ISAT SURFACE CHARGING AND THRUSTER PLUME INTERACTIONS ANALYSIS

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ABSTRACT

NASA is designing the Iodine Satellite (iSAT) cubesat mission to demonstrate operations of an iodine electric thruster system. The spacecraft will be deployed as a secondary payload from a launch vehicle which has not yet been identified so the program must plan for the worst case environments over a range of orbital inclinations. We present results from a NASA and Air Force Charging Analyzer Program (Nascap) - 2k [1] surface charging calculation used to evaluate the effects of charging on the spacecraft and to provide the charging levels at other locations in orbit for a thruster plume interaction analysis for the iSAT mission. We will then discuss results from the thruster interactions analysis using the Electric Propulsion Interactions Code (EPIC) [2,3]. The results of these analyses are being used by the iSAT program for a range of environments that could be encountered when the final mission orbit is selected.

1. PROGRAM OVERVIEW

Characterizing the electromagnetic interaction of a satellite in low Earth, high inclination orbit with the space plasma environment and identifying viable charging mitigation strategies is a critical mission design task. High inclination orbits expose the vehicle to auroral charging environments that can potentially charge surfaces to kilovolt potentials and electric thruster propulsion systems will interact with the ambient plasma environment throughout the orbit.

The Iodine Satellite (iSat) spacecraft will demonstrate a high change in velocity by using a Hall thruster technology and iodine propellant as the primary form of propulsion. In addition to a velocity change, the mission will demonstrate plane and altitude change, as well as a change in altitude to ensure reentry in less than 90 days.

Hall thruster technology is a type of electric propulsion which uses electricity from a power source, typically a solar panel, to ionize and accelerate the propellant. In general, the electric propulsion method is a much more efficient accelerant (~10 times) than chemical propulsion systems. This increased efficiency allow for high specific impulse and continuous thrust. A typical Hall-effect thruster (HET) is illustrated in Fig. 1. The hollow cathode source provides the electrons for the discharge and neutralizes the ion beam. The radial magnetic (B) field prevents electrons from streaming directly to the anode. They instead spiral along the B field lines and drift in the E x B azimuthal direction (Hall Current) and diffuse to the anode where they ionize the propellant. The ionized gas is then accelerated by the electric (E) field to form the thrust beam.

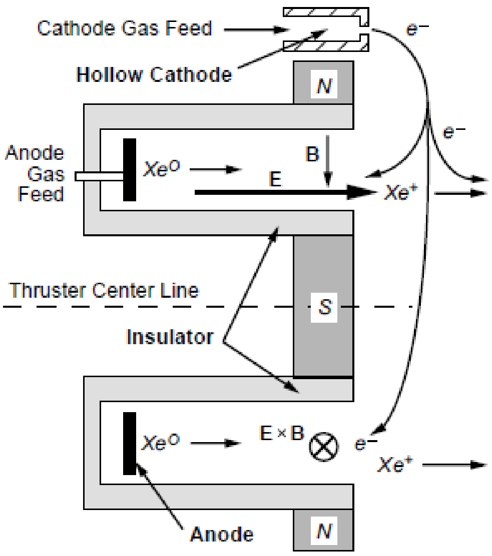

Figure 1. Operations of a typical HET.

The iSat spacecraft is a 12-unit (12U) cubesat, where one unit is 10 cm x 10 cm x 10 cm. An artist concept is shown in Fig. 2. ISat's iodine propulsion system consists of a 200 watt (W) Hall thruster, a heaterless cathode technology for better efficiency, a tank to store solid iodine, a power processing unit (PPU), and the feed system to supply the iodine.

Using iodine as a propellant allows it to be stored as an unpressurized solid on the ground and before flight. During flight, the tank is heated to vaporize the iodine propellant. The iodine vapor is then routed to the thruster and cathode assembly. The thruster then ionizes the

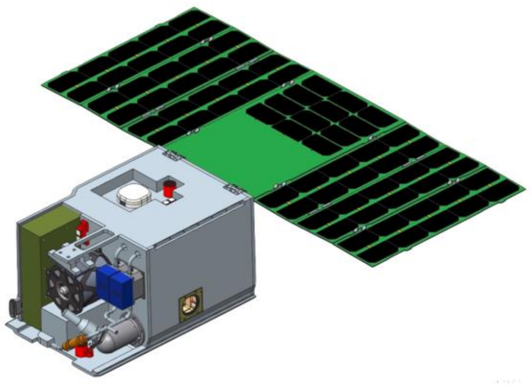

Figure 2. Artist concept of the iSAT cubesat.

vapor and accelerates it using magnetic and electrostatic fields. This results in high specific impulse, yielding a highly efficient propulsion system. The mission is planned for launch in fall 2017 and is managed by NASA's Marshall Space Flight Center (MSFC).

