The Issue of Space Debris and its Key Players

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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

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The issue of space debris is a large scale one that poses a serious threat to our global technical infrastructure and subsequently our society. There are no international laws about space debris management. We currently lose three to four satellites a year due to debris collisions, and debris has been projected to triple within 20 years (David, 2011). First, I have briefly examined how the current method of tracking debris and establishing mitigation guidelines came about. Next, I explore how the commercialization of the space industry and expansion of privatized launches right now is changing the finances and priority of the issue. Lastly, I investigate what emerging technologies are available to help us deal with the issue, who is motivated to develop them, and what their motivations are.

The problem launches

The issue of space debris did not begin with Sputnik, the first satellite launch, as both the main stage of its rocket and the satellite itself had both fallen out of orbit within months. In March of 1958, the US placed Vanguard 1 into medium Earth Orbit (MEO). It is no longer operational, yet it is expected to stay there for almost 200 more years (Hall, 2014). Just 13 years later in 1970, there were about 2,000 objects in orbit and 7,500 in 2000. (Witze, 2018) Today 25,000 objects are being tracked by U.S. Space Command (Erwin, 2020). International guidelines have been written by both the United Nations Office for Outer Space Affairs (UNOOSA) and Inter-Agency Space Debris Coordination Committee (IADC) to help mitigate debris. The ESA reports increasing compliance with these guidelines, but it is far from universal (ESA, 2020). Only about 15-30% of objects launched into non-compliant orbits from 2008-2018 featured efforts to comply with measures by exiting at the end of service (ESA, 2020). Even then, only 5-20% did so successfully. Rocket body guideline compliance has been much higher with roughly 70-75% successful compliance in 2017-2018 (ESA, 2020). Launches however are increasing much faster than compliance with mitigation measures. There were roughly 400 satellite launches a year from 2017-2019, (ESA, 2020) which is over four times the annual average from 2000-2010 (Witze, 2018). As a result, despite efforts at mitigation, space is getting more crowded. Figure 2 below, retrieved from the European Space Agency (ESA) shows the total area of objects in orbit over time. This figure demonstrates how even with guidelines to combat debris, the issue has been steadily progressing for the worse. Below I examine if any new technologies or mitigation methods are poised to change the observed trends.

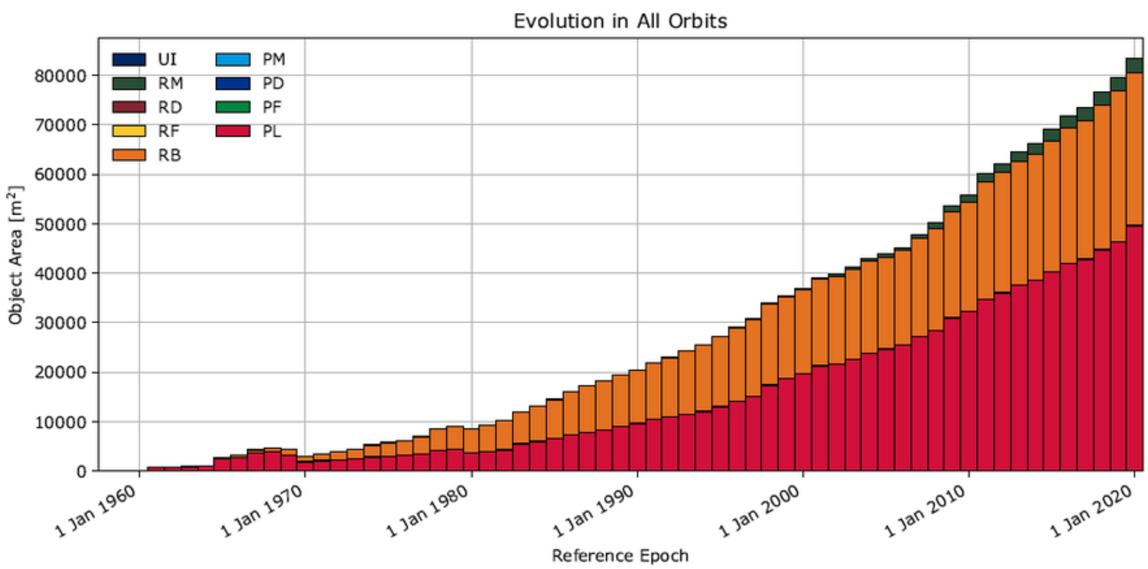

Figure 2: The total area that debris objects take up over time. "Red (PL) = Payload; Orange (RB) = Rocket Body; Dark Green (RM) = Rocket Mission Related Object."

