Titan Turtle

AE: 460B – Space Design

Section 02

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Abstract

During this modern space race, there are countless missions in development to further the human knowledge of our vast universe. Titan X has dedicated its work to discovering other existing lifeforms within our solar system, specifically on Saturn's moon, Titan. Our company decided to focus on this moon because it is the most Earth-like body within the Solar System. If humans are to find other living organisms within reach, the celestial body most closely resembling Earth is the first place we should search. The journey to Titan is by no means an easy task, our primary and secondary loads will experience several gravity assists from Earth and Venus in order to reach Titan. Once on the surface of Titan, our amphibious rover known as Turtle Z, will endure freezing cold temperatures and a nitrogen-thick atmosphere that makes solar power a hundred times more difficult than on Earth. To combat the challenge of solar power, we are planning to install an MMRTG in our payloads to power them for about 15 years. The cold temperatures will pose challenges for the internal components of our rover, so we have proposed insulating Turtle Z with aerogel. With its robotic arm and sonar capabilities, the rover will be able to collect/examine Titan soil and map out liquid bodies on the moon. Meanwhile, our CubeSat known as Hare Y, will orbit the moon to provide us with a more detailed topography of Titan.

Abbreviation List

Titan X	—	Company Name
Hare Y	—	CubeSat to orbit Titan
Turtle Z	—	Amphibious Rover
CCSFS	—	Cape Canaveral Space Force Station
CMG	—	Control Moment Gyro
EGSE	—	Electrical Ground Support Equipment
EPS	—	Electrical Power System
HITL	—	Hardware in the Loop
IMU	—	Inertial Measurement Unit
IP	—	Internet Protocol
MLI	—	Multi-Layer Insulation
MMRTG	—	Multi-Mission Radioisotope Thermoelectric Generator
OBC	—	On Board Computer
RHURPS	—	Radioisotope Heater Unit-based Radioisotope Power System
RTG	—	Radioisotope Thermoelectric Generator
2U	—	2-Unit

Objectives

The primary objective of our mission is to land an amphibious rover on the surface of Titan in order to detect, evaluate, and analyze any forms of extraterrestrial life. Turtle Z will navigate through the hydrocarbon lakes on Titan, collecting samples within the lakes of liquid ethane and methane. Our rover will also swim onto shore and switch into terrain mode. On the dry surface, Turtle Z will be able to use its arm to collect and scan soil samples to determine the composition of Titan. The secondary goal of our mission is to successfully orbit our CubeSat, Hare Y, around Titan and map out its surface in high resolution. Hare Y will be able to give us a more accurate representation of Titan's atmosphere. This mission will demonstrate to the public the possibility of extraterrestrial life within our solar system, improve the technology of laser altimetry and to introduce Titan X into the space industry.

System Overview

Attitude Determination and Control Subsystem

Three Sun Sensors will be installed on Hare Y to determine its attitude. The three sensors will be responsible for measuring the three principal axes for the CubeSat's rotation. Reaction wheels will be installed to control Hare Y, except the reaction wheels will be purposely reduced in power and weight to reserve more power for the rest of the satellite and have a lighter payload. We will utilize magnetorquers for the momentum dumping of the reaction wheels.

Turtle Z will utilize IMU's that can be reset at any time when stationary on the surface of Titan. We are unable to use Sun Sensors and Star Trackers because the limited visibility through Titan's nitrogen-thick atmosphere. We are also uncertain about the strength of Titan's magnetic field, so it would be too risky to attempt the use of a magnetometer.

Mechanical Subsystem

The amphibious rover will include wheels that can rotate and transform into propellers for exploring Titan's seas. Its wheels are to be made of high-grade stainless steel to withstand the cold temperatures under the liquid ethane/methane. The code used on the Perseverance Rover (AutoNav) will be modified to let Turtle Z navigate autonomously through Titan. In the event of our rover getting stuck on harsh terrain, we will utilize Turtle Z's mechanical arm to return the rover to safety. The MMRTG will be placed on the opposite end of the mechanical arm to balance out the weight of the rover.

To combat the cold temperatures on Titan, Turtle Z will be lined with aerogel insulation and have a polytetrafluoroethylene coating on the wheel bearings. These materials are made to withstand the crucial temperatures prevalent on Titan.

Electric Power Subsystem (EPS)

Turtle Z will utilize an MMRTG to generate power for about fifteen years on Titan. It would be insufficient to use solar power due to the reduction of sunlight through Titan's atmosphere as well as the astronomical distance between Titan and the Sun. Solar panels are much more efficient on Earth. The PCDU-P3 EPS will be used to channel power throughout the rover.

Command and Data Handling Subsystem

A Radiation Assessment Detector, mass spectrometer, neutron spectrometer, seismometer, sonar, and multiple cameras will all be included on our primary payload. We do not want to hold back on Turtle Z's hardware because of the many potential discoveries it may encounter when on Titan. Every piece of technology being installed on Turtle Z will be used to learn as much as we can about Titan.

Communication and Payload Subsystem

Turtle Z will have a BAE RAD750 microprocessor as its OBC. A deep space mission to Titan will require technical components that can withstand the harsh levels of radiation in space. BAE is well-known for their radiation hardened processors and is already being used in over 100 satellites. Our primary and secondary payloads will have radio modems with frequency boards and antennas to transmit radio signals with each other.

Requirements Verification Overview

The requirements of our mission and details of the constraints are listed below.

- **Trajectory from Earth to Titan**
    - Our payload will launch at a similar orbital trajectory as NASA's dragonfly.
- ***Hare Y* orbits and examines the surface and bodies of liquid ethane and methane of Titan**
    - The Hare Y will examine Titan in order to evaluate where the Turtle Z will be landing.
- ***Turtle Z* will land near the Kraken Mare and begin collecting data**
    - The Turtle Z will be able to collect data from the Kraken Mare and from the surfaces. While using a mass spectrometer, the Turtle Z will be able to study the samples.
- **Relay of information from *Turtle Z* to *Hare Y* to Earth.**
    - The *Turtle Z* will be able to relay the information collected back to the *Hare Y* and the *Hare Y* will relay it back to Earth which will take about 72-90 minutes to reach Earth depending on planetary positions.
- **Temperature:** Titan is a very cold and desolate moon, which requires the materials of the technology to sustain these harsh temperatures.
- **Solar Power:** Power is also limited because solar power would be highly ineffective due to the distance between Saturn and the sun and due to the thick atmosphere.
- **Oxygen Supply for Power:** Combustive systems would also be ineffective since combustion requires the presence of oxygen.
- **Weight:** Having to carry enough oxygen to power Turtle Z would add more weight and time wasted since the Turtle Z would have to resurface in order to receive packages of oxygen from a primary payload.
- **Terrain:** We know that the terrain of Titan consists mostly of flat plains, a bit of sandy dunes, hills and mountains, and valleys.

Satellite Tool Kit (STK) Simulation

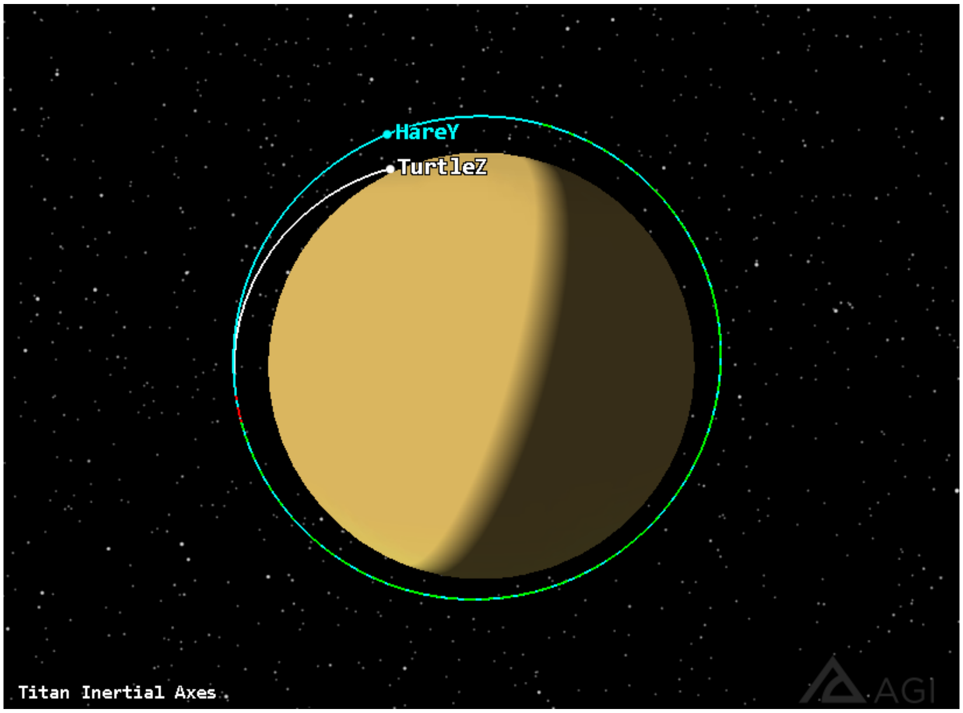


Figure 1 : 3D Model of Hare Y 3-unit CubeSat Orbiting Titan and Turtle Z Separation.

