Spacecraft Charging during Docking Operations in the Outer Radiation Belt

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Introduction

Spacecraft charging can occur when a spacecraft vehicle is subject to space plasma environments and varying sunlit conditions. The trajectory of the spacecraft will determine the specific impinging environment while the spacecraft geometry and material properties determine the susceptibility to various charging issues. In general, spacecraft charging is separated into two categories, **surface charging** (~<100 keV) see Figure 1, and **internal charging** (~>100keV) see Figure 2.

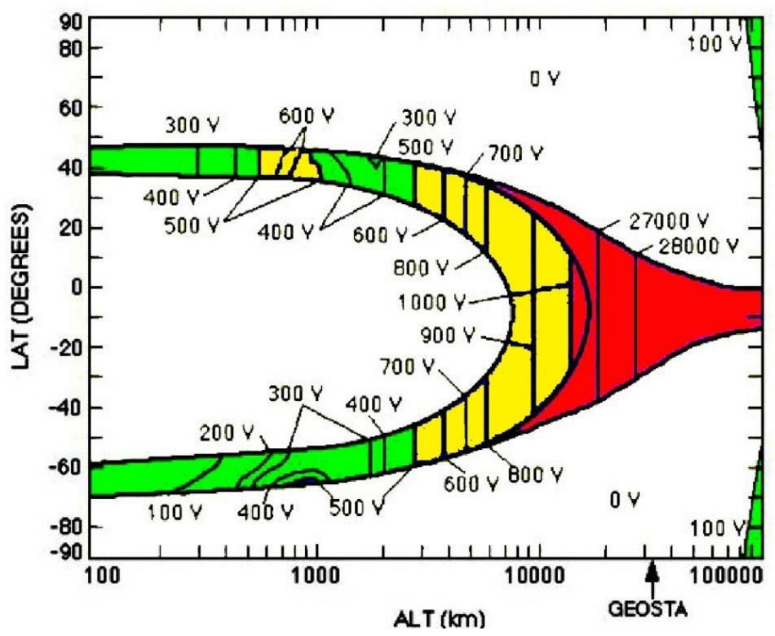

Figure 1: Earth Regimes of concern for on-orbit surface charging hazards for spacecraft passing through indicated latitude and altitude (NASA HDBK 4002A).

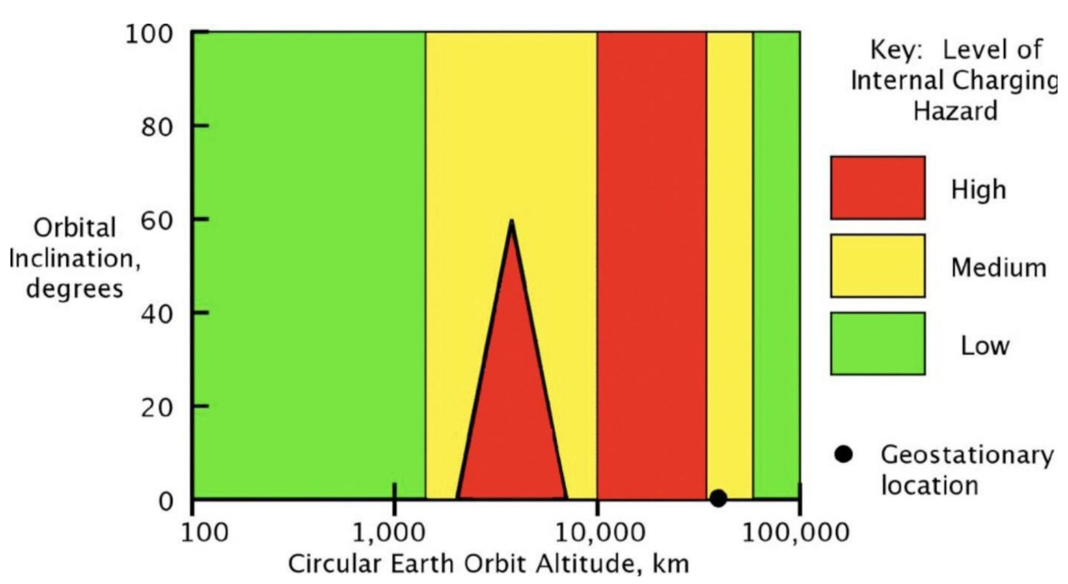

Figure 2: Earth regimes of concern for on-orbit internal charging hazards for spacecraft with circular orbits (NASA HDBK 4002A).

