Prospectus

Creation of Space-based Methods to Improve Virginian Roadways
(Technical Topic)

The Consequences of Space Debris
(STS Topic)

By

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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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Introduction

Transportation is key to quality of life and economic development. However, congestion on roadways, especially congestion due to inclement weather, costs billions of dollars, loss of life, and negatively affects daily life (Federal Highway Administration, 2020). Currently, Virginia collects weather data through Doppler radar systems, local ground-based weather stations, which include manual observation, and weather satellites, such as the National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES). This weather data is then combined and put into publicly available sources such as browser-based weather maps (National Weather Service, 2020). Although many drivers consult weather information services before driving, there are currently few services that offer real-time weather data designed to be used during transit for route planning or rerouting (Barjenbruch, 2016).

Satellite imagery is at the core of real time weather data. Due to the high initial cost of designing and launching a satellite, it is often desired for these satellites to have the longest mission lifetime possible. However, a major threat to satellite longevity is impacts from space debris, including micrometeorites and broken parts from previous satellites. Currently, there are thousands of pieces of space debris large enough to be tracked in orbit around the Earth. Each one of these can present serious danger to satellites in orbit (European Space Agency, 2005). Space debris has three main sources: defunct satellites, satellite-satellite collisions, and military testing of anti-satellite weapons. Defunct satellites are satellites that fail to deorbit, never burning up in the atmosphere on their return to Earth. These defunct satellites tend to stay in one piece, not contributing much to the total amount of space debris. Satellite-satellite collisions, on the other hand, while rare accidents, result in the near complete disintegration of the two satellites, creating an enormous amount of orbital debris. Military testing of anti-satellite weapons also results in a similar amount of orbital debris created, yet this source of orbital debris is consciously made by governments. For instance, just two events: an accidental collision between an American and Russian satellite in 2009, and a Chinese anti-satellite missile test in 2007, increased the amount of large orbital debris in low Earth orbit by 70%. Currently, orbital debris is exceptionally difficult and costly to remove. Therefore, the best way to mitigate this problem is to limit its production (NASA, 2019). This project will to create a satellite in order to collect real time weather data that can improve the safety and efficiency of Virginian roadways. Alongside this, it will explore the harmful consequences of space debris and the factors that lead to its production in order to advocate against the usage of anti-satellite missiles.

Real Time Weather Data

The state-of-the-art weather satellite technology in the United States is the GOES-R series satellite. GOES-R contains two Earth-pointing sensors, the advanced baseline imager (ABI) and the geostationary lightning mapper (GLM). The ABI contains a 16-band imager capable of viewing multiple wavelengths in the visible, near-infrared, and infrared spectrum. The GLM is capable of detecting the location, frequency, and extent of lightning discharges, allowing it to identify intensifying thunderstorms and tropical cyclones. This allows GOES-R to detect various elements on the surface or in the atmosphere, including cloud formation, atmospheric motion, surface temperature, ocean dynamics, fire, smoke, and many other weather or weather-related indicators. According to NASA (2010), GOES-R “provides three times more spectral information, four times the spatial resolution, and more than five times faster temporal coverage than the previous system”.

