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Commercial Space Debris Removal

Safety of Nuclear Powered Missions

Introducing IAASS

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Commercial Space Debris Removal

Debris Removal, Wholesale

The nearly 2,200 spent stages and dead satellites in low Earth orbit (LEO) – a mass of nearly 2,000 tons – is starting to act as a slow-release anti-satellite (ASAT) system, randomly targeting valuable space assets. The Cosmos-Iridium collision of 2009 produced an effect very similar to the Chinese ASAT test in 2007: the satellites shredded each other, producing over 2,000 tracked fragments and over 100,000 untracked fragments, a cloud of "shrapnel" potentially lethal to operational spacecraft. These debris clouds have spread out and will persist for decades. The probability of more catastrophic collisions is no longer negligible: it has now reached 8% per year, and will scale with the square of the number of large objects in congested regions of LEO. Given the current launch rates, this collision rate could double within the next 20 years.

The Cosmos-Iridium collision involved a total mass of 1.5 tons, which was substantially less than what was statistically expected to be involved in an average collision between intact objects. The next catastrophic collision is more likely to be on a larger scale, which could easily outweigh the Chinese ASAT test and the Cosmos-Iridium collision combined.

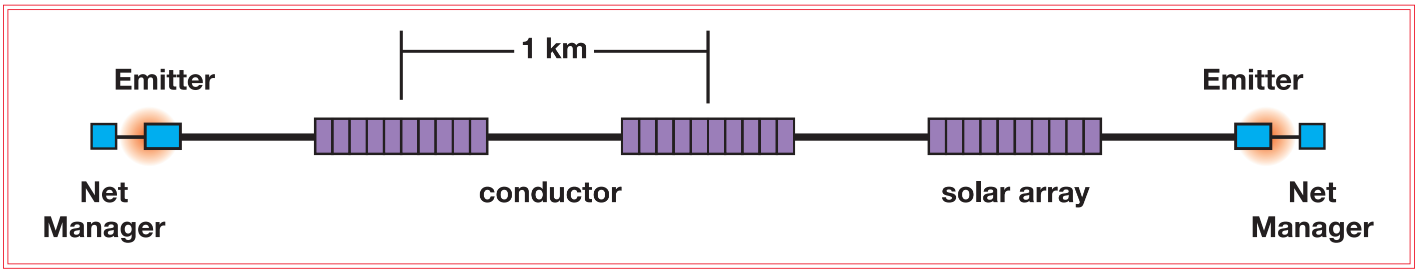
Neither better conjunction analysis nor common debris mitigation measures address the root cause of the problem, the generation of untracked "shrapnel" in collisions between large debris objects. To make a real difference, most large debris objects, the primary source of "shrapnel," must be removed from crowded low Earth orbits.

Space Shuttle window being inspected for orbital debris impacts. - Credits: NASA/JSC

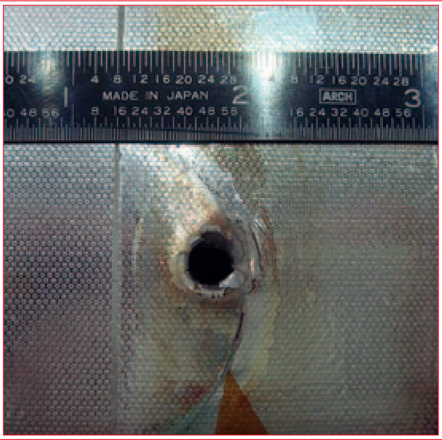
> "To make a real difference, most large debris objects must be removed from low Earth orbits"

The task of wholesale debris removal is very challenging. It would take 2,200 trips with an average payload of 900 kg to remove all spent stages and dead satellites from LEO. Even though many of them are clustered in inclination and altitude, it would require many large velocity changes (delta-Vs). Neither passive drag devices nor rockets are well suited for this task. Passive drag devices have to be delivered and attached to the objects. Slowly spiraling down in large numbers through populated regions in LEO, they would increase the collision risks to operational satellites, the ISS, and each other until they reenter. Rockets can be less risky, but the existing propulsion systems have specific impulses much lower than needed for affordable wholesale debris removal from LEO.