2. NASCAP-2K MODEL DEVELOPMENT

The spacecraft frame will be constructed from aluminum with a finish to prevent possible corrosion by the iodine. An image of the model built from basic building blocks supplied in Object Tool Kit (OTK) is shown in Fig. 3. The thruster itself is comprised of iron, aluminum, and an Inconel mesh. Other material components on the cubesat range from dielectric such as Kapton to conductors, such as aluminum. The solar arrays use the default solar cell material, a user defined printed circuit board (PCB) material, with the backside coated in aluminum. Additional cases were run with the backside of the solar arrays as Kapton to provide a bounding case. An additional model was developed in OTK for the EPIC analysis that employed less cells, nodes, and materials, as the original model developed was over the maximum size limit for the EPIC code to process.

3. SURFACE CHARGING ANALYSIS

At the time of the analysis, the exact orbit and inclination had not been finalized for the iSat project. A low Earth orbit (LEO) is expected to be the final orbit, however the inclination possibilities range from mid-latitudes to a polar orbit. Therefore, the auroral environment shown in Tab. 1 is assumed as the worst case surface charging environment and used for input into the Nascap-2k. The first column in Tab. 1 is the ambient cold plasma environment, assuming quasi-neutrality. The remaining three columns are the inputs for the Fontheim distribution describing the energetic particle population. Three particle species were used: electrons (100%) and hydrogen (91%), and oxygen (9%) for the ion species.

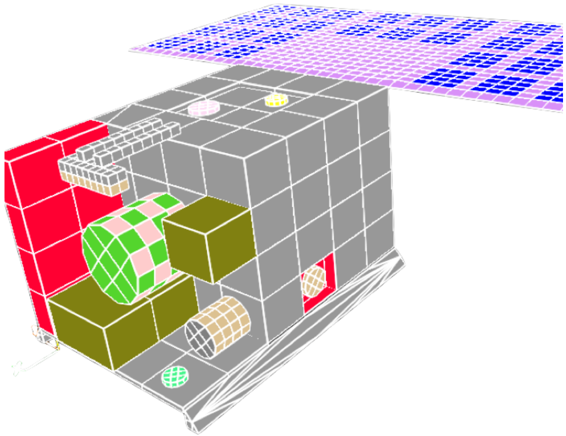

Figure 3. Object for surface charging analysis.

This environment is used to simulate a polar environment at approximately 700-800 km. Velocity of the spacecraft was set to be 7000 km/s and sunlight was incident on the solar arrays at full intensity when applicable. For the final surface charging case with the plume model analysis, we used the imported plume map from the EPIC analysis.

Table 1. Plasma environment used for surface charging analysis.

	Ambient	**Power Law**	**Maxwellian**	**Gaus-sian**
n (m^{-3})	6.0e5			
Electron current (A/m^2)	7.2e-9	5.0e-8	5.0e-7	2.0e-6
E_1 (keV)	0.2	0.050	25	25
E_2 (keV)		1.6e3		
Width (keV)				5

We show in Fig. 5 and Fig. 6 results from a surface charging case in eclipse with aluminum used on the backside of the solar arrays. Surface potentials range from -1000 V on the topside of the solar array to -1230 V on the tank. The model was run for 120 sec to simulate passage through the auroral oval. However, Fig. 6 shows surface potentials trending towards equilibrium after approximate 60 seconds. Surface potential results are smooth with no numerical noise.

Additional surface charging cases were in both sunlight and eclipse conditions. While it is understood that auroral charging occurs in eclipse conditions only, the additional cases with sunlight were run to show photoelectric effects on the spacecraft as it is unknown the final orbit. The range of possibilities was needed for the iSat Project to have as much information as possible to plan accordingly. The sunlight cases had the largest differential potentials ranging from -300 to an extreme of -3000V for the case with the aluminium on the backside of the solar arrays. The case with Kapton on the backside of the arrays in eclipse conditions (shown in Fig. 5 and Fig. 6) yielded results with the least amount of differential charging.

