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SPACE DEBRIS

Space debris consists of millions of pieces of man-made material orbiting the Earth. Debris poses a growing threat to satellites and could prevent the use of valuable orbits in the future. Many pieces of debris are too small to monitor but too large to shield satellites against. This POSTnote looks at measures to protect satellites and international agreements and guidelines to reduce the amount of debris generated. In the long term, experts agree that it will be necessary to remove debris from orbit, but this is technically and politically challenging.

Background

Uses of Satellites

Satellites are used in many critical military and civilian applications. There are over 900 active satellites in orbit around the Earth, of which about half are operated commercially and half by governments and the military. Approximately two-thirds of active satellites are used for communications. The rest are split roughly equally between navigation, military surveillance, Earth observation and remote sensing, astrophysics and space physics, and Earth science and meteorology.[1] Satellites orbit the Earth at a range of altitudes and orientations depending on their function (Box 1).

Origin and Types of Space Debris

Space debris generally refers to man-made material in orbit that no longer serves a useful purpose. Because of the high speeds of objects in orbit (7.5km/s is typical in low earth orbit), even small pieces of debris can be very damaging in a collision. There are several types of debris:

- defunct spacecraft, such as satellites that have ended their useful life. Commercial satellites have an average lifespan of only around 15 years, due to the harsh radiation environment in space;
- spent rocket bodies used to launch satellites into orbit;
- objects released during missions, such as waste vented from the Space Shuttle;
- small fragments caused by collisions, explosions or deterioration of active satellites or larger pieces of debris.

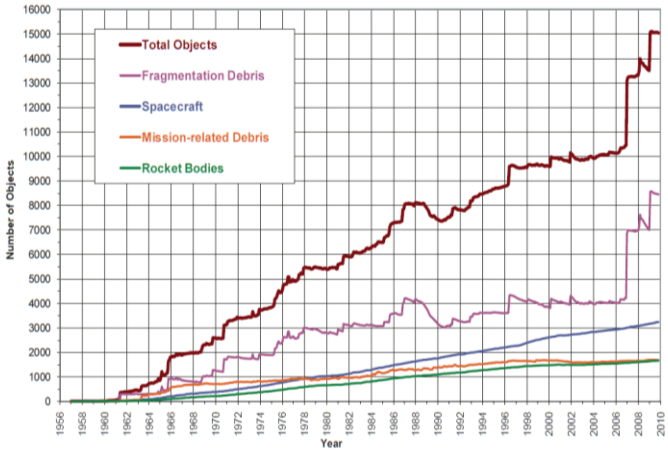
Box 1. Types of Orbit

Orbits are classified according to their altitude:

- **Low Earth Orbit** (LEO) from 160km to 2000km above the Earth's surface, used for Earth monitoring, military surveillance and some communications satellites. The International Space Station is in LEO at around 350km. Below LEO, objects rapidly fall back into the Earth's atmosphere and burn up;
- **Medium Earth Orbit** (MEO) from 2000km to 36,000km, mainly used by navigation satellites such as the Global Positioning System (GPS) network at around 20,000km;
- **Geostationary Orbit** (GEO) at 36,000km. Satellites at this altitude orbit the Earth in exactly one day, so they are always above the same spot on the Earth's surface. This makes them useful for communications, as receivers on Earth can always point in the same direction. However, it is expensive to launch a satellite to GEO and to amplify its signal to reach Earth. Many communications satellites are thus placed in LEO instead, with continuous coverage provided by a 'constellation' of many satellites;
- **High Earth Orbit** (HEO) at above 36,000km, little used by satellites.

Chart 1. Number of Debris Objects

The graph shows the number and type of catalogued debris objects over time.[2] The large jump seen in 2007 was due to the destruction of a defunct Chinese weather satellite, while the smaller jump in 2009 was caused by the collision of two satellites (Box 2).



Box 2. Recent Debris Incidents[3]

In February 2009, the first collision between two satellites occurred 800km above Northern Siberia. One was an active US communications satellite, while the other was a defunct Russian satellite. They collided at a speed of over 40,000km/h, causing complete break-up of both satellites. The event created around 1400 catalogued debris objects.

Other incidents of debris creation have involved the deliberate destruction of a satellite by missiles launched from Earth. In January 2007, China destroyed one of its defunct weather satellites orbiting at about 900km. This created around 2700 new pieces of tracked debris and NASA estimates more than 150,000 pieces of debris larger than 1cm were created. When the US destroyed one of its satellites in February 2008, few lasting pieces of debris were created as the satellite was in a lower orbit, from which most debris rapidly re-entered the atmosphere.

