The Existence and Dangers of the Accumulation of Space Debris in Low Earth Orbit and How Analogies Can Be Used to Better Explain Complexities in New Technologies

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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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Overcrowding of Low Earth Orbit

Governments, civilians and especially private companies are launching rockets and satellites at unprecedented rates (Stephen Clark, 2021, n.p). This rise is shown in Figure 1 and is predominantly caused by the increase in spacecraft launched by private companies. These satellites serve many purposes such as communication, imagery and even global wifi in the near future. While these spacecraft provide many benefits, some trouble will arise in the future if more attention is not paid to the potential for overcrowding space. Of the 2,666 satellites in orbit around the Earth, 1,918 or 72% are in Low Earth Orbit (LEO) (Datta, 2020). This congestion has the potential to lead to collisions between spacecraft causing damage and even destroying operational satellites.

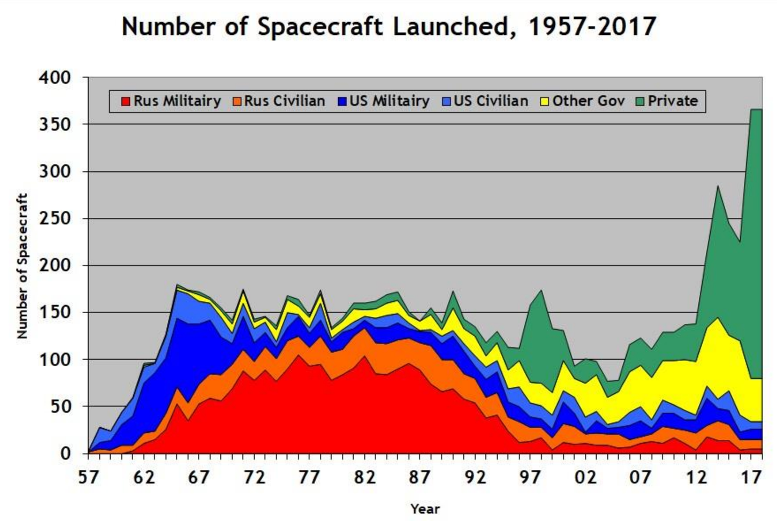

Figure 1: Number of spacecraft launched per year by different groups (Lafleur, 2017)
This image shows the progression of how many spacecraft were launched each year from the beginning of space exploration to 2017. It displays a large increase in private spacecraft being launched in the last 10 years.

One NASA scientist, Donald J. Kessler, proposed a hypothesis in 1978 called the Kessler Syndrome. The situation he describes is, “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” (Kessler et al, 1978, p.1). This potential exponential growth of debris travelling at around 7.8 km/s would be disastrous as even small flecks of paint can cause damage when moving at velocities of this magnitude (ESA, 2020).

This is a problem that was identified decades ago, just 9 years after Neil Armstrong stepped foot on the moon. Now, 43 years later, we are facing the consequences of ignorance and inaction and need to find ways to slow this issue down soon. In researching this topic, I will attempt to understand the effect of rocket launches and satellites in orbit as well as the best ways to demonstrate this complicated problem to the general public through the use of STS methods and analogies.

The Causes and Effects of Space Debris

The number of spacecraft in Low Earth Orbit (LEO) will only continue to increase as companies such as SpaceX are assembling large constellations of satellites that have already begun to be put into orbit. SpaceX currently has 1141 of its Starlink satellites in orbit with up to 42,000 total planned (Huang et al, 2021). Other companies are planning on launching their own constellations as well leading to an extreme surge in satellites in LEO in the coming years. As discussed earlier, this overcrowding of LEO has potential to lead to an exponential growth of space debris caused by extraterrestrial collisions. In orbit collisions have already occurred. In 2009, Iridium 33 crashed with Kosmos-2251 (Stuart Clark, 2010, n.p). As shown by the spike on the Total Objects line around 2009 in Figure 2, when these satellites crashed into each other they released thousands of pieces of space debris all travelling at extremely high speeds. The European Space Agency currently estimates there are over 29,000 objects in space larger than 10 cm that could cause “catastrophic fragmentation of a typical satellite” and over 170 million objects larger than 1 mm that could destroy subsystems on board a spacecraft (ESA, 2021).

