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ENVIRONMENTAL INTERACTIONS IN SPACE EXPLORATION: ANNOUNCEMENT OF THE FORMATION OF AN ENVIRONMENTAL INTERACTIONS WORKING GROUP

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INTRODUCTION

With the advent of the Space Exploration Initiative, as mandated by the President of the United States in his Twentieth Anniversary speech commemorating the first Moon landing, the possibility of designing and using systems on scales not heretofore attempted presents exciting new challenges in systems design and space science. The environments addressed by the Space Exploration Initiative include the surfaces of the Moon and Mars, as well as the varied plasma and field environments which will be encountered by humans and cargo traveling to these destinations from Earth or from low Earth orbit. It is fully expected that in order for systems designers to take into account the environmental characteristics for which they are designing they will need to understand the interaction mechanisms their systems will encounter and be able to model these mechanisms from the earliest conceptual design stages through design completion.

To catalog and understand the environmental interactions for the Exploration Initiative and to establish robotic precursor mission requirements for the Moon and Mars, an Environmental Interactions Working Group has been established as part of the Robotic Missions Working Group. Table I shows an organizational chart of the Robotic Missions Working Group and its two subgroups and table II provides a listing of the other working groups involved with the Engineering Requirements Subgroup to date. The Environmental Interactions Working Group, cochaired by Joe Kolecki and Barry Hillard of NASA Lewis, draws its membership from a broad scope of disciplines. The current paper describes the working group and gives an update of its current activities. The working group charter and operation are reviewed, background information on the environmental interactions and their characteristics as presently understood is offered, and the current status of the group's activities is presented along with anticipations for the future.

BACKGROUND

Space system/environmental interactions comprise a set of phenomena which occur when a system is placed in an environment whose local characteristics are such that the system and the environment are somehow able to exchange "information" and thereby influence or modify each other. Put another way, one can imagine the various environments of concern each to be characterized by some parameter set (like an Earth Standard Atmosphere model) and likewise for the various systems. An environmental interaction is what occurs when one takes a system parameter set from shelf A and an environment parameter set from shelf B, places them into a sealed container, and shakes well. The objective of any environmental interactions study team is to classify, prioritize, and model interactions, to advocate and/or conduct all necessary validating experiments, whether in space or on the laboratory, and to place the best possible user friendly codes and/or design guideline documents possible into the hands of systems designers so they can optimize their systems to the environments in which they must function from the earliest design stages through to completion and use.

This type of work is already being carried out in a number of discipline areas, some of which have been ongoing for a considerable time. These areas include radiation effects, having to do with particles and fields; collision effects, having to do with micrometeoroid and orbital debris; effects connected with dusty plasmas, like those found on the Moon or in the vicinity of comet nuclei; plasma and spacecraft charging effects; chemical processes; Martian eolian processes; and temperature cycling effects. Historically, systems which have been impacted by interactions with their local environments include the "big" missions systems such as those associated with Apollo, Viking, and the planetary and cometary probes of the past few decades, and the geostationary satellites which, from the first, displayed anomalous behavior most readily accounted for by charge/discharge phenomena associated with the complex and highly variable plasma and field environment at geostationary altitude. The space environment, in general, is dominated by plasmas and fields with a wide range of energies and other physical characteristics. Electrical coupling phenomena, which abound in all the known plasma regimes, depend sensitively on such parameters as local particle densities and temperatures. In low Earth orbit, the Space Shuttle has exhibited an interaction phenomena known as Shuttle glow, which is caused by chemical interactions of various species taking place on or near Shuttle surfaces.

The Space Station, whose size and complexity have led to a reconsideration of environmental interactions in LEO, has also been the subject of study in the area of plasma interactions, particularly with regard to grounding its solar arrays to the station structure. The type of problem considered herein involves developing a grounding scheme to minimize both the potential differences between the structure and the local plasma and the voltage excursions which accompany such events as thruster firings or gas dumps. Under "proper" conditions, as when neutral gases discharged near the Space Station become partially ionized by ambient energetic electrons and form an electrical "bridge" to the LEO environment, these excursions may be considerable, on the order of >100 V with ampere-level currents in the structure. Avoidance of such phenomena is desirable.

