National Aeronautics and Space Administration

ANALYSIS AND DESIGN OF ABORT OPTIONS FOR LOW ENERGY LANDING TRAJECTORIES

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Program: Spontaneous Concepts

Project Objective

Develop a methodology to design abort trajectories for low energy landing trajectories involving direct approach (i.e., no orbit insertion) to airless bodies, like our Moon or Europa.

What IF…

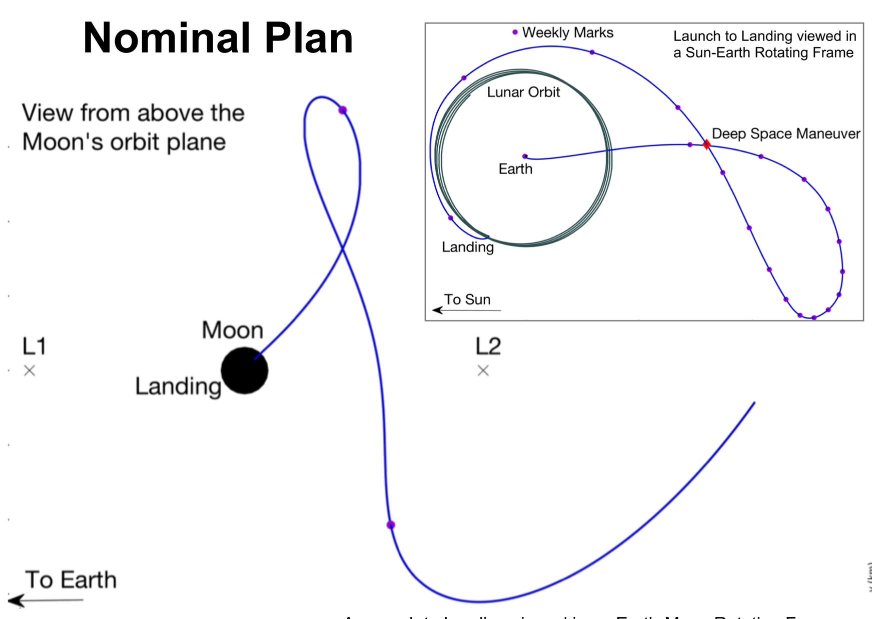
…things don't go as expected and the spacecraft is unable land when and where it was supposed to?

A number of abort scenarios are considered in this investigation, ranging from onboard software malfunction to natural disasters:

- **Hurricane**, resulting in severe adverse weather that could cause a city-wide outage of 3-4 days.
- **Software bug**, or any issue detected onboard of any of the spacecraft systems could take 3-4 weeks to fix, test, and uplink.
- **Earthquake or meteor strike**, resulting in major property and life damage that could disable tracking and operations facilities for 3-4 months.
- **Flooding** of the JPL Spacecraft Operations Facility, causing an electrical system failure that would take up to a month to fix.

