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A Montreal Protocol for Space Junk?

On November 15, 2021, the crew aboard the International Space Station (ISS) received an early wake-up call from NASA's mission control. The day before, Russia had unexpectedly conducted an antisatellite technology (ASAT) test that had destroyed its defunct Cosmos 1408 satellite in an orbit near the ISS, immediately creating a cloud of thousands of pieces of high-speed debris. There wasn't time to adjust the orbit of the ISS to avoid the debris, so the crew—which included two Russian cosmonauts—quickly donned their spacesuits and took shelter in the attached Soyuz and Dragon spacecraft.

The White House, US Space Command, State Department, NASA, and many prominent observers immediately denounced the test as irresponsible—a charge denied by Russian officials. Although the ISS crew resumed normal operations on November 17, NASA specialists determined that debris from the Russian ASAT test will persist and elevate risk in low-Earth orbit for years, if not decades.

The problem of orbital debris, from ASATs as well as from other activities, has worsened over time and as more countries and private companies have become involved in space. The United States and Russia have conducted ASATs since the earliest days of the Space Age and debris has accumulated ever since. A 2007 Chinese test created over 3,500 pieces of long-lived debris in highly trafficked orbits. And in February 2009, an Iridium satellite collided with a defunct Cosmos 2251 satellite to produce more than 1,600 pieces of long-lived debris.

It is, however, possible to avoid leaving debris: in 2008, the US military deliberately shot down one of its own nonfunctioning satellites in an operation called Burnt Frost. To ensure that no debris was left in space, they did so at an altitude much lower than the ISS, and involved a NASA orbital debris expert in the operation. Likewise, in 2019, India conducted its own ASAT test at a low altitude, generating new debris that was not as long-lived because material in lower orbits reenters the atmosphere and burns up over relatively short timeframes. Altogether, NASA estimates that there are more than 25,000 pieces of debris 10 cm or larger in orbit, and approximately 500,000 pieces between 1 and 10 cm.

As private companies launch myriad new small satellites, the potential to create more debris only increases. Companies including SpaceX and Amazon have been working to deploy large "megaconstellations" of communications satellites. Since May 2019, SpaceX has launched over 2,000 Starlink satellites and plans to launch tens of thousands more. Even if only some of these megaconstellations come to full fruition, accidental collisions are likely to happen more frequently, creating more orbital debris. In late 2021 China formally complained to the United Nations that it had been forced to maneuver its space station to avoid a Starlink satellite twice within the span of a few months.

The growing number of near misses between orbital debris and functioning spacecraft has prompted calls for a more robust and consistent space traffic management system to safeguard spacecraft crews and to ensure the continued functioning of crucial satellite infrastructure. But it has been difficult to spur action on debris. The technical and legal challenges of dealing with space debris are daunting, as is the complexity inherent in managing a global common resource. And there is little public sense of urgency on this issue, reflecting a widespread lack of appreciation for how reliant modern society is on space systems.

We propose that orbital debris is a form of pollution and that past efforts to address global pollution crises can provide lessons for dealing with the orbital debris problem. The Montreal Protocol—a uniquely successful story of global environmental regulation—provides a particularly constructive example. However, space agencies need to first communicate the urgency of orbital debris as a global environmental threat with potentially serious consequences for people on the ground below.

Policy focused on mitigation

Despite the looming magnitude of the problem, government policy has long been primarily focused on preventing the creation of new debris (mitigation) rather than the larger challenge of actively removing existing debris (remediation). In the United States, NASA specialists first internally developed what became in 2001 the US government's Orbital Debris Mitigation Standard Practices (ODMSP). These were largely adopted by international organizations such as the Inter-Agency Space Debris Coordination Committee and the United Nations' Committee on the Peaceful Uses of Outer Space, which have also focused on mitigation.

