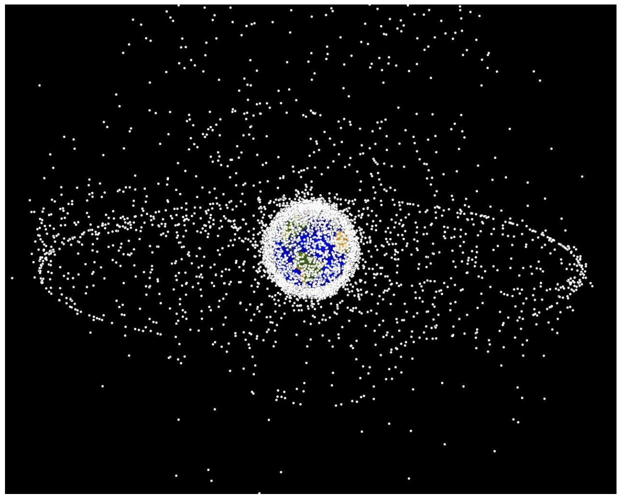

Space Debris: Obstructions in the Final Frontier

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INTRODUCTION

As prominently highlighted in the movie "Gravity" (2013), space debris is a threat to cybersecurity and national interests around the world. This paper will serve to explore various aspects of space debris, from the sources, to threats posed to manned missions and machines placed in orbit. As will be demonstrated in this paper, space debris is a clear and present danger, and its removal is both essential and mandatory for the safety and future of the international space program. Finally, we end with a hopeful resolution that once the threat of space debris is realized, mankind will continue to make efforts to literally and figuratively remove these obstructions to future space as well as extraterrestrial planetary missions.

The opening scene of the Warner Brothers movie "Gravity" (2013), featuring Sandra Bullock as biomedical engineer Dr. Ryan Stone and George Clooney as veteran astronaut Matt Kowalski, shows a spacewalk mission with repairs to the Hubble Space Telescope via the Space Shuttle Explorer. Soon after these repairs are completed, a Russian space debris cloud from a defunct satellite rapidly approaches from the east (with reference to the earth below) and severely impacts the Hubble Telescope, the Shuttle, and ultimately the entire mission.

This initial scene is the highlight of the entire movie, and the 17-minute-length of this unedited take is highly unusual within Hollywood blockbuster productions. The goal of director Alfonso Cuarón's story is to slowly immerse the viewer into the reality and awesome scope of spaceflight, while exposing the significant dangers that space debris introduces to manned missions. (Lubin, G.)

(For the record, the rest of the 91 minute drama focuses on Dr. Stone's heroic recovery and journey back home to Earth. Despite some flaws, misconceptions and some artistic-license exaggerations, it is a must-watch for any space enthusiast.)

As demonstrated in the first module of our class at Webster University, CSSS 5250 OA with Mr. John Sprague, Deputy, Technology & Innovation Division and End User Architect at NASA, such spacewalking missions will prove futile with the increase of debris found orbiting around our planet. Since this debris is almost entirely manmade, it is up to mankind (all of us) to remove as much debris as we can, either by sending it back down to Earth for destruction by the atmosphere, or by finally removing it from Earth's gravitational pull altogether.

We now turn to the various sources of debris and how we are continuing to add to the problem with each new space launch. Typically, space debris will fall under four general classifications: (1) Dead spacecraft, (2) Lost equipment, (3) Launch Boosters, and (4) Space Weapons. As a reference point,. The Union of Concerned Scientists has classified 902 fully or partially functional satellites within a database of over 19,000 large objects launched. ("UCS Satellite Database").

In terms of spacecraft that has expired its mission lifecycle, Derelict, Kosmos 1402, and Kosmos 954 stand out as prime examples. Vanguard I, currently the oldest surviving artificial satellite, was launched in 1958 into a Medium Earth Orbit (MEO), a distance between 2,000 Km (1,243 miles) Mean Sea Level (MSL) and 35,786 Km (22,236 miles) MSL.

Unfortunately, space debris collisions do not cease. In February of 2015, the United States Air Force DMSP-F13 suffered an explosion while in orbit, creating a debris field of over 150 objects, estimated to remain in orbit for several decades before returning to Earth. (Gruss, Mike.)

Lost equipment includes anything lost, misplaced, or any object that floated out of the reach of astronauts during a mission. These objects can include gloves, nuts, bolts, camera equipment, garbage bags (lost by Soviet cosmonauts during manned missions on the Mir Space Station), and everything in between. Depending on the vector of the initial trajectory when lost, these small objects could either float harmlessly back towards the earth's atmosphere, or stay in orbit indefinitely.

In terms of the weaponization of space, much of that study has been shelved because of the unintended consequences of blowing stuff up, thereby creating large debris fields. As our textbook indicates, "One can only imagine, for example, the different outcome in the New World if-as with orbital space debris-all of the arrows and bullets fired in those wars of conquest had continued to speed around the Earth causing damage for decades after they had been fired." (Moltz, p. 17)

Cubesats, as introduced to Webster University's CSSS 5250 OA F2 2016 class in Module 3 (Week 3) are a unique solution to the problem of space debris, but are no means the final word in satellite design and functionality. They are designed to fall back to Earth after an expected mission end time of usually a few months, but are limited in duration to short-term projects due to their size and limitations of hardware. That said, they are designed by students, and provide an excellent opportunity for the exploration of space while not significantly adding to the space debris field. (Robertson, G. A.)

