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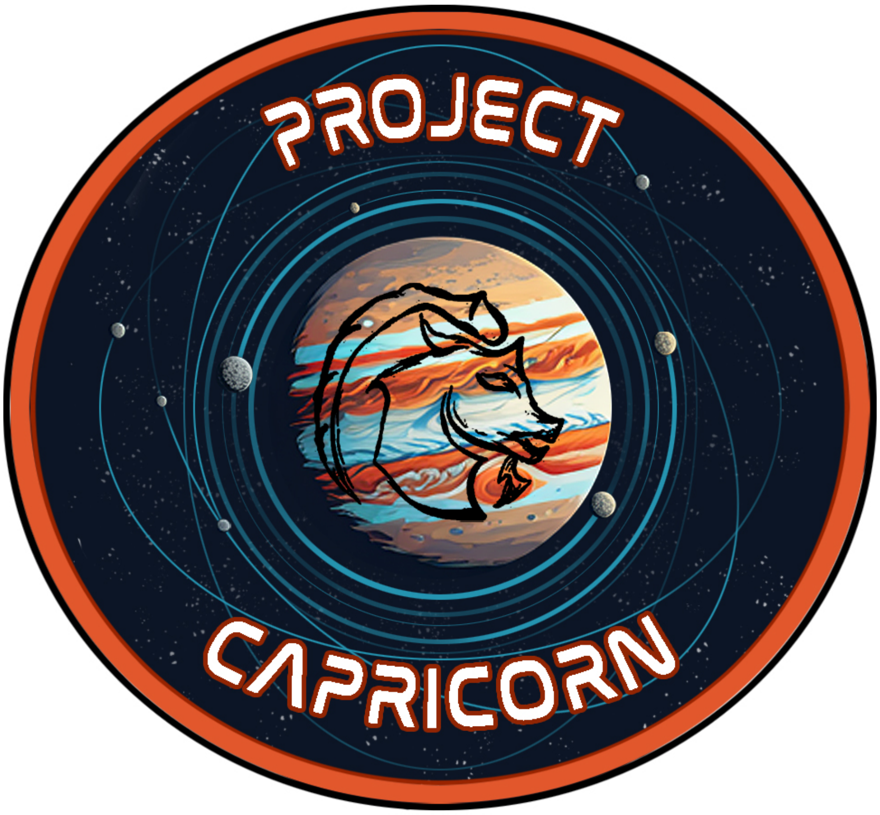
MMAE 411 Spacecraft Dynamics - Hamster Team

Project C.A.P.R.I.C.O.R.N.



Characterization of Ananke, Pasiphae, Retrograde Irregulars, and Carmae in Orbital Research of New moons

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1 Abstract

The CAPRICORN mission aims to explore Jupiter's retrograde irregular moons, focusing on Carme, Ananke, and Pasiphae, to determine whether they were captured by Jupiter's gravity, formed from larger parent bodies or developed during the planet's formation. By capturing the first detailed surface images and compositional data, the mission will shed light on these moons' origins. CAPRICORN will also study smaller moons and conduct follow-up observations of the Galilean and inner moons, concluding with a descent into Jupiter's atmosphere. Spanning 3,230 days, the CAPRICORN mission includes multiple phases: a transfer to Jupiter, extended observation of its outer irregular moons, and secondary flybys of the Galilean and inner moons. The mission culminates with a controlled descent into Jupiter's atmosphere. Throughout, CAPRICORN must manage strict dynamical constraints, minimizing radiation exposure, and maintaining communication with Earth, all while ensuring high-resolution imaging and data transmission.

2 Science Justification

The CAPRICORN mission is a targeted exploration of Jupiter's retrograde irregular moons, which remain some of the least studied objects in our solar system. The mission's primary objective is to observe the Carme, Ananke, and Pasiphae moon systems to determine whether these irregular moons originated from the fragmentation of larger parent bodies or were independently captured by Jupiter's gravity. CAPRICORN will also explore the hypothesis that these moons may have formed during Jupiter's planetary development, potentially mirroring the dynamics seen in the Sun's Oort Cloud. By comparing data from the Irregular Moon groups with Oort Cloud objects, CAPRICORN seeks to investigate whether Jupiter's irregular moons might serve as a dynamical analog to the distant, icy bodies orbiting our Sun.

Since most of these moons have only been studied through dynamical surveys, CAPRICORN will be the first mission to capture detailed, close-up imaging of their surfaces and compositions. Using high-resolution cameras, spectroscopic analysis, and orbital mapping, CAPRICORN will study the surface composition, structure, and trajectories of these moon systems to determine whether they are remnants of primordial Jovian system materials or products of later cosmic events.

In addition to its focus on larger moons, CAPRICORN will conduct a secondary mission to image smaller moons within these systems. This comprehensive survey will provide essential comparative data, offering a more complete picture of the diversity and dynamic evolution of Jupiter's irregular satellites.

Upon completing its primary mission, CAPRICORN will move toward the inner system, conducting flybys of the Galilean moons to follow up on any findings from NASA's Europa Clipper or ESA's JUICE missions. CAPRICORN will then continue its exploration by visiting Jupiter's inner moons, including Thebe, Amalthea, and Adrastea, before concluding its mission with a descent into Jupiter's atmosphere.

The results of CAPRICORN will not only illuminate the origins and evolution of Jupiter's irregular moons and planetary development but will also contribute to broader questions about moon formation and capture mechanisms in planetary systems. By examining whether Jupiter's irregular moons form a system similar to the Sun's Oort Cloud, CAPRICORN aims to enhance our understanding of the solar system's history and the processes that shape planetary satellite systems throughout the cosmos.

3 Mission Timeline

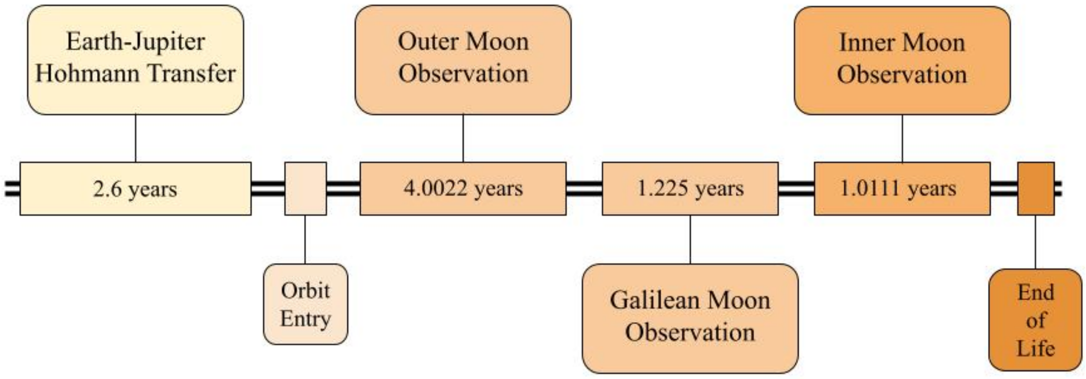

Figure 1: Project CAPRICORN ideal mission timeline

The CAPRICORN mission spans 8.8383 years, including the initial Earth-Jupiter transfer and subsequent moon transfer orbits. The mission plan follows this timeline:

The Earth-Jupiter Transfer phase requires approximately 2.6 years, with margin for initial insertion errors. The Outer Moons (Carmae, Pasiphae, and Ananke) observation phase spans 4 years. As the primary mission targets and furthest objects from Jupiter, these require the longest observation period.

Galilean Moon observations take approximately 1.225 years, while Inner Moon observations (Amalthea, Adrastea, and Thebe) require 1.0111 years, including transfer times between intercept points and apojove positions.

