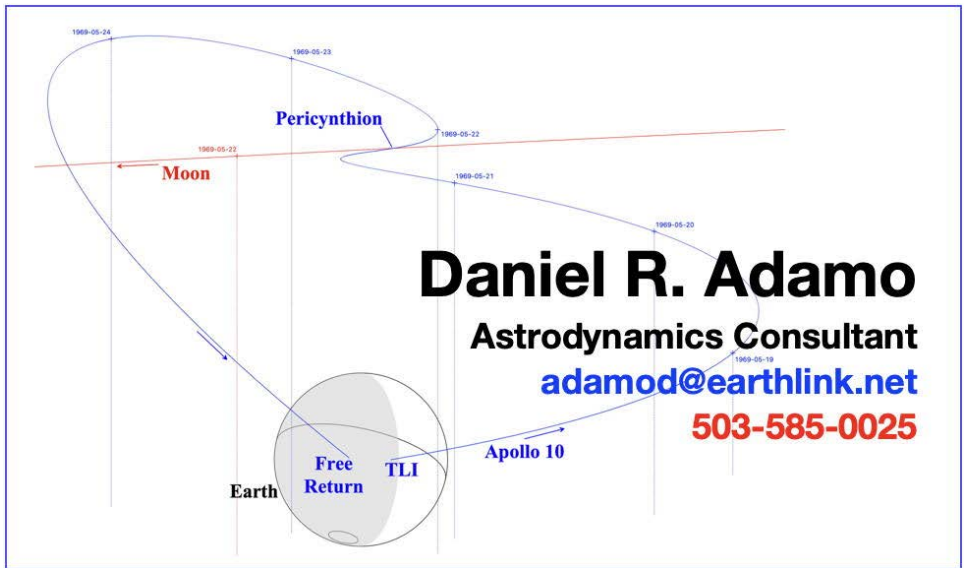
A Tale Of Two Translunar Aborts



AIAA-Houston Section, History Technical Committee

Virtual Lunch 'n Learn

26 February 2024

A Tale Of Two Translunar Aborts

Which Aborts?

- Jan 2024: *Peregrine*, the first Commercial Lunar Payload Services (CLPS) lunar landing attempt
- Apr 1970: Apollo 13, the third human lunar landing attempt

Source Material At http://www.aiaahouston.org/adamo_astrodynamics/

- ATIG_147: "An Account of the *Peregrine* Lunar Lander's Abort"
- ATIG_144: "Insights From Reconstructing Apollo 13's Abort Trajectory"

Shared Abort Scenarios

- Both missions suffered acute capability loss from over-pressurized onboard storage tanks (official *Peregrine* mishap investigation results are pending), resulting in lunar landing aborts
- Both aborts declared enroute to the Moon after trans-lunar injection (TLI)
- Neither spacecraft had stable attitude control post-abort, nor were trajectory adjustments precise
- Persistent overboard venting from both spacecraft was a navigation nightmare

