NASA Psyche Mission: Sampling System

Final Proposal

Psyche Sampling Team

Andrew Acosta

Sultan Almarzouqi

Sam Armstrong

Karissa Barroso

Scott Sprauer

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Project Sponsor: National Aeronautics and Space Administration & Arizona State University's School of Earth and Space Exploration

Sponsor Mentor: Dr. Catherine (Cassie) Bowman

Instructor: Dr. Sarah Oman

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EXECUTIVE SUMMARY

The Psyche Sampling Capstone Team has been tasked with creating a sampling device that would be operable on the surface of the Psyche asteroid. Psyche is an asteroid positioned in the asteroid belt between Mars and Jupiter and is the first asteroid to be explored that has a hypothesized composition of iron-nickel metal. This capstone project, sponsored by the National Aeronautics and Space Administration (NASA) and Arizona State University's (ASU) School of Earth and Space Exploration, works towards creating a sampling system capable of operating under the environmental conditions of the asteroid. Therefore, the success of creating a sampling system that can efficiently retrieve the required samples is vital. It is important to note that the Psyche surface has not yet been explored, therefore the true composition and topography of this asteroid is still fully unknown. This allowed the team to work closely with their client, Dr. Cassie Bowman, the Psyche Mission Co-Investigator, to develop a unique and effective design to meet all customer and engineering requirements developed for a successful product.

Using the design for practice processes with background research and benchmarking, as well as creativity brainstorming methods, the team created a final solution that successfully met all customer and engineering requirements. This design used weight-based scales to compare the various solutions to finalize the design of the most effective and unique final solution. The current state of the design is within its beta prototyping phase and contains four essential subsystems. These subsystems include a drilling mechanism, a collection/distribution system, a storage subunit and a stability factor to further analyze the full system operability. The drilling mechanism is composed of a carousel of multiple sized drill bits for different cutting methods for the surface and subsurface of the asteroid. The collection/distribution system is responsible for collecting the loose surface materials and transporting them to storage. The storage subunit holds premeasured sized samples and keeps them separated to avoid cross contamination and to keep desired sample size. Lastly, the stability factor contains a metallic base that stabilizes the entire system to the asteroid using a magnetic bottom to utilize the ferromagnetic properties of the asteroid's hypothesized material. The computer aided design model of this problem solution can be seen in Figure I.

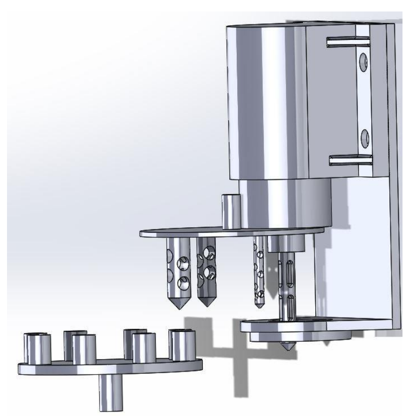

Figure I: CAD Model of Final Sampling System

The next step in validating the integrity of this design and its ability to reach all customer and engineering requirements will be to begin testing the functional prototype of the final design. This will focus on the effects of the magnetic base on the system, the drills operability on various hypothesized surfaces and the efficiency of the collection and distribution subsystem. Prototype building will follow all NASA codes for space exploration mechanics and testing will be completed through a pre-approved procedure from the team and ASU's testing labs, which will be further discussed within this report. Through this rigorous testing, the team will be able to further create a final and effective product to present to the Psyche team.

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1 BACKGROUND

1.1 Introduction

The Psyche Mission is an expedition within the National Aeronautics and Space Administration (NASA) that explores the asteroid Psyche, the 16th asteroid ever found, that resides at about 3 Astronomical units away within the asteroid belt between Mars and Jupiter [1]. The purpose of this mission is to further explore the building blocks of planet formation and to visit a new type of unexplored asteroid surface. NASA is exploring this particular asteroid with the following scientific goals: "to understand a previously unexplored building block of planet formation with iron cores, to look inside terrestrial planets, including Earth, by directly examining the interior of a differentiated body, which otherwise could not be seen, and explore a new type of world. For the first time, this mission will examine a world made not of rock and ice, but metal [2]".

The properties of Psyche are not yet fully known, but it is hypothesized that the asteroid is made largely of an iron-nickel material and may contain a material mixture of metal, rock, and/or pore spaces and fractures. Psyche is approximately 200-kilometers wide, so it is important for NASA to first gain a better image of the asteroid features before considering sending data collection systems to the surface of the asteroid. The mission will begin in 2022 by launching an orbiter that will travel using low-thrust solar electric propulsion. Upon arrival in 2026 it will orbit the asteroid for approximately 21 months to gather remote sensing data from Psyche.

Students have been tasked with designing a robotic explorer alongside a sampling system that could be sent in the future to the asteroid to retrieve material samples to obtain further insight of the asteroid's surface. For this project, the Psyche Sampling Team will be collaborating with sponsors from NASA and Arizona State University's (ASU) School of Earth and Space Exploration to create a sampling system that can efficiently collect and store material samples from the surface. These samples are vital to a future mission in understanding the material properties of this asteroid, so this system's operability and reliability is of high importance to the team's sponsors.

The team's stakeholders to consider for this project include Dr. Cassie Bowman, who is the project client from ASU School of Earth and Space Exploration. She will be the main contact that will give the team advice, updates on the mission and project goals, as well as presenting the team with challenging critiques to help them design the most effective product for this mission. NASA will also be a main stakeholder from this project. As the main sponsor, they will be giving the team opportunities to have their work reviewed by and presented to professional engineers and management within this program. Northern Arizona University (NAU) and this team's project manager will also be small stakeholders from this project. How well the team collaborates with NASA teams, ASU teams, and their client can be considered a reflection of NAU, and the success of this project highly reflects the work from the team. The project manager will oversee the work of this team, and each member is responsible for updating the manager with project tasks, as well as, having their work reviewed before being submitted to the sponsors.

This project's successful completion is important not only to provide the team insight on industry methods, but also to possibly aid NASA in the future in exploring the first metallic world to better understand and analyze protoplanetary formation.

1.2 Project Description

So far, the composition of Psyche has only been informed by radar and optical observations, as well as measurement data of thermal inertia. Scientists have combined radar and optical observations to generate a 3D model of Psyche [1]. The model shows evidence for two crater-like depressions. It suggests that there is significant variation in the metal content and color of the asteroid over its surface. It is important to note that no one has seen the Psyche asteroid yet, so the team will not know what it actually looks like until the spacecraft arrives.[2]. This generated 3D model can be seen in Figure 1.

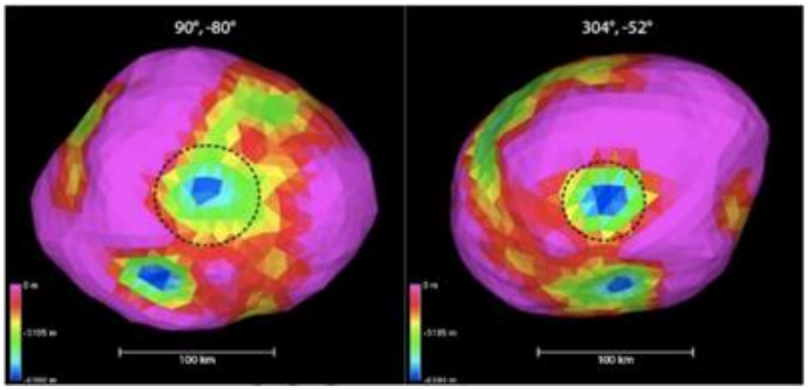

Figure 1: 3D Illustration of Crater Depressions on Psyche [1]

Once a better vision of the surface is attained, it is possible that a team of scientists and engineers would want to propose to NASA to send a sampling system to Psyche to retrieve surface samples to be used in analyzing the asteroid's composition. The following statement is the full project description that was provided by the sponsor:

> *"Designing to the range of hypothesized surfaces that might be found at Psyche (and keeping in mind other constraints such as its gravity), you will design (and, if your capstone supports/allows, create a prototype of) a sampling system capable of effectively extracting scientific samples from each of the hypothesized surfaces and, potentially, a single caching system able to cache each type. Hypothesized surfaces may include: mostly flat metallic surface, flat metallic with metal and/or rocky debris, rough/high-relief metallic and/or rocky terrain, high-relief metallic crater walls. Specifications will be provided for the team to inform the design [3]."*

In summary, our client has asked the team to create a sample processing and handling system for a possible future mission to Psyche. This design will be a stand-alone system that can be efficiently powered and operated independently. The team will focus on creating a system that is effective not only in collecting the samples from the surfaces, but also can cache the scientific samples by specific sample type. Since the surface of Psyche is still unknown, the team must collaborate to create a system that can sample from any of the above hypothesized surfaces described by our client. The team will have to factor in the space-like conditions that will be experienced by the asteroid. Although they are not clearly defined in the original problem statement, the client has specified those environmental conditions. The Psyche asteroid is assumed to experience low gravity, extremely low temperatures due to its distance from the sun, and a four-hour rotational orbit. Therefore, there are many factors that the team must consider, with guidance from the client, before designing a system for a fully hypothesized mission.

2 REQUIREMENTS

For this capstone, certain requirements were established to validate the success of the project. For the possible future mission, it is required that the sampling system drill through the metallic surface, collect the sample, store the said sample, and be stable enough to complete all the actions. Above all, the sampling system must also be able to complete all these actions while running off a sustainable power system, such as either solar or nuclear battery. With these demands, the team created a list of customer and quantifiable engineering requirements.

2.1 Customer Requirements

After talking to the sponsor, Dr. Bowman, the team gathered all the customer requirements in order to create quantifiable engineering requirements. The customer requirements collected fully incorporate the project's demands. The customer requirements are weighted percentages, out of 100, shown in Table 1 to demonstrate the importance of each customer requirement.