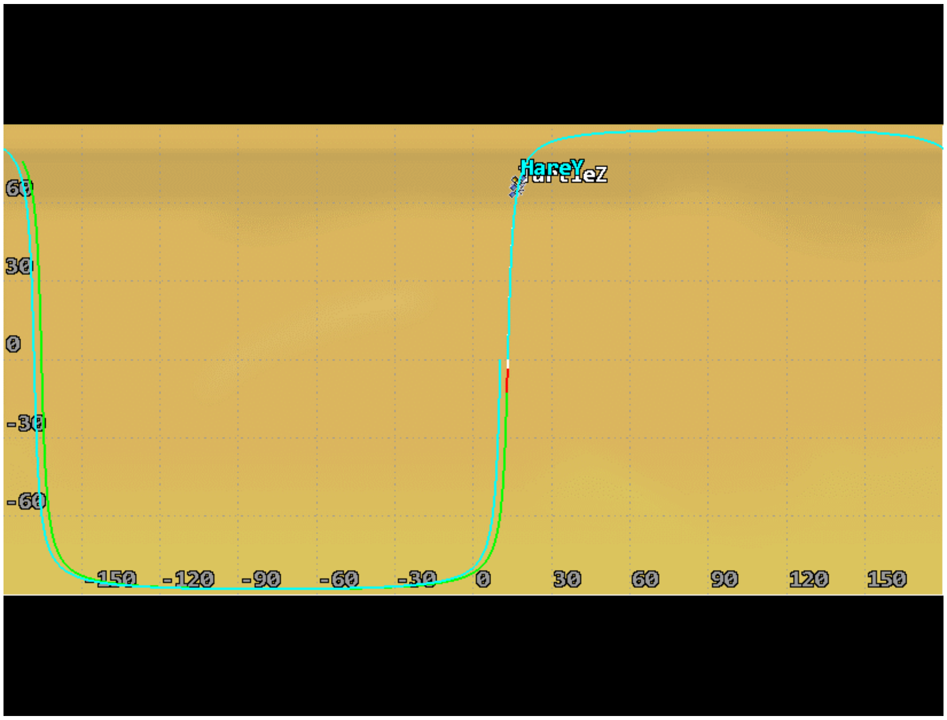


Figure 2 : 2D Model of Hare Y 3-unit CubeSat Orbiting Titan and Turtle Z Separation.

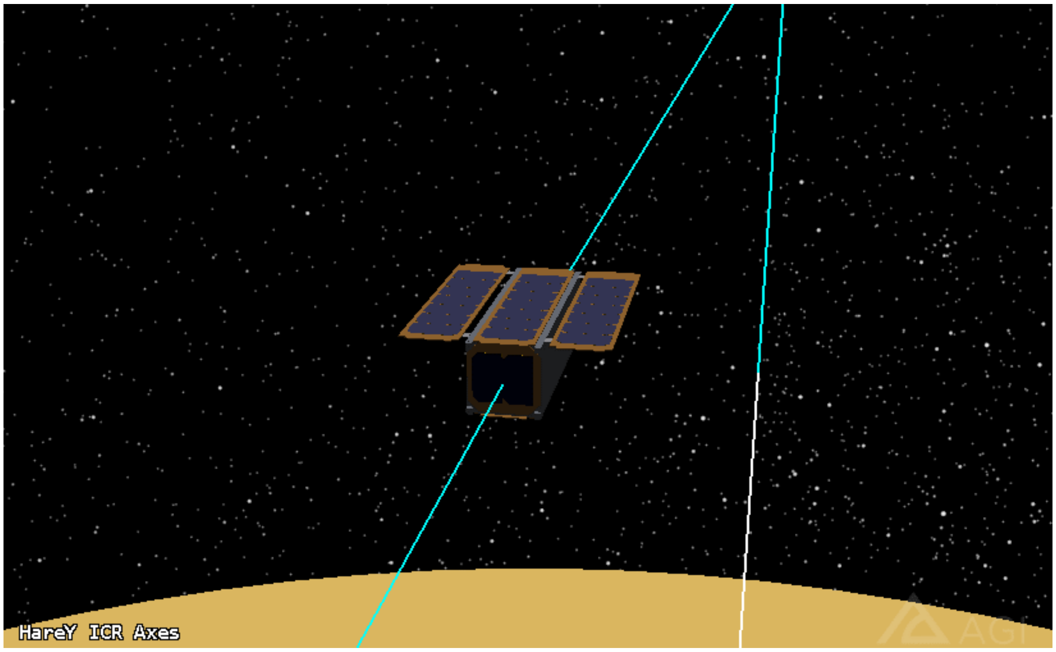


Figure 3 : 3D Model of Hare Y 3-unit CubeSat Orbiting Titan.

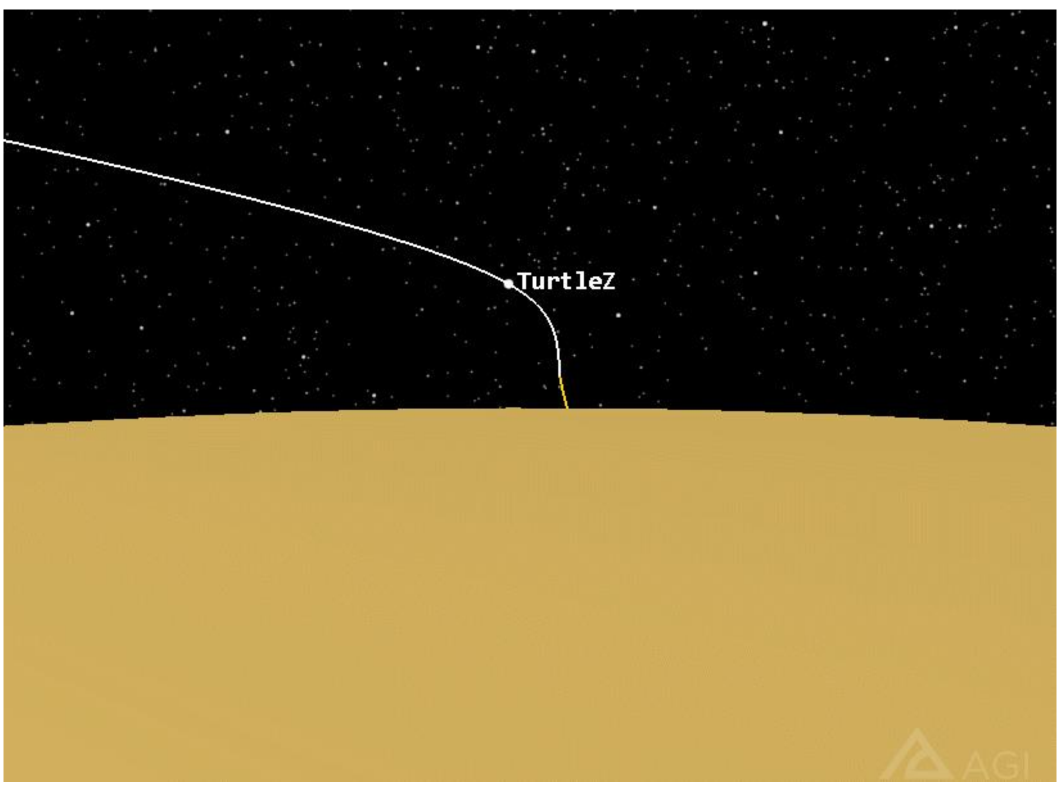


Figure 4 : 3D Model of Turtle Z Landing Safely via Parachute Deployment on Titan.

Ground Station

1) Overview

- The launch vehicle used for this mission will be the Falcon Heavy. Even though the Falcon Heavy has fewer total flights, it has the ideal payload capacity for this mission in comparison to Falcon 9. Falcon Heavy is inspired from Falcon 9, however; it is a heavier lift version of it by utilizing a stronger Falcon 9 first stage (center core) and two added Falcon 9 first stages which act as boosters. The vehicle is also partially reusable, which is an added benefit to its choice.

- The launch site for the vehicle would be the same as the Falcon Heavy in 2018 – Cape Canaveral Space Force Station LC-39A in Brevard County, Florida.

- The following table retrieved from *The Space Techie* [27] displays the differences between the two launch vehicles:

Parameter	**Falcon 9**	**Falcon Heavy**
Height	70 m	70 m
Payload to Low Earth Orbit (LEO)	22800 kg	63800 kg
Payload to Geosynchronous Transfer Orbit (GTO)	8300 kg	26700 kg
Cost Per Launch	$62 Million	$90 Million

Table 1 : Falcon 9 vs Falcon Heavy Comparison [27].