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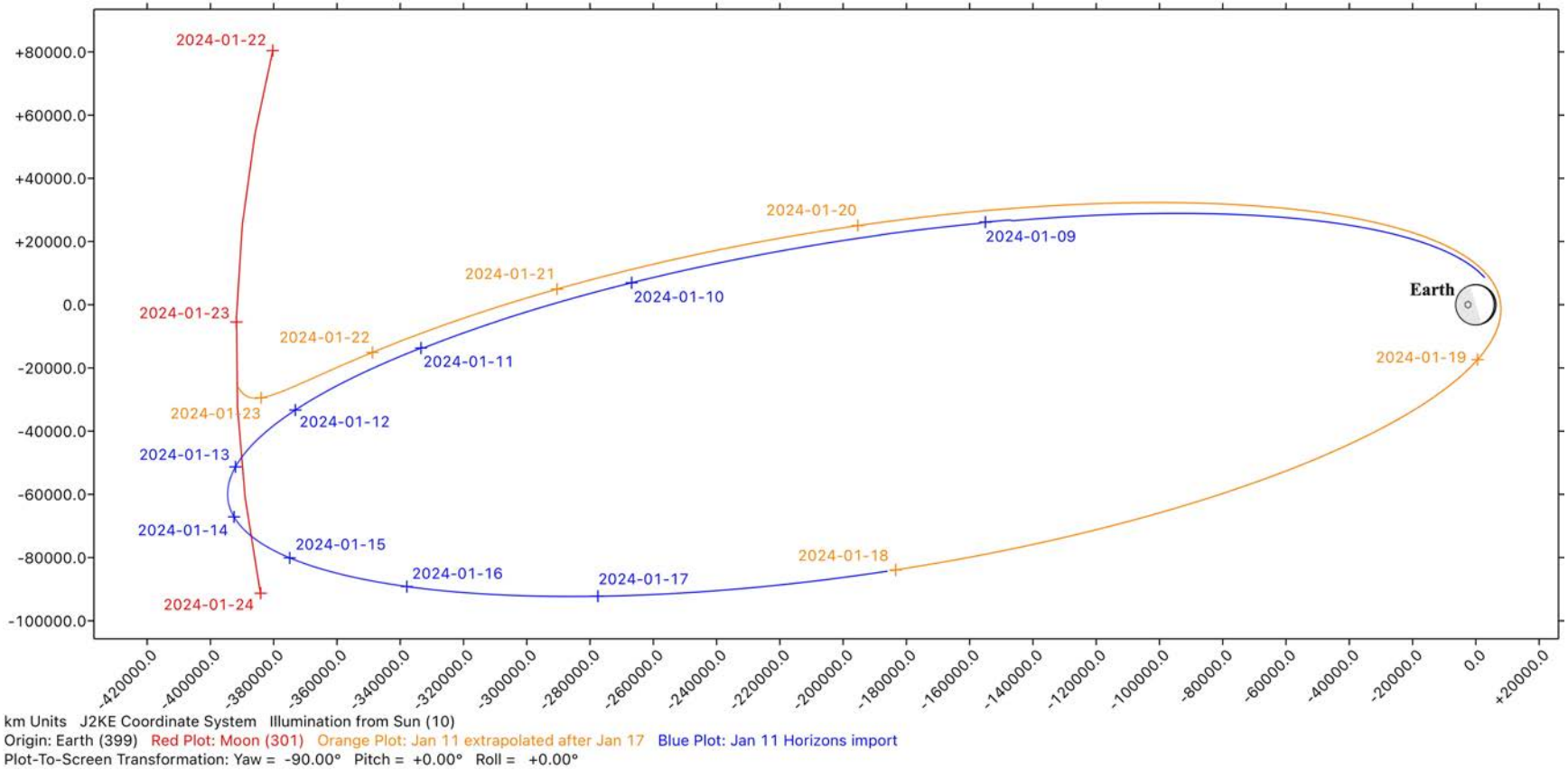
Peregrine Lunar Hypervelocity Impact Predicted From January 11 Data



- Even at this large scale, a trajectory discontinuity in the ephemeris posted by JPL-*Horizons* is evident just before the 2024-01-09 time tick
- Discontinuities are thought to arise from spacecraft operators issuing only predicted data and *Horizons* cobbling predicted arcs together (no coordination between operators & *Horizons*)