The characterization of space debris can be thought of as that of two separate mutually exclusive function parameters: size, and position (altitude). It is estimated as of July 2013 that there are over 170 million objects with a diameter of less than one (1) centimeter, while there exist approximately 670,000 objects ranging in size from one to ten centimeters. Anything larger than a decimeter across, currently counted at 29,000 objects, is tracked by the United States Strategic Command (USSTRATCOM) as well as the Union of Concerned Scientists (Union of Concerned Scientists).

In terms of location, two particular orbit standardizations remain paramount and critical to the nature of the utility of the satellite, and thus to the threat of data security. Upon a casual glance of the debris cloud image provided on the cover of this thesis, two orbital regions seem to stand out among all other orbital possibilities as primary and dominant. These are Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO), so named for its synchronization to certain locations on Earth's surface. The GEO is also referred to as the Clarke Belt, after Arthur C. Clarke, a British author of science fiction, who hypothesized in 1945 that such a belt would maximize the potential for worldwide radio broadcasts. Thus, the GEO or Clarke Belt is located in the plane of the earth's equator, at an altitude of 35,786 km or 22,236 miles (calculated to be over 4,000 times the height of Mount Everest from MSL), and is about 265,000 km (165,000 miles) in circumference. (Basics of Space Flight, Section 1 Part 5).

Again, the goal of mentioning and describing these two especially advantageous orbital regions at length is because of the high value of utility for global data and communication satellites, and by proxy, the degree to which such satellites in these regions face exposure to any breach or loss of data, encrypted or otherwise, during their mission lifecycles. They also happen to be where most of the concerned debris lies, so any current and upcoming technologies should focus on those areas as a primary and immediate goal.

In higher altitudes and especially in the region of geosynchronous orbit, moving communication satellites to an empty longitudinal coordinate is now a best practice. However larger satellites with large solar panels as a fuel source remain a primary concern to equipment designers on the ground, namely because of their exposure to smaller debris collisions.

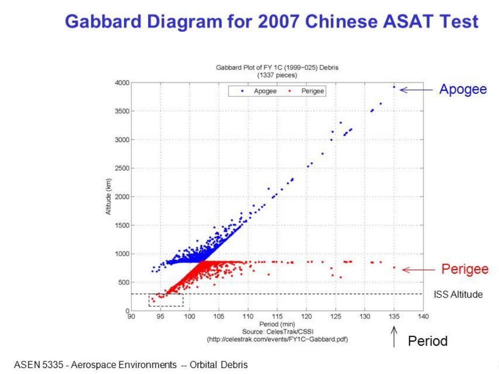
Of particular note is a region of orbital altitude nicknamed "The Graveyard Orbit" which lies outside the operational altitude of any currently functioning satellites. The purpose of the Graveyard Orbit is to maintain a space where defunct equipment may continue to soar in orbit ad infinitum, where it is either unfeasible or unable (through a lack of communication, for example), to bring the object back down through Earth's atmosphere for disposal through incineration. This orbital altitude is defined by a complex mathematical equation that consists of, among other things, aspect area [m^2] to mass [kg] ratio of the satellite in question, as well as the solar radiation pressure coefficient, a value which fluctuates slightly with relations to both solar and lunar gravitation. (Union of Concerned Scientists)

Various methodologies exist for the successful and accurate tracking and measurements of data, including those from the ground, as well as those measurements taken from space. They include the following:

Optical detectors including lidar as well as radar are the primary tools in tracking the trajectory and path of space debris as it orbits Earth. Various organizations play a role as well, and add to the body of knowledge surrounding the space debris problem. For example, the NASA Orbital Debris Observatory tracks items with a 3 meter (10 ft) mirror transit telescope via radio waves broadcast in frequency modulation (FM). In addition, the United States Strategic Command maintains a database of currently archived objects using a combination of ground based radar as well as space-based telescopes (just in case a closer look is warranted to warn systems against space-based armed weaponry, which in the 1980's was not out of the question from the USSR.) Finally, another major player in the constant battle to stay current with tracking all debris is the European Space Agency (ESA) Space Debris Telescope, as well as the 120-foot-tall AN/FPS-108 Cobra Dane radar system (pictured at right), located in remote Shemya, Alaska. The original intent of the Cobra Dane (built in 1976-77) was to verify the security of the United States with respect to any missiles or other ballistics originating from the Russian seashore, just across from the Bering Strait. It has now found a second life as an effective space debris cataloguer, aiding the United States Air Force and NASA with cataloging debris as far away as 2,000 miles away. (Moltz, J)

In addition to terrestrial-based measurements of space debris, hardware returning from space also provides an invaluable wealth of information. In addition to a number of months spent gathering debris data, the Long Duration Exposure Facility (LDEF) and EURECA satellites (1992-93) provided insight into the nature of sub-millimeter debris dust and flux... precisely the kind of debris that impacted the space Shuttle Challenger in 1983 with a fleck of white paint against the windshield, deeply embedding itself and causing a concern for the mission.