The mission baseline duration is 8.8383 years, with an additional

4 Mission Phases

The CAPRICORN Mission will complete flybys of 10 significant Jovian moons within a 10-year span. The mission phases will proceed sequentially from an established starting point and entry position relative to Jupiter.

Orbital calculations for these phases utilize two primary methods: Hohmann transfers and Lambert's Solution for two-position problems, supplemented by Euler numerical integration for object propagation and simulation continuation.

4.1 Orbital Mechanics

The Hohmann Transfer calculations rely on the Vis-Viva Equation for determining transfer velocities:

$$\vec{v} = \sqrt{GM\left(\frac{2}{r} - \frac{1}{a_T}\right)} \tag{1}$$

Where:

$$M = M_{\text{Jupiter}} \text{ for moon observations}$$
$$a_T = \frac{a_{\text{current}} + a_{\text{target}}}{2}$$
$$a_{\text{current}} = \text{initial 25 million km semi-major axis}$$
$$\vec{r} = \text{probe's current position}$$

Lambert's Problem is concerned with the determination of an orbit between two specified points over a given time. This problem has been solved through many methods. For the following Lambert determinations, we will use the solution presented by (Gooding, 1990). The Python package using this method provides a highly accurate Lambert solution (M.G., 2021)which will be useful for each step describd below. Visualization was accomplished with the python package reboound. (Rein, H. & Liu, S.-F., 2012)

Euler's method of integration will be used to propogate each object and determine the positions, velocities, and various orbital elements.

When the first burn phase occurs, the moons will have the following orbital elements given by JPL/NASA's Horizons Orbital Elements: (NASA JPL Solar System Dynamics, 2024):

Satellite	a (km)	e	ω (deg)	M (deg)	i (deg)	node (deg)
Io	421800.	0.004	49.1	330.9	0.0	0.0
Europa	671100.	0.009	45.0	345.4	0.5	184.0
Ganymede	1070400.	0.001	198.3	324.8	0.2	58.5
Callisto	1882700.	0.007	43.8	87.4	0.3	309.1
Amalthea	181400.	0.003	180.1	310.6	0.4	282.9
Thebe	221900.	0.018	26.6	182.1	1.1	340.4
Adrastea	129000.	0.000	0.0	214.5	0.0	0.0
Carme	23144400.	0.256	155.0	234.0	164.6	117.5
Ananke	21034500.	0.237	56.2	259.4	147.6	17.6
Pasiphae	23468200.	0.412	264.8	277.8	148.4	312.3

Table 1: Orbital Elements of Jupiter's Natural Satellites

4.2 Launch Conditions

The payload mass calculations for the Earth-to-Jupiter transfer mission are based on a two-stage launch vehicle design and are crucial for ensuring the spacecraft has enough mass for both propulsion and scientific operations. The calculations begin by splitting the total Δv between the two stages. The total Δv for the mission is 10.18 km/s. This Δv includes both the entry burn required for orbit insertion at Jupiter (4.58 km/s) and the transfer burn to escape Earth's gravity and enter an interplanetary trajectory (5.81 km/s).

To calculate the payload mass for each stage, the Tsiolkovsky rocket equation is used, which relates the required Δv to the mass ratio of the rocket. The payload fraction for each stage is determined by the effective exhaust velocity, which is a product of the specific impulse (I_{sp}) and gravitational acceleration (g_0). For this mission, the specific impulse (I_{sp}) is set at 400 seconds, and the structural mass ratio is assumed to be 1/10, meaning 10% of the total mass is allocated to the structure and other non-propellant components. Using these parameters, the payload fraction for each stage is calculated to be 0.1391, meaning that 13.91% of the mass for each stage is allocated to the spacecraft's payload.

The initial payload mass for Stage 2 is calculated using the final payload mass (300 kg) and the payload fraction for Stage 2. The initial mass for Stage 2, before the burn, is 1217.28kg. This mass accounts for the payload, structure, and propellant required to perform the necessary maneuvers. To determine the total mass for Stage 1, which includes the payload for Stage 2, the initial payload mass for Stage 2 is divided by the payload fraction for Stage 1, yielding the initial mass for Stage 1. The total initial payload mass for the mission, which combines the structural mass and propellant for both stages, is calculated to be approximately 4939.24kg.

These calculations ensure that the spacecraft can execute the necessary Δv maneuvers for the Earth-to-Jupiter transfer while maintaining a payload that is sufficient for scientific operations once in orbit around Jupiter.

4.3 Earth-Jupiter Transfer

The mission commences with launch from Cape Canaveral Space Force Station on December 25, 2028. Following liftoff, the spacecraft is first inserted into a temporary low Earth orbit (LEO) at an altitude of 200-300 kilometers. From this staging orbit, a Trans-Earth Injection (TEI) maneuver is executed with a ΔV of 8.95 km/s, placing the spacecraft on its interplanetary trajectory.

The cruise phase spans approximately 936 days (2.6 years), during which the spacecraft traverses the interplanetary void between Earth and Jupiter. This phase incorporates planned trajectory correction maneuvers (TCMs) at two key points: an early correction 30-90 days after launch, and a mid-course adjustment at roughly the halfway point. While these TCMs require minimal propellant, they are essential for maintaining the precise trajectory needed to intercept Jupiter's sphere of influence with the desired approach conditions.

The mission culminates in the arrival phase on July 19, 2031. A Jupiter Orbital Insertion (JOI) maneuver, requiring a ΔV of 1.23 km/s, decelerates the spacecraft from its approach velocity (V_∞) of 5.81 km/s. This critical burn establishes the spacecraft in its operational orbit at 1.0×10^7 km from Jupiter with a velocity of 4.58 km/s. The complete mission design achieves an optimal balance between transfer duration and propulsion requirements, with a total ΔV budget of 10.18 km/s—well within the capabilities of current interplanetary propulsion systems.

Our investigation utilized the DE421 ephemeris pulled using the python package jplephrem (Rhodes et al., 2019) for precise planetary positions and implemented Gooding's method for solving Lambert's problem. The search space encompassed launch dates beginning January 1, 2025, with daily trajectory calculations. Each potential launch date was analyzed with transfer durations ranging from one to four years, providing comprehensive coverage of possible mission profiles.

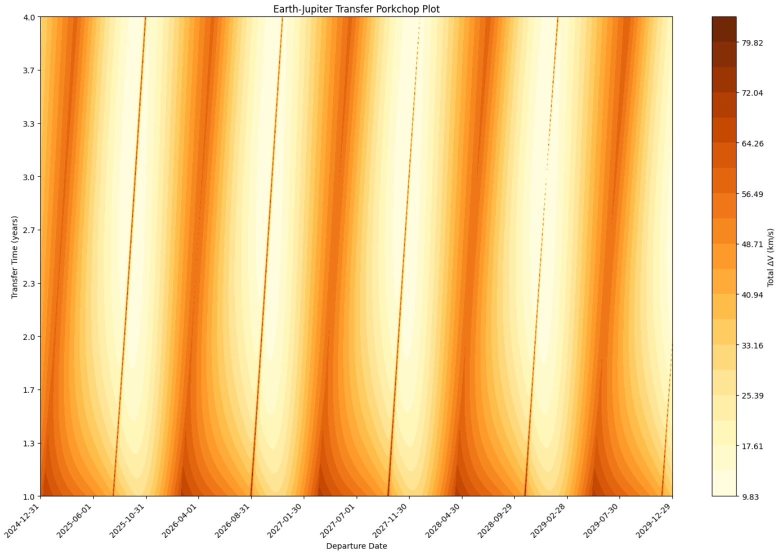

Figure 2: Porkchop plot showing delta-V requirements (km/s) as a function of departure date and transfer time. Lighter regions indicate lower delta-V requirements.

