Study of Gravity Tractor efficiency for a NEO

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Abstract.

The most talked about topic in the 21st century is climate change and global warming, about how it can cause the extinction of the human race. But there is another unpredictable, yet inevitable event, which could cause mass extinction and catastrophic damage to the Earth, which most researchers believe to be long overdue. It is an event of asteroid collision. This scenario is filled with uncertainty and was previously thought to be unavoidable. But, with the current advancements in space technology, scientists have developed a concept of a spacecraft which is capable of steering the asteroid off its course to prevent a collision. This paper analyses the feasibility of such a spacecraft, i.e., the Gravity Tractors by making use of a strawman asteroid.

Keywords. Gravity Tractor, Asteroid, Near Earth Object, Artificial Gravity

1. INTRODUCTION

Since the dawn of humanity, uncertainty regarding the fragility of civilization has loomed over us. Mostly regarded as a sign of something divinely by the previous generations, meteor showers and comets have always been a subject of interest to humans.

This belief changed after the accidental discovery of the first ever asteroid, Ceres, by Giuseppe Piazzi in 1801 (Asteroids | Exploring the Planets).

And since the discovery of asteroids, we have acquired the knowledge of the threat they pose as well, to humanity as well as our planet Earth. To put it in perspective, it is presumed that an asteroid, approximately 10 kms wide, collided with Earth millions of years ago, resulting in the extinction of the entire species of dinosaurs.

With asteroids having the potential to cause catastrophic damage to the planet, it has become a matter of importance to carefully study and observe these objects. There are more than 27,000 near Earth objects and according to NASA's Center for Near Earth Object Studies, over 26,000 of these objects classify as near-Earth asteroids (Asteroids | Exploring the Planets). Harnessing the clean energy is novel approach for the space mission [1]. For the space mission small thruster like hall and ion will be effectively work , hall thruster draw the attention from the researcher recently.[2]

Hence to tackle this life-threatening problem, many nations have collaborated to start ‘Spaceguard', to study, analyse and survey all the NEOs. In addition to this, Spaceguard has also been researching methods to avoid asteroid collisions.

2. THE KEYHOLE CONCEPT

One of the most significant concepts Spaceguard came up with was the Gravity Tractors. In theory, gravity tractors are deflector machines, using gravity to change the trajectory of the incoming asteroid. To understand how gravity tractors work, you would first require to understand the keyhole concept. When an asteroid in space is predicted to collide with the Earth, it is vital that it follows a certain path to do so. But, before reaching our planet, the NEO has to go through a ‘keyhole’ in space, to ensure its collision. To explain further, just like a ‘lock and key’ system, where a key of particular shape and size only can open the lock, the ‘keyhole’ in space is a similar concept, where the asteroid acts as a key and this particular area as the lock. Upon successfully passing through this area, the asteroid has the maximum possibility to barge into the Earth’s surface. Therefore, a target plane is usually chosen to define the keyhole, hereby referred to as the b-plane. This plane is perpendicular to the path followed by the asteroid during a close planetary or lunar approach.[3]

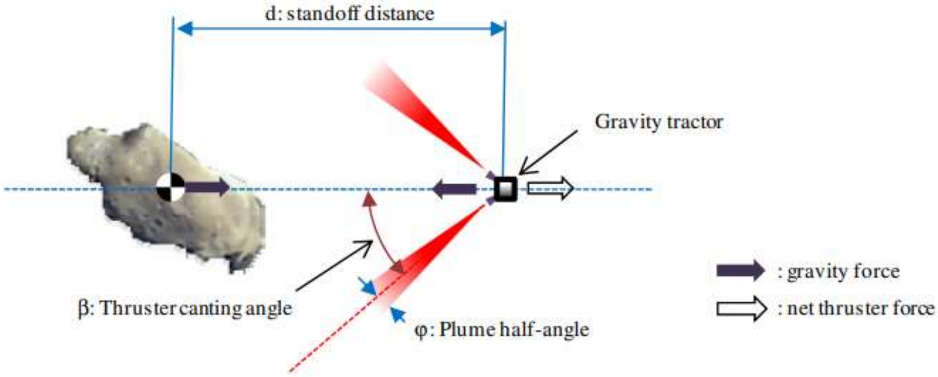

Fig 1: Conceptual figure of a Gravity Tractor [4]

3. Working of Gravity Tractors

3.1. Theoretical Deflection Formula

When it comes to asteroid collisions, there are two primary planes at play. The A plane is the plane of the asteroid, located in space, whereas, the B plane is the predicted impact area, located on the Earth, i.e., the projected plane. The distance from the Earth's surface to the undeflected impact point is used to calculate the deflection required to be caused by the gravity tractor.

