Final Report
Team Chariot

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To Dr. Davide Conte, Assistant Professor of Aerospace Engineering, ERAU

II. Abstract

The Chariot Mission will determine the viability of the potentially hazardous asteroid (PHA), 3361 Orpheus, as an intermediate staging location via in-situ resource utilization (ISRU). The Chariot Mission will launch from Cape Canaveral via a Falcon Heavy launch vehicle on September 22, 2025. Launching on this date will allow the spacecraft to meet near Orpheus's point of closest approach on January 5, 2026. The Chariot Mission consists of the main spacecraft, Eurydice, and its lander, the Heliocentric Asteroid Drilling Experiment System (HADES). Upon transferring to Orpheus, Eurydice will map the surface of Orpheus before deploying the HADES lander. The HADES lander will collect and analyze various asteroid samples at both the exterior and a depth of 50 centimeters. Specifically, HADES will analyze the samples to detect minerals or volatile-rich materials as those can be used for ISRU.

For subsystems, various trade studies are done to determine the ideal candidate. Eurydice will use chemical propulsion via hydrolox propellant. For structural composition, Eurydice and HADES will primarily be composed of titanium; depending on radiation and weight needs for specific subsystems, aluminum, polyethylene, and lead may be used. Eurydice will use Sagitta Star Trackers and NSS Fine Sun Trackers for guidance, navigation, and control subsystem for attitude determination. For attitude correction, Eurydice will utilize a combination of Rockwell Collins RSI 18-220/245 reaction wheels and MR-104H vernier thrusters. As HADES will be deployed directly onto Orpheus by Eurydice, HADES will only contain Sagitta Star Trackers to measure positional data to relay back to Earth. For the electric power subsystem, Eurydice and HADES will have a combination of MMA Design Hawk solar panels and EaglePicher NPD-002271 power cells. The Jet Propulsion Laboratory Space Slights Center will be used for ground control. Additionally, Eurydice will gather topography data, whereas asteroid composition data will be gathered by HADES after deployment and relayed back to ground control. Eurydice will gather topography data via LiDAR, and HADES will gather composition data by using a mass spectrometer, a drilling apparatus, a CheMin, and a ChemCam system. The thermal control system will utilize a kinetic centrifugal pump. LEON GR740 will be used for data processing on Eurydice and HADES due to its high performance, low power draw, and good radiation hardness. Although these subsystems have been determined, the exact position and configuration of the subsystems have yet to be determined.

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IV. Introduction

A. Mission Purpose

Recently, space exploration has experienced accelerated growth from the rise of private space companies to the increased public interest in extraterrestrial exploration on planets such as Mars. As a part of this growth, new methods of space travel will be necessary to facilitate missions to further and further distances. Today's challenge is to maximize payload mass while carrying propellant for extended deep space missions. New methods must be made to enter this new age of space exploration. One of the many options available is to use asteroids as an intermediate refueling station via in-situ resource utilization (ISRU). The Chariot mission will explore the potential of 3361 Orpheus as an ISRU spacecraft refueling station in future manned missions.

B. Objectives

Main Objectives [1]:

- To send the Eurydice spacecraft and its lander, the Heliocentric Asteroid Drilling Experiment System (HADES), to 3361 Orpheus with the necessary equipment to intercept, survey, and mine the minerals within.
- Record positional data of the orbit of Orpheus using HADES.
- Use LIDAR on Eurydice to map the surface of 3361 Orpheus and record the light levels of the surface.
- The primary mission will conclude when HADES sends data on the rock composition of the surface of Orpheus.

Secondary objectives:

- Survey the surroundings along the disposal orbit of Eurydice for other asteroids with potential as an intermediate resupply staging location.

C. Overall Design

The overall design level of the mission is at the preliminary stage, given that specific parts of subsystems still need to be tested for subsystem interface compatibility. Some aspects of the mission will use proven and tested methods such as the LEON GR740, Rockwell Collins reaction wheels, Sagitta star tackers, and the Falcon Heavy. The mission details such as the general two impulse transfer and transfer time of one hundred and five days have been determined, but additional dates in the case of developmental days will be researched as well. Additionally, some subsystems will need to be custom designed for this mission, such as the communication subsystem

The mission will cost $860 million. Eurydice and HADES will have a combined weight of 20 metric tons and a combined volume of 25 m^3. And finally, Eurydice will have a peak power draw of 1856.71 W of power for operation and HADES will peak at 366.3 W.

V. Mission Requirements

A. Ground Rules

1. Eurydice must be capable of accommodating the required LIDAR system up to 3361 Orpheus and then into a safe disposal orbit after the deployment of HADES.
2. The mission launch date must not be after September 22, 2025. [1]
3. The total cost of the mission must not exceed $1.5 billion.
4. The mission must result in the surface mapping of 3361 Orpheus and the analysis of the surface material of Orpheus to a depth of no less than 50cm.
5. The mission must investigate the potential of the ISRU capabilities of 3361 Orpheus for crewed missions.
6. HADES must relay sample analysis results and position data directly to ground stations.
7. The equipment used for this mission must have an operational lifespan long enough to collect the desired data.
8. HADES must be capable of analyzing the composition of the surface samples of 3361 Orpheus

B. Top-Level Requirements

1. Eurydice shall be capable of carrying the LIDAR system and HADES into the required orbit.
   Related Ground Rules: GR1, GR6
2. Eurydice shall be capable of locating ideal positions for the landing of HADES and possible future locations for a fueling station on the surface of Orpheus.
   Related Ground Rules: GR4
3. HADES and its survey equipment will have a minimum operational lifespan of 6 years.
   Related Ground Rules: GR7
4. HADES shall be capable of drilling into the surface of 3361 Orpheus and performing composition analysis on the extracted material.
   Related Ground Rules: GR4, GR5, GR8
5. HADES shall be able to supplement its power supply to maintain its capability of necessary operations.
   Related Ground Rules: GR7
6. HADES shall be able to report the positional data of 3361 Orpheus during the attachment period.
   Related Ground Rules: GR5
7. The total cost of the mission shall not exceed $1.5 billion.
   Related Ground Rules: GR3
8. Eurydice shall be capable of creating a topographical 3D scan of the surface of 3361 Orpheus and a measurement of its light levels.
   Related Ground Rules: GR4
9. The Chariot mission shall launch on September 22, 2025, in preparation to intercept 3361 Orpheus near its closest approach to Earth on January 5, 2026. [2]
   Related Ground Rules: GR2
10. The survey equipment used in the Chariot mission shall be resistant to radiation.
    Related Ground Rules: GR6, GR7
11. Eurydice shall be capable of performing further data collection while in its disposal orbit.
    Related Ground Rules: GR7

C. System-Level Requirements

1. HADES shall be capable of collecting multiple 20-gram samples of the surface of Orpheus at a minimum depth of 50 cm inside a 1-meter square area of the surface in the initial landing position.
   Related Top-Level Requirements: TL4
   Involved Subsystems: SIP, TC&DH
2. HADES and the connected survey equipment shall maintain a physical connection with 3361 Orpheus while in microgravity.
   Related Top-Level Requirements: TL4
   Involved Subsystems: S&M
3. HADES shall have a primary power source and a secondary rechargeable power source to sustain the continuous operation.
   Related Top-Level Requirements: TL5
   Involved Subsystems: EPS
4. HADES shall communicate the data from the sample analysis to ground control.
   Related Top-Level Requirements: TL8
   Involved Subsystems: Comms, GC
5. The launch vehicle chosen shall be capable of accommodating the mass and dimensions of the mission's payload.
   Related Top-Level Requirements: TL1
   Involved Subsystems: Prop, LV
6. Eurydice shall record the surface topography of 3361 Orpheus with a LIDAR system.
   Related Top-Level Requirements: TL8, TL2
   Involved Subsystems: SIP, TC&DH
7. HADES shall report accurate positional data while attached to the surface of 3361 Orpheus.
   Related Top-Level Requirements: TL6
   Involved Subsystems: GNC, TC&DH
8. HADES and Eurydice shall be capable of maintaining communication with the Earth at least 70% of the time.
   Related Top-Level Requirements: TL6
   Involved Subsystems: GNC, TC&DH
9. HADES shall analyze the composition of extracted surface samples with a Near-Infrared Spectrometer.
   Related Top-Level Requirements: TL4
   Involved Subsystems: SIP, TC&DH
10. Both HADES and Eurydice shall have computational redundancy in Triple Modular Redundancy, which has three computer systems running together; the majority voted bit is used to handle error-correcting of a single failed CPU.
    Related Top-Level Requirements: TL3
    Involved Subsystems: SIP, TC&DH
11. All electronic communication and data gathering equipment shall be protected with radiation shielding.
    Related Top-Level Requirements: TL3, TL10
    Involved Subsystems: S&M

