

# The ElectroDynamic Debris Eliminator (EDDE): Removing Debris in Space

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Space is littered with debris far more dangerous than the litter on our highways, and it's getting worse.

Figure 1 is an artist's concept of the junk in low Earth orbit (LEO). These thousands of pieces of space junk pose risks to our space assets such as communication and navigation satellites, environmental monitoring satellites, the Hubble Space Telescope, and the International Space Station (ISS).

More importantly, they pose a risk to astronauts who work in the space station or repair the Hubble, as the space shuttle *Atlantis* astronauts did last year. In addition to the bad camera and failing gyros, Hubble's solar array had a hole in it the size of a .22-caliber bullet.

Most highway debris is paper and plastic, but there are occasional tire treads and hubcaps that require drivers to take evasive maneuvers. Similarly, the ISS and the space shuttles occasionally have to jog their orbits to avoid known pieces of space junk. The U.S. Strategic Command tracks about 21,000 pieces of debris larger than 10 cm, and there are an estimated 300,000 pieces larger than 1 cm (about a .38-caliber bullet). These *bullets* and *hubcaps* (and the occasional *bus* or spent upper stage) can hit satellites with relative speeds of 5-10 km/sec; at those speeds, a *bullet* or *hubcap* will leave a trail of destruction through the satellite, and a *bus* will obliterate it, creating thousands of new *bullets* and *hubcaps*.

There have already been four recorded collisions with space debris. In 1991, the Russian satellite *Cosmos 1934* collided with debris from *Cosmos 926*. In 1996, the French satellite *Cerise* was hit by a debris object. The next identified event was the 2005 collision between *Thor Burner* and debris from a Chinese long-march rocket. On February 10, 2009, the *Iridium 33* satellite was destroyed in a collision with *Cosmos 1421*. Major collisions are now predicted to occur about every five years.

There have also been deliberate acts that caused debris, most notably the Chinese anti-satellite weapon test of January 11, 2007, which destroyed an aging Chinese weather

