Explore the impact on Sustainability by Space Companies

Aditya Drolia
Cambridge International AS & A Level
Inventure Academy
Bangalore, India
itsadityadrolia@gmail.com

Dr. Shekar Babu PhD
Professor & Founding Head
Amrita Vishwa Vidyapeetham University
Bangalore, India
sb@amrita.edu

Abstract

In current times of Space Boom, many companies and space agencies are working towards the development of space for common man. With the affordable space development and with the regulations still in its infancy there are a lot of opportunities towards disposal, debris and usage of sustainable materials. In this research, the authors are exploring a study towards sustainable materials used in space exploration. In addition, the authors are also exploring the various solutions and processes that are available in using them across space initiatives. The authors also explored the various systems in addition to the solutions that are used to address the materials and debris in space. The authors use the qualitative exploratory method to collect the data and explore the study.

Keywords
Sustainability, Space, Active Debris Removal System, Kessler Syndrome. Reusable Rockets

1. Introduction
This is the era of Space boom, and everyone wants a piece of it. With new space start-ups joining the industry there has been a significant rise in satellites, rockets, and other crew or payload vehicles being launched to orbit and beyond. This has helped progress towards development as a space-faring civilization. Flood monitoring, earthquake monitoring, and national security are just a few positives, the new start-ups have helped make space accessible to the common man. Even students are able to send experiments to space at an affordable price point. We are truly entering the era of "Space is for everyone".

When there were fewer cars, and when we didn't have a lot of regulation regarding their disposal, similar situation is happening for our orbits, when a break down happens we don't have anything for repair services. But now that "space is for everyone" we need to plan our space disposal in addition to the break down and repair services. Access to space is a necessity and by leaving our debris we are essentially blocking our access point into space.

Due to multiple encounters in the last few years, awareness has been raised and developments are being made by the space industry. They have started to show proposed solutions to solve these issues. However, the question remains, are these solutions making space activities more sustainable or are they just solving the current issue, and even in that case are these sustainable solutions effective? Are some of these sustainable actions actually doing good or more harm by increasing the launch frequency?

In this research paper, the authors analyze some of the best proposed and active solutions. The paper explored the side-effects or unwanted by-products of these solutions and how some of these by-products might undermine the primary purpose of the solution.

1.1 Objectives
The primary aim of this research paper is to analyze the sustainable products and solutions in the area of space and their effects/impacts on long term sustainability.

2. Literature Review
2.1 Space Sustainability Rating System (SSR)
The Space boom poses a new man-made snag, when the systems have to be retired or when do they fail or break. What happens to them? Do these space systems stay there and orbit? Do they re-enter the atmosphere and incinerate themselves? Do they crash into the ocean and if so how do we salvage and dispose them?

Many systems have been programmed to launch further into outer space into sections called "graveyard or disposal orbits," some others re-enter the atmosphere in a way that they are incinerated there during re-entry. Others just float around in the atmosphere.

While disposal orbits and incinerating haven't raised the alarms yet. Letting space junk float around has been a very alarming situation that the space community is working actively to solve. The rationale behind this is that calculations have shown millions of pieces of space junk that orbits our planet travels at tens of thousands of miles an hour and at that velocity, any form of collision with another active satellite or spacecraft could mean instantaneous destruction.

The calling off of a Nasa Spacewalk in November, 2021 citing risks posed by space debris amplified these concerns.

But even before the Nasa Spacewalk, the Space Industry realizing this was a real and worsening condition, started to develop the Space Sustainability Rating (SSR) in 2019. Launched by the World Economic Forum, The European Space Agency, an American Team lead by Assistant Professor Danielle Wood, and Minoo Rathnasabapathy of MIT's Media Space Enabled Group, along with Moriba Jah at The University of Texas Austin and Simon Potter of BryceTech were selected to design the SSR.

The SSR which is expected to go live early 2022 has been designed to score the sustainability of Space Systems, Vehicles, Satellites, and other man-made orbiting bodies manufacturers, and operators. Some of the factors that influence this rating include but are not limited to plans on de-orbiting systems at end of life cycle, orbital altitude, collision-avoidance measures, size, number of objects left in space from the particular launch vehicle.

Already the SSR has major Aerospace companies and organizations such as Lockheed Martin, Airbus, Boeing, Voyager Space, Bryce, European Space Agency, MIT Media Lab, Plant labs, and UT Austin as its partners.

2.2 Reusable rockets and the environmental impacts of Spaceflight
The 3 R's have been ingrained into the brains of every elementary school child, recycling has become a trend, reusable bags have become the new normal. Everyone wants to know about the carbon footprint of their food and move to veganism. Much research has been done on the environmental impact of cars, planes, trains, buses, etc. But not much attention is being given to the environmental impacts of orbital launch vehicles. Unlike traditional orbital launch vehicles, all the vehicles mentioned above can be reused again and again.