12. Eurydice shall be capable of propelling itself and HADES to an orbit identical to 3361 Orpheus within the established timeline.
    Related Top-Level Requirements: TL9
    Involved Subsystems: Prop
13. Eurydice shall be capable of moving to a statistically safe orbit after the deployment of HADES.
    Related Top-Level Requirements: TL11
    Involved Subsystems: Prop
14. Eurydice shall be capable of avoiding ice build-up via a surface temperature control system.
    Related Top-Level Requirements: TL3
    Involved Subsystems: TCS

VI. Mission Architecture

A. Mission Overview

The mission will launch from Cape Canaveral, Florida, USA, on September 22, 2025. Initially, the launch vehicle will enter a low Earth orbit (LEO). A double impulse maneuver will transfer Eurydice from LEO to 3361 Orpheus near its closest approach [2]. The transfer will take 105 days, arriving on January 5, 2026. Upon arrival, Eurydice will utilize LIDAR to map the entire asteroid occurring March 15 to June 20 and repeat until the end of its life. Afterward, Eurydice will deploy HADES on the optimal landing spot for HADES. As part of the requirements, HADES will drill at least 50 cm into the surface, then collect and analyze samples to determine if Orpheus contains minerals or volatile-rich materials used for ISRU purposes for future manned purposes missions. Once primary mission objectives have been met, the remaining propellant on Eurydice will be used to dispose of the spacecraft and meet secondary objectives adequately from July 1 and on. Below in Fig. 6.1, a visual illustration of the presented ConOps can be seen.

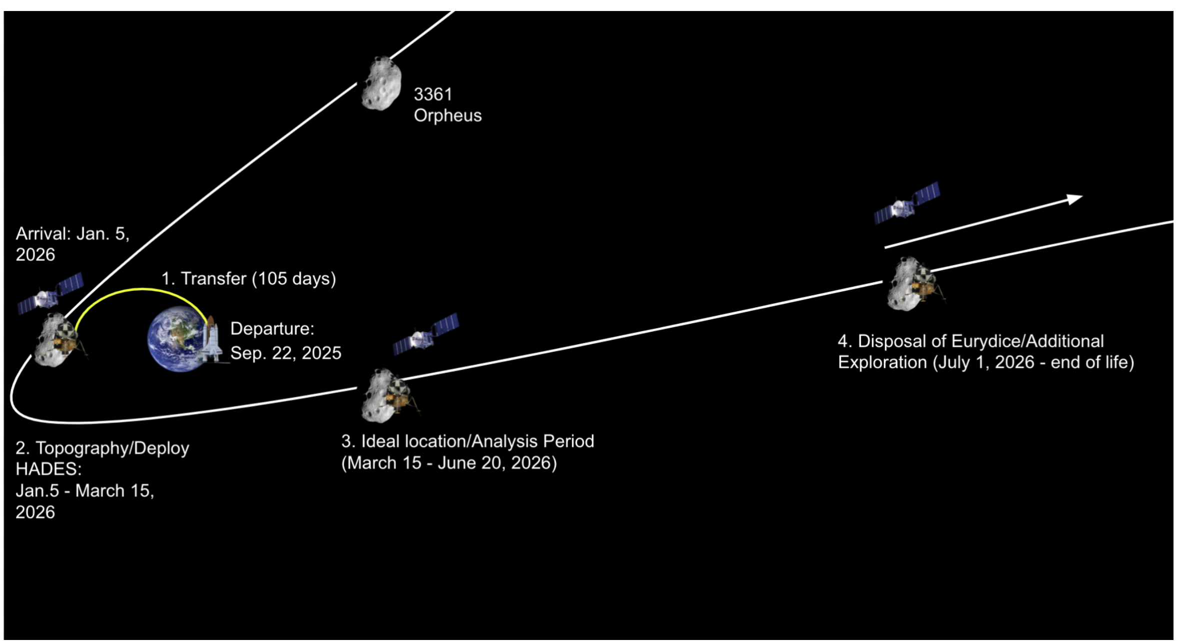

Fig. 6.1 Chariot Mission Concept of Operation

The optimal transfer was generated using Lambert's method and ephemeris data for September 22, 2025. Table 6.1 in the appendix shows the calculated Δv of 4.844 km/s, a time of flight of 105 days, and the number of maneuvers in the transfer [2].

As seen in Table 6.1, these values have been the most desirable by performing a trade study of different orbital transfers. The Δv relies partially on maneuver number and, in the case of the Lambert transfer, comes to be the lowest Δv value. Having a lower Δv allows for a lower cost and propellant consumption, thus allowing for a larger payload. Although there is no rush in getting to Orpheus, the Lambert transfer still proved to be the fastest TOF of 105 days, giving Orpheus an extremely efficient transfer time.

B. Timeline

The mission's timeline shall consist of three phases during its lifetime. These phases are Initial Launch and Setup, 3361 Orpheus Analysis, and Spacecraft Disposal. Timeline analysis diagrams of the Chariot mission are located in the appendix.

During the first stage of the launch – Initial Launch and Setup – the critical substages shall be Escaping Earth's Orbit, Transferring to Orpheus, Conducting Initial Topography Scans, and Deployment of HADES lander. The anticipated period for these sections is 2 days, 105 days, 100 days, and 10 days respectively.

The second phase of the mission will be the Analysis of Orpheus. This frame will consist of 4 more substages to complete. These stages will be Navigation to an Ideal Mining Location, Drilling and Collection, Composition Analysis, and Repeating any Necessary Analysis. These stages are anticipated to conclude within 5, 20, 10, and 60 days.

The final part of the timeline will be the Spacecraft Disposal, consisting of 3 substages. These substages are the placement of Eurydice in a Safe Orbit, Additional Exploration of Eurydice, and Ceasing Command of HADES. These processes will be 30 days, 180 days, and 12 hours. The 12-hour period will take place two months into the Additional Exploration stage.

C. Preliminary Configuration

Figures 6.2 through 6.6 show the dimensions of Eurydice and the HADES lander, respectively. As seen in Table 8.1, the 5.2 m fairing diameter and 13.1 m fairing height of the Falcon Heavy launch vehicle should accommodate Eurydice during launch. HADES will be slotted into Eurydice, as visible in Figure 6.4.