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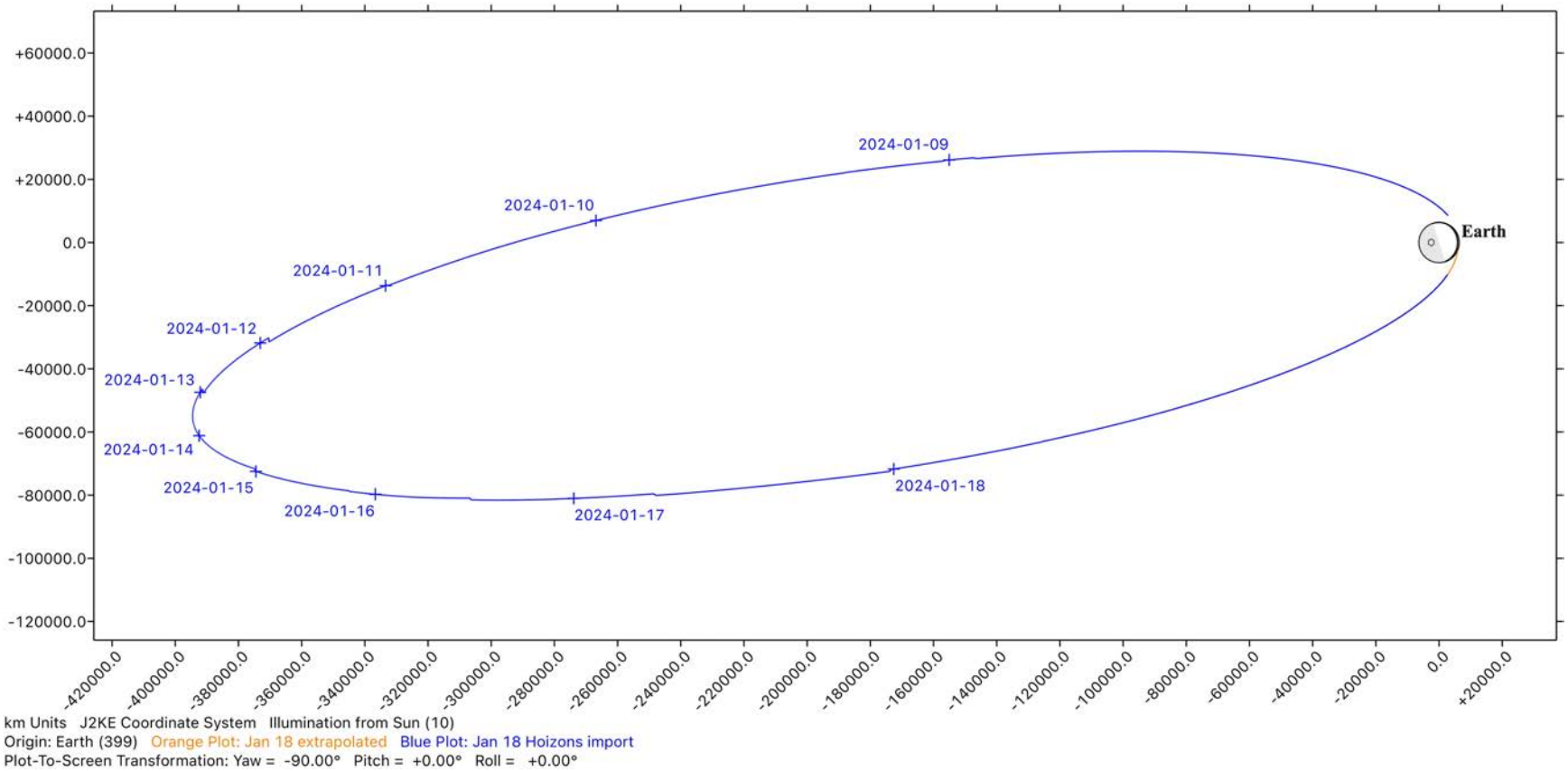
Ultimately, *Peregrine* Disposal Achieved Through Safe Atmospheric Incineration



- The final *Horizons* ephemeris posted Jan 18 (blue) is riddled with position discontinuities
- Typically, a spacecraft's final posting on *Horizons* is a best-estimate as-flown ephemeris, but this end state was never coordinated or funded. The above plot in blue persists.

