NASA Psyche Sample Return

Final Report

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College of Engineering

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ABSTRACT

As a part of the MIME 497 and 498 capstone design class series, Team 23-16 was tasked with developing a sample collection device for a hypothetical future NASA mission to the 16 Psyche asteroid. Psyche is hypothesized to be the core of an ancient planetesimal, and analyzing its surface could provide insights into the formation of our own planet.

The team initially explored multiple concepts, including a traditional rover and lander setup similar to those implemented on Mars' surface. However, throughout the design process, the team chose a different method altogether, which eliminates creating a spacecraft to land on Psyche's surface. This method has three stages: Impact, Collect, and Return. This idea involves striking the surface of Psyche with a high-velocity impactor to generate particle ejecta, sending a drone to capture the particles in orbit, and returning the drone to a satellite currently orbiting Psyche.

Our focus within this project is the sample collection process. The drone includes a capture mechanism mounted on the front of the body machined out of titanium with Aerogel-filled compartments. The Aerogel compartments will slow down and collect the particles as the drone moves through the debris cloud. After collecting the samples, the capture mechanism will retract into a sealed capsule, and the drone will return to the satellite. Once the satellite returns to Earth with the asteroid samples, scientists will analyze their composition and determine if the theories of Psyche's origins are correct.

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all the people affiliated with the project for their unwavering support and collaboration throughout the past two terms. Special thanks to our esteemed faculty mentor and advisor Dr. Sarah Oman for their guidance and invaluable insights over the course of this project. Additionally, this project would not have been possible without the generous support of our project sponsors Dr. Cassie Bowman, ASU and NASA. Moreover, we would like to extend our gratitude to Dr.Simone Marchi, co-investigator of the NASA Psyche mission, as his expertise added a unique dimension to our project. Additionally, the support and mentorship of our class TA, Kevin Boesky, played a pivotal role in our project's trajectory.

This endeavor was a collaborative effort, and we are thankful for the combined expertise and encouragement from each member of the team and the influential guidance from our mentors and sponsors.

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1 BACKGROUND

1.1 *Introduction*

The NASA Psyche Mission is one of the latest efforts to further our understanding of the solar system and its formation. Discovered in 1852, 16 Psyche is one of 16 large metal-type asteroids orbiting the Sun in the asteroid belt between Mars and Jupiter. Psyche is hypothesized to be the core of an ancient planetesimal due to its possible high composition of metal, and by studying its composition, scientists can conclude how our planet was formed. Moreover, NASA scientists launched an expedition on October 13, 2023 to study the asteroid from orbit to more accurately map the topography of the surface [1]. NASA will likely send another spacecraft to collect physical samples from Psyche in the future. These samples can return to Earth for testing, allowing scientists a possible glimpse into the formation of our planet's metal core. Studying these samples is very valuable to planetary geology because directly studying Earth's core is not feasible due to its accessibility and environmental considerations.

1.2 *Project Scope*

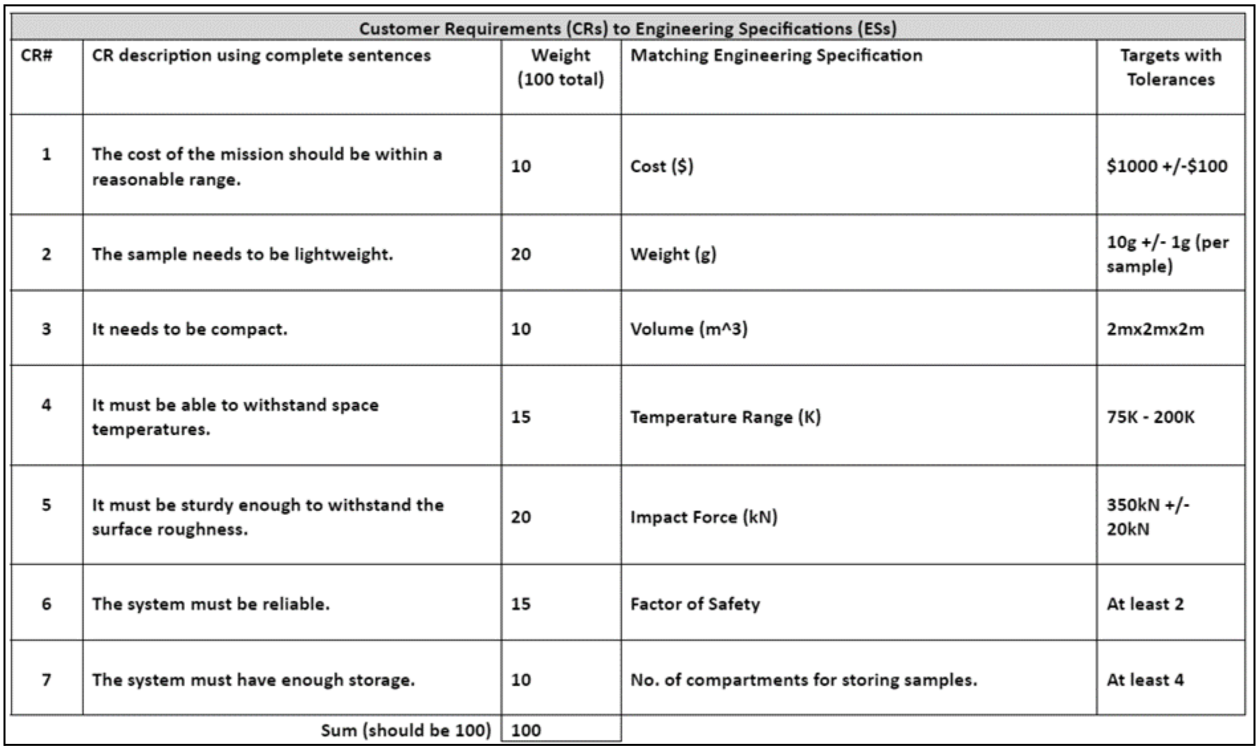
The project objective was to design a system to collect the physical samples from Psyche's surface and send them back to the satellite in Psyche's orbit. The team's primary focus was designing the sample capture mechanism and ensuring that the spacecraft components were structurally and thermally sound to withstand the operating conditions around Psyche. The team also dedicated time to researching the topographical features of Psyche and created detailed models of its known geometry to understand the gravitational and surface conditions. These models of Psyche and data from our research informed the flight parameters, such as drone velocity and orbital radius.

2 DESIGN PROCESS

2.1 *Customer Requirements and Engineering Specifications*

To initiate the design process, the team had several discussions with Professor Cassie Bowman and gathered relevant information about the project scope. Due to the atypical nature of the project, the team should focus on the system functionality and refer to comparable space missions to define the project requirements and objectives. Following these suggestions, the team produced a set of Customer Requirements and corresponding Engineering Specifications (shown in Table 1) verified by Dr. Bowman.

Table 1. Customer Requirements and Engineering Specifications.



Customer Requirements (CRs) to Engineering Specifications (ESs)				
CR#	CR description using complete sentences	Weight (100 total)	Matching Engineering Specification	Targets with Tolerances
1	The cost of the mission should be within a reasonable range.	10	Cost ($)	$1000 +/-$100
2	The sample needs to be lightweight.	20	Weight (g)	10g +/- 1g (per sample)
3	It needs to be compact.	10	Volume (m^3)	2mx2mx2m
4	It must be able to withstand space temperatures.	15	Temperature Range (K)	75K - 200K
5	It must be sturdy enough to withstand the surface roughness.	20	Impact Force (kN)	350kN +/- 20kN
6	The system must be reliable.	15	Factor of Safety	At least 2
7	The system must have enough storage.	10	No. of compartments for storing samples.	At least 4
	Sum (should be 100)	100		

2.2 Concept Generation

This sample return mission requires an unprecedented design solution, so the team went through the next step of the design process by generating several concepts and diversifying approaches through the application of a morphological matrix. Each concept encompassed a mix of approaches to fulfill each function of a lander-rover system: sample collection, mobility, propulsion to orbit, and power. For example, one concept variant consisted of a cylindrical bin, thrusters, magnetic levitation, and solar panels.

Referring to previous space missions, the team attempted to examine various functions to evaluate possible applications to the Psyche mission. However, the unique metallic surface characteristics and the difference in gravity on Psyche posed significant challenges, which eliminated many existing collection systems as references. The OSIRIS-REx mission and the Touch And Go Sample Acquisition Mechanism functioned with significantly lower gravity and weaker surface structure. These challenges led the team to base many of the earlier concepts on the Mars landing missions, with ideas revolving around rovers and landers, such as the examples shown in Figures 1 and 2.

