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CONNECTING EUROPE'S SPACEPORT TO THE LUNAR GATEWAY USING INTERMEDIATE NRHOS.

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The ESA Explore2040 strategy aims for European lunar exploration by the 2030s, with the Argonaut program and NASA's Gateway playing key roles. Reaching the Lunar Gateway, from equatorial launch orbits, is challenging, due to the required Moon position for the Earth–Moon transfer and the Gateway position for the rendezvous which need to be correctly phased; naturally respecting this phasing would impose too stringent launch windows constraints, hence a mitigating solution shall be found. This research aims to identify a lunar exploration architecture for Europe by solving the Earth-Moon transfer and Moon-to-NRHO insertion problems using an intermediate NRHO, and coupling them with the phasing problem, ensuring sustainable and continuous access to the Moon and supporting future lunar missions and crewed spaceflight.

INTRODUCTION

Despite Europe's rich history in space exploration, it has yet to land on the Moon, making the upcoming ESA missions an exciting opportunity to drive the European eco-system in lunar exploration. One of ESA's Explore2040 strategy goals is to have Europe explore the Moon in the 2030s with the Argonaut program and the synergy with NASA's Gateway being the pillars for robotic and human exploration. Nonetheless, going to the Moon is a complex space endeavour where few countries have achieved success in landing on its surface. Additionally, reaching a Near Rectilinear Halo Orbit (NRHO), the orbit for the Lunar Gateway, from Europe's equatorial spaceport, is challenging when considering the required position of the Moon at the nodal crossings for the Earth–Moon transfer and the correct phasing for rendezvous with the Gateway. The reason for this complexity is that the typical maximum performance launch trajectory injects the spacecraft into an equatorial orbit, thus requiring the proper phasing of the lunar encounter; high-inclination trajectories, which would enable daily launch opportunities, typically entail loss in performance for the launch vehicle. These parameters all in turn limit the launch opportunities. Solving the problem of reaching the Gateway from Europe's spaceport is the first step towards this architecture and will be detailed in this paper. In the "Background" section of this paper, the problem is outlined in its entirety with a timeline. The following section describes the dynamical models used for the study. The "Methodology" section includes four sub-sections which detail out the steps followed throughout the study

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to set up the problem and solve each sub-problem. The "Results" section outlines the main findings of the paper and finally the "Conclusion" section gives an overview of future work that could be performed to further extend this study.

BACKGROUND

The goal of this study is to complement the phasing problem solution already analysed previously[1] considering also the study of the Earth–Moon and Moon to NRHO insertion (NOI) transfer and integrate both into a continuous solution to the problem. In Figure 1, the Earth–Moon transfer is the part of the timeline from T_0, Lunar Transfer Orbit (LTO) injection epoch from the launcher, until T_1, arrival at the Moon and Moon–NOI is between T_1, arrival at the Moon, and T_2, injection into the intermediate NRHO. These two parts need to be coupled with the solutions found previously,[1] which depict the phasing problem defined from T_2, injection into the intermediate NRHO, to T_4, rendezvous with the Gateway. The phasing problem (T_2 – T_4) was studied first separately as it is the part of the problem which drives the rest. The Gateway epoch is fixed and therefore an optimal configuration for phasing towards the Gateway exists. Determining this optimal configuration and possible strategies to reach it (i.e. loitering time on an intermediate NRHO) will drive the rest of the transfer from Earth to NOI. Thus, the Gateway accessibility problem was decoupled into two separate ones: the first one, a phasing problem introducing an intermediate NRHO to phase with the Gateway NRHO, and the second one, an Earth–Moon–NOI transfer problem. Previous work[1] found a set of solutions to arrive at the Gateway with respect to the NOI epochs T_2. This showed that introducing an intermediate NRHO brought a high level of flexibility for phasing with the Gateway removing all the constraints on the available launch windows. Thanks to the intermediate NRHO, a spacecraft could reach cis-lunar space taking up the first launch opportunity and wait on this intermediate NRHO until the right configuration for a transfer to the Gateway NRHO. This configuration was seen to reoccur at every revolution of the NRHO allowing more compatibility with different launch windows from Earth.

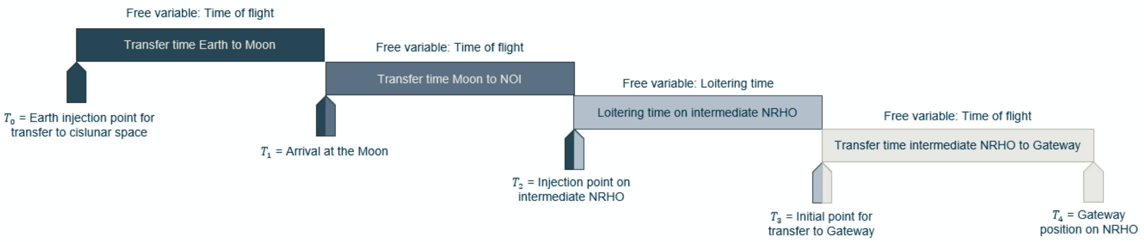

Figure 1. Problem timeline for a mission from Europe's spaceport to the Lunar Gateway.