2) Hardware, Software & Handheld Operation Equipment

Falcon Heavy shares multiple similar ground station criterion with Falcon 9 due to its derivative design. The following points were observed from *Falcon User's Guide* released by SpaceX in April 2020. [28]

- A software that tracks the health of the engines on the vehicle is required during the first stages of the launch as a part of the ground equipment to ensure the proper function of the engines. The system-level vehicle management software assists in the shutdown of the engines incase improper activity or function is observed.
- An all-liquid population architecture which includes the fuel, and the oxidizer is stored on the ground station and in the vehicle itself. This helps improve the safety of the launch by removing any hazardous ground handling operations that might tamper the systems that utilize boosters or the solid propellant cores.
- A key hardware utilized on the ground is the hardware-in-the-loop (HITL) software testing which helps provide the functionality status of the mission systems prior to

flight. Furthermore, the all-pneumatic separation systems help simulate the simulation on the ground pre-flight which helps minimize the debris created the process.
- Electrical ground support equipment (EGSE) will be present prior to launch to track the electrical interfaces. Substantial ground support equipment (GSE) will also be present for their respective systems. The hardware and associated ground support equipment is managed by the payload integration manager.
- The ground team must ensure the functionality of the crucial wire lightning protection system on the LC-39A launchpad to protect the vehicle from direct lightning strikes, help avoid a conflict between the overhead wires, flight hardware, and ground systems. This system also helps to minimalize the electromagnetic coupling between the flight hardware and ground systems which helps ensure the safety and health of sensitive electronic components.
- S-band transmitters will be required to transfer telemetry details and video recording to the ground crew. S-band transmitters and C-band transponders will also be used to tack the range of the vehicle from ground.

3) Antenna installation
   - Two Ultra High Frequency Antennas (UHF) were installed for communications purposes.
   - Two LMRE radio modems were also installed in the rover and the CubeSat. Reference to communications sections for further details.

4) Set up & Operation
   - As mentioned previously, the launch and the mission itself will take place at CCSFS (– Cape Canaveral Space Force Station). The launchpad used will be the LC-39. The launch control will also be set up in the same area from where all the post-launch operations would occur.
   - The mission will use utilize computer and display systems with software designed for industrial system control. The launch control would also include voice communications capabilities, including voice nets, voice-over Internet protocol (IP) integration with remote sites, and IP phones. Video viewing and control are provided using the video-over-IP systems. [28]

Assembly Integration Verification

Most of the assembly will take outside San Diego State University's campus due to a lack of resources. Turtle Z's complex build consists of a hybrid system that combines the characteristics of a submarine and rover which would likely be manufactured at a JPL facility. The vehicle will have an ovular shaped, turtle like, shell with 4 legs for which high-alloy steel would need to be maintained benefiting its navigational and structural efficiency. Materials such as Titanium are also considered, however; its performance in Titan's atmosphere is speculative. For power sources, a radioisotope heater unit (RHU) would be assembled for Hare Y which and a Multi Mission Radioisotope Thermoelectric Generator (MMRTG) would be maintained as the power source for Turtle Z.

Turtle Z will have a double walled shell, insulated with a form of aerogel and multi-layer insulation (MLI). Aerogel is a synthetic insulating material that is lightweight and has extremely low thermal conductivity. MLI is a lightweight insulation blanket composed of multiple layers of thin sheets. As a result, Turtle Z's interior will be at optimal operating temperatures and shielded from Titan's harsh climate. Turtle Z will be fitted with wheels that include two configurations: terrain mode and aquatic mode. On land, the wheels will operate as traditional land-vehicle wheels. To clear the terrain, the wheels will have a radius of 90 cm. When submerged in liquids, the wheels will rotate into a position perpendicular to the body to act as propellers.

We would need to integrate high-resolution camera equipment that will be used for navigation and analytical purposes. Furthermore, the equipment acquired for laser altimetry (GPS Precision Laser Altimeter) that will be used to analyze the topography and terrain of Titan via Hare Y would also be integrated and verified. Ultra-High-Frequency (UHF) antennas will be incorporated on the rover and the CubeSat to communicate with Earth. We would also need to integrate the parachute system for a safe landing. The pattern would be like the Mars EDL landing. Test and verify that all the primary systems are functioning up to the required standards.

Entry and Decent System

The Titan X mission will use an entry and decent system similar to NASA's Dragonfly mission to Titan. Turtle Z will be in a capsule that has a parachute deceleration system to safely lower it to the surface. Once the capsule reaches a height of 1250 km above the surface, the decent process will start. First, the capsule will spin and stabilize itself with respect to the ground. Once the capsule reaches an altitude of roughly 200 km, a drogue parachute will deploy. It is estimated that this deployment will occur at roughly Mach 1.5 and will stay deployed for 60 minutes. As the capsule approaches 100 km above the surface, the main parachute will deploy. Unlike the drogue parachute, the main chute will be deployed at much lower subsonic speeds and can therefore be much larger. It is important to note that both the drogue and main chute will be disk-gap-band (DGB) models which is a common, effective design to slow structures traveling at high speeds. Figure (5) shows the parachute deceleration system that will be used in our mission. The main parachute will descend the capsule to under one km above the surface and the lander release module will lower the Turtle Z from the capsule to the ground of Titan. A detailed timeline of the decent process is shown in Fig. (5)

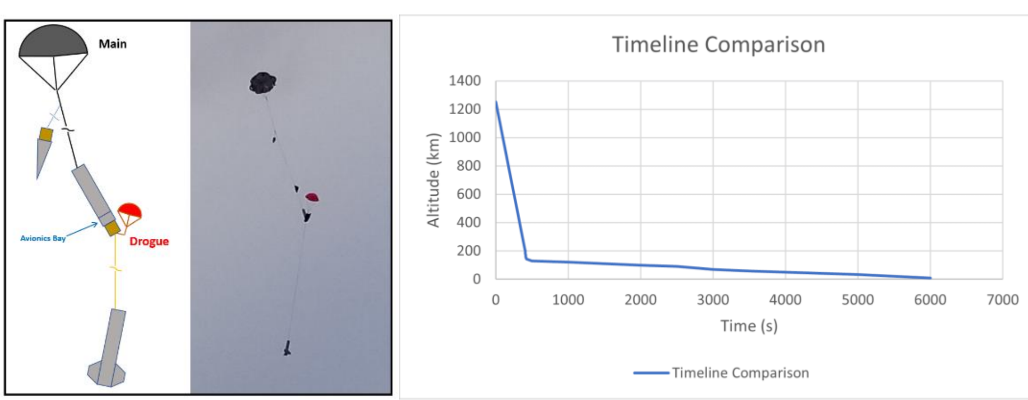


Figure 5 : Parachute Deceleration System (left) and Timeline of Decent to the Surface (right).

Payload Process and Design

Turtle Z will be constructed by combining elements of a standard submarine and the Perseverance Mars Rover. There will be aspects of each that we incorporate in Turtle Z and some elements that we will leave out. Unlike a standard submarine, Turtle Z will not be a cylindrical shape. It will resemble more closely to a rectangular prism with rounded edges and will have dimensions of 305 x 229 x 168 cm. The We are hoping that by mimicking a turtle shell, there will be increased strength and stability when the rover is submerged in Lake Kraken Mare. Images show that Titan has a very rocky surface so Turtle Z will have to have legs that can climb over and clear any obstacles in the way. Turtle Z will have legs roughly 320 cm in length, that will elevate Turtle Z off the ground and will have joints that can rotate to any desired direction. The legs will hold wheels made up of either titanium or steel with cleats imbedded for traction and will have a diameter of roughly 90 cm. The wheels will also have a coating over them to ensure that they do not rust when submerged in the lake. When rotated ninety degrees, the wheels will act as propellers, giving our rover movement when submerged in the lake. In future modifications, Turtle Z will have a robotic arm that will pick up and move objects, like the mechanical arm on the Perseverance Rover. However, for our project, the mechanical arm will not be modeled due to limited resources and time.

In order to get Turtle Z to the depth in needs to be to collect reliable samples, it will have ballast tanks on each side that will inflate once it is in Lake Kraken Mare. They will inflate with the methane from the lake that will descend Turtle Z to the depths necessary to collect samples. Once it has collected the samples, there will be an air pressure system that will blow all the liquid out of the ballast tanks, replacing it with air, and Turtle Z will ascend to the surface. When on land, Turtle Z will detach the ballast tanks and will leave them on Titan to reduce the weight of the payload.

Turtle Z will need to maneuver through terrain and perform different tasks, such as collecting test samples. To complete these tasks, Turtle Z will need to have cameras that give a good field view of the surface as well as mechanical arms to pick up the specimens. Also, sonar transducers will accompany the camera system, so the machine knows where the object is in space. Turtle Z will be able to decipher the images that appears from the cameras and will be able to make proper movements based on the sensor system. For example, if Turtle Z is moving in Lake Kraken, and is on track to hit something, the cameras will be able to see the object and the sensors will let the machine know that something is getting closer, so Turtle Z will adjust its wheels to move around the object. Also, when collecting testing samples, Turtle Z will need cameras to see the specimen and will need to move the mechanical arms to the respective space. The camera system with the sonar transducer will be necessary tools for Turtle Z to successfully preform the tasks at hand.

Hare Y will also add to the payload traveling to Titan. Hare Y will be a small CubeSat with dimensions 30cm x 10cm x 10cm. It will be mostly composed of aluminum alloys and will not add a lot of weight to the payload. Hare Y will be used to communicate with Turtle Z and back to earth.

