Preliminary Design Review Final Report

Chris Ngirumpatse, Ethan Kuo, Jonah Wilkes,
Marko Nikoletic, Shreyas Suresh, and Yasmin Alaya

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I. Executive Summary

The TITANIC mission will aim to study the methane cycle on Titan and relay data collected to Earth. This mission will involve the usage of the SLS Block 1B to deliver the payload, consisting of one semi-submersible data collection vehicle and three supporting relay satellites, into orbit around Titan. TITANIC is expected to collect data for at least two months after its six year journey to Titan, providing valuable insight into the unique nature of this moon.

The environment of Saturn's moon Titan is of incredible interest to the scientific community, and the TITANIC mission could transform the understanding of environments beyond Earth. The Cassini-Huygens mission showed that Titan's surface is strikingly similar to Earth's - with rivers, lakes, and seas of liquid ethane and methane. Titan's climate allows the methane to form clouds, and precipitate in a cycle similar to that of Earth's water cycle. Methane and nitrogen are both able to form a variety of complex organic compounds, so Titan is an ideal place to begin a search for life beyond Earth. Taking samples of the liquid lakes and measurements of atmospheric data could provide insight into the interaction of known molecules in a unique environment. Nitrogen and methane interact uniquely in cold conditions, and theories of molecular evolution could be tested through the collection of real data.

To collect this data, the TITANIC mission will send a semi-submersible lake lander to one of Titan's largest lakes. The submersible, nicknamed "JACK," will roam the lake for an estimated two months, during which it will sample the dense nitrogen-rich atmosphere and the methane lakes. Its sonar capabilities will provide accurate mapping of the lake, improving our understanding of how these lakes may have formed and their similarities to Earth lake formation. These measurements will refine our understanding of extraterrestrial body formation and possibly even provide our first clues to the building blocks of new life.

JACK will be supported by three communication and relay satellites orbiting Titan: a primary relay and transport satellite named ROSE, and two supplementary communication satellites named PHILLIPS and SMITH. These satellites will collect the data recorded by JACK each day, and relay this information back to Earth through the Deep Space Network (DSN) for further Earth study. Each satellite will travel in a phased, inclined orbit such that JACK will be in constant communication with at least one satellite, ensuring that no recorded data is lost. Three satellites also provide redundancy in case of failure.

This report will provide a comprehensive outline of each aspect of the TITANIC mission. It will start with a Mission Timeline, outlining each significant event during the mission. From there, the TITANIC Trajectory will be described including justifications for each maneuver. The Propulsion systems required for each event are determined next, along with the overall Configuration required to achieve TITANIC's goals. This configuration requires Structural considerations, along with Attitude Determination and Control System determinations for each maneuver throughout the mission. The Power requirements are evaluated next, and finally the design is confirmed for Thermal security.

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Mission Overview

Titan is of incredible importance to the scientific community for its unique environment, with a dense nitrogen atmosphere and vast methane-ethane lakes.

TITANIC is a mission intended to study the unique nature of Titan's lakes along with the methane cycle of this moon.

TITANIC is designed to sail the lakes of Titan and collect samples of the dense atmosphere and liquid surface, refining our understanding of extraterrestrial body formation and will possibly even provide the first clues to the building blocks of new life.

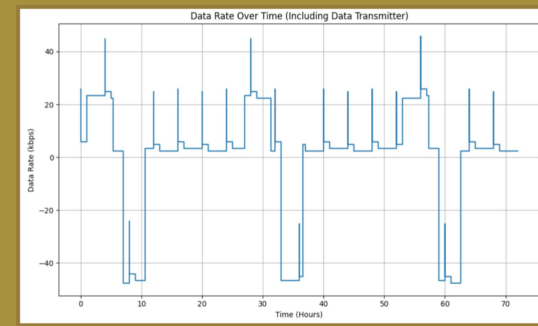
Key Objectives

A	Environmental-based methane study
B	Surface survey

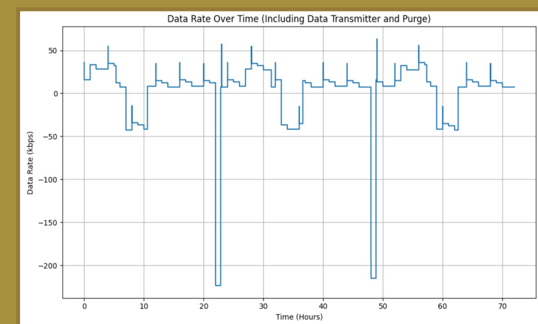
Key Observation Methods

	Instruments	Purpose
A	GCMS	Environmental Sampling
	ENV-TULTRA	Temperature Measurements
B	Oculus M370s	Sonar Imaging
	Raptor Imager	Photography

Data Collection



Total Earth Transmission Data rate

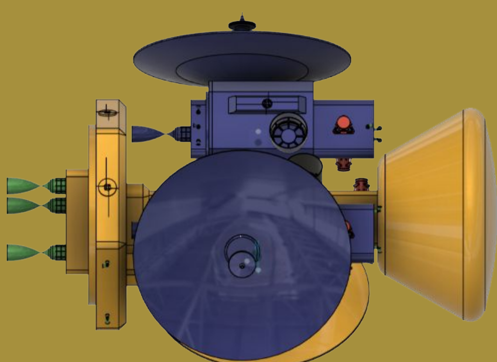


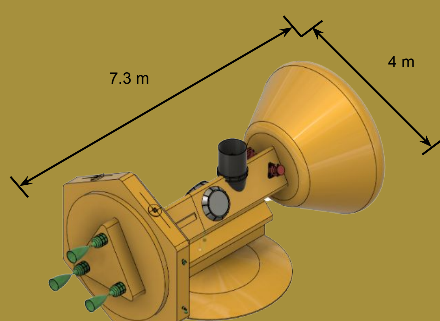
Total Orbiter Transmission Data rate

Key Components

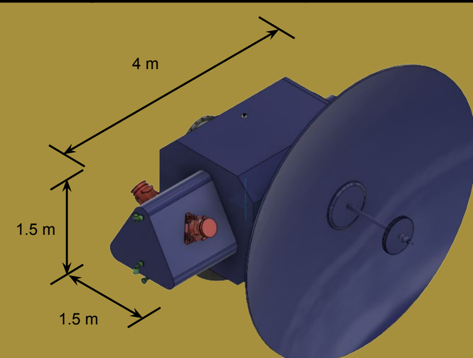
Components	Dry Mass (kg)	T (Average)	Purpose
JACK Semi-Submersible	997.25	20 °C	Surface Data Collector and Imager
Smith & Phillips Satellites	320	25 °C	Orbital Information Relay to Earth
Rose Satellite	505	30 °C	Primary Control Device, Secondary Relay
Aeroshell	2607.7	30 °C	Aerobraking Shield

Spacecraft Configuration

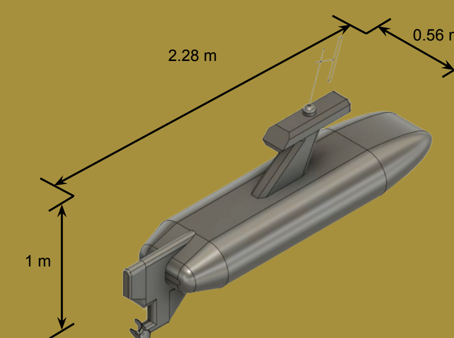




ROSE



SMITH and PHILLIPS



JACK

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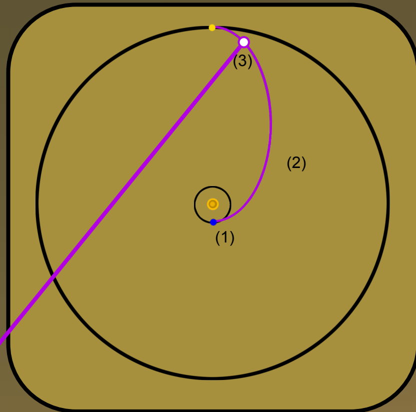
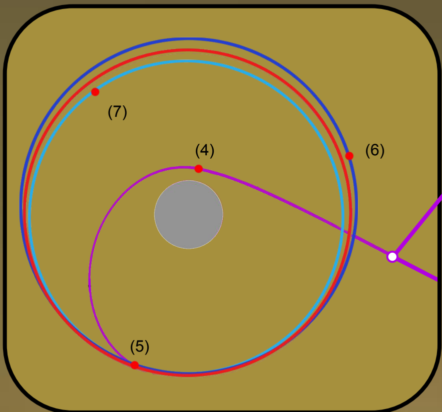
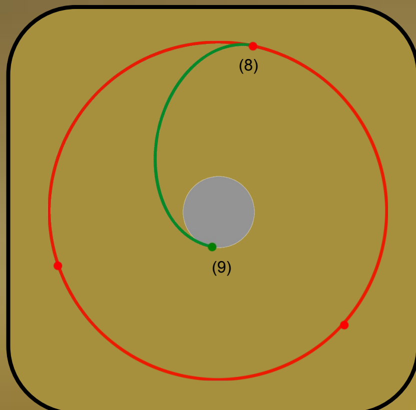


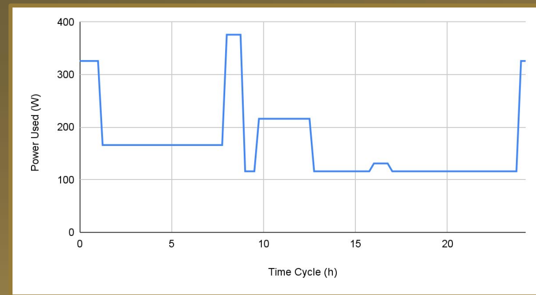




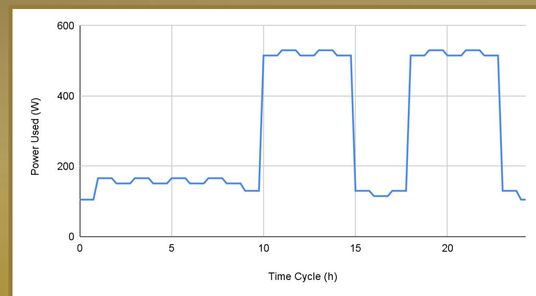
Phase	Date
1: Launch	01-May-2028
2: Interplanetary Coast	02-May-2028
3: Titan Entry	02-Jun-2034
4: Aerocapture	03-Jun-2034
5: Circularization Burn	04-Jun-2034
6: PHILLIPS deployment	05-Jun-2034
7: SMITH deployment	05-Jun-2034
8: JACK separation	16-Jun-2034
9: Splashdown	17-Jun-2034
Mission Termination	17-Aug-2034
Full Mission Duration	2300 days

Power Generation

Internal Power generation will stem from RTGs in each component.



Power Generation for each Satellite



Power Generation for JACK

Uplink/Downlink Rates

Uplink (Earth-to-Orbiters)	
Signal Spacing	**240 kHz**
Link	**Frequency**
Earth -- PHILLIPS	33.9998 GHz
Earth -- ROSE	34 GHz
Earth -- SMITH	34.0001 GHz
Downlink (Orbiter-to-Earth)	
PHILLIPS -- Earth	31.9998 GHz
ROSE -- Earth	32 GHz
SMITH -- Earth	32.0001 GHz
Uplink (JACK-to-Orbiters)	
JACK -- PHILLIPS	8.1996 GHz
JACK -- ROSE	8.2 GHz
JACK -- SMITH	8.2003 GHz
Downlink (Orbiter-to-JACK)	
PHILLIPS -- JACK	8.3997 GHz
ROSE -- JACK	8.4 GHz
SMITH -- JACK	8.4003 GHz

III. Member Contributions

Chris Ngirumpatse Chris was in charge of all power budgeting determinations, as well as mass budget contributions through selecting instruments and equipment. Chris began with assisting in determining which devices were required to achieve the proper measurements and compiling their data sheets to assess all requirements. Through a focus on the power requirements of each component, power sources were determined for each element and power budgets assigned. From there, the full power budget for each element of the mission could be determined, with power generation and power consumption rates being modeled.

Ethan Kuo: Ethan was responsible for designing the communication links between Earth and the three orbiters (ROSE, SMITH, and PHILLIPS), as well as designing the link between the orbiters and the lake-lander JACK. This involved creating a dynamic model to simulate communication link performance throughout the entire duration of the mission. Once successfully modeled, Ethan was responsible for selecting specific antenna hardware solutions that met the link margin, antenna gain, and transmission power requirements. Finally, Ethan was responsible for designing the spacecraft's/lake-lander's external and internal configurations. He used the CAD software Fusion 360 to aid in the design process.

Jonah Wilkes: Jonah was responsible for designing the mission trajectory, planning the timeline, computing propulsive maneuver and fuel requirements, as well as performing ADCS computations. The mission trajectory design consisted of orbital simulation and ΔV analysis, confirming aerobraking maneuver feasibility and orbital deployment methods. Once the trajectory had been completed the mission timeline was established for each mission phase and incorporated into other essential aspects of the mission, including communication and power budgets. Once base payload masses had been computed via other team members, Jonah used the ΔV requirements to compute fuel requirements and the eventual launch vehicle. From these final mass computations and further vehicle dimensions determined by other team members, ADCS maneuvers were computed to ensure each maneuver was feasible for the desired control system element - including thrusters for aerobraking and reaction wheels for repointing. Jonah was in charge of ensuring each aspect of trajectory, fuel, and attitude determination was scientifically sound.

Marko Nikoletic: Marko did the initial thermal analysis, he calculated the thermal equilibriums of the three satellites in power off conditions, meaning that no RTGs were running and producing heat. To do this he calculated the solar constant at 9.5AU's. He then calculated the temperature with the additional heat produced by the RTGs, ensuring that the overall temperature remained within the range of operation of our instruments. Marko selected the paint that the spacecraft was coated in to get the correct absorptivity and emissivity for the spacecraft to stay within the allowed temperature limit. Marko also calculated the temperature of the JACK semisubmersible, once again making sure that the interior temperature remained within the operational limit of the sensors onboard. He also calculated the buoyancy of the lakelander, helping in the overall design of the craft. Lastly, he calculated the masses of both the lakelander and the aeroshell.

Shreyas Suresh: Shreyas was in charge of the devices aboard the JACK lander. This involved finding the precise model for each required device, alongside feasible data rates, operation procedures, and environmental requirements for each device. This was done by first determining what instruments were needed based on the mission's parameters, goals, and constrictions. Once this was done, and the precise models were found, research began into the specifics of each model. Data sheets created by the manufacturers of each device were investigated to find critical information, such as operating temperature, data rates, and power consumption. These values would be implemented into thermal, communication, and mass budgeting respectively. This data would be used to create models of information transfer between Earth, the three orbiters around Titan, and the JACK lander itself.

Yasmin Alaya: Yasmin was in control of calculating the amount of data collected on each respective component of the mission. This consisted of finding the functioning data rates for the instruments on each satellite and lake-lander with respect to the duration of time it is on. With this information determined, the amount of data collected per Titan day was able to be computed and adjusted to fit into the transmission rates. Once this was calculated, an analysis of the system had to be done to recalculate the data collected per day with compressions of a couple of the instruments. The compressions were chosen to prove efficiency and proper transmission of important data. After this, the data rates and collection were able to be dynamically modeled to visually show the patterns throughout the duration of three Titan days. The data collection for each component of the mission can be analyzed and reformed to prioritize certain measurements over others, and therefore be altered to reach the best optimization for the systems.

IV. Mission Timeline

A. Overview

The TITANIC mission will embark on a 6-year journey to Saturn's largest moon, Titan, with the primary objective of exploring Kraken Mare—the Solar System's largest known liquid body outside of Earth—to elucidate Titan's methane cycle and its analogies to Earth's hydrological processes. Launched aboard an SLS Block 1B into a 500 km parking orbit, the spacecraft will execute a Hohmann transfer trajectory optimized via porkchop plots for minimal ΔV, then perform targeted aerobraking through Titan's upper atmosphere to shed excess velocity. After jettisoning its aeroshell, the vehicle will circularize into a 10,000 km Titan orbit and deploy two relay satellites, PHILLIPS and SMITH, into phase‑shifted orbits to maintain continuous communication. The lander "Jack" will then descend on a guided parachute into Kraken Mare, where it will conduct fluid sampling, sonar mapping, and in situ chemical analyses for up to two months, relaying data through the satellite constellation back to Earth. As JACK's mission concludes, the orbiters will continue surface observations until their systems can no longer operate, maximizing scientific return on Titan's unique environment.

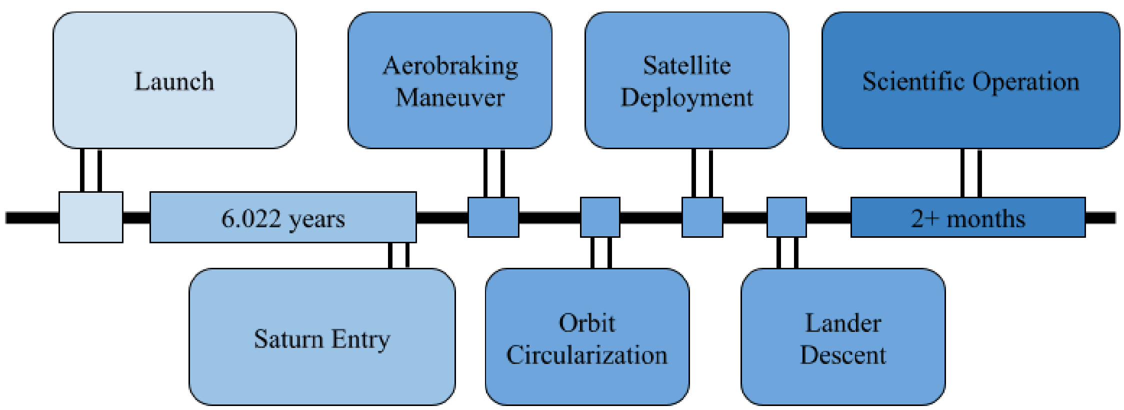


Figure 4.1: TITANIC mission general timeline

B. Target Selection

The primary target for the TITANIC mission is Titan's Kraken Mare lake, the most promising candidate for a landing site. Situated at approximately 68° N latitude and 310° W longitude, Kraken Mare is the largest extraterrestrial lake in the Solar System. Its immense size makes it ideal for the deployment of a semi-submersible data collection vehicle, while also providing abundant opportunities to study Titan's methane cycle—a process remarkably analogous to Earth's water cycle. Titan's methane cycle involves evaporation, cloud formation, precipitation, and runoff, effectively mirroring Earth's hydrological cycle but under vastly different temperature and compositional conditions. Kraken Mare offers a unique natural laboratory for observing these processes in situ: from methane rainfall patterns and surface currents to potential seasonal changes in lake level. Studying such phenomena at high resolutions will deepen our knowledge of planetary climates and inform models of habitability beyond our home planet. To achieve landing at this site, the semi-submersible must be launched from Earth through a support vehicle containing relay satellites and a delivery aeroshell into Titan's orbit, from which it will descend to the Kraken Mare lake.

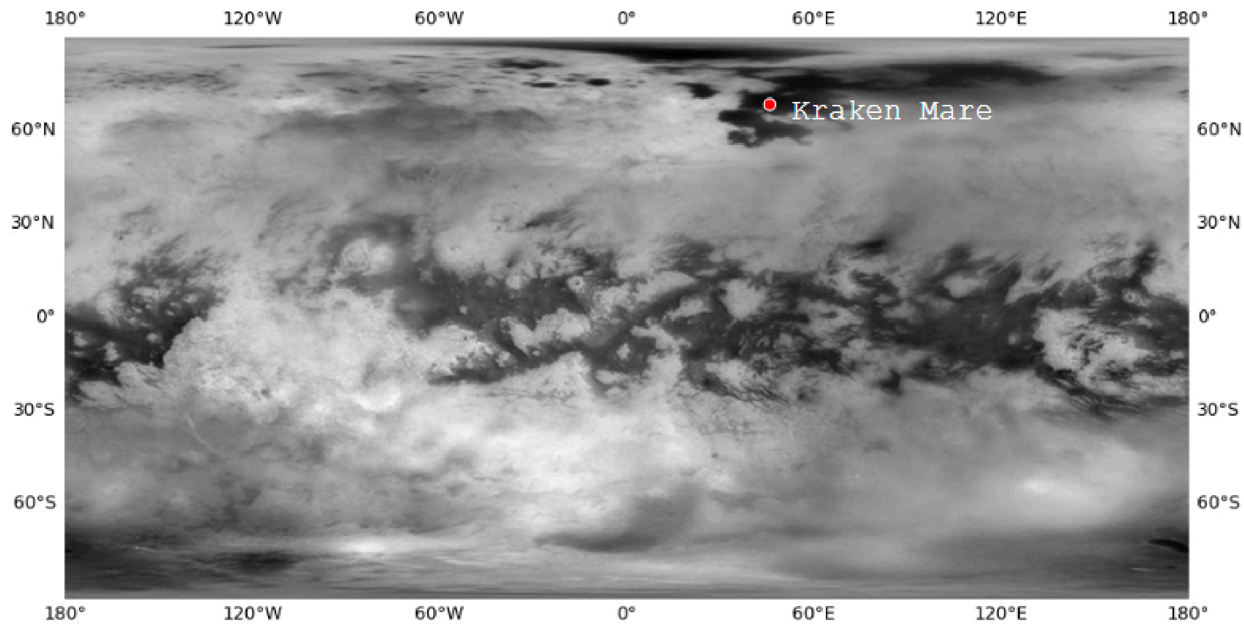


Figure 4.2: Map of Titan's surface, with the Kraken Mare Lake highlighted.

C. Launch

The mission's launch timing is chosen to coincide with the optimal Hohmann transfer trajectory to Titan, minimizing the total ΔV (characterized by the lowest C3 energy) while maintaining a single, well-timed burn. Porkchop plots generated for Earth-to-Saturn trajectories highlight launch opportunities where Earth's and Titan's orbital positions align to reduce propellant requirements. Selecting the best window also provides ample time for spacecraft assembly, testing, and integration at the launch site. We begin our porkchop plot analysis by assuming we have the opportunity to launch over the next four years, focusing on launch dates from 2026 through 2029. We find three primary ideal opportunities for direct Hohmann transfers within that window, as outlined in **Figure 4.3**. The simple Hohmann transfer window coincides with a C3 value of approximately 107 km^2/s^2.

The May 2028 launch date was chosen both for the minimum C3 requirement and time it gives to build the elements of this mission. With a launch date of May 2028, TITANIC will arrive at Titan in July of 2034.