DYNAMICAL MODELS

In this paper, both the Circular Restricted Three-Body Problem and the full-ephemeris models were used. As detailed in previous work,[1] the phasing problem was first studied in the CR3BP before it was transferred to the full ephemeris. It was seen that the results between the two models were quite comparable and that the CR3BP model allowed to build a good understanding of the dynamics and specificities of the problem applicable to the full ephemeris model. Similarly here, the Earth-Moon transfer, the Moon flyby and the injection in the intermediate NRHO were first performed in the CR3BP before using the full ephemeris. The paper focuses on the full ephemeris trajectories, nevertheless, the CR3BP framework is described given its importance in the preliminary phases of the analysis. The circular restricted three-body problem is useful for preliminary studies which cannot be performed using Keplerian dynamics. The problem allows to take into account two primary masses (m_1 and m_2), the Earth and the Moon, which act upon a negligible mass (m_3), the spacecraft. The motion is described in a rotating reference frame where the x-axis is directed from the largest primary m_1, (the Earth, in this case), to the smallest primary m_2, (the Moon). The y-axis is in the orbital plane of the primaries perpendicular to the x-axis and the z-axis completes the coordinate system. The distance, length, time and mass units are all normalised, such that the gravitational constant of the system is unitary. The mass parameter can be written such that $\mu = m_2/(m_1 + m_2)$.[2,3] The equations of motions describing the dynamics in CR3BP are given by:

$$\begin{aligned} \ddot{x} - 2\dot{y} &= -\Omega_x \\ \ddot{y} + 2\dot{x} &= -\Omega_y \\ \ddot{z} &= -\Omega_z \end{aligned} \tag{1}$$

where $\Omega_{x,y,z}$ are the partial derivatives of the effective potential function given by:

$$\bar{U} = -\frac{1}{2}(x^2 + y^2) - \frac{1-\mu}{r_1} - \frac{\mu}{r_2} - \frac{1}{2}(1-\mu)\mu \tag{2}$$

where $r_1 = \sqrt{(x+\mu)^2 + y^2 + z^2}$ and $r_2 = \sqrt{(x+\mu-1)^2 + y^2 + z^2}$ are the distances from the primary masses to the spacecraft. The motion described by Eq.(1) exhibits five equilibrium points, the Lagrangian points, three co-linear with the two primaries and two at the vertices of equilateral triangles where m_1 and m_2 are the base. The orbits studied in this papers are near-rectilinear halo orbits about the second Earth-Moon Lagrangian point (EML2). Such orbits are periodic in the CR3BP but not in the full ephemeris model.

The full ephemeris model is taken from JPL DE432 ephemeris which takes into account the Sun as point mass gravity, and 10×10 spherical harmonics for the Earth and the Moon, with their real motion. The Solar Radiation Pressure (SRP) is not included in this model as the point mass and spherical harmonics are sufficient for the preliminary nature of the work and the SRP can be included at a later stage when more information about the spacecraft itself is known. The kernel for the real trajectory of the Gateway station was also used in this study.[4]

METHODOLOGY

In the context of the phasing problem, the following nomenclature is used for the study:

- Intermediate NRHO: NRHO of greater period than that of the Gateway used for phasing.
- Transfer time: time of flight during the transfer arc departing from the intermediate NRHO until injection into the Gateway NRHO.
- Loitering time: time waited on the intermediate NRHO before the right configuration to perform the transfer.
- Phasing time: total time or sum of both the loitering time and the transfer time.

In the context of the Earth-Moon transfer, transfer time will also refer to the time to go from the Earth to the Moon.

The study also uses the concept of mean anomaly to define a specific location along an NRHO; although NRHOs cannot be described by classical Keplerian elements, the mean anomaly is defined as[5]

$$M = \frac{2\pi}{T}(t - t_0) \tag{3}$$

where T is the NRHO period in the CR3BP and t_0 is the reference time instant. Assuming to use the closest approach of the NRHO to the Moon (equivalent to the Keplerian definition of pericentre), the mean anomaly is null at this location, and π at the furthest point (equivalent to the apocentre).

