The Final Draft (25% of Total Grade): Due Week 15

Make sure you completely fill out *all* the information in the sections below. Failure to complete these sections fully and honestly may incur a loss of points. Responding to some questions with “no” or “n/a” or “I don’t know yet” *is* acceptable; however, leaving any responses blank is not. If you do not understand any questions you are encouraged to contact your instructor.

Section 1

Name: Raghed Hamza

Your Major: Industrial Engineering

Section 2

On a scale of 1 to 10, how confident are you *now* feeling about writing for this course?

1/ 10

Section 3

Final grade you received from your previous assignment (Working Draft):

1/ 90

Section 4

Based on your last assignment and the lessons you have received so far in ENG 204, what **three** things have you given extra care and attention towards for this assignment?

SATELLITE CONSTELLATIONS

1/ Topic openers.

2/ Topic closers.

3/ Fixing “This, These” problems.

4/ Parallelism

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Checklist

Before submitting, make sure that you can write “YES” for each of the items below.

1/ I understand that if I write “YES” to any of these statements then such a response is completely true. I further understand that if there is evidence that I have not responded accurately then my paper will be returned to me ungraded. In such a case, I will have to correct my paper and resubmit it. In so doing, I will be subject to a “late penalty.”

YES

2/ I have accurately and fully completed an Auto-Peer review of my paper.

YES

3/ I have named the file for submission as follows: Working Draft [my iLearn name]

For example: Final Draft Philip Michael McCarthy.

YES

4/ The file I am submitting is a Microsoft Word document.

YES

5/ I have read the rubric and all relevant course material, and included all the information required.

YES

6/ I have changed the header of this paper to the ALL CAPS title of my paper.

YES

7/ I have pressed spellcheck/grammar check and corrected any text as appropriate.

YES

8/ I have carefully read *out loud* my entire paper and corrected issues where appropriate.

YES

9/ I have carefully checked my paper to ensure there are *no* examples of any form of plagiarism. I fully understand what these forms of plagiarism are and I realize fully that any examples of plagiarism will have severe consequences (including *but not limited to* a zero grade, an F for the course, a formal report to administration, and/or having to write a completely new research paper on a different topic). I further confirm that I have had ample opportunity to discuss issues of plagiarism with my instructor and that any and all of my questions have been addressed.

YES

10/ All work submitted in this paper is my own. No other person was involved in any of the actual writing of this paper.

YES

Write Your Paper Below

Begin your paper at the ***start of the next page***. Note that APA Level 1 and Level 2 headers have *not* been provided for you: You are now required to complete these yourself. Complete the paper using appropriate paragraphs. Remember to leave the rubric at the end of the paper.

Abstract

A satellite constellation (SATCON) is a network of artificial satellites that provides services globally. Many SATCONs have already been deployed in low-Earth-orbit, and hundreds more are in-development. These constellations are being deployed at unprecedented rates with little regard to their dangers. This paper sheds light on these dangers. First, SATCONs threaten environmental sustainability with the numerous rocket launches they require. Second, SATCONs hinder astronomical research because of their reflective nature. Third, SATCONs generate large volumes of space-debris in low-Earth-orbit. I also consider alternative positions. These positions argue that satellites are advanced enough to prevent space debris, and that space debris is not hazardous to Earth. While these arguments have merit, I show that SATCONs are not advanced enough to prevent space-debris, and that space debris is already ~~is~~ an immediate problem. The paper ends with recommendations for operators and designers to work with stakeholders to address the dangers of SATCONs.

Keywords: Satellite constellations, mega-constellations, Starlink, OneWeb, space debris

The Risks of Satellite Constellations

A satellite constellation is a group of small satellites in low-Earth orbit (McDowell, 2020). Such a constellation provides services to remote or disadvantaged areas of the globe. These constellations comprise hundreds to thousands of relatively small, almost identical satellites that orbit the Earth in unison, i.e., a “constellation.” Because of their placement in low-Earth orbit (LEO, an altitude of 80-100 kilometers), the satellites have insignificant signal latencies with receivers on the ground, making them ideal for communication and broadband satellite Internet (“Satellite constellations,” 2020). This placement is advantageous to areas of Earth where access to the Internet is negligible because of lack of communicative infrastructure, such as telephone lines. Although these constellations certainly appear to be beneficial, their risks to Earth and its occupants far outweigh ~~its~~ their benefits. As such, in this paper, I argue that current satellite constellations are dangerous and need to be modified.