Government Rules and Negotiations

A conference by the American National Standards Institute (ANSI) on December 7, 2020, addressed *Standardization and the Commercial Space Industry – Space Situational and Domain Awareness, Space Traffic Coordination and Management, and Orbital Debris Mitigation.* ANSI is a private non-profit interested in national and international standards-making practices. ANSI is often sought out by various government and private interests to step in and help with the process of standardization. Material from this conference sheds some light on the interplay between US government and private space agencies and their stances on orbital debris. There have been several shifts in space governance during the past several years within the US, some of which relate directly to debris mitigation while others have more indirect effects.

One recent development is the update of orbital mitigation rules for the first time in 15 years by the International Bureau Satellite Division of the Federal Communications Commission. This represents renewed effort towards the governance of space, at least at the national level. Also on the government side, Colonel Curtis L. Hernandez, Director, National Security Space Policy, National Space Council echoed sentiments from the president of ANSI that it is vital for the private and public space sectors to work together to combat orbital debris and other issues. Beyond sentiment however, the US has had trouble garnering action within the government. The president put out Space Policy Directives (SPD), of which SPD 3 targeted orbital debris. It is subsequently up to Congress to assign roles and responsibilities for the details laid out in SPD 3, but they have not yet done so. This means that while the Executive branch has laid out their desire to have more governance over space activities, including debris mitigation, Congress has not yet formalized a plan to build out a robust regulatory agency-group for that role. If Congress were to do so, it would expand the executive branch and be another agency on the budget, so while Col. Hernandez said that support was easy to find on both sides of the aisle, the support may not be passionate and strong enough to build out the proper infrastructure to enforce regulations.

On a more promising note, the FCC, modified its rules to match the US Government Orbital Debris Mitigation Standard Practices. These standard practices were drafted by NASA and the Department of Defense (DoD). Having all three agencies in agreement on a list of best practices is a big step towards standardization and enforcement. The Federal Aviation Administration (FAA) also has authority over orbital space debris. They are planning on coming out with further debris guidelines in the next year. They have been working on for over a decade, and it will be interesting to see how their guideline align with existing ones. As those who draft these documents continued to converse, Dr. Jer Chyi "J.-C." Liou, Chief Scientist for Orbital Debris from NASA warned that while large debris is easily tracked, small debris accounts for roughly 99 percent of the risk due to orbital debris a typical mission. Continuing, he warned that compliance with existing measures far outweighed the need to create new measures. This breaks from what ANSI would like to hear as experts in writing standards and it does not receive much attention before the topic is quickly shifted by the moderators. Dr. Liou is a scientific authority on this topic. His statement that compliance with existing measures is poor and increasing it is vital can be found as a theme throughout scientific literature on the orbital debris. In 'Orbital Debris Threat for Space Sustainability and Way Forward" Abid Murtaza (2020) echoes Dr. Liou's sentiment. Both researchers then immediately go on to say that in the future a complete halt in launches could not even halt the issue and Active Debris Removal (ADR) will eventually be necessary.

Influenced by Dr. Liou and other scientific literature, SPD 3 states that the US should pursue Active Debris Removal (ADR) as part of their long-term solution in conjunction with mitigation. Continuing his talk at the ANSI conference, Dr. Liou did say that the priority was mitigation for now as the cost of ADR is still high and there is a hope that with time and research more low-cost methods can be developed. Murtaza (2020) discusses the challenges in his writing as well and states that no successful demonstration of this technology has taken place yet, but referenced the RemoveDEBRIS mission as ongoing. This mission has since ended and successfully performed two of the three attempted ADR methods on simulated targets.

