THE IMPACT OF THE SPACE DEBRIS DILEMMA

A Research Paper submitted to the Department of Engineering and Society
In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

By

Del Irving

March 28, 2022

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

ADVISOR
Catherine D. Baritaud, Department of Engineering and Society

Beginning in 1957 with the launch of Sputnik 1, the Space Age has seen some of the greatest achievements of mankind, from Apollo 11 and the first man on the moon in 1969 to the New Horizons mission traveling past the dwarf planet, Pluto, in 2015 (Johns Hopkins University Applied Physics Laboratory, 2021, para. 2). Constant development of new aerospace technologies hopes to bring spacecraft and humans further into the unknown of the solar system and beyond, but the window of the Space Age may not remain open for much longer. Each new mission, successful or not, would see the addition of yet another metallic hunk introduced into orbit. In 2002, Crowther (2002) numbers around 9,000 cataloged (greater than 10cm in size) objects in orbit (p. 1242). By 2014, "NASA's Orbital Debris Program Office estimates that there are currently over 21,000 fragments larger than 10 centimeters in orbit" (Finkleman, 2014, para. 6). Today, over 27,000 pieces of orbital debris are currently being tracked by the Department of Defense's Space Surveillance Network, with much more lethal debris that is too small to be tracked but large enough to result in devastating collisions in Low Earth Orbit (LEO) (Garcia, 2021, para. 1).

The technical project focuses on creating a reduced model for the combustion of solid fuel butadiene with air, more specifically hydroxyl terminated polybutadiene (HTPB), in hypersonic engines. The current model takes several days to run but is extremely accurate so the goal of the research is to reduce the model to a point where calculations can be done rapidly while maintaining the most accuracy possible for this level of reduction. This is done by modeling flamelets along the hybrid-propellant (gaseous oxidizer and solid fuel) boundary using a non-premixed counterflow diffusion model as outlined in Sarnacki et al. (2012, p. 1032). The technical work has strongest applications in the fields of hypersonic flight and rocket propulsion and has the potential to be the next big leap in rocketry to send spacecraft even further beyond

what has been currently explored. This work was completed with the help of Harsha Chelliah, a professor in Mechanical and Aerospace Engineering at the University of Virginia who served as the advisor for the technical project.

The motivation for the STS project on space debris is that if nothing is done about the inactive crafts orbiting Earth, space travel will eventually become impossible and an end to the Space Age will come, not to mention the clutter that will prevent new satellite technologies from being put into orbit. The technical and STS research are moderately coupled based on this fact that if space junk is not dealt with rapidly, all aerospace research will soon become futile as the heavens are closed off by a layer of metal in low Earth orbit. The objective of the STS project is to resolve the question about what solutions there are to prevent the escalation of the space debris dilemma and how to raise awareness of the severity of the issue, both of which are accomplished through use of the actor network theory framework.

THE IMPACT OF THE SPACE DEBRIS DILEMMA

THE SPACE AGE

Sputnik 1, the first manmade object to be sent into space, orbited Earth for three weeks until the three silver-zinc batteries powering the craft died; Sputnik then orbited for over two months before burning up in the atmosphere (Williams, 2022, para. 4). The small Soviet satellite caught the attention of the entire world, sparking what would become known as the Space Race. After a second Sputnik mission before the end of 1957, the United States followed with the launch of Explorer 1, less than a month after Sputnik 1 reentered the atmosphere. Within the next few decades the two powerhouses feverishly launched thousands more satellites, with Europe and China not far behind. By 2015, Ault (2015) reported that a third of all active satellites were owned by militaries, of which between a third and half were being used for surveillance.