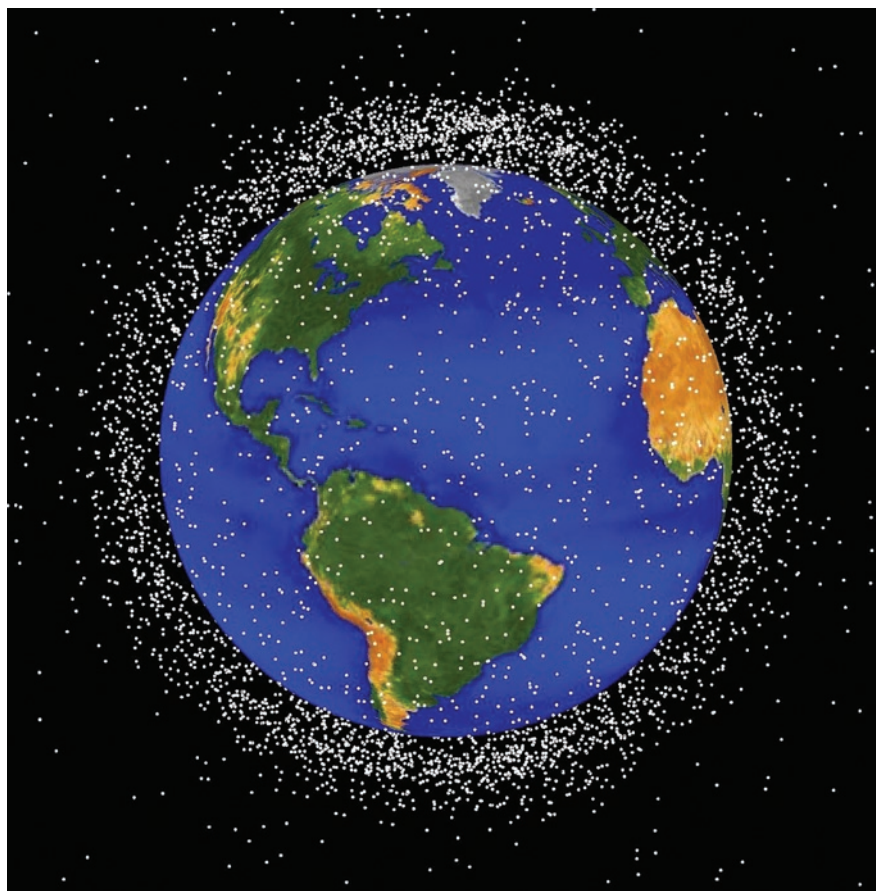


Figure 1. There are about 2,500 pieces of junk in low Earth orbit larger than 2 kg, which represent a threat to satellites, astronauts, and the International Space Station. (NASA Image)

satellite, *Fenyung 1-C*. The collision was purely kinetic, without explosives, and caused a debris cloud of about 900 tracked objects and perhaps 35,000 bits larger than 1 cm. The debris objects ranged from 200 to 3,850 km in altitude and endangered all satellites in LEO. The U.S. also tested anti-satellite weapons in 1985 and in early 2008, the latter to destroy a malfunctioning spy satellite, but these were at lower altitudes and produced far less debris than the Chinese test. Because of the international outcry over the Chinese test, no other tests like these are expected.

## Keeping Track of Debris

General Kevin P. Chilton says his U.S. Strategic Command tracks 21,500 catalog objects, involving about 800 active satellites, calculates potential collisions, and issues warnings to satellite operators. Each day it produces 800

conjunction analyses, about one for every active satellite. Many satellites can maneuver out of the way of debris when a near approach is predicted. However, STRATCOM does not have resources to predict every potential conjunction and issued no warning on the Iridium satellite last year.

NASA has an office of safety and mission assurance at the Johnson Space Center in Houston that studies debris and formulates rules to limit its creation. Rules include eliminating throwaway bolts and latches when spacecraft are placed in orbit, venting fluid tanks to prevent explosions, and requiring that satellites re-enter the atmosphere within 25 years after their missions end.

But the leader of that office, Nicholas Johnson, says that unless we begin removing large debris from orbit, the inevitable collisions involving objects like eight-ton rocket bodies and five-ton dead satellites will create tens of thousands of new pieces, resulting in a *debris runaway* that would make LEO unusable for hundreds of years.

Until 2009, the dangers of debris

were generally ignored under the *big sky* view that space is nearly empty. But the loss of the *Iridium 33* satellite caught everyone's attention. Since then, there have been Congressional hearings and international conferences discussing space debris, how to reduce risks, and whether we can afford it.

A December 2009 conference sponsored by NASA and DARPA (Defense Advanced Research Projects Agency), featured many proposals, including large orbiting shields to catch small debris, ground-based lasers to ablate the front side of debris objects to lower their orbits, and active spacecraft to capture larger items and drag them to atmospheric entry.

The most near-term and technically advanced method presented was a roving space vehicle that can capture LEO debris objects in nets and drag them down safely from the space lanes. EDDE, the *ElectroDynamic Debris Eliminator*, is the first space vehicle that can remove all the large debris from LEO at reasonable cost to prevent debris runaway.

### The EDDE Solution

EDDE is a new kind of space vehicle. It is not a conventional rocket that accelerates a payload by throwing propellant mass in the opposite direction. EDDE is a propellantless electric motor/generator in space that accelerates by reacting against the Earth's magnetic field. This means that it is not limited by the Tsiolkovsky rocket equation and can produce cumulative velocity changes of hundreds of km/sec during its operational lifetime. An EDDE vehicle equipped with solar panels for power and expendable capture nets could safely remove debris from orbit 300 times its own mass

per year.

