Prospecting Lunar Polar Ice from Low-Altitude Orbits.

J. Shannon, C.A.. Hibbitts[2], K. Runyon, M. Nord, and J. Berdis
Johns Hopkins Applied Physics Laboratory, Laurel, Md, 20723, United States, Jackson.Shannon@jhuapl.edu

Introduction: Neutron spectroscopy (NS) observations have previously provided robust information on the water-equivalent hydrogen abundance in the near surface [1]. However, the spatial resolution of orbital NS measurements is essentially equivalent to the spacecraft altitude above the surface, and perilune significantly less than 30 km have yet to be achieved. As a result, current maps have spatial resolutions of several 10's of kilometers [1-3]. Higher spatial resolution near-surface hydrogen measurements could enable better constraints of the location and amount of potentially viable near-surface water ice resources [4,5]. Thus, we have conducted a feasibility study for the accessibility and stability of very low-altitude polar lunar orbits.

This work sought to evaluate the stability of low-perilune (~ 5 km) south pole orbits for permanently shadowed crater observations near potential Artemis Base Camp sites. We explore the lowest achievable orbit altitudes and lifetimes and formulate a concept of operations (ConOps) for high-altitude terrain avoidance when necessary.

Science Phase ConOps: The lunar south pole contains regions of high-elevation terrain that pose an impact threat to a low-altitude orbiter. A potential solution to this issue is to define longitude regions that are safe for low-altitude observations and regions that require terrain avoidance. Low-perilune polar orbits were simulated in the Systems Took Kit software with a high-fidelity dynamics model to determine the orbit stability and ΔV costs for impact avoidance. To avoid impacting the high-altitude terrain shown in Figure 1, impulsive maneuvers were used to adjust the perilune altitude at the critical longitudes between the two regions shown. The spacecraft's osculating body-fixed Longitude of Ascending Node (RAAN), Ω, was tracked for crossings between the two regions, with perilune being dropped to 5 km altitude above lunar datum in the observation region and raised to 30 km altitude for terrain avoidance. The observation regions are defined as $65^{\circ} \leq \Omega \leq 115^{\circ}$ and $245^{\circ} \leq \Omega \leq 295^{\circ}$, with the terrain avoidance regions constituting the remaining longitudes.

Due to the Moon's rotational period of 27.3 days, the spacecraft rotates out of the observation region in approximately 4 days and must wait approximately 10 days for the observation region to rotate back beneath the spacecraft. During terrain avoidance, lower-resolution NS data will be available. Typically, low-perilune orbits are at significant risk of impact due to third-body and aspherical gravity perturbations. However, the need

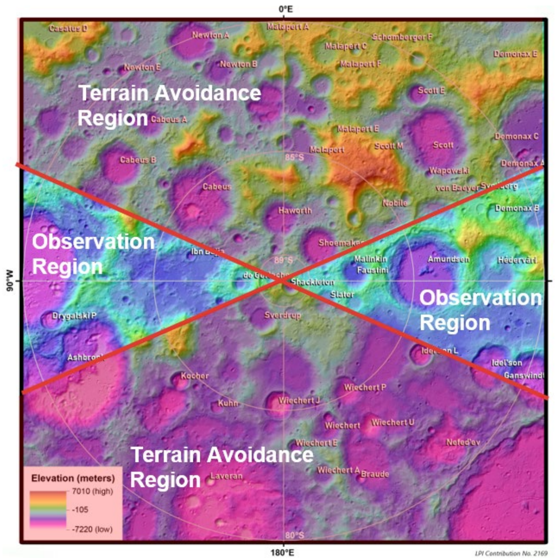

Figure 1. Lunar south pole terrain. Potential observation regions exist in low-altitude terrain regions.

for terrain avoidance maneuvers bounds the duration of the low-perilune phases to be so short that the orbits do not have enough time to impact. We note that targeting an initial perilune lower that 5 km increases the chance of impact. The ΔV for perilune adjustments is relatively low, typically 3-5 m/s per maneuver depending on apolune altitude. Given that WEH concentrations greater than 500 ppm are of interest for defining a water-ice reserve [5], and can be measured in only a few flybys [4], this measurement can potentially be met with a small satellite.

Conclusion: Very-low altitude orbit passes above the Lunar south pole for enhancing hydrogen map resolution to ~ 5 km with high SNR have potentially feasible small satellite ConOps for needed perilune adjustments to ensure impact avoidance.

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