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Repercussions of Anti-Satellite Missile Tests, Alternate ASAT Technologies, and Preventive Techniques for Mitigation of Space Debris

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Abstract - The proliferation of Anti-Satellite (ASAT) missile tests poses significant challenges to the sustainability of space operations, exacerbating the issue of space debris accumulation. This paper examines the repercussions of ASAT missile tests on space debris generation, evaluating the environmental and operational risks they entail. Additionally, it explores alternative ASAT technologies that may offer less destructive means of incapacitating adversary satellites, thereby reducing debris creation. Moreover, preventive techniques for mitigating space debris, including debris removal and collision avoidance strategies, are analyzed for their efficacy in preserving the long-term viability of space activities. By assessing the interplay between ASAT tests, space debris proliferation, and mitigation measures, this study aims to inform policymakers and spacefaring nations on the importance of responsible space operations and the adoption of sustainable practices to safeguard the space environment for future generations.

Key Words: Anti-Satellite (ASAT) missile tests, Space debris, Sustainability, Space environment, Mitigation techniques, Collision avoidance, Debris removal, Alternative ASAT technologies, Environmental risks, Policy implications

1. INTRODUCTION

In the early days, the space activities were a matter of national prestige. Every nation wanted to become ace and hence the technological progress in space research was driven. A silent race started between the nations to conquer the space which resulted in large number of space activities which includes launching of military and commercial satellites. That gave rise to ASAT missile tests inevitably and has its roots in history. The first US anti-satellite weapon was tested in 1959. An "air-launched ballistic missile" was fired from a B-47 bomber of the US Air Force at an Explorer VI satellite. The ASAT weapon "apparently came within four miles of its target"; the programme was called 'Bold Orion' [1]. China's destruction of the Fengyun-1C satellite in 2007 created thousands of pieces of catalogued debris, most of which remains in orbit. The Fengyun-1C satellite was modestly sized, about 750 kilograms. The destruction of a large satellite, such as a 10-ton military reconnaissance satellite, could easily double the amount of dangerous debris in low earth orbit at altitudes that are mostly used [2].

The Indian government characterized the Mission Shakti test as responsible because its target was at such a low altitude that all the debris would flush out "within weeks." However, the kinetic energy of hit-to-kill intercepts can kick debris pieces into new, higher orbits, which prolong the debris lifetime and threatens other satellites [2].

India's ASAT test is not the first to provoke controversy. In 2007, China downed a satellite at LEO at an altitude of 800km and at that time explosion resulted in more than 2,000 pieces of debris; hundreds of which are thought to be still believed to be floating in orbit now and have little chance of being disposed of for decades to come [4].

The ASAT tests of the major space-faring Nations are not available- Chinese ASAT test in January 2007, 2008, 2013, 2016; US ASAT tests 2008, 2010; Russians ASAT tests 2010, 2014, 2015. The world is weeping over the debris issue, posing a potential threat to the humanity's common wealth, upon which the entire planet has become dependent as before.

Is it really necessary to obliterate the satellite completely in ASAT missile tests? Aren't different methods of ASAT tests available like Fly-by or jamming? Such questions grabbed our attention and motivated us to take a look at the repercussions of ASAT missile tests, what are the alternate methods of tests, and we also aim at providing some preventive techniques that could be used in future ASAT tests and space launches for India.

2. CURRENT STATUS AND CHALLENGES

Today commercial and scientific applications is imperative in space. We have now become familiar to many services provided from space. In our daily lives communications, weather forecasts, television, remote sensing of the environment, and navigation are our daily activities which left traces behind in space.

After the launch of 104 satellites in February 2017, the year 2019 has proven to be a very successful year for Indian space missions, starting with the successful execution of Mission Shakti, followed by launching our own reconnaissance satellite along with 28 other satellites in different orbits, and the most recent Chandrayan2. India has become only the fourth country to complete a controlled soft landing on the moon. All of these feats were highly notable.

On March 27th 2019, Indian Prime Minister Narendra Modi announced to world that India had conducted its first successful Anti-Satellite (ASAT) missile test launching a 3 stage missile from Abdul Kalam Island Chandipur, Orissa on north eastern coast of India with a trajectory that eventually lead to it intercepting India's military satellite Microsat-R, 283km overhead. The 783 kg satellite was eventually destroyed when the interceptor, PDV Mk-II, ploughed through it over the Bay of Bengal. The test was successful and India became only the fourth nation after China, USA and Russia with antisatellite missile capabilities.

