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An integrated laser anemometer and dust accumulator for studying wind-induced dust transport on Mars

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Abstract

Windborne dust is one of the most important and dynamic factors affecting the Martian surface and its atmosphere, yet there lacks a detailed physical understanding how it is transported. We present a miniature laser-based optoelectronic instrument for use on a Mars lander. It integrates sensors capable of quantifying important parameters needed for the understanding and modeling of dust transport on Mars, these include wind speed, wind direction, suspended dust concentration, dust deposition and removal rates as well as the electrification of the Martian dust. Dust electrification has been seen from experimental simulations to be of considerable importance to the processes of adhesion and cohesion, specifically prompting the formation of low mass density dust aggregates. Testing of this prototype instrument has been performed under simulated Martian conditions in a wind tunnel facility. The results and analysis of its functionality will be presented.

Keywords: Mars; Dust; Aerosol; Anemometer; Electrification

1. Introduction

One of the most active processes shaping the Martian surface and influencing the Martian atmosphere is the transport of granular material by the wind (Bell et al., 2000; Newman et al., 2005). Dust entraining events called 'dust devils' have been seen widely across Mars from orbit (Stanzel et al., 2005) and from the surface (Metzger et al., 1999; Ferri et al., 2003; Ringrose et al., 2003), yet they seem only to entrain dust (grains smaller than 63 μm) and not sand-sized grains (larger than 63 μm) (Greeley and Iversen, 1985; Greeley et al., 2004). This is unlike terrestrial dust devils and is not in agreement with the current models of dust entrainment on Mars. This indicates that the physical processes are not well understood (Renno et al., 1998; Ferri et al., 2003; Toigo et al., 2003).

In order to model the wind-induced transport of surface material (dust and sand) on Mars or perform more realistic laboratory simulations, it is necessary to obtain a more detailed knowledge of the physical nature of the Martian dust and the conditions of wind flow at the surface (Bertelsen et al., 2004; Merrison et al., 2002a). Specifically it would be desirable to quantify the wind velocity (speed and direction) and turbulence close to the surface and study the diurnal and seasonal cycles as well as characterize transient events such as dust devils or global dust storms.

Clearly determining the suspended dust concentration and the deposition/removal rate of dust are important factors for transport theory, but they are also of technical importance for the protection of robotic and possible human missions to Mars. The same is also true of the electrical properties of the Martian dust, about which practically nothing is known. In several simulation studies, the electrification of Martian analog dust and sand material has been observed (Sickafoose et al., 2001; Kraus et al., 2003). Such electrification affects strongly the binding of dust grains to surfaces and can cause the aggregation of dust into low-density (sand-sized) composites (Greeley, 1979; Merrison et al., 2004a). The entrainment and breakup of such dust aggregates has been suggested as a mechanism capable of resolving the

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apparently paradoxical transport of dust in Martian dust devils (Merrison et al., 2004a; Calle et al., 2004). Dust electrification could also be associated with atmospheric discharges (Farrell et al., 1999).

The size and mass density of the dust are crucially important parameters used in modeling the transport of dust from both the surface and through the atmosphere.

Current knowledge of dust grain size/shape and concentration is limited to light absorption and scattering observations integrated over the atmospheric column upon which model parameters have been extracted. The conclusions indicate that the Martian dust grains are slightly non-spherical with an average diameter of around 3 μm and the typical concentration appears to be around 1–10 cm^{-3} (Pollack et al., 1995; Smith and Lemmon, 1999; Tomasko et al., 1999; Lemmon et al., 2004).

The specific size (distribution) and mass of suspended grains close to the ground is not known.

Wind speed and direction have been measured on the Pathfinder and Viking missions (Schofield et al., 1997; Larsen et al., 2001) using 'hot wire' techniques in which the cooling efficiency of an electrically heated conducting film/wire has been measured (Seiff et al., 1997). This parameter is, however, made greatly less sensitive due to the low pressure on Mars, and factors such as the environmental temperature, gas pressure and composition will affect the measurements. Uncertainties in calibration and stability have made interpretation problematic. The same general problem affects other wind sensors proposed for use on Mars, such as mechanical anemometers and sonic anemometers. Laser anemometers, however, operate by measuring the velocity of suspended grains and therefore have the benefit of not being in contact with the fluid, i.e., they are insensitive to pressure, gas composition, temperature and so on. The most common type of instrument is the Laser Doppler Anemometer, which relies on the shift in frequency of reflected light due to the motion of grains. They are commercially available and widely used on Earth. They also have the great benefit, for use on Mars, of being capable of measuring the suspended dust concentration.