Currently, collisions are the smallest contributor to fragments of debris. However, as the number of debris objects increases, collisions become more likely, thus creating yet more debris. This cascade process is known as the Kessler syndrome and space experts argue that without mitigation it could make it impossible to operate satellites safely in the future. Box 2 describes recent incidents that have generated large amounts of debris.

Size and Impact of Debris

Debris is placed in one of three categories according to its size and potential impact (Table 1).

- Debris in LEO with a size greater than 10cm can be tracked from Earth (see Monitoring Debris) and so it may be possible to take measures to avoid a collision. In GEO, the lower size limit for tracking is around 1m.
- Debris between 1 and 10cm is known as the 'lethal population' because it is large enough to destroy a satellite but too small to be tracked.
- Debris smaller than 1cm is usually not large enough to destroy a satellite it impacts. Satellites can be protected from small debris by shielding.

While almost all of the total mass of debris is contained in larger objects, collisions and explosions transfer mass into the smaller categories.

Table 1. Size of Debris Objects[4]

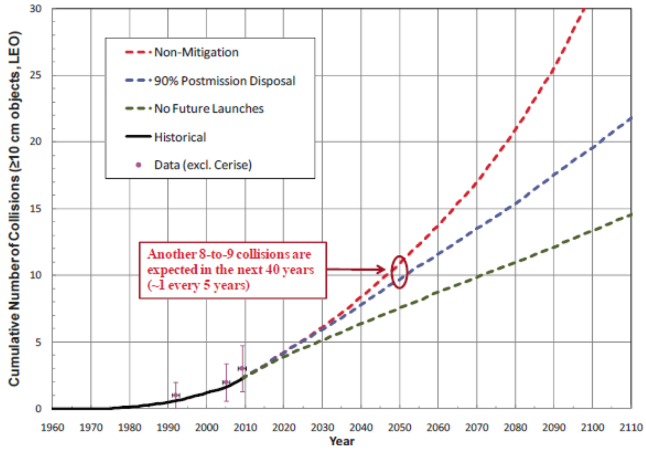
Size	Number of objects	Potential risk to satellites
>10cm	19,000+	Complete destruction
1-10cm	Several hundred thousand	Complete to partial destruction
< 1cm	Several hundred million	Degradation, loss of certain sensors or subsystems

Likelihood of Collisions

Because satellites are clustered in a few useful orbits and objects remain in those orbits for many years, the risk of a collision is higher than might be expected. To date, there has been only one major collision of a satellite with debris (Box 2), but this is forecast to increase. Computer models based on observations of debris are used to predict future growth of the debris population, and thus the probability of collisions with satellites, under different assumptions (Chart 2).

Chart 2. Future Probability of Collisions

The graph shows the cumulative number of accidental collisions with objects larger than 10cm in LEO expected over the next century.[2] In the next 40 years, such a collision is expected to occur every 5 years on average. Mitigation measures reduce the number of collisions (middle line), but even if no satellites are launched from now on, the number of collisions will continue to increase (lower line). Current trends lie somewhere between the upper and middle lines.



Space Law

Human activities in space are governed by international space law set out in United Nations treaties. The UN Outer Space Treaty of 1967 was written before wide awareness of the debris problem and so does not contain specific provisions about it. There is not even an internationally agreed definition of space debris. The Treaty states that space exploration shall be conducted to avoid "harmful contamination" and that states should adopt "appropriate measures" to ensure this, but it does not define these terms.[5]

Monitoring Debris

Debris is monitored from Earth using radar (for LEO) and telescopes. This allows larger pieces of debris to be tracked and catalogued. The largest catalogue is maintained by the US military, using its worldwide Space Surveillance Network (SSN), which includes the Fylingdales radar base in the UK. It contains around 19,000 objects. However, only relatively crude information about the orbital paths is made available for wider use; and no information at all on around 25% of the objects for security and other reasons. The European Space Agency (ESA) is developing a European surveillance network to catalogue debris (Box 3) and provide a source of information independent of the SSN. Some UK space users worry that the UK's involvement in an independent European capability could affect the UK's current privileged access to SSN data.[6]

While it is desirable to extend tracking to smaller objects, this would lead to a huge increase in the number of objects in the catalogue. For example, the US Space Fence radar system, scheduled to come online in 2015, is predicted to add 100,000 or more new objects in the 1-10cm range to the SSN catalogue. Modifying the catalogue to accommodate these data will be complex and expensive. The properties of debris that is too small to be observed directly can be inferred by examining its impacts on satellites such as the International Space Station (ISS) and the Hubble telescope, which are visited regularly by Space Shuttle missions.