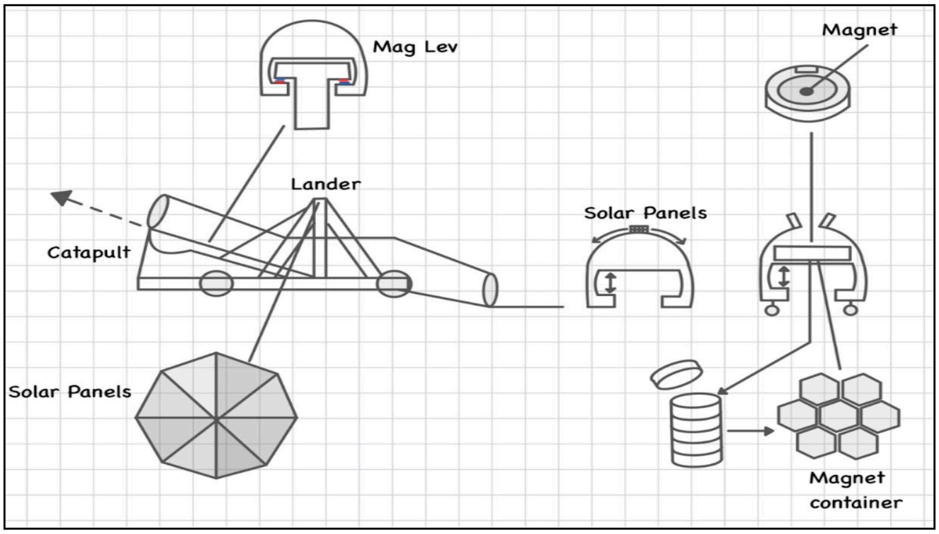


Figure 1. Initial Lander and Sample Return Mechanism Concept.

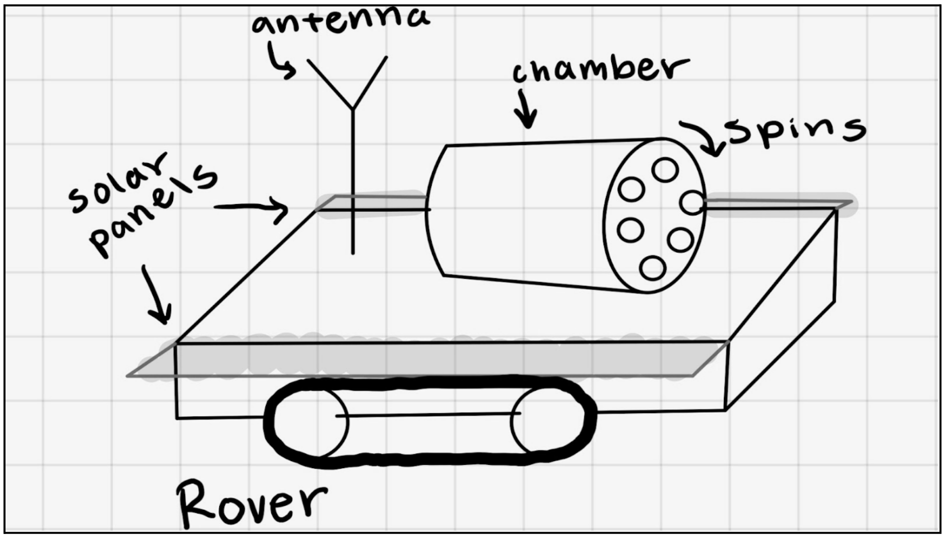


Figure 2. Initial Rover and Sample Storage Concept.

The application of a rover or lander setup is a conventional and relatively straightforward approach, but its corresponding operational demands are highly complicated and costly. The requirement of a landing system, impact mitigation, and the energy required to return the sample back into orbit against Psyche's gravity are significant challenges to consider when designing a system. There were also concerns about how a rover would navigate the steep, rocky terrain of Psyche in such irregular gravity.

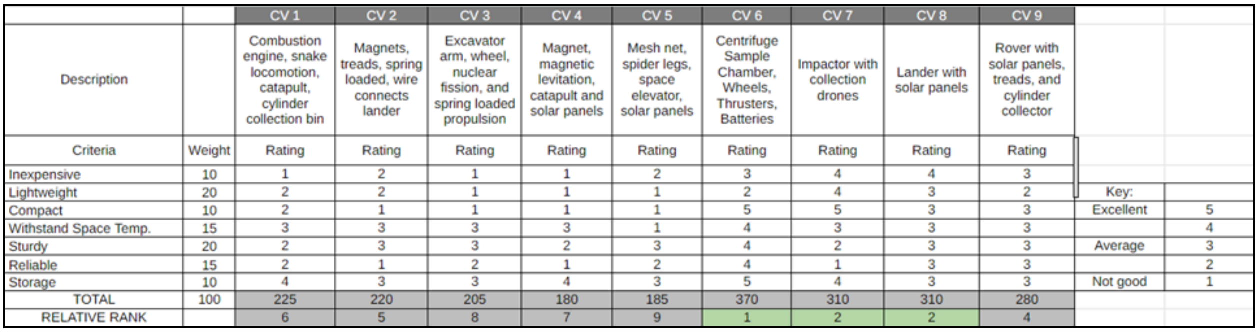
Consequently, the team created another concept to avoid the challenges of landing on the surface of the asteroid and optimize the efficiency of the mission. To emulate the effectiveness of the successful OSIRIS-REx and Hayabusa asteroid sample collection missions, the team employed a much less demanding impactor and collection drone system compared to the lander and rover concepts. In addition to following the OSIRIS-REx and Hayabusa missions' simple and compact approach, this concept also made adjustments to take advantage of Psyche's gravitational potential energy and reduce the risk of interacting with an unfamiliar surface.

While this solution is more efficient, it also comes with significant risks and uncertainties pertaining to the shape of the ejecta cloud and possible damage to the spacecraft collecting the samples. Therefore, the team decided to evaluate all possible concepts and discuss them with the sponsor to select which concept (rover, lander, or impactor) to develop.

2.3 Decision Matrix and Stakeholder Assessment

To select the most feasible design and decrease the number of options, the team used the Decision Matrix shown in Table 2. This method evaluates the feasibility of the concepts based on the CRs. The matrix also reflects the advantages and disadvantages of each concept, as discussed in part 2.2, such as the efficiency of the impactor concept and the risks and uncertainties associated with it. Therefore, the more likely the concept was to fulfill the customer requirements, the higher the viability.

Table 2. Decision Matrix.



		CV 1	CV 2	CV 3	CV 4	CV 5	CV 6	CV 7	CV 8	CV 9		
Description		Combustion engine, snake locomotion, catapult, cylinder collection bin	Magnets, treads, spring loaded, wire connects lander	Excavator arm, wheel, nuclear fission, and spring loaded propulsion	Magnet, magnetic levitation, catapult and solar panels	Mesh net, spider legs, space elevator, solar panels	Centrifuge Sample Chamber, Wheels, Thrusters, Batteries	Impactor with collection drones	Lander with solar panels	Rover with solar panels, treads, and cylinder collector		
Criteria	Weight	Rating	Rating	Rating	Rating	Rating	Rating	Rating	Rating	Rating		
Inexpensive	10	1	2	1	1	2	3	4	4	3		
Lightweight	20	2	2	1	1	1	2	4	3	2	Key:	
Compact	10	2	1	1	1	1	5	5	3	3	Excellent	5
Withstand Space Temp.	15	3	3	3	3	1	4	3	3	3		4
Sturdy	20	2	3	3	2	3	4	2	3	3	Average	3
Reliable	15	2	1	2	1	2	4	1	3	3		2
Storage	10	4	3	3	4	3	5	4	3	3	Not good	1
TOTAL	100	225	220	205	180	185	370	310	310	280		
RELATIVE RANK		6	5	8	7	9	1	2	2	4		

According to the analysis, the impactor concept was among the top three that the team presented to the sponsor. While the rover concepts were initially more favorable according to the matrix evaluation, Dr. Oman and Professor Bowman encouraged the team to move forward with the impactor concept due to the uniqueness of the idea. With the impactor system selected, the team formulated a basic mission plan with three major phases, which is shown below in Figure 3.

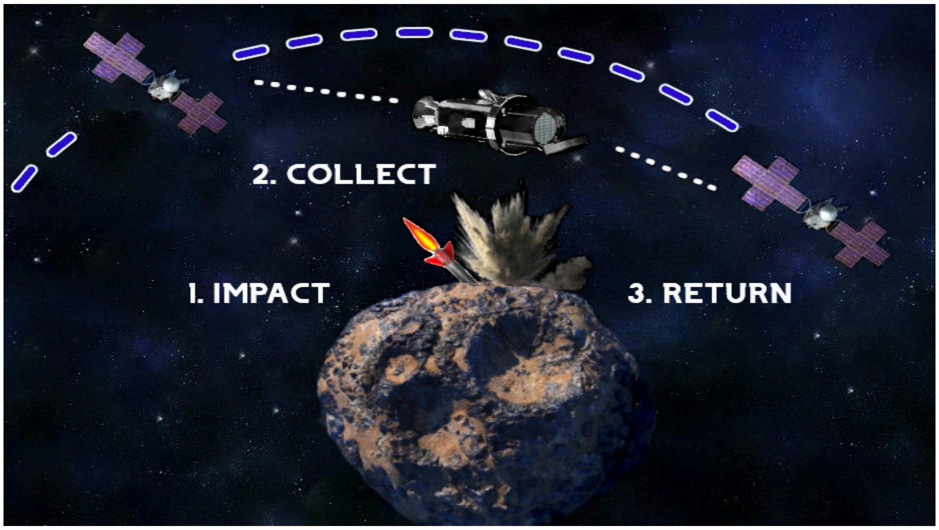


Figure 3. Impactor and Spaceborne Drone Concept without Active Surface Device.