A traditional orbit launch vehicle refers to all makes and versions of a rocket before the reusable rocket.

The environmental impact of a rocket can be massive. It could be in the form of pollution to earth's atmosphere, soil or even as space debris to our planets lower earth orbit. The common understanding seems to be that reusable rockets solve the issue of launch vehicles creating space debris. But often it is overlooked that due to lower costs, reusable rockets would increase launch frequency. Another commonly overlooked fact is that even reusable rockets like the SpaceX Falcon 9 and Falcon Heavy are only partially reusable. They recover their first stage for reuse but much like traditional orbit launch vehicles discard their second stage after payload deployment.

The environmental effects common to both types of rockets include but are not limited to:

- Noise pollution

- Visual and Thermal Radiation
- Chemical and toxin emission (byproducts, fuel spills to name a few)
- Debris

These types of pollution have increased ever since reusable rockets have been commercialized. More frequent launches owing to lower costs and greater accessibility have increased the overall contribution of spaceflight to pollution.

With reusable rockets, it would have been expected that the Debris environmental effect would decrease. But the fact that they discard their second stage coupled with more frequent launches actually could lead to a worsening of the debris issue. There might be more second stages in orbit that there would have been entire single-use rockets due to launch becoming more economical. To solve this issue companies like SpaceX intentionally destroy the stage but sometimes leave it lingering in orbit. One of the alarming concerns was, when a SpaceX rocket debris fell in a farm in Central Washington after a fiery display that could even be seen from some part in Canada.

A form of unnoticed pollution except in the launchpad is acoustic pollution, which was mentioned in the list above. The propellant of a rocket is combusted to accelerate at a speeds greater than that of sound, and when it reaches speeds multiple times the speed of sound. It could create acoustic shock waves. Research shows that the Falcon 9 Rocket has triggered concentric traveling ionospheric disturbances. Due to the acoustic shock waves the rocket produces. These disturbances can travel extremely fast and up to heights of a thousand kilometers. There is nothing conclusive about the impact of these ionospheric disturbances yet as they are a recent discovery. But it was caused by a reusable rocket, while there is no correlation between the two as something like this could also be caused by a regular single-use rocket. If this does become a common occurrence with Falcon 9, and has an environmental impact. This must be accounted for as the Falcon 9 has launches frequently.

(Note Concentric traveling ionosphere analysis & Falcon 9, Falcon Heavy comparison adapted from Torres A, Reusable Rockets and the Environment, escholarship.org/uc/item/1v52510j *UC Merced Undergraduate Research Journal*, Vol 12 no 2, 2020)

While there is nothing conclusive about the effect on the atmosphere rocket pollution has. Research does quantify the terrestrial impact. These effects were detailed when observing crash sites. Many of the rocket stages discarded over land leak Carcinogens like UDMH which pose a serious environmental risk. Issues like these could decrease or increase based on what reusable rocket manufacturers use. UDMH is a popular propellent and while not used in reusable rockets. It soon might make its way into them as it is very reliable.

The biggest issue with reusable rockets and environmental impacts is that to reduce said impact companies will try to make more of their rocket reusable, another stage or even the entire thing. But this in turn will reduce costs and increase launch frequency. Which would then drive up the effect rocket launches have on the environment and the again companies rush to make it more reusable to compensate for the extra impact over and over again. It results in a never-ending cycle that can only end for the worse.

A case study was conducted comparing the Falcon 9 and Falcon Heavy through a sustainability assessment which evaluated the environmental, economic and societal impact of these two rockets and for the environmental portion. The Falcon 9 was taken as the baseline. The study showed that the Falcon Heavy reduced global warming potential by 64% but the cost also dropped down by 65% so the 64% drop could be offset by more frequent launches. But what is a relief is that this 64% drop actually came from the production of the vehicle and not launch.

The reason why this is relevant is that the Falcon Heavy can carry more payload and yet have a smaller environmental impact when compared to the Falcon 9. This shows that there is a probability that launch frequency may not increase to the degree we expect it to, because advancements like these will allow us to carry more per launch whilst keeping the launch impact the same and reducing production impact.

2.21 Kessler Syndrome

Proposed initially in 1978 by Nasa Scientist Donald J Kessler. Kessler Syndrome is a phenomenon due to which more in-junk orbit is created from existing space debris/junk

Satellite collisions produce a large number of orbiting fragments. Which in turn increases the number of junk pieces floating around. This increases the probability of a further collision. While most junk can be detected. This can be caused even by small undetectable pieces of junk, which is generally under ten centimeters in size. The number of these objects is an estimate. Making it harder to predict when the start of Kessler Syndrome might be.
Ever since the dawn of the space age in 1958. Humans have collectively launched about 12,170 satellites. Out of which 7,630 are still in orbit. Out of 7,630 only about 4,700 are still operational. So about 2930 defunct spacecraft travel at high velocities in our orbit. Out of any man's control, and this number does not include other big, dangerous pieces of debris like upper stage rocket bodies.