Box 3. European Space Situational Awareness
The European Space Agency (ESA) is developing a European surveillance network to track and catalogue debris, as well as other phenomena such as space weather and near-Earth objects. A three-year preparatory phase for this Space Situational Awareness programme, with a budget of €50m (of which the UK will contribute around €1m) was approved in November 2008. It will address:
- how existing sensors will contribute and what new infrastructure will be required;
- governance and data policy;
- how to combine information with other space surveillance networks such as the US Space Surveillance Network.

ESA is looking at a ten-year timeline for development of the system, which is a step towards a 'space traffic management' system analogous to air traffic management.

Mitigation of Debris
Mitigating space debris falls into two main categories:
- protecting satellites from debris by avoiding collisions and shielding;
- reducing the amount of new debris created and, in the longer term, removing existing debris.

Protecting Satellites from Debris
Satellites can be shielded against smaller pieces of debris and they can attempt to actively avoid larger tracked debris. It is also important to reduce the 'gap' between these two regimes by improving shielding and tracking.

Shielding
The main problem with shielding satellites from debris is that it adds considerable mass to the satellite. Launch costs, at several thousand pounds per kilogram, are highly dependent on mass. Shielding is essential for manned missions such as the ISS, which would lose pressure if there were a leak in its surface. Research continues on light but strong materials for shielding.

Collision Avoidance
Tracking information can be used to predict a collision in time for a satellite to manoeuvre out of the way. For example, the ISS performs around one avoidance manoeuvre each year. However, the relatively crude information available from the SSN makes it difficult to predict collisions accurately and there are so many close approaches that most cannot be acted on.

This problem will grow as the number of debris items increases. Modelling work has suggested that close approaches will rise from 13,000 a week in 2009 to 20,000 by 2019 and more than 50,000 by 2059, meaning satellite operators will have to make five times as many avoidance manoeuvres in 2059 as in 2019.[7] Since each manoeuvre requires fuel, this shortens the active life of satellites, or requires additional fuel to be carried into orbit thus increasing the cost of launch.

Reducing the Debris Population
Longer-term solutions to the problem involve reducing the amount of debris created and removing existing material from orbit.

Box 4. International Agreements
Debris mitigation principles were first put into practice by the US, starting in the 1980s. Since then, a series of voluntary, non-binding international agreements and guidelines have been agreed.
- The Inter-Agency Space Debris Co-ordination Committee (IADC) was founded in 1993, comprising 11 national space agencies including NASA, ESA and the British National Space Centre (BNSC).[8] In 2002, the IADC adopted a set of recommendations for debris mitigation covering the points in the main text, which has achieved wide international recognition.[9]
- The UN Committee on the Peaceful Uses of Outer Space developed these recommendations into a set of guidelines which were adopted by the UN in 2008.
- Several European space agencies developed a European Code of Conduct consistent with the IADC recommendations.
- ISO (the International Organization for Standardization) is currently transforming the recommendations into a set of International Standards, the first of which should be published in April/May 2010. BNSC chairs the ISO group responsible for developing these standards, which aim to assist the space industry in complying technically with the IADC guidelines.

Reducing Creation of Debris
General principles for reducing the amount of debris created are well-established. They have been codified in international agreements and guidelines (Box 4), though these are not legally binding.
- Limit debris released during normal operations. France is particularly strict, requiring no more than one object to be released per launched satellite.
- Implement collision avoidance procedures while a satellite is in use.
- Avoid intentional destruction of satellites in orbit (such as the missile launches described in Box 1).
- Avoid explosions, currently the main source of fragments, by 'passivation' of satellites and rocket bodies at the end of their useful life. This includes burning or venting remnant fuel, venting pressurised gases and short-circuiting batteries.
- Reduce the orbital lifetime of satellites and rocket bodies. Objects in LEO should be designed to leave orbit within 25 years of ending their life. This can occur naturally if the orbit is low enough, or by using drag devices or propulsion to speed their re-entry.
- Move satellites in higher orbits (particularly GEO), which are too far away to re-enter the atmosphere, into a 'graveyard' orbit well outside the region used by active satellites. This would create a 'protected zone' of a few hundred km either side of the GEO ring.

Many nations require compliance with mitigation guidelines as a condition of licensing the launch of a satellite. For example, to receive a licence from the British National Space Centre,[8] satellite operators must demonstrate their plans for end-of-life procedures, passivation and collision avoidance. To create a 'level playing field' internationally, a legally-binding agreement would be desirable but there has been resistance from some countries to putting the international guidelines on a legal footing.

