How has Space Commercialization Impacted the Environment?

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Morgan Myers

Bachelor of Science, School of Engineering

Spring 2024

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

Joshua Earle, Department of Engineering and Society

Introduction

In 2023, there were a total of 221 rocket launches, 96 of them launched by SpaceX (Romera, 2023). Remarkably, this one company was responsible for almost half of the total global launches during this period. This number will only grow each year as other space companies enthusiastically join space commercialization. For example, Virgin Galactic's CEO, Michael Colglazier, has stated that he plans on sending 400 space tourism flights per year. The space industry grew immensely since its privatization. In fact, as of July 2023, the global space economy is worth $546 billion, which is a 91% increase in the last decade. It has the capacity to grow to $800 billion in the next 5 years ("Space Foundation Releases", 2023). This is only just the start to a huge industry that will continue to grow and evolve over the next decades.

This industry is not without its environmental challenges. The increase of launches translates to a surge in hazardous emissions into the atmosphere (Twiss, 2022). Additionally, the proliferation in satellite technology contributes to a heightened spacecraft density in the Low-Earth Orbit, leading to more orbital debris (Miraux, 2022). There are very limited policies that currently exist regulating private companies in space. The commercialization of space demands urgent attention for the formulation of policies that effectively address its environmental impact.

The upcoming methods and frameworks section will provide the paper's approach and analytical framework. Subsequently, the results section will delve into the specifics of space commercialization, environmental harms, and existing policies. The analysis will apply the framework to unravel the intricate interactions among each component. Finally, discussion will underscore the significance of this issue and propose possible solutions.

Methods and Framework

In order to perform a comprehensive understanding of the impact of space commercialization on the environment, I conducted a literature review. I reviewed a broad spectrum of sources related to the intersections of government, spacecraft, scientist, companies, and the environment. I investigated scholarly articles, research papers, and other relevant publications. Research papers provide evidence of how space commercialization is impacting the environment. Scholarly articles investigate the current policies that exist in this realm as well as ones that should exist and the impact of current and future space commercialization policies on the environment. Recent publications and articles provide current technological advances in this topic as well as future plans for these topics. This review provides a foundation for synthesizing information and developing an in depth understanding of the networks and interactions in the space commercialization domain. Synthesizing the information gathered from the literature review involved a detailed oriented process for analyzing, organizing, and integrating the multiple perspectives and findings. By combining the insights from various sources, a cohesive narrative will capture the complex relationships among the key actors in space exploration and space commercialization.

The framework I will be using in this paper is Actor-Network Theory. Actor-Network Theory provides a conceptual framework for understanding the dynamic interplay between different actors. This framework identifies the actors of a system and holds them all at the same level, so that essentially each actor can affect the network. All actors are actively involved in impacting and shaping the networks that define their relationships (Sismondo, 2009). By using Actor-Network Theory, I can gain a perspective to examine the influences each actor has upon each other and their networks in the concept of space commercialization.

Each actor plays a role in space commercialization. The actors I have defined are: companies, governments, spacecraft, environment, and the scientists researching this problem. Companies have interest in technological innovation and potential to earn money, governments fund and regulate space activities, scientists advance the knowledge of the technology and its effects, the environment is both a subject of study but also an entity that affects the actors, and spacecraft is the technological artifact in this network that interacts with the environment and provides invaluable data.