The full problem (T_0 – T_4) was solved combining the constraint from the launch windows, the Earth–Moon transfer, the injection into the intermediate NRHO and the phasing with the Gateway. It needs to connect a fixed Gateway epoch, T_4, to an NOI mean anomaly (i.e., a specific geometric location along the orbit) and epoch, T_2, which is itself dependent on the geometry of the Earth–Moon transfer and the arrival at the Moon. Thus, given a fixed Gateway epoch T_4, an optimal configuration, T_3, for transferring to the Gateway is found. This is done allowing a certain loitering time (T_3 – T_2) on the intermediate NRHO. In case of only sub-optimal configuration, adding multiple revolutions for the intermediate NRHO is allowed. The optimal intermediate NRHO is selected according to the mean anomaly of the NOI and an intermediate NRHO is generated from that point, thus the period of the intermediate NRHO is free in the problem. The NOI mean anomaly and epoch themselves depend on the arrival at the Moon and the geometry of the Earth–Moon transfer, and can be varied only within a bounded range of values. The Moon arrival epoch bounds the problem from the left-hand side and the optimal configuration for the phasing with the Gateway bounds the problem from the right-hand side. The Earth–Moon transfer is therefore free in terms of time of flight and will have different geometries. Among the high energy transfers, the direct transfer is often discarded as it is always more expensive than a transfer with a Lunar Gravity Assist (LGA). Low energy transfers are also possible for an Earth–Moon transfer, but it is expected that the time of flight can be selected to allow direct phasing with the Gateway and therefore not require an intermediate NRHO.[6] The Earth–Moon transfer strategy will impact the geometry at the Moon arrival and therefore the mean anomaly of the NOI. The full problem was solved performing a trade-off between time of flight and cost of transfer. The problem was set up in the full ephemeris model using ESA's mission analysis tool GODOT as will be described in the following sections.

Earth-Moon Transfers

Europe's spaceport, Centre Spatial Guyanais (CSG), located in Kourou, French Guyana, comes with its constraint for any lunar mission. It is located at a latitude of 6 deg above the equator meaning that maximum launcher performance from this launch site will only be achieved for equatorial orbits, with an East-bound launch. The Moon's orbit has an inclination of 5 deg with respect to the ecliptic plane and the Earth's tilt is 23 deg, therefore the largest inclination between the Moon plane and the Earth's equator is 28 deg. Thus, a launch window for an Earth-Moon transfer from an equatorial launch site is not available daily contrary to a launch site with a latitude of 28 deg or above. For the Moon to be reachable from an equatorial launch site, it needs to be near the intersections of these planes, i.e. either the descending or ascending node of its orbit. This occurs twice per month, allowing for bi-monthly launch opportunities from the CSG.[6,7]

Using ESA's GODOT tool*, direct transfers between a 28 deg inclination LTO and a polar LLO were computed in full ephemeris over a month. Daily transfer solutions were found and the lunar declination for each solution can be computed. The evolution of different parameters of the transfer can be seen in Figure 2 where the reference epoch 10000 TDB corresponds to midnight on May 19, 2027. Note that at each epoch, two solutions exist, according to whether the Moon is encountered on the ascending or descending arc of the LTO. This distinction is not considered in the current study, for simplicity's sake, since the focus is on the lunar transfer patching with the NRHO phase. The change in the lunar declination is shown in Figure 3 and it can be seen to be 0 deg twice in a month, corresponding to the ascending and descending nodes.

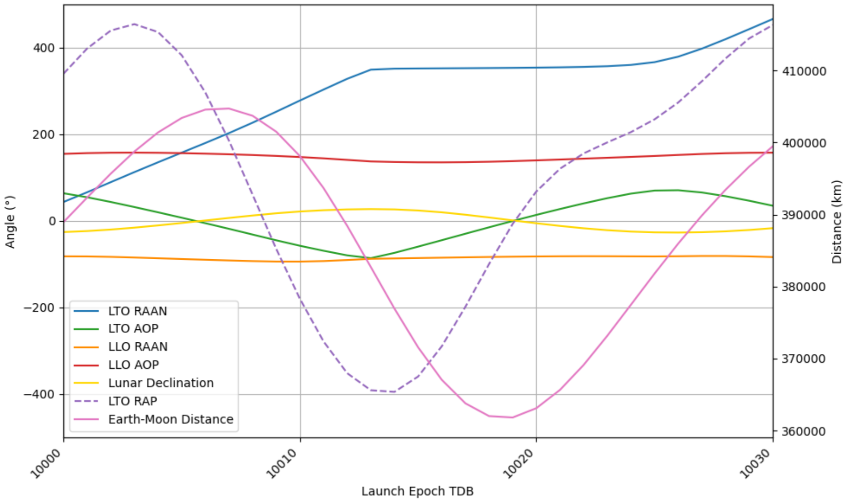

Figure 2. Evolution of selected orbital parameters: LTO RAAN, LTO AOP, LTO apogee distance, LLO RAAN, LLO AOP, lunar declination and the Earth-Moon distance.

