Numerical Simulation of Cube-Probe in-Orbit Plasma Environment, Using Particle-In-Cell (PIC)

***Abstract*– The purpose of this paper is to present the importance to predict possible ion collection under plasma parameters. In this case, the computational object is a cube 10x10 x10 cm, similar in shape and size of a nanosatellite, surrounding by atomic oxygen ions and a constant flux of ions hitting one side of its surface. Particle-in-Cell (PIC) and Particle Tracking simulation code were performed to quantify the expected potential and charge density. Additionally, a bias negative surface is also simulated to verified the ion flux deflection into the bias surface. A comparison between a bias surface and non-bias surface is performed to verified that ion collection is enhanced.**

***Keywords*—PIC simulation, spacecraft, ion current.**

I. Introduction

In recent decades, hundreds of universities have successfully launch small spacecraft to space for research goals [1]. Those spacecraft are constantly hitting by ions in Low Earth Orbit. However, there is an interested to measure plasma density in altitudes around 500 km since It may be used to deorbit spacecraft [2]. As the solar panels becomes high efficiency to provide current to the spacecraft, payloads of the spacecraft, generally uses high energy for long time, so it is necessary that solar panel increases the voltage supply in spacecraft. Due to that electric charge may be attracted to a potential source of potential. A discharge in solar panel may become a serious issue during spacecraft mission [3]. This paper presents a numerical simulation in orbit condition of a 10x10x10 cm object to verified the electric potential and the plasma density.

I. Numerical Simulation

Using a combination of Particle-in-Cell and Particle Tracking algorithms. The algorithm is explained in Ref. [4]. The simulation consists of an iterative calculation of the electric potential and the ion current.

A. Simulation Model

The cube model and plasma simulation parameters are shown in Fig. 1 and Table 1, respectively, below. This configuration formed a cube of 10 cm in dimension length, 10 cm in width and 10cm in height. There are two cases: the object is inside the computational domain a constant flux of ions is simulated. The other case is one side of the cube which is normal to the ion flux is biased (-10 Voltage) and a constant ion flux is applied similar to the previous case. The computational domain is 128cmx64cmx64cm with each grid of 1 cm. The computational boundary is fixed at zero potential. The plasma was injected from the boundary according to the plasma condition specified. No magnetic field is included in the simulation as the ion motion is not greatly affected. The plasma densities from 200 to 1000 km altitude above the Earth's surface was assumed. Figure 3 shows the plasma densities**.** The ion density was taken from IRI-2012 in Ref. [5]. The date and time was assumed to be 1:30 Universal Time on March 12, 2018. The location was -12.04 latitude and 282.9 longitude (assuming Lima region). For simplicity, the numerical simulation is performed assuming that the ion species are composed of atomic oxygen only as shown in Figure 2.

Each simulation time step is selected so that fastest ions travel less than one cell per iteration. Moreover, each simulation is run for 5000 iterations to reach a steady state which is a dynamic equilibrium with the object surface and the ion flux. A simulation can typically be completed in 20 hours when run workstation Dell 5810 type tower, processor Xeon 4 cores at 2.4 Ghz with 8GB of Ram, Fig. 3.

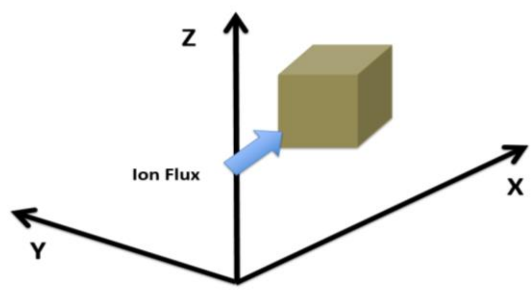

Fig. 1 Simulated cube

Table 1. Simulation Model for Ground Experiment

Simulation Parameters	Values
Domain size (cm)	128 x 64 x 64
Object size (cm)	10 x 10 x 10
Grid size (cm)	1
Plasma density (m^{-3})	$5x10^{11}$
Plasma temperature (eV)	0.1
Prism surface potential (V)	-10

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B. Simulation Conditions

At the beginning of the simulation, the computational domain is uniformly filled with Maxwellian plasma. All the body surface potential is zero at the initial condition. There are two case: Non-bias and bias cases. Bias is when one side of surface (-X in Fig.4) is biased to a negative potential. The other one is neither side of its surfaces is biased. This process is calculated using the PIC algorithm [4]. Ion and electron motions are tracked while keeping all the electric potential constant. The simulation is continued until the plasma environment surrounding the body settles to the steady state [6].

II. Simulation Results

After simulation, the main outputs were the ion current collected by the bias surface. Figure 5 shows an example of ion current collected by all of the body surfaces. The ion current that is necessary for the research is the y-z plane facing the –x direction. Figure 5 shows that most of the ion current is collected by the biased surface [7]. The other surface just collects thermal ion current from the plasma environment. The other non-bias case is also compared to the bias case.