At about the same altitude as the International Space Station, orbital velocities of 27,500 kph or 17,100 mph can be seen. At this speed, the smallest shard can critically damage any spacecraft. This is what the Kessler Syndrome warns of, and how this could potentially hinder humanities space ambitions down the road.

With companies like SpaceX and Amazon launching their own internet satellite network potentially with tens of thousands of spacecrafts/satellites its not hard to see the problem. Many in the Industry have recommended anything flying at or above ISS altitude should be equipped with propulsion systems to maneuver away from possible collisions.

2.3 Active Debris Removal (ADR) System

The issue of orbit debris can be confronted through three different approaches:

1. Mitigation (limiting the creation of more space junk from Kessler Syndrome)
2. Remediation (removing debris from orbit)
3. Space situational awareness (prevent operational satellite collision).

Unfortunately, the practical efforts on these three fronts so far have been insufficient.

Orbital Debris are an obstacle to space exploration and development, and the Kessler syndrome only makes matters worse as time goes on. An effective measure to combat the debris and Kessler issue would be through an Active Debris Removal System or ADS system.

Sources of debris:

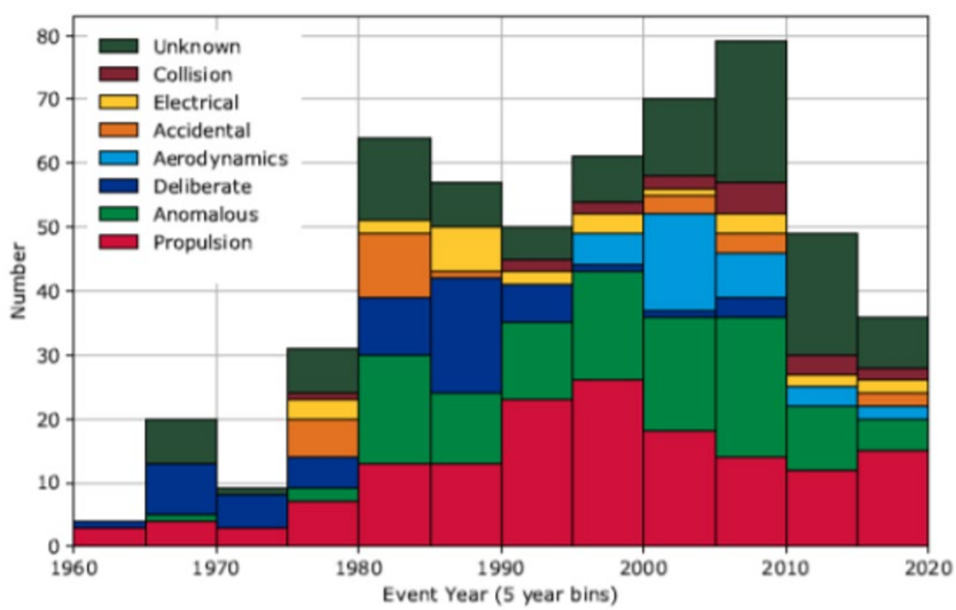

Figure 1. The historical trend of fragmentation events per event cause

Figure 1 above shows the various contributing factors to debris, the origin of the debris and their proportions over the years in 5 year intervals. The numbers indicate fragmentation incidents caused.

