Active Debris Removal: It's Complicated

ClearSpace-1: Earth´s First Space Debris Removal Mission (ClearSpace SA)

Orbital debris jeopardizes indispensable space-based services and future space exploration. Solving this problem will require the active removal of existing space debris in addition to mandating self-disposal mechanisms for all future launches. According to the European Space Agency (ESA), "even in a future scenario in which no further objects are added to the space environment (no launches, no debris release, no explosions), the results of simulations by ESA and NASA show that the number of debris objects would continue to grow." Thus active debris removal (ADR) is crucial to remediating orbital debris. However, selecting and developing ADR technologies must account for a variety of complicating factors, from the size and location of debris targets to unresolved technical challenges.

(2) nudging objects into natural disposal orbits using electric propulsion, rocket propulsion, or solar sails; and (3) decelerating debris in near-Earth orbit using ground-based lasers, inflatable braking devices (IBDs), or maneuverable vehicles (tugs) to propel objects into denser layers of the atmosphere where they burn up upon atmospheric re-entry. (The few fragments that survive should have planned trajectories to land on pre-identified 'safe' regions of the Earth where their impact won't jeopardize human lives, infrastructure, or delicate ecosystems.) The diversity of these methods is a good thing; we cannot efficiently and effectively mitigate orbital debris using a one-size-fits-all technology. However, selecting which technologies merit priority investment and development remains challenging, not least because prioritizing which debris is most important to remove (ESA tells us it's high mass objects at high altitude with high collision probability—see here for more details) is crucial to selecting appropriate ADR technologies.

Considerations and Challenges:

It's important to know which type of debris is first in line for deorbiting because the design and cost of ADR technologies often vary based on the size and location of their targets. For example, the optimal method sometimes depends on debris' orbital height; IBDs (thin shells filled with gas to increase aerodynamic drag forces on an object) are more effective below an altitude of 800 km, while solar sails capture light pressure provide superior performance above that range. Evaluating the cost-benefit tradeoffs of various ADR techniques is further complicated by the fact

ADR technology is a thermal-solar system in which a pair of parabolic mirrors (one large and one small) focus sunlight onto debris to deorbit it. Scaling the larger mirror to a radius of 5 meters enables it to vaporize 6 grams of aluminum in one second; at a radius of 25 meters, the system could vaporize 172 grams in the same timeframe. But, if the mirror's diameter exceeds 10 meters, the solar-thermal system could not be launched intact and would instead have to be broken into several hexagonal pieces and assembled in orbit—a far more complicated and resource-intensive process.

Even if we narrow our suite of potential ADR technologies based on debris prioritization, determining the optimal techniques may remain complicated. One proposed method for an IBD demonstrates further challenges facing many ADR technologies: Guerra et. al (2017) argue that de-orbiting five of the largest discarded rocket bodies in the 800-1000 km altitude range annually should be adequate to decrease debris in the long-term, and present an expandable foam sail technology (which could be attached by satellites that rendezvous with the target debris) as a solution. Many aspects of this proposal are relatively reliable as they either derive from existing technologies or emerging technologies with high 'Technology Readiness Levels;' however, while the authors claim their concept "can be implemented with a low cost, high reliability and high impact," they do not closely address the crucial stage of debris docking and capture. In some cases, the devil is in the details; it may be difficult to select general approaches to space debris mitigation at the preliminary stages of technology development because as-

Another challenge facing many ADR techniques is the lack of technologies to enable precise maneuvering in orbit. Many proposed methods for debris removal require capturing the debris in one way or another, for instance in a net or by attaching it to a tether line, IBD, or sail. However, human direct control of these tasks from the ground is not feasible due to (1) the time delay, which can exceed one-second roundtrip in orbital communication, and (2) the extremely complicated kinematics of space robots. The fully autonomous control technology is also currently out of reach. One solution to this challenge is teleprogramming space robot systems (essentially remote programming), in which a ground operator uses a virtual simulation of the operating environment to provide instructions for the robot (which executes the actions). NASA and DARPA should develop this technology and fund research into its visual representations, which are needed to aid ground operators. On the other hand, most contactless approaches to decelerating debris (e.g. using laser ablation or ion-beam shepherding) require very precise control of (1) the satellite's velocity relative to the debris and (2) the force imparted to the debris itself. Manipulating the debris through electric propulsion or plasma ejection creates an equal and opposite reaction on the satellite, further complicating these tasks. This crucial technical challenge for electric propulsion ADR might be addressed by bi-directional plasma ejection adjustment (see Takahashi et. al 2018 for more). The technologies needed to achieve this thruster system and telerobot control are promising but remain in the prototype stage. Furthermore, R&D is required not only to develop these supporting technologies independently but also to integrate them into debris-deorbiting systems.

Things are on the move. Late last year, ESA signed a contract for the first-ever debris removal mission with the Swiss start-up ClearSpace SA, and other companies like Astroscale are also aiming to clean up other people's junk. But the US must invest in developing a variety of technologies for our debris deorbit toolbox, because (1) the best methods differ depending on which debris (by size and orbital location) we intend to deorbit, and (2) some technologies may encounter unforeseen challenges and barriers at later stages in their development. To focus our resources, in addition to R&D into removal mechanisms themselves, we should fund research into which types of debris merit the highest priority for removal (e.g., large pieces that explode into many smaller ones upon impact versus smaller pieces that are more numerous and more difficult to track and therefore more difficult to avoid). Another step toward debris mitigation might be to perform a comprehensive cost-benefit analysis of proposed technologies to identify which candidates warrant further investment. In order to accelerate R&D, the government might also consider offering payments to corporations and even other governments per an amount of debris mass deorbited.

Of course, we need to prevent the accumulation of additional orbital debris as well as removing existing objects. The United States should create domestic regulations requiring all objects entering orbit to be equipped with a self-disposal system (some companies already do so voluntarily). Small CubeSats, for instance, which are becoming increasingly common, can be equipped with IBD shells and the gas to fill them, with one satellite in each cluster dedicated to the removal and also eliminates the issue of contested responsibility for debris cleanup (the communal nature of Earth orbit—and the inability to determine from where smaller debris originated—raises difficult questions over who bears responsibility for removing existing debris).

We have barely scratched the surface of outer space's scientific, spiritual, and economic potential. It is well worth investing in research and development as well as in national and international rules of behavior to create a space environment that is accessible to current and future American space programs, to our international partners, and to spacefaring corporations and individuals. Negotiating international treaties to address these challenges could take decades and could soon become out-of-date pending technological developments. As the nation most active in space and most dependent on space for economic and security purposes, the United States has a vested interest in leading the development of space debris removal technologies and best practices.

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Orbit

Liberalism?

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