EURYDICE

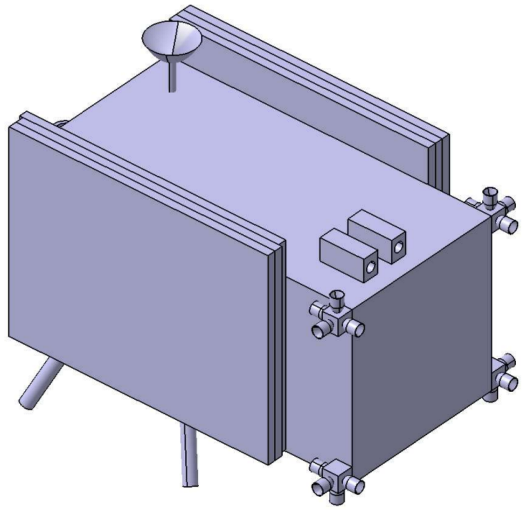

Fig. 6.2 Eurydice in Folded Configuration

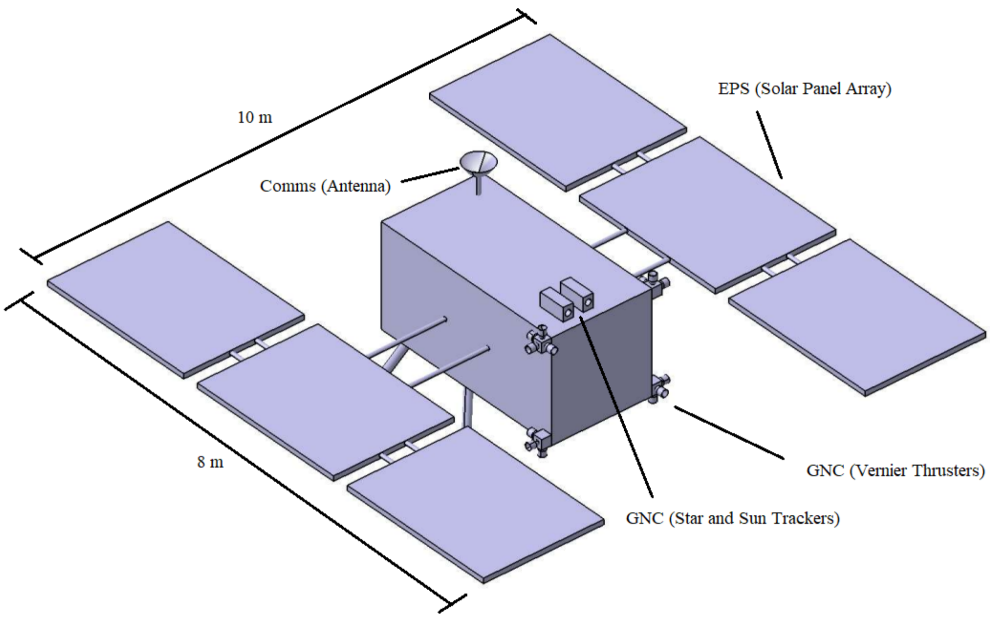

Fig. 6.3 Eurydice in Unfolded Configuration

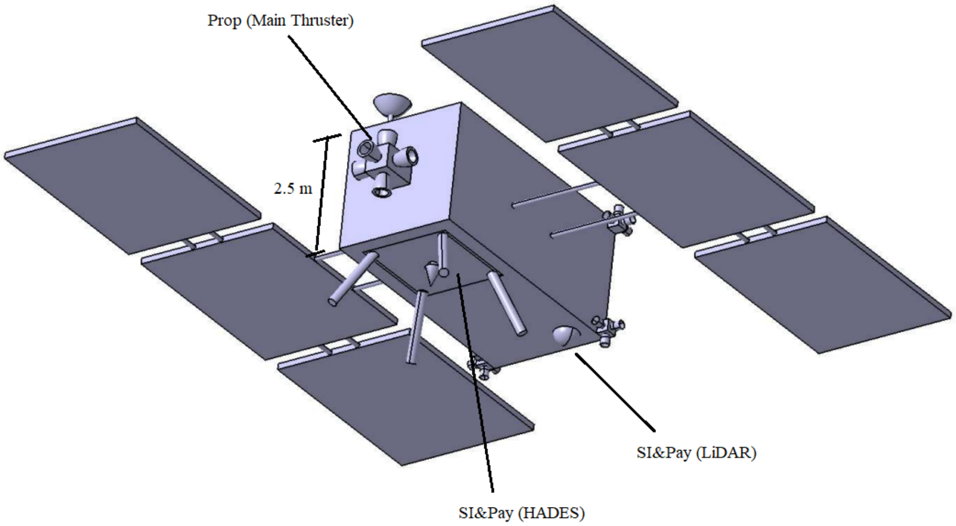

Fig. 6.4 Bottom View of Eurydice

HADES

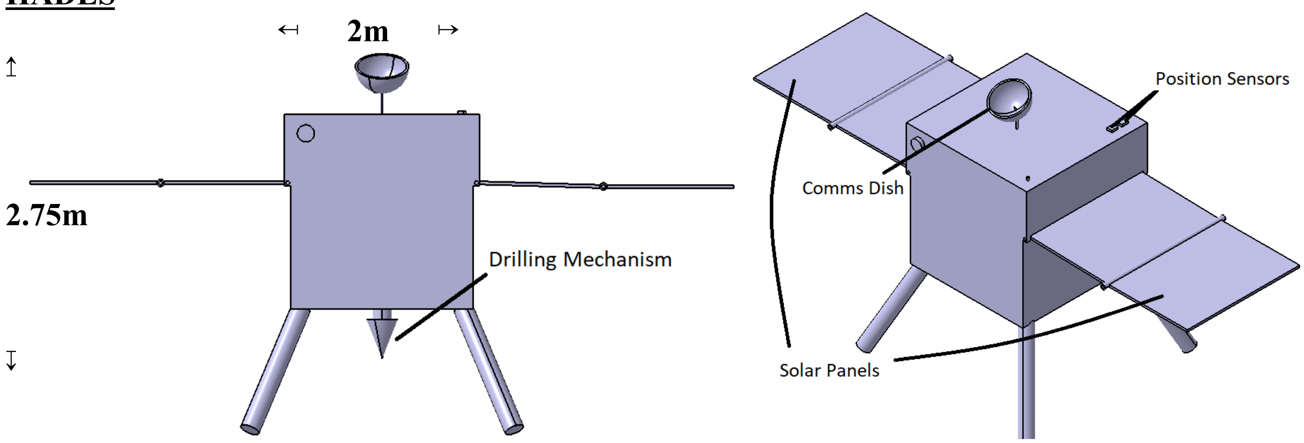

Fig. 6.5 HADES Unfolded Front and Isometric Views

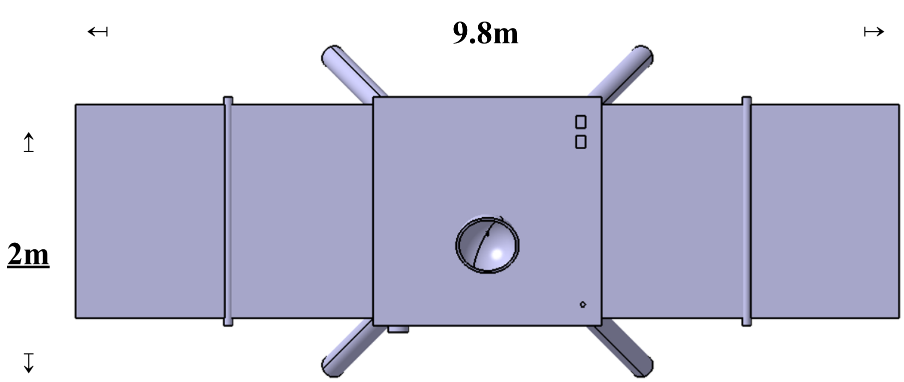

Fig. 6.6 HADES Unfolded Top View

VII. Mission Analysis

A. Final Orbit

The final orbit of HADES will be the orbit of 3361 Orpheus, while Eurydice will transfer into a disposal orbit. The orbit parameters of Orpheus are listed in Table 7.1 [2].

These orbital characteristics play a crucial part in the decision of not only choosing the desired PHA but also the type of orbital transfer used to reach Orpheus. The low inclination of the orbit is desirable because although Orpheus is close in orbit to Earth, it could stray far away from the plane of orbit if the inclination was more significant, ultimately leaving minimal opportunities to complete a transfer. An orbital period close to Earth's has similar benefits, as it also presents more opportunities to transfer. An obvious advantage in an orbital parameter is the nearest approach. The comparative approach benefits costs due to less propellant and lower transfer time. It ultimately places less stress on the launch window and offers flexibility in the launch. Finally, 3361 Orpheus has a relatively high eccentricity, meaning a lower necessary Δv near its apoapsis; incidentally, this is near its closest approach to earth.