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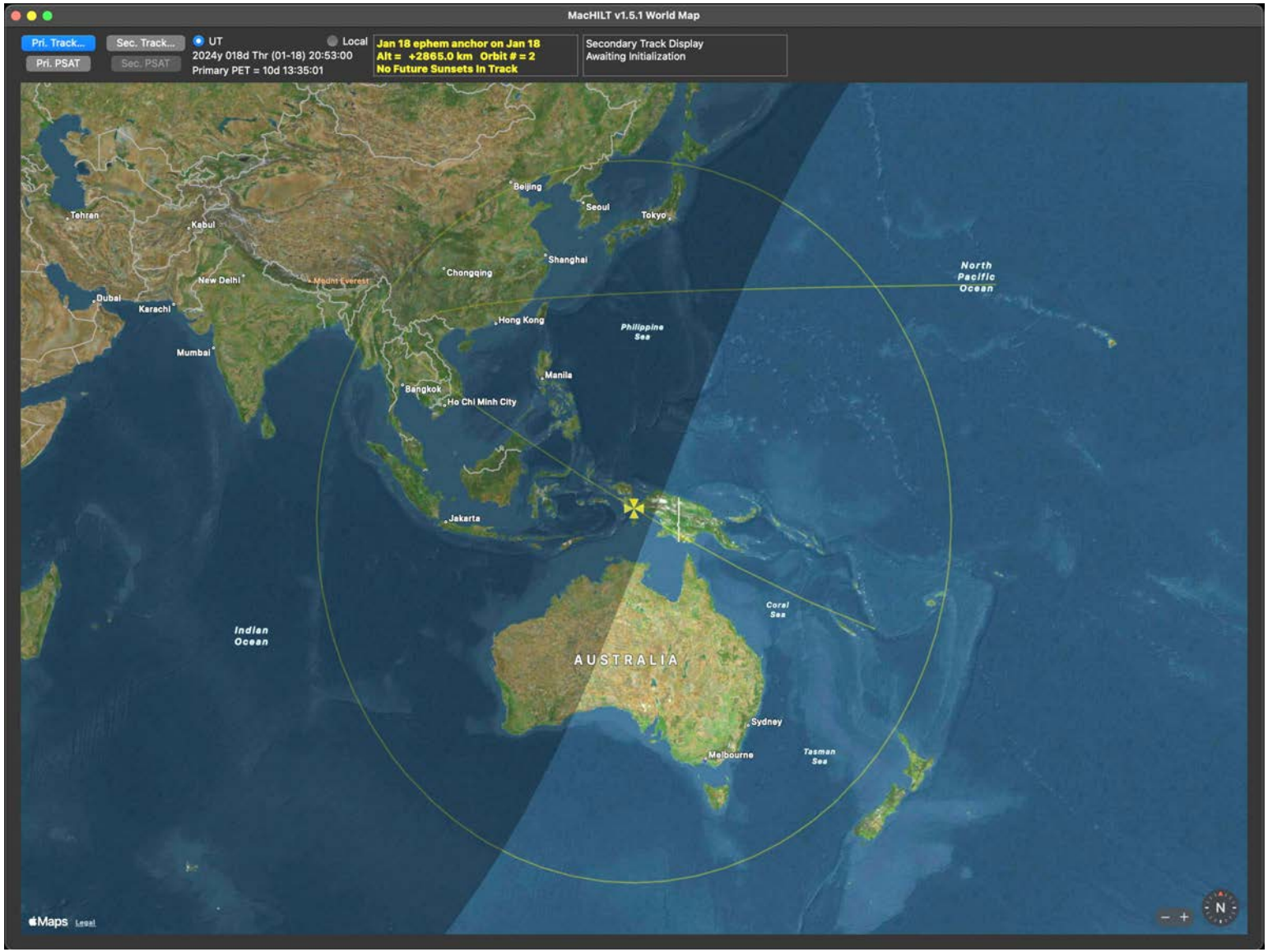
Peregrine's Final Plunge Ended On A SE Heading E Of Australia



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Heroic *Peregrine* Entry Targeting Was Required To Achieve Safe Disposal

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Peregrine Lesson Learned: Timely Trajectory Data MUST Be Made Public

- Missions conducted under U.S. auspices incur U.S. liability as an Outer Space Treaty signatory (ref. Article VII at https://outerspacetreaty.org/res/outer_space_treaty.pdf)

  "*Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the Moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or to its natural or juridical persons by such object or its component parts on the Earth, in air space or in outer space, including the Moon and other celestial bodies.*"

  - *How* a trajectory is designed or determined can be proprietary, but the trajectory itself is <u>not</u>
  - Trajectory data must be diligently posted for public access in a timely manner on platforms like *Horizons* to facilitate coordination with planetary defense, military, aviation, maritime, and spacecraft operations organizations worldwide (and off-Earth someday)
  - Three times daily, SpaceX shares trajectory data from over 4600 operational Starlink satellites for public access via space-track.org. Trajectory data-sharing per Article VII is practical!
- Analogously, if Earthly air transport regarded routes and flight plans as proprietary, air traffic control would be ineffective and incur frequent loss of life and property

