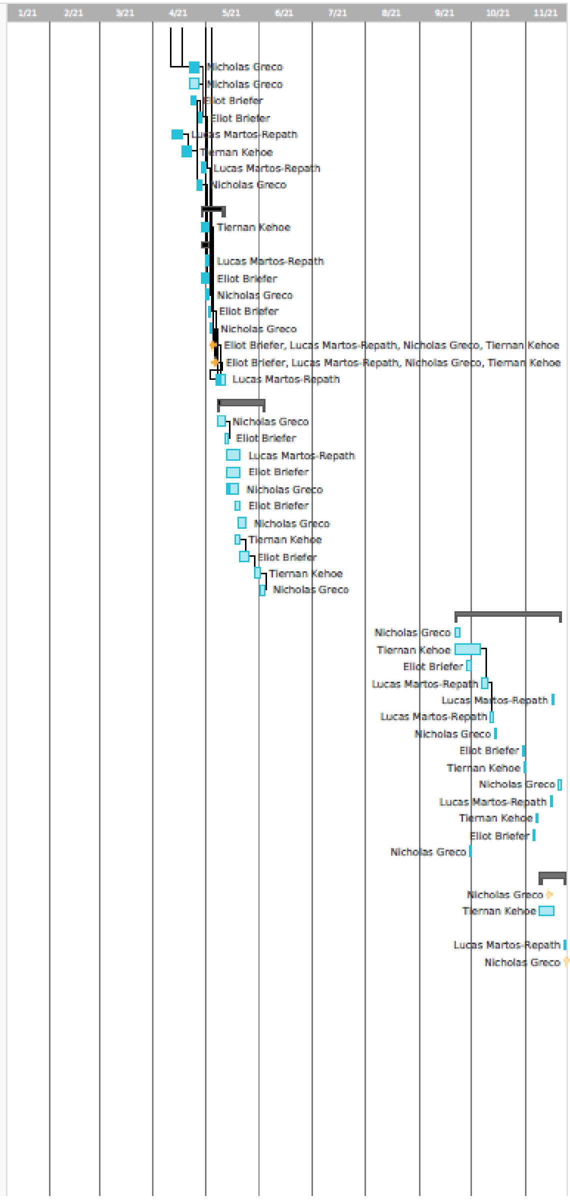
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	HOW MUCH: Target Values	16 Fluid Oz	Mug Exterior Within 40-110 F at all time	6" tall, 3.5" in diameter	Spill less than 0.5 oz of water	Microwave and Dishwasher Safe/BPA	No fractures in Drop test from 6ft	No Liquid Leakage after 10 Minutes	3 lbs	Width: 1" Height: 4"	95% of users understand	$100	Withstand temperatures of 212	Withstand temperatures of 32 F		
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9		
	Technical Importance Rating	123.2	123.2	255.6	286.4	195.5	171	206.6	192.3	234.1	192	148.9	272.6	191.9	0	0
	Relative Weight	5%	5%	10%	11%	8%	7%	8%	7%	9%	7%	6%	11%	7%	0%	0%
Curr. Products	Previous Senior Project	5	0	0	0	0	0	5	5	5	0	3	0	0		
	Competitor #1: Liftware Spoon	0	5	5	5	5	2	5	5	3	5	2	5	5		
	Competitor #2: Weighted Cup	3	5	5	2	3	4	5	5	3	4	5	4	5		
	Competitor #3: Imagiroo	1	5	2	2	5	5	5	5	4	5	5	5	5		
	etitor #4: Handsteady Drinking Aid	1	3	5	3	5	4	5	5	4	2	5	5	5		
	Competitor #5: Easy Grip-In Mug	5	5	2	3	3	5	5	5	2	5	5	3	2		
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Appendix 3: Gantt Chart

W15 Mug for Veterans	0h	67%
Problem Definition	0h	100%
Choose Project	0	100%
Meet Team	0	100%
Customer/Need Research	0h	100%
Interview Sponsor	0	100%
Interview all customers	0h	100%
Interview Care Providers	0	100%
Interview Veterans with Hand Tr...	0	100%
Technical Research	0h	100%
Identify technical challenges	0	100%
Find relevant journal articles	0h	100%
Research Gimbal Technology	0	100%
Research Vibration Mitigation	0	100%
Research Neurological Causes of...	0	100%
Product Research	0h	100%
Ask sponsor/users about current pr...	0	100%
Search online for current products	0	100%
Search patents for similar products	0	100%
Search for complaints online	0	100%
Capture Customer Needs/Wants	0	100%
Write Problem Statement	0	100%
Perform QFD	0	100%
Create Specification Table	0	100%
Write Specification Descriptions	0	100%
Create Initial Project Plan	0	100%
Write Scope of Work	0h	100%
Write Introduction	0	100%
Write Background	0	100%
Write Objectives	0	100%
Write Proj Mgt	0	100%
Write Conclusion	0	100%
Complete Scope of Work (SOW)	0	100%
Concept Generation & Selection	0h	100%
Create Functional Decomposition	0	100%
Perform Initial Ideation	0	100%
Perform More Ideation and Refine	0	100%
Build Ideation Models	0	100%
Complete Concept Selection	0	100%
Complete Preliminary Analysis	0	100%
Build Concept Prototype	0	100%
Create Concept CAD	0	100%
Draft PDR	0	100%
Revise PDR Report	0	100%
Complete Preliminary Design Review ...	0	100%
Detailed Design & Analysis	0h	87%
Perform FMEA	0	100%
Design Analysis	0h	100%
Build Tremor Simulink Model	0	100%
Perform Hand Calculations for Reac...	0	100%
Build Reaction Wheels Simulink Mo...	0	100%
Reaction Wheel Sizing and Optimiz...	0	100%
Choose Design Direction	0	100%
Complete Interim Design Review (ID...	0	100%
Perform CAD/Part Selection	0	70%
Complete Puck Design	0	30%
Final Motor Selection	0	100%
Final Boards Selection	0	100%
Complete Mug Design	0	100%
Complete Drawing Package	0	100%
New Group	0h	0%
Manufacturing	0h	90%
Complete Manufacturing Plan	0	100%
Create a Project Budget	0	100%
Order Parts	0	100%
Electronics Discussion with Professor...	0	100%
Build Structural Prototype	0h	64%



Wire structural prototype electroni...	0	100%
Write reaction wheel controller cla...	0	0%
Machine reaction wheel	0	100%
Assemble structural prototype	0	100%
SP List of Electronics Required	0	100%
Construct an iBOM	0	100%
Design Verification Plan & Report	0	100%
Updated Manufacturing Plan	0	100%
Critical Design Review Deliverables	**0h**	**88%**
Create CDR Presentation Outline/Te...	0	100%
New Chapters for CDR	**0h**	**100%**
Create Final Design Chapter	0	100%
Create Manufacturing Plan Chapter	0	100%
Create DVP Chapter	0	100%
Assemble CDR Report	0	100%
Send CDR to Sponsor	0	100%
Present CDR	0	100%
Present CDR to Sponsor	0	100%
Update CDR Report (from Advisor/Sp...	0	50%
Manuf. Part 2 & Testing	**0h**	**5%**
Rough Draft of Risk Assessment on P...	0	10%
Complete Risk Assessment	0	0%
Additional Parts Ordering	0	0%
Complete Safety Review	0	0%
Completed Simulink Model of Mug D...	0	30%
Mug FEA for drop test	0	0%
Invest in VP Build-time	0	0%
Experimental Design Planning Form	0	0%
Test Procedure for Uncertainty Exper...	0	0%
Complete Manufacturing & Test Rev...	0	0%
Prepare Manuf. & Test Review Presen...	0	0%
Project Wrap-up	**0h**	**0%**
Electronics Wiring	0	0%
3D Printing Mug Body and Elec. Puck	0	0%
Machining Reacton Wheels	0	0%
Final Assembly	0	0%
Verification Prototype Sign-Off	0	0%
Shake Table Test	0	0%
Strength Test	0	0%
Outside Temperature Reading Test	0	0%
Leakage Test	0	0%
Weight Test	0	0%
Instruction Readability Survey	0	0%
Hot Liquid Degradation Test	0	0%
Cold Liquid Degradation Test	0	0%
Battery Life Test	0	0%
Final Approval, Exams, and FDR	**0h**	**0%**
DVPR Sign-Off	0	0%
Write FDR Report	0	0%
Create Expo Poster	0	0%
Senior Exam	0	0%
Final Design Review (FDR)	0	0%



Appendix 4: Design Hazard Checklist

Design 1: Reaction Wheels

Y	N	
	N	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 sheer points?
Y		2. Can any part of the design undergo high accelerations/decelerations?
	N	3. Will the system have any large moving masses or large forces?
	N	4. Will the system produce a projectile?
Y		5. Would it be possible for the system to fall under gravity creating injury?
	N	6. Will a user be exposed to overhanging weights as part of the design?
	N	7. Will the system have any sharp edges?
	N	8. Will any part of the electrical systems not be grounded?
	N	9. Will there be any large batteries or electrical voltage in the system above 40 V?
Y		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	N	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	N	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
Y		13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	N	14. Can the system generate high levels of noise?
Y		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
Y		16. Is it possible for the system to be used in an unsafe manner?
	N	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, on the reverse side add:

- a complete description of the hazard,
- the corrective action(s) you plan to take to protect the user, and
- a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Aca
This design relies on reaction wheels which generate forces through acceleration, so by necessity there are high accelerations and decelerations involved in this design.	Design an enclosure to fully contain the reaction wheels.	4/8/21	
By nature, mugs can fall from shelves or be dropped by the user.	Minimize the mass of the final design. Design a handle that minimizes the grip strength required for a user to hold the mug.	4/19/21	
This design stores mechanical energy reaction wheels and electrical energy in a battery to power the reaction wheels; However, due to the low mass of the system and small amplitude of hand tremors the mechanical energy stored in the reaction wheels is minimal.	Research charging circuitry for batteries to prevent over-charging. Research battery chemistries and select the least volatile chemistry that meets the energy requirements of the design. Develop a system for balancing the reaction wheels or find pre-balanced off the shelf reaction wheels.	3/29/21	
Most battery chemistries are hazardous to humans and this design requires a battery.	Design a waterproof enclosure for the battery to prevent the user from accessing the battery and prevent and liquids from getting in and out.	3/29/21	
This mug will be filled with boiling water as well as be microwaved and cleaned in a dishwasher.	Design a removable enclosure to hold all electronics (battery controller and reaction wheels) and allow the user to remove them when microwaving or washing the mug. Design the interior of the mug out of high temperature, food safe materials.	3/29/21	
Users wish to be able to microwave this mug and clean it in a dishwasher. Doing so with the electronic components installed in the mug could irreparably damage the mug, create a fire hazard, and possibly release toxic fumes from the electronics and battery.	Design a removable enclosure to hold all electronics (battery controller and reaction wheels) and allow the user to remove them when microwaving or washing the mug. Create a clear operating manual and training instructions for primary users and their care providers. Design warning labels for the electronics package to remind the user to remove it before microwaving or dishwashing.	3/15/21	

Design 2: Recessed Gyroscope

Y	N	
√		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 sheer points?
	√	2. Can any part of the design undergo high accelerations/decelerations?
√		3. Will the system have any large moving masses or large forces?
	√	4. Will the system produce a projectile?
	√	5. Would it be possible for the system to fall under gravity creating injury?
	√	6. Will a user be exposed to overhanging weights as part of the design?
	√	7. Will the system have any sharp edges?
	√	8. Will any part of the electrical systems not be grounded?
	√	9. Will there be any large batteries or electrical voltage in the system above 40 V?
√		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	√	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	√	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	√	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	√	14. Can the system generate high levels of noise?
√		15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
√		16. Is it possible for the system to be used in an unsafe manner?
	√	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any “Y” responses, on the reverse side add:

- a complete description of the hazard,
- the corrective action(s) you plan to take to protect the user, and
- a date by which the planned actions will be completed.

