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Monday

Session: Spacecraft Charging Simulations and Testing – Charging I
Chairs: Dale Ferguson, Colby Lemon

Spacecraft Charging and IESD Characterization of Carbon Composite Materials with Multiple Electron Beams

Justin Likar, JHU/APL, Allen Andersen, JPL, David Knapp, Lockheed Martin Advanced Technology Center, Brian Xiaoyu Zhu, JPL, Jaykob Maser, Lockheed Martin Advanced Technology Center, Meredith Nevius, Lockheed Martin Advanced Technology Center, Wousik Kim, JPL, Matthew Bray, JHU/APL, Jason Feldman, JPL, Michael Noyes, Applied Aerospace Structures Corporation

The use of carbon fiber composites is ubiquitous within the modern spacecraft industry owing to its desirable mechanical, thermal, and RF properties. It is known, however, that these materials are susceptible to spacecraft charging and electrostatic discharges (ESD) as a result of non-conductive surface resins present in the carbon fiber composite layup. In vacuo flood beam or similar test conditions are necessary to properly characterize the charging and IESD hazards as familiar, contacting, electrical measurements are overly influenced by the conductive carbon fibers. The effects of Radiation Induced Conductivity (RIC) on the charging and ESD hazard – specifically on discharge magnitude and rate – may be significant. Simultaneous inclusion of a second electron beam enables better matching of the predicted in-flight charge deposition rate, energy deposition rate, and ultimately less conservative and better representative results. We present methods, processes, and results from a series of multi-electron beam tests performed at cryogenic temperatures on a variety of carbon composite materials.

Electron Beam Tests of Carbon Composite Materials with Conductive Resin for Preventing Spacecraft Charging-Induced ESD

Allen Andersen, JPL, Nick Patz, Patz Materials and Technologies, Michael Noyes, Applied Aerospace Structures Corporation, Wousik Kim, JPL, Matthew Bray, JHU/APL, Justin Likar, JHU/APL, Jason Feldman, JPL

Carbon fiber composite is an increasingly common spacecraft material due to its favorable mechanical, thermal, and RF properties. Despite the intrinsically conductive nature of the carbon fibers, it has been shown that the dielectric resin that binds the laminate together can cover much of the surface of the finished structure and pose a serious electrostatic discharge (ESD) concern. Previously recommended ESD mitigations such as abrading off the surface resin or applying a static-dissipative coating to the surface of the structure may not be amenable to all spacecraft design needs, and can be difficult to implement. The ultimate solution to the carbon composite ESD problem is a material made entirely of constituents conductive enough not to pose any risk of ESD. We present two carbon composite materials with conductive resins that did not discharge under severe electron exposure at cryogenic temperatures, conditions under which the standard formulation produced copious discharges.

NASA Air Force Spacecraft Charging Analyzer Program Confirmation of GPS Arcing

Karin Fulford, UNM, **Dale Ferguson**, AFRL/Space Vehicles Directorate, Ryan Hoffmann, AFRL/Space Vehicles Directorate, Vanessa Murray, NRC, Daniel Engelhart, Assurance Technology Corp, Elena Plis, Assurance Technology Corp

GPS satellites undergo surface contamination on the solar array coverglasses from repeated arcing events. Using Nascap-2K spacecraft charging simulation software, a GPS Block IIF satellite model was constructed and analyzed in realistic MEO environments. GPS Block IIF satellites have CMG coverglasses (as do all other GPS satellites). The Nascap-2K model with CMG coverglasses charges to high differential levels in maximum charging environments, in the range above the arcing threshold as determined by studies at the Air Force Research Laboratory, and so arcing is confirmed by theory. This finding agrees with on-board Los Alamos National Laboratory (LANL) measurements and Arecibo observational data for GPS satellites. Other AFRL results show that CMX coverglasses, being more bulk-conductive, should charge less and perhaps mitigate arcing on the solar arrays. A Nascap-2K model using CMX coverglasses is shown to charge differentially much less than CMG, and not reach levels above the arcing threshold. In the simulation, the commonly used CMG coverglass charges quickly, exceeding its arcing voltage threshold of 1500 V in about 1 hour and 10 minutes. In comparison, CMX results indicate an ability to remain well under its arcing threshold throughout the orbit.

Just-In-Time Charging Risk Analysis Service with the H2O2O/PAGER Space Weather Predictions Framework

Benoît Tezenas du Montcel, Artenum, Toulouse, Arnaud Trouche, Artenum, Toulouse, Julien Forest, Artenum, Paris, Yuri Shprits, GFZ, University of Postdam, Melanie Burns, GFZ, University of Postdam

Initiated in January 2020, funded by the European Union (EU) in the frame of the H2020 framework program and leaded by the GFZ department of the Potsdam University, PAGER, for Prediction of Adverse effects of Geomagnetic storms and Energetic Radiation, aims to provide an online framework for space weather and related effects forecasts. One of the innovative concepts and challenging objectives is to plug, downstream of the environment prediction models, surface and internal charging risk analysis services to forecast an evaluation of the risk for operated platforms in flight, including future commercial ones in GEO and constellations.

For this activity, driven by the Artenum Company in a dedicated work package, the main difficulty is to perform charging analysis in a relatively short CPU-time to respect the forecast rate and on systems (platforms, devices, payloads) realistic enough to evaluate a final charging risk in a most accurate and robust way possible. Indeed, the real impact on orbital systems is also depending on their own design, technological choices and possibilities of mitigations. It is quickly needed to model a complex and realistic system, close to targeted platform, on one hand, and consider that the environment might be strongly antagonistic, as well, both making the real-time modelling challenging.

To address this, several approaches have been proposed and are currently investigated in parallel, this for both surface and internal charging. Firstly, a set of reference charging models, corresponding to observed cases or configurations commonly used in the space industry have been identified. Their objective is to allow 3D simulations fast enough in operational mode (i.e. forecast) but realistic enough as well to provide a relevant risk analysis. Secondly, a set of highly optimised 0D/1D semi-analytical models has been implemented. Their objective, in spite their limitations, is to provide a first quick and indicative answer in a robust way. In complement and as core approach, a modelling chain based the open-source SPIS software, reference 3D charging analysis tool in EU, has been implemented in an optimised way, to be run on the reference charging cases. These simulations should give more accurate and relevant risk evaluations. For the internal charging analysis, Monte-Carlo based model (i.e. GEANT-4) are used to previously computed the transport of high-energy particles through the shielding of studied systems. Last, recent evolutions of SPIS-IC, version dedicated to internal charging, allow addressing the dynamic evolutions and the history of the high-energy environment, for a better evaluation of risks resulting from cumulative events and/or iterative across through critical regions (e.g. radiations belts, Polar regions...).

Last, results are finally displayed as simple risk indicators, easy to read by non-experts, through a Web based client.

The proposed technical approaches, implemented models, current progress status and first examples of charging analysis with the PAGER/Charging Analysis Service will be presented and discussed.

Spacecraft Charging in Sunlight, Physical Mechanisms, Mitigation Techniques

Shu Lai/MIT

Spacecraft charging is determined by the balance of currents. A spacecraft spends most of its time in sunlight. The photoelectron current generated on most sunlit surfaces in sunlight often exceeds the ambient electron and ion currents by an order of magnitude. Yet, spacecraft charging and discharging can occur in sunlight. Negative voltage charging in sunlight can occur if the surface is highly reflective. Discharging may occur if the neighboring surfaces charge to very different voltages. Monopole-dipole charging can occur if the shadowed side charges to high negative voltages and the negative voltage contours wrap around the sunlit side. As a result, the entire spacecraft charges to negative voltages. We suggest a novel mitigation technique by using mirrors. If we can mitigate the charging of the shadowed side, we mitigate the entire spacecraft. We suggest using multiple mirrors in the style of James Webb Mirrors for mitigating negative voltage charging of spacecraft deployed in herds possibly in the future. Preliminary estimates are already encouraging.

Session: Radiation Effects on Parts and Testing
Chairs: Michael Campola, Richard Altstatt

Invited: The Europa Clipper Mission - Hardness Assurance through Mission and System Design

Steve McClure, NASA/JPL

The Europa Clipper Mission will conduct detailed reconnaissance of Jupiter's moon Europa and investigate whether the icy moon could harbor conditions suitable for life. The mission will place a spacecraft in orbit around Jupiter in order to perform a detailed investigation of the giant planet's moon Europa -- a world that shows strong evidence for an ocean of liquid water beneath its icy crust and which could host conditions favorable for life. The mission will send a highly capable, radiation-tolerant spacecraft into a long, looping orbit around Jupiter to perform repeated close flybys of Europa.

Trapped by Jupiter’s strong magnetic field, the high energy electron and proton environment poses a significant challenge, with a mission dose of about 3 Mrad behind 100 mils of Aluminum. The design of the Europa Clipper mission addresses this challenge through, minimizing encounters with the radiation field, system and subsystem shielding, maximum use of radiation hardened parts and materials, and mitigation of effects in electronic design. This presentation will summarize the approach taken and the challenges encountered thus far in the efforts to assure operation and survival of the spacecraft and its instruments in the radiation environment at Jupiter.

Current Challenges and Solutions in Nuclear Rocket and Orbital System Design

Tom Jordan, EMPC, Bryan Fodness, Ball Aerospace

The paper examines certain radiation transport challenges faced by current technologies/programs. It focuses on two specific topics: nuclear rocket development and modern orbital system design.

The recent decision to pursue Nuclear Engine for Rocket Vehicle Application (NERVA) capability raises challenges including radiation scatter from the engine components, exhaust plume below the core, shielding above the core, and crew and systems exposure to significant neutron levels near end-of-propellant.

This paper will summarize those challenges and describe solutions, applying some lessons learned in earlier NERVA work.

Current approaches to electron total dose in satellite design tend to rely solely on ray-trace, overlooking little-known deficiencies in min-path/slant-path analysis. First, min-path/slant-path analysis being performed is methodologically incorrect in some analysis systems. Second, ray-trace produces analysis substantially less precise than analysis from the preferable approach of using ADJOINT (‘reverse’) Monte Carlo (the option insisted on by several contractors with the most rigorous design requirements, but not by many others).

This paper will detail the methodological problems. It will then describe the correct, validated method.

The paper will also perform a ray trace (min-path/slant-path) analysis and an ADJOINT (‘reverse) Monte Carlo analysis of a sample using the NOVICE software frequently relied upon by the designers currently facing the above-described challenges, then compare the results including a 2x2x2 cubesat experimental data set.

Some specific solutions are anticipated to include: importance sampled Monte Carlo adjoint-forward particle transport, ray trace solid angle sectors and packaging, specifically electrons, minimum-path and slant-path variations, mass-thickness moments, high ray trace counts: 40k igloo rays, 80k Mercator rays default, CAD model ray trace acceleration, grid sorts, tree and object level, and orthogonal whole system geometry ray trace validation at ≤1 mm.

SIRE2 Toolkit Version 1.80 Update

Zachary Robinson, Fifth Gait Technologies, James Adams, Fifth Gait Technologies, Jonathan H. Fisher, Fifth Gait Technologies, Joseph Nonnast, Fifth Gait Technologies, Jeren Suzuki, Fifth Gait Technologies, Paul Boberg, Fifth Gait Technologies, Zachary Lane, Fifth Gait Technologies, David Hope, Applied Research Associates, Robert Reed, Vanderbilt University, Kevin Warren, Vanderbilt University, Brian Sierawski, Vanderbilt University

The Space Ionizing Radiation Environment and Effects (SIRE2) provides space environment and effects calculations for spacecraft based on the latest models of the space radiation environment. With a planned Q3 2021 release for SIRE2 version 1.80, we are introducing a lot of updates to the toolkit. SIRE2 toolkit now incorporates 3D plotting of the spacecraft’s trajectory or orbit instead of the latitude, longitude, and altitude plots that were display on the graphic user interface (GUI) in previous versions. In addition, we have included updated environment models. The Mission Specific Solar Radiation Environment Model (MSSREM) version 1.20 and IRENE version 1.57 has been updated and included in SIRE2.

SIRE2 now includes the option to use the high charge and energy transport (HZETRN) model to transport radiation through the spacecraft shielding along with the legacy UPROP model. HZETRN has been shown to provide results that more closely match the monte carlo transport calculations (Lin et al., 2012). The Fifth Gait internal version of SIRE2 also includes an environment grid generator that allows environment calculations for up to 100,000 locations around the Earth.

Fifth Gait Technologies is also working to incorporate the output generated by the improved Particle Acceleration and Transport throughout the Heliosphere (iPATH) model. The iPATH model is a physics-based tool that drives the particle radiation environment from a CME to multiple locations in the Heliosphere. The iPATH output will be able to be used for the solar radiation component in the SIRE2 calculation. This version of SIRE2 is being referred to as the SIRE2 Advance Climatology, or SIRE2-AC.

