DAY ONE PROJECT

Taking Out the Space Trash: Creating an Advanced Market Commitment for Recycling and Removing Large-Scale Space Debris

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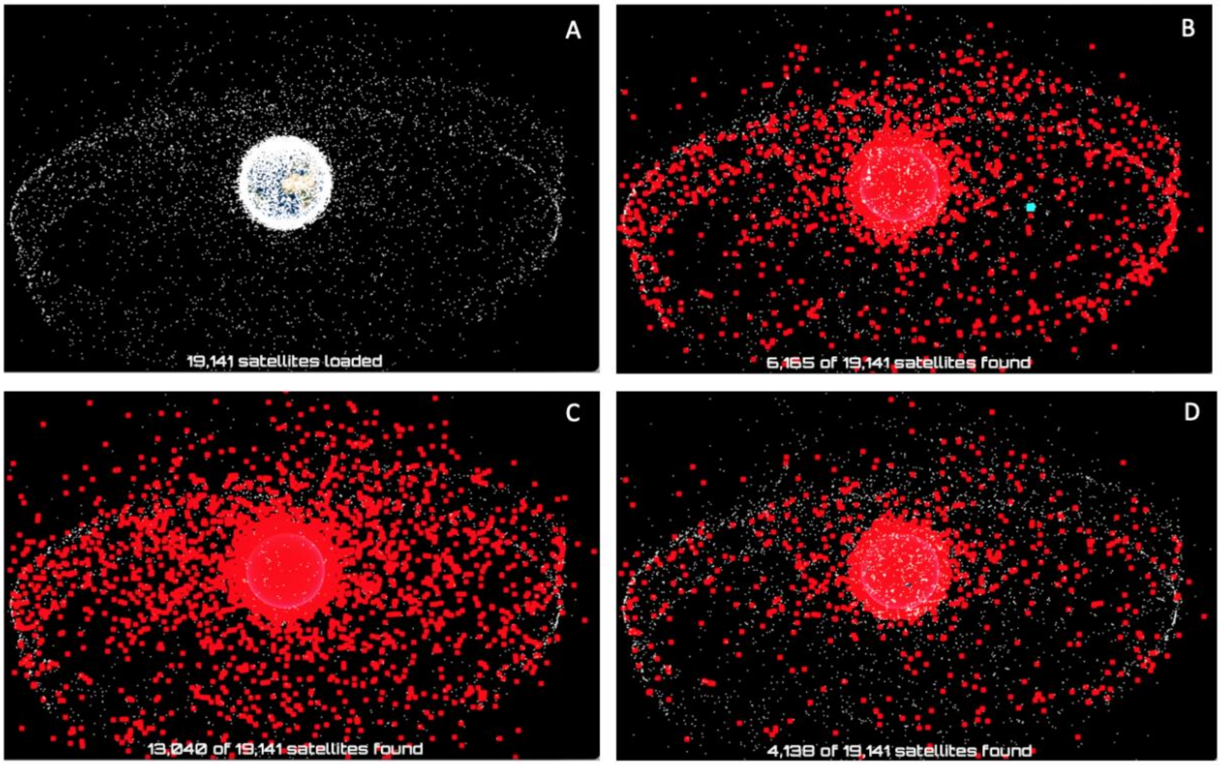
Summary

In the coming decades, the United States' space industry stands to grow into one of the country's most significant civil, defense, and commercial infrastructure providers. However, this nearly $500 billion market is threatened by a growing problem: space trash. Nonoperational satellites and other large-scale debris items have accumulated in space for decades as a kind of celestial junkyard, posing a serious security risk to future business endeavors. When companies launch new satellites needed for GPS, internet services, and military operations into Earth's lower orbit, they risk colliding with dead equipment in the ever-crowding atmosphere. While the last major satellite collision was over a decade ago, it is only a matter of time until the next occurs. As space traffic density increases, scientists project that collisions (and loss of satellite-based services as a result) will become progressively problematic and frequent.

Due to the speed of innovation within the space industry, the rate of space commercialization is outpacing the federal government's regulatory paradigms. Therefore, the U.S. government should give businesses the means to resolve the space debris problem directly. To do so, the Federal Communications Commission (FCC), National Aeronautics and Space Administration (NASA), the U.S. Space Force, and the Department of Commerce (DOC) should create an advanced market commitment for recycling and de-orbiting satellites and large-sized debris. By incentivizing businesses with financial stimulus, novel regulation, and sustained market ecosystems, the federal government can mitigate the space debris problem in a way that also bolsters national economic growth.