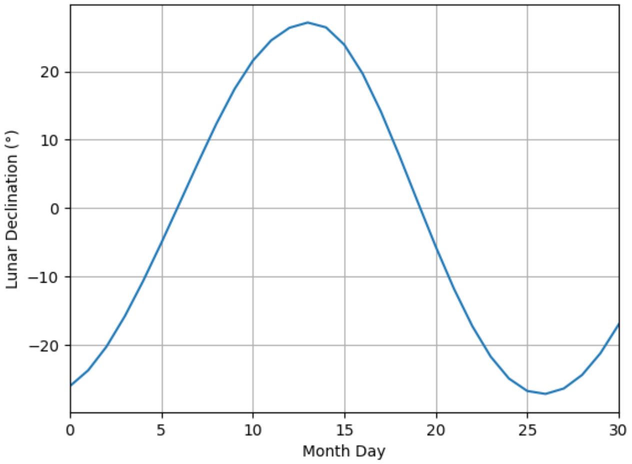

Figure 3. Evolution of the lunar declination over a month.

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*`https://godot.io.esa.int/godotpy/`

The two transfer solutions associated with the lowest lunar declination two weeks apart were used as an initial guess to produce direct transfers between a 6 deg inclination LTO and a polar LLO. These solutions are shown in Figure 4 using dimensional units in the inertial frame centred at the Earth. The Moon's orbit is shown over one month. Considering the value for the Right Ascension of the Ascending Node (RAAN) of the LTO in Figure 2 when the lunar declination is 0 deg, it is expected that the two solutions appear at about 180 deg difference in RAAN. The two solutions from Figure 4 can be used as an initial guess to find all trajectories over one year. This will ensure faster convergence considering the large difference in both the RAAN and the Argument of Periapsis (AOP) of the LTO for each solution.

This two-step approach, starting from 28 deg inclination and then computing the 6 deg LTO solutions, helps in clarifying the launch window limitations of equatorial launches, which lead to the need of phasing NRHOs.

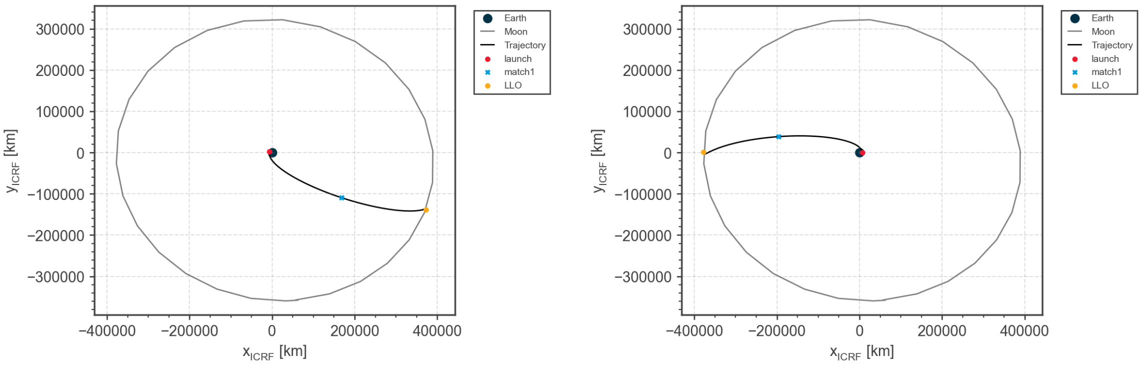

Figure 4. Two types of solutions for a direct transfer from Earth to the Moon with launcher injection into an LTO at 6 deg inclination.

In Figure 5, the first solution from Figure 4 is shown again with the left side being in the Earth-Moon rotating reference frame and on the right in the inertial frame centred at the Earth.

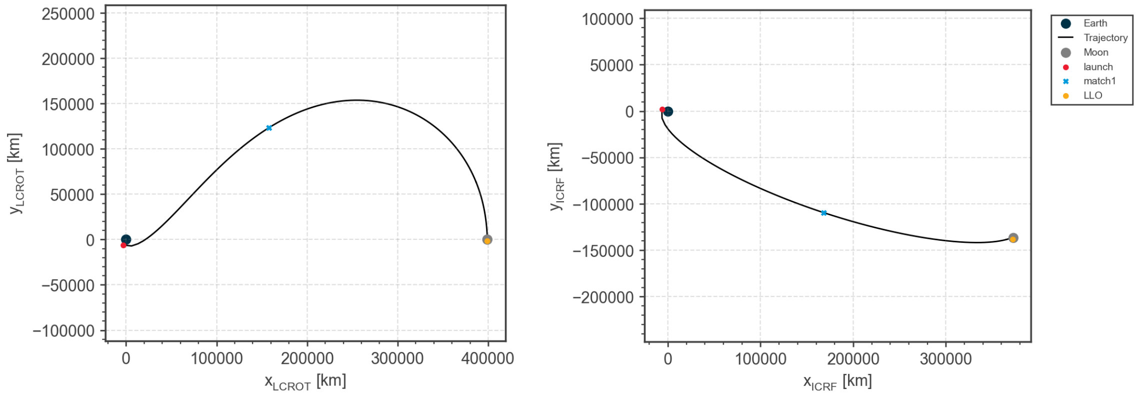

Figure 5. Example direct transfer from Earth to the Moon with launcher injection into an LTO at 6 deg inclination.