-

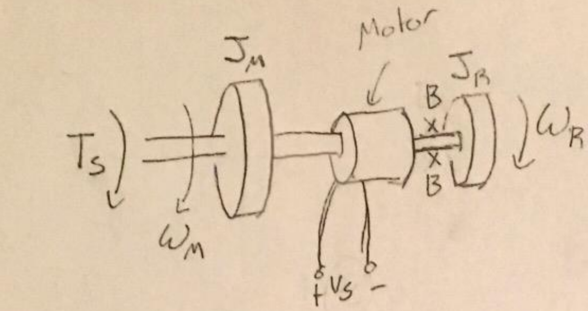
Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The arm bar in the recessed slot allows for a pinch. This arm bar also must withstand high stress.	Design arm bar with intent of withstanding transmitted forces. Design recessed portion to be mindful of the sharp edges.	4/15/2021	
The design contains the movement of the handle portion and arm bar.	Design the structure sturdy enough to allow for the arm bar and connected motors and handles.	4/8/2021	
The batteries will be enclosed in the bottom removable portion of the design. This will be interesting as we are making a mug to hold liquid and the combination of liquid and battery could lead to a potential short.	Design the removable bottom portion to withstand leaks regarding the battery pack.	4/2/2021	
The device will be subject to high heats and cold heats as it contains coffee, tea, ice water, etc.	We will design the mug to have the correct thermal insulation, so the user does not get burned.	4/6/2021	
The system should not be thrown.	The mug will be designed to be structural sound enough to withstand drops from 6 feet however a projectile use of the mug is highly not recommended.	4/10/2021	
Users wish to be able to microwave this mug and clean it in a dishwasher. Doing so with the electronic components installed in the mug could irreparably damage the mug, create a fire hazard, and possibly release toxic fumes from the electronics and battery.	Design a removable enclosure to hold all electronics (battery controller and reaction wheels) and allow the user to remove them when microwaving or washing the mug. Create a clear operating manual and training instructions for primary users and their care providers. Design warning labels for the electronics package to remind the user to remove it before microwaving or dishwashing.	4/29/2021	

Appendix 5: Tremor Modeling MATLAB Code

```
%TREMOR SIMULATION FOR SENIOR PROJECT W15, 2-19-2021
%
%NOTE: CONVERT ALL VALUES TO BASE METRIC UNITS!
%
%This program simulates a rotational hand tremor acting on a mug modeled
%as a solid cylinder of constant density. The tremor is modeled as a
%sinusoidal moment along the +y axis of a magnitude calculated to produce
%the desired tremor amplitude. Coordinate system: +z = up, +x = away from
%handle, right handed


clear all
clc
close all


%D = mug diameter, H = mug height, M = tremor moment, m = total mug mass,
%I = mug moment of inertia about the x axis, alpha = angular acceleration
%about the y axis, f = tremor frequency
syms D H M m I alpha omega theta M_max t theta_max f
format short


%Equation for uniform density, solid cylinder, about x or y axis
I = (1/12)*m*(3*(D/2)^2 + H^2)
%Model Tremor as a sinusoidal moment with amplitude M_max and frequency f
M = M_max*sin(2*pi*f*t)
%From M = I * alpha
alpha = M/I
%Integrate to get angular velocity
omega = int(alpha, t)
%Integrate again to get angular position
theta = int(omega, t)
%Slove for M_max, let sin(2pift) = 1 to solve for M_max in terms of f,
%theta_max and mug properties
S_Mmax = -1 * solve(theta_max == theta, M_max) * sin(2*pi*f*t)


% D, H in meters. m in kg. theta_max in rad. f in Hz.
M_max_Nm = double(subs(S_Mmax, [D H m theta_max f], [0.0889 0.1397 1.4
deg2rad(15) 8]))
```

Appendix 6: State Space Time Domain Model

REACTION WHEEL MUG STATE SPACE MODEL



J_M = Rotational inertia of the mug

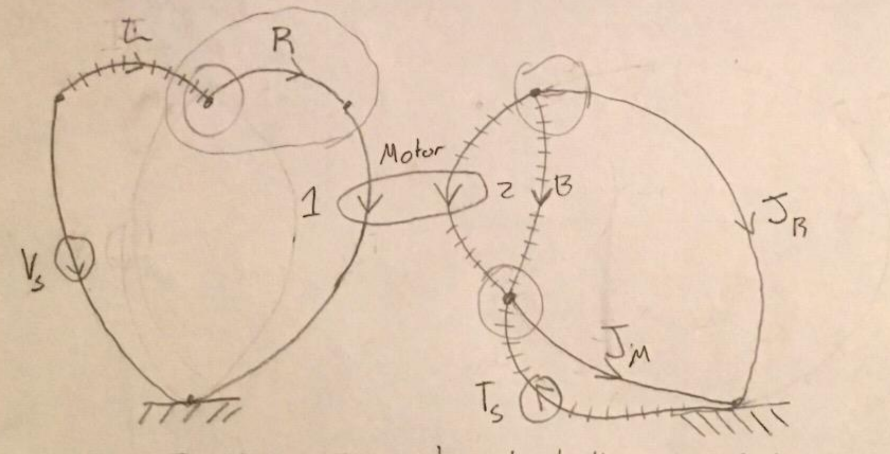
ω_M = Mug angular velocity

V_s = Battery Voltage source

J_B = Motor + Reaction wheel rotational inertia

ω_B = Reaction wheel angular velocity

LINEAR GRAPH + NORMAL TREE:



$n = 3$, I, J_B, J_M contribute to the order of the system

state variables: i_I, ω_B, ω_M

$\frac{d\omega_M}{dt} = \frac{T_M}{J_M}$, $\frac{d\omega_B}{dt} = \frac{T_B}{J_B}$, $\frac{di_I}{dt} = \frac{V_I}{L}$

$T_B = B\omega_B$, $V_R = R i_R$, $T_2 = K_T i_1$, $V_1 = -k_v \omega_2$

$\omega_B = \omega_R - \omega_M$

$\omega_2 = \omega_R - \omega_M$

$V_I = V_s - V_R - V_1$

$T_R = -T_2 - T_B$

$T_M = T_s + T_B + T_2$

$i_R = i_I$

$i_1 = i_I$

CONSTRAINT EQUATIONS

System Variables: $i_I, \omega_R, \omega_M, T_s,$
V_s, V_R, V_1, T_2, T_B

$T_2 = k_T i_I \quad , \quad V_1 = -k_V(\omega_R - \omega_M)$

$V_R = R i_I$

$T_B = B(\omega_R - \omega_M)$

$$\frac{di_I}{dt} = \frac{1}{L}(V_s - V_R - V_1)$$

$$\frac{d\omega_R}{dt} = \frac{1}{J_R}(-T_2 - T_B)$$

$$\frac{d\omega_M}{dt} = \frac{1}{J_M}(T_s + T_B + T_2)$$

$$\frac{d\omega_M}{dt} = \frac{1}{J_M}\left(T_s + B(\omega_R - \omega_M) + k_T i_T\right)$$

STATE EQUATIONS

$$\frac{d\omega_R}{dt} = \frac{1}{J_R}\left(-k_T i_I - B(\omega_R - \omega_M)\right)$$

$$\frac{di_T}{dt} = \frac{1}{L}\left(V_s - R i_I + k_V(\omega_R - \omega_M)\right)$$

State Space Model:

$$A\dot{x} = Bx + Cu \quad , \quad x = \text{state vector}, \quad u = \text{input vector}$$

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{\omega}_M \\ \dot{\omega}_R \\ \dot{i}_L \end{bmatrix} = \begin{bmatrix} \frac{-B}{\cancel{J_M}} & \frac{B}{\cancel{J_M}} & \frac{k_T}{\cancel{J_M}} \\ \frac{B}{\cancel{J_R}} & -\frac{B}{\cancel{J_R}} & -\frac{k_T}{\cancel{J_R}} \\ \frac{-k_V}{\cancel{L}} & \frac{k_V}{\cancel{L}} & \frac{-R}{\cancel{L}} \end{bmatrix} \begin{bmatrix} \omega_M \\ \omega_R \\ i_L \end{bmatrix} + \begin{bmatrix} \frac{1}{\cancel{J_M}} & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_s \\ V_s \end{bmatrix}$$

$$\boxed{\begin{bmatrix} J_M & 0 & 0 \\ 0 & J_R & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} \dot{\omega}_M \\ \dot{\omega}_R \\ \dot{i}_I \end{bmatrix} = \begin{bmatrix} -B & B & k_T \\ B & -B & -k_T \\ -k_V & k_V & -R \end{bmatrix} \begin{bmatrix} \omega_M \\ \omega_R \\ i_L \end{bmatrix} + \begin{bmatrix} 1 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_s \\ V_s \end{bmatrix}}$$

$$y = \begin{bmatrix} \omega_M \\ \omega_R \\ V_s \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \omega_M \\ \omega_R \\ i_L \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} T_s \\ V_s \end{bmatrix}$$

SYSTEM OUTPUT FOR MATLAB

```
%MUG FOR VETERANS WITH TREMORS
%State Space Time Domain Model
%By Eliot Briefer 5/11/2021


%System Parameters
B = ??? %Damping Coefficient: N*s/m
J_m = 1/12*1.3*(3*0.0508^2 + 0.14^2) %Mug Moment of Inertia: kg*m^2
J_r = 0.5*0.005*(0.016^2) %Reaction Wheel Moment of Inertia: kg*m^2
K = 750 * 60/(2*pi) %Speed Constant: V*sec/rad
R = 2.7 %ohms
L = ??? %Motor Inductance: H


%State Space Model: x_dot = A*x + B*u, y = C*x + D*u
%x = state vector = [omega_m omega_r i_L]
%y = output vector = [omega_m omega_r V_s]
%u = input vector = [T_s V_s]
%See hand calculations for derivation
A_matrix = [-B/J_m B/J_m 1/(K*J_m); B/J_r -B/J_r -1/(K*J_r); -K/L K/L -
R/L]
B_matrix = [1/J_m 0; 0 0; 0 1/L]
C_matrix = [1 0 0; 0 1 0; 0 0 0]
D_matrix = [0 0; 0 0; 0 1]


sys = ss(A_matrix, B_matrix, C_matrix, D_matrix)
```

Appendix 7

Design Failure Mode and Effects Analysis

Product: Reaction Wheel Mug

Prepared by: Lucas, Eliot, Nick, Tiernan

Date: 3/11/2021(orig)