A Gabbard diagram is a scatter plot used to study debris clouds as they are formed by the collision of large debris. They provide information as to the directional velocity, as well as the point of impact. For example, the Gabbard diagram for the 2007 Chinese Anti-satellite (ASAT) space weapons test is shown at right. (Matney, M.)



Among the obvious threat scenarios of debris hitting a functional satellite in LEO, a communication or data satellite orbiting in GEO, or any interplanetary manned mission leaving Earth, we explore the threat posed by debris hitting other debris, causing a cascading effect of destruction known as the Kessler Syndrome.

The Kessler Syndrome (also known as the Kessler Effect) is a worst-case scenario involving space debris, introduced in 1978 by Donald J. Kessler. He hypothesized that at some point in the future, the number of space debris objects in Low Earth Orbit is high enough per unit of area that any collision between any object would cause a cascading domino effect, generating further debris clouds. Eventually, this would cause many areas of orbital space useless for many generations, as satellites could not function for long without getting hit and destroyed, and manned missions would suffer as well, as per the opening scene for "Gravity" introduced at the top of this thesis. For small bodies of less than 10 centimeters, this may not pose a threat, as systems are currently designed to move around known debris clouds, but given a hypothetical scenario of a large enough object impacting the International Space Station for example, and we have enacted a classic case of Kessler Syndrome. (Kessler, D. & Cour-Palais, B. G., 2637-46)

In 2009, Kessler summarized his findings thusly: "Aggressive space activities without adequate safeguards could significantly shorten the time between collisions and produce an intolerable hazard to future spacecraft. Some of the most environmentally dangerous activities in space include large constellations such as those initially proposed by the Strategic Defense Initiative in the mid-1980s, large structures such as those considered in the late-1970s for building solar power stations in Earth orbit, and anti-satellite warfare using systems tested by the USSR, the U.S., and China over the past 30 years. Such aggressive activities could set up a situation where a single satellite failure could lead to cascading failures of many satellites in a period much shorter than years." (Kessler, D. & Cour-Palais, B. G., 2637-46).

Shielding technologies such as Kevlar (used in bulletproof vests) and Whipple shielding, designed for such spacecraft as the International Space Station as well as fuselage design for extraterrestrial telescopes and scientific equipment such as the Hubble Space Telescope, continue to evolve with micrometeoroid threats and space debris for hypervelocity objects travelling at speeds greater than 22,000 miles per hour. As we design these technologies, we must take into consideration the durability of such equipment, so that the Kessler Syndrome does not become such a grave threat as to permanently prohibit the exploration and functionality of Low Earth Orbit. (Christiansen, 220).

To resolve these issues, numerous ideas about regarding the reduction and elimination of debris are available. Some of these ideas border on science fiction, but others are quite feasible. They include the following: (1) The European Space Agency (ESA) considered an "e.DeOrbit mission" which would essentially hunt and gather debris between 500 to 620 miles (800 to 1,000 km), using a mixture of technologies including nets, robotic arms, harpoons, tentacles, etc. (2)

The Japanese Aerospace Exploration Agency (JAXA) would consider using an electrified tethering rope used to shock debris with a current, which would then slow a satellite down to deorbit. (3) Without using artificial energy but rather the simple laws of physics, Texas A&M invented a "Sling-Sat Space Sweeper" which would use the force of capitulation to sling an object down towards Earth, while using the centripetal force gathered to propel itself to the next target for disposal. As of 2013, they are still in the conceptual blueprint phase. (4) Next up, we have a project called "Space Debris Elimination" (SpaDE) which would use high-altitude balloons to send airbursts out to space, disturbing the orbit of surrounding debris. (5) Finally, a project entitled "CubeSail" from Surrey Space Centre would use a solar-wind sail to drag and simply push down debris to be consumed by the atmosphere.

Of all these projects, I would prefer a mixture of (2) and (3). A clean sweeper network, with an effective solar-powered electroshock, could easily clean up significant portions of LEO within ten to fifteen years. Of course, the composition of the machines built to clean space debris would have to be durable and long lasting, lest they themselves ironically cause more debris than they were originally designed to clean up.

CONCLUSIONS

At the end of the day, the global public, and especially those involved in national or international space agencies, must appreciate the value of orbital space, and never diminish the qualities that zero gravity affords scientific research, as well as related strategic cybersecurity and national security interests that it poses. Through careful study and historical analysis of previous space missions and manned launches, we can learn from the mistakes of the past, as well as intelligently plan for future manned and unmanned space missions with a reduced risk of collision with space debris. The eventual pursuit and elimination of this evolving threat will continue to allow mankind to explore unobstructed views of our own home planet, as well as to view and eventually explore the universe around us via space telescopes such as the Hubble. And on a final humorous note, should we be fortunate or unfortunate enough to encounter extraterrestrial visitors, we owe it to future generations of our collective species to at least clean up the trash that lies outside the front door of our home planet.

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