For this approach, there would be three major phases: impact, collect, and return phases. The impactor will launch toward Psyche's surface to create a plume of debris, which the capture device will collect. Due to the unique gravity of Psyche, the plume will remain afloat for a notable duration, which eases the process of the capture system. Then, the capture system would deliver the samples back to the orbiting satellite. Sensors or devices on the satellite may perform some processing procedures on the samples before sending them back to Earth.

3 DESIGN PROPOSAL – First Term

For the first few weeks of the fall term, our team focused on research, concept generation, and concept selection. A large portion of team resources were allocated to comprehending the problem and determining engineering specifications. The next process was to create design ideas for all the critical components of the drone. We used the aforementioned engineering specifications to inform our CAD process. In the following sections, we will discuss the designs our team developed during the first round of our capstone design.

3.1 Sample Collection

For the first term, the team had two competing solutions for collecting the suspended samples: a disk and a net. The disk is based on the sample collection grid used in the Stardust mission, with small compartments of Aerogel, a lightweight solid, to slow down and contain the particles [2]. This disk design has a diameter of 0.4 meters, which can easily fit inside a capsule on the front of the drone that seals to prevent contamination after collection. The double-sided collection disk will be attached to an arm that extends out of the capsule to capture particles as the drone moves through the debris field created by the impactor. It will rotate 180 degrees to utilize both sides of the disk, with each side collecting different sample types. One side (Figure 4) will have Aerogel compartments similar to the Stardust collector for small particles. The other side of the disk (Figure 5) will contain an electromagnet to attract larger magnetic samples that the Aerogel would be unable to absorb.

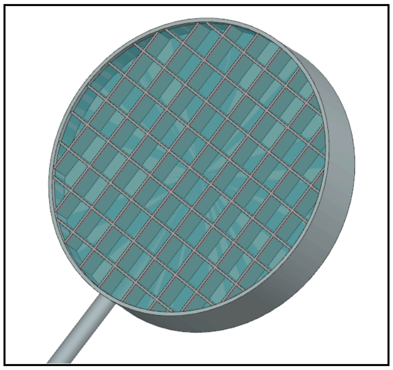


Figure 4. NX Model of Side A (Aerogel) of Metal Disk.

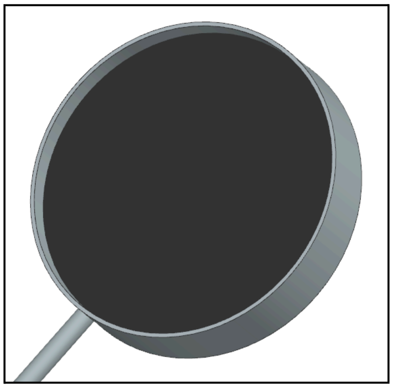


Figure 5. NX Model of Side B (Magnet) of Metal Disk.

The net design, shown in Figure 6 below, fulfills a very similar function to the disk and would also use a mechanism to extend and contract from the sealable capsule to prevent contamination. Because this mission will take place in a location without an atmosphere and the sample particles will have sizes in the scale of microns, a typical net or mesh with holes is insufficient. Instead, we propose using Kevlar fabric for the net material due to its flexibility, ability to withstand the space environment, and strength against projectiles. While the intended sample size is very small in relation to the capture device, there is still a risk of stray high-velocity debris colliding with the net and damaging it if the material is not durable enough.

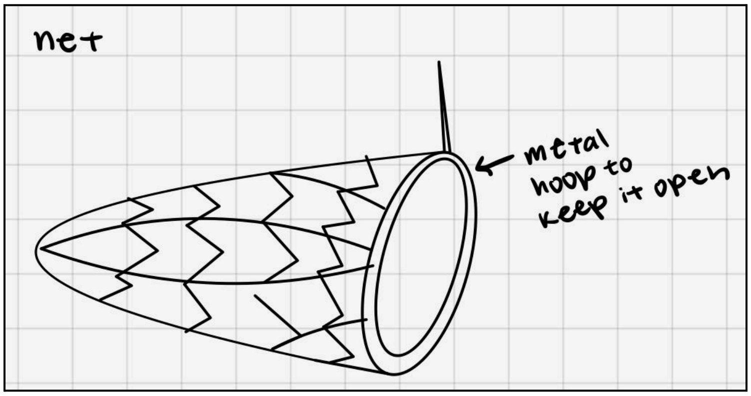


Figure 6. Drawing of Net from the Concept Generation Stage.

Because these designs are similar in function, they were analyzed in the same way regarding the customer requirements. These requirements were influenced by the harshness of space and concerns for the mass of the spacecraft. The most important CRs for this design are shown below in Table 3. To meet the sturdy and reliable aspects of the customer requirements, the team researched the material properties of Kevlar and commonly used materials in space applications. Kevlar, used in the net design, has a high ultimate tensile strength of 3000 MPa, so it can withstand impacts from the particle debris spray without tearing [3]. A metal ring-like opening will ensure the Kevlar net remains open during collection.

The metal components in either concept will consist of aerospace-grade titanium due to its lightweight property and high yield tensile strength of 880 MPa [4]. Furthermore, both designs are lightweight due to material selection and air pockets in the form of a lattice pattern on the disk’s front face and the net’s bag-like structure. Neither design will significantly affect the payload mass of the spacecraft, so the propellant mass needed will not drastically increase. These concepts and their chosen materials fulfill the customer requirements because they are both sturdy through metal reinforcements, compact, and easily retractable to seal for contamination prevention.

Table 3. Weight of Customer Requirements.

Criteria	Weight
Inexpensive	10
Lightweight	20
Compact	10
Withstand Space Temp.	15
Sturdy	20
Reliable	15
Storage	10
TOTAL	100

3.2 Drone Body

The overall drone shape and capsule designs were inspired by the NASA Stardust mission. The drone body included a rear thruster for propulsion, solar panels, and a sample capsule on its front. The solar panels would provide energy to the drone during flight and assist power generation in the event of a battery failure. The capsule will contain the collectors and prevent contamination of the samples after the drone's flight. The sample capsule will utilize pneumatic hinges, modeled in NX using basic shapes, to open and close to seal the collector before and after the sample acquisition phase. During the first term, the team was still in the process of selecting a collector concept, so both the net and disk collectors are shown in the assembly views below (Figures 7 and 8).

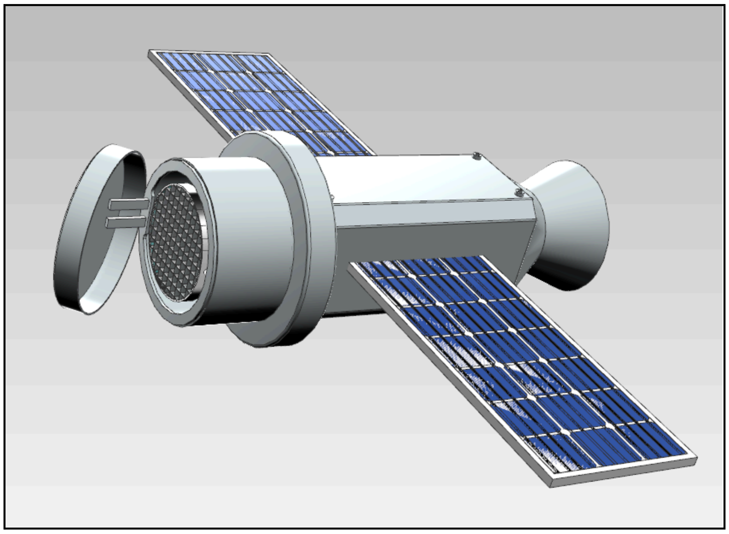


Figure 7. Assembly of Drone with Clamshell and Disk.

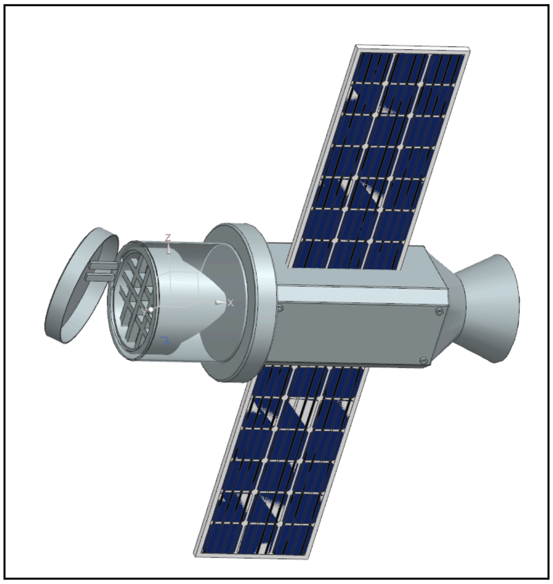


Figure 8. Assembly of Drone with Transparent Clamshell and Net.