To focus on practically achievable trajectories, we first applied a ΔV threshold of 10.5 km/s, eliminating high-energy transfers that would exceed reasonable propulsion capabilities. Among the remaining trajectories, our optimization weighted transfer time reduction at 70% and ΔV efficiency at 30%. This weighting reflects our mission priority of minimizing flight duration while staying within acceptable propellant limits. The recommended trajectory offers an ideal compromise between flight time and propellant efficiency, while maintaining mission limitations.

4.4 Retrograde Orbit Insertion

Once the Earth-Jupiter Transfer has been completed, the probe will be directed to the following position with the entry velocity change accounting for the following velocity:

r = [0.0, -10000000000.0, 0.0] m
v = [-4135.71634734, 1974.97378999, 0.0] m/s

Each transfer from this point on will occur at an inclination of 0 degrees, both to simplify intercept coordinates and reduce Δv usage.

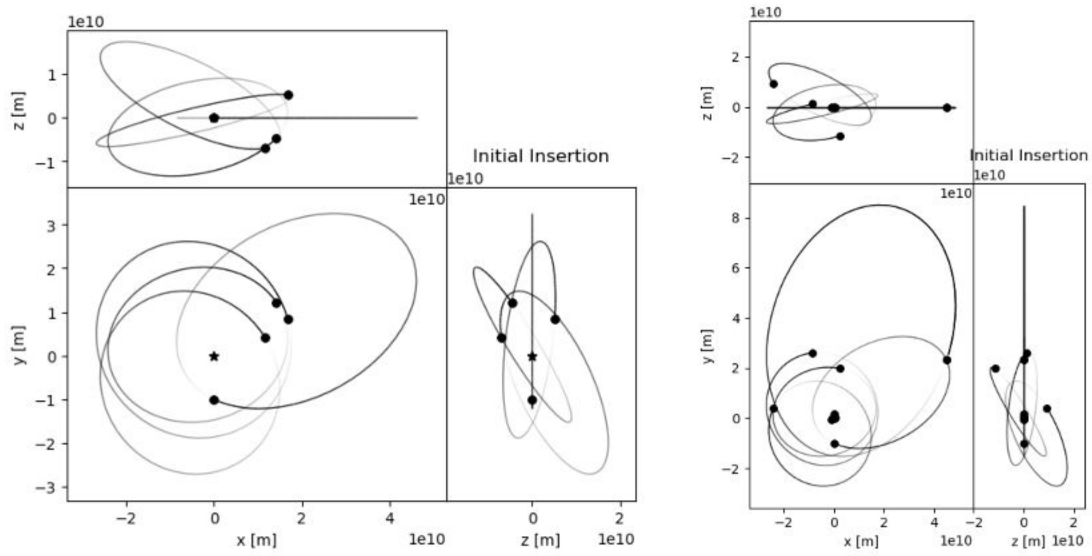

Figure 3: Initial Insertion point and progression to first maneuver point.

The probe will progress on this orbit for 1.5 years, at which point it will perform the following maneuver:

r = [45015463860.11271, 23243574338.21035, 0.7857613833189621]
Initial velocity = [332.9107, -746.8351, 0.] m/s
Post burn velocity = [-493.4415, -1513.0831, 0] km/s
Total Δv = 1126.9401 m/s

Current Time used: 3.85 years
Current Velocity used: 1126.9401 m/s

Once this maneuver has been completed, the initial states of the moons will be confirmed and the CAPRICORN probe will progress to its first two flybys.

4.5 Pasiphae and Carmae Intercept

From the insertion maneuver, the probe will progress 0.7041 years until it reaches Pasiphae. While the direct observation window is brief, CAPRICORN will maintain a position within the orbital belts of both moon groups, enabling extended observation of multiple objects within these retrograde satellite families. The close approach to Pasiphae occurs at 1126.9 m/s, providing optimal conditions for high-resolution imaging and compositional analysis.

The spacecraft then progresses to Carmae after 0.0465 years (approximately 17 days) from the Pasiphae encounter. This efficient transfer between the two moon systems maximizes scientific return while operating within the mission's Δv constraints. The proximity to both moon groups allows CAPRICORN to study smaller satellites and debris that may share similar orbital characteristics.

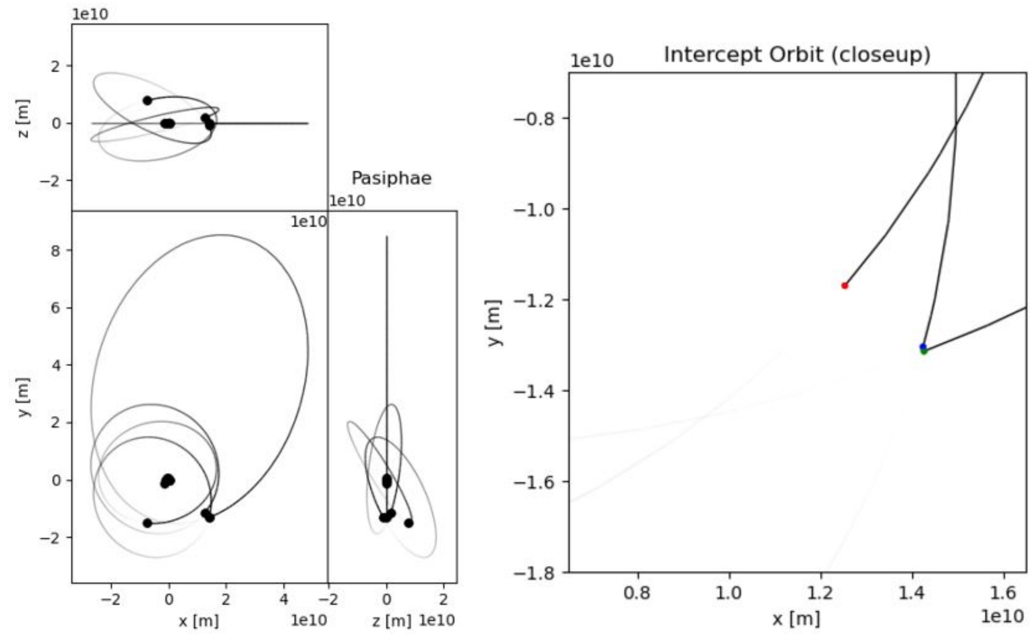

Figure 4: Pasiphae Intercept point. Pasiphae (blue), Carmae (red), and the Probe (green) are shown.

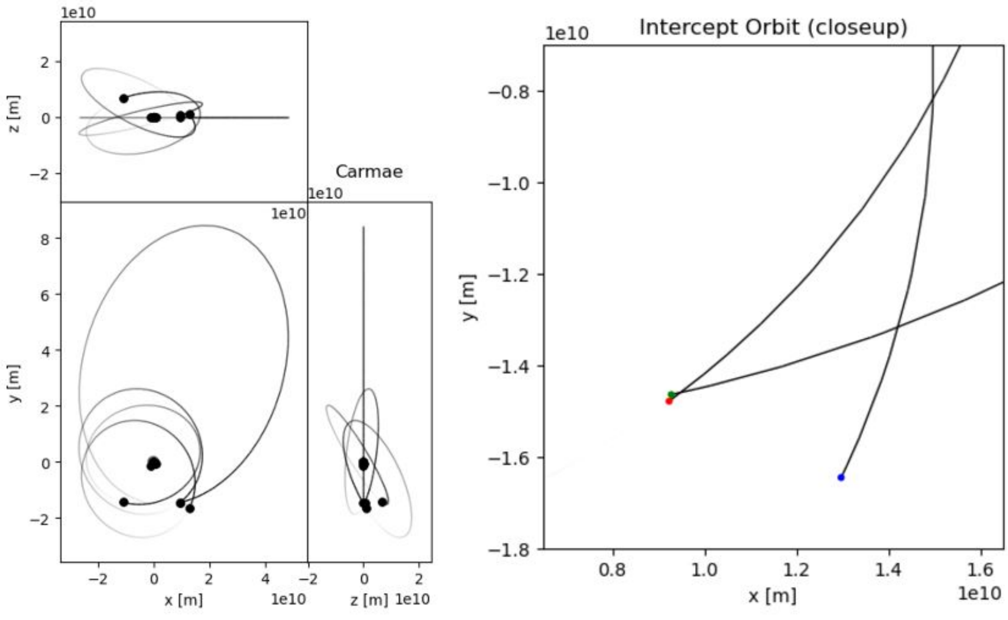

Figure 5: Carmae Intercept point.

