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ANALYZING THE INFLUENCE OF ASTEROIDS GEOMETRY AND VELOCITY ANGLE TO THE GAINS OF OFF-CENTER IMPACT STRATEGY IN ASTEROID KINETIC DEFLECTION MISSIONS

Abstract

Planetary defense has garnered significant attention in recent years, particularly following the success of NASA's Deep Impact and Double Asteroid Redirection Test (DART) missions. These missions have substantiated the feasibility of asteroid kinetic impact deflection as a viable method for preventing potentially hazardous asteroid (PHA) collisions with Earth. However, it is noteworthy that the majority of research has focused on impacts along asteroid's geometrical center. In that case, by introducing a normal momentum enhancement factor β , it is sufficient to describe the momentum equation of the kinetic impact. While S.D. Raducan conducted an in-depth investigation into the ejecta distribution from oblique impacts on asteroid surfaces. Their study showed that in oblique impact scenario, two momentum enhancement factors, β (normal) and γ (tangential) are needed to accurately describe the dynamics of the collision.

This paper examines the effects of various impact surfaces on real asteroid shapes. By defining α as the angle between asteroid's velocity $\mathbf{v}_{ast}$ and the relative velocity of impactor with respect to asteroid $\mathbf{U}_{imp}$. It is determined that when $\alpha \neq 0$, the optimal deflection point on the asteroid diverges from the asteroid's geometrical center. Additionally, utilizes asteroid 199942 Apophis as a case study to examine the subsequent alterations in its heliocentric orbit, particularly focusing on its Closest-Approach (CA) to Earth. In order to address the uncertainty associated with the asteroid's attitudes and the parameters (β, γ), we employed the Monte Carlo method. Specifically, we generated 500,000 random samples of asteroid's attitude and (β, γ) values from a Gaussian distribution. Calculate the ΔV resulting from all possible surfaces and identify the optimal outcome. Subsequently, we derived the final distribution representing the changes in the CA with Earth.

The results indicate that, despite impacts at the geometrical center resulting in more significant alterations in the velocity of Apophis, with $\Delta\mathbf{v}_{\text{geocenter}} = 4.97$mm/s as compared to the method proposed in this study, $\Delta\mathbf{v} = 4.68$mm/s, the modifications in the Closest Approach (CA) distance utilizing the methodology delineated herein, $\Delta CA = 1575$km, surpass those achieved through the geometrical center approach, $\Delta CA_{\text{geocenter}} = 1486$km. Furthermore, the proposed method is characterized by a significantly lower standard error of ΔCA, with $\sigma = 52$km, in contrast to the geometrical center method, which exhibits a standard error of $\sigma_{\text{geocenter}} = 170$km.