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Possibility of Asteroid Deflection by Electric Solar Wind Sail

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Abstract

The Electric Solar Wind Sail (E-sail) is a new propulsion method for interplanetary travel which was invented in 2006 and is currently under development. The E-sail uses charged tethers to extract momentum from the solar wind particles to obtain propulsive thrust. According to current estimates, the E-sail is 2-3 orders of magnitude better than traditional propulsion methods (chemical rockets and ion engines) in terms of produced lifetime-integrated impulse per propulsion system mass. Here we analyze the problem of using the E-sail for directly deflecting an Earth-threatening asteroid. The problem then culminates into how to attach the E-sail device to the asteroid. We assess a number of alternative attachment strategies and arrive at a recommendation of using the gravity tractor method because of its workability for a wide variety of asteroid types. We also consider possible techniques to scale up the E-sail force beyond the baseline one Newton level to deal with more imminent or larger asteroid or cometary threats. As a baseline case we consider a 3 million ton asteroid which can be deflected with a baseline 1 N E-sail in 5-10 years. Once developed, the E-sail would appear to provide a safe and reasonably low-cost way of deflecting dangerous asteroids and other heavenly bodies in cases where the collision threat becomes known several years in advance.

1. Introduction

There are an estimated 100 000 Near Earth Objects (NEO) of effective diameter of 140 m or bigger. One fifth is assumed to be potentially dangerous and one will hit us every 5000 years [6]. Asteroid with volume equivalent to 140 m sphere and density of 2.1 g/m³ has a total mass 3 million tons. An asteroid with this mass, hitting Earth 30 km/s, would yield an energy release equivalent of 300 MT of TNT explosive, causing serious regional damage.

If an asteroid is observed on a collision course with the Earth, there are two options. The first is to blow the asteroid apart into smaller pieces, many of which could still cause local damage and problems to near Earth space operations. Thus, time permitting, we should as a first option try to deflect the asteroid gently without breaking it. We propose that this could be done with the Electric Solar Wind Sail. [5]

Our asteroid is 15 million times larger than typical E-Sail payloads. However, its deflection is feasible because the required asteroid Δv is quite small. The continuous propellantless thrust of an E-Sail increases its relative merit over other propulsion systems with increasing deflection mission duration.

2. Electric Solar Wind Sail

The Electric Solar Wind Sail (E-Sail) uses charged tethers to extract momentum from the solar wind particles to obtain propulsive thrust. It is a new propulsion method for interplanetary travel, which was invented in 2006 and is currently under development [2, 3]. According to current estimates, the E-Sail is 2-3 orders of magnitude more efficient than traditional propulsion methods (chemical rockets and ion engines) in terms of produced lifetime-integrated impulse per propulsion system mass.

The force of an E-Sail is inversely proportional to the distance from the Sun as $F \alpha (1/r)$ [4]. In comparison, the force produced by a photonic solar sail is $F \alpha (1/r^2)$. The E-Sail has thus particular potential for outer solar system missions, on more eccentric asteroid tracks and on sample return missions.

As the E-Sail requires no fuel (charging of the wires can be accomplished by an electron gun powered by modest-sized solar panels), it allows quite small total spacecraft mass. The E-Sail thrust can be steered in a cone of 30° around the solar wind velocity vector. By inclining the sail in a braking orientation, E-Sail can also track towards the Sun.

1.1 E-Sail deflection performance

A rough way to estimate the time required for asteroid deflection is to assume that Earth is heading towards an asteroid along a straight line and then to calculate the time required to pull the asteroid away from Earth's way, i.e. to move it by one Earth radius with the E-Sail. For an E-Sail thrust of 1N it takes 6.2 years to deflect an asteroid of 3 million tons mass. With 2N thrust, the deflection takes 4.4 years. With a 3 N thrust it takes 3.6 years.

1. Attaching E-Sail to the asteroid

Due to its low mass, an E-Sail vessel is easily carried (or carries itself) to the asteroid. This leaves the problem of how to transmit the pull force of the E-Sail to the asteroid. The continuous, gentle pull of the E-Sail facilitates the task when compared with more violent means such as nuclear explosives or ordinary rocketry. One can use either:

1.1 Harpooning

Directly attaching a towing cord to the asteroid is the most straight-forward solution. An assisting small spacecraft is needed to fly into the proximity of the asteroid to shoot the harpoon, which carries the towing cord to the rotational pole of the asteroid. If the asteroid is pulled along the rotation axis, the process does not much disturb the asteroid's rotation state. Depending on the case this may or may not be close to optimal pulling direction. If it is not, one may attach the cord to both poles and pull sideways or to reattach the cord again when needed

1.2 Gravity tractor

By placing a mass close to the surface of an asteroid, their mutual gravitational attraction can be used to transfer the towing force of an E-Sail wirelessly to the asteroid [1].

In order to transfer the 1 N force of a baseline E-Sail to a spherical asteroid holding the tractor body right at the surface of the asteroid, the needed mass of the tractor would be 24 500 kg. For a safe limit of one asteroid radius away from the volume equivalent surface, the required tractor mass would rise to 98 000 kg. To avoid bringing this mass from the Earth, the mass should be mined from the asteroid itself. For example, stones and regolith could be collected by a robot to a bag which is then lifted from the surface. The required auxiliary chemical propulsive maneuvers are modest; the main challenge may be in controlling the procedure remotely.

6. Summary and Conclusions

Once developed, the E-Sail would appear to provide a safe and reasonably low-cost way of deflecting dangerous asteroids and other heavenly bodies in cases where the collision threat becomes known several years in advance. The first test mission to measure the E-Sail effect in small scale is ESTCube-1, which is to be launched in 2012 (www.estcube.eu).

Acknowledgements

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References

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