Remaining is a third civilian owned and a third commercial (para. 10). Because of the nature of military satellites, especially those used for surveillance on other nations, it is impossible to keep track of all active satellites. This fails to include the thousands of satellites that are inactive but continually powered by solar panels as well as tens of thousands of pieces of debris that orbit Earth as a byproduct of satellites failing and being fractured by other debris. Satellites have always been extremely valuable pieces of technology to governments, militaries, private companies, and civilians alike, and especially as rocket launch costs decrease, the number of satellites in orbit will only go up. For now the space debris dilemma is stable, but if human ignorance continues the issue could quickly spiral out of control.

INITIAL IGNORANCE AND TRAGEDY OF THE COMMONS

The space debris dilemma at its core is a tragedy of the commons. All of the actors in the satellite and aerospace industries work independently for personal gain, whether that be money, intelligence, or data, with no regard for the impact on the environment of space. As a consequence, not just Low Earth Orbit (LEO) but also geostationary orbit and all the space between has been littered with debris of all sizes, as seen in Figure 1.

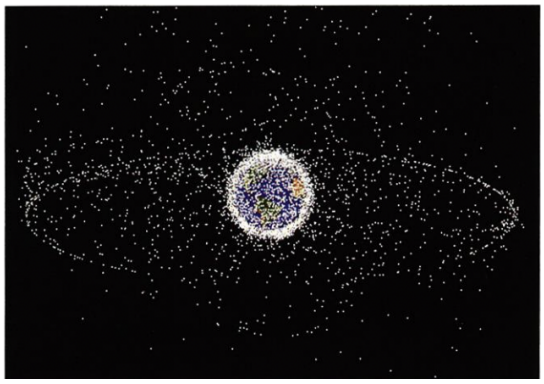

Figure 1: Visual representation of space debris. Close to Earth is a heavily concentrated zone of debris known as low Earth orbit (LEO). The ring further from Earth represents a geostationary orbit, common for communication satellites since the orbit remains above a fixed point on the surface. (Crowther, 2002, p.1241)

Precautions have been put into place to prevent the pollution of space before, namely in the Outer Space Treaty of 1967 which states that “nations are responsible for damage caused by their space objects and must avoid contaminating space and celestial bodies” (Space Foundation Editorial Team, 2022, para. 7), but the treaty does not define what a space object necessarily is. Since the law is vaguely written, there is room for nations to exploit a loophole where satellite debris is no longer the responsibility of that nation. Furthermore, the treaty declares that “there is no claim for sovereignty in space; no nation can ‘own’ space, the Moon or any other body” (Space Foundation Editorial Team, 2022, para. 3). Such a law directly supports the ignorance of the space debris dilemma and single handedly creates a tragedy of the commons. If no nation has a claim over space, then no power has the responsibility to clean up the mess created.

As a result of this mindset, nations and private aerospace companies are joining in the common practice of sending up rocket stages and satellites with no plans to return. Recently, a rocket stage on a crash course with the moon left SpaceX at the center of some criticism. Though it was later found that the object was not the Falcon 9 booster, an astronomer at the Harvard Smithsonian Center for Astrophysics pointed out that “it’s not as much about what SpaceX [and other companies] do now because it’s a perfectly standard practice to leave your junk in deep Earth orbit and just abandon it” (Bella, 2022, para. 6).

More than anything, the largest deterrent to cleaning up space has been the time and money needed to remove even one piece of debris. Declining launch costs have pros and cons, as more satellites crowd LEO but more efforts for retrieval of debris may be attempted. For now time and money are wasted on sending up missions to take down individual pieces of debris one at a time, and the variation in debris size means there is no universal solution to the problem. The implication here is that the best solution at current time must be finding a way to prepare

satellites to return to the atmosphere for incineration, especially as the dilemma increases with the addition of large constellations of satellites and the impacts of global warming.