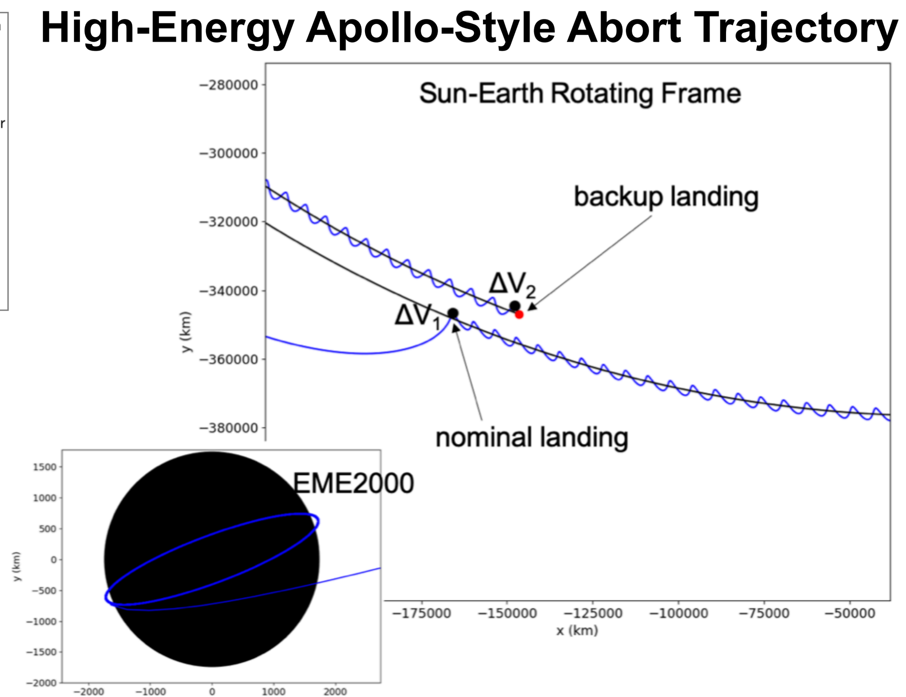
Earth-Moon System

Nominal Plan



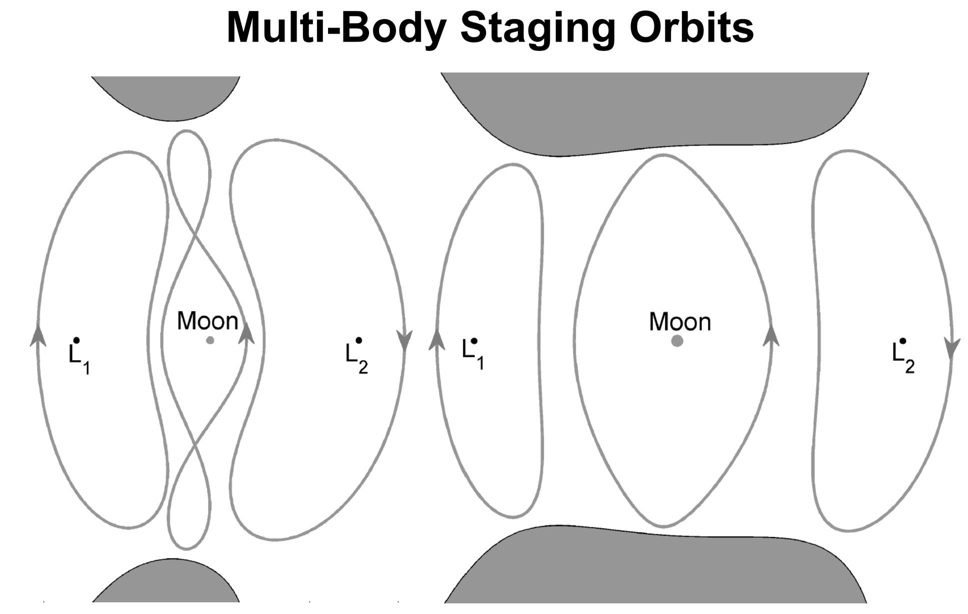
Nominal Landing Epoch	December 25, 2025 17:30:45 UTC
Backup Landing Epoch	January 24, 2026 09:53:34 ET
Altitude	14.52 km
Latitude	8.335 deg
Longitude	33.222 deg
Inertial Velocity	2340 m/s
Flight Path Angle	-4.00 deg
Flight Path Azimuth	180 deg

High-Energy Apollo-Style Abort Trajectory



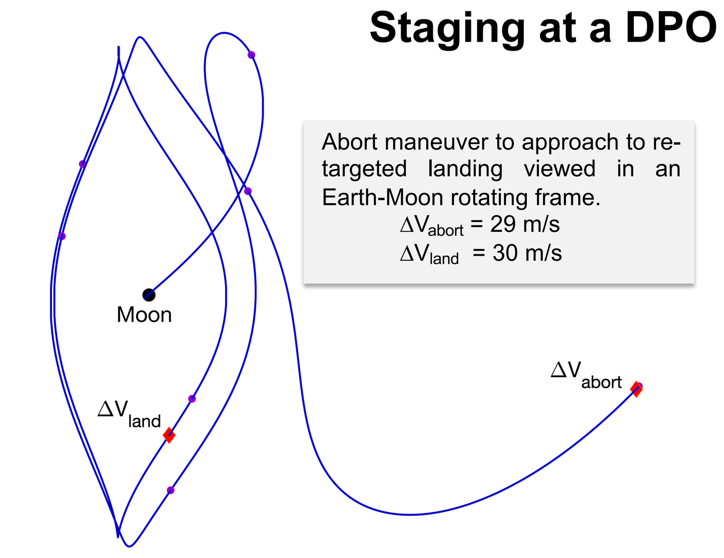
Last-minute abort scenario depicting an abort maneuver performed minutes before the Entry-Descent-Landing interface point to circularize the orbit at an altitude of 100 km over the lunar surface (ΔV_1), followed by a landing burn approximately a month later to re-target the original landing conditions (ΔV_2). The total abort ΔV penalty is 806 m/s.

Multi-Body Staging Orbits



Representative Distant Prograde Orbits (DPOs) and L_1 and L_2 Lyapunov Orbits at different energy levels in the Earth-Moon system. The selected DPOs for Jacobi Constant values C = 3.05 and C = 3.12 are unstable and, therefore, possess stable and unstable manifold trajectories that asymptotically approach and depart the orbit. These natural transfers make excellent candidates for low ΔV cost abort options.