The principle of operation of an EDDE vehicle is shown in Figure 2. The vehicle is in low Earth orbit, moving in the Earth's dipole magnetic field and surrounded by the ionized plasma from the solar wind that is trapped in the ionosphere. Solar arrays generate an electric current that is driven through the long conductor; the magnetic field induces a Lorentz

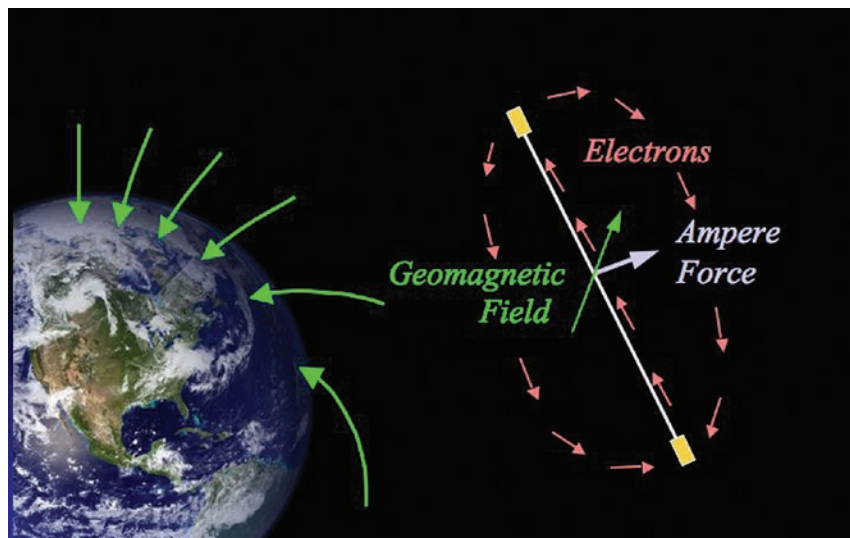


Figure 2. The EDDE vehicle principle of operation is based on a motor/generator that reacts against Earth's magnetic field to provide thrust without rocket propellants. (STAR, Inc.)

force on the conductor that is proportional to its length, the current, and the local strength and direction of the magnetic field. Electrons are collected from the plasma near one end of the bare conductor and are ejected by an electron emitter at the other end. The current loop is completed through the plasma. This propellantless propulsion was demonstrated in orbit by NASA Johnson on its plasma motor generator experiment.

The EDDE vehicle is an unusual spacecraft. It is two micro-satellite end bodies connected by multiple 1-km-long segments of aluminum ribbon conductor just 30 mm wide and 38 microns thick (Figure 3). The bare aluminum conductor is an electron collector, and each end body contains an electron emitter. Solar arrays are distributed along the length, and the entire structure rotates slowly end over end to maintain tension and stability.

Because there are many units of each element in the electrical circuit, if EDDE were cut by untracked debris, each end could still function as an independent debris-removal satellite, albeit

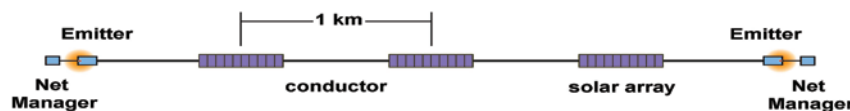


Figure 3. The EDDE propellantless spacecraft consists of identical end bodies connected by a kilometers-long conductor and solar arrays to generate thrust. The end bodies can extend large nets to capture debris objects. (Tether Applications, Inc.)

at a slower rate. For debris removal, each end body is equipped with a net manager that carries about 100 house-sized Spectra nets of 50g each. To catch a debris object, a net is extended by the rotational force as the EDDE end approaches the target at a few meters per second. The net snares the target, and EDDE actively damps out the dynamics, even if the object is spinning or tumbling up to one revolution per minute.

Most debris objects are rotating much slower than this because of the eddy-current damping from their aluminum structure.

A further advantage of the propellantless spacecraft is that it folds compactly into a box 60 cm square and 30 cm deep. This allows it to be launched in one of the secondary payload slots of the Boeing Delta 4 or Lockheed Atlas 5 ESPA ring (Figure 4). It can also be launched as a secondary payload on the Orbital Sciences Pegasus air-launched vehicle and the new SpaceX Falcon 1 and Falcon 9. If there

is payload margin for the launch vehicle, then there is no additional cost to launch EDDE vehicles piggyback. One or two vehicles can fit into each secondary payload slot, leaving room for several nanosatellites that EDDE can carry to custom orbits after the primary payload is released.

