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Kinematic Impactors – Improved Modelling of Asteroid Deflection

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Abstract

With current technology the utilisation of kinematic impacts has been widely acknowledged as one of the most feasible methods of deflecting and mitigating potential hazardous objects. This includes asteroids and other small solar system bodies. Kinematic impacts are achieved through the release of impactor(s) against a given body, where the associated change in delta-V is a result of imparting a highly impulsive transfer of momentum. Current models of kinematic impacts have been limited, only considering centred impacts that occur along the track of motion, with no displacement in its dynamic delivery. This is coupled with imposing conservative assumptions about the nature of the ejecta distribution and its overall contribution to the impulsive momentum exchange. In an attempt to provide an improved modelling technique, the results from analytical modelling and experimental investigation will be present.

Introduction

With current technology the utilisation of kinematic impacts has been widely acknowledged as one of the most feasible methods of deflecting and mitigating potential hazardous objects. This includes asteroids and other small solar system bodies. Kinematic impacts are achieved through the release of impactor(s) against a given body, where the associated change in delta-V is a result of imparting a highly impulsive transfer of momentum (Izzo, D, Walker, 2007)

However the success of this mitigation strategy is highly dependent on many interrelated variables. This includes the physical characteristics of the asteroid – density, yield strength, porosity, Centre of Mass (CoM) etc - and the impactor(s)-to-asteroid local geometry. This is in addition to the relative mass and velocity of the impactor(s) against the asteroid, and the distribution and characteristics of the associated ejecta, and its overall contribution to the impulsive momentum exchange. Furthermore, past analysis has restricted each impact to apply the delta-V along the track of motion, and assumed no deviation in its dynamic delivery (Ahrens & Harris, 1992, 1994). Analysis was also restricted to occur within a two body – Sun and asteroid – circular orbit approximation. Also no accountability of the asteroid's initial state of angular velocity (rotation rate and spin orientation) was considered. Therefore, current models of kinematic impact deflection have been limited and provide significant opportunity for error.

In an attempt to provide an improved modelling technique, analytical and experimental investigation has being conducted into the kinematic deflection scenario. When two or more bodies collide, there is an immense spectrum of possible outcomes. This ranges from the re-adjustment of shape, size, external surface and rotational states. Therefore, this analysis provides a detailed insight into a range of mechanical processes that has yet to be quantified. Thereby offering a new enlightened understanding into the theory of the cratering phenomenon, collision response and the final velocity changed induced by the kinematic impact deflection technique.

Analytical Analysis

In an attempt to refine the kinematic impactor model, numerical code has been written to model the kinematic impact(s) against a non-spherical, rotating body, with impacts occurring from a given distance from the CoM. Furthermore, the overall efficiency of the impactor(s), the imposed impact geometry and the composition (in-situ and associated ejecta) of the given asteroid has been considered. This provides a far more realistic mission scenario and deflection technique, where the ultimate success of the kinematic impactor(s) depends on many external factors.

In modelling the kinematic impact event, the impactor(s) and the given asteroidal body are considered to act as rigid bodies (Neumann, 2004). The impactor(s) are further defined as a point contact. Throughout which each collision event will act impulsively and occur within three dimensional space. This offers two defining assumptions that govern the nature of the analysis, including, an infinitesimally small collision time and the accountability of fiction (Taiwan, 2006; Neumann, 2004; Mirtich B, 1996).

To offer a realistic deflection and mitigation scenario, analysis has been performed on size and mass analogues of 99942 Apophsis, in addition to Apophsis itself. The five test cases include Aten, Apophis, NYX, Itokawa and Castalia. These are either considered to be Earth-crossing or Earth-approaching asteroids.

This offers a statistically viable range of data points, at varying conditions of composition - porosity, hardness, rubble piles - , rotational rates and eccentricity. The aim was to represent the diversity of shapes and morphological profiles within the asteroid population, while still offering a realistic deflection scenario of kinematic impactors

Experimental Analysis

The accurate modelling and prediction of the ejecta impulse, known as momentum enhancement coefficient, is considered critical in the application of mitigation approaches and techniques. In an attempt to understand the long-term impact evolution and the cratering response of asteroidal models, a series of centrifugal impact testing experiments were preformed. This was achieved through the ESA Education 2010 Spin Your Thesis Campaign, where the following objectivities were to:

- Reproduce, investigate and define the physical conditions of large scale, low velocity impact cratering events on highly porous asteroidal bodies
- Provide cratering response data for the validation and advancement of numerical models
- Support the generation of a reliable scaling theory detailing the cratering response of large scale, low velocity cratering events for highly porous bodies within the solar system

The principle of using a centrifuge is based on similarity analysis where, under elevated acceleration, a small scale centrifugal crater (and its associated low cratering velocities) becomes a geometric and physical replica of an asteroid's much larger in-situ impact cratering event (Housen & Holsapple, 2002). This is only possible through the linear scale factor of the centrifuge that ensures similarity between the lithostatic stress (ρgh), shear stresses and ejecta profile (Schmidt & Holsapple, 1980).

Throughout the experiment, the overriding influence of the projectile's density, target material's porosity and the corresponding impact angle in relation to an impact cratering event has will be assessed. The assessment is made as a function of the ejecta distribution and crater formation, and includes both singular and multiple impacts. This paper will present a detailed design of the experiment, similarity analysis and preliminary analysis from the centrifugal impacting events.

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