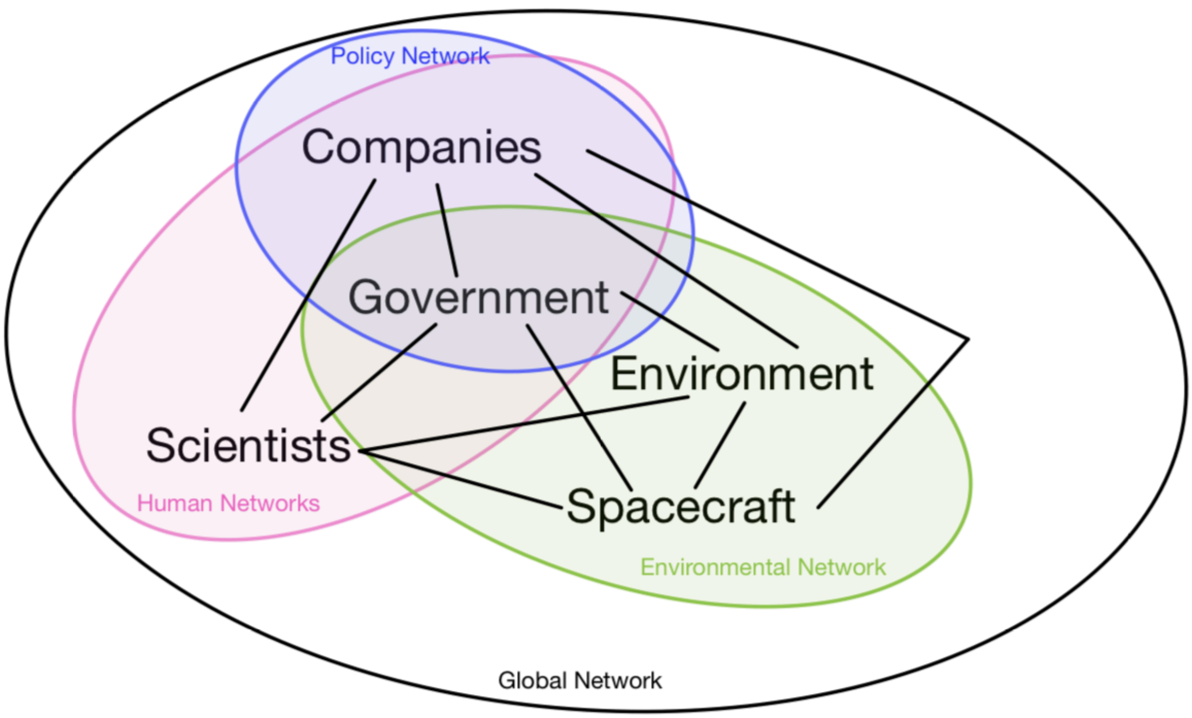

Figure 1: Actor Network Theory Set-up for Space Commercialization

Using Actor-Network Theory the space commercialization topic can be broken down into different networks. Networks include: human networks, environment networks, and policy networks. In human networks, scientists perform research that expands the knowledge of environmental impacts, working with the government to create policies for the companies. The human network will shape the future of space commercialization. Governments work with space companies to both regulate and support their activities. In environmental networks, spacecraft developed by companies are launched and operated to gather data, make money, and perform tasks while creating potential environmental consequences that may affect future space commercialization. In policy networks, governments play a critical role in regulating and guiding space commercialization and its impact on the environment.

In addition to actors and networks, there exists black boxes. Black boxes are parts of the paper where it's clear what the input and output of the actor is but not how anything actually happens. For this paper, the black boxes include the inner workings of the government. Nothing about how the government actually regulates space tourism, will be elaborated on. The science behind space technology is also a black box in this paper, as well as global warming and climate change.

Results

The Commercialization/ Privatization of Space

The privatization of space is the shift of space-related functions from government control and ownership to private control and ownership (Krombach, 2011). The commercialization of space is the engagement of the private sector in the development and utilization of space-related technologies with the goal of generating profit (New Space Economy, 2023). Privatization and commercialization of space are very similar, the only difference being commercialization is the broader concept of private companies participating in space exploration and space exploitation, whereas the privatization of space just focuses on the transition of ownership of space related technologies and missions from the government to private. Prior to the privatization of space, governments only conducted a couple launches every year, resulting in minimal environmental impacts as compared to other industries (Twiss, 2022). This is one reason why the environmental impacts of space exploration are ignored and minimal policies currently exist.

The Environmental Concerns

The commercialization of space has environmental impacts associated with it, specifically stratospheric ozone depletion and atmosphere warming from rocket exhaust. Rocket exhaust can contaminate the upper atmosphere where the collection of combustion byproducts contribute to the ozone layer loss (Dallas, 2020). One study, performed by Ryan and collaborators, looked into the impact of rocket launches on the atmosphere in 2019. In this study they found that after a decade of contemporary rocket emissions, only the ozone layer would deplete by a small fraction. However, with the increase of the privatization of space, the percentage is sure to increase and move to be a huge issue in the space industry (Ryan et al, 2022). If space tourism is in the mix, it would double the global warming forcing due to black carbon after just 3 years of space tourism. This means that 6% of the total global warming is attributed to black carbon from rocket emissions(Ryan, 2022). This number is only going to increase as space commercialization increases, overall contributing to the global warming crisis. In addition to ozone depletion due to all types of rockets, another study by Dallas and coauthors state that the black carbon emitted from solid rocket propellant and kerosene propellant can accumulate in the upper atmosphere and keep the Earth's warmth contained instead of letting it escape like normal (Dallas, 2020). SpaceX uses kerosene for their Falcon 9 and Falcon Heavy (SpaceX). The Falcon 9 uses 112 tons of kerosene for its launch, which pumps 336 tons of carbon dioxide into the atmosphere (Nam, 2023). This is about 23 times the amount an average

