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NEW MULTIPLE KINETIC-ENERGY IMPACTOR VEHICLE (MKIV) MISSION CONCEPT FOR DISRUPTING/PULVERIZING SMALL ASTEROIDS

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ABSTRACT

This paper presents a multiple kinetic-energy impactor vehicle (MKIV) system that can be used to disrupt or pulverize asteroids smaller than approximately 150 m in diameter. Its baseline architecture is comprised of a carrier vehicle (CV) and a number of attached kinetic-energy impactors (KEIs) that utilize the hypervelocity kinetic energy for intentionally disrupting or pulverizing a target body. The proposed MKIV system with its total mass in the range of approximately 5,000 to 15,000 kg can be launched from a single large booster such as Delta IV Heavy, Falcon Heavy or the SLS. Near a target asteroid, the CV will dispense several KEIs and guide them to hit near-simultaneously different locations widely distributed across the target surface area. The simultaneous imposition of multiple impacts maximizes the fragmentation benefits of large-scale crack propagation over a large fraction of the target asteroid body. It may be impractical to design a single massive (> 5,000 kg), yet highly agile, kinetic-energy impactor with a precision terminal intercept maneuvering capability. In this paper, the multiple shock wave interaction effect on disrupting or pulverizing a small asteroid (without employing nuclear explosives) is examined using hydrodynamic simulations. This paper also describes a multi-impact terminal guidance problem as well as a worst-case asteroid defense mission scenario for the proposed MKIV mission concept employing heavy-lift launch vehicles.

NEW MKIV MISSION CONCEPT

As discussed in [1], a hypervelocity kinetic-energy impactor (KEI) with an impact speed larger than approximately 5 km/s has a "mass-multiplication efficiency" of approximately 1E5 to 1E7. That is, a unit mass of optimally configured KEI can pulverize 1E5 to 1E7 times its own mass of a target asteroid. For example, a 1000-kg hypervelocity KEI may be able to pulverize and disperse an asteroid with a mass of 1E8 to 1E10 kg. In [1], the specific energy (per unit asteroid mass) required for dispersive pulverization of asteroids of 30 m to 10 km in diameters is stated as approximately 100 to 10,000 J/kg and the specific energy for vaporizing them is stated as approximately 1E6 to 3E6 J/kg.

A 1,000-kg KEI with an impact speed of 10 km/s has a kinetic energy of 5E10 J, and it can cause a center-of-mass Delta-V of at least 1 cm/s for a 100-m (diameter) spherical asteroid with a uniform density of 2000 kg/m^3 via an ideal linear momentum transfer. Note that a 100-m (diameter) spherical asteroid with a uniform density of 2000 kg/m^3 has a mass of 1E9 kg and that its gravitational binding energy is approximately 8E5 J, which is relatively small compared to the kinetic energy (5E10 J) of a 1000-kg hypervelocity KEI with an impact speed of 10 km/s.

In [1], dispersive pulverization of an asteroid into meter-scale fragments by exploiting the hypervelocity kinetic energy was proposed as an option for mitigating the impact threat of small asteroids, especially with short warning times. However, fragmenting a solid object into pieces of pre-specified maximum scale (e.g., 1-m fragments) requires the imposition of a fracture-level stress field having the same periodicity. In order to maximize the fragmentation benefits of large-scale crack propagation, the simultaneous imposition of such stress field over a large fraction of the object was considered in [1]. As a result, various innovative ways (e.g., a massive 3D penetration projectile lattice, multiple large spinning nets, etc.) of effectively distributing the hypervelocity kinetic-impact energy to pulverize a small asteroid were proposed in [1]. However, a deployment of such large complex structures in space will require advanced space technologies that will not be readily available in the near future.

In this paper, expanding upon the fundamental "mass-multiplication efficiency" property of the hypervelocity KEI as described in [1], we present a new non-nuclear MKIV mission concept as illustrated in Figure 1 [2] for disrupting small asteroids detected with short warning times (< 10 years). The MKIV system proposed for asteroid disruption (without employing nuclear explosives) consists of a carrier vehicle (CV) with on-board visual/IR seekers and a number of KEIs attached to the CV, each equipped with its own divert and attitude control thrusters. The MKIV mission concept is basically similar to the concept of an MKV (Multiple Kill Vehicle) system developed by Lockheed Martin [3] as part of the Ballistic Missile Defense System of the United States. Two different deployment schemes of the MKV system have been developed. The MKV-L by Lockheed Martin consists of a CV and attached KEIs, while the MKV-R by Raytheon consists of identical multiple KEIs without a CV as illustrated in Figure 2 [3, 4] The MKV was once envisioned in early 2000s and is currently being re-developed as an MOKV (Multi-Object Kill Vehicle) since 2015.