Mission Time: 4.6006 years
Encounter Velocity: 1126.94 m/s

4.6 Ananke Intercept

The probe will progress 0.1199 years to the perijove of its orbit, at which time it will perform its second maneuver to intercept the final outer moon, Ananke.

r = [-4351738005.358082, -14130638815.837841, -32076.058020162458] m
Initial v = [-3659.2803130597144, 1134.5527952054567, 0] m/s
Final v = [-3189.32964, 558.528248, 0] m/s
Total Δv = 743.4097 m/s

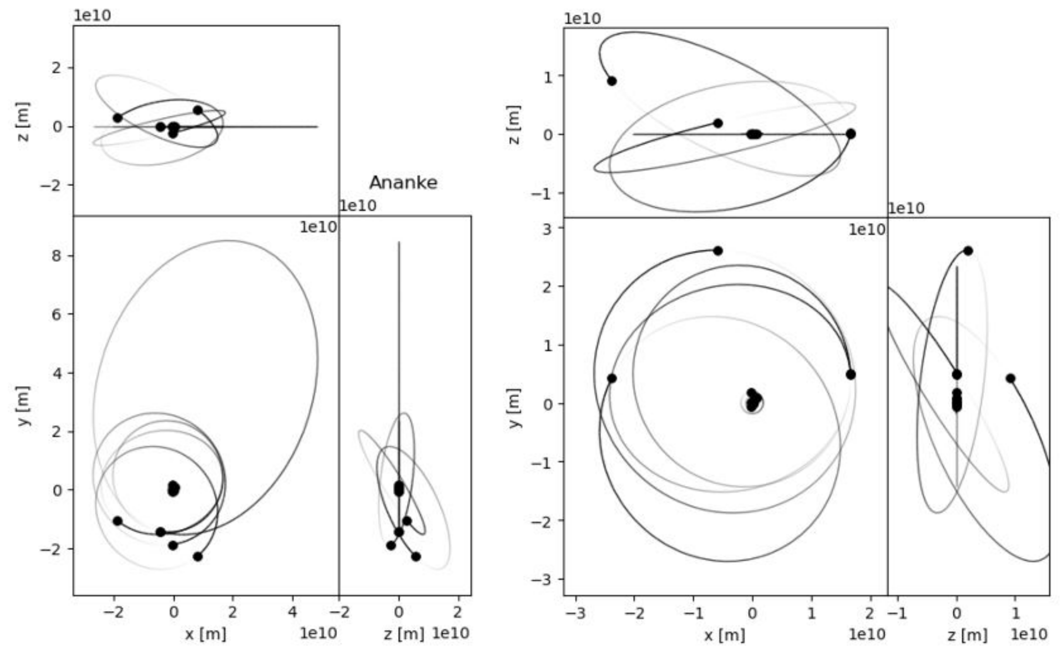

Figure 6: Ananke Transfer Orbit. The initial transfer from perijove is shown on the left, and the Ananke intercept point is shown on the right.

Once this orbit has been achieved, the probe will progress 1.143 years to the Ananke intercept point at:

r =[16652173552.811317, 5076947924.163416, 0] m

This intercept is much closer and longer than the previous two intercept points, allowing for a longer time to observe the Ananke moon and its surrounding objects. The probe will be within observation range for an estimated 30 to 40 days, with a minimum altitude of approximately 10-50 km.

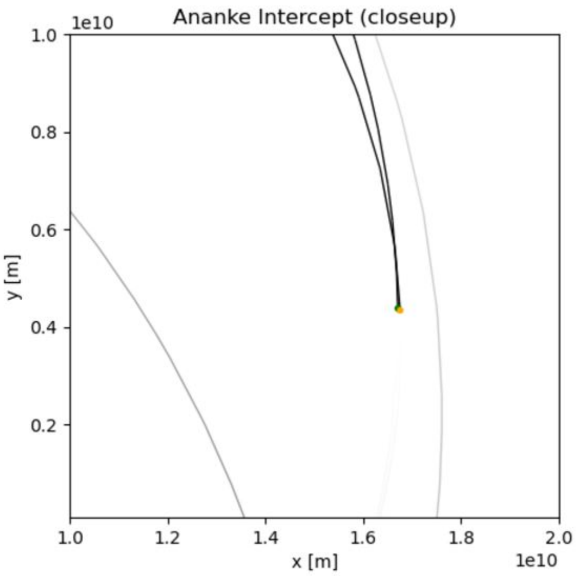

Figure 7: Point of closest approach between Ananke (yellow) and the probe (green), along with general path of each.

Once observations of Ananke have been completed, the probe will progress 0.2304 years to the perijove of its orbit, where it will perform its next burn.

Current Time used: 6.0939 years
Current Velocity used: 1870.3498 m/s

4.7 Inner Orbit Alignment

To begin the process of observing the inner moons, the probe will progress 0.2304 years to the perijove of its orbit. From here, the probe will perform a small burn along its velocity vector to obtain a circular orbit about Jupiter, where it can align itself with the inner moons. It will progress 10.1817 days to align itself with Castillo, at which point the probe will execute a Hohmann transfer burn.

r = [5100113905.740538, -13189631676.24127, 0] m
Initial v = [-3129.5116028049138, -1210.1070018802955, 0] m/s
Final v = [-2792.254046449707, -1079.6976018906335, 0] m/s
Δv = 361.5927 m/s