With the help of a unique Mars simulation wind tunnel facility at the Aarhus University (Merrison et al., 2002b), three separate instrument development programs have (and are) being carried out: (1) the study of wind flow and dust suspension (Merrison et al., 2004b), (2) quantifying the accumulation (deposition/removal) of dust (Gunnlaugsson et al., 2004) and (3) quantification of the electrical properties of the suspended dust (Merrison et al., 2004a). All three prototype instrument designs have utilized optoelectronics and have now been integrated into a single instrument design called a Laser Anemometer and Martian Dust Accumulator (LAMDA). As well as now allowing simultaneous measurement of these transport parameters at the same location, this new instrument prototype can perform the first in situ measurement of suspended dust electrification, and with temporal resolution. Also improving on previous measurement of wind velocity, the direction and wind speed can now be measured with full angular acceptance. By quantifying the dust accumulation on upward and downward facing surfaces, the processes of gravitational and wind-induced deposition can be distinguished, this is of importance in understanding dust transport mechanisms.

2. Instrument design and testing

The instrument contains six laser light sources, each consisting of a laser diode and a collimating lens. Three of the laser systems also contain specially designed/etched holographic beam pattern generators that convert the beam into a three-lined light intensity pattern. These three patterned laser beams converge on one side of the disc formed instrument (Fig. 1), the light scattered from this focal point is collected by a Fresnel lens onto a central photodiode detector giving a 'wind speed' signal (Merrison et al., 2004b). The three non-patterned laser beams are directed to the other side of the instrument. All six laser beams have a photodiode mounted beside them which collects light scattered by the laser beams as they pass through the instrument surface, giving a measurement of

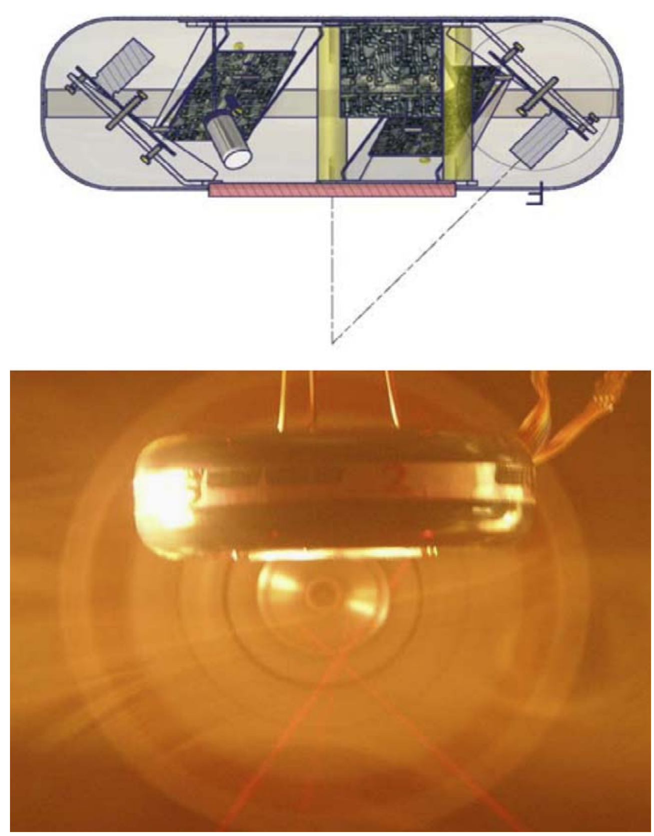

Fig. 1. Technical drawing of the integrated LAMDA instrument showing a side cross section (upper). Three of the six cylindrical light sources are shown mounted on circuit boards containing a photodetector for monitoring surface dust. Also shown is the downward facing Fresnel light collecting lens for anemometry. In the lower part is a photograph of the instrument being tested in the Aarhus wind tunnel under Martian simulated conditions.