At the international level, guidelines have been written by both the United Nations Office for Outer Space Affairs (UNOOSA) and Inter-Agency Space Debris Coordination Committee (IADC). These are only guidelines though as many international laws are. Space agencies, militaries, and private industry are complying with them at an increasing rate, but there is no consequence if they choose not to. The IADC meets semi-regularly in conferences featuring experts from several different space agencies around the globe to reevaluate the position of the issue. In 2002 they drafted a set of best practices during one of their conferences. The UN largely drew its 2007 guidelines from that 2002 document with minor updates and modifications. The guidelines set forth by these two groups were also later used to create a set of standards by the International Standards Organization (ISO) in 2010. Each of these is a good reference for best practices and what we are striving for as a community, but none of them feature any enforcement.

Expanding the need for interventions and new stakeholders: private interests and new international programs

As mentioned before, the number of objects launched into space has been rapidly increasing largely driven by the explosion of the commercial space industry. Figure 3 below demonstrates just how much of the increase orbital objects per year is due to the private industry. Showing the number of new objects each year from roughly 1955 to 2020.

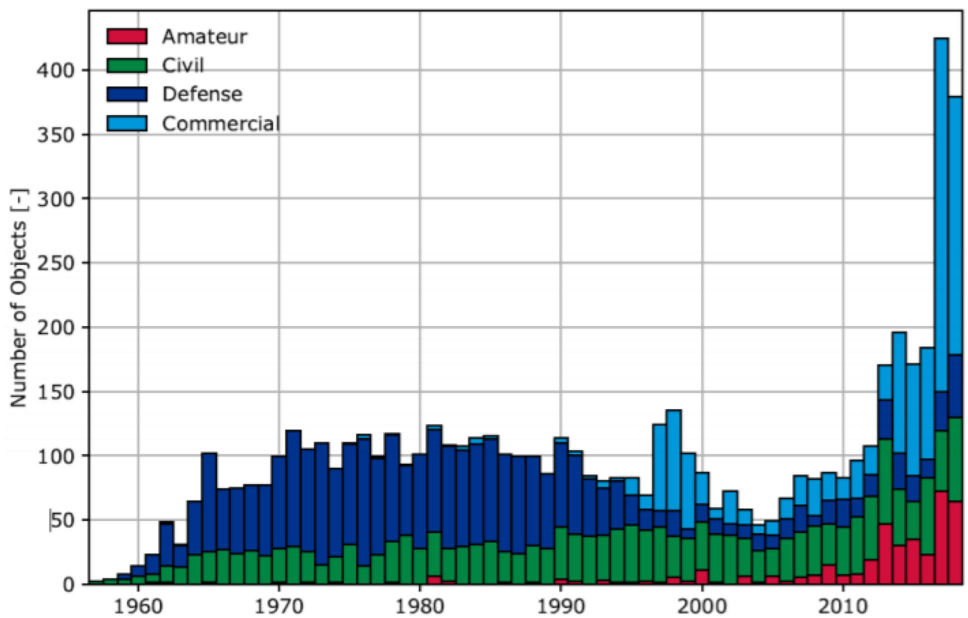

Figure 3: The number of objects launched into LEO each year divided by sector.

As pointed out by Murtaza (2020), this trend shows no promise of reversing as companies such as OneWeb, SpaceX, Boeing, and Telesat are planning to launch over 15,000 objects into orbit for internet coverage not long from now. These companies rely on their ability to launch into space for profit so they would have no interest in instituting any kind of maximum on the number of launches or objects allowed. They have each released plans to deorbit their satellites, but if they do not make good on their public promises or their methods fail it could be a catastrophe. Even if their plans are successful, space is set to become far more crowded and we could be moving closer to unavoidable collisions and a chain reaction. This means that need for compliance with mitigation measures is at an all-time high. Compliance is still optional however and enforcing it is getting increasingly more difficult for several reasons. For one, even if one country set up mitigation enforcement there would be several others where the government agencies continued to do as they pleased. In the private industry, companies could travel to other countries fr launches or move their facilities to avoid regulations that hampered them. Effective debris mitigation guidelines would have to be universal.