Table 1: Weighted Customer Requirements

Customer Requirements	**% Weight**	**Customer Requirements**	**% Weight**
Reliable	12	Sample caching	10
Durable	8	Utilizes minimal power	10
Safe	10	Sample caching is compact	6
Inexpensive	12	Operates under cold temp.	5
Functions on different surfaces	15	Stable under orbital rotation	5
Operates under minimal gravity	7		

These customer requirements are important for the team to achieve in order to create a device that will be approved by the client. The customer requirements of highest importance included the reliability of the design to operate as needed, the safety of the design, the low cost of the product, its ability to operate on multiple different surfaces, its sample caching capabilities and its usage of minimal power in order to operate efficiently. Customer requirements that were of lower percentage weights were still important, however, these aspects could be neglected if it risked the integrity of the system, affected the higher ranked customer requirements achievability, or did not seem to be a tough obstacle for the team to work around. These lower scale requirements included the systems durability through multiple operational trips, the compatibility of the sample caching mechanism, it is able to operate in low temperature and can remain stable under the asteroid's orbital rotation. Although these requirements were vague, it gave the team more freedom with creating unique and creative solutions for the Psyche sampling system. However, the team will still focus on making the final project design operable within the requirements asked by Dr. Bowman. With these customer requirements clearly identified, the team was able to convert these specifications into quantifiable engineering requirements.

2.2 Engineering Requirements

After discussing the customer requirements with the client, the team generated engineering requirements that numerically sets a target value with a tolerance. These engineering requirements were created to produce quantifiable measurements to define the customer requirements. These requirements are shown in Table 2.

Table 2: Engineering Requirements and Target Values

Engineering Requirement	**Units**	**Target Value**	**Tolerance (±)**
Weight	kg	4	2
Cost	$	1000	250
Storage	cm^3	100	20
Hardness	HB	150	50
Velocity	m/s or rpm	1000	250
Lifespan	Ah	4	1
Factor of Safety	[-]	1.5	0.5

These target values were created by defining at what value would the project solution be successful in reaching the engineering requirements. The weight value was determined based on the solutions ability to stay stable under orbital rotation and be a compact system. The team wanted to make the product light enough to be easily compact and loadable, but also heavy enough to not be affected by the minimal gravity and can be easily stabilized using stabilizing mechanisms. The cost target value was based off the budget the team was given at the beginning of the project. Although the team was only given $1000 initially, the project has the opportunity to gain more funding through fundraisers and program fees if necessary. The customer requirement was to keep the product cost effective, however the team was sure not to let cost affect the integrity of the design. The storage requirement was dependent on the sample sizes needed for the mission and to quantify the sample caching requirement. The Brinell hardness factor was created in respect to the drill hardness. The drill must be able to take samples of any hypothesized material thus the need for a drill bit of a high Brinell hardness. The device must also be reliable and durable in order to efficiently operate with minimal power. The team created a target value for the lifespan of the battery/power source so that the customer requirements are met. Lastly, although the sampling system will not be humanly operated on the asteroid, the team decided that there should still be a factor of safety included in the requirements. The requirements of the sampling system is to create a safe system that does not detrimentally affect the asteroid's environment, therefore it was important to create a factor of safety requirement. These requirements will help the team analyze the effectiveness of the system by reaching the desired values.

2.3 *Functional Decomposition*

The functional decomposition of this project breaks down the functions of the sampling system and clearly defines the physical requirements of the system. Both the Black Box Model and the Functional Model were used before developing concept designs. The main purpose of this Black Box Model was to break down the basic inputs and outputs of the design centered around its main functions. The Functional Model further details the basic functions of the system when operating. Each model used within the functional decomposition allowed the team to better understand the operations that each design must contain in order to operate efficiently.

2.3.1 **Black Box Model**

The Black Box Model is designed to represent the underlying functions and signals of the sampling system. The Black Box Model, shown in Figure 2, has been updated to better show the major inputs and outputs of the final design.

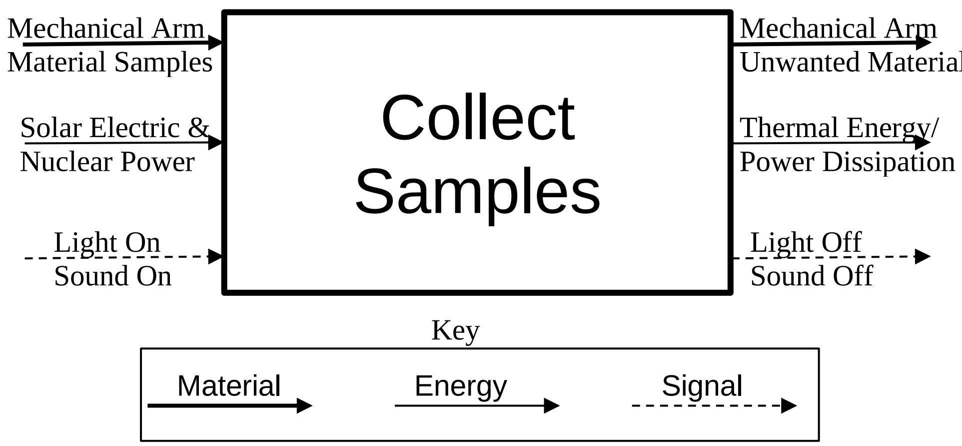

Figure 2: Current Black Box Model

Shown from the line key below the model, the material, signal and energy input and outputs were defined in order to achieve the systems main function of collecting samples. The majority of the Black Box model is similar to the original model created before the concept generation process of the design methods. The material entering the sampling system is still the sample material itself and the supposed mechanical arm of the assembly that operated the drill bit and the collection subsystems. From this, any unwanted material is discarded, and the mechanical arm would then retract, representing the loss of material input from the system. The power supply of the system represents the energy put into the system. This is where the model had changes. As represented in the model, the chosen energy input the team would be using will be through solar-electric and nuclear battery power. This power usage was unknown prior to the design creations. Any excess energy lost, however, will still be given off as thermal energy. Finally, the drill will give some visual and sound signals to denote when it is powered or idle. This system would be created by a computer program, created and operated from Earth, as the sampling system will not be human operated on the asteroid. This model gives a clear representation of the basic function of the design and the inputs and outputs that will denote the success of this function. During the final building and design process, the inputs and outputs were important to utilize to ensure the success and operability of the system.

2.3.2 **Functional Model**

A Functional Model was then created to define all the necessary functions that will occur throughout the sampling system. Like a Black Box Model, the model represents the main function of the device, however it provides more detail for all the functions needed in order to complete the collection of samples. For this point of the project, the Functional Model was redesigned to outline all functions of the final design of the Psyche sampling system due to the complexity of the team's design. As seen below in Figure 3, each function, as well as the inputs and outputs of each function are detailed.

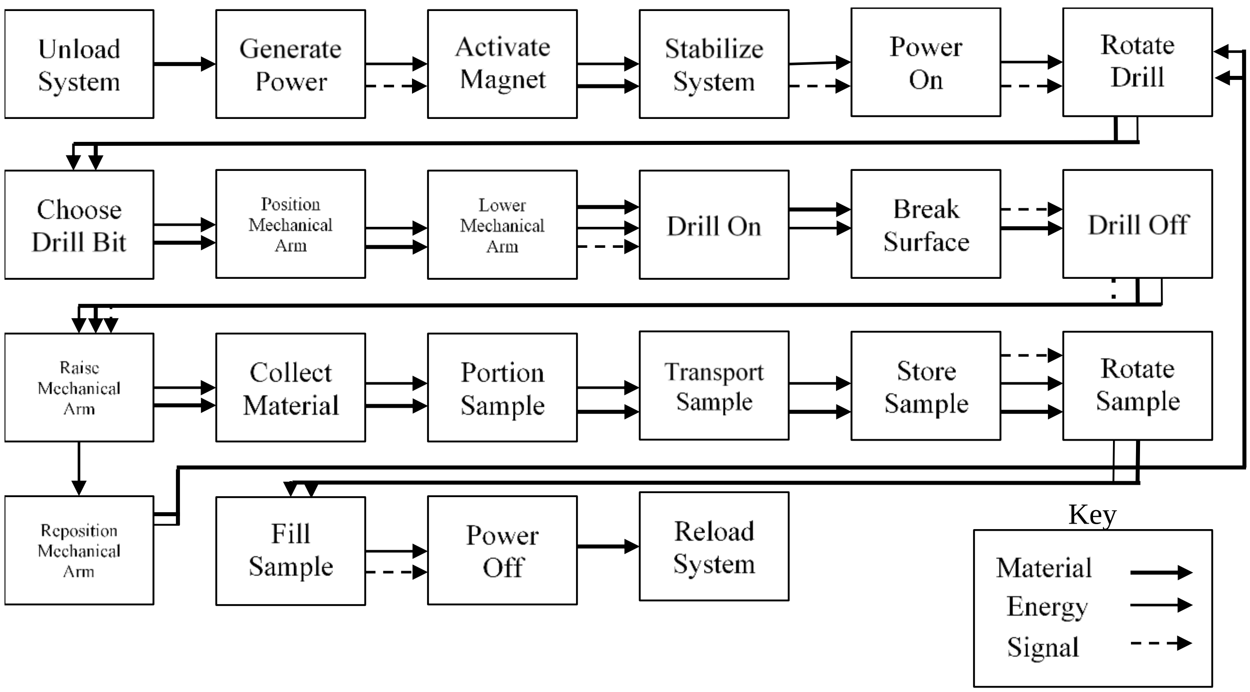

Figure 3: Updated Functional Model

Once the system is unloaded from the travel bus, the system will then activate its electromagnetic base to stabilize the device onto the asteroid's surface. Power is then generated using solar electric mixed with nuclear battery power to turn the system on. The drill bit carousel sub assembly rotates and loads a drill bit into the drill. The drill is then placed against the surface in order to drill into the surface. The sample material is collected and decontaminated. This material is then sorted and stored in the storage subsystem. This process is then repeated until all sample collections are complete. Once all samples have been taken for the set period of operation, the system shuts down, powers off and reloads to wait for the next operation cycle. The original functional model did not change a lot from the new version presented above. More input and output materials, energy and signals were added, as well as, defines more minor functions of the entire system.

2.4 House of Quality

Using the House of Quality (HoQ), the group compiled the information and developed strong, medium, and weak relationships between the customer and engineering requirements. As well, the team assigned weights of importance to the customer requirements so that when calculating the absolute technical importance (ATI), the team was able to calculate the relative technical importance (RTI) and determine the more important engineering requirements to focus on. This table is shown in Appendix A. After completing the HoQ, it was revealed that the order of importance of the engineering requirements, with one being the highest, are:

1. Lifespan
2. Hardness
3. Velocity
4. Weight
5. Cost
6. Storage

The House of Quality helps the design process because the team now knows that as the team designs and prototypes, the lifespan of the battery is the most important factor to consider, then hardness and so on. The HoQ also allowed the team to create design specific towards certain requirements that were ranked high on the list.