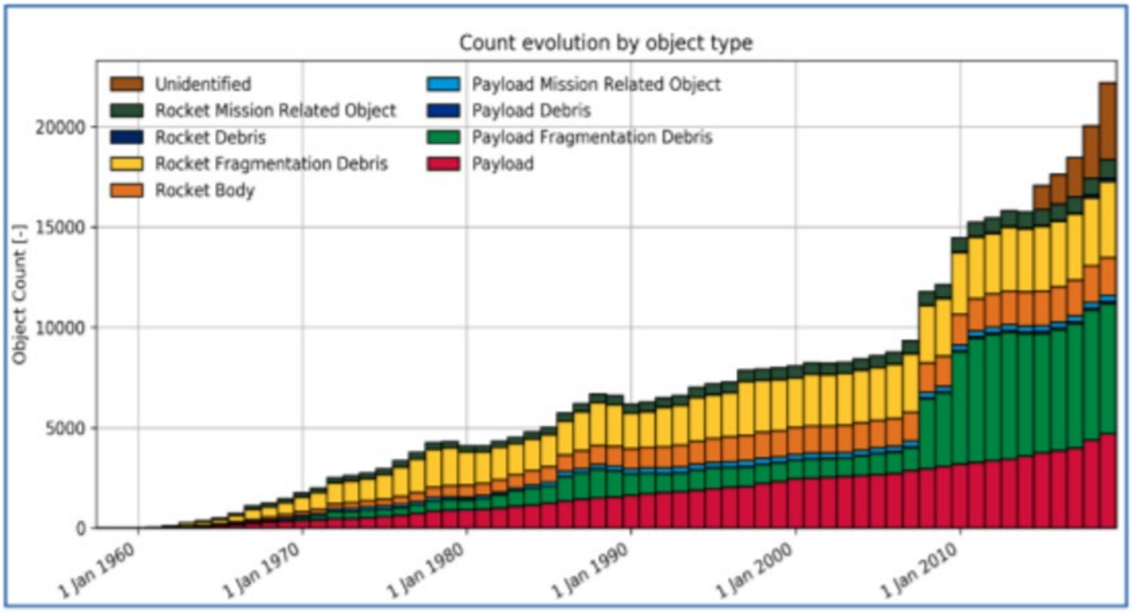

Figure 2. Orbital evolution by object type

Figure 2 above shows the various contributing factors to debris, the origin of the debris and their proportions over the years with datasets shown per year. The number indicates the number of objects or debris fragments as opposed to instances of fragmentations in figure 1.

(Note Figure-1 and Figure-2 reprinted from Murtaza A et al. "Orbital Debris Threat for Space Sustainability and Way Forward," in *IEEE Access*, vol. 8, pp. 61000-61019, 2020)