I support my position with the following three arguments. First, I argue that satellite constellations are detrimental to Earth because their carbon footprint is substantial. Each rocket launch used to deploy satellites into orbit releases harmful greenhouse gases (Ross et al., 2010). Second, I argue that satellite constellations obstruct astronomers' views into deep space (Mróz et al., 2022). Image-altering flashes of light in telescope imagery have been recently associated with satellite constellations (Massey et al., 2020). Third, I argue that the rate at which space debris is generated by satellite constellations is dangerous. Pardini and Anselmo (2020) have concluded that current constellations are expected to collide at high rates in the near future.

I also consider alternative positions supporting the deployment of satellite constellations. One of these arguments is that satellite constellations are fully equipped with maneuvering systems that help them avoid crashes with other satellites (Walker et al., 2001). Another argument is that space debris does not pose a risk to Earth's inhabitants. While these positions have merit, I show that these arguments are invalid as even highly successful maneuvering satellite systems are dangerous to Earth. Furthermore, Pardini and Anselmo (2020) conclude~~d~~ that even constellations with highly efficient post-mission disposal systems still pose a risk to the population of low Earth orbit. Additionally, major space agencies such as NASA closely monitor the orbits of space debris, making necessary positions adjustments to at-risk satellites. Therefore, space debris is currently a large obstacle that can only be worsened with satellite constellations.

This paper is important for many reasons. Earth's orbits have been inhabited by satellites and humans for less than 60 years, an extremely short time in Earth's 4-billion-year age (Kuznestov et al., 2015). In addition, many organizations have already started deploying their satellite constellations into these orbits, and hundreds more are currently applying for permission to deploy their own constellations (Engber, 2005). As such, the sustainability and effects of these constellations must be reassessed by all stakeholders~~,~~ because data on the long-term effects of constellations is minimal. Therefore, stricter measures should be implemented regarding the deployment of satellite constellations, and more research should be conducted into the long-term effects of satellite constellations.

The Challenges of Satellite Constellations

Even though they are especially new, satellite constellations have attracted plenty of attention. However, most of this attention is negative and critical. Satellite constellations pose many challenges to Earth and its inhabitants, such as their unsustainability, their obstruction of the night sky, and their collision risks. As more agencies set out plans to launch new constellations, the effects of these constellations must be more closely monitored.

The Sustainability of Satellite Constellations

Satellite constellations pose a pressing risk to Earths' environment. Every single satellite ever manufactured has been launched into Earth's orbit aboard rockets, which release exorbitant amounts of green-house gases (Ross et al., 2010). Green-house gases refer to infrared active gases such as carbon dioxide and ozone, which are naturally present in Earth's atmospheres. These gases trap heat, or infrared light, and consequently, warm the Earth (Ledley et al., 1999). As such, the more of these gases that are present, the warmer the Earth becomes, and this phenomenon is aptly named "global warming." Therefore, satellite constellations indirectly lead to global warming.

This global warming is a result of extensive carbon emissions. In fact, these emissions are so massive because of the sheer size of satellite constellations. As of 2022, the largest satellite constellation in terms of number of satellites is Starlink, which is owned by the American private space agency SpaceX. Starlink currently consists of around 1800 satellites of a planned 42,000 (Mann & Pultarova, 2022; Sheetz, 2022) and each deployment is carried out using SpaceX's Falcon 9 rocket. Each Falcon 9 Starlink mission carries a maximum of 60 Starlink satellites and burns 112,184 kilograms of kerosene, which amounts to a total of 336,552 kilograms (kgs) of carbon dioxide (Doyle, 2017). According to the United States

Environmental Protection Agency, the average car emits 4600 kgs of carbon dioxide yearly ("Greenhouse Gas Emissions," n.d.). To put this number into perspective, the emissions of one Starlink mission are equivalent to the yearly emissions of 73 cars. If SpaceX were to proceed with its plan to place a total of 42,000 satellites into orbit, a minimum of 235 million kgs of carbon dioxide will be dispensed into Earth's atmosphere. Therefore, satellite constellations are major sources of carbon emissions.

