EFFECTIVE CREWED SURFACE SCIENCE NEAR THE LUNAR SOUTH POLE: SOME ILLUMINATION CONSIDERATIONS. C. I. Fassett[1] and M. Zanetti[1], [1]NASA Marshall Space Flight Center, Huntsville, AL 35805 (caleb.i.fassett@nasa.gov).

Introduction: Exploration near the lunar South Pole has substantial scientific promise for expanding our understanding of the Moon beyond what has been accomplished by Apollo and other lunar missions. An obvious difference from the Apollo experience is that the polar location for Artemis will guarantee the Sun is going to be low above the horizon (**Table 1**). A great deal of excellent work has been, and is being, done on the *availability* of light ("yes/no") for exploration purposes [e.g., 1-4]. However, we raise the additional consideration of the qualitative effects of low solar elevation on crew traverses, crew observations, and other science measurements [see also 5, though ground rules of that study presumed higher Sun]. We emphasize that our view is that these issues are unlikely to be mission objective-threatening, particularly if adequately considered in advance.

Orientation Effects: *Looking directly down-Sun (approaching 0°-phase; Sun behind observer).* During Apollo, virtually every astronaut mentioned the challenges of walking or roving with the Sun behind them (i.e., in the zero-phase direction) [6]. There are several causes that lead to an enhanced reflectance directly at zero phase [e.g., 5-7]. One is the intense opposition surge and coherent backscatter that occurs on the Moon. In addition, shadows of craters, rocks, and regolith become hidden when looking down-Sun. Consequently, recognizing obstacles becomes challenging, particularly in the far-field (**Fig. 1)**. Note that the Apollo astronauts suggested this this was not just a single azimuth but a zone; Dave Scott is quoted as saying the washed out zone was toward zero phase ±20˚ [6]. Planning traverses that go directly down-Sun should be avoided, if possible.

Looking up-Sun (approaching 180°-phase, towards the Sun). It almost goes without saying that the main issue looking sunward is the intense light from the Sun (e.g., **Fig. 1**). Obstacles and shadows are recognizable, but working in that direction is not ideal even if the intense Sun is mitigated by a well-designed helmet. The combination of the glare from the Sun and numerous local shadows may be problematic. For example, when crew is partially blinded by Sun, the surface roughness casting shadows on their feet may make it hard to establish the quality of footing (*Armstrong,* MET 109:27:13 [5]: "It's quite dark here in the shadow and a little hard for me to see that I have good footing." *Armstrong Debrief* [6]: "When you walk out into the sunlight and then back into the shadow, it takes a while to adapt.")

Apollo EVA	**Sun angle above horizon (90-*i*) for EVA**
12 EVA-1	7.5 - 9.5°
14 EVA-1	13.0 - 15.5°
15 SEVA	13.0 - 13.3°
11 EVA-1	14.0 - 15.4°
17 EVA-1	15.3 - 19.0°
12 EVA-2	15.8 - 17.8°
15 EVA-1	19.6 - 22.9°
14 EVA-2	22.0 - 24.3°
16 EVA-1	22.1 - 25.7°
17 EVA-2	27.3 - 31.2°
15 EVA-2	31.0 - 34.7°
16 EVA-2	34.1 - 37.9°
17 EVA-3	39.0 - 42.6°
15 EVA-3	41.7 - 44.2°
16 EVA-3	45.8 - 48.7°
Artemis LS1	< 2.1°
Artemis LS2	< 1.75°

Table 1. Solar elevation (90° - incidence angle) for the Apollo EVA's (source [5]). Bottom two rows are two potential Artemis locations (authors' calculations for a 12/2024 mission).

Optical systems or other instruments will also have to be engineered so as to handle the low solar elevation. Recall the Apollo 12 TV system was rendered inoperable after being inadvertently pointed sunward. Modern sensors can to be made more resilient, but getting usable surface observations in the sunward direction with the Sun ~2° above the horizon might still challenge instruments without appropriate planning and accommodation for low Sun in advance.