For typical values of a few kilowatts of electric power from large, thin-film solar cells, a few amps of current, and a 10-km-long conductor, the force is typically half a newton. This is a small force compared with typical rockets, but its advantage is that it operates continually, orbit after orbit, persistently changing the orbital elements to make large orbital changes. By changing the direction of the current and the angle of the conductor, the force can be used to change every orbital element at once, including altitude, inclination, node, and eccentricity. The force can also be used to change the attitude of the conductor by changing the EDDE rotation rate and plane.

By using lightweight solar arrays, a reinforced aluminum ribbon conductor, and hollow cathodes at each end to run reversible currents, a typical EDDE spacecraft produces about 7 kw of power, weighs 100 kg, and can make large changes in orbit in a fairly short time. A bare EDDE vehicle without a payload can change its orbit by 1.5° in inclination and climb 160 km or descend 600 km each day at a typical 75° inclination orbit. These rates are possible over altitudes of 300 to 1,000 km, but are reduced at higher altitudes by lower magnetic field strength and plasma density. Such

a vehicle could go from the ISS 51.6° inclination orbit to polar orbit in about three weeks, a change in velocity of nearly 5 km/sec.

Using conventional rockets for space-debris removal is extremely expensive. A satellite launched into low Earth orbit requires a velocity of 7 to 8 km/sec. With chemical propellants, even our best launch vehicles put only about

four percent of the total launch mass into orbit. Changing the orbit of a satellite already in orbit can require even higher velocities. Launching a chemical rocket from the ground to remove the debris, each piece in its own orbit, would be expensive and would leave upper stages as more debris.

The enormous advantage that the propellantless EDDE vehicle has over conventional rockets is shown in Table 1, which compares different propulsion systems in performing the task of removing the 2,561 objects in LEO weighing over 2 kg. The performance of a rocket

is commonly measured in specific impulse *I<sub>sp</sub>*, which in English units of pound-seconds of thrust per pound of propellant expelled is measured in seconds. In SI units, this has the dimensions of velocity—the rocket exhaust velocity. A typical bipropellant chemical rocket might have *I<sub>sp</sub>* of 300 seconds, and the table shows that this task would require 900 vehicles weighing 800 tons. Higher-*I<sub>sp</sub>* systems include arcjets, ion rockets, and the recently-tested ‘variable specific impulse magnetoplasma rocket (VASIMR) championed by former NASA astronaut Franklin R. Chang-Diaz of Ad Astra Rocket Company. But even that would require 25 tons in orbit to remove all the debris, more than 20 times the one-ton mass of 12 EDDEs. Twelve EDDEs could remove all 2,561 objects—2,155 tons—in fewer than seven years.

### Removing Space Debris

The EDDE capability to remove all the large debris from LEO has been analyzed in detail by Tether Applications and Star Technology and Research, two small companies that developed the EDDE concept and vehicle. Table 2 is a simplified *traffic model* of LEO debris.

Of the total LEO debris mass of the 2,561 largest objects over 2 kg, the 22 bus-size Zenit upper stages are nearly 10% of the mass, while *hubcaps* are less than 1%, and untracked numerous *bullets* are probably less than 0.1% of the mass. The peak of the distribution is 822 car-size rocket stages of three types. They weigh 1,400-1,450 kg each and account