Removing Existing Debris
The mitigation measures described have slowed the rate of increase in debris (Chart 2). However the Kessler syndrome described earlier will continue to increase the number of fragments through collisions. Experts agree that to stabilise the amount of debris in the long-term will require existing objects to be removed from orbit. Removing even three or four large objects from orbit each year would vastly reduce the amount of debris generated. Several techniques have been proposed for removal of debris, also known as 'remediation':[10]

- attaching a propulsion device to a debris object to push it out of orbit;
- using a robotic grappling device on another spacecraft to tug an object to a new orbit or to cause it to re-enter the atmosphere destructively;
- using a momentum exchange tether, which acts like a swing, to pull an object out of orbit;
- using an electrodynamic tether, which causes a drag on the satellite due to the magnetic field of the Earth;
- slowing objects using high-powered lasers fired from Earth, so that they move out of orbit.

Such methods would be expensive and technically difficult. The main problem with accessing existing pieces of debris is the fuel expenditure needed to reach more than one piece of debris per launch. Using lasers works only for small objects and they are difficult to point accurately. Furthermore, removal suffers from a collective action problem: since all users of space benefit from the reduction in debris, it is not clear who should bear the costs. There are also legal problems: defunct space objects still belong to the launching party and so cannot be removed from orbit without permission. However, some experts believe that there is potential in the future for a commercial removal service.

Risks on Re-entry
When removing objects from orbit, the risk of matter reaching the Earth must be considered. Re-entry manoeuvres are designed to control the point of impact (ideally over an ocean), to keep the probability of a casualty below an acceptable threshold. Many agencies use a threshold of 1 in 10,000 for a single re-entry.

Liability and Insurance

The cost of damage or destruction of a satellite by space debris could run to many millions of pounds. The UN Liability Convention 1972 holds that liability for incidents in space falls on the state responsible for the launch of the offending object. There are several problems with applying the Liability Convention to debris:[11]

- if a collision is caused by an object too small to track, it may be impossible to identify the launching state;
- a claimant must prove that the launching state was negligent. It is difficult to identify a particular negligent act that created a debris object, though international guidelines could provide a legal benchmark;
- a state must prove causation. When two objects collide in space, both states involved could claim the other caused the collision.

To date, no cases for damage caused to satellites by debris have been pursued under the Liability Convention. The Outer Space Act 1986 requires UK-based companies to indemnify the government prior to launch, without limitation, against all liability. Satellite operators argue that this requirement is a barrier to entry into the space market for UK companies and places them at a competitive disadvantage internationally.

Insurance
Satellite operators insure themselves against accidents on launch or while in orbit. Currently there is no exclusion in insurance policies for accidents caused by space debris, as the risk of collisions is considered small compared with other threats such as malfunction. If the number of incidents increases, then insurance premiums are likely to rise, or damage due to debris could be excluded entirely. This would impose a significant additional cost or risk to operating a satellite.

Overview

- Space debris refers to any man-made material in orbit that no longer serves a useful purpose.
- Debris poses a growing threat to satellites, which provide critical services such as communications, navigation and Earth monitoring.
- Short-term mitigation measures include shielding satellites and monitoring debris to avoid collisions. However, many debris objects are too small to monitor but too large to shield against.
- There are various non-binding international agreements and guidelines to reduce the amount of debris being produced. Even if these are effective, the total amount of debris will continue to increase through collisions.
- To stabilise the growth of debris, objects must be actively removed from orbit, but this is technically difficult and expensive, and it is unclear who is prepared to invest in it.

Endnotes
1 *Union of Concerned Scientists Satellite Database*, www.ucsusa.org
2 *NASA Orbital Debris Quarterly News*, January 2010
3 www.celestrak.com
4 "The Numbers Game", *The Space Review*, July 2009
5 J Wheeler, "The Current Legal Framework Associated with Space Debris Mitigation", *Proc IMechE, Part G* 221 6 (2007), pp 911-14
6 "Standing watch over a crowded space", *BBC News*, 10 April 2009
7 "Space debris threat to future launches", *New Scientist*, Oct 2009
8 The BNSC will be replaced by the UK Space Agency in April 2010
9 *Space Debris Mitgation Guidelines,* IADC, 2002
10 H Klinkrad and NL Johnson, "Space Debris Environment Remediation Concepts", *Fifth European Conference on Space Debris*, 2009
11 M Taylor, "Orbital Debris: Technical and Legal Issues and Solutions", 2006

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