Roughness Effects on Hazard Perception: Even in the cross-Sun direction, which is optimal for traverses given the above considerations, low solar elevations combined with the Moon's inherent topographic roughness will produce numerous shadows at cm-to-m scale on the surface. According to the Apollo experience, seeing into many of these shadows will probably be possible (at least if not blinded by the Sun). However, astronauts reported challenges getting a sense of scale on the Moon and interpreting shadowing without landmarks. The Apollo 12 crew, whose first EVA had the lowest solar elevation (**Table 1, Fig. 1**), may have had this worst. In [6], astronauts Bean and Conrad are quoted as follows (see also **Fig. 1**):

> *Bean* - "….I can remember the first time I looked at it and I thought it [Surveyor] was on a slope of about 40 degrees (instead of the actual slope of about 10 degrees). And I remember us talking about it in the cabin, about having to use ropes. How are we going to get down there? How come they screwed up so badly (on the slope estimate)? And I think I was fooled because, on Earth, if something is sunny on one side and very dark on the other, it has to be a tremendous slope. We weren't getting (scattered) light in there like you do on Earth. So when light finally did strike, it was real..."
>
> Conrad - "It turned out it was real flat."

Obviously, during Artemis planning, we have extraordinarily valuable and high fidelity information about lunar topography, and we can select a safe landing area. We can also simulate lighting conditions based on knowledge of the mission during planning. However, some of the topographic roughness that will induce shadows is below the resolution of LRO instruments. Crew should be trained to expect terrains that look very rough or steep at first glance could ultimately prove traversable.

Low Sun, Roughness, and Differences in Color / Optical Maturity: Another consequence we expect of low Sun and frequent shadows is that subtle variations in color or optical maturity may prove hard to discern with the human eye (or with any optical system that relies on reflected solar illumination). For example, we speculate that the orange soil recognized at Apollo 17 may be hard to distinguish from background regolith at ~2˚ solar elevation (though this might be a good test to run in an analogue laboratory experiment to see if we are right). If color variations – limited as they are on the Moon – are as hard to discern as we expect, it will potentially hamper geologic interpretations such as distinguishing potential contacts between units or the ability to recognize rock type variations. Admittedly, given the regolith processing the Moon experiences, surficial contacts can be pretty hard to see on the surface even in optimal conditions. With careful science planning and/or advanced instruments deployed in situ, it will nonetheless be feasible to recognize and sample different lunar materials.

Speculation about How to Combat Illumination Challenges: We speculate that one simple possible mitigation strategy for the illumination challenges near the South Pole may be to bring an artificial light source. For example, artificial light might improve seeing into shadows, or color or multispectral imaging of the lunar surface that is otherwise impossible with low Sun. LIDAR could improve hazard avoidance and situational awareness through rapid topographic scanning that is difficult from cameras alone when confronting low solar elevations [8].

References: [1] Bussey, D.B.J. et al. (2010), *Icarus*, 208, 558–564. [2] Mazarico, E. et al. (2011), *Icarus*, *211*, 1066–1081. [3] Speyerer, E.J. & Robinson, M.S. (2013), *Icarus*, 122–136. [4] Gläser, P. et al. (2018) *PSS*, *162*, 170–178. [5] Eppler, D. (1991), NASA TM-4271. [6] Jones, E.M., Apollo Lunar Surface Journal, www.hq.nasa.gov/alsj. [7] Hapke, B. et al. (1998) *Icarus*, *133*, 89–97. [8] Zanetti, M., abstract for this meeting.

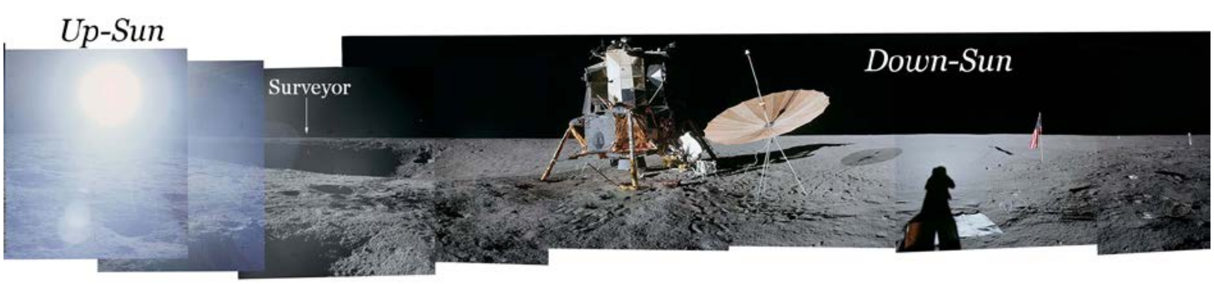

Figure 1. Section of Apollo 12 EVA1 Al's 4 o'clock pan (processed by Dave Byrne; MET 118:33:10) [6]. Note the long shadow cast by the LM, and the washed out region directly down-Sun, and glare up-Sun. The approximately ~9° solar elevation on Apollo 12's first EVA was the lowest during any Apollo EVA (see Table 1). Surveyor 3's is visible in Surveyor crater, surrounded by shadow.