# IMPACTS ON EARTH FROM SPACE

- *What are the risks?*
- *What safeguards are there?*

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*POSTnotes are intended to give Members an overview of issues arising from science and technology. Members can obtain further details from the PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (extension 2840).*

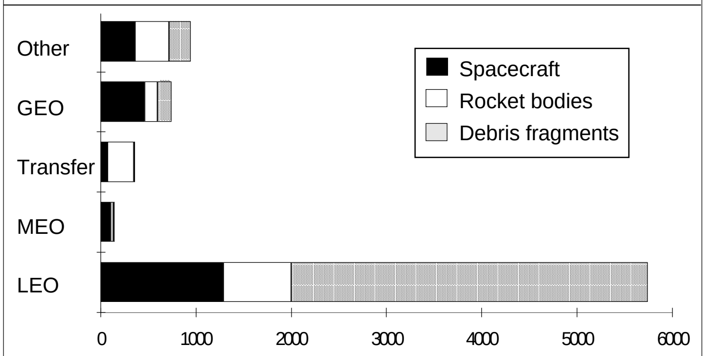
The growing number of man-made objects in Earth orbit are a potential hazard to space missions and satellites, and the uncontrolled re-entry of the Chinese FSW-1 5 ('China 40') reconnaissance satellite in March 1996 was a reminder that 'space debris' can also pose a threat on the ground. More is also being learnt about the threat from asteroids.

***This note examines the risk of terrestrial damage from space and what safeguards are available.***

## 'CONGESTION' IN SPACE

Since 1958 there have been some 3750 space launches resulting in nearly 8,000 objects larger than 10cm in orbit around the Earth (**Figure 1**). As shown in Figure 1, only about 30% of these objects are telecommunications or other satellites; the rest are spent rocket stages, mission-related objects (launch adapters etc.) and debris from the 129 spacecraft which have broken up in orbit. 80% of the satellites **no longer function**, e.g. because they have run out of fuel or failed.

**Figure 1 VISIBLE OBJECTS AND THEIR ORBITS**




*Source: ESA*

**Table 1 NATURAL ORBITAL LIFETIME**

| Altitude (km) | Earth Orbit (EO) | Lifetime |
|---|---|---|
| 200 | Low (LEO) | 1-4 days |
| 600 | | 25-30 years |
| 1000 | | 2000 years |
| 2000 | | 20,000 years |
| 5,500 | Medium (MEO) | 100,000 years |
| 36,000 | Geostationary (GEO) | >1M years |

## RISK OF RE-ENTRY

The Earth's atmosphere thins progressively towards space and the drag exerted on satellites is less at higher altitudes. This affects the orbital lifetime of a satellite as shown in **Table 1**. Satellites in the lowest orbits (often military 'spy' satellites at around 200km) have natural orbital lifetimes of only days before they re-enter the lower atmosphere. At higher altitudes, orbital lifetimes extend to thousands of years and satellites in geostationary Earth orbit (GEO) can remain there almost indefinitely.

To compensate for atmospheric drag (and for the smaller effect of 'orbital drift' caused by gravitational pull of the sun and the moon), many satellites carry small **rocket thrusters**. These also can be used to adjust the 'attitude' of the satellite in space; e.g. to point an instrument or antenna in a specific direction. When a satellite reaches the end of its useful life, the thrusters can sometimes be used to boost the satellite into a higher **'graveyard' orbit** or to attempt a **'controlled re-entry'** to allow the satellite to burn up or land harmlessly.

Such plans can go wrong and satellites can become '**re-entry risk objects**'. For example, FSW-1 5 was designed to re-enter under control 8 days after launch so that its payload could be recovered. However, its motors were fired in the wrong orientation and the satellite was pushed into a higher orbit, also running out of fuel. The satellite then took 2.5 years to re-enter, out of control. Risks can also arise when spacecraft fail to reach the desired orbit because of some malfunction in the launch phase. For example, in February 1996 a Chinese Long March rocket (carrying an Intelsat satellite) veered off course and crashed near the launching pad.

Other forms of **launch failure** include booster malfunctions so that satellites are deployed into lower orbits, damage to satellite control mechanisms during deployment and 'on-orbit' explosions. For example, the Russian Raduga 33 military communications satellite failed to reach geostationary orbit in February 1996 due to the explosion of its fourth booster stage; it has been left (together with about 200 fragments) in an elliptical geostationary transfer orbit (GTO) which approaches within 250km of the Earth's surface.