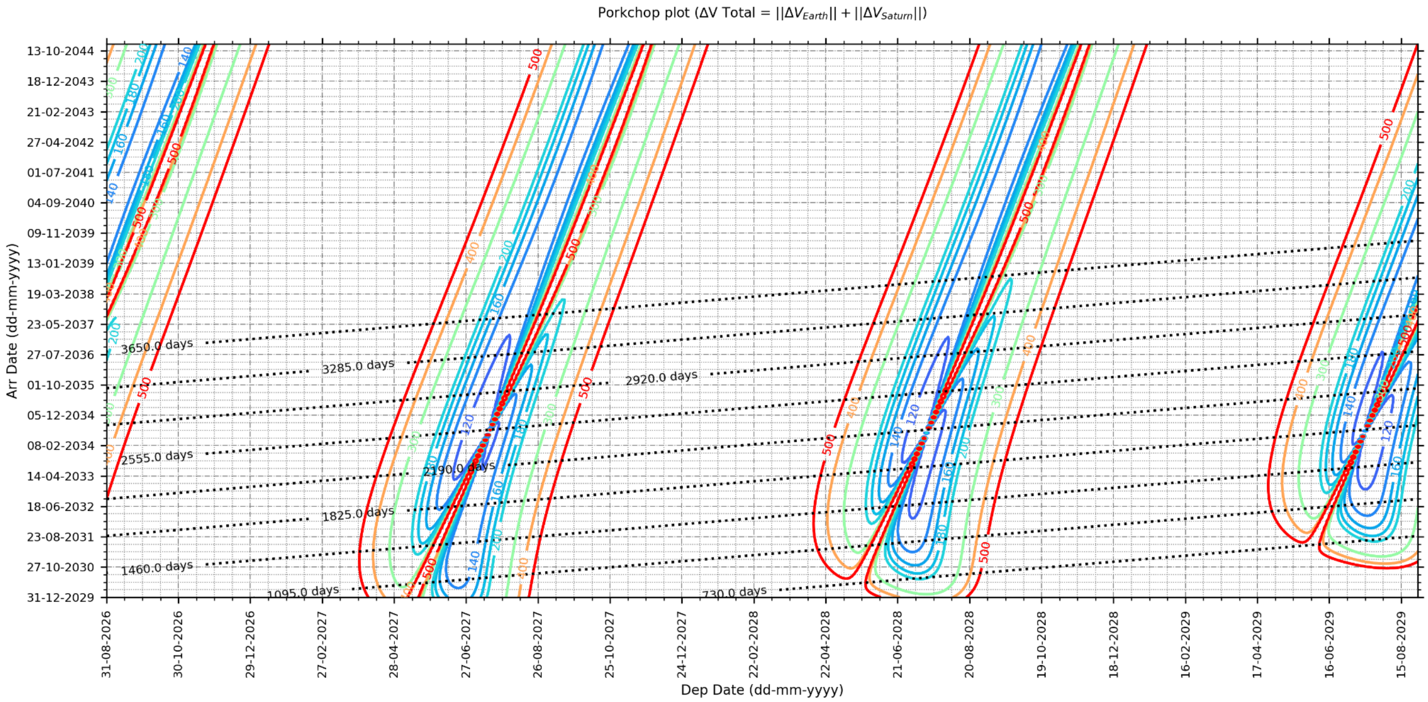


Figure 4.3: Porkchop Plot showing Launch C3 Values between launch dates of 2026 through 2029

Launch will occur in May of 2028. The launch vehicle will lift off from Cape Canaveral, riding the first stage into a 500 km altitude LEO parking orbit during which it will confirm its location and prepare for its second boost. The second stage boost to Saturn Transfer Orbit (STO) will occur shortly after LEO insertion, after which the second stage will separate and the upper fairing will open to release the full spacecraft. Throughout the Launch and Interplanetary Insertion burns, the spacecraft will be in its initial Launch Configuration mode, consisting of a total shutdown of all systems. All science instruments will be shut down and all outer elements will be stowed. Once the secondary burn has been completed and fairing released, the central transit computer in ROSE will activate to begin Interplanetary Transfer.

D. Interplanetary Transfer

After the second stage has been burned and jettisoned along with the outer fairing, the spacecraft will consist of an aeroshell covering each key component of the mission. STO transit will occur over the span of just over 2223 days (6.088 years) and will require periodic communication with the Deep Space Network (DSN) for possible velocity adjustments. At this point the spacecraft will enter Interplanetary Cruise mode, during which the primary computer of ROSE will be the central control system. ROSE will periodically reorient the spacecraft's outer shell to repoint the patch array toward Earth's location for communication. ROSE will also be in charge of any course correction maneuvers required throughout transit. All other mission components will be completely shut down during this phase.

E. Aerobraking

After the spacecraft has entered Saturn's Sphere of Influence, it will fall into Saturn's gravity well until it intercepts Titan. ROSE will use minor course corrections to ensure this intercept occurs properly. Upon entering Titan's atmosphere the spacecraft will use its aeroshell with a leading heat shield to cut a major portion of its velocity and achieve Titan orbit capture. Onboard sensors will monitor deceleration and pressures, allowing for real-time adjustments to attitude and pointing. Deviations up to 5 degrees are expected and will be corrected via attitude control thrusters located on the outer hull of the craft, as detailed in the ADCS plan. At this point the TITANIC will experience a communication blackout with Earth, and the craft will switch to Aerobraking Mode. ROSE will be controlling the ADCS based on sensor feedback and will monitor outer hull telemetry for later information transfer and further analysis back on Earth. Entry will occur over the last month of the transfer period, with the aerobraking maneuver accounting for mere hours. Again, all other instruments from SMITH, PHILLIPS, and JACK will be deactivated at this time.

F. Circularization

After sufficient aerobraking has reduced the spacecraft's apoapsis, the aeroshell is jettisoned to expose the propulsion stage and scientific payload. The spacecraft transitions into Orbit Correction Mode to align for the circularization burn, which includes final orbital insertion and any remaining inclination adjustments needed to achieve a near‑equatorial 10,000 km Titan orbit. A precisely timed hydroxide propellant burn completes circularization. Once the orbit is stabilized, the PHILLIPS and SMITH relay satellites will be switched on, fully powered, and undergo system checks - preparing them for phased deployment into their respective operational orbits. ROSE will still be the primary control system for this maneuver, directing burn times and eventual deployment. This maneuver will take approximately 12.144 hrs between aerobraking and apoapsis burn.

G. Satellite Deployment

Over a period spanning 10.44 to 11.18 days post‑circularization, the PHILLIPS and SMITH satellites are sequentially released. PHILLIPS undergoes a slight retrograde burn to achieve its designated relay orbit, while SMITH performs a brief prograde burn for phase separation. These maneuvers establish a 120° phase-shifted constellation, optimizing continuous communication coverage with the eventual lander positioning. ROSE will enter Observation mode after releasing PHILLIPS and SMITH, and begin observations of Titan. ROSE will survey the surface for the proper landing site, preparing for the release of JACK. ROSE will undergo periodic repointings toward Earth utilizing its High Gain Antenna (HGA) during communication. SMITH and PHILLIPS will each enter Deployment Mode, during which their internal systems will provide timing for their eventual correction burns. They will also be utilizing this time to perform system checks and ensure each system is working properly. After 10.44 days, PHILLIPS will perform its prograde burn, and after 11.18 days, SMITH will perform its retrograde burn to re-circularize each orbit. After this point, SMITH and PHILLIPS will also enter Observation Mode for moon observation and Earth communication. JACK will also begin power up sequences to prepare for its descent.

H. Lander Descent

Once ROSE has confirmed landing coordinates and trajectories based on positioning from its cameras and star tracking systems, ROSE commands the release of JACK. The semi-submersible performs a burn to enter a controlled free-fall trajectory, using its heat-shield casing to shed heat through atmospheric interaction until it reaches a predetermined altitude. At this point, the heat shield will be jettisoned and JACK will release its parachute to slow descent into Kraken Mare. JACK will activate its sensors immediately, collecting atmospheric and surface data until splashdown. During descent, JACK will be in Descent Mode: onboard instruments record temperature, pressure, and composition profiles, storing data for later transmission. SMITH, PHILLIPS, and ROSE will each remain in Observation Mode - continuing satellite operations, observations of Titan, and periodic communication with the DSN and Earth.

I. Scientific Operation

Once afloat, JACK transitions to Scientific Observation Mode. It conducts fluid-sampling, sonar mapping of lake depths, and in situ chemical analysis of methane and ethane composition. Power and thermal systems are designed to sustain operations for an estimated 31–62 days in Titan’s frigid environment. ROSE, PHILLIPS, and SMITH support JACK by entering Data Relay Mode: they alternately point toward JACK and Earth to store and downlink science packets. A combination of continuous and scheduled communications minimizes blackout risks and maximizes data return.

J. End of Life

JACK is only estimated to survive on TITAN for at most 62 days (2 months). This is due to the harsh environment and a number of unknown factors. As JACK’s ability to collect and transmit data ceases, the relay satellites will continue surface observations until their own systems degrade. JACK will remain in Scientific Observation Mode until its transmission systems no longer function. At this point, ROSE, PHILLIPS, and SMITH will switch back to Observation Mode, capturing additional imaging and any possible sensor data of Titan until their own systems finally degrade. Periodic HGA repointings will remain the method of communication through the end of each satellite's lifetime, marking the close of the TITANIC mission's exploration of Titan and Kraken Mare.

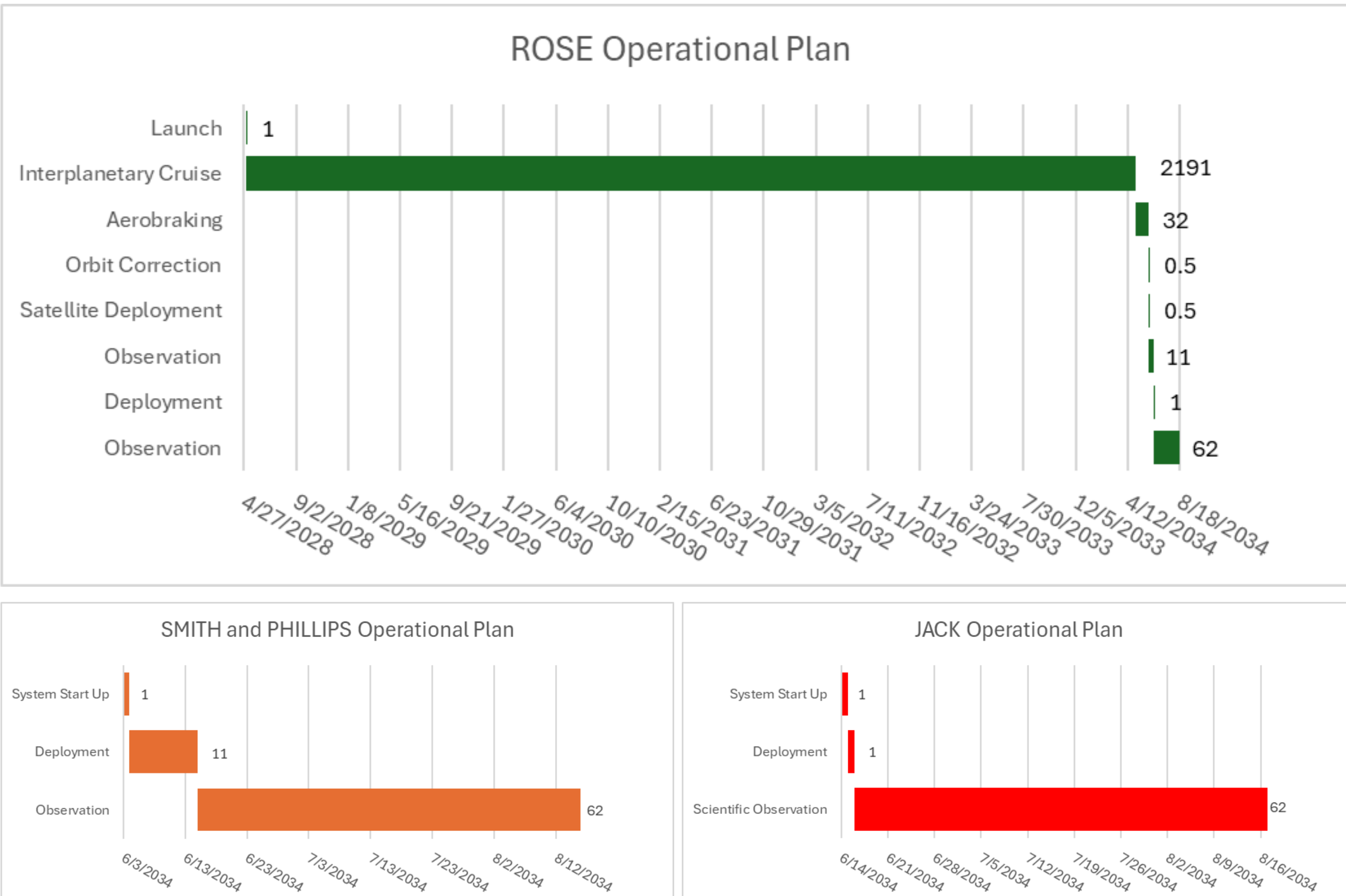


Figure 4.4: Gantt Charts for each Mission Element: ROSE, SMITH and PHILLIPS, and JACK. The vertical axis represents each operating Mode, and with each element including the number of days for expected operation.

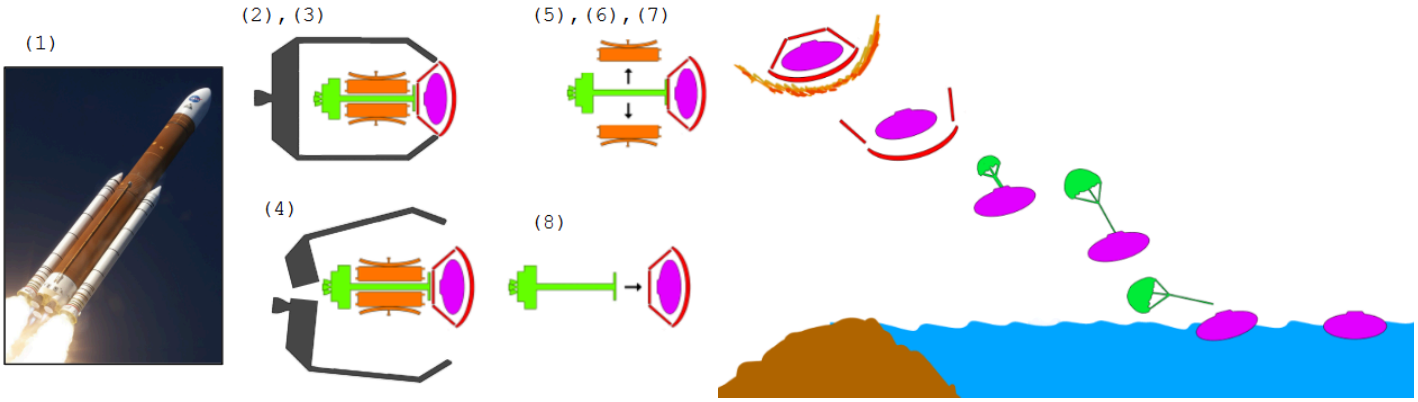


Figure 4.5: Mission Phase depiction

V. Mission Trajectory

A. Launch

The mission begins with a launch to a 500 km low Earth orbit (LEO), requiring an initial ΔV of approximately 8.000 km/s to account for both ascent velocity and atmospheric drag. This corresponds to a characteristic energy (C3) of about 107 km^2/s^2. Achieving a stable 500 km orbit at roughly 7.6167 km/s provides an optimal staging point for the interplanetary transfer injection burn. Once in LEO, the spacecraft can perform final checks, adjust its attitude, and, if necessary, wait for the precise departure window before executing the second-stage boost of 7.2856 km/s to inject onto a Saturn-transfer trajectory. A schematic of the two-phase ascent—from Earth's surface to LEO and then into transfer—is shown in **Figure 5.1**.

Total ΔV burn requirement for Launch: **+8.000 km/s**

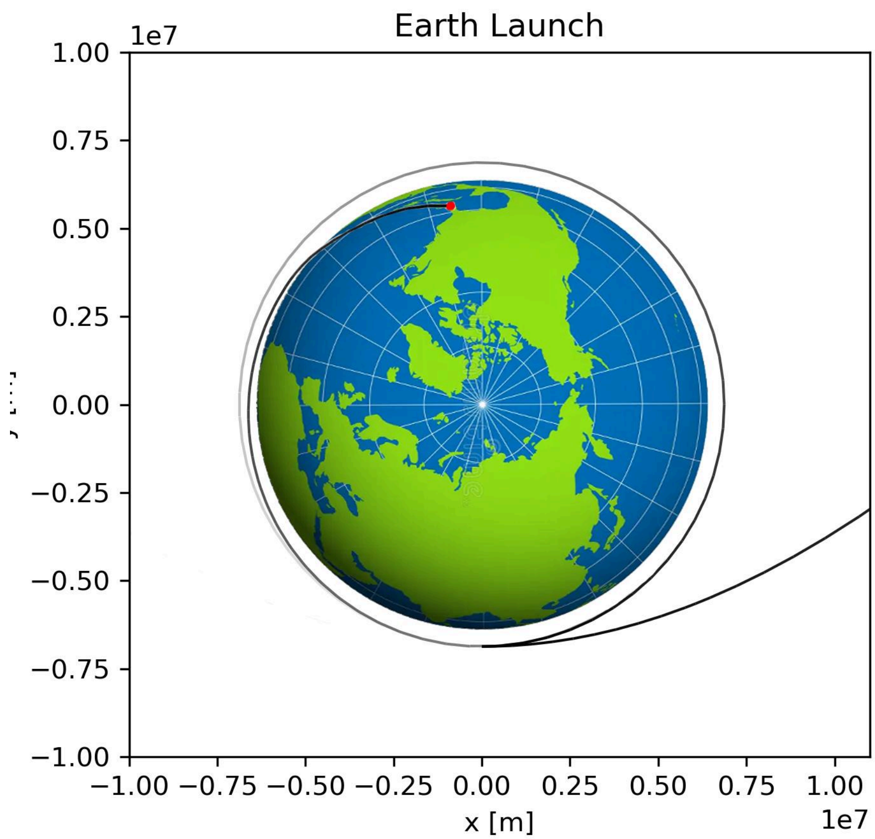


Figure 5.1: Earth Launch to 500 km altitude LEO and subsequent secondary stage boost Trajectory.

B. Interplanetary Transfer

Following orbit checkout, the spacecraft executes a 7.2856 km/s burn from LEO to depart Earth's gravity well and enter the Hohmann-like transfer to Saturn. During the coast phase, periodic trajectory correction maneuvers (ROSE burns) refine the path to ensure accurate arrival at Saturn's sphere of influence (SOI). Upon crossing into Saturn's SOI, the spacecraft velocity is approximately 4.2025 km/s relative to Saturn. It then "falls" inward along an elliptical capture trajectory toward Titan's orbital distance of about 1.2 million km, reaching a hyperbolic excess speed of roughly 8.9294 km/s at Titan's encounter. **Figures 5.2** and **5.3** depict the Earth-to-Saturn transfer and the inbound trajectory from Saturn SOI down to Titan's orbit, respectively.

Total ΔV burn requirement for Interplanetary Transfer: +7.2856 km/s

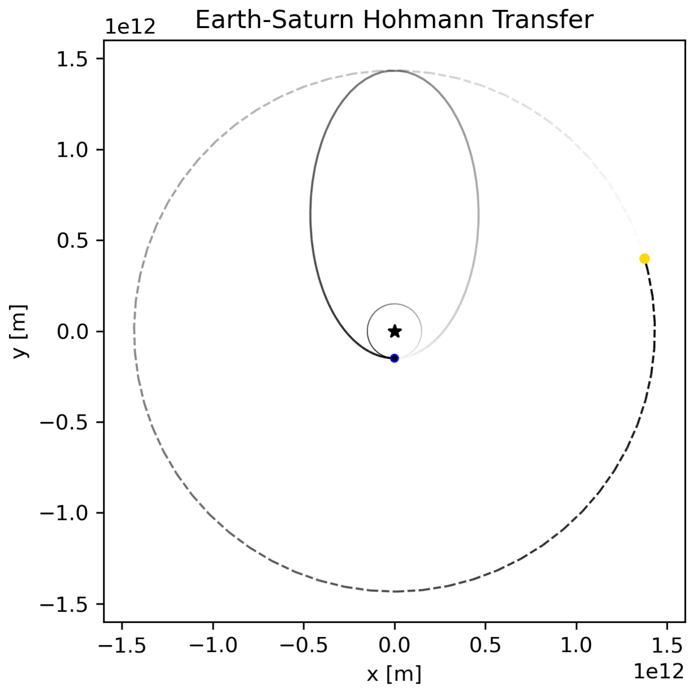


Figure 5.2: Earth-Saturn Interplanetary Transfer trajectory. Earth (blue) and Saturn (yellow) are at their initial positions relative to each other for launch. The Hohmann transfer trajectory is displayed between the two orbits.

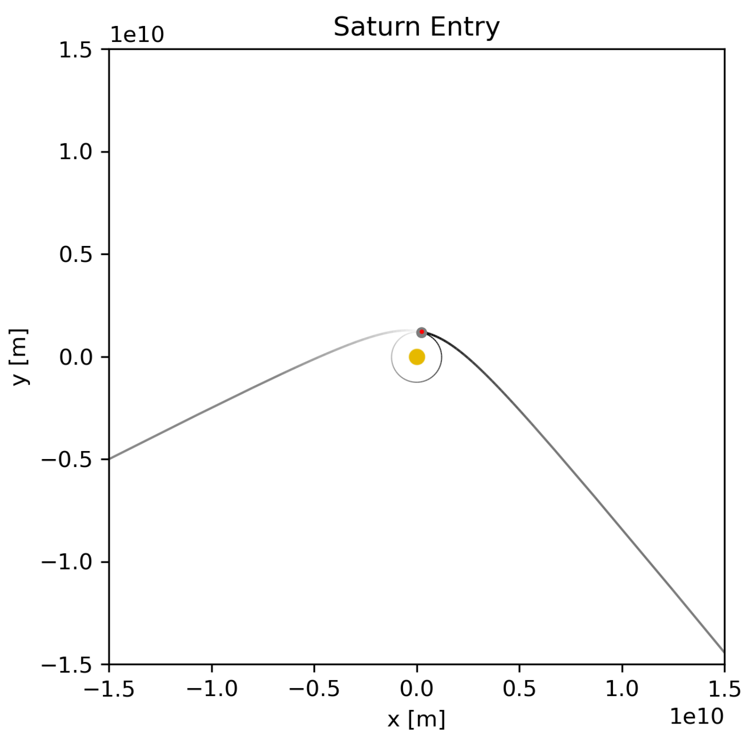


Figure 5.3: The Saturn Entry trajectory is depicted with Saturn (yellow) at the center. The Satellite (red) follows the hyperbolic trajectory depicted here and intercepts Titan (gray)

C. Aerobraking

Upon Titan approach, the spacecraft's inbound velocity relative to Titan is about 3.3583 km/s (subtracting Titan's orbital speed of 5.5711 km/s). The vehicle performs a single aerobraking pass at an altitude of 100 km above Titan's surface, leveraging the dense nitrogen-methane atmosphere to dissipate roughly 1.3808 km/s of velocity over the course of one hour. This maneuver lowers the apoapsis to the mission's target of 10,000 km without expending propellant. The aerobraking trajectory and resulting orbit adjustment are illustrated in **Figure 5.4**.

Total ΔV burn requirement for aerobraking: **0 m/s**

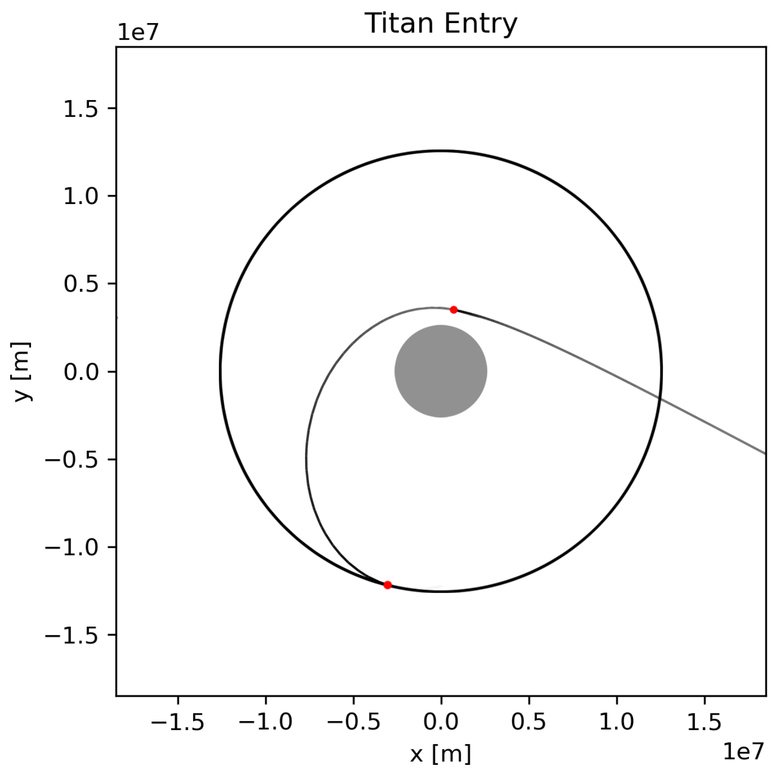


Figure 5.4: Titan Entry Trajectory depicting the two event points (red) during this phase. The spacecraft travels on a hyperbolic trajectory to its aerobraking point, and from there progresses to its circularization burn point.

