LIFTING DUST ON MARS: RESULTS FROM THE INSIGHT SOLAR ARRAY CLEANING EXPERIMENTS.

M. Golombek[1], C. Charalambous[2], C. Newman[3], N. Williams[1], M. Baker[4], R. D. Lorenz[5], and W. B. Banerdt[1], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA., [2] Imperial College, London, [3]Aeolis Research, Chandler, AZ, [4]Smithsonian Institution, Washington, DC, [5]Johns Hopkins Applied Physics Laboratory, Laurel, MD.

Introduction: Lifting dust into suspension on Mars is difficult because the particles are small and the density of the atmosphere is low. Because very high wind speeds are needed to overcome the threshold friction needed to move micron size dust particles, the impact of saltating sand size particles, which occurs at lower wind speeds, has been invoked to lift dust particles into suspension [1]. The InSight (**In**terior Exploration using **S**eismic **I**nvestigations, **G**eodesy and **H**eat **T**ransport) mission performed the first semi-controlled in situ experiments on Mars that support sand impacting the surface as a means to lift dust into the atmosphere.

Background and Method: The InSight mission, a NASA Discovery Program lander to Mars [2], is powered by two solar arrays, each roughly 2.2 m in diameter. It also has an arm with a scoop that scraped and scooped soil. After two martian years on the surface, power produced by the solar arrays dropped by about 90% due to dust that accumulated on the spacecraft [3]. A variety of ideas were considered to remove the dust from the panels but most were not feasible, potentially harmful, or did not help (pulsing/shaking the arrays).

When soil was dumped on the tether from 45-55 cm height some of the sand was dispersed 0.5-2 m downwind with the amount of dispersion scaling with the wind speed (1-10 m/s). Volume estimates from before and after digital elevation models of the scoop and pile indicate that 15-25% of the sand in the scoop was entrained and dispersed by the wind during the dumps [4].

Soil dumped above the surface provides a means for the sand to be entrained and dispersed by the wind without having to overcome the threshold friction wind speed. The dispersion of particles is dependent on the atmospheric drag forces compared to gravity and the transport likely depends on particle size and was observed by Phoenix [5]. The rationale is that sand dumped on the lander deck would be dispersed sideways impacting the solar panel, kicking the dust into suspension, which would reduce the amount of dust on the panel and improve power production.

In order for this process to work individual sand grains must both kick the dust into suspension when they impact the surface and they must clean an area of dust that is larger than their diameter as the sand grain would likely eventually come to rest on the panel (reducing power production). Several lines of evidence argue that individual sand grains striking a dusty surface remove dust from a substantially larger area than their intrinsic area [6]. The estimates of soil volume dispersed suggest the layer of soil moved by the wind is less than one sand particle thick (assuming sand is ~140 μm in diameter as indicated by the thermal inertia, [7]). IDC images of individual 1-2 mm in diameter circular dark spots, indicate they were most likely produced by individual sand grains, and the area of the dark spot is of order 100 times larger than the area of a sand particle [8].

Solar Array Cleaning Experiments: Seven solar array cleaning experiments were done by dumping soil onto the lander deck with sand particles dispersed by the wind hitting the solar panel, kicking dust off the panel into suspension in the atmosphere [4]. The first solar array cleaning experiment was conducted on sol 884. A fairly full scoop of soil (~96 cm^3) was dumped on the northwest portion of the lander deck at ~11:40 LMST when strong winds were expected to be from the southeast with dispersion of soil expected onto the western solar panel. The dump of soil was from an elevation of about 35 cm above the lander deck. A portion of the solar array to the northwest of the dump site was visibly darkened (Fig. 1) and fitting an ellipse to this darkened area suggests soil was dispersed about 2 m towards the northwest. Soil dumped on the spacecraft panel shows a broad pile at least 30 cm across (e.g., Fig. 2).

During the time of the dump (11:40 and 11:42 local mean solar time), winds varied from 6-14 m/s, and were

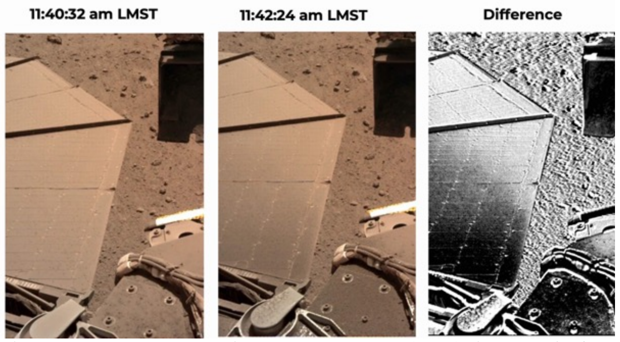

Fig. 1. Instrument Deployment Camera (IDC) images before (left) and after (middle) the main avalanche from the first dump of soil on the northwestern edge of the lander (on sol 884). Right image is the IDC differenced image [8] showing areas where the surface has been darkened from soil dumped on the lander deck and where dust has been removed on the west solar panel. For scale, the full diameter of the circular solar panel is 2.2 m.

from ~140°. The western solar array current increased by ~3% and produced a 4 W instantaneous increase in power at the time of the dump and the energy improved by 24 W hr sol^{-1} and produced a long-term improvement of 35 W hr sol^{-1}.