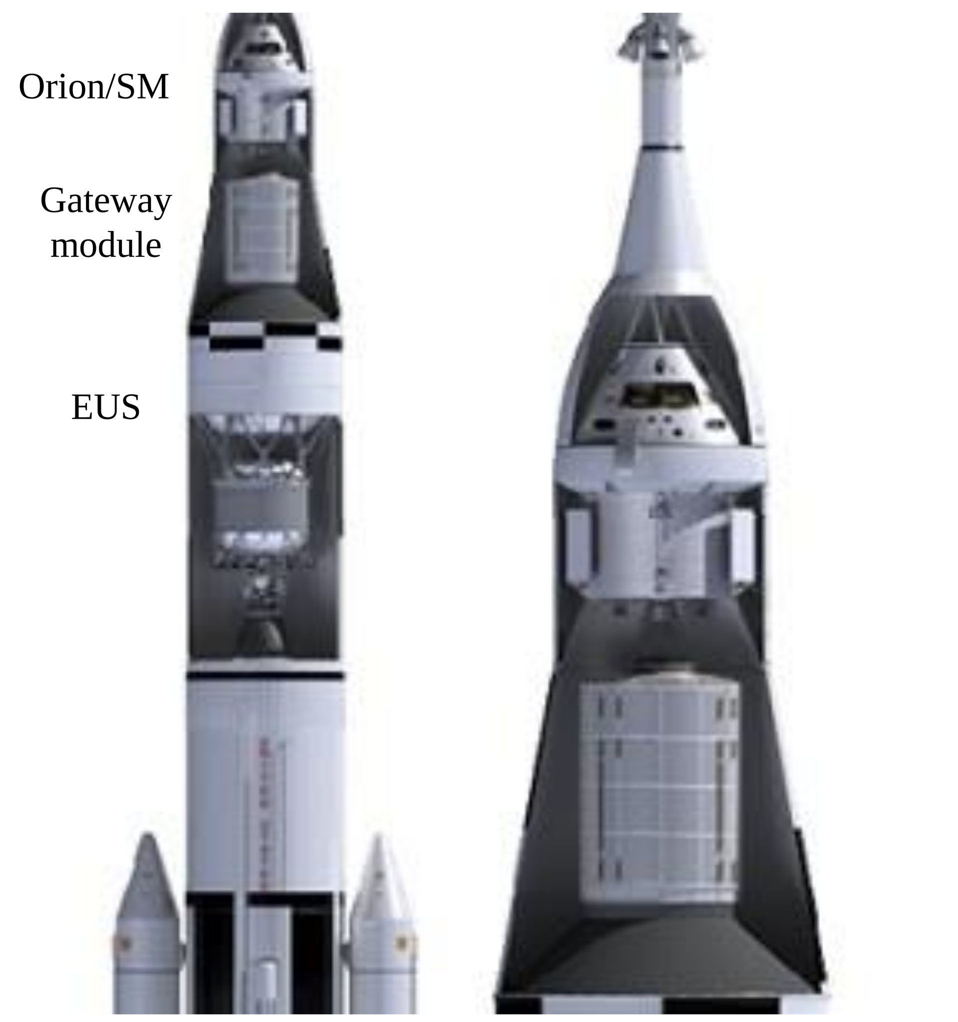

Figure 3: Example of the Space Launch System (SLS) payload placement of Orion, the co-manifested payload (Gateway module), and Exploration Upper Stage (EUS) (https://www.nasaspaceflight.com/2013/11/new-sls-options-new-large-upper-stage/).

Methodology

In this surface charging analysis, we are concerned with computing the **differential voltage** between the Orion and Gateway/EUS element, in addition to understanding the **total charge** accumulated on both vehicles. We employ the **NASCAP2K** software package to estimate these quantities. There are five sets of parameters we need to establish:

1. The appropriate **material properties** (see Figure 4) on the OML of each element
2. The **worst-case charging environment** (see Figure 5) for the given docking operation
3. The **outer mold line** (OML) of Orion, the Gateway module, and EUS (see Figure 6 for a preliminary example)
4. The **angle between the Sun** and **tail of Orion**
5. A representative **length of charging**

The **separation distance** between the Orion and Gateway/EUS elements is defined in Figure 9, where we chose a **separation of 0.7m** in the simulation. The meshes begin to overlap for distances much closer than this.