D. Circularization

After aerobraking, the spacecraft coasts to apoapsis at 10,000 km altitude over approximately 12 hours. During this coast, the aeroshell is jettisoned to expose the propulsion module for the circularization burn. A ΔV of 282.74 m/s is then applied to circularize the orbit at 10,000 km, with any residual inclination trimmed to achieve the 75° orbital inclination required for optimal satellite deployment. Once the spacecraft achieves the desired orbit, system checkouts for the PHILLIPS and SMITH satellites commence. The circular orbit and visibility coverage plot are revisited in **Figures 5.4** and **5.5**.

Total ΔV burn requirement for circularization: +282.74 m/s

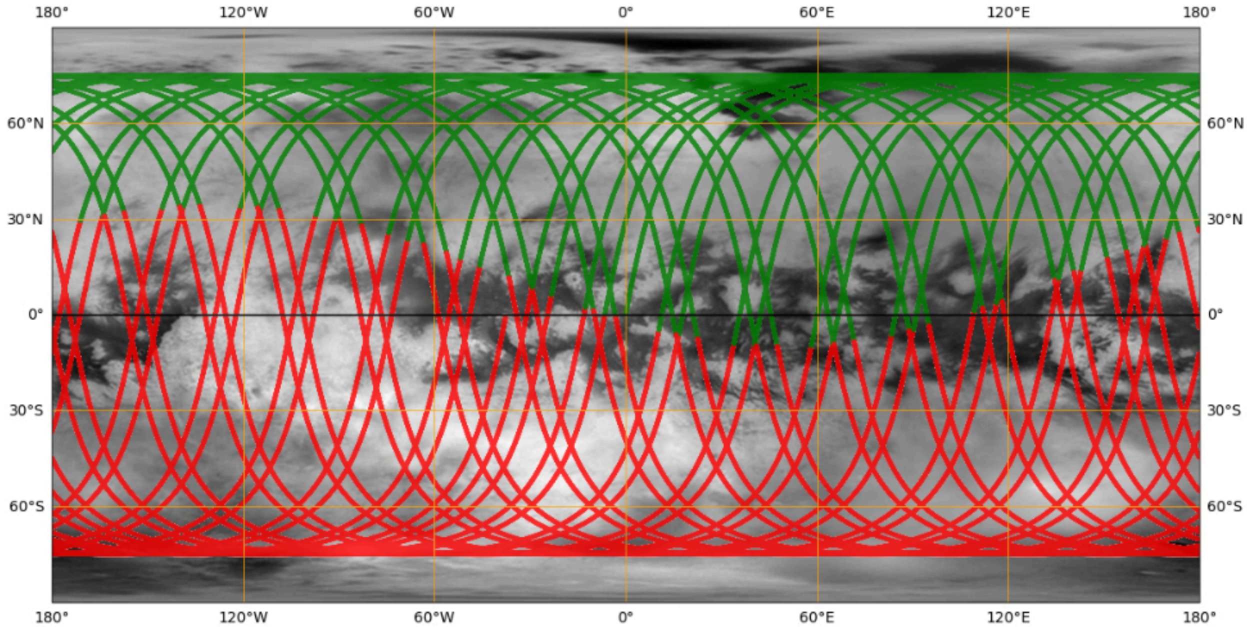


Figure 5.5: Visibility plot for the 10000 km altitude, 75 degree inclination orbit each satellite will orbit Titan in. This is one ground track for one satellite over the course of 31 days, or about half of the expected observation mission. Each orbit will have a clear period of visibility, and thus communication with the lander JACK at Kraken Mare.

E. Satellite Deployment

With the primary orbit established, the carrier vehicle (ROSE) sequentially deploys the PHILLIPS and SMITH satellites. PHILLIPS executes a 9.7130 m/s retrograde burn to initiate its phase-shift insertion, while SMITH performs an 18.7993 m/s prograde burn. Each satellite then completes 10 orbits before performing a secondary burn—PHILLIPS 9.7130 m/s prograde, SMITH 18.7993 m/s retrograde—to achieve their final 120° phase separation. **Figure 5.6** illustrates the deployment sequence, including the initial burn, orbital progression, and final insertion maneuvers.

PHILLIPS total ΔV burn requirement: +19.4260 m/s
SMITH total ΔV burn requirement: +37.5986 m/s

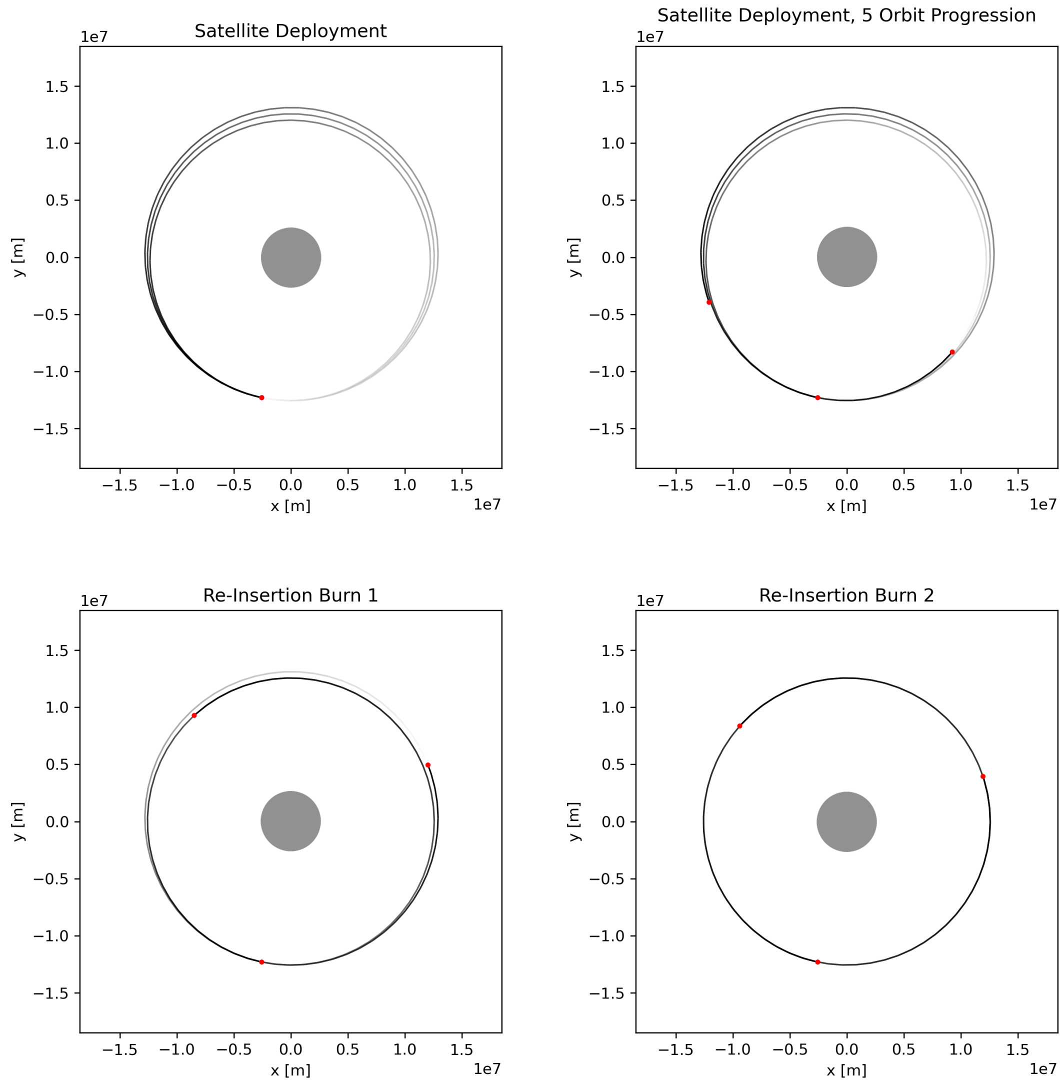


Figure 5.6: Satellite Deployment Sequence. After progressing 10 orbits, PHILLIPS will perform the first re-circularization burn at 10.44 days followed shortly by SMITH's recircularization burn at 11.18 days.

F. Lander Descent

Following satellite separation, the lander JACK prepares for descent by performing a 352.31 m/s retrograde transfer burn to lower its periapsis toward Titan's surface. An additional 538.58 m/s of ΔV will need to be reduced in order to match Titan's rotational frame to ensure a safe splashdown in Kraken Mare. The vehicle uses its heat shield to passively decelerate through Titan's atmosphere until reaching about 200 km altitude, at which point the shield is jettisoned to deploy the parachute. Descent through the atmosphere takes approximately 12 hours with the last few hours reserved for heat shield separation and parachute deployment, culminating in a splashdown on the lake surface. Titan's low gravity and the buoyancy of Kraken Mare both aid in reducing landing stresses. The descent profile is detailed in **Figure 5.7**. At this point, JACK will have reached the surface of TITAN and each relay satellite will be in continuous operation and communication with both JACK and Earth through the remainder of the mission.

Total ΔV burn requirement for lander descent: +352.31 m/s

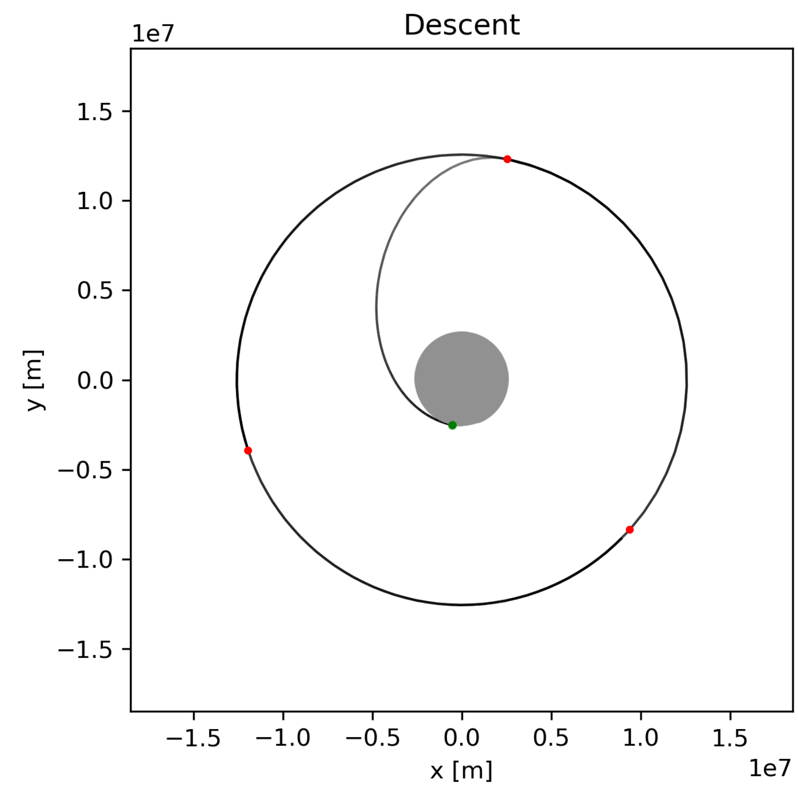


Figure 5.7: Descent trajectory of JACK after ROSE release.

VI. Propulsion

A. ΔV Requirements

To this point we have defined all our Velocity requirements in the previous section, Mission Trajectory. Collectively these elements define the sizing parameters for fuel and propulsion system performance. The events that require fuel burns are as follows:

Mission Event	**ΔV Requirement**
Launch:	8.0000 km/s
Interplanetary Transfer Boost:	7.2856 km/s
Primary Orbit Correction:	282.74 m/s
PHILLIPS:	19.4260 m/s
SMITH:	37.5986 m/s
JACK Descent:	352.31 m/s

B. Dry Mass Definitions

The next stage of propulsive calculation is the need of understanding for each payload element. These elements are detailed in the Configuration and Structure sections, and feed directly into the rocket equation to determine propellant requirements for each maneuver. The masses are as follows; for more detailed information see sections **VII** and **VIII**:

Component	**Baseline Mass**
JACK, with Heat Shield and Parachute:	1147.25 kg
PHILLIPS, before Fuel Structure:	320 kg
SMITH, before Fuel Structure:	320 kg
ROSE, without attachments:	505 kg
Aeroshell:	2607.7 kg

C. Wet Mass Determination

Propellant mass is computed using the ideal rocket equation and assumes a structural mass fraction equal to 10% of the required fuel mass. Two propellant types are specified: liquid oxygen (LOX) for the high‑thrust first and second stage boosts, and hydrazine for all attitude control, orbital corrections, and circularization maneuvers. **Table 6.1** lists the specific impulse values used in these calculations.

Table 6.1: Fuel Types and Isp values

Fuel Type		Isp (seconds)
Liquid Hydrogen	(sea level)	391
	(vacuum)	450
Hydrazine		228

Applying these ISPs to the ΔV budget yields the fuel masses required at each mission event (detailed in **Table 6.2**), which in turn determine the wet mass at each stage. Once aggregated, the stage-by-stage wet masses define the lift requirements and inform launch vehicle selection.

Table 6.2: Mission Phases and Fuel Requirements at each Event

Phase	Maneuver	Operation mode	ΔV requirement	Fuel Type	Dry Mass at Event	Fuel Usage
1	Launch to LEO	Launch	8.0000 km/s	Liquid Hydrogen	46,651.785 kg	182,212.225 kg
2	Saturn Transfer Boost	Interplanetary Cruise	7.2856 km/s	Liquid Hydrogen	7,530.269 kg	20,900.291 kg
3	Titan Entry	Aerobraking	1.3808 km/s	Aerobraking	5,440.240 kg	N/A
4	Orbit Correction	Titan Cruise	282.74 m/s	Hydrazine	2,526.762 kg	305.778 kg
5	Satellite 1 Deployment	Titan Cruise	19.426 m/s	Hydrazine	320.254 kg	2.538 kg
6	Satellite 2 Deployment	Titan Cruise	37.5986 m/s	Hydrazine	320.493 kg	4.932 kg
7	Titan Descent	Descent	352.31 m/s	Hydrazine	1,165.043 kg	177.926 kg
8	Titan Splashdown	Surface Operation	538.58 m/s	HS + Parachute	997.25 kg	N/A

D. Launch Vehicle Selection

Table 5.3 consolidates the dry, fuel, and wet masses for every mission segment, revealing an initial launch wet mass of 228,864.03 kg. Given this payload requirement to 500 km LEO—and accounting for fairing dimensions and margin—the NASA SLS Block 1B is the optimum choice. The Block 1B is one of the few fairing sizes large enough to accommodate the entire payload, including the protective aeroshell. Its certified capacity of up to 105,000 kg to LEO comfortably exceeds the mission's 46,651.97 kg payload, providing performance reserves for contingency propellant and future upgrades.

Table 5.3: Final Stage Masses, including wet masses at each Configuration.

Phase	Configuration	Dry Mass (kg)	Fuel (kg)	Wet Mass (kg)
1	Stage 1 (Launch)	46,651.79	182,212.23	228,864.03
2	Stage 2 (Transfer)	7,530.27	20,900.29	28,430.56
3	Interplanetary Coast	5,440.24	N/A	5,440.24
4	Aeroshell Release	2,832.54	N/A	5,440.24
5	Satellite Correction	2,526.76	305.778	2,832.54
6	PHILLIPS release	320.254	2.538	322.79
7	SMITH release	320.493	4.932	325.43
8	JACK release	1,165.04	177.926	1,342.97

VII. Configuration

A. Mission Configuration Evolution

Throughout the TITANIC mission, the spacecraft's configuration will undergo several evolutions. At the beginning of the mission, JACK and the three orbiters will be housed inside an aeroshell, which will be launched aboard an SLS Block 1 payload fairing. **Figure 7.1** displays a CAD model rendering of the aeroshell inside the SLS Block 1 fairing. **Figure 7.2** displays the specific dimensions of the payload fairing.

Figure 7.1: SLS Block 1 Fairing Configuration

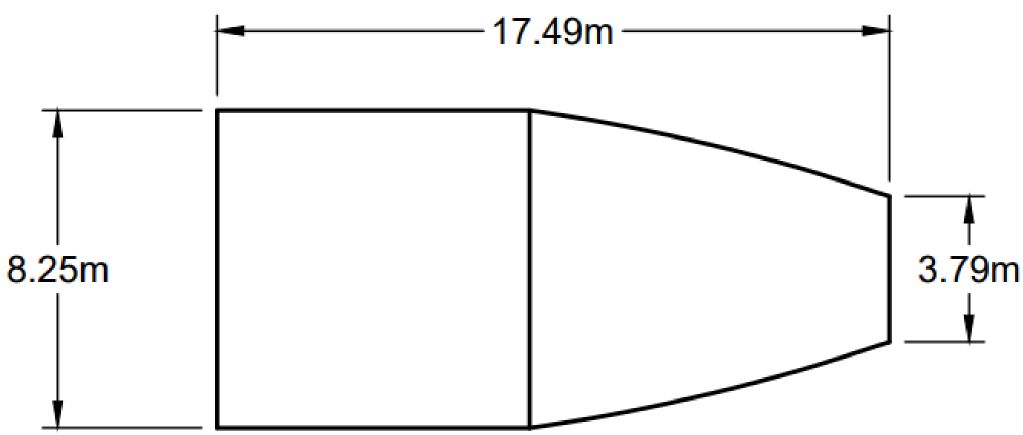


Figure 7.2: SLS Block 1 Fairing Dimensions

After the payload fairing jettisons the TITANIC spacecraft, it will continue its journey to Titan in its aeroshell configuration. **Figure 7.3A** and **7.3B** display a CAD rendering of TITANIC's aeroshell as well as ROSE's transit configuration inside. **Figure 7.4** displays the dimensions of the aeroshell.

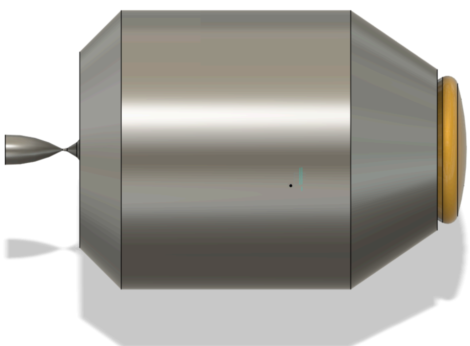


Figure 7.3A: TITANIC Aeroshell

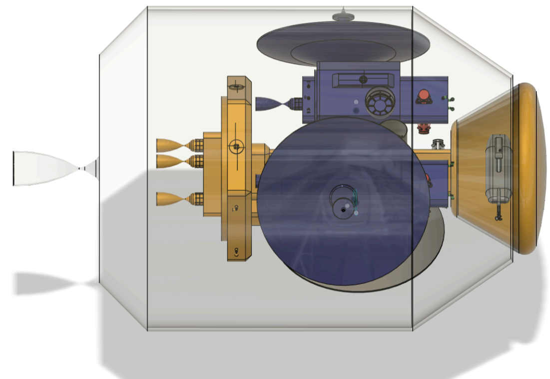


Figure 7.3B: Aeroshell Interior Configuration

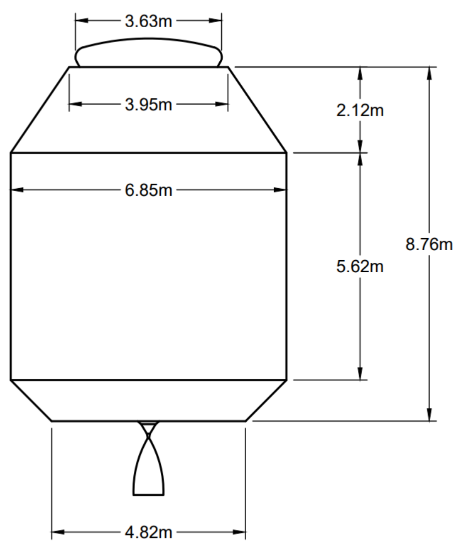


Figure 7.4: Aeroshell Dimensions

After successfully completing the aerobraking maneuver through Titan's atmosphere, ROSE will shed the aeroshell, exposing the docked orbiters (SMITH and PHILLIPS). This configuration will be briefly maintained while ROSE travels to the orbiter separation orbit position. **Figure 7.5** displays a render of the orbiter docking configuration directly after shedding the aeroshell.

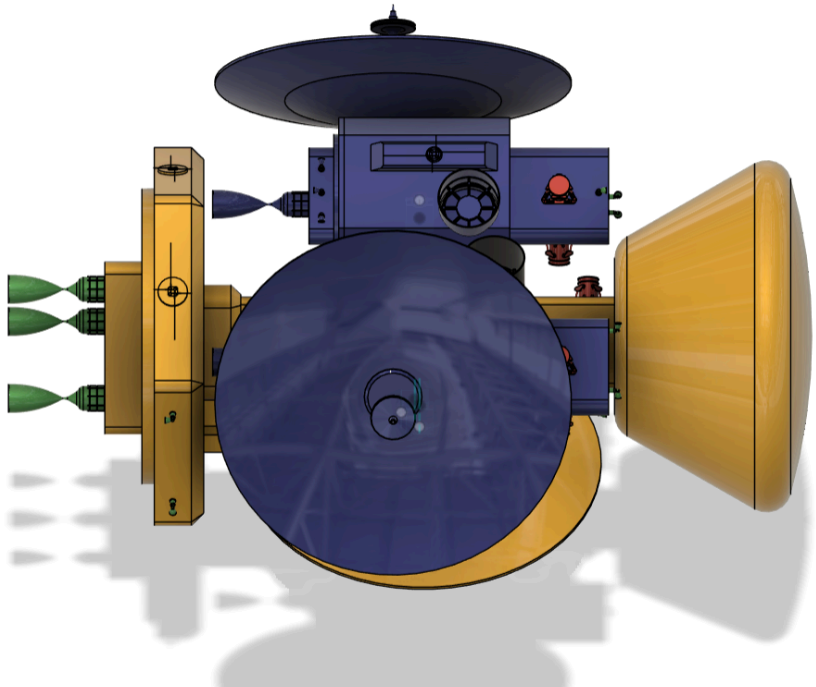


Figure 7.5: Docked Orbiter Configuration

Upon reaching the separation point, both SMITH and PHILLIPS will separate from ROSE and begin their phase change maneuvers until they reach their final orbit spacing of 120 degrees. Shortly after, JACK will descend to the Kraken Mare methane lake. Further configuration analysis will be done on each orbiter/lander.

B. SMITH & PHILLIPS Configuration

Both the external and internal configurations of SMITH and PHILLIPS orbiters are identical to one another. **Figure 7.6A** and **7.6B** display the external configuration of the SMITH and PHILLIPS orbiters. Important components are labeled. **Figure 7.7** displays the dimensions of the SMITH and PHILLIPS orbiters.

