

ABSTRACTS (PH D THESIS)

On Asteroid Deflection Techniques Exploiting Space Plasma Environment

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Introduction

The collision of the asteroid with the Earth is one of the devastating disaster which has been studied by many astronomers and researchers. In this thesis, two techniques to deflect an asteroid with unacceptable Earth colliding risk away from the original course are proposed and studied. Compared with the method proposed before, the effectiveness of the methods has been extended by exploiting the space plasma environment. The first method is the kinetic impactor (KI) which sends a spacecraft to impact against the target asteroid for deflection. To increase the impact velocity, the electric solar wind sail (E-sail), which generates the thrust acceleration force with the interaction between the charged conducting tethers and the solar wind plasma stream, is assumed as the propulsion system. Second method is the Coulomb force attractor, which tows the asteroid by using the electrostatic attraction between the asteroid and the spacecraft both of which are artificially charged.

Electric solar wind sail kinetic impactor

The E-sail [1] is the next-generation space propulsion system. The E-sail based spacecraft has many long thin conducting tethers which are connected to electron guns mounted on the spacecraft main body (see also a conceptual sketch shown in Fig. 1). The tethers are charged up through the loss of electrons caused by the electron gun and interact with the natural solar wind plasma stream. Since the E-sail enables a spacecraft to generate the thrust force without consuming any reaction mass, it can be attractive to increase the impact high velocity required by KI technique.

The advanced solar wind force model is proposed considering the configuration of the E-sail base spacecraft. The direction and the magnitude of the solar wind thrust force of the E-sail is expressed as a function of the attitude of the E-sail. To reduce the energy required to change the direction of the thrust force by changing the attitude of the E-sail, a new orbital maneuvering technique not changing the attitude of the spacecraft actively but changing the voltage of the conducting tethers is also proposed and investigated. The usage of the maneuvering technique has been proven by analytical and numerical approach.

Finally, numerical simulations of the E-sail KI are performed for the scenario created from fictional Earth impactors. The mass of the asteroids is assumed to be 1.0×10^9 kg and the mass of the projectile mounted on the E-sail is assumed to be 1,000 kg. The trajectory of the E-sail to impact to the asteroid is solved in an optimal frame work. The results show that the E-sail KI achieves deflection distances larger than the Earth radius for Apollo asteroids which has a semi-major axis larger than 1 au. Figure 2 is an example of the optimized trajectory of the E-sail. Results for the Aten asteroid which has the semi-major axis smaller than 1 au, on the other hand, the deflection distance achieved by the E-sail KI is smaller than the Earth radius. To investigate the characteristics of the E-sail KI, trajectory optimization for the solar sail which produces the thrust force by reflecting the Sun light with a large thin mirror is also performed. Since the solar radiation pressure force is proportional to the inverse of the square solar distance of the spacecraft, the thrust

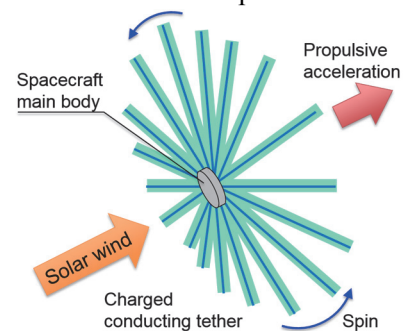


Figure 1. A conceptual sketch of the E-sail based spacecraft.

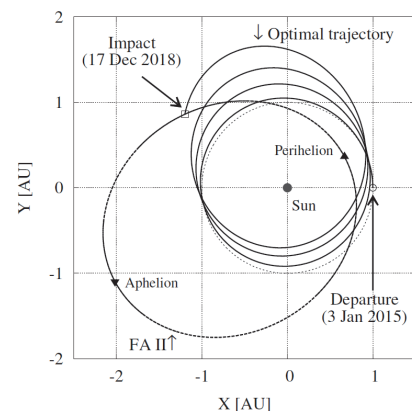


Figure 2. An example of the optimal trajectory for E-sail.

