The Electrostatic Environment at the International Space Station

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***Abstract*— The International Space Station (ISS) orbits the Earth in the ionosphere at an altitude of 400 km and at an inclination of 51.6 degrees. In this region, solar radiation and cosmic rays ionize the oxygen and nitrogen atoms, producing free electrons and ions with equal densities. The concentrations of these electrons and ions are relatively high and change with altitude, orbit inclination, and solar activity. The complex electrostatic environment that results creates several charging sources for ISS. In this paper, we describe this environment in detail and discuss its possible implications for astronauts, for docking spacecraft, and for external payloads. We also include results of charge decay measurements with Electrodynamic Dust Shield (EDS) panels being developed for inclusion on an ISS external payload. These panels were corona-charged to the maximum potentials expected on ISS. Charge decay at near zero relative humidity was monitored to assess the possible effects of charge on the EDS operation.**

INTRODUCTION

The International Space Station (ISS) orbits in Low Earth Orbit in the *F* region of the ionosphere, at an altitude of 400 km at an inclination of 51.6 degrees. In this region, at altitudes above 90 km, ultraviolet radiation from the sun splits diatomic oxygen molecules into individual atoms. Solar radiation and cosmic rays ionize the oxygen and nitrogen atoms, producing free electrons and ions with equal densities. The concentrations of these electrons and ions are relatively high and change with altitude and solar activity [1]. Since electrons have higher mobilities, they are collected more easily, negatively charging spacecraft in this region. Although the LEO plasma density is high, the energy is normally low, at about 0.1 eV.

SOURCES OF ELECTROSTATIC CHARGING FOR ISS

Orbiting spacecraft in the *F* region move at about 8 km/s in this dense, low-energy plasma. This orbital velocity is slower that the electron thermal velocities, which are about 200 km/s, but faster than the 1 km/s thermal velocities of positive ions. Thus, spacecraft in LEO orbit supersonically relative to the ambient ions and subsonically relative to the thermal electrons. As a result, a wake forms behind the spacecraft where the ion density is much smaller than that of the ions in the plasma. This unequal flux results in electrons being able to reach all spacecraft surfaces while ions can only impact ram surfaces. However, electron impact is not uniform throughout the spacecraft. The faster moving electrons that enter the wake form a space charge that repels additional electrons, excluding them from the wake region [2]. As a result, the wake is essentially devoid of plasma particles of both polarities.

Thus spacecraft charge only to a few volts negative, which is not an issue [3].As stated earlier, the relatively high plasma density in LEO limits spacecraft surface charging to a few volts negative. Due to its large size and power requirements and to the inclination of its orbit, the ISS has three additional sources of charge that can be important: The large photovoltaic array system, the magnetic induction process, and the interaction with the high energy electrons in the polar regions.

A. ISS Photovoltaic Array

Electric power systems on spacecraft normally operate at the 28-V DC standard of the aircraft industry. Interaction with the ionospheric plasma at this relatively low voltage generates low surface charges and is not a concern. However, ISS is not just a spacecraft but a habitat, with much larger power requirements. The ISS photovoltaic power system operates at 160 V to reduce weight and power loss. As is the case for most spacecraft, the solar array system on ISS has the negative end connected to the ISS ground. This set up is due to the scarcity of space qualified power systems with a positive ground when ISS was being constructed. With this arrangement, the positive end of the arrays collects electrons from the dense ionospheric plasma while the negative end collects ions. Although the ion and electron currents are about the same, the electron current density is much higher, and the array and consequently ISS charge negative to values that can reach about -80 V [4]. On their own, these array voltages need to be mitigated perhaps by encapsulation of the array edges to prevent arcing due to contamination of the arrays or by bakeout in orbit at 100 °C for about a week to remove contamination [1].

