A Notional Round Trip To The Trans-Lunar Libration Point (EML2)

Many specialists in the astrodynamics field are currently studying trajectories between Earth and the trans-lunar libration point (EML2). Located about 60,000 km beyond the Moon from Earth, EML2 is a strategic location from which to explore the Moon's far side. With very little propellant, a spacecraft located near EML2 can remain nearly stationary with respect to the Moon's surface. Periodic orbits about EML2 are also possible at low propulsive cost. One such orbit, called a "halo" can be selected with a radius sufficient to permit continuous communication with Earth while keeping nearly the entire lunar far side in view.

Two types of trajectories connecting Earth and EML2 are under study. The *Flyby* trajectory is constrained to pass very close to the Moon on the way to or from EML2. Kinetic energy gained by falling toward the Moon greatly magnifies effects of any propulsive maneuver performed in the Moon's vicinity, but a Flyby may also incur a delay in transit time between Earth and EML2. In contrast, the *Direct* trajectory never gets closer to the Moon than when in the vicinity of EML2.

This paper describes a notional round trip from Earth with a brief one-day loiter at EML2. The Multi-Purpose Crew Vehicle (MPCV) under development by NASA and named *Orion* is assumed to be making the trip. A Flyby trajectory is used outbound from Earth, and a Direct trajectory is used to return from EML2. The following terminology is used throughout.

H_A x H_P ≡ maximum x minimum orbit heights above a spherical Earth or Moon
Δv ≡ change in velocity magnitude
v_i ≡ inertial speed with respect to Earth's or Moon's center

Table 1. The notional round trip's sequence of events is summarized. All propulsive "burns" are approximated as instantaneous events.

Year 2017 UTC	Event
01 Jan 16:05	Launch from Kennedy Space Center
01 Jan 16:13	Launch vehicle main engine cutoff (MECO): H_A x H_P = +1806 x -93 km
01 Jan 16:53	Perigee raise burn: Δv = 73 m/s, H_A x H_P = +1806 x +157.5 km
01 Jan 17:35	Trans-lunar injection (TLI) burn: Δv = 2764 m/s
05 Jan 14:39	Lunar flyby burn at H_P = +100 km: Δv = 213 m/s
09 Jan 01:40	Halo orbit insertion (HOI) burn: Δv = 137 m/s
10 Jan 01:40	Trans-Earth injection (TEI) burn: Δv = 1200 m/s
15 Jan 17:19	Earth atmospheric entry interface (EI): v_i = 10.998 km/s