Communication and Payload Subsystem

As Turtle Z is conducting is traveling through the lake and conducting its tests, it will need to communicate back the information it collects. That is why it is important to have an OBC board and processor that can manage and send the data. During the mission, Turtle Z will experience very hard conditions and it is important to have an electronics system that can withstand the elements. That is why we are choosing to use a BAE RAD750 microprocessor, shown in Fig (6). BAE Systems has been known for creating a reliable radiation-hardened electronic components for space applications for more than 50 years and that is why we chose to use their processor. Radiation from space can be very damaging to the electronics but BAE Systems has decades of experience creating products that can withstand in them. Their products can also endure very extreme temperatures – ranging from -155°C to -125°C. Specifically, we chose to use the RAD 750 because it is used in more than 100 satellites today that carry out various missions in space. The RAD 750 is trusted to successfully preform in the harshest environments in deep space and has multiple configurations allowing it to fit various demands in space.

Figure 6 : BAE RAD 750 microprocessor.

The next crucial component of the communications hardware is the electrical power system (EPS) board. The whole purpose of the electrical power system is to transfer and distribute energy that the rover needs as it preforms its missions such as, rotating the wheels as the rover travels through the lake, to ability to scan the land when driving on Titan's surface, as well as the ability to supply reliable power during the day and night. Our rover will generate most of its power from the Radioisotope Thermoelectric Generator and the electrical power system will deviate where this energy is focused depending on the mission at hand. The electrical power system that will be incorporated on Turtle Z is the PCDU-P3 which is a compact, 12-channel power unit, shown in Fig (7). This system has 6 customizable converters that can be connected to any output channels. Therefore, one outlet would be connected to the legs that will power the wheels when on surface and in the liquid ethane/methane. Another outlet would be connected to the arm and others would be connected to the sonar module and ballast tanks. The PCDU-P3 is a very important aspect of Turtle Z that will enable it to perform the missions we need on Titan.

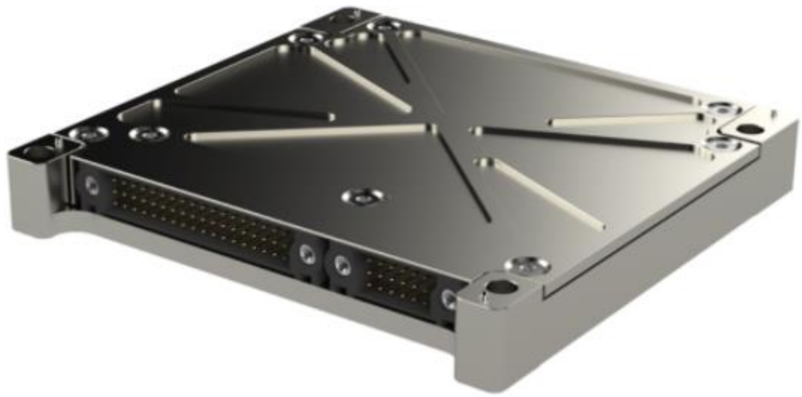


Figure 7 : PCDU-P3 Electrical-Power System.

There will be four components of telecommunications between Turtle Z and Hare Y. Both Turtle Z and Hare Y will have a radio modem that will have a radio frequency board as well as antennas to ensure effective transmission of radio waves. The purpose of having a radio modem in Turtle Z and Hare Y is to give them a route of communication by sending and receiving digital symbols or “packets” that can consist of 2000 eight-bit bytes. These packets can transfer images as well as information regarding the tests performed on Titan. The purpose of having antennas is to make sure there is effective transmission of radio waves between Turtle Z and Hare Y. The specifications of the radio modems and antennas are seen below in the Tables.

Specifications	Hare Y Radio Modem	Turtle Z Radio Modem
Mass	105.9 g	265.2 g
Dimensions	8.74” x 3.78” x .3”	4.2” x 2.8” x 2.1”
Operating Voltage	+7.5 Volts	+7.5 Volts
RF Center Frequency	14.5 GHz	14.5 GHz
RF Transmit Power	10 W	10 W
RF Channel Bandwidth	25 kHz	25 kW

Table 2: Radio Modem Specifications.

Specifications	Hare Y Antenna	Turtle Z Antenna
Overall Length	45 cm	33.6 cm
Materials	Fiberglass, Aluminum, Teflon, Coaxial cable	Fiberglass, Aluminum, Teflon
RF Center Frequency	14.5 GHz	14.5 GHz
RF Bandwidth	700 kHz	16 MHz
RF Gain	1.4 dB	1.4 dB

Table 3: Antenna Specifications.

The fundamental equation for designing spacecraft communications systems is the Link Power Budget Equation which is represented by the equations below. This equation says that the Link Power Budget equals the effective isotropic radiated power plus the received antenna gain subtracted by the free space path loss. The corresponding effective isotropic radiated power and the free space path loss equations are also found below and equal 20.06 dB and 138.2 dB respectively. After calculating those and referring to the tables above for the received antenna gain, the Link Power Budget equals –116.678 dB with this given communications system.

$$Pr = EIRP + Gr - Lfs \qquad \textit{(Eqn. 1)}$$

$$Lfs(dB) = 20\,log\left(\frac{4\pi r}{\lambda}\right) \qquad \textit{(Eqn. 2)}$$

$$EIRP = Pt + Gt \qquad \textit{(Eqn. 3)}$$

Mechanical and Structural Subsystem

For this mission, we are required to launch a satellite from Earth to Titan, the largest moon of Saturn. This mission would utilize gravitational assists to reach Titan and from there we would put our satellite, named “Hare Y,” into the orbit of Titan in order to collect data from the moon so that we can study the geography and map out most, if not all, of Titan’s lakes. Our objective during this phase is to examine the terrain of Titan by using laser altimetry. With known depths and locations of obstacles the lakes, we will then send in our amphibious rover named “Turtle Z” which will be deployed by from our payload down onto the moon. Turtle Z will land in the Kraken Mare, which will use parachutes to safely land in the ethane lake. Our Turtle Z will be made of titanium, Kevlar, and high-grade steel. While Turtle Z is in the lake, it will collect multiple samples from the liquid, dirt, ground, or anything that can be taken as a sample for research. Turtle Z will be integrated with the ability to take these samples and study whether they contain signs of life using mass spectrometry. Turtle Z will be able to propel through liquid ethane/methane as well as move across land, just like a turtle can on Earth. While Turtle Z is outside of the Kraken Mare, it will be able to take samples from the terrain and the atmosphere and study the samples. The data that will be collected by Turtle Z will then be sent directly to Earth via a high gain antenna. We have calculated that it will take about 72-90 minutes to reach Earth from Titan, depending on the planetary positions.

Some constraints that we ran into are concepts such as temperature, power, weight, and terrain. Titan is a very cold and desolate moon, which requires the materials of the technology to sustain these harsh temperatures. Power is also limited because solar power would be highly ineffective due to the distance between Saturn and the sun and due to the thick atmosphere. The moon of Titan does not get heat from the sun itself, but rather from its extremely heated core. Combustive systems would also be ineffective since combustion requires the presence of oxygen. Having to carry enough oxygen to power Turtle Z would require much more weight and time wasted since the Turtle would have to resurface to receive packages of oxygen from the primary payload. In order to have an efficient but quick launch from Earth to Saturn, we must not have an excess of weight such as oxygen if the propulsion idea was feasible. We know that the terrain of Titan consists mostly of flat plains, a bit of sandy dunes, hills and mountains, and valleys which have been carved overtime by rain and erosion.

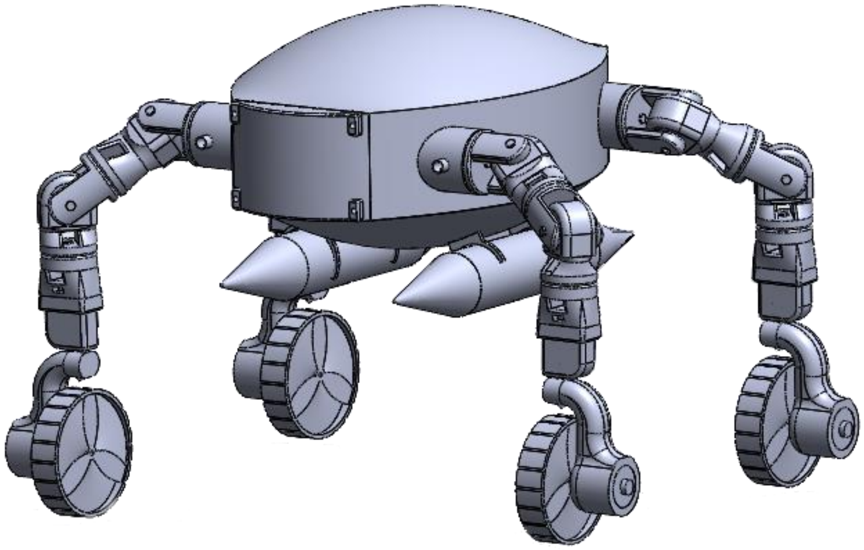


Figure 8 : 3D CAD Model of Turtle Z in Terrain Mode.

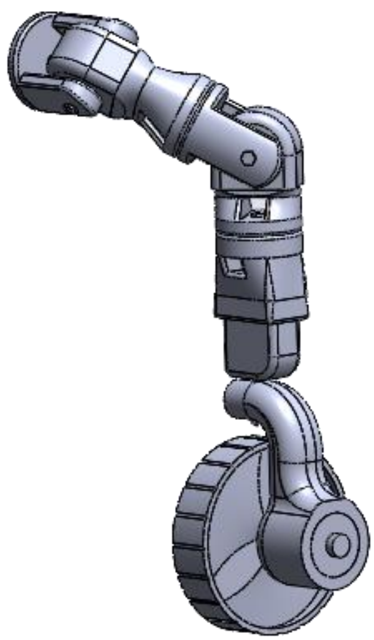


Figure 9 : Wheel/Propeller Exploded View.

