EFECTIVE ION CURRENT COMPUTATION ALGORITHM FOR MODELING OF LEO SPACECRAFT CHARGING

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Abstract

Cold plasma ion capture surface construction algorithm was developed in terms of the classical approach to solution of the severely charged body problem (Al'pert et al, 1964). The algorithm makes it possible to create the effective surface for complicated spacecraft outer surface. Peculiarities of the severe charging case modeling, as far as the computation results are presented and discussed.

Computations reveal that noticeable distortions of the primary spacecraft surface arise in the case of differential charging corresponding to the spacecraft with dielectric elements on its surface.

Effective method for color visualization of the electrostatic potential distribution on the spacecraft surface was developed for analysis of the spacecraft charging modeling. Typical screenshots of VRML images are presented in the work for various charging cases

General

Typical peculiarities of spacecraft charging in the low Earth orbit (LEO) are determined by impact of cold ionospheric plasma providing omnidirectional low energy electron flux and unidirectional ram ion flux, as far as of the Solar light and high energy electrons (for the spacecraft orbit parts passing through auroral regions) on the spacecraft surface. The auroral electron impact may produce, in the definite conditions, severe charging of the spacecraft up to ~-5–10 kV. The case is dangerous for spacecraft operation in orbit, and so it requires detailed investigation.

The general theory for plasma probe charging in cold plasma ('big plasma probe' theory) under the ram ion flux was developed in [1] for simple model object (sphere and cylinder). In this work, we extended the theory to the analysis of charging of objects with complicated surface and applied it to LEO spacecraft charging investigation. For real spacecrafts, the method of construction of geometrical model of spacecraft was described in [2].

The main feature of the approach [1] was to construct the effective ram ion capture surface. The problem was solved in the case of severe charging, i.e. the electric potential of the probe φ is high enough:

$$|\varphi| \geq \frac{kT_e}{e}\left(\frac{R}{D}\right)^{4/3}. \qquad (1)$$

Here R – sphere radius, D- Debye length in the plasma, T_e – electron temperature, e – electron charge, k – Boltzmann constant.

Following [1, 3], we compute the size of the effective ion capture surface for severely charged spacecraft. Note, that for electron repulsion from the negatively charged surface is described by the ordinary Bolzmann law. Photoemission current value for model computation is selected from material data base.

Algorithm

The starting point of the computation algorithm is the spacecraft geometrical model with initial values of electric potential set for every triangle of the model. The electric field vector value and direction are computed in every triangle vertex. Next, we move along the vector direction calculating the potential value $\varphi(\mathbf{r})$ and comparing it with kT_e/e until $|\varphi(\mathbf{r^*})| \sim kT_e/e$. The **r*** point is the new coordinate of the vertex. The computation is done for every vertex of the model. Some stabilization procedures (e.g. one step displacement length limitations) are used to avoid formation of holes on the effective surface or triangle 'degeneration', i.e. reduction of triangle square to zero.

After the 'inflation' procedure above is completed, we calculate currents of all components on the every surface element taking into account that ram ions are captured by the newly constructed capture surface. The surface reconstruction procedure is repeated for new values of electric potentials on every triangle of the model.

Iterations are repeated till the convergence is reached. The computation accuracy achieved in the case of severe charging is of order of several volts. Obviously, the model provides very low accuracy for potential distribution on the spacecraft surface in the case when (1) is violated.

Note, that displacements of the triangle vertexes are significant in the case of severe charging, and the effective surface shape may differ significantly from the original spacecraft surface. So we included special sub-procedure to determine whether a given triangle is opened for the ion flux, or screened by the other surface elements on every iteration step ('dark/light' procedure. Similar procedures (used only once on the initial step) are used for Solar light and auroral electron fluxes.

The iterative capture surface inflation procedure and the 'dark/light' procedure above enable to compute the distribution of the electric potential on the spacecraft surface in the case of simultaneous impact of the cold ionospheric plasma electrons, ram ions, the Solar light and auroral electrons.

Computation results

To verify the algorithm developed, we have done test computations of charging of sphere (R=3m) for various values of the cold plasma density n_i and auroral electron current density j_{aur} and energy E_{aur} in cases of the Solar light impact and without it. The computation results which are in good agreement with [3] are presented in table below.