Table 1. InSight solar array cleaning experiments

Sol, Cleaning event #	Scoop volume cm^3	Wind speed Mode & range m/s	Wind direction °clockwise from north	Dispersion: length (m), direction	Portion on solar panel	Energy improvement W hr sol^{-1}
884 1st	96	10, 6-14	130-140	>~2 NW	All	24
897 2nd	49	10, 6-14	90 or 130	~1 W, NW	All	6
911 3rd	139	10, 4-14	160-170	~2-3 NNW	Third	6
939 4th	83	9, 6-12	140-150	~2-3 NNW	Little	3
1061 5th	152	14, 10-18	100-130	>~1 W	Most	15
1143 6th	125	1-2, 4-8	175, 60	Little SW	Some	7
1238 7th	50	N/A	N/A	Very Little	Very Little	0

Wind speed and direction are from where the winds are coming from

The second, third and fourth solar array cleaning experiments (sols 897, 911, and 939) were also done with soil dumped adjacent to the west solar array with winds of 9-10 m/s to the west and/or northwest (Table 1). Instantaneous power increased 1-2.5 W and energy improved 3-10 W hr sol^{-1} during each experiment. The experiments improved power sufficiently to keep the seismometer on during aphelion and conjunction when power was at a local minimum [4].

The fifth and sixth solar array cleaning experiments (sols 1061 and 1143) each improved the instantaneous power by 1-2.5 W and energy improved by 7-15 W hr sol^{-1}, which was sufficient to keep the seismometer on continuously through a seismically quiet period that was between sols 750 and 1200 (Table 1). The seventh, and final solar array cleaning experiment occurred on sol 1238 and was the last chance with sufficient power to support the scooping and dumping activity. This was also the first experiment to dump soil on the east side of the spacecraft deck with dispersion of soil expected onto the east solar array, but winds were expected to be low. A small scoop of soil was dumped, but there was no instantaneous change in current or power.

Altogether, the solar array cleaning campaign was able to increase the energy generation capacity of the lander by a total of ~80 W hr sol^{-1}, or ~20% of the energy output in that timeframe. This allowed the seismometer to remain powered on continuously throughout the low power period near aphelion and the seasonal seismic quiet period, which was between sols 750 and 1200. It is unlikely that any science operations would have been possible after ~sol 1200 (an additional 240 sols of operation) without this energy boost [4].

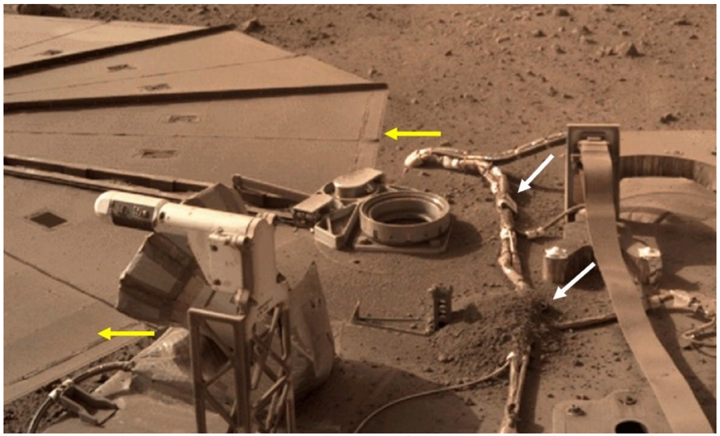

Fig. 2. IDC image acquired on sol 1143 after the sixth solar array cleaning experiment showing the accumulation of soil on the western spacecraft deck (white arrows) from the first six soil dumps and the darkening of the western solar array (yellow arrows) from the dispersion of soil during the dumps.

Science Observations. Taken together the results from the solar array cleaning experiments are the first semi-controlled experiments on Mars that directly address how dust enters into suspension via impact by sand sized grains. Sand, which makes up most of the soil, was dispersed by drag forces from the wind that at least partially overcame gravitational forces, when dumped from ~1.4 m over the surface. The majority of soil landed on the deck, but a portion (~16-25%) was dispersed by the wind, with higher winds dispersing particles several meters and lower winds dispersing the sand less (and very little in very low winds). Sand size particles that were dispersed impacted the solar panel, removing the dust and improving power generation. The area cleaned of dust is ~100 times the area of a sand particle, so that power improves even though the sand particle most likely remained on the panel. Repeat soil dumps that dispersed sand over the same part of the solar array did not show a decrease in cleaning, arguing that only a small fraction of the dust was removed during a cleaning attempt.

Because wind speeds decrease logarithmically towards the surface, winds at about 1 m above the surface near the lander deck would be expected to be higher than those at the surface. Nevertheless, no cleaning was observed in between dumps, even though piles of soil were available on the deck (Fig. 2), suggesting saltation was no more active than at the surface [8].

References: [1] Greeley, R. (2002) PSS, 50. [2] Banerdt W.B. et al. (2020) Nat. Geo. 13(3). [3] Lorenz et al. (2021] PSS 207. [4] Golombek M. et al. (2023) SSR. [5] Holstein-Rathlou C. et al. (2010) JGR 115, E00E18. [6] Charalambous C. et al. (2023) this issue. [7] Golombek M. et al. (2020) Nat. Comm. 11(1), 1014. [8] Charalambous C. et al. (2021) JGR 126(6).