7th IAA Planetary Defense Conference 26 April-30 April 2021, Vienna, Austria

Optimal Interception Orbit Analysis in the Kinetic Impact of Potentially Hazard Asteroids

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INTRODUCTION

Deflecting the orbit of a potentially hazard asteroid by kinetic impact is currently the most technically feasible defense concept . Finding the optimal interception orbit of the impactor to the asteroid, so as to achieve the maximum orbit deflection under a given fuel consumption, is of great significance to the design of the defense scenario. This paper takes the kinetic impact on the Apophis asteroid as an example, a method to design the optimal interception trajectory of the impactor is proposed and illustrated. First, the orbit deflection of the asteroid caused by impact is regarded as an impulse maneuver, and the motion of the asteroid is simplified into a two-body problem. Then, the optimal interception position and interception orientation of the impactor on the asteroid is determined using classical theories of orbital dynamics and control, which maximizes the orbit deflection of the asteroid for a given fuel consumption. Finally, the obtained interception position and orientation are used as end point constraints of the transfer orbit of the impactor from an Earth orbit. Based on the assumption that the orbit transfer is realized by impulse maneuvering, the best starting point for orbit transfer with the optimal fuel consumption is obtained. Despite some assumptions and simplifications, the result obtained can be used as an initial guess for the search of a more elaborate interception scheme.

OPTIMAL IMPACT POSITION OF APOPHIS

Problem and Solution

The kinetic impact on an asteroid will make asteroid instantaneously obtain a velocity increment ΔV, which will deflect its orbit. The problem is to find the optimal position and orientation of kinetic impact to minimize the ΔV required to reach the predefined deflect goal.

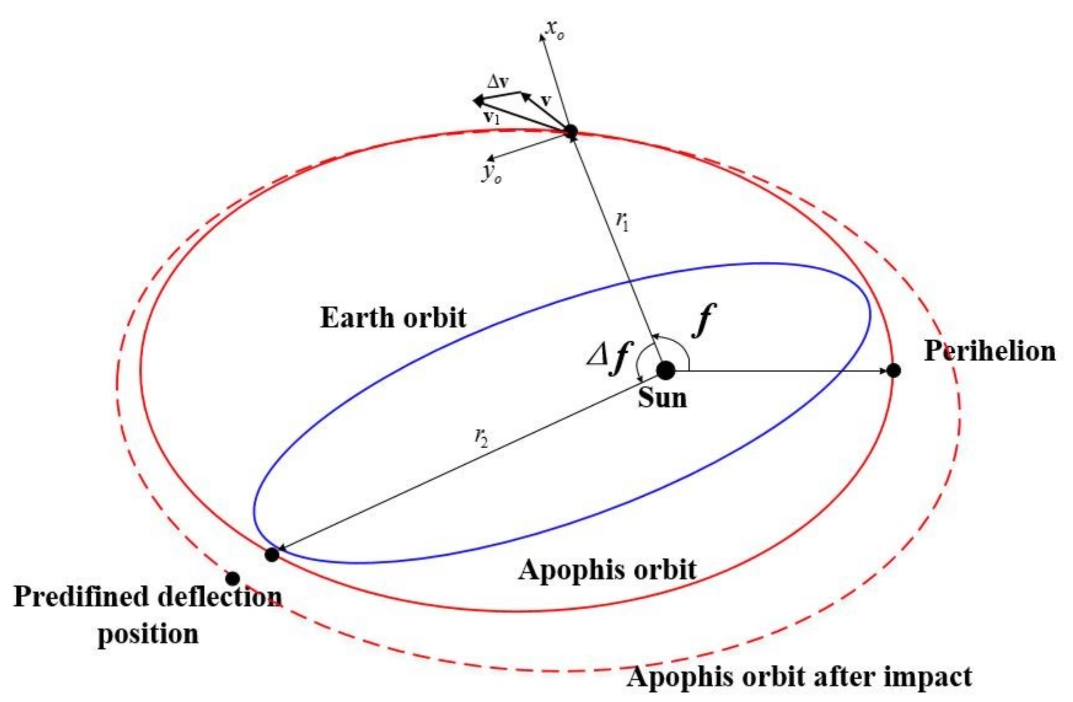
- The movement of Apophis is simplified as the Sun-centered two-body movement
- The goal of impact is to deflect Apophis from the nearest position of Earth by a radius of Earth equator
- Analyze and compare the minimum ΔV and the optimal impact direction required for different impact positions

Solution - the theory of minimum energy interception

$$
\begin{aligned}
\min \quad & f(\Delta v_x, \Delta v_y) = \sqrt{\Delta v_x^2 + \Delta v_y^2} \\
s.t \quad & \Delta v_x \in R \\
& \Delta v_y \in R \\
& \Delta v_x = a_1(u_{1y} + \Delta v_y) + \frac{b_1}{u_{1y} + \Delta v_y} - u_{1x}
\end{aligned}
$$

Analysis Result

- True anomaly of Apophis at impact $f = 69^o$
- Minimum velocity increment ΔV = 0.32 m/s
- The angle between ΔV and the orbital velocity of Apophis θ = 5°



OPTIMAL INTERCEPTION ORBIT OF APOPHIS

Problem and Solution

On the premise of assuming that the interceptor changes its orbit with impulse thrust, the analysis gives the optimal intercept orbit for the interceptor to impact Apophis the Earth orbit.