Team: W15

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Electronics Puck/ Respond to tremors	Electronics puck does not respond to user tremors.	User cannot drink.	8	a) Motor has too long of delay for accurate response b) Motor saturation occurs	a) Install powerful enough motors to minimize delay in response b) Controller is designed to prevent saturation	3	a) Design controller to detect when motors reach max RPM b) Design controller to operate at point lower than saturation by good margin	3	72	a) Analyze operating speeds for effective torque outputs as well as time delays for generation of these based on motor choice	Lucas Martos-Repath 5/1/2021		7	1	7
Electronics puck/ Stabilize tremors	Electronics puck does not stabilize user tremors.	User spills drink.	8	a) Motors overheat b) Reaction wheels come off shaft	a) Provide ventilation for the motor b) Pick motor with sufficient power capacity (motor trade study)	1	a) Temperature gauge inside the puck b) Auditory test	5	40	a) Create a test flywheel/motor rig and measure operating temperatures b) Perform a trade study on available motors	a) Eliot Briefer - 4/26/2020 b) Nick Greco - 4/12/2021	Performed trade study on available motors.	6	1	6
Electronics puck/ House the electronics	Housing breaks.	User may get electrocuted. User is uncomfortable.	7	a) Puck crumbles b) Puck allows liquid into system c) Puck breaks after drop	a) FEA on puck structure b) Provide protective outer shell to electronics puck	1	a) Visual Inspection	2	14						
Electronics puck/ Detect tremors (IMU)	Electronics puck cannot recognize tremors.	User spills drink.	8	a) IMU is not accurate enough b) Data is too noisy c) IMU relays no data at all d) IMU delay too long	a) IMU trade study b) Pick responsive enough IMU to minimize noisy data	6	a) Testing IMU in controlled setting, and compare to measurable parameters	1	48	a) Perform a trade study on IMU b) Perform initial testing of tremor inputs and analyze data given. Analyze output of data filter	Eliot Briefer a) 4/27/2021 b) 8/30/2021	Performed trade study on IMU.	7	3	21
Electronics puck/ Provide power to the motors	Motors do not receive power.	User spills drink.	8	a) Battery runs out of charge b) Wire breaks c) Motor controller overheats d) Battery will not charge	a) Power budget analysis b) Provide ventillation through puck	2	a) Multimeter test of battery and motor b) Temperature gauge within the puck c) Visual inspection of motor leads	1	16						
Mug body/ Prevent spills	Mug does not prevent spilling.	User spills drink.	8	a) Tremor input too big to stabilize with current control system	a) Designing features to reduce fluid oscillation b) Designing a flexible grip/handle	6	a) User Testing b) "Shake Test"	1	48	a) Implementation and testing of ridges on the inside of the mug b) CAD/FEA modeling of a non-traditional mug handle	Nick Greco a) 4/30/2021 b) 4/12/2021	Created CAD model of mug handle.	6	1	6
Mug body/ Provide secure grip	Mug does not provide secure grip.	User drops mug.	6	a) Handle not integrated into mug body appropriately	a) Deflection analysis of mug handle b) Stress analysis of handle connection to mug body	1	a) Visual Inspection	3	18						
Mug body/Hold fluid	Mug does not hold fluid (fluid leaks).	User gets burned.	9	a) Mug body cracks from thermal shock b) Mug cracks from dropping	a) Research into material capable of holding fluids with wide temperature range b) Perform FEA analysis	1	a) Test range of temperatures b) Leave mug full for 24-hr period, then inspect for dampness	1	9						
Mug body/ Connect puck to body	Electronics puck does not attach to mug body.	User drops puck.	8	a) Clips wear out b) Bottom breaks off c) Contamination prevents electronics puck from fitting	a) Strength testing of simple mechanical clips b) Stress analysis of mug c) Testing for leakage	3	a) An audible "click" when properly inserted b) "Shake" test, horizontal mug test	1	24						
Mug body/Look normal	Mug surface gets damaged.	User is uncomfortable. User is unhappy.	3	a) Mug is too bulky b) Mug is an ugly color and shape	a) Existing products research b) Conducting interviews	1	a) Visual inspection b) Multimeter Test	1	3						
Mug body/ Dishwasher safe	Mug is not dishwasher safe.	Mug body degrades. User ingests chemical from mug body.	9	a) Material selection failed to properly analyze material integrity	a) Research and testing of common dishwasher safe materials	2	a) Complies with FDA approved food-safe regulations	3	54	a) Research of common dishwasher safe materials. b) Research of the criterion for defining a dishwasher safe material.	Tiernan Kehoe 4/30/2021	Found a potential food safe epoxy on Amazon, that can be used to coat 3D printed mug basin.	6	1	6
General/Provide electrical connections	Electrical connections not provided, so no power provided to the device.	User spills drinks.	8	a) Wire breaks b) Over-current condition c) Poor soldering technique	a) Soldering practice	1	a) Visual inspection b) Multimeter Test	1	8						
General/Comply with standards	Liquid cannot be consumed from mug.	Mug cannot be used to drink from.	9	a) Chosen material hazardous b) Coating ineffective /breaks down	a) Becoming familiar with FDA standards b) Research into common food safety design methods	1	a) Standard FDA tests to determine presence of hazardous chemicals	3	27	a) Determination of mug materials to be used and research to find the FDA testing procedures associated with said material	Tiernan Kehoe 4/30/2021		6	1	6

Appendix 8

DVP&R - Design Verification Plan (& Report)

Project:	W15 - Mug for Veterans	Sponsor:	TECHE		Edit Date:	4/28/21

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
1	Outside Temperature Range	Pour boiling liquid into mug basin. Attach thermocouples to the outside wall of the mug and measure the temperature in 30-second increments until the mug wall reaches steady state. Pour chilled liquid (<40 deg F) into mug basin. Repeat the above test.	Temperature	40 - 110 deg F	Thermocouples Thing to hook the thermocouples up to measure temperature (or thermocouples with a D.R.O)	Mug Body	Tiernan	10/30/21			
2	Vibration Simulation Test	Use vibrational "shake" table to simulate range of vibrations in the range of most tremor frequencies (5-8 Hz).	Amount of water spilled from mug	Spill less than 0.5oz of water	"Shake" Table Digital Scale	Mug Body Electronics Puck	Lucas	9/25/21			
3	Strength test	Drop the mug from increasing heights up to 6 ft (simulating falling off a high shelf). Electronics Puck will NOT be included. It will be simulated by weight.	Deformation; Crack formation	Dfrm < 0.125 in No visible cracks are acceptable	Digital scale	Mug Body Ballast (stand-in for electronics puck)	Nick	10/7/21			
4	Leakage	Fill mug with set amount of water. Leave the mug overnight. Observe whether or not leakage has occurred the following day. Run this test both with liquid that is initally boiling and that is initially chilled.	Quantity of water remaining in mug.	100% of water still in mug.	Digital scale	Mug Body	Eliot	10/31/21			
5	Weight	Weigh fully assembled mug with electronics puck inserted.	Weight (in grams)	<1.36 kg	Digital scale	Mug Body Electronics Puck	Tiernan	11/20/21			

Complete these columns when you conduct the tests.

DVP&R - Design Verification Plan (& Report)

Project:	W15 - Mug for Veterans	Sponsor:	TECHE		Edit Date:	4/28/21

TEST PLAN										TEST RESULTS	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
6	Instruction Readability Survey	Provide potential users with a copy of the user manual. Have them take a comprehension test to test their understanding of the user manual.	Percent of users fully understanding	95%	Computer to create survey	User manual	Lucas	11/15/21			

Materials Budget for Senior Project

Appendix 9

Title of Senior Project: W15 - Mug for Veterans with Tremors

Team members: Eliot Briefer, Tiernan Kehoe, Nicholas Greco, Lucas Martos-Repath

Designated Team Treasurer: Nick Greco

Faculty Advisor: Eileen Rossman

Sponsor: Oliver, Melissa RICVAMC McGuire VA Medical Center, Richmond, Virginia

Quarter and year project began: Fall 2020

Materials budget given for this project: **$750.00**

Remaining budget for this project: **$329.39**

Date purchased (or planned to be purchased)	Vendor	Description of items purchased
04/12/21	Amazon	Electronic speed controller
04/12/21	Amazon	DYS D2830 1000KV Brushless Motor for Multicopters RC Plane Helicopter
04/12/21	DF Robot	MTO1804 Brushless DC Motor (CW) with 20A ESC
04/12/21	Amazon	Ginyia Brushless Motor, 5010-360KV 1PCS Metal Outdoor Big Load Multiaxis Thick Line Hollow Cover Double Bearing Brushless Motor
05/20/21	ST Microelectronics	Microcontroller - Nucleo-L432KC
05/20/21	Blue Robotics	2 Basic 30A ESC v3 (w/forward/reverse firmware)
05/20/21	Adafruit	Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout - BNO055
05/20/21	HobbyKing	2 Turnigy nano-tech 260mAh 2S 35~70C Lipo Battery
05/20/21	Pololu Robotics and Electronics	Pololu 5V, 1A Step-Down Voltage Regulator D24V10F5
05/20/21	Amazon	Enegitech RC Battery Charger for 7.4V 11.1V 14.8V 2S 3S 4S LiPo Life Battery
05/20/21	Amazon	ArtResin - Epoxy Resin - Clear - Non-Toxic - 16 oz
05/25/21	Amazon	DYS D2830 750KV Brushless Motor for Multicopters RC Plane Helicopter
05/25/21	McMaster-Carr	M3 Mounting Screws 91290A113
05/25/21	McMaster-Carr	M2 Mounting Screws 91290A013
05/25/21	Elegoo	Assorted Dupont Wires (f-f, m-m, f-m)
05/25/21	McMaster-Carr	9657K628 Spring

Appendix 10

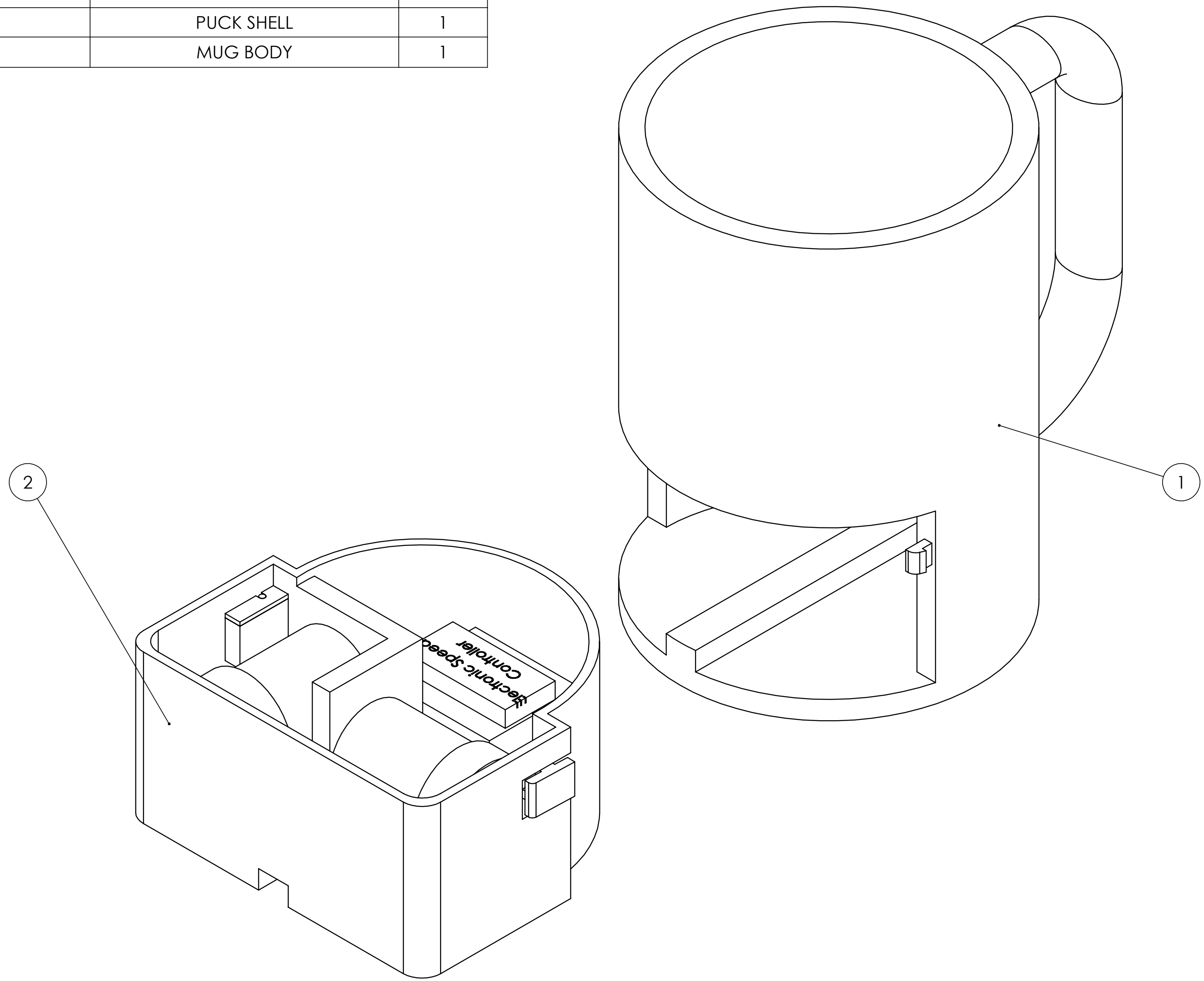
W15 Tremor Mitigating Mug

Indented Bill of Material (iBOM)