Astronomical Reflectance Spectroscopy (ARS) Characterization of Various Polymer Materials in a Simulated GEO Environment

Jainisha Shah, ATC, Miles Bengtson, NRC/Research Associateship Program, Elena Plis, Assurance Technology Corp, Sydney Horne, Assurance Technology Corp, Dale Ferguson, AFRL/Space Vehicles Directorate, Ryan Hoffmann, ARFL/Space Vehicles Directorate

As the frequency of government and commercial space missions involving the launch and deployment of space hardware continuously increases, the population of objects in Earth orbits has grown. Upon launch, these space objects are in immediate danger of potential collision with active or inactive spacecraft and space debris. Increased population of orbital debris in space necessitates development of techniques that can be used for their remote characterization. Astronomical Reflectance Spectroscopy (ARS) is one such technique that can be used to characterize the orbital debris. ARS utilizes changes in the material optical characteristics when the materials are exposed to the harsh environment of the geosynchronous Earth orbit (GEO). The radiation environment in GEO comprises of several damaging species with the electrons being the primary source of damaging species due to their high energy. Radiation exposure leads to continuous chemical changes to the object's optical properties- the brightness and color index at certain wavelengths. Understanding these changes in optical properties as a function of time in orbit can be a powerful tool for remote characterization and identification of space orbital debris. In this study, the effect of space-simulated environment represented by high-energy (100keV) electrons, on optical properties of several spacecraft relevant polymer materials is investigated.

Session: Instrument and Measurement Techniques I
Chairs: Henry Garrett, Tim Guild

Invited: HERMES: NASA's Space Weather Payload for Gateway

William Paterson, NASA/GSFC, Daniel Gershman, NASA/GSFC, Shri Kanekal, NASA/GSFC, Roberto Livi, University of California, Berkeley, Mark Moldwin, University of Michigan, Brent Randol, NASA/GSFC, Marilia Samara, NASA/GSFC, Eftyhia Zesta, NASA

The Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES) comprises charged particle detectors and magnetometers in a compact package that will be attached externally to Gateway's Habitation and Logistics Outpost (HALO). The HALO, along with its companion module, the Power and Propulsion Element (PPE) will be launched together not earlier than November, 2024. The transit to the moon will be approximately 1 year, after which the Gateway modules will enter a highly eccentric 7-day polar lunar orbit with apoapsis 70,000 km below the Moon's south pole and periapsis 3,000 km in the north. From this orbit, HERMES will acquire data to support studies of the interplanetary medium and the terrestrial magnetotail. When data are compared with measurements from other, existing heliophysics missions, the Hermes orbit will allow for studies of solar-wind structures, and it will provide a basis for studies of the vertical structure of the magnetotail. Additionally, HERMES is a pathfinder that will establish observational capabilities for measuring local space weather to support deep-space and long-term human exploration. Interpreting measurements of the space environment from Gateway or other large and complex vehicles is expected to offer challenges due to surface charging, limitations on fields of view, particle scattering, and magnetic noise. Experience gained with HERMES will be advantageous for future missions of exploration that may employ similar space weather monitors to improve predictions and provide alerts for astronauts.

Considerations for Optical Sweep Rates of Sweeping Langmuir Probes in Space Plasmas

Rachel Conway, ERAU, Aroh Barjatya, ERAU, Shantanab Debchoudhury, ERAU

One of the most common challenges of sweeping Langmuir probe implementation is contamination on the surface of the probe. This contamination presents itself as hysteresis of the collected Current-Voltage (IV) curve between consecutive up and down voltage sweeps. There is significant disagreement in the literature on whether the up or down sweep is more reliable, as the contamination effects are not well understood. This is problematic, as hysteresis can shift the IV curve and lead to an erroneous value for spacecraft floating potential and associated plasma parameters. This paper presents SPICE simulations to investigate probe behavior for a variety of contamination layers, modeled as resistors and capacitors in parallel. These simulations are then compared to experimental results of Langmuir probes in an Argon discharge plasma. The amount of hysteresis experienced by the probe is shown to be a function of both plasma density and sweep rate, and therefore, suggests that the sweep rate required to bypass contamination varies for different plasma environments. This work necessitates considerations for optimal sweep rates of future science missions depending on the plasma region of interest.

Data Products from the Floating Potential Measurement Unit (FPMU) onboard the International Space Station

Shantanab Debchoudhury, ERAU, Aroh Barjatya, ERAU, Joseph Minow, NASA/MSFC, Victoria Coffey, NASA/MSFC, Linda Neergaard Parker, Space Weather Solutions

The Floating Potential Measurement Unit (FPMU) has been operational aboard the International Space Station (ISS) since 2006 providing a wealth of data to scientists and engineers alike on the varying plasma environment. The FPMU is a suite of four instruments – a floating potential probe (FPP), a narrow-sweep and a wide-sweep Langmuir probe (NLP and WLP respectively) as well as a plasma impedance probe (PIP). While the FPP describes the level of spacecraft charging, the current-voltage relationship recorded by the in-situ Langmuir probes can be analyzed to get background electron-temperature and plasma densities. Recently, the FPMU WLP data have been re-analyzed and the data analysis process is presented through this study. We describe how the ion-saturation region of the WLP has been used to extract the O+ abundance information in the F-region ionosphere, which shows interesting features in the post-midnight nighttime sector of the F-region ionosphere in solar minimum. In addition, we also present the distribution of the spacecraft floating potential from the measurements of the FPP and its variability as a function of factors such as local time and season.

Adding Triboelectric Charging Parameters to the Spacecraft Charging Materials Database

Charles Buhler, NASA/KSC, Joseph Faudel, UCF

The Spacecraft Charging Material Database (SCMD) was expanded in order to include triboelectric charging data for numerous spaceflight materials that have been tested over many decades at Kennedy Space Center (KSC). Included in the expansion of the SCMD is triboelectric charge decay data measured in 30% and 45% relative humidity environments. The database this information was extracted from was found by members of the Electrostatics and Surface Physics Laboratory (ESPL), and it features various physical/mechanical material properties, flammability testing criteria, electrostatic discharge testing criteria, and spark incendivity testing criteria. Some of the data seen in this KSC database is referenced in a Kennedy Technical Instruction (KTI) document used during the material selection process across the agency, known as KTI-5212, which mainly features information on hypergolic ignition and breakthrough resistance for materials. The electrostatic discharge testing is mentioned in KTI-5212, but the associated data has not been made available until now. Also included in the SCMD expansion is triboelectric charge decay data for materials used during a NASA spacewalk repair mission, with the tests being carried out in either a near 0% relative humidity environment, or in vacuum. Electrostatic discharge on spaceflight materials has become an important consideration during the material selection process at NASA in order to prevent damage and interference with equipment and instrumentation, which will help to ensure long term operation in the space environment. Making additions to the SCMD was done with the aim of helping the ESPL demonstrate its capabilities for the agency, and to continue expanding, restoring, and localizing electrostatic discharge measurement techniques at KSC to help streamline obtaining the information NASA needs to ensure safety in current and future missions.

Comparison of Space Charge Distributions in Polymers Irradiated with Monoenergetic Electrons: Pulsed Electroacoustic Measurements and AF-NUMIT3 Modeling

Zachary Gibson, USU/Materials Physics Group, JR Dennison, USU/Materials Physics Group,
Brian Beecken, Bethel University

Successful spacecraft design and charging mitigation techniques require precise and accurate knowledge of charge deposition profiles. This paper compares models of charge deposition and transport using a venerable deep dielectric charging code, AF-NUMIT3, with direct measurements of charge profiles via pulsed electroacoustic (PEA) measurements. Eight different simulations were performed for comparison to PEA experiments of samples irradiated by 50 keV or 80 keV monoenergetic electrons in vacuum and at room temperature. Two materials, polyether-ether ketone (PEEK) and polytetrafluoroethylene (PTFE), were chosen for their very low conductivities so that minimal charge migration would occur between irradiation and PEA measurements. PEEK was found to have low acoustic attenuation, while PTFE has high acoustic attenuation through the sample thicknesses of 125 μm and 250 μm for each material. The measurements were directly compared to AF-NUMIT3 simulations to validate aspects of the code and to investigate the importance of various simulation options, as well as to characterize the PEA instrumentation, measurement methods, and signal processing used. The measurement and simulation values for magnitude of charge deposition, penetration depth, and charge deposition spatial profiles are largely in agreement, though spatial and temporal distributions in incident electron flux and effects of radiation induced conductivity (RIC) and delayed RIC during the deposition process complicate the process. This work provides an experimental validation of the AF-NUMIT3 deep dielectric charging code and insight into the accuracy and precision of the PEA method.

Tuesday

Tutorial: The SPace ENVironment Information System (SPENVIS): A New Framework

Erwin De Donder, Royal Belgium Institute for Space Aeronomy, Neophytos Messios, Royal Belgian Institute for Space Aeronomy, Stijn Calders, Royal Belgian Institute for Space Aeronomy, Antoine Calegaro, Royal Belgian Institute for Space Aeronomy, Sami Mezhoud, Royal Belgian Institute for Space Aeronomy, Daniel Heynderickx, DH Consultancy, BV Mourad Akandouch, Space Applications Services NV/SA, Simon Clucas, ESA/ESTEC, Hugh Evans, ESA/ESTEC

In order to facilitate access to space environment and effects models, the SPace ENVironment Information System (SPENVIS) has been developed for ESA by BIRA-IASB since 1996, under ESA contracts. SPENVIS is a web-based interface to a comprehensive set of models of the space environment and its effects on spacecraft components and astronauts. It has been operational for more than twenty years and has a large international user community who is using the system for various purposes like mission analysis and planning, education and scientific research.

In this poster we present an overview of a new project (recently started under ESA Contract No. 4000134504/21/NL/CRS) that aims to re-design the current system in order to improve the usability of the models and the user interaction/experience. The novel SPENVIS system will also incorporate new models and make use of ESA's Network of Models (NoM). The latter is a lightweight framework that provides access to models and data via a common web API allowing to run models available in other external frameworks and vice versa.

Session: Spacecraft Charging Simulations and Testing – General I
Chairs: Justin Likar, Insoo Jun

Real and Imaginary Permittivity Testing in High-Vacuum and Variable Temperature Settings

Jordan Lee, USU, JR Dennison, USU

A high vacuum experimental system has been developed to determine permittivity of solids down to cryogenic temperatures. The measured real and imaginary components of the permittivity of a dielectric material characterize how it responds to time-varying external electric fields and the associated energy loss mechanisms. Permittivity of solid materials may be affected by many factors, including thermal expansion, phase transition (induced by temperature), charge deposition from irradiation, and radiation-induced material modifications. Understanding the dependence of permittivity on temperature and radiation from exposure to the harsh space environment is critical to predict and mitigate changes in spacecraft materials over mission lifetimes. An experimental system has been designed, using a custom parallel plate sample test fixture amenable to high vacuum and cryogenic temperatures. A closed-He cryostat cools samples to 80 K; they can also be heated to ~350 K. A similar system employing liquid nitrogen cooling is under development. A standard Agilent 4194A Impedance Analyzer is used, with fully automated Labview data collection of sample capacitance and dissipation between ~1 kHz and ~15 MHz. Design and calibration of the instrument and characterization of precision and accuracy of the measurements are discussed. Representative measurements of real and imaginary components of permittivity for polyether ether ketone (PEEK) between 1 kHz and 15 MHz are presented, which demonstrated no significant effects on the permittivity of PEEK with temperature (83 to 296 K) and dose (up to 600 kGy). Permittivity was found to decrease monotonically with temperature, but with small changes (< 3-4%) over the full temperature range.

*Research was partially supported by the NASA Jet Propulsion Laboratory for the Europa Clipper missions though award 1584146.

Using a Pulsed Electron Beam to Prevent Charging While Sensing Electric Potentials

Julian Hammerl, UCB, Hanspeter Schaub, UCB

Spacecraft tend to charge in the space environment, which affects spaceflight in various ways. Arcing can occur between spacecraft components if the spacecraft is not fully conducting and some parts are charged to different electric potentials than other parts, referred to as differential charging. A solar panel's lifetime can be reduced significantly if arcing occurs on the panel. Two nearby spacecraft can also be subject to electrostatic discharges if they are charged to different potentials and are very close to each other, for example during docking. Additionally, even if two spacecraft in close proximity are charged to the same potential, they exert electrostatic forces on each other if the electric potentials are high enough. These forces can affect rendezvous and proximity operations, but can also be used to one's advantage for active debris removal.

Remotely sensing the electric potential of a nearby spacecraft is valuable for spaceflight as it provides a warning for probable electric discharges during docking, reduces the control effort during rendezvous and proximity operations for charged spacecraft, and increases the safety of the Electrostatic Tractor relative motion control. Two promising remote electric potential sensing methods have been proposed recently: the electron method and the x-ray method. Both methods utilize an electron gun that is attached to a servicing satellite. The electron gun is aimed at a target object and excites secondary electrons and x-rays from the target. The electron and x-ray method use the secondary electrons and x-rays to estimate the electric potential of the target.

Both methods have been validated experimentally. However, the potential of the target object was held constant during these experiments using high voltage power supplies, so the effect of the electron beam's negative current on the target's electric potential was not considered. In contrast to the experimental setup used in prior experiments, an electron beam applied in space can significantly change the target object's potential. To what extent the target's electric potential is affected by the electron beam depends on the space weather conditions and the electron beam parameters, e.g. the beam current and beam energy. The electron beam current and energy could be chosen such that the electron beam does not change the target potential significantly, however, the remote sensing methods impose some restrictions on the beam parameters in order to generate a sufficient amount of secondary electrons and x-rays.