MAGNIFICATION OF ISSUE

Ignorance has let the space debris problem accumulate to this point, but humans continue to make matters worse instead of looking for a solution. The current situation with orbital debris only sees a 1 in 10,000 chance for a necessary orbital maneuver by a satellite to avoid a collision, including 25 debris avoidance maneuvers by the International Space Station (ISS) since 1999 (O'Callaghan, 2021a, para. 14). However, this could very well change in the future as SpaceX and Blue Origin plan to launch large constellations composed of tens of thousands of satellites into LEO in the next few decades. The result in the crowding of Earth orbit and the necessity for more orbital maneuvers, means a greater chance for failure. Any single collision has the potential to generate a significant amount of debris, which could set off a chain reaction known commonly as Kessler Syndrome, proposed by NASA scientist Donald Kessler in 1978 (Matignon, 2019, para. 1).

The current clean up effort in place can only remove larger inactive satellites, with the millions of fragments of paint chips and metal that are undetectable from Earth still posing a lethal threat to satellites and astronauts alike. As previously discussed, efforts to move even the largest debris are still extremely expensive and time consuming, moving pressure to resolve the space debris dilemma to preventative measures placed on satellites before launch.

Large Constellations

Private companies such as SpaceX and the Amazon owned Blue Origin have begun launching satellites to create large constellations that will orbit close to the surface and be composed of tens of thousands of satellites in order to provide internet access around the globe,

even to remote locations that traditional internet providers do not cover. The SpaceX large constellation, named Starlink, is an extremely advanced system which has already benefited tens of thousands of people, most recently in Ukraine, where "the Starlink technology is being used by civilians in areas under attack that have lost Internet service, and by government officials" (Lerman & Zakrzewski, 2022, para. 12). Starlink is a perfect example of revolutionary technology being put into orbit that will benefit the planet, yet severely crowd space. If LEO continues to fill up at this rate, the next revolutionary advancement in satellite technology may not be able to reach orbit, abruptly stopping progression in the aerospace field.

SpaceX has acknowledged the issue with space debris and plans to program all satellites in Starlink to reenter the atmosphere to burn up after they become inactive, but this does not change the fact that the satellites will each orbit for five years (Subspace Team, 2022, para. 23). The atmosphere remains as the best solution to the space debris dilemma, but global warming threatens to decrease the effectiveness of this solution.

Global Warming and the Thinning of the Atmosphere

The atmosphere, like any other gaseous object, is composed of atoms that collide with any other object moving through it. Earth's atmosphere becomes thinner and thinner as altitude increases, meaning there are less and less atoms for objects to collide with. However, as an object in orbit reaches the thin outer layer of the atmosphere, collisions with these atoms slow the speed of orbit. Slower orbital speed means an object loses orbital momentum and gravity begins to take over, decreasing the altitude of orbit and thus bringing the object closer to Earth. As more atoms collide with the object in the thicker lower atmosphere, there is friction produced that generates heat, the same way the friction from rubbing your hands together feels hot. As the object falls closer to Earth and further into the thick atmosphere, this friction heat is enough to

melt and disintegrate most substances, and thus provides the best method of getting rid of debris. However, “increasing carbon dioxide levels are lowering the density of the upper atmosphere, which may diminish this effect” (O’Callaghan, 2021b, para. 3). Global warming has a direct impact on the severity of the space debris dilemma; the extent of which needs to be recognized as most companies rely on atmospheric drag to eventually bring satellites out of orbit and have them burn up on reentry. Recognition of this issue all begins with updating current NASA atmospheric models, which do not reflect the deterioration of the atmosphere. Once this issue is resolved, the hope is that government and private aerospace companies will factor this issue into their orbital calculations. However, a global effort must be made to slow the impact of global warming, not just for the sake of space debris, but for the sake of the entire planet.

RECENT EVENTS, NEAR DISASTERS, AND A WAKEUP CALL

Recent events from the end of 2021 into early 2022 have shocked the world into realizing the extent of the space debris dilemma and may help to encourage more measures to be taken. From here, emphasis on regulations and new technological advancements have the potential to maintain safety in space.