Equilibrium potential values for the model object in various charging conditions*

n_i, m^{-3} / j_{aur}, A/m^2	$1.0\cdot10^{-6}$		$1.58\cdot10^{-4}$	
10^8	-32	-32	-6076	-8775
	+	+	-3304	-4907
$3.55\cdot10^9$	-0.3	-0.4	-1700	-1921
	-0.1	-0.1	-952	-1080
10^{10}	-0.3	-0.3	-1087	-1179
	-0.2	-0.2	-609	-658
10^{11}	-0.3	-0.3	-1.2	-1.3
	-0.3	-0.3	-0.4	-0.4
10^{12}	-0.3	-0.3	-0.3	-0.3
	-0.3	-0.3	-0.3	-0.3
$3.0\cdot10^{12}$	-0.3	-0.3	-0.3	-0.3
	-0.3	-0.3	-0.3	-0.3

*in every table cell: top left – for E_{aur}=10 keV, no Solar light; bottom left – the same with Solar light; top right – for E_{aur}=30 keV, no Solar light; bottom right – the same with Solar light.

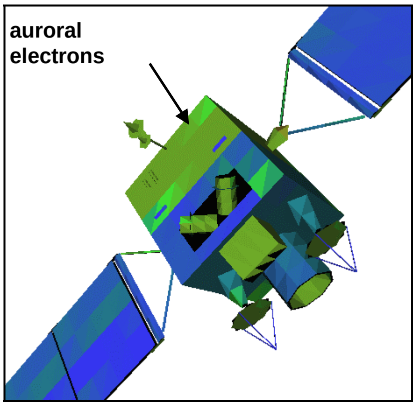

Fig. 1. Spacecraft image with grayscale notification of the potential distribution: dark gray – low charging, light gray – high potential values

The test results of the work were obtained for typical models of spacecraft. Differential charging of the spacecraft surface is seen clearly in the case when some spacecraft design elements are dielectric, and some are conductive ones. Special method for computation result analysis was developed in terms of VRML approach to the problem of 3D surfaces visualization. The solution of the problem here includes conversion the modeling data into VRML format using color notification of the every spacecraft surface element potential.

The figures below are screenshots of various spacecraft 3D models charged in various space environment conditions.

Conclusion

Ram ion capture surface construction algorithm was developed and used for LEO spacecraft charging analysis in the case of simultaneous impact of cold ionosphere plasma electrons, ram ions, the Solar light light and high-energy auroral electrons.

Descriptive method for color visualization of the computation results was developed for analysis of the spacecraft charging peculiarities. 3D scene constructed according to the computation results and standard VRML browsers may be used for analysis of the spacecraft charging in the given space environment conditions.

References

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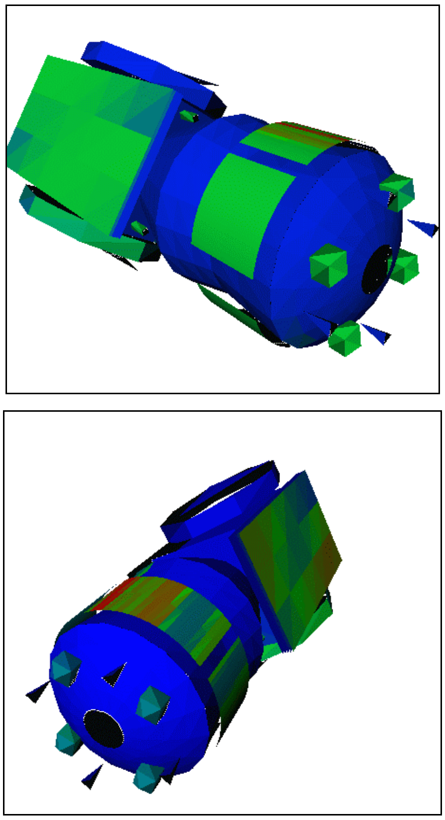

Fig. 2. Electric potential value of various spacecraft surface elements: dark gray – metal elements with low potential, light gray – high potential on solar batteries and radiators directly irradiated with aurorlal electrons. Two different screenshots of the same model are presented