Research Needs in Electrostatics for Lunar and Mars Space Missions

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The new space exploratory vision announced by President Bush on January 14, 2004, initiated new activities at the National Science and Space Administration (NASA) for human space missions to further explore our solar system. NASA is undertaking Lunar exploration to support sustained human and robotic exploration of Mars and beyond. A series of robotic missions to the Moon by 2008 to prepare for human exploration as early as 2015 but no later than 2020 are anticipated. In a similar way, missions to the Moon and Mars are being planned in Europe, Japan and Russia. These space missions will require international participation to solve problems in a number of important technological areas where research is needed, including biomedical risk mitigation as well as life support and habitability on the surface of Mars.

Mitigation of dust hazards is one of the most important problems to be resolved for both Lunar and Mars missions. Both Lunar and Martian regolith are unique materials and completely different from the terrestrial soils that we are exposed to on earth. The total absence of water and an atmosphere on the moon and the formation of soil and fine dust by micrometeorite impacts over billions of years resulted in a layer of soil with unique properties. The soil is primarily basaltic in composition with a high glass concentration. The depth of the soil layer varies from a few meters in the mare areas (dark areas on the Lunar near side) to tens of meters in the highland areas (the lighter mountainous areas) and the particle size distribution of this dust layer varies widely with a major mass fraction less than 10μm in diameter.

The hard soil from the moon which has been extensively studied by several researchers showed clearly unique properties of Lunar soil. Apollo astronauts became aware of the potentially serious threat to crew health and mission hardware that can be caused by the lunar dust. As reported by McKay and Carrier the mass fraction of the lunar dust with particle diameter smaller than 20μm probably represents up to 30% of the total mass of regolith. Apollo astronaut Dr. Harrison Schmidt reported that these fine dust particles were clinging to the Extra Vehicular Activity (EVA) suits and to the visors and were limiting the activity on the surface of the moon. The dust particles that were transported with the EVA suits into the lunar module floated throughout the cabin. Crews inhaled the dust particles and noted that they smelled like gun smoke, caused a chocking sensation in the throat and eye irritation. In addition, some of the mechanical systems were not functioning well because of the dust deposition. It appeared that the dust particles are highly charged electrostatically and Dr. Schmidt noted that future successful Lunar missions will require appropriate dust mitigation technology for protecting astronauts from inhaling toxic particles and mission's life supporting equipment from contamination with the dust particles.

Martian Environment

Mars also does not have a planet-wide magnetosphere that covers the entire surface although there are networks of magnetic loops with magnetic fields of the order of 0.5 Gauss that deflect the incoming charge particles from the areas coming from the magnetic field to those areas that lack magnetic field. The radiation level of charged particles in the non-magnetic areas can be grater than 2 x 10^6 rads. Extended robotic and human missions to Mars have high probability for encountering with dust devils and global dust storms. Windblown dusts on Mars have higher velocities than those commonly observed on earth therefore the high speed movements of the dust particles will become a major hazard to EVA suits, vehicles, filtration systems and solar panels. These particles are expected to be penetrating to accessible surfaces of exposed equipment since they are both adhesive and abrasive, considerable damage is expected from these dust particles.

CHARACTERIZATION OF DUST PROPERTIES ON MOON AND MARS

Although samples have been returned from the Moon and their mineralogy has been studied in detail, there have been no in-situ studies on particle size and particle charge distribution on the Moon. From Mars, no samples have been returned so far. Therefore, our knowledge on dust composition and particle size is based on remote sensing and instrument missions. A detailed characterization of particle size and charge distribution is not available to date. In order to understand dust deposition, dust adhesion and health hazards, these properties need to be characterized.

An instrument for the measurement of particle size and charge distribution (E-SPART) based on Laser Doppler Velocimetry (LDV) is available for operation under Earth conditions. For operation under Martian conditions, a Dust Particle Analyzer (DPA) is currently being developed. On the surface of the Moon, the lack of an atmosphere makes it impossible to operate the Dust Particle Analyzer in its current design. It is necessary to adapt the technique to this environment.

For in-situ measurement of dust properties on the surface of the Moon, a Dust Particle Analyzer consisting of a sealed canister where the relaxation chamber is filled with CO_2 and a robotic arm is used to sample dust and deposit it through an airlock mechanism into the chamber is proposed.