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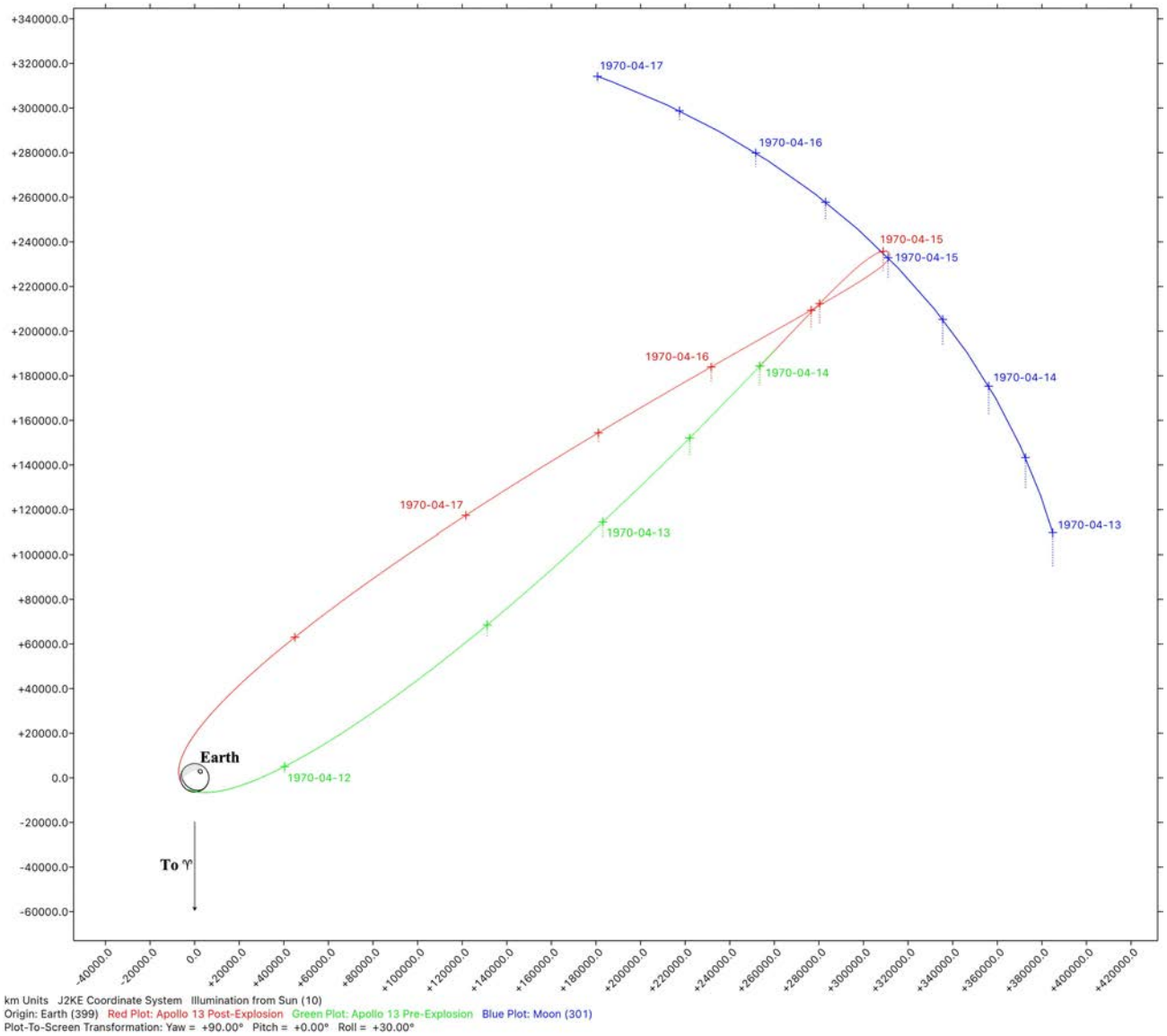
Apollo 13 Lunar Module "Lifeboat" Abort Mode Initiated At 83% Moon Distance



- As-flown Apollo 13 trajectory reconstruction (green pre-abort; red post-abort)
- Dotted lines are projections onto ecliptic plane
- Shaded area is Earth's nightside
- Safe crew return entailed three trajectory-related tasks

