NASA/TM—2013-218068

“Kicking Up Some Dust”: An Experimental Investigation Relating Lunar Dust Erosive Wear to Solar Power Loss

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September 2013

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Prepared for the
68th Annual Meeting and Exhibition
sponsored by the Society of Tribologists and Lubrication Engineers (STLE)
Detroit, Michigan, May 5–9, 2013

National Aeronautics and
Space Administration

Glenn Research Center
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September 2013

Acknowledgments

The research in this work was supported by the NASA Graduate Student Researchers (GSRP) grant (NNX09AK96H). Additional funding for this work was supplied by the Alfred P. Sloan Foundation. The authors would like to gratefully acknowledge Richard Mondry, Jr. (NASA Glenn) for his help constructing the experimental rig on which the tests were performed. The authors would also like to gratefully acknowledge Philip Metzger (NASA Kennedy), James Gaier (NASA Glenn), Geoffrey Landis (NASA Glenn), and Anthony Colozza (NASA Glenn) for helpful and insightful discussions.

Level of Review: This material has been technically reviewed by technical management.

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Introduction

Wear was a critical problem caused by the sharp and jagged lunar dust particles during the Apollo missions of the 1960s and 1970s (Ref. 1). Lunar dust particles abraded the spacesuits of the Apollo astronauts and scratched their visors making it difficult to see. Additionally, evidence was collected that exhaust from retrograde rockets, fired by spacecraft landing on the Moon, accelerated lunar dust particles to high velocities causing erosive wear to nearby lunar structures. This evidence was provided by the Apollo 12 mission which landed approximately 155 m away from the Surveyor III lunar probe. The crew of Apollo 12 returned material coupons of the Surveyor III lunar probe back to Earth and they were analyzed by several investigators (Ref. 2). Most recently, Immer et al. (Ref. 3) analyzed the coupons and observed pitting and scouring that were indicative of erosive wear damage to the surface of the Surveyor III lunar probe. Understanding the effect that lunar dust erosive wear can have on lunar hardware is critical for future plans to return to the Moon. In particular, optical components such as solar concentrators, lenses, and mirrors, are uniquely susceptible to such damage. The change in surface roughness caused by lunar dust particle impingement on these components can affect their reflectance and transmittance resulting in severe losses in performance (Ref. 4). Solar concentrators are devices which collect sunlight over large areas and focus the light into smaller areas for the purposes of heating and energy production. In the current work, a laboratory-scale solar concentrator was subjected to erosive wear by the JSC-1AF lunar dust simulant. The concentrator was focused on a photovoltaic cell and the degradation in electrical current, due to the erosive wear, was measured.

Experimental Methods

Erosive wear tests were conducted in the Erosion Laboratory at the NASA Glenn Research Center. A TOPAS Solid Aerosol Generator was used to aerosolize the particles. A laboratory-scale solar concentrator was created by using a stainless-steel parabolic dish that was approximately 4 in. in diameter.

Aerosolized JSC-1AF lunar dust simulant particles were accelerated toward the solar concentrator by a secondary fast-moving air stream. Each quarter of the concentrator received 4 minutes of exposure to erosive wear. After being exposed to erosive wear, the concentrator was gently cleaned with a solvent. A dual-disc tool was used to determine that the average impact velocity of the particles in the current study was approximately 105 m/s. The 105 m/s impact velocity in the current study is moderate compared to the numerical predictions of Lane et al. who estimated particle velocities in excess of 1000 m/s (Ref. 5) in lunar conditions. The results in the current study represent a less-severe scenario than what may be experienced on the lunar surface. Even at the moderate velocities used in this study, these tests provide important data which can help to determine the susceptibility of lunar hardware to performance degradation when exposed to lunar dust erosive wear. A photovoltaic (PV) cell was used to determine the effectiveness of the solar concentrator by measuring the electrical current output before and after erosion. A schematic of the test setup is provided in Figure 1.

Results and Discussion

In this section, a quantitative comparison of the effect of erosive wear on the solar concentrator is presented. Portions of the concentrator were masked so that the effect of progressive exposure to lunar dust on the concentrator could be observed. Figure 2, an image of the fresh, non-eroded, concentrator is displayed along with a concentrator that has been half-eroded.