Russian Missile Test on Dead Satellite

A Russian missile test on a dead satellite in November 2021 sent hundreds of pieces of debris hurtling around the Earth, forcing all astronauts to take cover and severely increasing the population of space debris in orbit (Bugos, 2021, para. 1). Similar tests on anti-satellite weaponry have been performed by the United States and China in the past, but this test from Russia came without warning and risked the lives of all astronauts actively in space, not to mention adding to the millions of pieces of lethal debris already in orbit. Currently, the Outer Space Treaty states that “weapons of mass destruction are forbidden in orbit and beyond, and the Moon, the planets,

and other celestial bodies can only be used for peaceful purposes" (Space Foundation Editorial Team, 2022, para. 4), though this law only prevents nuclear weapons from being used in space. Although more than a tenth of all active satellites are used for espionage and anti-satellite weaponry is critical for protecting the nation, further regulations must be put into place to limit the creation of debris when disabling satellites.

Erroneous Rocket Booster Crashing into Moon and Implications

What was thought to be a SpaceX Falcon 9 rocket booster but more recently discovered to be a Chinese Long March 3 rocket booster crashed into the back side of the moon on March 4, 2022. The implications of this problem are twofold: first that deep space is being polluted with space debris, just as the problem in LEO started to be addressed, and second that if current tracking systems are not accurate enough to identify a huge booster rocket, how are all of the small particles in LEO and beyond supposed to be tracked. Additionally, SpaceX could not confirm nor deny it was their rocket because they had no reason to track its path after the payload was delivered (Chang, 2022, para. 22). Although the current focus remains on clearing debris out of the orbit closest to Earth, future technologies will most likely venture into deep space orbits where debris will be more difficult, more expensive, and more time costly to resolve. Furthermore, this accident, although non-lethal and inconsequential to the lunar surface which is already covered in craters, emphasizes the inability of tracking systems to identify even the largest of objects in deep space. The implication here is that tracking systems must develop significantly in order to address all of the issues with debris in LEO and deep space in order to aid satellites in making important orbital maneuvers to avoid collision. The location of the Falcon 9 rocket booster is still unknown.

THE IMPACT SPACE DEBRIS HAS ON THE WORLD

What affects will space debris have on mankind? There is much more reliance on satellites than can even be comprehended. Space debris "could jeopardize satellites that connect rural and underserved areas with broadband, as well as those that take images that help farmers track their crops' health. It even could endanger the International Space Station, its astronauts and research aboard that could fuel cancer treatments and the creation of organs for transplant. A too-cluttered sky could also get in astronomers' way of learning more about the cosmos. And surrounding Earth with a continually denser layer of outmoded junk means that eventually there wouldn't be room for the new, useful satellites of the future" (Masunaga, 2021, para. 2-3). Figure 2 illustrates all of the actors that directly influence the space debris dilemma, with new aerospace technology sitting directly in the middle. Current and future technology must not only aid in the effort to remove junk from orbit, but must also remove the old and outdated satellite technology for new and advanced satellites that will greatly impact the entire globe.