Figures 8 and 9 show a generalized idea for the main body, legs, and wheels of Turtle Z. When designing the main body, we used biomimicry from a turtle shell to provide strength and efficiency to our rover when submerged in the lake. There will be silica aerogel inside the rover as an insulator for temperature sensitive instruments. The legs have main joints to provide maneuverability over the terrain and can be manipulated into different modes: aquatic, terrain, and hover mode. These three positions will allow the rover to move across the terrain, provide thrust in the lake, and will allow the rover to recover from compromised positions. The wheels are designed as propellors to navigate when the Turtle is in the lakes on Titan. A detailed list of the design requirements, production process, constraints, and challenges are shown below.

Design Requirements and Specifications

- Sizing: less than or equal to 10 feet long, 9 feet wide, and 7 feet tall
    - This ensures that the Turtle will fit the size requirements that the rocket has.
- Weight: less than or equal to 900 kg (1984.16 pounds)
    - This ensures that the Turtle will meet the weight requirement that the rocket has.

Production Process

- Cleanliness
    - During the production process, the environment must be clean and free of any contaminants that might skew the results once on the surface of Titan.
    - During the loading process, the Turtle must be sanitized to ensure that no living organisms might travel with the Turtle on its voyage to Titan.
- Functionality
    - During the production process, testing of each instrument will be required to ensure the functionality of the components.
    - Each instrument must meet certain qualifications for duration purposes to ensure that the Turtle will work for an extended period while it is on the surface of Titan.
- Scheduling
    - Ensure that each deadline for the production process is met.
    - Implement extended amounts of "gap time" to ensure that in the event of a setback to the production process the overall deadline will not extend.
- Budgeting
    - Ensure that the budget is met during the production process.
    - Implement an overestimated budget in the event of an unavoidable price increase; for example, innovative technology that comes out that is tested and can be implemented replaces an outdated instrument, which costs more than the original instrument.
- Final Testing
    - Ensure that once the Turtle is fully built that it functions to the quality that is needed according to the challenges of the harsh conditions on Titan
    - Once the Turtle is tested and approved for operation, the Turtle must then be loaded into the rocket in accordance with the rocket's specifications for weight loading.

Constraints and Challenges during Design and Production

- Constraints
    - Sizing
        - Ensure that the sizing of the Turtle does not exceed the maximum volume of the rocket's storage space, keeping in mind that the CubeSat will also be included in the rocket as well.
    - Weight
        - Ensure that the weight of the Turtle does not exceed the maximum weight requirements of the rockets specified loading, also keeping in mind that the weight of the CubeSat will be included in the overall loading of the rocket.
- Challenges:
    - Budget and Timing

        - More details provided above.
- Conditions
    - The surface of Titan has an average temperature of about -290 F or about -179 C which means that the components must be insulated with materials that allow the instruments to be within a functional temperature according to the instrument itself. Some instruments perform better under colder conditions so each instrument must be insulated accordingly. The main source of heat generation will come from the RTG power source which naturally admits heat.
        - Aerogel will be utilized to insulate the heat generation of the Turtle. This material is an excellent insulator and is extremely light and moldable as well. The only downside of this material is the price that comes with it.
    - The frigid conditions also mean that the Turtle's structure must be suitable for the environment. Selecting a metal that is durable enough to support the Turtle during its mission without exceeding the weight requirements is crucial to the mission's success.
        - Stainless Steel is a candidate for a metal to use for the structure of the Turtle due to its high resistance to corrosion as well as its high resistance to low temperatures. It is used to store liquid Nitrogen which has a temperature of -196° C.
    - The frigid conditions also pose a threat to the functionality of the Turtle's wheels. The bearings used in the Turtle's wheels must be durable enough to continue to function while in the air of Titan, and in the lakes of Titan.
        - Polytetrafluoroethylene will be utilized as a synthetic fluoropolymer that will coat the bearings of the Turtle. It has one of the lowest coefficients of friction values of any known solid. It can stay flexible at temperatures as low as -425° F or about -253° C. It also has an extremely high melting point ensuring that it will not burn up on any entry phase, although it will be coating the inside and outside of several components.
- Navigating
    - The Turtle will have to be completely autonomous such that it can navigate the terrain of Titan on its own. To do this we will be implementing an updated version of the code used on the Perseverance Rover. The updated version will allow the Turtle to navigate in the lakes on Titan.
    - The Turtle will also have mechanisms that will be implemented in the event of the Turtle becoming stuck on terrain. To do this the Turtle will have multiple avenues. It can use the arm attached to the front of the Turtle if on land, and it can use the Ballast Tanks if stuck while submerged in the lakes on Titan.
- Obtaining Samples
    - The Turtle must implement the use of the arm to obtain samples from the lakes and land on Titan.

Attitude Determination and Control Subsystem

For determining the attitude of both the Turtle and the Hare, we must state what is currently available on the market and what are the conditions orbiting Saturn. We have five main categories for attitude determination systems, IMU's, sun sensors, star sensors, horizon sensors, and magnetometers. After selecting an attitude determination system, we will then need to determine how we are going to control each spacecraft.

IMU's are a set of gyroscopes and accelerometers imbedded in computer circuits that digitally keep track of the satellite's trajectory utilizing the conservation of angular momentum for the gyroscope and oscillatory mechanisms and materials for the accelerometer. A drawback from the IMU is the prevalence of gyro drift or when the gyroscope continues to assume the satellite is moving when it is not. The causes of this issue are vast and dependent on how a particular gyroscope was built but it requires an additional non-IMU sensor to recalibrate.

Sun sensors work by detecting the light with a photocell coming from a power source through a narrow column. The intensity of light is a function of the angle the column is with the power source. This angle determines the attitude of the satellite. Nearby bright objects can contaminate the signal by confusing internal computers into recognizing these bright objects as the sun and recalibrating with respect to them. This issue can be overcome by theoretically predicting the intensity of sunlight from Saturn, and the nearby moons and asteroids brightness patterns and programming the computer to look for the sun's particular intensity.

Star trackers are amongst the oldest attitude determination systems built. They work by having photocells or cameras receive the light from stars, record the positioning and brightness of the stars and back track the position and attitude of the satellite from a star catalog. Drawbacks are that the cameras and photocells can easily get distracted by external sources of light like thruster firings, the sun, and asteroids. These systems are also substantially more expensive due to the need for extremely sensitive tracking software, highly accurate databases, and precise measurement of the stars and their changing positions and brightness

Horizon sensors work by receiving infrared light from the planet or moon. The generates a square wave plot of the irradiance of the planet with respect to the time, also known as the dwell time. Major drawbacks include these components are expensive and most commercial products are built for Earth and would require a custom-built sensor for other worlds.

Magnetometers operate by being subjected to an external magnetic field that creates an electrical flow inside a coil of conductive wire. The magnitude of the electrical flow is proportional to the intensity of the magnetic field but also how the electrical coil is oriented with respect to the magnetic field. As a result, magnetometers record the rotation of a spacecraft but are unable to determine the translational attitude. A major drawback of magnetometers is that they only work in the magnetic fields of planets.

Now to determine the method to control the attitude of the spacecraft. The available options are Reaction wheels, Momentum wheels, Control moment gyros, Magnetic torquers, and Thrusters.

Reactions wheels utilize electric motors attached to metal cylinders using the induced torque applied by the motors to rotate the spacecraft. Momentum wheels are the same as reaction wheels except that they spin at much faster speeds. A couple of major drawbacks from reaction wheels include momentum saturation, moving parts, heavy weight, high power consumption.

However, momentum wheels are useful and reliable in providing high stability when requiring precise positioning.

Control moment gyros work with the same fundamental principles as the reaction wheels and the momentum wheels with the main difference being the motors themselves are allowed to rotate while the wheels are held stable. A drawback of CMG's is gimbal lock or when the gyroscope loses a degree of freedom when two of the gimbals move in parallel.

Magnetic torquers operate with the same principle as magnetometers only that the electric coil is being supplied with power while inside a magnetic field to produce an external torque on the vehicle. This method is primarily used to dump momentum from reaction wheels, and only works while near a planet's magnetic field.

Thrusters are the most direct method to control a spacecraft's attitude. Using the same method to produce the thrust needed to get off the ground, smaller engines can be used to rotate a spacecraft or move it translationally. However, with thrusters there is a finite amount of fuel which creates a lifespan for the spacecraft.

For this mission to Saturn, it is important to determine what are the conditions the Turtle and the Hare will experience in orbit or on the surface of Titan. Starting with the Turtle, the surface of Titan is obscured by the thick nitrogen atmosphere. This fact knocks out the sun sensor, the star tracker, and the horizon sensor leaving only the IMU and the magnetometer as the only viable options. The strength and prevalence of Saturn's magnetic field on the surface of Titan is currently unknown but has been detected to be stronger than anticipated in Titan's ionosphere at 26 nT [26]. This fact makes having a magnetometer on the Turtle a risky venture, so to counteract the concerns, the magnetometer will be removed from consideration only leaving the IMU for the Turtle. Issues with gyro drift can be corrected by back tracking towards a previous gyro setting that we determine to be correct and apply those older settings onto the current settings, allowing us to reset the IMU from time to time. Controlling the Turtle will be done through the wheels, the joints, and hydraulic suspensions.

