

The Threat That Satellite Infrastructure Poses to Itself

In the past several years, private companies have made headlines by launching satellites and other objects into space independent of any government agency. In February of 2018, for example, SpaceX completed the first test flight for its “Big Falcon Rocket” by launching an electric sports car into orbit around the sun (SpaceX). However, these private companies do not exist in a vacuum. Spaceflight and the space industry has been in development since the Orbit of Sputnik 1 in 1957. In the sixty or so years since that first orbit, a community of experts has developed around the globe, and infrastructure both on the ground and in orbit has formed. Since the first, roughly 6,000 satellites have been launched, and the largest estimates have 3,600 still in orbit. Of those, roughly 1,000 satellites are operational (Bolonkin 2). This network of satellites supports a vast amount of the services that many countries enjoy today. GPS, weather tracking, communications, and scientific observational satellites are just a few examples of the tasks given out to these objects in orbit. Aside from those, the International Space Station supports manned research in space, and requires routine visits by rocket for resupply (stuffin.space). But what about the remainder of the estimated 3,600 satellites in orbit? Those satellites no longer serve a purpose in any activity useful to those living back on earth, yet their orbit continues. They become part of a constellation of space junk that accumulates slowly with each new mission—public or private—to launch something into space. As the number of objects launched per year rises, the environment around the earth becomes more crowded. The increasing number of objects in space comes with an increased risk of collision, which over time would make earth-

orbit as an environment much more dangerous and chaotic. In that sense, the industry around the infrastructure of satellites in orbit poses a threat to itself simply by continuing to operate.

The “near earth” environment, as Rand calls it in *Orbital decay: Space junk and the environmental history of Earth's planetary borderlands* is massive—naturally—and seemingly empty. Rand points out, however, that not everyone sees it as a void. “Not yet five years after Soviet engineers launched Sputnik into orbit, a rapidly coalescing international community of space scientists discovered a complex topography of magnetism, radiation, energy, dust, and atmospheric and trapped solar particles extending tens of thousands of kilometers from Earth into space” (24). This environment was a new area of study with a huge potential for discovery, but had already been altered through the launching of Sputnik and the military satellites that followed. “In The Exploration of Outer Space, however, the near-Earth space environment—new to human access and study had already been polluted beyond repair...in a jingoistic race to technological supremacy, Cold Warring states had taken egregious risks by launching dangerous materials—including nuclear devices—into a poorly understood, fragile environment that scientists could no longer study in its natural state” (25). These frustrations were expressed by the British Astronomer Bernard Lovell, who Rand compares to Rachel Carson and her work, *Silent Spring*, in his protests of an environment being altered beyond repair before the scientific community really had a chance to understand it.

Lovell’s protestations in the 1960’s fell on deaf ears however, because the past several decades of spaceflight have transformed the near-earth environment into a complex traffic of satellites and debris moving around in orbits that can often cross close together. The pre-anthropogenic environment of unending space around the earth has been filled with junk.

Though rare, several collisions between satellites have occurred in the history of space

junk. Of these few, the most notable occurred in 2009 when the Iridium-33 and Cosmos-2251 satellites hit each other and created around 1,000 new pieces of debris (Oleksyn). Iridium-33 was a communications satellite still in operation, and Cosmos-2251 was a Russian military satellite that had been decommissioned in 1995 and stayed on its orbit as junk.

The reason the 2009 collision stands out, however, is that the two satellites were predicted to pass within 584 meters of each other. This was a close approach, but computer models showed that they would miss one another. Dr. Kelso, an American astrophysicist, operates a satellite tracking database called CelesTrak, and wrote a report shortly after the collision to discuss what might have happened. “There has been much discussion about why this collision wasn’t reported [by the system] ... In reality, SOCRATES did predict a close approach between Iridium-33 and Cosmos-2251 at the time of the actual collision in each of the 14 reports in the week leading up to the event. As of 2009 August 5, the SSN has cataloged 386 pieces of debris (16 pieces of which have already decayed from orbit) associated with Iridium 33 and 927 pieces of debris (30 pieces of which have decayed) associated with Cosmos 2251.” (Kelso 1).

The reality is that tracking satellites, especially those that are non-operational and no longer signal to anyone, is difficult. Collisions like the one between Iridium-33 and Cosmos-2251 might happen rarely, but as each collision generates more debris the likelihood of further accidents only increases. This phenomenon is known as the Kessler effect.

The Kessler effect, or “Kessler Syndrome,” is a theory developed in 1978 by Donald J. Kessler, an American astrophysicist who worked at NASA as part of the Environmental Effects Project Office. In simple terms, Kessler Syndrome predicts that collisions between space debris becomes more and more likely as more objects are launched into orbit. These collisions cause satellites to break apart, creating smaller debris objects that become harder to track, recover, or

remove. The implication of the Kessler Effect is that the more objects that are launched into orbit to support projects on the ground or on the space station, the more at risk those projects become.