2.5 Standards, Codes, and Regulations

Standards, codes, and regulations are essential when creating a new system that is to be implemented into society. There are many standards to keep in mind, such as American Society of Testing and Materials (ASTM) when dealing with testing procedures, American Society of Mechanical Engineers (ASME) when dealing with mechanical design processes, and in this particular project, the NASA standards for space vehicles. The team browsed different websites from different code standards and evaluated the codes and standards that related most to the Psyche Sampling System. In Appendix B, the team identified all the relevant standards and codes that applies to the project. Within this table, we identified 4 different organizational standards that applies to the sampling system and identified the top 20 most relevant codes. These organizations include the NASA technical standards, ASME standards, IEEE standards and ASTM codes. These codes will further help the team in understanding real world regulations for mechanical designs to advocate for the safety and integrity of the designed system.

3 TESTING PROCEDURES

The testing procedures used is to meet each customer requirement and engineering requirement that was created by the NASA Psyche Sampling Team. The engineering requirements are taken from the House of Quality seen in Appendix A. The engineering requirements to be met are lifespan, velocity, hardness, storage, cost, and weight. In these requirements there are four tests that special equipment is needed for; pressure test, vibration test, temperature test, and drilling test. These four tests are able to test the engineering requirements of storage and hardness, while also testing the durability and reliability of the system. The lifespan, velocity, cost and weight requirements are easily tested with simple testing that is described in the below sections, along with all other testing procedures that are to be carried out. Due to the need for testing procedures needed for each requirement presented in the House of Quality, the first three testing procedures are demonstrated to be what would be the best procedure to follow for real life application. However, due to the budget restrictions the pressure, vibe and high temperature testing will be completed using ANSYS and SolidWorks software applications to do virtual tests on the system.

3.1 Testing Procedure 1: Pressure Testing

This test is to understand how the system created will perform in a zero pressure environment. This will be done because the system will be operating at zero pressure on the asteroid in space. The team will conduct many tests in zero pressure for a long period of time to endure the system will not fail when in space. The test would use a large vacuum chamber that can be found in many testing facilities that are easily rented. This test will fulfill the customer requirements of durable and reliable, testing how the system will work in the environment it will be subjected to for many years will prove to be vital information to understand as well as the engineering requirement of the Factor of Safety. For testing the team has allocated a month for testing, all of March. This will be considered one of the most important test so it will have to be done first to be sure the design is adequate for the client.

3.1.1 Testing Procedure 1: Objective

The objective of this test is to put the system under pressure conditions it will be experiencing in space, which is zero pressure. This will test the electronics of the system in zero pressure confirming that the product is reliable and successful when experiencing this type of pressure. This test will be conducted using a large vacuum chamber that can be found in facilities that create systems for space explorations like NASA. The system will be run at full capacity for many hours under vacuum pressure. This test will help confirm that the electronics will work as wanted, and reliability in the conditions that the system will be experiencing. This test is the most important because this is the environment the system was created for and will be performing in.

3.1.2 Testing Procedure 1: Resources Required

This test will require a system/ subsystem to be fully functional including electronics. The electronics will be the most critical part of the system, while being the most likely to fail under vacuum pressure. To pass the test the system must work and meet expectations of the team and client for long durations in the pressure chamber. These vacuum chambers are found in many testing facilities that can be rented out or hired. One of facilities that is available for use is the ASU Satellite Laboratory, that may be accessed with the client’s permission. The hardware and software will be provided by the lab that will be provided or hired. Along with the personnel needed to run these tests and understand data being provided. Although a vacuum chamber is available to the team at the ASU lab and is a more realistic test procedure, this testing would call a need for vacuum rated materials to be used in the system. The team does have a limited budget, therefore acquiring vacuum rated system components would be to challenging. The team will instead, for capstone purposes, utilize the ANSYS Fluent software provided by NAU.

3.1.3 Testing Procedure 1: Schedule

This test will not take more than two days, the team will push the CAD design to the limits and against harsher computer generated environments than expected. Keeping the system in these conditions for a large amount of time is important due to the many years the system is expected to be operating at zero pressure. This will fit into the month that is scheduled for testing in the Gantt chart provided. Testing the system at zero pressure is the first test the team needs to provide, being sure the device will work in the conditions it was made for is the first step. This step will need to be done in the beginning of the month, the second week of March, or even earlier to fix and iterate if the design fails and retest. The entire system needs to be completed by the time of this testing, for this testing the team needs to perform the test on the system that is going on the mission and testing that each subsystem is compliant and work together in compliance.

3.2 Testing Procedure 2: Vibration Testing

The vibration testing will be used to test the system against strong vibrations in all three dimensions. A vibration testing system from Embry Riddle in Prescott, Arizona has been often used by the Psyche research teams. This device is able to vibrate on a horizontal plane to mimic car/vehicle vibration and vibrate on a vertical plane to mimic a vibration from a rocket going into space. From these tests the team plans to use the data to be certain each part is secure and will not come loose at any point during the mission. This test will meet the requirements of reliability, durability, and safety. Overall, the team is testing how the system and subsystems will handle the extreme vibrations. To perform this test the subsystems must be completed and preferably the full system for the test. During the testing month, March, this test can be completed at any time during this month, with the test able to be done on the subsystem and full system at separate times. From the test the team will expect to do iterations of the design by securing the system in different ways in order to reduce vibrational errors. With advice from the project client, however, she found that testing prototypes on the vibe bench to be ineffective with the scope of the Psyche sampling project. Although vibration testing using a bench is most efficient, the team decided that the vibration tests will be run through SolidWorks and ANSYS Fluent to create simulation vibrations to the CAD model of the design. This will allow the team to use simpler resources for material to ensure that the team stays under budget.

3.2.1 **Testing Procedure 2: Objective**

A vibration test is needed to test the system's structure with violent vibrations. This is to model the vibrations of the rocket that will be carrying the system and the landing of the system. During these two parts of the mission the system will be experiencing an immense amount of vibration that will easily break the system. The objective of the test is to understand how vibration will affect the system created. From these tests the team will be able to secure every component of the system will be secure during launch and any other vibrations the system will experience.

3.2.2 **Testing Procedure 2: Resources Required**

A vibration table is required for these tests, these are found in labs funded by NASA and those who are contracted by NASA to do work. Getting access to this device will have to be done through the client, who has connected with Embry Riddle in the past for previous Psyche projects. The tester will need to be trained, or personnel will have to be obtained to run the vibrations test. These types of vibration tests uses a large platform that produces strong shaking in all three axes. These products are very expensive and must be rented or provided by a testing facility. However, since the Psyche team is not guaranteed access to the vibration bench, the team will need to utilize the SolidWorks and ANSYS simulation software applications to complete this testing.

3.2.3 **Testing Procedure 2: Schedule**

The vibration test will only last a few hours maximum, the team plans to simulate the system at vibration levels much more intense than the vibrations that are expected from the mission. This test will need at least the full subsystems completed. If the full system is not created by the expected testing time the test may be performed on each subsystem separately to understand the effect of the vibrations on each subsystem. During the month-long testing period that is scheduled, the vibration test can be performed at any time during the month as long as it allows for iteration and retesting. The team plans to have the vibration test done the first week of March to coincide with the pressure testing.

3.3 Testing Procedure 3: Extreme Temperature Testing

A temperature test in needed to understand and predict how the system and subsystems will react while subjected to extreme heat, extreme cold, and the instantaneous change from the two extremes. This test is done because the system will be operating in extreme cold when the sun is blocked and extreme heat when the system is subject to direct sunlight. The instantaneous change from these two extremes is due to the fact of no convection in space and only conduction. Testing the systems electronics and mechanics functionality when subjected to these temperatures will meet the customer requirements of durable, reliable, and operating under cold conditions. The team plans to temperature test the system after the full system is designed and all other tests are concluded.

3.3.1 **Testing Procedure 3: Objective**

The objective of this test to put the system under temperature stress and test the mechanics and electronics during high heat, freezing temperatures, and the quick change between the two extremes. This test is used to understand how the system will perform in the extreme temperatures that are experienced in space. When the system is exposed to the sun the system will experience high heat and when not directly exposed to the sun the system will experience extremely low temperatures. The temperature changes will be very rapid due to no convection in space, so understanding how the system will react to the quick change of extremes.

3.3.2 **Testing Procedure 3: Resources Required**

For this test a temperature chamber would be needed. These chambers use forced air to heat and evacuate the air to cool the chamber. This will allow for the testing of temperatures of extreme cold and extreme hot. Although these chambers are the best resource to use for extreme temperature testing, the access to these chambers is limited. Due to this, the team will be utilizing SolidWorks and ANSYS software to simulate the extreme temperature variations. These software programs are provided by NAU and are easily accessible for the team to use with their CAD model designs.

3.3.3 **Testing Procedure 3: Schedule**

This test is planned to be done at the end of the testing period and should take the team about a day of testing. The fully system is needed to be complete by this testing so that the full system is subjected together and not separately, causing any unwanted defects. The team will plan to have this test done by the week of April 6th. This will be the final test needed to determine the system is able to perform and work in the harsh conditions of space.

*3.3.4 **Testing Procedure 4: Drill Testing***

The drill testing is one of the most important tests. The team will be testing the drilling bit and mechanism on material provided by the client to represent what is thought to be the makeup of Psyche. This test is to prove the system created is fully functional and does what the system is meant to do. This test meets the customer requirements of sample caching and collection of unknown material. The team is to test this system once the full system is created and functional. This testing will not have to be in the testing period, preferably the testing will be done before this period.

3.3.4.1 **Testing Procedure 4: Objective**

The objective of this test is to test the drilling and sampling system. This will give data on whether the materials used for the drill and the mechanism for collecting the samples are sufficient and will work for what is needed. The main function of the drill test is to make sure the material selection for the drill is adequate to drill into the assumed material of the asteroid. The next subsystem that will be tested is the collection system, this is to test it is functionality of the collection system and reliability of the system as the designed system will need to collect multiple samples.

3.3.4.2 **Testing Procedure 4: Resources Required**

The resources used are provided to the team by ASU. The system will be tested on the material slabs created by the NASA/ASU team. These slabs of metal replicates the material makeup of what is thought to be on the asteroid. This test would require, like all other test methods, travel to the test center. The personnel will be available at the testing site. Another option for this test is to create the slabs from the instructions given to the team by the client. This test will be considered if the system is able to sample and cache many samples of the test surface.