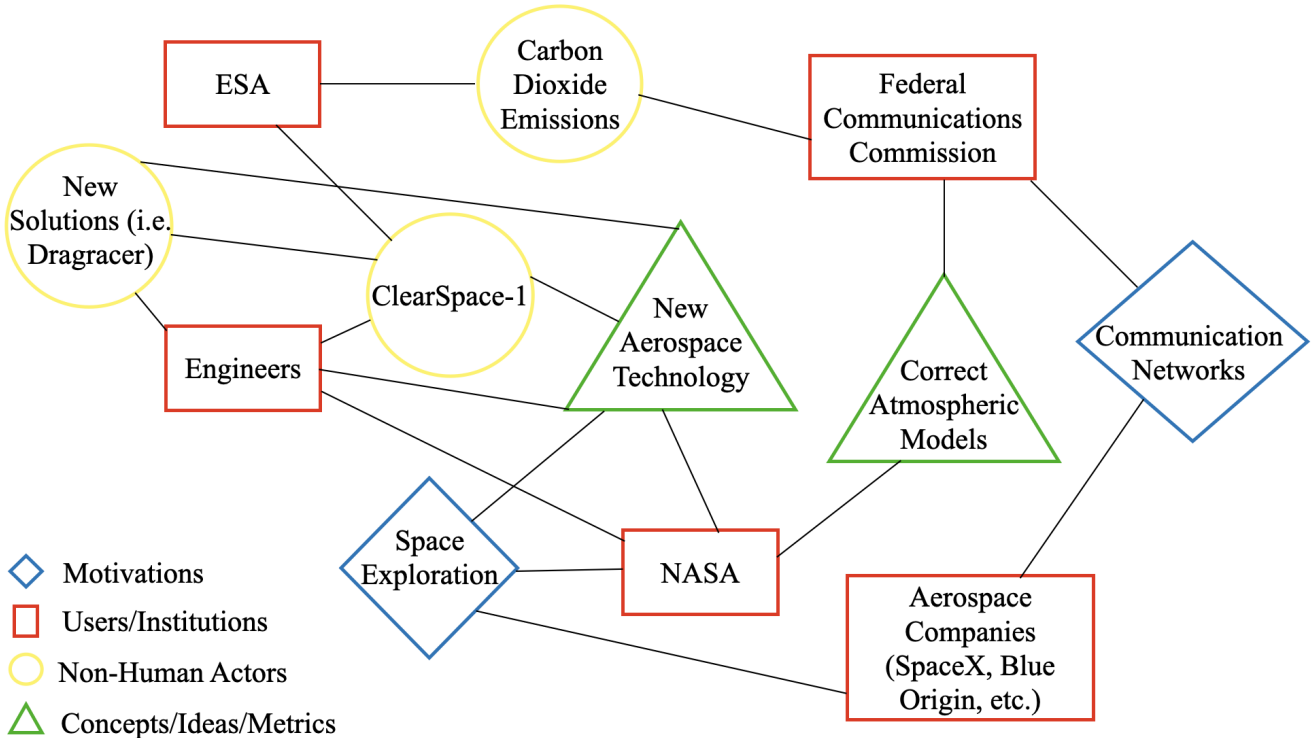

Figure 2: Actor network theory web for the space debris dilemma. Relates motivations, users/institutions, non-human actors, and concepts/ideas/metrics for the space debris dilemma. (Irving, 2021)

Thanks to new aerospace technology, projects such as ClearSpace-1 are able to spearhead a movement towards cleaning up space and inspire other companies to find new and unique ways to do the same. At the same time that new technologies such as the large constellations being installed by SpaceX and Blue Origin aid the world, they also clutter orbit, emphasizing the need to remove inactive satellites: out with the old, in with the new. Several organizations such as the European Space Agency (ESA), NASA, and the Federal Communications Commission (FCC) have the responsibility of providing valuable information that is imperative to remedying the space debris dilemma such as making an impact in slowing global warming and at the same time correcting atmospheric models as carbon dioxide emissions thin the upper atmosphere. To this point, many argue that space, especially LEO, should be considered an extension of the environment, and should be protected equally. Such debate has been seen the most in the

implementation of the large constellations of satellites ‘polluting’ space, leading many companies to ask “the FCC to conduct an environmental review before granting the license modification as part of the National Environmental Policy Act (NEPA), which currently categorically exempts satellite systems, but says this did not happen despite megaconstellations bringing new considerations for regulators” (Rainbow, 2021, para. 10). Large constellations definitely bring in new considerations for regulations in space, and many of the current regulations are extremely outdated. Just as there are rules on Earth for traffic laws and pollution of the environment, space should be treated the same. The space debris dilemma has impacted the view of space to the point where humans should consider near orbits to be part of the Earth and its environment.