B. Magnetic Induction Charging

The second source of charge on ISS is the magnetic induction process that results from the motion of the conductive components of ISS through the magnetic field of the Earth. From Faraday's law we know that a magnetic field **B** produces an electromotive force (emf) that drives a current through a conductor moving with a velocity **v** in that magnetic field. The potential difference of this motional emf is given by

$$\varepsilon_m = \oint \mathbf{v} \times \mathbf{B} \cdot d\mathbf{l}$$

where d**l** is an element of length in the conductor pointing in the direction of the current. Long, conducting ISS surfaces moving with a velocity component perpendicular to the Earth's magnetic field can generate these voltages. The effect is larger when ISS orbits through the more concentrated magnetic field lines near the Earth's poles. Potentials of about -90 V relative to the plasma environment have been measured on of the photovoltaic arrays [2, 4, 5]. These values are not of concern by themselves but, when combined with the negative photovoltaic charging, they can reach values that need to be mitigated.

C. Charging Through the Polar Region

The third source of ISS charging is due to the daily passage of ISS through the auroral or polar region, where the Earth's magnetic field lines plunge, allowing for high energy electrons in the 7-10 keV range to reach LEO altitudes. Measurements of the DMSP satellites, which orbit in the auroral region at an altitude of 840 km, show that it can charge to -2 kV when it encounters intense electron flux [3]. At the lower altitude at which ISS orbits, the plasma density is much higher and high-level charging should not normally take place. However, the plasma density in the wake can be up to 2 orders of magnitude lower [3]. High energy electrons in the auroral regions can charge surfaces in this area. Data from the US Department of Defense/European Space Agency/Russian Roscosmos State Corporation satellite, the probability for this charging effect is low but not zero [5].

To mitigate these problems, NASA installed a system to ground ISS to the ambient plasma. This system, called the *plasma contactor unit* (PCU), generates a high-density plasma that makes electrical contact with the ambient plasma [6]. The system uses a cathode that converts a small supply of xenon gas into ions and electrons that are discharged to space, thus carrying away the excess charge (Fig. 1). With the plasma contactor in place, voltages on ISS conducting surfaces do not exceed ±20 V [2]. For redundancy, two PCU were installed on the Z1 truss of ISS. The units operate only during astronaut extravehicular activities and during spacecraft docking.

Insulator surfaces on ISS in general do not build up charges due to the neutralizing effect of the surrounding plasma. This neutralizing effect does not happen in the wake, where, as stated above, the plasma density can be two orders of magnitude lower. In the unprotected region of the wake, differential charging can develop on insulating surfaces when ISS passes through the auroral region, where it is exposed to high energy electrons.

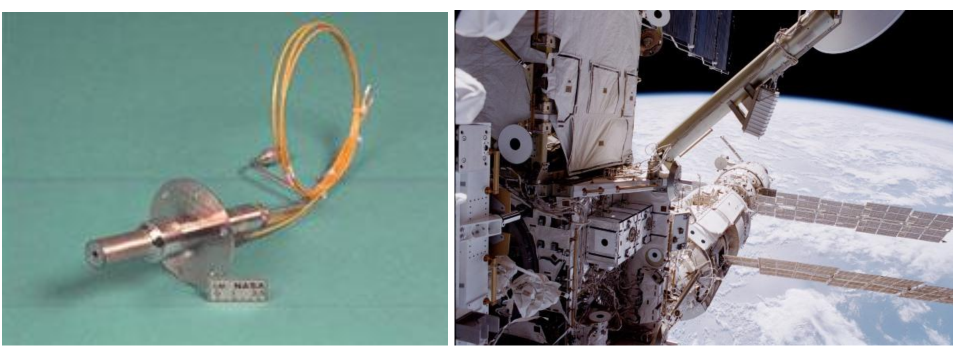

Fig. 1. (Left) Hollow Cathode Assembly in the plasma contactor on the International Space Station. (Right) the Plasma Contactor Units installed on ISS. [Courtesy NASA]

ELECTRODYNAMIC DUST SHIELD EXPERIMENT ON ISS

The Materials in Space Station Experiment Flight Facilty (MISSE-FF) is a research facility for testing materials in the space environment. The MISSE FF provides exposure to space in the ram, wake, nadir, and zenith orientations. The wake orientation approximates the lunar environment, since the facility itself shields the experiments on this orientation from exposure to atomic oxygen. Materials placed in the MISSE wake orientation would be exposed mostly to the plasma particles in LEO and to solar ultraviolet radiation.