Challenge and Opportunity

The sustainability and security of Earth's outer orbit and the future success of launch missions depend on the removal of sixty years' worth of accumulated space debris. The space debris population in the lower-Earth orbit (LEO) region has reached the point where the environment is considered unstable. Over 8,000 metric tons of dead, human-deposited objects orbit the planet, including over 13,000 defunct satellites. While this accumulated trash is the product of numerous countries' space activities, the United States is an undeniably large contributor to the problem. Approximately 30% of orbiting, functional satellites belong to the United States. As such, we as a nation have a responsibility to tackle the space debris challenge head-on.



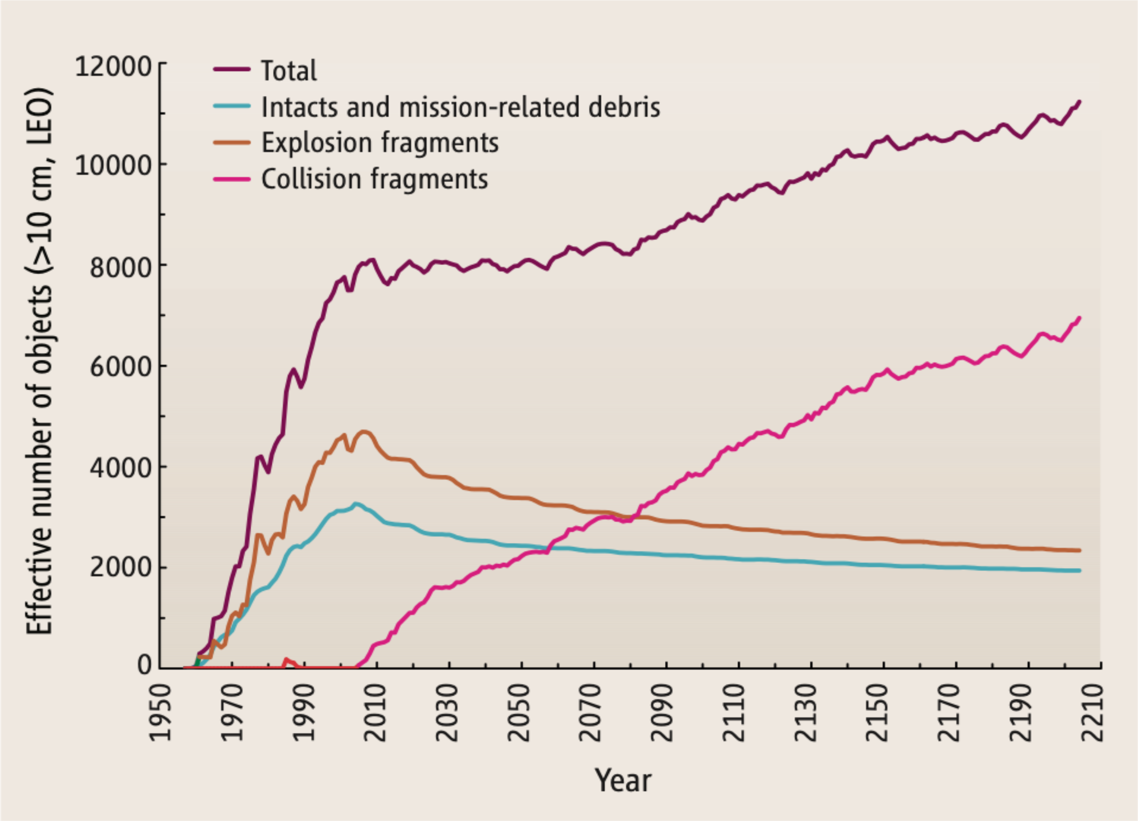
Space is becoming littered with dead satellites, and the United States is a major contributor. *Over 19,000 satellites have been launched between 1950 and 2020 and currently orbit the Earth (Tile A). The red dots in Tile B above represent the satellites, both dead and active, owned and launched by the United States. Nearly 70% of all satellites in orbit are classified as "junk" (Tile C). The United States is one of the largest contributors of satellite refuse, second only to Russia (4,138 satellites vs. 4,714; Tile D). (Source: Generated using ESRI satellite data)*