Previously the evolution in our knowledge of environmental interactions has been driven by the growth and variety of space infrastructure elements placed in Earth orbit and elsewhere. Systems of increasing size and complexity and the placement of such systems in active new environmental regimes have repeatedly necessitated developing new interactions knowledge and system design guidelines. The United States Space Program, which began with suborbital and Earth orbital missions, reached a peak with Apollo, Skylab, and the Space Shuttle. Now the Space Program looks ahead to the President's Exploration Initiative, which is orders of magnitude larger than anything attempted in space date. Its ultimate objectives are permanent human settlement of the Moon and human travel to Mars. Therefore, our understanding of environmental interactions must continue to grow to meet these future challenges.

We know from Apollo and its precursors that lunar dust plays an important role in human and systems interactions with the Moon. Lunar dust physics is dominated by electrodynamic forces and presents designers with a variety of contamination issues. Surfaces coated with lunar dust may be expected to experience variations in optical, thermal, and dielectric properties. These variations, in turn, will effect instrument operation, system coupling with the environment, and system component-to-component coupling. Physically, the Moon is not a totally inert body without detectable changes; a variety of dynamic processes certainly do occur on the Moon and have been observed from both the Earth and space. The horizon glow is a natural lunar process in which fine surface dust is suspended from meter to kilometer heights near the morning terminator. While the cause of the dust suspension remains a question, the occurrence of such a phenomenon suggests that lunar dust may be redistributed from the surface onto artificial structures. Impact phenomena also occur from time to time and inject material into near lunar space. This material may travel many miles before settling again. Some idea of the dust interaction severity (or lack thereof) may be gained from the experimental packages left behind by the Apollo astronauts. These packages, which have stood undisturbed on the lunar surface since the last Apollo mission, can give some idea of just how much these and other naturally occurring dynamic processes on the Moon will effect manmade systems. The data from the Apollo experimental packages may not be sufficient in and of themselves; however, the wide scale presence of permanent human activity, with construction of facilities, continuous motion across the lunar surface, periodic landings and liftoffs, generation and distribution of electrical power, venting of gases, and outgasing of materials and/or wastes, will produce considerable additional disturbances to the lunar environment, over and above the natural processes. These disturbances will greatly enhance the mobility of lunar dust contaminants. It is almost certain that with time other issues will also become apparent.

The Martian surface environment differs from that of the Moon in that it contains both sand and dust and a dust-laden, low-pressure atmosphere with local and large scale winds. In such an environment, contamination issues similar to those suggested for the Moon certainly may be anticipated. Dust deposition will modify surface optical, electrical, and thermal properties as previously suggested. Additionally, wind-borne dust will produce mechanical erosion over sufficiently long periods of time, and low-pressure gas discharge phenomena like Paschen electrical breakdown will occur at voltages ranging from a few hundred volts upward. Paschen discharges in the Martian atmosphere, which has a surface pressure approximately 0.01 atm., are long, "spider-like" discharges, capable of extending for distances of centimeters to meters when kilovolt electrical potentials are present. The discharge characteristics may vary widely with atmospheric wind dust content. To date, no one has produced a Paschen curve for a low-pressure gas with the percentage gaseous composition found on Mars, let alone for such a gas with dust and/or wind motion. The facilities to do so exist. Other electrical interactions to be anticipated when systems are placed on the Martian surface include charge/discharge phenomena associated with electrostatically charged dust and differential settling after dust storm events, modification of discharge onset characteristics depending on wind and wind-borne dust conditions, and charge/discharge phenomena during descent and ascent of manmade vehicles. Chemical effects and effects due to the presence of energetic solar photons at the Martian surface are also to be anticipated with active chemical species in both the Martian atmosphere and soil and with species present in manmade surfaces exposed to these elements.