4 DESIGN SOLUTION

The final drone design was determined by a wide set of requirements. The team ensured all of the customer requirements were met, and the parts were durable enough to survive in the environment of space. Previous space missions were referenced for feasibility and effectiveness. After a general design was created, our team conducted a series of structural simulations to determine the stresses and deformations it would experience within the debris field and extreme temperatures. Physical tests were performed on Aerogel samples to determine how well the material would capture particles and retain their shape.

4.1 Description of Solution

Our team's final design for the sample collection drone is shown below in Figure 9. The drone body has a cylindrical shape with a length of 3.52 m and a diameter of 1.38 m. On the rear of the drone is the main thruster, with cold gas thrusters located on the sides of the central body. The cold gas thrusters are based on the GR-1 thruster developed by Aerojet Rocketdyne, which uses an environmentally friendly monopropellant named AF-M315E [5]. Cold gas thrusters are implemented in this design to assist in minor course corrections while the drone is orbiting Psyche. Also located on the main body are antennae and cameras for capturing and transmitting images while flying close to Psyche's surface. On the front of the collection drone is the sample capsule, which houses the collection disk. The capsule will open as the drone travels through the debris field, exposing the collection disk and close to seal and protect the captured samples during the return trip.

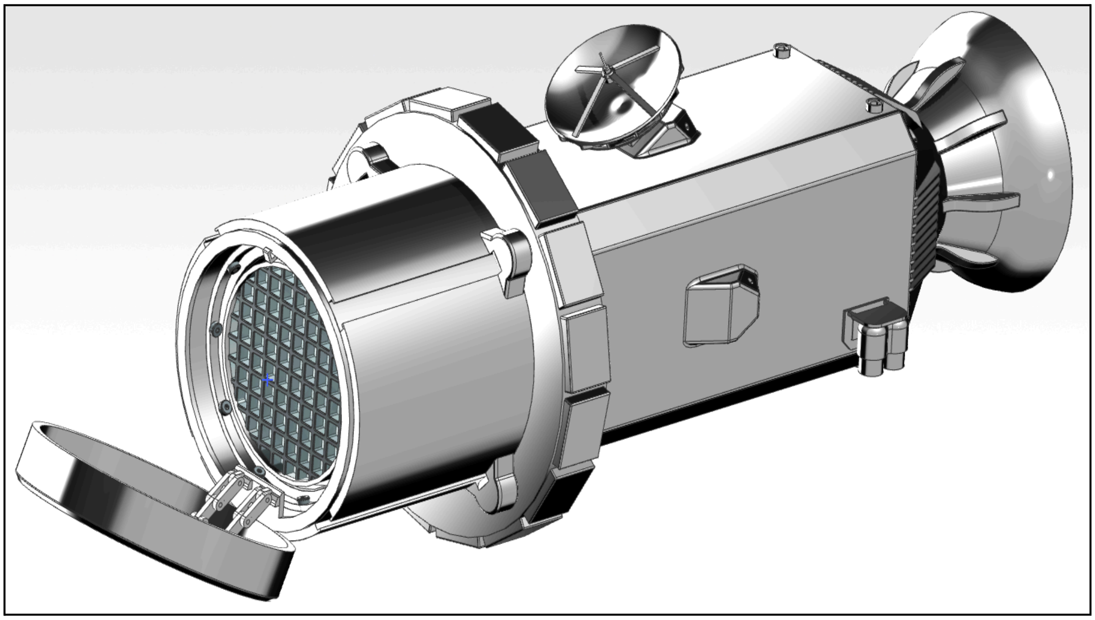


Figure 9. Final CAD Model of the Drone.

4.1.1 *Sample Collection Disk*

The collection disk consists of a Grade 5 titanium alloy (Ti-6Al-4V) grid with Aerogel compartments designed to absorb the impact debris samples in the ejecta field. After the impact debris is absorbed, the samples will remain suspended within the Aerogel for ease of containment. The disk has two sides, shown in Figure 10, with each side designed to collect samples from different altitudes. The Aerogel sections on Side A have a 55 mm grid and a depth of 35 mm, and the sections on Side B have a 75 mm grid and a depth of 45 mm. Side A was designed to collect smaller sample particles located within a higher orbit while Side B was designed to collect the larger samples located closer to the impact site on Psyche's surface. The differing grid depths accommodate a worst-case scenario of both the speed and mass of incoming particles. The grid patterns on both sides of the disk are curved to aid the titanium machining process and prevent high-stress concentration from the debris impact forces.

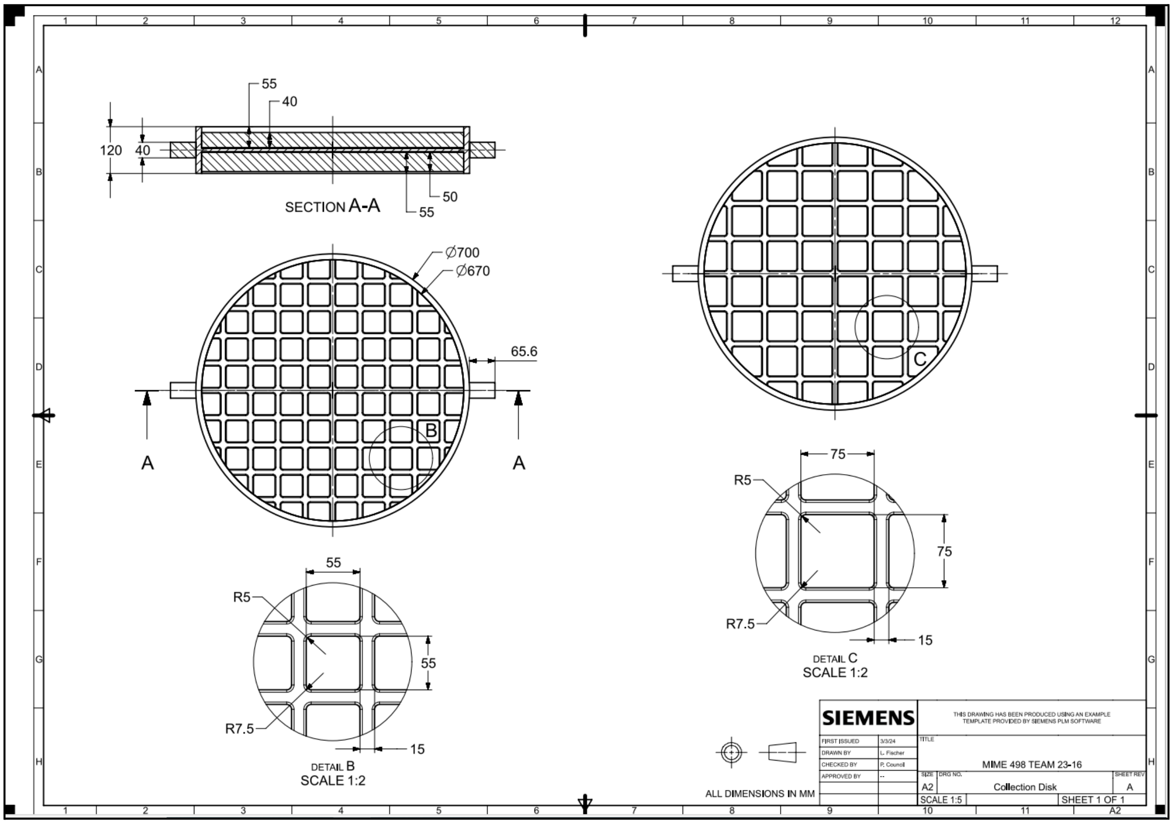


Figure 10. Technical Drawing of Collection Disk.

In the initial stages of the collection disk design, our team planned on implementing an electromagnet on one side of the disk to aid in capturing the ejecta particles predicted to contain high amounts of the iron-nickel compound. However, through more consideration, our team decided to remove the electromagnet from the design. The Aerogel compartments are necessary on both sides of the disk to reduce the speed of the incoming particles. Because the drone travels through the debris field at such a high speed, the particles need no assistance to impact the disk with a greater force. Including an electromagnet within the disk would only serve as a redundancy and introduce a new set of risks related to wiring and electrical disruptions. With the collection method finalized, the team designed the sample capsule to contain it.