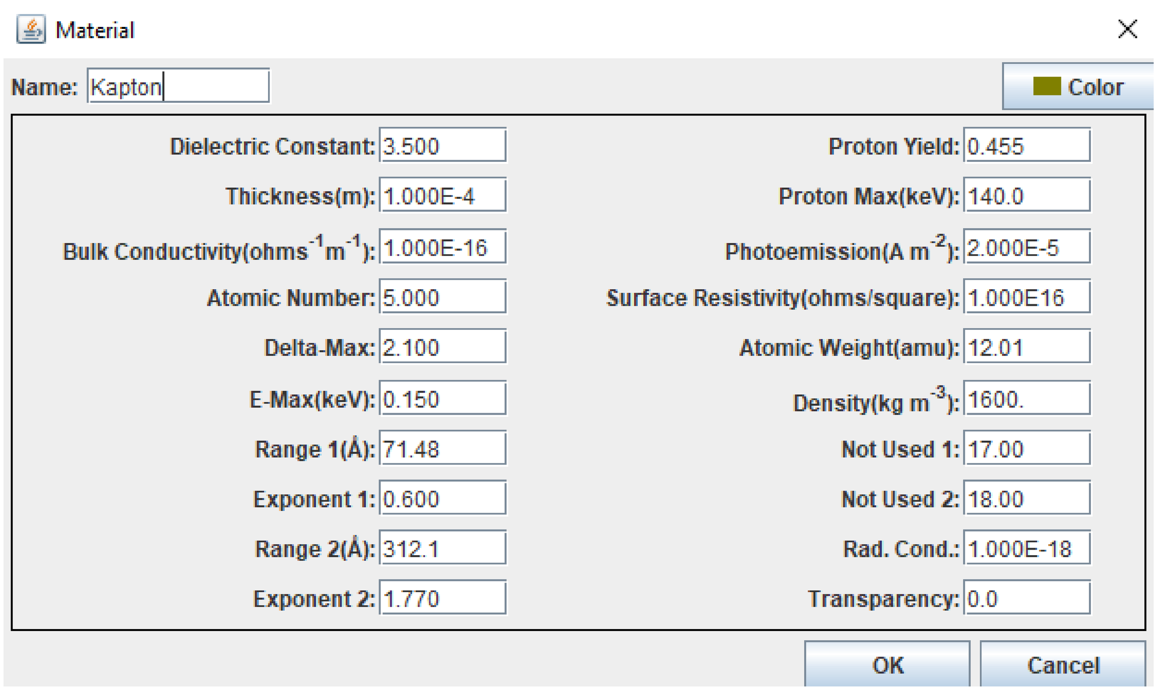

Figure 4: An example of the material properties of Kapton in NASCAP2K (Davis et al. 2016).

Table 3.3.3.3-1. Geosynchronous Orbit (GEO) Plasma Environment Parameters

Parameter	SCATHA "Worst Case" Environment	
	Electrons	Ions
Single Maxwellian		
Number density (#/cm³)	3.00	3.00
Temperature (eV)	12,000	30,000
Current density (nA/cm²)	0.501	0.016
Double Maxwellian		
Number density, population 1 (#/cm³)	0.87	0.97
Temperature, population 1 (eV)	600	333
Number density, population 2 (#/cm⁻³)	1.73	1.63
Temperature, population 2 (eV)	25,800	25,300

Figure 5: Worst case GEO environment in the DSNE (Roberts et al. 2017) from the SCATHA spacecraft.