B. Transfers

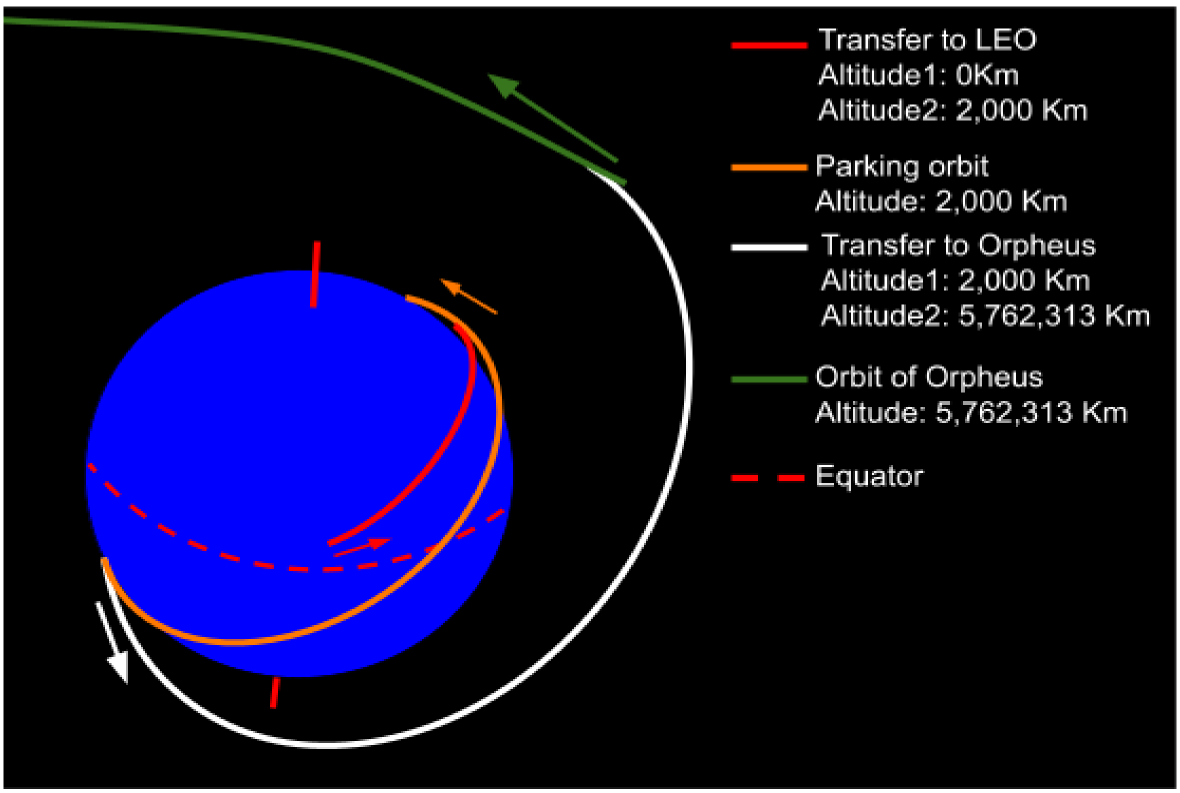

Fig. 7.1 Orbital Transfer from LEO to Final Orbit

The Chariot mission will consist of two main transfers. The first transfer will be the launch of Eurydice from Cape Canaveral to a low Earth orbit (LEO) via the Falcon Heavy on September 22, 2025. Eurydice will use a general two impulse transfer once in LEO to maneuver it from LEO to Orpheus, near its point of closest approach. As seen in Table 6.1, this transfer will require a Δv of 4.884 km/s, which will take 105 days. The final orbit of Eurydice can be idealized as a two-body orbit between the Sun and Eurydice, given the relatively low mass of Orpheus.

VIII. Subsystem Trade Studies[1]

A. Structures and Mechanisms (S&M)

The primary goal of the material chosen is to protect the electronic components from the hostile space environment. These hazards include drastic changes in temperature, exposure to cosmic and solar radiation, and potential micrometeorites collisions. In addition, the material needs to have sufficient structural integrity to carry the loads experienced during launch, landing, and maneuvers. The secondary goal is to minimize the shielding mass to lower the energy needed for operation. Moreover, heritage is considered to assess the reliability of the structure. Finally, the cost of the material used should remain reasonable. These requirements lead to the following importance rank:

1. Mass attenuation coefficient (MAC)
2. Tensile strength
3. Density
4. Thermal conductivity
5. Heritage
6. Cost

Material Options:

- Lead shielding can be used for multiple purposes. Lead is mainly used to create a lead lining in containers and cabinets to store radioactive materials but can also shield barriers. [3]
- Polyethylene is a good shielding material because it has high hydrogen content, and hydrogen atoms are good at absorbing and dispersing radiation. Researchers have been studying polyethylene as a shielding material for some time. It is an efficient ballistic shield that can deflect micrometeorites and shape them into specific spacecraft components. [4, 5, 6]
- Boron Nitride ceramics are strong enough to withstand extreme temperatures up to 2000°C (3632 °F); they display a low thermal expansion coefficient, making them perfect for heat sinks and long-term durability. [7,8]
- Boron Carbide’s growing importance in the aerospace industry is based on its ability to withstand extreme temperatures with a melting point of over 5600 degrees Celsius and an excellent resistance against corrosion from molten salts found at various levels inside jet engines during the takeoff phase. [9]
- Titanium is commonly used in the aerospace industry for its incredible strength and remarkable mechanical properties, such as radiation resistance and low thermal conductivity. The only downsides are its higher price and density compared to other metals.
- Aluminum alloy 2024 is seen by many aircraft manufacturers as the “best” material for aircraft components carrying tensile loads (airframe, wings, ...). It is low cost, easy to shape, and lighter than titanium.
- Titanium alloyed steels such as 321 stainless steel are exceptionally resistant to intergranular corrosion. The alloy can withstand temperatures of 1500°F and still maintain its stability, making it a material of choice for engine components.

[1] Refer to the Appendix Tables 8.1 - 8.10 for trade studies for the various subsystems

The trade study results determined that the principal material to be selected for this mission is titanium, which received the highest overall score. Polyethylene should shield heat-sensitive components and/or create lightweight parts. Aluminum appears to be a concrete alternative to titanium for components carrying reduced loads. Lead may only be employed to shield components exposed to extreme radiation. [10]

B. Launch Vehicle (LV)

The potential launch vehicles will be evaluated by their maximum payload to low Earth orbit (LEO), cost, reliability, payload fairing diameter, and payload fairing height. Maximum payload to LEO is a published parameter of almost all launch vehicles. A higher max payload to LEO means more mass can be transported to the targeted orbit. More mass means more scientific instruments that can be attached to Eurydice. With cost kept in mind to fit into the $1.5 billion budget for the entire project. Reliability is essential to avoid Eurydice failing before completing its mission. Reusability is considered because more reused parts lead to less waste and are more sustainable and environmentally friendly. Payload fairing diameter is considered because it governs the maximum width of Eurydice. Payload fairing height is considered because it governs the maximum height of Eurydice.

Based on the trade studies in Table 8.2, the ideal launch vehicle to use for the Chariot mission is **Falcon Heavy**. [11,12,13,14]

C. Propulsion Trade Study (Prop)

The spacecraft propulsion system will be essential to transfer from low Earth orbit to 3361 Orpheus. The system must be selected to provide the maneuverability required to complete the mission and additional considerations required to implement the system. Ground safety must be considered in the development and implementation of the system, as some propulsion systems require dangerous propellants. Power requirements are considered as some propulsion systems require additional electrical power to run.

The rank of importance is

1. Thrust/Impulse Ratio
2. Relative Power Requirement
3. Relative Ground Safety

Propulsion Options:

- Bipropellant, such as hydrolox (LOX+H2), is used in several rockets at different stages. While typically more complex in design, it is a well-versed system, and many existing systems would be operable for this mission. [15]
- Monopropellant (Hydrazine) is used primarily in orientation control and satellite navigation. While simple and reliable in design, mono-propulsion has a low impulse, which requires additional propellant for long-distance missions, and the toxic nature of the hydrazine propellant it uses. Using monopropellant would require additional costs in development and precautions taken. [15]
- Electric propulsion (Xenon) is an efficient but low impulse propulsion system, primarily used in long-distance missions. Electric propulsion has significant power requirements, which would require additional power generation on the spacecraft. [16]

Hydrolox was selected through the highest J score, as seen in Table 8.3. The main criteria hydrolox met was the high specific impulse value that reflects the engine's efficiency.

While it comes at an energy cost to power propellant pumps and cryogenics, this can realistically be accomplished through the EPS that will be implemented. Along with that, the propellant and propulsion system will be safe to install, requiring few special precautions.

D. Ground Control (GC)

Ground Control facilities, primarily the Mission Operation Control Center and the Space Operations Control Center must be determined to provide the mission with an experienced staff and capable infrastructures to run the program safely. Keeping the Ground Control facilities under NASA or at least the United States will be important to shorten communication loopholes and accessibility to our scientists. Sufficient and well-experienced staff will be critical. As this is a NASA mission, the selected Mission Operation Control Center will be the Lyndon B. Johnson Space Center in Houston, Texas.

Space Operations Control Center Options:

- Marshall Space Operations Center
- Consolidated Space Operations Center
- **Space Flight Operations Center**
- European Space Operations Center
- Combined Space Operations Center
- Air Force Satellite Control Center
- 614th Air and Space Operations

The Space Flight Operations Center located at the Jet Propulsion Laboratory was selected as the Space Operations Control Center (SOCC) for the mission. With the highest J score, tied with the Marshall Space Operations Center, the Space Flight Operations Center was selected as NASA has historically used it for unmanned missions and satellites.