4.1.2 Sample Capsule

Our team's final design for the sample capsule is shown below in Figure 11. The capsule underwent several upgrades to enhance its functionality and protection. An inner shell was added behind the collection disk to protect the outer capsule from stray debris that might be missed by the disk, reducing the risk of damage during its mission. The inner shell is also designed for ease of separation from the main body to aid in sample analysis once the satellite returns to Earth. Additionally, the outer shell features integrated tracks to optimize the removal of the capsule upon its return to the satellite, which ensures efficiency and reliability throughout its operation. Finally, the capsule includes dynamic hinges and a latch, shown in Figures 12 and 13, designed to seal it effectively, preventing contamination or damage to the samples during transit.

Figure 11. Final CAD model of Capture Mechanism.

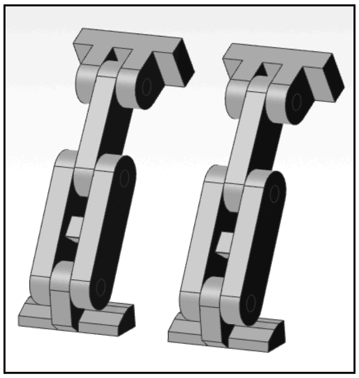


Figure 12. Final CAD Model of Dynamic Hinges.

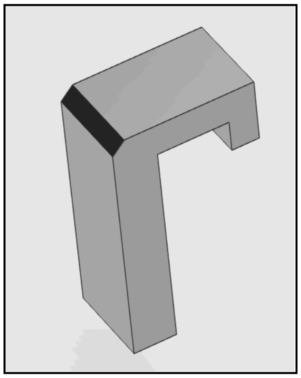


Figure 13. Final CAD Model of Latch.

4.1.3 Impact Ejecta and Drone Interaction Simulation

To further evaluate the feasibility of the design, the outcomes of the impactor phase were simulated based on materials referenced by our sponsor and affiliated experts, which covered impact crater calculations and information about Psyche's astronomical conditions. There were several assumptions used to simplify the calculation process and determine the amount of particles. The gravitational force only depends on the distance between the object and the center of Psyche; the effects of the asymmetric geometry of Psyche on the gravitational field are negligible. The geometric center of Psyche and the center of gravity of Psyche are at the same location. All particles and the drone are point mass and behave according to the rectilinear motion characteristics. The gravitational force of Psyche is the main acting force. Other gravitational forces, electromagnetic forces, and thermodynamic effects are negligible. Given the aforementioned documents and assumptions, the team's first step was to estimate the initial condition immediately after the impact, as shown in Figure 14, Figure 15, and Table 4.

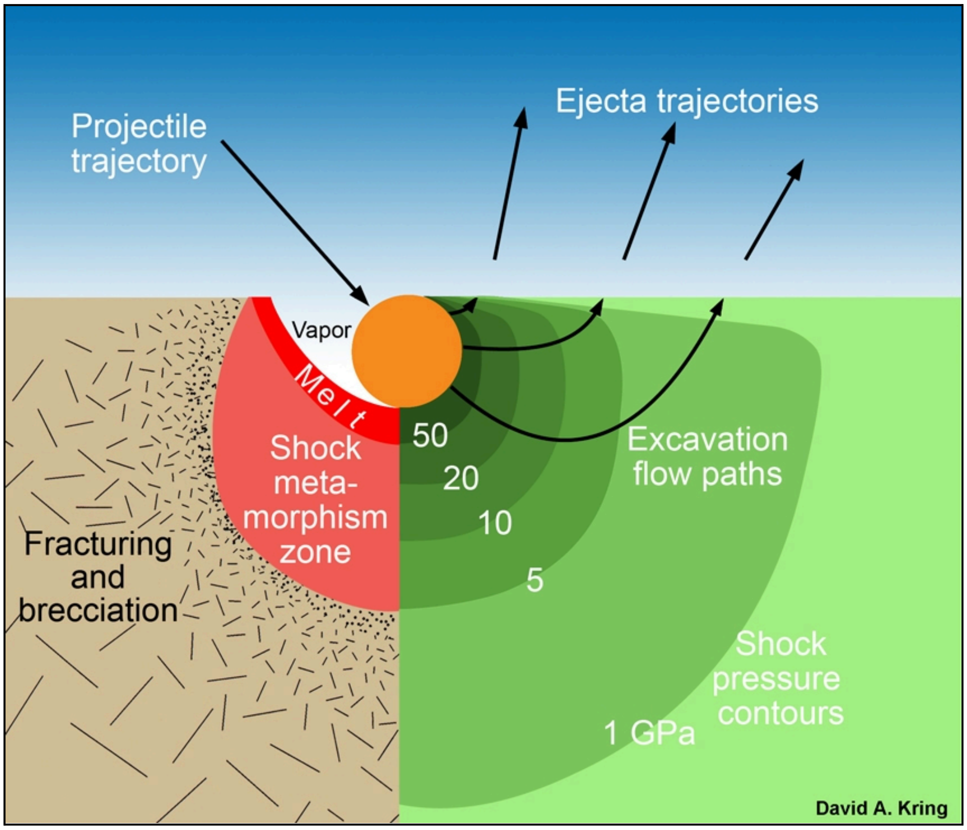


Figure 14. Diagram of impact cratering and initial ejecta formation [6].

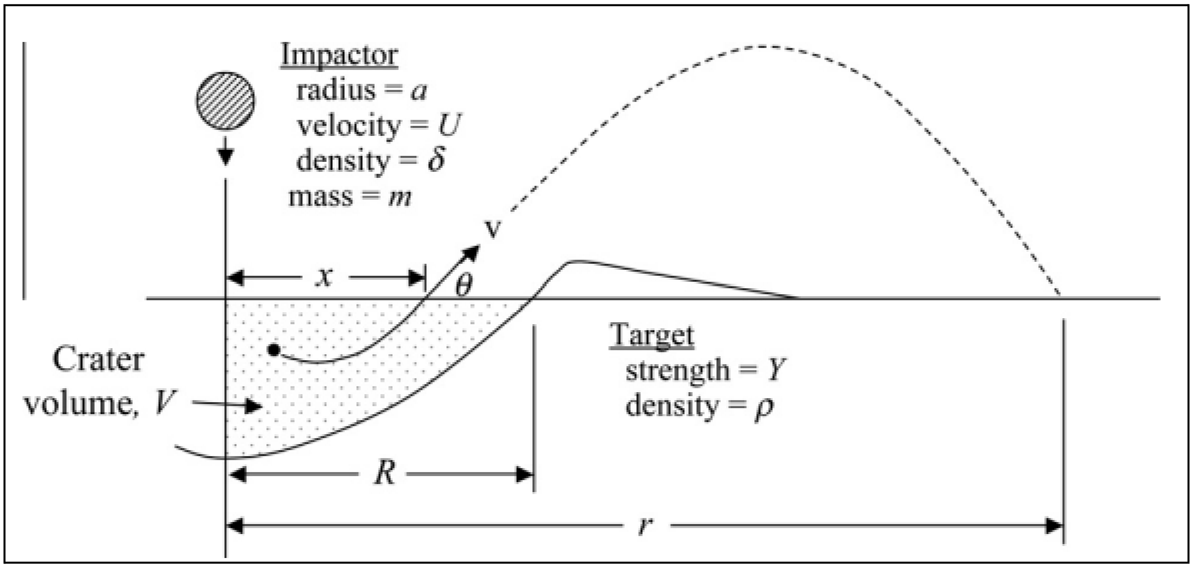
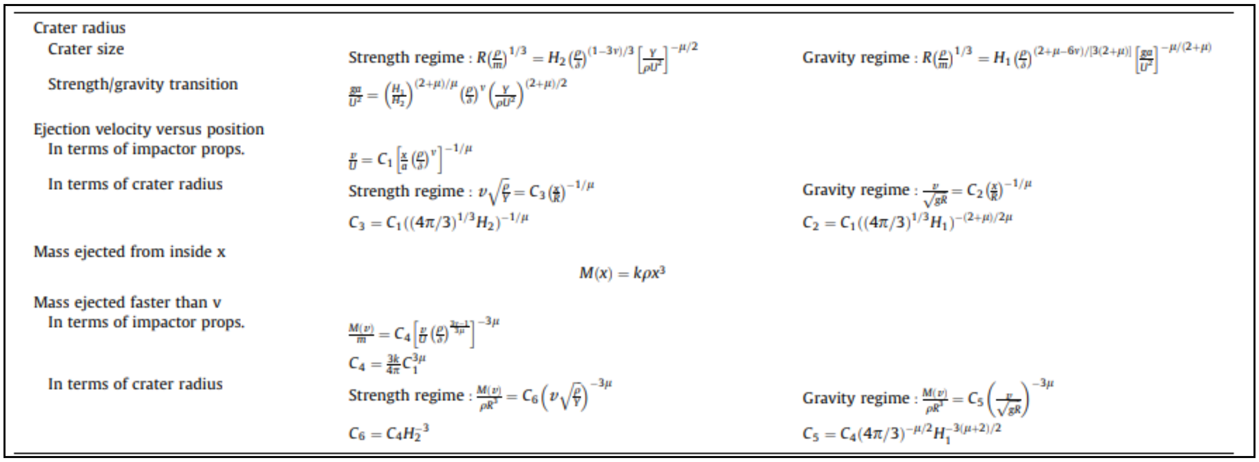


Figure 15. Definition of variables for impact crater and ejecta calculations [7].