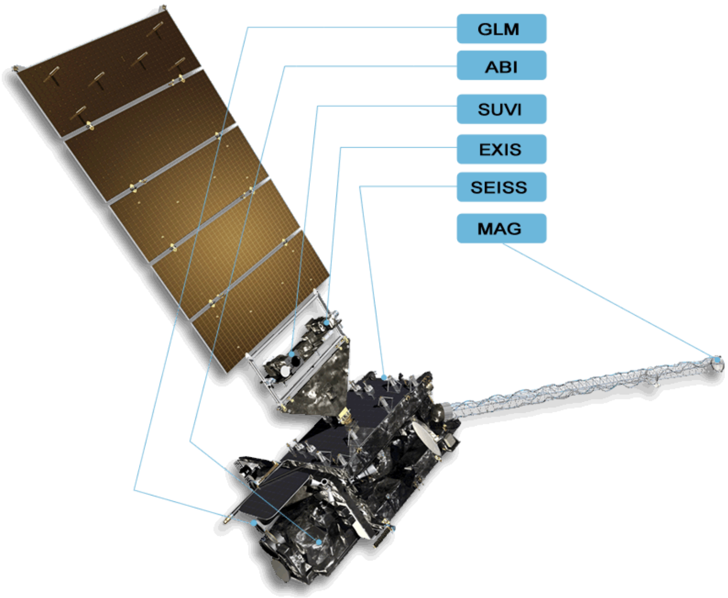

Figure 1. GOES-R satellite featuring the earth-facing GLM and ABI sensors (NASA, 2010)

NOAA's weather data collection has never been better, with increasingly accurate and frequent data allowing for extremely reliable short-term forecasts and improved long-term forecasts. Even with the incredible capabilities of the GOES satellites, integration of this data into preexisting, popular route planning apps is minimal, even though adverse weather conditions are a significant cause of vehicle crashes every year (Federal Highway Administration, 2020). By integrating real time weather data into navigational apps for drivers, both lives and money can be saved.

Even though GOES seems to be able to detect all forms of weather, many weather measurements are still done by hand. For example, depths of precipitation like snow and rain are typically done by a human at ground-based weather stations (Rasmussen et al., 2012). This leads to precipitation measurement stations being far apart and infrequently updated data reports. According the snow measurement guidelines memo from the National Weather Service, snowfall is one of the most important weather elements to measure in an accurate and consistent manner. Augmenting current weather satellites, either by adding an advanced precipitation depth and intensity sensor to an existing spacecraft or constructing a new, dedicated satellite, would be a tremendous increase in abilities for current weather data technologies. In a personal interview with Michael Fontaine of the Virginia Department of Transportation, he stated that any and all data that can be generated about the weather would be well received by government officials. Most importantly, the data resolution must be fine enough in order to detect conditions on roads, as opposed to a large chunk of land that contains a road.

Michael Fontaine stated that road weather condition sensors require more maintenance as they get older. Therefore, the total cost of these sensors goes up as time goes on. The range of these sensors is also limited and, in many areas, there are no sensors. Instead of adding a snow and rain depth sensor to the existing fleet of sensor suites, a single space-based solution, possibly in geosynchronous orbit constantly watching Virginian roadways, can maintain higher frequency updates with greater resolution for less cost, especially if preexisting ground stations are used to collect the data sent from the satellite. Many vehicle crashes are due to wet and slick roads (Federal Highway Administration, 2020b), and according to a study in Utah by Barjenbruch (2016), given advanced warning of weather events, 66% of commuters will change their commuting behavior to account for adverse weather. With improved resolution and frequency of precipitation levels and more reliable sources of weather information, more accurate weather warnings can be given, which will save drivers' lives.

My team will create a CubeSat, the state of the art in satellite technology, in order to observe weather phenomenon from space. A CubeSat is a modular, standardized launch bus used mostly for educational projects. Sizes are typically anywhere from 1U, up to 6U, where a U is a 10cm cube that weighs no more than 2kg (The CubeSat Program, 2020). In order to detect weather, I will place a spectrometer onto a 6U CubeSat and then place the satellite into low Earth orbit. The spectrometer will detect the wavelengths of radiation reflected off the Earth, allowing me to correspond a wavelength signature to a certain weather phenomenon. I will focus on detecting flooding and snowfall depths on roadways, two weather measurements that still rely on manual measurement (Fontaine, 2020).