3.3.4.3 **Testing Procedure 4: Schedule**

This test is expected to be carried out while creating the system and will be the first test that needs to be passed before all other tests are to be conducted. The full system is preferred for this test, however can be tested per subsystem to determine that each subsystem is successful. The team expects to have this test completed before the testing period, March, shown in the Gantt chart. This test is the highest priority of the team as it is the primary function of the system being created.

3.3.5 Testing Procedure 5: Life Span Testing

The lifespan test is done to test how long the battery of the sampling system is planned to last on one charge of the battery. The goal of this is to have 4 Ah during test. To test this the team will let it run to the extent of battery life. This test is to confirm the engineering requirement of lifespan. This test will be done after the full system is created and towards the end of the testing period.

3.3.5.1 **Testing Procedure 5: Objective**

The objective of this test is to test how long the battery will last while the system is running at the maximum. This will be done by using the system until the battery dies and the system no longer has power to work.

3.3.5.2 **Testing Procedure 5: Resources Required**

The resources needed is the drilling material so that the system is able to drill and collect real material until the system dies.

3.3.5.3 **Testing Procedure 5: Schedule**

This test will be done at the end of the testing period. However, this engineering requirement will be considered when purchasing batteries and power systems during the beginning of the year.

3.3.6 Testing Procedure 6: Cost

This engineering requirement does not require any tests, the project is expected to cost the team $1,000. The budget given to the team is $1000 and the system is expected to be under this by the client's suggestions. This test will be conducted the whole year and will require each team member to keep track of all spending using the budget.

3.3.7 Testing Procedure 7: Weight

Weight is an important factor as it will need to under the maximum load the rover can carry and move around. This test is to meet the engineering requirement of weight and will be conducted by simply weighting the whole system. This test will be completed after the final design is produced.

3.3.7.1 **Testing Procedure 7: Objective**

The objective of this test is to create a system that can be easily moved by a rover that will deploy the sampling system, it cannot be too heavy for the rover to move and not too light do that it will have no gravitational effects. The target ER value is 2kg and is determined to be the desired weight.

3.3.7.2 **Testing Procedure 7: Resources Required**

The resources required for this test is a scale, if the system is too large for an in home scale then an industrial scale will be needed. These types of scales are easily found in many rentable testing facilities.

3.3.7.3 **Testing Procedure 7: Schedule**

This test is expected to be done when the final design is produced, the full system is required for this test.

3.3.8 Testing Procedure 8: Velocity Testing

Velocity testing refers to the engineering requirement of the system overcoming the centrifugal forces do that it will not fly off the surface. This test will be done mathematically first then tested using multiple magnets. This test will need to be done before the full system is put together it will affect the entire design.

3.3.8.1 **Testing Procedure 8: Objective**

The objective of this test is to make sure the magnet used to keep the sampling system on the surface. This will be affected by the rapid spinning and low gravity of the asteroid. The system will need to overcome the forces acting on it by these forces. The objective is to confirm the magnet used for stability meets what is required.

3.3.8.2 **Testing Procedure 8: Resources Required**

Calculations must be done to determine the force acting on the full system. This will be done by using the rotating velocity and gravity of Psyche. After the force is determined a magnet must be purchased that is strong enough to overcome the forces acting on it. This can be tested using a force gauge and hydraulics. These machines are found in machine shops where testing of stress and strain occurs for different metals, personnel that have access to these machines is required. Having a machine pulling on the magnet will allow the team to determine how much force the magnet will be able to overcome.

3.3.8.3 **Testing Procedure 8: Schedule**

The velocity test must be done before the whole system is completed. This is because the magnet is a large part of the design, and if it is wrong after the full system is created it will be difficult to change. The testing will need to be done before buying the magnet needed and right after it is received to be sure the magnet is strong enough.

4 RISK ANALYSIS AND MITIGATION

To proceed with the desired design, the team conducted a Failure Modes Effect Analysis (FMEA) to analyze every component' severity if failed and the probability of failing. Each subsystem was carefully analyzed and a total of forty components was included, ten components per subsystem. The entire FMEA can be seen in Appendix C. After conducting the FMEA, the top ten highest elements were sorted out based on the risk priority number (RPN), which is a score based on severity and probability of the part. These top ten highest components will be the ones that the team mostly focuses on to ensure that the final product works efficiently and safely. This is shown within Appendix C, in Figure C.5. One of the main aspects to note is that all of the parts in the shortened version of the FMEA has a severity of number of ten and the reason why is that this project will be sent to space, theoretically. Therefore, if any of these top ten parts were to fail, the entire project is a catastrophic failure.

4.1 Critical Failures

4.1.1 **Potential Critical Failure 1: Tightening System**

This component is one of the highest RPN in the entire FMEA. With an RPN of sixty, this component must be focused on. The tightening system is part of the collection subsystem. This part would tighten and loosen the drill bits as it changes drill bits. The failure in this component is that if won't tighten or loosen the drill, causing the drill to be obsolete. The failure would be caused by not properly creating the part to work, since there will be many different elements within it to make it work. This failure can be mitigated by having the team working on this part and ensuring it will work.

4.1.2 **Potential Critical Failure 2: Carousel**

This part is the other highest RPN, with a value of sixty. The carousel is responsible for rotating so that the drill can change out its drill bits. The failure is that the carousel will not rotate and then causing the drill to be stuck with one drill bit. This failure can be caused by an inefficient setup of the carousel. This failure can be mitigated by again having the team work on the part to ensure that it will work.

4.1.3 **Potential Critical Failure 3: Electro-Magnet**

This component had an RPN of forty. This component's failure is that if the electromagnet does not have enough force, the entire sampling system would fly off the asteroid. This failure could be caused by an incorrect analysis of the force required by the electromagnet. This failure can be mitigated by correctly doing the analysis on the force required to hold the sampling system to the asteroid.

4.1.4 **Potential Critical Failure 4: Motor of Tightening System**

This failure coincides with the tightening system, and so if the motor stalls, the tightening system cannot hold the drill bits. This failure could be caused by an efficient motor that has been used with the tightening system. Whether the motor does not provide enough torque or rotates too fast, this failure can be mitigated by correctly choosing the motor that does completes the action the best.

4.1.5 **Potential Critical Failure 5: Power Supply for The Carousel**

This component is responsible for delivering the power and energy to rotate the drill carousel so that the drill can change between drill bits. If the power supply is interrupted, the drill will only have one drill bit to used which will limit the sampling systems functionality. This failure can be mitigated by making sure the wiring and power supply is connected correctly.

4.1.6 Potential Critical Failure 6: Wires

These specific wires are for the electromagnet and creates a magnetic field when a current is passed through. This is for the stability subsystem. The failure of this component is that too much current could pass through, therefore melting the wires used to create the magnetic field, causing the sampling system to fly off. This failure can be mitigated by correctly doing the analysis of the force required to keep the sampling system on the asteroid and correctly choosing the type of wire that is sufficient.

4.1.7 Potential Critical Failure 7: AC/DC Converter

This part is used to help control the current passing through from the power supply to the sampling system. This failure has an RPN of thirty. The failure of the part is that the sampling system would not have power, causing the system to be stagnant. This failure can be caused by having an insufficient converter to complete the job. This failure can be mitigated by researching the correct converter to use in the project.

4.1.8 Potential Critical Failure 8: Drill Bits

This component is important because it will actually drill into the asteroid. The failure of this component is that they break due to the asteroid being too hard. The effect of this failure is that the sampling system will fail in collecting samples. This failure can be easily mitigated by researching the best drill bits that have a Brinell Hardness number higher than that of the asteroid.

4.1.9 Potential Critical Failure 9: Coring Bits

The coring bits are the drill bits that collect the samples. These coring bits could fail by inducing too much stress on the bit and either breaking the diamond edges or the cylinder itself. The effect of the failure would be that the sampling system could not collect samples. This failure, however, can be mitigated by choosing an effective and strong coring bit to accomplish the job.

4.1.10 Potential Critical Failure 10: Test Tubes

This failure is at the lowest because it4 does not require attention, but it is still important. The failure of the test tubes is that they can break and cause the samples to be unsecured. Because the team wants the samples to be secured, this failure can be mitigated by choosing the best material to hold the samples so that the samples are secured when collected.

4.2 Risks and Trade-offs Analysis

To mitigate the failures of the elements that have the highest RPN, the team will have to determine which of the components are to be focused on less or not at all. To begin with, the first critical failure the team will have to mitigate will be electromagnet because it is the base that carries the entire sampling system. Next, the drill itself will have to be focused on the most, such as the tightening system and the carousel for drill bits. Because the team will be focusing mainly on these two sections, the team will have to trade-off mitigating the failures of the drill and coring bits, and some electrical components. As well, trying to mitigate the tightening system will make induce more work on mitigating the failure of the motor responsible for the tightening system. However, it will have to be done in order to ensure success within the project. Lastly, because the collection subsystem had too many failing parts with the hollow auger and retrievable packer device, the team changed the design to implement coring bits to collect the samples. This lessened the amount of failing components and simplified the design as well.

5 SEMESTER I FINAL DESIGN SELECTION

The final section of this report describes the final design solution chosen by the Psyche Sampling Team. This section consists of two parts including the design description and how the team plans to implement this design. In the design description, the Psyche sampling system team will focus on describing how each subsystem functions and how the design functions as a whole and justifying the logistics of the functionality of the design with some calculations, as well as using some figures from the CAD model and the beta prototype for better demonstration. In the implementation plan section the Psyche sampling system team will focus on ways to implement the design and fabricate the alpha prototype, as well as creating a proof of concept and a bill of materials that includes manufacturing processes and purchases if needed.

5.1 Design Description

The Psyche sampling system team came up with the final design shown in Figure 4. The design consists of four main subsystems, drilling, sample storage, collection/distribution, and stability. Each subsystem in the beta prototype was chosen using a decision matrix and the Pugh chart. The top scoring subsystems from the concept selection process were chosen to create the beta prototype. Appendix D breaks down the full CAD model displayed in Figure 4 into each of the subsystems.