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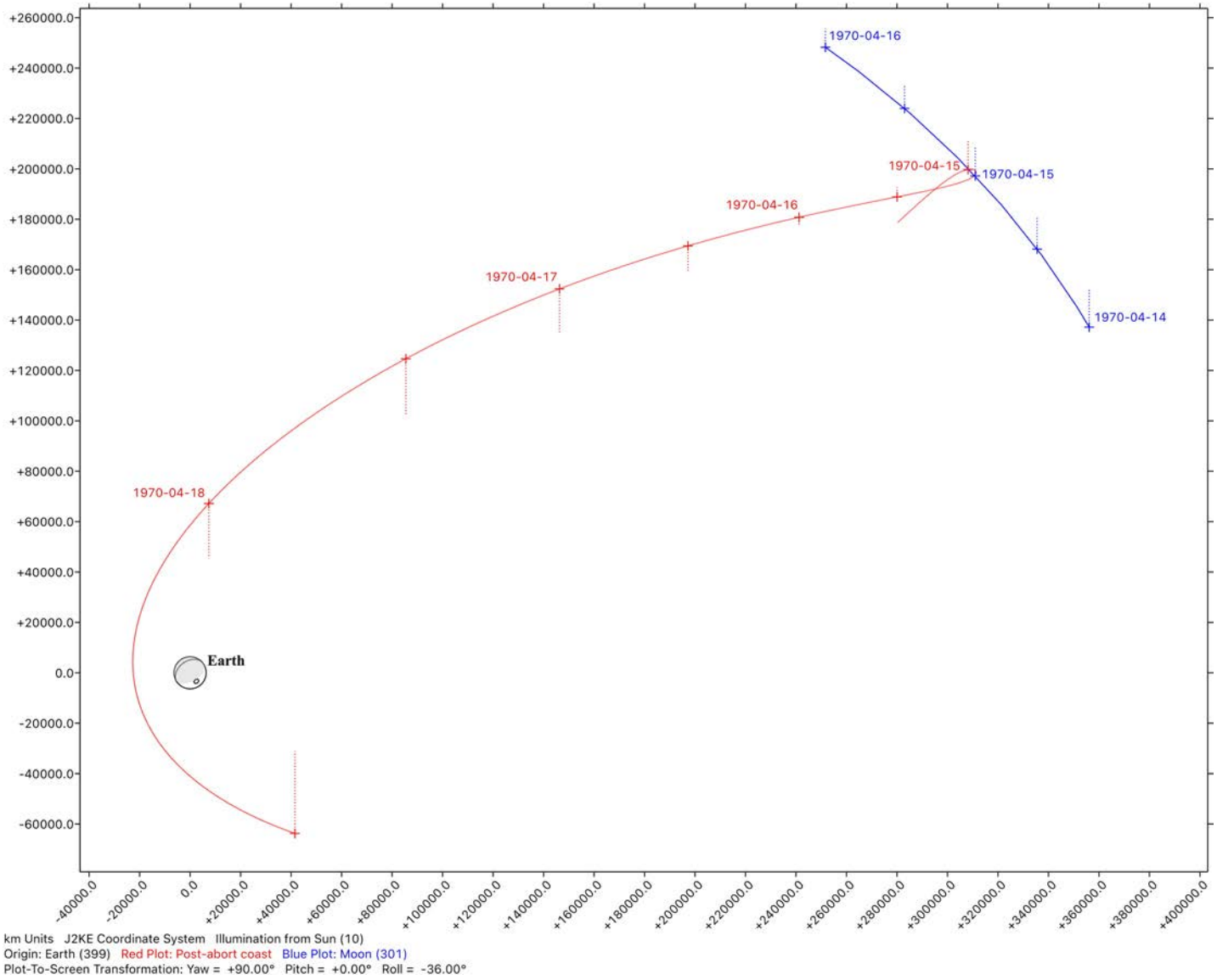
Task 1: Achieve An Earth Return With MCC2 Burn