Consequences and Causes of Orbital Debris

United States is dependent on satellites to provide for current lifestyles. GPS, television, weather forecasts, and telephones are all examples of widely used technologies that would be either worse off or impossible without satellites (Union of Concerned Scientists, 2014). Even if a group does not use any of these technologies, they are certainly impacted by people who do use these technologies. For example, the Amish, a group of people famously known for being slow to adopt technologies or even not adopting them at all if they are deemed unnecessary, often use outside technology that would not be possible without satellites or make others use such technology for them, such as delivery networks and GPS or websites and satellite internet (Wetmore, 2007).

Satellites must be protected from damage while they are in orbit. Currently, this is accomplished by providing satellites with extra fuel in order to maneuver around orbital debris or simply adding armor to sensitive parts. This can raise costs, since each pound taken into orbit can cost upwards of $10,000 (NASA, 2004). For example, the ISS has performed several maneuvers to avoid debris since 1999 and also has armor, known as a Whipple bumper, to protect its inhabitants from deadly collisions (Staff, 2020; Committee on International Space Station Meteoroid/Debris Risk Management, 1997). According to the European Space Agency (2005), the amount of space debris is increasing each year, as seen in Figure 2. As the amount of space debris increases, the risk of collisions will grow exponentially.

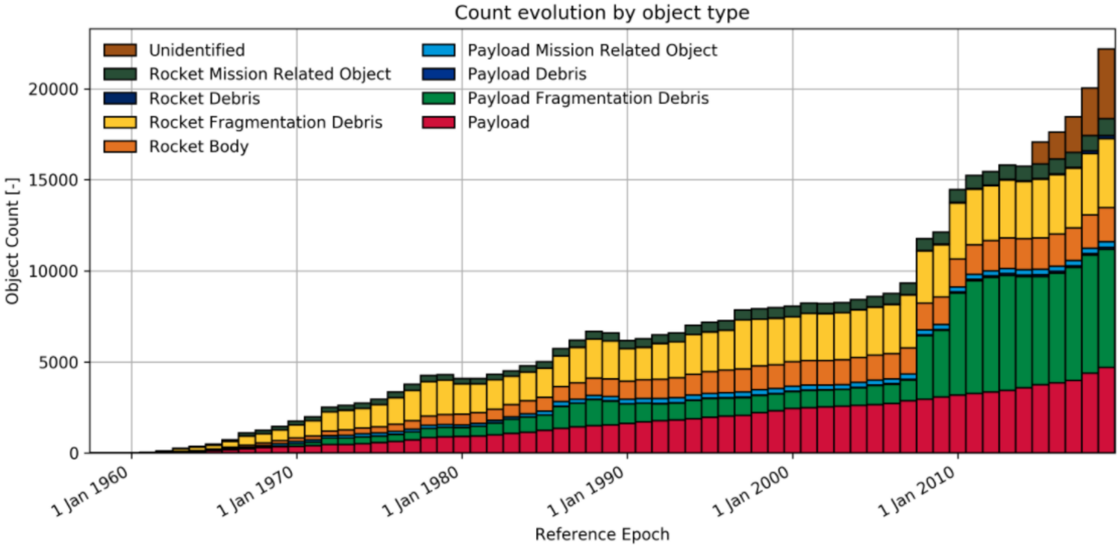

Figure 2. The increase in space debris count with time (European Space Agency, 2005)

Collisions with even the smallest pieces of space junk can do a significant amount of damage, as orbital velocities are in excess of 20,000 miles per hour. Not only can space debris present a one-time hazard to satellites, it can also render entire orbital zones untenable for future missions. Space debris can cause a cascade effect, known as Kessler syndrome, where space debris damages a satellite, creating even more space debris, which then spirals out of control until all satellites in an orbit are completely destroyed (Kessler, 2010). In Kessler's article, he states that "we must obtain near 100% compliance with guidelines… and, in addition, we must retrieve a number of objects that are already in orbit" in order to prevent this catastrophic collapse of orbital areas. Currently, NASA has published a handbook showing how to limit the production of space debris, but there are no international laws constraining its production (NASA, 2019).