Table 4. Scaling laws for the ejection velocity and crater size [7].



Crater radius		
Crater size	Strength regime : $R\left(\frac{\rho}{m}\right)^{1/3} = H_2\left(\frac{\rho}{\delta}\right)^{(1-3\nu)/3}\left[\frac{Y}{\rho U^2}\right]^{-\mu/2}$	Gravity regime : $R\left(\frac{\rho}{m}\right)^{1/3} = H_1\left(\frac{\rho}{\delta}\right)^{(2+\mu-6\nu)/[3(2+\mu)]}\left[\frac{ga}{U^2}\right]^{-\mu/(2+\mu)}$
Strength/gravity transition	$\frac{ga}{U^2} = \left(\frac{H_1}{H_2}\right)^{(2+\mu)/\mu}\left(\frac{\rho}{\delta}\right)^{\nu}\left(\frac{Y}{\rho U^2}\right)^{(2+\mu)/2}$	
Ejection velocity versus position		
In terms of impactor props.	$\frac{v}{U} = C_1\left[\frac{x}{a}\left(\frac{\rho}{\delta}\right)^{\nu}\right]^{-1/\mu}$	
In terms of crater radius	Strength regime : $v\sqrt{\frac{\rho}{Y}} = C_3\left(\frac{x}{R}\right)^{-1/\mu}$ $C_3 = C_1((4\pi/3)^{1/3}H_2)^{-1/\mu}$	Gravity regime : $\frac{v}{\sqrt{gR}} = C_2\left(\frac{x}{R}\right)^{-1/\mu}$ $C_2 = C_1((4\pi/3)^{1/3}H_1)^{-(2+\mu)/2\mu}$
Mass ejected from inside x	$M(x) = k\rho x^3$	
Mass ejected faster than v		
In terms of impactor props.	$\frac{M(v)}{m} = C_4\left[\frac{v}{U}\left(\frac{\rho}{\delta}\right)^{\frac{3\nu-1}{3\mu}}\right]^{-3\mu}$ $C_4 = \frac{3k}{4\pi}C_1^{3\mu}$	
In terms of crater radius	Strength regime : $\frac{M(v)}{\rho R^3} = C_6\left(v\sqrt{\frac{\rho}{Y}}\right)^{-3\mu}$ $C_6 = C_4H_2^{-3}$	Gravity regime : $\frac{M(v)}{\rho R^3} = C_5\left(\frac{v}{\sqrt{gR}}\right)^{-3\mu}$ $C_5 = C_4(4\pi/3)^{-\mu/2}H_1^{-3(\mu+2)/2}$

The following calculations were discretized into multiple layers similar to the illustration in Figure 14. According to the scaling laws, the layers closer to the center of the impact would be subjected to higher energy transmission, which in turn resulted in higher velocity and degree of fragmentation (smaller particles) and vice versa. Then, Psyche's parameters such as its geometry, rotation, and gravitational properties were incorporated into the simulation to match the data mentioned above, as shown in Table 4.

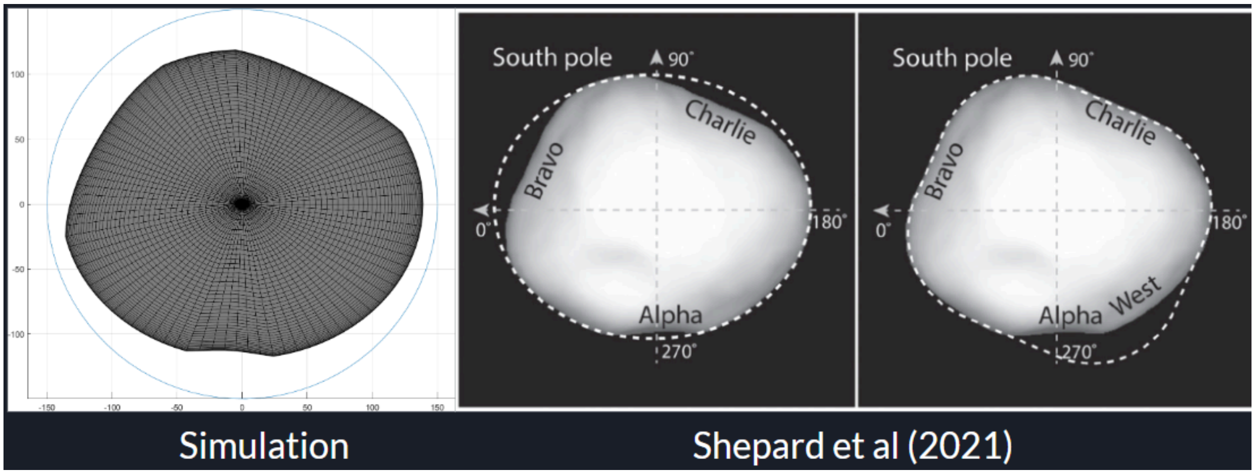


Figure 16. Simulation Geometry Following Shephard et al's Psyche Model [8].

Subsequently, the impact site was assigned and evaluated using the results from the ejecta calculations and simulated Psyche model, and the transient state of the debris field was determined using a Matlab differential equation solver with Psyche's gravity as the main acting force. With the initial position and velocity estimated, the general mathematical equations to solve are shown below, and the solution to the position of the particles over time is illustrated in Figure 17.

$$F_x = m\frac{d^2x}{dt^2} = -\frac{GMm}{r^2}\hat{x} = -\frac{GMmx}{r^3} \Rightarrow x'' + \frac{GMx}{(x^2+y^2+z^2)^{3/2}} = 0$$

$$x'' + \frac{GMx}{(x^2+y^2+z^2)^{3/2}} = 0$$

$$y'' + \frac{GMy}{(x^2+y^2+z^2)^{3/2}} = 0$$

$$z'' + \frac{GMz}{(x^2+y^2+z^2)^{3/2}} = 0$$

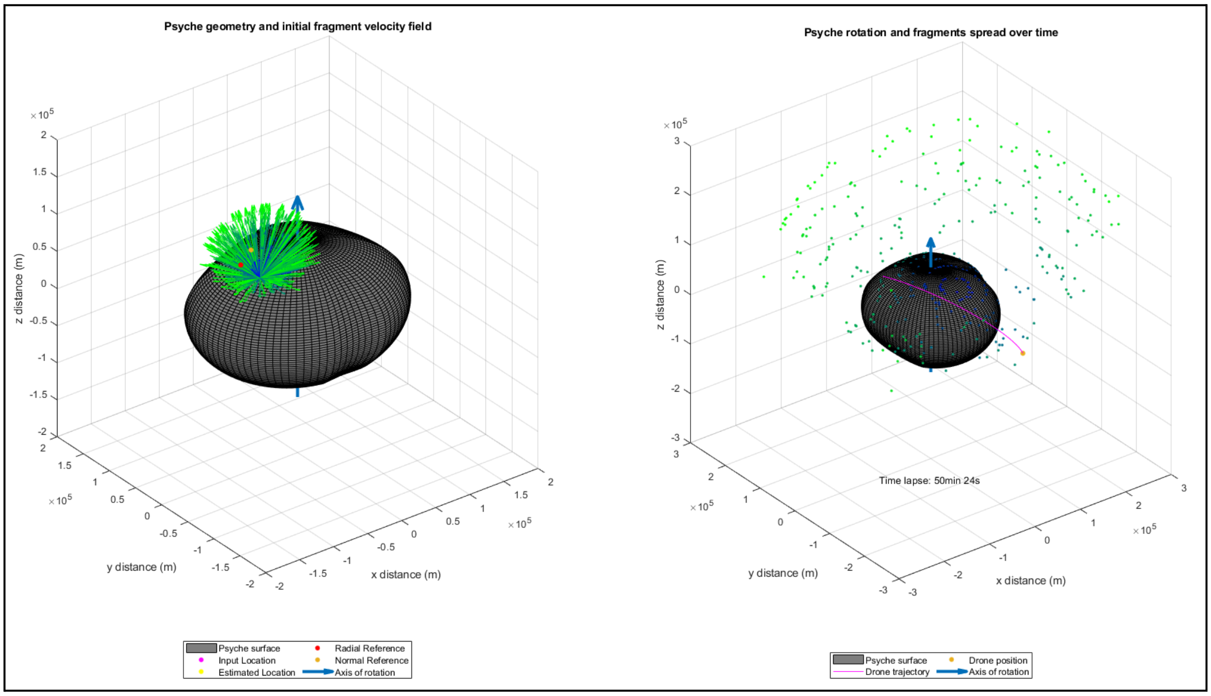


Figure 17. Simulation of the Debris Field Over Time.