Our nation's responsibility is especially acute since rapid growth in the American commercial space sector is likely to further exacerbate the space debris problem. New technology advancements mean that it is cheaper than ever to manufacture and launch new satellites. Additionally, recent improvements in rocket engineering and design provide more economical options for getting payloads into space. This changing cost environment means that the space industry is no longer monopolized by a select number of large, multinational companies. Instead, smaller businesses now face fewer barriers-to-entry for satellite deployment and have an equal opportunity to compete in the market. However, since space debris management is not yet fully regulated, this increased commercial activity means that more industries may be littering LEO in the near future.

America's mounting demand for satellite-based services will congest LEO's already crowded environment even further. The U.S. defense sector in particular requires further space resources due to their reliance on sophisticated communication and image-capturing capabilities. As a result, the Department of Defense (DOD) has started recruiting space industries to provide these services through increased satellite deployment in LEO. Additionally, the COVID-19 pandemic has boosted consumer demand for satellite-based internet. In response, space industries are racing to extend broadband access to rural areas and remote populations, an effort which the Biden Administration hopes to support through the Bipartisan Infrastructure Deal. Overall, this combined demand for commercial satellite services from the American public and federal government means that more launches will occur in the years ahead and add to the ongoing debris issue.

The worsening congestion in outer space is a severe nuisance for America's space industry. Floating trash in LEO creates an immediate physical barrier to commercial space activity. Rocket launches and payload delivery must first chart a safe flight that avoids collision with pre-orbiting objects, which, given the growing congestion in LEO, will only become more difficult in the future.

The space debris issue is also a serious security risk that may one day end in disaster. If space traffic becomes too dense, a single collision between two large objects could produce a cloud of thousands of small-scale debris. These fragments could, in turn, act as lethal missiles that hit other objects in orbit, thereby causing even more collisional debris. This cascade of destruction, known as the Kessler Syndrome, ultimately results in a scenario where LEO is saturated with uncontrollable projectiles that render further space launch, exploration, and development impossible. The financial, industrial, and societal consequences of this situation would be devastating.



Space debris, especially debris resulting from collisions, is projected to grow significantly in the years ahead. *Lines in this figure represent the number of* *trackable low-Earth orbit (LEO) objects (based on a NASA-based mathematical simulation). The blue line represents rocket bodies, spacecrafts, and other launch-related refuse that have not experienced breakups. The brown line represents debris resulting from explosions, which are caused by internal malfunctions of a given piece of equipment. The pink line represents debris resulting from two or more objects colliding with one another in orbit. (Source: Science Magazine)*

If outer space is to remain a viable environment for development and industry, the space debris problem must be solved. NASA and other space agencies have shown that at least five to ten of the most massive debris objects must be removed each year to prevent space debris accumulation from getting out of hand. Orbital decay from atmospheric drag, the only natural space clean-up process, is insufficient for removing large-sized debris. In fact, orbital decay could compound problems posed by massive debris objects as surface erosion may cause wakes of smaller debris cast-offs. Therefore, cleanup and removal of massive debris objects must be done manually.

According to the National Space Policy, the U.S. government can "develop governmental space systems only when it is in the national interest and there is no suitable, cost-effective U.S. commercial or, as appropriate, foreign commercial service or system that is or will be available." As such, any future U.S. space cleanup program must actively involve the space industry sector to be successful. Such a program must create an environment where space debris removal is a competitive economic opportunity rather than an obligation.

Presently, an industrial sector focused on space debris removal and recycling—including on-site satellite servicing, in-orbit equipment repair and satellite life extensions, satellite end-of-life services, and active debris removal—remains nascent at best. However, the potential and importance of this sector is becoming increasingly evident. The U.S. Defense Advanced Research Projects Agency's Robotic Servicing of Geosynchronous Satellites program seeks to cheaply recycle still-functioning pieces of defunct satellites and incorporate them into new space systems. Northrop Grumman, an American multinational aerospace and defense-technology company, as well as a number of other small and medium-sized U.S. businesses, have ongoing projects to build in-orbit recycling systems to reduce the costs and risks of new satellite launches. However, federal intervention is needed to rapidly stimulate further growth in this sector and to address the following challenges:

(1) The cost of active space debris removal, satellite decommissioning and recycling, and other cleanup activities is largely unknown, which dissuades novel business ventures.