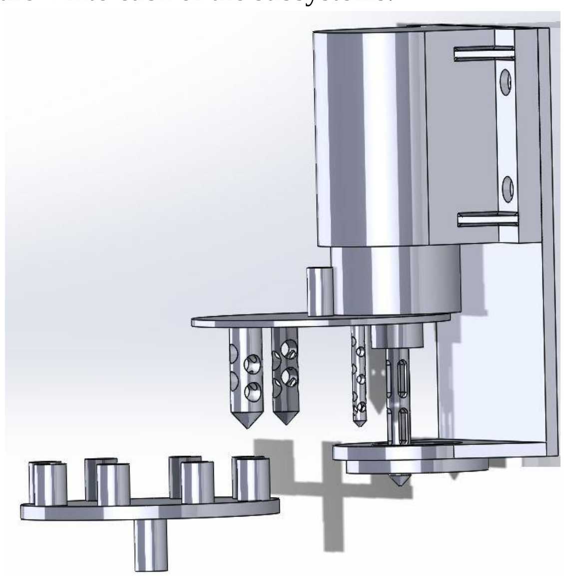

Figure 4: Full sampling system

The design functions as follows: first, the sampling system stabilizes itself on the surface of Psyche by using the magnet located underneath the base of the sampling system shown in Appendix D, Figures D.1 and D.2. Since the surface of Psyche is mostly made out of iron and nickel, the team decided to take advantage of the ferromagnetic properties of the asteroid and use a magnet for stabilizing the system. After the stabilizing process is done, the sampling system then begins to drill and collecting samples simultaneously. The drilling subsystem consists of three drills with three different sizes, as seen in Appendix D, in Figure D.3. The drill is three different sizes so the sampling system can have a variety of choices to choose from when drilling depending on the conditions of the surface. Each drill has a hollow stem auger inside of them and the hollow stem auger is demonstrated in Appendix D, Figure D.5. This hollow auger design acts as the collection subsystem of the sampling system. As the drill is drilling, the hollow stem auger will collect the surface particles and then distribute the samples to the storage test tubes. Finally the data will be distributed to the eight test tube located on the rotating carousel shown in Appendix D, in Figure D.6. The sampling system will then keep repeating the drilling and collection process until the test tubes are filled.

Once the final CAD model was designed, the team began creating the first prototype of each subsystem. The alpha prototype was fully made out of resources provided by NAU's Cline Library Maker Lab. Using these resources allowed the team to spend no money and reallocate budget funds to the final prototype. The Psyche sampling system team did not change the design due to the positive feedback from the project client. As for the beta prototype, the team are currently in the process of creating this functional prototype. Changes to the final prototype may arise if the team finds issues while testing with how the subsystems interact with each other. The original alpha prototype can be seen in Figure 5.

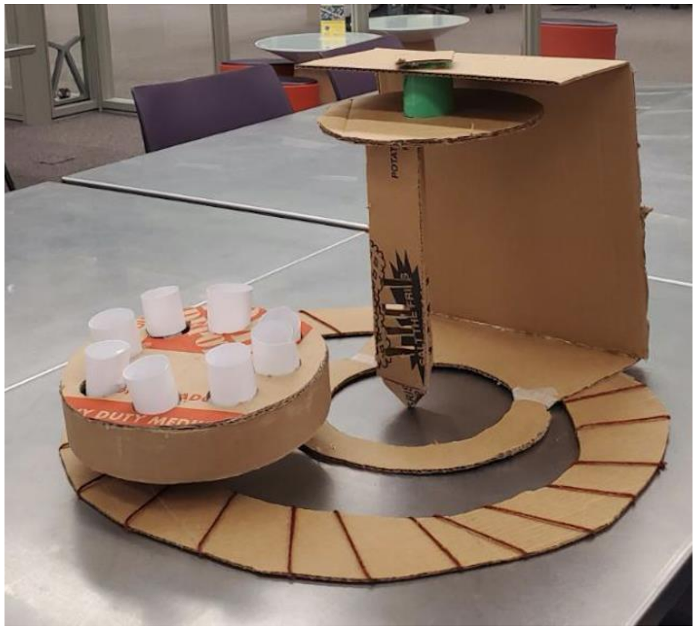

Figure 5: Alpha Prototype

Finally the team did some engineering calculations to back up the validity of the functions of the subsystems for the Psyche sampling system. The team calculated the rotational surface speed using the equation 1. In equation 1, v represents the velocity, ωrepresent the angular velocity and r is the radius of Psyche. Psyche completes one rotation in 4 hours and 12 minutes, that means that Psyche completes one rotation in 15120 seconds. Psyche has a diameter of 140 miles which converts to 225308.16 meters. The following calculations show the velocity of the psyche rotation which is equivalent to approximately 104.71 mph.

$$v = \omega r \qquad (1)$$

$$t = 15120s, r = 225308.16/2 = 112654.08\, m$$

$$\omega = \frac{2\pi}{t} = \frac{2\pi}{15120} = 4.156 \times 10^{-4}\, rad/s^2$$

$$v = \omega r\ = 4.156 \times 10^{-4} \times 112654.08\ = 46.81\, m/s$$

$$v = 46.81\, m/s\ \times 60s/min \times 60\, min/hr \times 1mile/1609.34m = 104.71 \text{ mph}$$

The team has also researched the hardness of the materials Psyche is made of to see if a diamond drill bit will drill through the surface of Psyche. The team found that the diamond drill bit can drill materials of up to 70 Rockwell hardness [4]. Whereas Iron, which may make up most of Psyche’s composition, has 20 Rockwell hardness [5]. This ensures that the diamond drill bit can drill through the surface of Psyche efficiently.

The last calculation the team did is the calculation of the volume of storage system carousel and test tube. Equation 2 is the volume equation used for the calculations, r is the radius of the carousel and test tubes, T is the thickness of the carousel and test tubes.

$$V = \pi r^2 T \qquad (2)$$

Carousel Volume calculations:

$$V = \pi \times 10^2 cm \times 2cm = 628.32\ cm^3$$

Test tubes Volume calculations:

$$V = \pi \times 2.5^2 cm \times 4cm = 78.54\ cm^3$$

After doing the calculations the team speculate the carousal volume to be around 628.32 $cm^3$and test tubes volume to around 78.54 cm^3. The team will do more in depth calculation in their individual analysis of each of the materials and material selections.

5.2 Implementation Plan

In order to implement the final sampling system design and develop a working prototype, the team will be following a strict implementation plan. To begin, the beta prototype will be developed where the team will understand the real-world presence of the final design. The creation of a functioning prototype will follow, where either the entire sampling system, or the drilling subsystem is made to function as the real design should. The creation of the final prototype will require many materials, parts, and analysis to be done in the team's individual analysis reports.

The beta prototype has already been developed and represents the basic ideas and subsystems to be implemented into the final prototype. Built from cardboard, the beta prototype does not function. This design was created using all the chosen subsystems found to be ideal using the decision matrix and Pugh charts. As seen above in Figure 5, the design features a placeholder model for each of the subassemblies; drilling, storage, drilling cache, stabilization, and collection. This is the base from which the final prototype will be developed around.

To begin the development of the final prototype, an entire model placeholder is designed in CAD seen in Figure 4. Containing each of the subsystem needed to satisfy all customer requirements, the CAD is still structured to change. Nearing the end of the semester and into the beginning of the second semester, the CAD will continue to develop as seen in the schedule, located in Appendix E. The development of the CAD is the highest priority as it will decide the dimensions and placement for parts in the final prototype.

In order to facilitate and ensure the completion of the final design, the team plans to develop only the drilling subassembly to completion and with full functionality. All other assemblies may be built as a proof of concept, but may not have full integration into the final design. That being said, the building of the final design will require materials and parts. Each part, its material, quantity, and price, is detailed in the bill of materials found in Appendix F. To save money, the team plans to utilize the machine shop for any custom parts, and any other parts are sourced from the respective manufacturer or reseller. For example, the back plate of the motor assembly will be machined in house to save money, where the motor for the drilling assembly will be bought from a reseller. This is the method that will be used to source parts for the design.

The implementation of the various steps taken to develop the final prototype are detailed in the Gantt chart for semester two, found in Appendix E. In order to ensure the prototype is finished on time, the bill of materials and CAD are scheduled to finalized and completed in early March. Of course, any CAD parts needed for machining purposes will need to be completed prior to manufacturing. To ensure the CAD and bill of materials can be made final, any changes to the design before manufacturing are due at the end of January. This is to ensure that if the team choose to add or change an aspect of the design, there will be ample time to implement said change successfully. The finalization of the CAD will mark the point for digital structural analysis of the model. This will give the team an idea of what to expect from the final design. The physical design manufacturing will begin the twenty-fourth of February, this date represents the final day for receiving parts. All orders will take this date into account to ensure that nothing is missing from the model before building. As the schedule is currently written, the testing procedure is due to be executed on the ninth of March in the second semester. All prototype development will need to be done at this point. This is the precise schedule that will be followed in order to develop the final prototype on time.

6 CONCLUSIONS

Psyche is an asteroid hypothesized to be likely made largely of metal. Possibly the core of planet that did not fully form, Psyche serves to be a possible model to study the formation of planetary cores. The team is tasked with designing a sampling system able to explore and better understand this asteroid. The client of this project, the NASA Psyche Mission Student Collaborations Program, has detailed some requirements for the final design. These requirements were put in a House of Quality where the team was given a set of engineering requirements (weight, cost, storage, hardness, and lifespan) to follow and implement in the design. Utilizing this information, a black box model, seen in Figure 2 above, was created to show the signals sent into and out of the machine. This was followed by a functional model designed to break down the individual functions of the device in detail, seen in Figure 3. The design will eventually undergo testing and will be subjected to various tests in order to ensure its viability. Vacuum pressure, vibration, extreme temperature, and drill bit testing will be the subjects of the four major tests. The vacuum pressure test will ensure the design can function in the low pressure of space. The vibration test will look at any vibrations created by the rocket during launch will not damage the sampling system. The extreme temperature testing will expose the device to the extreme high and low temperatures that the sampling system will be operating under in space. Lastly, the drill bit testing will determine if the proposed drill bit material will be sufficient for drilling into Psyche’s metal surface. With the testing in place, a Failure Mode and Effect Analysis was done on the design. It was found that each part is integral to the success of the design, and therefore if any subsystem fails, the entire design will fail. Throughout the course of the semester the final design has been solidified. The design features a magnetic base to stabilize the system, a drill carousel to store multiple drill bit types, a hollow auger to collect the sample material, and a rotating storage cache for samples. The design is slated to be built at the end of February of the 2020 year, and testing will be executed in early March. The team plans to follow this schedule in order to ensure the success of the design. The design fulfills all the engineering and customer requirements, is on schedule for manufacturing, and will be the final design that the team will manufacture in the spring semester.