Not only is the number of private companies with space-launch capabilities increasing but the number of countries has as well. Figure 4 below demonstrates the number of countries that had satellite capability in 1966 versus 2016 and that number of countries can be anticipated to grow still after 2016. Therefore, while Murtaza (2020) states that compliance to the guidelines set forth by the UN must be binding, it could be difficult to get developing and emerging countries on board as with many sustainability issues. Debris mitigation requires extra capabilities within satellite missions that cost money. Developing countries do not have as much money as the first world and therefore may feel that they are excused from such practices. This may be especially true because it is the decades-long irresponsible spacefaring of the first world and not the developing world that has made our current situation hazardous.

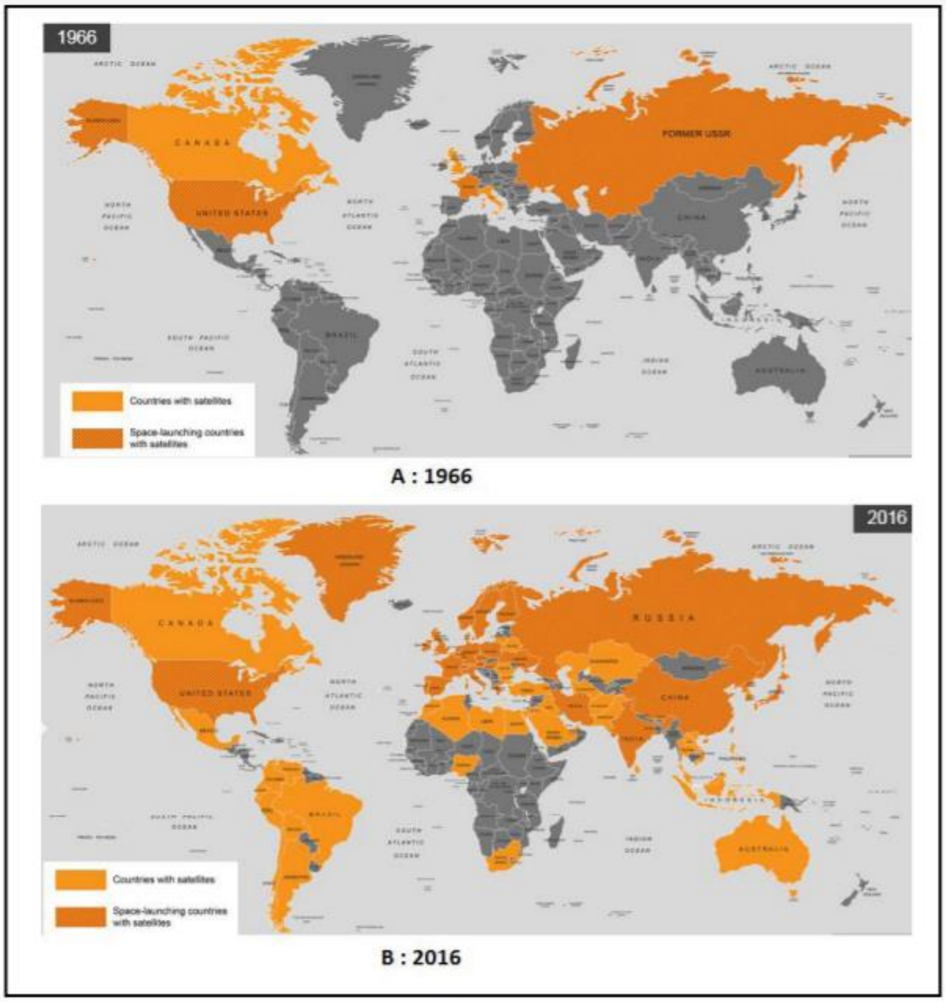

Figure 4: The number of countries with satellites in orbit shown in orange, countries with the ability to launch their own satellites being the darker of the two shades. The top map is in the year 1966 and the bottom map is 50 years later in 2016.