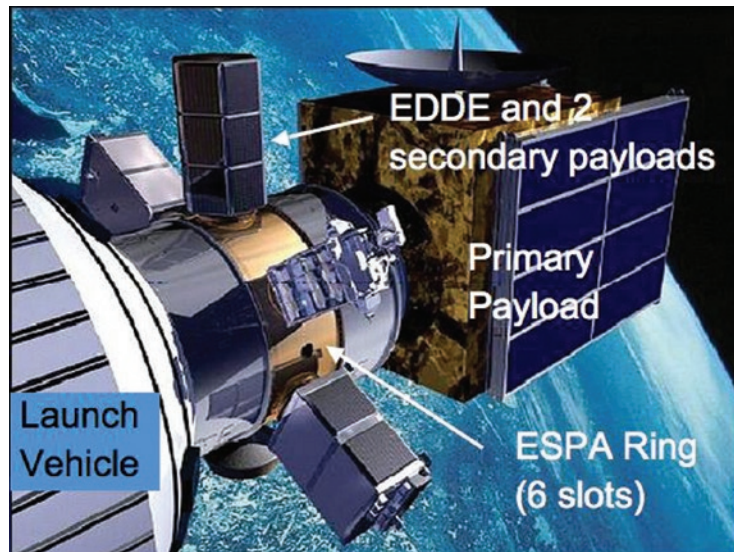


Figure 4. The EDDE spacecraft weighs only 100 kg and fits into a secondary payload slot on a Delta 4 or Atlas 5 launch vehicle. One launch can put the entire fleet of 12 EDDE vehicles in orbit. (Lockheed Martin image)

for 35% of the total mass. Most are in orbits of 81°-83° or 70°-74° inclination. There are many satellites in *sun-synchronous* orbits that allow them to pass over the same spot on the Earth at the same time each day; these are typically 400-800 km in altitude and 97°-99° in inclination, slightly retrograde.

A simulation of LEO debris removal of everything from buses to bikes and skates, using 12 EDDE vehicles in 6.7 years, is available at: [www.star-tech-inc.com](http://www.star-tech-inc.com).

### GEO Debris Removal

EDDE can remove all large debris objects in LEO, but its electrodynamic thruster cannot function at the high altitude of geostationary Earth orbit (GEO) where television broadcast satellites are located. There is also a danger from debris in GEO, caused by dead satellites drifting by operational satellites. The international community has adopted guidelines for removal of satellites from the GEO ring by raising them 300 km at the end of their lives, but this will only apply to future launches. To remove the few existing derelict GEO satellites will require the use of rocket-powered grapple vehicles to capture them and raise their orbits to a safe distance. DARPA, the Naval Research Laboratory, and aerospace contractors are evaluating rocket vehicle concepts for this task, as illustrated in Figure 5.

### Constraints on Removal

The EDDE vehicle addresses the technical and cost problems of removing space debris, but there are legal, political, and economic constraints that must be overcome before the general cleanup of space can begin. Now is the time to address these more difficult problems.

Removal of highway debris is straightforward: the responsible state, county, or city collects taxes and hires people to clean the roadways. Volunteers can also do the job for civic pride and recognition, because it is inexpensive. Cleaning space, however, is not so simple.

One problem is legal. The Outer Space Treaty of 1967, signed by all space-faring nations, says that the launching nation owns its satellites, even if they are defunct and abandoned. Unlike the maritime law, space law does not allow for salvage rights or treasure hunters. To remove debris objects, we need permission from each original owner. Since most of the mass of defunct satellites in orbit was launched by the Soviet Union, we need permission from the successor states of Russia and Ukraine to remove these objects. This leads to the legal problem of liability for damages. If we deliberately cause a space object to enter the atmosphere, we are responsible for any damage or injury it causes. This is why the U.S. and Russia tried to de-orbit the Skylab and Mir

space stations over remote areas of the Pacific. Total potential liability could be enormous as a result of the removal of the most dangerous debris objects in LEO that weigh more than 2 kg.

Another problem is political. Space is like the *commons* of the Middle Ages, land that everyone used, no one owned, and no one was responsible for its upkeep. It deteriorated from overuse. **Norman R. Augustine**, *New Jersey Delta '57*, chair of the 2009 NASA spaceflight review panel, calls space our *global commons*. It is open to everyone for satellite launches, but there is no requirement for launch organizations to capture debris or remove their dead satellites from

orbit. No one nation or group is responsible for cleaning space, and there is no international authority empowered to collect taxes or fees to pay the costs of cleaning space. Space is rapidly becoming more dangerous.

