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Martian airfall dust on smooth, inclined surfaces as observed on the Phoenix Mars Lander telltale mirror

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ABSTRACT

The telltale mirror, a smooth inclined surface raised over 1 m above the deck of the Phoenix Mars Lander, was observed by the Surface Stereo Imager (SSI) several times per sol during the Phoenix Mars Lander mission. These observations were combined with a radiative transfer model to determine the thickness of dust on the wind telltale mirror as a function of time. 239 telltale sequences were analyzed and dustiness was determined on a diurnal and seasonal basis. The thickness of accumulated dust did not follow any particular diurnal or seasonal trend. The dust thickness on the mirror over the mission was $0.82 \pm 0.39\ \mu\text{m}$, which suggests a similar thickness to the modal scattering particle diameter. This suggests that inclining a surface beyond the angle of repose and polishing it to remove surface imperfections is an effective way to mitigate the accumulation of dust to less than a micron over a wide range of meteorological conditions and could be beneficial for surfaces which can tolerate some dust but not thick accumulations, such as solar panels. However, such a surface will not remain completely dust free through this action alone and mechanical or electrical clearing must be employed to remove adhered dust if a pristine surface is required. The single-scattering phase function of the dust on the mirror was consistent with the single-scattering phase function of martian aerosol dust at 450 nm, suggesting that this result is inconsistent with models of the atmosphere which require vertically or horizontally separated components or broad size distributions to explain the scattering behavior of these aerosols in the blue. The single-scattering behavior of the dust on the mirror is also consistent with Hapke modeling of spherical particles. The presence of a monolayer of particles would tend to support the spherical conclusion: such particles would be most strongly adhered electrostatically.

1. Introduction

Understanding dust deposition on landed spacecraft on Mars is critical to estimating equipment degradation rates and lifetime. For solar-powered spacecraft, the rate of dust deposition also affects overall mission lifetime as the total power generated is a function of the dust accumulation on the solar panels (i.e. Drube et al., 2010, Landis and Jenkins, 1999, Haberle et al., 1993). Dust deposition also has applicability to settling rates of airborne dust on the planet more generally and allows for the estimation of burial rates of geomorphological features (e.g. Aharonson et al., 2003). Several studies of dust deposition have been undertaken at landing sites in the past. Values for the settling rate have varied from $0.034\ \mu\text{m sol}^{-1}$ at the Mars Pathfinder (MPF) landing site (Matijevic et al., 1997) to $0.065\ \mu\text{m sol}^{-1}$ averaged over a year at the Viking Lander 1 (VL1) landing site (Pollack et al., 1979). At the Phoenix Mars landing site (Smith et al., 2009), the calculated value for dust settling varied depending on the specific micro-environment with rates of $1.08 \pm 0.16\ \mu\text{m sol}^{-1}$ for the magnet rings and only $0.05 \pm 0.4\ \mu\text{m sol}^{-1}$ on non-magnetized areas of the deck (Drube et al., 2010).

Each of these measurements were made on large, flat, horizontal surfaces located reasonably close to the ground. In these environments, the ability of wind to affect the dust has been minimized. However, since scientific equipment often has protrusions which may be inclined to the horizontal and elevated into the wind, and inclined solar panels have been proposed/

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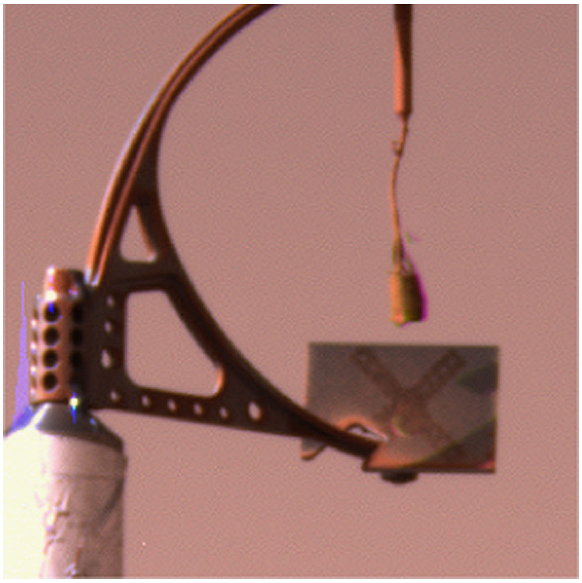

Fig. 1. The wind telltale, showing the orientation marker and its reflection (i.e. the "cross"), support system, bob and polished titanium mirror. The mirror is inclined such that it reflects the Zenith and shows deviations of the bob from the vertical. Note the significant dust accumulation on the Kevlar® fibers that connect the bob with the orientation marker. The rough structure of the fibers may encourage dust retention compared to the smooth mirror. The mirror itself appears somewhat speckled in terms of its accumulation of dust with greater amounts located in wind shadows near the support.