E. Communications (Comm)

The communication system of this mission consists of a 3-meter diameter antenna on Eurydice used for uplink and downlink with both HADES and Earth. HADES has a 0.5-meter diameter antenna for relaying information from HADES' scientific equipment to Eurydice, which will then pass the information on to the ground station. Spacecraft communication systems are custom made for individual spacecraft and are rarely off-the-wall designs. For this trade study, the specific parameters of the communications system needed for our mission were found by creating a MATLAB code to manipulate the link budget equation. The design parameters of the communications system for both Eurydice and HADES are listed in tables 8.5.1 and 8.5.2, included in the appendix.

F. Telemetry, Command, & Data Handling (TC&DH)

The computer used inside Eurydice and HADES is in charge of receiving and manipulating all of the data collected by the data measuring instruments onboard each spacecraft. Thus the computer must reach the standard for each of the components. The priority of the characteristics of the computers is as follows:

1. Performance
2. Radiation hardness
3. Operational environment score
4. Power Draw
5. SRAM

6. Word Length (WL)

The operational environment score was developed separately from radiation hardness and is based on three characteristics of each computer: operational temperature, volatile memory, and feedback. The computers were then given a score based on these metrics.
Data Handling Options:

- RAD750 is the most used space-hardened CPU in the aerospace industry, having been used as recently as 2021 in the James Webb Space Telescope. The computer sports a decently high clock rate along with exceptional radiation hardness. [17]
- RHPPC was developed by Honeywell and is based on the PowerPC 603e architecture. It was designed to control satellite control systems with its high clock rate CPU and a large array of interfaces. [18,19]
- CAES UT700 is a newer space-hardened computer; the main feature of this bus is that it allows systems that use 8 and 16-bit operations to interface and use a bus capable of 16 and 32-bit word length for faster data handling.[20]
- **LEON GR740** is the newest processor of the four and is being used in many European space flight missions. The processor is used due to the exceptionally high clock rate of the CPU and the exceptionally high power efficiency. [21,22]

From Table 8.6 Computer Trade Study in the appendix and the J equation associated with it, the processor that best meets the requirements necessary for the space mission Eurydice and HADES are embarking on is the **LEON GR740**. The LEON scored very high on the performance and power draw scores outperforming all its competitors while not lacking in any other categories.

G. Guidance, Navigation & Control (GNC)

3361 Orpheus is a small target for Eurydice to reach as Orpheus has a diameter of approximately 0.30 km. Thus, the GNC subsystem is critical to ensure Eurydice reaches its final orbit with Orpheus. For the GNC subsystem, a system of sensors to track position and reaction wheels and vernier thrusters will be used for attitude control.

A higher field of view allows for the sensor to read a larger portion of the sky for sensors. High accuracy is necessary to ensure that Eurydice can accurately relay positional data back to Earth. Lower peak power is desired to reduce the size of the EPS subsystem. Radiation resistance protects necessary hardware as no atmosphere is available to protect the sensors from the sun's radiation. Finally, the cost plays a minimal role in the overall mission budget. The order of importance for sensor specifications is as follows:

1. Accuracy
2. Field of View
3. Radiation Resistance
4. Peak Power Draw
5. Cost

A star and sun sensor will be used for Eurydice. Based on the trade study in Table 8.7.1 in the Appendix. The **NSS Fine Sun Sensor** will be used for more general position measurements. In contrast, the **Sagitta Star Tracker** will be used for more precise position measurements, especially when maneuvering to an orbit around Orpheus.

A system of reaction wheels and vernier thrusters will be used for attitude control. For reaction wheels, the larger output torque is desired as it decreases the amount of time to orient Eurydice to a specific attitude. A lower mass is desired in the reaction wheels to help reduce the overall mass of Eurydice and thus lead to lower field propellant costs. A lower peak power reduces the necessary mass of the EPS subsystem. A higher radiation resistance offers environmental resistance to the reaction wheels as well. The order of importance for these characteristics is as follows:

1. Output Torque
2. Peak Power
3. Mass
4. Radiation Resistance

As determined by the trade study in Table 8.7.2 in the Appendix, Eurydice will use three **Rockwell Collins RSI 18-220/45 reaction wheels** for attitude control.

In addition to the reaction wheels, vernier thrusters will be used for attitude changes that do not require as fine of an attitude adjustment as reaction wheels. A higher I_{sp} means higher efficiency for the thruster for the thrusters. A wider range of thrust is ideal as it allows for a wider range of control for attitude changes. A lower mass of the thruster is desirable to reduce the overall mass of the spacecraft. A lower value power also reduces the necessary size of the EPS subsystem. The order of importance for these characteristics is as follows

1. Thrust
2. I_{sp}
3. Valve Mass Power Consumption
4. Mass

Based on the trade study in Table 8.7.3 in the Appendix, Eurydice will use **MR-104H vernier thrusters** for larger necessary changes in attitude.

In conclusion, the GNC subsystem for Eurydice will consist of NSS Fine Sun Sensor, Sagitta Star Tracker, Rockwell Collins RSI 18-220/45 reaction wheels, and MR-104H vernier thrusters. HADES will not require attitude control as Eurydice will orient itself (and thus HADES) before launching HADES into the surface of Orpheus. However, HADES will include Sagitta Star Trackers and NSS Fine Sun Sensors to relay positional data back to Eurydice.

H. Power / Electrical Power System (EPS)

Power and the Electrical Power System of Chariot are critical because nearly all systems onboard Eurydice and HADES require electrical power. Chariot uses predominantly solar power and power cells to support these systems as the mission’s farthest point from the Sun is just past Mars’ orbit distance. The power cells and solar panels were evaluated independently to find the best combination of the two systems for the mission parameters. For the solar panels of the mission, the criteria were prioritized as follows:

1. Peak Beginning of Life Solar Array Power per 3 units (BOL)
2. Specific Power
3. Panel Type Score
4. Technology Readiness Level

- Each panel type was given a score between one and three based on its compatibility with the mission, whether the panel was deployed rigidly or otherwise.

For the power cells, evaluate them based on the following characteristics. The typical capacity of the power cells and the specific energy were valued the highest due to how much equipment is using power at any given time and the overall weight of the power/electrical system compared to the rest of the craft.

1. Typical Capacity
2. Specific Energy
3. Max Discharge Rate
4. Energy Density
5. Technology Readiness Level

Based on the results of the two independent trade studies and their J equations listed in tables 8.81 and 8.8.2, the combination of solar panels and power cells that make up the electrical systems of Eurydice and HADES was determined. **MMA Design Hawk** rigidly deployed solar panels and high Peak Solar Array Power with a high J score of 12.74 and power cells from **EaglePicher Technologies NPD-002271** power cells that resulted in a high J score of 25.48 due to its typical high capacity and specific energy.

I. Thermal Control Systems (TCS)

Managing thermal control systems in HADES consists of several components. The most important contributing factor of thermal control it will be equipped with is a fluid pump. With that being said, fluid pumps often present the most reasons for failure in TCS. There are two main types of pumps: Kinetic (centrifugal) and positive displacement. A trade study will be conducted to dictate what pump will best fit HADES. The *best* pump will be the type offering the highest J value. This equation for J was developed by considering several factors [32]. Among these factors, each one will receive a score out of 10 regarding how well it will fit with project Chariot. The trade study and individual scores for each category can be seen in Appendix, and the order of importance for each specification can be seen below.

1. Flow Control
2. Risk/Failure Modes
3. Flow Rate
4. Size
5. Heritage

Flow control is most important as it will ensure the quality of our product. With proper control, the possibility of failure within our system will reduce overall. Second is the history of failure or risk because if our pump fails, it will greatly affect our mission. But, as mentioned, the possibility of failure is minimized with good fluid control. Next is the flow rate. A pump with a steady flow rate that can consistently manage TCS is desirable because the cooling rate will increase proportionally to the flow rate. Size is fourth, as it is more desirable that the pump be small. We have relatively small spacecraft, but they do not get large as pumps go. Finally, heritage is last. Simply because it is noteworthy of the overall usage of the pumps, but one or the other may fit better with our requirements regardless of its popularity.

Considering each category of Table 8.9 seen in the appendices, the **kinetic (centrifugal) pump** proves to be the best fit for our mission and its goals, with a J score of 27.25. The model used is simply a standard kinetic pump [33].

J. Scientific Instruments and Payloads (SI&Pay)

The main goal of the scientific instruments subsystems is to determine the surface composition, the concentration of materials of interest (ice, oxygen, etc.), and the hardness of the surface, and the topography of 3361 Orpheus. The function of the overall scientific equipment system is to collect, analyze, and potentially conduct scientific experiments. Based on the requirements previously stated, the desired functions of each instrument are composition analysis, hardness testing, topography determination, and concentration analysis. Given that a single instrument cannot achieve all of these objectives, a combination of instruments is required.

