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Sources, Categories and Impacts of Space Debris: A Review

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Abstract:- The activities of man in space environment have resulted in several disused satellites, rockets, and fragments of these and other machines being littered over the Earth's orbit thereby interfering with the smooth operations of active and useful spaced based technologies. In this paper we reviewed relevant literatures in order to comprehend the meaning, sources, categories and impact of Space debris. The paper also identifies solution being proffered by various nations and researchers. From the review we found that more needs to be done because of some limitations. The review is aimed at creating awareness and adding to existing literatures on the subject.

I. INTRODUCTION

Man is a social being who interacts with his environment to make it more useful to him. Today, technology has made these interactions even more interesting giving room for more innovative ideas to make man's environment more habitable. He makes use of the materials in his environment to make life meaningful and in the end generates a lot of wastes which nowadays are becoming more difficult to manage.

Presently, tons of wastes have been generated in space just like on land, as a result of human space activities. Orbiting our planets are thousands of dead satellites and fragments from the rockets launched over the years. Objects left in orbit were given little consideration in the early days of the space age. However, as the number of these objects has increased steadily and exponentially over time, so have concerns about the polluted orbital sphere[2] .

- *Definition of Concept*

According to [3] In Earth's orbit, whichever kind of artificial item that has become inactive is referred to as Space debris. This can include out-of-mission entire spacecraft, launch vehicles, or fragments thereof, as well as every discharged item or tool misplaced by astronauts while on space missions; and breakup actions, which can be accidental or deliberate.

Also, the Inter Agency Space Debris Coordination Committee (IADC) defines space debris as" all man -made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional"[3].

It is estimated that about 23,000 non useful objects of sizes larger than 10cm exist in earth's orbit and particles of sizes between 1 and 10 cm in diameter amounting to 500,000 presently floats in orbit. The number of particles larger than 1 mm, according to records, reaches 100 million. The amount of materials orbiting the Earth as of January 1, 2020 exceeded 8,000 metric tons, with several millions of pieces too small to be monitored[4] . The largest proportion of this debris is in low earth orbit, within 2,000 km of earth's surface; nevertheless, a number of debris can be found in geostationary orbit 35,786 km above the equator[5].

This growth in Space debris has become a great concern since it presents threats to satellites, piloted spacecraft, as well as humans. As a result of very high speed of objects in orbit, debris as small as a centimeter in diameter can seriously damage or destroy a satellite [2].

II. ORIGIN OF SPACE DEBRIS

Space debris may originate from any of these three ways:

Accidental or intentional creation as a result of collision or explosion

A. *Accidental or intentional creation as a result of collision or explosion.*
B. *Fragmentation*
C. *Mission Related operation [6].*

Most space debris result from disintegration caused by explosions and collisions, mostly deliberate [3].

During the 1960's, many spacecraft were deliberately demolished through self-destruct mechanism or anti-satellite test (ASAT). The two most terrible incidences recorded during the era of space debris build up were the intentional ruin of the Chinese Fengyun-1C satellite by arsenal deployed from Earth on 11th January, 2007 and the unintentional crash of Iridium 33, (a functional US communication satellite) into COSMO 2251, (a non-operational Russian satellite) on 10th February, 2009 in North Siberia. They collided at a speed of over 40,000km/h, causing complete breakup of both satellites [3]. It's worth noting that when the Chinese military destroyed the Fengyun-1C weather satellite in a test of an anti-satellite system, more than 3,000 fragments were produced,

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accounting for over 20% of all space debris. In not more than two years, the fragments had dispersed from Fengyun-1C's original orbit, forming a massive collection of debris that had fully surrounded Earth and about to re-enter the atmosphere. [2].

Also, the Russian laser-ranging satellite BLITS (Ball Lens in Space) suffered an abrupt shift in orbit and spin on January 22, 2013, forcing Russian scientists to abandon the project. [2]. A collision between BLITS and a piece of Fengyun-1C debris is considered to have caused this incident. Fifty percent of the debris below 1,000 km is made up of wreckages from Fengyun-1C, Iridium 33, and Cosmos 2251. [4]. [2] Indicated that fragmentation has been identified as the primary source of space debris, with three countries accounting for nearly 95 percent of all space debris currently in Earth's orbit. About 42% is attributed to China, the nation on the lead of debris generation, while the United States and Russia account for (27.5%) and (25.5%) respectively.