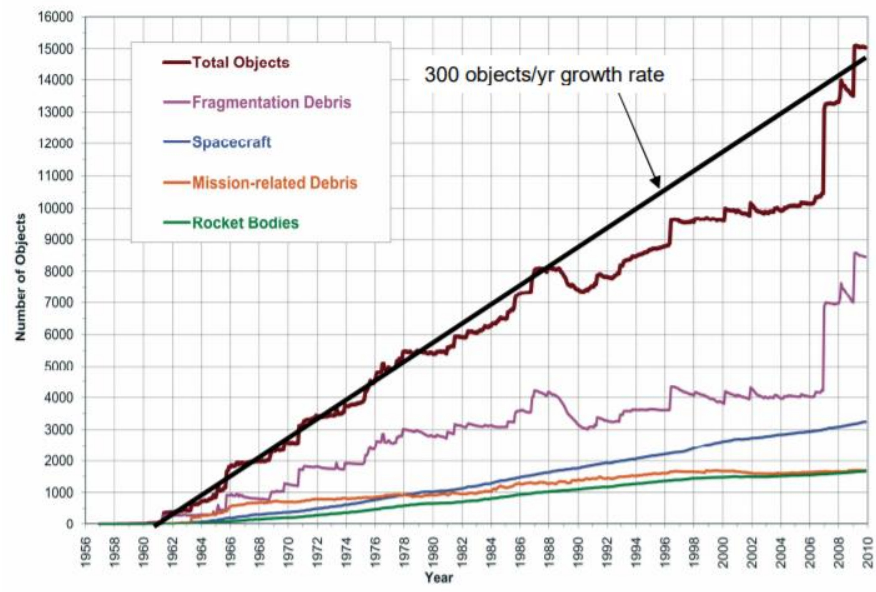

Figure 2: Number of Catalogued Items in Low Earth Orbit (Kessler et al, 2010, p.4)
Figure shows how the number of objects has increased since humans first began space programs. Huge jump in 2007 shows the impact an orbital collision can have.

The worst-case scenario is the full development of Kessler Syndrome. This would occur if collisions create more pieces of debris, which in turn create more collisions leading to exponential growth of the number of objects in orbit. With so many objects in orbit, an impenetrable barrier would form around the Earth to where it would be impossible to launch new satellites or rockets without being bombarded by debris travelling at destructive speeds (Kessler, 1978). At this point humans would be grounded and cut off from the rest of the universe.

There are some secondary consequences that can develop from this situation. Ground based astronomy will be adversely affected as large bright satellites have the potential to interfere with images taken from the surface. As shown by Figure 3, large satellites such as SpaceX Starlink, can create streaks in images taken by telescopes, ruining the pictures and the data and limiting our ability to inexpensively study far away objects (McFall-Johnson, 2019). Another potential effect comes as a result of orbital decay. Due to the presence of a small amount of air resistance in LEO, objects in orbit are slowly falling toward the Earth. Active satellites use thrusters to occasionally boost their orbit back to their original location, however pieces of debris and dead satellites do not have this capability. This means that eventually they will fall low enough to feel the full effects of atmospheric drag, and if the object is large enough could potentially crash back onto the ground (Kennewell and Panwar, 1999, p.2) .