4.2 Project Results

4.2.1 Structural Analysis

After creating the general design for the drone and collection disk, we implemented different structural and thermal simulations to determine the reliability of the components. Using the information from these simulations, we iterated the design of the collection disk until the maximum stress and deformation values would not affect the structural integrity of the titanium alloy. Ansys software was utilized for these simulations, and the results on the final design are shown below in Figures 18 and 19.

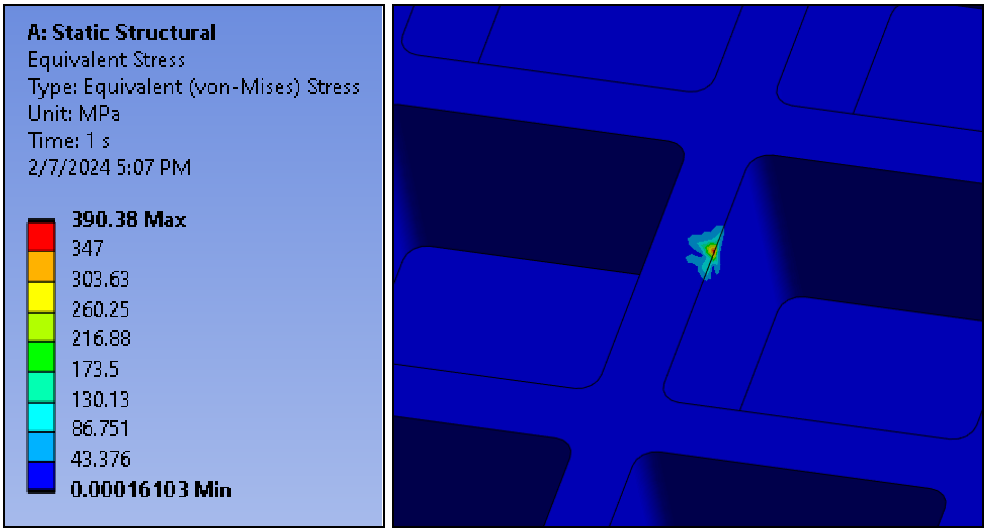


Figure 18. Ansys Stress Simulation for Collection Disk.

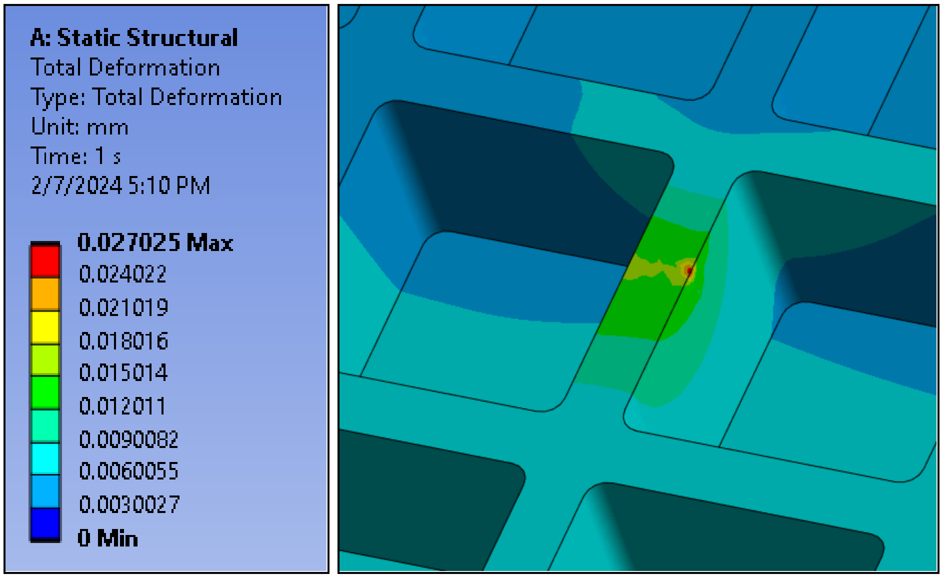


Figure 19. Ansys Deformation Simulation for Collection Disk.

These simulations were performed using the conditions of the worst-case scenario determined by our ejecta calculations. The maximum force expected to impact the disk during the sample collection process is 1.6 kN, so the team decided to place this force with an angled trajectory on the weakest portion of the disk. With this worst-case scenario, the maximum stress experienced by the disk is 390 MPa, and the maximum deformation is 0.027 mm. Both of these values on the final design are well within the factor of safety of this project and do not negatively affect the reliability of the disk.

4.2.2 Thermal Analysis

One of the engineering specifications for this project was to ensure that our drone could operate in the temperature range around Psyche. Based on the information published in the article “The Geologic Impact of 16 Psyche's Surface Temperatures” the temperature range for Psyche is approximately 75-200 K [9]. We conducted thermal experiments in Ansys (see Figure 20) to find the temperature distribution and any thermal degradation along the disk.

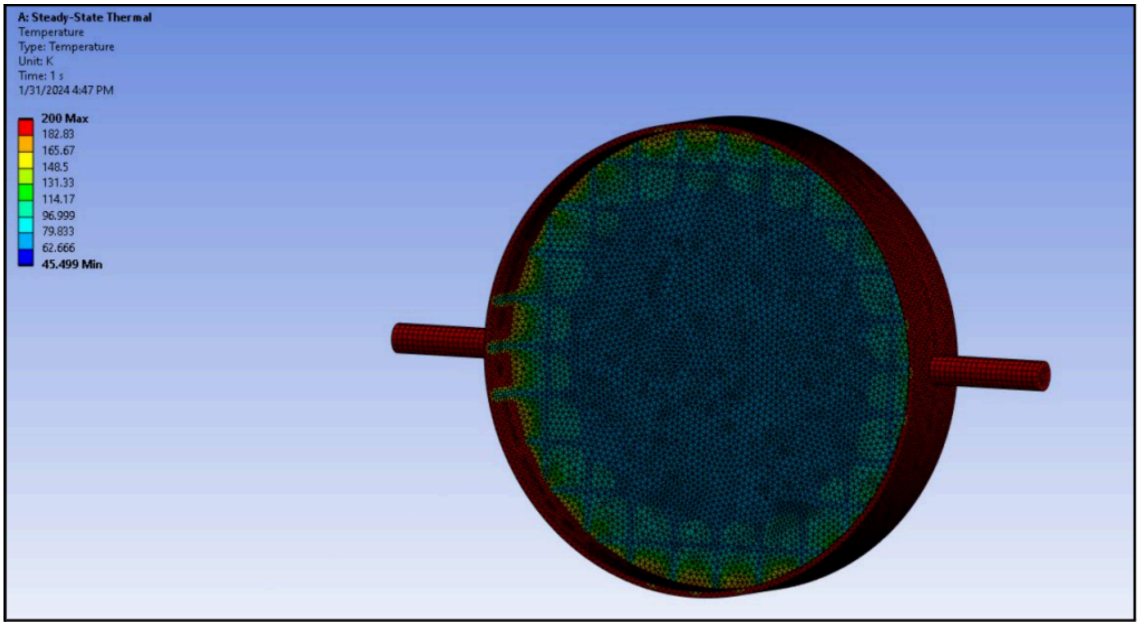


Figure 20. Thermal Analysis of the Temperature Distribution for the disk.

As shown in Figure 21, Ti-6Al-4V titanium (green line) can maintain its structural integrity and high tensile strength in temperatures as low as -250 degrees Celsius [10]. The temperatures in space will not have a significant impact on the structural strength because the maximum temperature of 16 Psyche's surface is 200K (-73.15 degrees Celsius), which is above the temperatures that cause deformation. This thermal analysis proves that our design meets the criteria of withstanding the temperature range of Psyche.

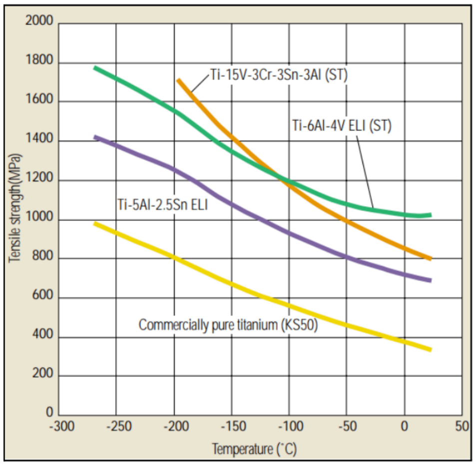


Figure 21. Tensile strength of titanium at below freezing temperatures [10].

4.2.3 *Mass of Collected Samples*

From the results of the particle and drone position shown in Section 4.1.3, a multilevel Matlab logic loop was written to determine if the drone is in the vicinity of the particles. Because of the computational limitation and our discrete approach, not every single particle and every point in time were simulated. Therefore, an approximation method was necessary to determine if the drone came into contact with the particles or not, which is shown in Figure 22.

