# SURFACE CHARGING MODELING FOR NASA'S PLANNED EUROPA MISSION

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## ABSTRACT

Spacecraft surface charging is of particular concern in the electron-heavy Jovian environment for missions such as the Juno, JUICE, and NASA's planned Europa missions. Due to launch in 2022, NASA's planned mission to Europa would need to carefully consider both frame and differential charging in order to meet spacecraft requirements and mission objectives. Differential charging is of concern in the auroral environment (~15 $R_J$), particularly with regard to eclipses, since it is expected that the large solar arrays would have significant areas of exposed nonconductive surface. Near Europa, the PIMS plasma instrument would measure low-energy electrons and ions, making relatively low levels of frame charging of interest. Plasma parameters for the Jovian environment are taken from an updated plasma model by H. Garrett [1]. Surface charging modeling is performed using the *Nascap-2k* code, using complex spacecraft geometry and materials. We present early results for surface charging modeling in these environments.

## 1. INTRODUCTION

### 1.1. Planned Mission to Europa

The overarching scientific goal of NASA's planned mission to Europa is to assess its potential for habitability. Science objectives include characterization of its ice shell and subsurface ocean, understanding of the ocean's composition and chemistry, learning about the formation of the moon's surface features, and performing reconnaissance to characterize scientifically compelling sites, and hazards, for a potential future landed mission to Europa. In order to achieve these goals, NASA has selected a comprehensive payload of scientific instruments [1].

The planned Europa mission, due to launch in 2022, would enter orbit around Jupiter after a cruise phase. It would then remain in Jovian orbit while conducting dozens of flybys of Europa, approaching the moon from various angles to give extensive coverage of its surface.

The mission presents a number of extreme environmental challenges. These include very low temperatures, as low as -130°C in sunlight and as low as -243°C at the end of a 9 hour eclipse. At Jupiter's orbital distance of 5.2 AU, sunlight is only a few percent of that at Earth, necessitating very large (> 70 $m^2$) solar arrays. The mission is quite long, with 3.5 years of operation in Jovian space following the cruise phase, for a total of 6-8 years depending on the launch vehicle (not yet selected). Due to Jupiter's radiation belts, the spacecraft would experience a very stressful radiation environment, with a Total Ionizing Dose (TID) of ~3 Mrad(Si) behind 100 mils of aluminium. TID would need to be carefully assessed for both materials and EEE parts, as would Displacement Damage Dose (DDD), particularly for solar array damage.

### 1.2. Surface charging for planned Europa mission

Spacecraft charging, both internal and surface, also require serious consideration for this mission. For the purposes of this study, we considered surface charging only. There are two principal concerns for surface charging for this mission: the possibility of differential charging in the worst-case auroral environment near ~15 $R_J$ and low-level frame charging near Europa.

Low-level charging near Europa is of particular concerns to PIMS (Plasma Instrument for Magnetic Sounding). Plasma near Europa has a strong contribution to the observed magnetic field and masks the induction response from the subsurface ocean. PIMS measures the plasma around Europa to determine Europa's magnetic induction response, corrected for plasma contributions. The PIMS team is especially interested in measuring low energy positive ions at closest approach to Europa, but would also like to measure electrons at relatively low energies in order to characterize the plasma. Therefore it is uniquely sensitive to low-magnitude frame charging during science operations.

The Jovian plasma environment is electron-heavy, leading to a large incident electron current, and a major role for secondary electron emission. Since Jupiter is so far from the Sun, photoemission is relatively less important (though not negligible, especially for Sun vs. eclipse cases). The distance from the Sun also means that materials would reach very low temperatures, especially in eclipse. Material properties such as conductivity/surface resistivity and secondary yield parameters are not well known at such low temperatures.

## 2. ENVIRONMENTAL SPECIFICATION

The Jovian plasma environment has been studied extensively over the years, incorporating data from the Pioneer, Voyager, and Galileo spacecraft [2,3,4]. Most recently, the Galileo Interim Radiation Model (GIRE) [5] was updated and expanded to include new estimates for the plasma environment [6,7]. Fits to this GIRE-2 model provide estimates for the Jovian plasma environment that can be input to surface charging modelling codes.

The plasma environments considered for this study fall into two categories. The worst-case auroral charging environment near 15 $R_J$ is characterized by multiple electron and ion components, including a diffuse auroral component that can lead to large-magnitude negative charging. Large negative frame potentials are common in Earth orbit and can be tolerated, so the concern here is for the magnitude of any differential potentials that might develop between different parts of the spacecraft. Estimates for the worst-case auroral charging environment at 15 $R_J$ are given in Table 1.