However, the test was condemned by many nations and agencies like NASA and especially by Pakistan who stated it as a completely unnecessary political posturing move that added significantly to earth's growing space debris problem. Just one collision in space can create thousands of new high speed, out-of-control pieces and threaten other spacecraft.

Indian Ministry of External Affairs said that the test was conducted at low altitude to ensure that the resulting debris would "decay and fall back onto the Earth within weeks." According to Jonathan McDowell, an astrophysicist at Harvard–Smithsonian Center for Astrophysics, some debris might persist for a year, but most should burn up in the atmosphere within several weeks.

Brian Weeden of Secure World Foundation warned about the possibility of some fragments getting boosted to higher orbits. US Air Force Space Command said that it was tracking 270 pieces of debris from the test. Jim Bridenstine, the head of NASA, stated that the explosion is supposed to have created 400 pieces of debris that puts the ISS, and the astronauts in 'danger'. He said that they are actively tracking the objects, and that 24 of them can be headed towards the orbit of the ISS.

As on date, there have been some 5000 successful satellite launchers and certain orbits are at risk of becoming congested. As on January 2019, 128 million pieces of debris smaller than 1 cm are in space, approximately 900,000 pieces from 1 to 10 cm and the current count of large debris > 10cm is 34,000. About 23,500 man-made objects are currently being regularly monitored by Space Surveillance Networks from the ground. Estimated number of break-ups, explosions, collisions, or anomalous events resulting in fragmentation are more than 500. Explosions are caused by energy reservoirs that remain unused upon completion of a mission. Only 5% of the monitored objects are functioning satellites. The effect has been particularly evident in the low earth orbit region. This extends to a height of about 2,000 kilometers. Two-thirds of all known artificial objects can be found in this comparatively small region. However, they are far from evenly distributed for most missions near polar orbits between 600 kilometers and 1,200 kilometers altitude are used for this reason. The highest collision risk can be found in the vicinity of the earth's poles. Mitigation is difficult and requires solutions that are practical, yet technically and economically feasible.

Before the active removal of objects can start, there are a number of legal issues to resolve. According to international space law, the responsibility for any debris object or abandoned satellite remains with the owner even though it is no longer functional. All risks associated with the mission are therefore the responsibility of the owner of the service vehicle and the owner of the target object. The selection of the target objects concerns all major spacefaring nations. Active removal measures must therefore rely on an international consensus. The technical and legal challengers must be overcome now.

3. PROBLEM FORMULATION

Today most of the debris is still caused by accidental explosions due to unused fuel on board. However, the problem can be alleviated by so-called passivation measures these include depleting unused fuel venting pressure tanks and switching of batteries. Collisions can also be prevented if satellites are removed from heavily frequented orbits at the end of their mission while they are still under control. If they are brought down to a height below 600km.

They will only remain in space for about another 25 years before re-entering the earth's atmospheric collisions with a few items of debris remaining in this area are very unlikely the passivation of objects and the reduction of their resistance time in space are measures that stem from recommendations by international experts they have already been incorporated in the guideline of many major spacefaring nations ISA also applies such majors the earth's observation satellites that provided data about our planet for more than 16 years was moved into a lower orbit in August 2011 the orbit altitude was reduced from 770 km to 570 km using several maneuvers the density of the atmosphere here is about 10 times higher meaning that the satellite will decelerate more rapidly and quickly lose orbital heights will therefore re-enter the earth's atmosphere through natural mechanism within 15 yrs and posed no further collision risk most of the remaining fuel on the satellite was used up by additional depletion maneuvers finally batteries were disconnected and radio contact was shut down is now completely passivated and will remain physically intact until it re-enters the atmosphere measures such as this need to be applied consistently and globally to limit the growing amount of space debris however it is going to take some time before this is implemented for all missions.

Unfortunately such measures can only limits the growth but not prevent it objects that are already in space still represent a risk and their number will further be increased by future launchers and collisions even if no more launchers took place and the space debris situation was left to its own devices simulations have shown that the number of objects will not decrease but increase this is caused by cascading collision between resident object and fragments of prior collisions that scenario indicates that the critical density of object in the low – earth orbits has already been exceeded active intervention is the only way to reduce the present critical density to sustainable level.