As a result of their enormous carbon dioxide footprint, satellite constellations are heavily contributing to climate change. Long-term climate change is an inevitability, but controlling how much climate change occurs is not. The number of emissions produced by humanity increases exponentially every year. In fact, Hansen et al. (2013) argues that these emissions, mainly carbon dioxide, will remain in the atmosphere for millennia. As a result of the greenhouse effect, the trapped emissions give rise to heightened global temperatures. This rise in temperatures causes polar ice caps to melt at a faster rate, raising sea levels globally. After conducting simulations of sea levels into the year 2100, Hansen et al. found that a sea level rise of multiple meters is expected. Consequently, such a rise would displace millions of refugees and force them to seek asylum from low-lying coastal areas (Ahmed et al., 2021). As such, with their expansive carbon emissions, satellite constellations are set to play a dense role in climate change.

The Impact on the Astronomical Community

Since the wandering gazes of Neanderthals, humanity has come a long way in astronomy and has accomplished prominent advancements. These advancements have helped humanity walk on the moon, observe the atmospheres and compositions of the planets in our solar system, and send satellite probes into interstellar (outside our solar system) space (McDougall, 2015). However, astronomy is now in jeopardy because of satellite constellations. The astronomical community has been largely averse to and concerned about the deployment of exorbitant numbers of satellite constellations. Indeed, their uneasiness was so great that highly reputable astronomers from around the world met virtually over three days in what is now called the Satellite Constellations 1 (SATCON1) workshop (Walker, et al., 2020). SATCON1 revealed many new findings about the effects of satellite constellations and presented 10 recommendations to help mitigate the effects of satellite constellations. Therefore, further analysis of these effects is necessary to the astronomical community.

Correspondingly, recent studies have established a direct correlation between Starlink Satellites and streaks of light. One such study was conducted by Mróz et al. (2022) and analyzed the impact of Starlink satellites on imagery captured by the Samuel Oschin Telescope and the Palomar Observatory telescope. The study searched for certain streaks of light that are typically associated with the reflection of light off a satellite. The researchers' results revealed that the number of images affected by these streaks rose from 6% in late 2020 to 18% in August 2021. This number suggests a direct link between the number of affected images and the number of satellites, as the bulk of Starlink satellites was deployed in early 2021 ("List of Starlink Launches," 2022). As a result, the number of telescope images affected by streak of light is increasing rapidly with the deployment of satellites.

In fact, it is streaks such as these that have drastic effects on telescope imagery. A Starlink satellite has an average brightness of 2.4 mag (apparent brightness), which means the satellite can be seen with the naked eye (Tregloan-Reed, 2020). Furthermore, as of 2020, Gallozi et al. (2020) estimated that between 60 and 180 satellites can be observed at all times in the night sky. This congestion of bright satellites is set to have a great impact on the natural darkness of the night sky. Consequently, such an alteration in brightness results in inaccurate information in telescope imagery, which would drastically distort astronomers' perceptions and calculations. In fact, some of the alterations were so significant that SpaceX attempted to redesign its satellites to lessen their effects on observatories on the ground. The product of this redesign was STARLINK-1130, a prototype satellite coated in a material designed to reflect less light (Mróz et al., 2022). Despite its success at lessening light reflection, the project was soon abandoned as the coating created thermal issues in satellites. The development of STARLINK-1130 is important as it shows that SpaceX itself is

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Commented [PMM3]: Twice – in the same paragraph?? odd acknowledging the negative effects of its constellation on astronomers. Since STARLINK-1130, there have been no other attempts to resolve the problem and astronomers' concerns went unanswered.