Debris removal has never been attempted before. There are several reasons: first of all, the ASAT nature of the LEO debris field was not experienced until recently; secondly, debris removal with rockets is too expensive; thirdly, debris ownership is international; finally, the overall task is daunting. As a result, debris removal technologies have not been developed. But now there is at least one way to affordably remove ▸▸



EDDE: an electrodynamic "garbage truck" for debris removal (not to scale).



Entry-hole damage (5.5mm diameter hole) to Endeavour's left-side aft-most radiator panel observed during post-flight inspection. - Credits: NASA/JSC

all existing large debris from LEO and start a regular service of removing newly launched upper stages and failed satellites.

One Enabling Technology

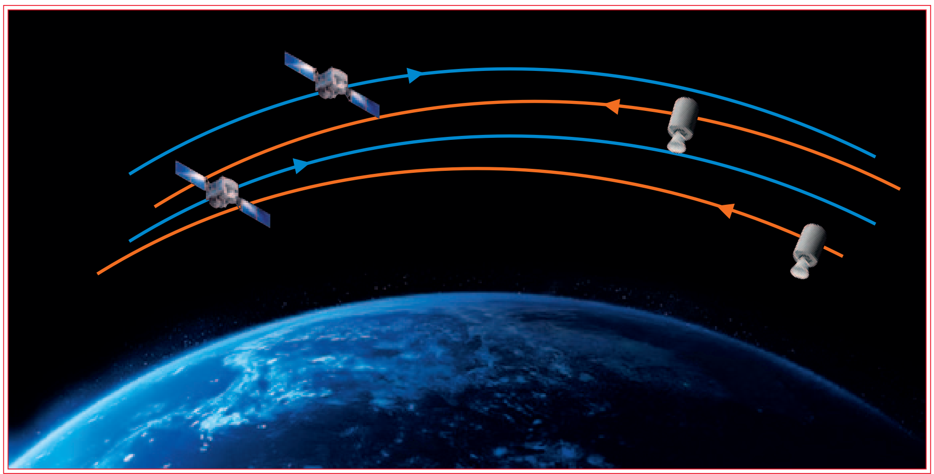
The ElectroDynamic Debris Eliminator (EDDE) is a vehicle of a new class that was unveiled at the NASA/DARPA International Conference on Debris Removal in December 2009. It is a propellantless roving space vehicle for LEO that "sails" in the magnetic field. EDDE is solar-powered. It uses electric current in a long conductor to thrust against the Earth's magnetic field. Electrons are collected from the plasma near one end by an electron collector, and are ejected at the other end by an electron emitter. The current loop is closed through the plasma. This kind of operation was demonstrated in orbit by NASA Johnson Space Center on their Plasma Motor-Generator (PMG) flight test in June 1993.

Operating without propellant, EDDE can repeatedly change its altitude by hundreds of kilometers per day and its orbital plane by several degrees per day, providing enormous delta-Vs of hundreds of km/sec over its operational lifetime. It can be described as several nanosats "taped" together with long conductor segments. EDDE weighs only about 100 kg, but it can move multi-ton payloads throughout LEO. It has a modular design and can be assembled in various configurations, depending on the mission. Recent innovations greatly improve its performance and reliability.

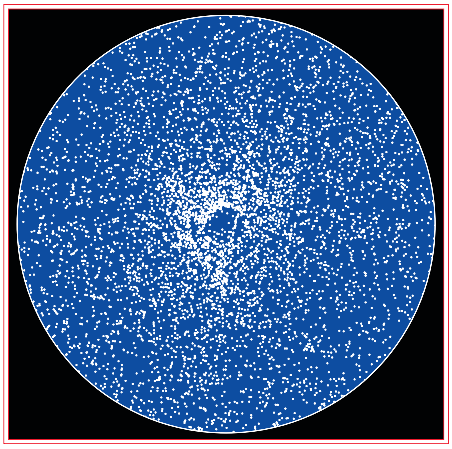
Propellantless thrust and on-board GPS allow EDDE to actively avoid all tracked objects by wide margins. The fiber-reinforced foil conductor tapes can tolerate most impacts by micrometeoroids and small debris. The probability of a tape cut by untracked debris in the centimeter range is much lower than a typical probability of failure of spacecraft avionics. And even if the conductive tape is cut, both halves of EDDE remain controllable and can deorbit themselves in days, avoiding all other objects.