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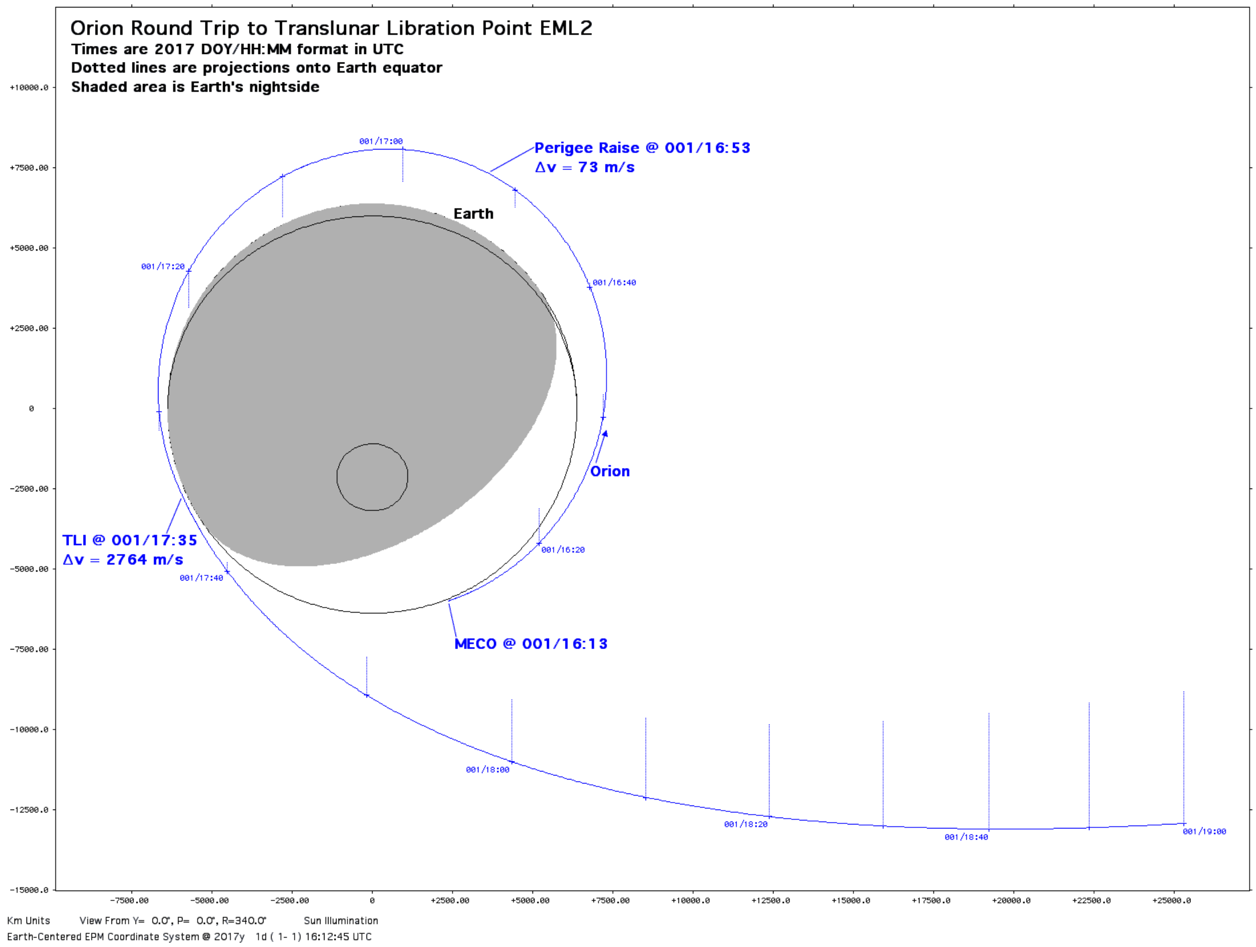

Figure 1. This Earth-centered trajectory plot is very nearly in the plane of *Orion*'s orbit following MECO. It extends from MECO to nearly 1.5 hrs after TLI. Even at the perigee raise burn, *Orion*'s crew would be farther from Earth than any humans have ventured since Apollo 17 flew to the Moon in December 1972.