In addition to visible alterations in the atmosphere, satellite constellations create invisible alterations in the form of radio frequencies. Telescopes can capture all forms of light along the electromagnetic wave spectrum, and many observatories choose to capture radio waves. This choice is because radio waves travel over long distances and are emitted from galaxies, black holes, and many other astronomical objects ("What are Radio Telescopes?", n.d.). In fact, the first image ever taken of a black hole, one of the most elusive celestial objects in our universe, was taken using a radio telescope (The Event Horizon Telescope Collaboration et al., 2019). However, satellite constellations pose a risk to radio telescopes because most satellites transmit information to the ground at radio frequencies. For example, OneWeb, a constellation funded by the UK government ("Our story," n.d.), comprises satellites that transmit data between 10.7 and 12.7 gigahertz frequencies (FCC, 2016). Thus, it becomes challenging for radio telescopes to distinguish between artificial and naturally occurring sources.

The Impact on Low Earth Orbit

Since Sputnik 1, the first artificial satellite, was launched into orbit in 1957, satellites have become much more complex and numerous (Kuznestov et al., 2015). As of January 2022, there are 4,550 satellites in orbit around Earth, and almost 2700 of them are attributed to satellite constellations in low Earth orbit (LEO) ("Every Satellite," ~~,~~ 2022). This "overpopulation" presents many drawbacks to the sustainability of LEO. To fully understand the impact of these drawbacks, understanding the life cycle of a satellite is necessary. First, a group of satellites is launched into orbit aboard a rocket. Second, each satellite gets placed into its predetermined orbital path to serve its function. Finally, at the end of a satellite's predicted lifetime, operators begin disposing of the satellite using its post-mission disposal system (PMD). As a result of the final stage's complexity, the Federal Communications

Commission (FCC) sets guidelines on the stage that all satellite operators must adhere to. The FCC expects “satellites that operate at lower altitudes [less than 36,000 km] … be maneuvered downward to ensure that it [a satellite] falls from space…” (FCC, 2004, as cited in Engber, 2005, p. 5). This decree means that all LEO satellites are expected to dive into LEO at the end of their lifetimes, where they would burn up in the atmosphere, possibly dispersing debris and shrapnel in their wake. Although most of these elements burn up in the atmosphere, between 10% and 40% of them survive the plunge (Engber, 2005), and hundreds of pieces crash into Earth’s surface every year (Aerospace, n.d.). Thus, satellite constellations generate harmful space debris.

In addition to generating space debris from stationary satellites, satellite constellations pose a threat to the sustainability of LEO. The threat to space sustainability is so detrimental that computer models of future LEO suggest that “the space debris population has reached a tipping point such that collisions will increase in frequency even in the absence of new space traffic…” (National Research Council, 2011, as cited in Virgili et al., 2016, p. 5). Virgili et al. (2016) conducted an experiment to measure the risks to space sustainability from large constellations and found that the LEO overpopulation wholly depends on high success rates of their post-mission disposal systems (PMD). Coupling this result with the fact that already existing satellite constellations, such as OneWeb, have PMD success rates lower than those in Virgili et al.’s study, a conclusion can be drawn (Pardini & Anselmo, 2020). This conclusion suggests that space debris has already reached the aforementioned tipping point, which would cause congestion, collisions, and a plethora of space debris in low Earth orbit. Therefore, the risks to LEO sustainability caused by satellite constellations are possibly calamitous.

In addition to possibilities of striking at-risk areas on the ground, a congestion of space debris in Earth’s atmosphere risks hypervelocity collisions between debris and functional satellites. Pardini and Anselmo (2020) conducted an experiment in hopes of quantifying the expected number of collisions caused by large satellite constellations in low Earth orbit. The result was dubbed the specific criticality index. The authors concluded that at an altitude of 800 km, the index would increase by 10% if only one hundred more malfunctioning satellites were placed into orbit. In addition, in less crowded orbits at an altitude higher than 1100 km, a 10% index increase would be caused by more than two hundred malfunctioning satellites. Collisions in near-vacuum mediums can be disastrous, possibly colliding with established singular satellites and the International Space Station. Therefore, collisions with the International Space Station could result in dire consequences, as concluded in Chan and Zhou (2020). Depressurization of the modules, and loss of research, and possibly even life is highly probable in the event of a collision. Thus, disastrous collisions are one risk of satellite constellations.

