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Overview of the legal and policy challenges of orbital debris removal☆

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ABSTRACT

Much attention has been paid recently to the issue of removing human-generated space debris from Earth orbit, especially following conclusions reached by both NASA and ESA that mitigating debris is not sufficient, that debris-on-debris and debris-on-active-satellite collisions will continue to generate new debris even without additional launches, and that some sort of active debris removal (ADR) is needed. Several techniques for ADR are technically plausible enough to merit further research and eventually operational testing. However, all ADR technologies present significant legal and policy challenges which will need to be addressed for debris removal to become viable. This paper summarizes the most promising techniques for removing space debris in both LEO and GEO, including electrodynamic tethers and ground- and space-based lasers. It then discusses several of the legal and policy challenges posed, including: lack of separate legal definitions for functional operational spacecraft and non-functional space debris; lack of international consensus on which types of space debris objects should be removed; sovereignty issues related to who is legally authorized to remove pieces of space debris; the need for transparency and confidence-building measures to reduce misperceptions of ADR as anti-satellite weapons; and intellectual property rights and liability with regard to ADR operations. Significant work on these issues must take place in parallel to the technical research and development of ADR techniques, and debris removal needs to be done in an environment of international collaboration and cooperation.

1. Introduction

Since the launch of the first satellite in 1957 humans have been placing an increasing number of objects in orbit around the Earth. This trend has accelerated in recent years thanks to the increase in number of states which have the capability to launch satellites and the recognition of the many socioeconomic and national security benefits that can be derived from space. There are currently close to 1000 active satellites on orbit, operated by dozens of state and international organizations [1]. More importantly, each satellite that is placed into orbit is accompanied by one or more pieces of non-functional objects, known as space debris. More than 20,000 pieces of space debris larger than 10 cm are regularly tracked in Earth orbit [1], and scientific research shows that there are roughly 500,000 additional pieces between 1 and 10 cm in size that are not regularly tracked [2]. Although the average amount of space debris per cubic kilometer is small, it is concentrated in the regions of Earth orbit that are most heavily utilized, as shown in (Fig. 1), and thus poses a significant hazard to operational spacecraft.

In the late 1970s, two influential NASA scientists, Burt Cour-Palais and Donald Kessler, laid the scientific groundwork for what became to be known as the "Kessler syndrome" [4]. They predicted that at some point in the future the population of artificial space debris would hit a critical point where it grew at a rate faster than the rate at which debris is removed from orbit through natural decay into the Earth's atmosphere. According to their models, large pieces of space debris would get hit by smaller pieces of debris, creating hundreds or thousands of new pieces of small debris which could then collide with other large pieces. This "collisional cascading" process would increase the population of space debris at an exponential rate and significantly increase the risks and costs of operating in space.

Although the exact tipping point at which this collisional cascading will occur is still a matter of debate, research and modeling done by both NASA and the ESA show that the growth of the space debris population will accelerate, largely as a result of debris-on-debris collisions [5]. The voluntary space debris mitigation guidelines developed by the Inter-Agency Space Debris Coordination Committee (IADC) and endorsed by the United Nations will reduce some of this growth. But, ultimately, actively removing space debris will be necessary to deal with the problem in the long-term [6].

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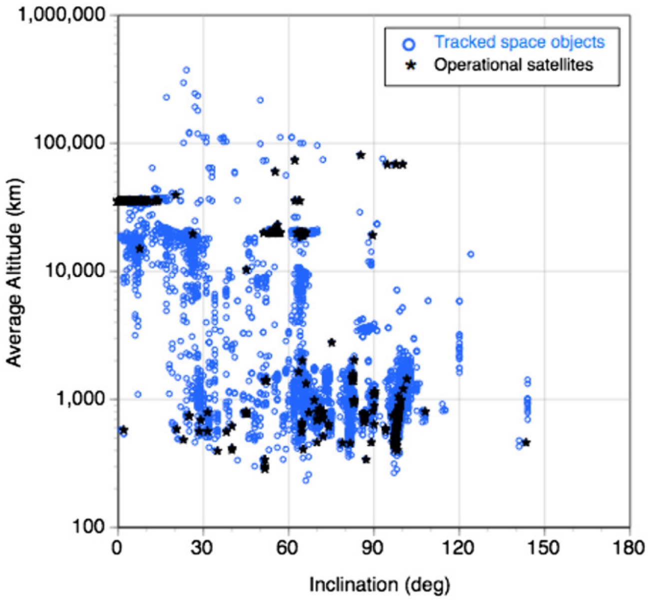

Fig. 1. All artificial space objects in Earth orbit [3].

This paper summarizes the techniques being proposed for performing active debris removal (ADR), and outlines some of the major legal and policy issues they raise. These non-technical issues are an important consideration for successful ADR operations, and demonstrate that the topic of ADR cannot be approached from a purely technical standpoint. Legal, policy and economic concerns are deeply imbedded in the notion of ADR, and will have important effects on its success. More importantly, a technically feasible solution may not be a politically feasible solution. A sub-optimal technical solution may be required to satisfy these other concerns. Thus, multidisciplinary and international perspectives should be included from the very beginning when considering ADR.