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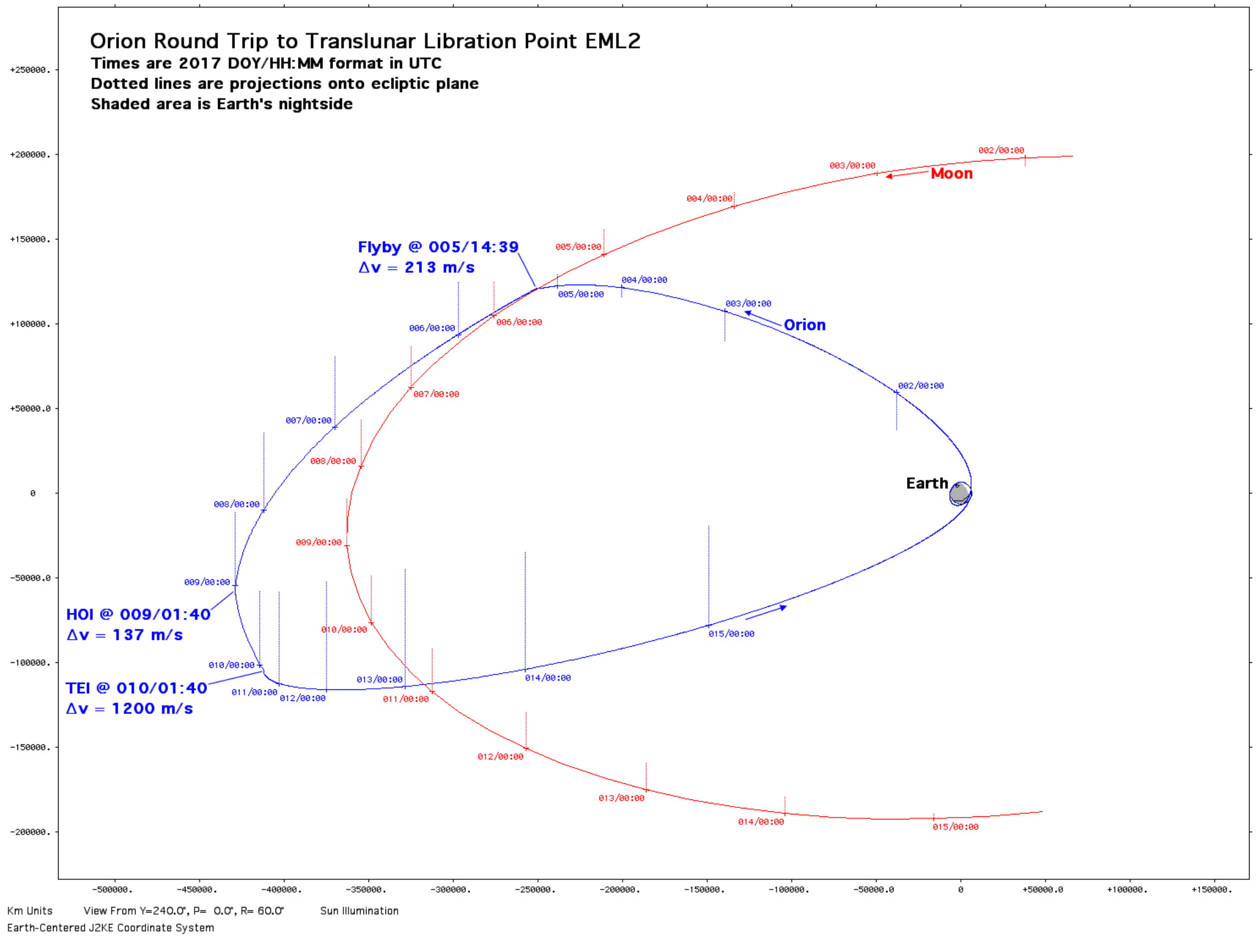

Figure 2. This Earth-centered trajectory plot views *Orion*'s path (blue) and the Moon's orbit (red) in a perspective conveying the impression of motion in three dimensions. It serves as an overview, covering nearly the entire two-week round trip starting at MECO and ending at EI.