The Opposition's Viewpoints

Ever since their inception, satellite constellations have been shrouded in plenty of controversy. Despite their clear drawbacks, many people support the deployment of satellite constellations. Satellite constellations appeal to many populations because of their easily accessible services. In fact, some people argue that overall, satellite constellations are safe and offer more benefits than drawbacks.

An example of one of these arguments is that satellites have highly successful post-mission disposal systems (PMD). Supporters of this argument argue that these high success rates mitigate space debris. However, while already implemented constellations do have high PMD success rates, they are still expected to generate high levels of space debris. In fact, Pardini and Anselmo (2020) found that Starlink satellites will collide at rates upwards of 20% at the end of their mission. As a result, even though Starlink satellites have high PMD success rates, many of their satellites will still collide decades from now. These collisions will result in increased levels of space debris. Furthermore, some studies have concluded that future satellite constellations are unlikely to have PMD success rates greater than current ones, and that getting close to 100% success rate is virtually impossible (McDowell, 2020). Consequently, supporters of satellite constellations cannot depend on the possibility of extremely efficient PMD systems. Therefore, highly successful PMD systems cannot be used to establish a correlation to highly effective space debris mitigation.

In addition to arguments regarding PMD systems, some critics argue that space debris is not hazardous to Earth's orbits. They base this argument on the fact that currently existing space debris occupies a negligibly small percentage of Earth's orbits (Nishida et al., 2009). Therefore, these proponents believe that the expected space debris from satellite constellations is inconsequential. However, space debris, despite comprising small shrapnel, is highly injurious to other satellites. In fact, the National Aeronautics and Space Administration (NASA) maintains a minute watch over as much space debris as possible in order to maneuver satellites to avoid collisions (Johnson, 2001). It is important to note that half of all space debris in orbit around Earth came from two events: "a 2007 anti-satellite test by the Chinese government, and an accidental 2009 collision between two satellites," (Harris, 2019, p. 1). If half of all current space debris, which is already worrying major space agencies, came from only two collisions, the expected hundreds of collisions of satellite constellations will heavily endanger Earth's orbits. As a result, space debris is already a paramount problem Earth faces, and satellite constellations will only elevate the problem.

Recommendations

Many organizations have outlined plans and suggestions to mitigate the negative effects of satellite constellations. Regarding the impact on astronomical observations, Walker et al. (2020) lays out 10 recommendations in the aforementioned SATCON1 workshop report. These recommendations are aimed at observatories, constellation operators, and both observatories and operators in collaboration. Perhaps the most viable recommendation for observatories is to fund and maintain the creation of a centralized software program that helps identify and subtract the satellite trails in telescope imagery. This recommendation is viable since observatories from all reaches of world already collaborate on projects, such as the Event Horizon Telescope, which photographed the first ever image of a black hole. Another recommendation for operators is to conduct heavier simulations and deeper analysis on the reflection of sunlight off the satellites. Currently, operators such as SpaceX design Starlink satellites to maximize coverage and minimize costs without considering their effects on observatories. Therefore, although STARLINK-1130 (dubbed “DarkSat”) was an acceptable attempt at mitigating the reflections of sunlight, the simulations in controlled environments on Earth were not thorough.

Conclusion

Since the end of the Cold War Space Race, the support for the exploration of space has been dwindling. Instead, Earth’s population turned its attention to utilizing the orbits of their habitat. This utilization includes deploying satellites into a multitude of different altitudes in order to provide services and scientific data of the Earth. An example includes the deployment of satellite constellations, which are collections of hundreds of satellites deployed into low Earth orbit. Although satellite constellations provide a myriad of helpful services, they are extremely hazardous to Earth’s population.