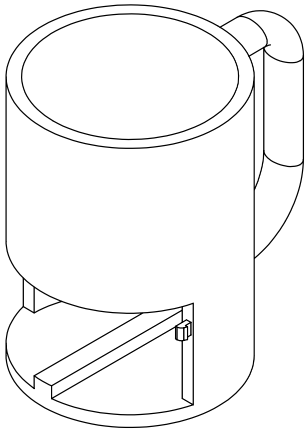
Assy Level	Part Number	Descriptive Part Name	Qty	Mat'l Cost	Production Cost	Total Cost	Part Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3 Lvl4						
0	100000	Tremor-Mitigating Mug Assembly					------	
1	110000	Mug Body					------	
1	120000	Electronics Puck Assembly					------	
2	121000	Microcontroller (MCU)	1	$11.00	$ -	$ 11.00	STMicroelectronics	item 98725
2	122000	Motor	2	$40.00	$ -	$ 80.00	Amazon	Exact motor TBD
3	122100	M3 Mounting Screws	1	$ 7.88		$ 7.88	McMaster Carr	91290A113
2	123000	IMU	1	$19.95	$ -	$ 19.95	Adafruit	BNO055
3	123100	M2 Mounting Screws	1	$12.89		$ 12.89	McMaster Carr	91290A013
2	124000	ESC	2	$20	$ -	$ 40.00	Amazon	Item 98725
2	125000	Battery Pack	1	$20		$20.00	Amazon	B0784CDD6F (14.8 V)
2	126000	Reaction Wheel	2	$ -	$ -	$ -	custom	Manufacture on lathe
2	127000	Assorted Wires	1	$ 6.98	$ -	$ 6.98	Amazon	Elegoo, 120 pcs
2	128000	Electronics Puck Shell	1	$ -	$ -	$ -	custom	SLA printing
3	128100	Puck Lid	1	$ -	$ -	$ -	custom	SLA printing
2	129000	Clip/Tab Mechanism	1	$ -	$ -	$ -	custom	SLA printing
3	129100	Clip Lid	1	-	-	-	Custom	SLA printing
3	129200	Springs	1	$ 5.66	$ -	$ 5.66	McMaster Carr	9657K601
2	129300	Voltage Regulator	1	$ 7.49	$ -	$ 7.49	Pololu	2831
1	130000	General Components					------	
2	131000	Soldering Wire	1	$ -	$ -	$ -		From Machine Shops
2	132000	Food grade epoxy	1	$54.99	$ -	$ 54.99	Amazon	PN: 4913263173106
2	133000	Battery Charger	1	$30.00	$ -	$ 30.00	Amazon	B07RY5RKK7
	Total Parts		**20**			**$ 296.84**		

Appendix 11

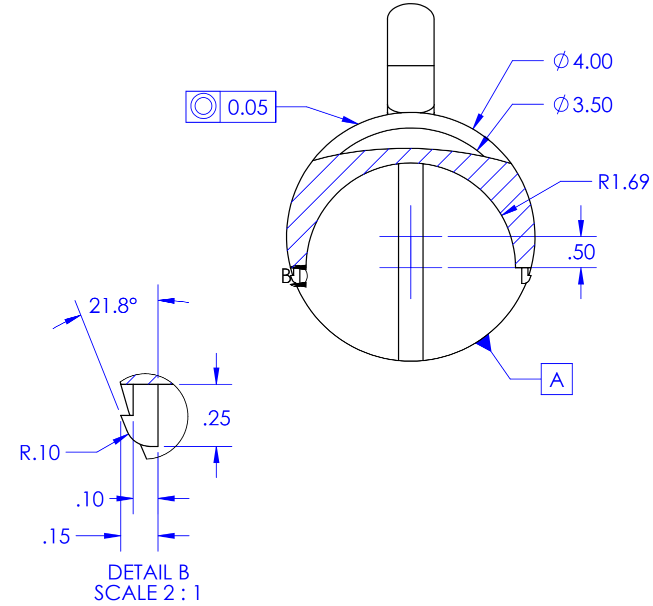
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
2	110000	PUCK SHELL	1
1	120000	MUG BODY	1

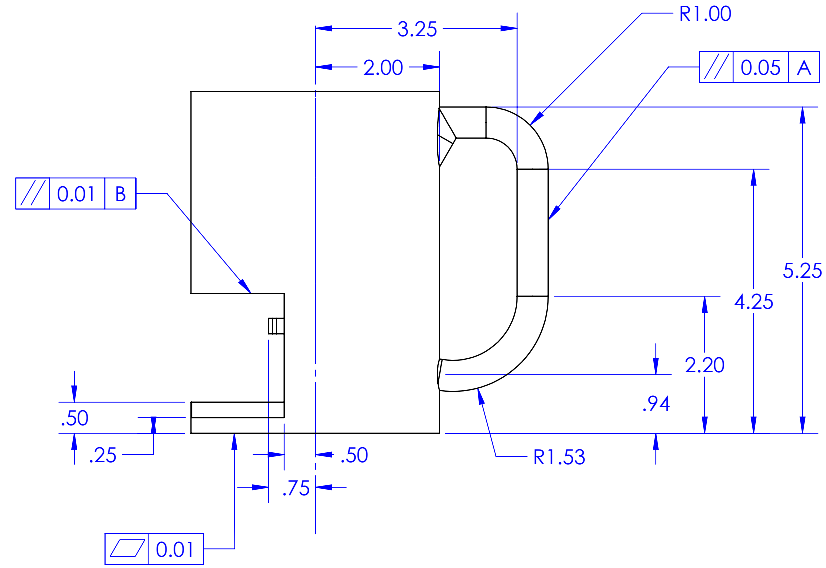


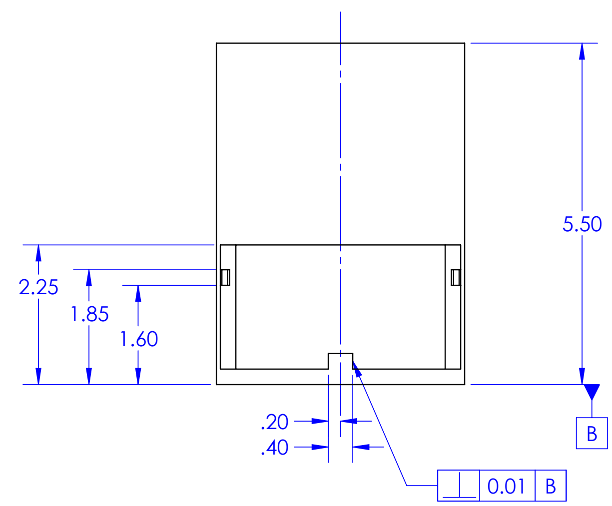
Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: TREMOR MITIGATING MUG		Drwn. By: NICK GRECO
ME 429 - SPRING 2021	Dwg. #: 100000	Nxt Asb:	Date: 5/6/2021	Scale: 1=1	Chkd. By: ELIOT BRIEFER



NOTES:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX = ±.05
X.XXX = ±.01
3. BREAK ALL EDGES .01 MAX

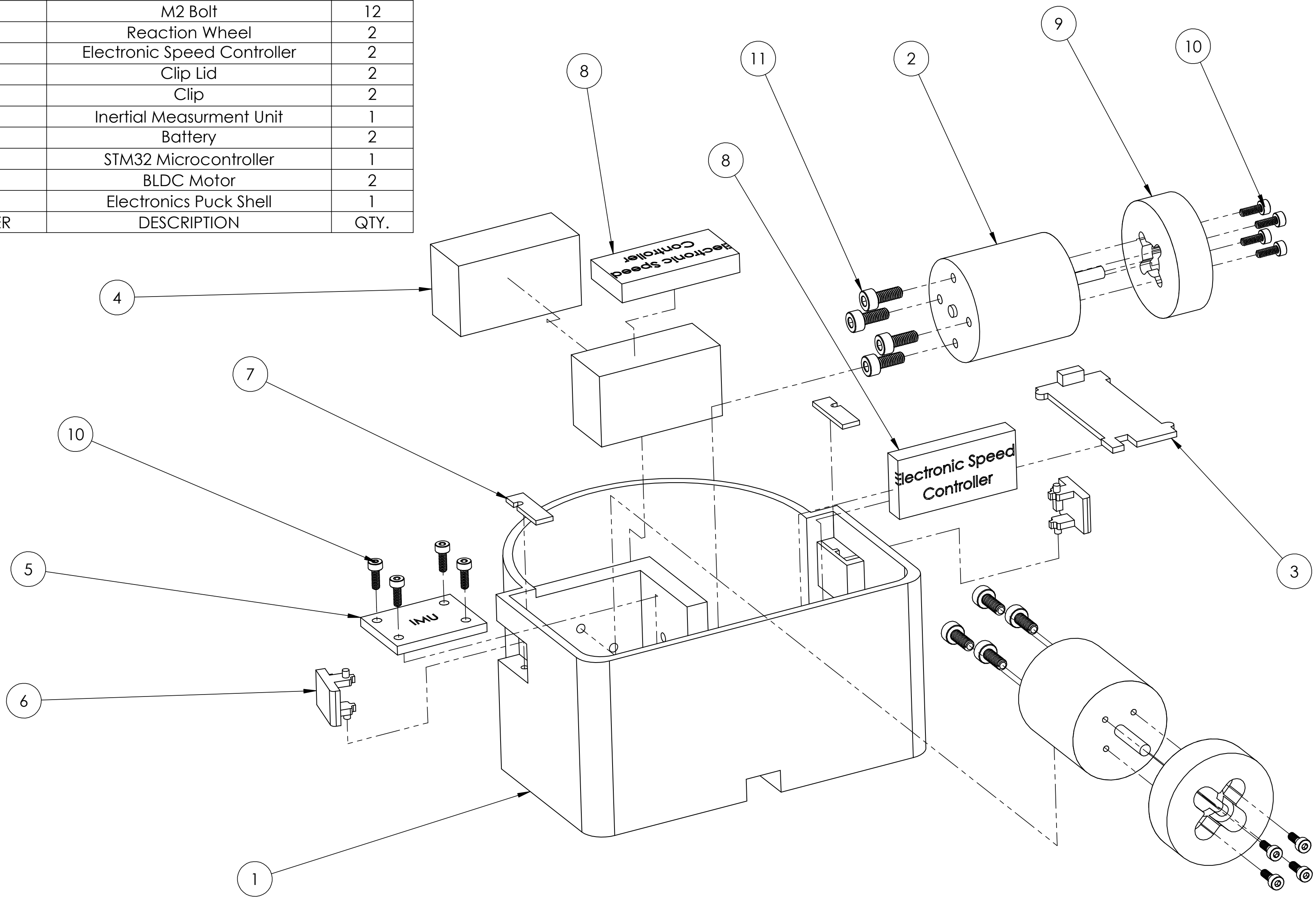






Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: MUG BODY	Drwn. By: NICK GRECO
ME 429 - SPRING 2021	Dwg. #: 110000	Nxt Asb:	Date: 5/5/2021 / Scale = 1:2	Chkd. By: ELIOT BRIEFER