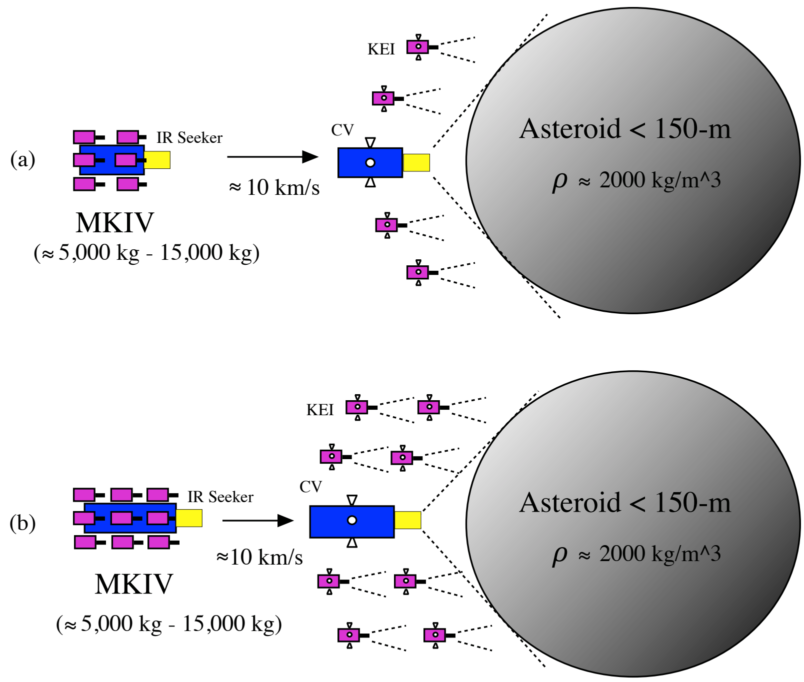
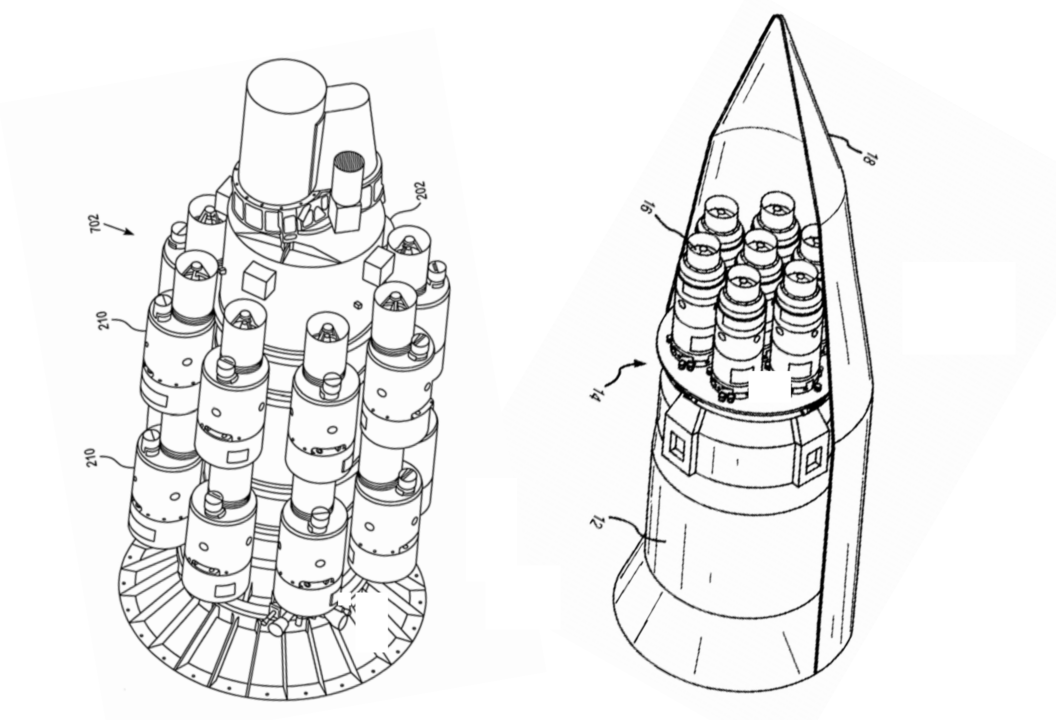


Figure 1: MKIV Concept [2]



(a) MKV-L by Lockheed Martin (b) MKV-R by Raytheon

Figure 2: MKV Concepts [3, 4]

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