The MISSE FF provides for a great opportunity to test NASA's Electrodynamic Dust Shield (EDS) in the LEO space environment [7,8]. The EDS, in development at NASA as an active dust mitigation system to enable the exploration of planetary bodies with dusty regoliths, such as those of Mars, the Moon, and the asteroids, has been tested in vacuum chambers that approximate the atmospheric pressure conditions of those bodies.

The EDS payload will be positioned on MISSE-FF in the wake orientation, which provides conditions somewhat similar to those of the lunar or the asteroid's electrostatic environments. Since the EDS payload will not be electrically connected to ISS, the photovoltaic charging and magnetic induction charging will not affect it. Expected potentials for the payload are of the order of a few volts negative. The sunlit lunar surface or the sunlit surface of an asteroid charges to about 10 V positive. Neither of these values are of concern. However, the possibility of high potentials during the daily passage of ISS through the auroral region is a concern.

Implications for the EDS Experiment Payload

Since the PCUs are only activated during EVAs and docking maneuvers, we should expect the insulating surfaces of the EDS panels to acquire a charge. Potential build up relative to the surrounding plasma on ISS is measured by the Floating Potential Measuring Unit (FPMU), which is located a few meters above the S1 truss surface [9]. The FPMU consists of four instruments: The Floating Potential Probe (FPP), the Plasma Impedance Probe (PIP), the Wide-sweep Langmuir Probe (WLP), and the Narrow-sweep Langmuir Probe (NLP). The plane containing the four probes is perpendicular to the ISS velocity vector (Fig 2). Potentials measured with the four probe are highly consistent among the probes. Measurements during one orbit on day 2006/217 showed a maximum potential of -25 V. This value includes the contribution of the $\mathbf{v}\times\mathbf{B}$ magnetic induction term. This term will not affect the EDS substrate and coating, which are insulating, but may affect the aluminum backing of the EDS for thermal radiators. In addition, as stated earlier, potentials of -90 V relative to the plasma have been measured when the PCU is off.

Since the EDS payload will fly in the wake of the MISSE-FF, where the ion density is expected to be lower, higher voltages are possible during ISS passages through the auroral region. This charge will decay slowly in the low-density plasma of the wake. At all other times, charging of the EDS should be lower, since electron energies in LEO are low. However, as stated earlier, auroral charging of ISS appears to have a low probability.

Charge Decay Measurements

Charge decay measurement of several EDS panels were made at the high voltages expected when ISS passes through the polar region. Experiments were performed with a JCI-155v6 Charge Decay Time Analyzer at 0% relative humidity. The JCI-155 deposits a high voltage corona charge on the surface of the EDS panels and a fast response electrostatic field meter monitors the voltage generated by this charge as it dissipates to a grounded conductor. Table 1 shows charge decays for EDS panels with indium tin oxide (ITO) electrodes on Corning alkaline earth boro-aluminosilicate glass coated with a polyethyline terephthalate (PET) film and with a broad band antireflective (BBAR) coating from Abrisa Technologies.

Fig. 2**.** The Floating Potential Measuring Unit on the International Space Station. [Courtesy NASA]

TABLE 1: CHARGE DECAY MEASUREMENTS

Coating	V_o (V)	V at 100 s (V)	V at 1/e (V)	V_f /Time to reach acceptable level
PET	-2,090	-957	-768	-41.4 V/255 ks
BBAR	-1,930	-791	-711	-15.3 V/1.3 ks

Although the PET coating that has been used for most laboratory tests is robust and performs very well, it also takes over 47 ISS 90-minute orbits to decay to acceptable levels. The relatively large magnitude of the charge that lingers on the EDS through several orbits will interfere with the EDS operating electric fields. The Abrisa BBAR coating dissipates relatively fast, taking 22 minutes to decay to a safe voltage of -15.3 V.

We note that the breakdown voltage of the BBAR coating exceeds the expected values of the potentials across EDS electrodes. This coating is also space-rated and meets the requirements of MIL-C-675C, MIL-C-14806A, and MIL-C-48497A. Although we expect to test additional coatings, the BBAR coating meets the needs of the EDS payload and will likely be the one selected for the MISSE-FF experiment.

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