Intermediate NRHO Construction

Another important building block to the final trajectory is propagating an NRHO after injection. This is done by using a multiple shooting scheme in which trajectories are integrated both forward and backwards in time from set intermediate points along the trajectory. This brings advantages over a multiple shooting scheme with only forward integration including a reduction in the accumulated integration errors and smaller gradients allowing for better convergence. An initial guess of several control points along the intermediate NRHO are given and propagated both forward and backward. The initial guess is built by taking the CR3BP NRHO states and transferring them into the ephemeris model, using the osculating length and time unit of the Earth-Moon system.The two arcs will be patched both in position and velocity at a match point. This is shown in Figure 6 where the control points such as *point1*, *point2* and *point3* are given and matched at *match1* and *match2*. This scheme is used when the NOI location is known on the intermediate NRHO, further points on this NRHO can be added and patched using the multiple shooting scheme to construct the intermediate NRHO.

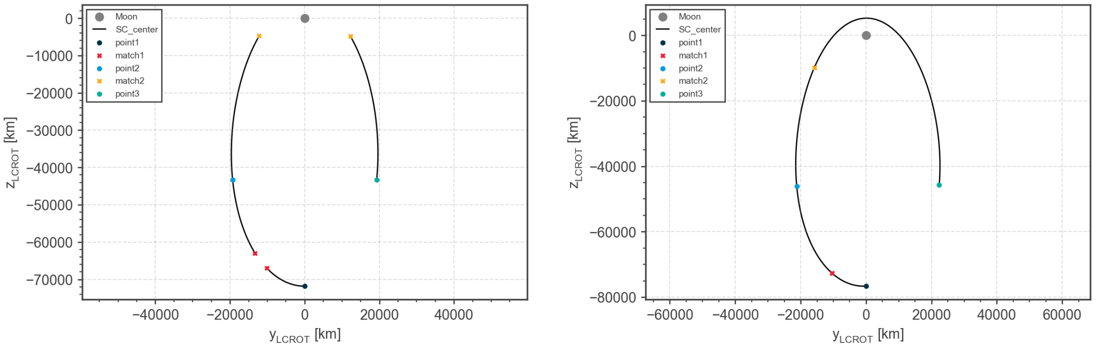

Figure 6. Multiple shooting method to produce an NRHO (T = 7 days) at a chosen epoch.

Phasing Solution

Thanks to the work done previously,[1] the most cost-efficient transfer configuration from an intermediate NRHO to the Gateway NRHO is already known. It was found that an injection into the intermediate NRHO with a mean anomaly of 80 deg, would yield an optimal Earth-Moon transfer. This is used as an initial guess for the control point to inject in the intermediate NRHO. Additionally, a Pareto front was built to retrieve the cost of transfer (ΔV) for any time of flight including multiple revolution transfers in the CR3BP. Using the solutions from CR3BP, the phasing transfer was also performed in full ephemeris. An example transfer was found to depart from the intermediate NRHO just before the aposelene and arrive at the Gateway right after the periselene passage. The transfer lasted 4.35 days and cost 16.7 m/s. This was used as an initial guess for the full problem in GODOT. The approximate phase angle along the intermediate NRHO was used to place the injection point on the NRHO orbit. The time of flight to reach the Gateway was also used as an initial guess to select the final Gateway epoch in the problem.

Final Trajectory

The full problem has been set up using ESA's GODOT tool and some nomenclature can be clarified first. Three types of events have been used in this problem: control points, match points and manoeuvres. Control points are fully defined reference states on the trajectory. The propagation will use control points as the initial state for both the forward and backward propagation. A match point is a point added between two control points to ensure continuity both in position and velocity. Manoeuvres are discontinuities in the trajectory allowing for a change in the velocity.