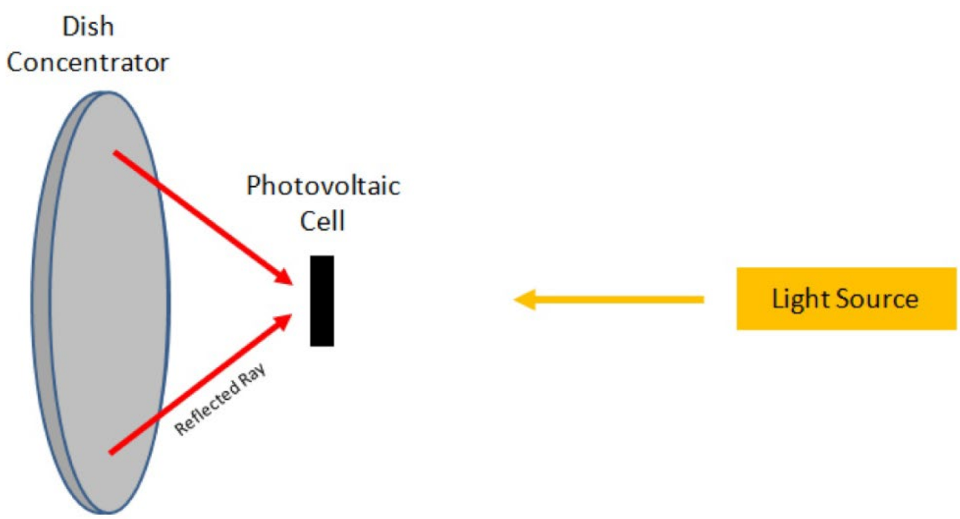
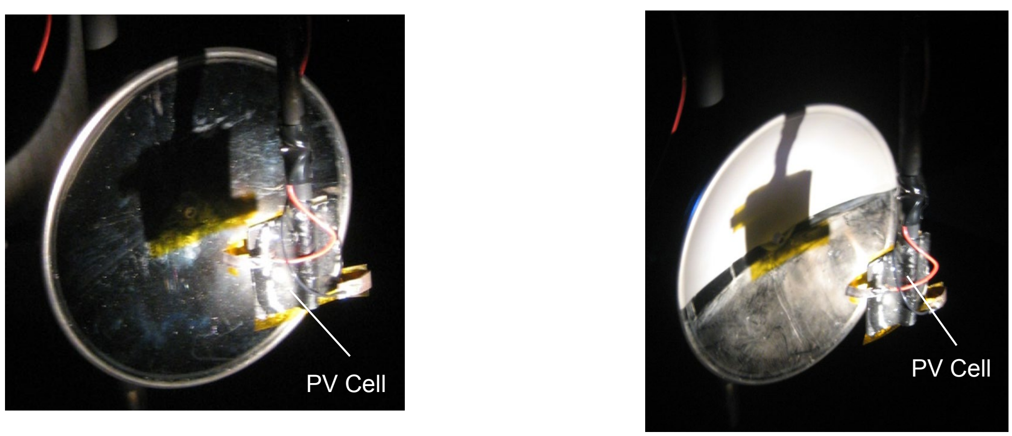


Figure 1.—Schematic of the concentrator and PV cell configuration.



(a) (b)

Figure 2.—Photographs displaying light reflected from the concentrator during test (a) fresh concentrator (b) half-eroded concentrator.

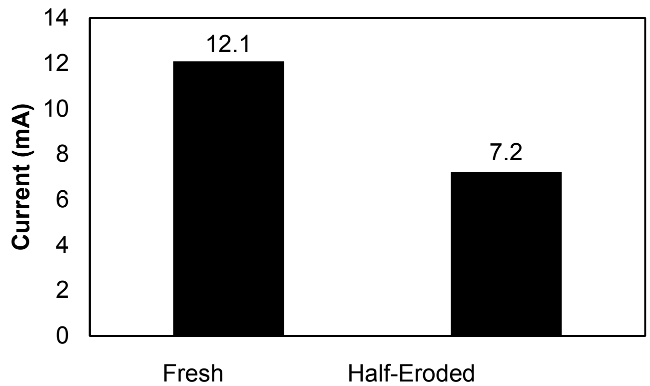


Figure 3.—Electric current output from PV cell for different areas of erosive wear exposure to the concentrator.