For determining the attitude of the Hare, one sun sensor and an IMU will be utilized. The IMU will be the primary attitude determination system along with a redundant IMU for emergencies. A single sun sensor will be used for recalibrating the IMU on the three principal axes of rotation. Sticking with the IMU for attitude determination increases potential rover weight, allows more room for scientific equipment and more dedication towards power consumption of those experiments. For controlling the Hare, reaction wheels will be utilized, however these wheels will be much lighter and more underpowered than traditional reaction wheels to reduce payload mass and allow more power to be utilized for experiments. As such, all the rotations the Hare will make will have to be planned to compensate for the delay in receiving the commands and making the proper attitude adjustments. A magnetorquer will be used to allow momentum dumping of the reaction wheels. These will slowly discharge the momentum from the reaction wheels as the Hare orbits Titan.

	IMU	Sun Sensor	Star Tracker	Horizon Sensor	Magnetometer
Price	$500 - $1,500	$2,000 - $15,000	$10,000- $50,000	$15,000 - $50,000	~$25,000
Error Range	0.003-1°/hr	0.005-2°	0.0003- 0.01°	0.1-1°	0.5-3°
Mass Range (kg)	1-15	0.1-2	2-5	1-4	0.3-12
Power Consumption (W)	10-200	0-3	5-20	5-10	< 1

Table 4: Attitude Determination Systems.

Power Subsystem

In terms of Institutional Resources and Needs, SDSU as an institution has scarce offerings for our project realization. The only potential resource that might be used from the university is Dr. Ahmad Bani Younes' space laboratory that could possibly help us simulate the orbit trajectory of our mission. Most of the project would require resources outside the university's offerings, starting with the major components such as the CubeSat (Hare Y) and the rover (Turtle Z) being used. The rover consists of a hybrid system that combines the characteristics of a submarine and rover. For ground movement the rover, Turtle Z, would need parts obtained externally such as: legs similar to the Perseverance Mars Rover to counter the rocky surface, a rectangular prism body type made out of titanium, Kevlar, and high-grade steel for higher navigational efficiency, and 15inch diameter cleats that are imbedded for traction purposes. For aquatic movement, the rover will have a traditional propellor in the rear that provides forward thrust, a forward rudder, a forward fin, and an aft fin that allows the rover to move horizontally while submerged. We would also need to obtain ballast tanks on each side of the rover to collect samples for analysis from the depths of the lake. A double walled shell insulated with multi-layer insulation (MLI) and aerogel will need to be obtained for the rover to protect it from Titan's extremely cold climate. A Multi Mission Radioisotope Thermoelectric Generator (MMRTG) would be obtained as the ideal power source for the mission. The rover would also require a set of configured wheels for both land and aquatic purposes.

High-resolution camera equipment that will be used for navigation and analytical purposes would also have to be attained externally. Furthermore, all the required equipment for laser altimetry that will be used to analyze the topography and terrain of Titan via Hare Y will also be obtained. The main source of power for Hare Y would be a radioisotope heater unit (RHU) based radioisotope power system (RPS). A few other needs of the mission that will be obtained outside the university are as followings: the parachutes needed to land on the ethane lake, sophisticated equipment to collect samples, and lidar equipment.

Electrical-Power Subsystem

Since our mission will be taking our primary payload, the amphibious rover Turtle Z, to Titan, instead of electrical power, the Turtle Z will be installed with a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). The reason for an MMRTG rather than any sort of electrical power is because the distance of Titan from the sun, as well as the dense atmosphere on Titan. Solar power would not be feasible since Titan is about 900 million miles from the sun. Neither would the atmosphere provide any sort of assistance if solar power were at all possible. Therefore, a radioisotope thermoelectric generator must be used in order to power our amphibious rover.

According to the National Aeronautics and Space Administration (NASA) [20], an MMRTG will generate about 110 watts of electrical power at launch. It is able to do this by using natural decaying radioisotope material and converting the heat produced into electricity using the Seebeck effect. The RTG which has measurements of 25 inches wide, 26 inches tall, and about 94 pounds in weight will be able to carry about 10 pounds of plutonium dioxide as fuel which will provide approximately 2,000 watts of thermal power. With a life expectancy of about 14 years, this will provide power to a rover with an efficiency of 80%. Any lower than 80% efficiency will be deemed as inefficient for the mission according to experts and researchers. The RTG will be integrated onto the back side of the rover similar to that of the Perseverance Rover on Mars. This is due to the fact that the mechanical arm that will be constructed on the front of the rover will center out the center of mass of the rover. Since our mission is a one-way trip, Turtle Z will be operating until the MMRTG is no longer effective.

MMRTG Technical Specifications	
Number of General-Purpose Heat Source (GPHS)	8
Thermoelectric Materials	Lead Telluride/ Germanium Telluride/ Silver Antimony Telluride
Number of Thermocouples	768
Beginning-of-Life Power (Watts)	110
Est. End of design life power (Watts) at 17 years	72
Beginning of life system efficiency	6%
Beginning of life specific power (watts/kilogram)	2.8
Load Voltage (volts)	30
Fin-root temperature (degrees C/F)	157/315
Mission Usage	Multi-mission: space vacuum and planetary atmospheres

Table 5 : MMRTG Technical Specifications.

Thermal Control Subsystems

When designing Hare Y and Turtle Z, it is important to control the heat within the system so the electronic equipment can operate efficiently. Most materials used on board have a non-zero thermal expansion coefficient so any large changes in temperature could cause distortions among the equipment. The fundamental principles of heat transfer and thermodynamics were used to manage the heat throughout the system. The main components of our design include what material to use on Hare Y and Turtle Z and other insulations to retain heat within the system. Hare Y will be subjected to multiple sources of radiation. It is exposed to direct solar radiation, solar radiation reflected by nearby planets, also known as albedo radiation, blackbody radiation from surrounding planets, known as planetary radiation, and thermal radiation from space. A depiction of this phenomenon is shown below.

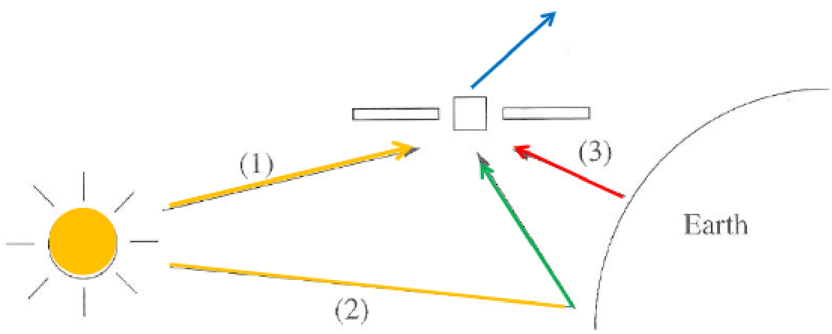


Figure 10 : Sources of Radiation.

To find the intensity of the direct solar radiation the power output from the sun must be divided by a function of the radius from the earth to the sun squared. Since not much information about Titan is available, we will be using the solar radiation with respect to earth and multiplying it by the solar coefficient on Saturn which is 0.011. Next, albedo radiation is found by finding the product of the solar radiation with the albedo coefficient and the visibility factor for Titan. After that, the black body radiation from Saturn is found by squaring the quotient of the radius of Titan with the distance of Saturn to Titan. Lastly, we can find the type of paint/material to use with the equation located below and solving for alpha over epsilon. The values for Titan's blackbody radiation, Saturn's solar constant, Albedo radiation flux and the operating temperature on Titan are shown in Table (6). From these values it is decided that polished beryllium, coupled with its internal RHURPS to provide heat, best suits our operating conditions for Hare Y. For Turtle Z, we will be using aerogel for insulation, radioisotope heaters with thermostat for heat control, and a multi-mission radioisotope thermoelectric generator to heat the system as well.

$$T^4 = \frac{J_p}{4\sigma} + \left(\frac{J_s + J_a}{4\sigma}\right) \cdot \frac{\alpha}{\varepsilon} \qquad (Eqn.\ 4)$$

Specification	Value
Titan Blackbody Radiation	1.5213 Wm^-2
Solar Constant at Saturn	15.0819 Wm^-2
Albedo Radiation Flux	0.4751 Wm^-2
Operating Temperature	-38.6327°C

Table 6 : Titan radiation values.

On-Board Computer and On-Board Data Handling Subsystem

- System Overview and Function
    - Turtle Z will employ the use of the following instruments:
        - Radiation Assessment Detector
        - Cameras
        - Mass Spectrometer
            - To analyze chemical compounds
        - Neutron Spectrometer
            - To analyze surface composition
        - Seismometer
            - To analyze the seismic activity on the surface of Titan
        - Sonar
            - To map the floor of a lake on Titan
    - The Turtle will employ the use of innovative technology as it is being built in the future. This will allow the Turtle to obtain more advanced data about Titan. It will allow us to complete our mission of finding out if life exists on the highly active surface of Titan.