Even though satellite constellations provide some benefits, they pose serious problems to Earth and its inhabitants. First, the sustainability of satellite constellations is not viable. This problem occurs because the assembly of a single medium-sized constellation requires an enormous amount of greenhouse-gas-emitting rocket launches. Second, the reflective properties of the satellites in constellations generate problems for the astronomical community. This predicament occurs because satellites alter original telescope imagery with reflected and infrared light emitted from the satellites’ surfaces. Finally, the sheer size of satellite constellations is a risk to low Earth orbit. This risk is caused by the overpopulation of constellations in low Earth orbit, which can lead to overpopulation, collisions with other spacecraft, and a plethora of space debris.

Although satellite constellations pose many risks to Earth, proponents of satellite constellations hold opposing views. Some proponents argue that satellite constellations are equipped with advanced systems that help with safe and sustainable disposal. While most satellites are equipped advanced systems, their effectiveness remains exceptionally low and unsustainable as of 2022. In addition, the opposition has also expressed that space debris is not a highly concerning issue. However, space debris already is a pressing problem to most space agencies, as agencies such as NASA closely monitor as much as space debris as possible.

Because the eradication of satellite constellations is unlikely, a multitude of steps can be taken to lessen their impact on Earth. First, operators and designers of satellite constellations should work closely with astronomers. Through this collaboration, more attempts at developing "dark," unobstructive satellites can be executed. Second, designers should devote more of their research and development into refining the post-mission disposal system of their satellites. Once a high enough effectiveness is achieved, the overpopulation of low Earth orbit would become less of a risk. In general, more research should be conducted into the effects of satellite constellations. If a space race were to ever happen again, humanity would need the space around it to be intact.

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well done! A VERY interesting and VERY original paper …

I suggest you address those very few issues above and then – yes – go ahead and submit it to Asrar!

good luck! 😊

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The Final Draft will be evaluated based on the rubric below as well as all materials, instructions, and feedback provided by the instructor. Note that evaluations assume good punctuation, word choice, grammar, presentation, and strength of arguments. Evaluations also assume an appropriate quality of writing, length of response, and that language issues discussed in class have been followed appropriately. Points will be deducted if these assumption are not met. Points will also be deducted if the template has not been completely and appropriately filled out, or if any item from the template is missing. A further points' deduction will occur if an incorrectly named file is submitted.

Rubric for Evaluating the Final Research Paper

Final Research Paper

The final research paper is 10-12 pages (3200 – 3850 words, excluding reference list, abstract, and title page) and incorporates feedback from the drafting process.

Elements		Points
Content		
	Title Page	
	Abstract and Key Words	/5
	Effectively summarizes research paper (between 130 and 150 words)	
	Lists 3-5 relevant key words	
	Introduction (~1 page)	/5
	Provides appropriate and compelling entry to the topic	
	Clearly articulates the research question(s) and/or thesis	
	Body (~9-11 pages)	/50
	Presents a well-structured, logically-argued, and cohesive discussion	
	Includes headings that reflect the paper organization	

	Supports all points/arguments with credible and relevant evidence and cites definitions of key terms/ideas as applicable	
	Synthesizes multiple sources	
	Shows originality, critical thinking, and in-depth, nuanced analysis	
	Conclusion (~up to 1 page)	/8
	Restates main points and addresses the research question/thesis	
	Comes to logical conclusion from evidence	
	Makes final comment(s)	
References		/7
	Uses correctly formatted APA in-text citations	
	Includes correctly formatted APA references	
	Contains all and only the cited texts	
Style	Entire paper	/10
	Is polished in tone and style appropriate for an academic audience	
	Uses clear and sophisticated language and variety in sentence structure	
Mechanics	Entire paper	/5
	Is accurate in terms of grammar, spelling, punctuation, capitalization, word choice, and transitionals	
Format/ Layout	Entire paper	/5
	Follows APA page layout (title page, running head, headings, font, etc.)	
Revision		/5
	Incorporates feedback from the Working Draft and any consultations	

SATELLITE CONSTELLATIONS

Total		/100