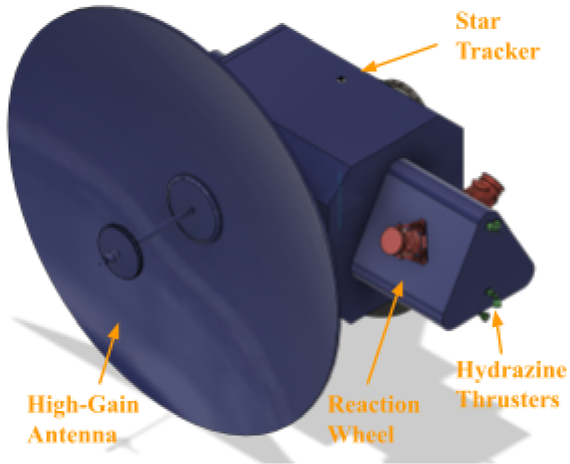


Figure 7.6A: External Configuration View 1

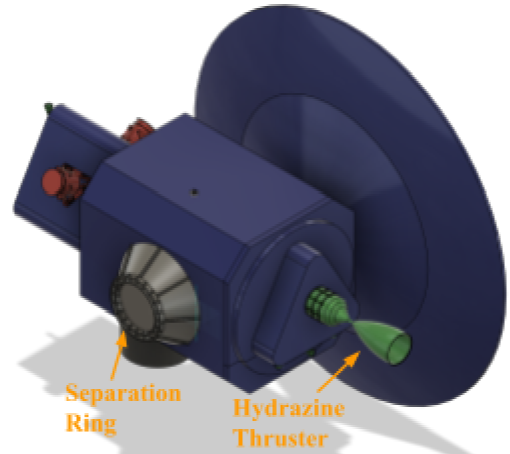


Figure 7.6B: External Configuration View 2

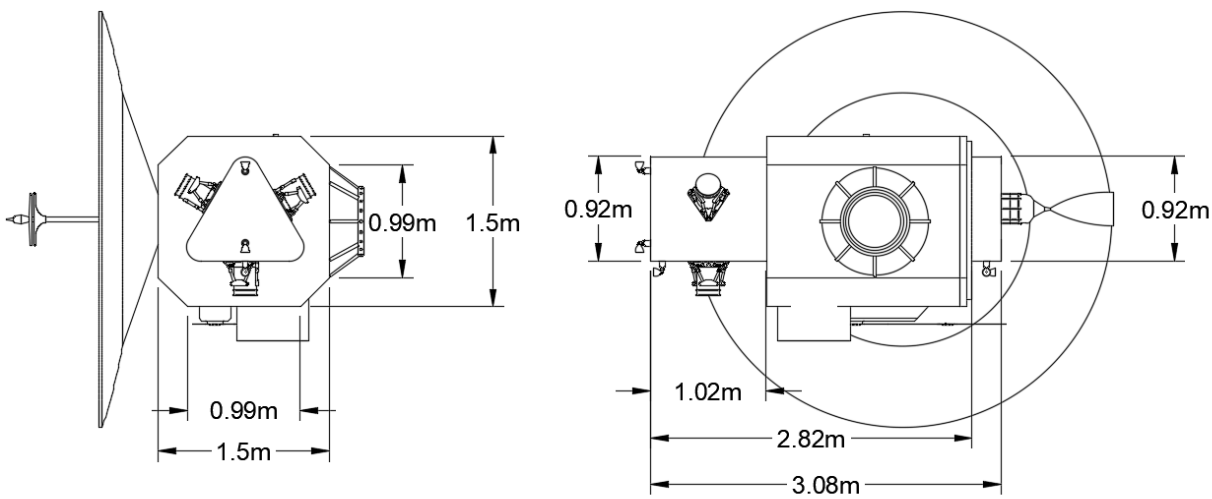


Figure 7.7: SMITH and PHILLIPS Dimensions

The interior of SMITH and PHILLIPS was optimized to reduce the overall size of each orbiter while allowing enough space for the heat emitted from the two RTGs onboard to dissipate, keeping the interior of the orbiter at a stable temperature for the various sensors and computer systems. **Figure 7.8A** and **7.8B** display a labeled interior layout view of the two orbiters.

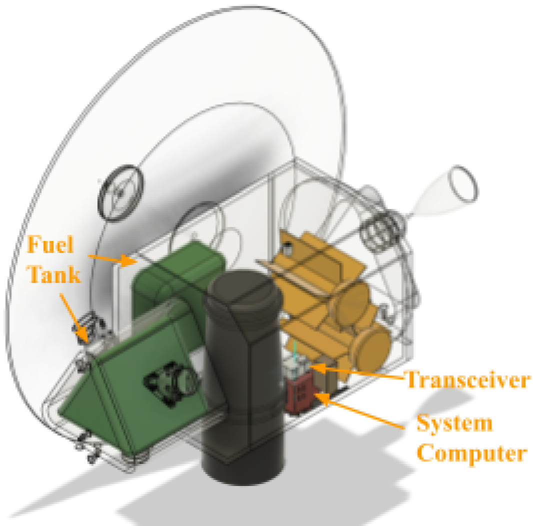


Figure 7.8A: SMITH Interior Configuration View 1

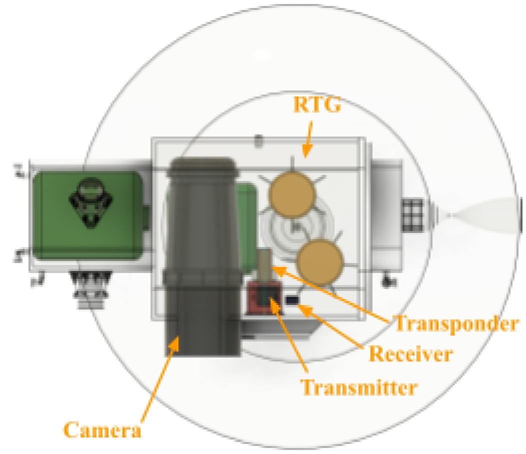


Figure 7.8B: SMITH Interior Configuration View 2

C. ROSE Configuration

The ROSE orbiter is the flagship of the TITANIC mission and will be responsible for carrying the landing module containing JACK for the entire transit duration of the mission. In addition to JACK, both SMITH and PHILLIPS will be docked to ROSE until they achieve a circular orbit around Titan. After SMITH and PHILLIPS deploy, ROSE will continue to orbit Titan until the lander is ready to be deployed. **Figure 7.9** displays a labeled rendering of the ROSE's external configuration post SMITH and PHILLIPS separation.

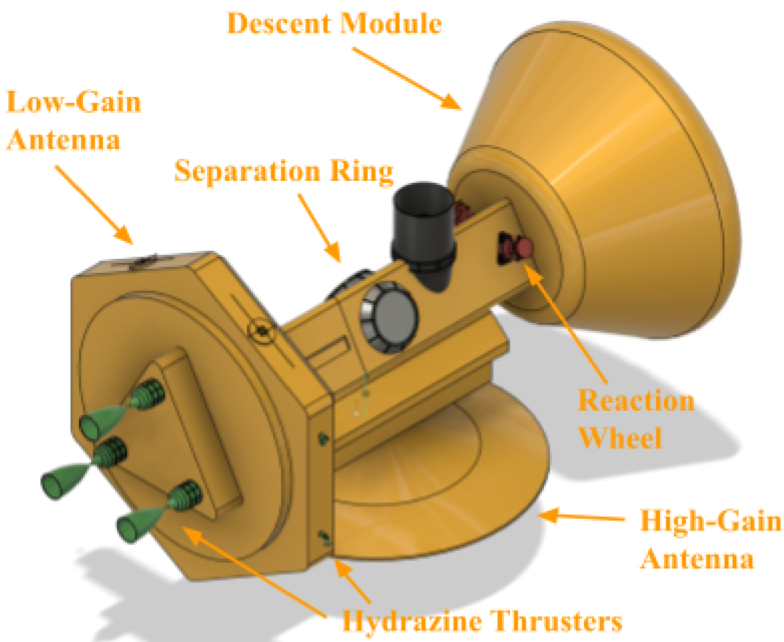


Figure 7.9: ROSE External Configuration

Another key feature of the ROSE orbiter is its size. To accommodate the docking needs of SMITH and PHILLIPS, ROSE is significantly larger than her partnering orbiters. ROSE's external dimensions are shown in **Figure 7.10**.

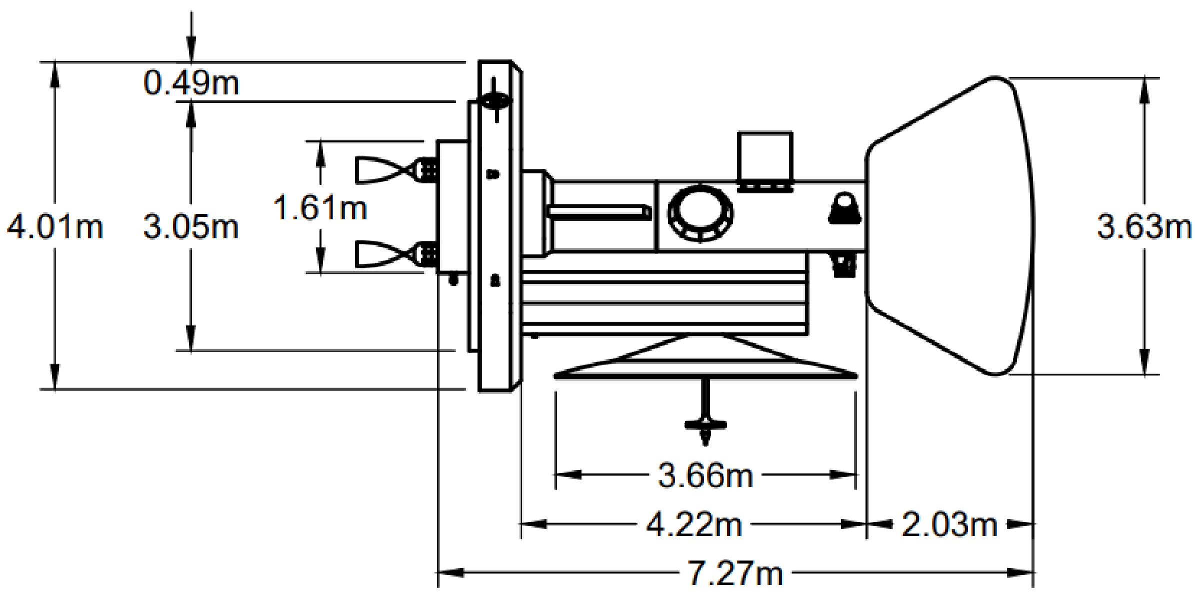


Figure 7.10: ROSE's External Dimensions

ROSE's internal configuration, while exhibiting a slightly different layout than the SMITH and PHILLIPS orbiters, contains all of the same instruments and computer systems. **Figure 7.11A** and **7.11B** show ROSE's labeled interior configuration.

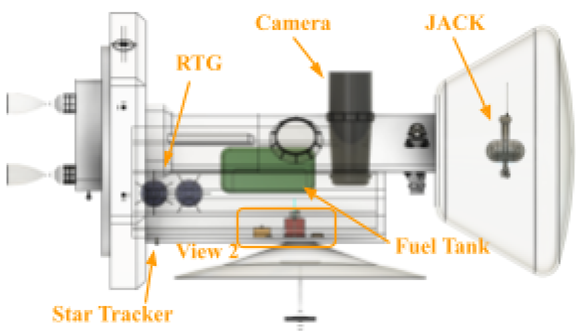


Figure 7.11A: ROSE Interior Configuration

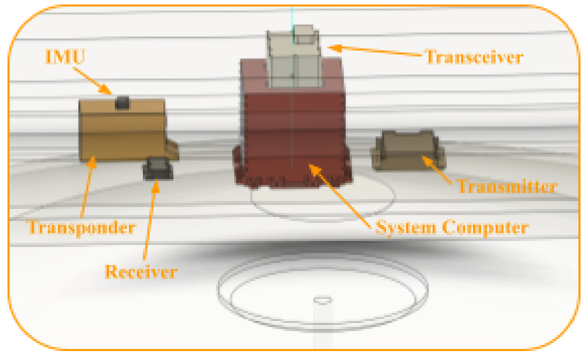


Figure 7.11B: View 2

D. JACK Configuration

After successfully descending and separating from the descent lander, JACK will immediately begin collecting scientific data on the methane lake conditions. It will spend the remainder of its service life in the configuration shown in **Figure 7.12**.

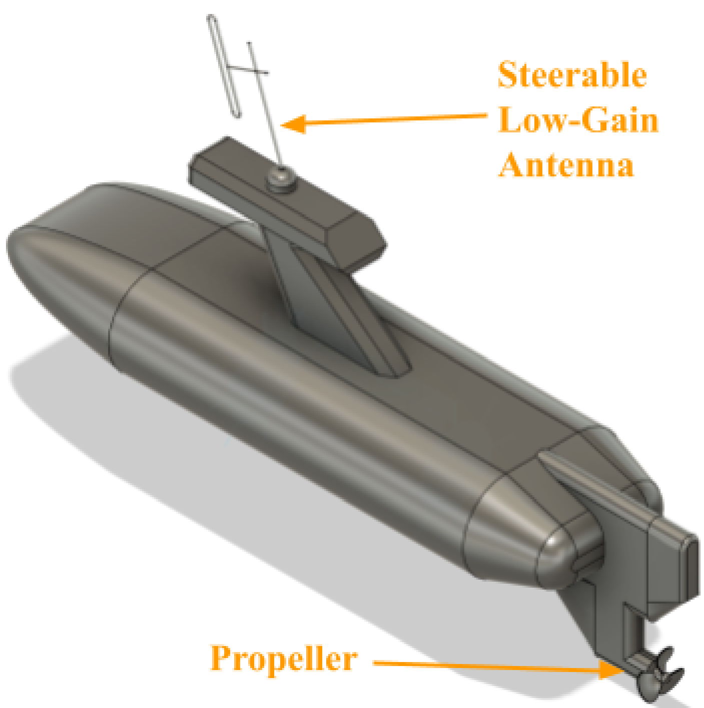


Figure 7.12: JACK's External Configuration

Figure 7.13 displays the external dimensions of JACK.

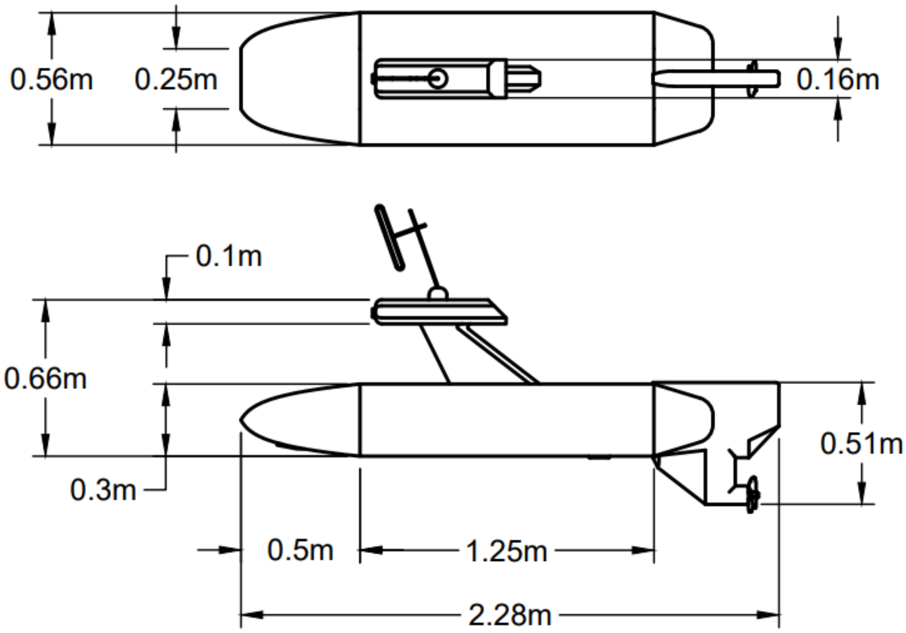


Figure 7.13: JACK's External Dimensions

To ensure that JACK was as small as possible (to reduce the required size of the descent module), JACK's interior layout is incredibly compact. Onboard the lake lander is an independent power system and motor train, data collection devices, system computers, and communication equipment. **Figure 7.14** shows a labeled view of JACK's interior layout.

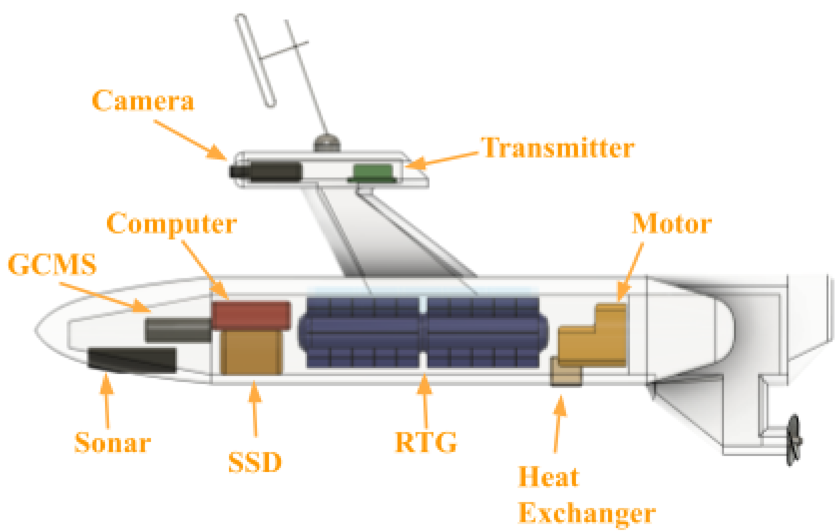


Figure 7.14: JACK's Labeled Interior Configuration

VIII. Structure

A. JACK Weight Calculations

Aluminum was chosen as the material to be used to make JACK's hull. It was chosen as it is the best blend of strength versus density, while also remaining as unreactive as possible to the methane environment. JACK's mass was calculated using the density equation ($\rho = m/V$) the probe was assumed to be a rectangle with the following dimensions: 2 meters by 0.5 meters by 0.5 meters. We calculated the surface area of the semi-submersible craft using the formula for the surface area of a rectangular prism and then multiplied by three centimeters which we determined to be the minimum safe thickness of the hull. When this was completed, we multiplied this volume by the density of the aluminum 2700 kg/m^3. Using this process, the mass of the hull was found to be 735 kilograms. We compiled all the equipment and instruments that JACK would need to complete the mission successfully and found the weights of each of those on their respective data sheets, adding it to the overall weight calculation. The weight of the instruments was found to be approximately 260 kilograms, leading to JACK's total weight being around 995.7 kilograms. We deemed this weight acceptable, as it falls well within the limits of our launch capabilities.

B. Buoyancy Calculations

The density of liquid methane is approximately half that of liquid water. Due to this phenomenon, we had concerns as to where the methane line would be on JACK, and how this could potentially compromise our mission. As such, we decided to calculate the volume of liquid methane JACK would need to displace to stay afloat. Buoyancy is calculated using the following equation, commonly known as Archimedes' Principle:

$$F_b = - \rho g V$$

Equation 8.1: Archimedes' Principle

F_b is the buoyant force, which is the same as the mass thanks to the gravitational term on the right side of the equation. The aforementioned g term is the acceleration of gravity on Titan, which was found to be 1.352m/s^2. Density of liquid methane was found to be 422.6 kg/m^3. We solved for V, which is the volume of liquid displaced. The volume was found to be just over 2.3 meters cubed for a craft that is about 1 ton. This means that the "methane line" would be almost at the top of JACK's hull, putting the craft in danger of filling up with liquid, sinking it or ruining our sensors. As such we decided to design our probe as a semisubmersible. Designing the probe as a semi-submersible craft solves this problem, as it can no longer be sunk by methane entering the craft. Another added benefit of this is that waves would have a far smaller impact on JACK, as he cannot capsize if hit by a large wave. Waves do create a problem, as it is theorized that they form on the surface of Kraken Mare.

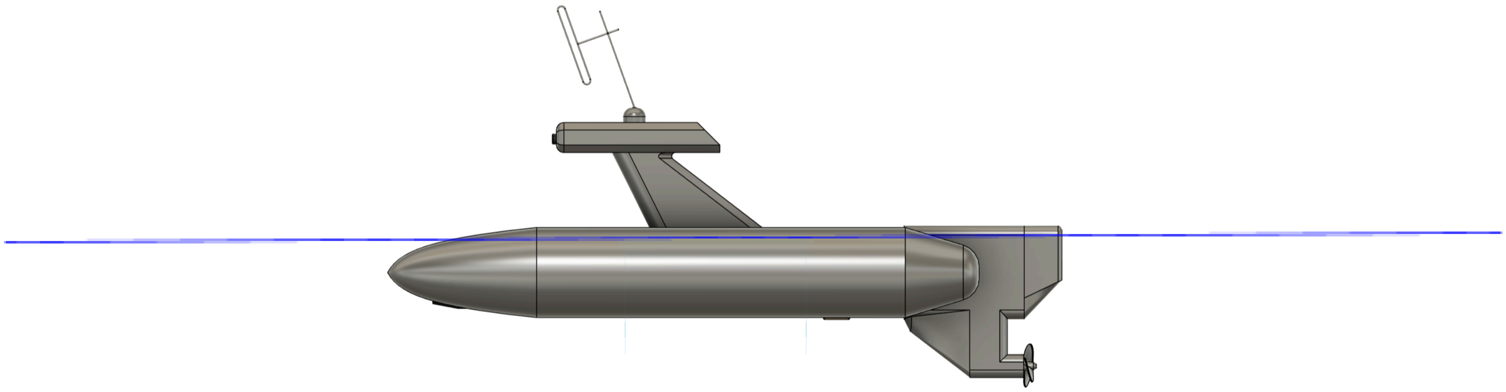


Figure 8.1: Approximate Methane Line

C. Mass of the Aeroshell

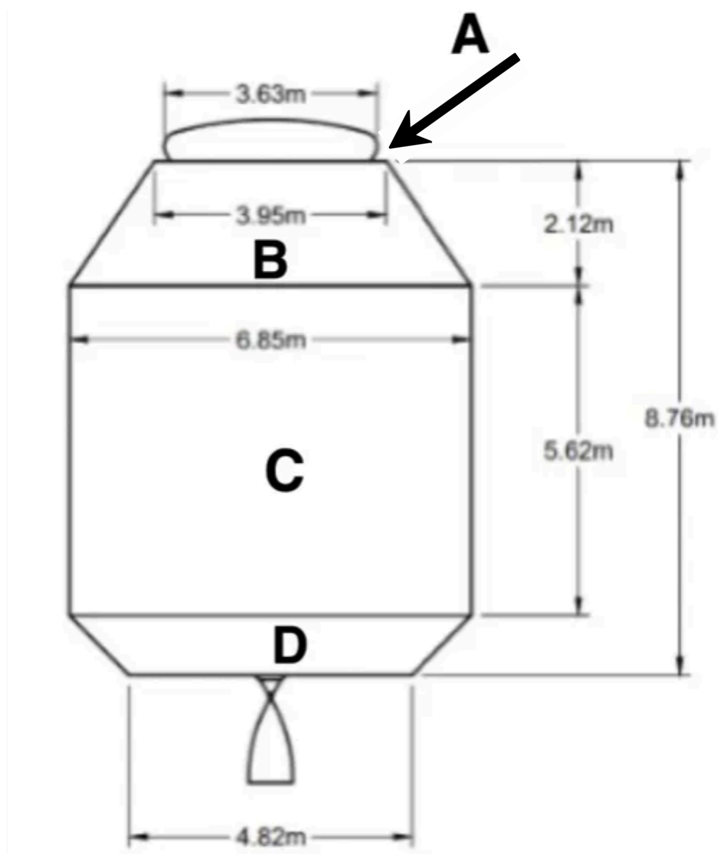


Figure 8.2: Aeroshell Dimensions and Drawing

Above are the dimensions and the general shape of the aeroshell. The mass calculations were broken down into 4 components. The top part of the aeroshell, which is labeled "A", is assumed to be a circle with a diameter of 3.95 meters. We calculated the area and then multiplied by 5 cm which we assumed to be the thickness of the aeroshell. This thickness was found by researching similar missions and finding the thicknesses employed on those. We then multiplied by 2.70 kg/m^3, the density of the material used. After this, we calculated the area of the middle section which is labeled "C". We assumed it to be a cylinder without the top or bottom sections. The circumference was calculated to be 21.52 meters, and the height was found to be 5.62 meters. We then multiplied that by 5cm to find the volume and once again multiplied by 2.70 kg/m^3 to find the mass. The third component we calculated was the top-middle section which is labeled "B". We assumed the shape to be a truncated cone. The formula was $V=1/3\pi h(r^2+r*R+R^2)$. R is the radius of the base of the original cone; the larger surface, and r is the radius of the smaller top surface. When we plugged the values in, we multiplied by 5cm to get the mass. Then we calculated the mass of the second truncated cone using the same strategy. The total mass was found to be 2607.7kg, well within our launch weight.