The two candidates for topography determination are LiDAR and Synthetic Radar Aperture Imaging (SAR).

- LiDAR technology was used in NASA's LiDAR in Space Technology Experiment (LITE) [34] and has constantly been employed in recent space missions. The advantages of the LiDAR system over SAR are its higher spatial resolution and lower power consumption [35]. Another outstanding characteristic of LiDAR is its ability to be scaled up or down depending on the mission requirements. On the other hand, laser diode failures have been a recurring problem and shorten the lifetime of the laser system [36].
- The advantages of the SAR system are its ability to "see" through dust clouds and its increased surface area coverage. However, SAR technology relies on heavy computational hardware and software systems as the spacecraft's position and velocity must be known with great precision, and its attitude must be controlled tightly. The levies demands on the spacecraft's attitude control system and requires spacecraft navigation data to be frequently updated [35].

After comparing both candidates, it was determined that LiDAR is a better fit for topography determination as 3361 Orpheus is small, and a SAR system is too power-consuming.

The candidates for composition and concentration analysis are:

- X-ray diffraction: used by the Mars rover Curiosity to analyze the minerals present on the planet's surface. The instrument determines the composition of crushed rocks by shooting x-rays at the powder and analyzing the refracted beams. Curiosity's Chemistry and Mineralogy X-Ray Diffraction (CheMin) is about the size of a laptop. [37]
- Spectrograph: An ingenious way to determine surface composition from a distance (up to 23 feet) while assisting drilling is used by the rover Curiosity's ChemCam system. This system comprises three components, a camera providing an image of the surface, a laser that vaporizes surface rocks, creating a plasma of their component gasses, and spectrographs that divide the plasma light into wavelengths for chemical analysis. [37]
- Mass spectrometry: can perform surface composition analysis and determine precisely the species of atoms or molecules present. The world's most miniature high-performance mass spectrometer is currently being used on the International Space Station (ISS). The

overall mass of the system is 2.3kg, and it is roughly the size of a shoebox, with a power consumption of 12.5 Watts. [38]

The drilling system used during NASA's icebreaker mission is selected:

- Drilling system: The drill can drill up to 1m below the surface. When operating, the drill is fully automated by an integrated control system that can change forces and speeds in response to changing downhole conditions. The drilling system includes a 3-degree freedom deployment boom, enabling multiple holes to be drilled.
- Data/sample collection: The drill is equipped with motion sensors measuring the penetration rate to determine the hardness and temperature sensors to prevent overheating. The collected data is typically reported at a rate of 4Hz. [39]

IX. Summary Tables

Table 9.1 Summary Table for Eurydice

Subsystem	Model	Mass (kg)	Volume (m^3)	Power (W)
S&M	Titanium	3536.44	0.8001	N/A
LVs	Falcon Heavy	---	42.0198 (Payload Fairing Size)	N/A
Prop	Hydrolox	13276.996	13.598	N/A
GC	JPL Space Flight Operations Center	N/A	N/A	N/A
Comms	Custom	7	0.021	448.25
TC&DH	LEON GR740	0.39	0.0001487	58.4
GNC	2x Sagitta Star Tracker	0.55	N/A	2.8
	2x NSS Fine Sun Trackers	0.07	N/A	0.26
	3x Rockwell Collins RSI 18-220/45 reaction wheels	18.9	0.035180	450
	12x MR-104H vernier thrusters	28.8	0.108842	624
EPS	MMA Design Hawk Solar Panels	76.5	0.00646	N/A
	EaglePicher Technologies NPD-002271 Power Cells	7.29	0.00018	N/A
TCS	Standard Kinetic (Centrifugal) Pump	569.712	1.104	250
SI&Pay	LiDAR HADES	7.4 2302.048	0.05 1.6706	23 N/A
Total Requirements		17530.048	15.7239	1856.71

Table 9.2 Summary Table for HADES[2]

Subsystem	Model	Mass (kg)	Volume (m^3)	Power (W)
S&M	Titanium	1616.66	0.36576	N/A
GC	JPL Space Flight Operations Center	N/A	N/A	N/A
Comms	Custom	3	0.1	$3.887*10^{-7}$
TC&DH	LEON GR740	0.13	.0001487	33.4
GNC	2x Sagitta Star Tracker	0.55	N/A	2.8
EPS	MMA Design Hawk Solar Panels	18	0.00152	N/A
	EaglePicher Technologies NPD-002271 Power Cells	7.29	0.00018	N/A
TCS	Standard Kinetic (Centrifugal) Pump	569.712	1.104	250
SI&Pay	Mass Spectrometer ChemCam CheMin Drilling Apparatus	2.3 4 2 33	0.005 0.01 0.01 0.02	12.5 5 12.5 50
Total Minimum Requirements		2251.348	1.6206	366.3

[2] HADES will be placed on Eurydice as a payload

X. Conclusion

The goal of the Chariot mission was to determine the viability of ISRU for PHAs. The Chariot mission targeted 3361 Orpheus due to its proximity, general composition, and orbital parameters. The Chariot mission will use various subsystems and a lander capable of drilling into Orpheus to determine surface and interior composition. Trade studies have been used at each step of the mission design process to maximize the success probability of this mission by using components that will be most effective for the Chariot mission. Various transfer orbits and subsystems have been researched to develop a mission plan that meets the RFP's requirements.

Two vehicles will be sent to reduce potential failures in the Chariot mission: the Eurydice spacecraft and the HADES lander. Eurydice will conduct an initial tomographic scan of the asteroid to ensure that HADES is deployed into an optimal spot to avoid potential failure. HADES will communicate data received from sample collection back to Eurydice for processing.. Both Eurydice and HADES have computational redundancies by utilizing a triple modular redundancy system, which has three computer systems running together. The majority voted bit is used to correct errors. HADES also has additional radiation shielding. The computational redundancies and adequate radiation protection ensure that samples can be analyzed for ISRU potential.

As discussed in the report, Chariot's mission subsystems have been determined. A Falcon Heavy launch vehicle will be used to launch Eurydice into orbit. Eurydice will use a Hydrolox-based chemical propulsion system. Both HADES and Eurydice will be constructed of titanium, aluminum, polyethylene, and lead materials based on individual subsystems' weight, radiation protection, and strength needs. Hydrolox propulsion will be used for Eurydice and HADES. Custom communication systems will be designed for both HADES and Eurydice. A combination of MMA Design Hawk Solar Panels and EaglePicher Technologies NPD-002271 Power Cells will be used for EPS for HADES and Eurydice. Eurydice will conduct a topography scan, HADES will determine compositional data, and they both will use their respective scientific instruments as previously discussed. The thermal control system will use a standard kinetic centrifugal pump. The LEON GR740 will manage telemetry, command, and data handling. These various subsystems are also based on use in previous missions. For example, the LEON GR740 microprocessor has been used on the BepiColombo mission to Mercury, the ChemCam and CheMin are being used by the Curiosity rover for composition analysis. The Falcon Heavy has successfully carried a Tesla Roadster into a heliocentric orbit. To reduce failures in the Chariot mission, it will use tested subsystems to ensure the further success of its primary and secondary objectives.

Overall, the mission has been designed to ensure a successful collection of data from 3361 Orpheus. Although the subsystems have been determined, their exact configuration and subsystem interface compatibility will continue to be developed. From the use of multiple vehicles to determining a viable asteroid candidate to utilizing tested subsystems, the Chariot mission shall strive to maximize the success of determining the viability of Orpheus as an ISRU refueling station for future human-crewed missions.

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Attributions

Contributor	Contribution
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Ryan Kendrick	Wrote: 5.Mission Requirements, 2.Abstract (Rough draft), 9.Summary Tables, 10.Conclusion (Rough draft), 12.Appendices Edited: 4. b: Objectives, 6. a: Mission Overview, 6. b: Timeline, 7. a: Final Orbit, 8. a: launch vehicle trade study, 8.d: data handling General corrections and tense editing throughout
Priyanshu Kumar	Wrote Abstract, Conclusions, 6.a Mission Overview, 6.d Made Eurydice CAD, 7.b.Transfers, 8.g GNC trade study, updated and formatted summary table, updated Eurydice CAD. Did overall edits and formatting of the paper
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Jeremy Nicholson	8.d: Researched and compiled data for trade study data, 8.d: Created the J equation and computed values. Assisted in the formatting of the document overall.