However, these are passive measurements. In this paper, we aim at finding the active solutions that can be applied during the launch of space objects and also discuss on few non-destructive methods ASAT tests. The paper ends with a discussion on different methods space debris mitigation.

4. IMPACT ON THE SOCIETY

Many of the critical flybys occur in the polar regions where all of the near polar orbits overlap. This is also where the collision between iridium and cosmos occurred. Such collisions currently take place about once every five years. The more objects accumulating orbit due to spaceflight activities, the more frequently such collisions are going to occur, In future, more and more collisions with fragments from earlier incidents are going to occur. This collisional cascading effect was already predicted some 40 years ago. The exponential increase in the number of objects is extremely difficult to slow down. If the current number of launches continues and no countermeasures are taken, the collision rate will eventually be 25 times what it is at present. This would make spaceflight and launching of satellites in the important low-earth orbits almost impossible. Hence, both active and passive measures of prevention are needed.

The act of destroying a satellite can damage the space environment by creating dangerous amounts of space debris. What's more, the impairment loss of an important satellite, such as one used for reconnaissance, can quickly escalate a conflict or produce other unexpected and dangerous consequences. And short of an actual attack on a satellite, even the targeting of satellites or the construction of space-based weapons could precipitate an arms race with its own disadvantage and far reaching consequences [5].

5. DESIGN APPROACH

In this section, we have addressed three issues. We have provided a brief introduction about different space debris mitigation techniques, followed by non-destructible ASAT techniques and finally we have suggested few preventive techniques.

A. Space Debris Mitigation Techniques

Many years ago, early orbital debris researchers foretold that parts of Earth's orbit could in due course become so jam-packed that accidental collisions would fuel a self-reinforcing crash in the hazardous debris population—even if we put a stop to future launches [6].

That runaway debris generation scenario, often called the Kessler syndrome, may seem far off. But in fact, the sheer density of neglected objects in orbit has already surpassed what many consider to be the mathematical point of no return [7].

In some of the most crowded regions of low earth orbit, this point was actually passed more than 10 years ago, although the onslaught of chain-reaction collisions will likely take decades to pick up steam. As a result, the risk of this potentially catastrophic domino effect has remained largely imperceptible [8].

That one accident created thousands of fragments big enough to be seen by ground-based radar antennas, as well as tens of thousands other pieces of debris that could damage satellites but are too small to detect and avoid.

The active elimination of large and overwhelming objects is a considerable technical challenge associated with high development costs. The usefulness of the measures particularly influenced by selection of the target objects whereby the following 3 criteria must be met: a high collision risk, a large mass, and a long residence time in space. As we have seen the collision risk is highest in immediate polar orbits between 800 and 1200km. This is the area that will see the highest growth rates preventive measures and mitigation measures are not strictly executed.

The individual object orbits need to be broken down into their respective heights and inclinations. Now several source regions for an amplified number of collisions can be identified within the polar orbits. Collisions are particularly likely in locations where many objects have already collected. In similar orbits, active interference in such regions would be especially effective.

The harshness of the contamination depends on the mass of the colliding objects; hence ideally large objects should be detached first from these regions. The higher the orbit, the longer debris from potential collisions will remain in space. Efforts should, thus, focus on critical regions in higher altitudes in order to allow spacecraft to continue without limitation in future. About 5 to 10 of these objects need to be actively detached every year. This is the only way to fully stabilize the space debris. However, there is a long way to go before the first service vehicle can actively eliminate objects. There are many technical problems to solve.

Approaching an unrestrained target object is a major challenge. This includes the avoidance of collisions with the target and finding its attitude motion. Because the target object is no longer transmitting telemetry data, the position need to be actively determined from the ground. This requires the use of radar systems. The method that is used to capture the target object can be chosen subjected to certain conditions such as rotation rate the structure of the surface and the size of the object.

There are many possible methods. Some of the methods are listed below:

1. Propulsive Maneuvers: Deorbit with a conventional propulsion system is effective for all orbital altitudes. For upper stages that have attitude control, large efficient engines, and multiple start ability and are, at the time of disposal, at less weight, the propulsion option is generally the best choice [11].

2. Drag Augmentation Devices: The purpose of drag augmentation devices is to generate a much larger drag area for the mass to be slowed so the effect will occur more speedily [11].