For debris capture, the payload managers at each end carry about 100 house-sized, lightweight nets weighing 50 g each. Once the debris object is captured, the multi-newton tension in the net induced by the rotation of the entire vehicle quickly de-tumbles and passively stabilizes the debris object, and continues to hold it firmly in the net during deorbit. The nets can handle even the heaviest debris objects in LEO, the 8300-kg Zenit upper stages.

> "In 9 years, 97% of the debris-generation potential can be removed"



Head-on traffic at high inclinations created by large debris from the 81°- 83° cluster and satellites in sun-sync orbits.



A "snapshot" of the tracked LEO debris in the Northern sky

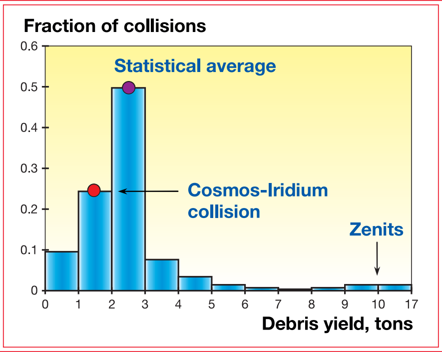
The Naval Research Laboratory plans to test key aspects of electrodynamic propulsion in orbit in 2012, with the Tether Electrodynamic Propulsion Cubesat Experiment (TEPCE). Two satellites share a 3U CubeSat slot and carry a conductive electrodynamic tether 1 km long. The next step will be to test a high-performance mini-EDDE, and then a full-scale EDDE. This development fits into the NASA Space Technology Roadmap and can be done with NASA support.

Commercial Service

When EDDE becomes operational, a commercial debris removal service can be offered to the government agencies and commercial satellite and launch operators. A dozen EDDE vehicles can remove all large debris from LEO in less than 7 years. They can all be launched on one ESPA ring, but our analysis shows that phased deployment has advantages. Two EDDE vehicles can be launched every year and retired after 5 years of service. In 9 years of operations, 2,000 tons of large debris and 97% of the debris-generation potential can be removed at an average cost under $400 per kg and an average annual cost of $84M. In this projection, we reserved substantial amounts for liability insurance, something that is ▸▸

currently not required, but that may become part of future regulations.

Being propellantless, EDDE reduces the unit cost of debris removal to a small fraction of the typical launch costs, and enables wholesale removal. In contrast, the unit cost of debris removal using rockets is comparable with the launch costs. The service must be much cheaper than launch to make economic sense to satellite operators: it would be hard in fact to justify debris removal if the cost per kg was comparable to those of a launch.



The next collision is likely to generate much more debris than the Cosmos-Iridium collision.

Since EDDE makes large-deltaV delivery affordable throughout low Earth orbit, it creates a novel opportunity to collect spent stages and selectively salvage their accessible aluminum alloys and other materials. This could generate a supply of up to 100 tons per year of metals deliverable to ISS or other orbits on demand. Such "barely extraterrestrial" materials could be the starting point for large-scale space manufacturing. They may also help pay for debris removal, if businesses can buy and recycle spent stages.

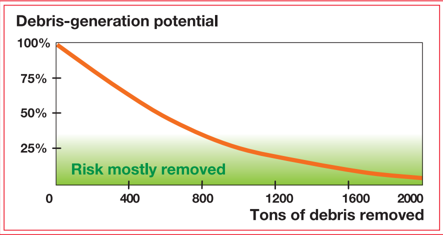
International Framework

Even though it is still in development, EDDE technology provides the first glimpse into a world where commercial debris removal services are not only technically possible, but also affordable. Better alternatives may be developed over time, but this technology is mature enough to provide an insight into how debris removal could actually work.