Figure 6 shows a comparison of the ion current collected between the non-bias case and the bias case simulations [8]. As it is expected the ion current collected by the bias case is higher than the non-bias cases. The main is that negative bias potential expand the plasma sheath around the surface. More ions are deflecting into the surface which increases the ion current. Other effect such the flow theory and the molecule collision are taking into account since the purpose of this paper is compared numerical simulation [9].

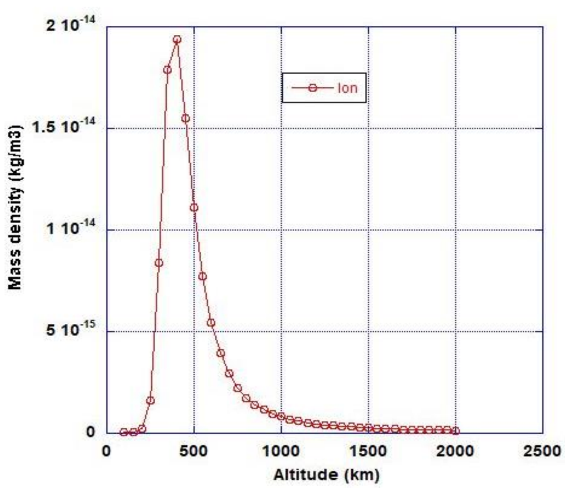

Fig.2. Mass density of ions

Fig 3. Dell 5810 Workstation

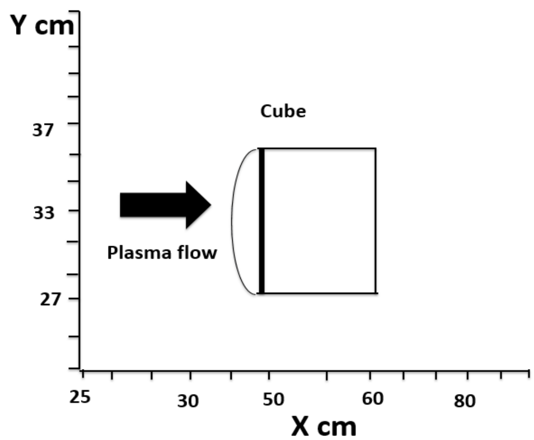

Fig.4. Plasma flow direction to simulate the orbit condition

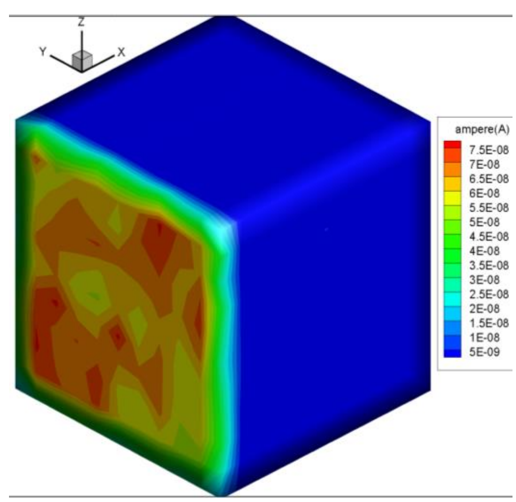

Fig. 5 Ion current collected by the simulated object

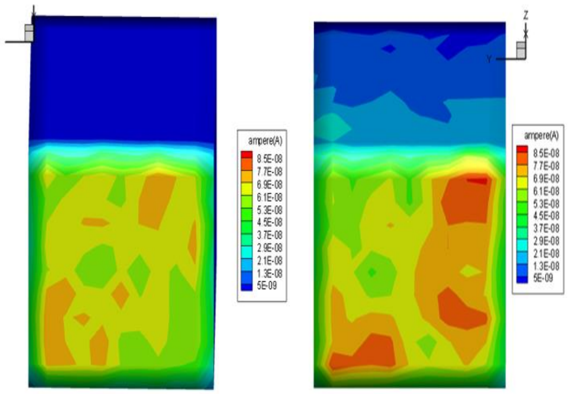

Fig. 6 Comparison between the ion current collected in the two cases

III. CONCLUSIONS

As the computer task performance has explosively increased, numerical simulations has become one source of validate/ predict future experiment results when a small spacecraft is in orbit. Due to the quick technological improvements high voltage solar panel may be used in nanosatellites which are the main target for universities engineering laboratories. It should be taking into account that higher voltage sola panel should be study as engineering part of the system and as a potential source of discharges to avoid unnecessary risk in future mission.

This research aims to provide another tools for scientist who are interested in space environment. Moreover, this numerical simulation may make large object however it is required parallel computing or large cluster to perform a quick and reliable simulation.

The future work, is to simulate different conditions such as higher altitudes and object size similar to a small satellite with a different direction of the ion flux. This will set minimum and maximum of the current collected by the object.

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