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acceleration magnitude of the solar sail rapidly increased when the spacecraft spirals inward to impact against Aten asteroid. On the other hand, the thrust force of the E-sail varies as the inverse of the solar distance and thus the E-sail experiences a small reduction on thrust when the spacecraft spirals outward to impact against Apollo asteroid. These results show that the E-sail KI is more effective to deflect Apollo asteroids.

Coulomb force attractor

The gravitational tractor [2] which tows the asteroid by using the gravitational attraction between a target asteroid and a massive spacecraft has been proposed and studied. The Coulomb force attractor extends the towing force by an electrostatic attraction between the asteroid and the spacecraft. Both the spacecraft and the asteroid are artificially charged and the electrostatic force is introduced.

The Coulomb force attractor cannot be used without charging the asteroid artificially. To study the charging mechanisms of a conductive asteroid, three-dimensional asteroid charging model is developed based on the finite element method. The voltage of the asteroid is formulated based on the three dimensional mesh to model the realistic shape of the asteroid. Current flows which are caused by the space plasma surrounding the target asteroid are modeled as the equivalent current sources. They are, currents caused by the primary electrons and protons, the secondary electron current caused by the incidence of the primary particles, photoelectron currents caused by the Sun illumination. To solve this non-linear problem, a numerical solver has also been developed. Our tool successfully works to solve the natural charging phenomenon of a conductive asteroid as shown in Fig. 3. The results for artificial charging cases show that the asteroids composed with conductive material can be charged artificially.

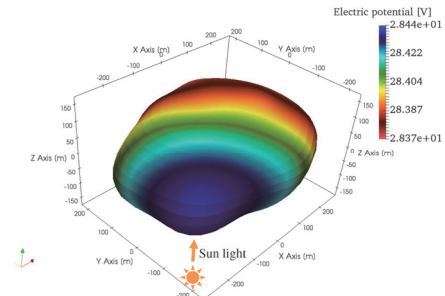


Figure 3. Natural charging analysis for a conductive asteroid.

The dynamics of the charged spacecraft in the vicinity of the charged asteroid is also formulated. The equations of motion are formulated for the rotating reference frame fixed in the initial heliocentric motion of the centroid of the asteroid. By numerically integrating these equations, it is demonstrated that the electrostatic attraction is effective to extend the change in the position and velocity of the asteroid. The achievable deflection distances between the asteroid and the Earth at the predicted Earth impact date are also calculated for fictional Earth impactor to investigate the effectiveness of the Coulomb force attractor. An 8.73×10^7 kg of asteroid artificially charged -20 kV is assumed to be a target. The spacecraft is charged up to 20 kV and the mass is assumed to be 500 kg. The eccentricity of this asteroid is assumed to be about 0.2. Such small asteroid is difficult to be deflected by using the gravitational attraction. In addition, achievable deflection distance is not so affected by the change in time to start towing. The result shown in Fig.4 tells that the Coulomb force attractor can extend the deflection distance of the asteroid with a small mass and small eccentricity efficiently.

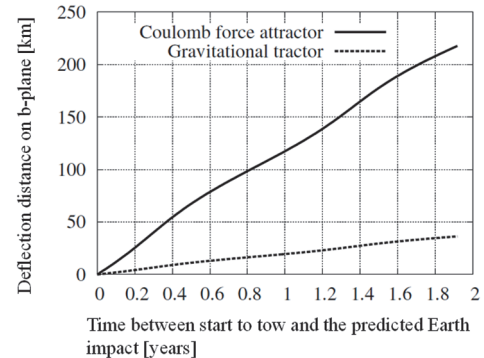


Figure 4. Comparison of the achievable deflection distances by two methods.

Acknowledgements

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References

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- [2] Lu, T. E. and Love, G. S., "Gravitational Tractor for Towing Asteroids," *Nature*, vol. 438, pp. 177-178, 2005.