BLINDED BY THE LIGHT: ILLUMINATION CONSIDERATIONS FOR ARTEMIS SITE SELECTION, TRAVERSE PLANNING, AND INSTRUMENT OPERATIONS.

N. E. Petro[1], E. M. Mazarico[1], J. D. Kendall[1,2], E. T. Wright[1,3], H. H. Schmitt[4], B. F. Feist[5], and D. B. Eppler[6], [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771, [2]UMBC at NASA Goddard, [3]USRA at NASA Goddard, [4]University of Wisconsin, P. O. Box 90730, Albuquerque, NM, [5]Jacobs Technology Inc. at JSC, [6]San Antonio Mountain Consulting. (Noah.E.Petro@nasa.gov)

Introduction: The lunar South Pole is host to some of the harshest illumination conditions in the Solar System. The 1.54° inclination of the Moon's rotational axis relative to the ecliptic pole [1, 2] ensures the South Polar surface region never exceeds a Sun angle of a few degrees. Depending on the specific landing site and local time of day, the Sun will always be within a few degrees of the horizon, making for a difficult viewing environment when looking up- or down-Sun. Based on Apollo missions 12 and 17, walking or driving up or down-Sun reduces mobility and visibility, and impedes maneuverability [e.g., 3]. Apollo experience [4-6] as well as FAA testing [7] suggest reduced visibility within ~25° of direct solar viewing. Here we discuss the impact of such constraints on surface operations and instruments operated during landed Artemis missions, implications for selecting a landing site, and the definition of traverses for such a mission.

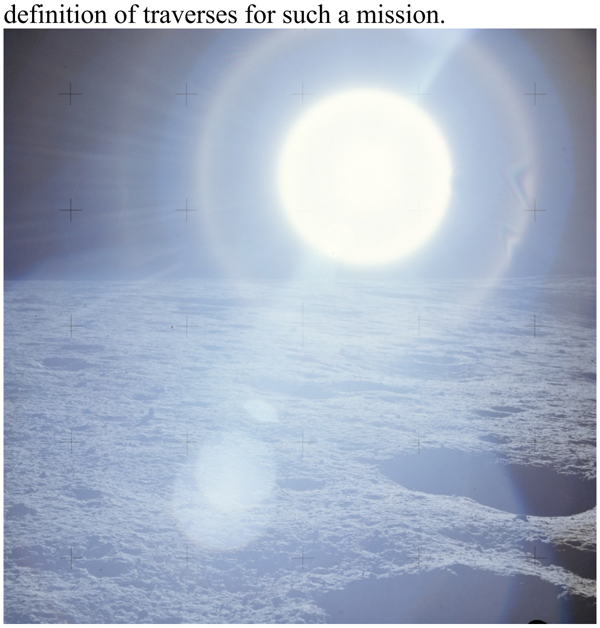

Figure 1. Photo from EVA 1 of Apollo 12, showing the glare in the up-Sun direction. The Sun was ~7.4° above the horizon at the start of the EVA, by EVA 2 the Sun was 15.8° above the horizon. AS12-46-6762.

Apollo Experience: The Apollo missions started their first EVAs when the Sun was between 5.1° and 14.8° above the horizon. With a landing poleward of 84°S, Artemis will explore the Moon in a completely different illumination regime than Apollo. Only the first EVA of Apollo 12 briefly approximated this condition, when the Sun was 7.4° above the horizon (Figure 1). For Artemis the Sun will only arc to a height above the horizon roughly equal to the number of degrees away from the South Pole.

The low-Sun angle at the start of EVA 1 of Apollo 12 contributed to the damaging of the color TV camera as well as forcing the commander to position themselves properly to be able to see without looking directly at the Sun while unloading the LM [8]. This EVA lasted 3 hours and 46 minutes and saw the crew traverse under 1 km, but never further than a few hundred meters from the LM. It is NASA's expectation that Artemis will, over several days, travel further and longer from the lander. In reviewing the Apollo 17 mission, Commander Cernan reported "…that any time you traveled east - particularly on that first day when the Sun was so low - you just couldn't see very well and just had to go slower." (see [3]). Both Apollo 17 crew members reported [9] that driving up-Sun was difficult but alleviated by blocking the Sun with a visor or gloved hand. Alternately driving down-Sun was challenging as shadows or less illuminated slopes were effectively lost as a tool to identify craters and boulders (Figure 2). On the other hand, back-scattered sunlight provided significant visual assistance in identifying distinct regolith components.

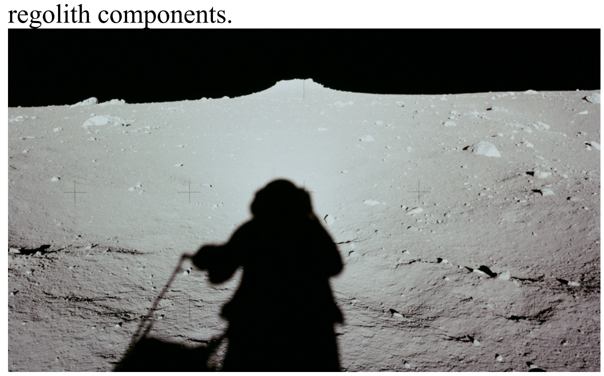

Figure 2. Cropped image from Apollo 12 viewing the down-Sun direction (AS12-46-6793), illustrating the loss of shadow detail when viewing along the 0° phase line.