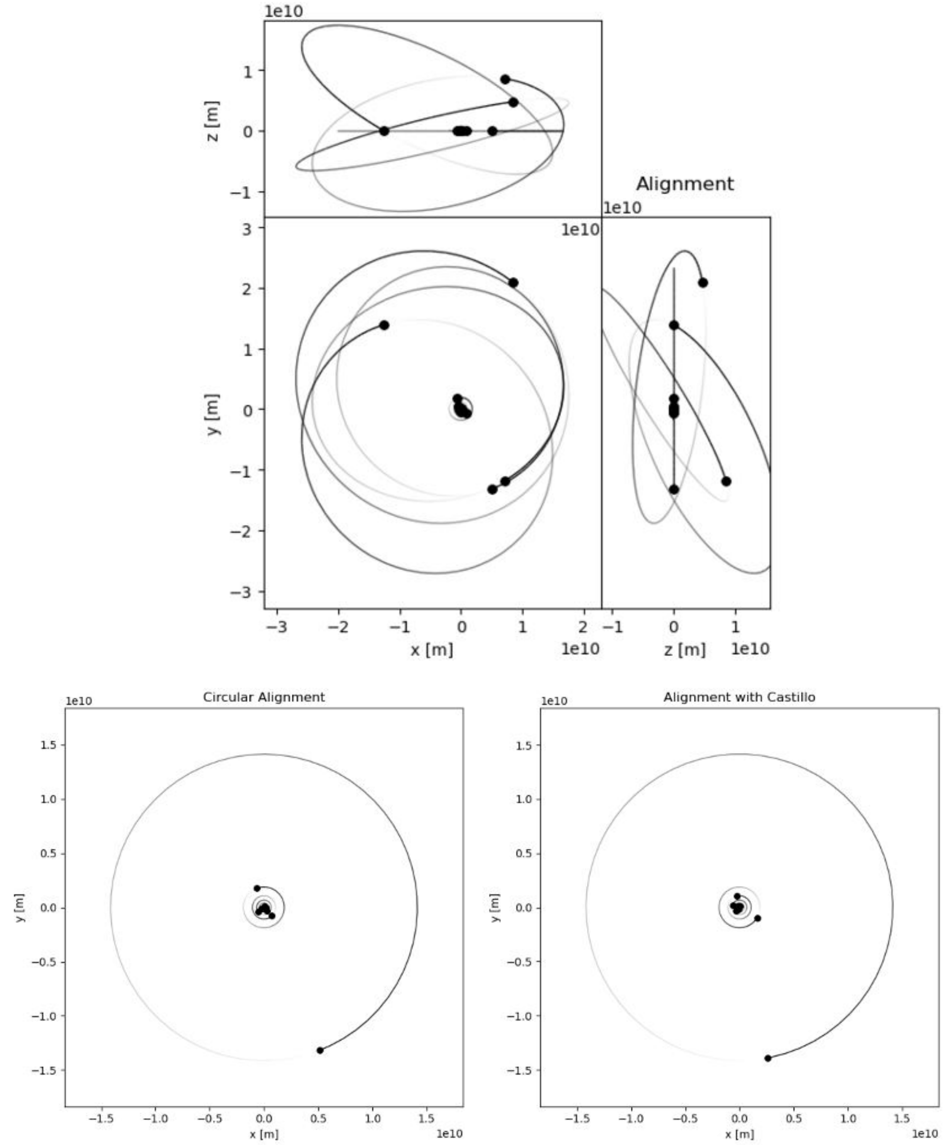

Figure 8: Progression to perijove (top), Circular Alignment burn (left), 10.1817 day progression to align with Castillo (right)

Current Time Used: 6.3522 years
Current Velocity Used: 2231.9425 m/s

4.8 Castillo Intercept

At this point, the probe will perform a burn of 1542.3897 m/s along its velocity vector, beginning a Hohmann transfer to Castillo. This dive will take a total of 146.4903 days to complete a full orbit, reaching the moon on day 73. The probe will be in observation range for approximately 12 hours, and never crosses under the 1,000,000 km limit on this pass. After passing Castillo the probe will progress to its apojove, where it will perform its next maneuver.

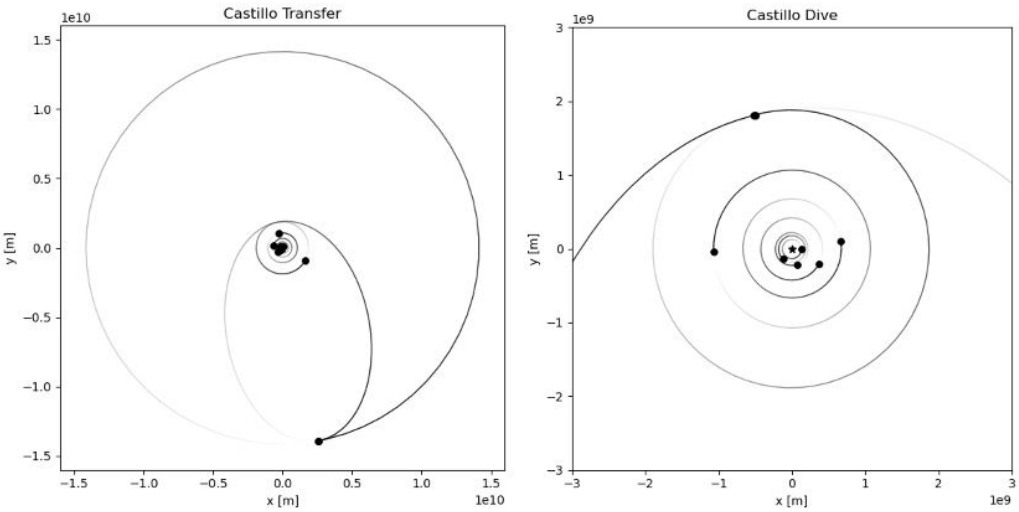

Figure 9: Orbit transition to Castillo Hohmann Transfer (left), and close up of intercept point (right)

Current Time Used: 6.7535 years
Current Velocity Used: 3774.3322 m/s

4.9 Ganymede Intercept

Once the probe reaches the previous orbit's apojove point, it will perform a burn of 328.1086 m/s along its velocity vector to begin its dive to Ganymede. This orbit will take 135.4795 days to complete, with an intercept point on day 68. The probe will be in observation range for a similar time, approximately 12 hours, and it does not pass under the 1,000,000 km limit in this orbit. After passing Ganymede the probe will progress to its apojove to perform its next transfer.

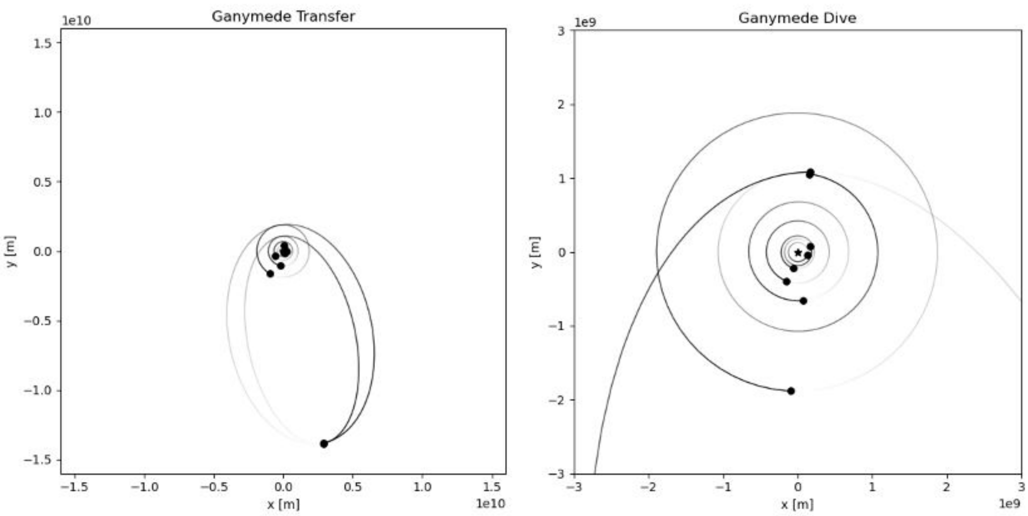

Figure 10: Orbit transition to Ganymede Transfer (left), and close up of intercept point (right)

Current Time Used: 7.1247 years
Current Velocity Used: 4102.4408 m/s

4.10 Europa Intercept

At this point, simple Hohmann transfers will not allow the probe to get close enough for observation. To solve this, Lambert's solvers are used to find proper orbits using time frames similar to Hohmann transfers so as to reduce changes in velocities. At the previous orbit's apojove, the probe's velocity will be adjusted and the probe will enter a new orbit with a period of 130.1976 days. It will intercept after approximately 65 days:

r = [2823754559.4816294, -13861182606.791199, 0] m
Initial v =[-1096.4766245795333, -228.00090398979273, 0] m/s
Final v = [-808.4016946, -182.17414182, 0.] m/s
Δv = 291.6972 m/s