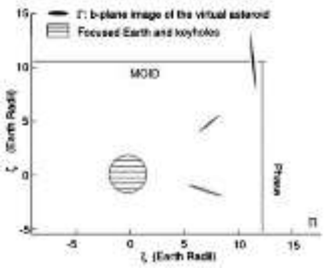

Fig 2: Keyhole and B-plane. MOID - Minimal Orbital Intersection Distance [5]

For example, in Fig.2 no impact on Earth can occur, as the impact location is not on Earth's image. This figure also shows that sometimes the impact plane might not be on Earth, but the close proximity of the asteroid trajectory paves way for future impacts. [5]

A generalised formula of asteroid deflection has been developed by Izzo. [3]

$$\Delta\zeta = -\frac{3 a v_{\mathrm{Earth}}(t_s)\sin\theta}{\mu}\int_{t_0}^{t_f}(t_s - t)[\mathbf{v}_{\mathrm{ast}}(t)\cdot\mathbf{A}(t)]\,\mathrm{d}t$$

This formula is used to calculate the deflection on the projected plane of the Earth and here, it denotes the estimated date of collision. From this formula, we get to know that impact intensity is dependent on when the deflection starts, i.e., the earlier the deflection starts, the more is the final deflection.

3.2. Working

In Izzo's concept of a gravity tractor, a spacecraft is sent into orbit, near the potentially harmful asteroid. It is then positioned either in front of or behind the NEO. To keep its relative position, the vehicle, with mass m1, is required to continuously apply a thrust of T, to maintain its relative position. Absence of thrust would lead to the crashing of the spacecraft into the asteroid.

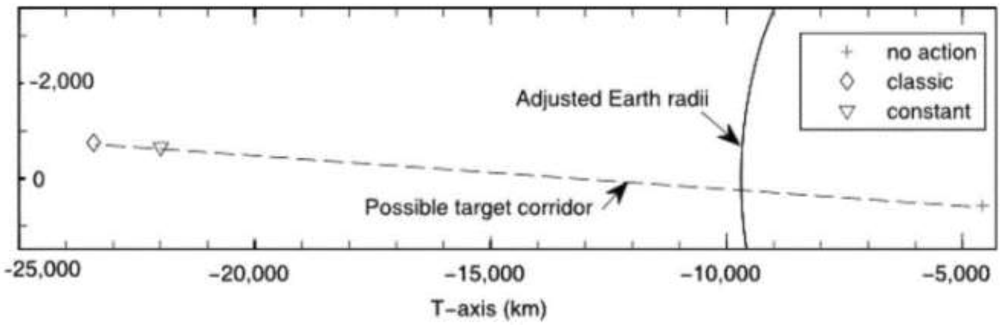

Fig 3: Classic and Constant profiles comparison [6]

The tilt in Fig.3, marked as possible target corner, is necessary, to avoid the crash of spacecraft onto the asteroid. Otherwise, in any other case, it would result in the generation of counteract force due to mutual gravity. This in turn adds thrust to the asteroid, lesser than the magnitude of gravitational potential binding force at that point.

4.3 Dynamics

The gravity tractor advances under the influence of both the asteroid as well as the Sun. The relative motion of the IDM with respect to the selected asteroid in heliocentric reference frame, given by the Newtonian dynamics is, [5]

$$\mathbf{f}_{sc}(\mathbf{x}_{sc}, \mathbf{x}_{ast}, \mathbf{u}; t) = \begin{bmatrix} \Delta\mathbf{v}(t) \\ -\mu_{sun}\left(\frac{\Delta\mathbf{r}(t)+\mathbf{r}_{ast}(t)}{\|\Delta\mathbf{r}(t)+\mathbf{r}_{ast}(t)\|^3} - \frac{\mathbf{r}_{ast}(t)}{\|\mathbf{r}_{ast}(t)\|^3}\right) - \mu_{ast}\frac{\Delta\mathbf{r}(t)}{\|\Delta\mathbf{r}(t)\|^3}\left(1+\frac{m_{sc}(t)}{m_{ast}}\right) + \frac{T}{m_{sc}(t)}\mathbf{u}(t) \\ -\frac{2F_{th}}{g_0 I_{sp}}\|\mathbf{u}(t)\| \end{bmatrix}$$

Where,

$\Delta\mathbf{r} = \mathbf{r}_{sc}(t) - \mathbf{r}_{ast}(t),$

$\Delta\mathbf{v} = \mathbf{v}_{sc}(t) - \mathbf{v}_{ast}(t)$

$\mathbf{x}_{sc} = [\Delta\mathbf{r}, \Delta\mathbf{v}, m_{sc}]$

5. Objective

This paper mainly focuses on analysing the viability of the concept of gravity tractors, mainly dealing with near earth objects' (NEO) impact mitigation.