There are two problems: legacy debris and an absence of rules requiring prompt removal of newly launched upper stages and failed satellites. Waiting for the nations to remove their own legacy debris may take a long time. But if the 12 members of the Inter-Agency Space Debris Coordination Committee (IADC) decide to undertake the removal of legacy debris, they will be in position to set rules going forward, untying both knots at the same time.

> "EDDE provides the first glimpse into a world where commercial debris removal services are technically possible"

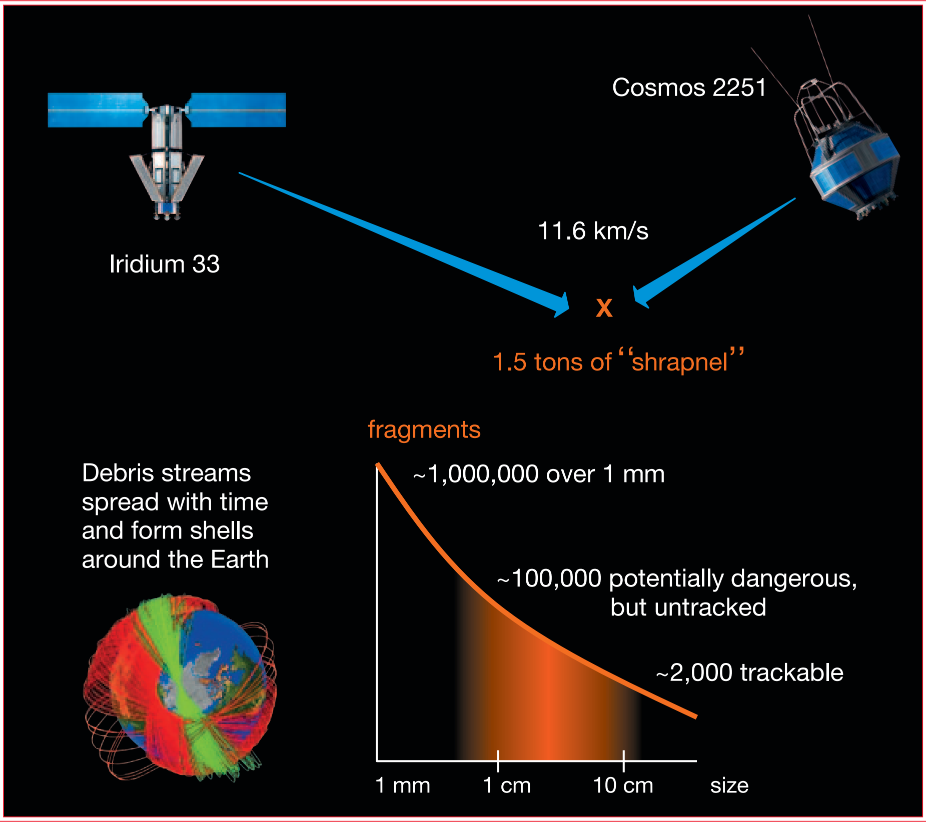
In financial terms, hiring a commercial operator to remove debris with EDDE-type vehicles may be surprisingly affordable, with a low price tag of only $6-7M per agency per year on average.



Only wholesale removal can radically improve the future debris environment in LEO.

In 10 to 12 years, all intact legacy debris could be removed, and the campaign will be over. Once removal is proven affordable, a legal framework requiring prompt removal of spent stages and failed satellites can be established. The 25-year rule is a good prototype, but a much shorter grace period is preferable, when it becomes technically possible and affordable. Once a system, process, and rules are in place, satellite and launch operators should be able to call on the service for the end-of-life removal of objects that cannot de-orbit themselves. This will make sense only if it costs a small fraction of the launch cost, as it is projected for EDDE.

As an added benefit, new norms regulating space activities and traffic will be created and tested in the process of debris removal. This may be very important for future space development.



The outcome of the Cosmos-Iridium collision.