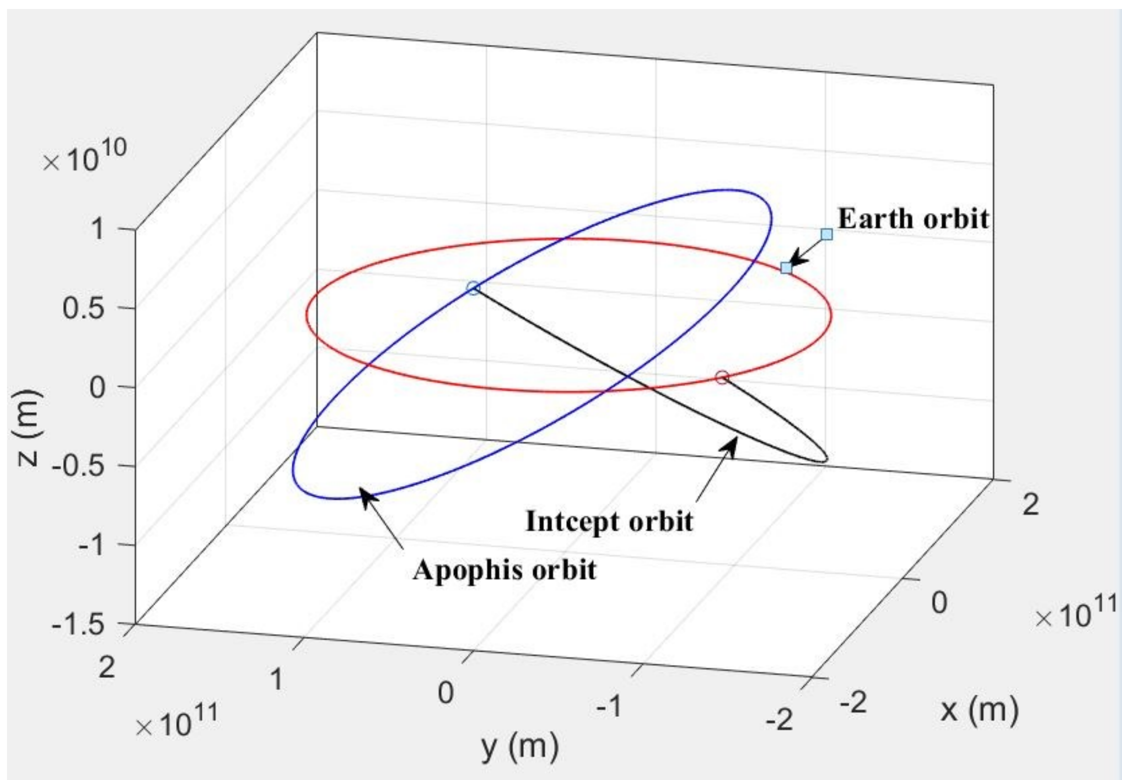
- The starting point of the interception orbit is represented by the true anomaly of the heliocentric orbit of Earth
- The ending point of the interception orbit is set as the pre-obtained optimal impact position
- Analyze and compare the interception orbit of minimum energy corresponding to different starting points.

Solution - Lambert theorem of minimum energy

$$\sqrt{\mu}(t_2 - t_1) = F(a, r_1 + r_2, c)$$

Analysis Result

When the interceptor is launched at the moment that the true anomaly of Earth's heliocentric orbit is 130 degrees, the energy consumption required for interception is minimal, and the corresponding interception time is 160.8 days.



CONCLUSIONS

1.When the true anomaly of the heliocentric orbit of Apophis is 69degrees, kinetic impact can be executed to achieve the orbit deflection goal with minimum energy consumption.

2.When the interceptor is launched at the moment that the true anomaly of the heliocentric orbit of Earth is 130 degrees, the energy consumption required for interception is minimal.

3.The analysis result is obtained under the assumption of two-body movement, but it can be used as an initial input for design of elaborate interception orbit.

REFERENCES

[1]. Oliver Montenbruck and Eberhard Gill. Satellite orbits — models, methods and applications. Springer –Verlag, Berlin Heidelberg, 2000.

[2]. WANG Yi-rui and LI Ming-tao, Orbital Design and Optimization of Kinetic Impactor for Asteroid Deflection, Space Debris Research, 2019,19(3), 44-49 (in chinese).

[3]. Fazle Siddique, Martin Ozimek, Wayne Schlei, et al., Trajectory Concepts for an Apophis Rendezvous Mission, 6th IAA Planetary Defense Conference – PDC 2019 29 April - 3 May, 2019, Washington, DC, USA