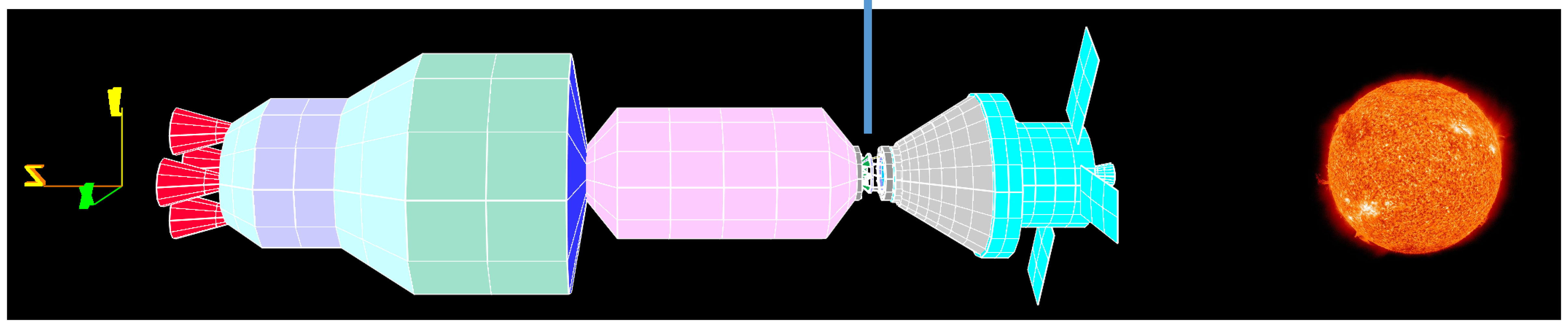

Figure 6: Example of a NASCAP2K (Mandell et al. 2006) spacecraft model of the EUS, the Gateway module (shown as ISS Node 2), and Orion/SM from left to right. The Sun (not to scale) is assumed to be in the tail direction of Orion during docking procedures. Each color in the model represents a different material.

Preliminary Results

Note that these preliminary results are based on a number of assumptions about the material properties. A test program is planned to refine the properties which will give more accurate charging results. Several simulations in NASCAP2K are necessary for encapsulating the general trends in the charging analysis. Here we show one particular example. Because of the different charging times of the conductors and insulating materials, it is difficult to find a range of simulation time steps that produce a smooth solution for all times.

The final differential voltage shown in Figure 7 is 5280 V.

The final charges for Q1 and Q2 are 3.52E-7 C and -5.32E-6, see Figure 8.

Differential Voltage:

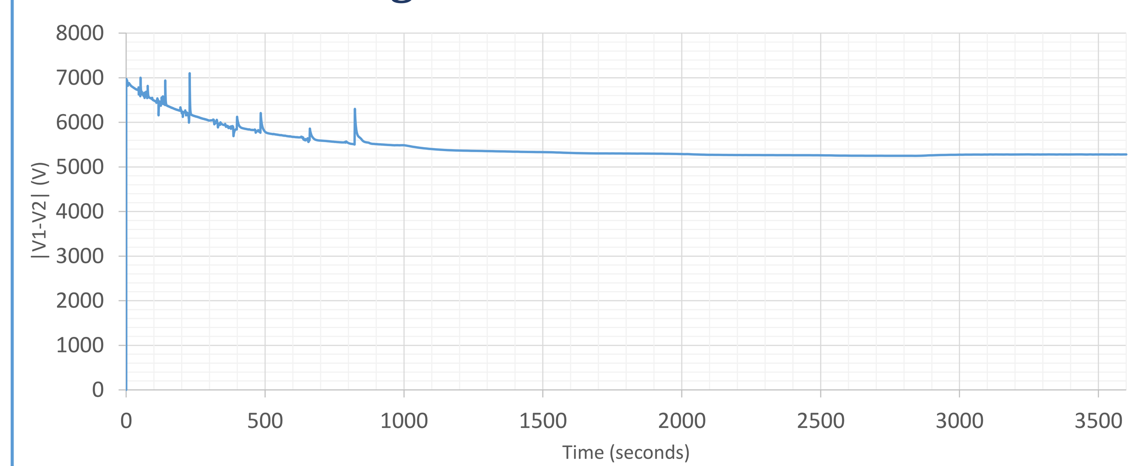

Figure 7: The absolute value of the frame potentials between Orion (V1) and Gateway/EUS (V2) as a function of time for a charging time of 1 hour.