D. Mass Budget for the components

All the masses for the different equipment and structure are accounted for within the mass budget calculation. The individual equipment and structural components are broken down into their quantity and material property to get a more in depth insight of the mass allocation. The mass budget is broken into the individual subsystems and the overall structural integrity of the heat shield and the aerobraking shield. All mass values are from industry use components that are commercially available and meet the system requirements.

Table 8.1: Mass budget of JACK

JACK Components	**Mass (kg)**
RTG	57
RTG	57
Low-Gain Antenna	1
Transmitter	0.5
Camera	8.5
Thermal Shield	40
Sonar	1
GCMS	17
SSD	1

REMS	1
Temperature Sensors	1
Gel	1.25
Computer	1
Motor and Propeller	75
Hull	735
TOTAL	**997.25**

Table 8.2: Mass Budget of the Orbiters

SMITH AND PHILLIPS Components	Component Amount	Mass (kg)	Mass Total (kg)
RTG	2	57	114
Low-Gain Antenna	1	1	1
High-Gain Antenna	1	100	100
Transmitter	1	0.5	0.5
Reaction Wheel	3	5	15
Cameras	1	8.5	8.5
Computer	1	1	1
Thrusters	6	5	30
Structure	1	50	50
TOTAL			**320**

Table 8.3: Total Mass Budget of the Different Components

Subsystem	**Mass (kg)**
JACK	997.25
SMITH & PHILLIPS	320
ROSE	505
Aeroshell	2607.7
TOTAL	**4579.95**

IX. ADCS

A. Aerobraking

During the hour‑long aerobraking pass at Titan, the spacecraft's aeroshell—modeled as a 6.85 m diameter by 9.0 m long cylinder carrying a mass of 5,440.24 kg—experiences aerodynamic torques due to any attitude misalignment. This simplified body has the following Inertia Matrix:

$$\text{Aeroshell:} \quad \begin{bmatrix} 100539.04 & 0 & 0 \\ 0 & 100539.04 & 0 \\ 0 & 0 & 382904.49 \end{bmatrix} \quad \text{(kg-m^2)}$$

With the calculated inertia matrix for this configuration, a worst‑case 5° misalignment about the body axes generates up to 3,735 N·m of torque. Left uncorrected, that torque would spin the vehicle up to 62.376 rpm, risking destabilization of the entry profile. To counteract this, the attitude determination and control system (ADCS) applies counter‑torques via hydrazine thrusters, firing perpendicular to the sensed misalignment vector. Assuming continuous correction over the aerobraking interval, as much as 248.50 kg of hydrazine propellant may be consumed. This ensures that the entry attitude remains within design limits, preserving both thermal protection performance and down‑track targeting accuracy.

B. SMITH and PHILLIPS

Once in their 10,000 km circular orbits around Titan, the SMITH and PHILLIPS microsatellites—each approximated as a 1.5 m × 1.5 m × 4 m rectangular prism—must perform three primary pointing maneuvers over their operational lifetimes.

$$\text{SMITH and PHILLIPS:} \quad \begin{bmatrix} 532.29 & 0 & 0 \\ 0 & 131.25 & 0 \\ 0 & 0 & 532.29 \end{bmatrix} \quad \text{(kg-m^2)}$$

First, they maintain continuous Earth‑line‑of‑sight to the JACK lander during an 8.65 hour imaging window. Generating the small, continuous torque required to follow the moving target introduces an angular momentum change of 0.1432 kg·m²/s, corresponding to a steady 0.0920 mN·m of torque and a reaction wheel spin rate of 58.135 rpm. Second, when relaying data back to Earth, each satellite executes a 180° repointing within one hour. Including wheel spin‑up and spin‑down, this maneuver demands 1.0322 mN·m of torque and an angular impulse of 1.8508 kg·m²/s, peaking at 754.301 rpm on the RW4-5.0 reaction wheel. Finally, cross‑linking between SMITH and PHILLIPS entails a 30° slewing in just 15 minutes. This rapid repointing requires 2.7527 mN·m, an angular momentum change of 1.2387 kg·m²/s, and wheel speeds up to 502.867 rpm. All three maneuvers fall comfortably within the 150 mN·m torque and 5 kg·m²/s momentum storage limits of the selected Rocket Lab RW4-5.0 reaction wheel system.

C. ROSE

After deploying JACK, ROSE transitions to a data‑relay bus performing identical pointing tasks, albeit with a different mass distribution. Modeled as a 4 m × 4 m × 7.4 m rectangular prism, ROSE's inertia matrix yields the following ADCS performance requirements:

$$\text{ROSE:} \quad \begin{bmatrix} 2915.95 & 0 & 0 \\ 0 & 1346.67 & 0 \\ 0 & 0 & 2915.95 \end{bmatrix} \quad \text{(kg-m^2)}$$

To lock onto JACK for 8.65 hours of data collection, the spacecraft requires only 0.0504 mN·m of continuous torque—changing its angular momentum by 0.7848 kg·m²/s—and spins its reaction wheel at 318.47 rpm. The one‑hour 180° repoint toward Earth demands 5.6548 mN·m and 10.1786 kg·m²/s of momentum, reaching wheel speeds of 4,132.15 rpm. Lastly, the 30° satellite‑to‑satellite repoint within 15 minutes imposes a peak torque of 15.079 mN·m, an angular impulse of 6.7857 kg·m²/s, and a maximum wheel speed of 2,754.77 rpm. These requirements are well under the ±200 mN·m torque and ±12 kg·m²/s momentum storage capabilities of the RW4-12 Rocket Lab reaction wheel, assuring robust attitude control throughout the relay phase. The RW4-12 is chosen for ROSE as its design is more massive and larger in dimensions than the SMITH and PHILLIPS satellites, requiring more Torque and Angular Momentum thresholds.

X. Instruments

The TITANIC mission is meant to be more than a transit mission. It is a data collection initiative intended to shed light on the conditions of Titan's lakes. An array of various instruments was implemented in order to capture and transmit a comprehensive analytic summary of the conditions in question. The two major functions of these devices are data acquisition and data transmission.

The composition of the array of instruments was chosen in order to provide an adequately encompassing data-based view of JACK's surroundings while also being streamlined enough to function within the limitations of the mission's communications system. The specific instruments used were chosen for a few characteristics. They were to provide useful information both to the probe and to Earth. They had to be operable within a certain temperature range, determined by the thermal equilibrium established within the vehicle they were within. They also had to be operable at data rates that were achievable with the onboard communications equipment. The specific instruments chosen for data collections were the Oculus M370s Multibeam Sonar, the Infrasensing ENV-TULTRA temperature sensor, the Gas Chromatography and Mass Spectrometer (GCMS) device, and the Raptor Imager onboard camera. For information storage and transmissions, JACK came equipped with a Samsung Supermicro U.2 PM9A3 NVMe PCIe 4.0 TLC solid state drive, a Campbell Scientific TX324 transmitter, and an array of onboard computing devices.

Though not every device would be running at all times, it was critical to ensure that no device, at any point, would be overbearing upon the communications array provided for the mission to circumvent the possibility of information overload. Some instruments, such as the camera, required little to no correction within this parameter due to their idle and active data rates being sufficiently low to ensure a smooth transmission. This was, however, not the case for every device. The sonar in particular would not be a feasible addition to the mission at its base data rate, as the transmission of full, in depth scans of the lakebed of Kraken Mare required data rates several orders of magnitude higher than what this mission could realistically handle. In order to circumvent this, for the sonar specifically, the information sent back was changed from a massive sonar scan to a series of almost two hundred images, allowing for a significant reduction of necessary data rate allocation towards the sonar, while also maintaining the usefulness of its transmitted data. Additionally, each of these devices has been shown to be capable of surviving within the internal climate of their vehicle, though this would prove to be a trivial task with the addition of insulation allowing for the internal temperature of any vehicle to be maintained at any desired temperature within reason.

Upon the commencement of the mission to Titan, the data collection and transmission process would be done in a cyclical fashion, rotating between periods of data gathering and data transmission. This yielded a data model of steady, rising peaks, followed by periodic sharp drops. This was done to best match the frequency of the presence of overhead orbiters relative to JACK, along with making best use of the transmission equipment available. Not all data would be communicated at the same time, however, as certain data, such as status updates, would be sent at a great frequency due to the importance of constant monitoring of the onboard environment of the lander.

A. JACK Data Collection

Each instrument's idle and active data rates were found to further determine the amount of data collected on JACK. To begin, the functional data rates of each device was found by taking the difference between the idle and active rates and multiplying by the duty cycle of the instrument. This will account for the actual time each device is running and collecting data, and therefore can determine the data rate value that will be used. Equation 11.1 presents the formula used to find the functional data rates for each component. The duty cycle was calculated by taking the run time per frequency.

$$Functional\ Data\ Rate\ =\ (Active\ -\ Idle)\ *\ (Duty\ cycle)\ +\ Idle \qquad \textbf{(10.1)}$$

After calculating the functional data rates, the amount of data collected per day can be found. With the given data rate values in kbps, a conversion will be done to find the amount of data collected in Megabytes. With the data collection per day, it will be accounted for one full Titan day, which is 26 hours. The conversion consists of converting bits to bytes and then the kilobytes to megabytes. Equation 11.2 shows the formula used for the conversion of kbps to MB/day.

$$Daily\ Data\ Collected\ (MB/Day)\ =\frac{(Functional\ Data\ Rate)[kbps]*(93600)[sec]}{(8)[bits/byte]*(1024)[KB/MB]} \qquad \textbf{(10.2)}$$

With the total data collected per Titan day for JACK, it was calculated to be about 205 MB. JACK will be able to transmit data for approximately 4.3 hours to the orbiters with a transmission rate of 20 kbps, or 37.79 MB/Day. From this, the data collected exceeds the amount that can be transmitted to the orbiters. To account for this issue, certain devices will be compressed to reach the transmission limit. The devices that will be compressed are the sonar instrument, the camera, and the computer. The sonar device will have a 5:1 lossless compression to be able to preserve the data and measurements of the lake's qualities with the exception of lower resolution or less frequent scanning. For the camera, a 5:1 lossy compression will be implemented to still be able to capture images of the lake and environment, but remove redundant or unnecessary images. For more critical images of the surface or lake, 5:1 lossless compression will be used. Lastly, the computer will have a 10% compression rate applied to the data transmitted. Although only 10% of the computer data will be transmitted, the critical logs and any important changes will be transmitted while the excess information can be stored to the SSD on JACK. With the 10-15 TB storage capacity of the SSD, the data can safely be stored in the device and transmitted to the orbiter on another satellite pass. With the compression of these instruments, there will be a margin of 3.23 to the transmission limit. **Table 10.1** presents all the calculated data collection and compressed values for JACK. As seen in the table, there will be data purged and the transmission rate that is not accounted for in the data collected since those two components do not provide any generated data. At the end of one full Titan day, the amount of data purged will be approximately 90.396 MB.

Table 10.1 : Data Collection Values on JACK

Data Collected Onboard JACK							
Device	**Idle Data Rate**	**Active Data Rate**	**Run Time**	**Frequency**	**Functional Data Rate**	**Daily Data Collected (MB/Day)**	**Compression**
Sonar	0 kbps	15 kbps	4 hours	8 hours	7.5 kbps	85.693	5:1 - 17.1386
GCMS	0 bps	0.04 kbps	3 hours	one time at the start	0.04 kbps	0.457	N/A
Camera	2.25 kbps	4.25 kbps	2 hours	8 hours	2.75 kbps	31.421	5:1 - 6.2842
Status Updates	0 kbps	20 kbps	0.0027778 hours	4 hours	0.013889 kbps	0.1587	N/A
Computer	5 kbps	10 kbps	2 hours	4 hours	7.5 kbps	85.693	10% - 8.5693
Instruction Download	0 kbps	20 kbps	0.0472222 hours	8 hours	0.1181 kbps	1.349	N/A
Data Purge	0 kbps	-242 kbps	0.85 hours	24 hours	0 kbps	0	N/A
Total					17.92	204.62	34.5568

Figure 10.1 represents the data rates on JACK with the inclusion of the data transmitter over a span of nearly 3 Titan days. The graph shows the data rate decreasing over time as it gets closer to the transmission window around the 20 kbps transmission rate. After transmission, it can be seen that the data rates increase to collect more data and then cycle back into the transmission stage.

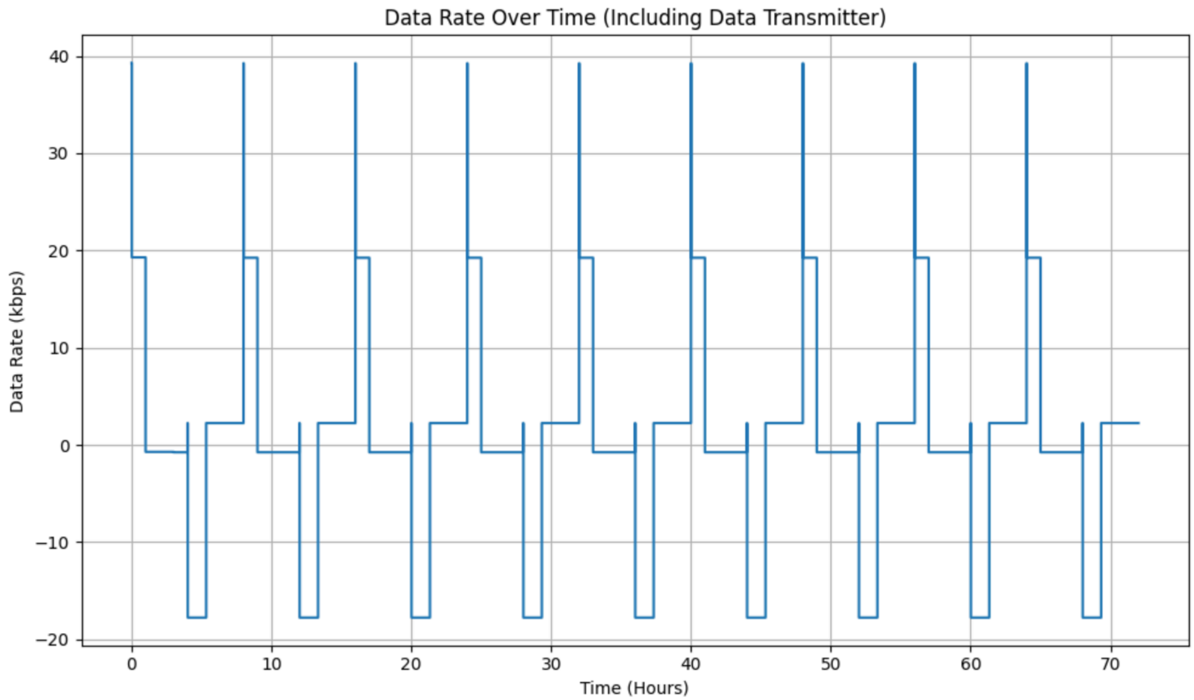


Figure 10.1: Instrument Data Rates Aboard JACK

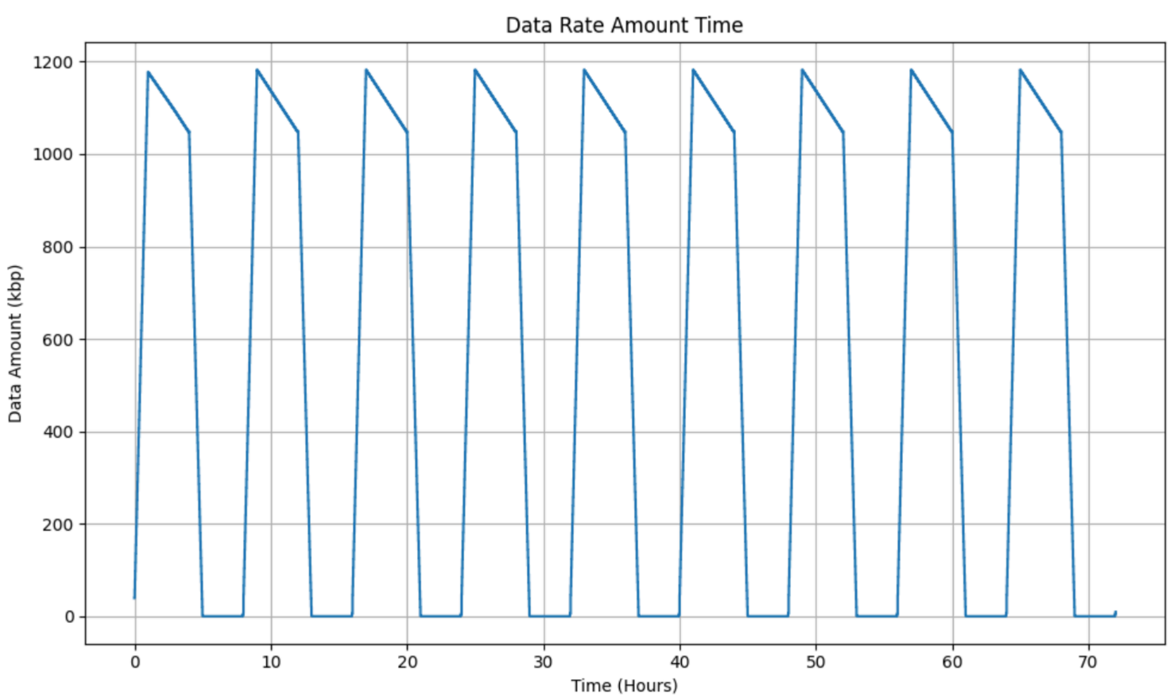


Figure 10.2: Total Data to be Transmitted to Orbiters

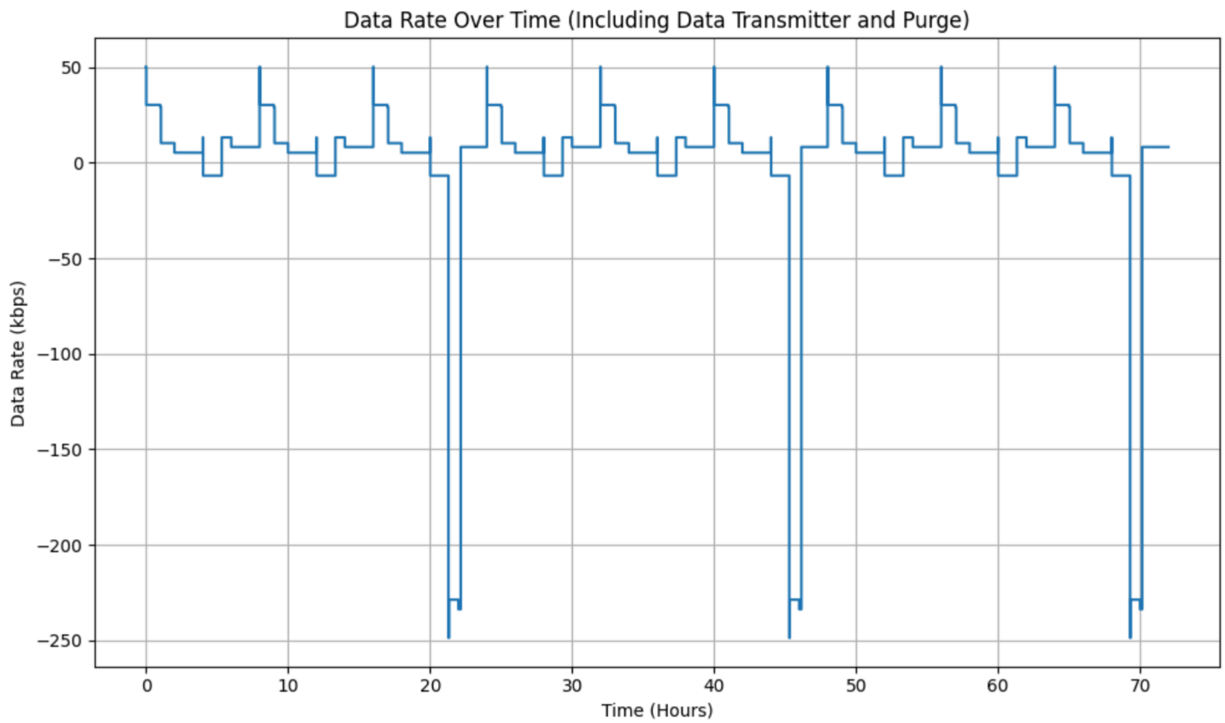


Figure 10.3: Total Data Rate Aboard JACK

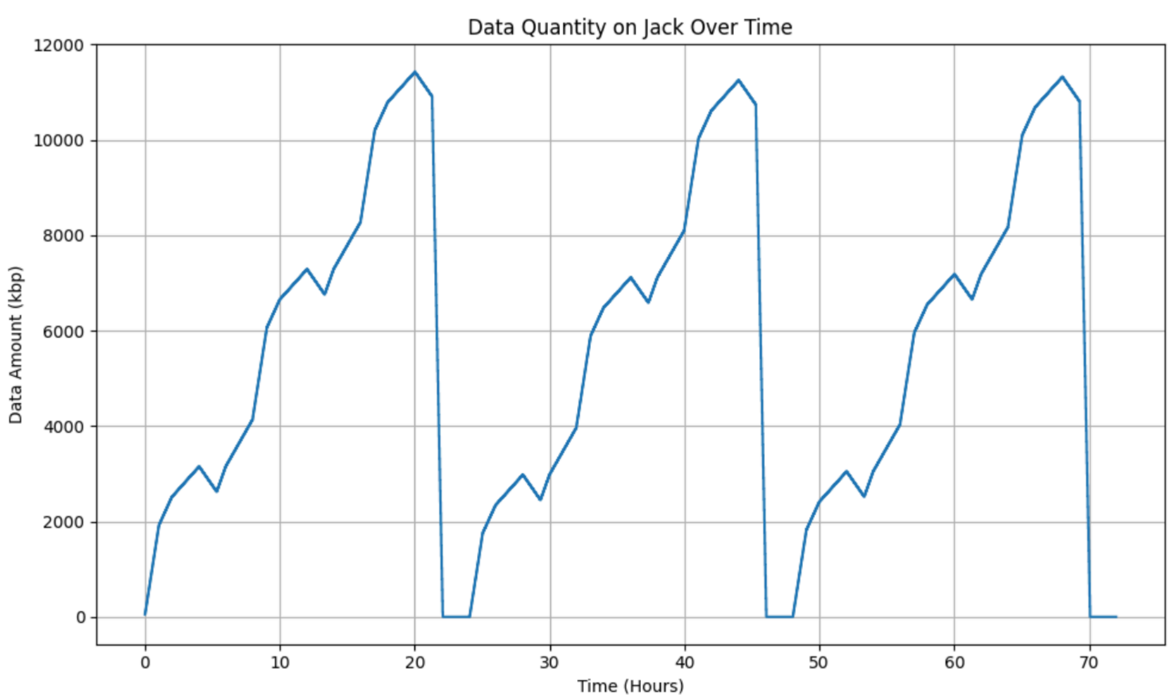


Figure 10.4: Stored Data Aboard JACK

Represented visually in **Figures 10.1-10.4**, the data aboard JACK will never be a constant quantity. While there is no variation in the rate at which any one instrument gathers data, the frequency at which they gather this data, the duration of measurement, and the variation of the amount of data gathered between each device cause nonlinear increases in data aboard JACK. JACK does, however, output data at a linear rate, as is visible in **Figure 10.4**.