In addition to the natural environments just described, humans will produce local environments of their own which will modify and interact with what is already there. These manmade environments will have to be dealt with on their own terms. They include discharge and waste gases and their byproducts, outgas products, biogenic wastes and their byproducts, thermal discharge, radiation (as from reactors), electric and magnetic fields, and others yet to be defined. The overall characteristics of system/environmental interactions depends on both the total characteristics of the local environment and those of the system. Different system scale sizes lead to different types of interactions and require different mathematical models to enable understanding, evaluation, and prediction. Long-term human habitation of the Moon and Mars necessitates developing systems in which interactions with the environment are understood in the earliest design phases and are taken into account throughout the design process. Similar arguments exist for translunar and interplanetary space through which humans and cargo must pass enroute to the Moon and Mars, as well as to low Earth orbit which may be the site of semipermanent human habitation in an Earth-orbiting Space Station. The size and complexity of new systems has already been cited as drivers for developing new environmental interactions knowledge, and the issues which have arisen with design parameters such as Space Station structure to solar array grounding must serve as fair warning of the need for constantly updating our interactions models and/or developing and experimentally validating new ones, as necessity determines.

ENVIRONMENTAL INTERACTIONS WORKING GROUP

To date, environmental interactions work has been carried out in several specific areas and completed to varying degrees. But this work has not been carried out in the "Integrated Program" fashion necessary to the scope and magnitude of a Space Exploration Initiative. The respective disciplines have evolved semiautonomously—that is, to a large extent independently of each other. Cross fertilization of ideas has occurred only as needed, as when the question of a plasma interaction arose around the issue of a hypervelocity impact between a solid object like a meteoroid and a spacecraft bumper shield in which material is vaporized and a hot transient gas is generated as a byproduct. No forum exists in which cross-disciplinary ideas are considered or integrated program elements developed.

An integrated, coordinated approach is required for future work in this area so that programs can develop with mutual knowledge of each other and knowledge of the mission and system definition activities already under way. To that end, an Environmental Interactions Working Group has been established with a broad charter to address issues and make recommendations; to define agency-wide areas of need for predicting and evaluating interactions; to establish what information is already available; and to formulate and implement a program to develop and experimentally validate models for use by system design engineers. As a point of ingress into a potentially infinite area of study, the working group will begin with a more focused charter to establish requirements for robotic missions to the Moon and Mars. The group will establish a data base of currently available information on the Moon and Mars, and it will define in broad terms the expected operating parameters of systems intended for use there. It will then define and prioritize the anticipated environmental interactions and establish those parameter sets most critical to developing interactions models. The parameter sets will be compared with existing data to determine where "holes" exist in our knowledge. This knowledge will in turn be used to define instruments, sensors, and/or experimental packages to be carried to the Moon and Mars during the robotic precursor missions. These items, which will be documented in the form of a set of recommendations, will be delivered to the Robotic Mission Working Group through the Engineering Requirements Subgroup, both of which are currently being established at the Johnson Space Flight Center and which will respond to the Exploration Codes at NASA Headquarters. The Environmental Interactions Working Group will expand its activities to embrace the broader charter described previously as appropriate. The working group will meet by videoconference approximately every six weeks, and it can meet more frequently on an as-needed basis.

In order to organize the working group, its activities are subdivided into several discipline areas. These subdivisions are defined by a two-dimensional matrix which maps interaction types against environments. The environments branch of the matrix includes space plasmas, the lunar and Martian surfaces, the Martian atmosphere, particle and radiation environments, the solar spectrum, and micrometeoroids. Where appropriate, induced or manmade environmental components will also be considered in dealing with the system/environmental interactions. The interactions branch includes chemical, mechanical, electrical, thermal, and optical interactions. The matrix in table III has dots representing individual discipline areas. Definitions intended to be used with the chart are included in the appendix. Many discipline areas have yet to be prioritized as of the writing of this paper. This prioritization is an action item being addressed by the working group. Thereafter, individual writeups will be produced for each of the discipline areas. Two meetings of the group have already been held, one to discuss working group charter and operation, and the other to discuss more fully the discipline areas and to survey the environments and their physical characteristics. Future meetings will involve similar surveys of systems and interaction types. The objectives of these meetings are to develop a common language for the group and to begin constructing a data base from which robotic mission requirements may be developed. The first publication of the group is anticipated sometime during the summer of 1992.