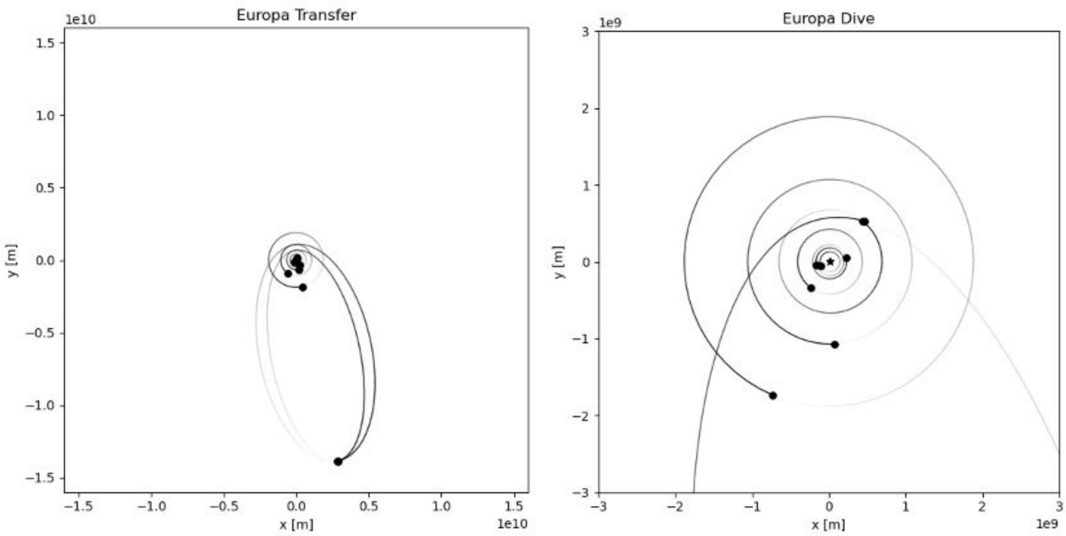

Figure 11: Orbit transition to Europa (left), and close up of intercept point (right)

This orbit will have an observation time of less than the 12 hours allotted for the first two inner moon intercepts. This is also the first orbit where the probe will be entering into the 1,000,000 km limit, for an estimated 4 days. The probe will then progress to its apojove for its next maneuver.

Current Time Used: 7.4814 years
Current Velocity Used: 4394.1380 m/s

4.11 Io Intercept

At the previous apojove, the probe will again perform a slight orbit adjustment maneuver in order to reach Io. The probe will progress on this orbit for one full period, taking 125.4166 days:

r = [2823754559.4816294, -13861182606.791199, 0]

Initial v = [-836.3962657611029, -78.99098409129003, 0]
Final v = [-688.91602219, -172.71381646, 0.]
Δv = 174.7409 m/s

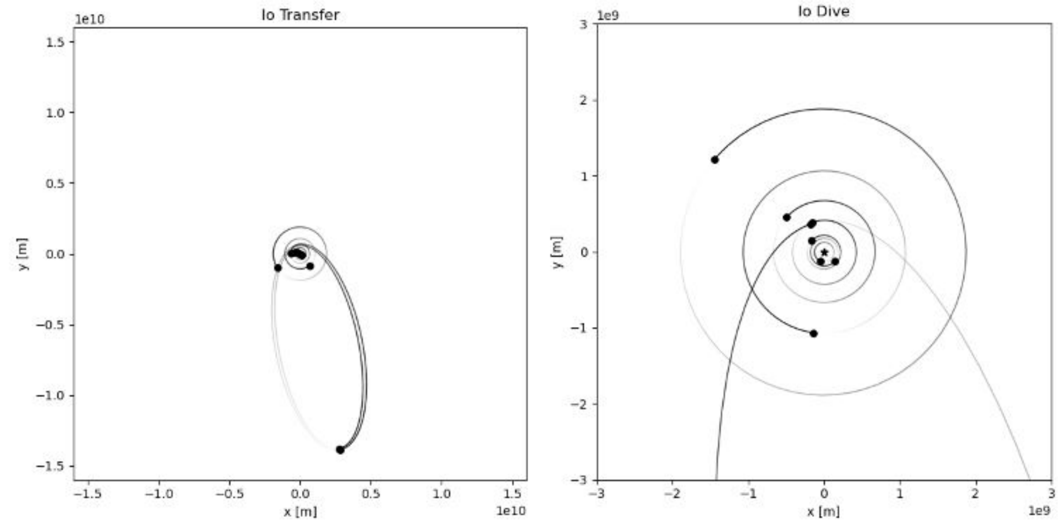

Figure 12: Orbit transition to Io (left), and close up of intercept point (right)

The probe will come into contact with Io 62 days after this point, and will be within observation range for a shorter time than previous moons. It will also be within the inner limit for approximately 5 days. Once the probe has progressed to its new apojove, it will perform the burn to Thebe.

Current Time Used: 7.8250 years
Current Velocity Used: 4568.8789 m/s

4.12 Thebe Intercept

Following previous methods, the intercept with thebe will require a burn of 204.9036 m/s and the orbit will occur over 124.0656 days. Thebe will be within observation range (and within 1,000,000 km of Jupiter) for approximately two days:

r = [2627280789.6956077, -13759070683.30284, 0.0]
Initial v = [-698.8644091858682, -133.44746014818838, 0]
Final v = [-494.01752034, -138.26764858 , 0.]
Δv = 204.9036 m/s

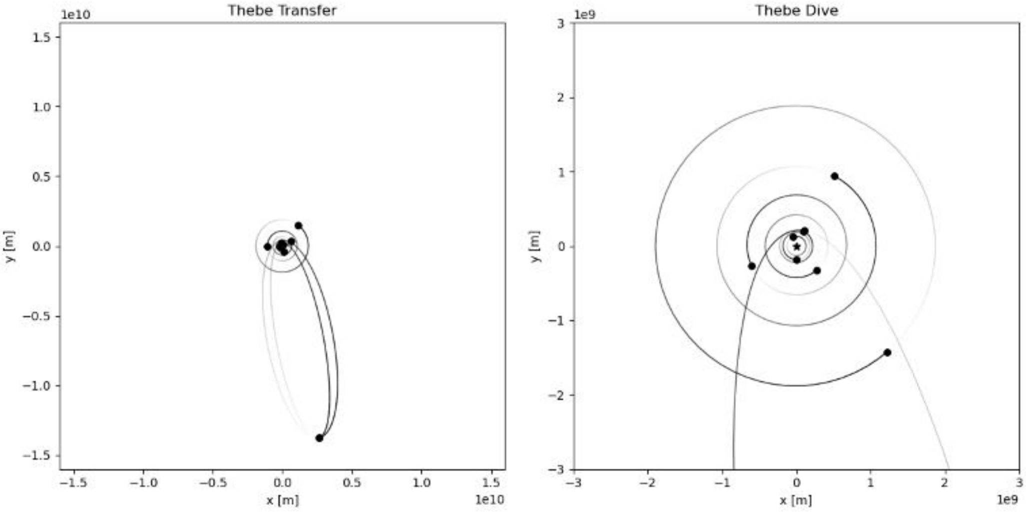

Figure 13: Orbit transition to Thebe (left), and close up of intercept point (right)

Current Time Used: 8.1649 years
Current Velocity Used: 4773.7825 m/s

4.13 Amalthea Intercept

Amalthea's intercept will require a velocity change of 73.5320 m/s to achieve an orbit that will progress for 123.1481 days.

r = [2561139646.726758, -13780843046.49349, 0] m
Initial v = [-509.3205988867885, -47.945610280104994, 0] m/s
Final v = [-472.65299515, -111.68295352, 0.] m/s
Δv = 73.5320