Radioisotope Power System In lieu of Solar Power

Our mission's primary and secondary payloads include a rover and CubeSat. Traditionally, rovers such as Mar's Perseverance and CubeSats such as the FireSat use solar panels to harness solar power. Therefore, as mentioned above, solar power at Titan is non-existent. To combat this problem, Turtle Z will be powered by an MMRTG. However, since an MMRTG is rather large, our CubeSat, Hare Y, must be powered by another power source.

Hare Y will be powered by a radioisotope heater unit-based radioisotope power system (RHURPS). This system is effectively a miniature MMRTG, also utilizing thermoelectric heat to convert into electricity. The only difference is the size and use of lithium-ion batteries. A standard RHURPS is about 6.2cm by 13.4cm. With this sizing, a two-unit (2U) CubeSat frame can house the RHURPS, batteries, charger card, and charging cable.

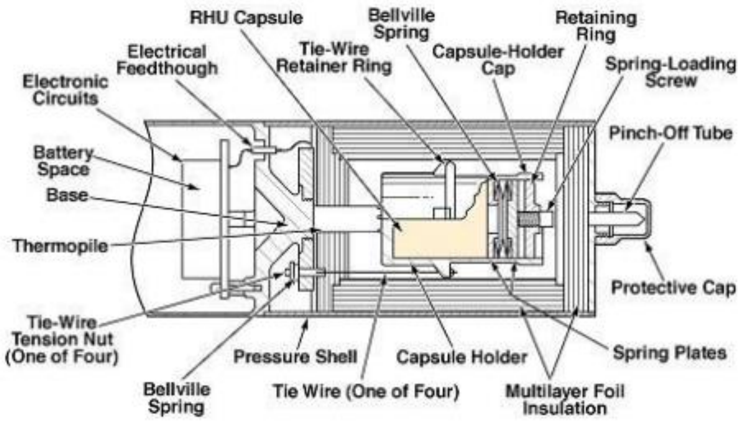


Figure 11 : Hi-Z RHURPS.

Main Components:

- Hi-Z 40mWe, 2.5V RHURPS
- Li-ion batteries
- Voltage Controller/Battery Charger Card
- Charging Cable Harness

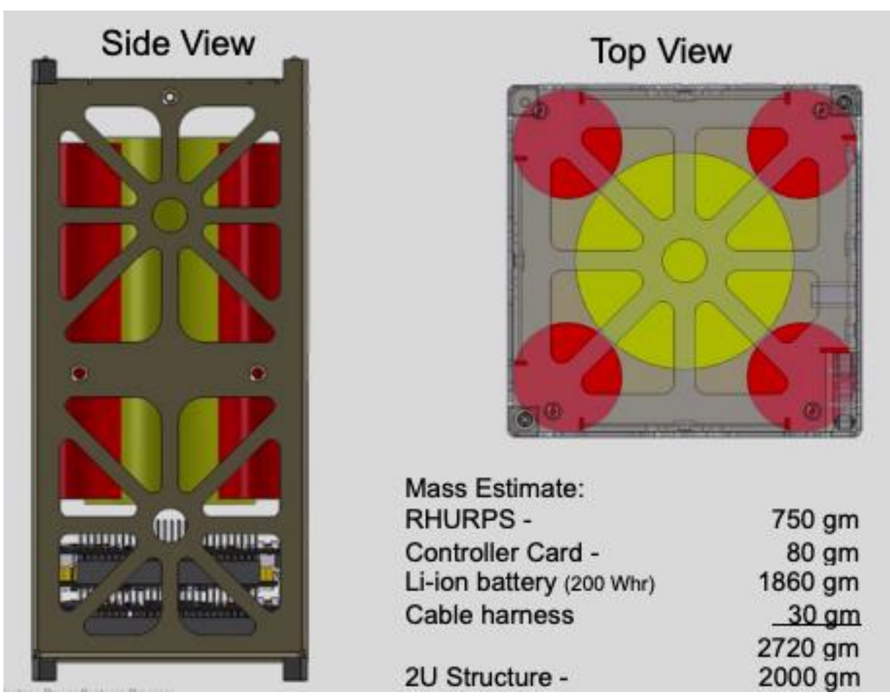


Figure 12 : 2U CubeSat Power System.

Final Estimated Budget for Theoretical Mission

The estimated budget is based on previous, current, and future interplanetary missions. This estimate is closely related to NASA's Dragonfly. Off the shelf component prices were used while more technical components such as the camera system, depth control aerogel insulation, R&D, etc. were estimated with respect to the current economic status. The table below shows the spread of the budget.

COMPONENT	ESTIMATED PRICE
Camera System	~ $1,000,000
CPU	$300,000
CubeSat & RHU	~ $1,000,000
Depth Control (Ballast Tank Design)	~ $10,000
Direct Communication	~ $100,000
Insulation	~ $100,000
Landing Gear	~ $100,000,000
Launch Vehicle	$62,000,000
Laser Altimeter	~ $10,000
Mass Spectrometer	~ $1,000,000
MMRTG	$109,000,000
Turtle R&D	~ $150,000,000
Sonar Equipment	$2,000
TOTAL: $425,000,000	

Table 7 : Total Estimated Budget.

References

[1] Moskvitch, Katia. "Astrophile: Titan Lake Has More Liquid Fuel Than Earth." *NewScientist*, 13 Dec. 2013, www.newscientist.com/article/dn24754-astrophile-titan-lake-has-more-liquid-fuel-than-earth.

[2] Amos, Jonathan. "Titan Probe's Pebble 'Bash-Down.'" *BBC News*, 12 Apr. 2005, news.bbc.co.uk/1/hi/sci/tech/4417503.stm

[3] Schulze-Makuch, Dirk, and David h. Grinspoon. "Biologically Enhanced Energy and Carbon Cycling on Titan?" *Cornell University*, 19 Jan. 2005, arxiv.org/ftp/physics/papers/0501/0501068.pdf

[4] Layton, Laura. "Saturn System Moves Oxygen From Enceladus to Titan." *NASA*, 7 Jan. 2010, www.nasa.gov/mission_pages/cassini/whycassini/saturn20100701.html.

[5] National Research Council of the National Academies. "The Limits of Organic Life in Planetary Systems." *The National Academies of Sciences Engineering Medicine*, 2007, doi:10.17226/11919.

[6] Dunbar, Brian. "Saturn System Moves Oxygen from Enceladus to Titan." *NASA*, NASA, https://www.nasa.gov/mission_pages/cassini/whycassini/saturn20100701.html.

[7] "Titan Mare Explorer." *Wikipedia*, Wikimedia Foundation, 16 Sept. 2021, https://en.wikipedia.org/wiki/Titan_Mare_Explorer#Similar_mission_concepts.

[8] "Titan - Exploration." *NASA*, NASA, 26 June 2019, https://go.nasa.gov/3oDWYEi

[9] *Dragonfly - Lpi.usra.edu*. https://www.lpi.usra.edu/opag/meetings/opag2020fall/presentations/Turtle_6017.pdf.

[10] "Collecting Moon Rocks." *Collecting Moon Rocks: Sample Collection Tools*, https://www.lpi.usra.edu/lunar/samples/apollo/tools/index.shtml.

[11] *Shibboleth Authentication Request*, https://agupubs-onlinelibrary-wiley-com.libproxy.sdsu.edu/doi/epdf/10.1029/2020JE006558

[12] *Dragonfly: A Rotorcraft Lander Concept for Scientific ...* https://dragonfly.jhuapl.edu/News-and-Resources/docs/34_03-Lorenz.pdf.

[13] *NASA Mars Internal Resources - NASA's Mars Exploration ...* https://mars.nasa.gov/internal_resources/788/.

[14] Loff, Sarah. "CubeSats Overview." *NASA*, NASA, 22 July 2015, https://www.nasa.gov/mission_pages/cubesats/overview.

[15] Talbert, Tricia. "Dragonfly." *NASA*, NASA, 26 Dec. 2019, https://www.nasa.gov/dragonfly/frequently-asked-questions/index.html.

[16] "Shopping." *CubeSatShop.com*, 13 Aug. 2021, https://www.cubesatshop.com/.

[17] *Low Power Long Life Radioisotope Power Systems - USRA*. https://www.hou.usra.edu/meetings/leag2016/eposter/5081.pdf.

[18] Schulze-Makuch, Dirk, and David h. Grinspoon. "Biologically Enhanced Energy and Carbon Cycling on Titan?" *Cornell University*, 19 Jan. 2005, arxiv.org/ftp/physics/papers/0501/0501068.pdf.

[19] Chakraborty, Soumya, et al. "Introduction to Submarine Design." *Marine Insight*, 8 Jan. 2021, https://www.marineinsight.com/naval-architecture/introduction-to-submarine-design/.

[20] "NASA Mars internal resources - NASA's mars exploration ..." Available: https://mars.nasa.gov/internal_resources/788/.

[21] "Low-Power Radioisotope Power Systems for Future Smaller Spacecraft and Low-Cost Missions" *NASA*, NASA https://nesf2014.arc.nasa.gov/sites/default/files/poster-pdfs/Cataldo_Robert.pdf.

[22] "An Overview of on-Board Computer (OBC) Systems Available on the Global Space Marketplace." *Satsearch Blog*, 14 Oct. 2021, https://blog.satsearch.co/2020-03-11-an-overview-of-on-board-computer-obc-systems-available-on-the-global-space-marketplace.