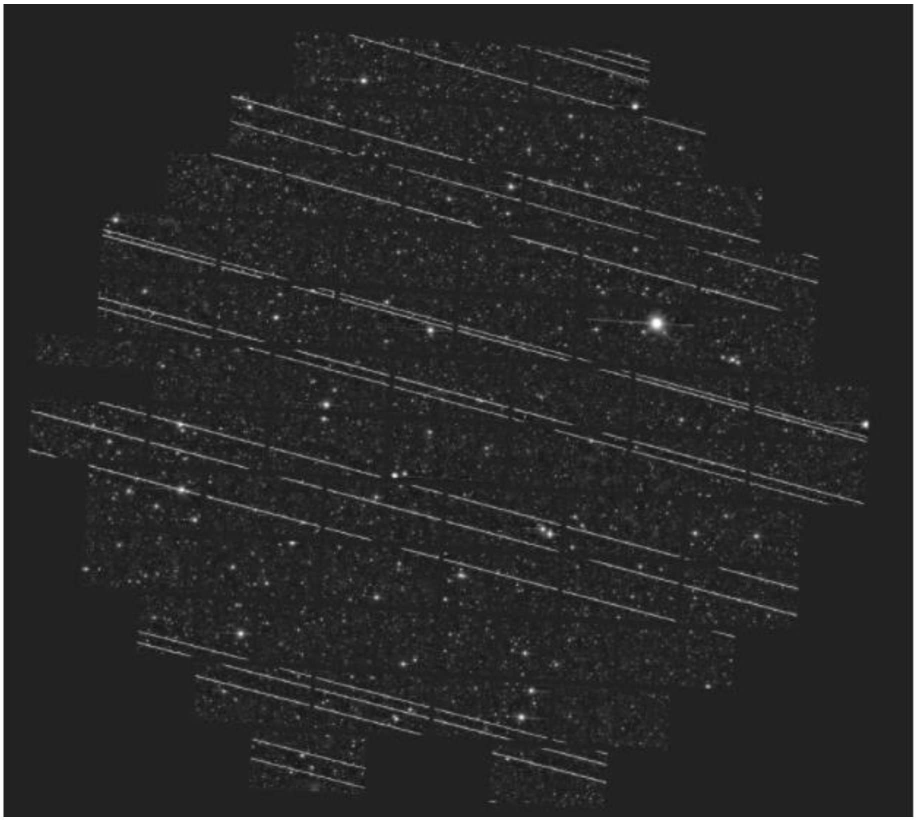

Figure 3: Telescopic Image Marred by Satellite Crossings (Leslie, 2020, n.p)
The white streams going horizontally across the image are the result of satellites. This interference can cause significant errors in lengthy extra-terrestrial investigations.

It is not known how long it will take for LEO to reach the full situation described by Kessler Syndrome or how many spacecraft it will take to reach the point of no return. This could be difficult to project because technological developments will hopefully delay this time and ideally stop it from ever occurring. Technology, such as satellites that deorbit when they have reached their lifespan, evasive maneuvering, and more detailed and exhaustive tracking of all space objects would all be greatly beneficial to preventing Kessler Syndrome. Other factors that influence the timeline of Kessler Syndrome include the number of spacecraft launched in the future, especially constellations by companies rivaling SpaceX, the pace of technological development, and the randomness of potential collisions of objects already in orbit.

While many technological developments have postponed Kessler Syndrome, they were designed mostly for other reasons. Helping avoid Kessler syndrome was more of a secondary benefit. Giving satellites the ability to maneuver around and adjust their orbits is a tremendous improvement, however this was created to give satellites more flexibility on what they could do, and how they could operate in space, not to prevent space debris. This technology is also completely useless if a satellite loses connection to the ground station and is no longer maneuverable. In this situation, the satellite turns into just another piece of space junk orbiting the earth at excessive speeds with zero control of where it is going. These types of objects are extremely dangerous and mission operators need to be diligent to keep their spacecraft out of the trajectory of dead satellites. As the number of these types of non-maneuverable objects grows, the likelihood that they crash into each other rises. A high percentage of satellites currently in orbit are non-operation and cannot be controlled from the Earth. Of the 1200 trackable objects in or near geostationary orbit, less than 400 or one third are active satellites (Stuart Clark, 2010, n.p).