(2) Space law can be convoluted and the right to access satellites and own or reuse recycled material is contentious. To generate a successful large-scale debris mitigation economy, business norms and regulations need to be further defined with safety nets in place.

(3) The large debris objects that pose the greatest collision risks need to be prioritized for decommission. These objects have not yet been identified, nor has their cleanup been prioritized.

Plan of Action

To address the aforementioned challenges, multiple offices within the federal government will need to coordinate and support the American space industry. Specifically, they will need to create an advanced market commitment for space debris removal and recycling, using financial incentives and new regulatory mechanisms to support this emerging market. To achieve this goal, we recommend the following five policy steps:

Recommendation 1. The Federal Communications Commission (FCC), Federal Aviation Administration (FAA), and National Oceanic and Atmospheric Administration (NOAA) should collaborate to provide U.S. space industries with a standard means of identifying which satellites are viable for recycling once they have reached the end of their life cycle.

One reason why the satellite and large debris object recycling and removal industry remains small is because the market is small. The market can be grown by creating a verified system for satellite providers and operators to indicate that their equipment can be recycled or decommissioned by secondary service providers once a mission is completed. To encourage widespread use of this elective registration system, it will need to be incentivized and incorporated into ongoing satellite and rocket regulatory schemes.

Because federal authority over space activity has evolved over time, multiple federal agencies currently regulate the commercial space industry. The FCC licenses commercial satellite communications, the FAA licenses commercial launch and reentry vehicles (i.e., rockets and spaceplanes) as well as commercial spaceports, and NOAA licenses commercial Earth remote-sensing satellites. These agencies must collaborate to develop a standard and centralized registration system that promotes satellite recycling.

Industries will need incentives for opting into this registration system and for marking their equipment as recyclable and decommission-viable. With respect to the former, the recycling registration mechanism should be incorporated into federal pre-launch or pre-licensing protocols. With respect to the latter, the FCC, the FAA, and NOAA could:

- Coordinate with satellite and space insurance industries to offer reduced premiums to those who elect into the registration system.
- Coordinate with satellite and space insurance industries to offer a subsidy for in-orbit satellites that retroactively enroll.

- Offer prioritized licensing or expedited payload launch to registered satellites and rockets.

Recommendation 2. NASA's Orbital Debris Program Office (ODPO), in coordination with the DOD's Space Surveillance Network, should create a prioritized list of massive space debris items in LEO for expedited cleanup.

Rocket bodies, nonfunctioning satellites, and other large debris represent the highest percentage of overall orbital debris mass in LEO. Since these objects pose the highest risks of additional debris generation through collisions and decay, reducing their stay in LEO is a priority. However, given the continuous generation of space debris and sometimes uncertain or tenuous ownership of older debris items, the federal government needs to create a public and regularly updated "large-debris criticality" index. This index would give large debris items a risk-assessment score based on (i) their ability to generate additional debris through erosion or collision, (ii) the feasibility of their removal, (iii) their ownership status, and (iv) other risk factors. Objects that were put into orbit before NASA ODPO issued its standard debris mitigation guidelines need to be assessed retroactively.

By creating and regularly updating this public index, the federal government would make it easier for public and private actors alike to identify which debris items need to be prioritized for cleanup, what risks are involved, and what technology may be required for successful removal.

Recommendation 3. The Space Force, in collaboration with the Department of Commerce (DOC), should fund removal and/or recycling of a set number of large debris objects each year, thereby creating a reliable market for space debris removal.

By committing to fully or partially fund the NASA-recommended removal of five to ten large debris items each year, the Space Force and the DOC would lower the risk of business entry into the orbital debris removal market and create a sustained market economy for space debris mitigation. The specific monetary reward offered by these agencies for debris removal could be commensurate with the nature and size of the debris item, the speed of removal, and the manner of removal. An additional payout could be offered for the removal of a high-priority large debris item (e.g., an item identified in Recommendation 2 above), or for debris removal that is done sustainably (e.g., in ways that recycle or reuse parts and do not generate secondary, smaller debris).