Sample Low-Energy Abort Trajectory Staging at a DPO

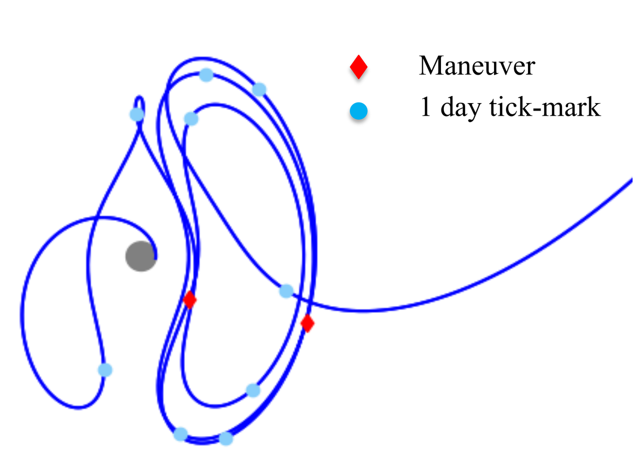


By exploiting multi-body dynamics and searching for the appropriate periodic orbit structure, a viable abort trajectory alternative is identified. The ΔV cost increase of 59.45 m/s does not jeopardize the mission; in fact, it could be used from the fuel margin in the tanks allocated for contingencies.

Jupiter-Europa System

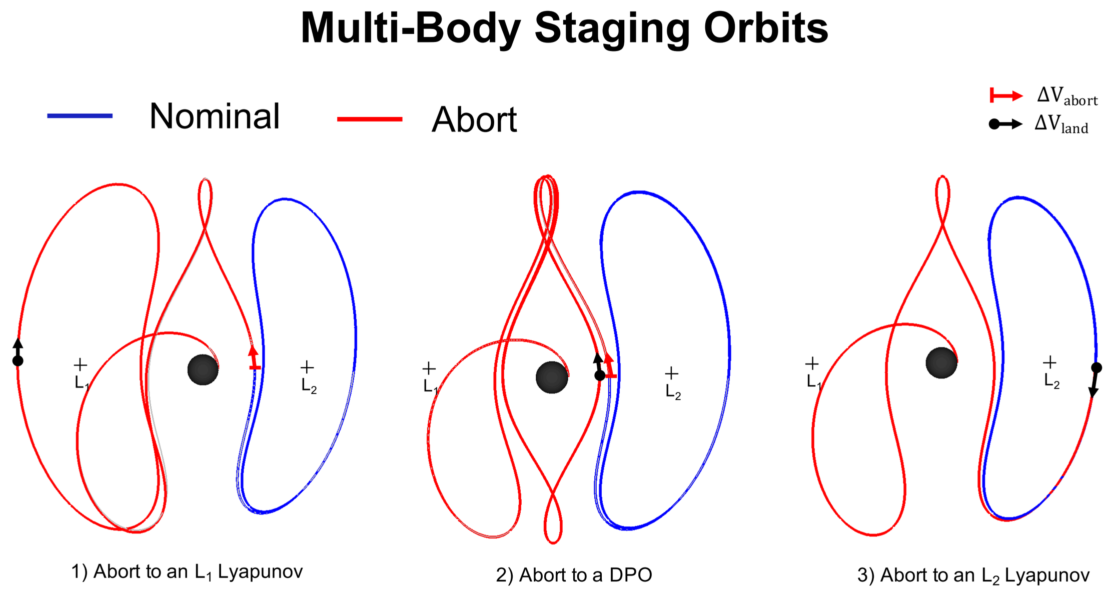
Nominal Plan

Europa Lander's nominal trajectory plan is to get loosely captured at Europa by entering through the L_2 gateway of the Jupiter-Europa three-body system. Two ΔVs are planned nominally, the first one to reduce the energy of the spacecraft and the second one to place it on its landing trajectory.