### Toward a New Era

EDDE is a new kind of space vehicle that can perform other useful tasks in space. After the EDDE fleet removes the large, dangerous debris objects, it could enter regular space service to remove all new upper stages and failed satellites in order to maintain a safe LEO environment.

**Table 1. Propulsion System Performance for Debris Removal**

Propulsion System	Isp, sec.	Typical No. of Vehicles	Total Mass in Orbit
<b>Bipropellant</b>	300	900	800 tons
<b>Ammonia Arcjet</b>	800	300	250 tons
<b>Ion Rocket</b>	3,000	120	65 tons
<b>VASIMR</b>	10,000	30	25 tons
<b>EDDE</b>		12	1 ton

**Table 2. A "Traffic Model" of LEO Debris**

Type	Mass Range kg	Number of Objects	Total Metric Tons
<b>Buses</b>	4,000-9,000	39	274
<b>SUVs</b>	2,000-4,000	180	465
<b>Cars</b>	800-2,000	822	1,075
<b>Motorcycles</b>	100-800	752	310
<b>Scooters</b>	25-100	668	30
<b>Bikes, skateboards</b>	2-25	100	1
<b>Hubcaps</b>	0.1-2	10,000	6
<b>Bullets</b>	<0.1	500,000	2

Vehicles like EDDE could also be used as an upper stage delivery service to deliver small satellites and secondary payloads to custom orbits. Such LEO mobility vehicles could transport grappling devices to satellites needing servicing, allowing aging satellites to receive fuel and updated electronics—such as the Hubble Space Telescope received from shuttle astronauts.

Perhaps more importantly, EDDE could be used in cooperation with astronauts on the International Space Station to repair and refurbish aged or failed satellites. EDDE could capture them with a gentle latching mechanism, avoiding damage to their solar arrays, and bring them to the ISS for test and evaluation. After they were fixed, perhaps with new components brought to the ISS from Earth, EDDE could return them to their original (or new) orbits for continued operation. There have been billion-dollar satellites that failed soon after launch, and such on-orbit repair operations could be a valuable part of full-scale ISS operations.

Instead of dropping debris objects to burn in the atmosphere, the EDDE mobility vehicle could capture them and take them to a “space junkyard” in LEO, providing tons of aluminum and other valuable materials for recycling and for space construction. This would support the installation of a commercial recycling facility in orbit. This facility could recover material that cost \$20,000 per kg to place in orbit and make further use of it, rather than launching new material. Recycling material in space would also lessen the risk to the ground from large objects re-entering the atmosphere.

Multiple EDDE vehicles in different orbits could provide real-time maps of the ionosphere, keeping track of *space weather*, which affects satellite communication, and could also provide warnings of solar flares and proton events on the sun, which are dangerous to astronauts.

The combination of rocket-propelled grapppler vehicles for GEO, ground-based high-power lasers for the smaller objects in LEO, and the electrodynamic EDDE for large objects in LEO could rid Earth’s orbit of virtually all debris and make it safe for satellites again. The most effective way to start the process is by launching a fleet of low-cost and technology-ready EDDE vehicles.



Figure 5. Most debris objects could be captured in nets, but some require a grappling device such as shown here. Devices like this have been developed and tested by NASA, DARPA, and the Naval Research Laboratory. (Canadian Space Agency, NASA, and wykesweb.com images)

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Before founding his firm, he was an engineer at NASA Langley and Ames research centers and a branch chief for the Air Force Research Laboratory. He has degrees in engineering and geology and is author of nearly 100 technical publications, including invited articles for *Encyclopaedia Britannica* and *New Scientist*. An associate fellow of AIAA, a fellow of the BIS, and a member of the International Academy of Astronautics, he has had television interviews about space elevators and climate change and was featured in the Discovery Channel series “Science of the Impossible.”