We propose to use a pulsed electron beam to sense electric potentials without actually changing the target's potential. A pulsed electron beam has previously been investigated in space research to improve the performance of the Electrostatic Tractor, but has not been considered for electric potential sensing applications. The beam can be pulsed in three ways. For the first method, the electron beam is periodically turned on and off. The second method repeatedly switches between a high and low beam current, and the third method cycles between a high and low beam energy. Using a pulsed beam, one can use electron beam parameters (beam current and energy) that are beneficial to the remote sensing methods, without changing the target's potential.

For this analysis, we investigate and compare the effects of an electron beam on the target's electric potential using a continuous beam, on-off pulsing, beam current pulsing, and beam energy pulsing. Although the most complex method, beam energy pulsing is especially promising as it is the only method that can maintain a constant potential of the target even when no external currents besides the electron beam current are present, by taking advantage of the secondary electron yield.

Methods for Yield Measurements of Highly Insulating Granular Materials

Tom Keaton, USU, Heather Allen, USU, Matthew Robertson, USU, JR Dennison, USU

This work presents a systematic study on sample preparation methods and accuracy of electron yield (EY) measurements of highly insulating, granular materials. EY measurements of highly insulating materials, especially those with high EY, are challenging due to the effects of sample charging even for very low fluence electron probe beams. EY measurements of particulates are complicated by: (i) roughness effects from particulate size, shape, coverage, and compactness; (ii) particle adhesion; (iii) substrate contributions; and (iv) electrostatic repulsion and potential barriers from charged particles and substrates. Numerous methods were explored to rigidly affix particles on conducting substrates at varying coverages for accurate EY measurements. Gravimetric deposition of particles suspended in deionized water onto standard scanning electron microscopy (SEM), aluminum backed, graphitic carbon tape with a carbon infused, acrylic-based, conductive adhesive top layer, proved the most successful method, with robust results for ranges of particle sizes, shapes, and coverages. To mitigate potential electrostatic lofting effects of charged particulates, less adhered particles were removed with dry nitrogen jets and applied high electric fields prior to EY measurements. Particle sizes were determined via laser diffractometry, while SEM measurements were used to determine fractional coverage of adhered particles. Low fluence, pulsed electron probes (3-5 μs at 1-30 nA-mm-2) used 100 to 102 electrons per pulse per particle to measure EY with minimal charging effects. Surface charge accumulation from each pulse was dissipated between pulses with 1-2 s bursts of ~4.9 eV photons from a UV LED and electrons from a flood gun; 3 to 6 hr thermal annealing of the samples at 310 to 340 K could also be used intermittently to dissipate deeper dielectric charging. Preliminary studies of highly insulating, 67±23 μm sized, angular Al2O3 polishing compound particles adhered to graphitic carbon conductive tape from 0% to ~100% coverage are presented to demonstrate the effectiveness of these methods. Results of high accuracy EY tests using these methods have important applications in lunar dust and asteroid technologies and lofting, electrostatic dust agglomeration in space, granular and aerosol coatings for spacecraft charge mitigation, and many coating, contamination and roughening issues applied to a wide variety of fields subject to charging.

Analysis of Extrinsic Factors of Electron Yield with a “Patch” Model

Matthew Robertson, USU, Trace Taylor, USU, Tom, Keaton, UT, JR Dennison, USU

Electron yield (EY) is a material attribute which describe the ratio of emitted electrons to incident electrons when irradiated with an electron beam. EY is incident energy dependent, distinctive for each material as determined by its chemical composition and electronic configuration, and modified by extrinsic factors including surface roughness and contamination. Measurements of EY are often made on pristine samples, with contamination and roughness not determined for the specific sample or sample preparation. The EY—as it was measured in its pristine state—will likely be modified as extrinsic factors change due to space environment interactions. Most current simple EY models are not well suited to handle extrinsic modifications to EY or more complex materials made of more than one constituent. This research proposes simple “patch” and “layer” models to characterize complex materials and extrinsic factors in EY analysis, akin to parallel and series models of resistivity components. The “patch” model considers the EY contribution of each material or feature independently, with the EY for a complex material as a linear weighted sum of the EY contributions of the constituent material “patches”. Models can be extended to any number of different types of “patches” materials or extrinsic modifications and periodic unit cells can characterize mean size, shape, or extrinsic features of constituent “patches”. Multilayers can be model by extending current two-layer yield models, which include linear energy transfer electron energy attenuation and backscatter reflections. More complex materials can be modeled by separating the EY contributions of individual components in terms of these simple “patch” and “layer” models. Once the extent of the effects of extrinsic factors on EY are characterized, it should be possible to model how the EY of a material will change over time in the space environment leading to better models of spacecraft charging and mitigation strategies.

Session: Space Weather Environments, Impacts, and Modeling I
Chairs: Yihua Zheng, Shawn Young

Invited: Cultivating Capabilities for Lunar Extreme Environments

Kevin Somervill, NASA/LaRC

Space Directive 1 establishes that NASA is to "return of humans to the Moon for long-term exploration and utilization". Inherent in this direction, there are environmental challenges including ionizing radiation, extreme thermal ranges, and lunar dust. NASA is making significant investments in technologies to address the array of destinations and mission applications inherent in that challenge. As part of commercial, industry, and academic engagement, NASA has established Lunar Surface Innovation Consortium (LSIC) as an open forum to engage a larger community through six focus groups: in-situ resource utilization (ISRU), excavation and construction, power, extreme access, dust mitigation, and extreme environments. A general overview of the investments – both technology and community development – is presented.

A Data-driven Global Magnetosphere Model to Simulate Solar Wind/Earth's Magnetosphere Interaction

Mehmet Yalim, UAH, Stefaan Poedts, Catholic University of Leuven

Geomagnetic storms cause space weather disturbances that affect the magnetic environment of the Earth and can have hazardous effects on both space-borne and ground-based technological systems as well as human health.

In this work, we present an overview of the data-driven 3D global magnetosphere model that we developed together with results of real-time 3D global magnetohydrodynamic (MHD) simulations of the interaction of solar wind with the Earth's magnetosphere driven by time-varying data from the NASA Advanced Composition Explorer (ACE) satellite during three geomagnetic storm events of different strength, namely the 06 April 2000, 20 November 2003 and 05 April 2010 storms. We compare our simulation results with OMNI and Geotail data in the upstream and downstream of Earth's bow shock. Our magnetosphere model has an inner boundary condition that tries to imitate the plasma flow in the coupling region with the ionosphere but is not coupled with an ionosphere model yet. For this reason, we introduce a numerical magnetic storm index that compares the geo-effectiveness of these events in terms of this storm index which is a measure for the resulting global perturbation of the Earth's magnetic field. We utilize a 3D, implicit, upwind finite volume compressible ideal MHD solver with an anisotropic grid adaptation technique applied to unstructured grids for our numerical simulations.

Disentangling Short- and Long-term Variations of the Galactic Cosmic Ray Flux for Future Space Missions

Catia Grimani, UUCB, Michele Fabi, University of University of Urbino Carlo Bo,
Mattia Villani, University of Urbino Carlo Bo

Significant space weather effects on space missions must be assessed before satellites are sent into orbit. The ESA Laser Interferometer Space Antenna with NASA and JAXA contributions will be the first interferometer for low-frequency gravitational wave detection in space. LISA has a nominal minimum characteristic strain of nearly 10-22 in the range 10-2 - 10-3 Hz. As a result, a dedicated environmental study must be carried out to evaluate the performance of this and similar future missions.

Metal free-falling test masses, playing the role of mirrors of LISA and LISA-like space interferometers, are charged by galactic and solar particles. This charging process must be monitored for different conditions of solar modulation and at the passage of interplanetary counterparts of coronal mass ejections and high-speed solar wind streams.

LISA is supposed to be launched in 2035 near the maximum of the solar cycle 26. All predictions for the next two solar cycles indicate periods of low solar activity. In other words, for the majority of time, the noise on LISA test-masses will be associated with cosmic-ray variations in the mission whole frequency sensitivity band between 2x10-5 and 10-1 Hz. The ESA LISA Pathfinder, precursor mission of LISA, hosted a particle detector that allowed us to study the energy dependence of galactic cosmic-ray long- and short-term variations in 2016-2017.

Lessons learned with LISA Pathfinder will allow us to optimize the Monte Carlo simulations of the LISA test-mass charging within the ESA Tender 10081 activity.

New JPL Website for Natural Space Environment Tools

Luz Maria Martinez Sierra, JPL, Insoo Jun, JPL, Henry Garrett, JPL, Andrew Kim, JPL

We have developed a web-based interface to provide centralized, user-friendly access to some of the environmental models (i.e., radiation and atmospheric) and spacecraft interactions tools that JPL uses. The website consists of Sections for Radiation Environment, Planetary Atmospheres, Effects, and References. Specifically,

The Radiation Environment section includes:

- The JPL solar proton model,
- Magnetic field tracing and trapped radiation models for the outer planets (i.e., Jupiter, Saturn, Uranus, and Neptune).

To define the radiation environment for mission designs, users can easily input a trajectory information and follow the steps to determine the mission total fluences.

The Planetary Atmospheres section provides visual and tabulated information about atmospheric, ionospheric, and temperature profiles for the atmospheres of the planets in the solar system.

The Effects section includes additional tools that can be used to estimate interactions with the spacecraft materials or components. The effects are divided into non-ionizing energy loss from electrons, protons, and alpha particles, total ionizing dose in silicon with spherical shell aluminum shielding, and internal charging in materials.

The last section contains the bibliography and references for all the tools and models. Additionally, multiple visualizations, validations, and verification steps are included throughout the site to ensure that user inputs are being utilized as intended. Finally, users are given several examples of run files and step-by-step tutorials to guide their interaction with the tools. Users are invited to explore the site and provide feedback on problems or suggested improvements and additions.

Session: Atomic Oxygen Environment, Effects, Testing, and Mitigation
Chairs: Kim de Groh, Tim Minton

Atomic Oxygen Treatment for Multipactor Performance Enhancement of RF Hardware

Cesar Miquel España, ESA/ESTEC, Isabel Montero, CSIC, Adrian Tighe, ESA/ESTEC

In this paper a novel (and beneficial) use of atomic oxygen (ATOX) exposure is presented. It will show the experimental results of how several dielectric samples that were exposed to ATOX in a ground based test facility had their effective Secondary Emission Yield massively improved. The consequent Multipactor delta improvement is shown using several simulation cases. This experimental result is very promising for the high-power RF community since it provides a simple solution to improve the Multipactor performance without a change in the RF design. The future work planned by the authors will also be described.

Invited: Atomic Oxygen Environment and Effects

Sharon Miller, NASA/GRC, Bruce Banks, SAIC

Atomic oxygen is the most predominant constituent in the low Earth orbital environment between the altitudes of 180 and 650 km. It is also a major constituent of the Mars orbital environment. It is very chemically reactive and can oxidize many spacecraft surfaces to form volatile reaction products. The importance of understanding atomic oxygen reactions with materials has led to both flight experiments in low Earth orbit and ground-based testing in vacuum chambers containing atomic oxygen to study its effect on materials. Testing has been performed in order to determine the extent of the atomic oxygen reaction and assess material and component durability. In addition, the effectiveness of mitigation techniques such as application of a protective coating, adding fillers, or using shielding and getter materials has also been studied both in flight and ground-based experiments. This presentation will focus on defining atomic oxygen environments, discussing its effect on spacecraft materials, and describing some of the testing and mitigation techniques that have been investigated.

Atomic Oxygen Density Variations in Sub-LEO Region: SLATS/AOFS Flight Data Analysis

Atsushi Fujita, Kobe University, Wataru Ide, Kobe University, Sasuga Horimoto, Kobe University, Shohei Urakawa, Kobe University, Santa Nishioka, Kobe University, Yuta Tsuchiya, JAXA, Aki Goto, JAXA, Kazuki Yukumatsu, JAXA, Eiji Miyazaki, JAXA, Yugo Kimoto, JAXA, Yasunobu Miyoshi, Kyushu University, Kumiko Yokota, Kobe University, Masahito Tagawa, Kobe University

We have analyzed the flight data of the atomic oxygen fluence sensors (AOFS) aboard super-low altitude test satellite (SLATS) which is orbiting in the altitude of 160 km. AOFS consists of temperature-controlled polyimide-coated quartz crystal microbalance (QCM) and a mechanical shutter system for measuring AO densities in sub-LEO. AO densities at 170-250 km in altitude are analyzed by the frequency shifts of AOFS sensors due to erosion of polyimide by AO in every 3 minutes. Effects of shielding by the satellite structure and simultaneous collisions of energetic N2 in sub-LEO are both taken into considerations. It is observed that the density of AO measured by the SLATS/AOFS is almost half of that predicted by NRLMSISE-00 atmospheric model. A low density of AO is also suggested by the satellite drag such that it is concluded that NRLMSISE-00 atmospheric model overestimated the atmospheric density in this altitude range. Variations on AO density distribution during geomagnetic disturbances will also be reported.

