Literature Review: Space Debris, Track methods and the Danger of the Future Debris Environment

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Abstract

The purpose of this review of literature is to examine information on Space Debris, how the debris is spread out in space, and the danger that accompanies this debris, either in space on in earth. Methodologies include radar and optical systems, ground and space based telescopes and radar for tracking data about their orbit and speed to avoid collision with satellites or other spacecraft. Two of the most promising programs for the maneuvering and removal of space debris are DETACT and MASTER.

Introduction

Research Problem Description

This paper reviews research associated with the following research problem: “Space Debris, Track methods and the Danger of the Future Debris Environment.”

Significance of Research

With the evolution of technology and the desire of humans to discover space, the “junk” or debris around the earth is increasing. The first human spaceflight was launched by the Soviet Union on April 12, 1961 (Johnson, 2007). Data about any launched spaceflight has been catalogued (Liou, 2006). Additionally, a Space Debris Tracking campaign has been undertaken to provide data and accuracy (Sang, Bennett, and Smith, 2014).

But how and why do these launches ended up as a” junk” in space? Will everything that goes up into space come back down to the earth? What are the origins of space debris? Are they rocket bodies, satellites, explosion fragments, or collision fragments (Liou, 2006)? Were these catastrophes predicted? Were there fatalities? See Figures 1 and 2.

A catastrophic space environment disaster happened on February 10, 2009, between the operational satellite Iridium 33 and the defunct satellite Kosmos 2251. This disaster generated more than 1600 catalogued objects and many more uncatalogued objects in the (LEO) region (Sang et al., 2014).

Figure 1. LEO images (200-2000km altitude)
Photo credit: NASA.
Space debris is an increasing threat for active satellites. An example of dealing with such threats was the Chinese anti-satellite test in January 2007. The Chinese deliberately exploded their own dead satellite Fengyun-1C, thereby generating about 2680 catalogued fragments (Sudheer Reddy, Gopal Reddy, and Anilkumar, 2011). Human space flight in the beginning was restricted to altitudes below 620 km above the Earth’s surface (Liou, 2006). Since then, many debris objects have resided in the LEO region, ranging from 200 to 2000 km (Sudheer et al., 2011). The highest object density is present at an altitude of around 900 km. The object density decreases in the higher altitude, GEO region, at 36,000 km (Wiedemanna, Oswalda, Stabrotha, Klinkradb, and Vörsmanna, 2005).

Another problem with space debris is it moves with an average impact speed of around 12 km/s. This is very dangerous for space stations and active satellites that come around the low earth orbit (Liou, 2006).

Between 1980 and 1988, sixteen nuclear powered satellites (RORSATs) were launched. Figure 3 shows the RORSAT activates a reactor core ejection system that causes an opening of the liquid coolant, called NaK coolant. NaK coolant forms droplets up to 5.67 cm in diameter. The primary coolant circuit of the reactor contains 13kg NaK-78 (Wiedemann et al., 2005). NaK droplets represent a significant contribution to the space debris environment. They are typically sized as centimeters and/or millimeters and are found only between 800 and 1000 km altitude range. Their velocity varies from 15-30 m/s (Flegel, Gelhaus, Möckel, Wiedemann, Krag, Klinkrad, and Vörsmann, 2011).

**Delimitations of the Problem**

Delimitation of this literature review focused on finding the orbits and maneuvering space debris. This review did not encompass issues involving debris removal using lasers or whether laser debris removal is viewed as a space weapon.

This review also does not encompass tax assessment data for each country regarding collecting and cleaning its own debris (Bennett, Sang, Smith, and Zhang, 2013).

**Literature Review**

**Space Tracked Debris**

At the end of 2008, NASA identified space debris resulting from no longer used spacecraft and from spacecraft explosions or spacecraft collisions. NASA found...
about 19,000 objects in space with a size greater than 10 cm. Approximately 13,000 of these objects were defined as “large objects”. 3,150 of these large objects were space vehicles. Only 4% of these objects were operational space-craft (Bordovitsyna and Aleksandrova, 2010).