Landing State	Full Ephemeris
Nominal Landing Epoch	June 13, 2032 20:44:31 UTC
Altitude	9.1 km
Latitude	30.0 N deg
Longitude	170.0 E deg
Inertial Velocity	1930 m/s
Flight Path Angle	0.0 deg
Flight Path Azimuth	260.5 deg
DV_1	57.7 m/s
DV_2	0.5 m/s

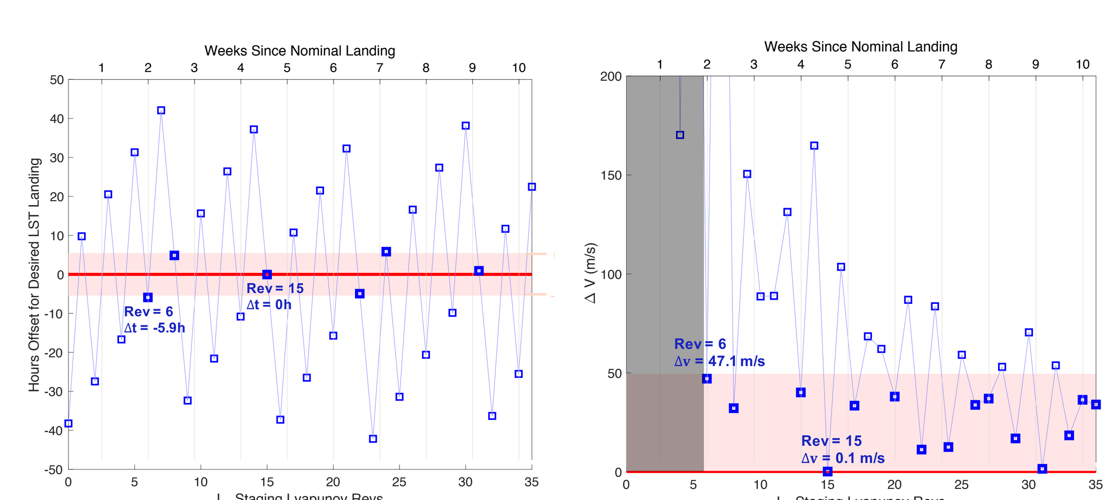
Multi-Body Staging Orbits

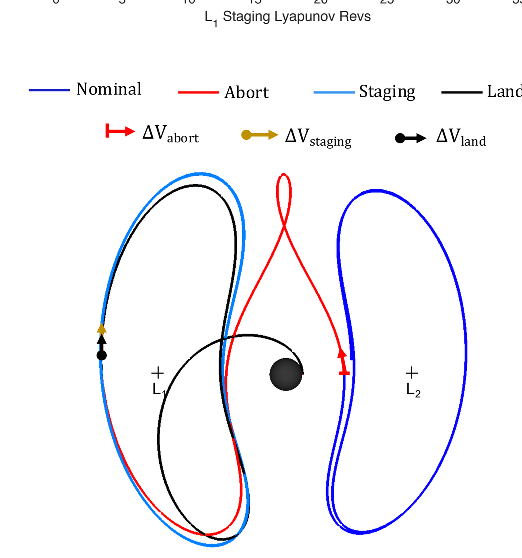


Landing at the same Local Solar Time (LST) is important for lighting conditions. ***Three abort scenarios*** are possible, exploiting multi-body staging orbits. The ***fastest*** landing option at the same location and LST is ***2 weeks*** after nominal landing time, with a combination of L_1, L_2, and DPO staging orbits, with ΔV = 17 m/s. To land at the same location and LST with no ΔV penalty, the spacecraft would need to wait for a minimum of 3.5 weeks after the nominal landing time.

Abort Type	Land ASAP w/$\Delta V \leq 50$ m/s				Land w/ $DV = 0$ m/s			
	ΔT_{land} (weeks)	N_{rev} -	Δt_{offset} (hours)	ΔV (m/s)	ΔT_{land} (weeks)	N_{rev} -	Δt_{offset} (hours)	ΔV (m/s)
$N_{rev}L_1$	2.0	6	5.9	47.1	4.5	15	0.04	0.1
$N_{rev}DPO$	2.5	7	7.9	44.4	3.5	10	0.15	0.6
$N_{rev}L_2$	2.0	7	4.9	38.8	4.5	16	0.96	3.5
$L_2DPOL_1 + N_{rev}L_2$	2.0	3	0.9	17.0	6.5	19	0.06	0.2

Sample Low-Energy Abort Trajectory: Staging at L_1 Lyapunov





Attempting a backup landing at the nominal LST

Option 1: maintain the orbit energy, wait in the selected staging orbit for 4 weeks (equivalent to 15 revs around L_1), resulting in a ΔV cost of 0 m/s.

Option 2: increase the energy of the L_1 Lyapunov orbit, wait for 2 weeks (equivalent to 6 revs around L_1), resulting in a ΔV cost of 47.1 m/s.

Benefits to NASA and JPL

- Directly applicable to low-energy trajectories currently supporting a variety of lander mission concepts, including Moon Diver and Europa Lander.
- Generalized method to find alternate landing trajectories is based on three staging structures available in *any* three-body dynamical system.
- Exploiting low energy transfers as abort mechanisms significantly reduces propellant costs if a backup landing opportunity is needed.

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