Recommendation 4. The Space Force – Space Systems Command should coordinate with NASA's Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR) program to issue a satellite design-based grand challenge aimed at facilitating future satellite recycling efforts.

Grand challenges are popular and often effective tools for stimulating public interest in a given issue and advancing technologies. However, they can fall short of creating a sustainable, long-lasting commercial industry. The Space Force and NASA can overcome this difficulty by designing a grand challenge wherein: (i) research and development costs are shared among private and public participants; (ii) multiple winners are selected at the end of the challenge; (iii) winners are chosen based on whether they meet government capability thresholds in addition to being commercially viable; and (iv) challenge winners are guaranteed a long-term government service contract.

For this grand challenge, Space Force and NASA should encourage the creation and, afterwards, widespread commercial use of satellite design strategies that facilitate satellite recycling, mission extension, or deconstruction. Specifically, the design challenge should focus on:

- Providing enhanced protection against mission-ending impacts by small orbital debris.
- Generating standardized features (e.g., docking mechanisms) that allow future servicing equipment to latch in orbit for repair, deconstruction, and recycling.
- Crafting modular and scalable components that can be easily swapped out, removed, and replaced and thereby lead to downstream recycling and repair.

Recommendation 5. NOAA's Office of Space Commerce, in conjunction with the Space Force and NASA's ODPO, should jointly issue an annual research report outlining risk, cost-benefit analyses, and the economics of orbital debris removal and recycling.

For the growing number of debris recycling and satellite maintenance industries, large orbital debris represent a potential source of valuable materials and resources. While it is theorized that repurposing or salvaging these large debris objects may be more cost effective than de-orbiting them, exact costs and benefits are often unspecified. Additionally, the financial repercussions of accumulating space debris and collisions are largely unknown.

If industries know the upfront expenses and potential profit of space debris removal, the debris removal market will be far less risky and more lucrative. NASA, NOAA, and the Space Force can fill that information gap by collaboratively creating better tools to assess both the risk and costs posed by orbital debris to future uses of space, including commercial development and investment.

Conclusion

For America's space industry to grow to its full potential, end-of-life satellites and other orbiting dead equipment need to be cleared from Earth's lower orbit. Without removing these items, the increasing possibility of a severe in-orbit collision poses a major security risk to civilian, military, and commercial infrastructure providers. By creating an advanced market commitment for recycling and de-orbiting large-sized debris items, the federal government does more than just address the growing space debris problem. It also creates a new market for the U.S. space industry and stimulates further economic growth for the country. Additionally, it encourages greater public-private collaboration as well as consistent communication between crucial offices within the U.S. government.

