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# System engineering analysis of derelict collision prevention options ☆

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ABSTRACT

Sensitivities to the future growth of orbital debris and the resulting hazard to operational satellites due to collisional breakups of large derelict objects are being studied extensively. However, little work has been done to quantify the technical and operational tradeoffs between options for minimizing future derelict fragmentations that act as the primary source for future debris hazard growth. The two general categories of debris mitigation examined for prevention of collisions involving large derelict objects (rocket bodies and payloads) are active debris removal (ADR) and just-in-time collision avoidance (JCA). Timing, cost, and effectiveness are compared for ADR and JCA solutions highlighting the required enhancements in uncooperative element set accuracy, rapid ballistic launch, despin/grappling systems, removal technologies, and remote impulsive devices. The primary metrics are (1) the number of derelict objects moved/removed per the number of catastrophic collisions prevented and (2) cost per collision event prevented. A response strategy that contains five different activities, including selective JCA and ADR, is proposed as the best approach going forward.



## 1. Introduction

Debris hazard in some low Earth orbit (LEO) regions will be modulated somewhat by atmospheric drag but derelict collisions will likely be massively debris-generating, adding many thousands of fragments from a single collision. The concern in LEO is that satellites will not operate reliably in the future due to the increasing lethal, yet nontrackable, fragment (5 mm to 10 cm) population created by collisional fragmentations involving derelict objects, and to a much lesser extent, operational payloads. Fig. 1 shows how four population components of the LEO environment interact to augment the lethal debris environment over time.

Collision Type I is the most likely relevant event[1] and involves a small (degrading/lethal) fragment striking, and possibly, disabling an operational satellite. The Type II collision, trackable fragment (greater than 10 cm) striking a large derelict object, is the next most likely and may result in thousands of lethal and trackable fragments being generated and strewn around LEO. The last collision scenario, Collision Type III (two derelicts colliding), is not as likely overall but probably results in at least double the number of lethal fragments of a Type II collision. Unfortunately, there are certain altitudes where these derelict-on-derelict collisions are more likely with key spikes around 760–780 km, 840–860 km, and 940–980 km.

The two options being considered to reduce the number of accidental collisional breakups involving massive derelict objects (i.e. Collision Type II and III from above) are

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Active Debris Removal (ADR) and Just-in-Time Collision Avoidance (JCA). These options are being evaluated to augment ongoing debris mitigation guidelines and active debris collision avoidance. The figure below depicts the relationship between these alternatives and highlights the work needed to be accomplished to field these solutions. While a satellite is still operational, and possibly even maneuverable, the user can take fairly simple actions to remove its own spacecraft from orbit or to avoid collisions. These are shown in the upper half of Fig. 2. Primarily, this includes following accepted debris mitigation guidelines [1] and active collision avoidance in response to predicted close approaches, usually provided by the US Joint Space Operations Center (JSpOC).

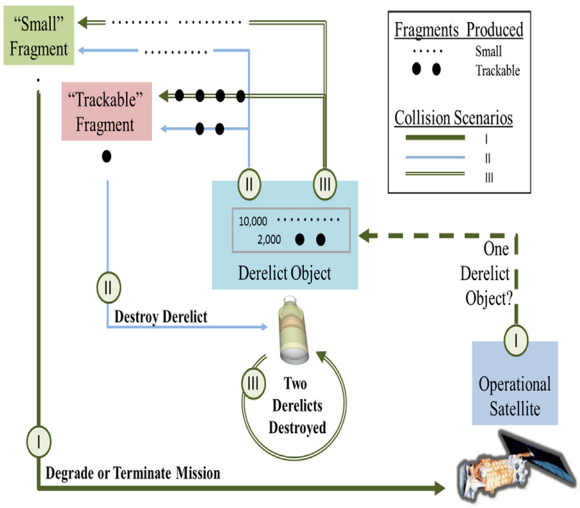


**Fig. 1.** The breakup of large derelicts will drive the future lethal debris population in LEO.

However, once the hardware has been abandoned, the only real options are removal by some intervening mission (i.e. ADR) or deflecting its trajectory to avoid a collision (i.e. JCA). Neither of these modes of debris management have been proven or executed systematically to date. The remainder of this paper examines the modes and challenges of the ADR and JCA options. Table 1 summarizes some of the key aspects of these two derelict collision prevention options.

## 2. Technical approach

While the general discussion of the absolute and relative benefits of ADR and JCA responses has taken place in the past, it is important now to move beyond generalities and perform an end-to-end engineering analysis to compare major options for derelict object collision prevention. Exemplar cases for ADR and JCA are selected that represent typical approaches for each and then an analysis is conducted examining time, cost, and effectiveness.

Table 2 summarizes the assumptions for the baseline designs that constrain the system analysis that follows.

## 3. Preparation

For the ADR mission, objects are selected that have the greatest mass and greatest likelihood of colliding with a trackable object and are then removed years to decades in advance of a potential collision. Clumps of these derelict objects have been identified in LEO by a variety of authors. [8–10] There is a significant energy requirement for the propulsion and guidance to rendezvous with a non-cooperative object followed by the reentry maneuver. Conversely, the JCA mission is planned out tens of hours to several days in advance, at the most, using orbital element sets from the Joint Space Operations Center (JSpOC), or other reliable source. An air-launched system

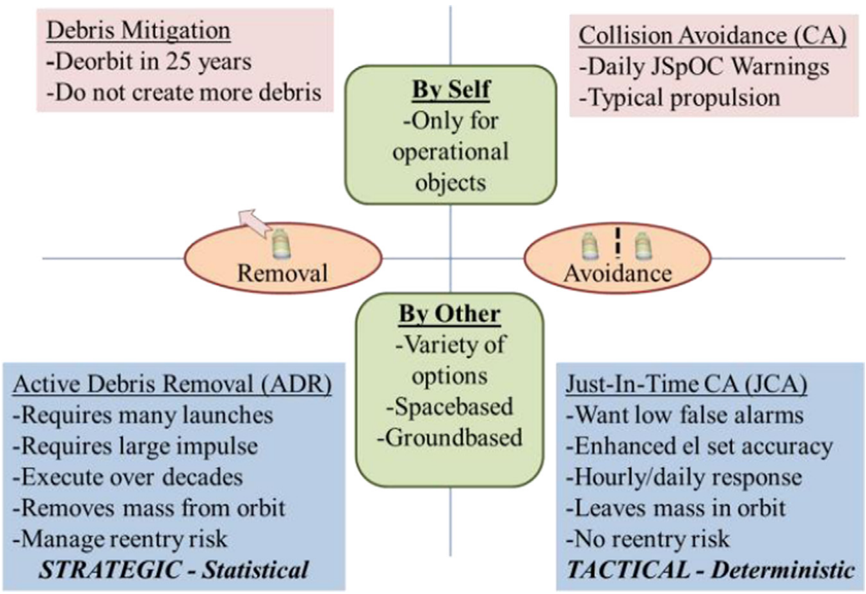


**Fig. 2.** Prevention of on-orbit collisions in LEO spans a wide variety of techniques.