Mission related operations have also added much debris objects of various sizes in space and they account for about 12 percent of the presently cataloged debris. For instance, exhaust emanating from solid rocket upper stages includes aluminum oxide particles, paint flakes, and particles from thermal insulation. Separation of satellites from its launch vehicles upper stages involves losing of explosive bolts that disintegrate into smaller particles.

Also, the discharge of protective materials, covers, and other discarded physical parts into orbit is a common part of the process of launching a spacecraft on orbit. [5]. Also contributing to the debris community was non-functional space vehicle that stayed in orbit longer than their planned lifespan [2].

Some objects in lower orbits of a few kilometers have the potential to rapidly fall down to Earth. After a few years, they normally re-enter the atmosphere and, for the most part, burn up before reaching the ground. However, debris or satellites left at higher altitudes of 36,000 kilometers where weather and communication satellites are often placed in geostationary orbits can continue to circle Earth for hundreds or even thousands of years.

III. TYPES OF SPACE DEBRIS

On the ground of their origins enumerated above, space debris can be classified as follow:

A. *Spacecrafts that is no longer available, such as satellites that have outlived their usefulness. Example NigriaSat_1, NigComSat_1, Chinese Fengyun_1C, Cosmo_ 2251etc.*
B. *Rocket bodies that have been applied in placing satellites into its path in space.*
C. *Objects that were let loosed inadvertently at some point in missions (e.g. spare thermal glove, Hasslblad camera, backpack size tool bag [5] as well as items or waste such as toothbrush, tissue paper, etc. ejected from the space shuttle.*
D. *Collisions, explosions, or decay of active satellites may result in fragments or large pieces of debris [2]. The diagram below gives a description of the classified space debris.*

Diagrammatic representation of types of space debris is shown in figure 1.

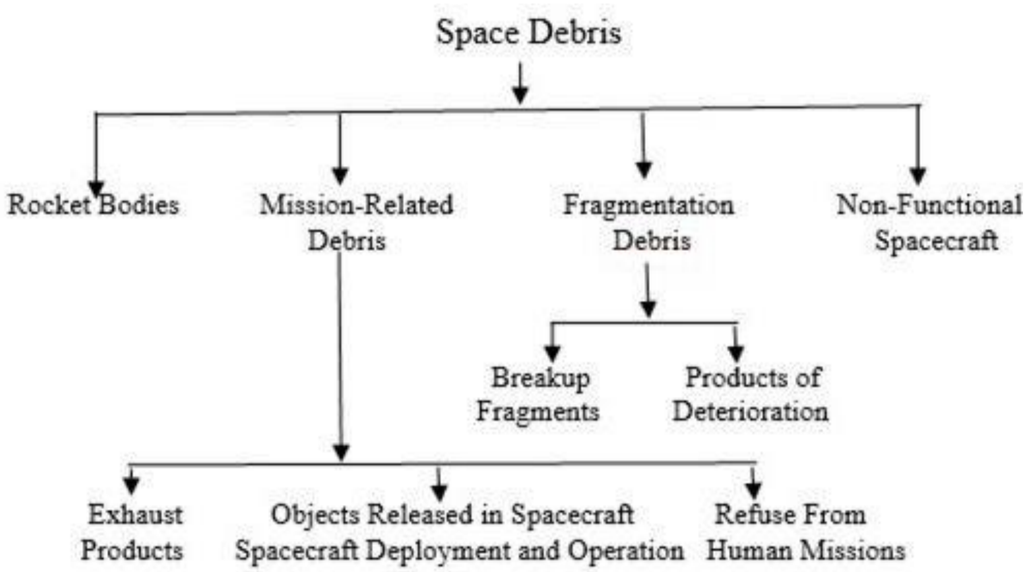

Figure 1: Representation of Objects in Earth's Orbit [7].