US citizen produces in a whole year (Center for Science Education, 2023). The figure below demonstrates just how much carbon dioxide the Falcon 9 produces in the atmosphere.

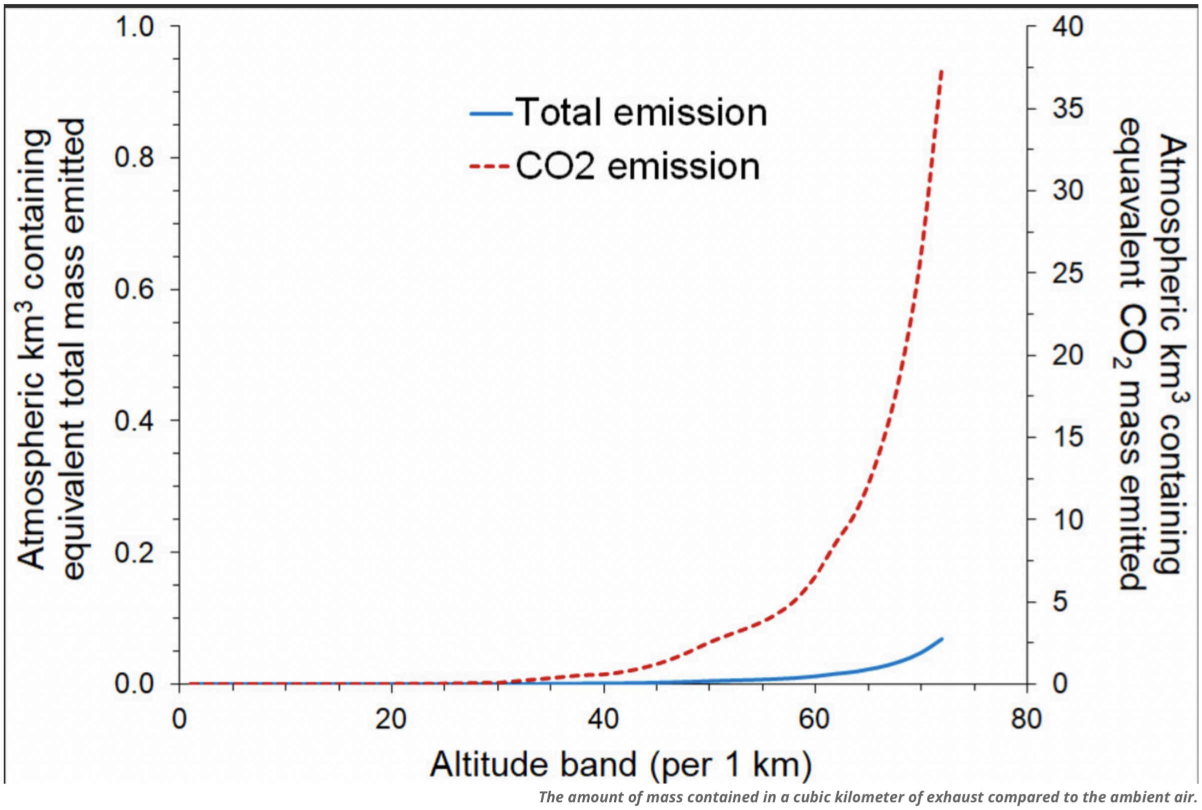

Figure 2: Amount of CO2 that the Falcon 9 introduces in the atmosphere (Currin, 2022)

A small portion of carbon dioxide is released into the lower atmosphere, but as the rocket reaches around 25 kilometers, it starts to release one cubic kilometer of carbon dioxide for each kilometer it goes, and then as it reaches 70 kilometers it outputs more than 25 times the amount of carbon dioxide found in the cubic kilometers at the altitude (Currin, 2022). Similarly, Virgin Galactic uses a hybrid rocket motor (Virgin Galactic). Hybrid rocket engines produce much more black carbon than kerosene propellants (Dallas 2020). Another study included a 40-year climate simulation that shows how the hydrocarbon rockets (hybrid engines) planned by space tourism will impact the earth's atmosphere (Ross, 2010). The study found that the stratospheric ozone will deplete by 1% in tropical areas, and 6% in polar areas (Ross, 2010).