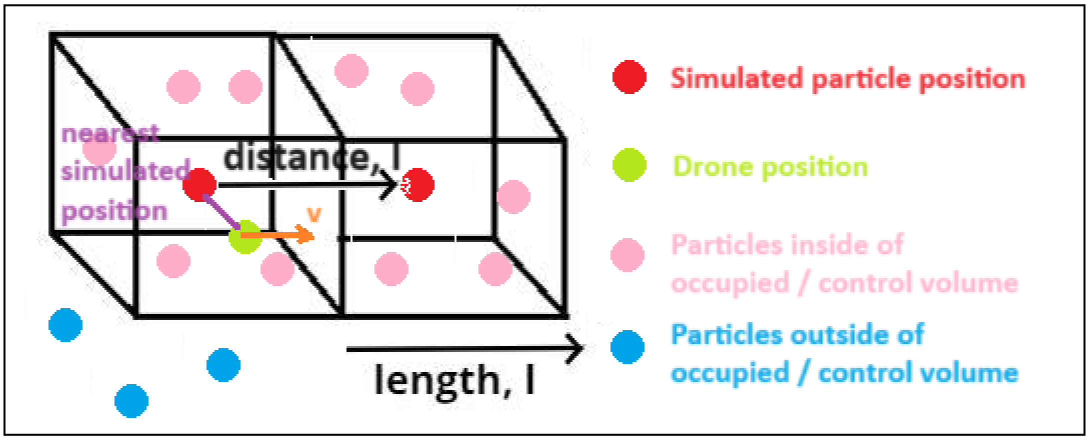


Figure 22. Approximation of drone and particle interaction.

If the drone came into contact with the particle, then the amount of sample collected is calculated as follows:

$$\rho_{particles\ in\ space} = \frac{\sum_i m_{particle\ i}}{V} = \frac{n_{particles} m}{l^3};\ with\ n_{particles} = \frac{n_{actual\ particles}}{n_{simulated\ particle}}$$

The actual number of particles are calculated using the impact crater formula, while the number of simulated particles are given Matlab inputs.

At a given time interval Δt:

$$m_{sample\ collected} = \rho_{particles\ in\ space} v_{drone} A_{aerogel\ disk}$$

Total amount of sample collected, with numerical results in Table 5:

$$M_{sample\ collected} = \sum_i m_{sample\ collected,\ i} \Delta t = \sum_i \rho_{particles\ in\ space,\ i} v_{drone,\ i} A_{aerogel\ disk} \Delta t$$

Table 5. Simulation Parameters and Resulting Amount of Collected Samples.

No. of simulated particles	200 particles	200 particles	200 particles	500 particles	500 particles	1000 particles	8000 particles
Amount of sample collected	2.818g	51.65g	4.25g	9.665g	156.16g	12.566g	31.128g

4.2.4 *Aerogel Testing*

In addition to the simulations and calculations, the team decided that physical testing of the design was an essential part of the process. Due to the difficulty and cost of obtaining the Ti-6Al-4V titanium alloy within the provided timeline, our team ordered Aerogel from a distributor to test in the OSU Innovation Labs. To replicate the unique conditions of flying the drone through the debris field, the team placed a test piece of Aerogel roughly 1 cm thick within a sandblaster to determine if the particles would remain embedded within the material after being struck at high speeds. After testing, the Aerogel sample had many particles of sand trapped within it without compromising the integrity of the material, although the thickness of the Aerogel was reduced by approximately 20%. Figure 23 shows the effect the sandblaster had on the Aerogel sample.

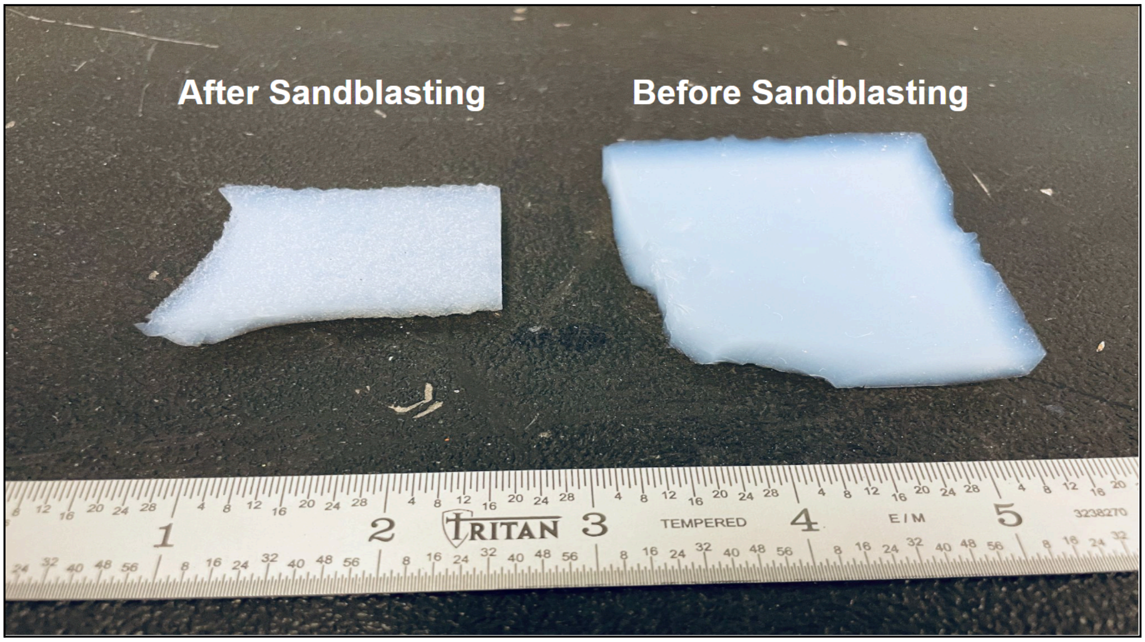


Figure 23. Aerogel Samples Before & After Sandblasting.

5 LOOKING FORWARD

One of the ways this project can be improved upon is by conducting more research into the material selection and properties. We decided to make the mission-critical components for the drone out of titanium. While titanium meets the design criteria for the project, it is difficult to machine and expensive. Because we did not have a budget requirement for the eventual manufacturing cost, we decided to over-engineer our drone, and as a result, it has a high stress and fatigue factor of safety. The upcoming teams could do more research into other metals that might be easier to machine, cheaper, and still meet the safety requirements for the missions. This will help reduce the budget significantly and increase the design efficiency.

Moreover, the team only conducted basic tests on Aerogel, and simple prototypes were made. Future teams will need to conduct material testing in test environments similar to the eventual use case and can also design higher-level prototypes to ensure the proposed design is manufacturable and reasonable.

There will likely be several design iterations before the final design because physical testing is the best way to analyze the weak points of any design.

The team also focused primarily on the mechanical design aspect of the drone. Future teams could work on the electrical components of the project. Setting up the Altitude Determination and Control System (ADCS) with all of its components and conducting Finite Element Analysis (FEA) on the key components to ensure design safety and efficiency could be the final deliverables. Teams could also work on integrating the mechanical and the electrical components. Furthermore, there could be a software engineering team focused on writing algorithms for the ADCS and other components responsible for real-time data processing and analysis.

Additionally, another way to improve the project is to focus on the third phase of the project: return. The future capstone teams can focus on how the drone will return to the satellite and the process of returning samples to the orbiting satellite and then back to Earth. This will require the teams to formulate ideas on how to power the drone for the return flight and calculate parameters, such as flight trajectory and gravitational assists.

Finally, we made several assumptions about the surface and space around Psyche due to a lack of information. As we discover more about Psyche's composition via the ongoing missions, future teams should be able to incorporate that information to improve the accuracy of our design.

6 CONCLUSION

The current NASA Psyche Mission aims to learn more about the processes that formed planets, including the Earth. In the future, NASA may attempt to collect and return sample fragments to Earth during another mission to 16 Psyche. To tackle the design challenges associated with sample collection from an asteroid where its gravity is minimal compared to that of Earth, our team came up with the Impact, Collect, Return concept. The idea is to impact the Psyche surface directly from the satellite using a high velocity impactor, causing its sample fragments to scatter in space. Models are created to simulate the location of the debris produced after the explosion to select suitable orbital altitudes. Then, a drone will acquire samples using a rotatable double-sided disk collector. After sample collection, the drone will return to the satellite and eventually back to Earth.

In summation, the team developed a unique and innovative design. Design for manufacturing and assembly (DFM/DFA) principles were utilized to ensure that our design meets the engineering specifications. The environmental impact of our design was taken into consideration while doing the simulations and calculations for the impact speed and location. This ensures that minimal damage is caused to the surface of Psyche, and there are no negative repercussions to the gravitational motion of the asteroid as a result of the impact. Rigorous testing and analysis of the design have made our design durable and safe even after repeated use. All of these factors make our design stand out, and we hope that our design process will serve as a template for future teams to create comprehensive and robust designs.

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