Since 1994, using radar and optical systems, USSpaceCom Space Surveillance System tracked and catalogued 7,255 objects larger than about 10 cm. Of these objects, 5% to 20% are untraceable (Klinkrad, Sdunnus, and Bendisch, 1995). The minimum observable diameter of debris is about 10 cm in LEO and 1 m in GEO. About 6% are active payloads, 23% are inactive payloads, 12% are operational debris (e.g. launch adaptors), and 43% are debris from 116 on-orbit fragmentation events (all of them from explosions, except for 1 or 2 collisions) (Klinkrad et al., 1995).

About 17,000 objects larger than about 10 cm were tracked by US Air Force and the number catalogued is expected to grow by over 100,000 with the introduction of a new space radar fence (Bennett et al., 2013).

Beginning in 2006, about 15,000 objects were tracked in the region below 600 km in altitude. Only one third of these objects were found in the 350 to 400 km altitude region. Almost 10,000 tracked objects were official catalogued. The others are unofficial catalogued (Johnson, 2007). Between 1995 and 2006, 48 satellites were involved in satellite fragmentations. Only two of those fragmentations produced clouds containing more than 100 trackable items of debris, and only four of these items were found in the 350–400 km altitude regime (Johnson, 2007).

Numerous incidents have increased the amount of space debris. These incidents include the Chinese anti-satellite test (January, 2007) which generated about 2680 catalogued fragments, the explosion of Briz-M (February, 2007) which generated 1000 objects of detectable sizes, the Cosmos 2421 breakup (March 2008) which generated 506 catalogued objects, and the accidental collision of cosmos 2251 and Iridium 33 (February 2009) which generated 1200 objects of detectable sizes (Sudheer Reddy, Gopal Reddy, and Anilkumar, 2011).

**Laser Tracking Methods with Accuracy**

Since 1978, methods to mitigate and potentially reverse the collisional cascading phenomenon have been widely investigated. Some simulations studied post mission disposal methods and were shown to reduce the growth rate of the debris environment (Bennett et al., 2013). Ground-based lasers used photon pressure for collision avoidance or pulsed laser ablation for removal of space debris. These methods need a laser beam to lock onto the target object and, as such, require the orbit of the object to be predicted very accurately (Bennett et al., 2013).

Three debris tracking campaigns have been conducted from Electro Optic Systems (EOS), using its Space Debris Tracking System (SDTS) from a single-station tracking at Mt. Stromlo, Canberra, Australia (Sang et al., 2014). The first was undertaken in May 2012 and was an optical (passive) tracking campaign. The second in July/August 2012 and was a laser tracking campaign. The third in April/May 2013 and was also a laser tracking campaign (Sang et al., 2014).

Many of the space situational awareness (SSA) applications use radar and optical tracking data to catalogue space debris. In the last 15 years, EOS has undertaken multiple research efforts to provide better space surveillance services, such as the laser tracking of space debris.
(Sang et al., 2014). This method of the laser tracking sub-system fires laser signals to a targeted space object and receives the signals reflected (returned) from the object. The measure of the two way distance between the tracking station and the object gives the result of the time difference between the firing and receiving epochs (Sang et al., 2014).

**Ground-based Laser Tracking and Manoeuver with Laser Beam**

To avoid debris collisions, the use of ground-based lasers has been proposed for orbit manoeuver of low Earth orbiting (<900 km in altitude) debris. The orbit of the debris object needs to be predicted accurately for the laser beam to be locked on the debris without any loss of operation time. The collected data from EOS SDTS using the method of sparse laser ranging has had good results on accurate LEO debris orbit prediction (Bennett et al., 2013).

To succeed on orbit prediction (OP) accuracy needs the estimate of the ballistic coefficients of the LEO objects from their long-term two line elements (TLE). These can be measured when an object is laser tracked for two passes over 24 h, and for the next 24–48 h a 10–20 arc seconds (OP) accuracy can be achieved (Bennett et al., 2013).

**Debris Laser Ranging**

There are only few ground stations that can track LEO debris objects with lasers. The EOS SDTS system is one of them. The debris system has a ranging accuracy of about 1-1.5m. A visible light acquisition camera is used for the laser ranging system to be performed and can only acquire targets when the object is in sunlight, which is about 4 h each day (Bennett et al., 2013).