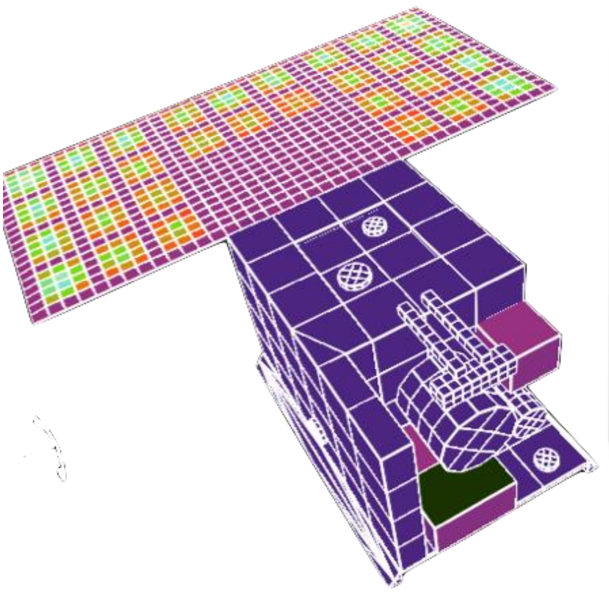

Figure 1. Nascap-2k potential measurements.

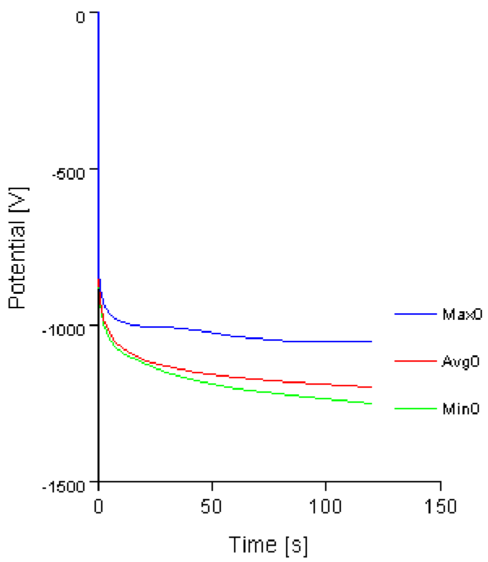

Figure 2. Potential versus time for eclipse charging case.

The results of a surface charging analysis that incorporated the thruster plume model were similar from those without the plume. The absolute potential of the spacecraft was 10 volts more positive with the plume than the case without the plume.

4. EPIC ANALYSIS

The EPIC model [2,3] calculates the interactions between electric propulsion systems and the spacecraft. Due to EPIC limitations, we used a simplified model of iSat for this set of calculations. In this model, the number of cells and nodes was greatly decreased from that used in the Nascap-2k analysis. Additionally, only three materials were used: aluminum, solar cells, and PCB. PCB material parameters, other than density, are unknown. They are currently set to the same value as solar cells.

There is also an inability to change the size of the thruster itself. As EPIC was originally built before the "popularity" of cubesats, the default thruster size is larger than required for a 12 U satellite. This somewhat limits the visibility of the immediately surrounding spacecraft surfaces, but should not affect the overall results.

Input parameters for the plume interaction model include EPIC default, program specified, and estimations when required. Some parameters were not able to be modified to be representative of iodine and were default parameters for xenon. Input for iodine was used when known and accepted by the model. Tab. 2 shows a list of specific input parameters used in this study.

Table 2. Input parameters for the thruster plume interaction modelling.

Description	Value
Atomic mass of propellant particle (I2 is 253.8) amu	126.9
Propellant flow rate injected through the anode (mg/sec)	0.82
Speed of propellant neutrals at the thruster exit (m/s). Assume Thermal Speed at 350C. Sqrt(2KT/π*m).	114
Neutralizer mass flow rate (mg/sec) (typically 1/12 of Fa)	0.07
Thrust(mN)	12.1
Plume electron temperature (eV)	2
Neutralizer effective temperature (K)	703.15
Reference electron density (m-3)	1.00E+15
Charge exchange cross section areas (Å^2)	59.2, 25, 10

With the plume thruster analysis, we can see ion density and velocity effects due to the thruster. Fig. 7 shows the iSat model with the thruster plume ion density output. The output includes the high energy main thruster beam ions, scattered ions in the intermediate energy range, and the low energy charge exchange ions. The ion density ranges from 10^8 (pink) to 10^{18} (orange) m^{-3} with the largest ion concentration in the immediate vicinity of the thruster, as would be expected. One item of note is EPIC does not calculate the neutral plume map and one was not provided as input to the model. Any results shown here are for charged particle interactions only.

