THE CHALLENGE OF THE MARTIAN SURFACE ENVIRONMENT: A MATERIAL ENGINEER'S PERSPECTIVE

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The space environment in general is one of the most challenging imaginable and impacts the operation of spacecraft as well as activities and scientific experiments that are carried out from a spacecraft platform. If not considered and mitigated appropriately such effects can severely affect a space mission's effectiveness, possibly resulting in the failure of a particular subsystem or even an entire mission. Studies by the National Aeronautics and Space Administration (NASA) and the United States Air Force (USAF) have concluded that 25% of all spacecraft failures are related to interactions with the space environment [1]. Subsequently the space environment strongly influences the size, weight, complexity and cost of operational space systems and can place various technical limitations upon a spacecraft's design and operating modes.

As humans seek to explore our solar system they will eventually arrive on the martian surface and will be required to survive there for extended periods as they complete their mission objectives and until such time as a return to Earth is possible. The principal challenges of the martian surface environment include its atmospheric composition, the presence of oxidants and other mechanisms for chemical deterioration, martian dust, the radiation environment and temperature variations as well as challenges common to all aspects of the space environment such as galactic cosmic rays and micrometeoroids.

The martian atmosphere primarily contains carbon dioxide with trace quantities of N_2, Ar, O_2 , CO and other species. The atmospheric pressure on the surface of Mars is less than $1/100^{th}$ of that experienced on Earth and intense photochemical activity is present as a result of this low density atmosphere and the atmosphere's transparency to solar ultraviolet radiation. Martian soil is extremely oxidizing with oxidants, alkalis, alkalines, superoxides and ozonides present [2, 3]. Hydrogen peroxide (H_2O_2) is of particular concern as it is a key component of the lower atmosphere chemistry, with concentrations of between 10^{-9} and 2 % by weight present [4]. At such concentrations H_2O_2 can condense onto soil grains and airborne dust [3] and may pose a hazard to spacecraft components and surfaces particularly after long exposure times.

Observations of Mars from orbit and from landers on the surface have shown that finely grained material forms dunes and covers local surfaces. Martian dust is porous and has a low cohesion making it similar in consistency to flour and therefore easily transported by the martian wind [4]. Aeolian processes, particularly dust storms, occur on a global scale on Mars as a result of large variations in the global atmospheric pressure. Local dust storms occur in the tropics and typically involve winds up to 100 km/hr. Global dust storms, which do not always occur annually, last for approximately one or two months and leave particles of dust lofted up to altitudes of 50 km [2, 4]. They can also result in attenuation of the total solar flux leading to a reduction in the visible range of up to a factor of 50 [5]. Martian dust is one of the greatest hazards to landers, rovers and other spacecraft on Mars as it can cause damage to and result in malfunction of optical systems, mechanical parts, environmental control systems, windows and other surfaces [2, 4-7]. In addition, the inhalation of martian dust and the cessation of surface operations, as a result of dust storms, could have a significant impact upon the health and psychology of crews working on the surface of Mars in the future.

The low density martian atmosphere is transparent to solar ultraviolet radiation. Coupled with Mars' lack of effective magnetic field this leaves the surface exposed to a substantial portion of the radiation received from space. The radiation climate on the surface of Mars is composed of charged particles from the Sun and other galactic sources. Sadly, no radiation measurements have been taken on the surface of Mars as yet. However the MARIE experiment aboard the 2001 Mars Odyssey Orbiter has given new insights into the prevalence of galactic cosmic rays and solar particle events in martian orbit. The mass shielding from the martian atmosphere at the surface is 16 g/cm^3 (compared to 1000 g/cm^3 for Earth) and subsequently the surface doses on Mars caused by galactic cosmic rays are about 100 times higher than on Earth. Charged particles from the Sun, expelled during solar particle events, reach the martian surface and consist of mainly protons and neutrons and some helium and heavier ions which have the potential to degrade materials, electronic components and impact on human health. The solar flux at Mars is approximately 43% of that received in earth orbit [8], but Mars' thin CO_2 atmosphere is not as effective at shielding its planet as Earth's ozone layer and subsequently ultraviolet radiation down to wavelengths of 195 nm reaches the martian surface. Unlike on Earth, Mars's surface is subjected to UV-C radiation emitted by the Sun which can pose unique challenges for certain materials such enhanced photodegradation of polymers.

Thermal cycling is also of concern on Mars with temperatures on the surface generally varying between -90º C to -30º C [5]. At the south pole of Mars the temperature can drop to as low as -110º C and at the equator in the middle of summer mid-day temperatures can sometimes rise to 20º C in localised areas [2]. Such large temperature variations can, for example, lead to structural deformation of components from expansion and contraction cycles and result in permanent equipment damage.

Micrometeoroid impacts are likely to be rare on the surface of Mars but not impossible. Such hypervelocity impacts can obviously cause physical damage to a spacecraft and equipment but also can lead to the erosion of surfaces, changes in thermal properties and the liberation of particles which could then contaminate sensitive surfaces. Furthermore, as particles vaporise upon impact there is evidence suggesting that electric charging takes place. This can generate electromagnetic interference capable of interfering with sensitive instruments and electronic circuits [1].

This presentation will review the challenges outlined above from a material engineer's perspective. Reference will be made to the impact of the martian surface environment on materials selection and its influence on the design of martian surface equipment, living quarters and the like. The effect of the surface environment upon the activities of crewed missions to Mars will also be discussed.

References

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