DUST STUDY, TRANSPORT, AND ELECTROSTATIC REMOVAL FOR EXPLORATION MISSIONS: THE DUSTER PROJECT

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Context

Charged dust-like particles at the surface of the Moon:
⇒ Major environmental constraint during exploration missions

Effects of lunar dust on Extra-Vehicular Activity systems during the six Apollo missions that landed on the lunar surface [1]:

- external vision obscuration
- false instrument readings
- dust coating and contamination
- loss of traction, clogging of mechanisms
- abrasion
- thermal control problem
- One of the most serious effects: compromising astronaut health by irritation and inhalation of lunar dust

Jack Schmitt's spacesuit during Apollo 17 (courtesy of NASA).

Apollo crews reported that the dust gave off a distinctive, pungent odour suggesting that reactive volatiles reside on the surface of the dust particles.

Dust exposure and inhalation could have a range of toxic effects on human lunar explorers.

⇒ It is essential to characterise the properties of the dust particles present on the exploration sites and their transportation mechanisms.

Several dust mitigation techniques have been studied and developed, for instance:

- Clean up dust-contaminated equipment [3, 4, 5]
- Prevent the dust particles to fall and stick on optics [6]
- Clean the air inside exploration shelters [7]

⇒ All these mitigation techniques must be thoroughly analysed and validated by in situ measurements.

DUSTER project

- Overall objective:

Develop instrumentation and technologies to study dust particles and electrostatic transportation for planetary and small body exploration missions.

- Specifically:

Design, manufacture and test in a relevant environment a compact multi-sensor instrument for in situ analysis of dust properties (mechanical and electrical) and electrostatic transportation that can be used on a small lunar lander.

- The instrument includes:
  - A dust collector: electrodes biased at high potential (a few kV) to attract/collect dust particles, coupled to an electrometer
  - Langmuir probes
  - E-field probes
- Using this instrument the following parameters will be derived:
  - Charging level of dust as a function of the environmental parameters (illumination, plasma density and temperature)
  - (gravity + cohesive forces)/charge ratio distribution of dust layer

  ⇒ These two parameters will allow the determination of the electric field needed to attract/collect dust according to the environmental conditions (illumination, plasma density and temperature), which, among other applications, will allow designing electrostatic dust mitigation devices and dust sample collectors.

Principle

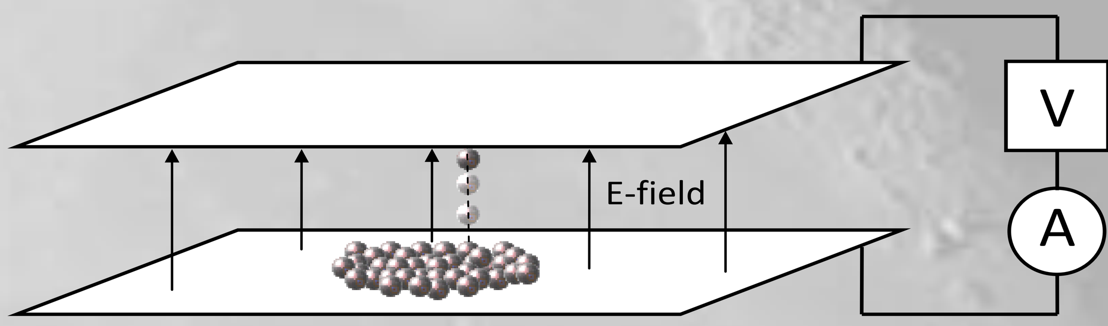
- Charged dust particles placed between two electrodes
- Voltage applied between these two electrodes
  ⇒ Creates an E-field that applies a force on the charged particles.
- When the voltage is high enough, the charged particles will move towards one of the electrodes (depending if the particles are positively or negatively charged) and ultimately will impact the electrode
- Measure the current resulting from the impact of the charged dust particles onto the electrodes

⇒ Quantify the amount of charged dust that has been moved (when the gravitational acceleration is known, and assuming a relation between dust size and charge).

- Gradually (step wise) increasing the potential between the electrodes

⇒ Mass distribution can be inferred (given some assumptions).

- This measurement principle is comparable to the Langmuir probe principle [8], where a probe placed in a plasma is biased to a positive or negative potential with respect to that plasma and attracts electrons and positive ions, respectively.



Measurement principle

Physical parameters

- For a layer of dust particles with given properties, the transport of those particles depends on several environmental parameters, namely:
  - Level of charging (which depends on UV and soft X-ray fluxes)
  - Gravity field
  - Applied E-field
  - Ambient plasma parameters (electron density and temperature)
- The charge distribution as a function of depth is unknown for a soil composed of dust particles such as the lunar regolith. It is assumed that the charge is carried by the uppermost layer of dust particles [9].
- Using the Gauss theorem, the charging at the surface of the dust layer can be described as follows:

$$Q_{surf} = \varepsilon_0 \varepsilon_r E_{ext} A_{surf} \quad \text{(eq. 1)}$$

where ε_0 and ε_r are the permittivity of free space and relative permittivity, respectively, E_{ext} is the external E-field above the surface of the dust layer and A_{surf} is the area of interest.

=> By measuring the electric field above the surface of the dust layer, the mean charging over the area of interest can be derived.

Measurements

- The UV and soft X-ray fluxes together with the surface gravity can be obtained by existing measurement data or reliable modelling.
- The E-field is known accurately because it is applied by the instrument itself.
- The remaining parameters that are needed to quantify dust charging and transportation are:

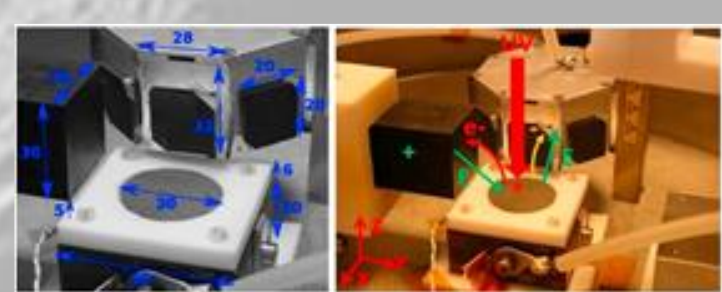
  1) Charging level => assessed by measuring the electric field above the dust layer with E-Field probes

  2) Ambient plasma density and temperature => measured with the Langmuir probe

  3) Current resulting from the impact of the dust particles onto the electrodes => measured by the dedicated front end that applies a given bias voltage (a few kV) to the dust electrodes and measures the resulting current.
- The solar illumination dependence of the charging properties of the dust will be studied by performing potential measurements
  1) as function of solar zenith angle
  2) across light/shadow terminator

Laboratory test and validation

- The existing dedicated measurement facility "dust regolith or particles" (DROP) at ONERA will be used to measure:
  - The E-field needed to move the charged grains
  - The current resulting from the impact of the charged grains onto the dust electrodes
  - The electric field at the surface of the dust layer
- DROP facility: cylindrical tank of dimension 40 × 40 cm covered with a hemispherical cap. It includes a vacuum ultraviolet deuterium lamp.
- DROP will be upgraded to allow measuring the current resulting from the impact of the charged grains onto the dust electrodes.
- This current, which is a proxy for dust transportation, will be compared to the output of an existing optical detection method [10].



Left: Experimental setup (dimensions in mm). Right: Expected relative charging of surface, orientation of the electric field E, and particle trajectories (electrons and dusts).

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