The first world and emerging markets such as the US, India, China, and Russia may remain wary of some mitigation guidelines as well. All of these countries have at times conducted Anti-Satellite Weapons (ASAT) Tests. These are terrible for the space environment as they intentionally destroy an intact satellite, fragmenting it into a much more dangerous field of smaller debris. As stated by Dr. Liou, smaller debris accounts for approximately 99 percent of typical mission risk due to debris. These countries however seem to each value the strategic knowledge they garner from their tests as more important than the environmental concerns they raise.

Interestingly, besides accounting for most future launches, the private industry is where the most practical and concerted efforts for ADR are taking place, even if they are receiving funding from governmental space agencies in some cases. The Astroscale U.S. Inc. Vice President of Global Space Policy Charit Weeden attended the aforementioned ANSI conference. Astroscale is one of multiple smaller aerospace companies that have seen the orbital debris problem as an opportunity to profit financially. Astroscale offers potential ADR solutions and what they call End of Life (EOL) services for other companies and government agencies. This makes it clear why Weeden stressed "action" several times while he spoke. His company stands to gain financially at the prospect of ADR becoming more mainstream and utilized. Another small company that stands to profit from ADR is ClearSpace who has been able to garner funding from the ESA. Clearspace has a conceptual design for a satellite that remains in orbit and continuously eliminates debris. They are planning on operating their first model by 2025.

Differing Academic Perspectives

Andrew M. Bradley (2009) explores the risks to our satellite infrastructure over the next several decades with several different levels of compliance to debris mitigation guidelines. It argues that if the guidelines put in place by IADC and UNOOSA can be met within a few decades and anti-satellite (ASAT) weapon tests are kept to a minimum then risk will be tolerable (Bradley, 2009). Anti-satellite weapons testing is a key component of the issue because in these weapon tests satellites are destroyed. This leads to several fragments, which contribute to the problem much more seriously than an intact satellite. Unfortunately, these tests have taken place as recently as an instance by Russia on July 15, 2020. These actions were denounced, but similarly to other debris-mitigation guidelines, there are no formal consequences to violations.

This would suggest that efforts should be focused on forcing compliance with guidelines and tracking debris as it arises. Several other articles are about potential methods of actively removing space debris, contrary to the framework put forward by Bradley. In fact, the European Space Agency states that active debris removal is “necessary”. A second peer-reviewed article “Active debris removal: Recent progress and current trends” describes the state of several of the most promising technologies to not just observe, but to actively remove debris at the time of publishing in 2013. The authors’ closing recommendation is to carry out active debris removal in one instance and use it as a test case to evaluate the financial viability of active removal overall (Bonnal, 2013).

Besides ADR, Murtaza (2020) suggests a couple of potential future approaches that could help minimize the debris issue in the future. His first suggestion is to utilize satellites for multiple missions. Most satellites are made and operated for a single purpose before they become derelict. He offers a range of specific suggestions that mostly center on heavily utilizing every satellite we put into LEO. He makes these suggestions for two main reasons. For one, LEO is the most congested and concerning section of our satellite regions. The second reason is that if we do take on the challenge of proposed satellite constellations in LEO, then performance is far superior for most tasks than when done by satellites in Geostationary orbit (GEO). This means that a satellite that performs multiple tasks in LEO is likely to be highly effective at each compared to most modern satellites. This is because satellites in GEO tend to perform most of our everyday tasks right now. The superior performance of LEO satellites simply relates to proximity. Because a satellite in LEO is so much closer to the surface, it can receive and return signals to the ground faster. It also benefits from higher resolution on cameras and spatial sensors because of its smaller distance from its subject. This means that other tasks like GPS performance are greatly enhanced as well. He goes on to say that GEO and Medium Earth Orbit (MEO) missions are likely to have the potential for dual to multipurpose utilization as well. He even points out that when a mission has multiple end goals, it theoretically becomes more financially viable as it can be sponsored for more than one purpose.