Effect of Direct Atomic Oxygen Exposures on Carbon Nanotube Field Emission Cathode – Comparison of Flight Data and In-Situ Ground-Based Experiment

Kazuki Itatani, Kobe University, Yuki Fukami, Kobe University, Kumiko Yokota, Kobe University, Masahito Tagawa, Kobe University, Yasushi Ohkawa, JAXA, Satomi Kawamoto, JAXA

Carbon nanotube field emission cathodes (CNT-FEC) are currently planned to apply electro-dynamic tether system for deorbiting of space debris by JAXA as one of the candidates. In this presentation, results of the in-orbit experiment of CNT-FEC flown on the HTV-VI spacecraft and those of ground-based experiment is compared. In-orbit test (KITE mission) is performed by HTV-VI in 2017 at altitude of 370 km. Relationship between the change in FEC performance and the satellite attitude is investigated. It is confirmed that the emission performance of CNT-FEC is restored when it is pointed in the wake direction, however, emission performance changes drastically when FEC is pointed in the RAM direction. Effect of atomic oxygen collision on the CNT-FEC performance is strongly suggested. On the other hand, ground-based experiment is conducted by using laser-detonation atomic oxygen beam source at Kobe University. CNT-FEC is exposed to atomic oxygen beam pulses during its operation. Similar performance change observed in the KITE mission is reproduced in the ground-based experiment. It is confirmed that the major origin of performance change of CNT-FEC observed in the KITE mission is due to atomic oxygen-induced erosion of CNT.

On the Utility of Coated POSS-Polyimides for Vehicles in Very Low Earth Orbit

Tim Minton, Ann and H.J. Smead Department of Aerospace Engineering Sciences/UC, Chenbiao Xu, Ann and H.J. Smead Department of Aerospace Engineering Sciences, University of Colorado, Thomas Schwartzentruber, Department of Aerospace Engineering and Mechanics/University of Minnesota

The environment encountered by space vehicles in very low Earth orbit (VLEO, 180 – 350 km altitude) contains mostly atomic oxygen (AO) and molecular nitrogen (N2), which collide with ram surfaces at relative velocities of ~7.5 km s-1. Structural, thermal-control, and coating materials containing organic polymers are particularly susceptible to AO attack at these high velocities, resulting in erosion, roughening, and degradation of function. Copolymerization or blending of a polymer with polyhedral oligomeric silsesquioxane (POSS) yields a material that can resist AO attack through the formation of a passivating silicon-oxide layer. Still, these hybrid organic/inorganic polymers become rough through AO reactions as the passivating layer is forming. Surface roughness may enhance satellite drag because it promotes energy transfer and scattering angle randomization during gas-surface collisions. As potential low-drag and AO-resistant materials, we have investigated POSS-containing films of clear and Kapton-like polyimides that have an atomically smooth AO-resistant coating of Al2O3 that is grown by atomic layer deposition (ALD). Coated and uncoated films were exposed to hyperthermal molecular beams containing atomic and molecular oxygen to investigate their AO resistance, and molecular beam-surface scattering studies were conducted to characterize the gas-surface scattering dynamics on pristine and AO-exposed surfaces to inform drag predictions. The AO erosion yield of Al2O3 ALD-coated films is essentially zero. Simulations of drag on a representative satellite structure that are based on the observed scattering dynamics suggest that the use of the Al2O3 ALD-coated POSS-polyimides on external satellite surfaces have the potential to reduce drag to less than half that predicted for diffuse scattering surfaces. These smooth and AO-resistant polymer films thus show promise for use in the extreme oxidizing and high-drag environment in VLEO.

Wednesday

Session: Spacecraft Charging Simulations and Testing – Charging II
Chairs: Shu Lai, Wousik Kim

Invited: Environmental Testing of the Solar Probe Cup

Kenneth Wright, STI/USRA, Todd Schneider, NASA/MSFC, Jason Vaughn, NASA/MSFC, Anthony Case, Center for Astrophysics Harvard Smithsonian, Justin Kasper, BWX Technologies, Inc.

The Parker Solar Probe (PSP) spacecraft was launched on August 12, 2018. The nominal mission for PSP extends into 2025 with 24 planned encounters with the sun. The PSP perihelion over the course of the mission will decrease from 35.7 solar radii to 9.8 solar radii. At closest approach, the solar radiation flux is approximately 520 times that as at 1 A.U. Consequently, novel spacecraft design must be considered (i.e. heat shield) to survive the closest encounter as well as novel design for any instrument exposed to this extreme solar flux. The Solar Probe Cup (SPC) is an instrument that extends beyond the spacecraft heat shield and is designed for sun viewing throughout the mission in order measure the solar wind. The SPC is a Faraday Cup (FC) patterned after the Massachusetts Institute of Technology design that began in the late 1960s and has successfully flown on Voyagers 1&2, Wind, and DSCOVR spacecraft. Operationally, the SPC uses the AC modulation technique like the FCs on these previous missions but both the materials used in and the construction of SPC are unique in order to accommodate the extreme environment. This paper will outline the SPC design and the novel testing approach to prove the design could survive and function during the PSP mission that includes a high fidelity solar simulator, developed at the Harvard Smithsonian Astrophysical Observatory, and a high fidelity particle beam source, developed at the Marshall Space Flight Center (MSFC). In addition, a thermal vacuum test was performed at

MSFC to monitor electrical behavior of the collector. Since its launch in 2018, the PSP spacecraft and science instruments have successfully executed nine encounters with the sun. A summary of SPC performance to date is briefly discussed.

Efficient Computation of Differential Charging Time Scales between Cover Glass and Spacecraft Body in Severe GEO Plasma Environment

Ashish Pandya, DDU, Nikhil KothariI, DDU, Rizwan Alad, DDU, Suryakant Gupta, FCIPT-Institute for Plasma Research, Gandhinagar

This article presents the efficient computation of the capacitance matrix and transient variation of body potential of an artificial orbiting satellite modeled as a structure consisting of a cuboid with two coplanar square plates. To mimic the cover glass on the solar panel, a thin layer of an insulator is considered on top of the metallic plates. Transient variation of body potential is obtained by numerically integrating differential equation using Runge Kutta method. The numerical data on the capacitance matrix which includes the absolute as well as the coupled capacitance of this structure have been presented. The capacitance for estimation of body potential is evaluated using the Method of Moments. The evaluation is based on boundary conditions for the potential on the conductor surface and the normal component of displacement density at the dielectric-free space interface. Charging analysis for the coupled bodies is carried out with reference to that of the isolated bodies. The consequence of diverse secondary and backscattered electron yield on the intensification of differential charging is investigated between the solar array cover glass and the spacecraft body in the normal and worst case of a single Maxwellian plasma environment.

Adding Radiation Induced Conductivity Test Capability to the JPL Dynamitron

Nelson Green, JPL, Dennis Thorbourn, JPL, Allen Andersen, JPL, Anthony Eyre, JPL, Michael McKee, JPL, Jarrett Chai, JPL

The Europa Clipper space environments test campaign has made extensive use of the Dynamitron electron accelerator located at the Jet Propulsion Laboratory. One of the most common uses of this facility was to gather data on the internal electrostatic discharge (IESD) properties of the various elements of the spacecraft. These testing needs often required some reconfiguration of the accelerator system. One of the most recent and most unique upgrades was adding the ability to measure Radiation Induced Conductivity (RIC) for spacecraft materials. Adding this one of a kind capability required incorporating a new low energy electron flood gun to the existing higher energy electron beam from the Dynamitron accelerator. This new system was also designed to obtain RIC data on multiple samples per test run allowing for the acquisition of a large quantity of data in a relatively short time period. This presentation will review the design of the new system. The preliminary results will be discussed in a separate presentation.

Preliminary Results of Radiation-Induced Conductivity Testing of Europa Clipper Dielectric Materials

Allen Andersen, JPL, Nelson Green, JPL, Qian Nataly Chen, JPL, Denis Thorbourn, JPL, Brian Xiaoyu Zhu, JPL, Wousik Kim, JPL

A key component to internal electrostatic discharge (IESD) mitigation for Europa Clipper is ensuring that charge accumulated in spacecraft dielectrics from the Jovian radiation environment decays to the spacecraft chassis ground quickly enough to avoid retaining charge from one orbit to the next. The charge-decay time-constant depends on the dielectric's conductivity, which needs to be short enough to bleed off charge accumulated during the short high-radiation portion of the orbit, around each Europa flyby. For some dielectrics with very low intrinsic

conductivity, this charge-decay time constant is more than one orbital period. However, the conductivity is sometimes increased by exposure to radiation, and this radiation-induced conductivity (RIC) may produce a charge-decay time constant short enough to bleed off charge within one orbit. These material properties were not available for most of the numerous dielectrics that would be used on Europa Clipper. JPL has developed a new test system to characterize RIC for up to 34 materials in parallel during a single test run using a modified charge storage conductivity test method. This enables dielectrics to be screened in batches and to be assessed in a reasonable timeframe by providing useful bounding values for both dark conductivity and RIC. We present the preliminary results of this test campaign. The implementation of the new test system is discussed in a separate presentation.

Internal ESD Control and Assessment for Europa Clipper Inter-subsystem

Kit P. Frankie Wong, Bastion Technologies, James Bodie, JPL,
Narek Shougarian, JPL, Wousik Kim, JPL

Space environment induced charging can occur due to its plasma and high energy particles. Charging is especially severe in certain earth orbits in the radiation belt region and highly inclined orbits. Spacecraft that travels to other planets such as Jupiter also encounters even higher level of charging due to its severe radiation belt. The major concern on spacecraft operation due to charging is the survival of its sensitive electrical circuits. Dielectric and floating metal can charge up and discharge onto interface circuits. This paper addresses the Internal ESD (IESD) on the Europa Clipper program. The potential damages on electrical circuits are required to be controlled and we present the method used to assess the survivability against those damages.

The important or sensitive electronics are often located inside a heavily shielded enclosure but IESD generated outside the enclosure can enter the circuits within the enclosure through the wiring that connect them. The electrical circuits that interface with the components in the high charging environment on the spacecraft where IESD can occur have been identified (e.g., units external to the enclosure).

The purpose of this article is to describe the four legs of the IESD mitigation program on Europa Clipper:

- IESD source and victim matrix:

Identify the IESD magnitude on each interface and the victim part ESD rating

- IESD dielectric keep-out-zone:

Identify the dielectrics near each harness that can couple the discharge onto the wiring and eventually onto the interface circuit

- IESD protection method trade study:

If IESD protection is needed, what is the best way to implement protection when a circuit has already been designed. Some electrical units have been designed and qualified in previous missions, and some units are in the process of qualification.

- IESD assessment on circuit damage survival:

IESD analysis is needed to evaluate all the interface circuits as an end-the-end system to evaluate the true impact due to IESD for both line-to-line and line-to-chassis discharges.

Session: Current and Future Missions
Chairs: Terry Onsager, Joseph Minow

Invited: The Commercial Lunar Payload Services (CLPS)

Darryl Gaines, NASA/JSC

The Commercial Lunar Payload Services (CLPS) project is opening the door to lunar exploration on a cadence not seen since the mid-1960s. Following a model similar to that of major national delivery services (e.g. USPS), NASA has contracted with 14 commercial companies that may propose to deliver payloads to the lunar surface in order to support scientific investigations, technology demonstrations, and reduce risk associated with the human return to the Moon. NASA intends to solicit for at least two deliveries to the lunar surface per year for the foreseeable future with the first two deliveries to Lacus Mortis and Oceanus Procellarum in 2022 followed by 6 other deliveries through 2024 spread around to scientific regions of interest including the lunar poles, lunar magnetic anomalies, as well as volcanic and impact terrains. Future deliveries beyond 2024 will focus on answering major scientific questions outlined in community documents and may begin delivering infrastructure associated with the Artemis humans to the surface campaign. This talk will outline the philosophy behind the CLPS model, describe upcoming lunar deliveries, and discuss the various opportunities open to the greater community for contributing/proposing a payload for lunar surface operation.

Materials Environmental Testing Challenges for ESA's Future Space Missions

Adrian Tighe, ESA/ESTEC, **Nuno Dias**, ESA/ESTEC, Johanna Wessing, ESA/ESTEC, Bruno Bras, ESA/ESTEC, Ricardo Martins, ESA/ESTEC, Riccardo Rampini, ESA/ESTEC, Bruno Delacourt, ESA/ESTEC, Yuriy Butenko, ESA/ESTEC

The European Space Agency (ESA) is preparing a portfolio of future missions, such as the "Voyage 2050" roadmap for Science. These missions which will encounter a multitude of characteristic environments from Earth orbit to deep space, including among others, the surface of the Moon, planets and asteroids, as well as missions to the inner and outer solar system. On the one hand, these missions will be more demanding in terms of performance requirements and will make use of new advanced manufacturing processes, while on the other hand the so-called "New Space" companies may increase the use of commercial parts and materials. The environmental testing group in ESA's Materials Physics and Chemistry section is tasked with supporting space projects to verify the performance of these materials and associated processes in simulated space environments. For this purpose, the group's experimental capabilities include a wide range of vacuum test facilities and measurement techniques ready to adapt for new missions.

This paper will present results of testing recently performed in our laboratories which are paving the way for future space missions. This includes simulation of electron charging, ultraviolet (UV) exposure and thermal endurance testing of materials for the Jupiter icy moons explorer (JUICE), the combined UV and atomic oxygen testing of coatings for future earth observation missions in low earth orbit, and the environmental testing of commercial-off-the-shelf optical coatings. The challenges and benefits of in-situ measurements will also be discussed, such as measuring the reflectance of coatings after UV irradiation without breaking vacuum in between. This technique was of particular benefit when testing high temperature white coatings for the BepiColombo mission which is now on its way to Mercury. Finally, an overview of some of the facilities and new testing techniques under development for future missions will be given. This includes a multipurpose radiation simulation facility for combined environmental testing, a dust contamination simulation facility for lunar surface studies and a compact particle accelerator for space debris impact testing. High temperature atomic oxygen testing of materials is also planned to simulate the aerobraking environment which will be encountered in the atmosphere of Venus by ESA's future Envision mission.