The most important impact that space debris has had on the world is in helping humans to realize the reliance on satellites that goes unnoticed every day. As mentioned by Masunaga (2021), satellites provide broadband internet access to almost every corner of the globe, provide stations for cancer research, allow farmers to track crop growth which in turn provides food for billions of people, and aid astronomers in studying and understanding the known universe (para 2-3). The modern world is highly dependent on satellites, and ignoring the dangers presented to satellites by space junk could lead to incomprehensible consequences.

A DIFFICULT SOLUTION AND DISCUSSION OF WORK BEING DONE

Because space debris comes in all shapes and sizes, most of which are completely undetectable, “there simply is no “one-size-fits-all solution” to the problem of space junk... removing large rocket bodies is a significantly different task than removing the equivalent mass of a lot more smaller objects, which are in a wide range of orbits” (David, 2021, para. 12). It is extremely difficult to remove every single piece of junk from orbit, not to mention extremely

costly to launch a rocket for each trip to clear the debris. Launch costs are very lofty, something Elon Musk is attempting to remedy at SpaceX, but for now the problem remains. Despite this fact, there are a wide range of solutions actively being developed for actively and passively dealing with space debris.

Shielding Methods

Active shielding methods are currently in use on long term satellites and the International Space Station in order to reduce the impact of collisions with smaller objects, but more work must be done to protect against larger collisions. Debris tracking is capable of monitoring all objects larger than about 10 centimeters, but smaller undetectable fragments of metal and even paint chippings can create serious problems for satellites as they travel at speeds of several kilometers per second. The current shielding technique, called a Whipple shield, was originally invented by Fred Whipple in 1947 to protect against collisions with micrometeoroids. The shield works by having two main layers; after collision with the first layer, the projectile is fragmented before reaching the second layer, thus distributing the energy and momentum of the once concentrated body and preventing penetration of the second layer. However, this technology was only intended to defend against impacts with natural objects and must be improved to successfully deal with man made debris, especially as the population of such debris increases exponentially. As a result, “the development of effective shields will become a major task for future research due to the steadily increasing debris problem” (Thoma, 2003, p.212).

ClearSpace-1

ClearSpace-1 is the joint effort of the ESA and a Swiss tech company proposed back in 2013. One of the first efforts at space debris removal, the project will test the effectiveness of a

spacecraft capable of grabbing a dead satellite with a claw-like device in order to guide the satellite into the atmosphere to be burned up upon reentry, as depicted in Figure 3.

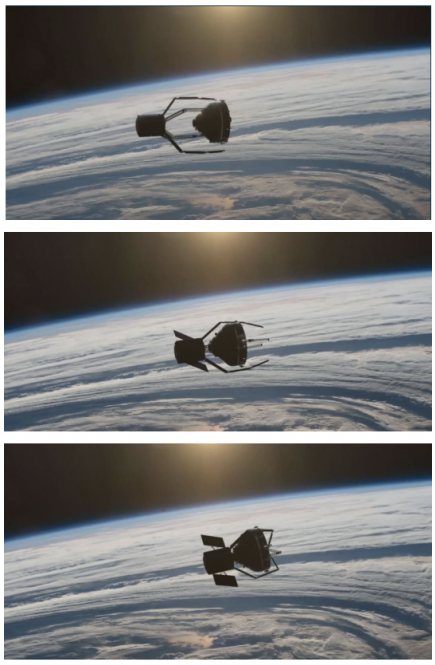

Figure 3: ClearSpace-1 operational mission frame by frame. Animated sequence of ClearSpace-1 capturing the target VEGA Secondary Payload Adapter upper stage with a claw-like device. After this maneuver the spacecraft would then thrust to decrease altitude and release the target into the atmosphere to be disintegrated. (Biesbrock et al., 2021, p. 2)

Clearspace-1 aims to remove a mere 100 kilograms of space junk by 2025 (Biesbroek et al., 2021, p. 1), but the effort is more significant than the actual amount of debris being removed. Since the creation of the ClearSpace-1 project, several other companies have followed suit with similar solutions that involve finding a way to decrease the altitude of dead satellites so that the atmosphere can do the rest. It is initiatives like ClearSpace-1 that have paved the way for greater change and further technological development to more cost efficiently and quickly remove debris from orbit.