In a worst-case scenario, if the problem of rogue debris is not controlled, then a domino effect of satellite and debris collisions could happen that would make future launches difficult and dangerous in the case of manned missions. The abstract to Kessler's paper in 1978 states that, "As the number of artificial satellites in earth orbit increases, the probability of collisions between satellites also increases. Satellite collisions would produce orbiting fragments, each of which would increase the probability of further collisions, leading to the growth of a belt of debris around the earth...Under certain conditions the belt could begin to form within this century and could be a significant problem during the next century. The possibility that numerous unobserved fragments already exist from spacecraft explosions would decrease this time interval" (Kessler, Cour-Palais 1). Uncontrolled and unregulated, Kessler predicted that the increasing number of satellites in orbit would become a threat to themselves, and that the timescale on which the situation would become difficult would decrease with each collision and subsequent explosion of new debris into the near-earth environment.

The phenomenon of the Kessler Effect has since become a trope in science fiction. It appearing notably in the 2013 film *Gravity* as the event that kicks off a desperate fight for survival against a debris cloud triggered by a Russian missile hitting a satellite in orbit (Cuarón). In the film it only takes a few hours for both the International and Chinese Space Stations to be torn to wreckage and kill all but one of the astronauts in orbit. Though the movie effectively shows what a domino-effect disaster caused by the Kessler effect could look like, it would probably not happen that fast.

In a paper written 30 years after the first was published, Kessler made an attempt to correct some of the misconceptions that had been tacked onto it during its time in the public's imagination. "In general, collisional cascading is a slow process, but very much depends on the population density and size of the objects in orbit. Current population densities would require decades to produce a significant change in the small debris environment, and much longer to approach a condition where the Earth might be 'completely cut off from space'." Kessler describes a much longer time scale here of decades verging on centuries to see significant change in the space-junk filled environment of near-earth orbit. "However, it is conceivable that some ill-planned rapid expansion in the use of low Earth orbit could produce a much more rapid increase in small debris as a result of collisional cascading" (Kessler, Johnson 4). A Cascade, according to Kessler, constitutes a chain reaction of collisions that becomes so numerous as to be self sustaining. In such an event, more debris would be created than would fall out of orbit and burn up in the atmosphere, which would mean earth's orbit would become crowded on a very rapid scale.

One potential trigger according to Kessler could be the Envisat Satellite, an earth-observation satellite launched by the ESA in 2002 that was decommissioned in 2012. "The cascade process can be more accurately thought of as continuous ...where each collision or explosion in orbit slowly results in an increase in the frequency of future collisions. But since Envisat is so massive... it would instantly produce a debris environment that, under the most optimistic conditions, we would not expect to have for at least 100 years" (Gini). Envisat is an eight-ton machine, that according to Kessler means it will take at least 150 years for its orbit to degrade enough to be safely burned up in Earth's atmosphere. In that time, all it would take to trigger a huge debris cloud to break off from the satellite would be an object as

small as 10 kg hitting it. Currently “two catalogued objects can be expected to pass within 200 meters of Envisat every year,” meaning it is in danger of being hit based solely on the objects that NASA and others are able to track (Gini).

Even if these organizations are able to track the debris currently in space, recovery and removal presents a challenge. In order to stabilize the debris environment, NASA and ESA analysts state that “10 to 20 pieces of orbital debris need to be removed per year to stabilize the orbital debris environment” (Barbee 1). The current best proposed solution to do that is to design a rocket trajectory that would rendezvous with as many objects as possible in order to push them into a safer orbit further from earth or into the atmosphere where they would burn up safely.

“However, no spacecraft trajectories have yet been designed for removing multiple debris objects and the size of the debris population makes the design of such trajectories a daunting task. The goal is to choose the order in which the objects are visited so as to minimize the total path distance traveled. In the case of orbital debris, the pieces of debris to be visited must be selected and ordered such that spacecraft fuel consumption is minimized or at least kept low enough to be feasible” (Barbee). It is a problem of fuel consumption with very small room for error when the number of steps that could go wrong is astronomical.

In order to ensure that the the number of debris objects in space remains somewhat manageable, policies have been enacted that ensure that current projects are less at risk of creating debris. “When satellites reach the end of their mission, satellite operators have the option of de-orbiting the satellite, leaving the satellite in its current orbit or moving the satellite to a graveyard orbit. As of 2002, the FCC requires all geostationary satellites to commit to moving to a graveyard orbit at the end of their operational life prior to launch” (Bolonkin 2). The International Telecommunications Union (ITU) also requires all satellites launched to be capable

of pushing themselves into a “graveyard orbit” where they are less of a hazard once they retire. Current launches of rocket stages and satellites containing propellant must store enough on board to de-orbit into the atmosphere in order to be disposed of safely (Bolonkin 7).