One organization, called the Inter-Agency Space Debris Coordination Committee (IADC), has put forth guidelines on how spacecraft need to be designed and operated to best mitigate the accumulation of space junk. The objectives they outline are limiting debris released during normal operations, minimizing the potential for on-orbit break-ups, post mission disposal, and prevention of on-orbit collisions (IADC, 2019, p. 15-37). Unfortunately, many spacecraft do not follow these guidelines. Connection is lost before mission ending orbital maneuvers can occur or accidents in set up lead to communications never being established.

This research will use STS methods to analyze how this problem is interpreted and can be better explained to the general public. Using analytical methods such as analogies to both expand and limit a person's mindset gives the ability to shape the public perception of different technologies and problems such as Kessler Syndrome. By coming up with unique and creative ways to raise awareness of the problem and put pressure on governments and private companies to design and operate their spacecraft in safe manners, hopefully Kessler Syndrome can be pushed back enough until we have the technology and resources to find a permanent solution.

<u>Analogies and Their Use in Governing Technology</u>

There has been a significant amount of research done on the accumulation of space debris in Low Earth Orbit (LEO) with a significant amount being inspired by the Iridium-33, Kosmos-2551 collision. This collision was the first, and so far only major accidental collision between two satellites in orbit, however the debris created from this was so vast that it has many space scientists worrying about the future. Figure 3 below shows all the debris currently being tracked from the Earth. This is limited to objects that are at least 10 centimeters in size or larger (Stuart Clark, 2010). The red dots in the image are debris thought to have originated from that 2009 coincidence of orbits. This image also is a great visualization of the sheer number of objects currently floating around the planet including satellites, old rocket bodies and even tools astronauts dropped while outside of their spacecraft. Any one of these could cause tremendous damage if they impact another object in space. Most of the concentration is in LEO but the belt 35,800 km out from the Earth is also filling up. This area is where satellites can sit in geostationary orbits and stay above the same place on Earth as the satellite orbits at the same rate that the Earth orbits (Britannica, 2016, n.p).

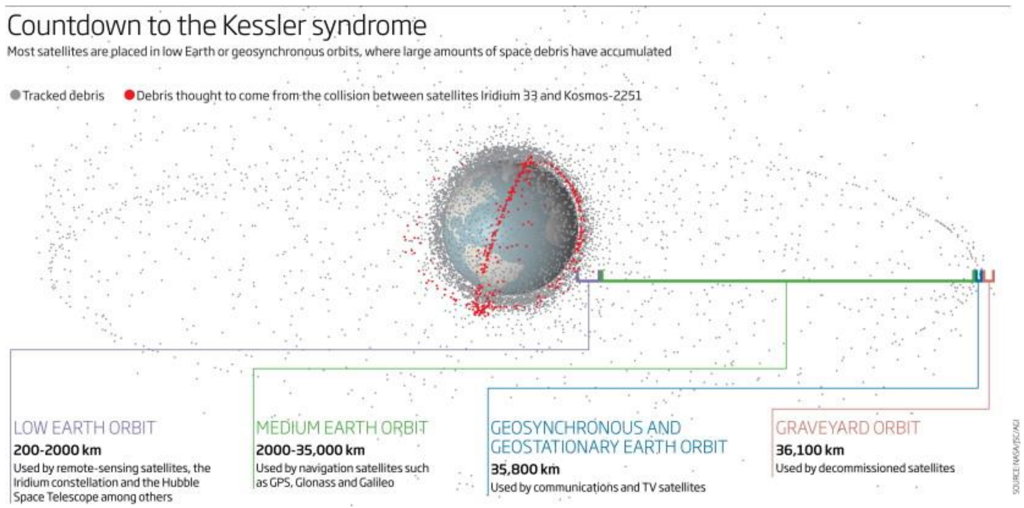

Figure 3: Pieces of tracked debris in orbit (Stuart Clark, 2010, n.p)

The pieces of debris currently being tracked from earth. High concentrations in LEO and geostationary orbit. Red dots indicate pieces of debris thought to come from 2009 collision between Iridium 33 and Kosmos-2251