7 REFERENCES

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8 APPENDICES

8.1 Appendix A: House of Quality

◉ = 9 (Strong)
◎ = 3 (Medium)
△ = 1 (Weak)

	Customer Requirement / Engineering Requirements	Weight (kg)	Cost ($)	Storage (cm^3)	Hard (HB)	Velocity (m/s or rpm)	Lifespan (Ah)	Factor of Safety
12	Reliable						◉	◉
8	Durable	◉	◎	△	◉	△		◉
10	Safe		△			◎		◉
12	Inexpensive	◎	◉		◎		◎	◉
15	Functions on different surfaces				◉			◉
7	Operates under minimal gravity	△				◎		◉
10	Sample caching			◉		△		◉
10	Utilizes minimal power	△				◉	◉	◉
6	Sampling system is compactful	◎					◎	◉
5	Operates under cold temperatures					△		◉
5	Stable under orbital rotation	◎				◎		◉
	Absolute Technical Importance (ATI)	158	142	38	243	179	252	900
	Relative Technical Importance (RTI)	7	6	4	4	8	5	1/2/3
	Target ER values	4	1000	100	150	1000	4	1.5
	Tolerances of Ers	2	250	20	50	250	1	0.25
	Testing Procedure (TP#)	5	6	4	3	2	1	NA

Appendix A.1: House of Quality for the Sampling System

8.2 Appendix B: Codes and Standards

Table B.1: Standards of Practice as Applied to this Project

	Standard Number or Code	**Title of Standard**	**How it applies to Project**	**REF #**
NASA	NASA-STD-5001	Structural Design and Test Factors of Safety for Spaceflight Hardware	This standard defines the factors of safety to ensure a safe a reliable structural design.	[6]
NASA	NASA-STD-5017	Design and Development Requirements for Mechanisms	The purpose of this standard is to establish common design development, and test requirements for mechanisms for safety.	[6]
NASA	NASA-STD-5020	Requirements for Threaded Fastening Systems in Spaceflight Hardware	This standard applies to the project because it defines the threaded designs of fastening systems.	[6]
NASA	NASA-STD-6008	NASA Fastener Procurement, Receiving Inspection, and Storage Practices for Spaceflight Hardware	This standard defines the use of fasteners and how to test them to ensure safety	[6]
NASA	NASA-STD-5006	General Welding Requirements for Aerospace Materials	This standard will be useful before manufacturing processes begin for the final product. Since the base will be welded. together, it will be important to follow all welding and manufacturing guidelines.	[6]
NASA	NASA-HDBK-7004	Force Limited Vibration Testing	Vibration testing will be conducted to test the durability, reliability and safety of the device. This code will be useful during this testing procedure.	[6]
NASA	NASA-HDBK-4001	Electrical Grounding Architecture for an Unmanned Mechanics	Since the sampling system will be unmanned and operated by itself, this will help the team understand some of the electrical components needed. Since this group does not contain electrical engineers this will help understand the basic standards of unmanned devices.	[6]
NASA	NASA-STD-6016	Standard Materials and Process Requirements for Spacecraft	This code will set a precedent of the standard materials and manufacturing processes that are expected from NASA for choosing material and processes for the team's final design.	[6]

NASA	NASA-STD-8719.14	Process for Limiting Orbital Debris	This standard provides specific technical requirements for limiting orbital debris and other methods to comply with the NASA requirements for limiting orbital debris generation.	[6]
NASA	NASA-STD-7009	Standard for Models and Simulations	This NASA Technical Standard establishes uniform practices in modeling and simulation to ensure essential requirements are applied to their design. This will help in the simulation testing for the teams CAD model.	[6]
ASME	ASME-B5.11	Spindle Noses and Adjustable Adapters	This code sets standards for interchangeable drilling equipment, which will be useful for the rotating drill cache system.	[7]
ASME	ASME-B94.11M	Twist Drills	This standard details standard drill size, type, and nomenclature, which will be useful for the drilling subsystem.	[7]
ASME	ASME-B46.1	Surface Texture (Surface Roughness, Waviness, and Lay)	This code lays out the standard for surface irregularity parameters. This code will be useful for preparing the sampling system for the proposed surface textures of Psyche.	[7]
ASME	ASME-B94.35	Drill Drivers, Split-Sleeve, Collect Type	This standard would be useful for the drilling subsystem as it details standard dimension for drill collets.	[7]
IEEE	IEEE 69-91 and 71-1928	IEEE Specifications for Cotton Covered Round Copper Magnet Wire, Specifications for Silk Covered Round Copper Magnet Wire, and Specifications for Enameled Round Copper Magnet Wire	This code provides standards for copper wire covered in various insulators. This will be useful when developing the electromagnetic base of the sampling system.	[8]
IEEE	IEEE 1642-2015	IEEE 1642-2015 - IEEE Recommended Practice for Protecting Publicly Accessible Computer Systems from Intentional Electromagnetic	This standard provides methods of protection for electronic equipment from electro-magnetic interference. This will be useful as the sampling system will contain sensitive electronic equipment and a magnetic base.	[8]

		Interference (IEMI)		
IEEE	IEEE 1028-1998	Standard for Software Reviews and Audits	This stander provides reviews for software audits that can help with the software of the sampling system	[8]
ATSM	ASTM E18 - 19	Standard Test Methods for Rockwell Hardness of Metallic Materials	The standard provides the requirements for Rockwell hardness machines and the procedures for performing Rockwell hardness tests. This test will prove useful to the team when testing the drill bit on the samples provided.	[9]
ATSM	ASTM D3580-95 (2015)	Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products	The standard provides a method of testing a product using vibration testing. This will helps the team when conducting vibrational tests on the system.	[9]
ATSM	ASTM E4 - 16	Standard Practices for Force Verification of Testing Machines	These standards provide methods of testing force using machines. This will help the team by providing information when testing the force of the magnet required for stability.	[9]

8.3 Appendix C: FMEA and Critical Failures

System	Sampling System		Potential			
Subsystem	Stability		Failure Mode and Effects Anal		Prepared By	Andrew A.
Component			(Design FMEA)		FMEA Date	11/1/19
Design Lead	Karissa B.				Page	1 of 1
Core Team	NASA Sampling System					

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Prob	RPN	Recommended Action(s)
Electro Magnet	Does not have enough magnetism to hold onto the surface	the sampling system would fly off the asteroid	10	not enough electricity going through; not enough surfce area of the magnet	4	**40**	make sure analytical analysis is done correctly
Wires	Does not carry enough energy	the sampling system would fly off the asteroid	10	wire is too small; wire burns out due to heat of electiricty passing through	3	**30**	make sure analytical analysis is done correctly
steel disc	not enough surface area	the sampling system would fly off the asteroid	10	wrong design	1	**10**	make sure analytical analysis is done correctly
Framework	breaks	sampling system would collapse	10	too much stress on the frame	1	**10**	make sure framework can support all components
power supply	interrupted	the sampling system would fly off the asteroid	10	over exerts, incorrect wiring	2	**20**	make sure wiring is good
AC/DC converter	it overheats and explodes	Sampling system would have no power	10	too much current going through	3	**30**	make sure wiring is good
Main body casing	it breaks	sampling housing would be exposed to outside debros	5	too much stress	1	**5**	continue current practices
wire insulator	exposes wire to debris	overheating of the wire	4	too much current going through	1	**4**	continue current practices
Connectors	connectors melt	elector magnet doesn't receive power to stabilize	10	too much current going through	1	**10**	make sure wiring is good
Bolts	breaks	framework collapses	8	too much stress on the frame	1	**8**	make sure framework can support all components

Figure C.1: FMEA of the Stability Subsystem

System: Sampling System
Subsystem: Drilling
Component:
Design Lead: Karissa B.
Core Team: NASA Sampling System

Drill bits	drill bits break	not able to gather samples	10	not hard enough to penetrate the surface	3	**30**	make appropraite assumptions
Carousel	carousel cannot rotate to change its drill	only one drill bit will be avvailable	10	motot stalls, drill cannot obtain drill bits	6	**60**	Continue current practices.
motor	motor stalls	not able to take samples	10	component failure	2	**20**	Continue current practices.
reduction gears	break	drill cannot rotate	10	component failure	1	**10**	choose sufficient gears
ball bearings	break or stall	drill cannot rotate	10	outside debris gets inside	1	**10**	choose sufficient bearings
step motor	motor stalls	drill cannot translate towards the surface	10	component failure	2	**20**	continue current practices.
armature	cannot produce rotational energy	drill cannot rotate	10	component failure	1	**10**	continue current practices.
bracing	bracing breaks	drill is unprotected	5	component failure	1	**5**	continue current practices.
casing	casing breaks	drill parts are affected by outside debris	6	component failure	4	**24**	continue current practices.
brushes	brushes break	cannot cause armature to produce rotational energy	10	component failure	1	**10**	continue current practices.

Figure C.2: FMEA of the Drilling Subsystem

System	Sampling System
Subsystem	Collection
Component	
Design Lead	Karissa B.
Core Team	NASA Sampling System

motor to rotate drill bits	stalls	cannot take more samples	8	component failure	2	**16**	continue current practices
motor to tighten and release clamped drill bits	stalls	cannot take more samples	10	component failure	4	**40**	make sure it works
power supply for tightening motor	gets interrupted	cannot collect samples	10	wiring overheats	2	**20**	make sure wiring is sufficient
gears	breaks	cannot transport samples	10	component failure	1	**10**	Continue current practices.
coring bits	breaks	cannot collect samples	10	component failure	3	**30**	make appropriate assumptions
power supply for rotating the different drill bits	gets interrupted	cannot collect samples	10	wiring overheats	4	**40**	make sure it works
tightening system	cannot hold the drill bits	cannot collect samples	10	not set up correctly	6	**60**	make sure it works
diamond edges	breaks off	cannot collect samples	10	too hard of material to drill	1	**10**	make sure the hardness is higher
framework	breaks	system exposed	7	component failure	1	**7**	continue current practices.
bolts	breaks	framework unsteady	8	component failure	1	**8**	continue current practices.

Figure C.3: FMEA of the Collection Subsystem

System: Sampling System
Subsystem: Storage
Component:
Design Lead: Karissa B.
Core Team: NASA Sampling System

test tube	breaks	cannot hold samples	10	pressure, material failure	3	**30**	Continue current practices.
holder	breaks	cannot hold samples	10	Process Failure	1	**10**	Continue current pracices.
Motor	stalls	cannot rotate the test tubes	10	Process Failure	1	**10**	Continue current practices.
base	breaks	cannot hold samples	10	Process Failure	1	**10**	Continue current practices.
lid	breaks	cannot contain samples	8	process Failure	2	**16**	continue current practices.
bracing for stroage	bracing breaks	storage area is unprotected	5	component failure	1	**5**	continue current practices.
Bolts	breaks	framework collapses	8	too much stress on the frame	1	**8**	make sure framework can support all components
power supply for carousel motor	gets interrupted	cannot rotate the test tubes	9	wiring overheats	1	**9**	continue current practices.
gears to rotate	breaks	cannot rotate the test tubes	10	component failure	1	**10**	Continue current practices.
nuts	breaks	cannot hold system together	7	component failure	1	**7**	Continue current practices.