CONCLUSION

The environments to be encountered in the Space Exploration Initiative present a complex variety of new system/environmental interactions. In order for systems designers to take into account the characteristics of the environments for which they are designing, they will need to understand the interaction mechanisms to which their systems will be subjected and be able to model them from the earliest conceptual design stages through to design completion. This paper reports on the Environmental Interactions Working Group whose objective it is to catalog and understand these environmental interactions and to establish robotic precursor mission requirements for the Moon and Mars. The Environmental Interactions Working Group is cochaired by Joe Kolecki and Barry Hillard of NASA Lewis. Interested persons may contact them:

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APPENDIX I: TERMS AND DEFINITIONS

Environments

Plasma environment: The charged particle and field environment that exists in space; dominated either by a planetary magnetic field and its associated trapped particles, by the solar extended atmosphere also known as the solar wind, and/or by locally generated charged particles due to photoemission (as secondary electrons) or photoexcitation (as photo ions). The plasma environment may also consist of system-generated components such as those due to neutral gas venting operations in which some fraction of the vented gas is ionized by collisions with energetic particles and/or energetic solar photons.

Lunar surface: The environment that exists near the Moon and consists of the actual lunar surface along with the space immediately above; dominated by lunar sand and dust which may be electrostatically charged by energetic solar photons and also by a tenuous plasma or dusty plasma made of solar-charged particles, byproducts of vented gases or discarded materials, cosmic rays, and electrostatically suspended lunar dust.

Martian surface: The environment that exists near Mars and consists of the actual Martian surface along with the space immediately above; dominated by Martian sand and dust which may be electrostatically charged by energetic solar photons and also by a tenuous atmosphere (0.01 terrestrial atm) with winds, temperature variations, active chemical species, and seasonal variations in composition. The Martian surface environment may also contain system-generated components.

Martian atmosphere: The gaseous envelope enclosing Mars which extends from the Martian surface upward to altitudes of a few hundred kilometers; contains both neutral and charged species whose densities vary as a function of the altitude and exhibits diurnal and seasonal variations in temperature, pressure, wind velocities, and composition. The Martian atmosphere may also contain system-generated components.

Ionizing radiation: The particle and field environment which is sufficiently energetic to produce ionization in ambient neutral species and which may result from natural or manmade sources.

Neutral environment: The unionized particle environment which may result from natural or manmade sources.

Solar spectrum: The solar photons (with their respective wavelengths and radiative intensities) which exist in a region and produce such effects as heating, photoionization, secondary electron emission, and ultraviolet destabilization of materials.

Micrometeoroids: The naturally occurring environment of solid objects ranging in size from microscopic grains to macroscopic objects orbiting either the Sun or a planetary body and resulting from such naturally occurring sources as comets and asteroids.

Interactions

Chemical: Interactions between a system (system element) and the environment which result in molecular products that differ from original molecular constituents in the system (element) and/or the environment (as in reactive sputtering or atomic oxygen erosion processes).

Mechanical: Interactions between a system (system element) and the environment which result in physical changes to the system (element) and/or environment. They may include abrasive erosion (as by aeolian wind/dust processes) and redeposition (as by nonreactive sputtering processes) of various materials.

Electrical: Interactions between a system (system element) and the environment which result in the exchange of charged species between the system (element) and the environment (or between various system elements through the environment) along with a shift in relative electrical potentials (as in a Paschen discharge event in a low-pressure gas environment).

Thermal: Interactions between a system (system element) and the environment which result in the exchange of heat energy between the system (element) and/or the environment (or between various system elements through the environment) along with a shift in relative temperatures (as in heating of an electrically solid surface collecting electrons from an ambient plasma).