**Table 1: Estimates for the worst-case auroral charging environment at 15 $R_J$.**

| Particle | Component | N ($cm^{-3}$) | T (eV) | κ |
|---|---|---|---|---|
| Electrons | Cold | 6.91 | 15 | |
| | Kappa | 0.4234 | 475 | 1.95 |
| | Diffuse aurora | 2 | 1500 | 2.4 |
| Protons | Cold | 0.683 | 15 | |
| | Warm | 0.341 | 30000 | |
| Ions | Cold | 6.91 | 15 | |

The GIRE-2 model can also be used to give plasma environment estimates at Europa's orbital location of 9.5 RJ, but these estimates would not be valid at closest approach, where the environment is dominated by the moon itself. We have therefore made separate estimates for near-Europa environment by assuming a low-temperature ionosphere with density taken from Galileo occultation data [8]. Since the condition of the ionosphere is not well known, we bound the environment by considering a range of electron temperatures. Plasma environment estimates for closest approach are taken at 25 km altitude from Europa and are given in Table 2.

**Table 2: Estimates for the plasma environment near Europa.**

| Particle | N ($cm^{-3}$) | T (eV) |
|---|---|---|
| Electrons | 8130 | 0.01 – 100 |
| Ions (mostly $O_2^+$) | 8130 | 0.01 – 100 |

## 3. GEOMETRY AND MATERIALS

All results shown here are for the Europa spacecraft configuration as of January 2016. The spacecraft is modelled in *Nascap-2k* Object Toolkit and is shown in Figure 1. The geometrical model includes the major spacecraft features, in particular the very large solar arrays (with surface area ~72 $m^2$). The arrays are coated with an antireflective (AR) coating over a thin layer of conductive Indium Tin Oxide (ITO). The ITO grounds the arrays to the chassis via conductive dots, while the AR allows for as much power as possible. All spacecraft materials are assumed to be electrically conductive except for the AR/ITO coverglass coating and small areas on the arrays of exposed CV2568 adhesive.

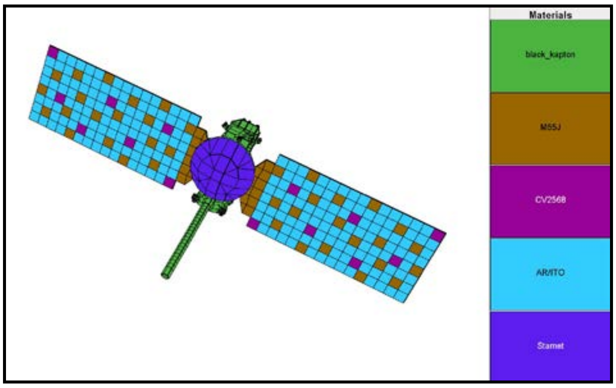


***Figure 1: Geometrical model of the Europa spacecraft in Nascap-2k Object Toolkit.***

The model uses the default *Nascap-2k* electrical properties for black Kapton. The solar array AR/ITO coating conductivity is taken from a study conducted for the Van Allen Probes mission [9]. Initial solar array voltages relative to chassis were provided by the Europa power team. The solar array string layout not yet decided, so for the purposes of this study we assumed one possible arrangement. The biases relative to chassis differ for sunlit and eclipse cases.

## 4. RESULTS

The *Nascap-2k* spacecraft charging analysis package [10,11] was used to solve for the steady-state spacecraft surface potentials. *Nascap-2k* is a three-dimensional spacecraft-plasma environment analysis computer code developed by Leidos, Inc. with funding from NASA and the Air Force Research Laboratory. It is distributed by NASA's Space Environments and Effects (SEE) Program (http://see.msfc.nasa.gov). *Nascap-2k* charging simulations account for incident plasma currents, secondary and backscattered currents, and photoemission.

The worst-case auroral environment is modelled at 15 RJ, in sunlight and in eclipse, as shown in Table 1. The near-Europa environment is modelled as shown in Table 2, and results are given here for the extremes of the possible plasma temperatures. Table 3 summarizes the results for the various cases.