It can be seen in Figure 2, that the non-eroded concentrator reflects light more uniformly than the half-eroded concentrator. On the half-eroded concentrator (Figure 2(b)), the distinction between the eroded region and the non-eroded region is clear. It is believed that this distinction is evident because the reflectance from the non-eroded portion of the concentrator in Figure 2(b) is more specular in nature and directs most reflected light toward the PV cell. In contrast, the reflectance from the eroded portion of the concentrator is more diffuse and scatters incident light. This also explains why the eroded portion of the concentrator in Figure 2(b) is "bright" as diffuse reflectance directs more light toward the camera than the specular reflectance of the non-eroded region.

Electrical power production is higher when more incident light is reflected from the concentrator toward the PV cell. To understand the effects that the erosive wear can have on the efficiency of the concentrator, the current output for the two scenarios depicted in Figure 2 is compared in Figure 3. In Figure 3, it is shown that the current output from the non-eroded concentrator is 12.1 mA while the current from the eroded concentrator is 7.2 mA. This reduction in electrical current output represents a 40 percent decrease from the PV cell and would be significant for a future lunar mission.

Conclusion

In this work, erosive wear tests were conducted using the JSC-1AF lunar simulant to assess the potential for lunar dust erosion to degrade the performance of solar concentrators on the Moon. Qualitatively, the surface's optical properties changed as the eroded surface reflected light in a more diffuse manner instead of directing light toward to the photovoltaic (PV) cell. Quantitatively, it was clear that the eroded concentrator was able to produce significantly less electrical current when paired with the PV. The results from this study indicate the need for a better understanding of lunar dust erosive wear on critical surfaces of lunar hardware. The changes in electrical performance presented in this work were significant even for moderate impact velocities and short test durations. The high-velocity impacts in lunar conditions and long-term exposure to lunar dust erosive wear may significantly exacerbate the effect. It is believed that lunar temperatures, the lunar vacuum, and lunar surface chemistry may have an effect on this phenomenon and more research is needed in these areas. Understanding erosive wear damage on the Moon is critically important for optical surfaces, such as mirrors and lenses, and solar concentrators.

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REPORT DOCUMENTATION PAGE						*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01-09-2013	Technical Memorandum	

4. TITLE AND SUBTITLE "Kicking Up Some Dust": An Experimental Investigation Relating Lunar Dust Erosive Wear to Solar Power Loss	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Mpagazehe, Jeremiah, N.; Street, Kenneth, W., Jr.; Delgado, Irebert, R.; Higgs, C., Fred, III	**5d. PROJECT NUMBER**
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER WBS 647280.04.02.03
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191	**8. PERFORMING ORGANIZATION REPORT NUMBER** E-18744
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001	**10. SPONSORING/MONITOR'S ACRONYM(S)** NASA
	11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2013-218068

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited
Subject Categories: 12 and 91
Available electronically at http://www.sti.nasa.gov
This publication is available from the NASA Center for AeroSpace Information, 443-757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The exhaust from retrograde rockets fired by spacecraft landing on the Moon can accelerate lunar dust particles to high velocities. Information obtained from NASA's Apollo 12 mission confirmed that these high-speed dust particles can erode nearby structures. This erosive wear damage can affect the performance of optical components such as solar concentrators. Solar concentrators are objects which collect sunlight over large areas and focus the light into smaller areas for purposes such as heating and energy production. In this work, laboratory-scale solar concentrators were constructed and subjected to erosive wear by the JSC-1AF lunar dust simulant. The concentrators were focused on a photovoltaic cell and the degradation in electrical power due to the erosive wear was measured. It was observed that even moderate exposure to erosive wear from lunar dust simulant resulted in a 40 percent reduction in power production from the solar concentrators.

15. SUBJECT TERMS
Erosive wear; Energy production; Solar power

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** STI Help Desk (email:help@sti.nasa.gov)
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	UU	12	**19b. TELEPHONE NUMBER** *(include area code)* 443-757-5802