Figure C.4: FMEA of the Storage Subsystem

tightening system	cannot hold the drill bits	cannot collect samples	10	not set up correctly	6	**60**	make sure it works
Carousel	carousel cannot rotate to change its drill	only one drill bit will be avvailable	10	motot stalls, drill cannot obtain drill bits	6	**60**	Continue current practices.
Electro Magnet	Does not have enough magnetism to hold onto the surface	the sampling system would fly off the asteroid	10	not enough electricity going through; not enough surfce area of the magnet	4	**40**	make sure analytical analysis is done correctly
motor to tighten and release clamped drill bits	stalls	cannot take more samples	10	component failure	4	**40**	make sure it works
power supply for rotating the different drill bits	gets interrupted	cannot collect samples	10	wiring overheats	4	**40**	make sure it works
Wires	Does not carry enough energy	the sampling system would fly off the asteroid	10	wire is too small; wire burns out due to heat of electiricty passing through	3	**30**	make sure analytical analysis is done correctly
AC/DC converter	it overheats and explodes	Sampling system would have no power	10	too much current going through	3	**30**	make sure wiring is good
Drill bits	drill bits break	not able to gather samples	10	not hard enough to penetrate the surface	3	**30**	make appropraite assumptions
coring bits	breaks	cannot collect samples	10	component failure	3	**30**	make appropriate assumptions
test tube	breaks	cannot hold samples	10	pressure, material failure	3	**30**	Continue current practices.

Figure C.5: Top Ten Highest RPN in the FMEA

8.4 Appendix D: Subsystems

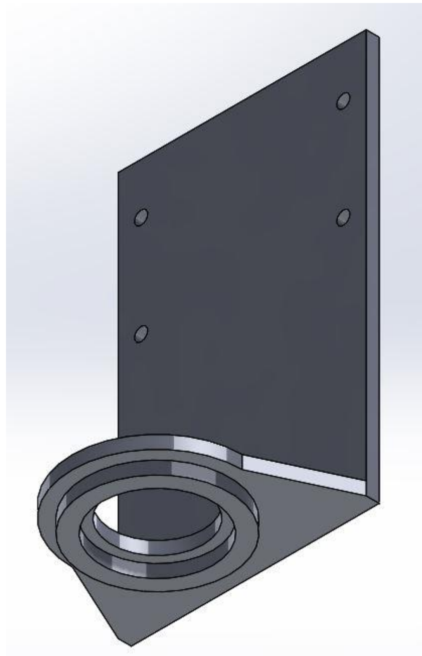


Figure D.1 : Base/Magnet Subsystem

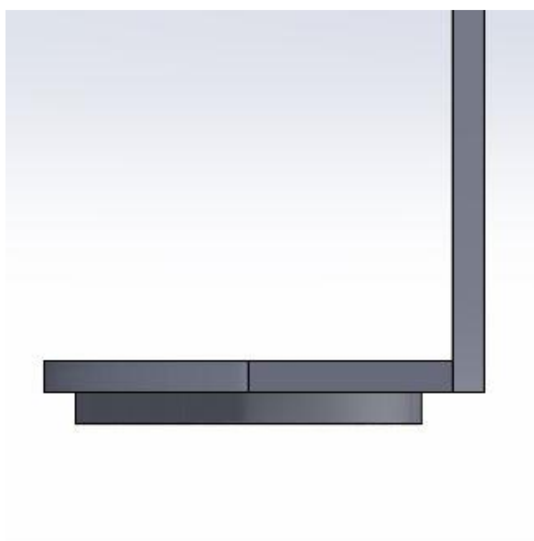


Figure D.2: Magnet

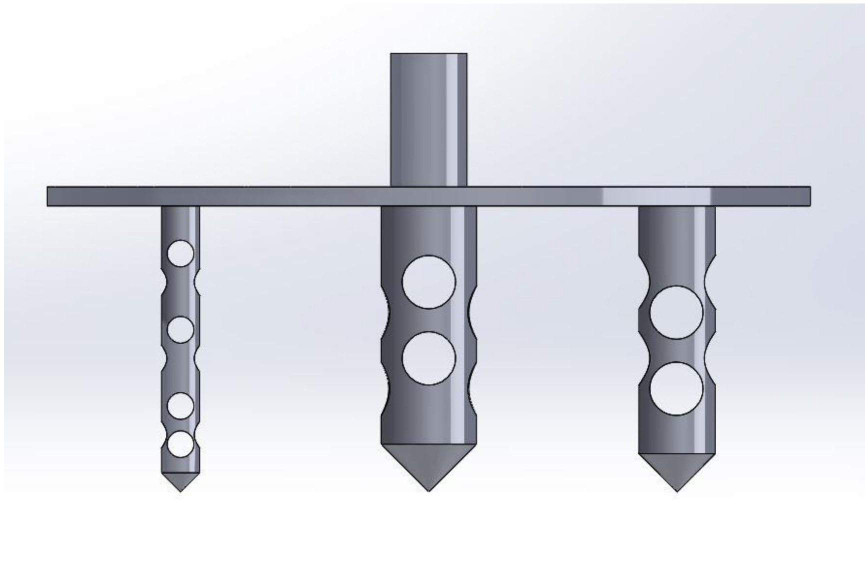


Figure D.3: Drilling Subsystem 1

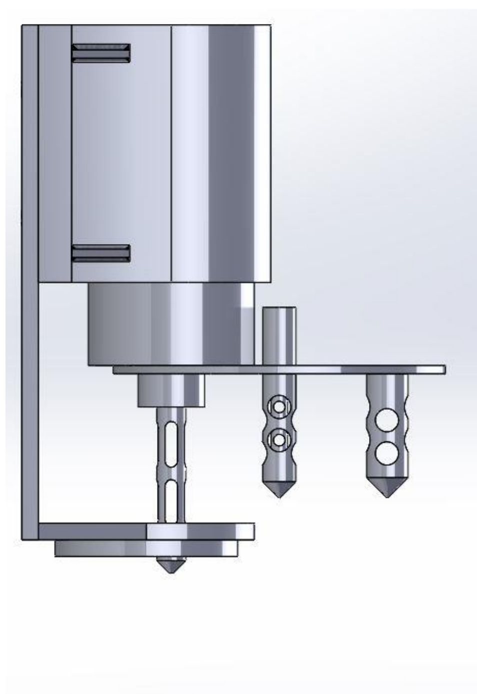


Figure D.4: Drilling Subsystem 2

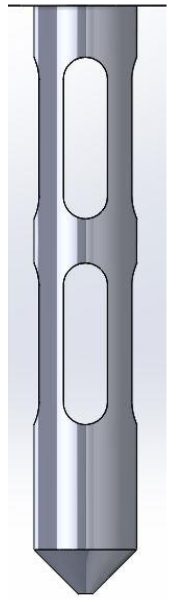


Figure D.5: Collection Subsystem (Hollow Stems)

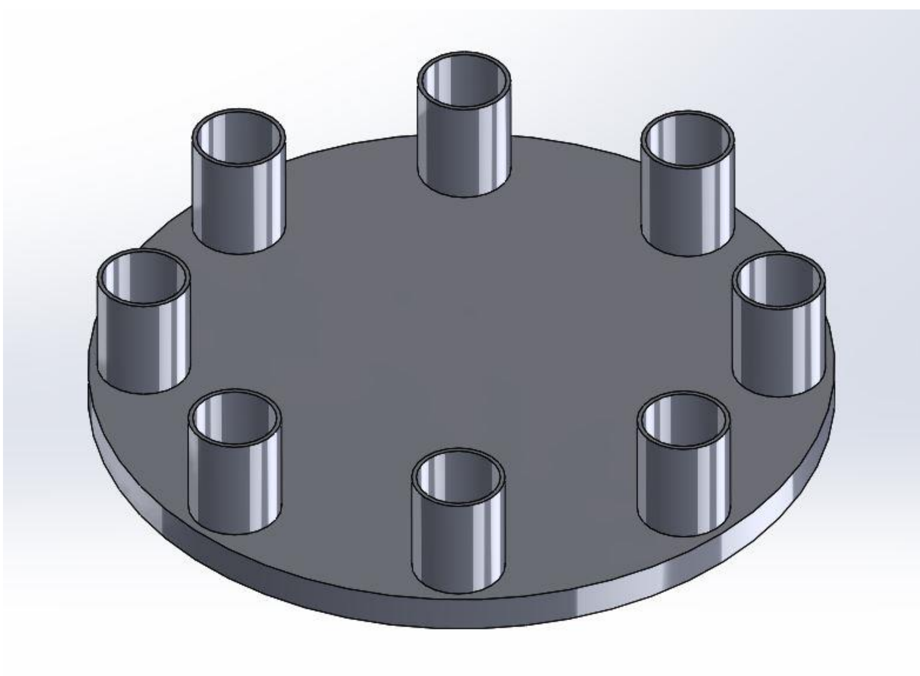
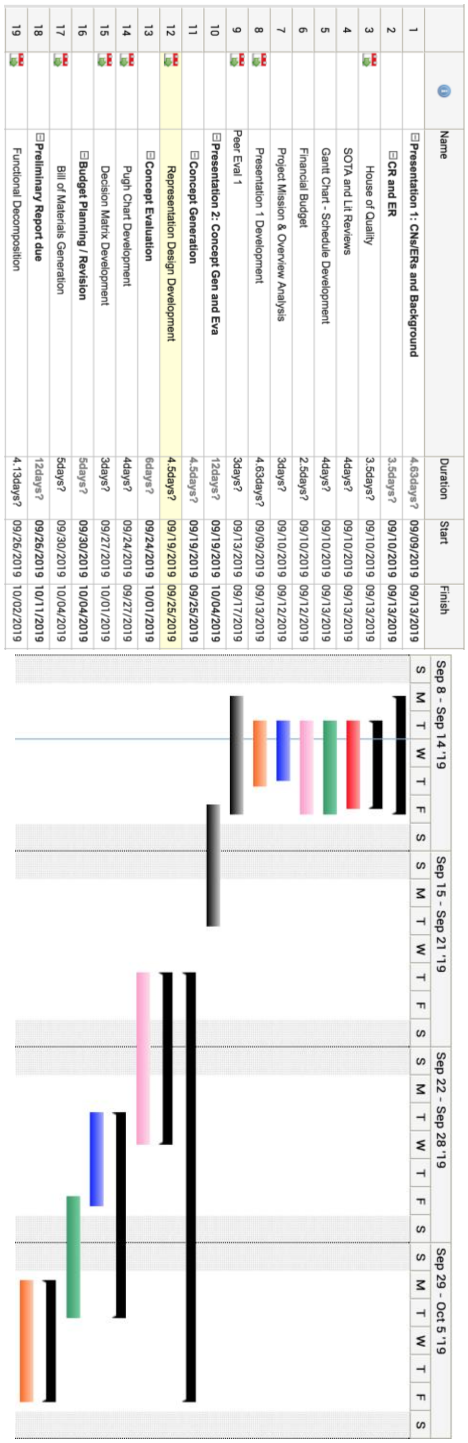


Figure D.6: Storage Subsystem

8.5 Appendix E: Schedule

The following schedules were rotated for some clarity and for them to fit on a page.