In addition to stratospheric ozone depletion and climate warming, space commercialization poses threats to Low-Earth Orbits by overcrowding and orbital debris. The number of man-made objects in LEO has increased greatly in the past decade as demonstrated by Figure 3.

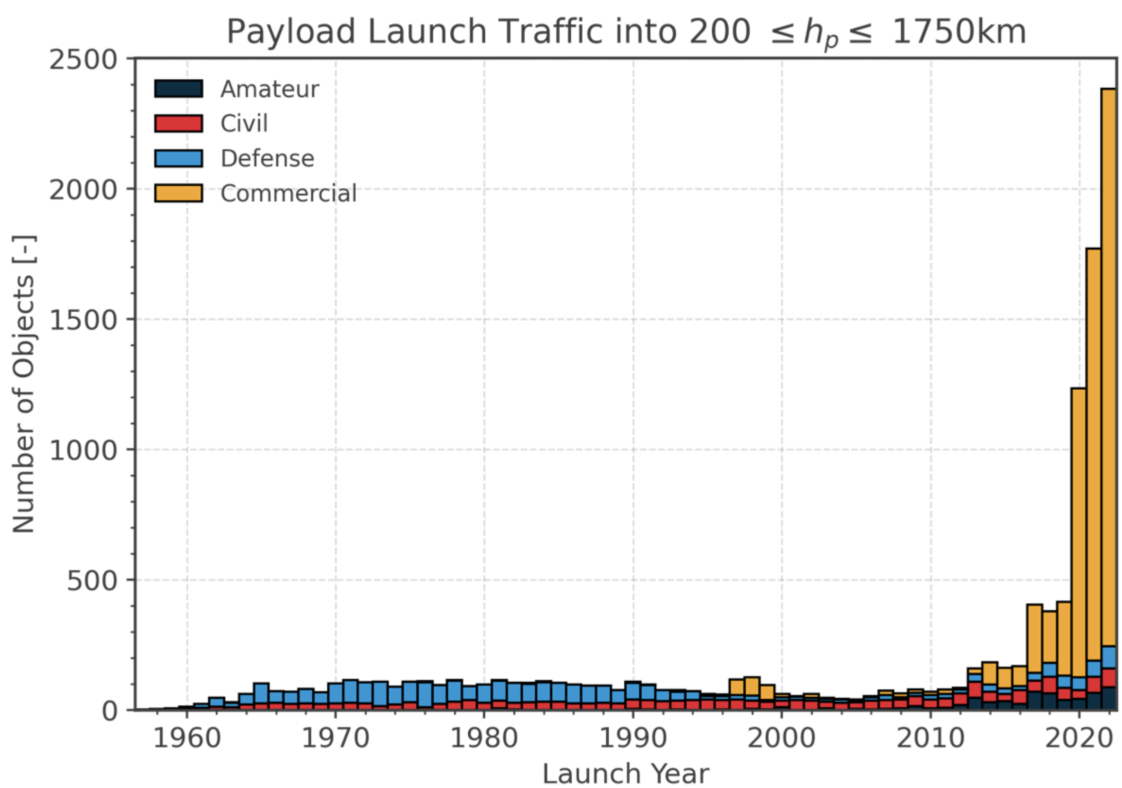

Figure 3: Number of objects launched into Low Earth Orbit by year (*Space Environment Statistics*, 2023)

Payload traffic isn't the only part of the overcrowding of LEO. Orbital debris is any object in space that is man-made and unwanted. As of 2022, there are over 100 million space debris objects that exceed 1 millimeter, 500,000 objects between 1mm-10cm, and 25,000 objects over 10cm (ARES, 2022). Of these space debris, only 55,000 are being tracked (Iyer, 2023). Because orbital debris is becoming an issue, most satellite constellations will be in LEO to prevent creating more debris (AREA, 2022). This, however, presents an overcrowding problem. Because of the rise of space commercialization and with satellite constellations like Starlink and Iridium in Low-Earth Orbit, the risk of collisions is increasing because of this new density. Unlike the International Space Station, most satellites do not have maneuvers built to quickly and effectively dodge space debris (Weedon, 2021). If the cluttering of LEO persists, it might get to the point where the Kessler Syndrome happens, where one collision can lead to many other collisions, ultimately resulting in an orbital debris belt around Earth (Whitt, 2021).