The procedure to set up this problem is as follows:

- A control point was used for a point at the perigee of the 6 deg LTO and another control point for the flyby with an initial guess of 100 km flyby altitude.
- The flyby state is parametrized using B-plane coordinates; the arrival hyperbolic velocity is not expected to vary significantly, whereas the BT/BR coordinates are varied such that the flyby is optimal for the patching with the following phases, balancing between an efficient manoeuvre (low altitude) and a smaller deflection (high altitude) to reach the NRHO.
- Between these two points, a match point is set.
- At the flyby control point, a manoeuvre is added to exploit the lunar gravity to efficiently reach the NRHO energy level.
- Another manoeuvre is added at the injection into the intermediate NRHO to account for the cost of injecting into the NRHO.
- Between these two manoeuvres, a match point is added.
- At the manoeuvre to inject into the intermediate NRHO, a control point is added on the NRHO.
- After the injection into the NRHO, another control point is added along the NRHO.
- A match point is added between the two control points on the intermediate NRHO. This is to allow for the loitering time on the intermediate NRHO.
- A manoeuvre is added at this second point on the intermediate NRHO to depart the latter and begin the transfer towards the Gateway.
- A manoeuvre is added at the control point of the Gateway, which is given as a state from the JPL ephemeris, to insert into the Gateway NRHO at the Gateway epoch.
- A match point is added between the departure manoeuvre and the arrival manoeuvre.

This allows to create the trajectory for the problem. It is important to note that to have a manoeuvre at a control point, the control point is given as a reference and the time between the manoeuvre and the control point is null. All manoeuvres in this set up are impulsive. The problem is optimised using SNOPT, a sequential quadratic programming (SQP) method which works well for constrained optimisation problems.[8]

RESULTS

The full problem was set up as described in the previous section and different solutions are presented here. The first solution presents an optimal ΔV transfer. The second is less optimal in terms of cost but faster in time of flight and allows for a rendezvous with the Gateway at the aposelene.

Finally, the third is a solution for a long loitering time of the intermediate NRHO. The first solution in Figure 7 is the most optimal trajectory found. It departs from a 6 deg inclination LTO on 2027-05-23 heading towards the Moon. A flyby is performed before inserting into an intermediate NRHO with a period of around 7 days. A loitering time of 1.21 days is spent on the intermediate NRHO before departing to perform the phasing with the Gateway. The Gateway is reached on 2027-06-04 near the periselene of the orbit. The total transfer costs 455.4 m/s and the time of flight is 12.09 days. The phasing transfer itself cost 1.98 m/s and lasted 4.43 days. Further details about the full transfer can be found in Table 1.

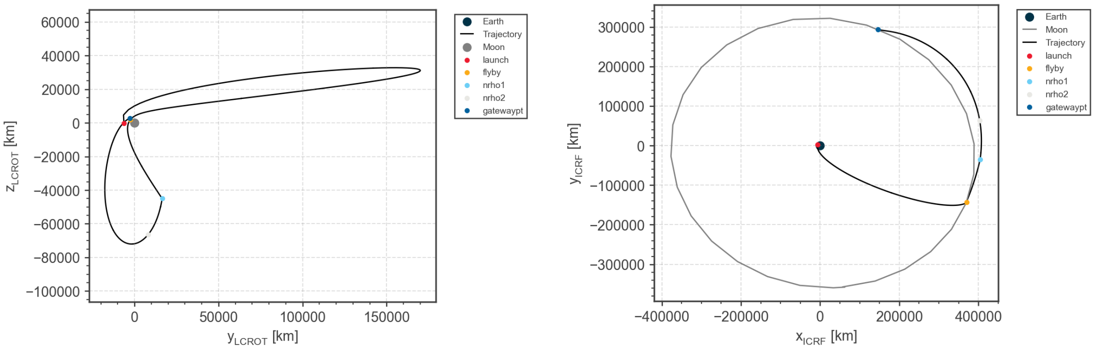

Figure 7. Optimal trajectory for a transfer between a 6 deg inclination LTO to the Gateway NRHO using a lunar flyby and intermediate NRHO with minimum loitering time.

Table 1. Summary of trajectory events epoch and ΔV with the total time of flight and the total ΔV.

Event	Epoch (days)	ΔV (m/s)
Launch	10004.27	0
Lunar flyby	10009.74	187.8
NRHO Injection	10010.72	265.6
NRHO Departure	10011.93	0.0
Gateway Arrival	10016.36	1.978
Total	12.09	455.4

Although the transfer time of flight is close to the one found in the previous work,[1] the cost of transfer is much lower. This can explained by the fact that in the full ephemeris, the NRHOs are not periodic and cannot be easily distinguished by their period. Therefore, an NRHO with a period of 6.56 days like the one of the Gateway and an NRHO with period 7 days like the intermediate NRHO will end up blending together in the full ephemeris. The point of injection into the intermediate NRHO could here already be very close to the Gateway NRHO leading to lower transfer costs.