This problem may be better understood if we apply Claudia Schwarz-Plaschg's idea that analogies are powerful tools to help humans comprehend more complex situations. She claims that having analogical imagination "helps to understand the relation of new and emerging technologies to other technologies or cases" (Schwarz-Plaschg, 2016, p.3). This framework is interesting because of the way the author describes the use of analogies as both a tool for expanding and limiting a person's mindset. By using analogical imagination, a person's mindset can be expanded and make them more receptive to new ideas about technology such as comparing them to old technologies that have favorable public opinions. On the other hand, analogical arguments can be used to restrict a person's thinking and focus it on one specific aspect. When used in tandem, these two methods of using analogies are extremely powerful (Schwarz-Plaschg, 2016, p. 3-6). The ability to shape how people think about and consider new and developing technologies is one that is incredibly useful. By using analogies to make new technologies more easily understood, an engineer can make it significantly less difficult to gain traction in public thought and raise awareness about a technology and its potential problems.

An example of a way to use analogies in technology, as well as to explain the problem of overcrowding in LEO, would be to view this growing overpopulation of space junk as a system similar to cars, traffic jams, and accidents here on the surface. When the roads are clear and empty cars are able to freely flow and collisions are quite unlikely. However, when a more densely populated area is analyzed, there are more cars on the roads which leads to more accidents and traffic jams. This is similar to the environment in LEO except instead of density changing in different areas, density is consistently increasing with time. The clear and empty roads relate to the beginnings of space travel when it would have been next to impossible to collide with anything. The denser situation is where space is trending to now, with spacecraft having to be extremely careful and move out of the way of other objects in order to avoid collisions. In other words, the lanes can be looked at like the path of an orbit, and if there are more cars than number of lanes or orbits, the possibility of accidents and crashes increases tremendously. Of course, analogies can only describe a situation so accurately, and in order to stretch an already existing analogy into something that fits a new technology, a person would have to morph the analogy into something so abstract it almost isn't recognizable or useful anymore. In this situation it may be useful to blend a couple analogies together to describe different parts of the system such as using one analogy to describe how a technology works and one to explain its societal impact.

This framework and evidence are extremely relevant to the problem as one of the biggest issues is the public's lack of awareness and understanding of the situation. By providing a method to frame new technologies with analogies, it can be easier to explain and understand very complicated processes and systems by just comparing them to simple situations of everyone's day to day life. A growing problem in society is that new technologies are getting more complex and difficult to explain their functionality. The average person who is not studying the field in which a new technology exists, will have extreme difficulties understanding how they work and what the purpose is. Analogies can be used to simplify how a technology works and what the purpose is. Analogies as explained by Schwarz-Plaschg, can be used in a variety of ways. They are a very powerful tool that can shape the way people form opinions about new technologies.

Discoveries and Their Significance

Based on the evidence presented so far in this paper, it is fair to infer that if left unchecked Kessler Syndrome is a legitimate possibility. The timeline initially set by Donald Kessler in 1978 was inaccurate as he projected collisions would begin around sometime between 1989 and 2005 (Kessler, 1978, p.3). Due to advancements in technology and some precautions the first collision was in 2009 and there has not been one in the 12 years since. However, if current practices continue, the situation will worsen. To ensure that the Earth's orbital landscape remains manageable, it is of utmost importance that spacecraft designers and mission directors follow the guidelines set by the IADC.

One of the surprising things that was uncovered during this research was how much of a problem dead satellites already are. According to a report from 2010, satellite operations are having to perform avoidance maneuvers over 3 times a week. These types of maneuvers require fuel which leads to increased costs and shorter mission times (Stuart Clark, 2010, n.p). Another surprising outcome of this research was that there is already an international committee designed to help mitigate and prevent Kessler Syndrome, however many mission operators and spacecraft designers are not following the guidelines set by this committee. Too many satellites are left in orbit past the mission expiration date and they become pieces of space debris. When satellites are not properly disposed of, they transition from a useful piece of technology into a form of pollution. The committee does not seem to have much influence on the industry as a significant amount of research was done before the IADC was even mentioned. The committee needs to find a way to have more of an influence as they are fighting for an important cause. The guidelines need to be more available and prominent so that spacecraft designers and mission operators know exactly what needs to be done to mitigate Kessler Syndrome