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IV. CATEGORIES AND IMPACT OF SPACE DEBRIS

Space debris has been categorized based on their sizes and impact by the US Space Surveillance Network (SSN) [2]. The space object catalogue is identified by launch date and country of origin [5]. The main categories of the space debris include:

A. Objects of debris with a diameter of around 10 cm.

These objects can be trailed by the SSN and they are cataloged in a local space object database. The impact of such sized objects is equivalent to a bomb exploding within the spacecraft. Objects of this magnitude can be traced and satellites can be maneuvered to avoid collision [2].

B. Debris objects between 1 cm and 10 cm.

The impact created from a 5cm object is the equivalent of being hit by a bus travelling at highway speed. Debris objects in this category cannot be tracked but are large enough to destroy a satellite or rocket body if it crashes with the main body of the spacecraft. Approximately 500,000 of these fragments are estimated to be in orbit at Low Earth Orbit altitudes. Any object that is struck by space splinter greater than 1 cm is likely to be fully fragmented and a collision of a huge object, such as a satellite or rocket body, will increase the space debris population by extra tens of thousands of particles [2].

C. Debris items of sizes between 3 mm and 1 cm.

This size of debris items has impact effect equivalent to being struck by a bullet. These pieces, which are estimated to number in the millions, are also untraceable. Due to the smaller nature of this range of debris, they will usually cause only localized damage but can still terminate a space assignment per adventure it strikes a vital part like a propellant tank, a computer, or sensor [2].

D. Debris items smaller than 3 mm.

The force of fragments from this size of junk is equivalent to being hit by a baseball thrown by a foremost league pitcher. Such bits of debris result in destruction to specific segment, especially if the surface portion of the spacecraft that is hit is critical to its operation, such as optical systems as well as solar arrays - telescopes, star trackers, cameras etc. In LEO there are projected 10 million space debris objects of sizes less than 3 mm [2]. Despite the sizes of this debris, even the smallest of objects, some of which cannot be detected by sensors, can be hazardous to manned and unmanned spacecraft. This is because they are orbiting at extremely high velocities [2]. Space debris moves about 10 times faster than a bullet (and no one sees a bullet coming), which means that the debris can easily punch through the protective covering on satellites or spacecraft [8].

V. INCIDENCE OF SPACE DEBRIS FALLING TO EARTH

Although most space debris burn up in the atmosphere, larger debris objects have reached the ground. On average, a total of between 200-400 tracked objects enters the Earth's atmosphere every year. That is about one every day [9].

About 20-ton chunk of a Chinese rocket (the Long March 5B, launched May 5) fell uncontrollably down to Earth and landed in the Atlantic Ocean as reported by Allen Kim on May 11th, 2020 for CNN.

The rocket has lost its core stage, which is essentially the spacecraft's backbone that supports its weight. Some reports have it that some of the debris reached the Ivory Coast[1].

Saphora Smith reported for the nbcnews.com that part of the Long March 5B rocket launched on April 29, 2021 hurled back to Earth on May 9, 2021 at about 10:24 am (Beijing time) crashing into the Indian Ocean. A greater part of this debris components burned up in the atmosphere upon re-entry.

Though it is usual for parts of rockets to return to Earth after a launch, this piece generated a little concern due to its lack of control and the uncertainty of where it would land on the planet[10].

Other instances of debris falling to Earth includes the premature return of the US space station Skylab (11th July, 1979) through the atmosphere, bringing down large mass of debris over the southern Indian Ocean. The Russian Space station (Mir heftier) made a return through the Earth's atmosphere on March 23, 2001 above the Pacific Ocean near Fiji. Although a large part of it burned up in the atmosphere, about 1,500 bits of it reached the Earth's surface[11].

Upon disintegration and return to Earth of the Space shuttle Columbia on Feb. 1, 2003, seven astronauts were killed. This tragic occurrence dispersed several thousand portions of debris across a 72,520 square kilometers area in Eastern Texas and Western Louisiana [11].

VI. SOLUTIONS TO SPACE DEBRIS PROBLEM

Since the first satellite-Sputnik 1- was launched into orbit in 1957, over 8000 satellites have been placed in orbit and 3000 of them are not operational, constituting space debris.

Hence, it is necessary to proffer solutions to space junks.

There are two basic actions to mitigate the problems associated with orbital debris:

A. Preventive actions
B. Removal actions.

Preventive actions forestall explosive failures of spacecraft and upper stages while the removal actions reduce the enormity of the trashes in orbit thereby reducing the chance as well as impact of orbit hyper-velocity collisions [2].