Implications for Artemis: While there will be many factors in selecting landing sites for Artemis missions (*e.g.*, local slopes, boulders, access to areas in permanent shadow), the position of the Sun constantly at or near the horizon will be more important factor than during Apollo when developing traverses and identifying modes of operations for telescopes pointing near the horizon (*i.e.*, Earth observing instruments). In Figure 3, we illustrate an area near the South Pole with

50° up- and down-Sun regions identified around an example landing site. Planned traverses for the period represented in the image should maximize time traveling cross-Sun, keeping in mind that the position of the Sun will move ~12.2° per Earth day and that subsequent traverses will need to be planned using an updated position of the Sun on the horizon.

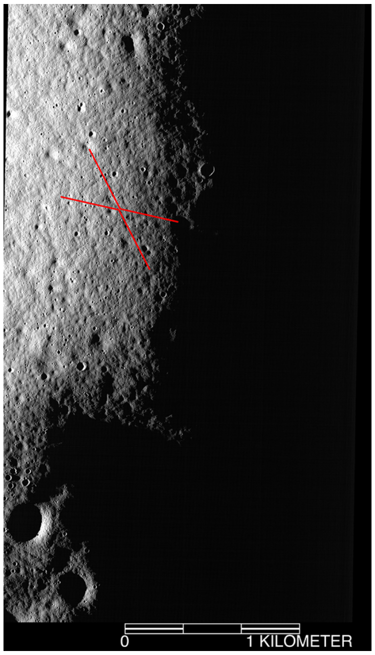

Figure 3. Example of a South Polar site (-88.7°, 123°) with 50° up- and down-Sun region marked. LROC NAC image M101336051R. While terrain in the cross-Sun viewing direction will be accessible, the 12.2° movement of the Sun each day across the horizon will shift this zone, requiring planning of traverses be dynamic and done with consideration of changing illumination conditions.

Mitigations: While we are not proposing that traverses only operate in the cross-Sun direction, it will likely reduce wear and tear on the crew and the possibility of rover damage if time traveling towards or away from the Sun is minimized. Apollo 17 utilized a tacking approach, minimizing the amount of time pointed up-Sun. Apollo crews utilized visors and Sunshades on their helmets or a gloved hand to block the Sun. However, in the case of Artemis, the Sun may be much closer to the horizon, making such mitigations challenging. The use of opaque visors may improve up-Sun viewing, at the cost of visibility of the surface and when viewing across-Sun. Sun visors, like the space suit generally, also need to be designed to reject dust that would jam their movement.

An additional possibility for surface operations is the inclusion of operations when the Sun is below the horizon and the full Earth is up, providing illumination akin to a period of civil twilight [4]. In this case the possibility of landing when the Sun is illuminating the landing site, but also operating in both sunlit and sun-dark but Earth-illuminated regions should be considered.

Instrument Implications: Sky-pointing instruments on the lunar surface will have to consider Sun-avoidance zones or other approaches to keep the Sun out of their telescopes. On Apollo 16, the UV telescope operated while in the shadow of the lunar module [10], an operational mode that will not support long-duration instrumentation during Artemis missions. Earth-viewing telescopes, for example, will need to avoid viewing a "New Earth" to keep the Sun out of the telescope field of view.

Conclusions: The promise of astronauts performing field geologic investigations of the lunar South Pole presents an incredible opportunity to advance lunar and Solar System science [11]. In the planning for Artemis field geology, it is critical to consider crew visibility during operations and factor the position of the Sun, which will always be low on the lunar horizon during their stay on the surface. Evaluation of Apollo experience [4] as well as tests for pilot visibility [7] suggest that the Sun, within ~25° of the line of sight, reduces the ability to discern detail and negatively impacts mobility (either on foot or in a rover). Additionally, the viewing conditions down-Sun reduce the ability of astronauts to identify hazards. Crew training should address low-Sun conditions, either *via* an arctic or snow-covered field site or at high-backscatter terrain of geologic interest for the short periods when the Sun is within a few degrees of the horizon. Artemis traverse planning should also reflect considerations for Sun visibility and will need to remain flexible given the Sun's movement over a ~6-day (or longer) landed mission.

References: [1] Williams, J.-P., et al., (2019) *Journal of Geophysical Research: Planets*, 124, 2505-2521. [2] Mazarico, E., et al., (2011) *Icarus*, 211, 1066-1081. [3] (http://apollo17.org?t=121:44:02). [4] Eppler, D. B., (1991) Lighting constraints on lunar surface operations, 91, 23014. [5] Eppler, D. B. and N. A. Budden, (2018), *Survive and Operate Through the Lunar Night Workshop*,Abst. [6] Heiken, G. and E. Jones, (2007) *On the Moon: The Apollo Journals*, 492 p. [7] Rogers, J., et al., (2015) Evaluation of Glare as a Hazard for General Aviation Pilots on Final Approach, [8] MSC, (1969) Apollo 12 Technical Crew Debriefing, [9] MSC, (1973) Apollo 17 Technical Crew Debriefing, [10] Carruthers, G. R. and T. Page, (1972) *Apollo 16 Preliminary Science Report*, Far UV Camera/Spectrograph, 13-11 - 13-14. [11] Schmitt, H. H., (2020) This workshop.