- Post-abort perigee on 1970-04-18 at 05:20:44 UTC with height = +18759 km

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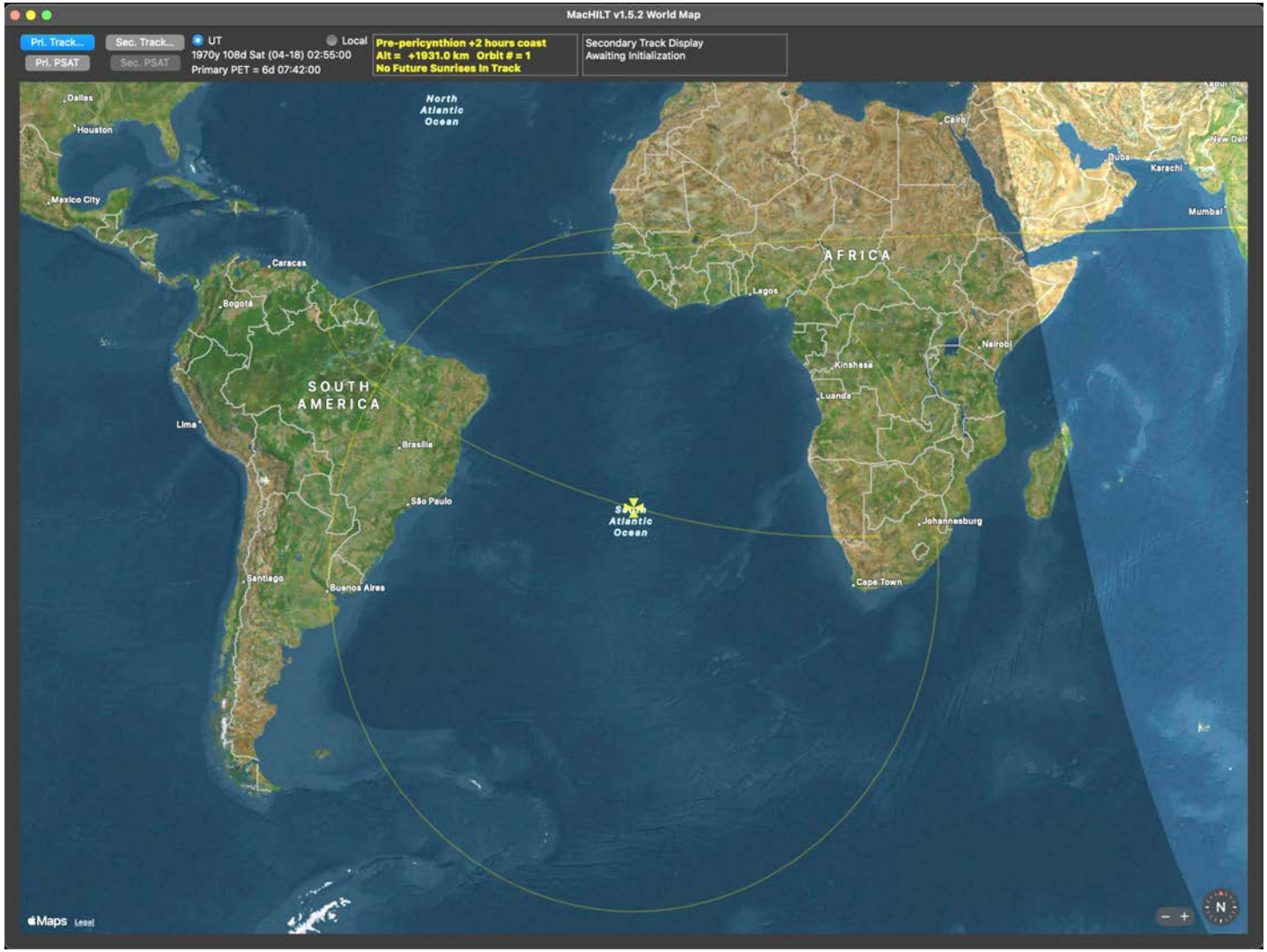
Task 2: Shorten Return and Relocate Splashdown Near Hawaii With TEI Burn



- Entry interface (EI) over South Africa eastbound on 1970-04-18 at 03:02:47 UT
- Splashdown in western Indian Ocean