Total Charges:

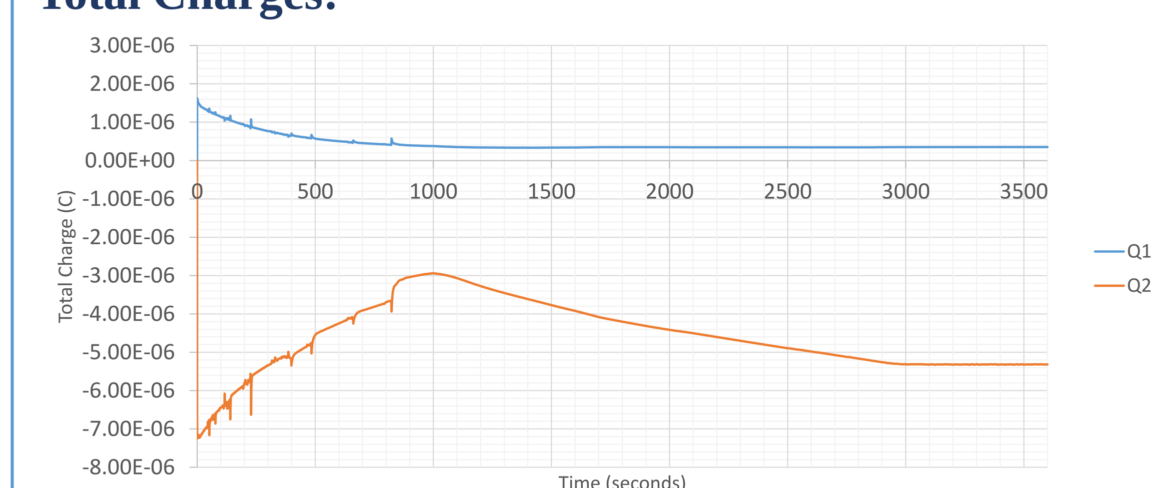

Figure 8: The total charge, derived from the normal electric field, of Orion (Q1) and Gateway/EUS (Q2) as a function of time for a charging time of 1 hour.

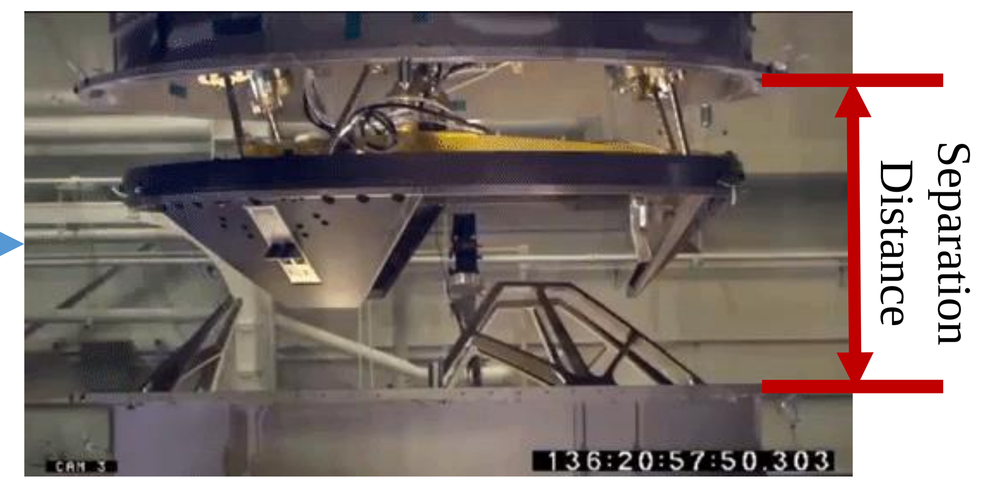

Figure 9: NASA Docking System (NDS) active (top) and passive (bottom) https://en.wikipedia.org/wiki/NASA_Docking_System.

Conclusions

Using NASCAP2K is one method of estimating the surface charging of various spacecraft in a user specified environment. For the Orion and Gateway/EUS docking operation in GEO, we see that differential voltages can be on the order of 1E3 V. However, this particular charging problem is extremely sensitive to material properties as well as the representative environment that is chosen. Therefore, care must be taken when interpreting the results shown here. In addition, the potentials and charges on the Orion and Gateway/EUS elements are dependent on their separation distance, their relative orientation, and the sun angle.