	Name	Duration	Start	Finish
1	⊟**Presentation 1: CNs/ERs and Background**	4.63days?	09/09/2019	09/13/2019
2	⊟**CR and ER**	3.5days?	09/10/2019	09/13/2019
3	House of Quality	3.5days?	09/10/2019	09/13/2019
4	SOTA and Lit Reviews	4days?	09/10/2019	09/13/2019
5	Gantt Chart - Schedule Development	4days?	09/10/2019	09/13/2019
6	Financial Budget	2.5days?	09/10/2019	09/12/2019
7	Project Mission & Overview Analysis	3days?	09/10/2019	09/12/2019
8	Presentation 1 Development	4.63days?	09/09/2019	09/13/2019
9	Peer Eval 1	3days?	09/13/2019	09/17/2019
10	⊟**Presentation 2: Concept Gen and Eva**	12days?	09/19/2019	10/04/2019
11	⊟**Concept Generation**	4.5days?	09/19/2019	09/25/2019
12	Representation Design Development	4.5days?	09/19/2019	09/25/2019
13	⊟**Concept Evaluation**	6days?	09/24/2019	10/01/2019
14	Pugh Chart Development	4days?	09/24/2019	09/27/2019
15	Decision Matrix Development	3days?	09/27/2019	10/01/2019
16	⊟**Budget Planning / Revision**	5days?	09/30/2019	10/04/2019
17	Bill of Materials Generation	5days?	09/30/2019	10/04/2019
18	⊟**Preliminary Report due**	12days?	09/26/2019	10/11/2019
19	Functional Decomposition	4.13days?	09/26/2019	10/02/2019

Figure E.1: Semester I Gantt Chart

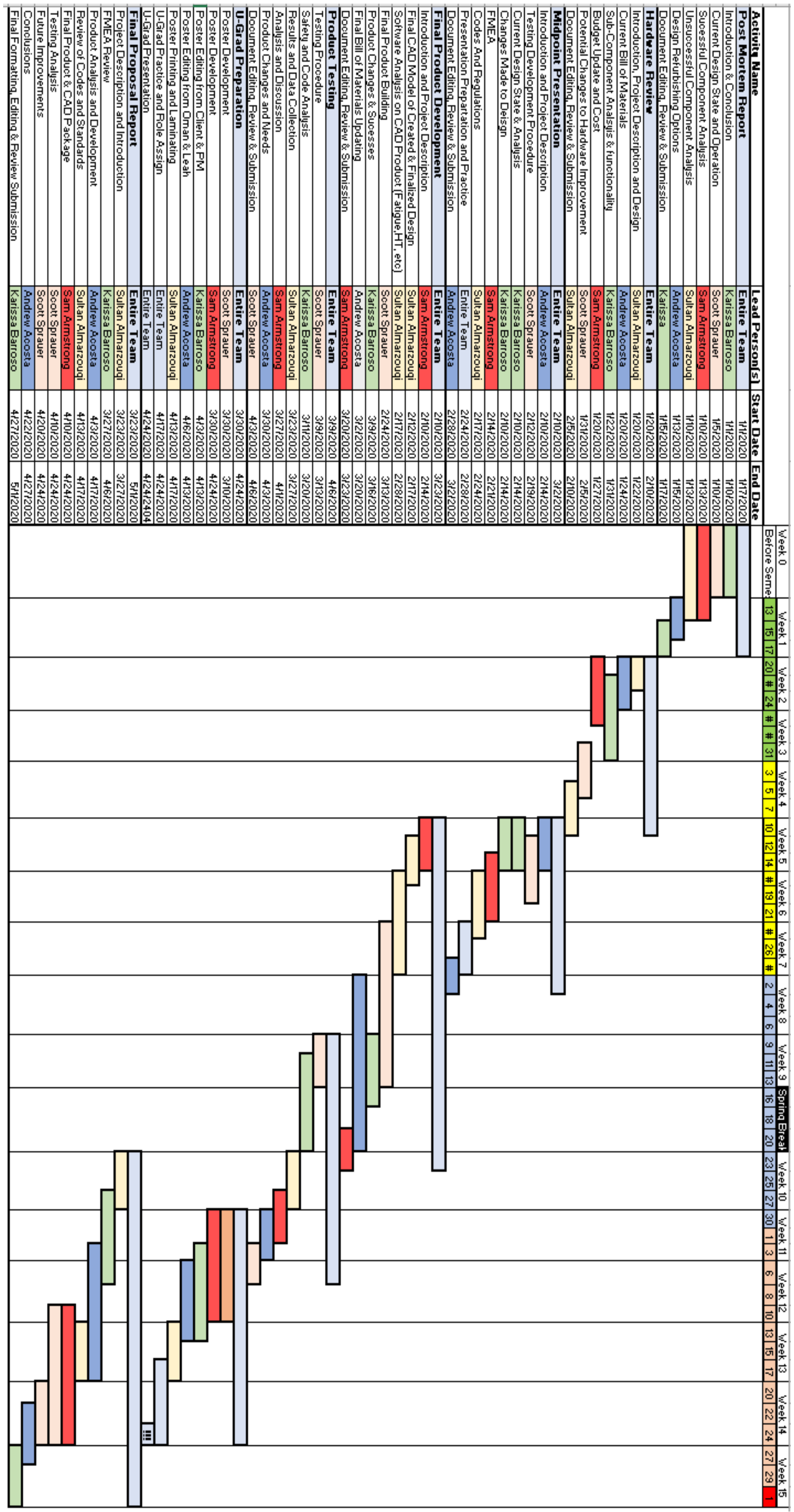


Figure E.2: Semester 2 Gantt Chart

8.6 Appendix F: Bill of Materials

Table F.1 Bill of Materials

Bill of Materials								
		Team						
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost**	**Link to Cost estimate**
1	Steel Disc	1	steel disc with a hole in it	Helps create magnetic field	Steel	10" diameter x 0.25" thick	$16.50	https://metalremnants.com/product/steel-discs/
2	Copper Wire	1	Copper wire	Wraps around steel disc to create magnetic field	Copper	26Ga x 100ft	$6.75	https://www.amazon.com/Bare-Copper-Wire-Choose-Spool/dp/B075K146HP/ref=asc_df_B075K146HP/?tag=hyprod-20&linkCode=df0&hvadid=366430786295&hvpos=1o2&hvnetw=g&hvrand=797737181249927 1447&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1013406&hvtargid=pla-813902387015&psc=1&tag=&ref=&adgrpid=75985294733&hvpone=&hvptwo=&hvadid=366430786295&hvpos=1o2&hvnetw=g&hvrand=7977371812499271447&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=1013406&hvtargid=pla-813902387015
3	Diamond Drill bits	set of 2	Drill bits with diamond tips	used to drill through materials	steel with diamond tips	1/16" and 3/32"	$14.98	https://www.lowes.com/pd/Dremel-2-Piece-Diamond-Grit-3-32-in-Cutting-Bit-Accessory/999901497
4	Hollow Stem Auger	1	Auger with hollow stem	used to collect/transport the elements	steel	2.25" diamter x 48"		https://geoprobe.com/
5	Braided fishing line	1	Fishing line that has been briaded to be stronger	used to pull up packer device	plastic	0.36mm x 100m	$6.38	https://www.walmart.com/ip/100M-Super-Strong-PE-Braided-Fishing-Line-8LB-Green-Gray-0-36mm/917917607?wmlspartner=wlpa&selectedSellerId=101002065&adid=22222222227289591628&wl0=&wl1=g&wl2=c&wl3=347850277116&wl4=pla-739767919369&wl5=1013406&wl6=&wl7=&wl8=&wl9=pla&wl10=127819733&wl11=online&wl12=917917607&veh=sem&gclid=EAIaIQobChMI0KX7kJD_5AIVlRx9Ch1u9w-9EAQYAiABEgI6wvD_BwE
6	Packer device	1	small steel disc	used to transport materials in hollow stem auger	steel	2" diameter x 18ga	$1.98	https://metalremnants.com/product/stainless-discs/
7	Motors	2	motors	used to bring up packer device and drill	steel	3"diamter x 3"	$140.06	https://www.amazon.com/Makita-XPH07Z-Lithium-Ion-Brushless-Driver-Drill/dp/B00M46N19K/?creativeASIN=B00M46N19K&linkCode=w61&imprToken=fEdpx-ItzvOZd7Tvr-LDRA&slotNum=0&tag=hawpt-20
8	Tray	1	Collecting tray	stores the samples taken	platic	60mm diameter, 28mm thick	$20	Capacity/dp/B07B73Z345/ref=asc_df_B07B73Z345/?tag=hyprod-20&linkCode=df0&hvadid=312276779400&hvpos=1o3&hvnetw=g&hvrand=12308175015041381837&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=&hvtargid=pla-569770007171&psc=1&tag=&ref=&adgrpid=57663040530&hvpone=&hvptwo=&hvadid=312276779400&hvpos=1o3&hvnetw=g&hvrand=12308175015041381837&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=&hvtargid=pla-569770007171
9	Steel		Steel	Used for housing, covering, supporting, etc.	steel		$200	
10	Misc						$200	
			Total Cost Estimate:				$606.65	