VI International Conference on Mathematics and its Applications in Science and Engineering
(ICMASE 2025)

VIBRATION-BASED REMOVAL OF VARIOUS MARTIAN DUST SIMULANTS FROM PHOTOYOLTAIC MODULES IN A LOW-COST SIMULATED MARTIAN ENVIRONMENT

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ABSTRACT

Solar energy is a crucial power source on Earth and for space exploration rovers. However, dust deposition can reduce solar panel power output by more than 50% on Earth [l], an average of 0.2% per Sol [2], and over 80% under simulated lunar conditions [3]. Traditional mitigation strategies such as electrostatic cleaning and coatings lose effectiveness under Martian conditions of low humidity and abrasive dust [4,5]. However, vibrational dust removal shows promise if the duration of vibration is optimized to avoid sensor damage [6]. Typical Martian simulation chambers fail to account for different gravitational conditions on both Mars and Earth. Since Martian gravity is a third of Earth's gravity, previous studies conducted by NASA have used walnut shell dust as a low-density simulant [7]. To investigate the performance of a vibrational system under realistic conditions, we designed a cost-effective experimental chamber simulating the Martian environment by combining vacuum conditions with rotation. Using this method, we increased gravitational acceleration by adding centripetal acceleration through rotation. While Martian gravity is lower than that of Earth, low-gravity simulation methods are inaccessible. Utilizing this increase in gravity, an exponential decay function was used to predict performance at Martian conditions.This device allowed the study of dust removal efficiency on solar panels at varying tilt angles $(0^\circ, 5^\circ, 10^\circ)$ and simulated gravity levels $(25, 35, 45\ RPM)$. True Martian dust is toxic and would behave differently on Earth compared to on Mars. Glass microbeads were used in this study to stand in for true Martian dust since they have the same density. This simulant underwent rotation in this chamber such that performance at a lower gravitational !eve! could be extrapolated. Walnut shell dust was the control simulant as it did not require rotation, as is already approximately a third of the density of true Martian dust. Restoration times required to recover 25% of original panel power output were recorded, alongside measurements of the power consumed by the dust removal system. Supporting the experimental work, a mathematical force-balance model was developed to describe dust partide acceleration resulting from the combined effects of gravitational, vibrational, frictional, and centripetal forces. The centripetal acceleration on a dust partide a was calculated in terms ofthe acceleration due to gravity g, the tilt angle ofthe solar panel 8, the vibrational intensity w, and the vibrational amplitude A in the equation. Scaling the extrapolated walnut shell durations by a factor of 2.9 aligned them with glass microbead results $(p > 0.05)$, validating chamber rotations as an effective means of gravitational simulation. The power consumed to clean rovers was derived by dividing the power needed to dean our panel by surface area of 5-inch by 7-inch panel and multiplying by the dust removal duration and surface area of the rover's solar panels. Calculations of power required for tilting and vibrating the test panel were scaled up using NASA specifications of rover solar panel areas. Results revealed

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that the In Sight mission (2018) would have allocated approximately 80.8% less ofthe maximum power for dust removal than Spirit/Opportunity (2003), reflecting improvements in panel efficiency over time. As panel efficiency improves in the future, our vibration dust removal will be more valuable to implement, as it requires a lower percentage of maximum power output. Limitations in this study include challenges in achieving 6-7 mbar pressure and vacuum loss during dust deposition. Future work should explore gyroscopic rotation for stability, improve pressure control, and refine dust deposition techniques. Other factors such as rotational behavior ofthe particles, collisions, and air resistance should be accounted for in future calculations.

***K*eywords** Dust mitigation · Solar panel cleaning · Martian environment · Power extrapolation · F orce-balance

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