2. Summary of ADR technologies and techniques

There are currently a number of technologies and techniques being proposed and considered for ADR. Most of these exist only as theoretical concepts and have not been operationally tested or proven. As shown in Fig. 2, they can generally be broken down by orbital regime, target object size, and whether or not the target object is cooperating.

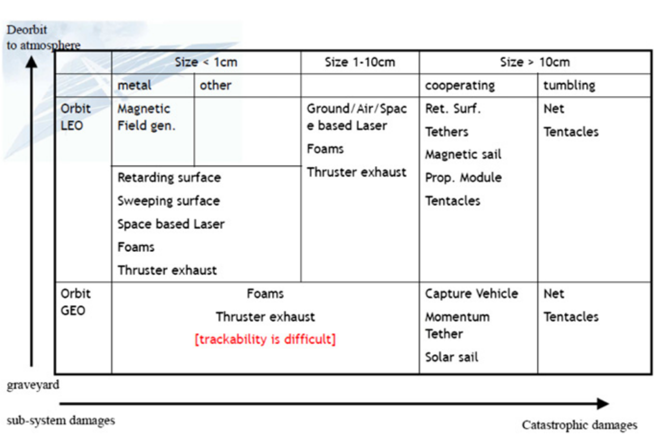

Fig. 2. Summary of ADR technologies and techniques [7].

2.1. Removal of debris in low-Earth orbit (LEO)

LEO is commonly defined as the region of Earth orbit below 2000 km in altitude [8]. This region is home to the vast majority of the space debris objects, a significant number of active spacecraft, and all the spacecraft carrying humans in Earth orbit. Space debris in this region will re-enter the Earth's atmosphere through a process known as natural decay. The upper atmosphere exerts a drag force on satellites in LEO which over time causes them to lose energy and altitude and eventually fall out of orbit and into the atmosphere. The length of time it takes for objects to re-enter is a function of their altitude as shown in Fig. 3, namely, the higher the altitude, the longer their orbits will take to decay naturally.

Most ADR technologies in the LEO regime take advantage of this natural decay process and perform their function by accelerating natural decay, either by increasing the atmospheric drag on the space debris object or moving the debris object to an orbit at lower altitude. For smaller pieces of debris, one of the most promising ADR techniques uses lasers, either ground- or space-based. These lasers are fired at a piece of space debris and exert a change in velocity (delta-V), either through ablation or momentum exchange, which changes the object's orbit [10]. Repeated firings over one or more orbit revolutions can be used to lower the object's orbital altitude and speed up its re-entry into the Earth's atmosphere. The primary challenge with enhanced drag techniques is controlling the atmospheric re-entry to ensure that the object does not endanger people or infrastructure on the ground. Laser techniques are also mostly limited to debris objects between 1 and 10 cm, largely because of detection and tracking requirements.

Larger pieces of space debris can primarily be removed through rendezvous operations. An ADR spacecraft can rendezvous with the targeted piece of debris and attach to it using nets, grapples, tentacles or harpoons. The removal spacecraft would then fire its maneuvering thrusters to move both objects into a lower orbit. The removal spacecraft can then separate from the target debris and, if remaining fuel allows, maneuver again to rendezvous with another debris object and repeat the process.

The ADR spacecraft could also attach a de-orbit aid, such as a thruster or a tether, to the target debris object and use that aid to remove it. One of the primary difficulties of these types of

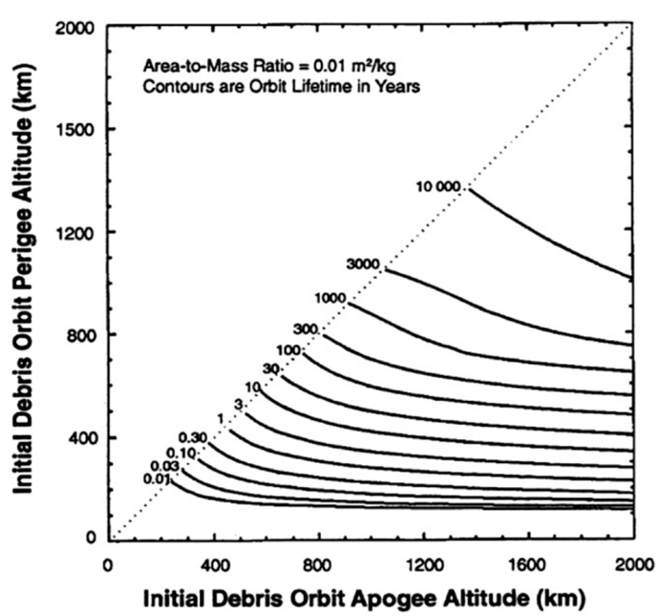

Fig. 3. Orbital lifetime as a function of altitude [9].