implemented for polar landers (Backes et al., 2000), it is important to understand the rates and patterns of dust settling that these types of surfaces might encounter. Unlike the fiducials and calibration targets on the Phoenix Mars Lander, as described by Drube et al. (2010), the telltale wind indicator (Gunnlaugsson et al., 2008; Fig. 1) sits atop the MET mast, over a meter above the lander deck and approximately two meters above the surface. The reflective mirror at the base is significantly inclined to the horizontal. Thus our study of the dust accumulated on this mirror and how the accumulated dust load varies on diurnal and seasonal time scales provides complimentary information to that obtained by Drube et al. (2010). Furthermore, the accumulation of dust on the Kevlar fibers that connect the Telltale Kapton cylinder to the Orientation Marker has been described (Holstein-Rathlou, 2011) and our results will be compared to this very different surface in an identical wind and dust environment.

2. Materials and methods

2.1. Telltale imaging and captured dataset

2.1.1. Dataset description

Unlike the images of the calibration targets used by Drube et al. (2010), which were captured by the Surface Stereo Imager (SSI) in 15 filters, most wind telltale images were captured in only one filter, R6, centered at 450 nm. This filter was chosen specifically to enhance the contrast of objects on the lander deck. A description of the SSI can be found in Lemmon et al. (2008) and the use of the SSI in capturing atmospheric image sequences is documented in Moores et al. (2010). Observation of the wind telltale was carried out with high frequency during the mission, as described in Section 2.1.2.

Telltale images come in two varieties with a changeover at sol 19 (Fig. 2). The early variety consists of 256×256 pixel subframes that allowed viewing of the entire Telltale apparatus including the top of the MET mast. By sol 19 sufficient statistics on the quality of image pointing had been obtained to allow a tighter subframing that, in turn, allowed a reduction in data volume for each individual image and an increase in the number of images in a sequence. The size of the subframe was reduced to 96 pixels wide by 208 pixels high, sufficient to capture the mirror and the Kapton-tape bob of the telltale that allowed detailed wind information to be extracted. This scheme worked very well until later in the mission when large excursions in temperature, particularly at night, caused some slight pointing errors of the SSI due to flexure in the SSI mast. Pointing for the SSI was towards the MET mast at an azimuthal angle of 235.7° and slightly upwards by 11.37° in the site frame.

The number of frames for each telltale sequence varies from 3 frames up to 100 frames depending on constraints. Generally, nighttime sequences, especially those requiring preheating of the SSI, and sequences early in the mission had fewer frames. Later in the mission an R7-filter frame was added to the start of the sequence as a spectral check on estimates of the dust fall-out rate. By sol 75, the typical telltale movie consisted of 32 frames in R6 (450 nm) with one frame of R7 (753 nm), referred to as a "baker's telltale". While this spectral information confirmed that the occluding material on the telltale mirror was dust, low contrast was observed at longer wavelengths for which the orientation marker and the zenith had similar intensities and the dust was more radiatively active.

Contrast for most image sequences is good. However, proper contrast proved challenging in the mid-afternoon when the sun would pass near the frame. This resulted in a decrease of perceived contrast between the telltale mirror and the reflection of the telltale orientation marker (cross) following on-board compression. This decrease started at 12:00 Local True Solar Time (LTST) with a worst-case time near 15:36 LTST and clearing into the evening hours. In addition to dust, frost condensed on the mirror at night (Holstein-Rathlou et al., 2010, 2011).

2.1.2. Temporal distribution

A total of 7449 R6 telltale frames were collected and analyzed as part of 283 sequences of which 239 sequences were of sufficient quality to be used in this work. Telltale sequences were collected for almost every sol of the mission and typically at more than one time of day. Efforts were made to improve the diurnal coverage with the result that most of the Martian day was covered on at least one sol by at least one telltale image every five minutes or better by the end of the mission. Overnight proved the most difficult time to collect data as the spacecraft was rarely awake due to power constraints. The specific temporal distribution of the data can be found in Holstein-Rathlou et al., 2010.

2.2. Calculation of telltale mirror dust loading

In contrast to the spectral method of Drube et al. (2010), analysis of the telltale must be completed based almost entirely upon a single filter. In order to extract information on dust, it is necessary to consider instead the contrast between the portion of the wind telltale mirror which views the zenith and the portion of the wind telltale mirror which views the orientation marker (referred to hereafter as the cross). Since both are reflections, they are equally covered by dust. Thus, by basing analysis on the contrast between the two reflections, it is possible to bypass the extensive analysis of the dust layer as described in other publications (e.g. Kinch et al., 2007).

2.2.1. Optical theory

As dust settles out of the atmosphere and lands on the telltale mirror, it will obscure the reflection of the sky at the zenith, and the reflection of the orientation marker. The perceived radiance from each reflection is a combination of reflected light attenuated