CONTINUOUS DUST MONITORING IN THE HUMAN HABITAT

During stays on the surface of Moon and Mars, astronauts will periodically leave the habitat and return after completion of outside missions wearing EVA suits. It has been found during the Apollo missions to the Moon that Moon dust adheres extremely well to the surface of the EVA suits. Although the suits are taken off in an airlock, some dust is typically introduced into the habitat. In order to ensure the health of the flight crew, dust levels in the habitat need to be monitored on a continuous basis. We propose to develop a miniaturized version of the Dust Particle Analyzer for continuous operation in the capsule.

Health Hazards due to Moon and Mars Dust Inhalation

The presence of large amounts of dust on the surfaces of Mars and Moon can pose a serious health hazard to flight crews. Inhalation of silica dust particles on Earth results in known diseases of the lung such as silicosis, coal miner's lung. etc.

Dust and rocks from the surface of the Moon have been returned to Earth during the Apollo missions and the materials have been extensively characterized. However, it has to be noted that some of the properties of Moon dust that make it particularly harmful may not have been preserved. Due to the lack of a gaseous atmosphere and of water, Moon materials do not experience the weathering processes known on earth. Also, due to the lack of atmospheric oxygen, iron can exist in its unoxidized form. The major soil formation process on the Moon is the impact of micrometeorites. Fine particles of Moon dust are therefore characterized by freshly exposed silica surfaces, which are very active, the presence of elemental iron and a large glass fraction in the dust. These properties make Moon dust extremely dangerous for humans. A significant fraction of Moon dust is in the size range below 20 μm, which can easily be inhaled and deposited in the deeped regions of the lung. In order to better understand the health hazards due to Moon dust, experimental studies both in-situ and on Earth are needed.

For Mars, the situation is even more difficult, since samples have not been returned. Experimental studies there fore depend on the use of Mars dust simulant. Typically, a volcanic ash from Hawaii with similar spectral properties as observed on the surface of Mars is used (JSC-Mars1).

Self-Cleaning EVA Suits

The transition from the protected habitat to the largely unknown environment on the surface of Moon or Mars is a critical step in any manned space mission and measures to protect the crew need to be taken. During the Apollo missions, astronauts were surprised how well Moon dust would adhere to their EVA suits and how much wear and tear the impact of dust particles caused. It was observed that the three missions conducted outside the capsule took the EVA suits to the limit. Pressure drops due to fabric wear was observed as well as wear in the joints. Upon entering into the habitat, cleaning of the suits was found to be difficult and took up a considerable amount of precious time. Some dust was carried from the airlock into the chamber causing throat and eye irritation.

For future missions, an integrated self-cleaning system needs to be developed to improve the cleaning. We propose a system based on the electrodynamic screen concept to remove dust from EVA suits. The screen consists of a system of parallel conducting electrodes to be incorporated into the layers of the EVA suit. Upon energizing of a connected AC source, a field is built up between the electrodes and adherent dust particles experience a force that removes them from the surface of the suit. Alternatively, the screen could be continuously energized to prevent deposition of dust on the surface, or only be energized upon re-entry into the airlock to assist in the cleaning process.

Self-Cleaning Optical Windows and Camera Ports

During the Apollo missions it was noted, that windows, visors and camera ports were soon obscured by adherent Moon dust. Cleaning efforts resulted in surface scratches which further obscured the view. In order to keep critical surfaces clean and facilitate the cleaning process, an electrodynamic screen that can be applied as a clear coating with embedded transparent electrodes is currently being developed. The screen consists of a system of parallel electrodes fabricated by photolithographic patterning and etching from a deposited Indium-Tin-Oxide (ITO) film, which are connected to an AC power source. Deposited dust particles on the surface of the screen can be removed by energizing the screen. The feasibility of the concept has been demonstrated in a prototype. Typical cleaning efficiencies are in the range of 80-90%. Further experiments including variations of electrode geometry, electrode shape, number of phases and signal shape are currently under way to optimize the screen.

DUST-REPELLING OPTICAL MIRRORS

Optical mirrors can also be adversely affected by dust deposition. Contrary to optical windows and camera ports, an electrodynamic screen in the form of a coating can not be applied without interfering with the mirror function. We propose, to install a free-standing metallic electrodynamic screen in front of the mirror to prevent dust from settling on the mirror surface.

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