Advances in Management of Decompression Sickness in Space

Peter Anto Johnson, University of Alberta, John Christy Johnson, University of Alberta

While microgravity can create physiological changes in the respiratory system, they typically influence respiratory function minimally. Instead, exposures to vacuum in space is an environmental factor which plays a much more critical role in the physical health of the respiratory system in astronauts. Direct exposure to the vacuum to breathing orifices, ears and eyes can be lethal leading to unconsciousness, respiratory collapse, and death, among its most severe effects if not addressed urgently. For the rest of the body, exposure to a vacuum will have milder effects, which is still dangerous if prolonged. Decompression is one of these effects and may result in the expansion of flesh up to twice its original volume, which results in a body-fluid imbalance, different effects on body systems, and often causes physical appearance resembling that of a bodybuilder. Pressure garments incorporated in current space suit designs ensures the maintenance of constant internal pressure and protection during extravehicular transport and as a safety precaution in cases of cabin pressure loss. However, in spite of this protection, sudden changes in pressure increase the risk of decompression sickness in either of these situations. Before entering a space suit, current designs recommend inhalation of 100% oxygen by the astronaut for approximately one to two hours as a preventative measure. Resuscitative interventions such as mechanical ventilation using pure hyperbaric oxygen can be a treatment for this condition. Currently, astronauts experiencing decompression sickness necessitate must travel to a vented airlock which is a depressurized recompression chamber typically in a space shuttle making it difficult during extravehicular transport.

Understanding Spacecraft Test Environments in JPL’s Twenty-Five-Foot Space Simulator

Maxwell Martin, JPL, Carlos Soares, JPL, John Alred, JPL, William Hoey, JPL,
John Anderson, JPL, Ned Ferraro, JPL

The Contamination Control Engineering group at the NASA Jet Propulsion Laboratory has developed analytical capabilities to simulate the transport of molecular and particulate contaminants across all spacecraft mission phases, including environments ranging from ambient pressure conditions to rarefied and fully free-molecular regimes experienced on-orbit and simulated in terrestrial vacuum chambers [1,2,3]. NASA has begun payload collaborations with non-traditional mission subcontractors, which has placed a new emphasis on applying these analysis tools to pre-launch thermal vacuum testing in order to protect institutional assets – such as JPL’s historic Twenty-Five-Foot Space Simulator – during full payload bakeouts. Featured analysis tools include ray-tracing Monte Carlo schemes for the high-resolution simulation of free-molecular transport in complex geometric environments and physics-based, multispecies outgassing rate models premised on rigorous materials testing. JPL CC has found analytical modeling to be a valuable step in augmenting vacuum chamber testing campaigns at spacecraft scale, not only in the interpretation of post-test results, but also in enabling informed pre-test preparations and mitigations. This presentation documents the process of developing chamber cleanliness success criteria; building, sourcing relevant boundary conditions for, and applying a spacecraft-chamber integrated outgassing transport model; advanced mitigation options available to protect chambers during high-risk tests; and the contamination, cost, and schedule impacts of neglecting such preparations.

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2. Alred, J., Martin, M., Hoey, W., Wong, A., White, L., Boeder, P., Cofer, S., Dias-Ribeiro, A., Soares, C., 2020. “Predicting Terrestrial Contamination of the Mars 2020 Sample Caching System with Novel Multispecies Outgassing and Transport Models,” Proceedings of the SPIE Optical Engineering + Applications Conference.
3. Martin, M., Wong, A., Hoey, W., Alred, J., Boeder, P., Soares, C., 2019. “Advancements in Monitoring and Operating Thermal Vacuum Environmental Test Chambers for Next-Generation Space Exploration Hardware,” 66th International Symposium of the American Vacuum Society.

Experimental and Simulation Studies of the Adhesion of Titan Dust Simulants on Transparent Windows

Jason Benkoski, JHU/APL, Timothy Montalbano, JHU/APL, W. Lloyd Luedeman, JHU/APL, John Teehan, JHU/APL, Ralph Lorenz, JHU/APL, Elizabeth Turtle, JHU/APL

The factors controlling the adhesion of dust particles are critical for the design of camera systems used on the Moon, Mars, asteroids, and now Titan. Previous experiments determined that the adhesion of Titan dust simulants to a transparent surface can be minimized by minimizing the sheet resistance and surface energy of the window. To test the effects of airflow velocity, sapphire windows with an indium tin oxide coating and fluorosilane treatment were exposed to aerosols of three Titan dust simulants: melamine, polymethyl methacrylate, and polystyrene. The primary finding was that severe fouling only occurred within a surprisingly narrow velocity range centered around 0.11 m/s. At slower velocities, few particles were lofted towards the window, and at higher velocities, the heavier particles cleared the smaller particles as they ricocheted off. The results are consistent with modeling to a first approximation of spheres on a flat surface if one considers that irregularly shaped particles have multiple point contacts with radii that are much smaller than that of the overall particle radius.

Work Function Matching Passive Lunar Dust Mitigation Coating Preparation for Lunar Flight Opportunities

Sharon Miller, NASA/GRC, Bruce Banks, SAIC

With the Artemis program, NASA is planning longer stays on the surface, with more activities that have the potential to put the astronauts and equipment in contact with greater quantities of lunar dust. The success of these missions will depend on our understanding of material interactions with lunar dust and the development of ways to mitigate dust effects. This is particularly true in cases where exposure to dust will lead to failure of components, unacceptable loss of power or thermal control, unacceptable loss of visibility, or health issues. Optically transparent, sputter deposited, work function matching coatings are being developed at NASA Glenn Research Center to reduce adhesion of dust to windows, lenses and display panels by matching the minimum energy to remove an electron from the surface to that of lunar dust in order to reduce adhesion due to charge transfer. One of these work function matching coatings will be tested as part of Aegis Aerospace Inc.'s Regolith Adherence Characterization experiment going to the lunar surface on a Commercial Lunar Payload Services (CLPS) lander in 2023. Preparation of the work function matching coating and initial characterization prior to delivery for flight integration will be discussed.

Session: Other Space Environments and Effects
Chairs: Dave Pitchford, Nicole Pothier McGillivray

Plume-Surface Interaction: Preliminary Observations from a Physics Focused Ground Test

Wesley Chambers, NASA/MSFC, Juan Sebastian Rubio, JHU, Matt Gorman, JHU, Miguel Diaz-Lopez, JHU, Rui Ni, JHU, Manish Mehta, NASA/MSFC, Chad Eberhart, NASA/MSFC, Ashley Korzun, NASA/LaRC

Near surface operations conducted by spacecraft using rocket propulsion, such as during landing or the initial portion of ascent, may induce surface interactions that pose a risk to the spacecraft itself or nearby assets. NASA's Space Technology Mission Directorate is conducting a multi-year project to mature the capability to predict plume-surface interactions (PSI) and reduce uncertainty through modeling, simulation, and ground testing. The Physics Focused Ground Test (PFGT), conducted in summer 2021, aimed to collect PSI data for plume, erosion, and ejecta physics to characterize PSI behaviors across a range of parameters relevant to the validation of computational modeling and with consideration to flight-relevant, though not flight-scale, environments. PFGT is a sub-scale, intrusive half-plane, inert-gas test conducted in a 15 foot-diameter vacuum chamber using a supersonic, heated, gaseous nitrogen plume. Tests were conducted with six regolith simulants, varying in complexity from spherical glass beads to BP-1 lunar soil simulant, and varied vacuum chamber ambient pressures to simulate Martian and lunar conditions. Nozzle height and mass flow rate were also varied to observe PSI behaviors and transitions of interest. Three high speed cameras captured crater formation and ejecta behavior during each test. An overview of this experiment is presented along with preliminary observations and analysis.

Meteoroid Ejecta of Lunar Secondaries Engineering Model

Anthony DeStefano, NASA/MSFC

The Meteoroid Ejecta of Lunar Secondaries Engineering Model (MELSEM) is a new engineering model to replace the Apollo-era lunar ejecta model defined in NASA SP-8013. MELSEM generates a secondary ejecta environment at a given asset from primary sources, sporadic meteoroids and near-Earth objects, that are incident on the lunar surface. For simplicity, the asset is assumed to be cylindrical in shape, although a relatively arbitrary geometry can be defined. For lunar lander applications, the asset would be on the lunar surface, but in general, the asset can have any location on or above the lunar surface. A complete trajectory of the asset may be used, which would require time-dependent primary sources. In this work, a single-point trajectory is employed to prove the concept.

The secondary ejecta environment at the asset originates from secondary ejecta generated by the impact of primary sources that occurs over the entire surface of the Moon for a range of impact sizes, masses, speeds, and directions. For each primary impact, the secondary ejecta production is based on scaling laws shown in Housen & Holsapple 2011. A fraction of the available secondary ejecta reaches the asset for any given primary impact, contributing to the secondary environment. A novel Monte Carlo method was developed for MELSEM to find that fraction, greatly reducing computation time compared to a more naïve Monte Carlo approach of randomly sampling secondaries strictly uniformly.

A format identical to the Meteoroid Engineering Model (MEM3) is adopted for the secondary ejecta environment produced by MELSEM to seamlessly be applied for risk analysis using Bumper codes lead by the Hyper Velocity Impact Technology (HVIT) team at NASA Johnson Space Center. The format includes information about direction in altitude and azimuth for each speed range. Additionally, a particle size distribution is tracked as well, since Bumper analysis hinges on ballistic limit equations that define penetration/no penetration/spallation using a combination of particle sizes and speeds.

Lunar Surface Environments Added to the Design Specification for Natural Environments

Aurelio Paez, NASA/MSFC

The Cross-Program Design Specification for Natural Environments (DSNE, SLS-SPEC-159) is a Natural Environments document that is baselined for Space Launch System (SLS), Orion, Exploration Extra Vehicular Activity (xEVA), Gateway, and Human Lander System (HLS). Since its adoption it has gone through various revisions. The discussion will revolve around the Lunar surface environments sections that have been updated in preparation of NASA's return to the moon.

Theory of Whistler Waves

Antony Soosaleon, MGU

Earth magnetosphere is rich in variety of musical notes which is called Whistler waves has been the subject of study ever since it has been detected. Several observations proves that these waves are electromagnetic and amplified by lightning discharge also it is propagating along the magnetic field, but the exact origin of these waves still found to be the mystery. Here, I want to discuss the theory of these waves using magnetohydrodynamical equations. Analysis shows that the gravitational drift of ions induces ion acoustic oscillations and the propagation of electromagnetic waves causes an inverse damping of electron energy which results to the acoustic waves causing a variety of whistler waves. A general formula has been deduced from the dispersion relation and which is used for generating various Whistling observed in the earth atmosphere. The formula clearly shows that the whistler waves are depending on the electron energy and density and the gravity but inversely related with the magnetic field.

Electrolytic Nickel Sublimation Barrier Films for Neutron Sensor Cadmium Shields

Milena Graziano, JHU/APL, David Lee, JHU/APL, Ray Liang, JHU/APL,
Curt Walsh, JHU/APL, Zachary Yokley, JHU/APL

Neutron spectrometers (NS) are key space exploration tools that identify the elemental composition of asteroid, lunar, and planetary surfaces through the detection of free neutrons produced from cosmic ray-particle interactions. NS can measure neutrons of a wide range of kinetic energies, generally classified in three main bands: thermal, epithermal, and fast. Neutrons of a certain energy can be targeted by implementing metallic shields on detectors, such as cadmium (Cd) foil filters for the selective absorption of epithermal (0.5 eV – 10 keV) neutrons. The use of bare Cd metal is largely prohibited in spaceflight hardware due to its toxicity and the risk for sublimation in space vacuum. To address these concerns, a process was developed to reproducibly deposit µm-thick electrolytic nickel (Ni) films on Cd metal foils. Test articles were characterized throughout the plating process and evaluated for Ni plating thickness, defects, and substrate adhesion. Results confirmed the coating is conformal to Cd test coupons, visually characteristic, and compliant to ASTM B571 adhesion tests. To confirm space environment survivability, Ni-coated Cd samples were subjected to temperature and pressure conditions below the Cd vapor pressure. Tests identified a Ni plating thickness range that proved to be an effective sublimation barrier for the Cd foils. The use of Ni barriers on Cd metal can eliminate personnel safety and NS instrument performance risks.