His second suggestion is more technical and complicated, but suggests, sharing information between satellites in orbit rather than relying on having multiple satellites for uplink and coverage purposes. He calls this system a Space Information Network (SIN). One specific example of the benefits this kind of system could yield is that an LEO satellite cannot transmit data to a single ground station for several minutes at a time because the station becomes out of range of the satellite due to obstruction from the horizon. If a GEO satellite is in place though that is part of the same network, then an LEO satellite can transmit data to the GEO satellite, which in turn, has continuous contact with a ground station. This would make our satellite system more optimized and eliminate some of the need for constellations and redundant satellite missions. Unfortunately, this scenario strikes me as unrealistic and overly academic because of the level of cooperation it would require among so many different countries and companies.

Are there any ongoing actions that show real promise?

There are several potential and tangible ADR projects that have materialized in recent years. JAXA (Japanese Aerospace Exploration Agency) has been working with the Japanese company Astroscale on a plan demonstrating Astroscale's ADR capability by removing a Japanese rocket-body. The mission is called Commercial Removal of Debris Demonstration project (CRD2). In England, the University of Surrey conceptualized a project to test ADR methods called RemoveDebris. They then fundraised their budget from companies and science foundations, the largest company of which was Airbus. They deployed two of their three test methods successfully as mentioned earlier in the article. While it is promising that the project gained enough financial traction to happen and operated mostly successfully, the academic world is not likely to remove enough debris to make a difference on its own. Thankfully, in addition to the promising cooperation between Astroscale and JAXA in Japan, the startup ClearSpace was recently commissioned by the ESA for an ADR mission. The mission, titled ClearSpace-1, is planned for 2025 and will be the first mission to truly remove something from orbit. During the ANSI conference, it was mentioned by multiple people that America must help lead the way on the issue of space debris. For America to do this they need to begin their own work soon. ADR sponsorship from the government is referenced in SPD 3, but like many other things laid out in the directive, it has yet to come to fruition.

Discussion: What have we learned about the evolving problem, of those who are involved what are they demanding/suggesting, and what have we learned from active removal tests and anti-debris proposals.

Overall, it seems like the objects in orbit are bound to increase with the growing commercialization of space. The private industry has been driving a recent explosion in the number of launches per year and with multiple plans for mega constellations and a continuing potential for profit, there is no reason to expect this to slow down. National governments and the UN have several guidelines for launch mitigation in place but no one has severe enough penalties to make compliance more than a suggestion. Therefore, overall compliance lingers around 60 percent. If there were to be another conference on these issues to reevaluate the current guidelines to include enforcement then more countries would have to be involved. This can be simply seen in Figure 4, where far more countries have space launch capabilities than 50 years ago. The trend of satellite launch and use becoming more important and affordable means even more countries will become stakeholders than those shown in Figure 4 in just a short time as well. Strengthening guidelines has been painted as vital by the scientific community and meets little outright resistance in the government, but it has trouble garnering significant funds and attention at least in the US. Overall, the push for guidelines to carry consequences could start to gain traction within the US, the EU, and Japan soon, but international consequences are still several years away at best.

Active Debris Removal on the other hand is coming into form as its own field within the spaceflight community. Ironically, the huge boom in private spaceflight launches that has reinvigorated the attention around this issue could also be where part of the solution lies. Japanese startup Astroscale is in the early stages of offering debris removal solutions, with a JAXA sponsored mission already targeting a Japanese rocket-body. RemoveDebris, the most noteworthy test of any kind, using simulated targets, came out of the academic world and happened just last year. ClearSpace, a Swiss startup has been commissioned to remove an object from orbit by the ESA as well. They plan to launch a satellite that can remain in orbit and continually deorbit objects. This is all promising and shows ADR moving from an academic theory and subject of research to a practical technology in use. Academics have said that it is an important part of the solution to stop a chain reaction catastrophe. Murtaza (2020) argues that by prioritizing large objects we can prevent fewer large bodies from breaking up and leaving a lot of small debris. This means that ADR is beginning to take on its required role through government and private industry support. Guidelines have been published by governments and the UN. Compliance with guidelines is therefore what needs to be prioritized moving forward. The scientific and academic community must continue to press the severity of the issue so that governments begin to add consequences to the guidelines with the UN hopefully following. By pressing the severity of the issue, the scientific community will also hopefully prompt more responsible for everyone since everyone with a satellite in orbit has a stake in avoiding a catastrophe.