Existing Policies

There exist five United Nation Treaties on Outer Space. These treaties all enhance that any use of outer space should be dedicated to increasing the well-being of human-kind (*Space Law Treaties*). Starting with the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space…", this treaty states that outer space is to be freely accessible for exploration by all states, no nation can claim sovereignty over it, no weapons of mass destruction allowed in space, states are liable for any damage caused by their space objects, and efforts need prevent harmful contamination of space and celestial bodies (*The Outer Space Treaty*). The Rescue Agreement pertains to the rescue of astronauts and the return of objects in space (*Rescue Agreement*). The Liability Convention states that anybody who launches a spacecraft is fully responsible for any damages to Earth, aircraft, and any other damages done in space (*Liability Convention*). Holding parties accountable for the damages done to Earth only recognizes the damage done by bringing space matter to Earth that is dangerous or can contaminate the Earth in a harmful way, it does not regulate the environmental harm as caused by space activities like rocket emissions. The last two treaties were an extension of the Outer Space Treaty as described first (*Moon Agreement and Registration Convention*).

In 2015, President Obama passed the Spurring Private Aerospace Competitiveness and Entrepreneurship (SPACE) Act, also known as the U.S. Commercial Space Launch Competitiveness Act (CSLCA) (Rep. McCarthy, 2015). This Act gave citizens the right to "engage in commercial exploration for and commercial recovery of space resources free from harmful interference," (Rep. McCarthy, 2015). This act encouraged private sector investment and innovation by limiting financial liability in launch events and ridding of unnecessary bureaucratic obstacles.

The U.S. National Space Policy of 2010 addresses the orbital debris problem and states that orbital debris creation needed to be minimized. The policy also outlines other responsibilities when using space, like transparency of space technology, national defense, and climate change and natural disaster monitoring ("Fact Sheet: The National Space Policy", 2010).

The Artemis Accords are a non-binding set of principles to lead the civil space exploration launched in 2020 with 35 countries having signed (Artemis Accords). There are 10 principles outlined in the accords, most of which are very similar to what is already defined in the Outer Space Treaty. Notable additions are the release of scientific data, protection of heritage, and orbital debris and spacecraft disposal (*Artemis Accords*). The National Environmental Policy Act requires federal agencies to assess the environmental impact of their actions prior to making decisions. They also require environmental impact statements of launch sites (US EPA, 2013). There also exists the Federal Aviation Administration, whose primary responsibility is providing licenses to space companies to launch in the US (Nam, 2023).

Analysis

The actors in this network are the governments, companies, spacecraft, environment, and scientists. Governments are responsible for setting the regulatory framework for the privatization of space, having to balance environmental concerns with economic interests. Companies drive technological innovation and economic growth by building spacecraft and launching them. Spacecraft are non-human actors that play a crucial role in space commercialization, they need regulatory approval from governments, and implement technologies that impact the environment. The environment is another non-human actor, it needs the government to provide it protection through policies, it gets influenced by companies' spacecraft and rocket emissions, and interacts with the scientific community by getting studied. Scientists are human actors who provide expertise on Earth's atmosphere and contribute data to inform policies and regulations, interact with companies by providing insight and solutions to multiple aspects, and interact with spacecraft by studying their impact on the environment. The challenge of this network is finding a balance that allows for the continued growth of the space industry while minimizing the harmful environmental impacts.