Thursday

Session: Spacecraft Charging Simulations and Testing – General II
Chairs: Nelson Green, Jason Vaughn

Space Environment Effects on the Electron Yields of Thermal Control Coatings from the Long Duration Exposure Facility

Trace Taylor, USU, Matthew Robertson, USU, JR Dennison, USU,
Michael Guy, NASA/MSFC, Emily Willis, NASA/MSFC

Space environment induced degradation of white thermal control coatings from the Long Duration Exposure Facility (LDEF) was investigated. Much of the exterior of LDEF was painted with a white thermal control coating Aeroglaze A276, and most of LDEF's interior was coated with a black thermal control coating Aeroglaze Z306. Many materials properties were modified due to the prolonged ~6 yr LEO exposure, but electron yield (EY) was the main focus of this study since it had not been previously measured and due to its dominance in spacecraft charging. Outgassing from these coatings and contamination from other LDEF materials interacted with the white surface when exposed to sunlight after volatile materials condensed on the LDEF surfaces. Polymerization of new chemical compounds on the LDEF exterior darkened the white paint, with obvious effects on surface optical reflectivity, emissivity, and thermal control properties. Surface morphology was characterized by optical and scanning electron microscopies. Fourier-transform infrared spectroscopy and energy-dispersive x-ray spectroscopy were used to identify the chemical compounds and elements present in the evolving contamination film. Measurements showed an increase in maximum EY with increased contamination, with nearly double the maximum yield at the highest surface contamination. Simulations for simplified models of LDEF show the impact of the degradation on spacecraft charging.

Dielectric Breakdown Simulations using Stochastic Tree Model

Gregory Wilson, EMA, Kevin-Druis Merenda, EMA, Bryon Neufeld, EMA

Internal charging simulations are a valuable tool when assessing the survivability of a component in harsh space environments. Generally, when such simulations are performed, associated risk is calculated based on maximum electric fields, total integrated energy, and total accumulated charge. By incorporating a dielectric breakdown model into internal charging simulations, the energy, current, and charge associated with a given electrical breakdown can be quantified. After a given breakdown, the resulting material change due to the conductive carbonized channel can be simulated, showing the evolution of charging after subsequent breakdowns. This allows a more in depth analysis of potential risks associated with internal charging.

Building Circuit Models of Internal Electrostatic Discharge Events

James Chinn, JPL, Wousik Kim, JPL

One of the challenges facing spacecraft in high radiation environments is internal electrostatic discharge (IESD). Electrons from the environment get trapped in nonconducting materials, resulting in dielectric breakdown, which can in turn inject current pulses into electronics. One way of ensuring spacecraft survival in these environments is to characterize the IESD sources on the spacecraft and their compatibility with victim electronics. To do this, electron beams are used to charge up samples to the level expected in flight, and IESD events are measured as the voltage across or current through a load connected to the sample. During testing, events are recorded for one particular load, but in flight, the ESD event may propagate to many varied loads. The response of these different components to the source event can be predicted with circuit models. Often, an RC circuit similar to that used for Human Body Model (HBM) ESD testing is used to model the IESD event. In this case, three parameters need to be specified: the capacitance, voltage, and resistance of the RC circuit. The parameters are usually chosen to match the peak current and total energy delivered to the load during the test. However, with only these two parameters linking the model to the test, the problem is underdetermined. For instance, the peak current is dependent on the ratio of the voltage and resistance, allowing for a high voltage with high internal resistance, or a low voltage with low internal resistance. The circuit parameters defining the energy are similarly underdetermined. One way to constrain the problem without being overly conservative is to use an internal charging model to simulate the test article, checking either at what voltage the geometry reaches the material's dielectric strength, or the maximum voltage the sample reached during the test. Of course, the results of these simulations are only as good as the material properties used and the detail of the modelled geometry, but these simulations can still be used to come up with a reasonable conservative upper bound for the voltage and a usable circuit model.

What is Real Conductivity under Radiation?

Wousik Kim, JPL, Allen Andersen, JPL, James Chinn, JPL, Insoo Jun, JPL,
Nelson Green, JPL, Dennis Thorbourn, JPL

Spacecraft may encounter high flux and high energy electron environments. Sufficiently energetic electrons may penetrate the spacecraft structure or electronics chassis and deposit charge within dielectrics and floating metal such as circuit boards, cable insulation, staking and potting materials, etc. Electrons can accumulate in these materials over the time and can lead to Internal ElectroStatic Discharge (IESD), damaging sensitive electronics. The evaluation of the electric fields and potentials in dielectrics is essential for an IESD risk assessment, and an accurate assessment depends on using accurate and appropriate material properties such as electrical conductivity, dielectric constant, and dielectric strength.

It is known that electrical conductivity has a component that is a function of instantaneous radiation flux (Radiation Induced Conductivity (RIC)) and a component that is not (such as dark conductivity). RIC is typically measured as an increase in conductivity as a function of instantaneous dose rate, which becomes zero when radiation stops. Dark conductivity is typically measured over long times (days or weeks) until a steady state value is reached. When using an electron beam to charge the sample prior to measurement, it is often observed that the apparent conductivity right after radiation stops is much larger than the steady state, or dark conductivity and keeps decreasing to the dark conductivity. In recent conductivity tests at JPL using the above method, a second charging flux was applied after the sample reached steady state. After the second irradiation, the material showed the similar behavior as after the initial irradiation (i.e. apparent conductivity is initially large and gradually decreases to dark conductivity). This repeated appearance may imply that transient conductivity is another type of inherent conductivity, and the conductivity during and after radiation may be larger than the dark conductivity (this is in addition to RIC). This presentation proposes to re-think what real conductivity under incoming radiation is.

Touchless Potential Sensing Model for Active Spacecraft Charging Scenario

Alvaro Romero-Calvo, UCB, Kaylee Champion, UCB, Hanspeter Schaub, UCB

Novel active sensing methods have been recently proposed to touchlessly sense the electrostatic potential of non-cooperative objects in Geosynchronous Equatorial Orbit and deep space. Such approaches make use of a positively charged servicing craft that directs a high-energy electron beam at the object of interest so that low-energy secondary electrons (SEs) and X-rays are emitted from its surface. The servicer measures the incoming fluxes and, knowing its own potential, infers that of the target.

Previous works have tested these methods in a controlled vacuum chamber environment by means of simplified geometries, such as spheres or flat plates. However, the electric field induced by a charged spacecraft is highly inhomogeneous and leads to non-trivial particle trajectories. In a differential charging scenario, the problem is further complicated by the electrostatic steering of SEs. Recent works have addressed the behavior of 3D shape primitives and multi-potential flat plates using relatively simple Matlab simulations, but real-life scenarios are significantly more complicated. Further efforts are consequently required to analyze such problems and develop more powerful simulation frameworks.

A general-purpose SIMION model is introduced to study the generation, propagation, and measurement of secondary electrons in active spacecraft charging scenarios. The electron beam dynamics, SE generation, and electrostatic environment are implemented by means of a series of user-defined LUA functions, resulting in a tool that provides key insights into the dynamics of SEs and that should eventually enable the analysis of cases of practical interest. The study of photoelectron emission is discussed as well. Initial results are presented adopting the geometry and physical properties of an ongoing vacuum chamber experiment.

Session: MMOD Environment, Effects, Testing, and Mitigation

Chairs: Anne Bennett, Martin Ratliff

Invited: Overview of the National Orbital Debris R&D Plan

Michael Squire, NASA/LaRC

In January 2021, the White House Office of Science and Technology Policy office released the National Orbital Debris Research and Development plan (ODRAD). This document was developed by a multi-agency team to present a national R&D plan for orbital debris mitigation, tracking, characterization, and remediation. This presentation will introduce the audience to the report, highlighting what are seen as the primary challenges relative to orbital debris and what is planned, from an R&D perspective, to address them.

Some Unexpected Risks from Lunar Ejecta

Mark Matney, NASA/JSC

Human or robotic operations on the lunar surface or other airless bodies are vulnerable not just to direct impacts from meteoroids, but by impacts of meteoroids or asteroids elsewhere on the planetary surface excavating a large mass of high-speed ejecta that may in turn impact the asset. While this ejecta environment has been known since Apollo days, recent analysis of this risk has uncovered some interesting and unexpected properties of the ejecta environment. This includes a non-trivial contribution from nearby primary impacts (within a few tens of meters) where the ejecta impact the asset while still ascending from the planetary surface, over and above the more "traditional" ejecta component that descends from above. In addition, the outsized contribution to the ejecta risk from nearby primary impacts (within a few tens of kilometers) relative to impacts far away means that the flux on an asset will show considerable stochastic variability, such that a simple average flux may not reveal the full impact risk to a mission. This presentation will describe some of these phenomena and offer suggestions for how these risks can be better calculated to ensure mission

Predicting the Size of the Largest Particle Fragment in a Debris Cloud Created by an Orbital Debris Impact and its Associated Velocity

William Schonberg, MUST, Joel Williamson, Institute for Defense Analyses

All spacecraft are subject to the possibility of high-speed particle impacts during their mission life. In low earth orbit, those impacts could be the result of collisions with pieces of orbital debris or with meteorites. Beyond LEO, and especially beyond GEO, those impacts will likely be caused by meteorites. Such high speed impacts on spacecraft surfaces create debris clouds that travel towards and eventually impact other downstream spacecraft components. In addition to the impulsive load that such debris clouds would impart to the spacecraft elements with which they subsequently collide, the largest fragment in these debris clouds poses a significant threat on its own to those spacecraft elements. In order to be able to assess the severity of the threat posed by such a fragment, it is important to be able to predict the size (or mass) of this largest fragment and its associated velocity. In this paper, we develop empirical equations that can be used to predict these quantities in terms of the material properties of the surface that sustains the initial impact, the characteristics that define the impact event, and the material properties of the impacting projectile. The predictions of the equations we develop are compared against experimental values for largest fragment velocity and its associated velocity and the predictions of these quantities obtained using numerical simulations of high speed impact events. These comparisons indicate that the empirical predictor equation for the size of the largest debris cloud fragment fairs reasonably well at lower impact velocities (i.e. below 7 km/s), but over-predicts this quantity at much high impact speeds (i.e. at 30 km/s). However, the empirical equation for the velocities associated with these largest fragments fairs reasonably well across the entire impact velocity regime considered. We end the paper with suggestions for how to improve the predictive capability of the empirical equation for size of the largest debris cloud fragment so that its predictions are more in line with experimental results and numerical simulation predictions.

Automated Detection, Location, and Evaluation of Hypervelocity Impacts to Space Vehicles and Structures

Aaron Trott, Invocon, Inc.

A system is being developed to autonomously detect, locate, and evaluate hypervelocity impacts (HVIs) to space vehicles and structures. Impact detection provides situational awareness to crew or ground personnel. Knowing the precise location of damage minimizes valuable search time. Understanding the magnitude of the damage aids in prioritizing and preparing for mitigation activities.

Visual observations are not always reliable indicators of impact damage. Therefore, Invocon is building upon its previously developed automated detection and location capabilities. The present work is adding evaluation of the impacts to these capabilities in order to prevent subsequent catastrophic breakup of space vehicles during re-entry or the loss of consumables due to latent leaks.

This presentation will discuss details of the problem along with Invocon's approach to solving it. Additionally, evidence of the drawbacks to inspection will be provided and discussed.

Session: Instrument and Measurement Techniques
Chairs: JR Dennison, Todd Schneider

Invited: US Air Force Academy Electrostatic Analyzer

Geoff McHarg, USAFA, Gabe Wilson, USAFA, Richard Balthazor, USAFA, Carlos Maldonado, LANL

We review the design and on-orbit data obtained from a flat plate electrostatic analyzer. This simple design allows undergraduate cadets at the United States Air Force Academy to participate in the design, implementation and analysis of ionospheric plasma data. The design relies on this stainless steel plates with small-etched slots, which allow ions to enter the analyzer. Depending on the arrangement of the slots in the plates, we can achieve either a retarding potential analyzer, or a ion energy bandpass filter. We review three different designs, which have flown on nine different instruments in low earth orbit. The USAFA flat plate analyzer has proven very successful, and given over 50 cadets direct experience making measurements of the ionosphere.

Potential for polSAR Technology to Characterize Martian Terrain Habitability

Peter Anto Johnson, University of Alberta, John Christy Johnson, University of Alberta,
Austin Mardon, University of Alberta

Since lava tubes or levees were first identified on Mars, there has been curiosity towards sampling cave minerals due to the potential for unraveling historical or current interplays between water and subsurface regolith. Drawing further, perhaps it can provide some of the first moves towards Martian habitability.

Akin to the Mauna Kea in the Hawaiian Islands on Earth, the Olympus Mons is the consequence of numerous basaltic lava flows from volcanic vents. Research in terrestrial analogues has indicated the presence of small mineralized nodes called coralloid speleothems in these tubes which have a postulated link with biofilm that forms in caves. As a plausible source/sink of microbial diversity and associated geo-microbiological interactions, the mineralization can provide an important historic time bank for Mars.

The utilization of polarimetric synthetic aperture radar (polSAR) data analysis has had a myriad of terrestrial applications, including but not limited to terrain and land use classification. Its use has previously been described in detecting anomalies on terrestrial levees. They report the high spatial resolution and soil penetration capabilities as important elements in identifying regions of interest. Typically, SAR imagery relies on algorithms that must be extensively optimized for reliably modelling the images statistically. However, fundamental to statistical modelling is an in-depth recognition of the terrain scattering mechanism. If we can train a machine learning algorithm to optimize edge detection of Martian levees, it could provide us a way to provide space agencies with the pinpointed longitudinal and latitudinal points for landing future spacecrafts.