References:

5 Top Space Debris Retrieval & Monitoring Solutions. (2020, November 20). StartUs Insights. https://www.startus-insights.com/innovators-guide/5-top-debris-retrieval-monitoring-solutions-impacting-the-space-industry/

ANSI_Commercial_Space_Industry_Meeting_Report_120720.pdf. (n.d.). Retrieved April 8, 2021, from https://share.ansi.org/Shared%20Documents/Standards%20Activities/Commercial%20Space%20Industry/December%207%2C%202020%20ANSI%20Informational%20Meeting%20-%20Standardization%20and%20the%20Commercial%20Space%20Industry/ANSI_Commercial_Space_Industry_Meeting_Report_120720.pdf

Bonnal, C., Ruault, J.-M., & Desjean, M.-C. (2013). Active debris removal: Recent progress and current trends. *Acta Astronautica*, *85*, 51–60. https://doi.org/10.1016/j.actaastro.2012.11.009

Bradley, A. M., & Wein, L. M. (2009). Space debris: Assessing risk and responsibility. *Advances in Space Research*, *43*(9), 1372–1390. https://doi.org/10.1016/j.asr.2009.02.006

David, L. (n.d.). *Ugly Truth of Space Junk: Orbital Debris Problem to Triple by 2030*. Space.Com. Retrieved November 4, 2020, from https://www.space.com/11607-space-junk-rising-orbital-debris-levels-2030.html

Erwin, S. (n.d.). *U.S. Space Command announces improvements in space debris tracking—SpaceNews*. Retrieved November 5, 2020, from https://spacenews.com/u-s-space-command-announces-improvements-in-space-debris-tracking/

ESA commissions world's first space debris removal. (n.d.). Retrieved December 6, 2020, from https://www.esa.int/Safety_Security/Clean_Space/ESA_commissions_world_s_first_space_debris_removal

Hall, L. (n.d.). *The History of Space Debris*. 13.

Keeter, B. (2018, December 5). *Space Debris* [Text]. NASA. http://www.nasa.gov/centers/hq/library/find/bibliographies/space_debris

Mark, C. P., & Kamath, S. (2019). Review of Active Space Debris Removal Methods. *Space Policy*, *47*, 194–206. https://doi.org/10.1016/j.spacepol.2018.12.005

Murtaza, A., Pirzada, S. J. H., Xu, T., & Jianwei, L. (2020). Orbital Debris Threat for Space Sustainability and Way Forward (Review Article). *IEEE Access*, *8*, 61000–61019. https://doi.org/10.1109/ACCESS.2020.2979505

RemoveDebris—Satellite Missions—EoPortal Directory. (n.d.). Retrieved December 6, 2020, from https://directory.eoportal.org/web/eoportal/satellite-missions/r/removedebris#references

The current state of space debris. (n.d.). Retrieved October 19, 2020, from https://www.esa.int/Safety_Security/Space_Debris/The_current_state_of_space_debris

The Quest to Conquer Earth's Space Junk Problem—Scientific American. (n.d.). Retrieved October 19, 2020, from https://www.scientificamerican.com/article/the-quest-to-conquer-earths-space-junk-problem/

Welna, D. (n.d.). *U.S. Space Force Accuses Russia Of In-Orbit Testing Of Anti-Satellite Weapon*. NPR.Org. Retrieved December 6, 2020, from https://www.npr.org/2020/07/23/894905696/u-s-space-force-accuses-russia-of-in-orbit-testing-of-anti-satellite-weapon