[23] "How the Mars Microrover Radios and Antennas Work." *NASA*, NASA, https://mars.nasa.gov/MPF/rovercom/itworks.html#lander-radio.

[24] "Radiation-Hardened Electronics." *BAE Systems | United States*, https://www.baesystems.com/en-us/product/radiation-hardened-electronics.

[25] Hendrix, Amanda R, and Yuk L Yung. "Energy Options for Future Humans on Titan." *Journal of Astrobiology & Outreach*, Astrobiol Outreach, 16 June 2017, https://arxiv.org/ftp/arxiv/papers/1707/1707.00365.pdf#:~:text=Despite%20the%20distance%20from%20the,source%20of%20power%20on%20Titan.

[26] Wei, H. Y. "Unusually Strong Magnetic Fields in Titan's Ionosphere: T42 Case Study." *Advances in Space Research*, vol. 48, no. 2, 2011, pp. 314–22, doi:10.1016/j.asr.2011.02.009.

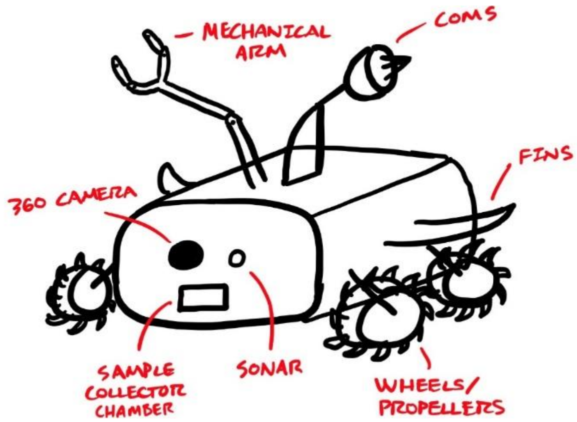
[27] Meha Patel 26 Jan. "Falcon 9, Falcon Heavy and Starship." *The Space Techie*, 12 Sept. 2020, https://www.thespacetechie.com/falcon-9-falcon-heavy-and-bfr/.

[28] SpaceX. "Falcon Users Guide - SpaceX." *Falcon User's Guide*, https://www.spacex.com/media/falcon_users_guide_042020.pdf.

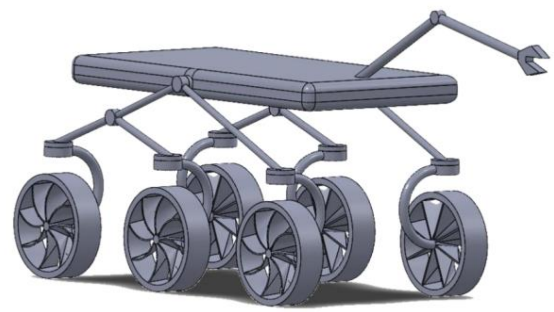
Appendices

[1]Kraken Mare is the largest of the lakes on Saturn's moon, Titan. Kraken Mare extends about 1000 km in the north and about 300 m deep with undiscovered possibilities of potential life.

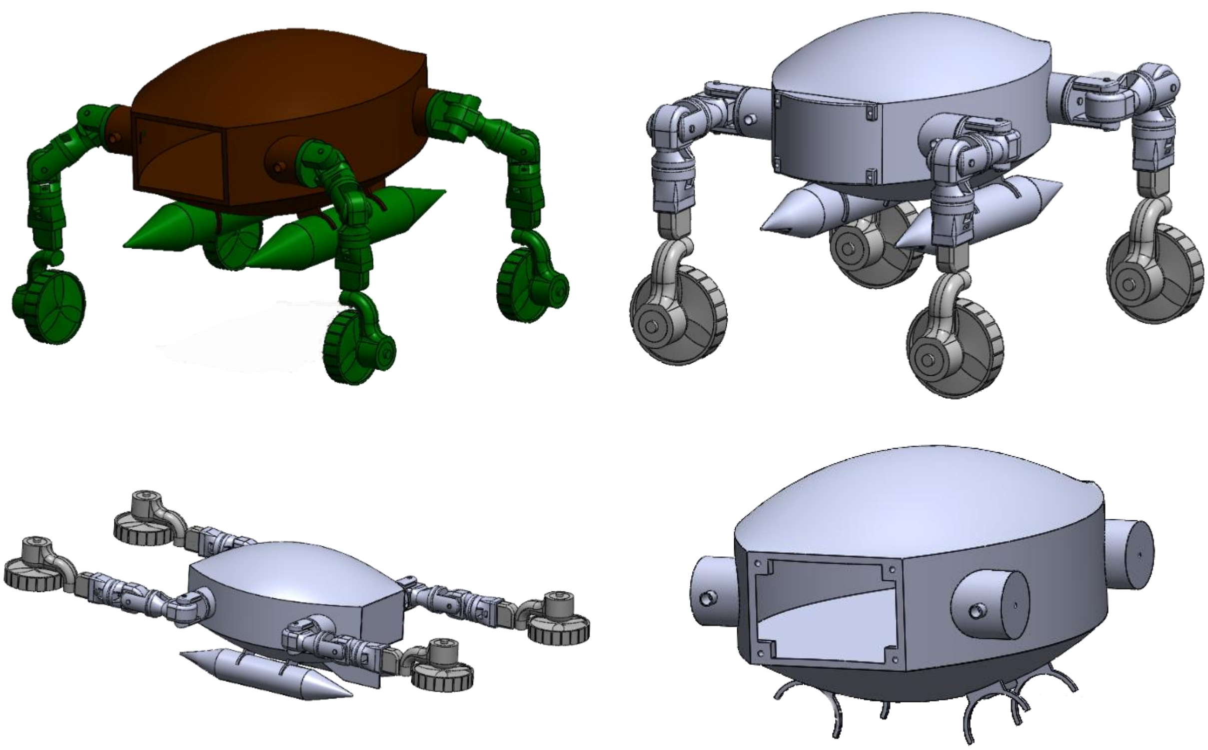
Turtle Z - M1



Turtle Z – M2



Turtle Z – M3 (Flight Model)



Biosketches

Thomas Tran – Team Lead

I am a fourth year Aerospace student with a double major in Astronomy here at San Diego State University. I am originally from a small town in the Bay Area called Castro Valley, where I graduated from Castro Valley High School. I am currently the Vice-Chairman for SDSU's AIAA branch and the president for the Schwartz Astronomical Society. I work for the Femineer® program at SDSU as a student intern. I hope to use all skills I have acquired in my four years of Aerospace Engineering to apply towards our mission to Titan. For this project, I wanted to stray away from the more common missions to Mars. I have always had a passion for space and exploring the greater depths of our solar system. Titan is like Earth in many ways, so I really wanted to design a mission to explore the moon for signs of life.

Riley Martin – STK Commissioner

I am a senior aerospace engineering student at San Diego State University, and I graduated from La Costa Canyon High School. I am currently two teachers' assistants, as well as a lab assistant under Professor Bani Younes. I feel my lab experience will add value into the budget making and real-life problems that have occurred along my line of work. I feel my value will come from problem identifying as well as advanced problem solving in astrodynamics as well. I believe our mission is creative and unique, and I do believe that with all our individual expertise, our mission will be successful.

CAD/Design Team

Kyle Switzer

I am currently a fourth year Aerospace Engineering student at San Diego State University. I graduated from Livermore High School in 2018. I am interested in space related topics, and expanding on space exploration as a species. I am excited to see how far humanity can reach in the coming decades. My favorite subject thus far has been aircraft propulsion systems which I am currently taking under Professor Pavel Popov. I work well with others, and believe I can help in a multitude of ways on our project.

Jesus Rodriguez

I am currently pursuing an Aerospace Engineering Major at San Diego State University. I graduated from Ontario Christian High School in Ontario, California. I am 21 years old and am interested in space related concepts such as astrodynamics, space travel, and astrophysics. I have studied AE 320 Astrodynamics under Professor Geoffrey Butler. Astrodynamics is my strong suit and I believe can help my group be successful in our mission.

Alexander Semon

I am a fifth-year aerospace engineering major from Kansas City, Kansas. I am currently leading the development of an experimental centrifugal pump with SDSU Rocket Project to design a pump with an overall efficiency greater than the industry limit of 88%. My abilities in working from a physics and mathematical understanding can give my group an edge in designing a highly successful unmanned rover to Titan.

Subsystems Committee

Koan Ng

I am a senior aerospace engineering student at San Diego State University. I am originally from San Francisco and graduated from Galileo Academy of Science and Technology in 2017. Relating to aerospace, I am more interested in space exploration due to the limited resources of our planet. After various coursework and cooperative projects, I believe I can contribute to multiple aspects of our mission design.

Dhruv Vij

Originally from New Delhi, India, I am a senior at San Diego State University, pursuing a degree in Aerospace Engineering. I graduated from Shri Ram School Aravali in 2018 and came to the United States to pursue my undergraduate education.

Alexander Donabedian

I am a fifth year, Aerospace Engineering major here at San Diego State University, originally from northern California. I currently do research in aerospace structures, and I hope to help develop a reliable spacecraft that will be sufficient in succeeding the objectives of our mission with the theories I have learned along the way.