In the optimal trajectory in Figure 7, the visiting vehicle would arrive at the Gateway to rendezvous when the station is near the periselene. Although this is the optimal transfer in terms of cost and time of flight, it could be more complex operationally.[9] The dynamics at the NRHO's periselene are much faster than at the aposelene and thus any error would propagate and grow much faster for any manoeuvre performed at the periselene. This optimal trajectory could still be used for the transfer and the Gateway followed until the aposelene to have slower dynamics for a rendezvous. Another solution is to use a sub-optimal solution to the problem as presented in Figure 8. Similarly to the optimal, the sub-optimal solution includes a departure from a 6 deg inclination LTO, a lunar flyby, an injection into an intermediate NRHO, a minimum loitering time of the intermediate NRHO and a phasing transfer towards the Gateway. However, the solution shows a departure from the intermediate NRHO slightly earlier than in the optimal trajectory and meets the Gateway in a shorter time allowing for a rendezvous while the Gateway is still close to the aposelene. The cost of transfer for this solution is 508.1 m/s for a time of flight of 10.1 days.

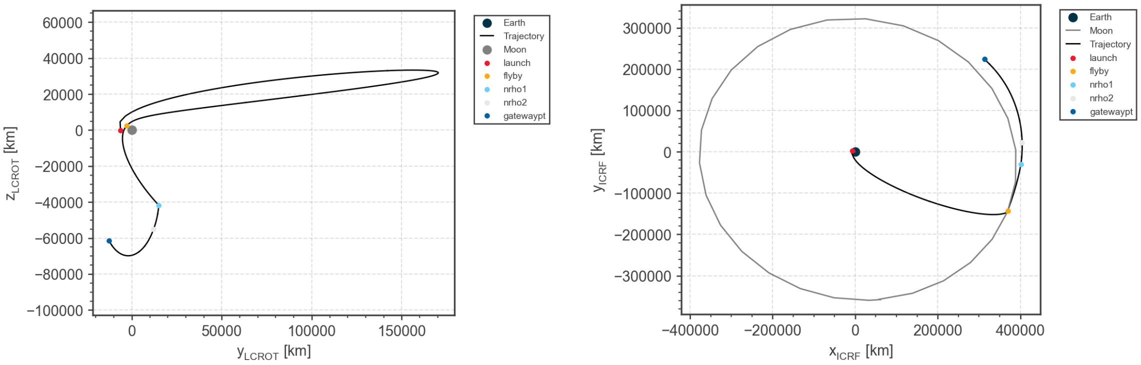

Figure 8. Sub-optimal trajectory for a transfer between a 6 deg inclination LTO to the Gateway using a lunar flyby and intermediate NRHO with minimum loitering time.

In the study for the phasing,[1] the possibility of multiple revolution transfers was studied. The goal was to try to understand if a longer time of flight would yield a lower cost of transfer. It was found that indeed, as the time of flight is increased, low cost solutions continue to be found with a repeating pattern for every revolution of the Gateway orbit i.e. if the transfer time of flight was increased by $\sim$ 7 days, a similar solution was found with a similar cost. This was verified in this study in the full ephemeris where the phasing cost went from 1.98 m/s to 0.0 m/s. The optimal transfer from Figure 7 was changed to add $\sim$ 7 days wait time on the intermediate NRHO. This can be seen in Figure 9 where the second control point on the intermediate NRHO, *nrho2*, is after a full revolution of the NRHO. It can also be seen that the optimal solution still finds its arrival at the Gateway near the periselene of the orbit. The epoch and cost of each event is reported in Table 2.

It is interesting to note that compared to the optimal trajectory without the 7 days loitering time, the cost of the flyby has increased but the cost of the phasing has completely disappeared. This can be explained by the fact that the flyby is performed at a higher altitude for this case than for the optimal trajectory and therefore is more costly to create the required deflection. It does have an advantage that the trajectory is directly injected into a trajectory which naturally approaches the Gateway, equivalently to a stable manifold of the target NRHO. This is explained again by the fact that in full ephemeris, it is difficult to distinguish each NRHO by their period and NRHO with only half a day difference in period would essentially have blended trajectories. The final trajectory cost 502 m/s and has a time of flight of 18.38 days.