XII. Appendices

Mission Analysis

Timeline analysis diagram

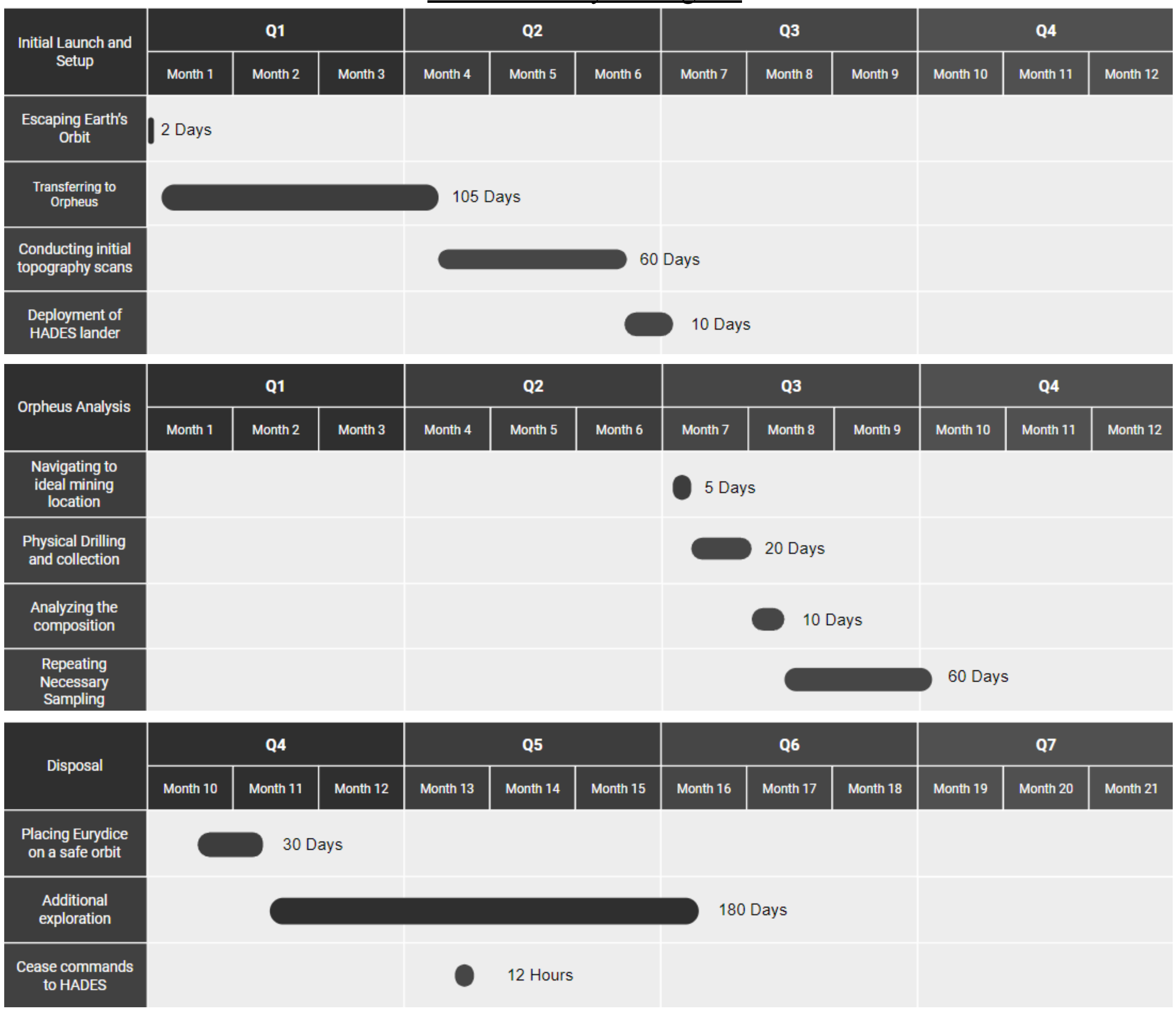

Table 6.1. Orbital Transfer to 3361 Orpheus

Orbit	Δv (km/s)	TOF (Days)	# of Maneuver
Lambert's	4.844	105	2

Table 7.1. Final Orbit Characteristics

Parameters	Semi-major Axis (km)	Inclination of Earth's equator (deg)	Eccentricity	Closest Approach (km)	Orbit Period (Years)
3361 Orpheus	1.81E+08	2.6	0.323	5.67E+06	1.33

Trade Studies

Table 8.1 Structures Trade Study [10]

Materials	Mass Attenuation Coefficient MAC [14] $(10^{-2}\frac{cm^2}{g})$	Thermal Conductivity $(\frac{W}{mK})$	Density (g/cm^3)	Cost ($/kg)	Tensile Strength (MPa)	Heritage Score	J
Lead	6.206	34.7	11.35	2.51	18	5	13.5
Polyethylene	1.658	0.4	0.96	0.93	27	10	18.0
Boron Nitride	1.368	550	1.9	24	55.15	8	8.6
Boron Carbide	1.368	29.5	2.4	30	415	9	15.8
Titanium	2.844	17	4.5	4.8	240	10	**19.7**
Aluminum alloy 2024	2.168	193	2.78	3.2	186	10	16.7
321 Stainless Steel	3.22	14	7.92	3	75	9	14.3

$$J = \frac{3*g}{cm^2} * MAC(\frac{cm^2}{g}) + \frac{mk}{W} log_5(thermal\ conductivity(\frac{W}{mk})) - \frac{cm^3}{g} * density(\frac{g}{cm^3}) - \frac{kg}{USD} * cost(\frac{USD}{kg}) + \frac{4}{MPa} * log_5(tensile\ strength(MPa)) + 0.5 * heritage$$

Table 8.2 Launch Vehicle Trade Study

Launch Vehicle	Max Payload to LEO (kg)	Cost (USD)	Reliability $\frac{successful\ missions}{total\ missions}$	Reusability	Payload Fairing Diameter (m)	Payload Fairing Height (m)	J
Falcon 9 [11]	22,800	$62 Million	140/142	yes	5.2	13.1	-1.04
Delta IV Heavy [12]	28,370	$350 Million	12/13	no	4.57	16.00	-291.83
Atlas V (551) [13]	18,850	$109 Million	81/81	no	4.57	16.49	-69.09
Falcon Heavy [14]	63,800	$90 Million	3/3	yes	5.2	13.1	**12.10**

$$J = \frac{10^{-3}}{kg} * Max\ Payload\ to\ LEO\ (kg) - \frac{10^{-6}}{USD} * Cost(USD) + 10\ if\ reusable + \frac{1}{m} * fairing\ diameter(m) + \frac{1}{m} * fairing\ height(m) + 10 * \left(\frac{successful\ missions}{total\ missions}\right)$$

Table 8.3 Propulsion Trade Study

Propulsion	Upper Limit Specific Impulse	Relative Power Requirements	Relative Ground Safety	Low Thrust Transfer	J
BiProp (Hydrolox) [15]	532.5	4	3	No	**16.1979**
MonoProp (Hydrazine) [15]	250	5	1	No	15.2755
ElecProp (Xenon) [16]	9000	1	5	Yes	12.4993

$$J = 2.2 log_{10}(N/s) + 1.8(Rel.\ Power\ Req.) + 1(Ground\ Safety) - 3(Low\ Thrust\ Transfer\ Boolean)$$

Table 8.4 Ground Control Trade Study

Facility	Operator	Location	Staff	# Operations	J
Marshall Space Operations Center	NASA (3)	Huntsville, Alabama	6000	10+	14.7782
Consolidated Space ops Center	Military (1)	Colorado	8000	UNK (Assumed 5)	12.9031
Space Flight Ops Center [17]	NASA (3)	JPL in California	6000	10+	**14.7782**
European Space Ops Center	European(-3)	Darmstadt, Germany	800	10+	7.9031
Combined Space Ops Center	Military (1)	Vandenberg AFB	UNK (Assumed 1000)	UNK (Assumed 5)	8.0000
Air Force Satellite Control Center	Military (1)	Onizuka AFS, California	UNK (Assumed 1000)	4	7.2000
614th Air and Space Ops	Military (1)	Vandenberg AFB, California	450	UNK (Assumed 5)	7.6532

$$J = Operator + log_{10}(Staff) + 0.8(Operations)$$

Table 8.5.1 Custom Communication System Parameters for Eurydice

Parameter	Units	Value
Uplink Frequency	Giga-Herts (GHz)	2.2
Downlink Frequency	Giga-Herts (GHz)	2
Receiver (Earth) Antenna Diameter	Meters (m)	70
Transmitter (Eurydice) Antenna Diameter	Meters (m)	3
Allowable Pointing Error of Earth Antenna	Degrees	0.05
Allowable Pointing Error of Eurydice Antenna	Degrees	0.5
Data Rate	Bits Per Second (bps)	50,000
Maximum Transmitter Power	Watts (W)	448.25