Dragracer

Inspired by projects like ClearSpace-1, project Dragracer encompasses the creation of a device jointly made by Tethers Unlimited and Millenium Space Systems which aims to help bring down dead satellites much faster than normal. This device is called Terminator Tape, which is “a box about the size of a DVD case that contains more than 220 feet of a folded-up film with an aluminum coating” (Masunaga, 2021, para. 17). The tape interacts with the particles in the atmosphere, plasma in the ionosphere, and the Earth’s magnetic field to bring the satellite down much faster than normal. Other solutions to remove debris in this fashion involve placing thrusters on the satellites to slow the orbital velocity and thus decrease the altitude of the satellite to be burned up in the thicker region of the atmosphere, but the Dragracer design is much more cost effective.

Other Signs of Change

In the past few years, dozens of companies such as Astroscale, Turion, and Morpheus have emerged with the goal of decreasing the amount of debris in orbit through removal devices such as ClearSpace-1 or preventative devices such as Terminator Tape. The ball is rolling to resolve the space debris dilemma and a combination of recent disasters as mentioned above and new technological developments from such companies gives a glimmer of hope that humans have the ability to stabilize the issue and keep space clear enough for the installment of new satellite technologies, continued research on the ISS, and whatever the future of space exploration may hold.

HOW DOES THE SPACE DEBRIS DILEMMA END

How does the space debris dilemma end? The answer is that at this point, it does not. There is far too much debris in space for all of it to be completely removed, but the good news is

that the dilemma has not yet reached a point of no return. If effort is put into ensuring that all new satellites are set to have some method of returning to Earth to be incinerated in the atmosphere, there will be enough space to continue putting more and more advanced technology into orbit without cluttering the skies. The effort needs to be made on multiple fronts, looking not only into having a way to return dead satellites faster, but also preventing disasters such as the Russian missile test and the rocket booster crashing into the moon. Additionally, efforts must be made to reduce the impact of global warming so that the atmosphere can continue to be used as it is the best method of removing satellites and debris from orbit. Future work must continue, searching for the most efficient and cost effective method of removal as new technologies are developed and spacecraft launches become more frequent.

REFERENCES

Ault, A. (2015, February 6). Ask Smithsonian: How does a satellite stay up?. *Smithsonian Magazine*. https://www.smithsonianmag.com/smithsonian-institution/ask-smithsonian-how-does-satellite-stay-180954165/

Bella, T. (2022, January 26). A SpaceX rocket will soon crash into the moon after 'chaotic orbit' for 7 years, experts say. *The Washington Post*. https://www.washingtonpost.com/technology/2022/01/26/spacex-rocket-moon-crash-march-gray/

Biesbroek, R., Aziz, S., Wolahan, A., Cipolla, S., Richard-Noca, M., & Piguet, L. (2021). The ClearSpace-1 mission: ESA and ClearSpace team up to remove debris. *ESA Space Debris Office*. https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/320/SDC8-paper320.pdf

Bugos, S. (2021). Russian ASAT test creates massive debris. *Arms Control Association*. https://www.armscontrol.org/act/2021-12/news/russian-asat-test-creates-massive-debris

Chang, K. (2022, February 14). China, not SpaceX, may be source of rocket part crashing into moon. *The New York Times*. https://www.nytimes.com/2022/02/14/science/china-rocket-moon-spacex.html

Crowther, R. (2002). Space junk—Protecting space for future generations. *Science, 296*(5571), 1241-1242. https://www-jstor-org.proxy01.its.virginia.edu/stable/pdf/3076795.pdf?refreqid=excelsior%3Abaf5a35eb0347e5030399888ea8a7162