**Laser Debris Orbital Manoeuver**

A method using the photon pressure generated from a medium-powered (5–10 kW) ground laser, has been proposed as a force to change or manoeuver the debris orbit. The method showed that after 2 days the range displacement for LEO debris objects was 17% for 100 m/day. Another method uses a high power pulsed ground laser system to make plasma jets on LEO debris objects to slow them slightly (Bennett et al., 2013).

**Tracking Campaigns**

OP is required for laser debris maneuver. When the tracking data is sparse, obtaining a reliable OP is very difficult. Using TLE data alone to obtain the OP accuracy may be insufficient. Obtaining a subsequent OP is required to create pseudo-observations for an orbit determination (OD). The OD process helps improve orbit prediction (Bennett et al., 2013).

**Iridium Campaign**

In August 2004, a laser tracking campaign was undertaken where Iridium satellites were successfully tracked over 4 evening sessions. They were catalogued as one tracking pass in the sessions, and two tracking passes in the same session. Different OD calculations were made using different subsets of the same data (Bennett et al., 2013).

**Optical Campaign**

In May 2012, an optical tracking campaign was undertaken where 75 LEO debris
objects were successfully tracked only in the evening sessions. They were catalogued per one observation pass was collected on that day or two observation passes were collected on that day (Bennett et al., 2013).

**DLR Campaign**

In June-August 2012, a DLR campaign was undertaken where 80 LEO debris objects were successfully tracked only in the evening sessions. In most cases, only 1–2 passes were collected for each object over the campaign making it difficult to assess their OP accuracy. Only a few of debris objects were tracked on multiple days and were selected for the OP accuracy analysis (Bennett et al., 2013).

**Fragmentation Clouds or Debris Cloud with DETACT or MASTER Programs**

Fragmentation clouds have been created after many cases of explosions or collisions. Fragments of the parent satellite are in the vicinity of its orbit. Fragmentation clouds region are very dangerous for the reliability of satellite systems because of high spatial density of debris objects (Theil, and Sdunnus, 2003).

The need to identify these fragmentation clouds has brought the use of some tools like DETACT, which describe each object’s position within a volume. DETACT studied two groups of objects. The first group of objects was the target objects (usually payloads or larger objects). The second group of objects was the projectiles (usually, fragments).

The program DETACT can study up to 15,000 projectiles and up to 3000 target objects. DETACT focuses on the region between 400-2000 km altitude (Theil, and Sdunnus, 2003).

MASTER is another program, available from European Space Agency (ESA). MASTER assesses the impact risk to a spacecraft. MASTER studies target orbits at altitudes between LEO and GEO called MEO (2000-35,586 km altitude) (Klinkrad et al., 1995).

**Summary**

Space “junk” or space debris consists of rocket bodies, satellites, explosion fragments, or collision fragments. Technological evolution and the human desire to discover space has created and increased the amount of man-made “junk” or debris travelling around the earth.

The first human spaceflight was launched on April 12, 1961 (Johnson, 2007). Since then, data about any launched spacecraft has been catalogued (Liou, 2006). Additionally, a Space Debris Tracking campaign has been undertaken to provide data and accuracy (Sang, Bennett, and Smith, 2014).

At the end of 2008, NASA identified about 19,000 objects in space with a size greater than 10 cm. Only 4% of these objects were operational space-craft (Bordovitsyna and Aleksandrova, 2010).

There have been numerous incidents causing space debris. Four incidents include the Chinese anti-satellite test (January, 2007) which generated about 2680 catalogued fragments, the explosion of Briz-M (February, 2007) which generated 1000 objects of detectable sizes, the Cosmos 2421 breakup (March 2008) which generated 506 catalogued objects, and the accidental collision of cosmos 2251 and Iridium 33 (February 2009) which generated 1200 objects of detectable sizes, (Sudheer Reddy, Gopal Reddy, and Anilkumar, 2011).

Since 1978, there have been methods to mitigate space debris. These
methods have included laser and optical tracking systems.

Two programs for tracking space debris are DETACT and MASTER. These ground-based programs are used for tracking and maneuvering. Although not completely successful, these programs show promise in removing space debris (Theil et al., 2003; Klinkrad et al., 1995).

References


http://www.nasa.gov.