Table 8.5.2 Custom Commuication System Parameters for HADES

Parameter	Units	Value
Uplink Frequency	Giga-Herts (GHz)	2.2
Downlink Frequency	Giga-Herts (GHz)	2
Receiver (Eurydice) Antenna Diameter	Meters (m)	3
Transmitter (HADES) Antenna Diameter	Meters (m)	0.5
Allowable Pointing Error of Eurydice Antenna	Degrees	0.5
Allowable Pointing Error of HADES Antenna	Degrees	0.5
Data Rate	Bits Per Second (bps)	500,000
Maximum Transmitter Power	Watts (W)	3.887*10^-7

Table 8.6 Computer Trade Study

Computer	Performance (MHz)	SRAM (MB)	Power Draw (Watts)	Word length (bits)	Radiation Hardness (kRad)	Operational Environment	J
RAD750 [18]	200	36	10	64	1000	5	80
RHPPC [19,20]	150	32	8	32	100	7	50
CAES UT700 [21]	132	64	12	32	100	8	31.4
LEON GR740 [22,23]	250	64	1.8	64	300	9	**123**

$$J = \frac{1}{5 * MHz} * Processor(MHz) + \frac{4}{log_{10} radiation(kRad)} * log_{10} radiation(kRad) + 2 * environment\ score - \frac{5}{2 * Watts} Power(Watts) + \frac{3}{4 * MB} * SRAM(MB) + \frac{1}{4 * bits} * WL(bits)$$

Table 8.7.1 Sensor Trade Study

Sensor	Field of View (Deg)	Accuracy (arc seconds)	Peak Power Draw (mW)	Radiation Resistance (kRad)	Cost (USD)	J
NSS Fine Sun Sensor [24]	140	360	130	10	$12,000	**-8.48**
Sagitta Star Tracker [25]	35.4	6	1400	20	$50,000	-18.10
nanoSSOC-D60 [26]	60	1800	115	30	$4,500	-15.75
SSOC-A60 Sun Sensor [27]	60	1080	36	100	$9,000	-13.41
Twinkle Star Tracker [28]	10.35	52.5	600	---	$50,000	-19.91

$$J = -\frac{1}{log_2(arc\ seconds)} * log_2(accuracy) + \frac{1}{20 * deg} * Field\ of\ View\ (deg) + \frac{1}{log_{10}(kRad)} * log_{10}(radiation) - \frac{1}{100 * mW} * Peak\ Power\ Draw(mW) - \frac{1}{10000 * USD} * Cost(USD)$$

Table 8.7.2 Reaction Wheel Trade Study

Reaction Wheel [29]	Mass (kg)	Peak Power (W)	Output Torque (N-m)	Radiation Resistance (kRad)	J
Rockwell Collins RSI 45-70/60	7.7	90	0.075	15	17.13
Rockwell Collins RSI 18-220/45	6.3	150	0.22	15	**25.97**
Goodrich Corporation TW-2A40	2.55	25	0.04	---	5.80
Bradford Engineering W18	7	64	0.3	---	25.20

$$J = \frac{50}{Nm} * Output\ Torque(Nm) + \frac{1}{20 * W} * Peak\ Power\ (W) + 1 * mass\ (kg) + \frac{1}{log_{10}(kRad)} * log_{10}(radiation)$$

Table 8.7.3 Thruster Trade Study

Thruster [30]	Mass (kg)	I_{sp} Average (Ns/kg)	Thrust (N)	Valve Max Power Consumption (W)	J
MR-107U	1.38	2216	182 - 307	34.8	13.326
MR-104H	2.4	2255	201 - 554.2	52	**27.515**
MR-104J	6.44	2148	440 - 614	56	22.888
MRM- 122	0.76	2182	51 - 142	43	11.792

$$J = \frac{1}{20 * N} * (Thrust_{max}(N) - Thrust_{min}(N)) + \frac{1}{kg} * mass(kg) + \frac{kg}{1000 * Ns} * I_{sp}(\frac{Ns}{kg}) + \frac{1}{10 * W} * Max\ Power\ (W)$$

Table 8.8.1 Solar Panels Trade Study [31]

Company	Panel Type	Specific Power (W/kg)	Peak BOL Solar Array Power (W) (3U)	TRL	J Values
AAC Clyde Space	Body Mount + Deployed Rigid	*	9.25	7-9	9.97
Blue Canyon Technologies	Body Mount + Deployed Rigid	*	28-42	7-9	11.49
DHV Technologies	Deployed Rigid	67	8.4	7-9	8.80
Exoterra	Deployed Flexible	140	150	5-6	11.51
MMA Design	Deployed Rigid	121	36-112	7-9	**12.74**
	Deployed Rigid	95	36	7-9	10.96
Airbus Defense and Space Netherlands	Deployed Rigid	165	66	5-6	12.31
Agencia Espacial Civil Ecuatoriana	Deployed Rigid	107	7.2	7-9	9.65
Redwire Space	Flexible Blanket	100	1000	5	12.07
	Hybrid Array	80	300	5-6	11.70
EnduroSat	Deployed Rigid	50	7.2	7-9	8.22
	Deployed Rigid	55	7.2	7-9	8.35

$$J = ln(Peak\ BOL) + \frac{Specific\ Power}{40} + Panel\ Type + TRL$$

Table 8.8.2 Power Cell Trade Study [31]

Companies	Energy Density (Wh/L)	Specific Energy (Wh/kg)	Typical Capacity (Ah)	Max Discharge Rate (A)	TRL	J Values
EaglePicher Technologies	271	153.5	14.5	15	7-9	**25.48**
GomSpace	228.7	150	5.2	2.5	7-9	14.06
	211.9	149.2	5.2	2.5	7-9	13.95
AAC Clyde Space	169.5	119	4.84	2.6	7-9	12.41
Ibeos	151.1	109.8	9.82	20	5-6	18.23

$$J = Typical\ Capacity + \frac{Specific\ Energy}{30} + ln(Max\ Discharge\ Rate) + \frac{Energy\ Density}{200} + \frac{TRL}{5}$$

Table 8.9 TCS Trade Study

Pump Type [32]	Size	Spaceflight Heritage	Flow Rate	Flow Control	Risk/Failure Modes	J
Positive Displacement	Larger	Less Used	Low	Lower	Less Risk	20.25
Kinetic (Centrifugal)	Smaller	More Used	High	High	Higher Risk	**27.25**

$$J = (size\ score) + 0.5(heritage\ score) + 1.25(flow\ rate\ score) + 1.5(flow\ control\ score) - 1.25(risk\ score)$$

Table 8.10.1 Scientific Instruments Function(s)

Scientific Instrument	Sample Collection	Hardness	Topography	Composition & Concentration	Mass (kg) / Power (W)
Spectrograph (ChemCam)				X	4 / 5
X-Ray Diffraction (CheMin)				X	2 / 12.5
Mass Spectrometer				X	2.3 / 12.5
LiDAR			X		7.4 / 23
SAR (not selected)			X		
Drilling Apparatus	X	X			33 / 50
Total					48.7 / 253

Table 8.10.2 Characteristics of Satellite LiDARs [23]

	LITE	GLAS	MOLA	MLA
Mass (kg)	2000	300	25.85	7.4
Power (W)	3000	330	34.2	23

Table 8.11 Cost equation

$C = \alpha Q^{\beta} M^{\Xi} \delta^{S} \varepsilon^{\frac{1}{IOC-1900}} B^{\phi} \gamma^{D}$

Parameters for AMCM^4	Values for AMCM^4
α	$5.65 * 10^{-4}$
β	0.5941
Ξ	0.6604
δ	80.599
ε	$3.8085 * 10^{-55}$
ϕ	-0.3553
γ	1.5691
AMCM Input	Values for AMCM Input
B	1.4
D	-2
IOC	2030
M	$14467.487626\ lbs$
Q	1
S	2.13
Inflation rate	72%
C	**$ 860 million**