This focus on mitigation may not be adequate for the long term, particularly if quantities of debris set off a cascade effect where collisions themselves create more debris. Although the amount of attention paid to remediation has grown, there currently are no proven or even likely technical solutions to clean up existing debris. The 2010 US National Space Policy directive, which focused on mitigation measures, also urged the Department of Defense and NASA to develop remediation technologies. But without specific congressional funding for this purpose, it will remain an unfunded mandate. In 2018, the White House's Space Policy Directive – 3 on space traffic management called for "both government and commercial sector technologies to track and monitor space debris."

In January 2021, the White House released a National Orbital Debris Research and Development Plan with three focus areas: limiting debris by design, tracking and characterizing debris, and debris remediation or repurposing. Although this report addresses both mitigation and remediation, it's still not clear that it will prioritize funding for active debris remediation research and development. Most recently, in December 2021, the White House released a national Space Priorities Framework that mentions debris several times but is a broad statement of principles, not an action plan.

Remediation is hard

Efforts to spur private companies to address the orbital debris issue remain nascent. Although NASA and the Department of Defense have funded several Small Business Innovation Research and NASA Innovative Advanced Concepts remediation projects, these are low dollar value and mostly support basic research rather than technology development and testing. Even seemingly positive steps suffer from low expectations. For example, SpaceWERX, the US Space Force's advanced technology development unit, recently solicited bids for Orbital Prime, an umbrella effort to invest in on-orbit servicing technologies, including debris removal. But when a top Space Force general announced Orbital Prime, he stated that with regard to orbital debris, "right now the most important thing we and others can do is stop making the problem worse"—again placing the emphasis on mitigation.

Without a sense of urgency, commercial remediation solutions have been slow to materialize. The 2021 National Orbital Debris R&D Plan noted that the "market for debris removal and supporting R&D is small." A few commercial space companies see a business opportunity in cleaning up existing detritus. For example, Airbus developed and tested debris removal technologies in 2018 and 2019. Astroscale's Elsa-D mission, launched in summer 2021, successfully completed several of its initial tests to capture and safely dispose of objects in space. More recently, Apple cofounder Steve Wozniak quietly cofounded another company, Privateer, that aims to track and characterize debris by aggregating information from various sources, including the US government, crowdsourced data, and even the company's own future satellites. Yet there is still not a clear commercial business case for debris remediation and given the inherent global nature of debris, a much more comprehensive consensus among commercial, government, and international actors is needed.

The Montreal Protocol as a possible model

Simply put, space junk is a form of pollution—only in space rather than on the Earth. This has been a topic of concern ever since the first satellites reached orbit in the late 1950s and 1960s. By 2011, a National Research Council report contended that the situation had already reached a "tipping point" of no return, arguing that a 1978 prediction by NASA scientist Donald Kessler that debris was likely to strike other debris, creating a cascade of more and more debris, had already been set in irreversible motion. But even this conclusion did not galvanize tangible efforts to address the mounting debris problem.

In discussing the potential losses caused by debris, the 2021 National Orbital Debris R&D Plan implicitly argued that space debris resembles pollution because it is "an externality that the market has little incentive to address." It also makes a certain level of intuitive sense; as engineering and physical sciences professor Hugh Lewis has said, "You can look at the build-up of plastic in Earth's oceans and the build-up of junk in orbit around the Earth as being very similar."

By considering orbital debris as a pollution problem, previous efforts to combat pollution may offer helpful lessons. The Montreal Protocol on Substances that Deplete the Ozone Layer is generally considered the world's most successful international environmental agreement. Although ozone depletion is certainly different from orbital debris, we find the protocol offers useful perspectives for space.

The Montreal Protocol involved several steps before the signing of the agreement, including consensus on the existence of the problem and government-led international collaboration to find potential solutions. The dangers associated with chlorofluorocarbons (CFCs) were brought to worldwide public attention in 1985 when a team of British scientists announced that there was a "hole" (really a pronounced depression) in the ozone layer over Antarctica. Remote sensing data gathered from satellites enabled researchers to create clear visualizations of the ozone layer depression growing in nearly real time.