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
11	91290A113	M3 Bolt	8
10	91290A013	M2 Bolt	12
9	126000	Reaction Wheel	2
8	124000	Electronic Speed Controller	2
7	129100	Clip Lid	2
6	129000	Clip	2
5	123000	Inertial Measurment Unit	1
4	125000	Battery	2
3	121000	STM32 Microcontroller	1
2	122000	BLDC Motor	2
1	128000	Electronics Puck Shell	1



Cal Poly Mechanical Engineering ME 429 - spring 2021	Lab Group: W15	Assignment #	Title: Electronics Puck Assembly	Drwn. By: ELIOT BRIEFER
	Dwg. #:120000	Nxt Asb:	Date: 5/5/2021 Scale: 1:1	Chkd. By:

Part No: 121000
Microcontroller

STM32L432KB STM3L432KC

Ultra-low-power ARM® Cortex®-M4 32-bit MCU+FPU, 100DMIPS, up to 256KB Flash, 64KB SRAM, USB FS, analog, audio

Datasheet - production data

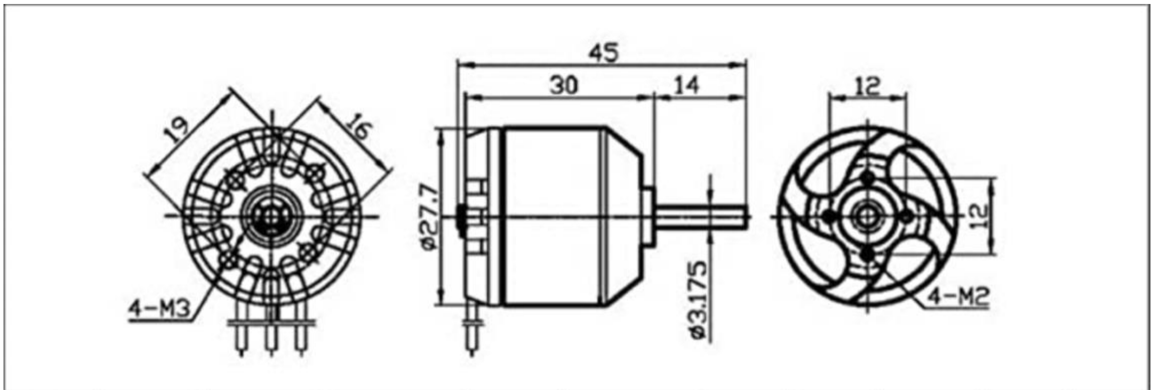
Features

- Ultra-low-power with FlexPowerControl
  - 1.71 V to 3.6 V power supply
  - -40 °C to 85/105/125 °C temperature range
  - 8 nA Shutdown mode (2 wakeup pins)
  - 28 nA Standby mode (2 wakeup pins)
  - 280 nA Standby mode with RTC
  - 1.0 µA Stop 2 mode, 1.28 µA Stop 2 with RTC
  - 84 µA/MHz run mode
  - Batch acquisition mode (BAM)
  - 4 µs wakeup from Stop mode
  - Brown out reset (BOR) in all modes except shutdown
  - Interconnect matrix
- Core: ARM® 32-bit Cortex®-M4 CPU with FPU, Adaptive real-time accelerator (ART Accelerator™) allowing 0-wait-state execution from Flash memory, frequency up to 80 MHz, MPU, 100DMIPS/1.25DMIPS/MHz (Dhrystone 2.1), and DSP instructions
- Performance Benchmark
  - 1.25 DMIPS/MHz (Drystone 2.1)
  - 273.55 Coremark® (3.42 Coremark/MHz @ 80 MHz)
- Energy Benchmark
  - 176.7 ULPBench® score
- Clock Sources
  - 32 kHz crystal oscillator for RTC (LSE)
  - Internal 16 MHz factory-trimmed RC (±1%)
  - Internal low-power 32 kHz RC (±5%)
  - Internal multispeed 100 kHz to 48 MHz oscillator, auto-trimmed by LSE (better than ±0.25 % accuracy)
  - Internal 48 MHz with clock recovery
  - 2 PLLs for system clock, USB, audio, ADC
- RTC with HW calendar, alarms and calibration
- Up to 3 capacitive sensing channels

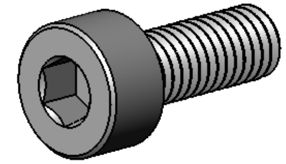
UFQFPN32 (5x5)

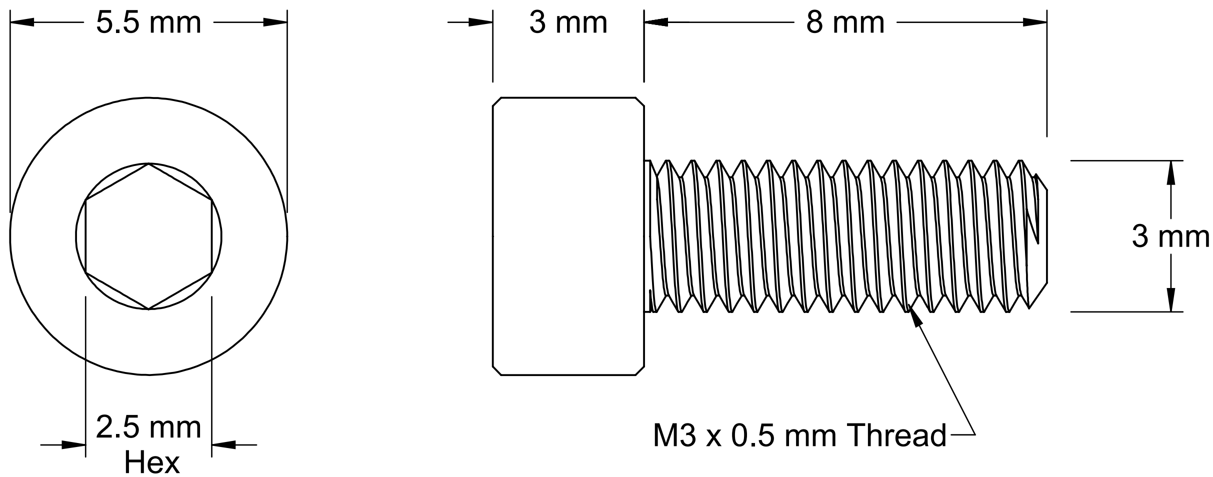
- 11x timers: 1x 16-bit advanced motor-control, 1x 32-bit and 2x 16-bit general purpose, 2x 16-bit basic, 2x low-power 16-bit timers (available in Stop mode), 2x watchdogs, SysTick timer
- Up to 26 fast I/Os, most 5 V-tolerant
- Memories
  - Up to 256 KB single bank Flash, proprietary code readout protection
  - 64 KB of SRAM including 16 KB with hardware parity check
  - Quad SPI memory interface
- Rich analog peripherals (independent supply)
  - 1× 12-bit ADC 5 Msps, up to 16-bit with hardware oversampling, 200 µA/Msps
  - 2x 12-bit DAC, low-power sample and hold
  - 1x operational amplifier with built-in PGA
  - 2x ultra-low-power comparators
- 13x communication interfaces
  - USB 2.0 full-speed crystal less solution with LPM and BCD
  - 1x SAI (serial audio interface)
  - 2x I2C FM+(1 Mbit/s), SMBus/PMBus
  - 3x USARTs (ISO 7816, LIN, IrDA, modem)
  - 2x SPIs (3x SPIs with the Quad SPI)
  - CAN (2.0B Active)
  - SWPMI single wire protocol master I/F
  - IRTIM (Infrared interface)
- 14-channel DMA controller
- True random number generator
- CRC calculation unit, 96-bit unique ID
- Development support: serial wire debug (SWD), JTAG, Embedded Trace Macrocell™

Part No: 122000
Motor



Order No.	Model	Motor size	Shaft size	Weight	KV (rpm/v)	Max Power	Battery	Prop	Ri(M Ω)	ESC
283008	D2830-08	Φ28*30mm	Φ3.17*45mm	52g	1300	275W	2-4Li-Po	9x6/7x3	0.075	30A
283011	D2830-11				1000	210W		10x7/8x4	0.127	
283012	D2830-12				850	187W		11X7/8x6	0.136	
283014	D2830-14				750	185W		12x6/9x6	0.192	





McMASTER-CARR® CAD	PART NUMBER **91290A113**
http://www.mcmaster.com 	Metric Alloy Steel Socket Head Cap Screw

Part No: 123000
IMU

BNO055

INTELLIGENT ABSOLUTE ORIENTATION SENSOR, 9-AXIS SENSOR FUSION ALL-IN-ONE WINDOWS 8.x COMPLIANT SENSOR HUB

Basic Description

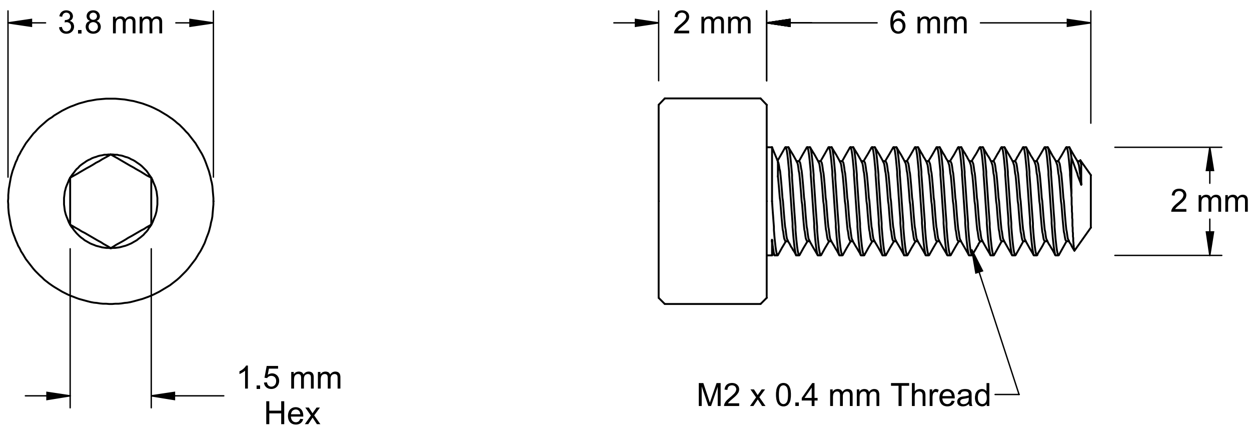
Key features:

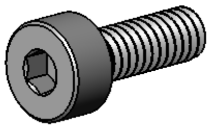
• Outputs fused sensor data	Quaternion, Euler angles, Rotation vector, Linear acceleration, Gravity, Heading
• 3 sensors in one device	an advanced triaxial 16bit gyroscope, a versatile, leading edge triaxial 14bit accelerometer and a full performance geomagnetic sensor
• Small package	LGA package 28 pins Footprint 3.8 x 5.2 mm², height 1.13 mm²
• Power Management	Intelligent Power Management: normal, low power and suspend mode available
• Common voltage supplies	V_{DD} voltage range: 2.4V to 3.6V
• Digital interface	HID-I2C (Windows 8 compatible), I²C, UART V_{DDIO} voltage range: 1.7V to 3.6V
• Consumer electronics suite	MSL1, RoHS compliant, halogen-free Operating temperature: -40°C ... +85°C

Key features of integrated sensors:

Accelerometer features

• Programmable functionality	Acceleration ranges ±2g/±4g/±8g/±16g Low-pass filter bandwidths 1kHz - <8Hz Operation modes: - Normal - Suspend - Low power - Standby - Deep suspend
• On-chip interrupt controller	Motion-triggered interrupt-signal generation for - any-motion (slope) detection - slow or no motion recognition - high-g detection





McMASTER-CARR® CAD	PART NUMBER 91290A013
http://www.mcmaster.com © 2014 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Metric Alloy Steel Socket Head Cap Screw

Part No: 124000
ESC

Basic ESC Documentation (New)

Introduction

NOTE: This is the new version of the Basic ESC, the documentation for old version is located here (http://docs.bluerobotics.com/besc/).