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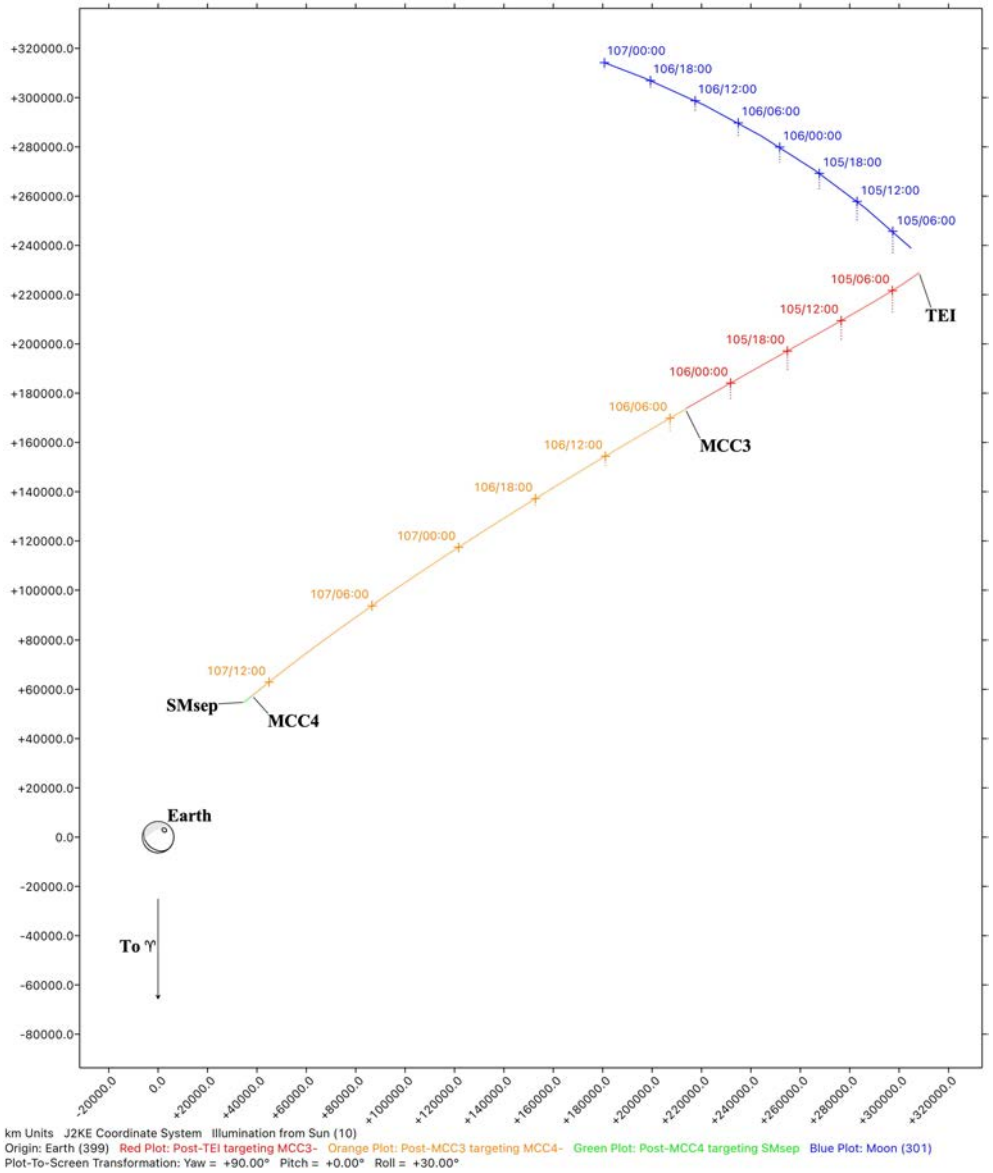
Task 3: Manage EI Flight Path Angle -7.4° ≤ γ_{EI} ≤ -5.25° (-6.5° Ideally) Post-TEI



- Post-TEI, coasted minimum altitude h = +133.08 km, but EI h = +121.92 km. Error likely caused by poor control during 263.8 s/262.3 m/s TEI burn
- Post-MCC3, coasted γ_{EI} = -6.20°
- Pre-MCC4, coasted γ_{EI} = -5.99°
- Post-MCC4, coasted γ_{EI} = -6.24°
- As-flown γ_{EI} = -6.27°
- Reconstructed MCC3 $\Delta\boldsymbol{v}$ points within 18° of the Sun at MCC3
- Reconstructed MCC4 $\Delta\boldsymbol{v}$ points within 14° of the Sun at MCC4
- Hypothesis: shallowed γ_{EI} caused by persistent overboard vent accelerations in the down-Sun direction