**Table 3: Charging simulation results at 15 $R_J$ and near Europa.**

| Case | Sunlit? | Chassis potential | Arrays potential |
|---|---|---|---|
| 15 $R_J$ worst-case | Yes | < -10 kV | < -10 kV |
| | No | < -10 kV | < -10 kV |
| Near Europa, cold | Yes | -81 V | -97 to +3 V |
| | No | ~0 V | -16 to ~0 V |
| Near Europa, warm | Yes | +2 V | -15 to +85 V |
| | No | +2 V | -14 to +2 V |

For the worst case auroral environment, the chassis potential quickly becomes significantly negative (< -10 kV, but with differential potentials remaining below 100 V. The population of high energy auroral electrons leads to negative potentials despite the importance of secondary electron emission. In sunlight, the differential potentials are driven by the underlying solar array voltages, as is evident in Figure 2.

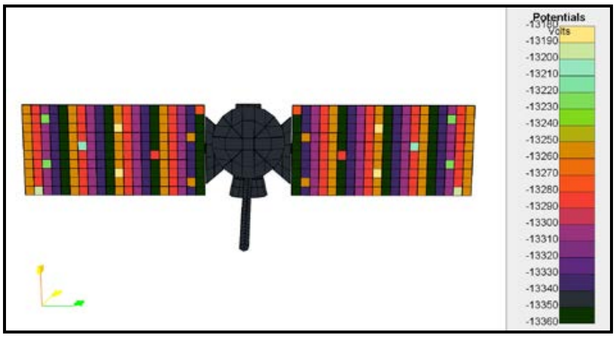


**Figure 2: Simulated spacecraft surface potentials for the 15 $R_J$ worst case auroral environment.**

For the near-Europa environment and cold (T=0.01 eV) plasma temperature (i.e. inside the Europa ionosphere), the underlying solar array string voltages "shine through" and the chassis floats to the negative of the highest string voltage. The array for a spacecraft so distant from the Sun would require significant power, so while the exact number would be expected to change along with the underlying potentials, floating to tens of voltage negative likely would not change. At such a cold electron temperature, secondary electron emission is minimal and would fail to counter the attraction of electrons by the positively biased arrays. For the eclipse case, the arrays are biased differently, leading to a near-zero chassis potential and string voltages no longer "shine through". Surface and space potentials for the sunlit case are plotted in Figure 3.

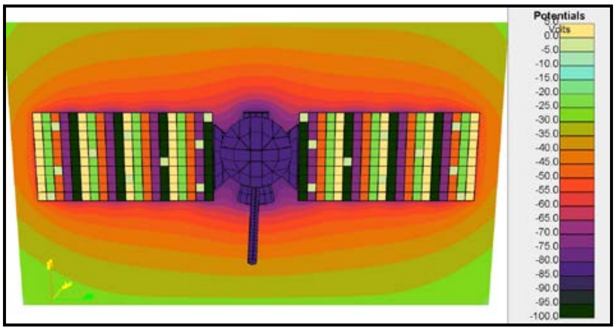


**Figure 3: Simulated spacecraft surface potentials for the cold near-Europa (ionosphere) environment.**

The situation is different for the near-Europa environment and warm (T=100eV) plasma temperature (i.e. in the torus). For the sunlit case, shown in Figure 4, the chassis potential is slightly positive. Although the string voltages "shine through", at this electron temperature, secondary electron emission is a large effect and keeps chassis from going negative. The chassis potential remains slightly positive in eclipse, with only mild differential charging on the arrays.

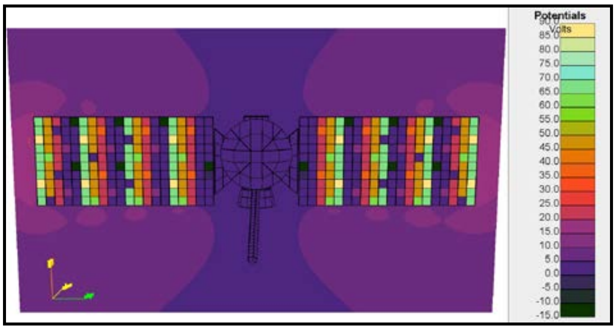


**Figure 4: Simulated spacecraft surface potentials for the warm near-Europa (torus) environment.**

## 5. CONCLUSIONS

We present here *Nascap-2k* simulations using planned Europa geometry and materials and several plasma environments. For the worst-case charging environment near 15 $R_J$, the chassis potential is expected to become significantly negative. Near Europa, for cold plasma temperatures, the chassis potential is predicted to float to the negative of the maximum string voltage, with array surface potentials varying along the strings. The situation differs in eclipse and for near-Europa with warm plasma conditions. The simulations will be iterated as the spacecraft development proceeds, and additional work will be needed to examine the impact on the science requirement for the PIMS instrument.

## 6. ACKNOWLEDGEMENTS

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