The Challenge of Actively Removing Space Debris: Initial Inquiry

Imagine you're ice skating for the first time. It's a little tricky at first, but once you get your footing you can pretty safely glide around the rink and avoid having too many collisions.
Now imagine that everyone is going 17,500mph and some people can't steer. And every time two people collide they explode, creating an exponentially growing mass of junk.

This mass of junk is a real concern in space, where over 20,000 orbital objects larger than a tennis ball are actively tracked, with possibly many more that are not catalogued. Only about 1,000 of those objects are operational satellites; the rest are simply debris [1]. "Debris" can include inoperative satellites, pieces of metal from explosive stage separations, and tool bags dropped by astronauts. When pieces of debris collide they make even more debris due to the extremely high velocities. For context, bullets travel at 2,000mph. Debris travels about 10 times that speed. Experts in the field agree that active debris removal is the only way to keep space from becoming clogged and unusable for future generations. The implementation of such a clean-up operation, however, presents enormous technical questions that remain unanswered.

We have become dependent on satellites for some of our most important technology. GPS navigation, credit cards, and weather forecasting would no longer work if our space systems were to undergo a catastrophic event. Unfortunately, our satellites are increasingly at risk as more and more are sent up.

Starting with Sputnik in 1957, space launches have created a cloud of man-made objects that jeopardize the safety of astronauts and the longevity of space travel. Early satellites had no plans for decommission; the engineers were focused on durability and protecting their satellites from solar flares and meteorites. In fact, the first satellite ever launched by the US is still in orbit and will be for hundreds of years. It wasn't until 1994 that the UN began to consider the problem, developing procedures to prevent future debris.They advised that satellites have a way to de-orbit after their operational lifespan. But de-orbiting is difficult and costly and was not really taken seriously until a few major events highlighted the urgency of the problem.

The first was a Chinese missile test in 2007 that generated 3,000 new pieces of debris when the missile struck a weather satellite. The next happened in 2008 when the US military intentionally destroyed a malfunctioning satellite, generating 174 new debris objects. The third was a collision between two satellites, one Russian and one American, that produced over 1,000 debris fragments larger than 10 cm, in addition to many smaller ones. The International Space Station (ISS) has been forced to perform collision avoidance maneuvers to protect astronauts from debris from all 3 incidents [2].

These incidents have confirmed the worries of Dr. Donald Kessler, a scientist at NASA who has studied space debris since 1978. He predicted a snowballing of satellite collisions that will happen more and more frequently as each collision generates more debris. This is called the "Kessler Syndrome" and in the worst case could lead to an impassable cloud of debris, preventing safe rocket launches entirely. Dr. Kessler asserts that preventing debris in future launches will not be enough - active debris removal is required to keep space open [3].

Currently there is no way to remove debris from orbit. Defunct satellites can be moved to a lower altitude where they will burn up in the atmosphere, but this only works if they still have fuel. Uncontrollable junk will require more drastic measures. To get rid of debris, three methods are viable: decelerate the debris so it enters the atmosphere, capture it with a net, or shoot it with a laser. In the past few years, multiple teams have proposed active removal technologies, but they are not without their problems.

One novel solution was presented by a team of scientists who demonstrated a plasma thruster prototype to decelerate debris. The thruster can thrust in two directions, meaning it can decelerate objects while maintaining zero net force on the thruster itself. Under laboratory conditions, they were able to deflect a plate without moving the device [4]. However, a satellite with two opposing thrusters adds weight, size, and significant development risk. Additionally, high power plasma can erode electrodes and metal over time.

The European Space Agency (ESA) has sponsored development of a “net capture mechanism” that fires an expanding net at the debris [5]. This method is promising because it would work with a variety of debris - it is not necessary to know the mass, size, or spin of the object to capture it. Nets are also relatively light and cheap, and the capturing device does not need to be in contact with the debris. Nets are kind of a one time thing though - the device would de-orbit, vaporizing itself and the debris in the process.

Laser systems have been proposed that would fire high energy pulses at debris, lowering its velocity and thereby decreasing its altitude. According to a paper by Claude Phipps, a 20kW laser could remove a significant portion of space debris within 4 years [6]. A ground-based laser system would be much cheaper and easier to maintain than any space-based solution. However, it could only remove debris within a certain size, mass, and altitude range, and the laser must be precisely aimed. Accurate tracking data is notoriously difficult to get; the best radar technology can only track objects with an accuracy of around 10 m [7]. When most debris is a few centimeters across, this is not good enough.

In our excitement for space, humanity has created a massive cesspool of debris that threatens to keep us on the ground. Ultimately, there is not yet a single method that is cost-effective, feasible, and can deal with all types of debris. Venturing out into the final frontier will soon require a clean up operation as technically challenging and expensive as the push that got us there.

References

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