B. Orbiter Data Collection

For each orbiter, the same approach for JACK was used to solve for the data collection. However, the orbiter has a transmission rate of 50 kbps with approximately a 2 hour-window period for communication with Earth. After implementing **Equation 10.1** and **10.2** for the orbiter, a total amount of data collected in a day was 173.82 MB. The daily transmission limit for the orbiter to Earth link is 43.95 MB. With the orbiters, data transmitted from JACK and the data generated on the satellite will both be accounted for since both sets of data will be transmitted. From the calculations on JACK, the total data collected and transmitted per day is 34.56 MB and the total data collected for the orbiter is 32.76 MB per day. The orbiter has similar compression applied to the instruments as JACK has. Again, the computer and camera have the same compressions, 10% for computer and 5:1 for the camera. For the JACK data transmission, it will have a 10:1 lossless compression. Although compression is rather large, this will ensure that significant data to the mission will be transmitted while allowing storage for the other instruments to perform and collect data. If a more critical part of the mission is taking place, the compression can be adjusted to 5:1 to allow more of the data and instructions to be sent from the probe to Earth. The total data collection including JACK and the generated data on the orbiter is 67.31 MB/Day. This value exceeds the 43.95 MB limit for the orbiter to Earth transmission but the important data will be the priority sent during the satellite pass. For the TITANIC mission, the data collected from JACK provides vital information on Titan's lakes and atmosphere, and therefore is critical data that will be prioritized in transmitting to Earth. The excess sensors' data from the orbiter will be stored in the SSD until able to be transmitted on another pass. Lastly, the data purged for the orbiters will be 86.02 MB/Day for redundant data and the orbiter will have a margin of 11.191 for the 50 kbps transmission rate/limit. Since all three orbiters are equipped with the same instruments and have the exact duration of communications with JACK and Earth, these calculations apply to all the orbiters.

Table 10.2 : Data Collection Values on Orbiter

Data Collected Onboard Orbiter							
Device	Idle Data Rate	Active Data Rate	Run Time	Frequency	Functional Data Rate	Daily Data Collected (MB/Day)	Compression
Camera	2.25 kbps	3.25 kbps	4 hours	8 hours	3.25 kbps	37.1337	5:1 - 7.426
Star Tracker	0.1 kbps	4 kbps	1 hour	4 hours	1.075 kbps	12.283	N/A
JACK Data Transmission	0 kbps	20 kbps	4.33 hours	26 hours	3.33 kbps	38.04	10:1 - 3.804
Status Updates	0 kbps	20 kbps	0.0027778 hours	4 hours	.01389 kbps	0.15869	N/A
Transmission Rate	0 kbps	-50 kbps	3.6 hours	26 hours	0 kbps	0	N/A
Computer	5 kbps	10 kbps	2 hours	4 hours	7.5 kbps	85.69	10% - 8.569
Instructions Download	0 kbps	50 kbps	0.0236111 hours	26 hours	.0454 kbps	0.51873	N/A
Data Purge	0 kbps	-231 kbps	0.85 hours	26 hours	0 kbps	0	N/A
Total					13.78929	173.82	32.759

Figure 10.5 represents the data rates for the orbiter with the data transmitter taken into account. As seen in the graph, the cycles of data rates are over the period of a Titan day with the 50 kbps transmission to Earth occurring for the 2 hour communication period.

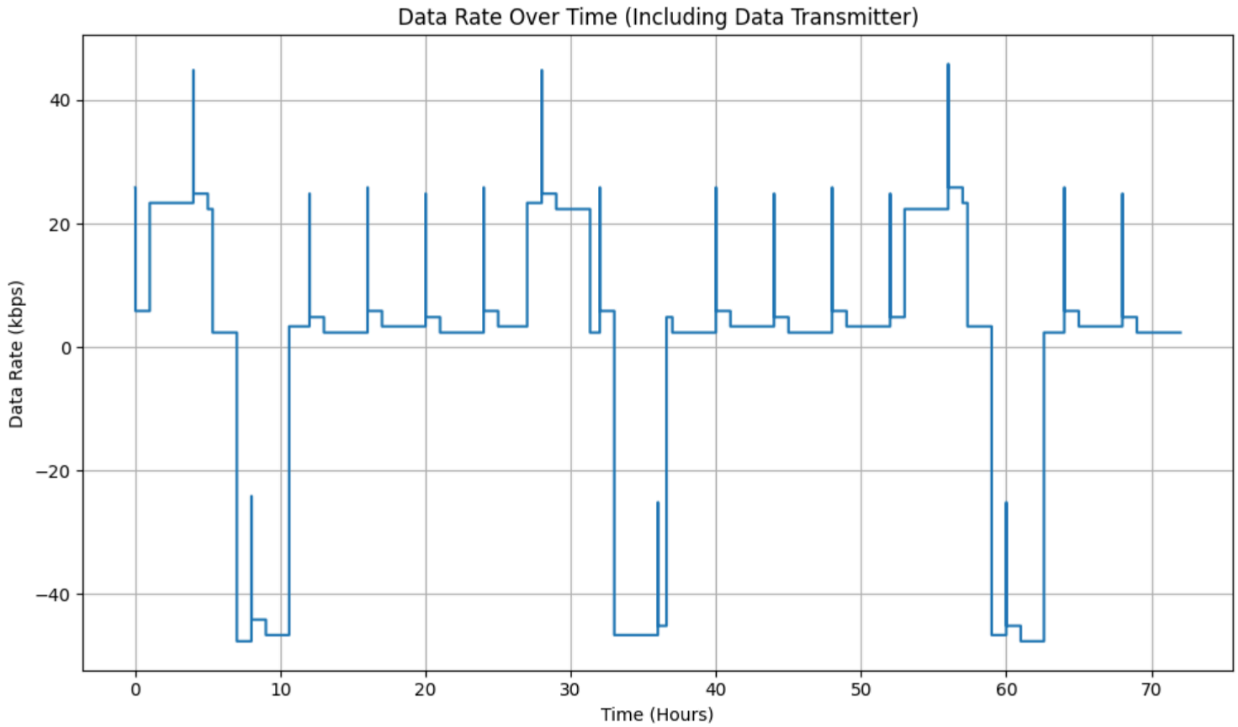


Figure 10.5: Data Rates for Transmission to Earth

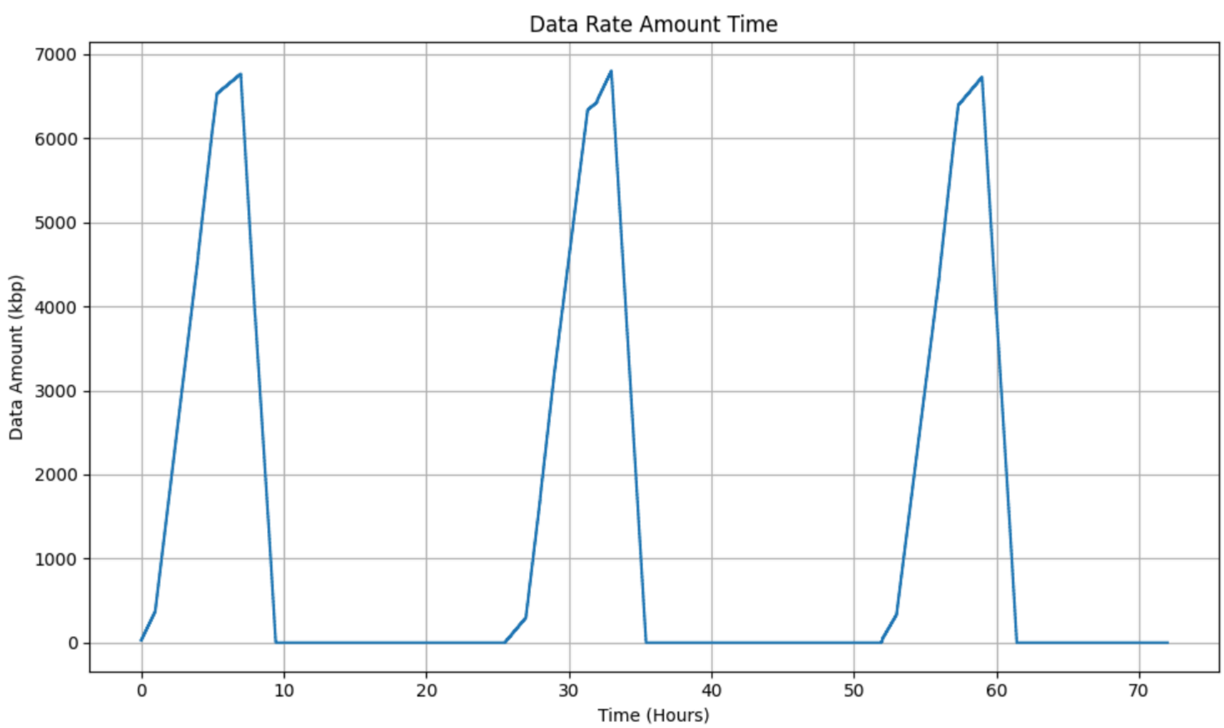


Figure 10.6: Total Data to be Transmitted to Earth

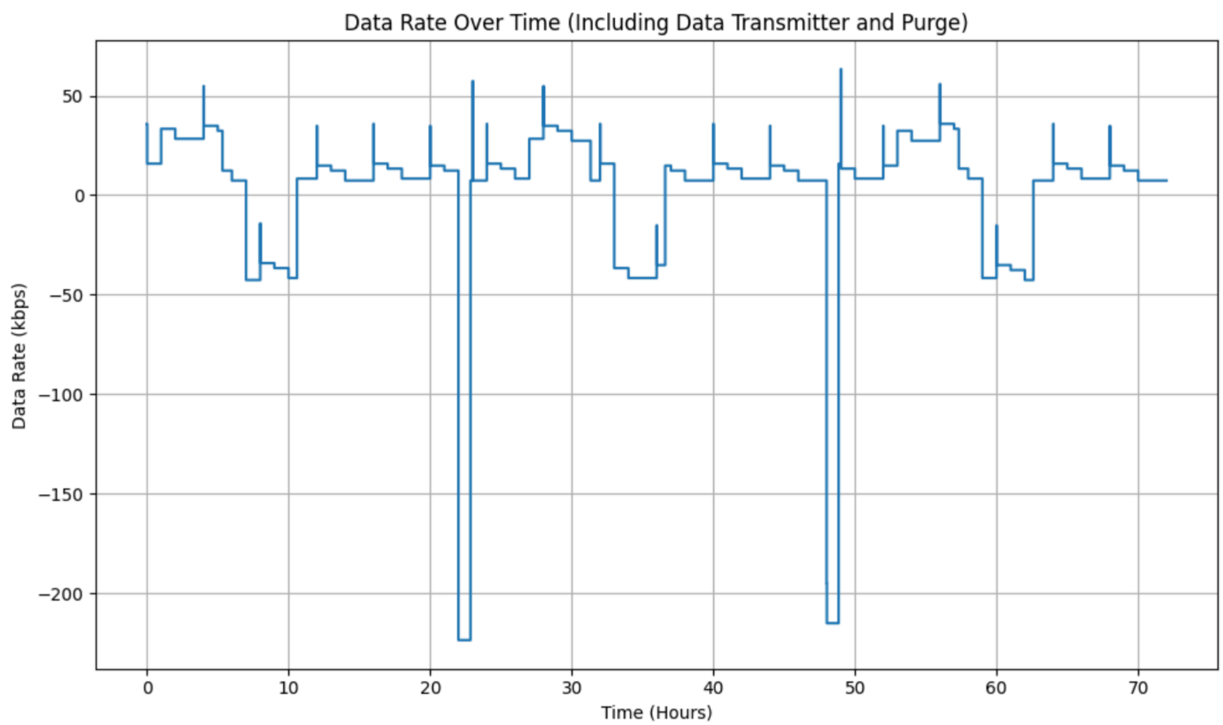


Figure 10.7: Total Data Rate for Orbiters

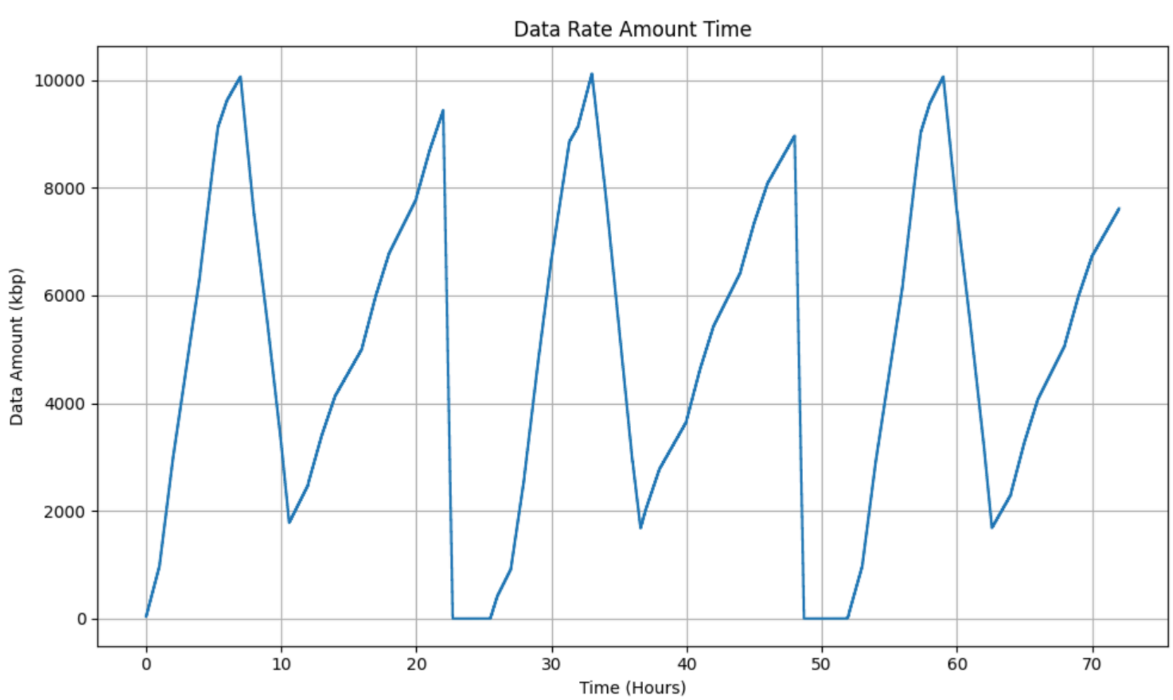


Figure 10.8: Total Data Aboard Orbiters

Figures 10.5-10.8 represent the data on the orbiters that are being received and transmitted. As included in **Figure 10.7**, the visual representation shows both the data rate over time and the transmission with data purged towards the end of each cycle. After the data purge, the cycle restarts and continues with the data collection. **Figures 10.6** and **10.8** demonstrate the total amount of data rates for and onboard the orbiters. It can be seen that the flat regions represent the time the orbiters are not communicating with the Earth or JACK.

XI. Communication

Throughout the TITANIC mission, two main communication links were designed. The first communication link is between Earth and the Orbiters. This will be the first and only communication link that is used for the first six years of the mission. Upon reaching Titan, the second communication link will come into play. This second link was designed for communication between each orbiter (ROSE, SMITH, and PHILLIPS) and the lake-lander JACK.

Critical performance requirements were targeted at the onset of the communication link design process. These essential performance requirements included communication characteristics like link margin, transmission signal frequency, and data bit rate. Using the Friis Transmission Equation, estimates for required transmitter power were made, and receiver and antenna gains were adjusted to bring required transmission power down to levels that the team deemed acceptable. This design method was used for both communication links. The two following sections provide additional information on what specific parameter values were targeted, as well as present dynamic modeling to forecast communication link performance.

A. Earth to Orbiter

While communication between the orbiters and Earth begins immediately after launch, the Earth-to-Orbiter communication link experiences the most strenuous conditions once it reaches Titan. This is primarily due to the free space path loss, which grows increasingly significant the farther the orbiters are from Earth. To ensure future communication hardware could withstand these conditions, initial antenna sizing was done assuming a worst-case scenario (i.e., Titan's furthest distance from Earth). With these initial conditions set, the link budget displayed in **Table 11.1** was made.

Table 11.1: Preliminary Link Budget Between Earth and Orbiters

Parameter	**Specs**	**Gain (dB)**
Free Space Loss	Frequency: 34 GHZ Distance: 1.4×10^9 km	305.47
Atmospheric Loss	Loss due to Earth's Atmosphere	-0.5
Pointing Error Loss Margin		-1
Boltzmann's Constant		-228.6
System Temperature	$f\,(T_{atm}, T_{ant}, T_{rx}, \Theta)$	19.09 - 25.18
Data Bit Rate	50 kbps	46.98
Required E_b/N_0		3
Receiver Antenna Gain	75 dB Gain DSN Antenna	-75
Transmitter Antenna Gain	55dB, 60dB, 62dB Antennas	Varied
Target Margin	Typical Link Margin for Mission Type	5
Transmitter Power		Varies based on antenna gain

Looking at the gain for System Temperature in **Table 11.1**, it's important to note that the gain values listed in the table represent a range of values. This is because several factors influence the overall system temperature of the communication link. Overall system temperature is influenced by receiver noise temperature, background temperature, and atmospheric temperature. **Equation 11.1** shows this relationship.

$$T_{sys} = T_{ant} + T_{rx} + T_{atm}\,(\Theta) \qquad \textbf{(11.1)}$$

Constants can typically approximate both receiver noise and background temperature. However, atmospheric temperature is influenced by how long the signal passes through the atmosphere, which can be reduced to the orbiter elevation angle. **Equation 11.2** shows the relationship between atmospheric temperature and elevation angle.

$$T_{atm} = T_m\,[1 - exp\{-(\tau / sin(\Theta))\}] \qquad \textbf{(11.2)}$$

Where τ represents the optical depth of Earth (approximated at a value of 0.1), T_m represents the mean atmospheric temperature of Earth in Kelvin (assumed to be 275 K), and Θ represents the elevation angle of the signal with respect to the receiver antenna's horizon.

Using the equations outlined above and the parameters contained in **Table 11.1**, a preliminary dynamic model was created to simulate how the transmission power requirement would change as the orbiter elevation angle increased from 0 to 90 degrees. **Figure 11.1** illustrates the results.

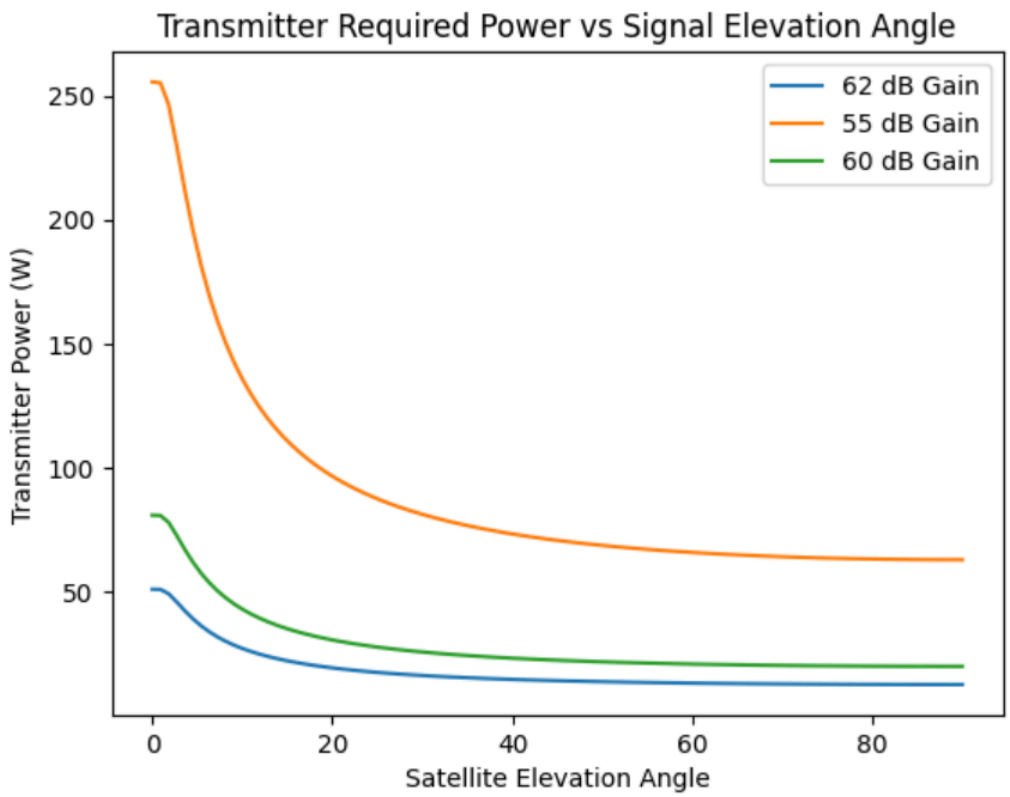


Figure 11.1: Required Transmission Power vs Signal Elevation Angle (Orbiter-to-Earth)

Based on the results displayed in **Figure 11.1**, a transmitter antenna gain of 62 dB was selected for future analysis.

After selecting a target transmitter antenna gain of 62 dB, further analysis was performed to capture the antenna's performance behavior as the distance between Earth and the orbiters changed throughout the mission duration. To capture broad performance behavior, four critical mission distances were considered: Fairing Casing Separation, the transfer's geometrical halfway point, the transfer duration's halfway point (i.e., 3-year point), and the arrival at Titan. **Figure 11.2** displays the required transmission power vs. elevation angle curves of a 62 dB transmitting antenna at those four mission distances.

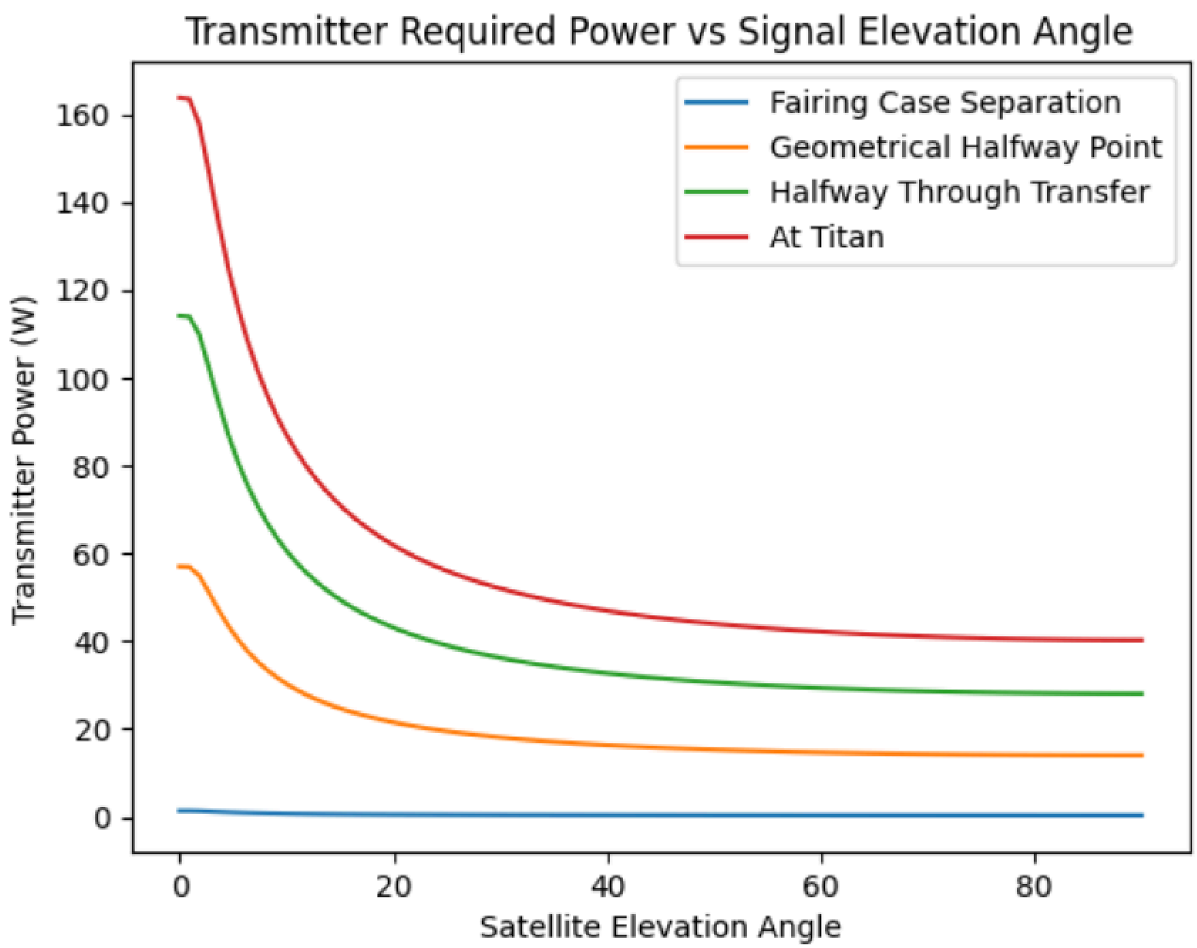


Figure 11.2: Required Transmitter Power vs Signal Elevation Angle (At Varying Distances)

Unsurprisingly, required transmission power is at its lowest when the orbiters are closest to Earth (i.e., Fairing Case Separation) and is at its highest when the orbiters arrive at Titan. Expanding on these results, a complete dynamic model was made for the Orbiter-to-Earth communication link. A constant stream of distances (obtained from the mission's flight trajectory) was used to simulate how transmitter power would fluctuate throughout the duration of the mission. The dynamic model includes the entire transit time from Earth to Titan as well as the first two months of the orbiters' orbiting around Titan. **Figure 11.3** displays those results.