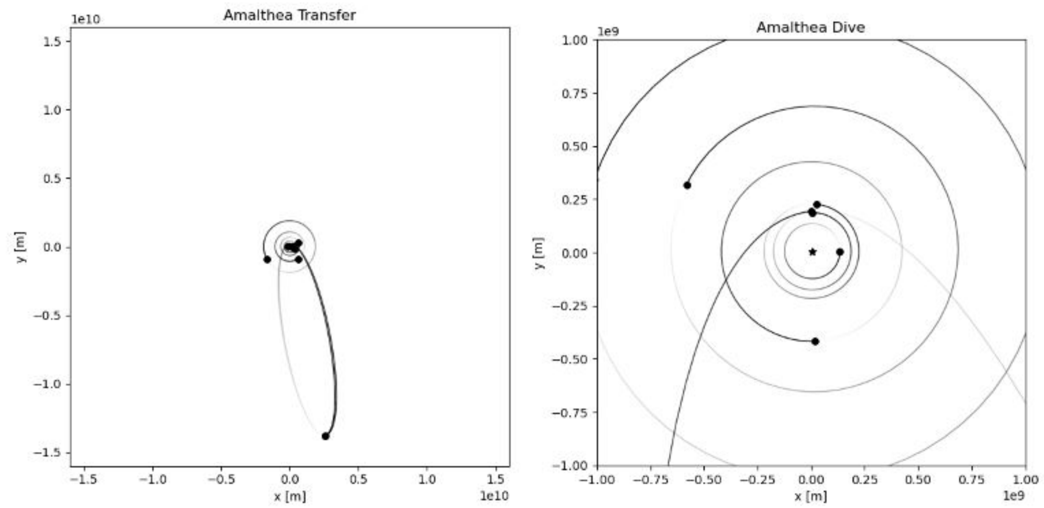

Figure 14: Orbit transition to Amalthea (left), and close up of intercept point (right)

For this orbit the probe will quickly pass by the moon, only able to observe for a few hours. This also has the benefit of reducing the time within the 1,000,000 km limit, which we estimate to a few days.

Current Time Used: 8.5023 years
Current Velocity Used: 4847.3145 m/s

4.14 Adrastea Intercept

for the 10th and final intercept, the probe will require a velocity change of 101.6234 to inject itself into an orbit with a period of 122.6273 days. It will pass by Adrastea and be within observation range for an (estimated) hour, at which point observations can be taken. Due to the high speeds required at perijove for this orbit the probe will only be within 1,000,000 km of Jupiter for a few days, as with the other inner moons:

r = [2520007963.817638, -13770068720.975266, 0] m/s
Initial v = [-484.3298422814824, -55.93920293280293, 0]
Final v = [-397.35450386, -108.49960994, 0]
Δv = 101.6234 m/s

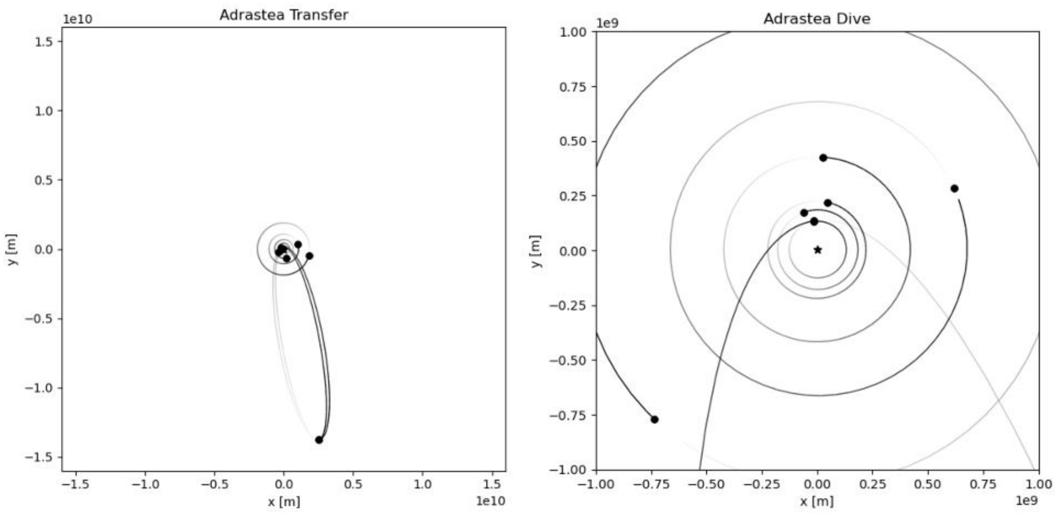

Figure 15: Orbit transition to Adrastea (left), and close up of intercept point (right)

Current Time Used: 8.8383 years
Current Velocity Used: 4948.9379 m/s

4.15 Final Elements

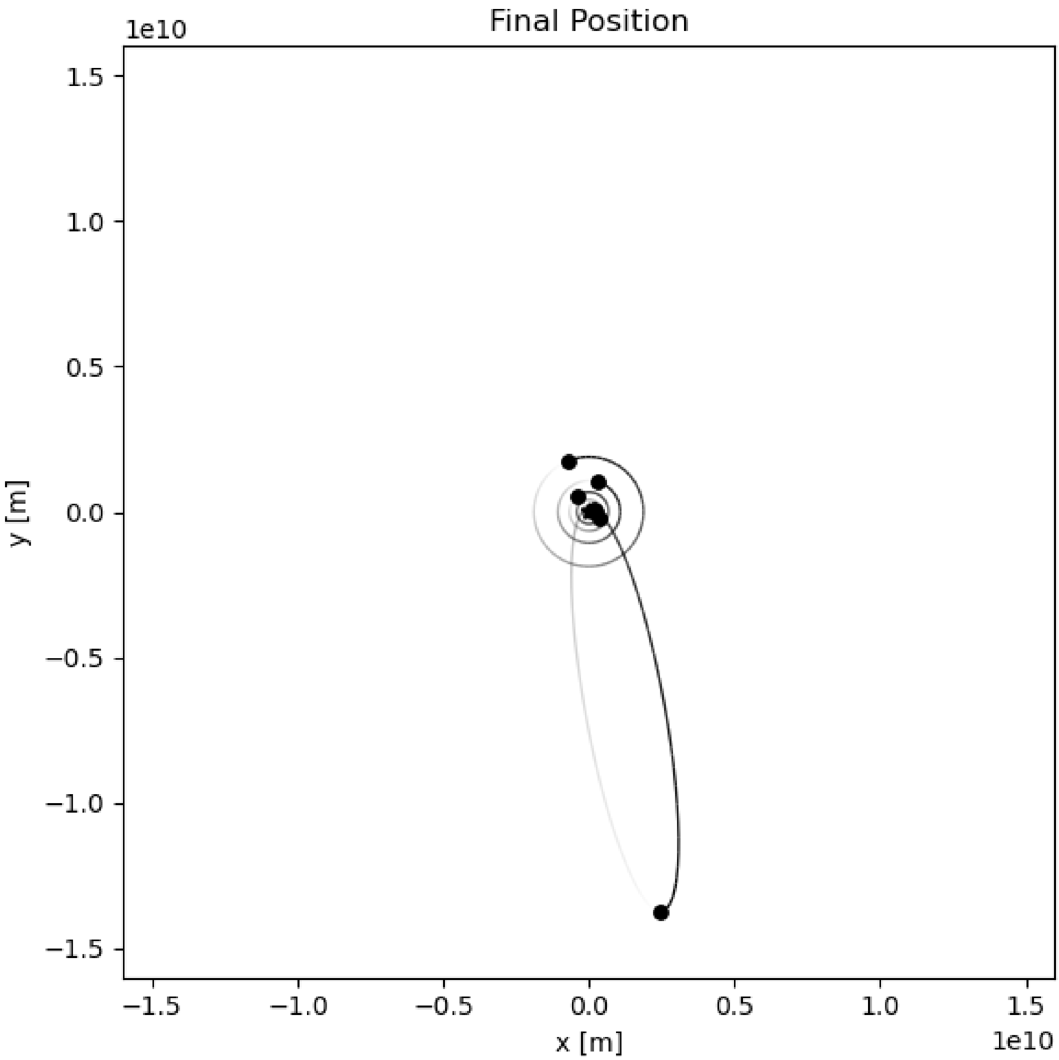

Figure 16: Final Position of the Probe

At its end point, the probe will be located at:

r = [2520007963.817638, -13770068720.975266, 0.0]
v = [-397.35450386, -108.49960994, 0.0]
Current Time Used: 8.8383 years from Launch to Date.
Current Velocity Used: 4948.9379 m/s within Jupiter's orbit.
With Orbital Elements:

a = 1883647790.5893133 m
e = 0.007354490764592433
inc = π
Omega = -0.9049104575996983 rad
omega = 0.7960495822294176 rad
f = π

These values leave the probe with an extra 1.1617 years and 51.0621 m/s leftover given the initial requirements of a maximum of 10 years and 5 km/s. The remaining velocity will be used to cut the probe's velocity as much as possible and place it into a decaying orbit into Jupiter. The probe is visually estimated to be within the 1,000,000 km radiation belt for a maximum of 15 days, which is 5 days over the limit. However given that the priority of this mission will focus on observing the Outer Retrograde moons, this radiation overshoot can be considered acceptable.

5 Probe Capacities

Based on the Mission Description, CAPRICORN will be required to hit these key objectives:

- **Constrain and Control Δv:** The mission will aim to minimize velocity changes, keeping the total Δv below 5 km/s once Jupiter orbit has been achieved. This will require the probe to be able to navigate on its own, making corrections for orbital error. The current plan is under this limit by 51.0621 m/s, which can be used for in-flight corrections and End-of-Life protocols.
- **Limit Radiation:** Time spent within a radius of 1,000,000 km must not exceed 10 days, in order to limit the harmful effects radiation will have on the probe. The current plan overshoots this objective by an estimate of 5 days, however this is seen as an acceptable error due to the focus of the mission being on the outer moons.
- **Mission Duration:** The entire mission, from launch to completion, must be completed within 10 years. This constraint has been achieved, with a remainder of 1.0117 years.
- **End of Life:** The probe must descend into Jupiter's atmosphere so as to not contaminate any of the orbiting moons. If the remaining 51.0621 m/s is not used for orbital corrective maneuvers, it can be used to reduce the probe's velocity to decay into Jupiter.
- **Probe Orientation:** The probe must have the capacity to orient its camera toward the surface of each moon during flybys for imaging.
- **Ground Communication:** The probe must have the capacity to transmit and receive data with Earth relays in order to obtain observations of each moon.

5.1 CAPRICORN Instruments

The CAPRICORN probe's instrument suite matches or exceeds the capabilities of ESA's JUICE mission European Space Agency (ESA), 2024, ensuring comprehensive analysis of Jupiter's moons through redundant sensing methods. The payload is optimized for rapid data collection during brief moon encounters while maintaining deep space operational constraints.

5.1.1 Surface Analysis Suite

Instruments designed for high-resolution imaging and compositional analysis during fast flybys:

- Visible Light Camera System (resolution up to 2.5m/pixel at 200km, similar to JUICE's JANUS camera)
- Laser Altimeter (surface mapping accuracy within 10m for topographical studies)
- Ground/Ice Penetrating RADAR (subsurface structure mapping to 9km depth)
- Mass Spectrometer (molecular composition analysis of surface material)

5.1.2 Atmospheric Analysis Suite

Detection systems capable of analyzing extremely thin atmospheres and surface-particle interactions:

- UV and Infrared Imaging Spectrograph (atmospheric composition and thermal mapping)
- Sub-millimeter Wave Instrument (atmospheric circulation and thermal structure analysis)

5.1.3 Field Analysis Suite

Instruments for characterizing the complex magnetic and particle environments of retrograde moons:

- Magnetometer (magnetic field strength to 0.1 nT accuracy)
- Particle Environment Package (charged particle detection and analysis)
- Microwave Radiometer (subsurface thermal and compositional mapping)
- Radio and Plasma Wave Investigation (plasma environment characterization)
- Ka Transponder with Ultrastable Oscillator (gravity field mapping)

5.1.4 Support Systems

Systems engineered for reliable operation at 5.2 AU from the Sun:

- Power Systems
  - Solar Panels (80m^2 array optimized for low solar flux)
  - Lithium-Ion Batteries (50 kWh capacity)
  - Power Distribution Unit (managing 2.8kW peak power)
- Propulsion
  - Main Thruster (Hypergolic, 500N for orbital maneuvers)
  - Momentum Wheels (0.1° pointing accuracy)

- Communications
  - Steerable X-Band Antennas (data rate up to 1.6 Gb/day)
  - Medium Gain System (continuous Earth contact)
- Protection Systems
  - Radiation Shielding (protection up to 100 krad)
  - Data Processing Equipment

6 Mission Success Criteria

6.1 Mission Success Conditions

Project CAPRICORN's mission success requires achieving all capacity constraints within a 10-year timeframe and a total Δv budget of 5 km/s. The mission will execute flybys and observations of 10 moons: three outer retrograde moons, the four Galilean moons, and three inner moons. While the mission includes approximately 15 days within 1,000,000 km of Jupiter's intense radiation belts, this exposure occurs primarily during the final mission phases after completing the primary science objectives at the outer moons.

The relatively brief radiation exposure presents minimal risk to the overall mission success, as CAPRICORN will have already completed its core objectives studying Carme, Pasiphae, and Ananke – moons orbiting well beyond Jupiter's most intense radiation zones. The inner moon observations and atmospheric descent represent supplementary science opportunities rather than primary mission requirements. This mission architecture strategically prioritizes the exploration of Jupiter's lesser-studied outer satellites while minimizing time in the challenging radiation environment near the planet.

6.2 Partial Success

Partial Success can be achieved through the success of individual phases. Project CAPRICORN aims to observe the retrograde nature of Jupiter moons, which will make the Outer Moon Observation phase the most important part of this mission. If clear imaging and observation can be achieved of the three target retrograde moons, the mission can be considered a partial success.

6.3 Failure Points

Failure of the mission can occur at multiple points During the Earth-Jupiter transfer, one of the primary risks is course correction failures. Deviations in the spacecraft's trajectory could lead to delays or even a missed arrival at Jupiter. To prevent this, mid-course correction windows can be incorporated, allowing for small adjustments to keep the spacecraft on track. Another risk during this phase is a delay in arrival time, which could disrupt the mission's carefully planned schedule. Upon retrograde orbit entry, a significant risk is orbital insertion failure, where the spacecraft may fail to perform the necessary Δv burn and either miss Jupiter or enter an unstable orbit. Additionally, Jupiter's intense radiation environment poses a threat to the spacecraft's systems during this phase.
For the outer moon observation phase a challenge would be the high-inclination orbits

of the outer moons, which require significant and precise Δv adjustments. During the Galilean and inner moon observation phases, a major risk is the high Δv requirements for close flybys Another risk comes from environmental hazards posed by Jupiter's intense radiation belts and Io's volcanic activity. Finally, during the end-of-life descent into Jupiter's atmosphere, there is a high likelihood of communication loss before the spacecraft can transmit all collected data.

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