Solar-powered Unmanned Aerial Vehicles for Crater Counting and Prospecting Planetary Bodies

John Christy Johnson, University of Alberta, Peter Anto Johnson, University of Alberta, Austin Mardon, University of Alberta

Unmanned aerial vehicles (UAVs) hold tremendous promise for the collection of atmospheric measurements, soil sampling, exploring lava tubes, and the search for extant life on Mars, the Moon, and other extraterrestrial bodies. It is important to consider and describe some specifications before deployment for design of UAVs that can effectively be used to better characterize craters. [1]

The craft must possess either a relatively long rotor battery life or some alternative form of fuel. For example, NASA's Extreme Access Flyers are using jets of oxygen gas and water vapor as propellant to aerially maneuver and are estimated to last ~20 minutes [2]. This is the time restriction for acquisition of photo and video data of the topography of the extraterrestrial body of interest.

The use of solar-powered UAVs for over grounds exploration, which effectively can overcome the time limitations. This will allow for more rigorous methods of crater counting such as the use of automated programs or real-time neural networks to calculate crater count from photo/video data.

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m-NLPs Inference Models Using Simulation and Regression Techniques

Guangdong Liu, University of Alberta, Sigvald Marholm, University of Oslo, Anders Eklund, University of Oslo, Richard Marchand, University of Alberta

Langmuir probes are often used on satellites or in lab plasma experiments to infer plasma parameters such as density, temperature, and satellite floating potential. An interesting application of such probes consists of using multiple fixed-bias needle probes (m-NLPs) to sample plasma simultaneously at different bias potentials. The use of fixed bias probes has the advantage of eliminating the need for sweeping bias voltages, thus increasing the instrument sampling rate. The current inference techniques for processing needle probe data are often based on the Orbit Motion Limited (OML) theory which relies on several simplifying assumptions. Some of these assumptions, however, are typically not well satisfied in actual experiments, thus leading to uncontrolled uncertainties in inferred plasma parameters. In order to remedy this difficulty, three-dimensional kinetic simulations are used to construct synthetic data sets, which are then used to construct and validate regression-based models capable of inferring electron density and satellite potential from 4-tuples of currents collected with fixed-bias needle probes similar to those on the Norsat-1 satellite. The trained model is then applied to actual Norsat-1 data to infer densities and satellite potentials.

Energetic Electron and Photo-electron Emission Impact on Spacecraft Potential

Richard Marchand, University of Alberta, Andrew Yau, University of Calgary

In the ionosphere, satellite potentials are commonly inferred to be significantly lower than the approximate -3 kTe estimate resulting from balancing thermal electron and ion fluxes at steady state. Several processes are at play to affect satellite potentials in space, including the use of electron beams in active experiments, photo-electron emission from surfaces exposed to solar radiation, and impact by energetic electrons. The effect of these processes on low Earth orbit (LEO) satellites are studied and quantified using 3D self-consistent kinetic simulations under representative conditions of ionospheric space environment, with realistic satellite geometries. While photo-electron emission from satellite surfaces and electron beam emission tend to raise a satellite potential with respect to the plasma background, the presence of energetic electrons is shown to significantly lower that potential. Example case studies are presented for simplified Swarm and CASSIOPE satellites geometries.

Session: In-flight Observations and Events
Chairs: Emily Willis, Linda Neergaard Parker

Invited: Identifying Minor Debris Strikes in Spacecraft Telemetry: Methods and Applications

Anne Bennett, CUBoulder, Hanspeter Schaub, UCBoulder

Debris strikes on operational spacecraft are becoming more common due to increasing numbers of space objects. Returned space objects indicate hundreds of minor strikes, but rigorous analysis is often only performed when a strike causes an anomaly in spacecraft performance. Developing techniques to identify and assess minor strikes that do not immediately cause anomalous behavior can help to validate models for debris populations, perform risk assessments, and aid in attribution of future anomalies. This topic is motivated by a 2017 NASA study which indicated discrepancies between predicted debris impacts based on models and impacts observed on orbit. A key recommendation of the report was to monitor on-orbit systems for abrupt momentum transfers to produce a dataset for further model evaluation.

This research models spacecraft dynamics to identify the effects of subtle debris strikes. Algorithms are developed to highlight these effects, permitting detection of subtle strikes when applied to spacecraft telemetry. Specific algorithms include digital signal processing techniques and change detection algorithms. The performance of these algorithms is tested on simulated data. The algorithms are then applied to the telemetry of NASA spacecraft, and the results are discussed. Potential applications for these techniques on both local scales (i.e, one operator) and global scales (i.e, space community) are discussed.

This research lays the groundwork for a novel approach to collecting in situ debris measurement data to support debris risk assessment validation and tuning. When a strike causes an anomaly the telemetry is analyzed thoroughly to determine causes and effects, but a minor debris strike causing no anomalous behavior can go unnoticed. This research develops techniques and algorithms to identify and assess these minor debris strikes using spacecraft telemetry. With the upcoming proliferation of large-scale constellations it is imperative to maintain accurate knowledge of the current debris environment and have effective risk assessment tools to incentivize appropriate behavior among the global space operator community. Using the satellites themselves to obtain in situ measurements provides a novel way to improve knowledge of the local debris environment in support of evolving space architectures.

High Energy Electron Flux Estimates of the Juno Environment Near Jupiter Compared to the JPL GIRE3 Model and the Galileo Data Base

Henry Garrett, JPL, Insoo Jun, JPL, Brian Xiaoyu Zhu, JPL

An extensive data base (Zhu et al., 2021) has been developed which provides estimates of the integral 1 MeV and 6 MeV electron fluxes estimated using observations by the Juno UVS and JEDI instruments. This data base provides a valuable resource for updating the JPL Jupiter GIRE3 environmental model. The latter model is extensively used by JPL and others in the design of spacecraft missions to Jupiter. This paper describes the first step in that updating. In particular, the Juno data base is "cleaned" to remove extraneous and obviously inaccurate data. The results are then analyzed by studying variations in the data with B field and L shell. The Juno data B-L coverage is compared with the Galileo data base and the GIRE3 model B-L data coverage. The end products indicate that while the Juno data demonstrate large orbit to orbit variations, there are observable trends in the data that can be applied to updating the high energy (1-6 MeV) electron environment in B-L ranges not previously included in the development of the GIRE3 model nor covered by Galileo.

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Use of Virtual Reality Environments in Manned Space Missions for Mental Health

John Christy Johnson, University of Alberta, Peter Anto Johnson, University of Alberta

This abstract argues that Virtual Reality [VR] has immense practical applications in fighting against fundamental mental health issues in long-term space exploration that develop in isolated, confined, and extreme [ICE] environments. Additionally, this paper will explore problems with VR as a solution to mental health issues in long-term space exploration and possible resolutions to these challenges.

In specific, we consider NASA's 2016 evidence report on the risk of cognitive or behavioural conditions and psychiatric disorders, and responds directly to the issues of mood disorders, neurasthenia, psychosomatic reactions, sleep, and cognitive functioning. Additionally, VR can provide psychiatric monitoring, exercise, continual and updated training, and sensory stimulation to fight monotony and boredom [1]. Further, VR can assist in psychosocial adaptation by supplying cooperative and leisurely activities for crews to play together to maintain team morale and unity while relieving stress and tension between members. "Sandbox" games, i.e. open-world games in which players have creative control over their environment and the objects around them, are discussed as a possibility to fight against the lack of space, autonomy, and privacy experienced by astronauts without overcrowding shuttle spaces. The use of artificial intelligence [AI] in VR Mars exploration training provides continuous practice with randomized scenarios to help astronauts retain their training over long-term space travel and to prepare for possible emergencies that require a quick improvised response.

NASA also reported those with eudaimonic well-being, i.e. well-being of personal satisfaction beyond hedonistic pleasure and avoidance of pain, are more likely to be autonomous and "thus the very nature of exploration missions will necessitate increased crew autonomy… thereby bolstering eudaimonic well-being" [1]. Monotonous tasks may be more frequent than those that are meaningful during long-term exploration missions, and if something compelling isn't occupying the crew, their eudaimonic well-being may go down.

Researchers have reported that increased autonomy for astronauts can negatively affect motivation and performance, and yet also astronauts desire and, in one case, have famously taken a stand for increased independence by shutting down communications with mission control [2]. Typical solutions like reading novels, photographing Earth, or allowing astronauts autonomy ("breathing room") can only go so far, and eudaimonic well-being may not sustain through this arduous mental period.

Salutogenic experiences, i.e. experiences that provide a sense of coherence and enduring positivity, associated with space travel, such as photographing the Earth are one of the most meaningful activities for astronauts, but this respite will no longer be available in extended length missions wherein the earth is out of view. Consequently, travellers spend months with the possibility of having no salutogenic experiences.

VR will be able to target these issues specifically, as VR "simulations are limited only by processing power and creativity" [3].

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Friday

Session: Space Weather Environments, Impacts, and Modeling II
Chairs: Anthony DeStefano, Luz Maria Martinez-Sierra

Electric Orbit Raising Radiation Environment and Solar Array Degradation

Soufian Yjjou, TRAD, Angélica Sicard, ONERA, Antoine Brunet, ONERA, Thibaut Prados, TRAD, Sophie Duzellier, ONERA, Thierry Nuns, ONERA, Christel Noemayr, Airbus, Athina Varotsou, TRAD, Hugh Evans, ESA/ESTEC, Carsten Baur, ESA/ESTEC

In the frame of this ESA ARTES Project a new proton radiation environment model and a Solar Array Degradation Calculator (SADC) have been developed to allow for more precise calculation of solar array degradation specific to EOR orbits.

The first part of the project was dedicated to the development of the OMEP-EOR (ONERA Middle Energy Proton) model, a global statistical model providing proton fluxes everywhere in the radiation belts between 30keV and 20MeV. In this model, the temporal dynamics of the radiation belt is accounted for at the scale of EOR missions, using a Gaussian Process model.

Then three activities run in parallel: a sensitivity analysis on key parameters used for the degradation calculation, a radiation test campaign on 3G30 solar cells and the development of the SADC.

The SADC is a standalone tool designed to account for several aspects of the solar array degradation to output a global electrical performance remaining factor. The proton fluence can be generated by the integrated OMEP-EOR model and the bare solar cell degradation is calculated after particle transport within the coverglass and the back side of the solar cell assembly. The cell's degradation is combined with the simulated darkening of the coverglass and adhesives to yield in a global degradation for the assembled solar cells. The tool is designed to work with multi-junction solar cells.

Different sources of uncertainties have been considered in the SADC in order to give a clear view of their impact on the final result. Validation of the SADC has been performed using the results of the electron and proton test campaigns.

An Analysis of the Magnetospheric Specification Model and other Related Models

Shawn Young, AFRL/Space Vehicles Directorate, Robert Hilmer, AFRL/Space Vehicles Directorate, Tanya Jeffries, Atmospheric and Environmental Research

A recent study validating, characterizing and comparing the Magnetospheric Specification Model (MSM) and the Magnetospheric Specification and Forecast Model (MSFM) against Van Allen Probes Hope data revealed that the MSM and MSFM electron models had biases that complimented each other. The MSFM flux, integrated above 9 keV, tended to be more accurate at low altitudes, while its specifications tended to be high at high altitudes. At the same time, the MSM specifications were more accurate at high altitudes and tended to under specify at low altitudes. This led to the creation of a simple ensemble described here.

An investigation into the reason for these bias differences between these closely related models identified differences in their strong pitch angle scattering thresholds. This led to the creation of a very simple hybrid of the two models, it is simply the MSFM, but it uses the MSM's high altitude strong electron pitch angle scattering threshold. Here we report on the results of this study, which ultimately included all four models

Comparison of JPL and ESP Solar Proton Fluence Models Using the RDSv2.0 Dataset

Brian Xiaoyu Zhu, JPL, Insoo Jun, JPL, Martin Ratliff, JPL

High energy protons from solar energetic particle (SEP) events are a hazard to spacecraft systems and instruments. For interplanetary and geosynchronous-Earth-orbiting spacecraft, a mission's cumulative SEP fluence is an important consideration for hardware design. The total solar proton fluence for a mission can be dominated by a small number of very high-fluence events. Because of the sporadic and unpredictable nature of these large events, data sets collected over multiple solar cycles are needed to construct a statistical model that can predict a mission's risk of seeing a given fluence exposure during its mission. Several statistical models have been developed, including the JPL model and the Emission of Solar Protons (ESP) model. The models produce somewhat different results, which could be due in part to the different data sets from which they were derived. To understand the sensitivity of predicted mission fluence to the choice of data set and to the statistical distribution to which that data set is fit, we present a comparison of the JPL and ESP cumulative fluence models as reformulated from the same SEP data set, the comprehensive Reference Data Set Version 2.0 (RDS v2.0). RDSv2.0 is based on data from IMP-8 and GOES, covering 41 years of SEP events from 1974 to 2015 with proton energies between 5 to 289 MeV. Notable sensitivity to both data set and statistical distribution is seen, in amounts that could cause the choice of SEP model to have practical effects on spacecraft design.