Space Infrastructure Services is a company based in the US proposed the MDA Space Infrastructure Servicing vehicle as a refueling depot to service other satellites in geosynchronous orbit. The system includes the “ability to "push dead satellites into graveyard orbits" which would be useful in the event of another satellite’s countermeasures failing. The system was slated to launch in 2015, but has since been pushed back to 2021 (SIS).

The difference between “de-orbiting” and a “graveyard orbit” is significant. De-orbiting is the safest in terms of adding to the risk of a triggering event as per the Kessler Effect, and involves the object pushing itself or being externally pushed into the atmosphere where it burns up and is destroyed.

However, to do this requires the object to have fuel left to burn and be able to safely increase its velocity into a de-orbiting trajectory. If the object can’t complete a de-orbit safely, then it must be able to put itself into a graveyard orbit. Graveyard orbits are considered a back up method because it lessens the likelihood of a collision significantly, but not to zero. The satellite still orbits the earth, only out to a distance where there is much more room to maneuver away from satellites that are operational and in use.

This case of the pollution of near-earth orbit as described by Lisa Ruth Rand is an interesting one. While it could be compared to other environmental hazards and health risks like the widespread use of pesticides on the environment, there are no birds in space. There is no *Silent Spring* factor because it is not an environment that sustains life. The environmental argument that is left would be one for unobstructed scientific study, but as Lovell pointed out in

the 1960's, the opportunity has already been missed. Since then, the network of satellites that have formed constellations around earth have become an infrastructure that is necessary to maintain and secure in order for it—by extension—to support an ongoing way of life back on earth. Navigation, communication, and weather prediction would not be what they are today without machines in orbit to observe and connect the rest of the world, but the paradox of the creation of the network is the threat that it poses to itself. As more satellites go up, especially now in a world where private companies race to build their own launch infrastructures to support new and evolving markets in which space can be profitable, the existing constellation has a higher risk of collision.

In a time where no reliable method of de-orbiting this space junk exists, populating near-earth orbits with satellites can in many ways be considered an extractive industry in comparison to coal, oil, and gas. Setting aside for a moment that the space industry contributes to these others in its use of propellant, satellite placement can be compared to this extraction on its own when you consider how each slowly contributes to its own undoing. As industry around fossil fuel contributes to the effects of anthropogenic global warming while at the same time using up a finite resource, the placement of a satellite in orbit contributes to an overall increase in the probability of disrupting communications networks and other important satellite functions. The continued operation of each contributes to its respective unsustainability. Additionally, failure to regulate—or obey existing regulations—within each industry can cause small disasters that contribute towards a drawn out bigger picture. Though these infrastructures contribute to disaster on a massive timescale, they do have an impact. The effects of an unchecked environment of space junk may only be a fringe concern today, they could have far reaching consequences for the future.

Bibliography:

- Barbee, Brent William, et al. "Design of Spacecraft Missions to Remove Multiple Orbital Debris Objects." *2011 Aerospace Conference*, 2011.
- Bolonkin A. New methods of removing space debris, <http://www.rxiv.org/pdf/1403.0670v1.pdf>, 2014.
- Cuarón Alfonso, et al. *Gravity*.
- Donald J. Kessler and Burton G. Cour-Palais (1978). "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt". *Journal of Geophysical Research*. **83**: 2637–2646.
- Donald, J. Kessler, N. L. Johnson, J. Liou, M. Matney, "The kessler syndrome: Implications to future space operations", *33rd Annual AAS Guidance and Control Conference AAS Paper Number 10–016*, February 6–10 2010.
- Gini, Andrea. "Don Kessler on Envisat and the Kessler Syndrome." *Space Safety Magazine*, 15 Sept. 2014, www.spacesafetymagazine.com/space-debris/kessler-syndrome/don-kessler-envisat-kessler-syndrome/.
- Kelso, T S. "Analysis of the Iridium 33-Cosmos 2251 Collision." *Celestrak: Publications*, celestrak.com/publications/AAS/09-368/.
- "Mars." *SpaceX*, SpaceX, 20 Sept. 2016, www.spacex.com/mars.
- Oleksyn, Veronika. "What A Mess: Experts Ponder Space Junk Problem." *USA Today*, Gannett Satellite Information Network, 19 Feb. 2009, usatoday30.usatoday.com/tech/science/space/2009-02-19-space-junk_N.htm.
- "On-Orbit Servicing Changes Everything." *Space Infrastructure Services (SIS)*, spaceinfrastructureservices.com/.
- Rand, Lisa Ruth, "Orbital decay: Space junk and the environmental history of Earth's planetary borderlands" (2016). *Dissertations available from ProQuest*. AAI10191526. <https://repository.upenn.edu/dissertations/AAI10191526>.
- Yoder, James. "Stuff in Space." *Stuff in Space*, stuffin.space