Even if all satellites are properly disposed of, the purposeful destruction of satellites via anti-satellite missiles can massively increase the amount of space debris in orbit (Mosher, 2019). As shown in Figure 2, the large increase in object count from 2007-2008 was due to China testing an anti-satellite missile against one of their own satellites. According to the ESA, this single event increased the amount of trackable space debris by 25%.

I will frame the negative effects of orbital debris using the social construction of technology. The social construction of technology claims that technology is created by social groups in order to provide for their needs and was developed in opposition to technological determinism. Where technological determinism says that technology influences social groups, the social construction of technology shows not only how technology influences social groups, but how social groups can influence technology (Pinch & Bijker, 1984). For example, a communications satellite can influence culture by permitting previously distant social groups to exchange ideas. However, social groups can also influence the technology. Militaries could restrict this satellite to solely battle-related communications, which could influence another social group to create an anti-satellite missile to destroy that satellite and limit military communications. In this case, countries represent social groups. Satellites and anti-satellite missiles are the technologies that provide for their needs. In turn, I will describe the potential impacts of anti-satellite missile technology on other social groups and how these groups have differing perceptions of this technology. The possibility of differing perceptions of an artifact is known as interpretive flexibility (ibid). For example, the American military might favor destroying a Russian spy satellite. The debris created by the explosion may destroy an emergency services communications satellite, causing delays in rescues that result in loss of life. Even though the military might favor the use of anti-satellite missiles, a different social group, in this case emergency services, certainly would not approve. By considering the motives of countries and governments and analyzing the pros and cons of creating such missiles, I will show that the risk of Kessler syndrome outweighs any benefits of their usage.

Why is Space Debris Created?

In the pursuit of creating a space-based solution to improving Virginian roadway safety and efficiency, I must consider the secondary effects of this solution. Basing roadway safety upon satellite services requires that the satellites are not disabled by space debris. Any satellite has a risk of becoming space debris, clogging up orbits and wasting valuable orbital resources (O'Callaghan, 2019). A responsible satellite operator and designer, thus, must provide for the proper disposal of a satellite once it has reached the end of its lifetime. This often means deorbiting the satellite, allowing it to burn up as it reenters the atmosphere, or putting the satellite into a "graveyard orbit" (NASA, 2020). Creating space debris on purpose via the use of anti-satellite missiles is dangerous and negatively affects all of humanity.

Overall, I want to figure out what motivates countries to use anti-satellite missiles, how targets are chosen, and the effects they might have on other social groups. I will create a historical analysis primarily focusing on a case study of the 2007 Chinese-led destruction of the defunct weather satellite FY-1C, which led to the production of a significant amount of space debris (Kelso, 2007). I will also focus on the Indian Mission Shakti, the Russian PL-19 Nudol missile, and the US Operation Burnt Frost, comparing and contrasting each scenario. I will also analyze each event from multiple perspectives, showing how other countries and social groups perceived each event. Information will be gathered from governmental and media reports, such as Department of Defense, Air Force, and NASA memos as well as descriptions from news services. As many of these events deal with classified topics, I expect to mostly be using NASA memos, which focus more on the scientific aspects of the events instead of political or military perspectives and are thus more likely to include useable information. I will interpret this information not as an American, but as an engineer concerned for the continued health of the Earth’s orbital environment.

Conclusion

By providing additional data on precipitation intensity, depths, and locations, I will to improve the safety and efficiency of Virginian roadways. This data will be gathered by a dedicated satellite or sensor hosted on a different satellite and then beamed to ground stations for processing and delivery. During this process, I hope to show the negative aspects of anti-satellite missiles and how misuse can lead to overwhelmingly negative outcomes. These two aspects should lead to safer and more efficient roads, where drivers can plan for or avoid sections of roads made dangerous and congested by inclement weather, as well as cleaner orbits in space. Secondary effects would be to raise awareness of the dangers of orbital debris and to urge drivers to take more precautions during inclement weather in order to avoid injury or death.

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