Human-made satellites are typically in one of the 3 popular orbit regimes

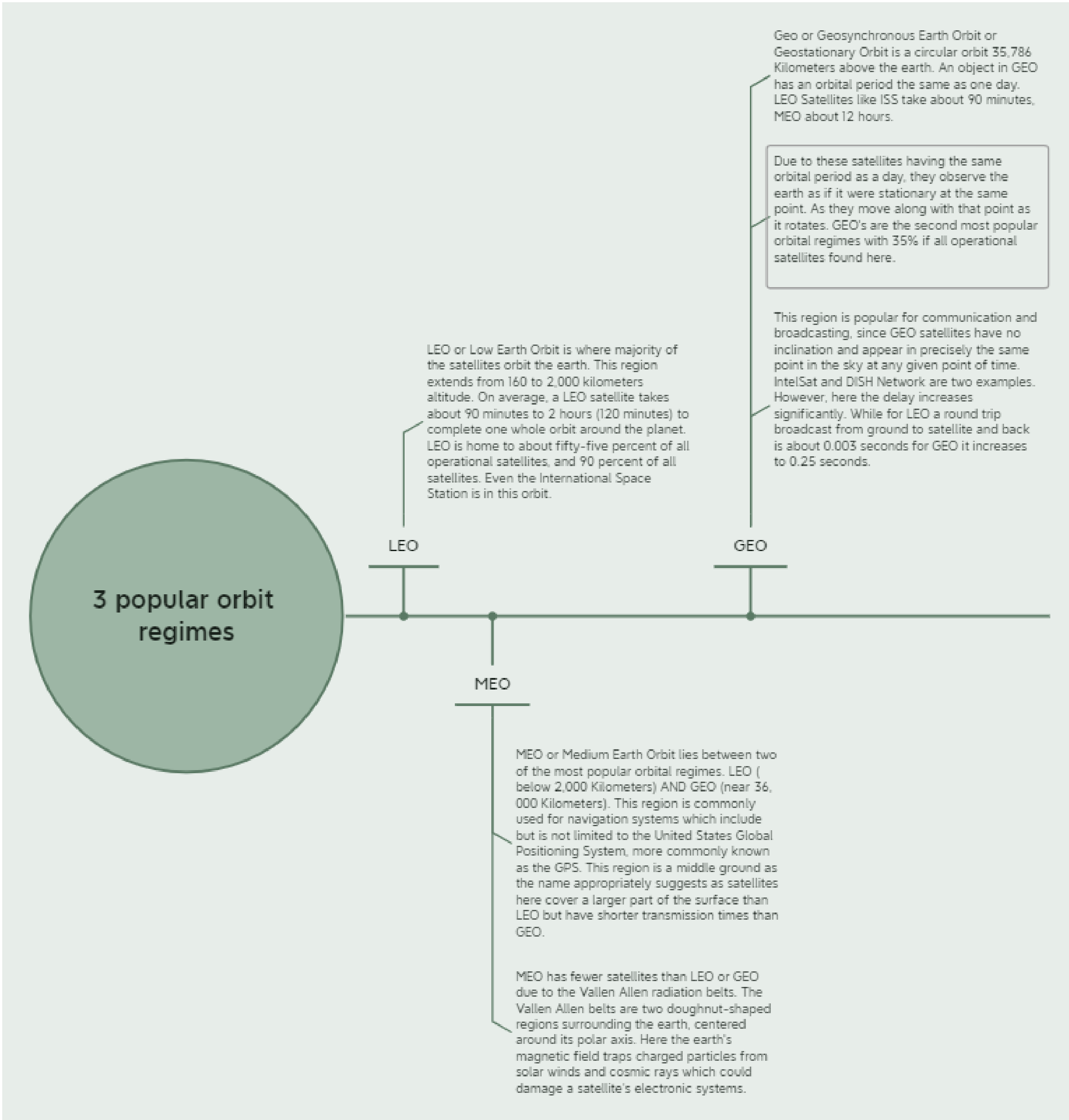

Figure 3. Earth's orbit regimes

While there are several more orbits, the issue with debris is mainly seen in one of the above three and therefore the Active Debris System and other measures are primarily focused on these regions. Modeling studies of the Debris population in LEO recently suggest that the present environment is already at a level of instability which points to the common mitigation measures adopted by the international space community being insufficient to stop future population growth.

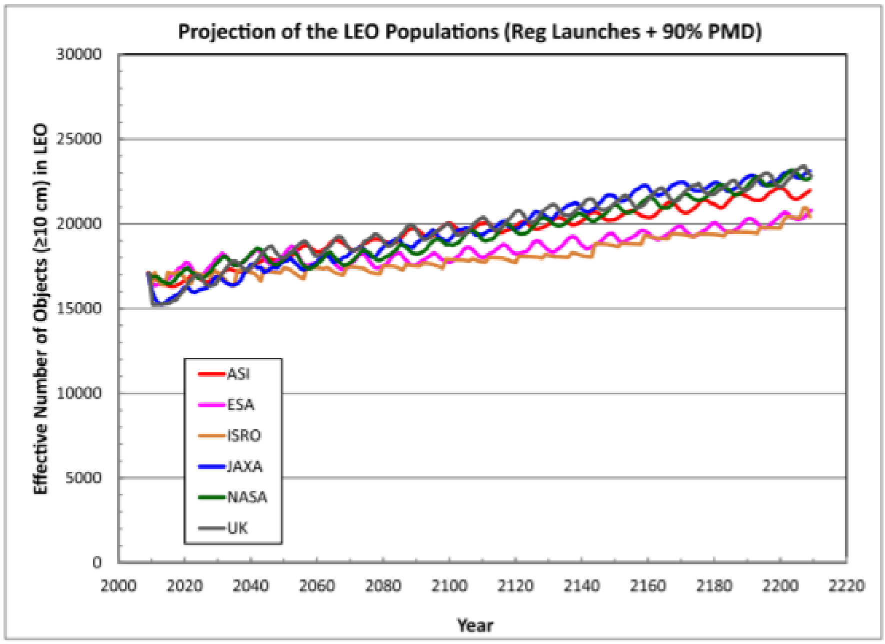

Figure 4. Projections of Leo Populations

(Note Figure-4 reprinted from Murtaza A et al. "Orbital Debris Threat for Space Sustainability and Way Forward," in *IEEE Access*, vol. 8, pp. 61000-61019, 2020)

Figure-4 above shows projections of orbital debris assuming there are no explosions in the future and that there is a 90% compliance of the common mitigation measures.

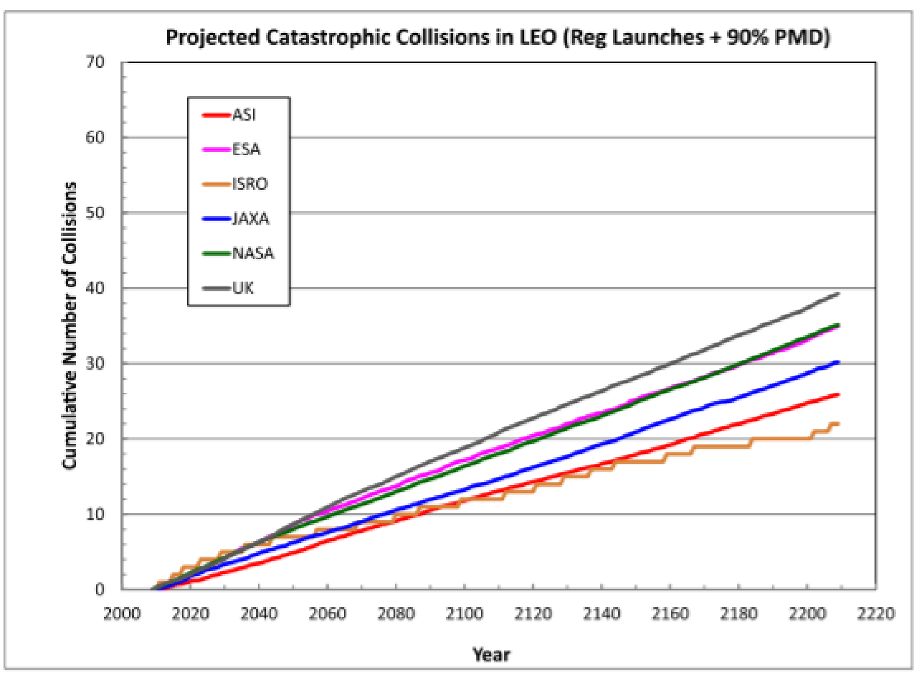

Figure 5. Catastrophic Collisions in Leo

(Note Figure-5 reprinted from Murtaza A et al. "Orbital Debris Threat for Space Sustainability and Way Forward," in *IEEE Access*, vol. 8, pp. 61000-61019, 2020)