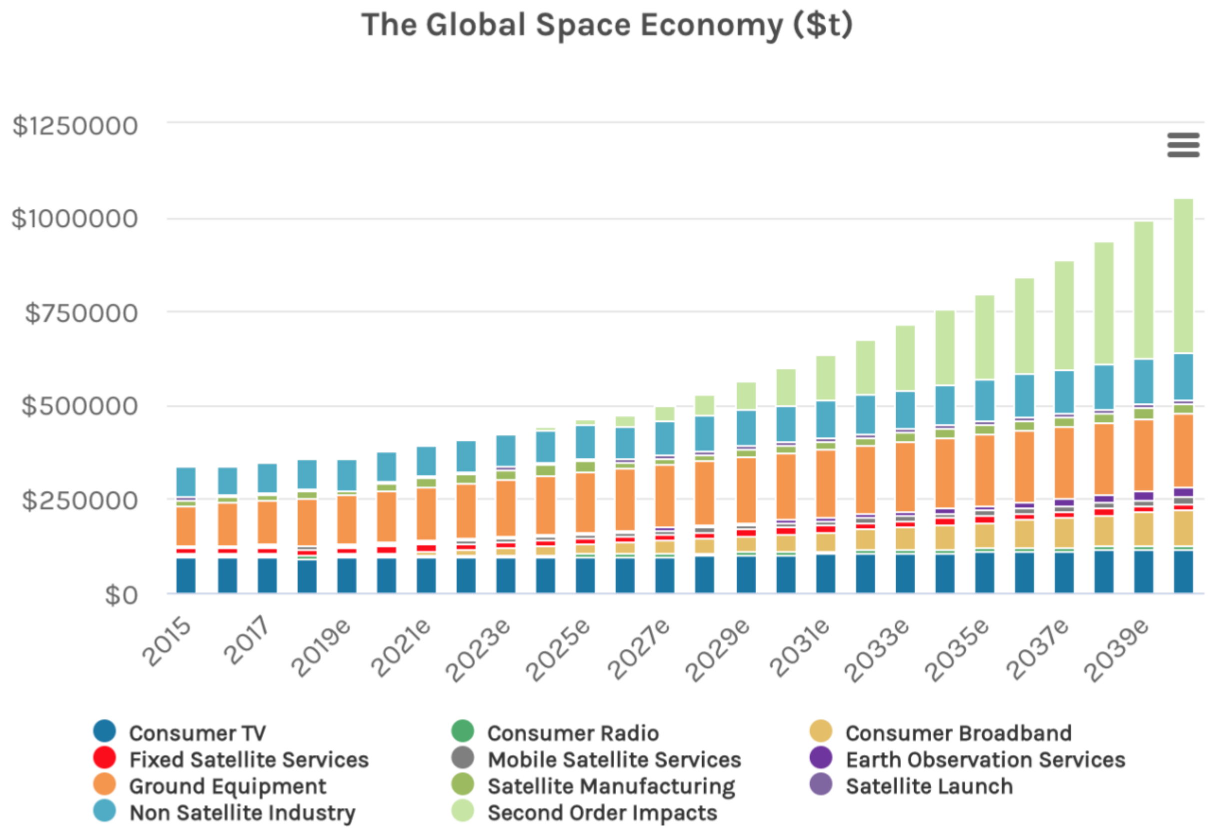
Frequently Asked Questions

1. Outer space is governed by international law. Why can't the United Nations (UN) or other international space agencies handle the space debris issue? Why should the U.S. government act?

Global space governance is very complicated since no single country has a right to this territory. As such, space activity is broadly guided by UN treaties such as the Outer Space Treaty of 1967 and the Moon Agreement of 1979. While these treaties establish important guidelines for the peaceful use of space, they fail to address important present-day concerns, such as governing space debris and private industry activity. Thus, these treaties are not fully able to guide modern challenges in space commercialization. It is also important to note that it took nearly ten years for diplomats to reach an agreement and ratify these treaties. Therefore, the timeline needed to either revisit outer space treaties or craft new ones is too slow to fully match the breakneck speed at which space activity is developing today. Given the U.S. space industry's influential role in shaping behaviors and norms in outer space, addressing the space debris problem effectively will require the U.S. space industry sector's involvement.

2. What is at stake—how much is the U.S. space industry worth?

In 2018, the FAA estimated the value of the U.S. space industry at approximately $158 billion. Since then, the space economy has continued to grow, largely due to a record period of private investment and new investor opportunities in spaceflight, satellite, and other space-related companies. As a result, the space industry was valued at $424 billion in 2019. By 2030, it is believed that the space industry will be one of the most valuable sectors of the U.S. economy, with a projected value of between $1.5 and $3 trillion.



The value of the global space industry is only expected to increase in the years ahead. *Morgan Stanley estimates that satellite broadband will represent 50–70% of the projected growth of the global space economy by 2040. With launch costs plummeting and the public demand for increased data services only projected to increase, the space industry stands to be a major source of economic growth for the United States. (Source: Morgan Stanley)*

3. Why is the American space industry growing so quickly?

It all has to do with cost. Mounting competition among private space companies means it is cheaper than ever to launch equipment into space, which creates numerous opportunities for businesses to meet the ever-increasing need for alternative supply chain routes and satellite-based internet connectivity.

From 1970–2000, the cost of launching a kilogram of material into space remained fairly steady and was determined primarily by NASA. When NASA's space shuttle fleet was in operation, it could launch a payload of 27,500 kilograms for $1.5 billion ($54,500 per kilogram). Today, SpaceX's Falcon 9 rocket advertises a cost of just $62 million to launch 22,800 kilograms ($2,720 per kilogram). In other words, commercial launch has reduced the cost of getting a satellite into LEO by a factor of 20. Additional developments in reusable rocket technology may decrease that cost to just $5 million in the future. Improvements in satellite technology and mass production will further cut costs and make more launches possible. It is projected that satellite mass production techniques could decrease launch cost from $500 million per satellite to $500,000.