During my research I have learned that at some point, we will need to design a spacecraft that is capable of either bringing dead satellites and space junk back down to Earth, or send it far enough away that it can no longer present any danger. Unfortunately, low earth orbit has reached a point where even if no more spacecraft were to be launched, the amount of debris in space would continue to increase due to inevitable collisions. The situation is significantly worse than I had initially thought. Satellites currently in orbit, consistently have to make adjustments and avoidance maneuvers to prevent collisions with debris, sometimes more than 3 times per week depending on the orbit (Stuart Clark, 2010, n.p).

While the car/traffic analogy simplifies the problem to allow better understanding, another analogy that perhaps gives a more complete picture would be a sports team. In this scenario the IADC would be represented by the coach. When the coach of a sports team does not have the authority over or the respect of his players, play on the field and attitudes in the locker room tends to devolve into chaos and problems begin to brew. If unchecked, these problems will snowball and become detrimental to the performance of the team. Eventually, the problems will grow so large that drastic change needs to occur and the coach and/or the players on the team will be removed. By comparing the IADC to the coach in this scenario, it is easy to see how a lack of leadership and accountability has allowed space agencies and companies to continue to practice unsafe and harmful methods of spacecraft design and management. In almost any situation, people or groups acting without leadership or direction leads to chaos and a surplus of mistakes being made.

Accidents such as collisions between spacecraft become much more likely. Another way LEO overcrowding can be compared to a sports team is how both players and spacecraft can be damaged. Similar to players suffering both contact and non-contact injuries, satellites can be damaged by contact with space debris and by internal system malfunctions. Just like non-contact injuries for athletes, a dysfunctional satellite won't necessarily have any visible damage but it can cause huge problems. When a satellite is dead in the air, it becomes a piece of space junk and is dangerous for all other objects on similar orbits. Contact injuries and space debris collisions are also quite similar. As shown by the athletes in Figure 4, collisions between any object or person moving at speed tend to be very violent and the impact damage is very visible. Collisions in space can release upwards of 1000 pieces of new debris into orbit and even the smallest pieces such as paint flecks can cause tremendous amounts of damage due to the high velocities.

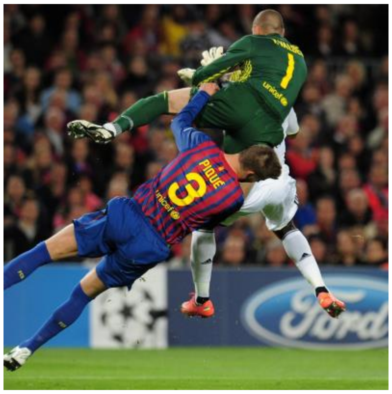

Figure 4: Violent physical collision between 3 soccer players (Botterill, 2012)
Gerard Pique (Red/Blue) sent to the hospital following collision with
Victor Valdes (Green) and Didier Drogba (White)

<u>Conclusion</u>

Creating awareness about Kessler Syndrome is very important. As this issue is not obvious from the surface, and has not yet started to disrupt the functioning of the system, much of the public is completely unaware that there is trouble brewing above them. Many people think of outer space as infinite, not realizing that the most important areas of space are already approaching maximum capacity. Unfortunately, this is a complicated issue with a variety of different levels that involves multitudes of complicated scientific theories. This means that to explain the gravity of the situation, we have to be creative. By using analogies in the way described by Schwarz-Plaschg, the problem can be framed in a way that is easier to comprehend. These analogies can be used in a variety of ways to both simplify a situation and also to allow someone to expand their mindset about a problem or technology. Hopefully, by using this method of explaining technology, awareness can be raised about the ongoing issues in Low Earth Orbit. If action is not taken soon, humanity will be facing a very difficult struggle when it comes to using satellites to improve our daily lives.

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