David, L. (2021). Space junk removal is not going smoothly. *Scientific American Space & Physics, 4*(2). https://www.scientificamerican.com/article/space-junk-removal-is-not-going-smoothly/#

Finkleman, D. (2014). The dilemma of space debris. *American Scientist, 102*(1), 26. https://www.americanscientist.org/article/the-dilemma-of-space-debris

Garcia, M. (Ed.). (2021, May 26). *Space debris and human spacecraft*. NASA. https://www.nasa.gov/mission_pages/station/news/orbital_debris.html

Irving, D. (2021). *Space Debris Actor Network Theory Web.* [Figure 6]. *Prospectus* (Unpublished undergraduate thesis). School of Engineering and Applied Science, University of Virginia. Charlottesville, VA.

Johns Hopkins University Applied Physics Laboratory. (2021). *Using Charon-light researchers capture Pluto's dark side.* http://pluto.jhuapl.edu/News-Center/News-Article.php

Lerman, R., & Zakrzewski, C. (2022, March 19). Elon Musk's Starlink is keeping Ukrainians online when traditional internet fails. *The Washington Post*. https://www.washingtonpost.com/technology/2022/03/19/elon-musk-ukraine-starlink/

Masunaga, S. (2021, June 27). A satellite's impending fiery demise shows how important it is to keep space clean. *Los Angeles Times*. https://www.latimes.com/business/story/2021-06-27/satellites-self-destruct-clean-up-space-junk

Matignon, L. (2019, March 19). The Kessler syndrome. *Space Legal Issues*. https://www.spacelegalissues.com/space-law-the-kessler-syndrome/

O'Callaghan, J. (2021a). What is space junk and why is it a problem?. *Natural History Museum*. https://www.nhm.ac.uk/discover/what-is-space-junk-and-why-is-it-a-problem.html#:~:text=Some%20space%20junk%20results%20from,blowing%20up%20their%20own%20satellites.

O'Callaghan, J. (2021b, May 25). When space junk meets climate change. *The New York Times*. D4. https://link.gale.com/apps/doc/A662816475/UHIC?u=viva_uva&sid=bookmark-UHIC&xid=c0d7687f

Rainbow, J. (2021, May 25). Viasat asks FCC to halt Starlink launches while it seeks court ruling. *SpaceNews*. https://spacenews.com/viasat-asks-fcc-to-halt-starlink-launches-while-it-seeks-court-ruling/

Sarnacki, B. G., Esposito, G., Krauss, R. H., & Chelliah, H. K. (2012). Extinction limits and associated uncertainties of nonpremixed counterflow flames of methane, ethylene, propylene and n-butane in air. *Combustion and Flame, 159*(3), 1026-1043. https://www.sciencedirect.com/science/article/pii/S0010218011002823?casa_token=LUHWXtF_UPkAAAAA:5M_0yZunPPdAkHjDJaF62C4biW2U-wz9ZcH6gDQWGgtjqtL0V_Wfsh81CDgPMbTPNg52YdjaIg

Space Foundation Editorial Team. (2022). International space law. *Space Foundation*. https://www.spacefoundation.org/space_brief/international-space-law/#:~:text=The%20Outer%20Space%20Treaty,-%E2%80%9CTreaty%20on%20Principles&text=There%20is%20no%20claim%20for,be%20used%20for%20peaceful%20purposes

Subspace Team. (2022, January 5). SpaceX is giving the internet lift with Starlink. *Subspace*. ht tps://subspace.com/resources/spacex-is-giving-the-internet-lift-with-starlink

Thoma, K., Riedel, W., Schäfer, F., & Hiermaier, S. (2003). Status and perspectives in protective design. *Space Debris, 2*(4), 201-224. https://www.proquest.com/docview/210096536? pq-origsite=gscholar&fromopenview=true

Williams, D. (2022). Sputnik 1. *NASA Space Science Data Coordinated Archive*. https://nssdc.gs fc.nasa.gov/nmc/spacecraft/display.action?id=1957-001B