Decreasing costs lead to increasing rocket and satellite launch rates and, hence, to increasing accumulation of space debris.

4. If two pieces of space junk are going to collide, can't you just make them move?

If the satellites in question are active, fully functioning, and capable of maneuvering, then to an extent—yes. Satellites can be remotely programmed to change course and avoid a collision. Even under these circumstances, though, these objects adhere to the laws of physics; it can take a lot of energy to alter their orbit to avoid a crash. As such, most satellite operators require hours or days to plan and execute a collision avoidance maneuver.

Not all active equipment is capable of maneuvering, though; there is no way to control objects that are inactive or dead. So, orbiting debris are uncontrollable.

5. Is there air traffic control in outer space?

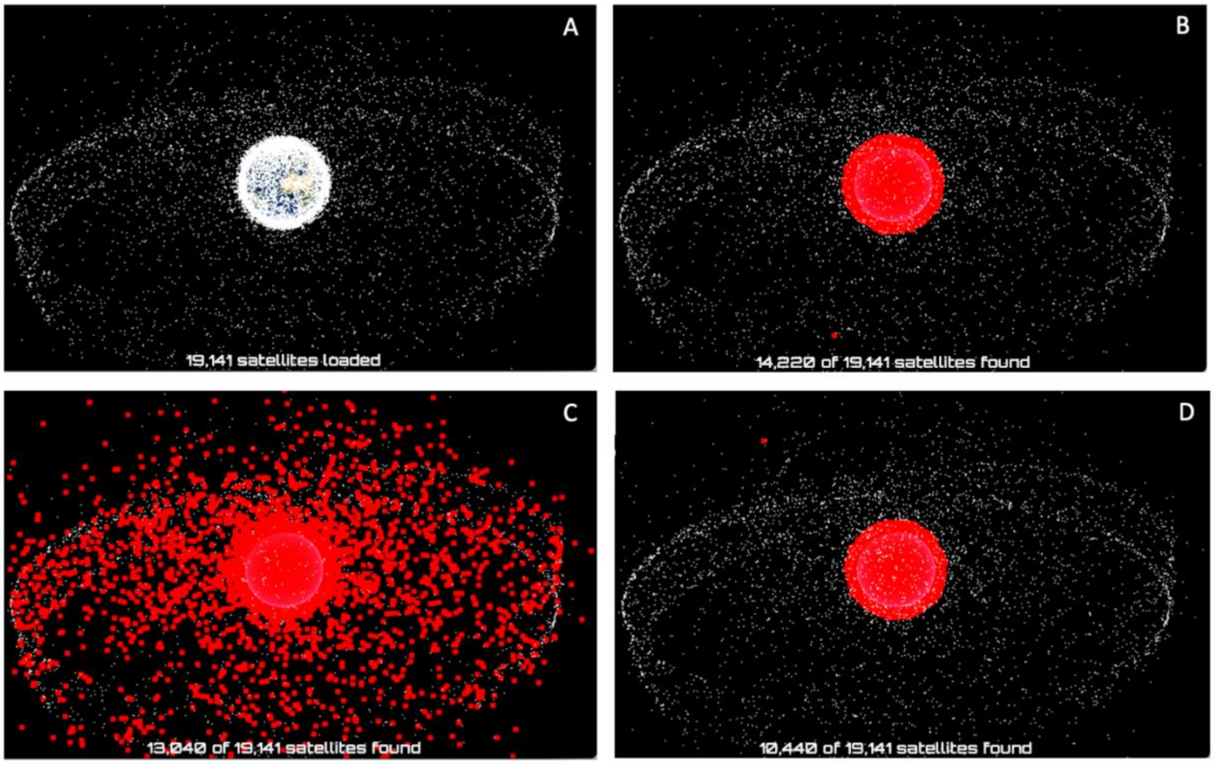
To date, there is no official or internationally recognized "Space Traffic Control" agency. Within the U.S., responsibility for space traffic surveillance is shared among numerous government agencies and even some companies.