Governments translate economic and geopolitical interests into regulations, while companies try to translate these regulations into profits. The space industry has grown at a remarkable rate since Obama's U.S. Commercial Space Launch Competitiveness Act. Policies and environmental scientists serve as intermediaries in facilitating this process. As shown in the results section, there is not much environmental regulation in the commercialization of space. The United Nations treaties were made with whole countries in mind, not private companies, and focused on keeping peace and in space sustainability, not regulating the on earth consequences. The collaboration between governments and private companies shape the trajectory of space commercialization, where the environment is a stakeholder of these associations. There are already environmental damages in the ozone layer from the increase in private rocket launches and this number will only continue to grow. The government needs to step in and regulate the actions of these private companies to protect the environment. Within this network, the potential consequences of overcrowding in Low-Earth Orbit need further examination. The LEO overcrowding element can have extensive effects in space commercialization and environment, but results of this are yet to be seen. Spacecraft and the environmental factors are the drivers of what shapes the network. Spacecraft provide the economic successes of companies, and environmental factors influence the regulations and sustainability of space privatization. Disputes in this network might come from the government regulating the companies, or scientists bringing light to the consequences of space commercialization. This network will change over time, with new policies and technology, and there will be shifts in the relationships between actors. Sustainable technologies or new policies will need to be made in order to provide resilience of this network.

Discussion

Ozone Depletion

If policies are not made to address the environmental impact of the increase in space commercialization, then there could be dire consequences. For example, in the 1970s, an ozone "hole" started to form in the stratosphere. Ozone depletion leads to an increase in UV-B radiation (different from UV-A radiation, needed for the formulation of vitamin D) (Makhijani and Gurney, 1995). An increase of UV-B getting in the atmosphere causes serious issues: DNA damage, human immune system damage, impairs photosynthesis in plants, and poses a massive threat to marine life (Makhijani and Gurney, 1995). In 1985, scientist Jonathan Shanklin found that there was a major decline in the amount of spring ozone. His findings lead to the 1987 Montreal protocol, which froze production and consumption of ozone depleting substances (UK Research and Innovation, 2022). If the Montreal protocol wasn't implemented, estimates say that there would be an additional 0.8 degrees Celsius rise in the global temperatures by the end of this century, and a huge increase in skin cancer deaths, as well as other consequences ((UK Research and Innovation, 2022). This event holds a similar network as space commercialization, just with industrial plants replacing space technology. In this case, the scientists studied and reported the problem, and since the problem was a threat to human life, policies were quickly made to address and correct the problem. The companies running the industrial plants changed their technology to suit the new policies, and so the network evolved. Because this event is similar to space commercialization, policies could be made now, before it really becomes an issue like in this case.

Possible Policies

Neither the Outer Space Treaty, the Commercial Space Launch Competitiveness Act, nor the Artemis Accords address the impact of commercial space on the environment. The National Environmental Policy Act and the Federal Aviation Administration have shown to not be useful in regulating emissions from rockets (Nam, 2023). In a paper written by Yuree Nam, they suggest the use of the US Clean Air Act to regulate US rocket emissions. The Outer Space Treaty is greatly outdated since it does not reference any private space activity, but it is the only international space law that exists (Nam, 2023). Nam proposes using the Clean Air Act (CAA) to regulate the amount of emissions from rockets. The CAA requires the EPA to establish emission standards that reduce the hazardous air pollutants by the maximum amount for any major source, that being a source that has the potential to emit 10 tons per year or more of a hazardous pollutants or 25 tons per year of a combination of hazardous pollutants (Nam, 2023). The challenge would be in the government identifying the rocket launch facilities as a major source, but if done, this would be a hopeful resolution to regulating US rocket launches and to limit environmental impact.

Orbital Overcrowding

Policies are needed to address the orbital overcrowding issue. In 2021, debris hit the International Space Station, and caused a hole in the robotic arm (Guzman, 2021). Again in 2023, an old Soviet satellite broke apart after an orbital debris collision, this time adding to the debris problem (Pultarova, 2023). Orbital debris will continue to be a problem if not addressed. In fact, NASA performed a risk assessment of orbital debris. A collision in space can create a major amount of debris. For example, the Russian satellite, Cosmos 2251, created 1559 pieces of known debris (Johnson, 2018). The Chinese satellite, Fengyun-1C, produced 3218 known pieces of debris after its intentional collision (Johnson, 2018). Just one collision can create so much debris, that can then translate into more collisions. Orbital debris risk mitigation needs policies.