Currently, several man-made objects re-enter the atmosphere **every week**: most of them disintegrate and burn up in the upper atmosphere, a long way from the Earth's surface. Some objects, however, can reach the ground and potentially cause damage for three main reasons (see **Table 2**) :

- because it contains too much mass to burn up (e.g. Skylab, Salyut 7);
- because it was designed to survive re-entry (e.g. FSW-1 5);

**Box 1 SPACE DEBRIS RESEARCH**

While space debris research is very much an international effort, the lead has been taken on by the USA. The **US Office of Science and Technology Policy** has published two key reports on orbital debris. The first (1989) prompted NASA and the Department of Defense to conduct an extensive exercise to measure debris in Low Earth Orbit (LEO), and the second was made generally available in Spring 1996. These reports are concerned primarily with orbital debris, rather than re-entry risk.

The **European Space Agency (ESA)** debris activity is coordinated by the **European Space Operations Centre (ESOC)** in Darmstadt and includes:-

- a database of known ('catalogued') space objects (DISCOS) available, to registered users, on the Internet.
- space debris and meteoroid computer models;
- results of optical and radar observation of space objects.

ESOC is preparing optical observations of high altitude orbits (e.g. GEO) with a 1 metre telescope located at the Spanish Teide observatory (Canary Islands). Radar measurement techniques for the detection of sub-decimetre size objects in Low-Earth Orbits (LEO) are also being developed and applied by the German FGAN radar (at Wachtberg-Werthhoven).

ESA also investigates the effects of 'hyper velocity' impacts on spacecraft and shielding techniques; and is implementing debris mitigation standards for its ARIANE launchers.

Historically, the UK has had a strong interest in space. Until 1992, the Royal Aircraft Establishment (RAE, now DERA Farnborough) compiled the **"RAE Table of Earth Satellites"**, which was a definitive list of all known satellites, with details of their orbits, specifications (where available) and predictions for their re-entry date. In 1992, DERA submitted its database to ESA where it now forms part of the DISCOS service.

The UK also has access to orbital tracking facilities through its partnership with the USA in the **RAF Fylingdales** early warning radar. Data from this source is made available by MOD to DERA for research purposes.

The UK has a strong academic research effort into space debris (e.g. at Southampton, QMW, Cranfield and Glasgow and the **Unit for Space Science and Astrophysics (USSA)** of the University of Kent at Canterbury (UKC). USSA conducts research into debris impact both on the ground and through participation in various international space missions. While in the past this research has been supported by the Research Councils, the majority of funding now comes from international sources, such as ESA.

The characteristics of objects which are too small to observe from the ground can be estimated from **space-based measurements**. So far this has involved the examination of impact damage and particles trapped in special 'aerogel' cells on recovered objects. New types of particle detector are being developed which can analyse small debris in orbit and in 'real time' and transmit the results back to Earth.

**TABLE 2 - SATELLITE EARTH IMPACTS**

| Object | Date | Mass(Kg) | Causes |
|---|---|---|---|
| Kosmos 954 | 1978 | 3000 | failed to reach boost orbit |
| Skylab | 1979 | 75000 | 'solar harvest' |
| Kosmos 1402 | 1983 | 3000 | failed to reach boost orbit |
| Salyut 7/ Kosmos1686 | 1991 | 40000 | 'solar harvest' |
| Express 1 | 1995 | 1000 | failed to reach initial orbit |
| Kosmos 398 | 1995 | >1000 | lunar module |
| FSW-1 5 | 1996 | >1000 | control failure |

- because it never achieved a high enough orbit to have enough time to burn up (e.g. Express 1).

The re-entry of the Soviet Kosmos spacecraft in 1978 highlights the particular danger from **nuclear power sources (NPS)**. Satellite NPS are small 'thermo-piles' of low grade uranium which are used to generate electricity to power the satellite. Today, NPS are used only for deep space probes (e.g. the recent Galileo mission to Jupiter and the forthcoming Cassini / Huygens mission to Saturn), for which solar power would provide insufficient energy. But there are still 42 Soviet NPS from the RORSAT series in '**nuclear graveyard orbit**' 650-1000km above the Earth. While an NPS contains a relatively small quantity of radioactive material, the consequences of part or all of an NPS reaching the ground can be significant: when Kosmos 954 landed in Canada, decontamination costs amounted to more than $1M.

## PREDICTING SATELLITE BEHAVIOUR

The first stage in keeping track of what is in orbit and where, is the **UN Convention on Registration of Objects Launched into Outer Space 1976** whereby launching agencies must notify the UN of intended orbital and spacecraft parameters. However, launch failures and on-orbit variations mean that the information may not remain accurate. **Ground-based observation** which can use **radar** or **optical telescopes** (see **Box 1**) are thus needed to supplement the catalogue of space objects. Objects larger than about 10cm can be **tracked** by radar, such as the missile early warning system at RAF Fylingdales, which gives accurate **trajectories** for objects as they pass through the field of view. These international observation and tracking campaigns (examples are given in Box 1) can identify likely re-entry events and submit them to closer scrutiny.