6. Why is recycling and decommissioning in-orbit satellites so difficult?

Satellites and rockets are not designed for disposal; they're designed to withstand the tremendous aerodynamic forces, heat, drag, etc. experienced when exiting the Earth's atmosphere. Furthermore, many satellites are built with reinforcements to maintain orbit and withstand minor collisions with space debris. Hence, breaking down, recycling, and fixing satellites in space is currently very challenging.

7. Why does this memo focus on LEO? Isn't space debris a problem at other orbits and distances too?

LEO is defined as the area close to Earth's surface (between 160 and 1,000 km). This territory is especially viable for satellites for several reasons. First, the close distance to Earth means that it takes less fuel to station satellites in orbit, making LEO one of the cheapest options for space industries. Second, LEO satellites do not always have to follow a strict path around Earth's equator; they can instead follow tilted and angled orbital paths. This means there are more available flight routes for satellites in LEO, making it an attractive territory for space industries. As a result, most satellites and, by consequence, the majority of satellite junk is located in LEO.



Most satellites and satellite debris are located in LEO. Over 19,000 satellites have been launched between 1950 and 2020 and currently orbit the Earth (Tile A). As seen in Tile B above, nearly 74% of all satellites are in LEO. Of the 19,000 satellites in orbit, 70% are classified as "junk" (Tile C) and nearly 80% of that debris is concentrated in LEO (Tile D). (Source: Generated using ESRI satellite data)

Why focus on large space debris, like defunct satellites and rocket cast-offs? What about smaller debris?

Smaller debris do outnumber larger debris in outer space. According to NASA, there are approximately 23,000 pieces of debris larger than a softball orbiting the Earth. There are 500,000 pieces of debris the size of a marble (up to 0.4 inches, or 1 centimeter), and approximately 100 million pieces of debris that are about .04 inches (or 1 millimeter) and larger. Micrometer-sized (0.000039 of an inch in diameter) debris are even more abundant. These small-sized space debris may be traveling upwards of 17,500 mph, meaning they can do massive amounts of damage during collisions.

Debris Size	Similar in size to	Mass (g) aluminum sphere	Kinetic Energy (J)	Equiv. TNT (kg)	Energy similar to	Quantity	Trackable
1 mm	medium-grit sand or poppy seeds	0.0014	71	0.0003	Pitched baseball	Tens of millions	Can't be tracked
3 mm	smaller than BBs	0.038	1910	0.008	Bullets	Millions	Can't be tracked
1 cm	blueberries	1.41	70700	0.3	Falling anvil	Hundreds of thousands	Can't be tracked
5 cm	plum	176.7	8840000	37	Hit by bus	Tens of thousands	Most can't be tracked
10 cm	softball	1413.7	70700000	300	Large bomb	Tens of thousands	Most can be tracked
> 10 cm	basketball to football field	1400 to 500,000,000	Up to 1x10^13	Up to 3,000,000	Very large bomb	Thousands	Tracked and cataloged by the space surveillance network

A summary of the collision energies of various sized particles. Smaller debris items that are <4cm in diameter are usually not detectable via radar. (Source: Aerospace)

Clearly, small debris are also a significant security risk and should be included in space debris cleanup considerations. However, an inability to track small-scale debris orbits, the specific challenges in "catching" these small, high velocity objects, and a significant lack of reliable information on small-sized space debris means that this aspect of space debris mitigation will likely require its own unique policy actions.

We presently have more data on large-sized debris, and these items pose the greatest threat to ongoing space efforts, should they collide. Therefore, this memo focuses on policy actions targeting these debris items first.

About the Author

Dr. Lyndsey Gray, PhD MSPH is a global health researcher and infectious disease epidemiologist with a lifelong commitment to addressing complex international problems through science diplomacy. She has trained at the Centers for Disease Control and Prevention, Carnegie Mellon University, Emory University, and Colorado State University while leading environmental disease prevention studies in Latin America, East and West Africa, and Southeast Asia. Dr. Gray previously served as a Community Health Peace Corps Volunteer in Peru and an inaugural Science Diplomacy Learning and Exchange (SciDEAL) Fellow with the National Science Policy Network (NSPN) and SciDipGLOBAL. Presently, she acts as Engineers and Scientists Acting Locally's (ESAL) Content Manager, NSPN's Science Diplomacy Committee Chair, and an Affiliate Fellow at Duke University – Rethinking Diplomacy Program's Space Diplomacy Lab.

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