Possible Policies

The U.S. National Space Policy and the Artemis Accords address space debris, but not nearly enough. Proposed policy includes: creating a list of massive debris to be removed, funding companies to remove the debris, performing a cost-benefit analysis of orbital debris removal, and requiring collision and deorbit maneuver technology on all spacecraft. Lindsey Grey of Day One

Project, proposed the first three policies (Iyer, 2023). Documenting debris to be removed is a strong start to tackling the debris removal efforts. Similarly, prioritizing non trackable debris for removal is important as well. Funding companies to remove the debris is the next logical step. The United Nations treaty states that a state is liable for any damage done in space by their satellite (*Liability Convention*). But if waiting around for another country is the only solution to solving the space debris problem, it would never get done. Funding a company to address this problem would not only be supporting the economy, but also following the Artemis Accords by making space more sustainable. A cost-benefit analysis of space debris removal would highlight how spending money on orbital debris removal would in the long run save money. The last policy is a no brainer, all spacecraft should definitely have the maneuver ability to both deorbit and to avoid collision.

Conclusion

There are environmental consequences associated with the commercialization of space that need policies to regulate the impact on the environment. Rocket launches are increasing at a rapid rate every year. Rocket emissions can be very harmful to the stratosphere and can cause ozone depletion. Low-Earth Orbit is becoming very dense due to many companies launching satellites, and can later cause the start of the Kessler Syndrome or major collisions if left unfixed. No policies currently exist to regulate the emissions or LEO density. Making policies is essential to both help the environment and help maintain the growth of the space industry. Space exploration and commercialization might face limits if authorities do not establish policies to minimize harm to the Earth. Some may argue that there is not enough research on either stratospheric damage or space debris collisions or evidence that certain policies may fix these issues. To that I say, make policies to mitigate the current known problems. It is possible to make policies that are broad enough to live in the ever changing space industry while being specific enough to address the damages that currently and will soon exist. The policies can help the companies by laying down the requirements and boundaries of their technology so that they don't get stopped along the design and production cycle later, after a ton of time and money spent. Creating policies now would save the companies money in the future. The growth of any large industry should also include the growth of policies in that industry.

Bibliography

ARES | Orbital Debris Program Office | Frequently Asked Questions. (2022). https://orbitaldebris.jsc.nasa.gov/faq/#

Artemis Accords. (n.d.). *United States Department of State*. Retrieved February 13, 2024, from https://www.state.gov/artemis-accords/

Brisco, E. (2022, August 5). Space: New Frontier for Climate Change & Commodification, or Conservation? (Commentary). *The Good Men Project*. https://goodmenproject.com/featured-content/space-new-frontier-for-climate-change-commodification-or-conservation-commentary/

Coykendall, J. (2023, March 22). *Future of the Space Economy*. https://www.deloitte.com/conf/modern/settings/wcm/templates/modern--di-research-template/initial.html

Currin, G. (2022, May 17). *Physicists figured out how launching a Falcon 9 changes the atmosphere*. Interesting Engineering. https://interestingengineering.com/science/physicists-spacex-falcon-9-atmosphere

Dallas, J. A., Raval, S., Alvarez Gaitan, J. P., Saydam, S., & Dempster, A. G. (2020). The environmental impact of emissions from space launches: A comprehensive review. *Journal of Cleaner Production*, *255*, 120209. https://doi.org/10.1016/j.jclepro.2020.120209

Fact Sheet: The National Space Policy. (2010, June 28). Whitehouse.Gov. https://obamawhitehouse.archives.gov/the-press-office/fact-sheet-national-space-policy

Guzman, J. (2021, June 1). Space junk crashes into the International Space Station, causes damage [Text]. *The Hill*.

https://thehill.com/changing-america/resilience/smart-cities/556368-space-junk-crashed-into-the-international-space/

Impey, C. (2021). Unbound: Ethics, Law, Sustainability, and the New Space Race. *Studia Humana*, *10*(4), 1–17.

Iyer, V. (n.d.). How do you clean up 170 million pieces of space junk? *Federation of American Scientists*. Retrieved February 22, 2024, from https://fas.org/publication/how-do-you-clean-up-170-million-pieces-of-space-junk/

Johnson, N. (2018). *Orbital Debris Management & Risk Mitigation*. NASA. https://www.nasa.gov/wp-content/uploads/2018/12/692076main_orbital_debris_management_and_risk_mitigation.pdf

Krombach, L. (2011). *Public or Private: How to Save NASA | Department of English*. https://english.umd.edu/research-innovation/journals/interpolations/spring-2011/public-or-private-how-save-nasa#

Liability Convention. (n.d.). Retrieved February 1, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introliability-convention.html

Miraux, L. (2022). Environmental limits to the space sector's growth. *Science of The Total Environment*, *806*, 150862. https://doi.org/10.1016/j.scitotenv.2021.150862

Moon Agreement. (n.d.). Retrieved February 1, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/intromoon-agreement.html

Nam, Y. (2023). *One-Way Ticket to Mars: The Privatization of the Space Industry and its Environmental Impact on Earth and Beyond*. *19*.