This new version of the Basic ESC is based on the BLHeli_S ESC design, providing an upgrade with newer technology, additional features, and improved performance. The Basic ESC is a simple brushless sensorless speed controller pre-programmed with custom firmware that allows forward and backward operation. The BLHeli_S firmware is open source and available on Github (https://github.com/bitdump/BLHeli/tree/master/BLHeli_S%20SiLabs).

Safety

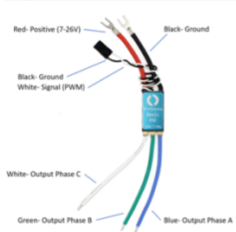
When working with electricity, especially in water, always practice caution. Always ensure that connections are secure and watertight. Keep your body away from spinning motors and propellers.

Quick Start

1. Connect the three motor wires to the motor. The order of connections does not matter, however, switching any two wires will change the direction of the motor. The output phases A, B, and C are completely interchangeable
2. Connect the red power wire and black ground wire to a power source like a battery. You will hear three beeps in rising pitch from the motor indicating all three phases are connected.
3. Connect the signal cable to your signal source like an RC radio receiver or microcontroller board. The white wire is the signal wire.
4. Send a stopped signal (1500 microseconds) for a few seconds to initialize the ESC. You will hear two tones indicating initialization, and then you can send a signal from 1100-1900μs to operate the thruster.

Specifications

Diagram



Specification Table

Electrical		
Voltage	7-26 volts (2-6S)	
Max Current (Constant)	30 amps (depending on cooling)	
Physical		
Length	35 mm	1.38 in

Electrical		
Width	17.1 mm	0.67 in
Height	5.5 mm	0.22 in
Weight	16.3g	0.036lb
Power Connectors	Spade terminals for No. 6 screw	
Motor Connectors	Tinned wire ends	
Signal Connector	3-pin servo connector (0.1" pitch) (ground, blank, signal)	
Pulse Width Signal		
Signal Voltage	3.3-5 volts	
Max Update Rate	400 Hz	
Stopped	1500 microseconds	
Max forward	1900 microseconds	
Max reverse	1100 microseconds	
Signal Deadband	+/- 25 microseconds (centered around 1500 microseconds)	

Part No: 125000
Battery Pack

PRODUCT DESCRIPTION | PRODUCT SPECIFICATIONS | VIDEOS | DISCUSS 0 | REVIEWS | MANUALS/FILES

More than just a fancy name. TURNIGY nano-tech Lipoly batteries were designed from the ground up with serious performance in mind. Utilising an advanced LiCo nano-technology substrate that allows electrons to pass more freely from anode to cathode with less internal impedance. In short; less voltage sag and a higher discharge rate than a similar density lithium polymer (non nano-tech) batteries.

For those who love graphs, it means higher voltage under load, straighter discharge curves and excellent performance. For pilots, it spells stronger throttle punches and unreal straight-up performance. Excellent news for 3D pilots!

Unfortunately with other big brands; numbers, ratings and graphs can be fudged. Rest assured, TURNIGY nano-techs are the real deal, delivering unparalleled performance!

Specs:
Capacity: **260mAh**
Voltage: **2S1P / 2 Cell / 7.4V**
Discharge: **35C Constant / 70C Burst**
Weight: **18.2g (including wire, plug & case)**
Dimensions: **36x20.5x15.5mm**
Balance Plug: **JST-XH**
Discharge Plug: **JST**

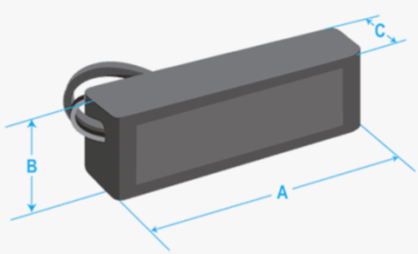
Advantages over traditional Lipoly batteries;
• Power density reaches 7.5 kw/kg.
• Less Voltage sag during high rate discharge, giving more power under load.
• Internal impedance can reach as low as 1.2mO compared to that of 3mO of a standard Lipoly.
• Greater thermal control, pack usually doesn't exceed 60degC
• Swelling during heavy load doesn't exceed 5%, compared to 15% of a normal Lipoly.
• Higher capacity during heavy discharge. More than 90% at 100% C rate.
• Fast charge capable, up to 15C on some batteries.
• Longer Cycle Life, almost double that of standard lipoly technology.

The nano-core technology in lithium ion batteries is the application of nanometer conductive additives. The nanometer conductive additives form ultra-strong electron-conducting networks in the electrodes which can increase electronic conductivity.

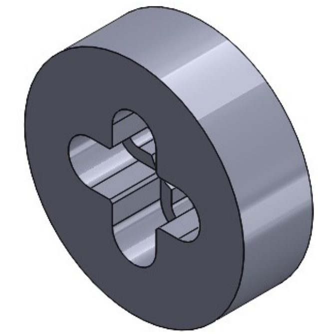
These additives create the ability for imbibition in the carrier liquid to supply more ion channels. This improves the ability of ion transmission and ion diffusion. Through improving electronic conductivity and ion transmission, the impedance is reduced and the polarization of high rate discharge decreases greatly.

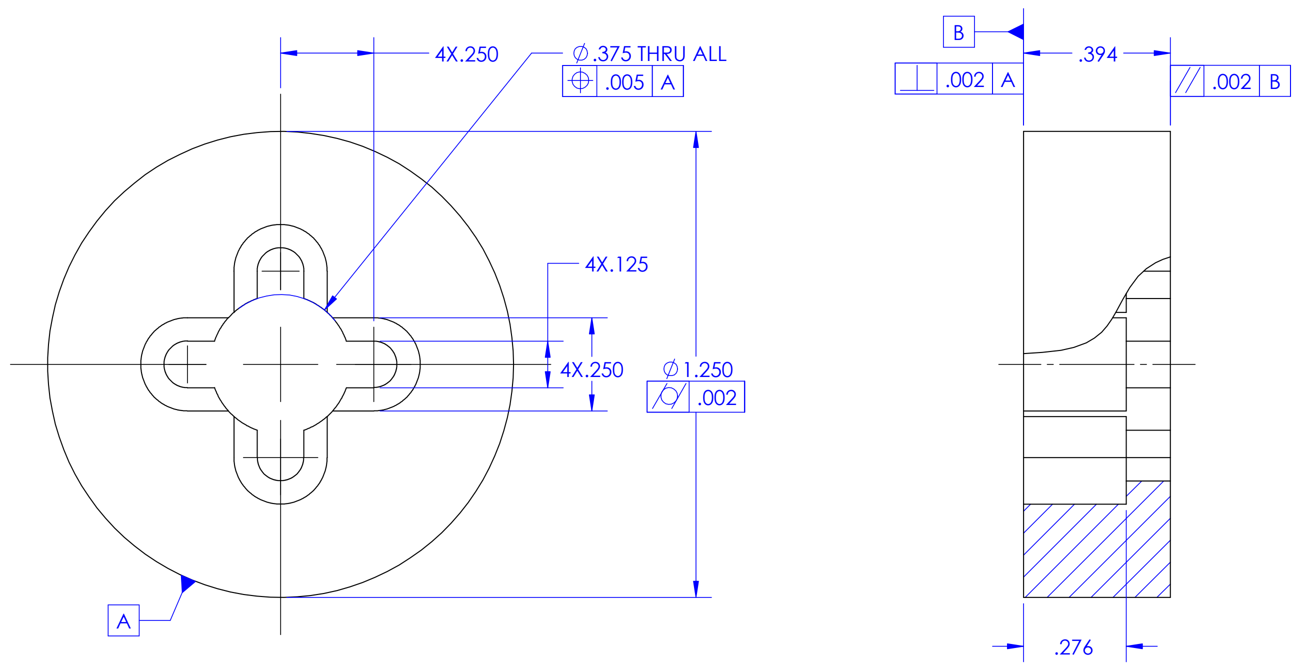
PRODUCT DESCRIPTION | PRODUCT SPECIFICATIONS | VIDEOS | DISCUSS 0 | REVIEWS | MANUALS/FILES

Capacity (mAh)	260.00	Discharge(c)	35.00
Max Charge Rate(C)	8.00	Length-A(mm)	36.00
Height-B(mm)	15.50	Width-C(mm)	20.50



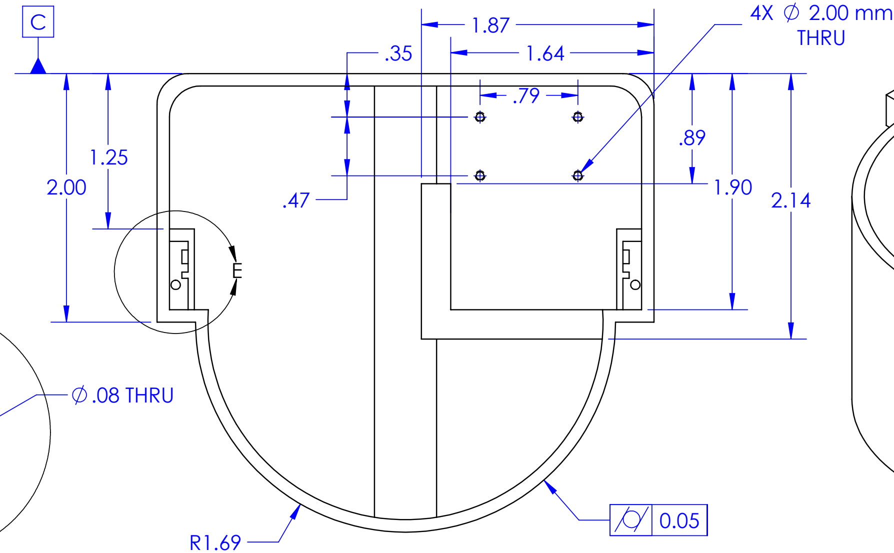
NOTES:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX = ±.05
X.XXX = ±.01
3. BREAK ALL EDGES .01 MAX
4. INSIDE TOOL RADIUS .03 MAX
5. MATERIAL: LOW CARBON STEEL

