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A1 7 Before and After-oid Impact

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Abstract

As an alternative method of redirecting the asteroid in the film Armageddon, we looked into the technique used by the DART mission; momentum transfer through a kinetic impactor. Through orbital trajectory simulations, we find that when applied to this scenario, a kinetic impactor of the same relative size as DART and its asteroid would need to have a mass of $\sim 1.6 \times 10^{14}$ kg and travel at a velocity of over 1960 km/s in order to avert catastrophe.

Introduction

In the movie Armageddon [1], the Earth's destruction is averted through an explosion, causing the approaching asteroid to split apart. In reality, the current methods for diverting asteroids are very different, involving momentum exchange to redirect the asteroid's orbital path. In this paper, we will investigate to see the quantities required for applying that to this scenario.

DART (Double Asteroid Redirection Test) was a NASA mission launched in 2021 with the intention of supplying a large enough thrust to an asteroid to change its trajectory. The asteroid chosen is called Dimorphos and in 2022 the impact event took place; the DART spacecraft collided with Dimorphos, altering its orbital period by around 4% [2]. This served as the test for the primary method that has been proposed for redirection of Potentially Hazardous Asteroids (PHAs).

Simulation

In order to investigate the properties of our kinetic impactor, we first needed to identify the parameters of the trajectory which would grant a safe path for our asteroid. In our previous paper [3], we found that in the film the asteroid was located when it was at a distance of $\sim 1.5 \times 10^7$ km from Earth. We first set up a model with an apoapsis (furthest point from Earth) equal to that of this initial identification distance, and a periapsis (point of closest approach to Earth) of 0 km (to represent collision with the surface). From here, we simulated a single instantaneous thrust event, in order to find the minimum change in velocity required to reach a trajectory with a new periapsis. The smallest value which would avoid a collision is an altitude of 625 km, equal to the radius of the asteroid according to our prior work [4]. This is because orbital mechanics operates from the centre of a body, meaning that an altitude equal to the asteroid's radius corresponds to the minimum height for it to not touch the ground. The software used for this simulation is called GMAT (General Mission Analysis Tool) [5], and is utilised in many professional circumstances. It was used by NASA to calculate the launch window, orbital path, and intercept trajectories for the OSIRIS-REx asteroid sample return mission

[6], and so will be well-suited for our shared purpose of asteroid rendezvous (Part of simulated path seen in Figure 1).

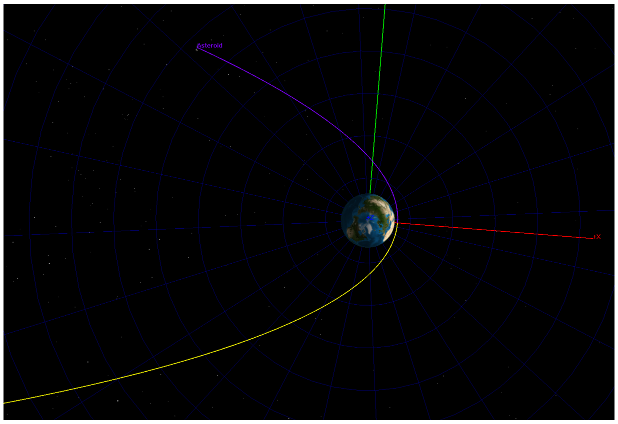

Figure 1: Excerpt of the simulation depicting the asteroid's motion with the minimum closest approach as to not impact the surface. The incoming trajectory is in yellow, whilst outgoing is in purple.

The simulation found that in order to change the periapsis of this trajectory, we require a change in velocity (Δv) of 2.274 cm/s.

Calculation

In order to calculate the momentum exchange required to divert the asteroid, we compare ourselves once again to the existing DART mission parameters. DART, with a mass (m_{DART}) of 580 kg, impacted Dimorphos ($m_{Dim} \approx 5 \times 10^9$ kg) [7]; this gives a ratio of masses equal to 1.16×10^{-7}. We choose to use this ratio relative to our asteroid in order to find the mass of our impactor.

The mass of our Armageddon asteroid (m_{Arm}) can be calculated through

$$m_{Arm} = \rho V = \rho \frac{4}{3} \pi \left(\frac{D}{2} \right)^3, \tag{1}$$

giving 1.39×10^{21} kg for an asteroid of diameter $D = 1250$ km, and asteroid density of $\rho = 2.71$ g/cm^3 [4]. From here we can calculate the mass of our kinetic impactor (m_{KI}) through scaling the DART mass ratio for our new asteroid, giving $m_{KI} \approx 1.607 \times 10^{14}$ kg.

Since momentum (p) is the product of mass and velocity ($p = mv$), we can find the change in momentum (Δp) required to alter the asteroid's orbit as $m_{Arm} \Delta v$. Since for an elastic collision the initial and final momentum are equal to each other, we can equate the momentum change of the asteroid with the momentum imparted by the impactor, which gives for the impactor mass we chose:

$$v_{KI} = \left(\frac{m_{Arm} \Delta v}{m_{KI}} \right) \approx 1960 \text{ km/s} \tag{2}$$

This is a very high velocity, however that will be required in order to move such an enormous body enough to save the Earth.

Conclusion

In order to operate a DART-style kinetic impactor redirection mission, the scientists in Armageddon would need an impactor of $m_{KI} \approx 1.607 \times 10^{14}$ kg, travelling at > 1960 km/s in order to save their planet.

References

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