Figure-5 above projects the cumulative number of catastrophic collisions within a 200-year period, collisions like the Iridium 22-Cosmos 2251 one in 2009 which lead to a complete fragmentation of the objects involved. This generated a significant number of debris and collisions like these are the biggest cause of orbital debris growth.

Both Figure 3 and Figure 4 only consider numbers from participating organizations, and the 90% compliance this was modeled assuming is a much higher number than in real life. With current compliance rates, the situation will only get worse. This is a very optimistic prediction hoping that the space community levels up. Both the graphs above show a crucial need for aggressive means to stabilize the environment. This is where options like ADR are considered.

For an ADR mission in LEO, a two-step initial approach has been envisaged. It starts with a small demonstrator (under 500 kilograms) mission that rendezvous with several targets with the intention of observation and in-flight qualification testing. This is a purely reconnaissance mission. The second step then is the actual Active Debris Removal mission that uses a larger vehicle adapted from a Orbital Transfer Vehicle (OTV) concept. This vehicle would capture and deorbit large preselected targets by attaching a propulsive kit to the target.

ADR provides several benefits.

- The Critical objects can be removed first (generators of the most fragments in the event of a collision and/or higher collision risk objects)
- Removal of decommissioned objects are also possible
- It is possible to have a controlled de-orbit (as large targets are most critical in terms of on-ground risk)

Based on the European Space Agency and NASA studies, the orbital environment could be stabilized by just a 5-10 object removal from LEO a year. But they did note that the effectiveness of each removal would decrease as more objects are removed.

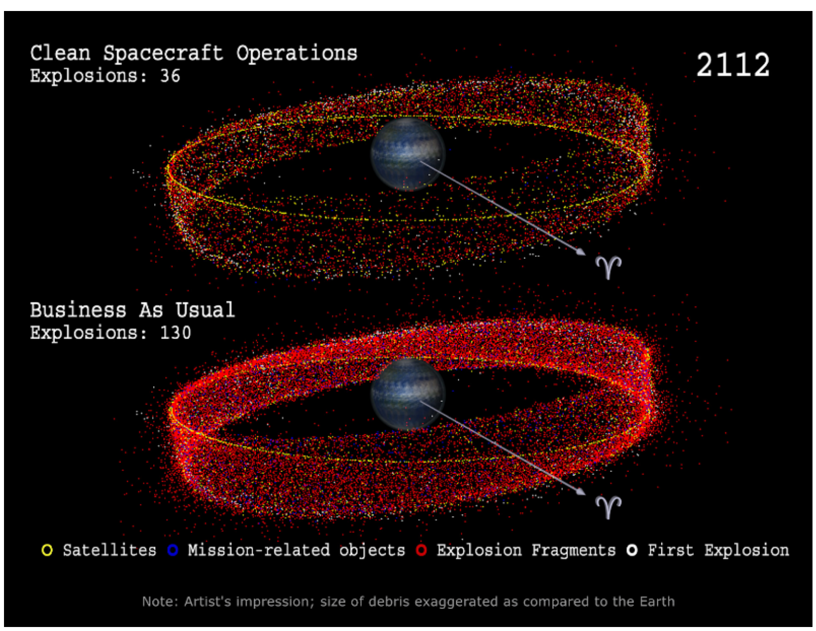

Figure 6. Comparing ADR orbit with non-measure orbit

(Note Figure-6 reprinted from Active Debris Removal, Available: www.esa.int/Safety_Security/Space_Debris/

Active_debris_removal, The European Space Agency)

Figure-6 above, The image above shows a distinction of the GEO environment with and without mitigation measures.

In order to make ADR efficient however we must look at the efficiency as the number of collisions prevented rather than number of objects removed.

To make it efficient, the selection criteria for ADS by the European Space Agency says that:

1. Selected objects should have a high mass, because large mass objects have the largest environmental impact in the event of a collision
2. The objects should have a high collision probability. This could mean say for example that they are in densely populated regions or have a large cross-sectional area.
3. Areas picked should be where orbital life of the resulting fragments is long.