Pultarova, T. (2023, August 30). *Old Soviet satellite breaks apart in orbit after space debris collision*. Space.Com. https://www.space.com/soviet-satellite-breaks-apart-after-debris-strike

Registration Convention. (n.d.). Retrieved February 1, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introregistration-convention.html

Rep. McCarthy, K. [R-C.-23. (2015, November 25). *H.R.2262 - 114th Congress (2015-2016): U.S. Commercial Space Launch Competitiveness Act* (2015-05-12) [Legislation]. https://www.congress.gov/bill/114th-congress/house-bill/2262

Rescue Agreement. (n.d.). Retrieved February 1, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introrescueagreement.html

Romera, A. A. (2023, December 31). SpaceX closes out record-breaking 2023, prepares for more records in 2024. *NASASpaceFlight.Com*. https://www.nasaspaceflight.com/2023/12/falcon-roundup/

Ross, M., Mills, M., & Toohey, D. (2010). Potential climate impact of black carbon emitted by rockets. *Geophysical Research Letters*, *37*(24). https://doi.org/10.1029/2010GL044548

Ross, M., & Vedda, J. (2018, March 31). *The Policy and Science of Rocket Emissions | Aerospace Center for Space Policy and Strategy*. https://csps.aerospace.org/papers/policy-and-science-rocket-emissions

Ryan, R. G., Marais, E. A., Balhatchet, C. J., & Eastham, S. D. (2022a). Impact of Rocket Launch and Space Debris Air Pollutant Emissions on Stratospheric Ozone and Global

Climate. *Earth's Future*, *10*(6), e2021EF002612. https://doi.org/10.1029/2021EF002612

Sismondo, S. (2009). *An Introduction to Science and Technology Studies* (2nd ed.).

Space Environment Statistics · Space Debris User Portal. (2023, December 6). https://sdup.esoc.esa.int/discosweb/statistics/

Space Foundation Releases The Space Report 2023 Q2, Showing Annual Growth of Global Space Economy to $546B. (2023, July 25). *Space Foundation*. https://www.spacefoundation.org/2023/07/25/the-space-report-2023-q2/

Space Law Treaties and Principles. (n.d.). Retrieved February 13, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html

SpaceX. (n.d.). SpaceX. Retrieved February 6, 2024, from http://www.spacex.com

The Outer Space Treaty. (n.d.). Retrieved February 1, 2024, from https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/introouterspacetreaty.html

The story behind the discovery of the ozone hole. (2022). *UK Research and Innovation.* https://www.ukri.org/news-and-events/responding-to-climate-change/topical-stories/the-story-behind-the-discovery-of-the-ozone-hole/

Twiss, S. (2022). *The Environmental Impacts of the New Space Race*. https://www.law.georgetown.edu/environmental-law-review/blog/the-environmental-impacts-of-the-new-space-race/

US EPA, O. (2013, July 31). *What is the National Environmental Policy Act?* [Overviews and Factsheets]. https://www.epa.gov/nepa/what-national-environmental-policy-act

Virgin Galactic. (n.d.). Retrieved February 6, 2024, from https://www.virgingalactic.com/spacecraft-fleet

Weedon, H. (2021, April 6). Reducing the Risk of Collision. *Space Data Association*. https://www.space-data.org/sda/blog/hmg-aerospace/

What Does the Phrase "Commercialization of Space" Mean? (2023, September 20). New Space Economy. https://newspaceeconomy.ca/2023/09/20/what-does-the-phrase-commercialization-of-space-mean/

What's Your Carbon Footprint? | Center for Science Education. (n.d.). Retrieved February 13, 2024, from https://scied.ucar.edu/learning-zone/climate-solutions/carbon-footprint

Whitt, K. (2021, November 15). *Kessler syndrome of colliding satellites could make low-Earth orbit unusable*. https://earthsky.org/human-world/kessler-syndrome-colliding-satellites/