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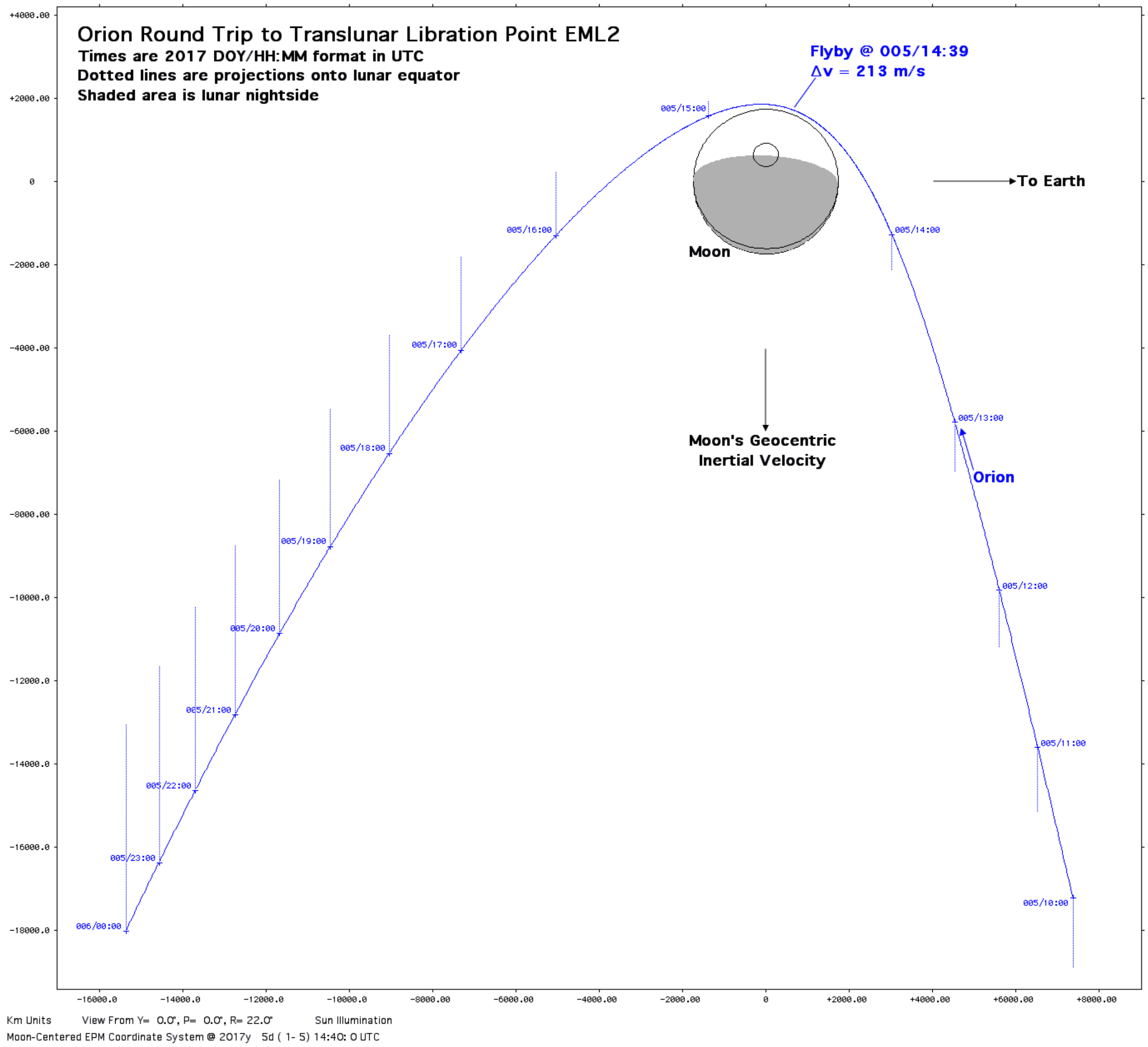

Figure 3. This Moon-centered trajectory plot illustrates *Orion*'s lunar flyby. As seen from Earth, *Orion* would disappear behind the Moon for about an hour shortly after performing its flyby burn. In departing the Moon's vicinity, note how *Orion* moves progressively farther below the lunar equator. Ultimately, this motion will efficiently establish a halo orbit about EML2 dwelling below the lunar equator most of the time. This bias would permit localized study of the Moon's southern farside with only occasional interruptions.