(Note above text adapted from Active Debris Removal, Available: www.esa.int/Safety_Security/Space_Debris/ Active_debris_removal, The European Space Agency)

Table 1. Size and risk of Debris

Physical Size	**Comments**	**Potential Risk to Satellites**
> 10 cm	-Can be tracked -No effective shielding	Complete destruction
1-10 cm	-Smaller objects in this range cannot be tracked consistently -No effective shielding	Severe damage or complete destruction
< 1cm	-Cannot be tracked -Effective shielding exists	Damage

(Note Table 1 reprinted from active Debris Removal – An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space (Jakhu R. et al 2012))

Table 1 above, Shows the various grouping debris are put in, the risk level they are associate with and the problems they pose.

The high-ranking hotspots regions are found around:

1. 100 km and 82 degree inclination
2. 800 km and 98 degree inclination
3. 850 km and 71 degree inclination

Some of the concepts for ADR solutions include but are not limited to:

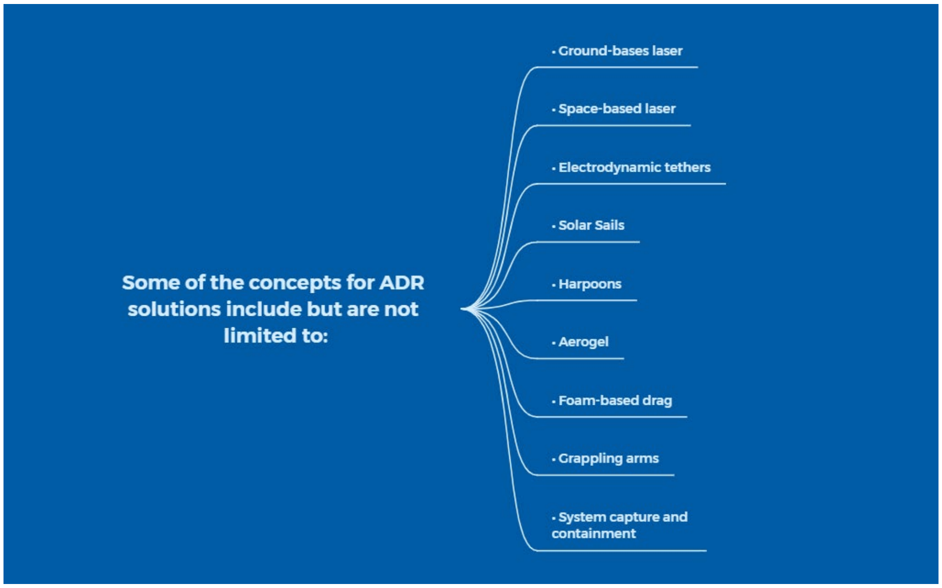

Figure 7. Possible Concepts for ADR Solutions

Figure 7, above shows many of the conceptual solutions for Active Debris Removal. This is list of some of the more discussed concepts with many other solutions being explored.

Many private ventures are looking to monetize the process by re-utilizing capture. Whilst government space organizations are looking at it as more of a protectionist measure.

3. Methods

In this research study, the authors used a qualitative exploratory method by collecting information from various sources.

The general understanding of the issue was explored. The authors covered the reasons that caused the field of space sustainably that emerge and the reasons that amplified the concerns. The authors explained – what it is, how it works and each industry specific naming system, acronym and phenomenon. Then the authors explained the functioning, objectives, action plan, execution of the system. Finally, the authors analyzed its effects across futuristic timeline. The authors also explored the various alternative methods, understanding its pros and cons. The authors also considered the collective perspective, considering all measures that meant for space sustainability, addressing the inherent flaws with our systems and understanding the effective solutions.

4. Data Collection

The authors collected data from past research papers, news articles, conference reports, space agency articles and evaluation reports.

5. Conclusion

Through a detailed analysis of the current condition and various measures being taken to combat, the authors can understand that it is a time taking process and requires consistent efforts from all stakeholders and space partners. While these measures are effective in improving the condition, it will not solve the problem. Another major issue with many of these active solutions are still optional, like the space sustainability rating system. This system is voluntary and many do not participate due to confidentiality or commercial benefits towards compliance. It is also not lucrative enough to offer for commercial players.

It was also observed that Active Debris Removal System is one of the best solutions due to Kessler Syndrome, to make more of our rockets reusable and not increasing launch frequencies. From the above analysis it can be seen that clean spacecraft operations could reduce the amount of collisions and explosions by 72%.

The above analysis also provides us hope for these operations. It was observed that there has been an decreasing number of collisions over the years despite Kessler syndrome. New technologies like Anti-collisions systems, monitoring, emergency maneuvering systems and better planning for disposal and emergencies are certain helping.

With ever increasing awareness there is certainly hope for the future but with the rate at which companies like SpaceX Starlink are launching satellites and reporting close encounters, the question is not whether this is enough but will it create new problems.