Efforts to fix the problem accelerated quickly as scientists from US government agencies collaborated with both domestic and international partners to identify potential solutions for the limited number of pollutants causing the problem. Soon, researchers found economical, efficient replacements for CFCs—although some of these replacements cause other environmental harms. The Montreal Protocol banning CFCs was signed in September 1987 and took effect in January 1989. The relevant industrial sectors got on board, and within a decade the ozone depression showed signs of recovery.

Scientists and engineers may know more about the dangers of orbital debris now than they did about ozone depletion in the mid-1980s, but there is not yet consensus about an action plan, particularly for debris remediation. This is because there's been relatively little debris remediation research and a technically feasible solution is still in the future. As with CFCs, government intervention likely will be needed to stimulate research and development of debris remediation techniques, despite the surge in commercial spaceflight generally and the still-evolving business case for private companies. And as with CFC replacements, such solutions may have unintended side effects.

One important feature of the Montreal Protocol is its provisions for financial assistance to developing nations, which were useful in getting international buy-in for a truly global problem—and for setting the stage for crucial North-South cooperation on other global environmental issues. The protocol's "breakthrough principle of common but differentiated responsibilities" allowed negotiators from both developed and developing countries to agree on a framework for financial assistance and made compliance nonpunitive. Similarly, today, utilizing economic "carrots" for nascent spacefaring nations and "sticks" for established actors to discourage polluting Earth orbits with debris merits serious consideration.

Another strength of the protocol is its flexibility: it has been modified multiple times in later decades to address evolving scientific consensus and to allow certain key exceptions. For example, while the protocol banned the use of methyl bromide, a toxic fumigant used to control agricultural pests that also significantly depletes the ozone layer, it permits "critical use exemptions." This is similar to the way the secretary of defense and NASA administrator grant waivers for launches of critical spacecraft that are likely to violate the ODMSP.

A final factor in the success of the Montreal Protocol is the human one. The risks posed by inaction on CFC regulation resonated on a personal level with many people as they became concerned about the predicted rise in skin cancers and cataracts. President Ronald Reagan and British Prime Minister Margaret Thatcher acknowledged the ozone hole as a human-induced environmental crisis and, in an unusual move for these two politicians, strongly supported a regulatory solution to this problem. Some writers have noted that Reagan's multiple skin cancer diagnoses and enjoyment of outdoor activities and Thatcher's background as a chemist may have motivated their understanding and personal investment in the issue.

Any approach to orbital debris will require similarly committed leadership. On the one hand, if practical technical and economic solutions are found for debris mitigation and remediation, world leaders might be more interested in addressing orbital debris. Alternatively, leaders who are passionate about orbital debris could push diplomats and engineers to find specific solutions.

The ozone example shows that rendering the threat as a personal one—a direct, immediate danger to individual leaders, industries, and especially consumers—can be an effective way to gain broad support for action. But with orbital debris, there are big questions about how to make collisions in space tangible to people on Earth. If satellites were put out of commission by debris, activities such as ATM transactions and airline travel could be disrupted. But most people who rely on satellites do so passively, unaware of their links to technologies overhead and out of sight.

Whether or how the same ordinary citizens who feared the looming personal health risks of a thinned ozone layer could learn to take as seriously the myriad threats posed by failing satellite infrastructure remains a complicated question. National defense, agricultural planning, emergency response, entertainment, transportation, and global financial systems would be severely hampered by the loss of satellites, but as-yet hypothetical threats do not resonate quite as clearly as a family member with skin cancer.

It might take the first dramatic loss of services to drive home the immediacy of the problem. Here, Montreal provides an ironic example: had a space pollution crisis destroyed ozone monitoring satellites, perhaps efforts to address the problem of ozone thinning would not have been as quick to gain scientific and political traction. US and international leaders would do well to heed the positive lessons of the Montreal Protocol to address the similarly global problem of orbital debris pollution.

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