3. Giant Lasers: Using high-powered pulsed lasers based on Earth to create plasma jets on space debris could cause them to decelerate slightly and to then re-enter and either burn up in the atmosphere or fall into the oceans. [12].

4. Space Balloons: The Gossamer Orbit Lowering Device, or GOLD system, uses an ultra-thin balloon (thinner than a plastic sandwich bag), which is exaggerated with gas to the size of a football field and then attached to large pieces of space debris. The GOLD balloon will rise the drag of objects enough so that the space junk will enter the earth's atmosphere and burn up [12].

5. Self-Destructing Janitor Satellites: clean space one is a small satellite which is concocted at Federal Institute of Technology by Swiss researchers, which could find and then clutch onto space junk with jellyfish-like tentacles. The device would then flip back towards Earth, where both the satellite and the space debris would be devastated during the heat and friction of re-entry [12].

6. Wall of Water: launch rocket full of water into space is another idea for cleaning up space. The rockets would release their payload to form a wall of water that orbiting junk would knock into, slow down, and fall out of orbit [12].

7. Space Pods: Russia's space corporation, Energia, is preparing a space pod to blow junk out of orbit and take back to earth. To keep pod powered for 15 years is said to use a nuclear power core as it orbit the earth, colliding non-operational satellite out of orbit. The debris would either burn up in the atmosphere or drop into the ocean [12].

8. Tungsten Microdust: In theory, to reduce speed of smaller space debris(with dimensions smaller than 10cm), tons of tungsten microdust lay in low earth orbit path opposite to targeted space junk. could be expected to fall into earth's atmosphere within a couple of decades [12].

9. Space Garbage Trucks: The US Defense Advanced Research Project Agency (DARPA) is spending on the Electrodynamic Debris Eliminator, or EDDE, a space "junk truck" equipped with 200 huge nets which could be extended out to measure space junk [12].

10. Recycling Satellites: As a replacement for destroying space debris, some numb satellites could be "extracted" by other satellites for operational components [12].

11. Sticky Booms: Altius Space Machines is currently developing a robotic arm system it calls a "sticky boom", which can lengthen up to 100 meters, and uses electroadhesion to induce electrostatic charges onto any material (metal, plastics, glass, even asteroids) it comes into contact with, and then lock onto the object because of the difference in charges [12].

12. Tether Systems: The use of electromotive tethers may well economical with drag devices as inactive and low cost systems to deorbit satellite [11].

13. Arm Control Method: A joint compliance control system enables active compliance at the arm tip using information collected by torque sensors at each joint. During target capture, contact points on the grasper make contact with the selected grasping point on the target, and corrects a position gap along with a V-guide by means of compliance control [13].

B. Alternate Non-Destructible ASAT Tests

Anti-satellite (ASAT) attacks can take a variety of forms and serve various goals. For example, they may cause momentary, reversible interference, or they may be intended to cause enduring destruction. They may target the satellite, the ground station, or the links among them. They may be overt, or they may be intended to be concealed and thus not attributable to the assailant.

This section includes information about these characteristics of interference, planned by the tenacity of the effects. This arrangement traces fairly well the gradation from technically uncomplicated to technically challenging [10].

Avoiding a satellite from completing its mission for the moment, reversibly, or nondestructively is commonly called denial, while enduring disabling is called destruction.

Momentary and reversible intervention with a satellite system is likely to be less challenging than damaging attacks and it would not damage the space environment by generating debris. These practices seem to be preferred by military engineers in the United States and elsewhere.

The following discussion considers active intervention with a satellite system, but some satellite missions can be unsatisfied with inactive events. For example, beating, masking, or moving treasured assets may reject a remote sensing satellite the ability to gain information about them. Similarly, for spacecraft designed to attack ground targets or other satellites, adding security to those objects can reject the satellite that capability.

1. Jamming/spoofing: Jamming refers to interrupting communication with a satellite by overwhelming the signals being sent to or from the satellite by using a signal at the same frequency and higher power. The jamming signal may simply be futile noise that covers the real signal at the receiver. Spoofing however, mimics the characteristics of a true signal so that the user receives the false (or spoofed) signal instead of the real one.

2. Laser Attacks on Satellite Sensors: The beams reach their targets rapidly since they travel at the speed of light, and the delivered power can be tailored to produce temporary and reversible effects or permanent, debilitating damage.