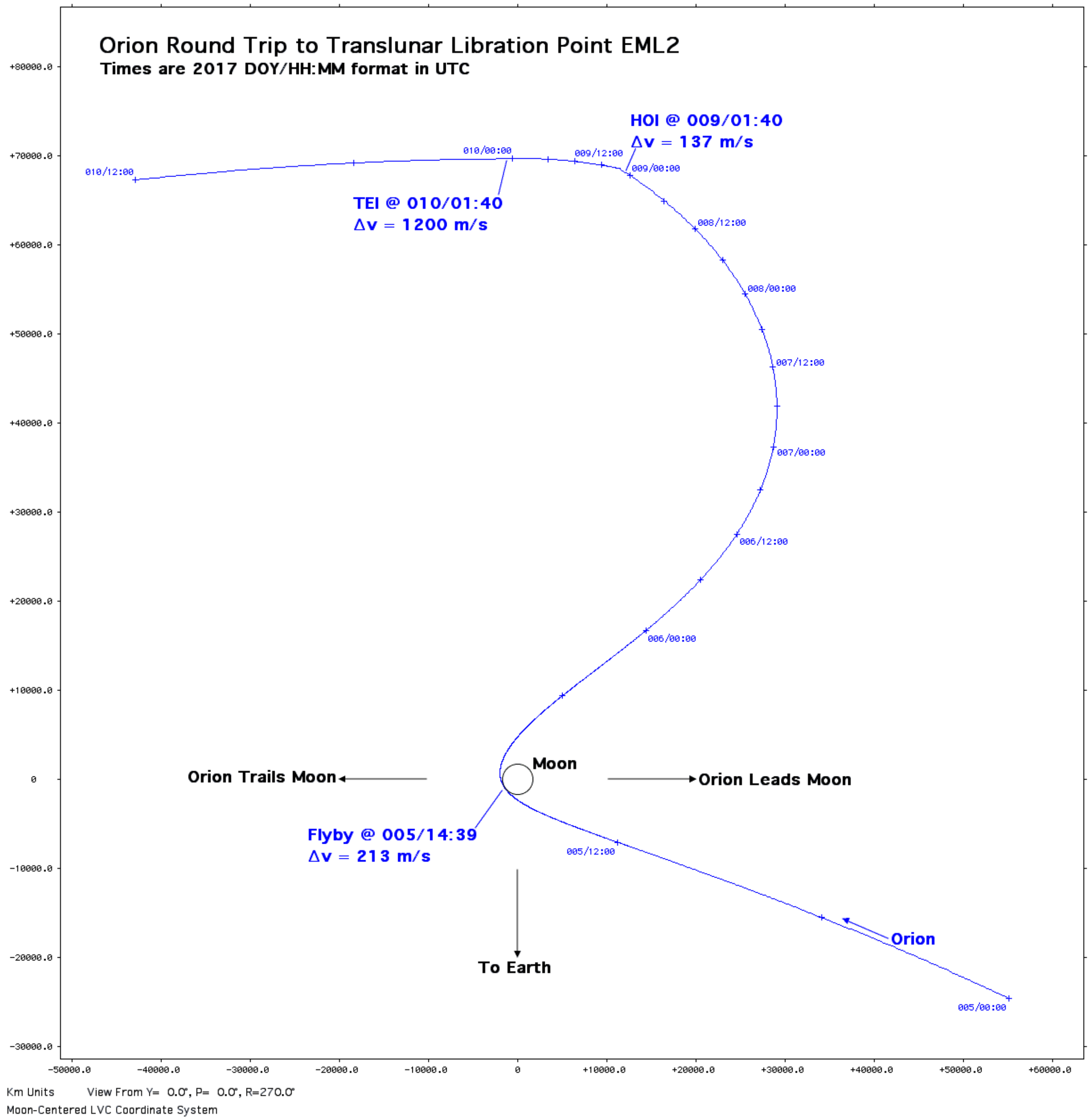

Figure 4. This Moon-centered trajectory plot is unique in this paper because it rotates to fix the line connecting Earth, Moon, and EML2 along the "To Earth" arrow. All other plots are inertial and do not rotate. The plot is aligned with the Moon's orbit about Earth and therefore does not capture *Orion*'s motion above and below this plane. Note how spacing between 6-hour time ticks decreases only slightly immediately before and after the HOI burn. Compare this to the dramatic increase in Moon-centered motion post-TEI. This burn nearly cancels *Orion*'s motion with respect to Earth, beginning a free-fall lasting nearly 6 days and ending with EI.