Our current and future work will aim to bound the charging problem by testing different materials in the simulation, choosing different worst-case environments, and changing the Sun-Orion angle. In addition, we plan to compare the charging analysis with simulation runs done in SPIS (Spacecraft Plasma Interaction Software) (Thiebault et al. 2015).

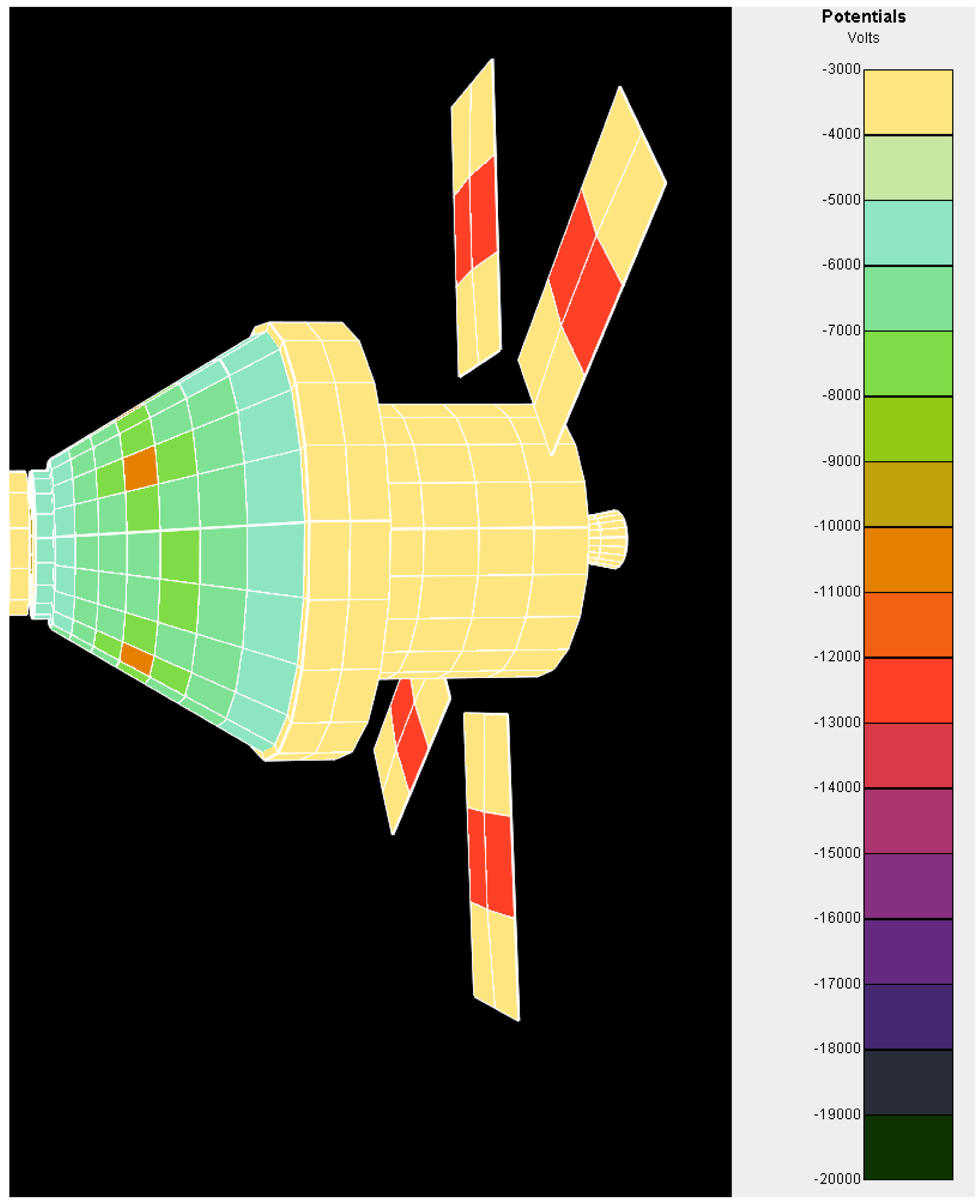

Figure 10: The surface charge after 1 hour of the SCATHA-Mullen1 environment with the Sun in the tail direction of Orion. It is evident that dielectric materials on the spacecraft have different charging properties than conducting portions of the spacecraft. The frame potential is affected by the charging properties of the surface materials.

References

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