However, whether a satellite is re-entering the atmosphere 'under control' or not, there are many factors which make its behaviour difficult to predict. First of all, most satellites have **complicated shapes and** protrusions such as solar panel arrays which make their 'flight path' difficult to analyse. Moreover, many satellites are **spinning** and may start to **tumble** as they re-enter the atmosphere. Thus it is difficult to calculate whether a satellite will burn up before hitting the ground, or where it might hit. A re-entering satellite may also break into pieces which will behave unpredictably. These difficulties can be compounded if the full specifications of the satellite are not known (an '**unco-operative risk object**') - e.g. for some military spacecraft or if an object re-enters in an unknown configuration because of rocket failure, etc.

There are other factors[1], but an increasingly significant source of uncertainty for re-entry risks is the possibility of **disabling collisions** between spacecraft and '**space**

**debris'**. Objects smaller than 10cm can only be estimated using statistical modelling techniques but there may be between 70,000 and 120,000 objects of 1-10cm and up to 35 million objects between 0.1 and 1cm. In addition, natural 'meteoroids' outnumber man-made debris at sizes of less than 0.1cm. Such 'space debris' poses a threat to space missions, since collision with even small objects at closing speeds of the order of 10km/s can damage a spacecraft, and collisions between larger objects would have an explosive effect[2].

Examples of damage by space debris include, cracked outer windows on NASA's Space Shuttle and a small hole punched in the antenna of the Hubble Space Telescope. Objects which have been recovered from space also display signs of damage by 'micro-debris' which, for example, causes a gradual degradation in the performance of solar panels. No satellites are known for certain to have been destroyed by space debris, although there are a few suspected cases.

When all these uncertainties are taken into account, forecasting satellite re-entries becomes very difficult. The best that can be achieved currently is to track all 'risk objects' and update predictions with increasing accuracy as their orbits decay. The key player here is the **US Space Command (USSPACECOM)** which monitors re-entering objects routinely to distinguish between 'benign' objects and potential ballistic missile attacks, using its early warning system (these include RAF Fylingdales). UK MOD makes its own assessment of likely risks to the UK from the Fylingdales data, as does the Defence and Evaluation Research Agency (DERA). The European Space Agency also has tracking facilities and distributes re-entry forecasts to national points of contact within ESA Member States.

## ISSUES

### *Who is responsible?*

There are already several **international agreements** which are relevant to space debris and re-entry risk. The basic principles were laid out in the **'UN Space Treaty' 1967**[3] which established that:-

- parties bear responsibility for 'national activities';
- non-governmental organisations require authorisation and continuing supervision;
- parties must have due regard for corresponding interests of others;
- parties that procure **or launch** a space object are internationally liable for damage on the Earth, in air-space, or in outer space;
- the ownership of a space object rests with the registered owner indefinitely, even after re-entry.

The **Convention on International Liability for Damage Caused By Space Objects, 1972** refines these terms and imposes:-

- absolute liability on a launching/owning state for damage caused by its space object on the Earth or to aircraft in flight;
- liability for damage to other space objects where "fault" can be demonstrated.

Thus, for example, the Soviet Union was required to pay the nuclear decontamination costs ($US1M) when Kosmos 954 crashed in Canada in 1978.

One concern about potential damage caused by satellites arises from the increasing numbers of commercial satellites in orbit. The Iridium global satellite telephone network will comprise 66 satellites in LEO, while the proposed Teledesic system would require a 'constellation' of 840 satellites, boosted into graveyard orbit and replaced every 5 years or so. Similarly, remote sensing satellites currently are operated by national organisations, but in the US private companies are developing specialised commercial satellites, and there is pressure in Europe and elsewhere to follow this trend (see recent POST report "Looking Down on Earth").

Hand in glove with the commercialisation of space is the pressure to reduce costs and increase efficiency, in the procurement of satellites, their launch and operation. This may squeeze out 'extras' designed to control the final fate of the satellite. Thus ESA's Envisat remote sensing satellite, due for launch in 1998, is the subject of on-going negotiations in ESA over cost, and is unlikely to carry an 'end-of-life' de-orbit motor (despite early attempts by the UK for one to be included).

The growth in the number of satellites, many of which will require continuous replacement campaigns, also will place pressure on the **launch rate**. The Ariane 5 launcher programme, which the UK joined in 1996, is seeking to cut costs by up to one fifth to remain competitive. Against a background of such international competition and cost-cutting, many are concerned that standards of safety may be compromised.

The potential proliferation of satellites and space missions, many of them outside the control of national space agencies, together with the pressure to reduce costs, raises the question of **regulation** of space activity. Internationally, this is being considered by the UN Committee on the Peaceful Uses of Outer Space (UN-COPUOS). However, some of the 'space faring' nations are concerned that nations not active in space may seek burdensome levels of regulation and standards which impede the development of space activities.