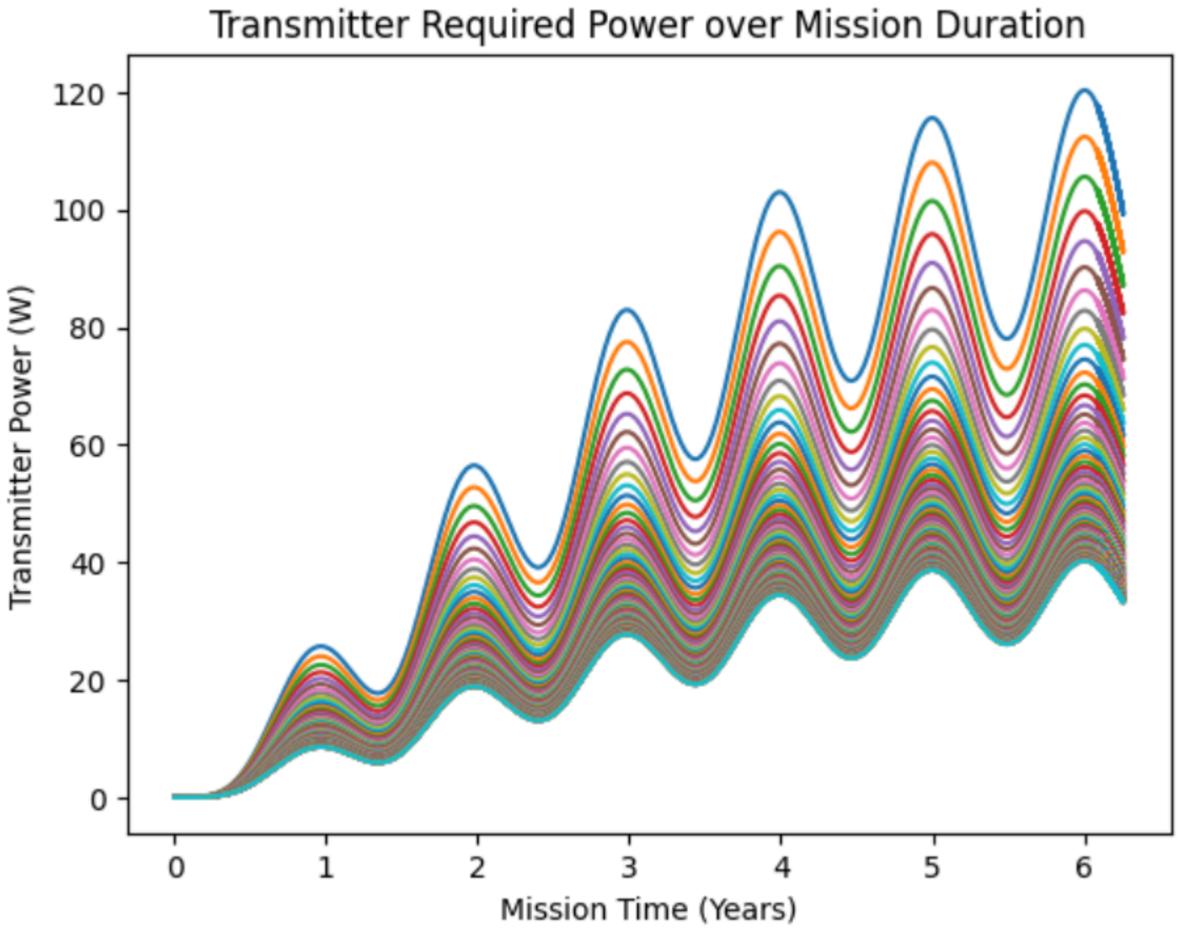


Figure 11.3: Full Dynamic Communication Link Model for Mission Duration

Each curve plotted in **Figure 11.3** represents the transmitter power solution assuming that a particular signal elevation angle is held constant throughout the entire mission. Elevation angles between 5 and 90 degrees are represented on this plot. While it's unrealistic to assume a constant signal elevation angle is maintained throughout the entire mission duration, this graph does capture the fluctuating behavior of the required transmitter power. We can safely assume that the real transmitter power will be encapsulated somewhere between the lower and upper bounding curves.

It's also important to note that while orbiting Titan, there is only a brief period of time when Earth will be in view for uplink and downlink communication. Since Titan is tidally locked by Saturn, there will be periods of the orbit where Saturn will block Earth from the Orbiters' view. **Figure 11.4** displays a diagram breaking down which portions of the orbiter's orbit will be available to communicate with Earth.

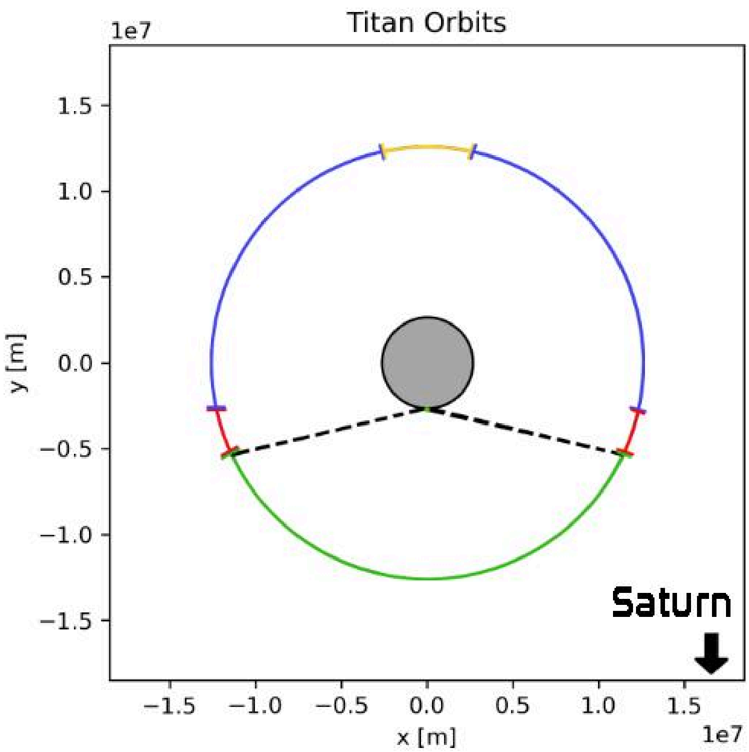


Figure 11.4: Orbit Phase Breakdown

The two blue sections in **Figure 11.4** represent the portions of the orbit where contact with and from Earth is possible. This represents a total of 13-15 hours of signal transmission/receiving period. The yellow section represents a 2-hour eclipse period caused by Saturn, while the red sections represent a repointing period for the orbiter to realign itself for communication. Lastly, the green region represents the portion of the orbit devoted to communicating with JACK.

To accomplish this level of communication performance, a 4-meter diameter reflector dish antenna was selected. This antenna type is known for its ability to accommodate high-level frequencies and generate high transmission gains. The center frequency for uplink communication between Earth and the Orbiters was set to 34 GHz, while the downlink center frequency was set to 32 GHz. This places the communication frequency firmly in the Ka-Band, which is uniquely suited for long-range communication and for high data bit rates. Each center frequency has a signal spacing of 240 kHz to differentiate the various signals transmitted to the three different orbiters. **Table 11.2A** and **11.2B** contain the frequency assignments for the three orbiters.

Table 11.2A: Frequency Assignment for Earth-to-Orbiter Comm Link

Uplink (Earth-to-Orbiters)	
Signal Spacing	**240 kHz**
Link	**Frequency**
Earth -- PHILLIPS	33.9998 GHz
Earth -- ROSE	34 GHz
Earth -- SMITH	34.0001 GHz

Table 11.2B: Frequency Assignment for Orbiter-to-Earth Comm Link

Downlink (Orbiter-to-Earth)	
Signal Spacing	**240 kHz**
Link	**Frequency**
PHILLIPS -- Earth	31.9998 GHz
ROSE -- Earth	32 GHz
SMITH -- Earth	32.0001 GHz

The specific hardware selected to fulfill these requirements is the legacy high-gain reflector dish antenna from the Mars Reconnaissance Orbiter (MRO) Mission launched on August 12, 2005. The antenna dish measured 3 meters in diameter and had a gain of 56.4 dB for Ka-Band frequencies. **Figure 11.5** displays a picture of the MRO's High-Gain Antenna.

Figure 11.5: MRO's High-Gain Antenna

Utilizing this pre-existing design and modern-day technology, we can achieve our heightened antenna specs of a 62 dB gain, 4-meter diameter dish in time for this mission.

B. Orbiter to JACK

Communication between JACK and the Orbiters starts immediately after JACK lands on the Kraken Mare lake. Orbiters will maintain an average altitude of 10,000 km above the Titan surface. Since each orbiter is spaced 120 degrees apart from one another, at least one satellite will always be in view of JACK. After some preliminary analysis, it was determined that as one orbiter begins to set below the horizon (once it dips below an elevation angle of 20 degrees), another satellite will be rising at a similar elevation angle. The cutoff elevation angle for all orbiters was found to be roughly 20 degrees. Once the satellite sets below this threshold, JACK will switch its transmissions to the rising satellite. **Table 11.3** displays the link budget for communication between JACK and the orbiters.

Table 11.3: Preliminary Link Budget Between JACK and Orbiters

Parameter	**Specs**	**Gain (dB)**
Free Space Loss	Frequency: 8.2 GHz Distance: 10,000 km	190.7
Atmospheric Loss	Loss due to Titan's Atmosphere	-2
Pointing Error Loss Margin		-1
Boltzmann's Constant		-228.6
System Temperature	$f\,(T_{atm}, T_{ant}, T_{rx}, \Theta)$	24.683 - 25.787
Data Bit Rate	20 kbps	43.01
Required E_b/N_0		10
Receiver Antenna Gain	15 dB Gain Antenna	-75
Transmitter Antenna Gain	8 dB, 6 dB, 15 dB Antennas	Varied
Target Margin	Typical Link Margin for Rover Communication	10
Transmitter Power		Varies based on antenna gain

Values for *System Temperature* displayed in **Table 11.3** were calculated using **Equations 11.1** and **11.2**.

Following the link specifications in **Table 11.3**, preliminary curves relating transmitter power to orbiter elevation angle were made. **Figure 11.6** displays the results for 6 dB, 8 dB, and 15 dB gain antennas.

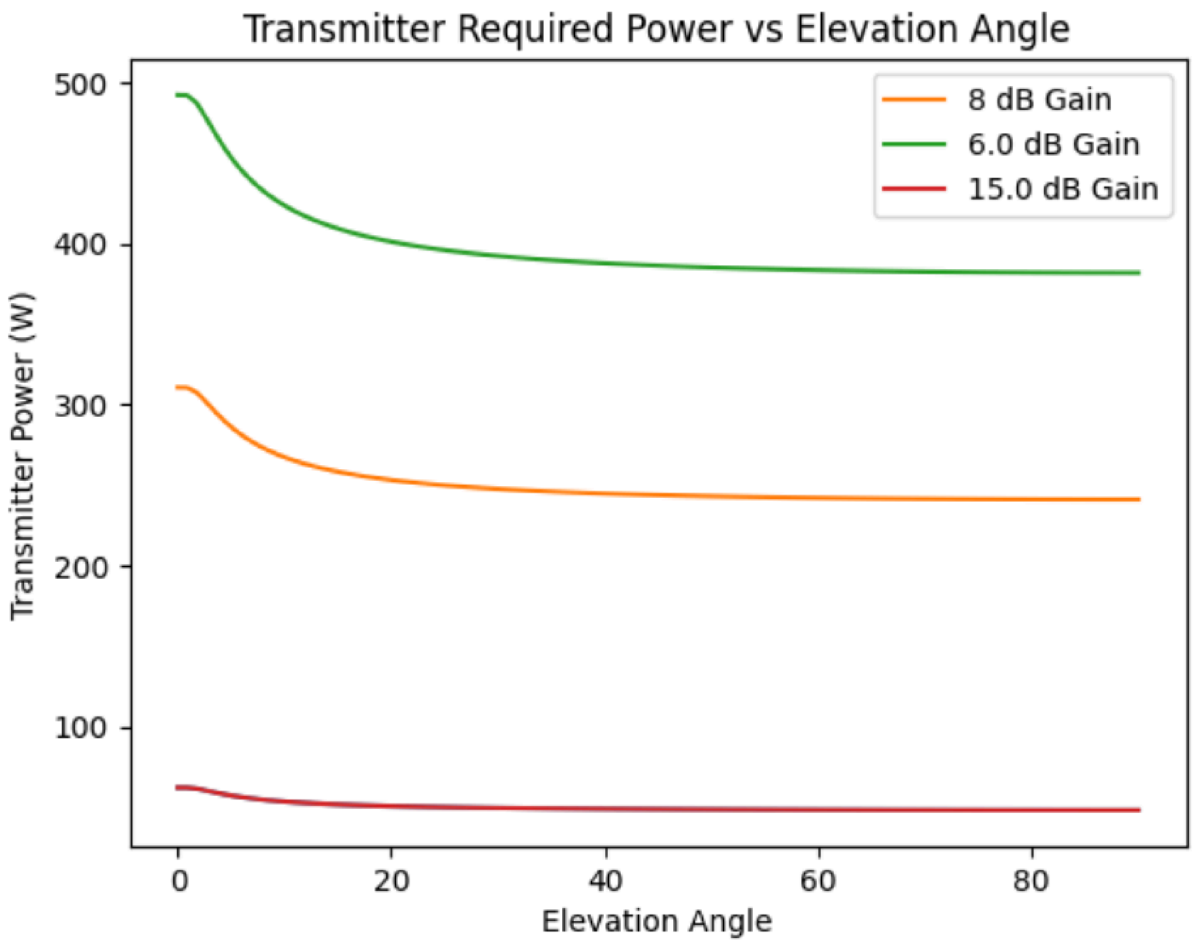


Figure 11.6: Transmitter Power Estimates vs Elevation Angle (Orbiters-to-JACK)

Based on the results displayed in **Figure 11.6**, an antenna gain of 15 dB was the only antenna that could be reasonably accommodated given JACK's available power constraints.

To better model how the orbiter elevation angles change throughout the transmission period, slant ranges from the orbital trajectories were used to find the dynamic position of the orbiters throughout the day. **Equation 11.3** was used to calculate the elevation angle from JACK and the orbiter's position.

$$\Theta \;=\; arcsin\left(\frac{r_{GS} \bullet (r_{SC} - r_{GS})}{R \bullet \|r_{SC} - r_{GS}\|}\right) \qquad \textbf{(11.3)}$$

Where Θ is the elevation angle, and $\boldsymbol{r_{GS}}$ is the vector form of the ground station's (JACK) position with respect to the center of Titan. $\boldsymbol{r_{SC}}$ is the vector representation of the orbiter's position with respect to Titan's center. R is the magnitude of the ground station's position vector, and $||\boldsymbol{r_{SC}} - \boldsymbol{r_{GS}}||$ is the slant range. Using this equation, an orbiter's instantaneous elevation angle could be calculated down to the second. Based on the orbital period breakdown shown in **Figure 11.4**, there is a maximum transmission/receiving window of 5.3 hours for each orbiter. **Figure 11.7** displays orbiter elevation angles from JACK's point of view plotted over a time series of 24 hours.

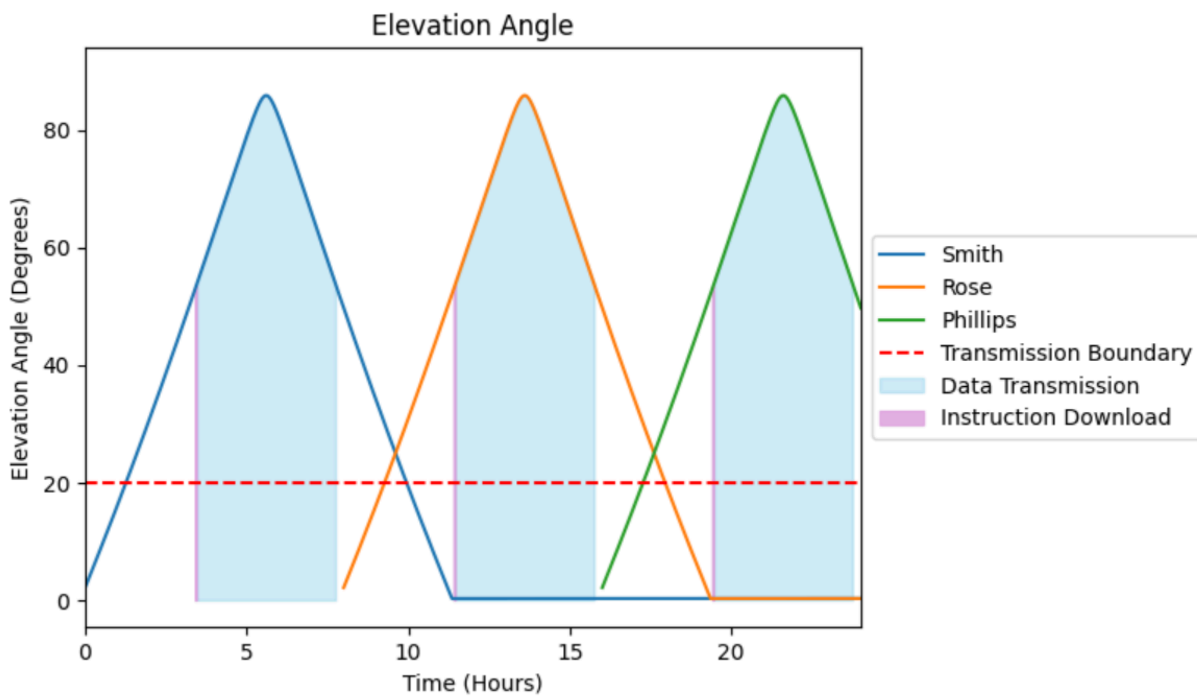


Figure 11.7: Orbiter Elevation Angles from JACK's Point of View

Due to orbiters' inclination angle around Titan, no orbiter will ever pass directly above JACK; however, the more detailed analysis shown in **Figure 11.7** reveals that JACK can transfer communication between orbiters once the setting satellite drops to an elevation angle of approximately 24 degrees. This is a significant improvement from the initial transmission boundary of 20 degrees and will help mitigate the impact of atmospheric signal losses at the end of the communication period. In addition, if JACK adheres to a transmission rate of 20 kbps, only 4.3 hours are needed to transmit all of the collected data back to the orbiter. This also helps JACK avoid having to transmit/receive signals once the orbiter has reached an unfavorable elevation angle.

Each communication period starts with JACK receiving a 3-minute-long signal from the orbiter containing commands/instructions for JACK to execute. However, if the command package is larger than expected, roughly an hour of time is built into the communication window to accommodate it.

With a heightened understanding of JACK's communication conditions, a more accurate estimation of the required transmitter power was made. The resulting curve displayed in **Figure 11.8** assumes a transmitter and receiver antenna gain of 15 dB. Results for elevation angles ranging from 45 to 90 degrees are shown below.

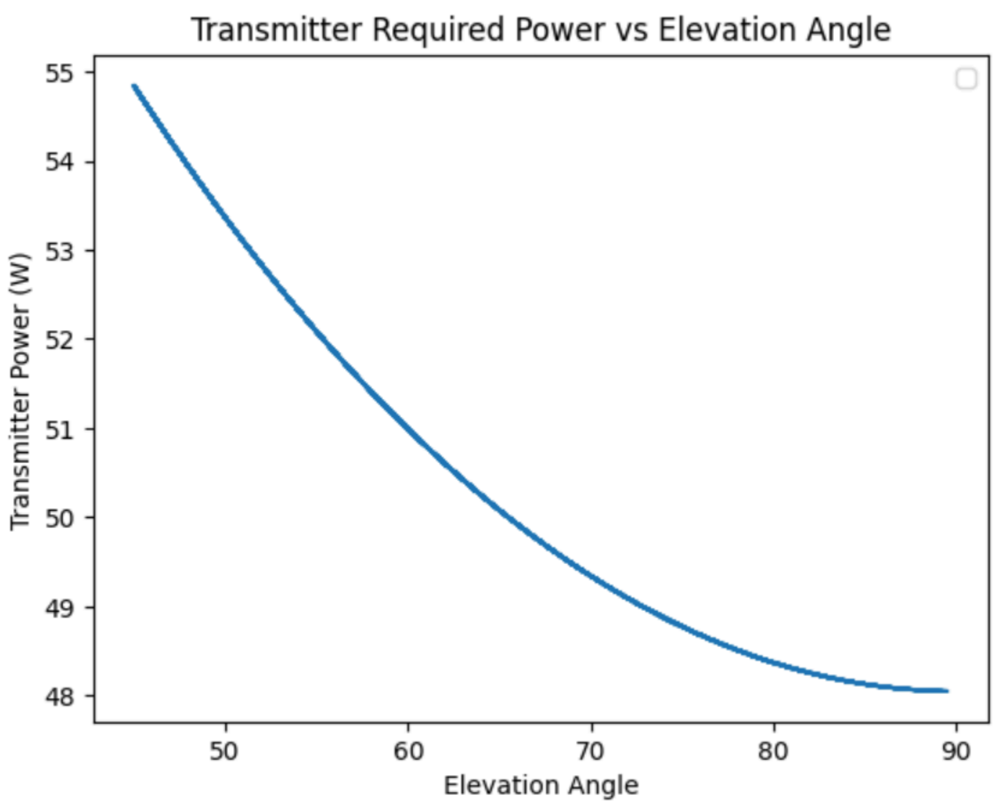


Figure 11.8: Final Transmitter Power Estimate for JACK-to-Orbiter Comm Link

The transmitter power predictions displayed in **Figure 11.8** are very promising and are much more manageable for JACK's onboard RTG's. To gain a better understanding of the power demands of JACK's communication system, power draw estimates were made and graphed in **Figure 11.9**. The resulting curves look at the required power draw over a 72 hour period.

