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Numerical Analysis of Potential Structure around Solar Power Sail IKAROS in Solar Wind Plasma

太陽風環境におけるソーラー電力セイルIKAROS周辺の電位構造解析

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We have numerically studied on the electrostatic potential structure around the solar power sail “IKAROS” in solar wind plasma. Solar power sail is expected to a candidate of the next-generation spacecraft for interplanetary flight. The potential structure is of importance for the payload design such as the location of onboard scientific instruments. A unique electrostatic potential structure is recognized as a result of interactions between ambient plasma and a large-scale membrane of the spacecraft. A wake potential in the downstream region and the reduction of the sheath by photoelectrons in the upstream region of the spacecraft are shown by the numerical simulation.

1. Introduction

Solar sail is one of a next-generation spacecraft that is regarded as a candidate for interplanetary flight. Solar sail consists of a large membrane that is typically made of strong metal-coated polymer material. The conductive surface of the membrane reflects the solar radiation, which results in converting the solar radiation pressure into the spacecraft thrust. If its electric power is supplied by onboard solar arrays, the spacecraft is called as “solar power sail”. Today, JAXA had launched the IKAROS spacecraft [1], the first demonstration spacecraft of a solar power sail, in May 2010 into the Venus transfer orbit. The scale of the membrane of the IKAROS spacecraft is 14 x 14 m^2 to obtain sufficient thrust from the solar radiation pressure, (e.g. 10^{-6} Pa at 1.0 AU).

During interplanetary flight, a solar sail is exposed to the solar wind plasma and photoelectrons that are emitted from the sunlit surface of the spacecraft. The Debye length of the solar wind plasma is comparable to the scale of the solar sail, and the plasma has the flow that is supersonic for ions (mostly for protons) but subsonic for electrons. Hence, the sail is expected to have the significant potential structure around itself, and its quantitative estimation is of importance for the payload design such as the locations of scientific instruments. We performed a numerical experiment for the interactions between charged particles and a solar sail assuming the IKAROS spacecraft by using a three-dimensional electrostatic full Particle-In-Cell (PIC) [2] code we had been developed [3]. The analysis was focused on the estimation of the potential structure around the sail including space charge effects of the charged particles around the sail.

2. Numerical Analysis of Interactions between Solar Sail and Solar Wind Plasma

We performed the numerical analysis for the interactions between charged particles and the IKAROS spacecraft at 1.0 AU. In the simulation, the motion of individual ions and electrons is explicitly solved, and the electrostatic field is computed self-consistently. Table I shows the computation parameters and Fig. 1 shows the numerical domain of the simulation. The IKAROS spacecraft is assumed an aluminium conductor plate whose area is of 14x14 m^2 and thickness is of 0.5 m. The thickness of the model is comparable with the Debye length of the photoelectrons but much

Table I. Computation parameters

Plasma density [m^{-3}]	$6x10^6$
Plasma temperature [eV]	10
Plasma drift velocity [m/s]	470
Photoelectron (PE) current flux [mA/m^2]	40
PE1 temperature [eV]	1.5
PE2 temperature [eV]	5.0
Flux ratio, PE1:PE2	9:1
mass ratio (m_i/m_e)	1836
Numerical domain [grid]	256*128*128
Object size [grid]	1*28*28
Grid size, dx, dy, dz [m]	0.5
Time width, dt [10^{-7} s]	1.0
w_{pe}*dt	0.0138

smaller than that of the ambient plasma. The directions of solar flux and the flow of the solar wind are normal to the surface of the sail in this simulation. As simplicity, we neglect ambient magnetic field. The emitting photoelectrons are considered to have double Maxwellian distribution as a better representation of the distribution in tenuous plasma environment [4,5]

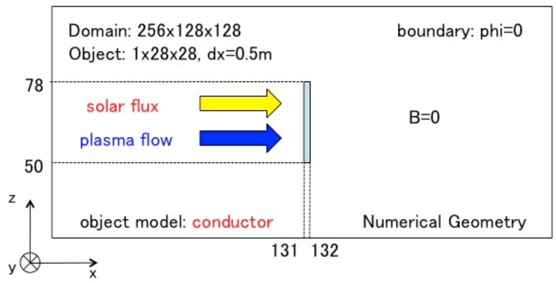

Fig.1. Numerical domain of the simulation. The rectangular object located at the center indicates the conductor sail model.

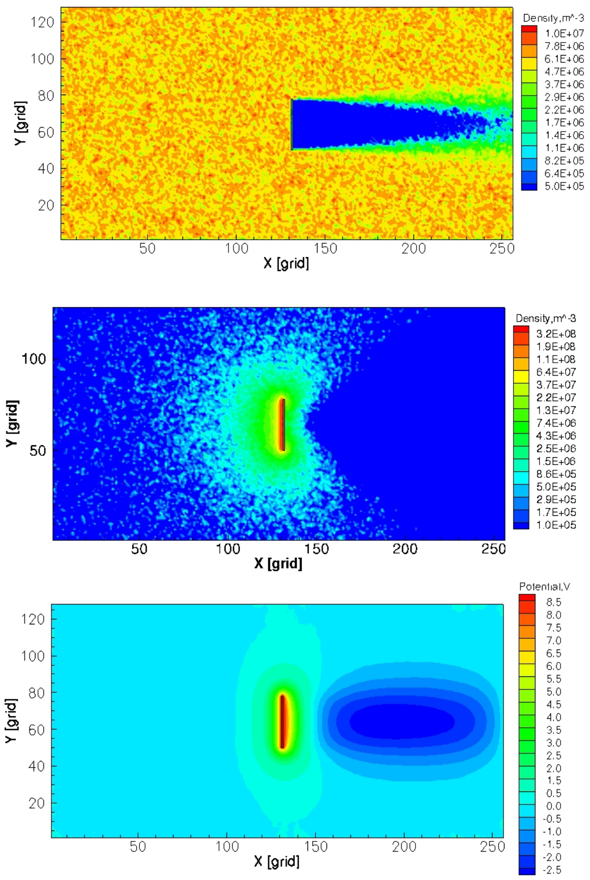

Fig.2. Spatial distributions of the charged particles and the electric potential around the IKAROS spacecraft at 2500 time steps. Contours show a) the ambient ions, b) the photoelectrons and c) electric potential in XY-plane at Z=64 from the top in this figure.

3. Results

Figure 2 (a), (b) and (c) shows the numerical results of the spatial distribution of the ambient ions, photoelectrons, and the electric potential at 2500 time steps, respectively. The saturation value of the floating potential of the sail is determined to be +8.3 V by the computation. A large ion wake structure is formed in the downstream region of the sail as shown in Fig. 2 (a). A wake potential whose minimum value is -3.0 V is formed due to the ion wake shown in Fig. 2 (c). The emitted photoelectrons from the upstream surface diffuse around the sail even to the downstream surface although the negative wake potential obstructs the diffusion shown in Fig. 2 (b). The dense layer of the photoelectrons whose magnitude is up to 3.8×10^8 m^{-3} in 1.5 m thick from the emitting surface is recognized in the figure. We also recognized reduction of the electron sheath in upstream region of the sail due to the photoelectron emission by another comparative simulation with or without the photoelectron emission.

Acknowledgments

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