A summary of a number of the proposals for clearing debris from space is given below.

A. Giant Lasers

Using high-powered pulsed lasers located on Earth to create plasma jets on space debris could cause them to slow down and return to the atmosphere, where they could either burn up or fall into the oceans. This process is referred to as Laser Orbital Debris Removal (LODR). It uses laser technology which is relatively cheap and readily available.

B. Space Balloons

The Gossamer Orbit Lowering Device, or GOLD system, uses an ultra-thin balloon which is inflated with gas to the size of a football field and then attached to large pieces of space debris. The GOLD balloon will increase the drag of objects enough so that the space junk will enter the earth's atmosphere and burn up.

C. Self-Destructing Janitor Satellites

Clean Space One is a small satellite developed by Swiss researchers at the Federal Institute of Technology that can locate and capture space junk with jellyfish-like tentacles. The devise would then plummet back towards Earth, where both the satellite and the space debris would be destroyed during the heat and friction of re-entry.

D. Space Pods

Russia's space corporation, Enregia, is planning to build a space pod to knock junk out of orbit and back down to earth. The pod is said to use a nuclear power core to keep it fueled for about 15 years as it orbits the earth knocking down defunct satellites out of orbit. The debris will either burn up in the atmosphere or drop into the ocean. It is believed that by gathering about 600 inactive satellites in the same geosynchronous path and sinking them into the ocean, this approach could clean the space around Earth in just ten years.

E. Tungsten Micro duct

Smaller space debris of sizes less than 10 cm could theoretically be slowed by deploying tons of tungsten micro duct into low earth orbit on a trajectory opposite that of the targeted space junk. The slowed debris would then decay into a lower orbit, eventually falling into Earth's atmosphere in a period of few decades. The most significant obstacle to this proposal is the potential risk of unhealthiness of tungsten entering the atmosphere. In some research, tungsten materials have been linked to death at births and irregular musculoskeletal growth.

F. Space Garbage Trucks

The US Defense Advanced Research Project Agency (DARPA) is funding an Electrodynamics Debris Eliminator, or EDDE, a space garbage vehicle fitted with 200 giant nets with capacity stretch out to collect debris in space. The EDDE could then either fling the trash back to Earth, where it would end up in the oceans, or it could force the objects into a closer orbit, keeping them out of the way of active satellites before they decay and fall back to Earth.

G. Recycling Satellites

Some dead satellites could be mined for usable components by other satellites instead of being trashed. The Phoenix program at DARPA may develop new technology that will allow for the harvesting of valuable components from satellites in so-called graveyard orbits.

H. Sticky Booms

Altus Space Machines is currently working on a sticky boom robotic arm device that can cover 100 meters in length, and uses electro adhesion to induce electrostatic charges onto any material (metal, plastics, glass, even asteroids) it comes in contact with, then clamp onto the object because of the differences in charges. Even if an object wasn't built to be grappled by a robotic arm, the sticky boom is enabled to adhere to any space object. The sticky boom could be used to grab and dispose of space debris. These ideas for space junk cleanup may be useful in removing some of the debris that is currently littering the Earth's orbit.

While the different strategies being suggested have potential, all of them still have one major drawback: they appear to concentrate on bringing the junk back to Earth to land in our oceans, which already have enough problems. Consequently, scientists must devise more reasonable alternatives to space debris that not only clean up the debris but also dispose of it in an environmentally conscious and environmentally sustainable manner [12].

VII. CONCLUSION

Human space activity has resulted in the generation of tons of debris which poses great threat to space facilities (rockets, spacecraft, satellites) in orbit as well as to humans on earth. Although, there have been few disastrous collisions for now, much attention needs to be given to the gradual but continual build-up of these debris in order to forestall unknown deadly consequences. Some of the mitigating approach to solving these problems as reviewed in this work has some limitations.

Space agencies and space craft engineers need to do more in terms of designing space facilities so as to minimize accidental breakup, collisions, release of object in space craft deployment and operations, refuse disposal from human mission and as well minimize the danger of human fatality upon re-entry to earth.

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