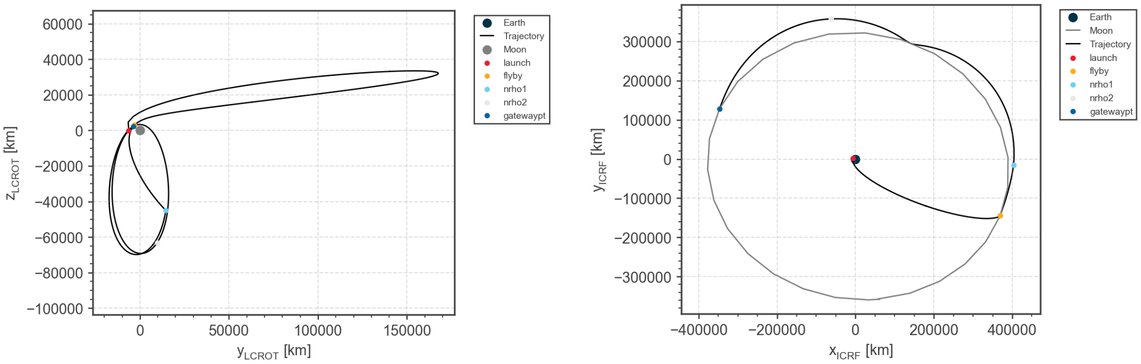

Figure 9. Optimal trajectory for a transfer between a 6 deg inclination LTO to the Gateway using a lunar flyby and intermediate NRHO with ~ 7 days loitering time.

Table 2. Summary of trajectory events epoch and ΔV with the total time of flight and the total ΔV.

Event	Epoch (days)	ΔV (m/s)
Launch	10004.31	0
Lunar flyby	10009.74	251.1
NRHO Injection	10010.98	250.9
NRHO Departure	10018.52	0.0
Gateway Arrival	10022.69	0.0
Total	18.38	502.0

CONCLUSION

The goal of this paper was to solve the problem of reaching the Gateway from Europe's spaceport in Kourou, French Guyana. As presented, multiple solutions were found which exploit an intermediate NRHO to decouple the launch window problem from the phasing with the Gateway. The optimal solution allowed for transfer costs as low as 455 m/s for 12 days of flight. It was seen that a more costly solution could be used to ensure an arrival at the Gateway at the aposelene of its orbit. Finally a third solution was shown to allow for a loitering time of 7 days on the intermediate NRHO. It increased the overall cost of the trajectory by 50 m/s but reduced to phasing cost to 0 m/s.

In future work, it would be of interest to expand the search to be able to have a Pareto front of the cost of transfer versus the total time of flight for the full trajectory. This was performed for the phasing problem only[1] and would be a good conclusion to the study. It would allow for any mission design to be able to know the cost of the mission by choosing the time of flight compatible with the type of mission. For example, cargo missions can admit larger time of flight compared to crewed. Additionally, this study could be replicated for other CR3BP orbits such as the EML1 NRHO or an Earth-Moon DRO. Further steps into understanding any tolerance to manoeuvre failure and mitigation strategies could be of interest for a robust architecture.[10] Further investigation is of interest for future European exploration missions to build a lunar exploration architecture for Europe to ensure sustainable access to the Moon.

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REFERENCES

[1] M. Burnichon, L. Bucci, and F. Renk, “Using intermediate NRHOs for phasing with the Lunar Gateway in future lunar exploration missions.,” *29th International Symposium on Space Flight Dynamics (ISSFD)*, 2024.

[2] W. S. Koon, M. W. Lo, J. E. Marsden, and S. D. Ross, *Dynamical Systems, the Three-Body Problem and Space Mission Design*. 2006.

[3] F. Bernelli Zazzera, F. Topputo, and M. Massari, “Assessment of Mission Design Including Utilization of Libration Points and Weak Stability Boundaries,” 2004.

[4] D. E. Lee, R. J. Whitley, and C. Acton, “Sample Deep Space Gateway Orbit NAIF Planetary Data System Navigation Mode,” 2018-07. Available at `https://naif.jpl.nasa.gov/pub/naif/misc/MORE_PROJECTS/DSG/`.

[5] E. Blazquez, L. Beauregard, S. Lizy-Destrez, F. Ankersen, and F. Capolupo, “Rendezvous design in a cislunar near rectilinear Halo orbit,” Vol. 124, No. 1276, 2020-06, pp. 821–837, 10.1017/aer.2019.126.

[6] W. Martens and L. Bucci, “Cis-Lunar Transfer Vehicle (CLTV) Mission Analysis Guidelines (OPS-GFA-TN-125),” European Space Agency, 2021.

[7] L. Bucci, M. Hutton, and M. Burnichon, “Human Inspirator Mission Analysis Guidelines (OPS-GFA-TN-132),” European Space Agency, 2023.

[8] P. E. Gill, W. Murray, and M. A. Saunders, “SNOPT: An SQP Algorithm for Large-Scale Constrained Optimization,” Vol. 12, No. 4, 2002-01, pp. 979–1006, 10.1137/S1052623499350013.

[9] L. Bucci, M. Lavagna, and F. Renk, “Phasing and Rendezvous Operations on Non-Keplerian Orbits in the Earth-Moon System,” *69th International Astronautical Congress*, 2018.

[10] J. Kikuchi, Y. Matsumoto, and S. Ueda, “Off-Nominal Trajectory Design of NRHO Transfer for Crewed Mission to Gateway,” *29th International Symposium on Space Flight Dynamics (ISSFD)*, 2024.