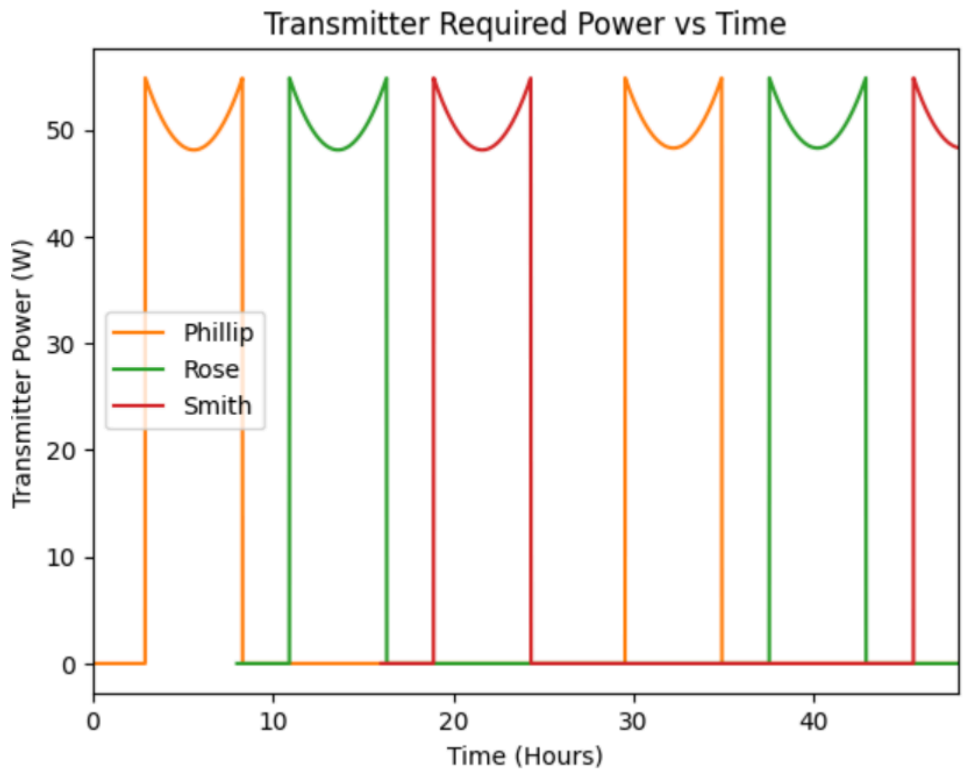


Figure 11.9: Projected Communication System Power Draw

The power draw behavior shown in **Figure 11.9** perfectly illustrates the power draw behavior displayed in **Figure 11.8**. Power requirements initially start at roughly 55 watts when JACK first locks onto the passing orbiter. As the orbiter rises in the sky, the required power decreases and subsequently rises back to the initial starting point as the satellite sets.

X-band signal frequencies were selected to ensure a strong and reliable communication link between JACK and the orbiters. X-band frequencies were selected due to their ability to pierce through the Titan atmosphere without incurring excessive noise or aliasing. In addition, X-band frequencies have the ability to support larger data bit rates. To distinguish between the various satellites, each uplink and downlink has three separate frequencies associated with a particular orbiter. **Table 11.4A** and **11.4B** display the uplink and downlink frequency details, respectively.

Table 11.4A: Frequency Assignment for JACK-to-Orbiter Comm Link

Uplink (JACK-to-Orbiters)	
Signal Spacing	**240 kHz**
Link	**Frequency**
JACK -- PHILLIPS	8.1996 GHz
JACK -- ROSE	8.2 GHz
JACK -- SMITH	8.2003 GHz

Table 11.4B: Frequency Assignment for Orbiter-to-JACK Comm Link

Downlink (Orbiter-to-JACK)	
Signal Spacing	**240 kHz**
Link	**Frequency**
PHILLIPS -- JACK	8.3997 GHz
ROSE -- JACK	8.4 GHz
SMITH -- JACK	8.4003 GHz

To achieve the specifications listed in the tables and figures above, an X-Band Patch 4 Antenna was selected as the ideal hardware candidate. **Figure 11.10** displays an image of the X-Band Patch 4 Antenna.

Figure 11.10: X-Band Patch 4 Antenna

Manufactured by the company Space Inventor, this antenna has a gain of 13 - 14.5 dB and a frequency range of 7.25 - 7.75 GHz. While both of these attributes are slightly lower than our requirements, Space Inventor specializes in satellite design solutions, making it reasonable to assume they have the capability to design and manufacture a custom antenna solution for this mission.

XII. Power

A. *Overall Power Consumption*

The primary power source for the spacecraft is the General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG). Each RTG provides between 285 to 300 watts of power at the beginning of its operational life (BOL) and has a mass of approximately 57 kilograms. To ensure sufficient energy supply, each satellite and semi-submersible in the mission is equipped with two RTGs.

The power consumption across the various components of the mission varies by spacecraft. In particular, the JACK spacecraft relies on its pair of RTGs not only for electrical power but also to provide necessary thermal energy to keep its onboard electronics within operational temperature limits. The RTGs are designed to supply continuous power and heat for over-effective mission duration, supporting the mission’s long-duration objectives. The ROSE satellite has a relatively high power draw when all its on board systems are powered on, producing a net consumption of around 16 watts. In contrast, the SMITH and PHILLIPS satellite consumes significantly less power, requiring approximately 109 watts. Meanwhile, the JACK spacecraft operates with a surplus power generation of around 18.8 watts. These values reflect the energy demands of each spacecraft’s systems during standard mission operations

Table 12.1: Overall Maximum Power Consumption of ROSE

Component	Number of Components	Power (W)	Total Power (W)
RTG	2	-300	-600
Low-Gain Antenna	1	50	50
High-Gain Antenna	1	100	100
Transmitter	1	1	1
Reaction Wheels	3	65	195
Camera	1	15	15
Computer	1	100	100
Thrusters	6	5	30
Main Thruster	3	15	45
GNC Computer	1	80	80
TOTAL			**16**

Table 12.2: Overall Maximum Power Consumption of SMITH/PHILLIPS

Component	Number of Components	Power (W)	Total Power (W)
RTG	2	-300	-600
Low-Gain Antenna	1	50	50
High-Gain Antenna	1	100	100
Transmitter	1	1	1
Reaction Wheels	3	65	195
Cameras	1	15	15
Computer	1	100	100
Thrusters	6	5	30
TOTAL			**-109**

Table 12.3: Overall Maximum Power Consumption of JACK

Component	**Power (W)**
RTG	-300
RTG	-300
Low-Gain Antenna	50
Transmitter	1
Cameras	15
Sonar	10
GCMS	5
REMS	0.1
Temperature Sensor	0.1
Computer	100
Motor and Propeller	400
TOTAL	**-18.8**

During the transfer to Saturn, all spacecraft ,JACK, ROSE, SMITH, and PHILLIPS satellites, maintain active onboard computers to ensure continuous system communication and coordination. Each computer consumes an average of 100 watts, reflecting the baseline operational power requirement during this critical phase. In addition to the computer systems, the ROSE satellite's propulsion and communications systems remain active throughout the Saturn transfer. These systems contribute a combined power draw of approximately 205 watts, supporting trajectory adjustments and sustained communication with mission control.

To ensure reliable data transmission during mission deployment, all communication devices across the satellites will be powered on prior to activating any scientific instruments or measuring devices. This sequence is designed to prevent data mismatches or losses during the transition to active science operations. Importantly, the mission architecture eliminates concerns related to solar eclipses or light availability, as all spacecraft are powered by radioisotope thermoelectric generators (RTGs). Since the RTGs provide a continuous and independent power supply, the mission is unaffected by the absence of solar power, ensuring consistent operation even in the shadowed environments around Saturn.

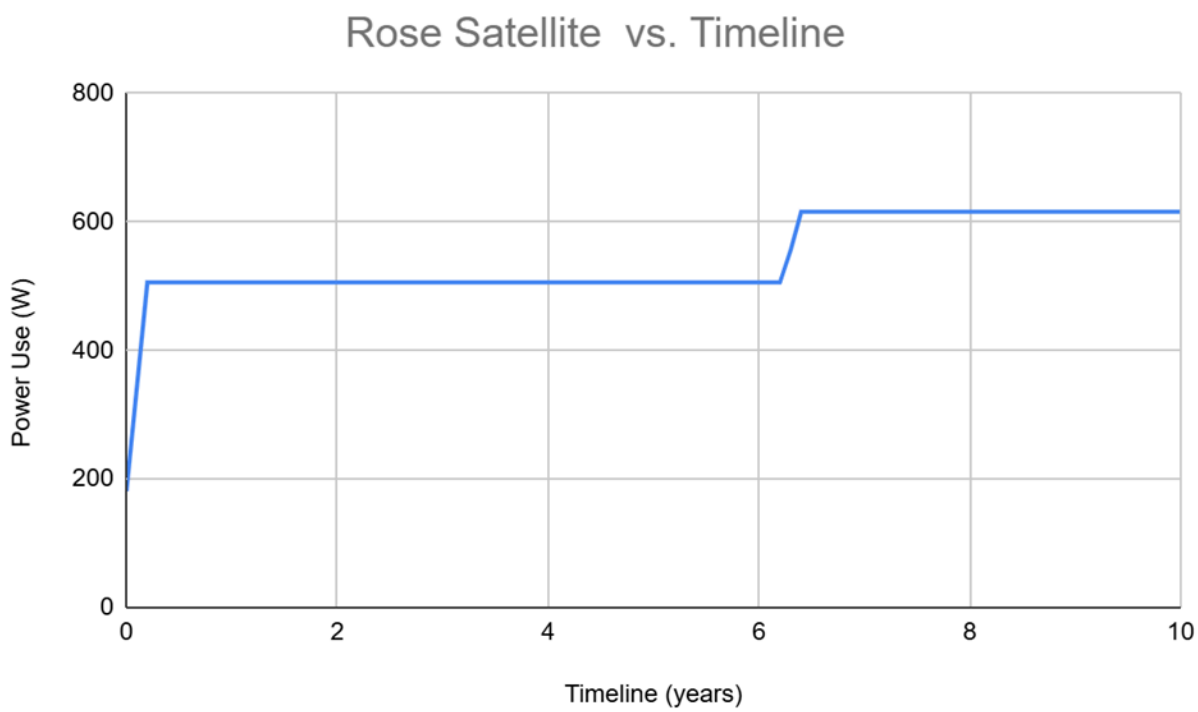


Figure 12.1: Power consumption timeline for the components in ROSE

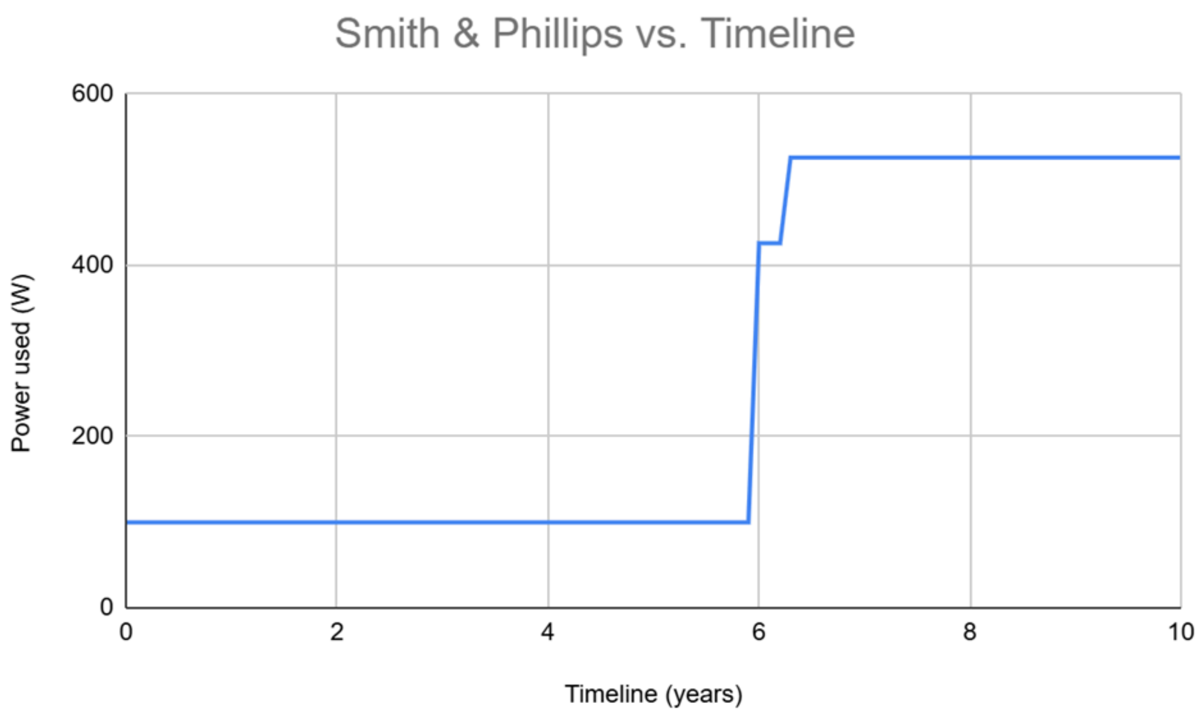


Figure 12.2: Power consumption timeline for the components in SMITH/PHILLIPS.

JACK also follows a similar trend as the curve displayed in **Figure 12.2**.

Given the sufficient and continuous power generated by the RTGs, batteries are not strictly necessary for maintaining constant power to the systems under normal operating conditions. However, batteries are included as a redundancy measure to ensure uninterrupted operation in the event of unexpected anomalies. The battery system is designed with a depth of discharge capable of delivering 450 watts over a minimum duration of five hours. This setup ensures that critical components can remain powered long enough to allow time for any issues to be diagnosed and resolved. To meet this requirement, the minimum power storage capacity of the battery system falls within the range of 0.8 to 1 kilowatt-hour, with a maximum voltage output of 33 volts. This capacity provides a reliable backup power source without adding excessive weight or complexity to the system.

B. Subsystem Power Analysis

After all the subsystems have reached their final configuration and all the components are turned, the scientific power consumption pattern is set on motion for each subsystem. All the system's power fluctuates in a periodic manner over the 26 hour cycle of Titan. The satellites have a 8 hour window where they spin up and point towards Titan and receive data. It is also allotted time to point at the other satellites and for communication amongst each other as well as pointing towards Earth for data relay.

Table 12.4: Table of components broken into hours in use for the satellites.

Time (Hours)	**0**	**1 - 7**	**8**	**9 -15**	**16**	**17 - 23**	**24**
LGA							
HGA				3 Hours			
Transmitter							
Reaction Wheel							
Camera							
Computer							
Thrusters							

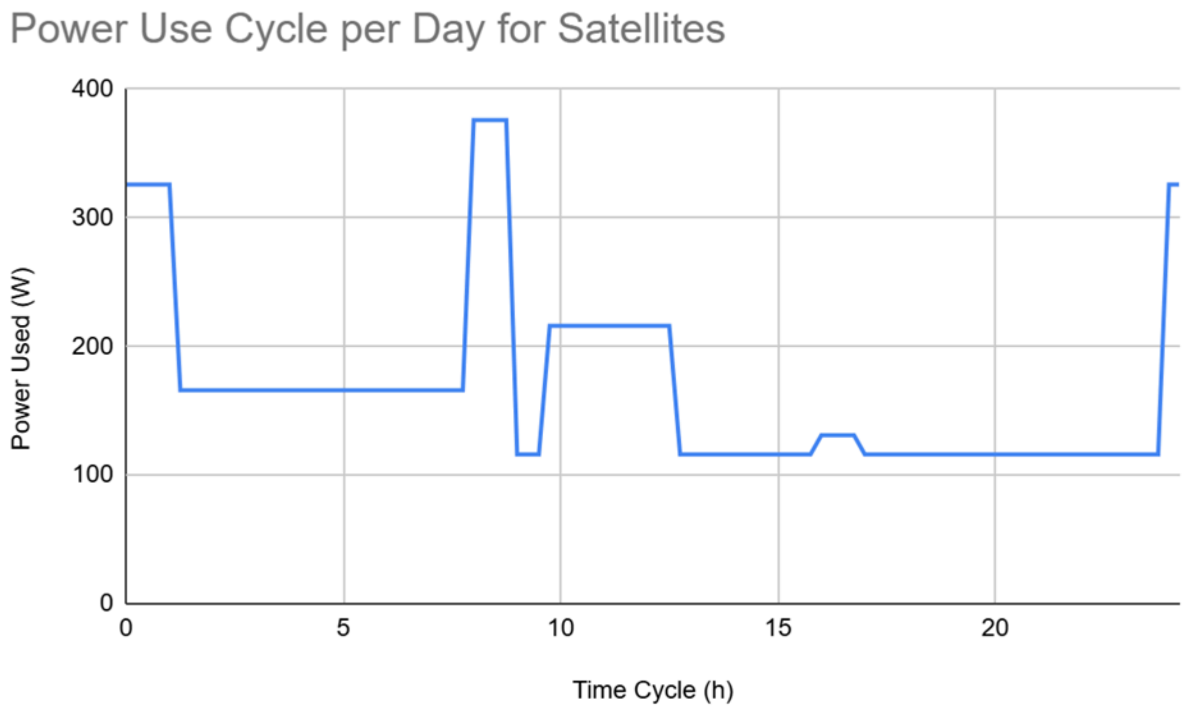


Figure 12.3: Daily power use cycle for the different satellites

The power configuration on JACK will be different as most of the sensors and data relay will be constantly on due to constant visibility from the satellites and data transmission to them. There are some fluctuations in the power consumption due to the equipment operation at certain discrete times. The two main power surges that have to be accounted for are for the motor operation. The semi-submersible will not be moving constantly to help with data collection and transfer. The boat will move in increments during certain periods to extend the longevity of the motor and ensure adequate samples are collected. The power cycle will also follow the 26 hour Titan cycle.

Table 12.5: Table of components broken into hours in use for the semi-submersible.

Time (hours)	0	1 - 7	8	9 - 15	16	17 - 23	24
LGA							
Transmitter							
Camera							
Sonar							
GCMS							
REMS							
Temperature Sensor							
Computer							
Motor and Propeller							

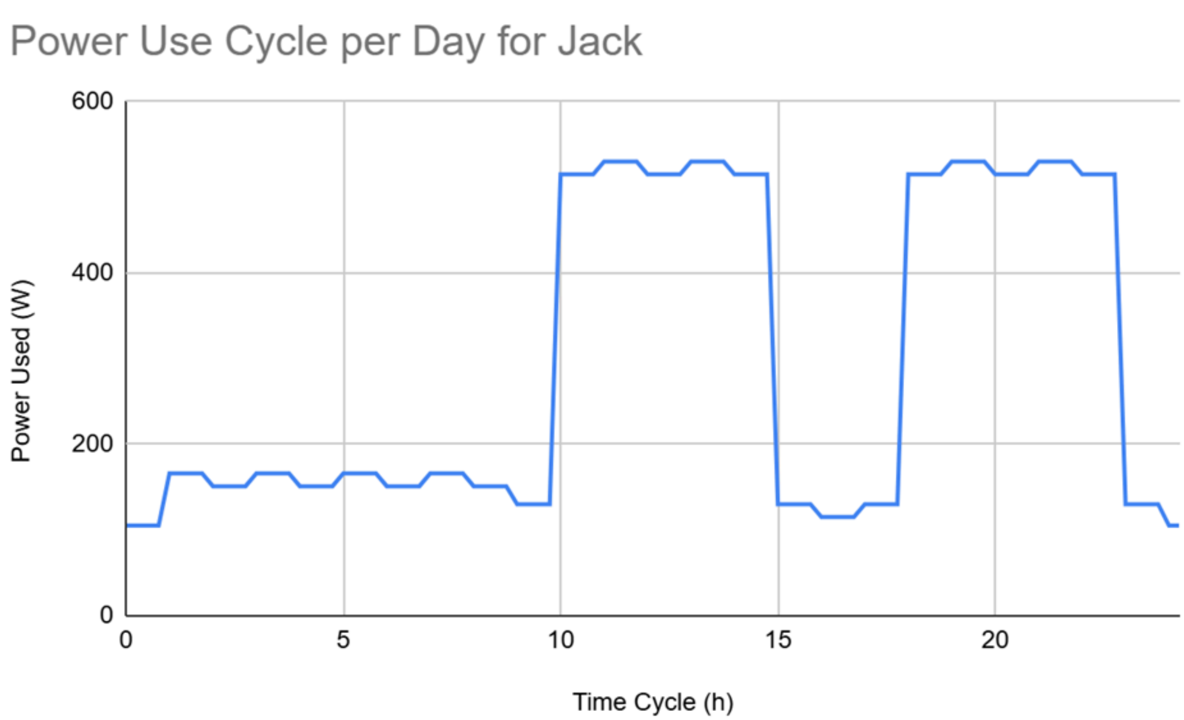


Figure 12.4: Daily power use cycle for the semi-submersible.

XIII. Thermal Design

A. General Overview

Thermal analysis was largely done using the Stefan-Boltzmann Law which took the following form:

$$A_{abs}\alpha S = A_{ems}\varepsilon\sigma T^4$$

Equation 13.1: Application of the Stefan-Boltzman Law

A_{abs} is the surface area that absorbs radiative heat, α is the absorptivity of the paint we are using. It is a fraction of the light that is absorbed by an object. S is the solar constant. The solar constant decreases with the square of the distance, so the calculation was simple. The solar constant was calculated by taking the solar constant value at 1 AU, and then dividing by 9.5^2 AUs, the distance from Titan to the Sun where our probes will orbit. The solar constant was found to be 15 Watts per square meter. A_{ems} is the emissive area, simply the overall surface area of the spacecraft. ε is the emissivity of the paint used. Emissivity is the fraction of energy emitted by a source. The symbol σ represents the Stefan-Boltzmann constant, which is approximately 5.67e^-8 Watts per Meter squared times Kelvins to the fourth. T is the temperature, the factor we solved for. This temperature is the temperature of the probes without the heating effect of the RTGs. The effect of the RTGs as well as the temperatures calculated without them are in the sections below.

B. Thermal Analysis of SMITH and PHILLIPS Satellites

The thermal calculations for the PHILLIPS and SMITH satellites were done with equation 13.1. These two probes are identical, so the temperatures can be assumed to be almost identical. The area that absorbs heat can be assumed to be a rectangle with a length of 4.2 meters and a width of 1 meter. Initially, the gold electroplate was used for these probes as our probes are extremely far from the sun. The temperature was found to be rather cold at 137K. Next, we calculated the power absorbed by the probe at 9.5AUs. The following equation was used to calculate it:

$$P = \varepsilon\sigma A T^4$$

Equation 13.2: Power Absorbed by the Spacecraft

The temperature being the previously calculated 137K using equation 13.1. When we added 2 RTGs at 2000 Watts apiece, the temperature was recalculated using the same equation as above, rearranging for T. The temperature was much too hot, at 250 degrees Celsius. The thermal coating was changed to AZ-95 Zinc paint with an absorptivity of 0.9 and an emissivity of 0.5. When calculations were repeated using the technique above, the temperature was found to be about 45 degrees Celsius at most. This was well within the operating temperature of our sensors and communication devices.

C. Thermal Analysis of ROSE Satellite

The ROSEe satellite is far larger than the other two, with an absorptive area that can be assumed to be a rectangle with the dimensions of 8 meters by 4.5 meters. The emissive area can be calculated with the assumption that the area is the area of a cylinder with a radius of 2 meters and a height of 8.5 meters. The equation used for the emissive area is as follows:

$$A = 2\pi r h + 2\pi r^2$$

Equation 13.3: Surface Area of a Cylinder

The calculations were done using gold electroplate with an emissivity of 0.05 and absorptivity of 0.25. The temperature was calculated using the exact same technique as above using equations 13.1 and 13.2. Even with the gold electroplate, thanks to the larger surface area of the probe and thus more emissive area, the temperature was calculated to be 50 degrees Celsius at a maximum. Once again, this is well within the temperature range of our instruments.

D. Thermal Analysis of JACK Probe

Liquid methane on the Kraken Mare sits at a frigid temperature of approximately -170 degrees Celsius. As such, instruments aboard JACK freezing are a real concern and proper precaution must be taken to ensure the continued operation of the probe. We equipped JACK with 3 centimeters of Spaceloft Aerogel, an excellent space-grade insulating material. In addition to this, JACK is equipped with two RTGs, each emitting a maximum of 4500 Watts of heat. JACK's floor plan is only an approximate 27 square feet. On Earth, we can assume that we need 10 Watts of heat per square foot of floor space to keep the temperature comfortable (about 25 degrees Celsius). Due to this and the excellent insulation properties of Spaceloft Aerogel, JACK is at a real risk of overheating past the 35 degrees Celsius, our maximum allowable temperature without putting the sensors at risk. To combat this issue, JACK is equipped with a heat exchanger which will be programmed to keep the temperature at 20 degrees Celsius, the optimal temperature for peak operational capacity of the sensors onboard.

XIV. References

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