Session: Radiation Effects on Humans and Materials
Chairs: Kerry Lee, Linda Neergaard Parker

Invited: Space Radiation Technologies for Human Missions beyond Low-Earth-Orbit

Lisa Simonsen, NASA/HQ

Ionizing radiation exposure is a pervasive occupational risk to astronauts and remains a major health risk associated with human exploration beyond low-Earth-orbit. Sustained lunar and Mars exploration crew will be at increased risk of radiogenic cancers and cardiovascular disease, as well as, the potential for in-mission performance decrements, immune system decrements, and late neurodegenerative conditions impacting crew health. Optimizing astronaut space radiation protection will incorporate both physical and biological radiological aspects and will implement protection strategies that span pre-mission, in-flight, and post mission timelines. Major facets of physical risk mitigation include accuracy in predicting the space radiation solar environment, monitoring environmental and human exposures, and minimizing exposure through vehicle shielding and design. Biological mitigation facets include understanding and predicting biological response to the space environment, developing advanced medical countermeasures, and identifying appropriate surveillance strategies to preserve long-term health. Coordinated investments in these major capability areas will support development of an integrated radiation protection solution to minimize astronaut risk for moon to Mars exploration missions.

New System for Temperature Dependent Radiation Induced Conductivity Measurements

Joshua Boman, USU, Brian Wood, Electro Magnetic Applications, Inc.,
Jordan Lee, USU, JR Dennison, USU

Radiation induced conductivity (RIC) can be a significant mechanism for charge dissipation in highly disordered insulating materials (HDIM) that are subjected to high doses of space radiation, reducing the chance of electrostatic breakdown due to excessive charge accumulation. As radiation passes through an HDIM, energy is deposited through scattering mechanisms which can excite charged carriers into the conduction band thereby increasing the conductivity of the material, a process that is both temperature and material dependent. If the thickness of the material exceeds the penetration depth of the incident radiation, then significant charge is deposited within the material. Materials with high RIC can dissipate charge faster than it is accumulated, which can be crucial for dielectric charging mitigation. A new test system was developed to measure the temperature and dose rate dependence of RIC in HDIM. Thin film samples were prepared with 0.5 μm vapor deposited metallic electrodes and held in a parallel plate geometry test fixture. An 80 keV electron beam was used to irradiate samples with dose rates from 0.1 mGy/s to 1 Gy/s. RIC of thin films with thickness ranging from 25 μm to 40 μm were measured, with the thickest films showing evidence of significant charge deposition. First, samples were irradiated with both electrodes grounded to measure charge deposited by the electron beam as a function of dose rate, then voltages ranging from 440 to 890 V were applied to the sample electrodes with no incident radiation and while the samples were irradiated to measure RIC. Results showed that RIC follows the theoretical power law model proposed by Fowler, $\sigma = k_{RIC} \cdot \dot{D}^{\Delta}$, where $\dot{D}$ is the incident dose rate and k_{RIC} and Δ are material and temperature dependent parameters for RIC at unit dose rate and the power-law exponent, respectively. Temperature dependent data were acquired from room temperature down to 120 K in increments of ~5 K, at a nearly constant incident dose rate, to determine k_{RIC} as a function of temperature. Additional data sets were acquired at several fixed temperatures over this temperature range, while varying $\dot{D}$ over a wide range to determine both k_{RIC} and Δ. Details of the instrumentation calibration; measurement precision and accuracy; and corrections for charge deposition in thicker films, leakage currents, and secondary and backscattered electron emission are discussed. Representative results for polyether ether ketone (PEEK) are presented.

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Development and Preliminary Characterization of a Novel Rotary Cell Culture System for Radiation and Reduced Gravity Cell and Tissue Studies

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A custom miniature rotary cell culture system (mRCCS) was developed to model cellular damage due to combined synergistic effects of microgravity and ionizing radiation present during spaceflight. The mRCCS was designed using vacuum compatible, radiation-tolerant, and biocompatible materials to synchronously rotate up to five isolated cell culture vessels by a motor-driven chain. Human brain organoids of ~500 μm diameter or C2C12 mouse myoblast cell clusters grown on 200 μm polystyrene microcarrier beads were suspended inside the vessels

in viscous neutral-buoyant fluid media with densities matched to the suspended biological materials. They reach terminal velocity as they fall with near-zero net forces from gravity, buoyancy, viscous drag, and vessel rotation, thereby approximating a reduced gravity environment from ~10 μg to ~20 mg, as determined by the vessel rotational speed; this is approximately the same g-level as obtained by commercially available systems. The entirety of the apparatus can be used in a standalone configuration for separate microgravity simulations or can be introduced into Utah State University's Space Survivability Test (SST) chamber for radiation exposure. The SST chamber has a ~90 mCi ^{90}Sr source that emits 0.2 to 2.5 MeV β radiation, with an average penetration depth in water of ~5 mm. The combined mRCCS and SST chamber system can provide average effective dose rates for the cells from ~3.7 mGy/day to 3.4 Gy/day, controlled over a broad range (>900X) by varying the source-to-sample distance and using graphite shields with varying slit widths. Calibration of the mRCCS radiation and microgravity values and their precision and accuracy are discussed. Ground-based proof-of-concept testing on cellular systems with the mRCCS presented here demonstrated that it can reliably simulate ionizing radiation and microgravity hazards of the space environment, by developing an unprecedented platform to safely and ethically evaluate the biologically-based damage, viability and remedies from these space-like conditions on biological systems. This also allows for economical extended multiparameter pathophysiology screening tests of the production and mitigation of harmful reactive oxygen species and DNA damage of cellular systems, particularly for long-duration missions. As such, this system can aid in bridging major gaps in knowledge, characterizing life-threatening damage, and acting as a platform to develop possible methods of protecting astronauts.

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NAIRAS Model Extension to the LEO Environment and New Products for Characterization of Single Event Effects

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NASA's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model is a real-time, global, physics-based model originally developed to predict exposure to cosmic radiation to air travelers from both galactic and solar sources. A prototype operational NAIRAS model has provided tabular and graphical data products via its public web site for a number of years. NAIRAS is now being transitioned to operations at the NASA Goddard Space Flight Center's Community Coordinated Modeling Center (CCMC) where global NAIRAS products will be available from a real-time space weather version of the model and a runs-on-request version will provide model output along user selected flight trajectories. In addition to the dosimetric output from the model, additional output options for energy spectra and linear energy transfer (LET) spectra are being added to support the evaluation and prediction of single event effects (SEE) and total ionization dose (TID) during commercial spaceflight missions to low-Earth orbit (LEO) and the International Space Station (ISS). This presentation will summarize the recent model developments and the new NAIRAS products at the CCMC.

Ground testing of the MISSE-16 Materials

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The harsh space environment imposes very stringent requirements upon spacecraft materials, especially those located on exterior surfaces of space objects in low Earth orbit (LEO). As humankind moves from space exploration to space commercialization, these materials may have to last for 15–20 years without considerable degradation of their optical, electrical, mechanical, and thermal properties. Operational requirements dictate that these materials continue to function according to expectations. Hence, we must understand the effects of the space environment on materials currently in use as well as on untested materials. For the years, the Materials International Space Station Experiment Flight Facility (MISSE-FF) have flown many different materials to investigate the effect of LEO space weather exposure on the performance and durability of materials and devices.

The MISSE-16 scientific team members plan to launch fifteen different novel and well-characterized spacecraft-relevant materials to the LEO environment for a duration of six months during the MISSE-16 mission. Changes in spectral reflectivity will be measured throughout the mission as the samples are exposed to the space environment. The same chemical damage the produces changes in optical reflectance also causes changes in numerous other physical properties such as electrical conductivity, mechanical strength, and chemical reactivity. Correlation of the changes in each of these properties as a function of radiation type, flux, and fluence allows various material properties to be inferred from one experimentally tractable measurement: color change. Flying identical test fixtures on the ram, zenith, and wake positions of the MISSE-FF, collecting spectrally resolved images of the materials, and concomitantly measuring the ambient space environment allows deconvolution of the material effects which occur as a result of exposure to neutral atomic oxygen (AO), unfiltered solar ultraviolet (UV) radiation, and electrons.

The flight experiment will function as a ground truth reference for our team's ongoing laboratory-based space weather-material interactions experiments. Comparison of the MISSE-16 data with extensive testing of "flight-duplicate" samples under simulated space weather conditions will enable development of chemical models for prediction of material degradation. This paper discusses preliminary results from the ground test campaign including measurements of optical and charge transport properties as well as surface morphology.

Session: Space Weather Environments, Impacts, and Modeling III
Chairs: Michael Xapsos, Erica Worthy

Prototype Surface Charging Product for Geostationary Orbit

Terrance Onsager, NOAA/SWPC, Dave Pitchford, SES S.A., Trevor Leonard, NOAA National Satellite Data and Information Service, Brian Kress NOAA National Satellite Data and Information Service, Thanasis Boudouridis, NOAA National Satellite Data and Information Service, Juan Rodriguez, NOAA National Satellite Data and Information Service

Surface charging continues to be a concern for satellites in a variety of orbits, including geostationary. With the launch of Geostationary Operational Environmental Satellite (GOES)-16, new instruments are now available to measure the low-energy (30 eV – 30 keV) electron and ion environment in geostationary orbit. The aim of this presentation is to obtain feedback on a prototype surface charging product derived from these low-energy measurements to indicate the likelihood of surface charging during eclipse periods. The product is based on the correlation of the observed GOES-16 surface charging with an estimate of the local plasma sheet electron temperature. A simple green-yellow-red indicator is proposed to show when the plasma sheet electron temperature indicates the likelihood of eclipse charging. By combining the measurements of the eastern GOES satellite (75 degrees West longitude) with the western GOES satellite (137 degrees West longitude), it may be possible to provide reliable information about the expected level of charging during eclipse for the large number of satellites in geostationary orbit over the North American sector of the geostationary ring.

Application of Machine Learning to Investigation of Arcing on Geosynchronous Satellites

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The harsh space environment at geosynchronous orbit (GEO) induces differential charging of spacecraft surfaces due to fluxes of high energy electrons onto and through them. Thus, satellite surfaces can charge thousands of volts with respect to each other whereas entire satellites can charge tens of thousands of volts negative of their surrounding space plasma. The ensuing electric fields can cause local discharges (arcs), endangering the normal operation of the satellite. Remote detection of spacecraft arcing is important for the satellite operators in order to properly respond to anomalies caused by spacecraft charging due to the space weather conditions. However, analysis of satellite data is laborious due to the amount of data generated. In this work, we explored the application of machine learning for analysis of GEO satellite arcing behavior using the radiofrequency observations by the Arecibo 305 m telescope.

VTEC Predictability by AfriTEC, IRI-2016, IRI-Plas 2017, and NeQuick-G Ionospheric Models over Africa During Geomagnetic Storm on March 17, 2015

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This study investigated daily variations of modeled and observed Vertical Total Electron Content (VTEC) obtained from models and ground based Global Navigation Satellite System (GNSS) data. The region under study was the entire African region (40^{o}N to +40^{o}S, 25^{o}W to 65^{o}E). The performance of regional and global ionospheric models was evaluated around the Saint Patrick's Day superstorm (Dst=-223 nT) of the cycle 24. The storm was a two-step storm of which the first step was associated with a southward component of the Interplanetary Magnetic Field (IMF) in the sheath region and the second one with southward Magnetic Cloud (MC). Its solar index was F10.7 was not so variable (~113 sfu) with a maximum speed of ~ 600 km/h and a maximum pressure of ~40 nPa. VTEC predictability by regional/global ionospheric models (AfriTEC, IRI-2016, IRI-Plas 2017 and NeQuick-G) was evaluated using root mean square error (RMSE) method and percentage deviation by comparing the GPS/GNSS-VTEC obtained from 10 IGS (International GNSS Service) stations with the modelled-VTEC values over Africa. It was observed that there was a peculiarity in VTEC values during the superstorm sudden commencement when compared to the pre and post-storm periods which lead to phase and/or amplitude in L1/L2 GPS bands scintillations or losses of lock. Northern hemisphere stations data displayed a twin peak in the diurnal VTEC patterns. Enhanced VTEC values were observed over all the 10 IGS stations. Moreover, during the post-storm days (18-20 March 2015), these VTEC values decreased more than on quiet days over the IGS stations in southern hemisphere (MBAR, MAYG, HARB, SBOK). On the other hand, during the post-storm days (18-20 March 2015), the VTEC values remained high over the geomagnetic northern hemisphere (NOT1, SFER, MAS1, CPVG, NKLG). Some stations recorded negative ionospheric storm effects (negative storm) whereas others registered positive ones (positive storm). It is worth mentioning that three northern IGS stations (NOT1, SFER and MAS1) displayed a VTEC increase record of approximately 75-90%, which is due to the extension of

Equatorial Ionization Anomaly (EIA) during the geomagnetic storm whereas the other northern stations at EIA trough region (CPVG, BJCO, NKLG) registered a VTEC increment of 7%, 26% and 25% respectively. Southern IGS stations registered an enhancement in VTEC of about 5%. The VTEC maps from AfriTEC, IRI-2016 and NeQuick-G were able to predict the feature of Equatorial Ionospheric Anomaly (EIA) at around 20^0N/15^0S. The GPS-VTEC values at IGS stations located on the geomagnetic EIA crests (in both northern and southern hemispheres) and in the trough (equatorial stations) were higher than those of the IGS stations situated at midlatitudes. AfriTEC, which is a regional model, recorded lowest RMSE values over all the stations. The prediction results showed that the regional model performance is better than the global ionospheric models (IRI-2016, IRI-Plas 2017 and NeQuick-G models) especially over EIA latitudes. However, NeQuick-G model was mostly able to follow the diurnal GPS-VTEC trends than all other models and IRI-2016 model mostly predicted well the diurnal and averaged VTEC with low RMSE values on the day of the storm than other global models.