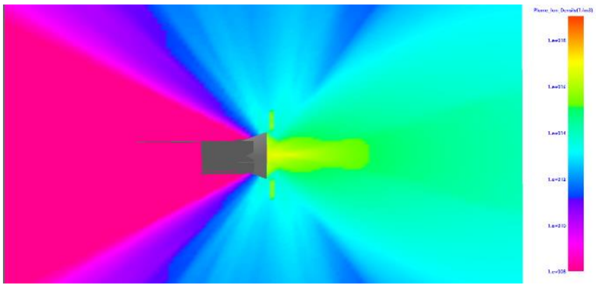

Figure 3. Thruster plume interactions.

4.1. Erosion and Deposition

EPIC calculates deposition of materials sputtered (deposited) from (to) the spacecraft over the duration of the mission. The rate of change is determined by the difference between the deposition and erosion rates. The sputtering yield (atoms/ion) depends on the ion incident angle, the energy of the ion, the masses of the ion and target atoms, and the surface binding energy of atoms in the target. Sputtering was calculated using the Yamamura-Tawara [4] model in EPIC. YT inputs for Solar Cells/PCB/Thruster are set to a default as recommended in [4].

The primary source of deposited materials comes from sputtering of thruster materials and other materials very near the thruster. Only one thruster material can be modeled, current values are estimates based on a boron nitride silicon dioxide (BN SiO_2) material as a placeholder. Deposition of neutral thruster propellant is not modeled. Fig. 8 shows the deposition of sputtered material given in angstroms for the 3.5 day thruster lifetime operation. The largest concentration of sputtered material is in orange near the thruster. Fig. 9 shows the ion flux to the spacecraft surface for the 3.5 day mission with a maximum total flux of $1x10^{20}$ ions / m^2 s.

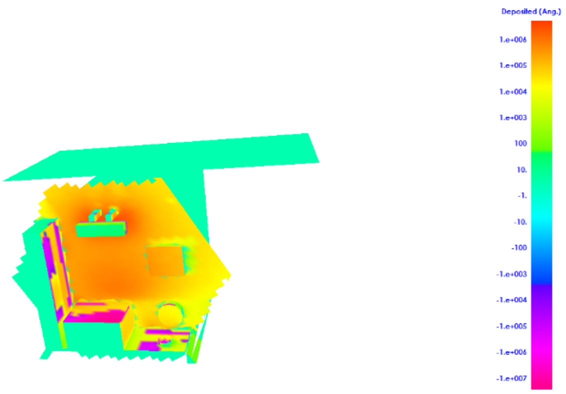

Figure 4. Deposition of sputtered materials. Total for 3.5 days of thruster operation. Zero deposition / erosion on surface of solar array.

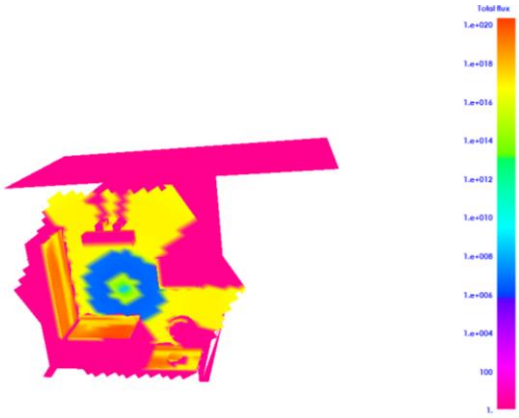

Figure 5. Ion flux to spacecraft surfaces. Total for 3.5 days of thruster operation. Zero flux to top of solar array.

5. SUMMARY OF RESULTS

Surface charging analysis using a polar environment shown in Tab. 1 showed relatively high charging levels (over a kilovolt) with ~200 V differential charging in eclipse conditions. The Nascap-2k surface charging analysis with plume had minimal effect on the absolute charging of 10 volts.

The thruster plume interactions analysis gave results for ion density and velocity for the main beam ions, charge exchange ions, and scattered ion. However, results do not include any neutral plume information as there was no neutral beam input information given by the program for input into EPIC. The plume ion density had a maximum of 10^{18} m^{-3}. The deposition and erosion analysis showed a range of results for -10^7 to 10^6 angstroms. The total ion flux to the surface reached a maximum of 10^{20} ions/m^2 s for the 3.5 day mission lifetime. When a final orbit is confirmed, Program may ask to redo the charging analysis with the appropriate environment. iSAT is scheduled to launch in 2017.

6. REFERENCES

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