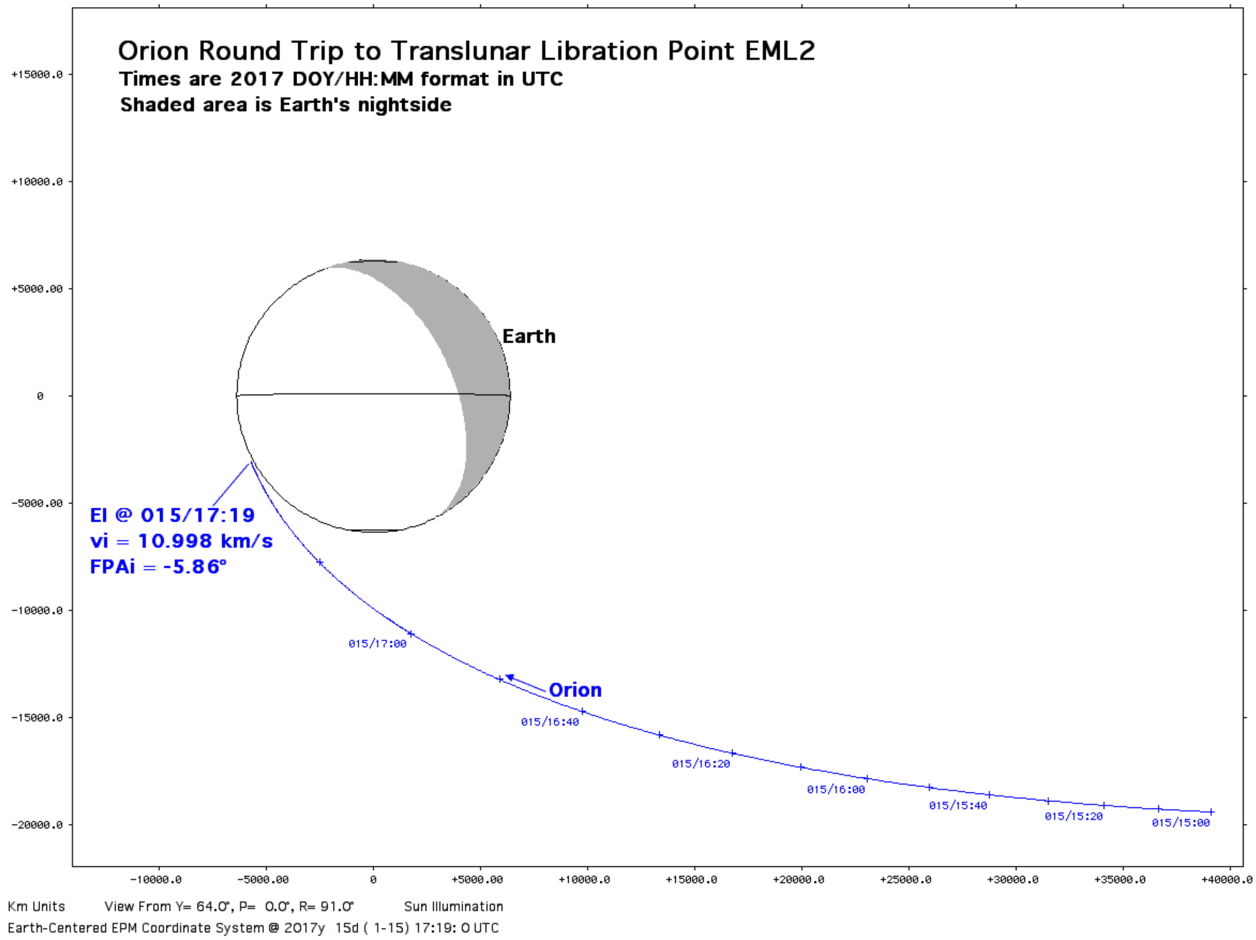

Figure 5. This Earth-centered plot is very nearly in the plane of *Orion*'s Earth return trajectory, ending at EI. The Antarctic approach targets northbound atmospheric flight and a splashdown off the southern California coast.