3. Dazzling: Lasers are commonly mentioned as being useful for interfering with satellites that take images of objects on the ground. The utility of lasers for temporarily interfering with the sensor a satellite uses for such imaging; such temporary interference is called dazzling.

4. Partial Blinding: The sensors of imaging satellites can be permanently damaged by laser light at sufficiently high intensities. This report refers to such damage as partial blinding, since such an attack will damage only a portion of the sensor. The detector material can ablate or evaporate from parts of the detector due to high intensity. The material or its fragile electronic connections can be melted.

5. High Powered Microwave attacks: A device which can produce high-powered microwaves (HPM) can be used as a second directed energy weapon to attack satellites [10].

C. Preventive techniques that could be used in future ASAT tests and space launches for India

In this section we provide few suggestions regarding future ASAT tests and future space launches

1. For significantly reduce the collision risk we have to to remove about 10 big satellites per year. With more than 100 satellites launched into space every year, pulling 10 down does not get us closer [3].

2. To design and operate launch vehicles and spacecraft so that have minimum potential for exploding or breaking up is also one of the preventive measure [14].

3. Environmental degradation from atomic oxygen and solar radiation and devising spacecraft and upper stage separation procedures that limit the spread of operational debris for designing and building spacecraft is opposed [14].

4. When the spacecraft is separated from the launcher spin-up devices or spring release mechanisms was been released [15].

5. Explosive bolts should be used with caution; covers should be attached to the vehicle even if they are not needed anymore, etc [5].

6. Large structural elements (dispensers) left in-orbit in the event of a multiple launch [15].

7. During deployment of antennae, solar panels and other appendages attach mechanisms were released [15].

8. During activation of optical, attitude and other sensor systems protective covers were released [15].

9. To limit the orbital lifetime of spacecraft is one of the effective measure to avoid debris creation [15].

10. Tracking measurements are performed using radar or optical telescopes to gain more knowledge about the object's trajectory then a potentially dangerous object is highlighted. Since the precise orbit of the satellite is known to its control center, it is then possible to determine the closest flyby distance and the probability of collision [15].

11. To limit the growth of the orbiting debris is to remove satellites and rocket upper stages at the end of their mission from the near Earth space is the only effective way [15].

12. A robotic space vehicle would grab a satellite nearing its end of life to refuel and service it is also an idea. One option is to recycle a satellite [3].

6. NOVELTY

We believe that destroying a satellite is not the right measure to test the capabilities of ASAT missile. A possible solution is using Fly-by test wherein the interceptor is brought to the closest and pre calculated proximity of the satellite. The test could be termed as successful when the missile passes the satellite by the desired distance and without destroying it. After the successful testing of ASAT missiles using Fly-by test, they should be brought back into the orbit through a controlled manner.

We also believe that instead of just leaving behind the rocket boosters and stages in the space, they should be brought back into the earth's atmosphere using a controlled mechanism, where they may get eventually destroyed due to the air drag. If not, then they can be dumped into nonresidential areas or into the ocean in a controlled manner. Doing this will not only reduce more space debris from accumulating but also may reduce the chance of further collisions. The rocket boosters and stages may also be reused or recycled, thereby saving important resources. Recycling or reusing may also reduce the cost of space missions.

7. RESULTS

ASAT Tests have many repercussions and the most dangerous is the addition to already threatening space debris problem. In this paper, we have an insight of various ASAT tests and their consequences resulting in more and more in space debris. We have also listed out few alternate ASAT tests and we also believe that in order to test the capabilities of ASAT missiles you may not have to actually destroy a satellite but there are also few "fly-by tests" and Jamming methods available. Also, there is an urgent need to resolve this space debris problem as the sheer density of derelict objects in orbit has already exceeded and what we consider to be the mathematical point of no return.

8. CONCLUSION

ASAT missile tests has resulted into repercussions in the form of space debris. Destruction of a satellite by impact is likely to generate some persistent debris; just how much and how long the debris persists depends on the altitude of the satellite and the details of the collision. One collision will lead to another in a form of an uncontrolled chain reaction, just like domino effect, as explained by Kessler about 40 years ago. Once debris is in orbit it will remain there and thus the amount of such debris will accumulate over time. Without efforts to minimize the creation of debris, some regions of space could eventually contain so much orbiting debris that it would be difficult to operate any space mission or satellites there without the risk of collisions.

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