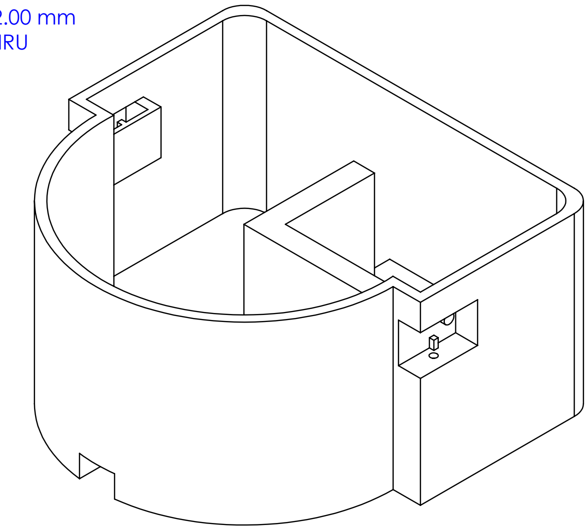


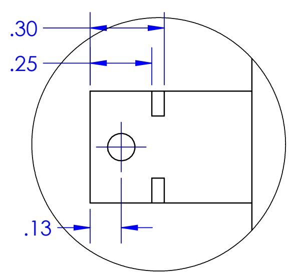


Cal Poly Mechanical Engineering ME 429 - SRING 2021	Lab Group: W15	Assignment #	Title: REACTION WHEEL		Drwn. By: ELIOT BRIEFER
	Dwg. #: 126000	Nxt Asb:	Date: 5/5/2021	Scale: 3:1	Chkd. By: ME STAFF

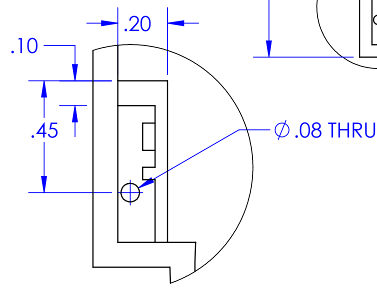
NOTES:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX = ±.05
X.XXX = ±.01
3. BREAK ALL EDGES .01 MAX
4. 3D PRINTED PARTS - REFER TO CAD GEOMETRY
5. THICKNESS OF PUCK WALLS IS A UNIFORM 0.10



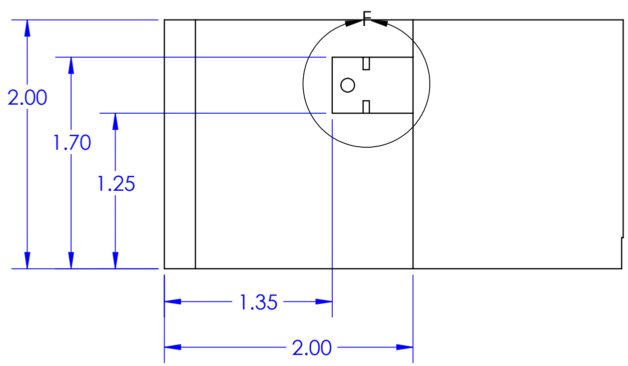


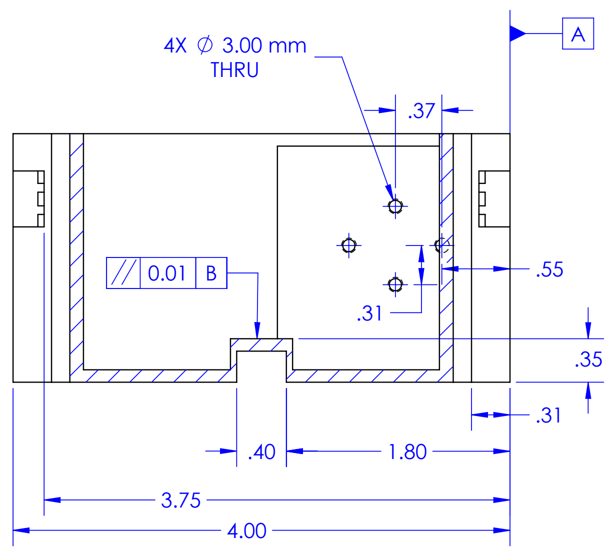


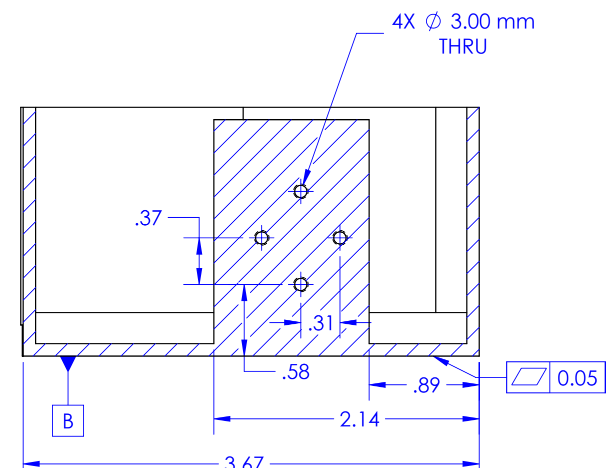
DETAIL F
SCALE 2 : 1



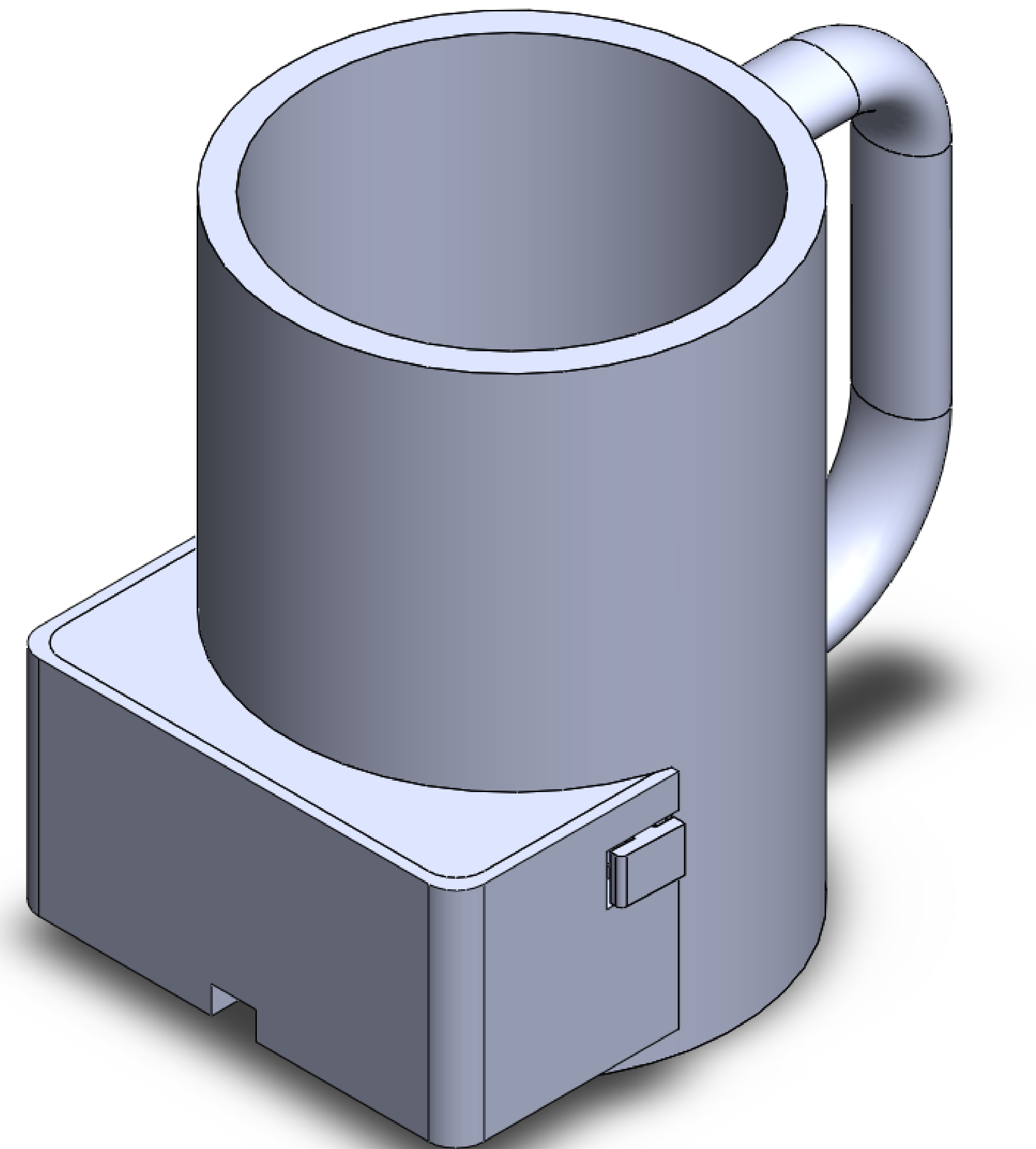
DETAIL E
SCALE 2 : 1

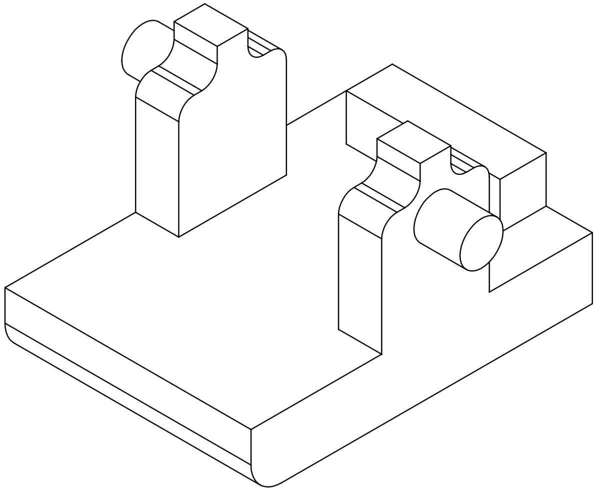


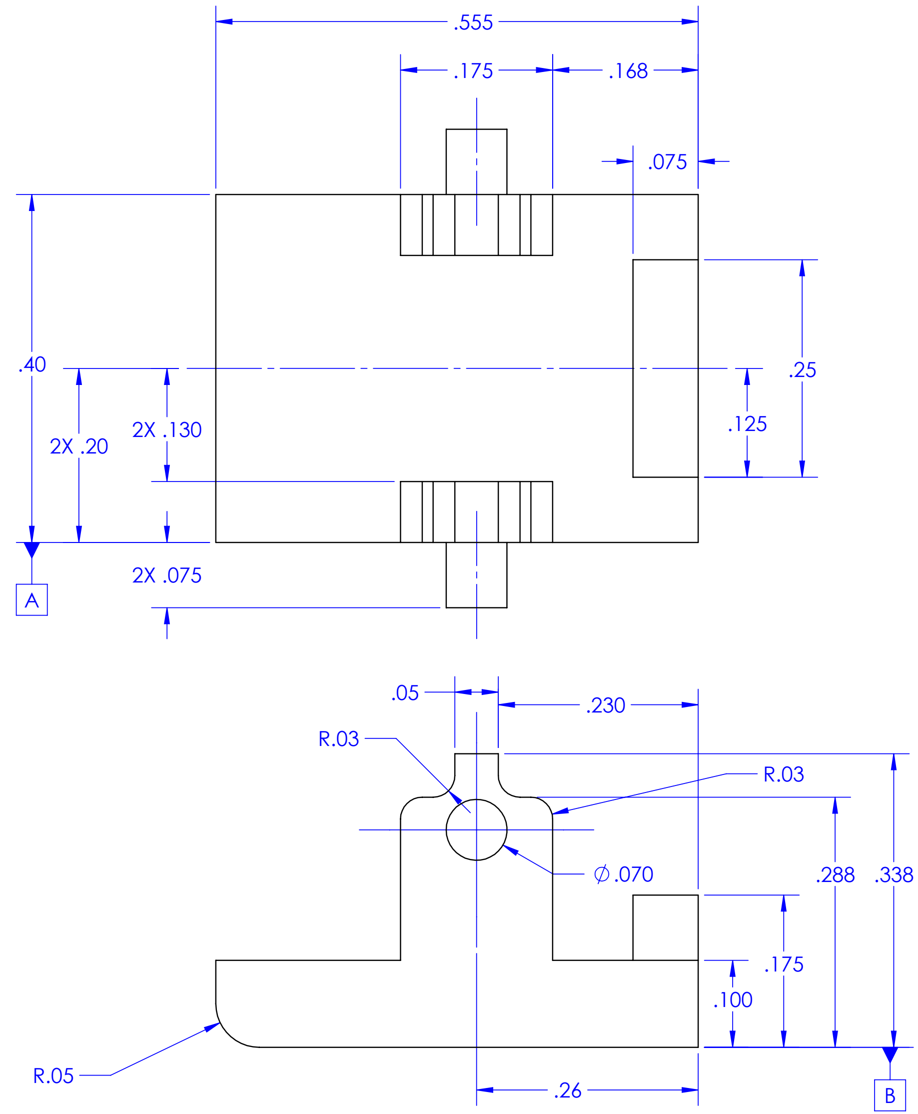




Cal Poly Mechanical Engineering ME 429 - SPRING 2021	Lab Section:	Assignment #	Title: PUCK CASING		Drwn. By: NICHOLAS GRECO
	Dwg. #: 128000	Nxt Asb:	Date: 5/6/2021	Scale: 1=1	Chkd. By: LUCAS MARTOS-REPATH

