SHADOWING ON APOLLO 12 SOLAR CELLS AND POSSIBLE MOVEMENT OF THE ALSEP CENTRAL STATION.

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A fortuitous arrangement of a west-facing solar cell and a bracket on the Apollo 12 ALSEP (Apollo Lunar Surface Experiments Package) has allowed us to precisely determine the relative position of the Sun near sunset relative to the Apollo 12 central station over a period of nearly 8 years. The small bracket, mounted on the central station due west of the cell, casts a shadow on the cell near sunset, decreasing the output of the cell proportional to the area of shadow covering the cell. The pattern of shadowing by the bracket gives good agreement with the known change of solar azimuth on a yearly timescale, but the pattern gradually but constantly changed from year-to-year, in a manner inconsistent with the known and changing position of the Sun. After ruling out many possibilities, we believe the movement of the shadow may be a result of very slow, yet continuous (on a yearly timescale) movement of the entire central station itself on the lunar surface, corresponding to a rotation of roughly 0.4 degrees per year over the nearly 8 year period. The central station appears to have been located on a slight slope, so the motion may be gravity sliding/settling, the impetus coming from a background level of meteorite strikes, seismic activity, or thermal expansion and contraction leading to shifting.

The Apollo 12 Dust Detector comprised a small (3.6 x 3.2 x 4.1 cm) box with three 2 x 2 cm solar cells mounted on the outside, one facing east, one facing upwards, and one facing west (Figure 1, lower left). The dust detector was mounted on the southeast corner of the top of the ALSEP central station. A deployment bracket was mounted on top of the south edge of the station, approximately 30 cm due west of the dust detector (Figure 1, upper right). For a better view of the deployment bracket see Figure 2, which shows the Apollo 14 central station. The bracket and relative placement on the Apollo 14 central station are similar to Apollo 12. The detector measured the voltage output of each solar cell and transmitted the data back to Earth in the form of raw counts ranging from 0 (no output) to 255. Unfortunately we do not have the information necessary to translate these raw counts into actual voltage outputs and proceed with the caveat that raw counts are not sufficient for rigorous numerical analysis.

Figure 1 - Apollo 12 Dust Detector (lower left, with black solar cell) and deployment bracket (upper right, tallest structure). Image AS12-47-6927 taken from the northeast.

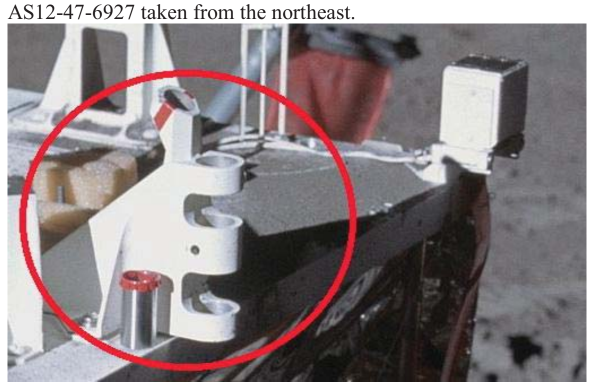

Figure 2 - Apollo 14 ALSEP central station, showing design and relative placement of the deployment bracket (circled) and the dust detector (upper right). Image AS14-67-9379.

We have determined that the upper two protrusions on the deployment bracket are casting shadows on the west facing solar cell prior to sunset (Figure 3), causing two distinct dips in the solar cell output (Figure 4). We have compared the values of the maximum (immediately before shadowing begins) and pre-sunset minimum at every sunset for which we have data available, these are shown in Figure 5. In cases where no minima were observed, the red and blue overlap, and are shown in blue.

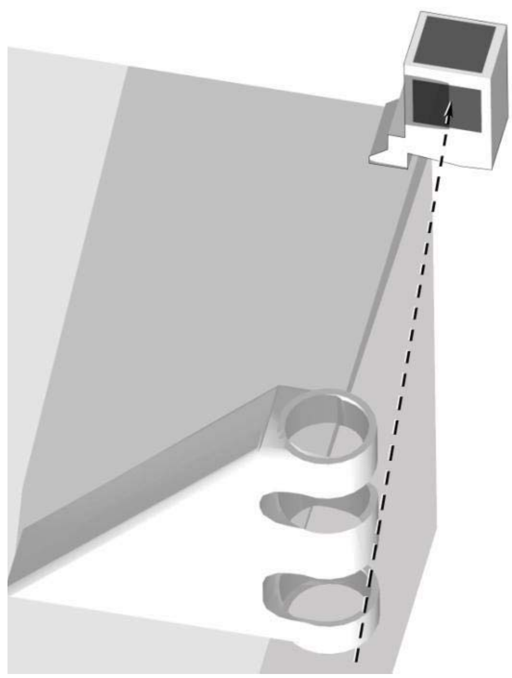

Figure 3 - Diagram showing geometry of shadowing on the solar cell. The shadow of the central protrusion on the bracket covers the cell from top to bottom at maximum shadowing, the solar cell output

at maximum shadowing is a function of the extent of the shadow across the cell, which depends on the position of the Sun (apparent solar azimuth).