Optical: Interactions between a system (system element) and the environment which result in a shift in optical properties in some wavelength band (not restricted to the visible band) in some system element or in the environment (as in the clouding of a lens due to material deposition from a local vapor, or the increase in optical background due to the introduction of a scattering medium to an observing field say by the venting of waste gas).

TABLE I.—AD HOC ORGANIZATIONAL STRUCTURE

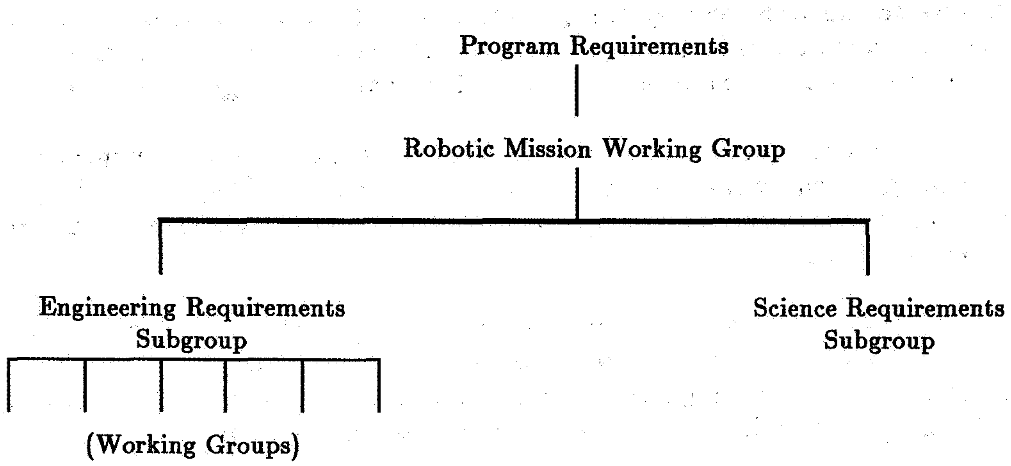

TABLE II.—WORKING GROUPS IN THE ENGINEERING REQUIREMENTS SUBGROUP

- Engineering Test and Demonstration
- Lunar Surface Knowledge Requirements
- Mars Surface Knowledge Requirements
- Mars Atmosphere Knowledge Requirements
- Environmental Interactions
- Human Support
- Navigation Requirements

TABLE III.—CROSS PLOT OF ENVIRONMENTS AND INTERACTIONS

	Plasma environments	Lunar surface	Martian surface	Martian atmosphere	Ionizing radiation	Neutral environments	Micrometeoroids	Solar spectrum
Chemical			X	X	X	X		X
Mechanical			X		X		X	X
Electrical	X	X	X	X	X	X	X	X
Thermal	X	X	X	X		X	X	X
Optical	X	X	X	X	X	X	X	X

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With the advent of the Space Exploration Initiative, the possibility of designing and using systems on scales not heretofore attempted presents exciting new challenges in systems design and space science. The environments addressed by the Space Exploration Initiative include the surfaces of the Moon and Mars, as well as the varied plasma and field environments which will be encountered by humans and cargo enroute to these destinations. Systems designers will need to understand environmental interactions and be able to model these mechanisms from the earliest conceptual design stages through design completion. To the end of understanding environmental interactions and establishing robotic precursor mission requirements, an Environmental Interactions Working Group has been established as part of the Robotic Missions Working Group. The current paper describes the working group and gives an update of its current activities. Working group charter and operation are reviewed, background information on the environmental interactions and their characteristics is offered, and the current status of the group's activities is presented along with anticipations for the future.

14. SUBJECT TERMS
Exploration; Environments; Environment effects; Environmental monitoring; Interactions; Lunar atmosphere; Lunar dust; Lunar environment; Mars; Mars atmosphere; Mars environments; Mars surface; Plasma interactions; Plasma-electromagnetic interaction; Interplanetary spacecraft; Manned spacecraft; Unmanned spacecraft; Planetary surfaces; Surface properties

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