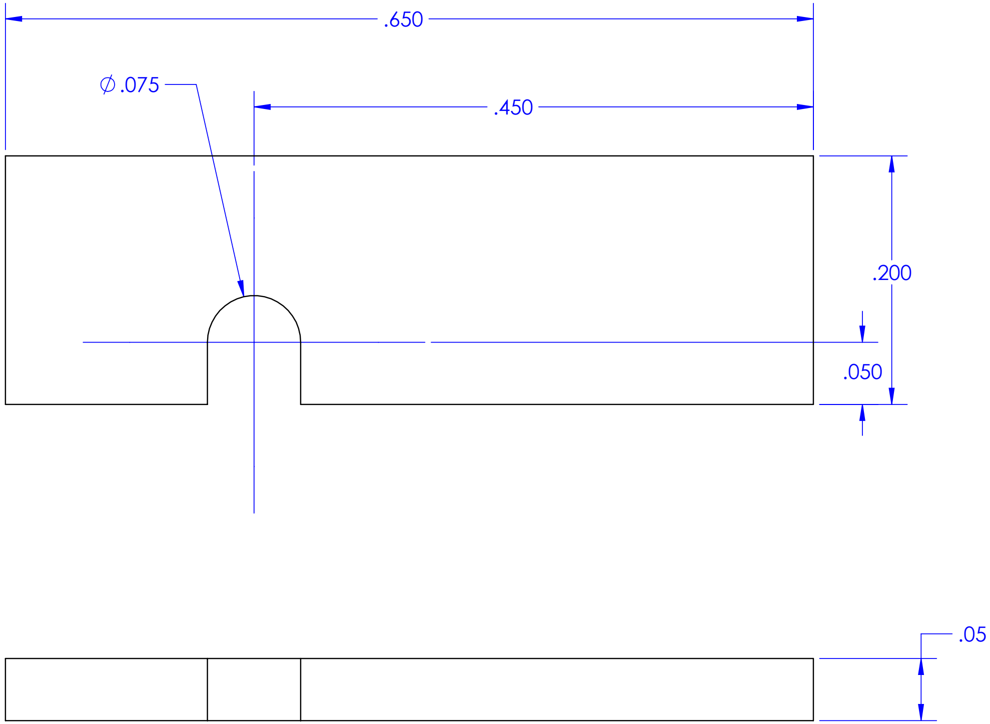






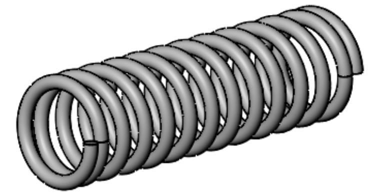
NOTES:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
   X.XX = ±.05
   X.XXX = ±.01
3. BREAK ALL EDGES .01 MAX
4. INSIDE TOOL RADIUS .03 MAX
5. 3D PRINTED PART - REFER TO CAD FOR GEOMETRY

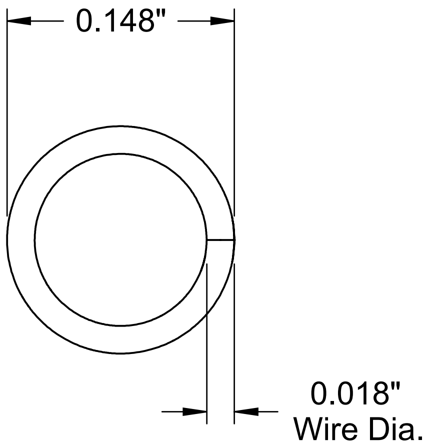
Cal Poly Mechanical Engineering	Lab Group: W15	Assignment #	Title: CLIP/TAB MECHANISM	Drwn. By: L. MARTOS-REPATH
ME 429 - SPRING 2021	Dwg. #:112000	Nxt Asb:	Date: 5-5-2021 / Scale: 7:1	Chkd. By: N. GRECO

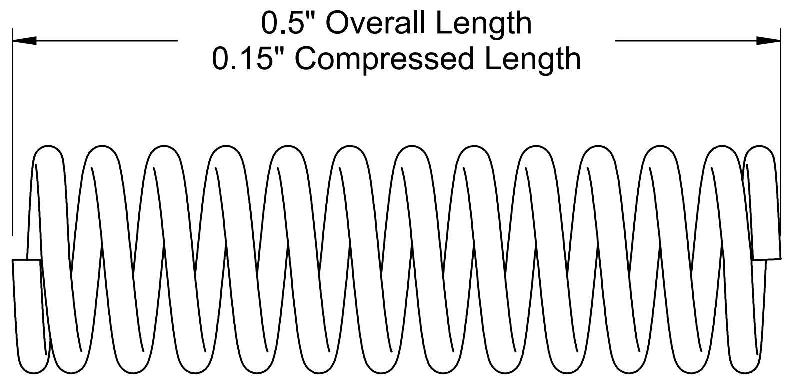


NOTES:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES
X.XX = ±.05
X.XXX = ±.01
3. BREAK ALL EDGES .01 MAX
4. INSIDE TOOL RADIUS .03 MAX
5. 3D PRINTED PART - REFER TO CAD FOR GEOMETRY

Cal Poly Mechanical Engineering	Lab Group: W15	Assignment #	Title: CLIP LID		Drwn. By: L. MARTOS-REPATH
ME 429 - SPRING 2021	Dwg. #: 112100	Nxt Asb:	Date: 5-5-2021	Scale: 10:1	Chkd. By: E. BRIEFER



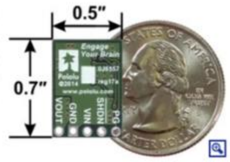




McMASTER-CARR® CAD	PART NUMBER	9657K628
http://www.mcmaster.com	Compression Spring	

Part No: 129000
Step-Down Voltage Regulator

Overview



The D24V10Fx family of step-down voltage regulators features the Intersil ISL85410 1A synchronous buck regulator and generates lower output voltages from input voltages as high as 36 V. They are switching regulators (also called switched-mode power supplies (SMPS) or DC-to-DC converters) with typical efficiencies between 80% and 95%, which is much more efficient than linear voltage regulators, especially when the difference between the input and output voltage is large. These regulators have a power-save mode that activates at light loads and a low quiescent (no load) current draw, which make them well suited for applications that are run from a battery. These regulators are available in five different fixed output voltages:

Alternatives available with variations in these parameter(s): output voltage Select variant…

Pololu step-down voltage regulators D24V10Fx and D24V5Fx next to a 7805 voltage regulator in TO-220 package.

The different versions of this regulator all look very similar, so the bottom silkscreen includes a blank space where you can add your own distinguishing marks or labels. This product page applies to all five versions of the D24V10Fx family.

The SHDN pin can be used to put the board in a low-power state that reduces the quiescent current to approximately 10 µA to 20 µA per volt on VIN, and a PG (power good) output can be used to monitor the state of the regulator's output voltage.

The regulators feature short-circuit/over-current protection, and thermal shutdown helps prevent damage from overheating. The boards do **not** have reverse-voltage protection.

If you do not need quite as much current, consider the very similar D24V5Fx family of step-down voltage regulators, which can deliver up to 500 mA in a wide range of output voltages:

Alternatives available with variations in these parameter(s): output voltage Select variant…

The picture on the right shows a 1 A D24V10Fx regulator next to a 0.5 A D24V5Fx regulator and a common 7805 linear regulator in a TO-220 package.

Features

- Input voltage: [*output voltage + dropout voltage*] to 36 V (see below for more information on dropout voltage)
- Fixed 3.3 V, 5 V, 6 V, 9 V, or 12 V output (depending on regulator version) with 4% accuracy
- Maximum output current: 1 A
- Typical efficiency of 80% to 93%
- 500 kHz switching frequency (when not in power-save mode)
- 2 ms soft-start reduces in-rush current on power-up
- 200 µA typical no-load quiescent current
- Over-current and short-circuit protection, over-temperature shutoff
- Small size: 0.7″ × 0.5″ × 0.14″ (18 mm × 13 mm × 3.5 mm)

Dimensions

Size:	0.5″ × 0.7″ × 0.14″[1]
Weight:	1.0 g[1]

General specifications

Minimum operating voltage:	5.1 V[2]
Maximum operating voltage:	36 V
Maximum output current:	1 A
Output voltage:	5 V
Reverse voltage protection?:	N
Maximum quiescent current:	0.2 mA[3]

Identifying markings

PCB dev codes:	reg17a
Other PCB markings:	0J8557, blank white box

Part No: 133000
Battery Charger

DESCRIPTION REVIEWS

Operating voltage:	100V-240V	Charge current:	1-3A
Support Battery Type:	LiPo/LiFe	Circuit Power:	30W
Cell Count:	2-4 Cell	Weight:	0.4lb

☀All Enegitech products are disinfected and passed quarantine.

☀LiPo/LiFe Focus：Enegitech RC balance charger focuses on 7.4V 2S 11.1V 3S 14.8V 4S LiPo and LiFe battery charging provide a better charging way for your battery. Be Concentrate, be Professional!
☀Easy to Operate: With 3 current options (1-3 Amp), just slide the switch to choose the compatible type and current for you battery. Easy operation,efficient charging.
☀Portable Charger: Light and easy to carry with only 0.4lb weight. Can be powered by portable generator (supporting AC output) so you don't worry about running out of the battery of your drone even in outdoor without socket.
☀LED Indicator：2 indicators (for cell and charging status) can not only remain you the charging status of the battery but also the error message while charging .
☀Exquisite Packing：With unique designed packaging, Enegitech product has its own style which is an ideal gift for giving yourself, your family and your friends.

Enegitech e340 Balance Charger have USA version, UK version, European version and Japan version.

Slide the switch to choose battery type and current.Very easy to operate.

We suggest that
For 1000mAh-1900mAh battery choose to the 1A current
For 2000mAh-1900mAh battery choose to the 2A current
For above 3000mAh battery choose to the 3A current
What's in the package?
1x Enegitech e340 Balance Charger
1x AC Power Cord
1x XT60 Charging Cable
1x Deans-T Charging Cable
1x User's Manual