The maximum values clearly show the variation in output due to change in Sun-Moon distance over the course of the year, and also the slow degradation (~ 1.7%/yr) of solar cells over the nearly 8 years in agreement with the initial work done by Bates and Fang (1992). The minimum values, indicating the unshadowed portion of the solar cell, also show a near-annual variation, but this is due to the change in apparent azimuth of the Sun at the ALSEP location which causes the shadows to fall differently on the solar cell at each sunset. The apparent azimuth at the near-equatorial (3 degrees south) location of the Apollo 12 station ranges over 3 degrees and stays within this 3 degree range from year to year. The key feature of the graph is the long-term change in the amount of shadowing. The cell appears to be completely shadowed in May, 1970 but only 30% shadowed (compared to the maximum unshadowed value) at the January 1977 minimum, despite the fact that the apparent solar azimuths are almost identical. The change follows a very linear pattern over the entire period of observation. The fact that the change is towards greater output from the cells eliminates the possibility of the solar cell degradation being responsible. We have considered changes to the electromics or solar cells over time, but cannot find a viable explanation for this effect.

We will discuss our results and the possibility that the change in shadowing may be due to a very slow movement of the ALSEP central station. We note that the maximum reading on the upper cell of the dust detector occurs roughly 6 - 8 hours before local noon, indicating that the cell, and hence the central station, is tilted to the east by 3 to 4 degrees. The north-south component of tilt cannot be estimated in this way, so this would represent the minimum slope on which the ALSEP was seated, and cannot give the direction of the slope. We can estimate the total long-term rotation of the central station, understanding that amount of rotation is uncertain due to use of raw counts and the possibility that solar cell output is not linearly proportional to shadowing on the solar cell. But the shadowing history example at sunset and the year-long variation shows shadowing is not pathologically disconnected from the output. Additionally, the variation over the first year is consistent with the expected change of roughly 3 degrees in solar azimuth. Given these sources of error, we find a total rotation over 6.6 years (using the yearly minimum values) of 2.6 degrees clockwise (dust detector moving south) would explain the change in shadowing, giving a rotation rate of roughly 0.4 degrees per year. The light gray line in figure 5 shows the expected output if no movement had occurred, using the first year as a baseline. The fact that the shadowing changes in a smooth fashion on a yearly time scale indicates a semi-continuous source of motion, possibly gravity sliding of the central station due to local meteorite impacts, seismic activity, or thermal variations.

One consequence of such motion on the lunar surface would be on planning for emplacement of future instruments, particularly those that must remain stationary over long periods of time. Such instruments should be precisely oriented initially, emplaced on near-horizontal surfaces, and strongly coupled to the lunar surface to prevent drift.

References

Bates, J.R., and P.H. Fang, Results of solar cell performance on lunar base derived from Apollo missions, Solar Energy Materials and Solar Cells, 26, 79-84, 1992.

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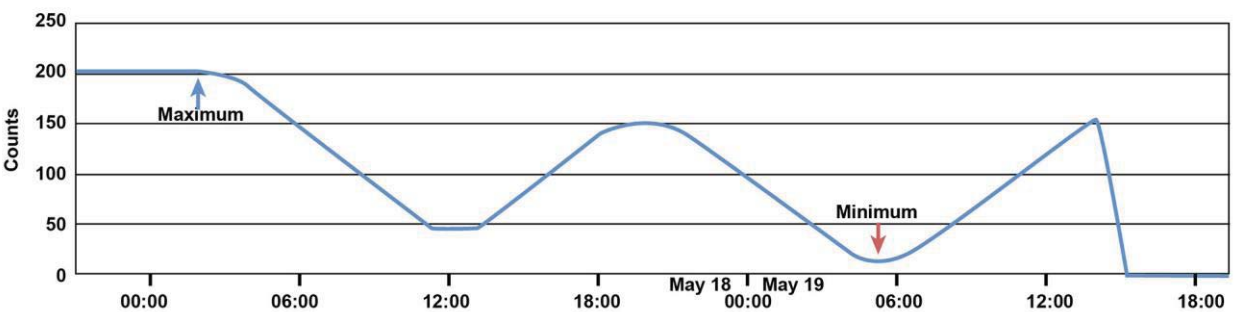

Figure 4 - Typical sunset output in raw counts of Apollo 12 west-facing solar cell showing maximum value before shadowing begins and minimum pre-sunset value (maximum shadowing from deployment bracket). Example for May 18-19, 1971.

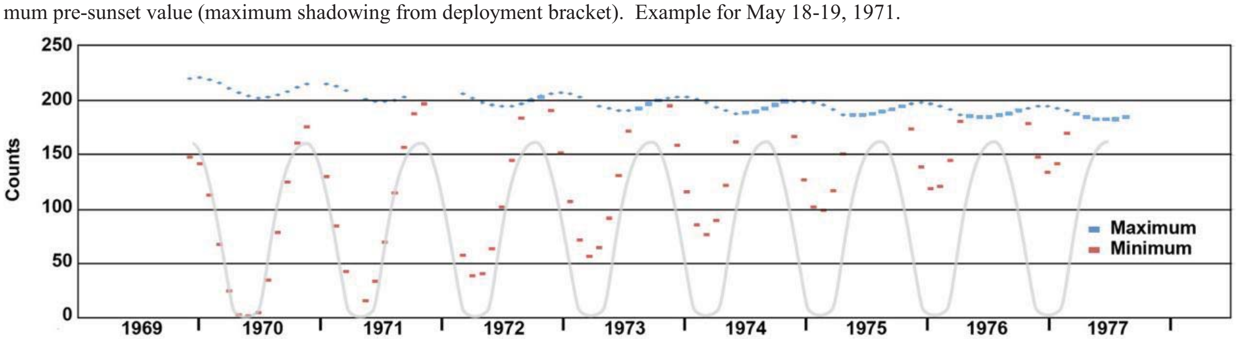

Figure 5 - Comparison of maximum (blue) and minimum (red) values for each lunation for all points for which data are available. The light gray curve shows the estimated solar cell output based on apparent solar azimuth over this period.