1. The 'size and shape' of the atmosphere itself can also change in ways which are difficult to predict - the effects of solar variations are particularly pronounced, causing periodic 'solar harvesting' of LEO.
2. For example, an 80 gramme object (about 5-10cm in size) with an orbital velocity of 10km/s has the energy equivalent of 1Kg of TNT.
3. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and other Celestial Bodies.

The **Inter Agency Space Debris Coordination Committee (IADC)** has as its members 'space-faring' nations (France, China, India, Japan, the USA, Russia and the UK) and provides a more focused forum than the UN for debate of the issues of space debris. IADC has a rolling programme (started in 1995), to coordinate space debris research and formulate recommendations for the management of the space environment, and also has been asked by UN-COPUOS to present preliminary findings to its Science and Technology Sub-Committee in February 1997. The **International Telecommunications Union (ITU)** is also concerned with space debris through its regulation of telecommunications satellites, and has made recommendations on the need to re-orbit redundant satellites.

The **European Cooperation in Space Standards** organisation brings together European space agencies and industry and has issued a draft standard for space debris and re-entry risks. This is expected to be adopted this year; India and China are considering its adoption.

In all of the international effort to regulate the space environment, the primary concern is to **mitigate the damage to satellites and spacecraft**. The high cost (more than £100M in some cases) of satellites, their commercial value (e.g. for telecommunications or remote sensing), scientific importance (e.g. monitoring the ozone layer) and risks to astronauts are seen as being **more significant than the re-entry risk to property and people**.

### *Will we get enough warning?*

Increasing space activity leads some to expect the risk from re-entering spacecraft to increase - possibly up to 10-fold by the next century. The exact 'risk' is however impossible to quantify, since while tracking space objects can give more than a year's notice of re-entry risk, current techniques can predict the 'landing site' little more than a day in advance. The only 'certainty' with long term forecasts is that objects in orbits which never pass over the UK pose no threat, and on this basis there are no re-entry risks to the UK in the forseeable future. However, failures or collisions with debris or meteoroids could conceivably cause re-entry with little notice.

Could our ability to predict re-entry risks be improved? At present, UK forecasts are provided by MOD (RAF Fylingdales) and DERA, both using modelling techiques based on theories developed 20 years ago which do not, for example, include recent understandings of atmospheric effects. Newer models are being developed by ESA and others, but the raw data from Fylingdales is militarily sensitive and access is restricted, particularly during the last few hours of re-entry.

DERA, which does have access to Fylingdales data, is no longer funded for re-entry forecasts[4], and provided predictions for the re-entry of FSW-1 5 *pro bono*. DERA is concerned that without funding, its expertise may be lost, new prediction techniques will not be matched with the best tracking data and even it's existing computer models will not be adapted to run on new equipment and fall into disuse. On the other hand, restoration of a modest budget would allow DERA's models to be updated, and quantitative risk assessments to maintain a 'map' of likely re-entry threats.

Another dimension to increase in importance recently is the possibility of **collision with asteroids or comets** too large (>10 metres) to burn up in the atmosphere. Such bodies can cause considerable damage (e.g.creating 'Meteor Crater', Arizona 50,000 years ago and destroying thousands of acres of Siberian forest in 1908) and objects larger than 1-2km may be responsible for the cataclysmic mass extinctions which have characterised the planet's geological history (e.g. dinosaur extinctions).

Concern about the scale of potential devastation from asteroid / comet impact has led to a few surveys of Near Earth Objects (NEO) and objects in 'Earth-crossing orbit' (ECO). Some work has been carried out - e.g. by the Anglo-Australian Observatory (AAO), the US Spacewatch survey and academic groups - these have already established about 200 objects, from a few metres up to 20km, in ECO. The most significant of these is 'EROS' which is 5km across and may collide with the Earth in 100,000-1.5M years. However, the orbits of such small objects (in astronomical terms) can be perturbed by complex gravitational interactions and many may yet be unidiscovered, so 'surprises' cannot be ruled out. Thus one asteroid about 400m across passed within 450,000km of Earth (about the distance to the moon) on 19 May 1996, and was detected only 5 days beforehand.

Although highly unlikely, the catastrophic consequences of such a collision mean that some scientists are arguing that an increase in monitoring programmes would be justified. In this context, NASA has proposed 'Spaceguard' to conduct an extensive survey, identify risks and consider options for 'planetary defence'. The initial survey would cost $24M p.a., to which NASA is contributing $1M p.a. and seeking funds from other US and international sources. In March 1996, the Council of Europe recommended international collaboration in this field. In the UK, the Royal Artillery is about to submit a report to Government, proposing a UK coordination group to direct research, formulate defence options and coordinate participation in international planetary defence activities.

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**4. BNSC funding for DRA's 'Space Debris' research programme was cut from £100k to £20k in 1994.**