References

Active Debris Removal, Available: https://www.esa.int/Safety_Security/Space_Debris/Active_debris_removal, The European Space Agency, Available: https://www.esa.int/, Accessed December 31 2021

Active Debris Removal – An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space (Jakhu R. et al 2012)

Aerospace Security, Available: https://aerospace.csis.org/, Accessed Jan 27, 2022

Harris T. M and Landis A. E., "Space Sustainability Engineering: Quantitative Tools and Methods for Space Applications," 2019 *IEEE Aerospace Conference*, pp. 1-6, 2019

Kahn A, A new chapter for space sustainability, June 25, 2021, https://news.mit.edu/2021/new-chapter-space-sustainability-0625, Accessed: December 15, 2021

Liou J C, Active Debris Removal and the challenges for Environment Remediation, *28th International Symposium on Space Technology*, pp. xx-xx, *Ginowan City, Okinawa Prefecture,* July 17, 2012

Martin Th, Perot Eline, Desjean, M. & Lorenzo, Bitetti. Active Debris Removal mission design in Low Earth Orbit. *EUCASS Proceedings* Series. 4. 763-788. 10.1051/eucass/201304763, 2013

Matignon G D L, The Kessler Syndrome. Available: https://www.spacelegalissues.com/space-law-the-kessler-syndrome/, March 27, 2019
Space Legal Issues, Available: https://www.spacelegalissues.com/, Accessed on Jan 5 2022.

May R. C, Triggers and Effects of an Active Debris Removal Market, Available: https://www.readkong.com/page/triggers-and-effects-of-an-active-debris-removal-market-7495168, January 2021
ReadKong, Available: https://www.readkong.com/page/triggers-and-effects-of-an-active-debris-removal-market-7495168, Accessed on January 15, 2022.

Murtaza A, Pirzada S. J. H, Xu T and Jianwei L, "Orbital Debris Threat for Space Sustainability and Way Forward," in *IEEE Access*, vol. 8, pp. 61000-61019, 2020

Roberts, G. T, Popular Orbits 101, Available: https://aerospace.csis.org/aerospace101/popular-orbits-101/#:~:text=Geosynchronous%20Earth%20Orbit%20(GEO)&text=Satellites%20in%20LEO%2C%20like%20the,precisely%20equal%20to%20one%20day, October 26,2020

Space Brief Types of Orbits, Available: https://www.spacefoundation.org/space_brief/types-of-orbits/, Space Foundation, Available: https://www.spacefoundation.org/space_brief/types-of-orbits/, Accessed January 22,2022

Space Sustainability Rating, Available: https://www.weforum.org/projects/space-sustainability-rating World Economic Forum, Available: https://www.weforum.org/, Accessed: Jan 17 2022.

Torres A, Reusable Rockets and the Environment, *UC Merced Undergraduate Research Journal*, Vol 12 no 2, 2020

Wall M, Kessler Syndrome and the Space Debris Problem, Available: https://www.space.com/kessler-syndrome-space-debris#section-kessler-syndrome-tipping-point-how-bad-are-things-now, November 16, 2021
Space.com, Available: Space.com, Accessed on Jan 1 2022

Weitering H, Debris from Spacex rocket launch falls on farm in central Washington, Available: https://www.space.com/spacex-rocket-debris-found-washington-farm, April 4, 2021
Space.com, Available: Space.com, Accessed: Jan 9, 2022

Biographies

Aditya Drolia is a high school Junior at Inventure Academy Bangalore. Interned at companies like Britannia Industries Limited, Indian Space Research Organization (ISRO), Space technology and Aeronautical Rocketry Labs. He has represented his school and country several times on International Platforms like the Round Square Global Conference, Generation Global SDG Conferences, IIMUN Championship Edition and more. He is also a member of the highly selective New York Academy of Sciences – The Junior Academy as a Student Researcher and Junior Member, a Conrad Challenge Conrad Innovator Awardee. He has also held a government organization leadership post in his school in the NCC (National Cadet Corps) Ministry of Defense, Government of India for two consecutive years.

Dr. Shekar Babu is a Professor and Director of "Amrita Center for Responsible Innovations and Sustainable Enterprises", "ARISE" Labs. He is also the Founding Head, Department of Management (DoM), Bangalore Campus, AMRITA Vishwa Vidyapeetham University, Bangalore, India. Dr. Shekar holds a Bachelor of Engineering (BE) degree in Electronics and Communications from Bangalore University and a Master of Science (MS) degree in Electrical and Computer Science from California State University, Los Angeles, and a Doctoral Degree in Strategic Management from Amrita University. He is a Management Consultant with over 30 years of experience in working at Price Waterhouse, Hewlett-Packard Co, and AMRITA University. His research areas are Environmental Social Governance (ESG), Corporate Social Responsibility (CSR), Corporate Governance (CG), Strategy and Social Development and Sustainable Goals (SDG). He has taught courses in Strategic Management, Leadership, Management Consulting, Marketing and Business Ethics.