6. Methodology

Since we are not equipped with the software and data to study and simulate the required objective, we have taken information from research conducted by NASA's JPL.[3]To understand how the asteroid behaves, we have to assume the required data of an asteroid: A strawman NEO with the following characteristics was selected as the target asteroid:

Table 1: Asteroid data [3]

Category	**Description**
Asteroid name	2016 NM4
V∞	5-10 km/s (with respect to Earth in the range)
Effective diameter	140 m
Bulk density	2.0 g/cm3
Axial ratios	1:1:2
Rotation period	12 hr
Rotation pole obliquity	45°
Size and spin	Varied
Discovery time	2016
Impact location	5400 km south of Los Angeles and 1500 km NW of Easter Island in the southern part of the Pacific Ocean
Impact time	2049

Fig 4: Impact location [3]

6.1 Understanding the asteroid's orbit

The hypothetical asteroid we considered comes under the Aten-class asteroids. Its mean motion ratio is close to 13:10, 13 indicates the revolution of the asteroid and 10 indicates the time period (in years) after which its orbit will repeat. The asteroid's closest approach occurs in 2046, where its minimum distance is about one lunar distance.

For the required calculations in this project, the motions of other objects were assumed based on the available data. The bodies include the Sun, the Moon, all the planets and 4 other asteroids, in addition to the effects of solar relativity.

Date	Body	Dist.(AU)
2016 Aug 27.94383	Earth	0.042706
2017 Oct 30.31594	Venus	0.080965
2020 Dec 5.38243	Venus	0.062307
2024 Jan 7.88372	Venus	0.046527
2026 Aug 15.82433	Earth	0.055507
2027 Feb 5.14327	Venus	0.042289
2030 Mar 5.01357	Venus	0.040493
2033 Mar 29.28549	Venus	0.052710
2036 Apr 17.59255	Venus	0.073968
2036 Aug 31.82278	Earth	0.033996
2039 May 11.61451	Venus	0.081424
2042 Jun 4.36096	Venus	0.087426
2045 Jun 26.60054	Venus	0.094500
2046 Sep 13.67208	Earth	0.002772
2049 Sep 11.98767	Moon	0.001902
2049 Sep 12.35720	Earth	0.000019

Table 2. Mapping the timeline of close approaches within 0.1 AU of 2016 NM4 from discovery to impact. [3]

7. Results

The probability of post-deflection orbit of the asteroid missing the keyhole is very high, despite the probability being only 10-4.

The close approach in 2046 enables us to increase the effectiveness of the gravity tractor, which increases the 2049 b-plane deflection factor relative to the 2046's b-plane of 100.

The t-Gt in the simulation can achieve an acceleration of 2.5 x 10-12 m/s2, which is 6.5 μm/s per month. The force corresponding to the asteroid's mass is 7.2 mN. It is assumed that the asteroid was successfully deflected before the secondary impact in 20149.

8. Conclusion

The concept of a gravity tractor spacecraft would not only prevent Earth-collisions, but also would help in mitigating the uncertainty of safety during any deep-space explorations. This paper studied the efficiency of the spacecraft, along with the asteroid trajectory, yielding positive results. The manufacturing and implementation of this vehicle would signify a great milestone in space-technology.

The problem of space debris is one drawback to this idea. We have deep dived the space-debris clean up system as a way to lessen this. We will launch our space debris clean up system, which will during the first stage reach the debris particles' speed, once we have determined the positions and speeds of the debris particles. The space debris clean up device and the debris are both relatively stationary. Following that, the space debris removal system will approach the debris and smash with it at a sufficient impact velocity for the debris to be cold welded to the system. We can remove a group of space debris particles since most small debris particles cluster around the earth's orbit. The space debris removal system experiences a lot of atmospheric drag after removing space debris from a group. As a solution for this, it uses its propulsion system to adjust its orbit to the International Space Station's height, where the collected debris is being removed. The system is then again put into use [7].

As Mars is the next big destination, due to its closeness to our planet, there are many reasons to explore this Red Planet and search for human existence and getting prepared for future human [8]. Therefore, with the growing need for space explorations, not just for Earth, but, this concept can be used to avoid asteroid collisions on any planet.

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